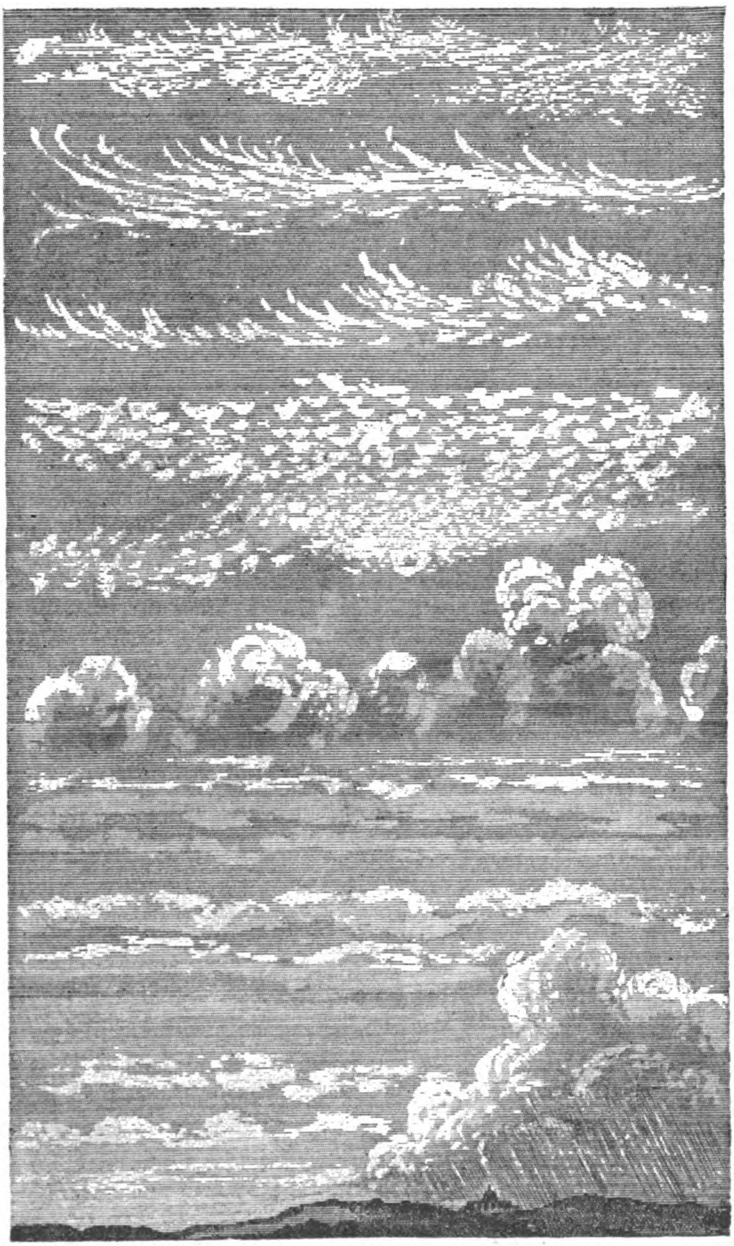
METEOROLOGY



METEOROLOGY

WEATHER, AND METHODS OF FORECASTING

DESCRIPTION OF

METEOROLOGICAL INSTRUMENTS

AND

RIVER FLOOD PREDICTIONS IN THE UNITED STATES

BY

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PREFACE.

In recent years there has been a great development of interest in scientific weather observation and prediction. Government weather services have been founded in most countries over the world, and weather-maps are published daily showing the weather over vast areas of country as reported by telegraph. The hopes that were once entertained that a precise knowledge of coming weather could be gained from the weather-map has not been fully realized. Cases are comparatively rare where it can be of use in predicting the weather. There are not more than six to twelve occasions in the course of a year for any part of the country where successful predictions can be made, and for some places successful predictions are never possible.

The main object of this book is to explain the use of the weather-map, where it can be of use, for the purpose of making predictions. The kinds of weather that can be foretold are the great changes, and these are the ones most interesting to know. Successful continuous predictions for every day are not possible. A fall of temperature as great as 40 degrees can be foreseen to a certainty for most parts of the country east of the Mississippi River. The north-east rain storms along the Atlantic coast can be successfully predicted in most cases. Floods along the lower Ohio and Mississippi rivers can be foreseen from one to three weeks in advance of their occurrence, and the height the water will reach can be assigned within a foot or two.

Rain occurs, as a rule, with the areas of low air pressure that cross the country from west to east and from south-west to north-east. The average direction and rate of motion of these areas are known, but they are subject to many irregularities. Rain can in most cases be inferred for regions over which the areas are likely to pass. At times, however, great downpours of rain and high winds occur out of all proportion to any condition of humidity of the air or pressure gradients that can be previously traced on the weather-maps. Persons interested in the weather, and in a position to examine the weather-maps from day to day, would do well to learn the methods of making predictions, and be able to draw conclusions in regard to the coming weather and to determine to what extent such conclusions are trustworthy. It is the aim of this book to be of use to such persons, and show in what cases useful forecasts of weather are possible. The method is based mainly on statistics of the observed condition of the air as to pressure, temperature, and humidity of particular types and the weather following twenty-four hours or more after the occurrence of the type.

A short account of floods is here given, and the methods of predicting river heights for some points along the lower Mississippi River and its tributaries. The various forms of meteorological instruments are described with reference to the principles involved in their construction. A general view is here taken of all the knowledge relating to the air commonly known as the science of meteorology. Climatology, or the treatment of weather statistically by average values, is only treated of in its broad, general features. Almost everything that is considered to be of interest in relation to the weather is here given. The principal weather changes are described as they occur in various parts of the world in different seasons on land and sea, and their causes narrated as far as known. A collection of facts is given useful in forming a conception of the phenomena of the atmosphere as a whole, so as to enable those with little time for consulting a multitude of books to form some notion of the science of meteorology as it is at present.

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T. R.

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INTRODUCTION.

The earliest ideas of the weather were that the stars and planets had some influence on it. Astrological meteorology began to decline with the invention of the thermometer and barometer, and with the discovery of the true theory of the solar system by Copernicus, which explains the motion of the planets in accordance with simple physical laws. The emptiness of astrology soon began to be perceived. The belief that the moon has some influence on the weather has survived and at the present time prevails to some extent. The changes of the moon, more especially, have been supposed to influence the weather. There has been a great deal of statistical research attempting to show a connection between the moon and the weather, and it is worthy of some attention. All such attempts, however, to connect the moon and the weather have signally failed. Newton's discovery of the law of gravitation, and that the attraction of the moon was the cause of the tides, strengthened the belief for a time that the moon must have an influence on the weather. It opened up a wide field of investigation, and a great deal has been done in comparing the weather with the motion of the moon and its changes of phase.

It was a matter of observation from the earliest times that the tides followed the moon. The real cause was a mystery until Newton's discovery. The speculations as to the cause of the tides were various. Galileo deplored the superstitious tendency of his time in attributing the tides to any action the moon could have. His theory was, that the tides were due to the double motion of the earth on its axis and around the sun, and the water of the ocean not following the change in the direction of motion as quickly as the solid parts of the earth.

The moon must cause a tide in the air as well as the ocean, and it seems reasonable that it might have some influence on the weather, though very small. The attitude of scientifically qualified persons towards the belief in the moon as affecting the weather has been one of disapproval or open contempt. This is not grounded on sufficient examination in most cases, but is largely the result of prejudice, possibly arising from the immense amount of charlatanism in connection with the moon and the weather of which the world has been the victim.

Weather records for a number of places that have been examined show that there is a somewhat greater tendency to rain in the quarter after full moon than at other times; there is a greater probability of rain with the moon in perigee than apogee. There is no doubt in regard to this relation of the moon and rain, but the difference is not known even approximately, and it varies for different parts of the earth. It is of no practical value for weather prediction. Attempts have been made to show that there is less cloudiness at full moon than at other times. The results are contradictory for different places. The effect is either so small that the longest series of records does not show it, or it does not exist. The effect of the moon on the frequency of thunderstorms is inappreciable. As regards the winds, northerly winds are more prevalent during the last quarter of the moon, and southerly winds more frequent during the first quarter than at other times. No conclusion can be drawn in regard to the varying force of the wind for the different quarters of the moon. With regard to change of the weather and change of the moon in five thousand cases examined, eighteen hundred showed a change of weather and thirty-two hundred no change.

The effect of the moon on the pressure of the atmosphere is very slight. There is an ebb and flow that is only perceptible near the equator by the most refined instrumental means of observation. The difference between the least and greatest pressure due to the effect of the moon is only 0.004 of an inch. The pressure of the air is probably greater with the moon farthest from the earth, and greater at quadratures than syzygies. No predictions of weather of any value can be made based on pressure variations due to the moon.

Some heat is received at the surface of the earth from the moon, and this being the case, some must be absorbed by the air. The planets, or brightest fixed stars, give no appreciable heat that can be detected with the most refined means of measurement. This is not conclusive, however, as the heat may be entirely absorbed by the air. It was a very pretty speculation at one time that the greater warmth of the northern hemisphere as compared with the southern was due to the radiation from the greater number of stars visible in the northern heavens. More extensive observations of temperature show that there is probably no difference between the two hemispheres. Comparative statistics for one hundred and fifty-three years, some of them comet years, show that comets have no effect on the temperature or any other element of the weather.

The vast number of meteors moving about the sun, some of which pass through the air leaving a temporary trail of light, and then passing on or sometimes falling to the earth, probably have no effect on the temperature of the air or the weather. There are two principal groups of meteors moving about the sun. It was at one time surmised that these coming between the earth and the sun, which occurs February 7th to 12th, and about May 11th, might cut off the heat of the sun enough to cause the peculiar anomaly of temperature observable about those times, especially in May. It is not, however, the cause. The phenomenon of the three cold days in May, the 10th, 11th, and 12th, is attested by the eighty-six years of weather record at Berlin, and is explainable by the general circulation of the air and the sequence of high and low pressure areas.

The attempts to prove a connection between sun-spots and the weather are of some interest. The subject once received a good deal of attention. As the sun is the prime cause of all changes in the air, any changes going on on the surface of the sun might have an influence on the weather. It is extremely doubtful, though, that there is any connection.

When the sun is examined with coloured glass, dark spots of various form and size are perceived singly and in groups. They are mostly seen in the latitude of 10 to 15 degrees on the sun, and not in the vicinity of its equator or poles. They appear first on the eastern edge of the sun, and moving west disappear in 13 days, to reappear after a similar period. Their apparent motion is due to the rotation of the sun on its axis, the period of which is 25.78 days. These spots are of great extent, occupying at times hundreds of thousands of square miles. The fact that they appear only in certain zones indicates that the surface of the sun is not physically the same everywhere. The spots seem to be associated in some way with cyclonic motions of the gases on the surface of the sun. They have a proper motion relative to a point on the surface of the sun, as shown by the fact that different spots, especially in different latitudes, give slightly different times for the sun's period of rotation. The spots are related in some way to the red protuberances seen at the edge of the sun, which are sudden bursts of heated gases from the surface of the sun into the higher regions of its atmosphere. From the known approximate height of these protuberances, and the law of the dynamical cooling of gases with ascent, the temperature of the sun's surface is estimated to be at least as high as 12,000° F.

There is a period observable in the frequency of the sun-spots. There is an increase in their number, and then a decrease. The period is slightly variable; on the average it is 11.1 years. The interval from the time of least to greatest frequency is 3.7 years; the time from the greatest to least is twice as long, or 7.4 years. The heat of the surface of a sun-spot is less than that from the bright surface of the sun as indicated by a thermopile. Among the first attempts to trace a connection between sun-spots and the occurrences on the earth was Herschel's notable investigation into the relation of the price of wheat and the frequency of sun-spots in different years. It was found that for Great Britain the years of lowest price corresponded with the greatest frequency of sun-spots, the inference being that years of great frequency are favourable to the growth of wheat, and on account of the larger yield the price is lower. The same was found to be true for prices on the Continent. Though this was true for the eighteenth century, it has not been true for the nineteenth. Herschel's inquiry was made before the periodicity in sun-spot frequency had been detected. The statistical examination of many things has been made in relation to sun-spot frequency, air-temperature, pressure, cloudiness, rainfall, auroras, and cyclones. The result for the temperature of the air in relation to the sun-spot frequency is very doubtful. There is apparently a relation between pressure of the air and sun-spots for southern Asia at least. In the years of greatest sun-spot frequency the pressure is slightly higher than in years of least frequency. Cyclones were found by

Meldrum to be most frequent in the south Pacific Ocean in sun-spot years.

If sun-spots influence radiation from the sun, it is natural to suppose they must have an influence on the rainfall over the earth through its effect on air currents. This is the more reasonable if cyclones which are always accompanied by rain are more frequent in years of great sun-spot frequency. There is greater difficulty in comparing rainfall with sun-spot frequency than any other meteorological element, as the annual rainfall varies greatly in places quite close together. One set of stations shows greater rainfall in sun-spot years, while another set shows less. The total rainfall of India shows no evidence of an eleven-year period. Stations on the sea-coast, where the rainfall is fully dependent on the wind, favour the view that sun-spots increase the rainfall. Inland stations, where the wind varies from local causes, are unfavourable. The year 1867, which was one of least sun-spot frequency, was rainy everywhere. That there is any dependence of rainfall on sun-spot frequency is very doubtful. If there is a period in rainfall corresponding to sun-spots, it should be reflected in the heights of rivers. In years of greatest sun-spot frequency more water flows through the rivers of Europe than in other years. In general, the years in which the high waters of the Nile are below the average are near the years of least sun-spot frequency. The same is true of the level of the great lakes in the United States and Canada. In the outflow of the Mississippi River there is no trace of an eleven-year period, nor does the high water have any relation to the years of greatest sun-spot frequency. The frequency of thunderstorms shows no relation to sun-spots. Hail-storms, it is claimed, are more frequent in years of greatest sun-spot frequency than in others.

On the whole, the weight of evidence seems to favour the view that there is no connection between sun-spots and meteorological phenomena, or at least the connection is a very slight or a very remote one. There does seem to be a period in the frequency of thunderstorms dependent on the time of rotation of the sun on its axis, 26 days, and likewise a period in the variation of the earth's magnetic elements depending on the rotation of the sun, but it is doubtful if even these are related in any way to the sun-spots.

There has been a great deal of research to discover some periodicity in the recurrence of weather. If such a period could be found, the prediction of weather would be a very simple matter, as it would only be necessary to have observations of the weather over one of the periods. No attempts to discover any such periodicity have ever been attended with the least success.

When the barometer was invented, and the daily variation of the air pressure discovered, it was expected that with the improvement of the instrument it would be possible to foretell the weather. The improvement was slow in realization. The most important step in the scientific study of the weather was taken about 100 years ago, with the founding of the Meteorological Society of the Palatine in Germany. It was then found for the first time that oscillations of air pressure occurred at the same time over large areas of country, and that low pressures occur earlier to the north and west of a place and later to the south and east of it, and in fact that there is a progression of the low pressure from west to east.

With the invention of visual telegraphy in 1793, there was a project formed for the transmission of weather-reports from place to place, but it was never carried out. Since the invention of the electric telegraph, government weather-services have been established in countries all over the world. Information of the condition of the air, its temperature, pressure, cloudiness, the wind and rain for some particular instant of time, is telegraphed from widely separated places to some central station, and shown graphically in a generalized form by lines or by shading on a map of the country. These maps, usually published once a day in large cities, are known as weather-maps. The first of modern weather-maps was made in the year 1854. During the Crimean War, on November 14, 1854, a great storm occurred on the Black Sea which almost destroyed the allied fleet, and caused the loss of the French man-of-war *Henry IV.* A storm was known to have prevailed several days before in western Europe. On the request of the French Minister of War Vaillant, the astronomer Leverrier investigated all the circumstances attending the progress and formation of the storm. Observations of pressure, temperature, and wind were gathered from all the observatories in Europe and charted. The investigation showed that the storm moved from the north-west to the south-east. With telegraphic communication between

Vienna and the Crimea, and weather-reports from the west of Europe, it was seen that it would have been possible to warn the fleet in time to have prevented disaster.

This event aroused very widespread interest, and stimulated the study and observation of the weather. The numerous weather-services that have been founded over the world since show the desire on the part of the public for as trustworthy information in regard to the weather as it is possible to obtain.

CHAPTER I.

THE AIR.

Meteorology. — Meteorology is the study of the air, all its properties, motions, and appearances. The orderly arrangement and statement of all facts relating to the atmosphere and its changes, and the assignment of their causes, is the province of meteorology.

The atmosphere is a body of mixed gases surrounding the earth and extending to a height of at least fifty miles above the surface. The component gases form a mechanical and not a chemical mixture. The various gases fit into the interstices of each other. Each one tends to form an atmosphere by itself as if the others were not present.

Air Pressure. — Air exerts a pressure on everything in it equal to the weight of the column of air above it. The air pressure varies from time to time. At the level of the sea, on the average, the air pressure is equal to that exerted by a column of mercury 29.92 inches in height, or a column of water about 34 feet high, equal to about 14.67 pounds to the square inch. The air tends to expand, but is restrained by the weight of the air above it, and the pressure of the air around it. The pressure diminishes with ascent in the air, there being less above a plane, the greater the height. This property of diminishing pressure with height is used to determine heights above sea level. A convenient approximate rule is the following: The height of a place in feet is equal to the product of two factors, the first a fraction equal to the difference between the pressure at the place and the sea level divided by the sum of the pressures; and the second, the number 55,630, when the average temperature of the air between the two places is 60°. The number increases at the rate of 117 for every degree above 60°, and diminishes the same amount for every degree below it.

Properties of Air. — A cubic foot of pure dry air, at a temperature of 32° and a pressure of 30 inches, weighs 1.294 ounces. The density of air is $\frac{1}{778}$ that of water. The whole body of air forms the $\frac{1}{1200000}$ part of the mass of the earth. A homogeneous atmosphere equal in mass to the present one, uniform in density, and of the same density as the average at the surface of the earth, would extend to a height of 26,223 feet. The duration of twilight would indicate that there is no appreciable light reflected by any atmosphere beyond a height of fifty miles, yet its free surface is probably much higher, as shown by shooting stars, the incandescence being due to friction of the meteors moving through the air at a very great velocity.

A volume of air remaining the same, its pressure varies with the temperature, being proportional to the absolute temperature. Absolute temperature is reckoned from absolute zero, a point 459° below the zero of the Fahrenheit scale. The absolute zero is a fiction derived from the kinetic theory of gases. Air expands the $\frac{1}{491}$ part of its volume for an increase of one degree in temperature. If restrained in volume, its pressure increases in the same ratio.

Air on being compressed is heated, and in expanding cools. Changes of pressure, and consequent change of temperature, without the addition or subtraction of heat, is called an adiabatic process. For air at a pressure of 30 inches and a temperature of 60°, an increase of one inch in pressure will raise the temperature 5°. Doubling the pressure to 60 inches will raise it to 175°.5; diminishing the pressure one-half lowers the temperature to 2°.4.

Specific Heat. — The amount of heat required to raise a given quantity of air a degree in temperature, when maintained at a constant pressure, is 0.24 of the amount required to raise an equal weight of water a degree. This ratio is called the specific heat of air. When the volume of air is maintained constant, the amount of heat required to change its temperature is less than when free to expand, in the ratio of 1 to 1.41. The greater amount required when free to expand is due to the expenditure of heat in doing the work of pushing the pressure of the surrounding air aside. The specific heat of vapour of water is 0.48.

Air cools in ascending at the rate of 0.55 of a degree for every 100 feet of ascent.

Air Constituents.—Air is composed of the gases nitrogen, oxygen, carbon dioxide (carbonic acid), vapour of water, and a slight amount of ammonia. In dry air the gases are in the proportion by volume of 100 parts; nitrogen, 79.02; oxygen, 20.95; carbon dioxide, 0.03. By weight, the composition of dry air is, nitrogen, 76.78; oxygen, 23.17; carbon dioxide, 0.05.

With the density of dry air as unity, the density of oxygen is 1.10563; of nitrogen, 0.97137; carbon dioxide, 1.5201; vapour of water, 0.622.

The percentage of oxygen in the air varies at different times and in different places from 20.47 to 20.96. When the wind is from the south there is less than when from the north. The amount diminishes slightly with ascent in the air; this is due to its greater density as compared with nitrogen.

All animal life and all fires are supported by oxygen. The combustion of carbon and oxygen, or their chemical combination, produces carbon dioxide. Plants decompose carbon dioxide and give off oxygen to the air. A grown person consumes about 420 gallons of oxygen in a day. All the fires on the earth burn in a century about as much as is contained in the air over a square degree on the earth's surface, equal to 70 miles on a side. The principal source of carbon dioxide is the sea. One litre of sea-water contains 98.3 milligrammes. One decimetre square of green leaves decomposes in an hour seven cubic centimetres of carbon dioxide in the sun, and three in the shade.

The invisible moisture contained in the air in the form of vapour forms a very variable part of the air at different times. It is no more than $\frac{1}{1000}$ part on a cold winter day, and on a warm summer day may be as much as $\frac{1}{40}$ by weight of the lower layers of air near the ground. The ammonia in the air is about the $\frac{1}{80000000}$ of it by weight.

Bacteria.—A highly important constituent of the air, as regards the well-being of humanity, is the minute vegetable organisms contained, floating around in it as dust, known as bacteria. These are the lowest forms of vegetable life. Over the oceans and on high mountains they are present in air to the extent of about one in every cubic yard of air. In the streets of a city there are about 3000 to the cubic yard;

in hospital wards there are as many as 80,000 in the same space. A few of the forms of these are shown in Fig. 1 magnified 500 diameters. Only a small proportion of the bacteria are disease germs. The remainder are workers that feed on animal and vegetable waste, resolving it into simpler compounds to be absorbed again by the higher members of the vegetable kingdom.

Ozone. — Ozone, an allotropic form of oxygen, its density being 1.5 times that of ordinary oxygen, is present in the air in small quantities. Ozone is produced in passing electric sparks through a tube containing dry oxygen, also by the electric decomposition of water and by the slow burning of phosphorus in moist air. Its presence in the atmosphere is supposed to be due to lightning. Ozone is a more powerful oxidizing agent than ordinary oxygen. An indigo solution shaken up in air containing much ozone soon loses its colour. The usual test for the presence of ozone is the property it has of decomposing iodide of potassium. Papers soaked in a solution of this become discoloured by the iodine set free on exposure to the air if there is much ozone present. The discoloration is, however, not a good measure of the amount of the ozone in the air, being hard to estimate by comparison with a scale of colours. The amount of discoloration depends, moreover, on the strength of the wind; the varying velocity at different times causes different quantities of ozone to come in contact with the paper.

FIG. 1.

Nitric acid, of which there is some trace in the air, produces the same sort of discoloration in iodide of potassium paper as ozone.

There is a decided discoloration of iodide of potassium paper in damp and especially in rainy weather, due, probably, to moisture facilitating the access of ozone to the iodide of potassium, and not to the presence of any greater amount than is ordinarily contained.

Heat of Air. — The sun heats the surface of the earth; the air in contact with it becomes heated and rises, on account of its lightness as compared with air higher up. By mixture with other air as it rises, the heat received at the surface of the earth is diffused throughout the upper air by convection. About one-third of all the heat received by the air is absorbed directly from the rays of the sun in passing through it. The amount absorbed varies with the condition of the air as to cloudiness, haziness, and humidity.

Insolation.—The direct action of the sun's rays in heating the surface of the earth is called "insolation." When the sun is low in the horizon the heating is less than when at a height, on account of the inclination of the rays and on account of the greater thickness of air traversed before reaching the earth. At an altitude of five degrees the sun's rays come through a thickness of air five times as great as when the sun is in the zenith; with the sun in the horizon the thickness is 35 times as great. A surface exposed vertically to the sun's rays at the upper limit of the atmosphere receives in one minute of time about 3.0 gramme-calories of heat on every square centimetre of surface. This quantity is called the solar constant. A gramme-calorie of heat is the quantity required to raise a cubic centimetre of water (one gramme) one degree centigrade. A centimetre is 0.3937 of an inch. A degree centigrade is 1.8° Fahrenheit.

The amount of heat received at a place depends on the duration of sunshine and the inclination of the sun's rays to the ground during the time.

Earth.—The earth is a flattened sphere. Its diameter at the equator is 7926.6 miles; at the poles, 7899.0 miles. The time the earth takes to make one complete revolution is conventionally divided into 24 hours. The velocity of a point on the equator due to the rotation of the earth is 1040 miles an hour; at latitude 60° it is one-half as much.

The earth moves around the sun in an ellipse once in 365.24 days, with the sun in the focus. The plane of the ellipse is the ecliptic. The distance of the earth from the sun at its greatest is 94,353,000 miles, on June 21, and at its least, 91,241,000 miles, on December 23. In its course around the sun the earth moves with a velocity on the average of about 65,940 miles an hour, slower in June and faster in December.

The plane of the earth's equator forms an angle of about 23° 27′ with the ecliptic, known as the obliquity of the ecliptic.

The intersections of the ecliptic with the equator, where the sun passes from one side of the equator to the other in spring and autumn, are called the spring and autumn equinoxes. From the spring to the autumn equinox is 184 days, and from the autumn to the spring 181.

Owing to the obliquity of the ecliptic, the duration of day and night is of varying length at different times of the year. At the pole the sun is above the horizon half the year and below half.

Amount of Heat. — The amount of heat received from the sun is different at different places, and varies at different times of the year at the same place. Taking the average amount of heat received on a surface at the equator in a day as unity, the quantity received in a year is 365; at latitude 30° it is 321; at 40° it is 288; at 50° it is 250; at 60° it is 208; at the pole, 152. The amount received at the equator in one day, March 20, being unity, the sun being at the equinox, at 30° it is 0.88; at 60°, 0.50; and at the pole, zero. The amount received in a day at the equator, April 12, is 0.98; at 30°, 0.97; at 60°, 0.69; and at the pole, 0.49. The amount received, May 5, at the equator is 0.99; at 30°, 1.05; at 60°, 0.89; and at the pole, 0.86. The amount received, June 21, at the equator is 0.89; at 30°, 1.10; at 60°, 1.10; and at the pole, 1.20.

The number of thermal days at the equator is 365¼, at the pole 151.6.

Differences in the heating of the air over different parts of the earth produce differences in density which give rise to motions of the air tending to restore equality. As there is much more heat received on the average at the equator than the poles, there is a general circulation of the air from the equator to the poles and back again. As the difference of temperature always exists, sometimes greater than at others, the motion and interchange of air between the equator and the region of the poles is perpetual. The varying difference of temperature at different times of the year causes periodic oscillations in the intensity of this circulation. The difference of temperature is twice as great in winter as in summer, and the upper currents twice to four times as great. The average difference of temperature between the equator and poles is 81° F. A surface of equal pressure at the equator and poles is one-sixth of its altitude higher at the equator than the poles. This is the slope or gradient which in the distance of 6000 miles gives the air its motion.

The average weather or climate at a place depends on the varying amount of heat received from the sun at different times of the year, and on the direction of the prevailing winds. The most potent factor is distance from the equator.

The main cause of seasonal variation of climate over the earth is the obliquity of the ecliptic. The obliquity is at present diminishing at the rate of $0''.4$ a year. The least value, $22° 15'$, will be reached in about 15,000 years. The greatest value in the past has been $24° 50'.5$. This oscillation cannot be productive of more than very slight secular variations in seasonal climate.

The differences in surface-heating over land and ocean have an appreciable influence on the general circulation of the air. Over the ocean the sun's heat penetrates the water to a considerable depth, instead of being concentrated at the surface as in the case of land. The specific heat of the land surface is only 0.2 that of water.

The distribution of land and water modifies climates. Winds are more potent than the direct action of the sun in making climate. In the arctic region the climate is more the direct result of the sun's action than elsewhere.

Area of Earth. — The area of the whole surface of the earth is 196,662,892 square miles. About three-tenths, or 52,500,000 square miles ($26\frac{3}{8}$ per cent), is land. The area between latitude 25° north and 25° south comprises 0.4 of the earth's surface; from latitude 25° to 60° on both sides of the equator comprises 0.5; the polar regions above 60° comprise 0.1; the oceanic islands form 0.007 of the land surface of the globe.

The eccentricity of the earth's orbit is now increasing; it was at its least value 50,000 years ago. When at its greatest, the earth at aphelion is 8,500,000 miles farther away from the earth than when the eccentricity is at its least. This, it is believed by some, would cause the mean temperature of the northern hemisphere to be forty-five degrees lower during the winter half of the year than it is now.

A flow of air takes place in the upper atmosphere from the equator toward the poles, and a counter-current sets in along the surface of the earth from the poles toward the equator. There must be neutral surfaces where there is no motion. In the upper northerly current in the northern hemisphere the greatest velocity is in the upper portion, and it diminishes to nothing at the neutral surface. For the lower southerly current the greatest velocity is at some distance above the surface of the earth, diminishing above to the neutral surface, and also below to the earth's surface on account of friction. As the upper currents go northward, the space they occupy is less as the meridians converge. The rotation of the earth modifies the motion, deflecting currents to the right in the northern hemisphere, and to the left in the southern hemisphere. The motion of the air in middle and high latitudes is from west to east, and the velocity increases with the altitude. In low latitudes the air has a motion from east to west at the surface which decreases up to a certain altitude, where the motion changes to the east and then increases with the altitude. Deflecting forces arising from the easterly motion in middle latitudes push the air towards the equator. A contrary but weaker force, the effect of the westerly motion in low latitudes, pushes the surface air poleward, the result being to heap up the air and increase the pressure at the surface at latitude thirty degrees, while in the upper air there is a maximum of pressure at the equator and a minimum at the poles.

Viewed as a whole, the general circulation of the air is two huge whirls, one in each hemisphere, with the poles as centres. The direction of motion is determined by the rotation of the earth. In the northern hemisphere it is opposite to the motion of the hands of a clock, and the reverse in the southern hemisphere. Each of the whirls has on its outer circumference an atmospheric ring, in which the motion of rotation of the air is in the opposite direction.

In the winter of the northern hemisphere the sun is nearer the earth than in summer. The greater intensity of insolation of the northern hemisphere over that of the southern is counterbalanced by its shorter continuance, so that the same amount of heat is received by both in the course of a year.

Trade-winds. — At the surface of the earth both on land and sea from latitude 7° to 29° north the wind blows almost constantly from the north-east all the year round. From latitude 3° to 20° south the wind is almost constantly from the south-east. These currents of air are known as the trade-winds. In summer they prevail over a region a few degrees farther north than in winter. In the northern half of the belt of north-east trade-winds the average direction of the wind is from a point 60° east of north; near latitude 10° the direction is more from the east, and near the southern limit almost exactly east. At the Hawaiian Islands, latitude 21° north, the trade-wind prevails 258 days in the year. The days when it does not blow are mainly from December to April.

The trade-winds extend through a height of 12,000 feet: the height is less near the northern limit of the north-east trades than near the equator.

Anti-Trade-winds. — Above the north-east trade-winds the higher currents of the air are from the south-west, and are known as the anti-trade-winds; in the southern hemisphere they are from the north-west. The direction of the anti-trade-winds has been shown by the smoke and ashes of volcanoes carried far to the north-east several hundreds of miles from the place of origin.

Calms. — Between the north-east and south-east trade-winds there is a belt of calms varying in width from 150 to 500 miles. On the Atlantic Ocean the width is less on the American than the European side, and wider in the middle than on either side. The width is less over the Pacific than the Atlantic Ocean. The average position of the middle of the belt of calms is in latitude 5° north; it changes with the declination of the sun, being at 10° north in August and at 1° in February. The belt of calms is the region of the ascending currents of air where the two systems of trade-winds meet. The region of calms is known by sailors as the "doldrums." Vessels have been sometimes becalmed in these regions for as much as six weeks at a time.

Horse Latitudes. — At latitudes 30° north and south there are regions of calms known as the calms of Cancer and Capricorn, marking the region of the descending currents in the circulatory system of the trade and anti-trade winds. Near the West India Islands this region was once known as the "Horse Latitudes."

Winds of Temperate Zone. — Beyond the region of the trade-wind the prevalent direction of the wind in the northern hemisphere is from a point a little south of west. This zone of winds is 2000 miles in width. The westerly motion is most decided in the middle of the belt, and diminishes on either side. In the United States, winds from the west are two and a half times as frequent as those from the east. In the southern hemisphere these winds blow with great intensity between latitude 40° and 50°, where they are called the "brave west winds," and the latitudes are sometimes known as the "roaring forties."

Above the south-west winds of the temperate zone the wind at a height is from the north-west. In ascending through the air, the direction gradually changes from the south-west around by the west to the north-west. Clouds prevail principally in the lower half of the air, and have generally the direction of the lower air currents. When the air is very dry and such cirrus clouds as can be seen are at a great height, they are generally observed to come from west 8° north in winter, and west 3° south in summer, in Canada. In Europe the direction is generally from the north-west or south-west more from the north in winter.

Polar Winds. — Above latitude 60° in the polar regions the general tendency is for ground surface winds to blow from the south-east.

The general tendency of upper currents is from the west all over the world.

On account of the different velocities of the earth on different parallels of latitude, air starting from the equator and moving northward has a greater component of motion than the place toward which it is moving. Consequently the current deviates toward the east, and the easterly deviation is greater the farther north it goes. Currents in the northern hemisphere are always deflected to the right of one looking in the direction the current is going, no matter what the direction.

Ocean Currents. — Ocean currents control very largely the distribution of surface temperature of the water. The currents are mainly due to the prevailing winds over the surface and the difference of density induced by differences of temperature in the equatorial and polar regions. The winds being the result of the distribution of air pressure, the pressures in a measure should represent the currents. There is a similarity in the average annual curves of isobars and the general circulation of the five great oceans.

The circulation is limited and controlled very largely by the shape of the continents. The rotation of the earth has the effect of deviating ocean currents the same as in the case of the winds, but much less, as the velocities are smaller. The average depth of the ocean is about 3000 feet.

There are minor modifications of currents due to difference in density caused by evaporation, producing concentration of the salt in some places, and rainfall diluting the surface salt water in others. This is of most importance, however, in the vertical circulation of the ocean. The average density of sea-water as compared with fresh water is 1.024. In the region of the trade-winds the density is greater than the average on account of the evaporation, and in the belt of calms less than the average on account of the rainfall.

The general tendency of ocean currents at the surface is from the equator to the poles. The return current from the poles to the equator is principally at a depth. Little is known of the currents at great depths in the ocean more than that the rate of motion must be exceedingly slow, moving perhaps not more than a few feet in a day in some places.

Strong and long-continued wind may raise to a very considerable extent the level of the water along a coast to which it is blowing. During and after a gale at sea a strong current is usually noticeable flowing to leeward. The westerly wind blowing over the North Sea sometimes raises the water 6.5 feet at Christiana, Denmark; an easterly wind will sometimes depress it 3.0 feet below the average. At Galveston, Texas, a strong wind at times will raise the level of the water in the bay 6 feet.

Equatorial Current. — The equatorial current of the Atlantic Ocean runs from the Gulf of Guinea, on the coast of Africa, west along the equator. At the easternmost point of South America, Cape St. Roque, it divides. One part turns to the north-west and enters the Caribbean Sea; the other turns south-west and moves along the shore of South America. This is called the "Brazil current."

Gulf Stream. — The part of the equatorial current that enters the Caribbean Sea passes through it and between Yucatan and the island of Cuba into the Gulf of Mexico. From the Gulf of Mexico it passes through the Straits of Florida into the Atlantic Ocean, where it is known as the "Gulf Stream." The temperature of the Gulf Stream in January is 60°. The current through the Straits of Florida has a velocity of 4 miles an hour and discharges 986,000,000 cubic feet of water per second. The current moves north-east, and at Cape Hatteras has a velocity of 4.4 miles an hour. From a region east of the Banks of Newfoundland it moves to the middle of the ocean. On the coast of Europe it divides. Part moves along the coast of Spain and Portugal towards the south, and along the north-west coast of Africa. Here its velocity is increased by the north-east trade-winds. The current joins in partially with the equatorial current, and part goes farther east, along the shore into the Gulf of Guinea, where it is called the Guinea Stream.

The other part of the Gulf Stream, where it branches in the North Atlantic, moves north-east to the north of the British Islands and along the coast of Norway. A part goes to the west of Iceland and, uniting with a cold current coming out of the Greenland Sea between Greenland and Iceland, moves down the east coast of Iceland. To the north-east of the Faroe Islands it unites with the principal current up to the Arctic Ocean, where it divides into two branches. One of these flows along the west coast of Spitzbergen, and the other farther east to Nova Zembla.

The elevation of the St. Louis city, Mo., plane of levels as determined by precise levels above the mean tide of the Gulf of Mexico at Biloxi, Miss., is 412.71 feet. The elevation of the same point determined by levels from the mean tide at Sandy Hook, near New York city, is 416.36 feet. The results in both cases depend on duplicate systems of precise levellings. Part of this difference of elevation is due to unavoidable errors of observation in such long lines of levels, and part, perhaps, to the disturbing influence on the level, in crossing the Allegheny Mountains, produced by slight variations in the direction of force of gravity from the true centre of curvature of the earth. But the main part is difference in water level between the Gulf of Mexico and the North Atlantic Ocean due to the surface slope which is the cause of the flow of the Gulf Stream water.

In the South Atlantic Ocean the Brazil current turns east at latitude 40° and moves towards the coast of Africa. It continues to the east to the south of the Cape of Good Hope, and nearly as far as Australia, and then turns and moves north-east. It is joined by the equatorial current from the north that comes down east of Madagascar Island.

Under the influence of the south-east trade-wind it joins in with the equatorial current.

Pacific Ocean Currents.— In the Pacific Ocean there are currents corresponding to those in the Atlantic. The one corresponding to the Gulf Stream passes along the coast of Japan, where it is known as the "Kuro Siwa," meaning a deep blue colour. This colour is also characteristic of the water of the Gulf Stream.

Kuro Siwa. — The Kuro Siwa carries a great deal of heat to the shores of Alaska and British North America. It turns south and moves along the coast of the United States, bringing relatively cold water from the north to the southern coast of California.

Humboldt Current. — From latitude 40° south in the Pacific Ocean a cold current, called the "Humboldt current," passes along the west coast of South America and joins in with the equatorial current.

Mozambique Current. — In the Indian Ocean the Mozambique current flows between the island of Madagascar and Africa. Its continuation along the coast to the end of the continent is called the Algulhas current. On the west side of Africa it continues to the north-east and joins in with the equatorial current.

CHAPTER II.

METEOROLOGICAL INSTRUMENTS.

PROPERTIES and conditions of the air not discernible to the unaided senses are observed with the aid of instruments. Appearances and conditions of the air that are discernible cannot always be estimated precisely enough for purposes of comparison with like conditions at other times and places, and instruments are devised for measuring them accurately.

The most important conditions of air are: —

Temperature, measured with thermometers.
Sun's rate of heating, measured with actinometer.
Pressure, measured with barometer.
Rainfall, measured with rain-gauge.
Soil-water reaching different depths in the earth, measured with a percolation gauge.
Snowfall, melted, measured with a rain-gauge.
Snowfall, unmelted, measured with a rod.
Vapour pressure, measured with psychrometer, or dew-point apparatus.
Wind direction, observed by a wind-vane.
Wind velocity, measured by anemometer.
Cloud motion, observed with a nephoscope.
Cloudiness, amount in fractional part of the sky covered, estimated with the eye.
Sunshine duration, measured with a sunshine recorder.
Electric potential, measured with an electrometer.
Evaporation, measured with an evaporometer.
Fog, haze, estimated.

In the observation of rivers the important conditions are: —

River stages, height of river-surface in feet above low water, measured by a river-gauge.
Current velocity, measured with a current-metre, or ship's log.

THERMOMETER.

The sensation of heat and cold in air and objects is called temperature, and is measurable with a thermometer. The most convenient and best kind is the well-known mercurial thermometer, consisting of a glass bulb and stem containing mercury sealed off from the air.

Mercury expands with changes of temperature seven times as much as glass. The height of the top of column of mercury in the stem of thermometer varies with the temperature.

Scale. — On the Fahrenheit scale the temperature of the melting-point of ice is taken as 32°, usually called freezing-point, and the boiling-point of water as 212°. The temperature of melting ice varies slightly with the pressure of the air. One atmosphere of pressure lowers the temperature by 0.0135 of a degree. But an increase of that amount of pressure on the bulb of a thermometer will compress it to such an extent that the column of mercury will stand 0.5 of a degree higher than without the pressure.

The tube of a thermometer is closed. When the top is broken, admitting the pressure of the air, it lowers the reading of the thermometer 0.5 of a degree.

Boiling-point. — The temperature of boiling-point varies with the atmospheric pressure. Doubling the pressure raises the boiling-point to 250°. A change in the pressure of one-tenth of an inch changes the temperature of boiling-point 0.17 of a degree. The pressure for which the temperature of boiling-point is 212° is 29.922 inches of mercury at the temperature of freezing-point, subject to the force of gravity at the level of the sea and latitude 45°.

Calibration. — The contents of a thermometer tube from 32° to 212° is divided into 180 equal parts by the graduations. The tube of a thermometer is of variable diameter from point to point. If the bore was uniform, a division of the scale to equal parts would correspond to equal volumes. This never being the case, the positions of the marks indicating equal volumes have to be ascertained by a calibration. Even when a thermometer is calibrated by a maker, which is usually the case, the small outstanding errors, where great refinement is required, as in the case of standard thermometers, have to be determined by a process of calibration. Calibration is effected by means of the measured lengths of detached threads of mercury in different parts of the bore of the stem, in terms of the scale on the stem.

Poggendorf Correction. — The calibration of a thermometer being made for the stem at a uniform temperature, the graduation will not correspond exactly to equal volumes when used at different temperatures. This correction for capacity of stem to reduce to a uniform temperature is very small. At its greatest, in the middle of the scale at a temperature of 122°, it causes a thermometer to read 0.12 of a degree too high. This is called the "Poggendorf correction," from the name of the physicist who suggested it.

Reduction to Gas-Thermometer. — Glass and mercury expand slightly more at a high than a low temperature for the same increase of temperature. On this account there is a correction to a thermometer, to reduce its indications to what they would be if the expansion of the materials was perfectly uniform. The main part of the correction is due to the variable expansion of the glass and not the mercury. Thermometers, from this cause, most generally read too high. The amount of the correction varies for thermometers of different kinds of glass. It is least for hard glass containing but little oxide of lead or manganese. At about 100°, where the correction is greatest, it amounts to 0.19 of a degree, and diminishes above and below that point.

This correction is derived by comparison of the mercurial thermometer with a gas-thermometer. A glass or platinum bulb is filled with gas kept at a constant volume at the different temperatures, except in as far as the volume of the bulb changes with temperature. The pressure of the gas at freezing and boiling point is observed by means of an attached manometer. At any other pressure the temperature is a proportional part of the interval from freezing-point to boiling-point corresponding to the pressure.

The gas-thermometer adopted by the International Bureau of Weights and Measures is hydrogen in a platinum bulb with the gas at a pressure of 39.37 inches of mercury (one metre) at freezing-point.

The hydrogen gas-thermometer reads at 104°, 0.018 of a degree higher than one filled with nitrogen, and 0.108 of a degree higher than one filled with carbon dioxide.

The indications of a gas-thermometer require correction to reduce to a perfect gas, that is, a gas in which the increase of pressure is strictly proportional to the increase of temperature. This correction, which, at its greatest in the middle of the scale, cannot amount to more than 0.03 or 0.04 of a degree, is called the reduction to the thermo-dynamic standard. No satisfactory method of making this correction has as yet been devised, and it is customarily omitted even in the most accurate investigations.

Freezing-point. — There is a constant rise in the freezing-point of a thermometer with age, due to a contraction of the glass bulb. A thermometer graduated the day it is filled will read a degree and a half higher at freezing-point a week after, when packed in melting ice. Fine instruments are not graduated until a year and a half after filling. Even then the rise in the freezing-point in the course of six years will often be as great as half a degree.

To obtain true temperatures, any change in the freezing-point after an instrument is standardized must be applied as a constant correction for every temperature along the scale being in the nature of an index-correction. Subjecting a thermometer to the temperature of boiling-point depresses the freezing-point by an amount varying from a third to a half degree, depending on the kind of glass of which the bulb is made. It regains its former freezing-point reading in the course of about a month.

Subjecting a thermometer to a very high temperature, as 500°, raises the freezing-point permanently from 10 to 18 degrees.

Subjecting a thermometer to a very low temperature, as −40°, raises the freezing-point a few hundredths of a degree. Exposure to low temperatures must be continued for several hours to make any appreciable effect. A coating of ice on the bulb at low temperature, by compressing it, may make the column read a few tenths too high.

A coating of copper, silver, or gold electrically deposited on a bulb, compresses it so as to make the column read several degrees too high, when the coating is thick. This effect has been called electro-striction.

The position of freezing-point of a thermometer to be used in correcting any observed temperature is the freezing-point observed immediately after exposure to the temperature.

In observing the freezing-point of a thermometer with melting snow taken from air at a temperature below freezing-point, it gives the freezing-point too low unless saturated with water.

Standard Thermometers. — A standard thermometer, carefully investigated and all its corrections applied as described above, can be made to give temperatures with an accuracy of two one-hundredths of a degree from 0° to 100°. From 0° to −39°.8, the melting-point of mercury, the mercurial thermometer is trustworthy to 0.05 of a degree.

Common Thermometers. — Ordinary thermometers are graduated by reference to the temperature of freezing-point in melting ice, and by comparison with a standard at the temperatures of 52°, 72°, and 92°, the intermediate spaces being divided into equal parts. Above the temperature of 32° comparisons with a standard are made with the thermometers in water well mixed to keep it uniform in temperature throughout. Below 32°, and down to −28°, comparisons are made in alcohol cooled down by means of liquefied ammonia escaping from a reservoir through a coil in a vessel surrounding it and containing the alcohol. From −28° to −68° the cooling of alcohol for comparing thermometers is accomplished by means of evaporating nitrous oxide, or by ammonia in case there is means for pumping out the ammonia from the vessel and thereby inducing a brisk evaporation sufficient to produce the low temperature. The evaporation of ammonia or nitrous oxide induces intense refrigeration down to −100° or lower. The apparatus for this purpose is shown in Fig. 2.

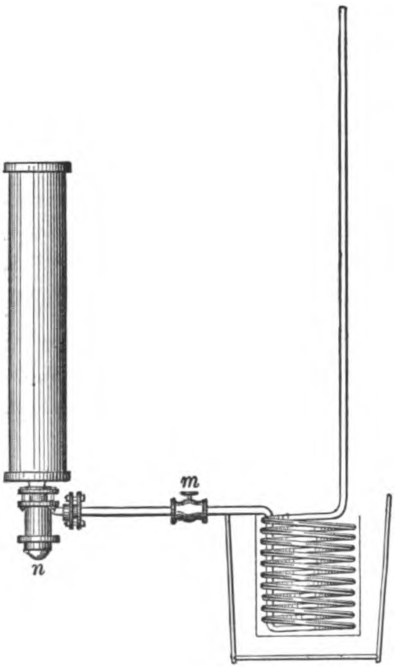


FIG. 2.

Low Temperatures. — For temperatures below the freezing-point of mercury alcohol thermometers are used, standardized by comparison at low temperatures with a gas-thermometer.

Cheap tin-case thermometers that sell for twenty-five cents apiece are fitted with ready-made scales. The thermometers are made in large numbers. A number of scales of different lengths are made, and one selected the nearest in length to a measured interval of temperature on a tube to be fitted; the distance taken is usually from 32° to 92°. Such thermometers are often in error as much as two degrees too high or too low at 70°, and often as much as five degrees at −30°, usually giving temperatures too low.

Maximum Thermometers. — The highest temperature occurring during the day is registered by a maximum thermometer. One form consists of an ordinary thermometer, with the bore of the tube near the bulb contracted, so that when cooling begins the thread of mercury separates, leaving the top of the column at the highest temperature reached. It is reset for observation again by whirling it on a pivot at the top of the metal strip to which the tube is attached. The centrifugal force developed drives the mercury back into the bulb.

When a thermometer of this sort is not read for several hours after the highest temperature occurs, by which time the air may have cooled down fifteen or twenty degrees, the highest recorded temperature may be half a degree too low from contraction of the detached thread of mercury in cooling.

When the fall of temperature is very slow, a little of the mercury will pass down at times before the thread breaks, especially when there is no wind to cause a slight jarring of the instrument.

In some instruments of this kind the narrowing of the bore develops a strong capillary action, and when the connection of the column is broken, the detached thread moves up a little, and causes the thermometer to register somewhat too high. This is apt to occur in winter, when the maximum temperatures are low and the detached thread short. It also occurs with long threads when the thermometer is nearly horizontal.

Another form of maximum thermometer consists of an ordinary mercurial thermometer with a detached thread of mercury an inch or so in length and an air-bubble interposed between it and the main column of mercury. A thermometer of this kind must have a very fine bore to work well, otherwise the index or detached thread is liable to be lost by joining on with the main column of mercury.

Minimum Thermometers. — For obtaining the lowest temperatures of the day, a minimum alcohol thermometer is used. An index, half an inch long, made of enamel is fitted loosely in the bore of an alcohol thermometer and immersed in the liquid. When the temperature falls, the index is carried along the bore and the top stops at the lowest point reached by the top of the alcohol column. It is reset for another observation by raising the bulb end of the thermometer and allowing the index to slide down the bore to the end of the column, where it stops. Jarring by the wind is apt to displace the index, and make the instrument read too low.

Gas-bubbles are apt to develop in the bulb or bore, and breaking the continuity of the column, make the instrument read too high. Small portions of the alcohol become detached at the top of the column, and remaining unnoticed for a time, cause the observed temperatures to be too low. The formation of these detached portions of alcohol can be prevented to some extent by wrapping tin-foil around the thermometer tube.

Detached alcohol can be reunited by repeatedly tapping the side of the instrument lightly on a block of wood with the bulb end held down, when the alcohol will gradually trickle down the tube in small streams.

An alcohol thermometer, under the most favourable circumstances, will not give temperatures with any greater accuracy than 0.6 of a degree. A mercurial thermometer, when it can be used, is always preferable to one with alcohol. For temperatures below the freezing-point of mercury, an alcohol thermometer must be used, and is preferable for that purpose to one filled with ether or bisulphide of carbon, which are sometimes used.

Thermometer à Marteau. — There is a form of alcohol minimum thermometer in which the index fits rather tightly in the bore of the tube. The tube contains a long piece of enamel below the index which moves freely when the instrument is inclined. The index is set for a new observation by hammering on the end with the long piece of enamel, whence the name from the French word "marteau" for a hammer.

Alcohol thermometers are liable to read too low by age, especially if much exposed to the direct light of the sun. Some change takes place in the nature of the alcohol or the impurities contained, which cause the formation of a thin skin on the inside of the tube which can be seen with a microscope. This sometimes causes a thermometer to read a degree too low. This masks the change due to contraction of the glass bulb with age. The change of freezing-point due to change in the glass is usually inappreciable in alcohol thermometers on account of the comparatively great expansion of alcohol, which is about six times that of mercury.

Solar Radiation Thermometer. — A radiation thermometer shown in Fig. 3 is a mercurial thermometer enclosed in a glass tube from which the air is exhausted. They are commonly used in pairs, one with the

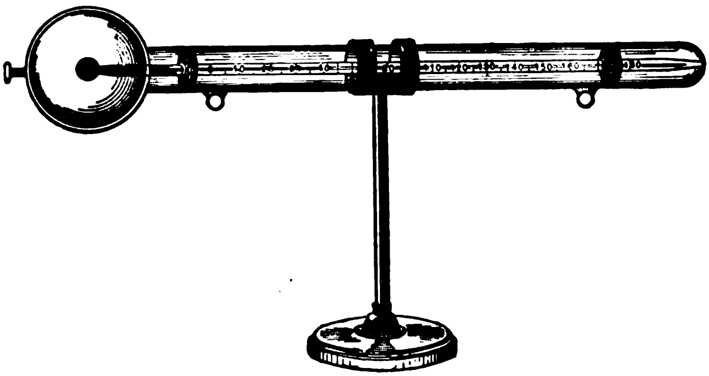


FIG. 3.

bulb blackened and the other bright. The instruments are known as bright and black bulb in vacuo. A black bulb will read in the sunshine from thirty to sixty degrees higher than the temperature of the air in the shade. The temperature to which the black bulb rises depends on the rate at which heat is received from the sun and radiated to the glass enclosure around the bulb. The glass bulb enclosure, about one inch and a half in diameter, is nearly at the temperature of the air in contact with it.

The bright and black bulbs are intended to get the difference in heating effect of the sun under different conditions of the air. When there is much moisture or dust in the air, more of the sun's heat is absorbed than when clear.

Not much of importance has yet been learned of the physics of the air from the use of these instruments. Different instruments are not strictly comparable. The results at one place cannot be compared with those at another. The readings are affected by the size of the thermometer bulbs, the thickness of the film of blacking, the thickness of the glass bulb of the enclosure, and on variations in its nature, not visible to the eye, some varieties of glass transmitting very much more of the sun's heat than others. Much also depends on the perfection of the vacuum. Instruments the same to all appearances may indicate temperatures different by six degrees when exposed in the sun side by side.

High up in the air, as on mountain-tops, the radiation thermometer in the sunshine may read as high as the boiling-point of water.

In the arctic regions in summer the difference in bright and black bulb is sometimes as great as ninety-six degrees.

The name "radiation thermometer" is also applied to an alcohol thermometer exposed on the ground in the night-time to get the radiation temperature of the soil. It is the same as the ordinary minimum alcohol thermometer, except that it has a glass tube over the scale to keep the dew from washing out the graduation marks. During the night it may take a temperature ten degrees lower than that of the air a few feet above the ground when the air is still.

Camphor Thermoscope. — A sealed glass tube containing camphor gum dissolved in alcohol is sometimes used to indicate changes of temperature. When the temperature is high, the camphor is all dissolved. When the temperature falls, the camphor crystallizes out, forming a flocculent, feathery-looking, whitish mass. Thermoscopes of this kind are sometimes sold mounted on the same board with a mercurial thermometer, and are erroneously supposed by some to indicate changing pressure, or electrical condition of the atmosphere.

Deep Sea Thermometers. — For deep sea temperatures, thermometers are used which register on being inverted by detaching a column of mercury. The thermometer is enclosed in a hermetically sealed thick glass tube, to protect it from the pressures at great depths, which would otherwise make it read too high or even crush the bulb to pieces. At a depth of three miles the pressure is two and a half tons to the square inch. The best form of the instrument is the Miller Casella.

Shape of Bulb.—Thermometers are made with bulbs of different shapes. The most common shapes are the cylindrical and spherical, the cylindrical bulb being the most popular form at the present time. A cylindrical bulb is usually more sensitive than a spherical bulb of the same volume, as it exposes more surface to the air. Spherical bulbs can, however, be blown thinner than cylindrical bulbs, and the glass is commonly more uniform in thickness than in cylindrical bulbs.

When the temperature of the air is changing rapidly, as in the case of observation during a balloon ascent, a thermometer must be sensitive to give a correct temperature. In fact, a correction must usually be applied for sluggishness in following the temperature of the air where the greatest accuracy is required.

Sensitive Thermometers.— A sensitive thermometer has been devised with a bulb about the dimensions of a coarse needle, but shorter. An instrument of this kind will give the temperature in a minute as accurately as one of the ordinary form in three minutes. A thermometer of this sort, having a very small quantity of mercury, the column, on account of its fineness, is very difficult to observe.

Magnifying Front.—This is obviated by having the bore of the thermometer well to the front of the stem, and the front very much curved. The effect of this is, that the column of mercury is magnified in width ten or twelve times, and can be seen very distinctly. Even with the bore in the centre of the tube, as it is ordinarily, the column of mercury, as viewed through the tube, is magnified two and a half times.

Thermometers are sometimes made with a flattened bore of elliptical section for ease in reading. It is not a good form. When the temperature is falling, the top of the mercurial meniscus is not flat but slightly slanting, and introduces errors in reading.

On rare occasions a thermometer will be found of which the indications are very puzzling without any apparent cause. This is due to the thermometer having two bores in the tube instead of one. The extra bore is unintentional, being an accident of manufacture, not discovered by the maker. The extra bore is often back of the enamel or in some other place equally difficult of discovery.

Centigrade Scale. — A thermometer with the interval from freezing-point to boiling-point graduated to one hundred parts, the freezing-point corresponding to zero, is on the centigrade scale, or Celsius scale, as it is sometimes called. The centigrade thermometer is in general use on the continent of Europe. The Fahrenheit scale is in common use in all English-speaking countries, the centigrade being only in use in laboratory work and in mathematical analysis.

Reaumur Scale. — A thermometer graduated to the Reaumur scale has the interval from freezing-point to boiling-point divided into eighty parts, and the freezing-point corresponding to zero. This scale is not much used any place now. There are, however, many valuable old temperature records in this scale.

De Lisle Scale. — In Russia, a century or more ago, the De Lisle scale was in use to some extent. The interval from freezing-point to boiling-point was divided into one hundred and fifty parts, and the freezing-point was taken as zero.

Thermometer Shelter. — To get the temperature of the air, the thermometer is set up inside of a cubical wooden lattice-work enclosure, called a "shelter." Sometimes the cube is eighteen inches on a side. The bottom is of close boards. The roof is also close and made double, one part being six inches above the other and open on two sides to admit of free circulation of the air. The object of a double roof is to prevent radiation to the thermometer bulbs from the roof boards heated directly by the sun's rays. The bottom of shelter is closed, to prevent any effect on the temperature of the thermometer by radiation, or upward warm currents from the roof of a building or the ground where the shelter is set up.

To get an accurate air temperature, a thermometer must be protected from the direct rays of the sun. There must be free ventilation inside the shelter, or the stagnant air will become heated from contact with the sides, which are heated by the direct rays of the sun.

A shelter is usually placed ten feet above a roof or the ground.

A shelter also protects a thermometer from radiating to the sky, and, in a measure, from the deteriorating effects of rain and snow on the instruments. Radiation to the sky is apt to make a reading of temperature too low, especially in the night-time. The ground is cooler than the air in the night, but the effect of direct ground radiation on a thermometer is usually inappreciable at a greater height than four feet above the ground.

Effects of sunshine and radiation on the temperatures shown by a thermometer are almost entirely removed by whirling it for three minutes before reading. A thermometer whirled in the sunshine gives a temperature about half a degree higher than in the shade.

A thermometer in quiet air in the sunshine may read ten degrees or more higher than the air temperature, depending on the strength of the wind prevailing. If the air is perfectly calm, the thermometer may even read twenty degrees higher than the air. If the wind is blowing twenty miles an hour, it will only read a few tenths of a degree higher than in the shade. Moving particles of air, coming in contact with the bulb, rapidly carry away by convection the heat received from the sun. When there is no wind the bulb creates a local atmosphere of warm air around it. The thermometer *in vacuo* shows that it is possible for a thermometer to become heated very greatly above the temperature of the air in the sunshine when all contact with the air is shut off. The record of a thermometer in sunshine has therefore no climatic or meteorological significance, for its reading depends at the same time on the strength of the wind as well as the temperature of the air.

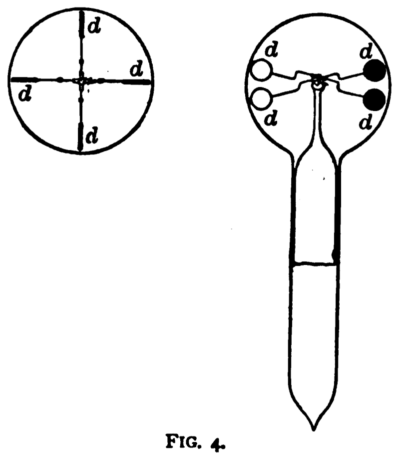


FIG. 4.

Radiometer. — Radiation of heat is illustrated by the radiometer shown in Fig. 4. Four light vanes of mica or aluminium on two cross-arms are set up, free to rotate in a glass bulb from which the air is almost entirely exhausted. One side of each vane is blackened. Black surfaces absorb heat better than bright ones. The greater amounts of heat received by the blackened sides as compared with the bright ones produce a greater repulsion on the black sides between the vane and the tenuous air than on the bright sides. The consequence is that, when exposed to any source of radiant heat, as the sun or a candle, there is a rapid rotation of the vanes. A candle held at a distance of four inches will produce a hundred and seventy revolutions in the time that two are produced with the candle at a distance of forty inches.

When the bulb contains air at the ordinary pressure there is no rotation of the vanes, as the feeble force developed is not sufficient to overcome the resistance of the dense air to the motion.

If the air is perfectly exhausted from the bulb, or if it is at least as free of air as an incandescent electric lamp, there is no motion of the vanes. The motion is at its greatest when the pressure of the contained air is about 0.012 of an inch.

The seat of the reaction of the rotating vanes is not at the source of heat, — the sun or candle, — but at the glass walls of the bulb, as shown by the fact that when the bulb is floated on water or delicately suspended in a vacuum it rotates in a direction opposite to that of the vanes, but much more slowly on account of its greater mass.

Actinometer. — An actinometer is an instrument for determining the amount of heat received from the sun on a surface of definite size in a given time. It consists of a mercurial thermometer with its spherical bulb in the centre of two concentric brass spheres. The space between the spheres is filled with water or chipped ice, so as to keep the enclosure around the bulb at a uniform temperature. An opening in the sphere permits of exposing the thermometer bulb to the rays of the sun and cutting them off at will. The thermometer takes on the temperature of the enclosure after it is within it for some time. When the sun shines on the bulb, its temperature rises. It warms up rapidly at first, then more slowly, and finally the temperature becomes stationary when the heat received from the sun is exactly equal to the heat radiated by the thermometer to the enclosure. The radiation is proportional to the difference in temperature between the bulb and the enclosure. The radiation increases as the temperature rises, until it becomes so great as to equal the rate at which heat is received from the sun. When the sun's rays are cut off, the temperature of the thermometer falls, rapidly at first, and then more slowly as its temperature approaches that of the enclosure. When the sun is shining on the thermometer, its temperature is increasing at a rate equal to the difference between the rate at which heat is being received by the bulb from the sun and the rate at which it is losing heat at the same time by radiation to the colder enclosure.

From a series of readings of the thermometer at intervals of a minute while exposed to the sun, and a similar series while cooling, the law of the heating and cooling as dependent on the time can be derived.

The rate of heating per minute, plus the rate of cooling per minute, is the rate at which heat is being received from the sun. This rate is usually expressed in centigrade degrees.

The dimensions of the bulb can be measured and the quantity of mercury contained in it computed and the area of the cross-section of the bulb ascertained.

The unit of quantity of heat is the amount of heat required to raise a cubic centimetre of water one degree centigrade.

To raise a given weight of mercury a certain amount in temperature takes only one thirty-third of the heat required to raise an equal weight of water the same amount. The specific heat of water being unity, that of mercury is 0.03. Mercury at 32° weighs 13.59593 times as much as an equal volume of water at the temperature of maximum density, 39°. By means of these figures, reducing the rate at which heat is received by the mercury of the thermometer-bulb from the sun to what it would be if the bulb contained water instead of mercury, and then dividing by the number of square centimetres in the cross-section of the bulb, the number of heat units is obtained, received from the sun in a minute on a surface of a square centimetre perpendicular to the sun's rays.

The amount of heat received in a minute on a surface of one square centimetre vertical to the sun's rays varies with the clearness of the air, and the height in the air at which the experiments are made. When suitable allowance is made for the amount of heat absorbed by the thickness of the air between the place of observation and the upper limit of the air, the number representing the solar-constant is obtained, which is about 3.0 gramme-calories.

BAROMETER.

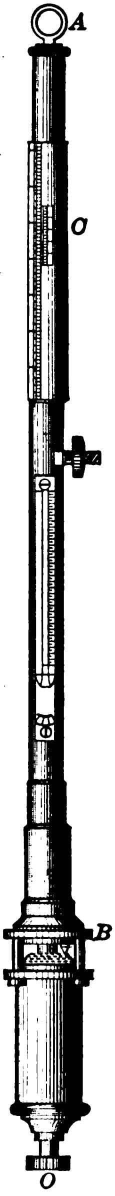


FIG. 5.

Air Pressure. — The air presses on everything at the surface of the earth with a pressure equal to the weight of the column of air above it to the limit of the atmosphere. Pressure is only noticeable to the senses in the case of sudden and very great changes, as in a balloon ascent or in ascending a mountain where there is a rapid decrease of pressure with the increase of height. The air pressures equal to two or three atmospheres experienced in the pneumatic chambers of bridge-caissons produce marked and peculiar sensations. Under a pressure of two atmospheres plants will not germinate and quickly die.

Barometer. — The barometer is an instrument for measuring the pressure of the air. The pressure is always expressed in an equivalent height of a column of mercury reduced to the temperature of freezing-point. The ordinary barometer shown in Fig. 5 is a glass tube closed at one end about 38 inches long and a quarter of an inch in internal diameter, enclosed in a brass sheath, with the open end dipping into a vessel, called the cistern, containing mercury which extends inside the tube up to a height corresponding to the pressure of the air. The vertical height of the top of column above the mercury in cistern is called the barometer reading. The instrument is suspended by the ring at *A*.

The height of the top of the column of mercury is perpetually varying with the changing pressure of the air. The barometer is set up by first filling the tube with mercury and inverting it with the open end immersed in the mercury in cistern, the end being closed temporarily with the gloved finger until immersed in the mercury. The mercury runs down the tube, when the finger is removed, oscillating back and forth until the column is of the right height to counterbalance the pressure of the air outside. In the tube above the mercury there is no air. This space is called the Torricellian vacuum.

Filling Tube. — A tube is filled by pouring three or four inches of mercury into the glass tube and boiling it in the tube so as to expel all the air adhering to the sides. The tube and mercury are heated slightly before the mercury is poured in. The tube is heated gradually by passing it to and fro through a flame. When the mercury boils and the tube is bright and free of all tarnish, three or four more inches of mercury are added after the tube has cooled down some. This is boiled as before, and so on, three or four inches at a time, until the whole tube is filled. The whole tube is not boiled at each addition of mercury, but merely the new portion added. An alcohol lamp with a broad flame is used in the boiling or a charcoal furnace. A good substitute for a lamp is a shallow earthenware dish holding salt or sand saturated with alcohol.

In filling barometer tubes pure mercury is used, prepared by distillation of commercial mercury in a vacuum. Numerous tubes are broken in this process of filling, and it is well to provide some means of saving the mercury in case a tube does break. The boiling should be done in the open air or at least in a room with free ventilation, otherwise the vapour from the mercury may cause salivation.

Only small tubes can be filled successfully in the way described. Large tubes, one inch in diameter, are almost certain to break if treated in this way. Even if they do not break in the process of boiling, they are sure to crack from flaws developing a few days or a week after.

A plan sometimes followed in filling tubes is to exhaust them of air in connection with a mercury-distilling apparatus, and allow the filling to take place gradually as the mercury distils over.

Measuring Pressure. — Measuring the pressure of the air by means of a barometer consists in ascertaining the vertical distance from the level of mercury in the cistern to the top of the column in the tube. As the pressure of the air changes, mercury is passing in or out of the tube and constantly changing the level of the mercury in the cistern. Before an observation of pressure is made, the level of the mercury in the cistern is brought to the ivory point shown at B, in the figure. This is done by means of the screw O at the bottom acting on the leather bag of the cistern.

The brass tube surrounding the glass tube carries a scale graduated to inches and tenths. The zero of the graduation is the ivory point in the cistern.

Vernier. — The reading of the scale at the top of the column of mercury is made by means of a vernier, as shown in Figs. 6, 7, and 8.

The vernier consists of a short tube sliding inside of the brass tube, and accurately adjustable to any position by a rachet motion worked

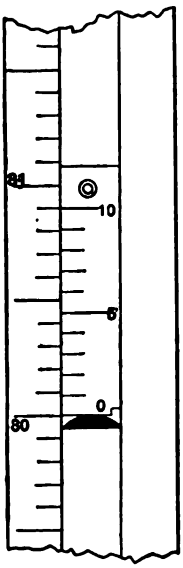


FIG. 6.

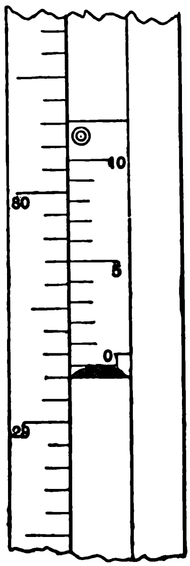


FIG. 7.

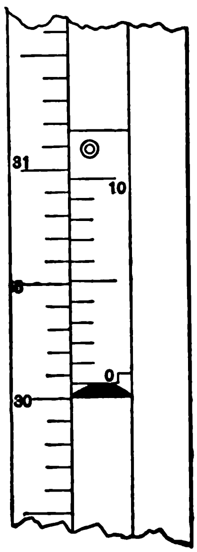


FIG. 8.

by a milled-head screw on the side of tube. In observing a pressure, the lower edge of the vernier is brought tangent to the top of the rounding end of the column of mercury, which is called the meniscus. A space of nine-tenths of an inch on the vernier, from the bottom, is graduated to ten equal parts. Each interval is therefore about 0.09 of an inch.

If the first mark above the bottom of the vernier coincides with a scale division, the intervals on the barometer scale being 0.10 of an inch, it shows that the top of the column of mercury is 0.01 of an inch above the even division on scale. If the second mark corresponds with a division on scale, it shows that the top of column is 0.02 of an inch above an even division, and so on for the third, fourth, fifth, etc., marks on the vernier.

When there is not an exact correspondence between any particular mark and division, then two marks of the vernier are inside of two division marks on the scale, and the reading is to be taken as half-way between the two one-hundredth marks, or to the nearest half-hundredth or 0.005 of an inch. The verniers in the figures read 30.000, 29.250, and 30.055 inches. The limit of accuracy of pressures obtainable with a portable barometer is about 0.005 of an inch.

Suspension. — The barometer when in use is suspended by a ring at the top of the brass tube and allowed to hang freely. The scale of the barometer is set, on leaving the marker's hands, so as to read the same as a standard barometer. In small tubes, only a quarter of an inch in diameter, the capillary action between the glass and the mercury depresses the surface of the mercury 0.04 of an inch. Setting the instrument by reference to a standard is equivalent to allowing for capillarity. The depression is greater the less the diameter of the tube. It is inappreciable (less than 0.0004 of an inch) for a tube 1.2 inch in diameter.

Repairs or alterations to the suspending ring of a barometer or the addition of any unsymmetrically disposed weight, as for instance a new and heavier attached thermometer after the instrument is standardized, may cause the axis of the barometer to hang in a slightly different position from what it did before. A displacement of the axis equal to three degrees in a direction from the centre of the tube toward the ivory point may make a difference of 0.04 of an inch in the reading, depending on the horizontal distance from the centre of the tube to the ivory point. This is a common source of error in barometers.

Standard Barometer. — A standard barometer is the same in principle as the instrument described. The tube is heavier, — half an inch or one inch or more in diameter. For measuring the differences in level of the surfaces of mercury a cathetometer is used, which consists of a pair of microscopes moving up and down on a steel bar. When the cross-wires of microscopes are adjusted to the heights of the mercurial surfaces, the steel bar is revolved so as to transfer the distance to a graduated scale. Great precautions are taken to have pure mercury in a standard barometer, and to have all air excluded from the space above the column of mercury. A number of tubes, if at least half an inch in inside diameter, will, on careful comparison, without any standardizing, give pressures agreeing within 0.005 of an inch.

Reduction for Temperature. — Barometers observed at different temperatures require reduction to a common temperature before the observations are strictly comparable as pressures. The temperature selected is the freezing-point. An attached thermometer at the middle of the barometer gives its temperature.

As the cubical expansion of mercury is about ten times as great as that of brass, the reduction for temperature is minus at ordinary temperatures, or the barometer readings are too high. The reduction is minus down to 28°, where it changes, for lower temperatures, to plus. The reason the turning-point is not at 32° is because the scale-length is reduced to a temperature of 62°, for which measures of length are standard, and the mercury to freezing-point, the whole correction to the reading being the difference of the two corrections.

Place for Barometer. — A barometer should be kept in a room of nearly uniform temperature. In heated rooms in winter there is often a difference of ten degrees or more between the top and bottom of a barometer. The attached thermometer in such a case does not give the average temperature of the barometer accurately. An error of one degree in the temperature introduces an error of 0.003 of an inch in the derived pressure.

Correction for Height. — As the pressure of the air varies with height, the observed pressures at different places, to be comparable, must be reduced to a common level. The level of the sea is usually selected for this purpose. For a height of 1000 feet above sea level the reduction when the temperature of the air is 60° is 1.06 inches to be added; at 30°, 1.12.

Gravity Correction. — As the intensity of gravity varies with latitude and height above sea level, the same pressures are represented by slightly different lengths of columns of mercury in different places. The reduction to latitude 45° and sea level is called the gravity correction. For a pressure of 30 inches, if observed at the equator, the corection is 0.078 of an inch to be subtracted; at the pole the same amount is additive. For a height of one mile above sea level, where the pressure is 25 inches, the reduction is about 0.012 of an inch to be subtracted.

Aneroid Barometer. — An aneroid barometer, shown in Fig. 9, consists of a metal box from which the air is exhausted, and a steel spring in the form of a folded leaf. The corrugated top of the box, of very thin and yielding metal, is fastened to the upper side of the spring. The bottom of the box is fastened to the lower end. The top of the

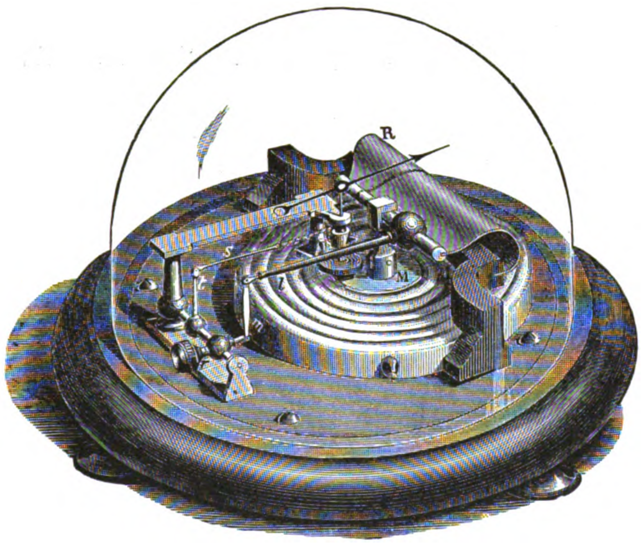


FIG. 9.

box exposes three or four square inches of surface to the air. The pressure of the atmosphere on this is from 40 to 60 pounds. It is sustained by the spring, which yields as the weight varies with the changing pressure of the air. A system of levers transfers and magnifies the motion of the end of the spring to an index which moves around a dial.

Compensation for Temperature. — Aneroids are graduated by reference to a mercurial barometer.

The elasticity of springs varies with temperature. A given weight will pull down a spring more at a high temperature than at a low one. In the best forms of aneroids an adjustment for temperature is introduced by making one of the transmitting levers a compound metal of steel and brass. The compensation for temperature is only rarely accomplished with accuracy, and is a mere accident when it does occur. A change of twenty-five degrees will often cause the pressure indication to vary 0.10 of an inch without any actual change of pressure, in some instruments one way and in others in the opposite way.

A compensation is sometimes attempted by leaving some air in the metal box. As the spring weakens at a high temperature, the increased pressure of the air inside the box counterbalances it to some extent. This is ineffectual as a compensation.

The tension of a spring not varying with latitude, aneroid barometers need no gravity correction.

The aneroid is not as good an instrument for indicating pressures as a mercurial barometer. Changes take place in the nature of the spring with age and extreme variations of pressure, which cause its indications to vary slightly, independently of variations in the pressure of the air. In three years the pressure indication of an aneroid will increase 0.08 of an inch. It requires constant correction and control by reference to a standard mercurial barometer. After subjection to a low pressure, as in a mountain ascent, an aneroid does not recover its original reading at once for ordinary pressures. After lowering to a pressure of 18 inches, its reading will be 0.3 of an inch lower when brought back to a pressure of 30 inches than it was before. The original reading is, however, recovered in a few weeks. There is a slow progressive rise with age in the pressures indicated by an aneroid. The instrument, however, on account of its convenience, is used a good deal in rough determinations of altitudes. It is rarely used in meteorological observations.

The words "fair," "stormy," "rain," etc., sometimes to be seen on aneroids, have no real significance as regards the weather, being a device intended to help the sale of the instruments.

Hypsometer. — The boiling-point of water is lower in temperature the less the pressure of the air. While the boiling-point is 221°.0 at a pressure of 29.922 inches, it is only 187°.5 at a pressure of 18 inches. This fact is sometimes made use of in determining pressure, especially in the measurement of altitudes in mountain ascents. A thermometer with its boiling-point apparatus, when used for this purpose, is called a hypsometer. Thermometers for this purpose are made short for convenience in carrying, and are only graduated from about 160° to 214°. Such a thermometer should also have some graduation in the vicinity of the freezing-point. An enlargement of the tube between the freezing-point and the graduation of 160° will permit of this without having the thermometer stem of an inconvenient length. After an observation, due allowance for the change of freezing-point of the instrument will greatly improve the accuracy of the temperatures observed, and consequently also of the pressures derived.

Vapour Pressure. — Vapour of water exerts a pressure in the air. Like the other constituents, it is transparent and only becomes visible on changing to fog or cloud, which is water in a very fine state of division, the particles varying in diameter from 0.0006 to 0.0050 of an inch.

Saturation. — The quantity of moisture that can exist as vapour in the air depends on its temperature. There is a certain pressure of vapour corresponding to every temperature, which cannot be exceeded. This is called the pressure of saturation for the temperature. If the temperature is diminished, part of the vapour is thrown down as fog, rain, or dew. The temperature at which this begins is called the dew-point. This property of vapour is made use of in determining the pressure of vapour in the air. The number of degrees the dew-point is below the air temperature is called the depression of the dew-point. The dependence of vapour pressure and temperature has been thoroughly investigated by skilful experimenters, on account of its importance in the theory of the steam engine.

The saturation pressure in inches, and weight of vapour in a cubic foot of air in grains, at temperatures ten degrees apart, from 0° to 100° F., are as follows: —

Temperature,	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
Pressure, inches,	0.045	0.071	0.110	0.166	0.246	0.360	0.517	0.732	1.022	1.408	1.916
Weight, grains,	0.54	0.84	1.30	1.97	2.86	4.09	5.76	7.99	10.95	14.81	19.79

The quantity of water in the air is nearly proportional to the vapour pressure. The air is rarely perfectly saturated, not always even when rain is falling. Neither is the air ever perfectly dry at any place.

Relative Humidity. — The vapour pressure actually prevailing in the air, divided by the vapour pressure at saturation for the temperature of the air, is the relative humidity. It is expressed in percentage of saturation. For perfectly dry air, the relative humidity would be zero; for saturation, one hundred. Relative humidity only expresses relative amounts of moisture in the air for the same temperatures. At a low temperature, a high relative humidity represents a very small actual amount of vapour in the air, while a low relative humidity at a high temperature may represent a great quantity. For instance, a relative humidity of 90 at a temperature of 30° corresponds to a vapour pressure of 0.149 of an inch, while 50 per cent at 80° corresponds to a pressure of 0.511, or more than three times as much. Relative humidities have, therefore, no significance as representing actual quantities of moisture in the air at different times and places.

Dew-point Apparatus. — A dew-point apparatus consists of a thin brass tube, one inch in diameter and six inches long, silvered or gilt on the outside. A thermometer fitted in a cork or rubber stopper has its bulb inside the tube, with the stem projecting. A quantity of some volatile liquid, as rhigolene or ether, is contained in the tube so as to cover the thermometer bulb. Openings in the cork contain tubes, one of which dips into the liquid, and the other has its end some distance above the surface of the liquid. By means of these tubes, a current of air is blown or aspirated through the liquid, and evaporation induced, which lowers the temperature of the liquid and the tube containing it. When the temperature of the dew-point is reached, a film of moisture forms on the polished surface of the tube. The temperature then shown by the thermometer is that of the dew-point of the air.

When the temperature of the dew-point is very much below that of the air, there has to be a lowering of the temperature of the liquid considerably below the dew-point in order to make an appreciable deposit of dew. For this reason, the temperature given by the thermometer is usually slightly lower than that of the true dew-point. As soon as the film of moisture is seen to form, the aspiration or blowing is stopped. Immediately the temperature begins to rise, and soon the film disappears. The mean of the temperatures at the times of appearance and disappearance of the film is usually taken as the true temperature of dew-point. These may differ as much as 0.6 of a degree.

The dew-point being known, the vapour pressure in the air can be found from suitable tables.

The dew-point apparatus is not used extensively in the regular work of determining vapour pressures, on account of the inconvenience of its use and the expense in the use of liquids. It is only used in the fundamental operation of standardizing psychrometers. For small depressions of dew-point, at ordinary temperatures, ammonia water can be used with brisk aspiration to produce a lowering of temperature. A brass tube, however, will be corroded by ammonia.

Psychrometer. — Evaporation from a water surface into the air takes place to a greater or less amount, depending on the dryness of the air, the rapidity with which the air over the surface is renewed, and upon the temperature of the water. Evaporation produces cooling. This property is taken advantage of to determine the vapour pressure in the air. A mercurial thermometer with a wrapping of muslin on its bulb, kept saturated with water, when read in connection with an ordinary dry thermometer, can be used for determining the pressure of the vapour in the air, and is then called a psychrometer. Water evaporating from the muslin cools the bulb. The dryer the air, the greater the evaporation and the greater the amount of cooling.

From a comparison of the indications of a psychrometer and a dew-point apparatus at the same time, it is ascertained that the vapour-pressure at the dew-point of the air is equal to the vapour pressure corresponding to the temperature of the wet bulb thermometer, minus the number 0.011 multiplied by the difference in degrees between the dry and wet bulb thermometers. This applies for a pressure of the air equal to 30 inches, and when the psychrometer is whirled. The quantity to be subtracted increases slightly with the pressure, and also with the difference between the dry and wet bulb.

The results for vapour pressure, obtained with a psychrometer, differ a little in still air, according as the bulb of the thermometer is spherical or cylindrical; they also depend on the absolute size of the bulb, and whether the stem is large or small, and whether or not the muslin is wrapped about the stem for some distance above the bulb, so as to cool it as well as the bulb and prevent conduction of heat from the stem to the bulb. All of these effects are obviated, and instruments of the most diverse shapes become comparable, when the psychrometer is whirled before readings are made, so as to keep up a brisk renewal of air around the bulb.

Where the greatest accuracy is required, the most minute corrections of the thermometers have to be applied. Small errors in the temperatures affect the deduced vapour pressures very much, especially at low temperatures. The thermometer readings should be corrected for the difference of temperature between the bulb and stem. No existing psychrometer tables, however, are constructed on that plan.

In the case of a still psychrometer about freezing-point the wet bulb, or bulb with a coating of ice on the muslin, is apt to read half a degree higher than the dry bulb. This difference is done away with also by whirling.

When there is a very thick coating of ice on the bulb, the contraction being greater than that of glass, there is an effect of compression which may cause an ice-covered bulb to read several tenths of a degree too high. This does not occur unless the ice around the bulb is heavy and continuous.

The vapour from ice at a temperature of 32° is of less pressure than from water of the same temperature.

Hair Hygrometer. — A human hair, when freed of oil by soaking in ether for twenty-four hours, has the property of changing its length by about one-thirtieth part between a very dry and very moist condition of the air at ordinary temperatures. A length of about 12 inches is usually mounted in a light brass frame, the lower end wound once around a pulley and stretched by a weight of about one gramme. As it varies in length, the pulley turns, moving an index along a scale graduated to represent relative humidities. It is graduated by reference to a dew-point apparatus or a psychrometer. The hair hygrometer is not an accurate instrument, its indications being complicated with temperature.

Rainfall. — A rainfall is measured as the depth of water it would form on the ground were it all to remain as it falls. In the case of snow, its depth is the depth of water it would form if melted. Rainfall, snowfall, and hail are known by the general designation of precipitation. It is always preferable to measure snowfall as depth of "melted snow" rather than only as depth of snow, but if possible both should be used. The specific relation between depth of snow and depth of "melted snow" varies from $\frac{1}{7}$ to $\frac{1}{34}$ in different cases, depending on the saturation of the snow. The factor $\frac{1}{10}$ is, however, commonly used to reduce depth of snow to depth of melted snow when it cannot be melted for measurement.

Rain Gauge. — For the measurement of rain a rain gauge, shown in Fig. 10, is used. It consists of three parts. The top is a funnel-shaped piece of galvanized iron with a vertical rim of brass, its inside diameter being 8 inches. It fits into a cylinder of galvanized iron 8 inches in diameter and 20 inches deep. Inside of this is a brass cylinder 20 inches long and the area of its interior cross-section just one-tenth that of the brass rim or funnel. All the rain falling over a surface equal to the section of the rim is gathered and runs into the brass tube. The depth of water in the tube is ten times the depth of the rainfall.

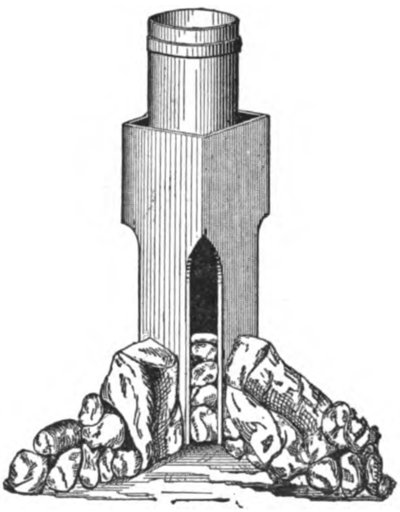


FIG. 10.

The depth of water is measured by dipping into it a thin cedar stick graduated to inches and tenths. On withdrawing it, the depth of water can be seen on the wetted part of the stick.

When the rainfall exceeds two inches, it runs out of the tube into the galvanized iron cylinder called the overflow.

Snow Gauge. — A snow gauge is simply a galvanized iron cylinder 8 inches in diameter. Usually a rain gauge is used in measuring snow which is melted before measuring.

The depth of rainfall collected by different rain gauges varies slightly with the size of the gauge. The larger the size the better, but there is very little advantage gained by a size greater than 8 inches. Funnels of 4 inches in diameter are too small, and do not give as great a depth of rain as larger ones.

Rain-gauge Exposure. — Rain gauges in slightly different positions differ greatly in the depth of rain indicated. Within a few yards of each other, the depth in a single rain-storm will sometimes differ 20 per cent, as shown by two gauges. The stronger the wind, usually, the greater the differences between gauges. In an exposed situation a wind creates eddies which divert the rain that would otherwise fall into the gauge. A gauge near the edge of a roof, on the windward side of a building, shows a markedly less rainfall than one in the centre of the roof. This is due to an ascending current vertically along the wall, spreading slightly over the edge and carrying away some part of the rain.

Forests intercept from 6 to 15 per cent of the rainfall by the leaves and branches of the trees.

A rain gauge at a height of 43 feet collects only 0.75 as much rainfall as one at the ground; at 85 feet, 0.64; and at 194 feet, 0.58. These differences are purely the effects of wind currents.

A fence three feet high around a gauge at a distance of three feet will cause it to collect six per cent more rain than when unprotected.

Percolation Gauge or Lysimeter. — An instrument for measuring the amount of rainfall that reaches different depths in the earth is called a percolation gauge or a lysimeter. It consists of an iron vessel three feet in diameter and three feet deep, filled with earth, and imbedded in the earth with its top surface level with the ground, and means provided for drawing off the water that collects at the bottom. The amount of rainfall that reaches a depth of three feet is about one-third or one-fourth of the annual rainfall at the surface of the ground; it varies with the nature of the soil. The maximum occurs at a different time of year from that at the surface.

Anemometer. — The velocity of wind is usually stated as the number of miles per hour travelled. Sometimes the intensity of wind is stated as the pressure exerted in pounds on a surface of a square foot. An anemometer is used for measuring the velocity of the wind. The form known as Robinson's anemometer is shown in Fig. 11, and is the form in general use.

The common form, the pattern used in the United States Weather Bureau, has hemispherical cups four inches in diameter on cross-arms, the centres of the cups 6.72 inches from the intersection of the cross-arms or centre around which they revolve. The cross-arms are fastened to an axis or spindle, free to rotate. A screw on the lower end of axis works a system of dials, so arranged as to register approximately in

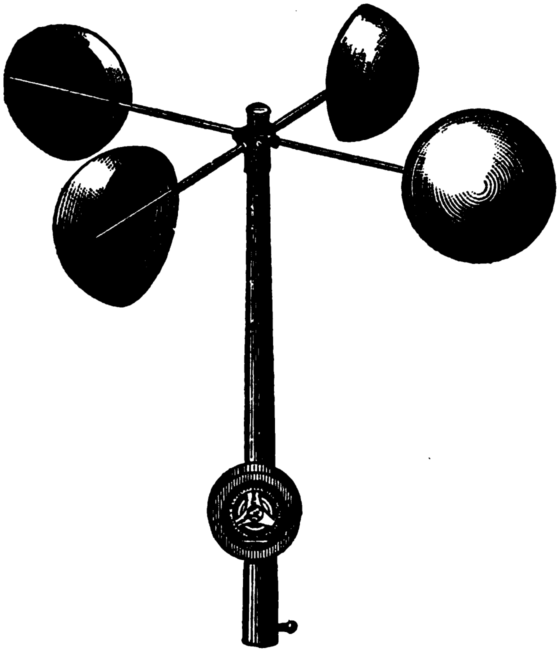


FIG. 11.

miles by the rotation of the cups the number of miles travelled by the wind. The difference in the pressure of the wind on the rounded and hollow sides of the cups at the ends of the arms cause the cross-arms and axis to rotate. The pressure on the hollow sides is greater than on the rounded. The dials are geared to register a mile for every five hundred turns of the spindle. This is equivalent to assuming that the wind travels three times as fast as the centre of the cups.

Corrections of Anemometers. — As a matter of fact the ratio between the wind and cup velocity varies with the size and inertia of the cups, the length of the arms, and the greater or less velocity and irregularity of the wind. At high velocities the ratio is less than at low velocities. In the form described the registered and true velocities have the relation given below, as shown by Marvin's experiments. The average ratio for ordinary velocities is 2.73 instead of 3.00, as is assumed in the dialing of the instrument to indicate miles travelled by the wind.

Registered velocity, miles per hour,	10	20	30	40	50	60	70	80	90
True velocity, miles per hour,	9.6	17.8	25.7	33.3	40.8	48.0	55.2	62.2	69.2

These results were ascertained by whirling an anemometer at different velocities, attached to the end of an arm 32 feet long, and comparing the registered with the actual velocity, known by counting the revolutions of the arm.

Wind Pressure. — The wind pressure in pounds per square foot on a surface is equal to 0.004 multiplied by the square of the velocity in miles per hour.

Beaufort Scale. — The velocity of wind at sea is estimated on a scale of numbers from 1 to 12, depending on the amount of sail a ship is capable of carrying in the different winds. The scale in common use is known as the Beaufort scale. The corresponding velocities in miles per hour have been ascertained by comparison of estimates of the wind on sea with wind velocities observed with anemometers on shore in the vicinity at the same time. The estimates on the scale are made, for the most part, according to the commotion the wind causes in the water or the rigging of the ship. The velocities are, of course, not as accurate as those obtained with an anemometer.

Wind Force. Beaufort Scale.		Velocity. Miles per hour.
0	Calm	0
1	Light air	3
2	Light breeze	13
3	Gentle breeze	18
4	Moderate breeze	23
5	Fresh breeze	28
6	Strong breeze	34
7	Moderate gale	40
8	Fresh gale	48
9	Strong gale	56
10	Whole gale	65
11	Storm	75
12	Hurricane	90

The above velocities, not being corrected for the errors of anemometer, are probably too large. The English Meteorological Service anemometers, on which these velocities are based, are of a larger pattern than those in use in the United States. The coefficient for 30-mile velocities is probably 2.40, as shown by Dohrandt's experiments, instead of 3.00, for which the English instruments are geared and dialed.

Storm Wind. — A storm wind at sea is 50 miles an hour, uncorrected velocity. This is the limit adopted by the English Admiralty Courts as the lowest for which a vessel can be excused on account of stress of weather in cases of non-fulfilment of contract in a specified time, as a common carrier, or in which insurance claims for damages can be allowed. A sea-worthy vessel is presumed, at the lowest, to be able to weather a wind velocity of 50 miles an hour.

Wind Vane. — The wind vane for observing the direction of the wind is the oldest form of meteorological instrument, being in use at Athens before the Christian era. It consists of an arrow on an upright rod, free to revolve and take the direction of the wind. The common form used in meteorological observatories is six feet long. The back half is of wood, ten inches wide, split down the centre, and spread to an angle of ten degrees. This diminishes the oscillation of the vane in a strong wind. The front part of arrow is an iron rod with a spear-head. A metal ball slides along the rod, and can be fastened in position to make the arrow balance on the centre around which it revolves. The arrow takes the position which exposes the least amount of surface vertical to the direction of the wind.

In speaking of the direction of the wind, the direction from which the wind comes is always meant. In meteorological observations the direction is usually taken to the nearest forty-five degrees on the circle, or half-way between the cardinal points of the compass, — north, south, east, and west.

Self-register. — In connection with an anemometer a self-register is commonly used, which saves the trouble of going to the roof of a building to consult the dials of the instrument. One is shown in Fig. 12. The anemometer self-register consists of a small drum 4 inches in diameter and 4 inches long, holding a fillet of paper. It is revolved by clock-work. An electric circuit extends from the register to the anemometer on the roof of building. Every mile registered by the anemometer completes the circuit and brings down an armature to which is attached a pencil, marking on the paper, making a notch in the continu-

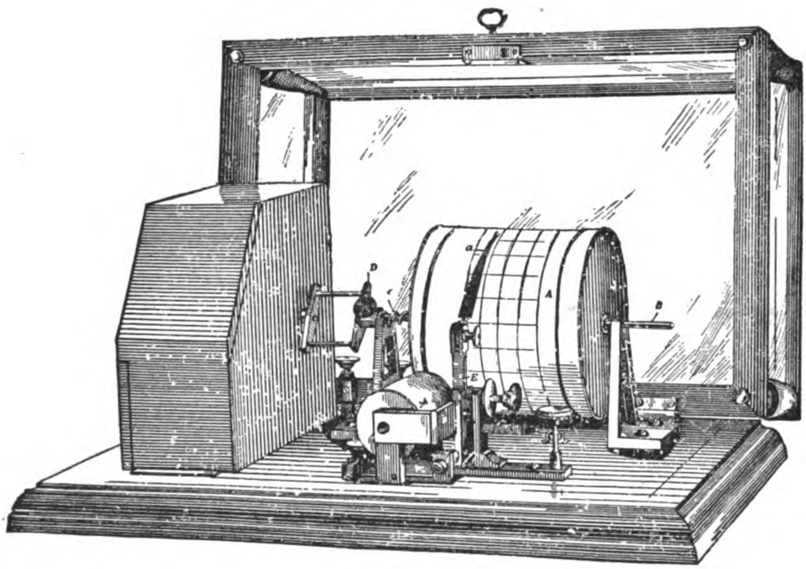


FIG. 12.

ous lead-pencil line. The process is repeated whenever a mile is completed. By counting the number of notches for a certain time, the velocity of the wind can be derived.

The velocity of the wind is usually taken as the rate at which it has been travelling for five minutes before the time of an observation. If, for instance, in the five minutes preceding eight o'clock in the morning the wind travel was 5 miles, the velocity was 60 miles an hour.

Anemograph. — For recording the direction of the wind a device called an anemograph is used, somewhat similar to the anemometer described above for recording wind velocity.

Pluviograph. — An instrument which records the rainfall, the simplest working by the rising and falling of a float attached to a pencil-marking on a sheet of paper, is called a pluviograph.

Self-registering Instruments. — Besides the forms of self-registering instruments described, there are various other forms for recording temperature, pressure, and humidity, both electrically and by photography, and in other ways. These are called thermographs, barographs, etc. The sheets of paper containing the records are called thermograms, barograms, etc. Instruments of this sort are often of complex construction, and costly. To keep them in working order requires the constant attention of a skilled mechanician. Great labour is required to turn their indications into numbers, before the results are of any use.

Cloud Motion. — A nephoscope, shown in Fig. 13, is an instrument used in observing cloud motion. One form of this instrument consists of a brass circle with divisions to five degrees. Inside the circle is a mirror. Two wires at right angles, intersecting at the centre, can be moved in any position around the circle. On the side of the circle there is a metal post with a knob on top. The post is hinged so that it can be inclined in any position, or shut down when the instrument is not in use. In use on land, the instrument is fixed with the zero of the circle graduation in some known direction as the meridian, or in an east and west line. For use on shipboard, the instrument is made with a circle of the silvering removed from the mirror, so that with the changing direction of the ship the zero of the nephoscope can be constantly referred to a compass needle placed beneath it.

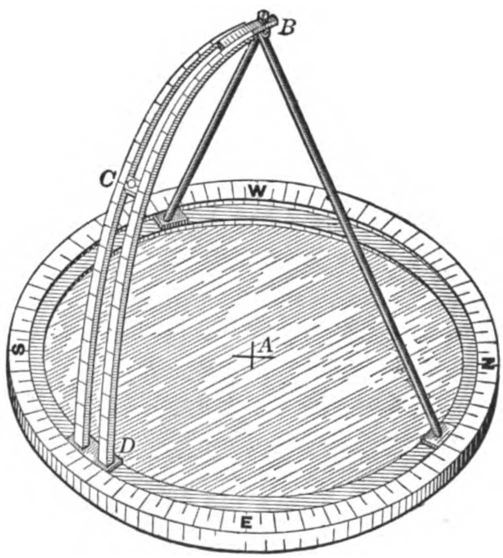


FIG. 13.

To observe the direction of motion of a cloud, the eye is so placed as to see constantly the reflection of the knob at the intersection of the cross-wires. The cross-wires are moved into such a position that a selected point on a cloud is seen to move along one of the wires. The direction of the wire, as indicated on the circle, is the direction of motion of the cloud. On some instruments there are concentric circles on the mirror; noting the times of transit over these circles, the angular velocity of the cloud can be derived. If the height of the cloud is known, its linear velocity can be computed.

From the observation of clouds at sea, the direction of motion and the rate of motion of the ship being known, the linear velocity and the heights of the clouds can be computed.

Amount of Cloudiness. — The amount of cloud is estimated by the eye, according to the fractional part of the sky covered. The estimate is made to tenths, sometimes only to quarters. On the first scale 10 indicates a sky wholly overcast; on the second scale the same condition is indicated by 4.

Sunshine Recorder. — For finding the number of hours the sun has been shining, an instrument called a "sunshine recorder" is used, shown

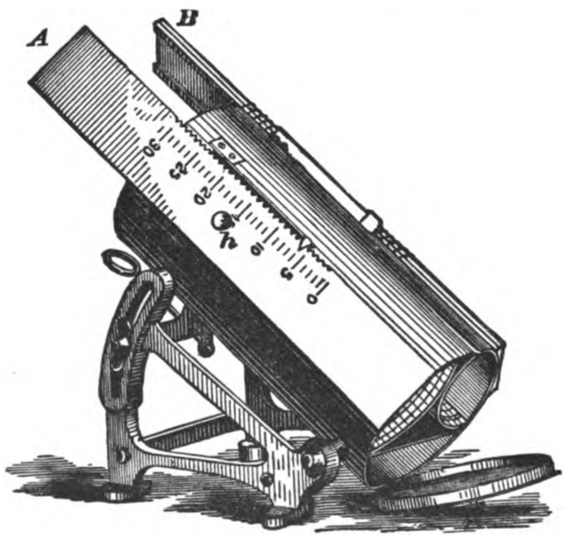


FIG. 14.

in Fig. 14. This is the photographic sunshine recorder. A half-cylindrical closed box contains a sheet of sensitized paper. The image of the sun is formed through a pin-hole. As long as the sun shines, a continuous line is traced on the paper. By one turn of a screw each day, the pin-hole is pushed along about one-fourth of an inch. One sheet of paper holds a record for a month. Another form of sunshine recorder consists of a glass sphere 4 inches in diameter set in a metal cup. A strip of paper, with rulings representing hours, is bent around the sphere. The sphere, acting as a lens, burns or scorches the paper, making a record of the number of hours' duration of sunshine.

Atmometer or Evaporometer. — Depth of evaporation from a surface of water is measured by means of an evaporometer or atmometer. A common form consists of a round dish a foot in diameter and four inches deep. The loss by evaporation is ascertained by weighing, or by means of a graduated scale inside the dish. The scale is inclined so as to give a magnified reading of the fall of surface. The vessel is kept in the open air. Readings of the scale are made at intervals of a day. Wind and rain interfere with the observation.

The Piche evaporometer is shown in Fig. 15. It consists of a glass tube about 9 inches long and 0.4 of an inch inside diameter, graduated to equal volumes. It is filled with water and the end covered with a paper disk 1.2 inch in diameter, held in place by a metal plate attached to a spring on a slitted brass collar which moves easily along the tube. The water is fed down from above by gravity to the paper, from which it evaporates both on the upper and under side. The amount of evaporation in a given time is found by taking the difference in the readings of the top of the column of water in the tube. A paper surface gives off one-third more water than an equal extent of water surface in a dish, in the same interval of time.

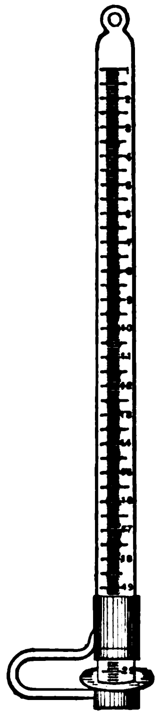


FIG. 15.

For an exposed paper surface of 11 square centimetres the number of cubic centimetres of water evaporated, multiplied by 0.068, gives the depth of evaporation in centimetres; multiplying by 0.0269 gives the depth in inches.

With a wind velocity of 5 miles an hour evaporation is 2.2 times as great as in a calm; with 10 miles, 3.8; with 15 miles, 4.9; with 20 miles, 5.7; with 25 miles, 6.1; with 30 miles, 6.3 times as great as for a calm.

Electrometer. — A quadrant electrometer, shown in Fig. 16, is used for measuring the difference in electric potential between the ground and the air at a height. It consists of a cylindrical metal case about 6 inches in diameter and 8 inches high surmounted by a glass tube 8 inches long and 1 inch in diameter. There is a circular glass window above the cylinder one inch and a half in diameter. A "needle," or disk, made of thin aluminium for lightness, is suspended through the tube and cylinder by means of a light platinum wire. Above the needle there is a convex mirror, and below the mirror, on the same wire, are three or four cross-pieces of wire, or a disk, which in hanging down through the cylinder dip into a dish of sulphuric acid at the bottom. The resistance of the liquid to motion of the cross-pieces immersed in it diminishes the oscillation of the suspended needle and brings it to rest when set in motion. The sulphuric acid serves also to keep the inside of the electrometer dry and preserve the insulation of the glass tube and the glass pillars sustaining the quadrants. A film of moisture on a non-conducting substance conducts electricity to some extent.

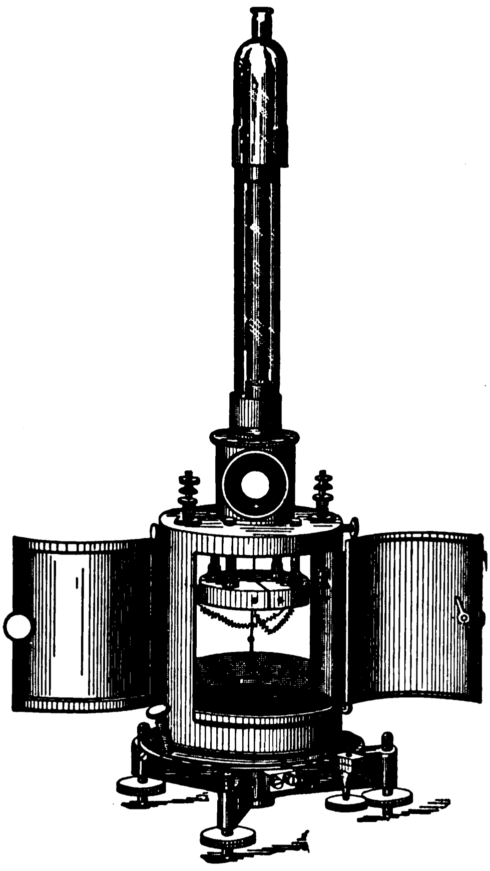


FIG. 16.

The quadrants are fastened to the top of the electrometer inside by glass pillars. The quadrants are two pieces of brass joined at the rounded edges with an interval of $\frac{1}{4}$ of an inch between them. The quadrants are $\frac{1}{8}$ of an inch apart; and the diagonally opposite pairs are joined by a wire.

When ready for use the needle is suspended inside the quadrants but not touching them. The electrometer works on the principle of repulsion of electricity. One pair of quadrants is joined by a wire to one pole of a battery of fifty cells, the other pair to the other pole. The needle is connected with a source of electricity to be measured. When the needle takes on a greater or less charge of electricity it turns through a greater or less angle. The connection of the needle with a source of electricity is by means of a wire leading from the place and dipping into the sulphuric acid, or through the suspending wire by the brass cap at the top of the glass tube. The resistance to the rotation of the needle is in the torsion of the wire.

The turning of the needle is noted by the reflection of a spot of light from the convex mirror. A lamp is so arranged that a beam of light thrown on the mirror is reflected back to a scale at a distance of about three feet from the electrometer. As the mirror turns, the spot of light moves along the scale. The higher the potential of the source of electricity, the greater the deflection of the needle, until it becomes so great that a spark flies between the quadrants and the needle.

A vessel insulated in some high position is used for obtaining the potential of the air. The vessel is filled with water, or sand in cold weather, which, as it falls from the vessel, enables it to take on the potential of the air where contact with the vessel is broken. By a connecting wire the potential is transferred from the vessel to the needle. Where the wire is supported at any points between the vessel and electrometer, it has to be well insulated. Insulators of a special form are used for this purpose, consisting of a rod of glass with a bell-shaped glass surrounding the rod and containing sulphuric acid inside to keep the glass rod free of any coating of moisture. The water-dropper is also insulated by a special form of glass insulating support. The potential of the air is determined by comparing it with a source of some known potential, such as a large number of cells of battery joined in series.

River Gauge. — A river gauge is used for ascertaining the height of river surface above some arbitrarily selected plane, usually at or somewhere near the lowest water that occurs at a place. The reading of the water surface on the gauge to feet and tenths is called the stage of water, or the river stage, and expresses the height of water surface above low water. When possible, without too great expense, a river gauge is made vertical. A bridge pier makes the most desirable location for a river gauge. The gauge, consisting of a plank 2 inches thick and 8 to 12 inches wide, is fastened to the pier, and made of sufficient length to cover the greatest range of water likely to occur. Sometimes the gauge consists of a portion of the pier dressed down to a smooth surface so as to receive the marking and numbering of the gauge. River gauges are marked to half-feet, sometimes to tenths of a foot; only the foot marks are numbered.

When a river gauge cannot be set vertically on a bridge pier, it is laid according to the slope of the river bank. It is then made of heavy timbers with a strip of iron nailed along the top, on which the marks are cut, showing vertical heights above the zero of the gauge. Sometimes a very substantial inclined gauge is made of lengths of stone with bars of railroad iron inlaid.

Bench Mark. — For the purpose of ascertaining from time to time any changes that may occur in the level of the zero of a river gauge or any of its marks, a bench mark is established. A bench mark consists of some accessible, presumably permanent, point or surface, in the vicinity of the river gauge, the difference in level between which and the zero or some other mark on the gauge is known by actual levelling between the two with a spirit level. A bench mark is essential in case a river gauge is to be repaired or renewed in order to set the new zero at exactly the same level as it was before. On a bridge pier, the top surface of the largest stone accessible in the top course of masonry is often used as a bench mark. Sometimes the bench mark is the top surface of a stone buried in the ground specially for the purpose of establishing a permanent surface. Stone buildings are good places for permanent bench marks. A copper bolt set in the wall of some public building, a custom house, post office or city hall, or the accessible surface of some large stone in a building, is a common device for a bench mark in large cities.

In establishing a river gauge it is customary to place the zero at the level of the lowest water known. But a gauge zero once established and a long record of gauge readings made, it is never advisable to change the zero without some very good reason. It is not changed even if there does occur a stage of water lower than any before known. When a stage of water below the zero occurs, it is read as a minus stage.

Current Meter. — A current meter, used for observing the velocity of the flowing water in a river, consists of a propeller wheel which revolves faster the greater the velocity of the current. The Haskell current

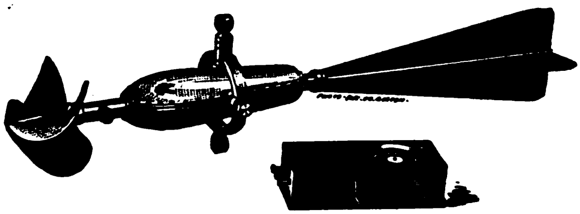


FIG. 17.

meter with register is shown in Fig. 17 one-tenth of the actual size. By an arrangement which makes an electric circuit every revolution, the revolutions of the wheel are recorded at a distance when the instrument is lowered in a stream. In observing a current, the number of turns made in five minutes is noted. By means of a coefficient previously determined for the instrument, from a known rate of motion in quiet water, the velocity of water in the river can be determined. A ship's log can be used for measuring surface velocities of water.

CHAPTER III.

TEMPERATURE AND PRESSURE.

Air Temperature. — The air receives one-third to one-half of its heat directly by absorption from the rays of the sun in passing through it, and the rest indirectly by conduction from the earth's surface after it is heated by the sun. The air in contact with the earth becomes heated. On account of its diminished density the heated air rises and mingles with the cooler air above. This process of convection extends up into the air and its temperature increases. The air is to some extent heated by radiation from the earth.

In the night the earth and the air cool by radiation. The air radiates both to space and to the cooler earth. The cooling of the earth by radiation only affects the air for a slight distance above it, unless there is some wind. The cooling of the air by contact with the earth produces no convection as in the case of heating, so there is no cooling of air at a height unless there is a mixture and contact produced by wind. The temperature increases upward for a height of about 200 feet. Radiation from the air and earth is favoured by a small amount of moisture in the air and by a clear sky. Cloud, fog, or haze, in fact, almost entirely prevent radiation. As the air diminishes to the temperature of its dew-point, the formation of a light cloud checks farther radiation. Radiation from the earth is so much greater than from the air that the temperature on the earth may be eight, ten, or even twelve degrees lower than the air a few feet above it. When the temperature of the air sinks below the temperature of saturation for the vapour contained, fog is formed, or dew is deposited. The moisture is taken out of the air by contact with the colder earth. When there is much wind the temperature of the earth does not get much lower than that of the air, as the cold of the earth is distributed throughout a greater depth of air, and both the air and the earth are at nearly the same temperature. In this case no dew is formed. A light wind is, however, favourable for the formation of copious dew by renewing the supply of moisture-laden air in contact with the earth.

Hoar Frost.—When the temperature of the dew-point is below 32°, instead of dew, frost is formed. It is not frozen dew. Hoar-frost is a name given to the curious, regular figures resembling ferns that form on objects, especially on the window-panes in houses.

Rime. — Rime is a thick, heavy frost forming on objects from frozen rain or mist, making them resemble stalactites. At Niagara Falls telegraph wires near the cataract sometimes become coated in this way to a thickness of six inches.

Convective action diminishes with height in the air. Just before sunrise the temperature of the air is the lowest of the day. It receives from the sun during the day an amount of heat increasing hour by hour until noon. The radiating power of the air increases with its temperature, and the mingling process by which it is cooled also; but not to such an extent as the heating effect of the sun. The consequence is that the air gradually warms up. In the afternoon the heat received decreases in amount, but continues greater than the cooling effect of radiation and convection combined until about two o'clock, when the heating and cooling effects are about equal. The highest temperature of the day, therefore, occurs usually at two o'clock in the afternoon at the surface of the earth. The time varies slightly with the season. On a mountain top the highest temperature is just about noon.

Unsteadiness of Air. — For an hour or more before sunset and until some time after, there is a period every day when the heat received by the earth from the sun is equal to the amount radiated to space. There is a similar period in the morning, from before until after sunrise, shorter, however, than the evening period. These periods are marked by steadiness of the images of distant objects viewed through the air. At all other times of the day and night, except sometimes when the sky is heavily clouded, in viewing objects only a few hundred feet away, there is a tremulousness about the images, and a waviness of outline, similar to the distortion seen in looking at objects across the surface of a hot stove. Distant objects look like a flag in a gale of wind. This is owing to unequal refraction of light in coming through the air from different parts of an object, due to differences of density in the hot and cold ascending and descending currents.

Unsteadiness of images is very plainly observed in sighting over long distances, fifty to one hundred miles, in measuring angles in the geodetic operation of triangulation. It is only at about sunrise and sunset, when the images of objects are steady, that angles are measured where the highest accuracy is required. The period of steadiness is longer in the evening than the morning. The unsteadiness of images is much greater during the day than the night. On days when the sky is overcast with dense clouds, the images of objects are steady the whole day. The air is always unsteady when the ground is covered with snow. The quality of the air called by astronomers good "seeing," that is, the steadiness of star images as seen through telescopes, is dependent on varying refractions of rays of light coming through air strata of different densities. On the average, the "seeing" grows worse, or the unsteadiness of images increases, from the early evening to midnight. On a night when there is a high wind the "seeing" is usually bad.

Daily Range of Temperature. — The difference between the highest and lowest temperatures of the day is called the "daily range."

It varies greatly at different places and at the same place at different times of the year. It is greatest over dry arid regions, and least near coasts. It is generally greater in summer than winter. San Diego, Cal., is an exception. While the average range is 9.4 degrees in June, it is 13.6 in January. The range diminishes in going from the equator towards the poles. It is greater on mountain summits, up to a certain height, than at sea level. It diminishes, however, with height in the air where no ground is interposed. The daily range, it is estimated, vanishes at a height of about 29,000 feet: it is less on a cloudy than a clear day. A partial cloudiness of the sky makes very little difference. A convex land surface, such as a hill, diminishes the range; a concavity, such as a valley, increases it. The greatest range occurs at places having the least cloudiness.

In the United States, east of the Mississippi River, the daily range of temperature varies from 12 to 20 degrees, being about 15 on the average; west of the Mississippi to the Rocky Mountains, it varies from 20 to 35 degrees.

The average at New York is 11.5 degrees in June, and 6.8 in January. At San Francisco, Cal., in December it is 6.0, and at Key West, Fla., 6.6. Over the plateau region of the Rocky Mountains the range is very large. At Fort Apache (height, 5050 feet) it is 42.0 degrees. At Campo, Cal. (height, 2710 feet) it is 45.4 from June until November, and occasionally as great as 50.6. On Mount Washington, N.H. (height, 6279 feet), the range is 18 degrees in January, and 10.6 in July. The mean for the year is about the same as at sea level. The temperature from its lowest about sunrise, increases almost steadily to the warmest part of the day at about 2 P.M., and diminishes steadily until near midnight. It then remains nearly the same, diminishing but slightly to the minimum near sunrise. In a very dry climate the diminution is more nearly uniform than when the air contains a good deal of moisture. The evolution of heat in forming dew retards the falling. On Pike's Peak, Col. (height, 14,134 feet), the range is 14.3 degrees in July, and 11.6 in December. The mean for the year is about what it is at the base of the mountain at Colorado Springs or at Denver. The highest temperature on a mountain corresponds to the time of least wind velocity, and the lowest to the time of greatest wind.

Temperature Range at Sea. — Over the sea, at a distance from shore, the average daily range in the temperature of the air is only 3.2 degrees. The daily range in the temperature of the surface water of the ocean is only 0.3 of a degree.

Mean Daily Temperature. — The mean of the temperatures at every hour of the day at a place is taken as the mean daily temperature. Hourly observations are made at only a very few places over the world. Approximate values of the mean daily temperatures are obtained by various short processes. The mean of the highest and lowest temperatures of the day, as determined with the maximum and minimum thermometers, gives a mean only two or three tenths of a degree too high, on the average, throughout the year for places in the United States. At places on the coast, the correction to the mean is half a degree greater than for places inland. At Greenwich, England, the same mean gives the temperature 0.6 of a degree too high, being 1.2 too high in August, and 0.3 too high in January.

One-half the sums of the temperatures at nine o'clock in the morning and nine in the evening, local times, gives the mean for the day too small by about 0.5 of a degree.

One-half of the eight o'clock morning and evening local time, in the United States, gives a temperature a few tenths of a degree below the mean of the day, and in central Europe gives a result just about right.

A good combination which gives a close approximation to the true value of the daily mean for most places is one-fourth of the 7 A.M., 2 P.M., and twice the 9 P.M., temperatures.

The mean of the maximum and minimum is in use by the United States Weather Bureau as the mean of the day.

The daily range of temperature is very great at some places in the tropics. In some parts of India the range is so great and the temperature goes so low in the night that water in shallow pans is frozen.

To the west of Lake Nyanza in Africa the rocks become so greatly heated during the day, and cool so suddenly at night, that cracks with loud reports are frequent. (Livingstone.)

Mean Monthly Temperature. — The average of all the mean daily temperatures for a month is the mean monthly temperature. It varies from 81° near the equator in January to −26° near the pole. In July it varies from 83° in latitude 10° north, to 34° near the pole. The lowest monthly temperature in the tropics is about 66°.

In the United States the monthly mean varies in January from 60° in Florida to −5° in North Dakota; in July from 82° to 68°. In the Ohio valley the mean temperature in January is about 30°, and in July 77°. At San Francisco the coldest month, January, is 50°.2, and the warmest, September, 59°.7. At Yuma, Ariz., the January mean is 50°, and the July 92°.

Mean Annual Temperature. — The mean of the twelve monthly temperatures gives the mean annual temperature. The highest mean annual temperature observed at any place in the world is at Massowah, on the Red Sea, 89°.2, in latitude 18° north, and the lowest at Fort Conger, latitude 83° north, −5°.

The distribution of temperature over the earth is not strictly dependent on latitude. It is largely modified by local conditions, and especially by the prevalent winds at a place.

In Italy the winter cold is less intense at the base of the Alps than on the open plains farther south, due probably to protection afforded by the mountains during north winds.

The mean annual temperature of the air near the ground for the whole surface of the earth is about 58°. Over forest land the mean temperature increases to the tops of the trees.

Ocean Temperature. — The surface temperature of the Atlantic Ocean varies from 84° on the equator to 28° in the Arctic Ocean. The freezing-point of ocean salt water is at 27°.5. At great depths in the ocean the water varies in temperature from 32°.0 in some places to 35°.5 in others, and is 28° at all depths in the polar seas. The temperature of maximum density of salt water, unlike that of fresh water, is greatest at its freezing-point. The average temperature of a column of ocean water at the equator from the surface to bottom is about 40°.

On the United States coast from Cape Hatteras to Boston, the temperature diminishes in winter from 70° to 30°, the greatest change to be found in the same distance at any place in the world. This is due to the warm water of the Gulf Stream that touches the coast of North Carolina, and the cold current from the north following down the New England coast. Shallow places distant from shore have cooler water than at the surface of deep waters adjacent. This is very marked over the Banks of Newfoundland, in contrast with the Gulf Stream near their eastern edge. In a distance of 300 miles there is a change in temperature of 33 degrees in the surface water. The cooler water over the Banks is due to the cold water in the currents at the bottom being forced in a measure to the surface by the obstruction formed by the Banks. Near shore shallow water is usually warmer than deep water.

From latitude 40° to 50° the ocean freezes near the shore. Ice forms all over the polar seas. Ice never forms at any place to a greater thickness than six feet, except by breaking and piling up.

The temperature of the whole body of water in oceans and lakes is mainly the result of surface temperature. No heat is received from the interior of the earth, even at the greatest depths.

Lake Temperature. — In fresh-water lakes in middle latitudes the water at a considerable depth is always at a temperature of 39°, the temperature of greatest density of water. As the water cools at the surface, it becomes heavier than the warmer water below and descends, to be replaced by the warmer water. When it cools to 39° it no longer descends. Below that temperature its density diminishes, as well as above it. When the cold of winter lasts long enough to cool the whole body of water to 39°, then, when the surface water falls lower, freezing begins, and no farther cooling goes on at a depth no matter how cold the air becomes, except the slight amount of heat lost through the ice by conduction. In the spring, when the ice melts, and the surface water warms, there is no downward convection of heat. The heating at a depth is limited to the heat that penetrates to a depth directly from the sun's rays. This heating extends to a considerable depth.

River Temperature. — In rivers the constant agitation of the water in flowing prevents freezing until the whole mass of water cools to 32° or lower. Ice sometimes forms at the bottom of streams on stones, and is known as anchor ice. It is especially noticed in forming on water-works inlet pipes projecting into streams, which furnish water supplies to cities. The cause of the formation of anchor ice is not understood. In some Siberian rivers, where the temperature of the air is −60°, ice forming on the bottom rises and thickens the surface ice. This is shown by the gravel it contains.

Earth Temperatures. — The ground at a few feet below the surface has nearly the mean annual temperature of the air above it. This applies to places where rain is equally distributed throughout the year, and the earth is covered with snow for only a short time. Where there is a wet or dry season, or there is much snow, the ground may be above or below the mean temperature.

The range of temperature in the earth diminishes rapidly with depth. The daily change is inappreciable at a depth of 3 feet, in middle latitudes; in the tropics at a depth of 1 foot. At Brussels, Belgium, the annual range at a depth of 3 feet is 19 degrees; at a depth of 13 feet, 8 degrees; at a depth of 26 feet, 2 degrees. At a depth of 26 feet the highest temperature occurs from November to January, the lowest in June and July. The annual range at a depth of 60 feet in latitude 50° is inappreciable. In the cellar of the Paris observatory, at a depth of 90.6 feet, the temperature is invariably 53°.3. In the Mammoth Cave, Kentucky, the temperature is uniformly 54°.

Below the layer of invariable temperature, the temperature of the earth increases downward at the rate of one degree in about 52 feet. There is not an increase in the rate of change in going down. This shows the source of heat is not near the earth's surface.

Where the mean temperature of the air is below 32°, the ground at a depth is frozen all the year round. At Jakutsk, Siberia, this depth is below 382 feet.

Maximum Temperatures. — The highest temperature that occurs during the day is called the "maximum temperature."

A temperature as high as 100° occurs occasionally in nearly every part of the United States. These high temperatures never occur over more than two or three hundred thousand square miles of country at the same time. In the Ohio valley the temperature in summer, in the hottest part of the day, sometimes reaches 105°. At Yuma, Ariz., a temperature of 118° has occurred. In Death Valley, Cal., the highest summer temperatures are about 122°. Occasionally the lowest occurring during a night is as high as 99°. At Pachpadra, in India, a temperature of 123°.1 occurred in May, 1886. At Sialkot 125°.0 occurred in 1873. The maximum temperature diminishes with height in the air. On Mount Washington the highest recorded is 74°; on Pike's Peak the highest is 64°.

Minimum Temperatures. — The lowest temperatures that occur vary widely in different parts of the country. In winter the temperature, on rare occasions, goes as low as 20° in northern Florida; 10° in North Carolina, Georgia, Alabama, Mississippi, Louisiana, and eastern Texas; 0° in Virginia, Tennessee, southern Arkansas, and northern Texas; −10° in Massachusetts, Connecticut, eastern Pennsylvania, West Virginia, Kentucky, southern Illinois, northern Arkansas, and Indian Territory; −20° in Maine, New Hampshire, Vermont, northern New York, western Pennsylvania, Ohio, Indiana, northern Illinois, Missouri, and Kansas; −30° in northern Michigan, Wisconsin, Iowa, Nebraska, and Colorado; −40° in Minnesota, South Dakota, and Wyoming; −50° in North Dakota and Montana, and −60° in northern Montana.

These very low temperatures, when they do occur, last but a short time, usually not more than a fraction of an hour. In the eastern and southern parts of the country, they do not occur oftener than once in 15 years; in the north-west, about as often as once in 5 years.

At Fort Conger, in the Arctic regions, the lowest temperature observed in two years was $-66°.2$.

In Siberia still lower temperatures occur. At Jeniseisk $-73°.5$ has been recorded.

In general, lower temperatures occur high up in the air than at the surface of the earth. On Mount Washington the lowest observed is $-50°$; on Pike's Peak, $-39°$. The lowest ever observed in any balloon ascent, even to the greatest height, five miles above the earth, is only $-40°$.

Freezing Days. — The average number of days with the temperature, at least part of the day, as low as 32° in various places in the United States are as follows: —

TEMPERATURES BELOW 32°.

PLACES.	NUMBER OF FREEZING DAYS IN JANUARY.	NUMBER OF FREEZING DAYS IN YEAR.
Jacksonville, Fla.	2	2
Washington City	24	90
Boston, Mass.	28	117
New Orleans, La.	2	4
St. Louis, Mo.	24	82
St. Vincent, Minn.	31	208
El Paso, Tex.	18	38

Days when the temperature does not go above 32° are called "ice days."

Temperature Variability. — The average difference of mean temperature at a place on successive days, regardless of whether it is a rise or a fall, is called the temperature variability, monthly or annual, as the case may be. It increases from south to north. In the United States the annual variability is 6 degrees in Georgia, 7 in New England, 8 in the Ohio valley, and 10 in Dakota and Montana.

Dew. — Dew forms in the night, and even in the day when the air is very damp. It is deposited when objects cool by radiation below the temperature of saturation of the air in contact with them. A strong wind may keep the air along the ground so constantly renewed that it may not fall in temperature as low as the dew-point, in which case no dew is formed. A slight agitation of the air, however, conduces to formation of copious dew by renewing the supply of air containing the moisture. Dew is not formed on the water surface of lakes or ponds unless below the temperature of 39°; for, when the water cools, it sinks, and other warmer water takes its place. The depth of dew that forms in a year in the eastern part of the United States is estimated to be one-quarter of an inch, which is probably too low. In moist climates, where the temperature fall is great, the quantity of dew is also great. On the Guinea coast of Africa, the dew at times runs off the roofs of huts like light rain, and in the morning mosquito netting is wrung out like a wet towel. In the Lake Superior region the dews are very heavy, at times dripping from roofs.

Frost. — When the temperature is below 32°, frost is formed instead of dew. A slight amount of cloudiness or haze diminishes radiation, and diminishes the amount of dew or frost, or entirely prevents its formation. An artificial haze or smudge of burning straw checks radiation, and is sometimes resorted to in order to save valuable crops, — tobacco, sugar-cane, and cranberries.

The damage to plants by frost is very variable at different times. Oftentimes no damage is done by frost when the rise to freezing-point and above is very gradual.

Frosts are called "light" when the temperature sinks no more than 4 degrees below freezing-point. When the temperature falls more than four degrees below freezing, the frost is called "heavy," a "killing frost," or a "black frost."

Frosts may occur with the temperature of the air a few feet above the ground 12 or 16 degrees higher than freezing-point.

The number of degrees the temperature falls below 32° is sometimes called "degrees of frost."

Frost is more apt to occur in a valley than on a hill top, as the wind is less apt to stir up the air in a valley.

The higher the temperature of the air in the evening and the greater the amount of moisture contained, the less the chance of frost occurring during the night. The condensation of moisture and its freezing to ice is a warming process, on account of the latent heat set free, and tends to retard and diminish the fall of temperature.

The temperature of the dew-point during the night will in most cases go at least 3 degrees lower than the dew-point on the afternoon preceding.

The temperature of dew-point, in the average of cases where the air is 40°, is about 6 degrees below the temperature indicated by the wet bulb thermometer.

First frosts in the autumn are subject to wide variations in the time of occurrence in different years. On the average, they occur as follows in the United States: —

September 1. — North Dakota, Minnesota, Wisconsin, northern Michigan.

September 15. — Nebraska, northern Illinois, southern Michigan, northern New York.

October 1. — Kansas, northern Missouri, central Illinois, Indiana, Ohio, Pennsylvania, Connecticut, Rhode Island, Massachusetts.

October 15. — Indian Territory, southern Missouri, Tennessee, Kentucky, Virginia, Maryland, North Carolina.

November 1. — The northern part of Louisiana, Mississippi, Alabama, Georgia, and South Carolina.

November 15. — Central Louisiana, and the southern parts of Mississippi, Alabama, and Georgia.

December 1. — Coast of Gulf of Mexico, and northern Florida.

December 15. — Central Florida.

The average last frosts in the spring occur as follows: —

February 1. — Central Florida.

February 15. — Gulf Coast and northern Florida.

March 1. — South Carolina, southern Georgia, southern Alabama, southern Mississippi, northern Louisiana, and southern Texas.

March 15. — South Carolina, and the central part of Georgia, Alabama, Louisiana, and Texas.

April 1. — North Carolina, Tennessee, Arkansas, Indian Territory, northern Texas.

April 15. — Massachusetts, Maryland, Virginia, West Virginia, Kentucky, Indiana, Illinois, Missouri, and Kansas.
May 1. — Northern New York, Michigan, Wisconsin, Iowa, Nebraska.
May 15. — North and South Dakota, Minnesota, northern Michigan.
June 1. — North of Dakota.

Frosts after April 1st are apt to affect the wheat-growing in the winter-wheat belt disastrously. This region comprises Missouri, Illinois, western Kentucky, north-western Tennessee, and southern Michigan. Corn, which is hardier, and not so much affected by frost, is grown principally in Kansas, Iowa, and Nebraska.

Frosts in the country to the north of Dakota cause the failure of about one wheat crop out of every three.

First frosts occur in some years as much as twenty-six days before or after the average times of first occurrence, and last frosts twenty-six days before or after the average times of last occurrence. The whole range of fifty-two days in the times of first occurrence, and the same range in the times of last occurrence of frost, takes place usually within a period of twenty years.

Lake Climate. — Where winter temperatures sink considerably below freezing-point, lakes produce an appreciable effect on climate in the vicinity. The great specific heat of water, and the fact that throughout the whole depth of a lake it must cool to 39° before the surface freezes, and the fact that there is a great amount of heat given off in the transition to ice, keep the air temperature in the vicinity higher than would otherwise be the case. In spring, the ice has an opposite effect, and keeps the air in its vicinity cool.

The difference due to this cause in the time of leafing of trees in spring on the shore of Lake Ontario and a few miles inland is a week or more.

To melt a kilogramme (2.2 pounds) of ice requires 79.06 kilogramme-calories of heat. On the English system of units, to melt a pound of ice requires 142 units of heat.

Temperature and Height. — The temperature diminishes with ascent in the air. The rate of diminution from the equator to 60° north latitude is, on the average, 0.321 degrees for every 100 feet of ascent for the first few thousand feet from the surface of the earth. There are local variations from 0.289 to 0.420 of a degree in different places. The variation has no relation to latitude as far as can be observed. The difference between the top of the Eiffel Tower, 1000 feet, and 62 feet above the ground is 1.6 degrees. The average diminution is one-third greater in summer than winter. Between the top and bottom of Ben Nevis in Scotland, 4368 feet, the difference is 0.363 of a degree for 100 feet; the greatest is 0.405 in April, and the least 0.326 in December. Between the top and bottom of Mount Fugiamo in Japan, a difference of 12,087 feet, the average rate of diminution is 0.305 of a degree per 100 feet. Between the top of Pike's Peak and Denver it is 0.347.

Taking the atmosphere as a whole, up to the limit of the free surface of the air, the rate of upward diminution of temperature must diminish with the increase of latitude. The air at a very great height is probably everywhere at the same very low temperature. Consequently the rate of diminution upward at the equator must be greater than at the pole, as the surface temperature at the pole is low as compared with that at the equator.

PRESSURE OF AIR.

Air Pressure. — Air pressure varies widely at different places, at the same instant of time. It is also very different at the same place from time to time. The average barometric pressure over the northern hemisphere, reduced to sea level, is 29.95 inches.

Diurnal Oscillation. — The pressure is subject to a double oscillation in the course of a day. It is the highest for the day at ten o'clock in the morning, and diminishes from that time until three in the afternoon; it then increases until nine o'clock in the evening, not, however, going as high as in the morning; from this it diminishes until three o'clock in the morning, but does not go as low as in the afternoon; then it increases again until ten o'clock. This is for places not very much above sea level. The continental type of pressure tends to but a single maximum and minimum for the day. The diurnal oscillation in a very dry climate tends to a single swing.

There are wide departures during the prevalence of storms. There are slight variations in the amount of change for various regions, characteristic of oceanic and continental climate. On high mountains the variation of pressure is very different from what it is at sea level, being complicated with, or largely dependent on, the daily range of temperature.

Variation with Latitude. — The average daily range of pressure diminishes from the equator to the poles. In the tropics the daily variation of pressure is very regular, so much so that it is said one can tell the time of day, within twenty minutes, from the reading of a good barometer. The least deviation from the regular daily march of pressure is evidence of a storm in the vicinity.

At Calcutta, India, latitude 24°, the daily range of pressure is 0.116 of an inch; at Greenwich, England, latitude 52°, 0.020; at Fort Conger, latitude 83°, only 0.010 of an inch. Over the Pacific Ocean, from 12° north to 12° south, the range is 0.087 of an inch.

In the United States the range, as determined from twelve years' observations, varies from 0.117 of an inch at San Antonio, Tex., and 0.068 at Dodge City, Kan., to 0.038 at Bismarck, N. Dak. It requires the average of years of observation to disentangle the diurnal range effect from the irregular oscillations accompanying storms.

The range increases from winter to summer. The range increases inland, being 0.061 at Philadelphia, 0.068 at St. Louis, 0.072 at Denver, 0.079 at Salt Lake City, and 0.094 at Winnemucca, Nev., and 0.058 at San Francisco. It is 0.129 at Yuma, Ariz. In approaching the great lakes the range diminishes; while at Albany the range is 0.074, at Buffalo it is only 0.047, at Chicago, 0.046. The principal minimum, in January, occurs along the Atlantic coast and in the region of the great lakes at about 2.30 P.M. As the year advances it becomes later, occurring at 5 P.M. in June along the coast, while in the lake regions it is delayed to 5.45 and 6 P.M. In the Pacific coast regions the winter minimum occurs at 4 P.M., and the summer at 6 P.M. At inland stations the minimum occurs from 3 to 3.30 P.M., and in summer two hours later.

Effect of Moon on Pressure. — The tides in the atmosphere produced by the moon have an effect on the daily range of pressure. At Batavia, Java, latitude 6° 11′, the means of fifteen years' observations, arranged according to lunar hours, — that is, by the hour angle of the moon from meridian, — show the difference between the greatest and least pressure due to the moon to be 0.0046 of an inch; at Singapore, latitude 1° 11′, 0.0064, and at St. Helena, latitude 15° 37′, 0.004. At the two latter places the maximum is precisely at the time of the moon's culmination; at Batavia 50 minutes later.

Cause of Range of Pressure. — On cloudy days the range of pressure is only half as great as on clear days. Over the land it is slightly greater than over the ocean. The range seems to be composed of two distinct oscillations superposed, one depending on the position of a place, and the other nearly the same at all places over the earth. One component, the greater, is due to changes in the lower air allied to temperature; the other to changes at a high altitude in the air.

The cause of the daily range of pressure is not fully understood. No theory as yet proposed accounts for all the facts. There seems to be no doubt it is dependent somewhat on the quantity of moisture contained in the air, and the fact that moist air takes more heat from the direct rays of the sun than dry air. Yet at Jacobabad, India, it is 0.187, in January and July, where the air is always dry. At Aden, Arabia, where it is dry all the year, it is 0.084 in January and 0.163 in August. At Bombay in January, which is dry, it is 0.119, and in July, which is wet, it is 0.067. The daily change is less in areas of high pressure, which are dry, than in areas of low pressure. If it were due to the heating effect of the sun on the surface of the earth, it would be very much greater over the land than sea, which is not the case. In deep narrow valleys there is a great increase of the daily range, the change being much larger than on open plains. At Gies and Klagenfurt in Austria, though in latitude 45°, the range is nearly as great as in the tropics. In Death Valley, southern California, 200 to 400 feet below sea level, the range is 0.186 of an inch in summer. This is due to the excess of cooling effect in valleys and their lower temperature in the night time as compared with plains.

On mountains the highest pressure occurs at noon. The daily range is almost wholly due to the effect of the heating of the air between the summit and base of mountain. The air between the base and summit expands by heating, and some of the air is pushed above the mountain, so that there is a greater quantity of air above the barometer at a warm than at a cold part of the day. On Mount Washington in January the pressure is 0.50 of an inch lower than in July; on Pike's Peak 0.59 of an inch lower. On Ben Nevis, Scotland, 4368 feet, a difference of 17.4 degrees increases the pressure 0.143 of an inch.

Monthly Range of Pressure. — The difference between the highest and lowest pressure in a month is the monthly range. It increases with latitude. At Key West, Fla., it is 0.35 of an inch, and at Eastport, Me., 1.16. At Brownsville, Tex., it is 0.55, and on the same meridian at St. Vincent, Minn., 1.02. The range is least for the month of July and greatest for January.

Annual Range of Pressure. — The difference between the greatest and least pressures occurring in a year is the annual range. At Key West, in 20 years, it has been 1.176 inches; at New York, 2.201; at Eastport, 2.523; at Brownsville, 1.896; and at Chicago, 1.775. At Toronto, Canada, the range, in 46 years, has been 2.77. Pressures below the average occur at the times storms are prevailing, and pressures above the average after they are past. This is especially the case in winter.

As a rule, in the United States, pressures rarely go as low as 28.9 inches, even in the greatest storms, and after they are past it rarely goes higher than 30.7 inches. Cases of much lower and higher pressure do, however, occur occasionally.

In a typhoon in the China Sea the pressure has been known to sink as low as 27.04 inches. At Reikiavik, Greenland, a pressure of 27.25 inches occurred February 4, 1824. February 5, 1870, on the steamer *Tarifa*, in latitude 51° north and longitude 24° west, a pressure of 27.33 inches was observed.

Pressures sometimes rise to 31.00 inches. At Fort Assiniboine, Mont., the pressure reached 31.21 inches January 6, 1886. At Semipalatinsk, Siberia, December 16, 1877, the pressure reduced to sea level was 31.72 inches (height above sea level, 597 feet). At Barnaul, Siberia, December 17, 1877, the pressure was 31.64 inches. The average of high pressures in Siberia in January is 31.10 inches.

Distribution of Pressure. — The average distribution of pressure at sea level over the surface of the earth is determined by the general circulation of the air. At a height in the air the pressure is dependent somewhat on the temperature of air in the lower layers. When the temperature is high, there is a greater quantity of air at a height than when it is cold. There is a constant interchange between the air at the equator and the poles. The rotation of the earth diverts a current to the right of the direction in which it is moving, no matter what the direction. The deflective effect varies with the velocity of current and the sine of the latitude of the place. The consequence is, there is a tendency to the formation of low pressure on the left side of a current, in opposition to the general tendency of air to move from a place where the pressure is high to where it is low until the pressure is equalized. For a given velocity of current in a given latitude there is thus a certain increase of pressure from the left to the right side of the current. The increase is greater the higher the latitude and the greater the velocity of the current. When a current of air describes a circle on the earth, or a mass of air is in rotation, there is therefore a lowering of pressure or an increase of pressure produced in the centre of the mass by the effect of the earth's rotation, depending on the direction of rotation of the air.

There is a general tendency of the whole mass of air north of latitude 40° to move from west to east around the earth. The consequence is, there is a permanent area of low pressure in the vicinity of the pole. The stronger the air currents the greater the lowering of pressure, as in winter, with the greatest difference of temperature between the equator and the pole. There is also, as a consequence of this, the heaping up of the air and a high pressure about latitude 30°.

Average January Pressure. — In January the average pressure over the north Atlantic Ocean in the vicinity of Iceland is 29.55 inches. In the southern hemisphere, in its winter, there is a very extensive area of pressure 29.3 inches or less surrounding the pole. In January, in Siberia, the pressure is 30.5 inches. In the north Pacific Ocean, off the coast of Alaska and Kamtchatka, the pressure in January is 29.55 inches, and in the United States it is 30.2 inches. The pressures at intervening places shade gradually between these values.

The circulation of the air over that part of the earth's surface where the trade-winds prevail, and the anti-trades above them, is almost independent of the circulation north of latitude 40°. The trades and anti-trades form a circulatory system, there being a generally ascending current at the region of calms near the equator, and a generally descending current at about latitude 35°. The deflecting force produced by the earth's rotation is small near the equator. At the equator, in January, the pressure is 29.91 inches, and at latitude 35° north, 30.14, at sea level; but on ascending in the air to 10,000 feet, the pressures become gradually equal from the equator to 35° north, and on further ascent they are found to diminish in the opposite direction. On the mountain of Antisana, in Ecuador, near the equator, the pressure at a height of 13,000 feet is 18.55 inches, while at the same height on Pike's Peak, Col., in latitude 39°, it is 18.04 inches.

The area of relatively high pressure of varying width around the earth about latitude 35° is somtimes known as the sub-tropical zone of high pressure.

Average July Pressure. — In July there is an area of low pressure 29.4 inches in Asia, from Mooltan to Muscat, a region east of the Caspian Sea. Around the north pole there is a very large area of 29.9-inch pressure. At latitude 30°, in the Atlantic Ocean, the pressure is 30.2 inches, and in the Pacific, 30.3.

CHAPTER IV.

EVAPORATION, CLOUDS, RAIN, AND SNOW.

Evaporation. — The air always contains some vapour of water, transparent and colourless like the other component gases. When the vapour condenses, it becomes visible as fog, cloud, rain, snow, or hail. From any water surface vapour passes into the air by evaporation. The rate of water evaporated depends on the temperature of the water, the dryness of the air, and the velocity of the wind. With a high barometric pressure evaporation is somewhat less than with a low pressure. Evaporation requires heat. The number of units of heat required to raise the temperature of a kilogramme of water from 0° centigrade to boiling-point, and convert it to vapour, is 607. To convert it from boiling-point to vapour requires 537 heat-units. On the English system, to vaporize a unit weight of water requires 967° F. This heat disappears on evaporation, and is rendered latent. It reappears again on the condensation of the vapour. A quantity of vapour cannot be made liquid unless there is some means of disposing of its latent heat. From this it results that condensation, and cloud or rain formation, are usually gradual processes. When the radiation of heat, or the mixture of warm moist air with cold air, causes the formation of cloud, fog, or haze, the reappearing latent heat of condensation retards further condensation until the temperature can be lowered.

Pure vapour is condensed by subjecting it to pressure. In the free air, however, where vapour and gas are mixed, pressures never increase sufficiently to produce appreciable condensation. Any increase of pressure beyond that for the temperature of saturation condenses part of the vapour. The latent heat diminishes with the temperature of vaporization.

Beyond certain very high temperatures, no pressure, however great, can render vapour liquid. This temperature, called the "critical temperature," is different for different liquids; for water it is 684° F.

The depth of water that will evaporate in the course of a year varies widely in different places; at Boston, as observed with a pan evaporometer in the shade, it is 39 inches; in the Ohio valley, 40 inches; over a wide extent of country in the southern parts of New Mexico, Arizona, and California it is about 100 inches; at Cumana, South America, 136 inches.

In full exposure to sun and wind the evaporation will be still larger. The actual water evaporated from soil, running water, and lakes is considerably less.

Daily Change of Vapour Pressure. — There is a daily variation in the pressure of vapour in the air. Near the sea-coast the variation corresponds nearly with the daily change of temperature; inland, it is somewhat different. The upward tendency of the lower air when heated during the daytime, and its mixture with the upper air, is the principal cause of the daily variation.

In the daytime the vapour is carried away from the surface of the earth and disseminated through the upper air so fast that even in the vicinity of the sea the vapour pressure diminishes as the day advances.

At places inland the vapour pressure decreases decidedly during the day, as there is but little evaporation from the ground to keep up the supply of vapour. The vapour pressure diminishes from the equator to the poles.

In the tropics, over the ocean, the vapour pressure varies, on the average, from 0.639 of an inch at 4 A.M., to 0.679 at 2 P.M.

At Batavia, on the island of Java, 6° south of the equator, the lowest vapour pressure at sunrise is about 0.783 of an inch; it increases by nine o'clock to 0.823; diminishes to 0.815 by eleven o'clock, then rises to 0.838 of an inch by 7 P.M., and then diminishes regularly until morning.

Yearly Change of Pressure. — The yearly change in vapour pressure is very similar to the yearly change in temperature. The difference between the greatest and least pressure is less on the coast than inland, and is smaller in the tropics than in the temperate zone.

The average vapour pressure at Jacksonville, Fla., in January is 0.360 of an inch, and in July, 0.732; at Washington City, in January, 0.124, and in July, 0.616; at Boston, in January, 0.088, and in July, 0.499; at New Orleans, in January, 0.310, and in July, 0.810; at St. Louis, in January, 0.101, and in July, 0.707; at St. Vincent, Minn., 0.020 in January, and 0.499 in July; at El Paso, Tex., 0.141 in January, and 0.448 in July.

Vapour pressure diminishes rapidly with ascent in the air. The air, up to a height of one mile, contains 40 per cent of all the moisture in the whole atmosphere; two miles, 69 per cent; three miles, 81 per cent; four miles, 89 per cent; and five miles, 94 per cent.

The small amount of moisture in mountain regions lends the air a peculiar transparency. At Denver, Col., mountain peaks forty miles or more away seem only a few miles distant. Such dry air is entirely lacking in colour-tone.

CLOUDS.

Cloud Formation. — Cloud forms when the air cools below its temperature of saturation (for the vapour it contains), either by dynamically cooling in ascent, or by convective intermixture with colder air in ascending or by radiation from the air. Low-lying clouds near the surface of the earth usually result from the air cooling below the dew-point by radiation. The degree of cloudiness depends jointly on the amount of vapour in the air and the activity of convection, which depends in turn on the decrease of temperature with altitude. When the air up to a great height is warm, there may not be any clouds, even with a good deal of vapour. The ascending currents of air around mountains in the daytime cause the formation of cloud-caps around their summits. The tops of high mountains are seldom free from clouds. The depth of a layer of cloud is not usually more than half a mile. Cumulus clouds, however, are sometimes several miles in thickness.

Classification and Nomenclature. — Clouds are broadly classified into upper and lower, according to height in air. Cirrus is the highest, and stratus the lowest. Ten varieties, or typical forms, of clouds are recognized in making meteorological observations. The typical forms are, however, of relatively rare occurrence. In noting the kind of cloud, the form is considered to be that which it most nearly resembles. The forms are as follows: —

1. Cirrus.
2. Cirro-Stratus.
3. Cirro-Cumulus.
4. Cumulo-Cirrus, or Alto-Cumulus.
5. Strato-Cirrus, or Alto-Stratus.
6. Strato-Cumulus.
7. Nimbus.
8. Cumulus.
9. Cumulo-Nimbus.
10. Stratus.

In the compound names the first part indicates relative height of clouds.

1, 3, 4, 6, 8, 10, are ordinarily fair-weather clouds. 2, 5, 7, 9, are bad-weather clouds.

HIGH CLOUDS.

Cirrus. — Cirrus is a streaky, gauzy, wispy, or feathery form of cloud, whitish in colour, usually not very abundant. It forms at a great height, 25,000 to 50,000 feet. It rarely occurs below 16,000 feet. It is sometimes known as "cats' whiskers" and "mares' tails."

Cirro-Stratus. — This form of cloud is a thin veil of extended cirrus. At times it is largely composed of ice particles, as shown by the coloured rings, halos, etc., seen around the sun and moon viewed through it; lunar halos are very frequent.

Cirro-stratus is a condensed and developed form of cirrus in which the streakiness is very marked, usually on account of the greater extent of the clouds. At times ribs of cirro-stratus stretch from a point on the horizon to the point directly opposite. From the perspective effect the ribs appear widest apart at the zenith and converge on either side. This form of cloud is sometimes popularly known as "Noah's Ark." The stripes or ribs are sometimes made of cross-bar patches, and then they are said to be striated.

This formation is also sometimes known as "polar bands." The fibres of cirro-stratus sometimes interlace and have a reticulated appearance like woven cloth; or, like the system of intersecting waves or breakers; or they are arranged like scales of fish, and are called "mackerel" sky.

As waves are produced on the surface of water by wind, so in the air, at the boundary between two currents moving one above the other, — especially if going in opposite directions, — there are very great waves which may be a mile or more from crest to crest. The rising of the air by the wave motion, and the breaking of the crest as in the formation of foam in white caps on the sea, is possibly the cause of striated and banded forms of cirro-stratus. Strong puffs of wind with light showers, alternating during the day with clear weather, called "squally weather," may be due to the same cause.

INTERMEDIATE CLOUDS.

Cirro-Cumulus. — This is a dappled or mottled cloud form, a sheet of cloud composed of little bunches of white like balls of cotton wadding. It consists of a broken layer of cloud made up of elliptical or elongated patches of cloud, with somewhat regular interstices, and without any shading of light. It is mostly visible near sunset, but always high up in the sky at a height of 12,000 to 22,000 feet. It is also sometimes known as "mackerel" sky. It is denser than cirrus and of a dark "tone."

Cumulo-Cirrus, or Alto-Cumulus. — This is like cirro-cumulus, but composed of larger bunches of cloud. Sometimes the bunches are very compact, with the edges close together. It is also a high form of cumulus, as the name *alto*-cumulus implies.

Strato-Cirrus, or Alto-Stratus. — This is a dense veil of greyish or bluish cloud, showing no optical phenomena such as coloured rings or halos when the sun or moon is viewed through it.

LOWER CLOUDS.

Strato-Cumulus. — This form is composed of great masses of dark cloud often covering the sky completely. It prevails at a height of 5000 to 10,000 feet. It is essentially a cloud of the night and of the cold season. The darker forms of strato-cumulus sometimes give the sky an undulatory aspect, especially toward the horizon an effect of perspective. This is what is sometimes called "roll-cumulus." In high latitudes in winter, thick masses of this cloud obscure the sky at times for weeks.

Nimbus. — This is a dense, thick layer of dark cloud, without shape or form, with tattered edges, ragged outline, from which ordinarily rain or snow continuously falls. Scud is small, detached masses of cloud, in advance or lower down than the main nimbus.

Cumulus. — Cumulus cloud is masses of cloud of a dense, rounded appearance, like cotton bulging from a bale. It is a heaped-up cloud, arch or dome shaped, and compact. It has a flat, horizontal base, 3000 to 5000 feet above the ground, and towers up conically in the sky. Its shape indicates it is the result of the condensation of moisture, as the air in ascending cools dynamically to the dew-point. Cumulus cloud is the visible capital of an ascending column of air. It is essentially a day cloud. It is more common in the afternoon than the morning, and is most noticeable when the sun is low. This form of cloud is frequent at all times of the year.

Cumulo-Nimbus. — This is the larger form of cumulus cloud, the thunderstorm cloud. It towers up to a great height beneath a layer of fibrous cloud (false cirrus), at a height of about 10,000 feet, or much lower. The false cirrus is related physically to the summit of the cumulo-nimbus. True cirrus is often seen above the false. When the rain begins, the base of the large cumulus clouds is seen surrounded by low, grey, irregular clouds like nimbus. This is called the "cloud-cravat." Ordinarily hail is falling from it, or torrents of rain. Above the false cirrus, real cirrus cloud is often seen.

The distant tall tops of cumulo-nimbus, visible near the horizon, are known as "thunder-heads."

Stratus. — Stratus is a widely extended sheet of uniform cloud named from its resemblance to the regular arrangement of a stratum of rock or clay. It is a fog lifted up floating in the air. It is the lowest of all clouds — height not more than 1000 to 2000 feet. It is essentially a night cloud, forming by radiation of heat from the lower layers of the air. In the Polar regions a singular form of stratus is met with. The wind raises clouds of snow to a height of 15 or 20 feet, which envelopes everything in a dense fog, as it were, for several hours, or even days, at a time. It is noted as "moving or driven snow." Sometimes these clouds of moving snow form masses of great white clouds for a certain distance above the ground. Ordinarily they are only in the lower layers of the air, and the masts of ships project from them as from a sea of fog or white smoke.

Clouds consist of minute globules of water surrounded by an atmosphere of vapour (which, being lighter than the surrounding air, buoys them up, and, farther, prevents the total evaporation of the globule, the atmosphere around it being saturated, thus giving it some stability, and only dissipating by diffusion when there is not much wind). Dines gives the diameter of particles as 0.016 mm. to 0.127 mm. Assmann gives 0.006 to 0.035 mm. They are at an average distance of 1.6 mm. from each other. A cubic meter of such a cloud contains about 262,000,000 globules. The weight of water globules in a cubic meter of cloud is 3 grammes.

In the apparent variations of cloud forms there is much that is fanciful, depending on the way in which the light strikes a cloud. Many of the forms and shades do not indicate any real difference in the mode of their formation. A few isolated clouds go by one name, and in another case the same clouds, if sufficient in amount to cover a large part of the sky, is apt to be called by a different name.

Cloud Shadows. — When the air is hazy, cloud shadows can sometimes be traced in the sky by dark lines pointing in the direction of the sun. This is known as "the sun drawing water." Similar appearances are observed at sunrise and sunset, when the shadows of clouds near the horizon are projected on the sky while the sun is below the horizon, and produce the effect of radiant beams diverging from the sun.

Variegated cloud forms occur mostly in relatively quiet atmosphere. No important rules have ever been formulated as the result of the investigations of cloud forms as indicating weather changes or approaching storms, and yet every observer and predictor makes use of them. Clouds mostly indicate regions of vapour change or temperature disturbance. A balloon will at times be seen moving into a cloud and then out of it, showing that the cloud does not strictly move with the air current, but is merely a locus of vapour condensation. The same thing is shown by the cloud-cap around a mountain-top, where the air is continually in motion, but the cloud does not move.

Cloud Variation. — The average amount of cloudiness is greatest for stratus cloud at sunrise all over the world, and more so over sea than land. The least cloudiness is at midday. There is a slight increase in the afternoon, and a falling off again to midnight. The daily variation of cloudiness, however, differs in different parts of the world. At Madrid, Spain, the greatest cloudiness for cumulus is at noon, and the least at night. Over the sea cloudiness is on the average slightly greater than on land.

The height of cumulus clouds increases during the day and diminishes during the night.

Near the equator, between the north-east and south-east trade-winds, the sky is almost constantly covered with clouds.

Days are classified as follows with regard to cloudiness: Clear days are days without any cloud; fair days are days when there is some cloud for a time, or the sky is wholly obscured by clouds for only a part of the day; cloudy days are days when the sky is wholly clouded all the day. The average condition of cloudiness for all places over the whole world for the whole year is about five-tenths of total cloudiness. The cloudiness in the Lake region from November to February is 0.8; in summer it is 0.4. The cloudiness increases in the winter, in going north, from 0.3 in Texas to 0.6 at the northern boundary of the United States. In June and July the amount of cloudiness is on the average the same over all the country east of the Mississippi, and about 0.4. It is greater in winter. The cloudiness west of the Mississippi in July diminishes to 0.1 to the Pacific coast, where there is a sudden increase. The average cloudiness at any time of the year along the Atlantic coast does not seem to be any greater than for places inland. It is the least for any month in August. At Unalaska, Alaska, the cloudiness in February is nine-tenths. At Sacramento, Cal., Keeler, Cal., and Yuma, Ariz., the skies are almost cloudless from June to September, the cloudiness in different years varying from one-hundredth to nine-hundredths.

The number of sunless, totally cloudy days in a year at Jacksonville, Fla., is 85; at Washington City, 100; at Boston, 111; at New Orleans, 73; at St. Louis, 100; at St. Vincent, Minn., 95; and at El Paso, 38. At London, England, the number is 94, — 50 in the winter and only 6 in the summer.

The number of "fair" days in a year, that is, days with cloudiness of five-tenths or less, but no rain, is at Jacksonville, Fla., 167; at Washington, 143; at Boston, 135; at New Orleans, 168; at St. Louis, 140; at St. Vincent, 148; at El Paso, 115. At New York City the average number of hours of sunshine daily, in December, is 5, or about half the possible amount; in July it is 11 hours, or 0.75 of all possible. At London, England, the average duration of sunshine all the year round is only 0.27 of the possible amount, or 3.3 hours daily. The amount is as small as 8 per cent in December. At Madrid, Spain, the sunshine is 60 per cent of all possible.

FOG.

Fog Formation. — The vapour ascending from warm water or warm, moist ground into cold air above it produces fog. The air in contact with the water contains more moisture than the cold air higher up. On account of its lightness it ascends. Mixing with the cold air above, it is cooled below the dew-point, and part of the vapour condenses as fog. It requires a diminution of vapour pressure of about 0.03 of an inch below the point of saturation to produce perceptible fog. Fogs form principally in the night-time and usually disappear with the increasing temperature after sunrise. Fog consists of minute drops of water, and not hollow spheres or vesicles. On being caught on a glass plate, examination with a microscope reveals a hemispherical drop, and not a ring of moisture, as would be the case if they were collapsed hollow spheres.

The ground becomes cooled by radiation, and the air in contact with it becomes cooled, causing condensation; the next air layers then become cooled, and condensation takes place in them. The formation of ground-fog thus proceeds from the bottom upwards; its dissipation takes place in the reverse manner. No considerable precipitation occurs as a result of this cooling, as the continual formation of a higher fog layer prevents the further cooling of the lower layers by radiation.

A warm, damp current of air flowing over a chilled surface, such as an ice-floe or a cold ocean-current, gives rise to a fog. Fogs on the banks of Newfoundland are of this kind. The warm, moist currents of air from the Gulf Stream, three hundred miles to the east, when carried over the cold water of the banks by the south-easterly winds of a low area of pressure advancing from the west, give rise to fogs. The temperature of water over the banks in July is 45°, while the Gulf Stream is 78°. The fogs are not very deep: the masts of ships often project above them. They are common at all times of the year, but more so in summer than winter; in summer they prevail about half the time. They are a serious detriment to navigation in that part of the ocean. The region lies in the shortest path from New York to Liverpool, the most frequented commercial ocean route in the world. The fogs are the cause of numerous collisions between vessels, and between vessels and icebergs.

The vicinity of Cape Horn, the region where the cold Antarctic and warm equatorial currents meet, is also notable for its fogs. In Behring Sea, fogs prevail from April to the middle of July.

Radiation Fog. — Fog is formed by radiation when the ground is cooled below the dew-point, and the air in the lowest layers, having parted with a portion of its moisture as dew, is still left in a saturated condition and colder than the air above it. If no mixture with the upper air takes place, as in the case of level ground, usually no fog forms. But if there is any slope to the ground, the colder air flows down and produces a disturbance of the layers of air in the low-lying parts of the land, which gives rise to a mixture of the air and the production of fog. This is the species of fog that rolls slowly down the low-lying slopes of mountain-sides in the night-time.

Woolly. — In Alaska this species of fog is known as the "woolly."

Pogonip. — The fog that forms in intense cold in the mountain regions of Colorado is called by the Indian name pogonip. It begins in the valleys and works up the mountain-sides, contrary to the usual mode of formation of fogs, which is, to begin at the top of the mountain and extend downward.

Arctic Fog. — There is almost constantly a fog in the Arctic regions in the summer months.

On the north Pacific coast of the United States, in winter time, there are heavy fogs preceding the rainy season. These fogs are so heavy at times as to produce over night a deposit of water equal to 0.05 of an inch in depth. Along the Atlantic coast, from latitude 30° to 35°, fogs are very rare.

Mist is similar to fog, but not so dense. It consists of streaks and patches of fog. The particles of moisture are larger than in fog.

Dust in the air is favourable to the formation of fog. All air, even the most transparent, contains myriads of small floating particles of dust.

Garuas. — In the rainless area along the coast of Peru, growing plants are dependent for moisture on the heavy fogs that occur called "garuas." These prevail from May to October after a summer that is very sultry. They extend over the country up to a height of 1200 feet above the sea. Above this level there is rain.

Iceland Fogs. — At times dense fogs occur on the coast of Iceland, with disastrous results to the hay crops. When large quantities of field ice become stranded along the shore, it produces fogs in the summer, which, by cutting off the sunlight, prevents the maturing of the hay. The inhabitants know that when these fogs set in the hay crop will fail. They depend very much on the work of their ponies. The matter is aggravated, too, by the fish leaving the shores at the same time on account of the cold water, and often famine is the result.

The fogs that roll along the Adriatic Sea when the Bora and Tramontana begin to blow are known as the "fumaria" and the "spalmeggio."

Haze. — The greyish tint of sky that is seen at times, especially in summer, is due to particles of dust in the air. This is especially marked in hot climates during a prolonged dry spell. The sky is often of a pea-soup colour. The colour is in marked contrast with the vivid blue of the sky after a heavy rain when most of the dust is washed out.

Indian Summer. — A condition of the air known as dry fog prevails sometimes in November or early December in some parts of the United States, that is called Indian Summer. It is caused by dust high up in the air due to the smoke of forest fires and to some extent, perhaps, by particles from the decay of fallen leaves. This species of haze sometimes prevails also in central Europe. It coincides with long spells of dry weather, and increases with the continuance of dry weather, disappearing on the occurrence of rain. Volcanic ashes sometimes cause these fogs. In Europe, in 1783, such fog prevailed for a month by the eruption of the volcano of Hecla in Iceland. A similar fog prevailed in 1831 in the United States, in Europe, and on the coast of Africa. The sun was so obscured it could be viewed with the naked eye at midday. The haze was phosphorescent at night, giving appreciable light.

Callina. — The "callina" of Spain is a dry fog. About a fourth of the sky, from the horizon up, is of a reddish-brown tint. High up the air is yellowish; occasionally the whole sky has an appearance as if covered with a leaden gauze.

ATMOSPHERIC ELECTRICITY.

Electricity of the Atmosphere. — The electrical condition of the air is exceedingly variable. The difference of potential between the air and earth increases with height in the air at an average rate of about 3 volts per foot, but at a height of 50 feet it may change in a few seconds from 150 to 300 volts, or even more. No daily period is perceptible in the variation of the potential. As yet but few observations of potential have been made. There are sudden increases and sharp variations in the potential of the air in the vicinity of thunderstorms. Possibly this is merely induction on the water-dropper. The electrical conditions of the air do not seem to have any simple relation to each other, even at places close together, as the potential changes at any place independently of the change going on at other places close by. There is generally a fall of potential of 150 to 1000 volts occurring from two to twenty hours before the beginning of rain. A maximum of wind corresponds to a minimum of potential. The potential rises as the wind veers from the north to the south, and falls as it backs from the south to the north. It rises or falls after a calm as the wind comes up from a southerly or northerly direction. There are rapid oscillations of potential in snow-storms. This applies to Baltimore for a point in the air 34 feet above ground and 145 feet above sea level. Fig. 18 shows a simultaneous record of the potential of the air for a part of the day on July 17, 1886, at Washington at the Weather Bureau office at a point in the air about 45 feet above the ground, and on the Washington monument at a height of 508 feet in the air and distant about 1000 meters from the office. The vertical distance on the figure represents volts, and the corresponding horizontal distances the time of observation. On that day the sky was cloudless, the atmosphere was hazy, the wind from the south-west light, and no indications of rain. During the forenoon the potential at the monument oscillated almost continually, being variable and high, often exceeding the range of the instrument, which was 3000 volts. In the afternoon the movements were less violent, although, apparently, the meteorological conditions remained sensibly the same. During thunder-storms the oscillations of potential are very great. At the monument, previous to a flash of lightning, the stream of water from a water-dropper collecting the electricity of the air is twisted and split into many fine threads and sprays; but instantly, with the occurrence of a flash,

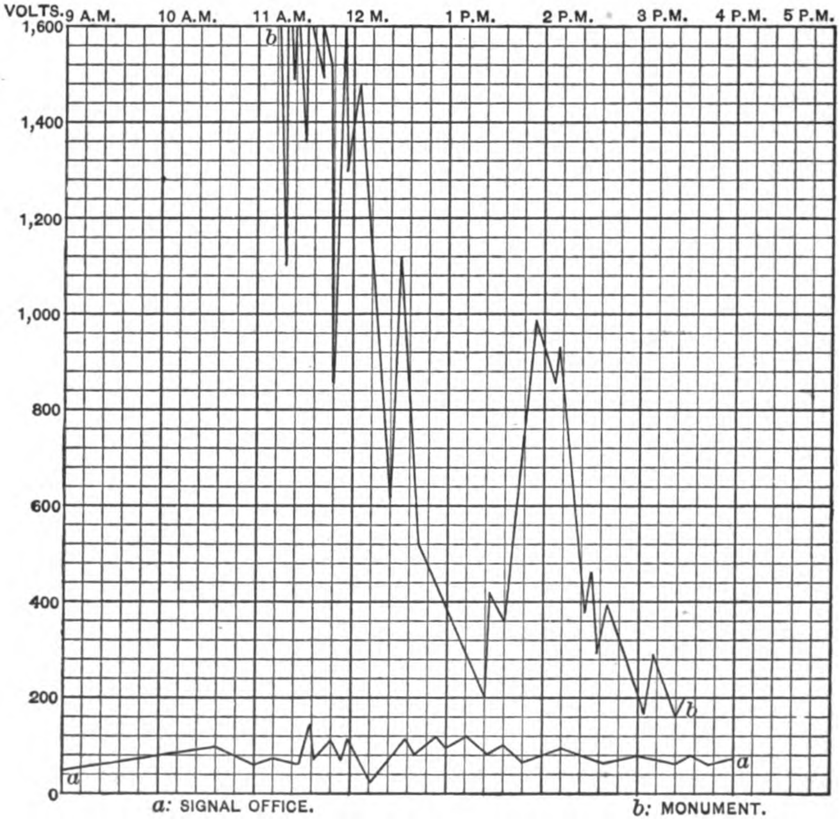


FIG. 18.

the stream assumes its normal character, maintaining it for a few seconds, and then gradually becomes more and more distorted until the occurrence of another flash, when the same state of things is repeated.

When rain falls the potential of the air falls to that of the earth; during snowfall the potential also falls. During an auroral display the potential of the air falls with a clear sky, indicating possibly invisible condensation of vapour in the higher air.

The electrical condition of the air is probably due in part to induction and in part to convection, as when electricity is carried up from the earth into the air by evaporation of water from the earth's surface, or by the rising of electrified dust particles in the air.

In volcanic eruptions there is often lightning from the smoke clouds around the crater. The clouds consist of volcanic ashes and vapour belching from the crater. The electric disturbance in this case is evidently convective. The ultimate source of the electricity or real cause of the electric condition of the earth and the air is problematic.

In the year 1631 a great volume of smoke, extending 160 miles, poured forth from Mount Vesuvius, from which there were numerous electric discharges as it passed along, killing cattle and people. In another outburst in 1794, the cloud, consisting mostly of fine ashes, was borne along as far as Tarentum, accompanied in its whole course by violent thunderstorms similar to those that ordinarily occur with rain.

Rainfall. — The condensation of vapour due to a convective mixture of air produces an abundant formation of cloud and finally rain, where there is a wide contrast of temperature in the upper and lower layers of the air, or when there is an ascending current. When rain results from an ascending current, it is usually very heavy over a small area from fifty to five hundred square miles in extent. Rains from convective mixture, when the upper layers of air have become relatively cold or the lower air relatively warm, are usually light and long continued, and extend over great areas — at times as much as half a million square miles.

The order of efficiency of the various causes of the formation of rain are direct cooling by contact with colder bodies, or through radiation; adiabatic expansion, or expansion with insufficient additions of heat to keep up the vapour pressure; and the mixture of moist masses of air having different temperatures.

If two masses of saturated air, one having the temperature of 0° C. and the other 20° C., be mixed, the greatest amount of rainfall that is possible from the mixture is 0.75 grammes per kilogramme of the mixture. To obtain this same amount of rain from the warm air alone by adiabatic cooling, it would have been necessary to lower the temperature only 1°.6 C., which would be accomplished by the air ascending 310 meters, or, if the warm air had been cooled by contact with a cold body or by radiation only 0°.8, the same amount of rain would have been formed.

Condensation by radiation in the upper layers of the atmosphere is principally active when cloudiness exists as a result of mixture or adiabatic expansion. It does occur without cloudiness, though, as shown by the fact of numerous well-attested cases of rainfall from a cloudless sky.

It is hardly possible for a difference of temperature to exist in two adjacent masses of air sufficient to produce appreciable rain by mixture alone without some expansion.

It may be that at times there is such a condition as super-saturation before condensation into rain begins. It has been found by laboratory experiments that air perfectly free from dust particles may become super-saturated with moisture, which suddenly condenses when fine particles are introduced.

The progress of a warm current of air from the south to a cold northern region is favourable to formation of rain. Winds from the ocean, which are usually moisture-laden, are producers of rain where they blow onto colder land. The frequency and quantity of rain at a place show marked dependence on the direction of the winds, being more frequent and heavier with some winds than others. In the United States, winds from the south-west to the south-east are more apt to be followed by rain than winds from other directions, at all times of the year. The region of the upper Missouri valley is an exception, the rains or snows in winter following winds from the north-west and north-east more frequently than from other quarters.

A current of air progressing inland over a gradually rising country is more apt to produce rain than where the country is flat. Deviations from prevailing wind-direction are apt to be followed by rain. A mountain range, or even a range of hills, when the air is near saturation, has a powerful effect in producing rainfall on the windward side by causing the current of air to ascend and to cool dynamically, producing a temperature so low that the vapour cannot be retained. Thus the topographical or relief features of a country exercise a very great influence on the distribution of rain. High mountain ranges cut off very largely the rainfall on the leeward side of the prevalent rain-bearing winds.

Rain and snow at times fall from cloudless skies. These rainfalls are invariably light. The cloud may be so gauzy as to have no visible body, or, between the time of its formation and that of the rain reaching the ground, it may dissolve and disappear. A case has occurred where such a shower lasted nearly an hour.

In the cases where snows occur without cloudiness, high winds prevail, and the snow is probably carried for a distance along the ground or from a region of cloud. Rainfalls of this kind are of more frequent occurrence just after sunset than at other times of the day.

One of the conditions that must precede rain formation is well understood, but there are only few places where the component factors are sufficiently well known to permit of foretelling its occurrence. The distribution of pressure, wind, and temperature at the surface of the earth is usually all that is shown by the weather-map. Nothing is known as to the amount of vapour, the temperature, and the wind velocity in the upper air except what little can be inferred from the observation of clouds. In judging of the coming of rain, a knowledge of the conditions at a height in the air is as important, or more so, than for the air at the surface of the earth.

Causes of Rain. — The conditions of pressure and temperature at the surface of the ground, which are seen at one time to be followed by rain, do not produce rain at another time, evidently from the absence of sufficient moisture in the upper air or a sufficient diminution of temperature to produce an upward convection. The amount of diminution of temperature upward not being known, the amount of convective mixture cannot be inferred.

In by far the greater number of cases, the most that can be done towards the prediction of rain from the weather-map is to state the presence of conditions favourable to rain. Whether rain will occur or not depends usually on the presence of a greater or less amount of moisture in the air and the height to which it will ascend. The conditions favourable to rain often apparently prevail at any place without resulting in more than cloud formation at that locality, but as the clouds drift along rain may occur at other places.

Rainfall and Battles. — Much has been written on the connection of rainfall and cannonading. It has been supposed that the concussion of artillery fire in battles produces rain, and that great battles are followed by heavy rainfall. There is no reason why this should be so. No physical relation has ever been traced between concussion of air and formation of water-drops. The belief is very ancient that battles are followed by rain. In "Plutarch's Lives" it is related that after the battle of Marsalia in France a great rainfall followed, and it is mentioned as being a well-known fact that all great battles are followed by heavy rain. This was certainly a case where the rain was not due to artillery fire.

Forests have no effect in increasing rainfall in their proximity. This question is one to be relegated to the infinitely little things of meteorology.

Distribution of Rainfall. — The rainfall in a year at the equator is 104 inches on the average; at latitude 60° it is 20 inches, or almost in the exact ratio of the amount of moisture contained in the lower air in the two regions. For intermediate latitudes, however, the ratio does not hold, more especially at latitude 30°, where the fall is only 40 inches, owing possibly to the general tendency of the air in that latitude to come down from above in the circulation of the trade and anti-trade winds.

All the vapour in the air at any moment, if condensed, would form a layer of water 4 inches in depth over the whole surface of the globe.

The total quantity of rainfall in a year over the land surface of the earth is estimated at 28,000 cubic miles of water, and averages over 20 inches in depth. About one-fourth of all the rainfall runs by rivers to the ocean; the remainder is evaporated into the air.

Rainfall is more frequent and greater on the sea-coast than inland, unless there is a considerable rise of the ground in going into the interior. On oceanic islands, with a high interior, the increase of rainfall from the coast is very notable. In Scotland along the divide, about 2500 feet high in the centre of the country, the rainfall in a year is over 100 inches, while along the coast it is only 40. On Ben Nevis, Scotland, height 4368 feet, the average rainfall is 129.5 inches, at the base 77.3

inches. In the island of Ceylon the fall on the coast is 34 inches, and in the interior, at a height of 6000 feet, 209 inches. On the island of St. Helena the rainfall on the coast is 5.4 inches, and at a height of 1763 feet 24 inches.

Rainfall with Height. — The increase of rainfall with height for about 2000 feet is at the rate of two-thirds of an inch for every 100 feet, as shown by a 20 years' series of observations in Saxony at 25 stations at different heights. In the Tyrol the amount of rainfall at 6000 feet is greater by 50 per cent than at 2000 feet. The rainfall, however, does not increase indefinitely with height. In Hindostan the rainfall is at its greatest at a height of 4000 feet, decreasing both above and below that level. The rainfall on Mount Washington is 83.5 inches in a year, one year as low as 55.8 and another as high as 121.1; on Pike's Peak it is 29.4 inches, one year as low as 9.3 and another as high as 44.6; at Boston the average fall is 46.8 inches, varying from 33.8 to 65, and at Denver 14.6, varying from 9.5 to 20.1.

Rain over Ocean. — Over the ocean there are no measurements of depth of rainfall of any consequence. On shipboard merely the number of times rain occurs is noted, and not the depth of rainfall. The rainfall about the equator is on the average great for most of the region. At Ascension Island, however, latitude 8° south, there is only 3 inches of rain in a year. At Malden and other guano islands in the Pacific Ocean, from latitude 6° north to 11° south, there is even less.

Daily Variation. — There is a marked variation in the amount of rainfall at different times of the day on the average. The greatest amount falls from 5 to 8 P.M., and the next greatest from 2 to 5 A.M. The times of least amount of fall are 10 to 12 P.M. and 8 to 10 A.M. The times of greatest fall correspond to the times of greatest rate of cooling in the upper air. At Batavia, Java, 5 per cent of all the rainfall occurs from 6 to 8 A.M., and 14 per cent from 4 to 6 P.M. In the island of Borneo, with a rainfall of 140 inches, twice as much falls by night as by day.

Variation in Amount of Rainfall. — There is great variation in the amount of rainfall over different parts of the earth. The wettest districts of the world are parts of the belt of equatorial calms and certain localities where damp winds meet mountain ranges and are forced upward. Cherrapunjee, on the Kassia Hills in Assam, India, has the greatest rainfall of any place in the world, 400 inches a year on the average for 24 years. One year the amount was as great as 905 inches. On the Western Ghauts Mountains, in India, the annual rainfall is 260 inches. On the coast of Alaska the rainfall is 110 inches; at Valdivia, in southern Chili, latitude 40° south, 116 inches. These places have westerly winds blowing over an extensive tract of ocean, and their moisture is largely thrown down on the first coast they meet.

Dry Regions. — To the north and south of the zone of calms there is a belt of almost rainless regions. In this region are the driest tracts of country in the world, the Desert of Sahara, in Africa, and the region extending eastward through Arabia to Persia and further east to the Desert of Gobi. These areas comprise about 5,000,000 square miles of the surface of the earth.

In south Africa, in this region south of the equator, is the great Kalahari Desert. In Chili and Peru there is a narrow strip of country between the Andes Mountains and the Pacific Ocean where it rarely rains.

In the United States, in Nevada, Utah, southern California, parts of Arizona and New Mexico, and the high plateau region of the western country, there is only about 7 inches of rainfall in a year. Here agriculture is carried on at a disadvantage. Water has to be stored in reservoirs and distributed by trenches for the irrigation of growing crops. In parts of Spain the yearly rainfall is only 6 inches. At Aden, Arabia, the rainfall in a year is 2.4 inches; at Leh Ladakh, near Thibet, 2.6 inches; at Petro Alexandrowsk, 500 miles east of the Caspian Sea, Asia, 2.4 inches; at Yuma, Ariz., 3.0 inches.

Some regions of small and medium amount of rainfall are at times subject to prolonged periods of drought, when very little or no rain falls. Such periods are disastrous to agriculture in places that rely on a regular rainfall.

The sugar crop of Mauritius Island is almost exactly proportional to the depth of rainfall. Sometimes, however, great excess of rainfall, without sufficient warm weather, makes sugar-cane watery and almost devoid of saccharine matter. In California rain is such an accurate measure of crop yield, an inch of rain is said to be worth a million dollars.

Great droughts rarely extend over more than a single season. Sometimes, however, they do last longer. The great drought in Argentine Republic, South America, called "Il grand seco," lasted three years, from 1828 to 1831. Vast herds of cattle perished. What little water there was in the few streams left became salty.

After a continued dry spell of weather, at times even when lasting no more than two or three weeks, the sickness that occurs is due to the drinking-water of springs and wells being contaminated from accumulated impurities on the ground.

Rainless Region. — Rains are nearly absent from the belt of trade-winds. The maximum rain is, in mid-summer, at 12° north, and in winter at 2° south, in mid-Atlantic. There is probably no part of the earth where rain does not fall occasionally. Regions with less than 10 inches in a year are called "rainless." Rain is a rare occurrence in the interior of Australia. In the Arctic regions, in Greenland, only 15 inches fall in a year; farther north there is only 5 inches. On the west coast of Africa, from Cape Town north, there is little rain on account of the relatively cool air from the cold ocean currents in the vicinity, warmed up on reaching the land and converted into dry winds.

Of all the land area of the world, 22 per cent has less than 10 inches of rainfall; 31 per cent, 10 to 25 inches; 25 per cent, 25 to 50 inches; 16 per cent, 50 to 75 inches; 6 per cent, over 75 inches.

Trade-wind Rains. — In the region of the trade-winds the rainfall is comparatively small, except where it blows over a mountain range. With the periodical change in the trade-wind belt, the dry regions change also. This occurs principally from latitude 30° to 40°. Most of the rain of this region occurs at the time of the year when the sun is lowest. This is the region of the winter rains, sometimes called "sub-tropical." It embraces the lands bordering on the Mediterranean Sea, the south-eastern part of the United States, and, in the southern hemisphere, Cape Colony, Africa, south-west Australia, and New Zealand. The districts between these latitudes, on the eastern sides of continents, have a good deal of rain in summer also. This is the case in the eastern part of the United States and in China, where the continental heating effect produces easterly winds. In China the summer rains are known as the monsoon rains. Natal, in Africa, and the Argentine

Republic, in South America, have rains of the same character. In all these countries the rains come at times most important for the growth of crops; this is especially the case in the part of the United States east of the Mississippi River. These countries, on this account, are the most favourably situated of any in the world for agriculture.

The amount of rainfall is different on the two sides of a mountain range. In the general circulation of the air, the average or resultant direction of the winds in the middle and higher latitudes in the lower strata of the air is nearly from west to east. Hence in the case of ranges north and south, especially on the coast, the west sides in middle and higher latitudes are rainy, and the east sides dry, and the reverse in equatorial and tropical latitudes.

Rainfall in United States. — In the United States east of the Mississippi River, the average yearly depth of rainfall diminishes from 60 inches along the coast of the Gulf of Mexico and along the south Atlantic coast to 30 inches in Minnesota. Along the Pacific coast the rainfall increases northward, from 10 inches at San Diego, Cal., to 50 inches at Portland, Ore., and 105 inches at Neah Bay, Wash. On the Atlantic coast it diminishes from 57 inches at Jacksonville, Fla., to 44 inches at New York City.

Pacific Coast Rain. — Rains on the Pacific coast occur only in winter, and are mainly due to the prevailing westerly winds and the difference in temperature over the land and sea. In winter the ocean winds, in passing over the cooler land, lose part of the moisture which in summer is sustained by the higher temperature.

In the following table is given the average rainfall for various places in the United States, by months and for the year, as derived from 18 years' observations — from 1870 to 1888. The rainfalls given are fairly representative for large districts of country around the places.

RAINFALL IN INCHES.

PLACES.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	YEAR.
						ATLANTIC COAST.							
Boston	4.56	3.88	4.49	3.95	3.30	3.58	3.57	4.26	2.72	4.12	8.46	3.50	46.76
Norfolk	3.96	3.82	4.38	4.21	3.74	4.49	5.10	6.30	4.86	3.71	3.25	3.92	51.74
Jacksonville	3.35	3.07	3.81	3.18	4.16	6.66	5.88	7.18	7.97	5.80	2.81	3.24	57.11
						MISSISSIPPI VALLEY.							
St. Paul	1.09	0.96	1.49	2.24	3.35	4.52	3.28	3.92	3.43	2.02	1.33	1.27	28.9
St. Louis	2.14	2.80	2.90	3.41	3.97	4.77	3.72	2.62	3.41	2.84	2.78	2.50	37.8
New Orleans	5.69	3.99	5.78	5.78	5.15	6.29	6.48	5.47	4.76	3.15	5.10	5.02	62.6
						ROCKY MOUNTAINS.							
Ft. Benton	0.72	0.42	0.54	1.13	2.59	2.37	1.65	1.03	0.93	0.72	0.58	0.57	13.25
Denver	0.69	0.54	0.96	2.08	2.64	1.37	1.59	1.55	1.02	0.71	0.86	0.71	14.72
Ft. Grant	0.81	1.23	1.06	0.44	0.30	0.70	3.34	3.57	1.36	0.80	0.72	1.45	15.78
						PACIFIC COAST.							
Portland	7.25	6.83	6.53	3.47	2.70	1.64	0.64	0.63	1.78	3.94	6.56	8.31	50.28
San Francisco	4.56	3.89	2.83	2.31	0.57	0.27	0.02	0.01	0.15	1.08	2.75	4.59	23.03
San Diego	1.77	2.34	1.27	0.96	0.39	0.06	0.02	0.16	0.04	0.45	0.78	1.94	10.18

Monthly Variation. — There are wide departures from the average of rainfalls in different years. At Neah Bay, Wash., as much as 141 inches has fallen in a year. In the lower Mississippi valley, at Baton Rouge, La., where the average fall is 63 inches, there has been as high as 116 inches. At Indio, in San Diego County, Cal., in the region of the Mohave Desert, where the fall is ordinarily 2.0 inches in a year, there has been a year with only 0.1 of an inch.

In the United States, except west of the Mississippi River, the rainfall is quite evenly distributed throughout the year. On the Pacific coast, the summer is a dry season. There is no rain in July and August in California, except in the northern part. In certain sections of Arizona, New Mexico, Nevada, and California, there is rarely any rain from April to October. The aridity of this region is mainly due to its being in the rain shadow of the Sierra Nevada Mountains. Most of the moisture is taken out of the air in ascending and crossing the range, which in only a few places is less than 10,000 feet above the level of the sea. The dryness of the southern part of the area is due, in part, to the prevalent western current traversing a relatively cool area of water over the Pacific Ocean, and on reaching land the higher temperature prevailing converting it into a drying wind.

Over the country east of the Mississippi River, the monthly rainfall varies from 2 to 4 inches; there are, however, large deviations from average values, in different years. The rainfall in June is slightly greater than in May, and usually not less than 4 inches; on the south Atlantic and Gulf coasts it is 6 inches.

Rainfalls greater than 10 inches in a month are common in the United States. They occur most frequently from March to October.

Monthly rainfalls in excess of 10 inches occur occasionally. Monthly rainfalls greater than 20 inches occur principally south of the Ohio River, and along the Pacific coast. There have been five monthly rainfalls in excess of 30 inches in the United States in twenty years. In June, 1886, there was a fall of 37 inches at Alexandria, La. As much as 41.6 inches has been known to fall in a month in California.

The average depth of rainfall in a rainy day in the United States is 0.2 of an inch.

Most of the rainfalls that occur are not more than 0.5 of an inch. A fall of 1.0 is, however, common. In most parts of the country a 2.0-inch rainfall is apt to occur. Rainfalls much in excess of this occur occasionally. There have been reported in the whole of the United States in about 12 years 1506 rainfalls, exceeding 4.0 inches in one day from about 1000 stations. The number of cases were as follows: 4 to 5 inches, 805; 5 to 6 inches, 352; 6 to 7 inches, 163; 7 to 8 inches, 83; 8 to 9 inches, 35; 9 to 10 inches, 27; 10 to 11 inches, 20; 11 to 12 inches, 6; 12 to 13 inches, 5; 13 to 14 inches, 6; 14 to 15 inches, 2; 17 inches, 1; 22 inches, 1.

The greatest measured rainfall in a day at any place in the United States is 22.3 inches, which occurred at Alexandria, La., June 15–16, 1886. On the day preceding there was a fall of 6.3 inches, and there had been previous rainfalls of 0.2 to 1.4 inches for the seven days before. The Red River rose at Alexandria 19 feet in one day. The discharge of water through the river showed that the excessive rainfall occurred over an area of at least 600 square miles. The same day at Cheneyville, 22 miles south of Alexandria, the rainfall was 13.3 inches.

In the arid regions the relatively small annual rainfall that occurs is often in the form of great downpours or cloudbursts that gully the country. A great part of the heavy daily rains in the United States occur west of the Mississippi River.

In the tropics very heavy rainfalls occur at times. At Delhi, India, there fell, September 26, 1875, 19.5 inches; at Rewah, June 6, 1882, 30.4 inches; at Nagina and at Purneah, September 13, 1879, 32.4 and 35.0 inches. October 25, 1882, 30 inches fell at Genoa, Italy; October 9, 1827, 31 inches fell at Joyeuse, France.

Duration of Rainfall. — The average duration of continuous rain in a rainstorm varies widely in different parts of the world. In northern Norway the time is 11 hours; in central Europe, 4 hours; in the United States east of the Mississippi River, 5 hours; in the Rocky Mountains, 3.2 hours; in Arizona, 2.6 hours. In most all rainstorms three-fourths at least of all the rainfall occurs in 24 hours. In most cases more than half of the rain falls in 8 hours.

Rate of Rainfall. — Rainfalls at the rate of 5 inches in an hour but lasting only from fifteen to thirty minutes are very common in the United States. In Washington City, July 26, 1885, 0.96 of an inch fell in six minutes. At Galveston, Tex., June 4, 1871, 3.95 inches fell in fourteen minutes.

Cloud-bursts. — A species of rainfall marked by an excessive downpour of rain in a short time is called a "cloud-burst." These occur in the United States mostly in hilly or mountainous parts of the country in the west. The water pours down to such an extent as to scoop holes in the ground on the hill-sides 6 feet deep and 30 feet in diameter. These rains do not extend over a wide area. They are very destructive in a mountainous country, producing torrents that carry everything before them.

Number of Rainy Days. — A "rainy day," meteorologically speaking, is one with a rainfall of 0.01 of an inch or more. The average number of rainy days in a year in latitude 43° to 46° is 103; from 46° to 50°, 134; 50° to 60°, 161.

The number of rainy days in a year at Jacksonville, Fla., is 146; at Washington City, rain or snow, 127; at Boston, 133; at New Orleans, 145; at St. Louis, 116; at St. Vincent, Minn., 96; at El Paso, Tex.,

55. In the vicinity of Lake Erie and Ontario the number is 170; very many days, however, with rainfall of only 0.01 of an inch.

At Toronto, Ont., the average for 30 years is 172 days, of which 63 are days with snowfall. The greatest number of rainy days in June and October was 22 in one year, the average 12, and the least in any year in the same months 5 each.

Over the Rocky Mountains and plateau region, the number of rainy days varies from 70 to 90. East of the Mississippi River the rainy days are equally numerous in January and July, on the average about 11 in each; at El Paso and St. Vincent they are twice as numerous in July as in January. On the Pacific coast the number of rainy days in a year increases from 42 at San Diego to 66 at San Francisco, 186 at Tatoosh, Id., 224 at Sitka, and 250 at Unalaska, Alaska. At Keeler, Cal., the number is 22 in a year and at Yuma, Ariz., 13.

In a given period the number of days with rain divided by the total number of days in the period gives a fractional number which is the probability of the occurrence of a rainy day for the period. The probability of a rainy day is different for different parts of the country and different for the same place for different times of the year. It increases from 0.1 in northern Texas and 0.3 in Florida, to 0.6 in the region of the Great Lakes in winter. For all the country east of the Mississippi it is about 0.4 in June and somewhat less in July. In September it is 0.2 in the central Mississippi valley, and increases to 0.5 in Florida and the lake region. On the Pacific coast it increases from 0.1 in southern California to 0.7 in Oregon from November to June. In California, in June, July, August, and September, it is only 0.01 to 0.04. In the mountainous region of Arizona and New Mexico it increases from 0.15 in January and June to 0.4 in July and August, and diminishes again in September.

The influence of the prevailing direction of the wind when blowing over water in increasing the number of rainy days is noticeable in the lake region. In January the number is 12 per cent greater on the east shore of Lake Michigan than on the west shore. Toledo, at the west end of Lake Erie, has a probability of a rainy day of 0.45 as compared with 0.59 at Buffalo, at the east end.

At London, England, there are on the average 145 rainy days in a year; on 16 to 30 of them the rain is heavy. The average number of rainy days at Dublin, Ireland, is 205; the number with heavy rains is 18 to 32. The average number of rainy days at places in Germany is 155. In Germany more rains occur with a rising than with a falling barometer.

Snowfall. — When vapour is condensed at a temperature below 32° it freezes and falls as snow. Depth of melted snow is preferable to depth of snowfall as a meteorological datum. The relation between depth of snow and equivalent water depth varies from $\frac{1}{7}$ to $\frac{1}{34}$, depending on the condition of the snow as to dryness. When it is not practicable to measure snowfall in a rain gauge by melting it, the measured depth is reduced to an equivalent depth of water by dividing by 10.

Snow often falls when the temperature of the air is 6 or 8 degrees above freezing-point. Two-thirds of the land surface of the earth never has snow. The lowest latitude in which snow has ever been known to fall is Canton, China, in latitude 23°, where on one occasion it fell to the depth of 4 inches (0.4 of an inch melted). Snow occurs everywhere in the United States, except over a small area in south-eastern Florida. It falls, however, only very rarely along the California coast from San Francisco south, or on the Atlantic coast of Florida. In the southern hemisphere snow has been known to fall at Sydney, Australia, in latitude 24°. Snow has never been known to fall at Buenos Ayres, in latitude 34°.5. South of latitude 33° snow never stays for any length of time on the ground, except in elevated or sheltered spots.

Depth of Snow. — The average depth of unmelted snow that falls in a year in different parts of the country is as follows: In Maine, 8 feet; in New York, 7 feet; in Michigan, 5 feet; in Iowa, 4 feet; in Minnesota, 3 feet; in North Dakota, South Dakota, Montana, Wyoming, and Nebraska, 2 feet. On the Sierra Nevada Mountains the depth of snowfall in a year ranges from 10 to 30 feet. Most of the snow falls from December to March. Usually about eight great snowstorms occur in a year in New England and New York State.

In the northern part of the United States snow occasionally occurs in May. At Quebec snow occurs at times in June. At Toronto, Ont., there have been three cases of snow in June in 30 years. Snow fell at Lynchburg, Va., June 14, 1857, and June 12, 1887 (height above sea level, 652 feet).

Forms of Snow. — Flakes of falling snow when seen with a magnifying glass show many curious and interesting forms of great delicacy and complexity. The figure is flat and perfectly symmetrical, made up in regular geometrical forms. The brilliancy of snow is due to the great number of reflecting surfaces, arising from the smallness of the spiculas of ice forming the flake.

Snow is feebly phosphorescent; that is, it retains light after the source of light is withdrawn. On dark nights, when the ground is covered with snow, it appears more luminous than the sky, owing to the light stored up during the day. If a surface of snow is covered with a screen on a bright day, at night it is found to be less luminous than the surrounding snow.

Coloured Snow. — In the polar regions at Cape York in Greenland, where snow lies unmelted from year to year, it acquires a ruddy colour; occasionally it becomes red like blood, but more usually of a faint, dull red. This sometimes occurs also on the mountains in southern Europe. In Spitzbergen the snow sometimes appears of a greenish hue. These colours are due to minute organisms.

Gold-dust Snow. — At South Bethlehem, Pa., there was a slight fall of snow March 16, 1879, during the night, and next day when the snow melted a yellowish deposit was found covering the ground. Examination showed it to be the pollen of pine trees. At Peckeloh, Germany, a yellow or "golden" snow once fell which had the appearance of a surface strewn with gold-dust.

Diamond Snow. — The form of snow known in Russia as "diamond snow" consists of very fine particles of snow suspended in the air and glistening in the sunshine.

Snow Line. — On high mountains the snow stays all the year round. The tops of some mountains, even within the tropics, are always covered with snow, owing to the low temperature at a great height. The limit of perpetual snow, or the snow line, is at the point where the mean temperature of the air in the warmest part of the year is at 32°, or only slightly above it for a short time. This disappearance of the snow depends on the quantity of the snow to be melted, as well as on the duration of the high temperature. In middle latitudes, on the north side of a mountain, the snow line is sometimes four or five hundred feet lower than on the southern side.

Height of Snow Line. — Near the equator and within the tropics the snow line is at a height of about 18,000 feet above sea level. On the north side of the Himalayas it is 21,000. In the Rocky Mountains and the Caucasus in latitude 43°, the snow line is at a height of about 11,000 feet. In the Alps it varies from 7500 to 9000 feet. In Iceland, latitude 65°, it is at a height of 3000 feet; in Spitzbergen, latitude 78°, it corresponds with the surface of the earth. The height of snow line varies slightly from the equator to latitude 20°; from 20° to 70° it falls equably; from 70° to 78° it descends very rapidly.

Glaciers. — Snow accumulates to a great depth in mountain ravines in some places. Under the great pressure it becomes compact, solid ice. These masses of ice, called "glaciers," move along the inclines of the valleys like water, only more slowly. There is little or no evaporation from snow surface except in the case of very dry air.

The water that runs from a melting glacier is composed of the part that melts by heat received from contact with the air, that from heat received by radiation from warm objects around, and the melting that results from the latent heat of the vapour condensed out of the air. The last of these is more considerable than the other two.

In the Alps there are about 400 glaciers between Mount Blanc and the Tyrol, covering an area of 1400 square miles. These follow the gorges from the summit of Mount Blanc down to a height of 2500 to 3500 feet above the sea. They move at a rate varying in different places from 274 to 876 feet in a year. At a height the motion is more rapid than lower down, on account of the greater steepness of the incline. In some places the velocity is 3 feet a day; in winter the rate of motion is only half as much as in summer. The ice in some places is 600 feet thick. The Aletsch glacier is 20 miles long. The water from melting glaciers forms milky-looking streams holding a good deal of pulverized rock. As glaciers melt they are continually renewed by the descending ice from above, so that the lower end remains nearly stationary, sometimes advancing a few hundred feet and at other times receding, depending on the temperature of the air near the end.

In the Sierra Nevada Mountains, in northern California, there are a number of glaciers the ends of which come down to a height of 11,000 feet above the sea. There are numerous glaciers in Alaska. In Spitzbergen there is a glacier that presents a front of 11 miles to the sea, with a cliff of ice 100 feet high.

In the Himalaya Mountains, in India, there are numerous glaciers of great extent which come down to a height of 9000 feet above the level of the sea. In the Caucasus they come down to the level of 6000 feet.

There are no glaciers in the tropics.

Icebergs. — Almost the whole of Greenland is covered with glaciers that extend down to the fiords and out into the water for several miles. By the buoyant effect of the water, the outer edge of the glacier is lifted and large masses broken off from time to time. This is called "calving." These masses of ice float away in the ocean and are the icebergs found floating in the lower latitudes sometimes as far south as latitude 36°. An iceberg in the north Atlantic has been measured three-quarters of a mile square and 315 feet high above the water. The part above the surface of the ocean is only about one-ninth of the part submerged. The density of ice, compared with pure water at a temperature of 39°, is 0.9182. The density of sea-water is 1.0256.

The enormous icebergs of the southern hemisphere come from the glaciers of Victoria Land in latitude 70° to 79° south. One seen in latitude 37° 32′ south measured 960 feet in height and 3 miles in length. Its great height indicates there must be ice at least a half a mile thick on the land from which it came. As the average snowfall in that latitude is about equal to 10 inches of depth of water, some of the snowfall that produced the iceberg must have fallen at least 3000 years ago.

In remote geologic times glaciers covered a great part of the surface of the United States when the mean temperature must have been much less than at present and the snowfall much greater. These glaciers performed a very important part in shaping the surface of the ground, scooping out valleys and throwing down masses of rock and débris carried from great distances.

Sleet. — Small pellets of frozen rain are called "sleet," and are formed by rain falling through cold air.

Hail. — Hail consists usually of a centre of soft snow surrounded by a number of layers of alternately transparent and opaque ice. It is usually the size of a pea, but often much larger. Hail is a rare occurrence at any place. It falls during thunderstorms preceded and followed by rain.

Large hail falls chiefly in dry hot climates in summer and in the hottest part of the day. The fall of large hail is commonly preceded by an unusual degree of heat. Large hail is sometimes irregular in shape. Sections of hailstones sometimes show a curious radial structure due to rows of air bubbles in regular order. Sometimes crystals of ice are imbedded in the body of the hail. Pyramidal crystals form on the exterior at times. When spherical in shape, hail has a tendency to split up into pyramids. Very beautiful forms occur at times, such as a cone with broad end on flat side of a fluted hemisphere, with grooves running spirally around the cone from the edge to apex. This form is evidently due to melting produced by the regular play of air currents around the hail in its rotation in descending.

Occurrence of Hail. — Hail does not usually fall to any depth that is measurable, consisting mostly of pellets scattered about on the ground. On rare occasions, however, it does form a layer of hailstones, and has been known to be 6 inches deep over limited areas.

Large Hail. — On August 13, 1851, in New Hampshire, during a storm, the ground was covered with hail to a depth of 4 inches. Some of the hailstones were of great size, 4 inches in diameter, about as large as an orange, and weighed 18 ounces. In a storm that passed over the Orkney Islands, Scotland, July 24, 1818, hail fell to the depth of 9 inches. In the City of Mexico hail fell to the depth of 16 inches August 17, 1830.

Frequency of Hail. — Hail rarely falls at the level of the sea within the tropics. When it does, the hailstones are apt to be of very great size. Hail is more common at a height of 1500 feet than at sea level. Hail in middle latitudes often does great damage to growing crops. In France there are 15 hailstorms in a year on the average; in Germany, 5; in Russia, 3. In the Ural Mountains, in Russia, frequent and great hailstorms occur. Hail is a very rare occurrence in the British Islands.

Hail in United States. — Hail occurs in every part of the United States. It is a regular accompaniment of thunderstorms, tornadoes, and cloud-bursts. The hailstones are often of very great size. After a tornado cloud passes, and 15 minutes after the rain and small hail cease, large bodies of frozen snow and ice fall, a pound or more in weight.

In the Upper Yellowstone valley, in Montana, after a cloud-burst, hail fell on one occasion for half an hour, reaching a depth of 14 inches, rooting up and destroying every growing thing in a strip of country 6 miles wide.

Extensive Hailstorms. — Hail usually occurs in bands or strips over the country, relatively narrow as compared with their length. In the United States these bands are about 3 miles wide and 40 miles in length. On the 13th of July, 1788, a hailstorm extended from Touraine in the south-west of France to the coast of Holland. There were two strips of hail. The width of the western one was 12 miles, that of the eastern one 6; the distance between the strips, on the average, was 14 miles; their length was 500 miles. Rain fell outside of the strips and between them.

Formation of Hail. — Hail forms at a height of 5000 to 16,000 feet. It always attains its greatest size below a height of 5000 feet. It seems to fall on the lee-side of a rise of ground in preference to other places. Sometimes before the fall of hail a peculiar crackling sound is heard in the air. Lightning is always an attendant of a hailstorm.

Constancy of Climate. — Animal and vegetable life over the earth are greatly influenced by climate, especially by the temperature. There are various mean temperatures, from 20° to 80°, that bear a critical relation to different kinds of plant and animal life. The successful cultivation of wheat depends on climate to some extent, but not to such a great extent as generally supposed. The soil and variety cultivated is more important, also the method of cultivation. Drilled fields of wheat in Ohio yield 50 per cent more than when sown broadcast. The liability to destruction by insects is an important matter. Poor soils produce good grain, but not a large yield. A cool, prolonged, and rather wet spring, with comparatively light rains after blossoming, is favourable to the crop, with hot and dry weather before harvesting. The best wheat climates are those with a mean annual temperature of 50° to 55°.

Climate, or average weather conditions in various parts of the earth, probably does not change in hundreds or even thousands of years. There are irregular variations from year to year in average temperature and rainfall, but there are no recorded observations that indicate any permanent change. The climates of the earth are probably much the same now that they were 2000 years or more ago. It is sometimes cited as an evidence of change that in the time of Julius Cæsar reindeer abounded in the forests of France and Germany, and that many rivers which used then to be frozen over in winter now remain open. The winter of 1890–1891, in Europe, was probably as severe as any experienced in a great length of time.

In the Eastern countries the camel has entirely replaced as a domestic animal the ox of ancient times, a change possibly demanded by the changing climate. Great changes have taken place in Europe, and in the East in the areas of date, palm, fig, vine, and olive culture, sometimes supposed to show changes of climate. These do not prove change of climate, but rather the greater adaptability of some regions over others to certain plants and animals, and increased facilities for transportation of products. Before the present cheap facilities for transportation existed in Europe, the vine was cultivated in regions farther north than at present. Cultivators were willing to take the risk if they got only one good vintage in six or eight years. Now it is more advantageous to raise a crop better adapted to the land and climate, which is not so apt to fail, and exchange products with countries farther south for wine.

Constancy of Rainfall. — There could scarcely be much change in climate without considerable changes in rainfall. The Nile in Egypt is very much the same river it was 2000 years ago. Good evidence that there has been no change in rainfall is afforded by the records of water levels in the landlocked lakes of Italy and Tunis, and the Dead Sea in Palestine. These show no permanent changes in level. Sometimes the water is high for a number of years and then again low, varying through wide extremes, but always returning to former levels.

The Caspian Sea, which covers an area of over 200,000 square miles, is landlocked and its surface several feet below the level of the ocean. The oscillations of its surface generalize the rainfall over a very wide area of drainage basin. The level rises for a number of years usually, and then falls. Roughly, the period from high water to high water is 34 to 36 years. The records of levels which have been kept for a long time show that its level is about the same now that it was more than 100 years ago.

An analysis of the rainfall for 321 stations scattered over the earth, for which there are records for 50 years past, shows that the period from 1831 to 1840 had a deficiency of rainfall as compared with the average, 1846 to 1855 an excess, 1861 to 1865 a deficiency, and 1876 to 1885 an excess. In the driest period the rainfall is three-fourths of that in the rainiest. This variation seems to be a real one for the whole land surface of the earth. A deficiency in one section is not counterbalanced by an excess in another. There is no successive change in the location of a region of maximum rainfall from one region to another either in latitude or longitude. In the centre of a continent there is a greater difference between the amount of rainfall in a period of maximum and minimum than there is for coast regions.

Climatic Changes in Geologic Time. — That there have been changes of climate in geologic ages, however, does not admit of doubt. Evidence enough of this is afforded in the fact that the country at one time was largely covered with glaciers, and that again the country must have been covered with a tropical luxuriance of vegetation to produce the coal fields. These changes in climate must have been exceedingly remote in time. The gorge below Niagara Falls, cut by erosion, for a distance of 7 miles by the water of the cataract, through the solid rock, shows that the waters of the Great Lakes must have been for 50,000 years at least very much what they are at present, and consequently that there has been no great change in rainfall over the drainage basin of the region within that time.

Ancient Lakes. — Between the Rocky Mountains and the Sierra Nevada, extending from Utah to Arizona and southern California, there is an inland drainage area of 232,000 square miles. As shown by shore marks and lacustrine formations, a great part of this region must have been in long-past geologic ages a lake, the waters of which flowed to the Pacific Ocean through the Columbia River. All that remains of it now is the Great Salt Lake. There must have been since that time a great change in climate over the region. The yearly rainfall over the region at present is 18 inches, and the possible evaporation 80. To keep the basin full and overflowing to the ocean, the rainfall in the region must have been much greater in the past than at present, and must have exceeded the evaporation.

Constancy of Temperature. — Observations of temperature with thermometers have only been made in comparatively recent times. Thermometers graduated arbitrarily were used for some time before the custom was adopted of marking the degrees with reference to freezing and boiling point, which was first suggested by Fahrenheit.

At St. Petersburg, Russia, there is a record of temperature since 1743. The average temperatures for groups of years are as follows:—

ST. PETERSBURG.	TEMPERATURE.
1743 to 1761	39°.0
1762 to 1779	39°.6
1780 to 1800	37°.9
1801 to 1821	37°.8
1822 to 1836	39°.2
1836 to 1869	38°.5
1869 to 1875	37°.9
Mean	38°.6

The highest annual temperature, 42°.4, was in 1822; the lowest, 34°.1, in 1815.

At Paris, France, occasional observations of air temperature were made as early as 1695, the first one recorded being on February 6 of that year. The average temperatures for groups of years are as follows:—

PARIS.	TEMPERATURE.
1735 to 1740	51°.26
1763 to 1785	52°.16
1804 to 1832	51°.26
1833 to 1861	51°.26
1862 to 1871	51°.44
1872 to 1890	51°.26

The highest annual temperature, 57°.56, was in 1781.

At Vienna, Austria, the average temperatures for groups of 10 and 12 years from 1775 to 1876 give the highest average 50°.72, and the lowest 49°.10. The highest annual temperature was 54°.0 in the year 1783, and the lowest 46°.6 in 1829.

At Philadelphia, Pa., the average annual temperatures for various groups of years are as follows: —

PHILADELPHIA.	TEMPERATURE.
1758 to 1777	52°.6
1798 to 1804	54°.2
1829 to 1838	51°.5
1825 to 1845	53°.1
1846 to 1867	54°.0
1871 to 1889	53°.1

The lowest annual temperature, 48°.2, was in 1836.

The discussions of temperature variation from long records over extensive regions show no difference between the average of a number of years greater than one or two degrees.

The records of the time of vintage in Europe extend back for several hundred years. The records show groups of years of early and late vintages corresponding to warm and dry and cold and wet periods; but on the whole there is no certain change in the average from the time of the oldest records to the present.

A record of the occurrence of severe winters has been kept in Europe as far back as the year 800. These show, according to Brückner a 34-year period of oscillation from 1020 to 1190; a 36-year period from 1190 to 1370; a 35-year period from 1370 to 1545; a 34-year period from 1545 to 1715, and a 35-year period from 1715 to 1890.

CHAPTER V.

WINDS, THUNDERSTORMS, AND TORNADOES.

Wind. — The general circulation of the air, or the prevalent wind, is subject in many places to a daily and seasonal variation, both in intensity and direction, and is also subject to irregular variations, due to the occurrence of storms. There is in many cases, no doubt, an inclination of the wind currents to the ground, so that the wind is blowing sometimes slightly up and at others down; but there is very little definitely known on this point, as no anemometer for measuring the vertical component of a wind has as yet come into extensive use.

On the Eiffel Tower there is a device for measuring the vertical component of the wind, consisting of a vertical tube with fan-wheels inside. An upward tendency of the air is frequently observed, a downward tendency less often. The greatest upward inclination observed has been nine degrees to the horizon.

Wind Velocity. — The wind velocity varies very greatly at different places. The average velocity of wind in the United States, all the year round, at a height of 50 feet above the ground is about 11 miles an hour. Over the sea it is much greater than at the same height over land. The difference is very marked between a point on shore and a headland jutting into the sea or a lake. At Cape Mendocino, Cal., the average velocity is 17.4 miles an hour as compared with 10.1 at Fort Canby in the vicinity. At Sandusky, Ohio, it is 12.8 miles as compared with 8.5 miles at Toledo, and 9.5 at Cleveland. The velocity at the Chicago waterworks crib, three miles out in Lake Michigan, is twice as great as on the top of a high building in the city. The average velocity increases from latitude 30° to 45°. Violent storm winds in the United States occur 2.5 times as frequently from a northern point of the compass as from a southern one.

Increase with Ascent. — The average velocity of wind increases rapidly with ascent in the air. On the Eiffel Tower at 1000 feet it is 3.1 times what it is 60 feet above the ground; the ratio is greatest at noon, and least at midnight; four times as great at noon, and twice as great at midnight. On Mount Washington it is, on the average, five times what it is at the level of the sea. On Pike's Peak the average is 20.1 miles an hour, while at Denver, 5294 feet above sea level, it is 6.3 miles.

Diurnal Range of Wind Velocity. — On the average, there is an increase in the velocity of the wind from the morning to the afternoon over the land. This range is small as compared with the irregular variations of velocity occurring. Over the ocean the diurnal variation is scarcely perceptible. This variation is especially marked when there are no clouds. On cloudy days the wind velocity is, on the average, only half what it is when the sky is clear. In some climates at certain seasons of the year this variation makes the wind a veritable storm in the afternoon. The wind dies down toward the evening, and at night there is a calm. There is a very great increase of this kind in the intensity of the north-east trade-wind in central Africa in the daytime. At Mauritius Island, in the south-east trade-wind, the velocity increases from 10 miles an hour at three o'clock in the morning to 18.5 miles at two o'clock in the afternoon.

Cause of Increase. — This increase of velocity is due to the interchange of air above and below, produced by the heating of the surface of the earth and the much greater velocity of air at a height brought down to the ground. This is shown, too, by the fact that the daily variation in the wind velocity on mountain tops is the reverse of what is observed at sea level. The wind on the mountain tops, though usually intense at most times, is greatest just before noon and diminishes in the afternoon in a manner corresponding to the increase in velocity at the surface of the earth. The average velocity on Pike's Peak is least from eleven o'clock to noon, equalling 17.5 miles an hour, and greatest from two to four o'clock A.M., when it is 23.2 miles per hour.

The average time of greatest wind velocity for the day is at 2 P.M. in the country east of the Mississippi River, and the time of lowest velocity at about 4 A.M. The difference between the average greatest velocity is about two miles per hour in winter and five miles in the summer.

There is, on the average, a slight increase in the wind velocity during the night. The fact that it is not as great as during the day shows that the cooling of the lower air in the night-time is due a good deal to radiation from the lower layers of air as well as to the downward convection of air from above.

Daily Variation of Wind Direction.—There is a daily variation in the direction as well as intensity of the wind, due also to air coming from above, where the direction of motion differs from what it is at the ground. The amplitude of this variation is very different in different parts of the earth, being complicated with other variations due to currents induced by the slope of the ground and the proximity of mountains or water. In middle latitudes, in the northern hemisphere, the general tendency in the case of a wind coming from the south in the morning is for it to change toward west of south in the course of the day, and then back again to the south during the night. On mountain tops the change in direction is the reverse. The average variation is about 12 degrees, but in some places it is much greater. For instance, at Pola, Austria, at the head of the Adriatic Sea, the wind which comes from a direction a little south of east in the morning turns to nearly directly west at five to six P.M., and then changes back during the night.

Land and Sea Breeze.— The land and sea breezes are well-known periodic winds arising from the difference of heating effect of the sun on land and water. The wind blows from the sea to the land in the daytime, and back from the land to the sea in the night. The land surface heats up more rapidly than the sea in the day and the air above it becomes warmer than over the sea. This effect is reversed in the night, the land radiating and cooling more than the water surface. The sea cools too, but the cool water, by the greater density than that below it, sinks and is replaced by the warmer water from below.

A long-continued wind from the land when it turns to come from the ocean is called along the coast of New England a "sea turn."

Cause of Sea Breeze.—As the air above the land warms up more than over the sea it expands and rises, so that at a height the pressure over the land is greater than at the same height over the sea. A flow of air takes place from where it is high to where it is low, which, in turn, increases the pressure at the level of the sea, causing a current to set in at the level of the sea toward the land. The sea breeze begins out at sea and extends to the land, as shown by the progress of the ripple over the surface when the sea is calm. The sea breeze increases in intensity during the day, and is strongest at three o'clock in the afternoon. It is stronger on clear than on cloudy days, and is more marked in summer than winter. In winter, in middle latitudes, it is often masked by storm winds and the currents of the general circulation of the air.

Sea Breeze First Visible. — Considering the cause of the sea breeze, it would seem that in the case of a flat shore and deep water the ripple ought first to be observed at the shore and extend out gradually into the sea; for it is just at the shore that the contrast or variation of surface temperature is greatest and the difference of pressure consequently the greatest. But the wind in a short distance is so light that it is not noticeable or capable of stirring the water. It requires a considerable width of land and water to produce a cumulative effect sufficient to make an appreciable ripple, and therefore it is usually observed first some distance from the shore. In the case of a slopping shore or steep mountains back from the shore, the interchange of air may first commence between the slopes and the air out some distance to sea, in which case the ripple is naturally first observed in the offing coming towards the land. The air over the land, when heated, expands sideways as well as upward, and causes a tendency to an outward current which counterbalances for a time the tendency of the air to flow from where it is denser. This may be, in part, the explanation of the ripple being first seen out to sea.

Regularity of Sea Breeze. — The land and sea breeze blows with great regularity in the tropics, except where masked by other stronger periodical winds, as in the case of the monsoon winds in India. In the sultry climates of the tropics, the coming of the sea breeze, which usually sets in about ten o'clock in the morning, is awaited impatiently by the inhabitants every day. With its appearance, the oppressive sultriness is relieved, and the refreshing air brings new life not only because of its relative coolness, but also by replacing the stagnant malarious air of the land.

Strong Sea Breeze. — Where the sea breeze has the same direction as the prevailing circulation of the air, in some places it increases to such an extent during the day as to become a storm wind. In the summer of the southern hemisphere the sea breeze at Valparaiso, Chili, is very strong. It blows regularly in the afternoons with such violence that pedestrians have to seek shelter. Public places are deserted and business suspended. Communication between ships and the shore is cut off. The sky is without a cloud and the atmosphere perfectly transparent. This occurs day after day with the greatest regularity. Late in the afternoon the wind quiets down very suddenly. The intensity of the sea breeze in this particular case is augmented by the specially low temperature of the sea in the vicinity of the shore, by the great heating effect of the sun on the dry, barren land and the mountain sides, and by the prevailing direction of the general current of the air, which is from the south-west. At Kingston, Jamaica Island, the sea breeze is almost as strong as at Valparaiso. The intensity of the wind is due to the Blue Mountains in the vicinity.

The differences of pressure associated with the land and sea breeze are very small. Still, they are perceptible in the differences of mean pressures for a number of years at coast and inland stations. In England the pressures at coast stations from 10 A.M. to 11 P.M. are perceptibly higher than at places inland. The heating and cooling are of such short periods that the winds do not reach any great development and extend only a few miles.

Kona. — In the Hawaiian Islands the interruption of the north-east trade-wind by a wind from the south-west is usually associated with rain. This occurs principally from December to April. The wind is called the "Kona."

Monsoon. — The monsoon winds of Asia, from a word meaning *season*, arise from the same cause as the land and sea breeze, but are due to seasonal differences in temperature effects over the continent of Asia and the Indian and Pacific oceans. The land warms up more in the summer than the sea, and in the winter cools off more. This gives rise to south-west winds from April to October over a district extending from Australia to India, completely breaking up the north-east trade-winds of the region. The wind then changes direction, and from October to April blows from the north-east. These are the famous summer and winter monsoons. The same differences of pressure exist as in the case of the land and sea breeze, only greater. In July the pressure over central Asia is 29.6 inches, and over the Indian Ocean 29.9. In January the pressure over Asia is 30.4 inches, and over the Indian Ocean 30.0.

Intensity of Monsoon. — The intensity of the south-west monsoon in India is greatly increased by the diminution of pressure over the land, produced by the collapse of the great quantity of vapour taken from the air in rising and crossing the Himalaya Mountains to the north of India. This produces the tremendous downpours of rain for which this region is noted, the greatest that occur anywhere in the world.

Differences of Wind Direction. — The direction of the wind is not everywhere south-west in the summer monsoon. The general tendency of the air is toward the centre of the continent of Asia. In some places the direction is locally modified. Along the coast of China the direction of the wind is southerly; more to the north it is from the east. In the arctic regions north of Asia, even, the monsoon effect is visible, but very weak; the direction is from the north-west. The effect extends south of the equator, whence air is drawn, thereby intensifying the south-east trade-winds.

There is no belt of calms in the Indian Ocean during the summer monsoon.

The cooling of the air over Australia while the air over Asia is being heated also adds to the monsoon effect.

Bursting of the Monsoon. — The turning of the monsoon current is called the "bursting" of the monsoon. It does not occur all at once or in a day. Sometimes for as much as three or four weeks at the epoch of change, the winds are feeble and uncertain in direction. At this time violent storms occur, especially when the "bursting" of the south-west monsoon is delayed. The wind finally settles to the south-west. After a few days the crashing sea waves along the shores tell that the monsoon is advancing. The lightning flashes, the thunder roars, and the rain comes down in torrents. The rivers rise thirty feet in a single night. The bursting of the monsoon lasts with varying intensity for three or four weeks. During this time it rains almost incessantly. Then it clears and the wind blows strong and steady from the south-west for the next five months. Rain occurs more or less all through this monsoon, which is called the wet monsoon as distinguished from the dry monsoon which blows from the north-east. This applies to Ceylon and southern India.

Mountain Winds. — There is a class of winds peculiar to mountainous regions, that blow with notable regularity. They are due to the heating on the inclined surface of the mountain. When not modified by the stronger winds of the general air circulation, they are up the mountain in the day and down in the night.

Cause of Wind. — On the side of a mountain, as shown in Fig. 19, when the air is calm, the surfaces of equal pressure are horizontal as

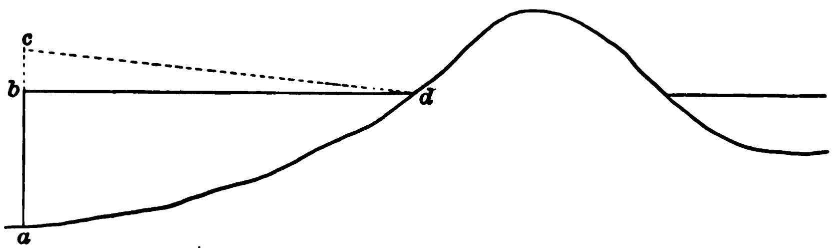


FIG. 19.

in the case of the line *bd*. When the sun shines on the mountain side, the column of air, *ab*, expands to the point *c*, raising the pressure at *b* to the point *c*, while at *d* it remains unchanged. There is consequently a flow of air from *c* to *d*, to restore the equilibrium. The consequence is there is a wind blowing up the mountain during the day. In the cooling during the night this process is reversed, and the wind is down the mountain. Hunters make camp-fires below their tents, so that the night wind may carry the smoke away.

The shapes of valleys modify these winds at different times of the day and at different seasons of the year. Sometimes the wind is stronger by day than night and again the case is reversed. In winter a snow covering is favourable to the night wind; in summer the heating effect of the sun in the day is favourable to the day wind. Where the air is brought together by a number of ravines into one contracted current, its force may become very great.

Names of Mountain Winds. — These winds are given names in some localities. On Lake Como, in Italy, the day wind is called "La Breva" and its opposite, the night wind, the "Tivano."

Any interruptions to these winds in countries where they blow regularly is very noticeable, and indicates some powerful disturbing cause, usually the proximity of a storm.

In some places only the night wind is noticed, being felt by its lower temperature. This is the case in narrow gorge-like valleys that connect with broader more strongly heated valleys.

The side of a mountain in shadow in the daytime may become colder than the surrounding air and send down an avalanche of cold air on the warm valley below.

Williwaus. — A most interesting climatic feature of Terra del Fuego, Patagonia, is the violent blast of wind called the "Williwaus," which at times comes down into the fiords from the mountain sides. It is of the most frightful intensity. A deep muttering is heard in the distance. Suddenly, without any gradation, a most terrible blast comes down upon the sea. Immediately the water is pulverized and scattered in fine drops, and driven through the air by the incredible force of the wind which resembles a hurricane. The shock lasts from 8 to 10 seconds, and a calm follows as suddenly as it was interrupted. A ship at anchor has about time to stretch its cable. No vessel could stand the wind for more than a few seconds. The barometric pressure suddenly increases 0.08 of an inch.

Avalanche Winds. — Avalanches in the Alps and other mountains — that is, the sliding down of great masses of snow, carrying with them rock and earth — produce winds of great intensity over restricted areas. Persons in the blast of an avalanche have their clothes torn to shreds by the violence of the wind. The extent of an avalanche is sometimes as great as 360,000,000 cubic feet of material, which falls at times 3000 feet or more.

Cape Town Wind. — A peculiarly violent wind blows down from Table Mountain, opposite Cape Town, in South Africa. A dense mantle of vapour rests upon the mountain and, when the wind begins, pours over its steep sides like a cataract of foam, suggesting the idea of a tablecloth. The storm wind is known locally as the "clearing of the tablecloth."

Föhn-wind. — There is a peculiar class of mountain winds associated with the movement of areas of low barometric pressure over the surface of the earth. A wind of this kind is the Föhn-wind of Switzerland. It is warm and very dry and comes down over the mountains with great violence. It blows from the south-east and south. Its direction depends on the valleys through which it comes. The intensity of the wind diminishes with distance from the mountains. It is the southerly current of air moving from Italy toward a centre of low pressure north of the Alps.

Cause of Föhn. — As the air ascends the mountains, it is cooled dynamically by expansion. This cooling condenses the vapour, and there is rain on the side of the mountain from which the wind comes. The latent heat in the vapour is set free. The air in descending the mountain on the other side is dynamically heated by compression. Air going over without any condensation of vapour would remain unaltered in temperature, for it would have been warmed in the descent just as much as it had been cooled in rising. But when there is condensation of vapour the latent heat is added, so that it is much warmer after its descent than before. The dynamic heating effect is 0.58 of a degree Fahrenheit for every hundred feet of descent. The potential temperature of the higher layers of the atmosphere is, in general, higher than that of the lower. The potential temperature increases when condensation occurs, and the increase is greater the more water the air loses. The warmth of the Föhn when it first blows, especially in winter, is not due to latent heat of condensing vapour, but simply to dynamic warming in descent. The upward rate of diminution being less than the adiabatic rate, there is relative warming in the case of descending air.

Prevalence of Föhn. — The Föhn blows with varying violence for two or three days, breaking trees and overturning houses — creating great commotion and uproar and causing terror to the country. The dreaded avalanches are coincident with its appearance. People suffer under the influence of the hot wind; it oppresses the spirit and is a strain on the nervous system. Domestic fires are extinguished under the supervision of a fire-patrol from house to house, so great is the dread of a conflagration which would be disastrous in the thoroughly dried condition of the timber in the houses, due to the dryness of the air. After the prevalence of the Föhn, there are usually heavy rainfalls.

Dryness of Föhn. — The Föhn occurs occasionally from November to March, there being about 30 days of it on the average. The temperature during its prevalence is about 30 degrees above the average for the time of the year. The moisture in the air is not more than one-seventh of what it ordinarily holds and only one-tenth of what it is capable of holding. The Föhn in the spring is welcomed, for it quickly disposes of the winter accumulation of snow and ice. In the Grindelwald valley it takes away 2 feet of snow in 12 hours, and does as much in a day toward clearing away ice as two weeks of ordinary spring weather.

Chinook. — The Chinook winds in the western part of the United States are of the same nature as the Föhn winds of Switzerland. They occur from the southern part of Colorado up into British America, principally in Wyoming and Montana. They occur as far up as the Arctic Circle. They soften the winter climate materially. They are warm, dry, westerly, or northerly winds on the eastern slopes of the Rocky Mountains, sometimes lasting for several days, and sometimes only a few hours. They occur when areas of low pressure pass along north of the places. The high temperatures are confined to the valleys, occurring in streaks. A person will sometimes pass from a very warm to a very cold atmosphere in crossing a valley.

Mistral. — The circulation of air induced by high and low areas of pressure sometimes carries cold bodies of air from high plateaus down onto warm regions. These winds in some places are given names. The "Mistral" is a wind of this kind which blows in the Rhone valley in the south-eastern part of France.

Bora. — The "Bora" of the Adriatic Sea is a wind which blows down off the high plateau of Carinthia. At Trieste, Austria, it is a furious northerly wind.

Tramontana. — On the Italian side of the Adriatic Sea, the same wind which blows from the mountain along the shore is called the "Tramontana."

Gregale. — At the island of Malta the same wind is known as the dreaded "Gregale."

Buran. — The steppes and deserts of central Asia are subject to a north-east wind called the "Buran," which blows as a gale. It is very cold and carries clouds of drifting snow.

Purga. — The "Purga" is another name for a more violent wind in Siberia, of the same kind as the Buran.

Blizzard. — In the United States the north wind in Montana and the Dakotas in winter is at times very strong and exceedingly cold. This wind is called the "Blizzard." In the most violent of these, the wind will blow at the rate of 50 miles an hour for a whole day, with the temperature 30° below zero. In these storms the wind has been known to blow at the rate of over 40 miles an hour for 100 consecutive hours. No one exposed to these winds can live for any great length of time. Low temperatures can be borne without much inconvenience when the air is still. The body creates about it a locally warm atmosphere. When, however, there is any wind, this atmosphere is carried away and has to be perpetually renewed, causing a great drain of heat from the system. In the arctic regions in quiet air, with the temperature 40° below zero, a person can be out-doors and take pencil notes with ungloved hands. But in a wind of 40 miles an hour even a temperature of freezing would be unendurable for any length of time.

The blizzard extends from Texas to Illinois, but is milder than to the west and north-west.

Northers. — From Missouri to the Gulf of Mexico the north winds of winter are known as "Northers." In Texas they are distinguished as dry and wet northers, depending on rain or its absence. There is less likelihood of their being wet the farther the low areas they are associated with are from the Gulf of Mexico.

Barber. — In the Gulf of St. Lawrence a strong wind blows at times, loaded with particles of frozen fog. Driven by the high wind, it almost cuts the face. This wind is called the "Barber."

Pamperos. — In southern Brazil, the Argentine Republic, and Uraguay the south-west winds which correspond to the "Northers" of the Gulf of Mexico are called "Pamperos," from the Spanish word for a plain.

Southerly Buster Nor'wester. — In New Zealand the southerly winds of the same nature as the "Northers" of the northern hemisphere are called the "Southerly Buster" and the "Nor'wester."

Scirocco. — The difference in heating effect over level ground, such as over desert and cultivated land, gives rise to winds of marked peculiarity, but no great violence. On the African coast of the Mediterranean Sea and in Malta and Italy, there is a south-east wind in summer called the "Scirocco." It is a hot and dry wind, and produces a feeling of lassitude. It comes from the moderately high lands of Africa. In the Island of Sicily it sometimes brings a temperature of 110°.

La Veche. — It reaches as far as Spain at times, where it is called "La Veche."

Leste. — In the north of Africa it is called the "Leste."

Desert Winds. — The easterly winds which blow on rare occasions in southern California in summer from the interior of the country toward the Pacific Ocean are called "Desert Winds." The temperature in these winds sometimes goes very high, 120° or more. During their prevalence shelter has to be sought by persons in the closed adobe houses or cool cellars. Persons in small boats on the ocean near the coast have lost their lives in these winds, not being able to reach the shore and shelter before exhaustion from the scorching heat. This wind lasts but a few hours.

There are desert winds that blow from the bad lands in Dakota, but of no great violence.

The hot winds of Kansas that blow in summer from the south-west are very dry, and parch the growing crops. In the hot winds of Kansas the air of excessively high temperature comes in streaks or patches, and blows along, lasting three to five minutes and in some cases even as much as half an hour, when there is a return to the ordinary temperature, and perhaps again a renewal of the warm stream. The warm currents prevail in narrow currents 100 to 500 feet wide, and the air, besides being very warm, is very dry. It withers growing vegetation. Sometimes the leaves of trees are so withered and dried as to fall to powder in one of these hot blasts. Associated with these hot winds of Kansas there are V-shaped areas of barometric depression, extending from north to south from Nebraska to Manitoba. The winds are due to descending currents of air, which are heated dynamically by compression in coming down. They occur in July and August from western Texas north to Kansas, and mostly after great rainfalls.

Harmattan. — On the west coast of Africa there is a hot east wind called the "Harmattan." Coming off the desert, it brings with it clouds of dust smutty red and white or copper coloured, which covers the sails and decks of ships far out to sea, and which is largely composed of the microscopic shells of infusoria.

Khamsin. — In Egypt the hot wind from the desert is known as the "Khamsin" or "fifty," from the prevalent notion that it blows for that number of days. It is at times a pestilence-bringing wind. When this wind begins to blow the natives gather in the churches, and a general burial service is performed. Any one dying during the prevalence of the wind is buried without further ceremony.

Simoon. — The "Simoon" is a sand whirlwind occurring in the desert. It sometimes overwhelms and buries whole caravans. Lightning occurs with the simoon (due to development of electricity by friction of sand on the air).

For the most part, the names given to winds do not signify any difference in their physical causes. The names originate from their effects on human beings and the different feelings aroused. The searching wind of the blizzard makes one feel as if pursued by a demon. The hot scorching blast of the simoon and the mysterious sand-column of the desert, wandering in its burning solitude, inspire awe and fear. The tendency to personify nature is strong in the human mind. Exposure to the inconvenience and suffering caused by wind makes a deep impression.

Wind Roses. — Cloudiness, rainfall, high or low temperature, are more frequent with winds from some directions than others. This is shown graphically by a device called a "wind rose."

From an initial point, distances are laid off in the various directions, forty-five degrees apart, proportional to the depth of rainfall occurring when the winds are from those particular directions. The ends of the lines are joined and the enclosure shaded. Temperature, vapour pressure, etc., as dependent on wind direction, are sometimes represented in this way also. Wind roses are, however, of very little value, except to show, graphically, the numbers from which they are derived. The same direction of wind, according as it is blowing out of an area of high barometric pressure or into an area of low pressure, blows from very different regions. Without separation of wind directions according to types of pressure, they are not useful in the investigation of weather. Wind roses, made up for places without reference to types of pressure, have been the cause of long prevalent erroneous conceptions as to the way in which rain originates.

Thunderstorms. — Downpours of rain are sometimes accompanied by thunder and lightning. Lightning is a disruptive discharge of electricity. The flash lasts but the millionth of a second. Thunder is caused by a sudden expansion of the air due to the heating effect of the electrical discharge, and the sudden rush of air to the track where the rarefaction is produced. The distance through which lightning may strike varies from a hundred or two hundred feet to a mile or more. Thunder is rarely heard at a greater distance from its origin than 12 miles. Sound travels at the rate of 1118 feet per second, in air at a temperature of 61°, and about one foot less for every degree of temperature below that. By noting the time between a lightning flash and thunder, the distance of the origin can be ascertained. The lightning flash and its visibility are practically instantaneous. The drops of rain, and especially flakes of snow, are sometimes so highly electrified as to be feebly luminous.

Rolling of Thunder. — Thunder sometimes rolls; that is, the sound continues for several seconds. This is due in part to the successive propagation of the sound from the different points in the path of the lightning, and in part to aerial echo, just as a wall reflects sound. The surfaces between layers of air, though not solid, reflect sound slightly; the composite of the successive innumerable reflections from every vertical section back of the lightning for some distance makes up the aerial echo, which is the roll of the thunder finally dying away as a faint reverberation from a great distance.

Air Pressure during Thunderstorm. — There is very little change in the air pressure before or during thunderstorms. There is a slight fall in pressure, about 0.10 of an inch, in the hour preceding the storm until rain begins, when the pressure suddenly increases 0.06 of an inch.

Description of Thunderstorms. — An hour or more before a thunderstorm, heavy black clouds are seen in the western sky. The wind is usually light from the south-west and the temperature very high, 85° to

90°, and the air very moist. As the storm approaches, the temperature falls slightly. A curtain of light greyish cloud is seen extending to a great height, while all below is of a uniform black tint. This front presents a vista, very long from south-west to north-east as compared with its height. It gives the appearance sometimes known at sea as the "arched squall." The clouds reach overhead a few minutes before thunder is heard, and from 10 to 30 minutes before rain begins.

Five minutes before the rain, the wind changes to the north-west, and becomes very strong. The wind advances with a rolling motion and raises great clouds of dust in city streets. There is usually a fall of temperature of 12 degrees; in the case of hail it is twice as great.

Squall. — At sea this wind is called the "squall." These puffs are sometimes called "white squalls," from the whitish appearance of the wave-crests on the ruffled sea. With the "squall" the temperature falls rapidly. The heaviest rain is at the beginning of the squall. The wind dies down as soon as the rain begins. The thunder grows nearer, until the time between flash and crash is hardly perceptible. The loudest thunder occurs from 10 to 30 minutes after the beginning of rain. Lightning strokes occur mostly during this time. The relative humidity falls to 40 per cent in front of the storm, and rises to 80 inside of it. When hail falls, it is in strips parallel to the line of progress of the storm. The rain lasts about half an hour. From an hour to one hour and a half after the beginning of storm the rear edge is overhead, and rainbows appear. The last thunder is heard from one to two hours after the beginning of storm. The rainfall in different storms varies from half an inch or less to one inch and a half or more, usually no more than half an inch. The rain is greater in intensity the shorter its duration.

Isobronts. — Thunderstorms occur successively over strips of country varying at different times from 10 to 50 miles in width and 300 to 400 in length. The motion of storm front is from south-west to north-east at the rate of about 34 miles an hour in summer. The lines joining the points where the first thunder is heard at the same instant of time are called "isobronts," or lines of equal front.

Sometimes the isobront is taken as the mean of the time when first and last thunder is heard at a place. This is the custom in France.

In winter the front moves faster than in summer, on the average at the rate of 50 miles an hour. At some places the storm is more violent than others. Sometimes a storm will die down during the night and begin again next day where it left off, and continue its progress. The isobronts or storm fronts move in the general direction of the prevalent current of the lower air. Sometimes thunderstorms progress from a centre and the isobronts are widening circles. This occurs in Switzerland. In Italy, thunderstorms often follow along in the same region at intervals of 3 hours or multiples of three hours; 24 hours or the day is a very common interval.

Lightning. — Lightning follows an irregular zigzag path through the air. What is called sheet lightning is the reflection of distant zigzag lightning from the clouds and the sky above the clouds. This is sometimes seen when a thunderstorm is as much as 250 miles distant.

Ball Lightning. — Ball lightning, seen at times, is a slowly moving ball of fire which finally explodes. It occurs when not only the potential of the electricity concerned in the production of lightning is great, but when the quantity of electricity is also great. Ball lightning can be produced experimentally on a small scale by sending the current from a dynamo through water contained in a glass. It occurs during a thunderstorm, mostly in wet places, along the ground, and only at times when there are great downpours of rain. It consists of a globe of incandescent rarefied air and gas from the decomposition of vapour of water. The ruddy hue is due to the hydrogen, this being characteristic of electrical discharges through hydrogen. The least current of air changes the spherical form.

Fulgurites. — Isolated trees, and trees on the edge of a forest, are more apt to be struck by lightning than those within it. Sometimes the lightning strikes into the earth. When this occurs in sand the sand is melted by the discharge, and the path is marked by a tube of vitrified sand. This is called a "fulgurite." These tubes are sometimes 30 feet long and very irregular, with walls an inch thick; the outside diameter of the tube is about 3 inches. The inside of the tube is smooth and bright. Fulgurites are very fragile, and can only be taken out of the ground in short lengths of a few inches.

Frequency of Thunderstorms. — Thunderstorms are of daily occurrence in some parts of the belt of calms near the equator. The frequency diminishes in going north. From 40 years' observations the average number in France in a year is about 29, counting at a place any day when thunder is heard as a day with thunderstorm. In Iceland there is, on the average, only 1 a year; in Finland, 2; in Java, 97. In the rainless area of Peru no thunder is ever heard. At Rio Janeiro, Brazil, a thunderstorm occurs regularly at eleven o'clock in the morning in summer, whence the local proverb, "as sure as a January thunderstorm." The same thing occurs at Puebla, Mexico, where, in the summer, there is a thunderstorm every afternoon from two to three o'clock. These storms are due to the mountains in the vicinity producing rain from the ascending currents along their sides.

Twenty-six Day Period. — There is some indication of a twenty-six day period in the frequency of thunderstorms. This corresponds to the time of rotation of the sun on its axis.

In middle latitudes thunderstorms are most frequent in summer and occur only rarely in winter. In Iceland they occur only in winter. At Spitzbergen, in latitude 78°, they occur rarely, and only in summer. In the United States the average number yearly in the lower Mississippi valley and Florida is 50; in the region of the Great Lakes, 20; in New England, 10. West of the Rocky Mountains the average number is less than 10; in southern California a whole year often passes without any.

Thunderstorms over Land and Sea. — Over the land the time of most frequent occurrence of thunderstorms is in the day, and from two to five o'clock in the afternoon; they occur, however, at all hours of the day and night. Over the ocean thunderstorms are essentially occurrences of the night.

Mountainous and swampy regions are favourable to the production of thunderstorms.

Daily Period. — There are two maximum periods in the daily frequency of thunderstorms: one in the afternoon, and the other not so decided in the early hours of morning before sunrise. The one is clearly connected with the warming of the lower air by the sun, and the other with the cooling of the upper strata by radiation in the night. The thunderstorms over the ocean are principally due to the latter cause. The time of maximum frequency of lightning without thunder is at an earlier hour than with it.

Atmospheric Electricity. — The air is usually in an electrified condition, as shown by observations with an electrometer connected with a vessel situated at a height in the air from which water is dropping, which enables it to take the electricity from the air. The potential of the air at Washington, 28 feet above the ground and 5 feet from a building, is, on the average, 55 volts, being 48 in summer and 65 in winter. The distribution of electricity in the air seems to be due to the varying proportion of vapour contained at different times. When it rains, the potential of the air becomes the same as the ground.

This may be sometimes due to a film of moisture on the insulating supports of the electrometer or water-dropper, causing an unavoidable error of observation. At times, in the dry air of the western part of the United States at high altitudes, light shocks are felt on touching metal objects; a tingling sensation in the fingers and ears is produced by light discharges of electricity from the air to the ground through a person's body.

Electrical Storms. — During such times electrical storms are said to prevail. When these occur, there are frequently thunderstorms in the vicinity. On Pike's Peak during such storms, the telegraph wires in the air appear luminous; the revolving anemometer cups resemble balls of fire; lightning-rods, trees, short stems, and other pointed objects have brushes of light. Snowflakes falling through the air and striking a horse's back give sparks of light. The sensations experienced during such a storm are decidedly unpleasant and often even dangerous.

Cause of Lightning. — When an object is charged with electricity and there is a flow of electricity from one part of the object to another, there is a difference of electric potential. The practical unit of electric potential is the volt. The wire connecting the two poles of a single cell of gravity battery, zinc and copper in a solution of sulphate of copper, is a charged body with a current flowing along it; the difference in potential of the ends of the wire is about nine-tenths of a volt, as long as the wires are not connected up; it diminishes somewhat on connecting the wires.

Substances vary very greatly in their power of carrying electricity when there is a difference of potential. Silver, copper, and all metals are good conductors. Glass, gutta-percha, india-rubber, feathers, wool, and air are bad conductors, or insulators, and carry very little electricity.

If a glass plate with a sheet of tin foil in the centre on each side be connected one with the positive and the other with the negative pole of a cell of active battery, the tin foil will take on charges of electricity, and the difference in their potential will be that of the poles of the battery. There will be no flow of electricity along the wire after the minute quantity is supplied which is sufficient to charge the tin foil. This arrangement of glass and tin foil is called a condenser, and is the Leyden jar in principle.

The air is always in an electric condition. There is a difference of potential between the earth and the air that increases with height in the air. The earth, the air near the earth's surface, and the rarefied air at a great height has been likened to a condenser. The earth is a good conductor, and corresponds to the tin foil on one side of the glass. The lower layer of the air for a few miles above the earth's surface is a bad conductor or insulator, and corresponds to the glass or dielectric of the condenser. The upper highly rarefied layer of air is a tolerably good conductor and corresponds to the other layer of tin foil on the condenser. The perfect vacuum above the highly rarefied air is again a non-conductor. As to the way in which a charge might originate on the earth and upper air considered in this way as a condenser, it is supposed it might be due to the rotation of the earth. The earth is a magnet, and the rotation of a magnetic field produces a current of electricity. A charged condenser rotating will produce a magnetic field, as shown by experiment. It is merely a surmise that the earth and the upper air is charged as a condenser as indicated. But it is unquestionably a fact that the potential of the air increases with the height.

The energy in a charged condenser is in the form of a strain of some sort in the dielectric between the two conducting surfaces. The surfaces of the charged condenser have opposite kinds of electricity, which attract each other. When the strain is greater than the dielectric can stand, it breaks and there is a sudden rush of the electricity to equalize the potential, accompanied by a snapping sound and a spark. The motion of the electricity is not simply one way but a very great number of motions, back and forth several thousand times in a small fraction of a second. The fact that the spark is not single but a series of sparks is shown by examining its reflection in a rapidly rotating mirror, when it is extended out as a series of points of light instead of a single one.

The flash of lightning is an equalization of potential between the upper and lower layers of the air, or the air and the ground. Disruption of the air and discharge occurs when the strain is greater than 0.5 of a gramme weight for every square centimetre of cloud surface.

In thunderstorms, the particles of water, as they form from vapour, take the potential of the air at the place of formation. As the particles coalesce in the contacts arising from continual intermixture, the electric potential on the drop increases. The quantity of electricity on a body is equal to its electrical capacity multiplied by its potential. The electrical capacities of spheres are proportional to their radii. Two spheres having the same electrical potential, but the radius of one being twice that of the other, the amount of electricity on the larger one will be twice that on the smaller one. If a thousand spheres or particles of water, of the same size and having the same electrical potential, coalesce to form a drop, the quantity of electricity on the drop is the same as the sum of all on the thousand particles, but the potential is 100 times as great as on any one of the particles separately.; for the electrical capacity of the drop is 10, while that of the spheres separately which compose it is 1000.

Striking Distance. — The distance through which the disruptive discharge takes place depends on the electrical potential; the higher the potential the greater the striking distance. When, by the coalescence of a large number of particles of water, the potential of the drops throughout a cloud is increased enough to overcome the intervening striking distance between the drops, the whole body of raindrops forming a cloud becomes a single drop, as far as the distribution of electricity is concerned, and its potential is correspondingly greatly increased. When the drops begin to fall, there is a disruptive discharge or flash of lightning as soon as the rain front reaches the striking distance from the earth. A number of seconds after a heavy discharge of lightning there is often noticeable a marked increase in the intensity of the downpour of rain.

The chance of a tower or steeple being struck by lightning is forty times as great as for an ordinary building. A tree in a clearing or on the edge of a wood is more likely to be struck that one in the depth of a forest. Oak is more likely to be struck than any other variety of tree. On the average, about four persons in a million are killed in a year in France and Germany, by lightning. Two hundred persons annually were killed in the United States by lightning, from 1880 to 1890. About eight hundred fires in a year are caused by lightning, in the United States. It is a prevalent misapprehension that lightning never strikes twice in the same place, or only strikes isolated objects.

Cause of Thunderstorms. — Thunderstorms are due to a rapid decrease of temperature, with ascent in the air and the presence of a great deal of moisture in the lower air. The veil of cirrus clouds seen

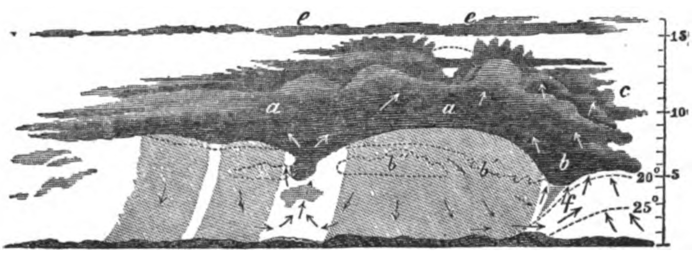


Fig. 20.

just before a thunderstorm is observed to be much lower at such times than ordinarily. Observations by aeronauts, made in balloon ascents at times of thunderstorms, show a rapid decrease of temperature with height. When the decrease of temperature with height is greater than 0.58 of a degree in one hundred feet of ascent, the equilibrium of the layers of air is disturbed, and the lower, warm air begins to change places with the upper, colder air. This tendency of the air to rise is increased by the moisture of the lower air when present in considerable quantities, being only two-thirds of the density of air of the same pressure. When the rate of decrease is not much greater than 0.58 of a degree, or extends only throughout a layer of air three or four hundred feet thick, the interchange of air above and below goes on slowly and imperceptibly. But when the rate is exceeded very much, and extends throughout a great depth of air, sufficient to carry a large body of the surface air to a point where the temperature is a good deal below the dew-point, then the conditions exist favourable to a thunderstorm. The rain occurs first in the centre of the ascending current. This cools the lower air in its descent, coming from a colder region above. It also cools the air some by evaporation. The result of this is that the air in the centre, becoming denser than the surrounding air, begins to descend. This is shown in Fig. 20, which is a longitudinal section of a thunder cloud in motion from left to right. The scale on right is the height in hundreds of meters. The highest clouds are *e, e,* about a mile high. The currents are shown by the direction of the arrows below the thunder cloud, *a, a.* The motion of the air is a whirl around a horizontal axis. Over the stretch of country shown, when the rain begins to fall, there is a downward and outward current at *b.* At this point the barometric pressure is greater than round about it. There is also a great contrast of temperature in the front. These are the conditions that precede the thunderstorm. The burst of wind or the squall, the change in wind from south-west to north-west, is the passage over a place of this downward cold current. The sudden increase of pressure at the commencement of rain is largely due to the column of cold air being of greater weight than the equally high column of warm air just preceding it.

Increase of Pressure. — The pressure increase may be due to some extent to the forcing down of the air caused by the falling drops of water. Some part of it, too, may be due to the increase of pressure due to evaporation from the water-drops. The difference in temperature of the air is adequate to account for the increase of pressure. A column of air 2 degrees colder on the average than the surrounding air, and of a height such as is ordinarily active in thunderstorms, would produce a rise of 0.07 of an inch in pressure. The difference in temperature at the surface of the earth extends up through only a relatively small height.

Cause of Squall. — A difference of 0.07 of an inch in pressure in the distance ordinarily observed is capable of producing a wind of 43 miles an hour, which accounts amply in all cases for the squall.

Tornado. — A tornado is a specially violent form of thunderstorm. A characteristic feature is a funnel-shaped cloud dipping down from the main storm-cloud, at times reaching the surface of the earth and causing devastation wherever it touches. The very great velocity of the wind in the vicinity of the funnel, estimated to be 300 miles or more an hour, destroys everything in the path of the funnel cloud, uprooting trees, levelling houses to the ground, and at times blowing locomotives off the track and lifting iron bridges from their foundations. The funnel cloud advances over the earth from south-west to north-east at the rate of about 30 miles an hour. It bounds along, sometimes skipping above the earth and then coming down again and swaying from side to side as it renews its ravages. The swath of destruction corresponds to the width of the funnel, and varies in different cases from 50 feet to 1000 feet, and its path extends over a strip of country from 5 to 50 miles in length.

A characteristic tornado cloud and funnel is shown in Fig. 21, obtained from a photograph of the cloud seen at Howard Mines Company, South Dakota, August 28, 1884, as it passed 22 miles to the west

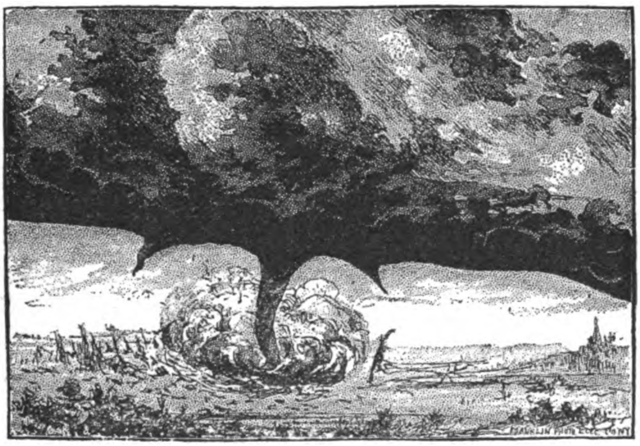


FIG. 21.

in a south-easterly direction. A peculiar form of cloud invariably present from 30 minutes to 2 hours before the tornado is characterized by ball-like masses of light grey or white colour often in long lines on a darker background or in clumps, often three or more side by side, the under side circular, the upper indefinite or shading into the main cloud. At times this gives the appearance of having scallops, or a shell-like edge, when the tufts are at the lower margin of the cloud; the under side is perfectly round, the upper side streaming out like cotton balls partially unwound.

Noise of Tornado. — A tremendous roaring sound accompanies a tornado in its progress, similar to the rushing of a thousand express-trains.

Tornado Wind. — The wind blows spirally inward around the funnel, contrary to the direction of motion of the hands of a watch, or from the east around by the north, the west, and the south. The funnel marks the surface where the moisture in the air in its ascent is condensing. It is a region of very low pressure, produced by the centrifugal tendency of the air from the centre of rotation. From the size and weight of articles carried up, it is estimated that the upward velocity of the air must be at least at the rate of 176 miles an hour. Iron objects weighing 1500 pounds have been moved as much as 20 feet; objects weighing 100 pounds have been carried several hundred feet; pieces of tin-roofing have been carried 17 miles; a letter has been carried 45 miles. The upward motion is in a zone some distance from the centre. There probably is no upward motion of the air right at the centre or axis. Fowls have been stripped of feathers in tornadoes and remained otherwise uninjured. All attempts to produce this result by the sudden exhaustion of air about fowls in closed vessels have failed. When fired from a cannon, the feathers are plucked, but the body is torn to pieces when the velocity is 340 miles per hour. The wind velocity in a tornado must be less in some instances than this, and probably a good deal less. By means of a mechanical air-blast, straws have been driven into wood a depth of one-tenth of an inch with a velocity of the air of 135 to 160 miles an hour. A velocity at least as high as that must have occurred in the tornado at Washington, Ohio.

Tornado Rain. — Rain invariably precedes a tornado cloud from 10 to 30 minutes, and hail follows it. The rapid ascent of nearly saturated air gives rise to great downpours of rain in tornadoes. The hail that accompanies a tornado is usually of very great size. Generally there is a great deal of lightning accompanying a tornado.

Tornado Lightning. — The funnel often has a ruddy smoky hue, as if the electrical discharges were continuous.

Time of Tornado Occurrence. — Tornadoes almost invariably begin in the afternoon from two to five o'clock. There is a previous great accumulation of cloud-mass going on for several hours before a tornado begins. This slow accumulation of energy is a distinctive feature of the tornado cloud.

Moisture and Tornadoes. — Tornadoes require for their production a great deal of moisture in the air and diminishing temperature extending to a great height. That the ascending current must reach to a great height appears from the universal occurrence of hail. The air must go high enough to freeze the water; and to do this readily the temperature must be considerably below freezing-point. As latent heat is given off by the condensation of vapour, it is a warming process, and there must be abundant masses of cold air to dispose of this heat by mixture or by cold of expansion in ascending.

Vertical Ring. — That there is a ring of vertically revolving air around an up-rushing current is shown by the concentric layers of soft and hard ice in hailstones. The hailstones take on a coating of snow in the higher air, but when in the course of its path it descends into the lower air this snow is melted and compacted somewhat; in ascending again the mass takes on another coating, and so on. The upward velocity required to sustain such masses is not very great. A vertical velocity of only 17 feet a second is sufficient to carry up raindrops one-tenth of an inch in diameter.

Spiral Motion. — When the upward velocity of the air is great the ascending air tends to a spirally outward and upward motion, similar to the spirally inverted and downward motion of water running through a hole in a basin or bath tub.

Lowering of Pressure. — The rotary motion of the air tending to fly off at a tangent develops a centrifugal force which produces a lowering of pressure in the whirl. The bursting of houses by the tornado funnel passing over them, and the arching of floors which occur at times, show that there is a very great reduction of pressure near the centre of the whirl. In the milder forms of tornado this is marked by the sudden puffing of volumes of soot from chimneys, showing a sudden up-rush of air on the release of the outside air pressure.

Motion of Tornado. — The fact that the motion of rotation in a tornado is contrary to the motion of the hands of a watch, and that the tornado moves from south-west to north-east, has never been satisfactorily explained. The two characteristics are so marked and invariable that they are probably related in some way to the rotation of the earth and the influence of its deflecting force on air currents.

Place of Tornado Occurrence. — Tornadoes occur most frequently in the south-east quarter of an area of low barometric pressure. The condition most favourable to their occurrence is the case of a warm current of air underrunning a cold one. The south-east quarter of a low area has more winds with northerly and southerly components than any of the other quarters.

Tornadoes in the United States. — Tornadoes are of frequent occurrence in the United States, and cause every year loss of life and destruction of property. The month of most frequent occurrence is May; next April, then June and July. They seldom occur in winter. They occur everywhere in the country east of the hundredth meridian, but never to the west of this. The regions of frequent occurrence are the upper Mississippi and lower Missouri valleys.

Series of Tornadoes. — Tornadoes occur in series on the same day, moving in the same direction, their paths a few miles apart. A series of this kind, comprising 60 separate tornadoes, occurred after ten o'clock on the morning of February 9, 1884, in Illinois, Kentucky, Tennessee, Virginia, North Carolina, South Carolina, Georgia, and Mississippi, in which 800 people were killed, 2500 wounded, and 10,000 houses were destroyed.

About 60 tornadoes of great destructiveness have occurred in the United States in the 20 years from 1870 to 1890, in which numerous lives were lost, and the damage to property in every case exceeded $200,000.

Waterspouts. — Waterspouts on lakes and the ocean are columns of water the result of a rotary motion in the air of no very great intensity.

CHAPTER VI.

OPTICAL APPEARANCES.

Refraction. — Air is a refracting medium, like glass, water, and diamond. The rays of light from an object to the eye as they pass through air of varying density along their paths are not straight lines, but slightly curved. The effect of refraction is to make the heavenly bodies — the sun, moon, and stars — appear higher up in the sky than they really are. The judgment of the direction of an object is based on the direction of the last part of a ray of light entering the eye, and which is tangent to the curved path of the ray.

Lifting of Sun. — When the sun appears with its lower edge just touching the horizon, it is by refraction lifted up in the sky more than its whole diameter, which is 32′ 3″, so that, though visible, it is really below the horizon. This fact was first observed about the year 1664, on the occasion of a Dutch exploring party wintering in the arctic regions. From the latitude of the place, it was calculated that the sun would reappear on a certain date. In the spring the sun was visible three weeks before the time. On the return of the party to Holland the explanation of the fact, as due to refraction, was given by Descartes.

Flattening of Sun. — The flattened appearance of the sun when near the horizon is also due to refraction, the lower edge being lifted up more than the upper one. The apparent lifting of objects diminishes rapidly with altitude in the sky. At an altitude of 30°, the sun is lifted only 2′ 40″.

Lifting of Objects. — Objects on the surface of the earth also are lifted up in appearance by the refraction of the air. Distant objects on the surface of the earth, such as ships and mountains, are hidden from view by the curvature of the earth, unless they reach up to a certain height. This height is about in proportion to the square of the distance of an object. Objects can be seen at about one-seventh greater distance on account of refraction than would be the case without it. This effect of the air varies at different times. In sighting over long lines in the surveying operations of triangulation, when the two distant points are nearly but not quite intervisible, as can be computed from the known heights, the curvature of the earth, and the average refraction, they will become intervisible on occasions of extraordinary refraction. With extraordinary refraction the distant place comes into view, and then slowly sinks out of sight to reappear again. This is repeated every few minutes, and is a phenomena that is seen most frequently in the evening.

Looming up. — Distant objects are often seen in the evening lengthened out vertically by refraction. This is called "looming up."

Mirage. — Inverted images of distant trees and ships are often seen near the horizon in the sky below the direct images. This is called "mirage." This name is also given to the delusive appearance of water, like a lake-surface sometimes seen in the desert, which is in reality the refracted image of the sky reaching the eye from such a direction as to make it appear on the ground. The layers of air at different heights have a varying density on account of the heat from the ground, such that the ray of light is so curved in passing through them that the tangent to the ray at the eye of the observer comes from below, and therefore the image seems as if it were below the ground.

In Australia, in recent years, the discovery of a great lake in the interior of the country was announced, which turned out to be only an observation of a mirage.

Dispersion. — White light is a mixture of various coloured lights. When a beam of light is separated into its constituent colours, as in a spectrum, it is called "dispersion." Dispersion is produced by either refraction or diffraction or interference.

Rainbows. — Rainbows are due to the combined effects of refraction and interference of the sun's rays as they pass through drops of falling rain, and are reflected from the interior surfaces of the drops. The colours, counting from the interior of the rainbow arch outward, are in the order of the spectrum, — violet, indigo, blue, green, yellow, orange, and red. The purity of the colours depends on the uniformity and size of the drops of rain. The width of the arch is 2¼ degrees, varying somewhat with the dimensions of the drops. The radius from the centre of the arch to the extreme outside red is 42.1 degrees. The centre of the arch is directly opposite the sun. Each observer sees his own rainbow about his own anti-solar point.

Secondary Bow. — A secondary rainbow with the violet above and the red below is formed outside the first by light twice reflected from the interior of the drops. The radius is 8.5 degrees greater than the first. Under the first rainbow, variegated green and reddish bands are sometimes seen. These indicate that the drops producing the rainbows are very small.

Centre of Rainbow. — When the sun is at a greater altitude than 42.1 degrees, the top of the rainbow is just at the horizon and no rainbow can be seen. On a high mountain or in a balloon, when the sun is near the horizon, the rainbow can be seen as a complete circle.

Wind Galls. — Portions of rainbows seen at times are called by sailors "wind galls."

Reflections of rainbows are sometimes seen from a surface of quiet water.

Moonlight Rainbows. — Rainbows are sometimes seen by moonlight. The colours are very dim.

Fog Bow. — When the particles of rain are less than the 0.01 of an inch in diameter, the interference is more effective than simple refraction, and the colours of the rainbow are mixed and confused and the arch widened out. It then becomes a faint band of light 5 degrees wide, with a slight rosy tint on the outside, and is then called a "fog bow." The radius is 3.5 degrees less than that of the rainbow. Fog bows are sometimes known as fog-eaters, from the fact that when they appear, by the sun shining on them, the fogs are quickly dissipated by the heat converting the fog to vapour.

Brocken Spectre. — The shadow of a person seen on a fog, usually observed from a mountain top, is called the "Brocken Spectre," from the name of a mountain in Germany.

Glories. — Coloured circles seen around the shadow of a person's head on a fog are called "glories."

Corona. — Small coloured rings or full circles of blue, white, golden, and red, 3, 6, and 10 degrees in diameter around the sun or moon, but seen principally around the moon, are called "coronas." Coronas are red outside. They are due to the diffraction of light in passing between the minute particles of cloud or haze covering the moon. Diffraction is the name given to the peculiar action of the edge of a body in dispersing light passing close to it. The smaller the intervals between the particles, provided the rays of light are not entirely cut off, the greater the diameter of the rings. The same appearances of coloured rings are seen on looking at any source of light through a network of fine meshes or a pane of glass covered with moisture from the breath or with fine dust.

Diminishing diameter of corona shows that the particles of fog are coalescing, and may fall as rain when sufficiently large.

Aureole. — The ring of white light about 12 degrees wide with the outside border of a ruddy tint, sometimes seen around the sun or moon, is called an "aureole." The outside diameter of ring is 22 degrees, the inside 10 degrees, and within this the sky is dark.

Halos. — The large circles, one 21.6 degrees in diameter, the other 45.8 degrees, and occasionally one of 90 degrees, seen around the sun and moon, sometimes coloured, but more usually white, are called "halos." Any ring greater than 16 degrees in diameter is a halo. Halos are red inside.

Parhelia, Paraselenæ: Mock Suns or Sun-dogs, Mock Moons. — Sometimes supernumerary circles not concentric with the sun or moon appear. These consist of intersecting and tangent or contact arches. Bands or stripes of light also appear at times. The intersection of these with the halos produce spots of more brilliant illumination than at other parts of the halos.

These are called "mock suns" or "parhelia," and sometimes "sun-dogs." Similar appearances around the moon are called "mock moons" or "paraselenæ."

Parhelic Circle. — Sometimes a circle of light extends all around the sky at the height of the sun or moon and parallel to the horizon. This is called a "parhelic circle."

Parhelia are sometimes visible on the parhelic circle at a distance of 120 degrees from the sun; very rarely they are also seen at distances of 50 degrees and 98 degrees.

Anthelion. — An image of the sun directly opposite, or 180 degrees distant from the sun, is sometimes called a "parhelion," but is more properly known as an "anthelion."

Luminous Cross. — Sometimes columns of light are seen, when the sun is near the horizon, extending vertically 10 to 15 degrees above the sun; sometimes a similar column is seen extending down from the sun. When both occur in connection with part of a parhelic circle, a luminous cross is produced. These columns are due to the reflection of sunlight from the upper and lower facets of ice-crystals floating in the air.

These various optical appearances are all due to the reflection, refraction, diffraction, and interference of light in passing near particles of water and ice-crystals in the air. They are most frequently to be seen in the arctic regions, where there is an abundance of ice-crystals in the air for their formation.

Blue Sky. — The blue colour of the sky is due to the sunlight reflected by minute globules of water in the air. The polarization shows the light to be reflected. The greatest amount of polarization is in a plane perpendicular to the sun's rays. This reflection of polarized light is called "selective reflection"; larger particles would reflect red light.

The thicker the layer of air the sun's rays pass through the more its light is absorbed. When there is a great deal of dust and moisture in the air the sun at sunset assumes a ruddy hue, and the clouds at times are red.

Red Sunsets. — The red sunsets of August, 1883, and the red skies which glowed long after dark, observed over many parts of the world, are considered to have been due to the reflection of sunlight by particles of vapour and dust probably high up in the air. The vapour and dust is supposed to have come from the great eruption of matter thrown into the air from Krakatoa, a volcano in the island of Java. The ashes and vapour were carried very high in the air and over all parts of the world by the general circulation of the air. It first extended rapidly eastward in the tropics and made a circuit of the earth in 12 or 13 days, showing a velocity in the upper eastward current of about 83 miles an hour.

Twilight. — Twilight is the illumination after sunset produced by the reflection of sunlight from the upper air. From its duration it is estimated there is not much light reflected by any air there may be above a height of 36 miles.

In high latitudes, in summer, the twilight lasts a long time on account of the inclined direction to the horizon in which the sun descends. In latitude 56°, on June 21, a book of ordinary print can be read by twilight as late as nine o'clock in the evening. Near the equator and in the tropics, where the sun goes down almost vertically, twilight lasts but twenty minutes. A similar rapid darkening is sometimes due to the extinction of light by haze in the air, as well as to the rapid descent of the sun.

Light through rifts in the clouds illuminating dust particles is sometimes known as the sun's drawing water; the beams are called by sailors the sun's "backstays."

The divergent rays sometimes seen after sunset and before sunrise dividing the sky into segments are known as "crepuscular rays." In Japan, they are known by the name of the ropes of Maui.

Ice-blink. — Ice-blink is a peculiar whitening of the sky, low down near the horizon, seen in the arctic regions on approaching an ice-floe. It looks brightest in clear weather, and is seen at a distance of 30 miles from the ice.

Snow-banners. — Snow-banners are long divergent beams or streamers from the tops of mountains sometimes seen from a great distance, 30 or 40 miles. They are due to the sunlight on fine particles of snow contained in the air currents diverted upward by mountains. They are only seen when very strong winds prevail.

AURORA BOREALIS, OR NORTHERN LIGHTS.

Arch. — The faint luminous arch seen at times in the night low down in the northern sky is the aurora borealis, or northern lights. Below the arch is what is known as the dark segment. The lower line of the arch is often irregular in outline, but is always well defined, showing a sharp separation between light and darkness.

Streamers. — Slender spears of well-defined, bright light, called "streamers," extend up into the sky from the arch for a distance of 20 and 30 and sometimes even 90 degrees. They are from half a degree to three degrees wide, and move or dance from side to side to the right and left and are of a pale yellow colour. Sometimes they are known as merry-dancers. The arch is continually rising and falling. In high latitudes there are generally several arches. The plane of the arch is generally perpendicular to the direction the magnetic needle takes.

Auroral Corona. — Sometimes beams of light shoot up all at once from every part of the horizon and form a tremulous mass of feathery flame in the zenith. This is the corona. These beams are parallel to the direction of the dip-needle. The apparent convergence is the effect of perspective.

Duration of Aurora. — Complete auroral displays seldom last more than one hour. Partial auroras last a whole night or occur on two successive nights, possibly continuing during the day, though invisible. Sometimes the auroral light is of a crimson hue, yellow, green, or blue.

Extent of Visibility. — Auroras are at times seen simultaneously over a great extent of the world, from California to Russia and from Jamaica to Labrador. Not more than six auroras, however, are visible in a century as far south as latitude 20°. Towards the north, they increase in frequency, and the arches are higher up in the sky. On an average, there are visible in a year at latitude 40°, 10 auroras; at latitude 42°, 20; at latitude 45°, 40; and at latitude 50°, 80. Between latitude 50° and 60° they are visible almost every clear night. From latitude 62° towards the north they diminish in frequency. At 62° the number visible in a year is 40; at 67°, 20; and at 78°, 10.

Frequency. — Auroras are less frequent in winter than at other seasons.

The number of auroras varies greatly in different years. Periods of greatest frequency are about 56 years apart, as indicated by records of the whole world since 1742. The years of greatest frequency were 1787 and 1845. There is some indication of a minor period of maximum frequency equal to about ten years.

There is a belief in some places that auroras are followed by cold weather; an examination of the records, however, does not show this to be, as a rule, the case. Being visible only when the sky is clear, the temperature is usually lower when they are seen than at other times.

Magnetic Storms. — During auroral displays there is a disturbance of the magnetic needle, causing it in middle latitudes to swing in half an hour three or four degrees in extreme cases from its average direction. The horizontal force of the earth's magnetism may change in the same time by one-ninth of its whole amount. These disturbances of the needle occur at very nearly the same time at places hundreds of miles apart. When the auroral light is rosy coloured, the magnetic disturbances are said to be greater than when white. Such disturbances of the needle are called "magnetic storms." At such times there are also strong electric currents in telegraph wires and cables, interfering with their working. These may be due to earth currents or may be induced currents in the wire due to atmospheric conditions.

Aurora Australis.— Auroral displays seen in the southern hemisphere about the south pole are called "aurora australis."

Cause of Aurora.—The aurora has many of the appearances produced by the passage of electricity through rarefied air in tubes.

There is great uncertainty about the height of the aurora above the earth.

The aurora may be such a phenomenon as the rainbow, for which every vision makes its own, and for which no height can be assigned. Various estimates and alleged measurements of the height vary from half a mile in the arctic regions to forty miles above the earth, and in the temperate zone for the lower edge of the arch as high as 100 or 150 miles.

According to De la Rive and Marsh and Edlund's theory, the aurora is due to the ascent of positive electricity to the upper layers of the air in the equatorial regions and its descent in a zone around the geographical and magnetic poles of the earth.

The magnetic pole, or place where the dipping-needle would be exactly vertical, is not in the same position as the geographical pole, but about latitude 70° 05′ and longitude 96° 46′, somewhere in the region west of Hudson's Bay.

Magnetic Elements. — The difference in direction of a magnetic needle from a true north and south direction is the magnetic declination. The angle a dipping-needle makes with a horizontal plane is the dip. The magnetic force usually observed is the horizontal component of the force and is called the "horizontal intensity." The maximum intensity is in the direction of the dip; it is equal to the horizontal intensity multiplied by the secant of the dip: the intensity is expressed in dynes. The dyne, the unit of force on the centimetre-gramme-second system of units (C. G. S.), is the force which, acting on a mass of one gramme for one second at a distance of one centimetre, will impress on it a velocity of one centimetre per second. The declination dip and intensity are called the "magnetic elements." They have daily, monthly, and annual variations. The effect of the moon on the declination is about 27″ in middle latitudes, the needle making two oscillations of that amount in a day. The daily range, apparently due to temperature, is about 15′. It is less on a cloudy than a clear day. There is some indication of an eleven-year period in the variations of the elements corresponding to the same period in the greatest frequency of sun-spots. There is a period depending on the time of rotation of the sun.

The diurnal range of magnetic phenomena is not the same in the arctic region as farther south.

There is no known relation between the weather and variations of the earth's magnetism.

The magnetic elements are subject to slow changes extending over great lengths of time, called "secular changes." At Washington the magnetic needle pointed 51° east of north in 1792 and 4° 15′ to the west in 1889; at Paris, in 1580, it pointed 11° 30′ east, in 1666, 0° 08′ west, in 1814, 22° 34′ west, since which time the declination has been diminishing, and in 1889 was 15° 32′ west.

The direction a freely suspended needle would assume in space is derived from a consideration of the observed values of declination and dip conjointly. As it assumes its successive directions, it describes a conical surface with the pivot of the needle at its apex. If a sphere be described with its centre at the pivot and the conical surface be extended to the sphere, the line of intersection of the two will graphically represent the actual secular motion of the needle. The values of the three magnetic elements are known with some accuracy for the inhabited portions of the world; for a few places the rates of secular changes in the elements are known with lesser accuracy. It is not known whether the needle, when it points in a certain direction at a given place, will ever return to the same position again, or whether it will, at the end of a certain period, assume the same direction and again sweep over the same path in the same period. It is not known whether the secular variation of the elements has a period or not, nor whether if there shall be one discovered hereafter it will be the same for all parts of the world.

CHAPTER VII.

WEATHER-MAPS.

THE condition of the air over a country as to pressure, temperature, etc., at a given time can be represented graphically on a map of the country by means of observations of these various conditions made at a number of scattered places. Maps showing the conditions of the air and the state of weather throughout a country, by conventional signs by lines and shading, are called "weather-maps."

Isobars. — The distribution of barometric pressure over the globe is very different at different times. On weather-maps pressures reduced to sea level are generalized and graphically represented by lines through the places of equal pressure. These lines are called "isobars." Isobars are usually drawn for pressures one-tenth of an inch apart, for the pressures 30.0 inches 30.1, etc., 29.9, 29.8, etc., inches.

Isotherms. — A similar graphical representation of temperature over a country without reduction to sea level, by lines joining places of equal temperature, are called "isotherms." Isotherms are drawn for temperatures 10 degrees apart, 30°, 40°, 50°, etc. On the United States weather-maps the isotherms are represented on the same map with the isobars; on European weather-maps they are separate.

Isohyetals. — A graphic representation of quantity of rainfall by lines through places having equal depths of rainfall are "isohyetals." On weather-maps rain is represented by shaded areas.

Cyclones, Lows. — At times the barometric pressure over a part of a country is much below the average, sometimes as low as 29.0 inches or even less. In such cases the pressure increases in widening circles for a distance of several hundred miles from the place of lowest pressure. A system of isobars of this kind is called a "cyclone." It is usually accompanied by rain and high winds in the country over which it lies.

An average cyclone ordinarily covers about 300,000 square miles of country, frequently much less, and occasionally very much more.

The lows are sometimes called storms. The centre of the smallest isobar is called the storm centre. When the shape of the isobars representing an area of low pressure are not rounding nearly circular, the area is called simply a "low" or a "depression."

Anticyclones, Highs. — At times the barometric pressure over an area of country is very much above the average, sometimes being as high as 31.0 inches, or even more. Areas of high pressure are commonly of much greater extent than lows. When the map is sufficiently large to show the enclosed isobars, the high areas are shown to be irregular, approximating in shape irregular triangles with rounded corners. These are called "anticyclones," but more commonly high areas or simply "highs."

The area of the earth's surface covered in the United States by a high pressure — that is, a pressure greater than 30.0 inches and increasing to 31.0 inches or so — is sometimes as great as 2,000,000 square miles. In Asia they occur in winter 4000 miles from west to east and 3000 from north to south within the 30.0-inch isobar.

Weather-Map. — The weather-map issued twice a day by the Weather Bureau shows the distribution of barometric pressure and temperature over the whole country by isobars and isotherms. The wind direction is represented by arrows flying with the wind.

Rain at a place at the time of an observation is represented by a black circle , clear sky by a light circle , snow by a cross-barred circle , clouded sky by a heavy ring with white centre , half-clouded sky by ring with black bar . The observations on which these maps are based are made at eight o'clock in the morning and evening, 75th meridian time, at 160 places throughout the United States and the Dominion of Canada. The observations are sent to the central office in Washington City by telegraph. A cipher code is used to save time and expense in transmitting messages. All the weather information from a station is comprised in five or ten words. Weather messages have precedence on the wires over all other telegraphic business. When cyclones prevail in the West Indies, reports of observations are received from Cuba, Hayti, San Domingo, and Jamaica. At times, reports are received from the Bermuda Islands.

The printed weather-map based on observations made over an area of more than three and a half millions of square miles of the earth's surface is issued to the public at half-past ten o'clock in all the large cities of the country, with forecasts of the weather expected in various parts of the country for the succeeding twenty-four hours.

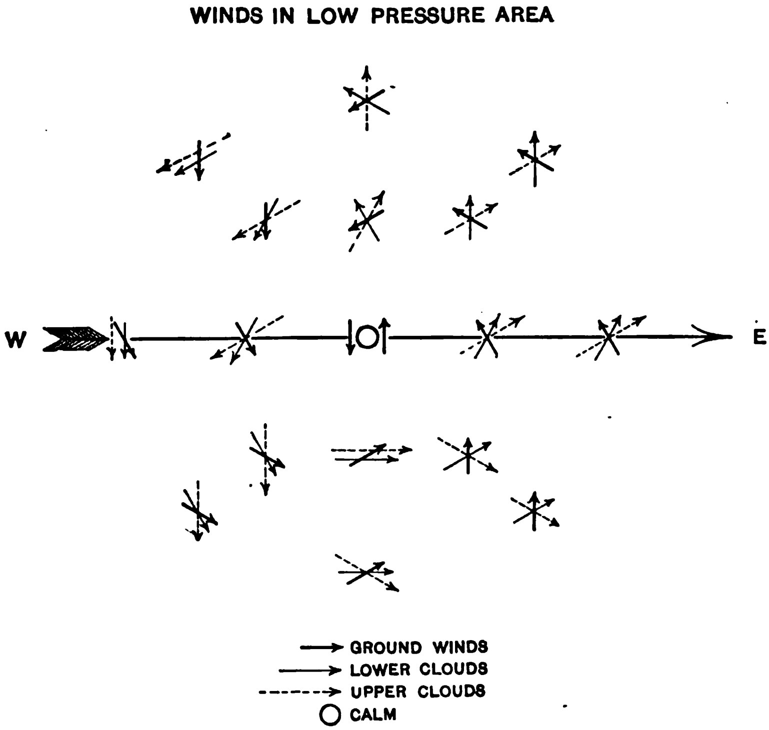


FIG. 22.

On the morning weather-map there is also printed the stages of water at a number of places on the principal rivers in the Mississippi valley. The stages are observed on the respective river gauges at eight o'clock each morning. Estimates of the high stages of water expected for several days ahead are given when the stages of the rivers are near the flood-line.

Warnings are sent by telegraph from the central office in Washington to various places on the lake and sea-coast when the presence of a cyclone indicates the possibility of high winds dangerous to shipping, also warnings of cold waves or tornadoes to places where they are expected to occur.

Baric Law of Wind. — On every map showing a cyclone, the winds over the region covered have a definite direction with respect to the centre of low pressure. They blow spirally inward contrary to the direction of motion of the hands of a watch lying with its face up. This relation of wind direction to isobar is called the "baric law of the wind." From a theoretical consideration of the dynamics of the air, and the deflecting influence of the earth's rotation on currents of air over the surface of the earth, the calculated wind directions around a low-pressure area are found to agree very well with those observed. Some slight local deviations are produced in places by the relief of the land, hills, etc.

The typical observed wind directions around a cyclone centre in middle latitudes are shown in Fig. 22 for the surface of the earth, at the height of the lower clouds and at the height of the upper clouds.

GENERAL VIEW OF CYCLONES AND HIGH-PRESSURE AREAS.

Direction of Winds around a Low-Pressure Area. — In a cyclone the wind in middle latitudes blows, on the average, approximately in a direction half-way between the tangent to the isobar and the radius drawn towards the centre of the cyclone. East of the centre, the wind is inclined more toward the centre, and west of it more towards the tangent. The average angle on all sides to the tangent is in the United States 45°.

The direction of the lower clouds is nearly tangent to the isobars. The motion of lower cumulus scud is inclined outward to the wind at surface of the earth, 14°.5, the cirro-stratus 22°.8, and the highest true cirrus 29°.6.

The upper clouds show a motion of the air out from the centre on all sides, but very much more so on the east side than the west. In the centre of a cyclone there is a region where the air is nearly calm. Away from the central region there must be an upward component of motion to the air. The fact that the wind is inclined in toward the centre of the cyclone makes it certain there is an ascending current.

For the regions near the equator the winds at the edge of a cyclone incline in towards the centre; near the centre, they are more in the direction of the tangent to the isobars. The higher the latitude the more the wind inclines outwardly from the centre of the cyclone, owing to the deflection produced by the earth's rotation being greater in high than low latitudes.

On the west side of cyclone centres in the United States, the wind direction is more inclined towards the centre than in the case of cyclones in Europe, where the direction is neary parallel to the isobar; but on the east side in Europe the wind is much more inclined to the centre than it is in cyclones in the United States.

The wind direction in cyclones is more toward the centre in the case of light than strong winds.

Height of South-east Winds. — The average height to which the south-east wind east of the low centre extends up in the atmosphere is only half that of the north-west wind. The wind directions do not depend on the direction of motion of the low centre.

In the United States the winds to the north-west and south-east of a cyclone centre are stronger than those to the south-west and north-east. The greatest velocity is at a height of about 5000 feet. At the surface of the earth, a few feet above the ground, the wind velocity is only about one-third what it is at a height of 50 feet. On Mount Washington, the average wind velocity in a cyclone is five times what it is at 50 feet above sea level. A low usually extends to a height of 10,000 feet; above that winds from the west prevail.

The lowest pressure on Mount Washington follows 200 miles or 5 to 10 hours behind the lowest pressure at sea level.

An approaching cyclone affects the currents at the surface of the earth earlier than at a height, or rather the winds themselves produce the low pressure in the lower layers of the air.

Pressure Gradient. — The more numerous the isobars in a given distance, the greater the velocity of wind in the region. The change of pressure in hundredths of an inch in a distance of 500 miles is a useful measure of pressure gradient. The measure is often taken as the number of millimetres of pressure change in a degree of latitude equal to 69½ statute miles.

The steepest pressure gradients occur to the north-west and south-east of a cyclone centre in Europe, and mainly to the north-west of the centre in the United States.

Winter and Summer Gradient.—The same pressure gradient in winter or in the night corresponds to a less wind velocity than in summer or in the daytime. Gradients and surface-wind velocities in the United States are as follows at 8 A.M.:—

Gradient and Wind Velocity.

Pressure Gradient Inches in 500 Miles.	Wind Velocity in Miles per Hour.
0.43	10
0.48	15
0.52	22
0.62	30
0.76	35

The wind is strongest in the vicinity of the centre of a cyclone, and diminishes in intensity towards the edge. From 3 P.M. to 11 P.M. the average velocity is one-fifth greater than the average for the rest of the day.

In a cyclone, the forces concerned in the motion of the air are: the pressure gradient from the edge of the cyclone to its centre; the centrifugal force developed by the rotation of the air around the centre, which tends to drive it from the centre; the deviating force due to the rotation of the earth; the resistance due to inequalities of the earth's surface; the friction of the air on the earth; and the friction of the air on itself, called "viscosity." Leaving out of account friction and viscosity, the velocity of a particle of air due to pressure gradient, which is the main element, would be the same as the velocity acquired by a body in rolling down an inclined plane at an angle corresponding to the pressure gradient. If, for instance, the centre of a cyclone is at Washington, and the pressure reduced to sea level is 29.5 inches, while at Chicago it is 30.5, also reduced to sea level, then the velocity due to this gradient would be the same as that of a particle moving on a plane, without friction, inclined at an angle equal to that of a line from a point in the air above Chicago where the pressure is 29.5 inches, to Washington where the pressure is the same. This, with the air at a temperature of 30°, would be at a height of 885 feet above Chicago. The distance is 580 miles.

As the effects of friction and viscosity are not known, this cannot be used in computing wind velocity. But from observed velocities and gradients, the effect of the inequalities of the earth can be derived.

Extent of Cyclones. — Cyclones vary greatly in the extent of country over which they occur. The distance across the outside isobar is sometimes not more than 200 miles, and in some rare cases as great as 1600.

Clouds in Cyclones. — Over a region covered by a cyclone the sky is cloudy. Cirrus cloud precedes a coming cyclone, and halos are visible. There is usually also rainfall in a cyclone; but often the gyratory ascending motion of the air produces only cloud, which drifts away or is redissolved in the air. Back of a cyclone rounded, sharp-edged, cumulus clouds follow. The average cloudiness diminishes from wholly clouded sky at centre, to half covered sky at 500 miles from centre.

Cyclone and Rain. — Cyclones usually come into an area of country under observation full-formed. Sometimes they originate over an area under observation, being preceded by a broad, indefinite, irregular area of pressure slightly below the average. In about half the cases of formation, the rain in the area of a cyclone is only 0.1 of an inch in the first twelve hours after the formation. Sometimes rain does not occur for twenty-four hours after the formation. Usually, however, it rains preceding and during formation.

Shape of Rain Area. — The shape of the rain area accompanying cyclones is highly irregular. The greatest extent of rainfall occurs usually to the north-east of the centre of a cyclone in the United States. It extends around the low on all sides, but farther on the east side than the west. The rain area sometimes extends 700 miles to the east of the centre. To the west of a centre of a low, except in its immediate vicinity, the rain is usually lighter than to the east.

The diminution of temperature upward in the air in the inner circle of a cyclone is 0.42 of a degree per hundred feet, as shown by observations at Clermont-Ferrand, and at the top of the Puy-de-Dome, a mountain in France where the difference of elevation is 3543 feet.

Between Denver, 5281 feet above sea level, and the summit of Pike's Peak, 14,134 feet, a difference of 8853 feet, in the case of areas of pressure as low as 29.6 inches, the difference of temperature at 5 hours and 7 minutes A.M. is 30.4 degrees; at 1 hour and 7 minutes P.M., 36.6 degrees; at 9 hours 7 minutes P.M., 35.4 degrees. In case of pressures as high as 30.6 inches, the difference in the temperatures at the same times as given above are 15.6 degrees, 36.8 degrees, and 25.6 degrees. The average rate of diminution for 100 feet, at 1.07 P.M., is 0.415 of a degree for both lows and highs.

Between Portland, Me., and Mount Washington, 6279 feet, the difference of temperature in lows, at 7 A.M., 3 P.M., and 10 P.M., are at the rates 0.281, 0.486, and 0.443 of a degree in 100 feet. In highs, the rates at the same hours are 0.146, 0.205, and 0.143 of a degree. The proximity of sea in this case may exercise a modifying influence.

Movement of Cyclone. — A system of cyclonic isobars has a proper motion over the surface of the earth. In the United States, the centres move generally in an easterly or north-easterly direction with a velocity of 25 miles an hour on the average. The velocity at different times in different cyclones varies from 15 to 60 miles an hour. While the most usual direction of motion is north-east or east, centres do move occasionally in other directions, south, south-east, and sometimes directly north. Very rarely they move north-west. Only in the tropics is the direction of motion of a cyclone towards the west or slightly south of west. Those moving from the south-west are only one-sixth of the number moving from the north-west. Sometimes lows originate in the north-west, and after moving south-east turn and move to the north-east. At the turning-point the motion is slow. The direction of motion of lows is that of the general circulation of the air. The motion north is more rapid than south. Those moving north extend to a great height in the air, and are controlled by the upper air currents.

In moving from the Gulf of Mexico to New England, the pressure at the centre of a cyclone diminishes, on the average, about 0.3 of an inch. A low moving directly east from Lake Superior to the Gulf of St. Lawrence often diminishes much more. It is a characteristic of the lows moving from the Gulf of Mexico north, that they are accompanied by heavy rains.

The low areas can sometimes be traced a long distance over the earth's surface before breaking up, sometimes as much as half-way around the globe.

There is a diurnal inequality perceptible in their motion. The average velocity from 7 A.M. to 4 P.M. is 25.9 miles per hour; from 4 P.M. to 11 P.M., 31.9 miles.

The average rate of motion of those crossing the Atlantic Ocean is 19.6 miles per hour, somewhat less than on land.

The tendency is for lows to move in the direction of the heaviest rain to the east of them. With very heavy rains accompanying them, the motion is slower than with light rains.

When a centre of low pressure, 29.5 inches, leaves the United States the chances are only one out of nine that it will pass over any part of Great Britain. The probability that it will give rise to a gale anywhere on the English coast is only one in six; the probability of a very fresh breeze is one in two.

The isobars of a cyclone are usually elliptical in shape. In 55 per cent of the cases the major axis exceeds the minor by ½ its length; in 30 per cent it is more than double the minor; in 9 per cent, 3 times the minor; and in 4 per cent, 4 times the minor.

The prevailing direction of the long axis is N. 40° E.

Changing Shape of Cyclone. — As a cyclone moves, it is attended in the regions over which it passes by its characteristic winds. Cyclones are subject to great changes in the shape of the isobars as they progress. The isobars may change from nearly circular to decidedly oval in shape; the area of country covered may increase as they progress; the distance between the isobars may diminish; sometimes the isobars become irregular and all resemblance to a cyclone is lost. There is a characteristic increase in the distances between the successive isobars from the centre of a cyclone outward in cases where the winds are strong, corresponding to the deeper depressions.

Regular Isobars. — Areas of low pressure, with the pressure at centre 29.3 inches or less, usually have regular isobars. In middle latitudes extensive areas of low pressure of various shapes often occur without the isobars being regular or approximately concentric as in the case of cyclones. In low-pressure areas in the tropics, only regular-shaped cyclonic isobars occur. Regular circular isobars indicate that great depth of air is concerned in the motions of a cyclone.

Height of Wind. — In cyclones of small diameter the circulating winds do not extend to a greater height in the air than 6000 feet. When the diameter of a cyclone is great, the wind system may reach to a very great height in the air.

Cyclones with very low central pressure occur mostly in winter; occasionally, however, such a one occurs in summer.

Shape of Low-Pressure Area. — In the United States the areas of low barometric pressure are usually of irregular shape. The cyclonic form is rather the exception than the rule. On account of the limited area of the earth's surface taken in by the weather-maps, the isobars of lows are in many cases not closed or apparently not continuous. In four-fifths of all the lows with closed isobars the shape of the low-pressure area is oval, with the long diameter lying from south-west to north-east, and about twice as long as the short diameter from north-west to south-east. In one-fifth of the cases the long diameter is 3 or 4 times the short one. Lows with open isobars may be open in any direction.

At times lows occur with highs from 400 to 1000 miles distant. A high area to the east or south-east of a low has no significance as regards coming weather in the United States. Any action there may be between a low and a high only takes place when the high is to the north, north-west, west, or south-west of the low.

Double Lows. — Sometimes a low occurs to the north over the Lake region, and one to the south in Louisiana, presenting a double V-shaped appearance, with a high to the north-west. Double lows also occur, one in Colorado and the other in the Lake region; and at times one in the Lake region and another on the Atlantic coast about New England.

Cause of Oval Shape. — In long oval lows with a high to the north-west, the winds on the north-west of the centre are stronger than the inflowing winds on the south-east, possibly due in part to the greater effect of the earth's rotation in deviating the northern winds, as compared with the same effect on the winds more to the south in a lower latitude.

Depth of Depression. — The amount of barometric depression in the centre of a low varies at different times. In the north it is greater on the average than in the south. The depth of depression has no relation to the amount of rainfall. Even the slightest depressions that first appear in the vicinity of the Gulf of Mexico are apt to be accompanied by great rainfall.

All the lows that appear in the United States may be divided according to the paths they pursue into eleven classes. These are as follows in the order of their relative frequency: —

I. Lows that first appear to the north of North Dakota and Montana and move directly east to the Gulf of St. Lawrence.

II. Lows that originate north of North Dakota and Montana and move slightly south of east to the region of the Great Lakes, and then turn and move north-east toward the Gulf of St. Lawrence.

III. Lows that originate north of North Dakota and Montana and move south-east to Nebraska and Kansas, and then turn and move north-east to the region of the Great Lakes.

IV. Lows that originate north of North Dakota and Montana and move south-east to the Gulf of Mexico, or vicinity, and then turn and move north-east across the country to the Gulf of St. Lawrence.

V. Lows that originate in Colorado or thereabout and move north-east.

VI. Lows that appear first in Colorado and move directly east.

VII. Lows that appear first in Texas and move north-east.

VIII. Lows that appear first in Texas and move east to the Atlantic coast, and then north-east.

IX. Lows that come from the Gulf of Mexico and move north.

X. Lows that come from the Gulf of Mexico and move north-east.

XI. Lows that appear on the North Carolina coast and move north inland a few hundred miles, then turn and move north-east.

On very rare occasions a low will move north-west. A case of this kind occurred March 3, 1881.

The paths of these areas are shown on the accompanying chart, Fig. 23.

CYCLONE PATHS IN THE UNITED STATES.

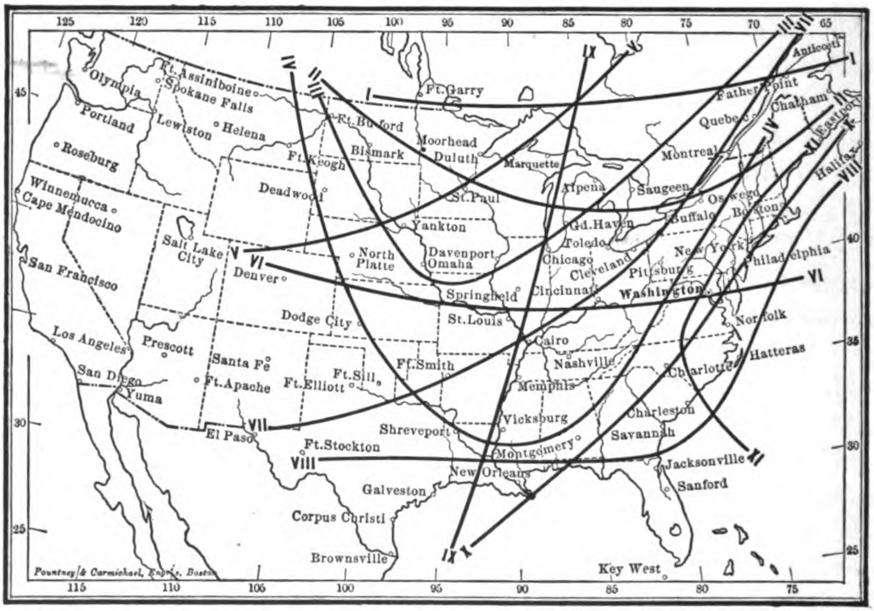


FIG. 23.

The following table gives the numbers of these various classes of lows that have appeared in the different months in 10 years, and the velocities of each class and for all the classes for each month.

NUMBER OF LOWS OF DIFFERENT CLASSES IN THE UNITED STATES, 1882 TO 1891, AND AVERAGE VELOCITY IN MILES PER HOUR.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	Total Number	Mean Velocity
January	6	6	23		7	3		11		6	1	63	40.0
February	7	8	16	3	6	3	2	13	2	2		62	38.3
March .	7	7	16	1	11	1	5	8	6	5	2	69	33.0
April .	3	7	6		16	5	2	7	1	3		50	28.7
May .	8	5	7		12	6	2	6		2	1	49	26.6
June .	9	2	3		9	3		3	1	2	1	33	24.9
July .	8	11	3		11	6	2	1		2	1	45	24.9
August.	11	9	8		8	3	1	3	1	2	1	47	28.1
September	11	7	7	1	8	2		2	3	1		42	25.4
October	11	11	7	2	7	3		5	2	5	1	54	29.2
November	10	7	7	1	11	1	1	9		4	1	52	32.3
December	25	5	11		10			13	5	2		71	36.6
	116	85	114	8	116	36	15	81	21	36	9	637	
Total .	31.1	33.2	34.6	35.6	30.5	30.8	27.1	32.5	27.1	29.0	24.2		31.7

In Russia the average velocity of cyclone centres is 26 miles an hour in winter, 25 in spring, 21 in summer, and 24 in autumn. In Russia the motion, the second day after the appearance of a cyclone, is eight-tenths what it is the first, the third day six-tenths, and the fourth day four-tenths.

For low-pressure areas, with the centres in Illinois and the isobars nearly regular and circular and the pressure at least as low as 29.3 inches at the centre, the accompanying chart Fig. 24 shows the average velocity of the wind in different parts of the country, at 8 A.M., as derived from ten selected cases.

CENTRE OF LOW-PRESSURE AREA IN ILLINOIS.

AVERAGE WIND VELOCITY IN MILES PER HOUR.

FIG. 24.

The greatest wind velocity in miles per hour at 8 A.M. in different parts of the country are shown on the chart Fig. 25 below, for a regular low-pressure area in Illinois, with the pressure at the centre 29.3 inches, selected from ten such cases.

In the following tables are given the statistics of the various characteristics of areas of low air pressure that have appeared in the United States and vicinity in the twenty years from 1870 to 1890, as obtained from the daily weather-maps of the United States.

Table I. shows the number of low areas that have appeared in different parts of the country, the lowest pressure at the centre, and whether the pressure was rising, falling, or stationary at the centre, as compared with the pressure at centre on the day following.

Table II. shows the number of low areas appearing in different months, and their direction of motion for the 24 hours following.

CENTRE OF LOW PRESSURE IN ILLINOIS.

GREATEST WIND VELOCITY IN MILES PER HOUR.

FIG. 25.

Table III. shows the number of low areas occurring in different months, and the lowest pressure at the centre of the areas.

Table IV. shows the number of low areas of pressure, and the number of cases in which the rise or fall of pressure at the centre in 24 hours was 0.1 in., 0.2 in., 0.3 in., 0.4 in., etc.

Table V. shows the direction of motion of the low area, with the high area in different positions with respect to the centre of the low.

TABLE I. — Number of Cases of Low Pressure and Rise or Fall at Centre.

	Pressure. in. in. Less than 29.2 to 29.2			Limiting Pressure. in. in. 29.3–29.4			Limiting Pressure. in. in. 29.5–29.6			Limiting Pressure. in. in. 29.7–29.8			Pressure. 29.9 in. and over.		
	Rising	Falling	No change	Rising	Falling	No change	Rising	Falling	No change	Rising	Falling	No change	Rising	Falling	No change
Mont., Wyo., N. Dak., Man., Minn.	10	0	1	28	3	3	37	16	13	14	16	13			
Wisconsin, Michigan	22	3	3	45	13	12	75	42	29	39	71	38	4	7	3
Ontario	7	0	1	21	5	3	37	25	12	30	32	21			
West Pennsylvania, West New York	4	0	3	6	8	2	17	8	4	9	12	5	2	6	2
Quebec	7	1	1	12	7		17	14	6	3	8	6		2	
Nevada, Utah, Colorado	1	1		7	3	1	17	17	7	13	16	10	1	2	1
Kansas	2	1		8	4	2	22	18	8	11	21	19	1	7	2
Iowa, Missouri, Illinois	3	1	1	9	5	3	20	13	15	21	11	3	2	10	6
Kentucky, Indiana, Ohio	2			9	8	2	13	15	10	14	31	12	1	7	4
Ariz., N. M., Tex., Ind. Ter., Ark.	1		0	0	1		7	6	4	15	20	9	1	11	2
South Texas, Louisiana				5	2	1	6	10	0	11	36	23	9	23	9
Florida				2			1	1	1	6	3	3	3	6	5
North Carolina	1		0	2	3	1	10	9	6	9	10	8	4	8	3
Virginia, New Jersey	3	2	1	2	6	1	5	8	2	9	12	3	1	3	2
New England	21	7	3	24	5	5	22	21	6	15	23	7			
Sums	84	16	14	180	73	36	306	223	123	219	322	180	29	92	39
Per cent	74	14	12	62	25	12	47	34	19	30	45	25	18	58	24

TABLE II. — NUMBER OF CASES OF LOW-PRESSURE AREAS AND DIRECTION OF MOTION.

	N. E.	E.	S. E.	S.	S. W.	W.	N. W.	W.	STAT.	
January . . .	216	41	26	9	3	1	4	9	8	
February . . .	213	53	42	5			6	6	4	
March	233	46	54	11	1		1	23	11	
April	180	61	49	5	4		5	22	12	
May	130	41	38	6	3	1	3	14	14	
June	76	24	23	1	2	4	3	7	10	
July	33	40	19	3	1		2	5	1	
August	45	25	15	3	5	5	8	21	2	
September . .	74	35	30	2	2	3	11	27	18	
October . . .	100	74	22	6	1	2	6	42	7	
November . . .	121	101	24	4			3	36	10	
December . . .	137	100	22	2	2	2	5	39	1	
Year . . .	1558	641	364	57	24	18	57	251	98	3068
Per cent . .	51	21	12	2	1	1	2	8	2	

TABLE III. — NUMBER OF CASES OF LOW-PRESSURE AREAS WITH DIFFERENT LOW PRESSURES AT THE CENTRE.

	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3	30.4
January . .	3	2	1	3	4	7	11	19	29	35	50	53	50	44	20	22	5	0	1
February . .		1	4	2	2	11	17	23	32	54	55	52	59	45	15	7	1		
March . . .			2	6	5	9	24	29	49	56	64	50	72	40	13	6			
April . . .				6	3	9	15	26	39	49	62	66	68	27	3	1			
May . . .		1				1	3	15	15	35	58	60	50	24					
June . . .					1	1	2	6	9	27	38	43	33	16	1				
July . . .							1		5	16	23	36	34	11	3				
August . . .				1				1	3	17	19	31	50	31	2				
September .			1		1		1	4	14	22	41	39	47	29	4				
October . .				4	1	2	6	19	23	38	46	53	55	22	8	2			
November .	1		2	2	5	9	8	19	31	38	49	55	52	42	19	8	2		
December. .			5	6	5	7	22	11	35	52	46	60	43	45	19	6			
Year . .	4	4	15	30	27	56	110	172	284	439	551	598	613	376	107	52	8		3446
Percentages	0.1	0.1	0.4	0.9	0.8	1.6	3.2	5.0	8.2	12.8	16.0	17.4	17.8	10.9	3.1	1.5	0.2		100

TABLE IV. — Number of Cases of Low-Pressure Areas with Change of Pressure at the Centre in 24 Hours.

Pressure at centre of low area.	Change of pressure in 24 hours and number of cases.							
29.2 in. and less.	0	+.1 in.	+.2 in.	+.3 in.	+.4 in.	+.5 in.	+.6 in.	+.7 in.
	16	10	19	13	10	10	5	15
		−.1	−.2	−.3	−.4	−.5	−.6	−.7
		9	3	1	1	1	1	
29.3 in. 29.4 in.	0	+.1	+.2	+.3	+.4	+.5	+.6	+.7
	36	50	44	46	18	8	8	5
		−.1	−.2	−.3	−.4	−.5	−.6	−.7
		30	21	10	10	5		
29.5 in. 29.6 in.	0	+.1	+.2	+.3	+.4	+.5	+.6	+.7
	126	112	103	64	17	7	2	
		−.1	−.2	−.3	−.4	−.5	−.6	−.7
		82	52	45	23	9	2	5
29.7 in. 29.8 in.	0	+.1	+.2	+.3	+.4	+.5	+.6	+.7
	231	157	55	26	7	1		
		−.1	−.2	−.3	−.4	−.5	−.6	−.7
		161	114	68	32	14	13	11

TABLE V. — Number of Cases of Low-Pressure Areas and Direction of Motion in Relation to High Pressure.

	N. E.	E.	S. E.	S.	S. W.	W.	N. W.	N.
High to s. w. of low	167	64	21	2	2	2	2	27
Per cent	58	22	7	1	1	1	1	9
High to n. w. of low	147	31	19	4	0	1	2	14
Per cent	67	14	9	2			1	7
High to n. e. of low	179	41	33	5	5	5	15	53
Per cent	53	12	10	1	2	2	4	16
High to s. e. of low	73	55	23	3	5	0	4	6
Per cent	43	32	14	2	3	0	2	4

The conclusions that may be drawn from the weather-maps, in regard to the low-pressure areas in the United States, are as follows:—

In the case of regular lows, with nearly circular isobars, which form about 10 per cent of all the lows appearing, the motion in 6 per cent of the cases is north; in 53 per cent, north-east; in 31 per cent, east; and in 10 per cent, south-east.

In the case of regular lows, with nearly circular isobars, where the pressure at centre is 29.2 inches or less, the velocity of the low centre is, on the average, 564 miles per day: where the pressure at the centre is 29.6 inches, the average velocity is 660 miles per day.

The velocity of motion of low-pressure areas in different directions in the interval of a day are, for the north-east, 704 miles; east, 593; south-east, 572; south, 385; south-west, 345; west, 334; north-west, 389; and west, 456.

Of all the low centres visible on two successive days, and moving eastward, 48 per cent preserve the same direction of motion on the two days; 30 per cent have the direction of motion on the second day forty-five degrees different from that of the first; 22 per cent have the direction of motion on the second day ninety degrees or more different from the first.

Of all the low centres of motion visible on two successive days, the direction of motion on the two days is as follows:—

2 per cent north and north.
3 per cent north and north-east.
3 per cent north-east and north.
32 per cent north-east and north-east.
6 per cent north-east and east.
4 per cent north-east and south-east.
12 per cent east and north-east.
9 per cent east and east.
3 per cent east and south-east.
16 per cent south-east and north-east.
5 per cent south-east and east.
4 per cent south-east and south-east.
1 per cent south-east and south.

In all the cases of low pressure, the pressure diminishes on two successive days in 40 per cent of the cases; in 34 per cent of all cases, the pressure diminishes for one day and increases on the next; in 10 per cent of the cases, the pressure increases on two successive days; in 11 per cent of the cases, the pressure, increasing one day, diminishes the next; in 5 per cent of the cases, the pressure remains the same, within less than than 0.1 of an inch, on two successive days.

Of all cases where the pressure is diminishing, in 54 per cent of cases it diminishes also the next day, and in 46 per cent increases.

Of all cases where the pressure is increasing, in 47 per cent of the cases it increases the next day, and in 53 per cent diminishes.

On the first appearance of a low pressure, in the 24 hours succeeding there is no change in the pressure at centre in 21 per cent of the cases; in 23 per cent of the cases there is an increase in the pressure at centre, and in 56 per cent a diminution.

On the second day of the appearance of a low pressure, in the 24 hours succeeding there is no change in the pressure at centre in 21 per cent of the cases; in 42 per cent of the cases there is an increase of the pressure at centre, and in 37 per cent a diminution.

In the case of an appearance of an area of pressure with the central pressure 29.6 inches, the chances are about equal that there will be an increase or decrease of the pressure at the centre the next day; for greater pressure it is more likely the pressure will decrease, and for less pressure increase

AREA OF HIGH PRESSURE.

In an area of high pressure, the winds blow from the centre outward, and the paths are slightly curved, as shown in Fig. 26. They are opposite in direction to the winds of a low-pressure area.

The winds in a high-pressure area are usually light. At times, however, the winds may be very strong when blowing from the north-west in a case where there is a low area to the south-east of a high-pressure area, closely adjoining, or there may be very strong north-east winds from it, in the case of a low-pressure area to the south-west of it.

In the centre of a high pressure it is calm. The winds increase in velocity from the centre outward.

WINDS IN HIGH PRESSURE AREA.

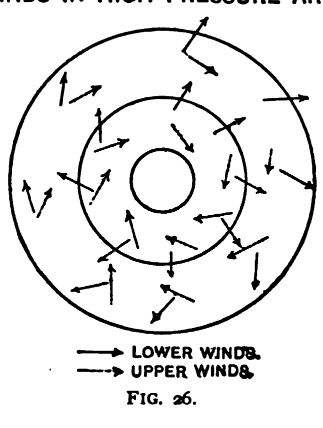


FIG. 26.

The intense high-pressure area is essentially an occurrence of winter time and of high latitudes. More than nine-tenths of all the highs, with pressures at centre 30.7 inches or more, in the United States, occur from October to April. The high areas of summer rarely have the greatest pressure much above 30.3 inches.

Over a country covered by a high pressure the sky is usually clear. Very little is known with certainty about the wind direction in the upper air in high areas, there being commonly no clouds visible by which the direction can be observed.

Motion of Highs. — Areas of high pressure move generally south or south-east, sometimes east. The motion is often of a desultory, uncertain character. The shape of the isobars changes a good deal as the high moves, and the centres often cannot be located closely.

The high pressures of the United States originate for the most part to the north of latitude 49° in the far north-west, and move down over the United States in a south-easterly direction. A few originate north of the Great Lakes, and move south-east or east; a few form over the Rocky Mountain region, and move generally east. In many cases highs originate in the north-west, after the wind has blown 40 miles an hour from the north.

Velocity of High Pressures. — The average velocity of a high-pressure centre is about 25 miles an hour; a little greater in winter, 27 miles; a little less in summer, 21 miles. Usually there is in winter a light fall of snow on the south-east border of a high area, equivalent to a depth of rainfall of about 0.1 of an inch. Over the central part of the United States, highs usually do not continue more than three days. Over central Europe, a high will sometimes last for two weeks or more.

Temperature with Ascent. — At the centre of a high pressure there is at times an increase of temperature with ascent in the air.

In the high of November 11–25, 1889, over Europe, there was an increase of temperature upward in the air at the rate of 0.07 of a degree per hundred feet. This is probably not generally the case in high areas; when the temperature in a high-pressure area is low at the ground, it is usually correspondingly low at a height, as, for instance, in the case of the high area of 30.5 in Colorado, on December 21, 1886; when it was −18° at Denver it was −32° on Pike's Peak. The inversion of temperature, or increase with ascent, in a high has been ascertained in Italy to extend only to a height of 2300 feet.

There is but little vapour in the air in a high-pressure area.

Temperature in High and Low Pressure Areas. — In the region covered by a cyclone, the isotherms passing through it are crowded together towards the centre; in an area of high pressure, they are spread out. This is shown on the map, page 190.

At the centre of a cyclone, and to the east of the centre, the temperature is relatively high; in a high-pressure area, the temperature is low. The general air current in a cyclone in the United States is from the south, and in an area of high pressure from the north. These winds carry with them, in a measure, the temperatures peculiar to the regions from which they blow.

Pressure Gradient Above. — The outward pressure gradient diminishes with ascent in the air over a region covered by a cyclone. At a height which is not known, but is considerably over 10,000 feet, the gradient is even supposed to be reversed, and the pressure increases from the edge toward the place vertically above the lowest pressure at the ground.

There may, however, be outward motion of air at a height from the centre towards the edge even with the pressure diminishing towards the centre the same as at the ground. In a high pressure the inward pressure gradients also diminish with ascent, and, it is supposed, become reversed at a great height. There are no actual observations, however, to indicate this, but it is inferred from the observed direction of the winds as shown by clouds, the gradients being assumed according to the wind direction. The excess of pressure at centre above the surrounding pressures is still perceptible at a height of 10,000 feet.

Circulation in High and Low. — There may be a partial circulation of the air from the cyclone to a neighbouring high or the region of relatively high pressure around a cyclone in the upper air, and from the high to the cyclone in the lower air. This, however, is not necessarily always the case, but is often so.

Axis of Cyclone. — A line joining the centre of a cyclone at the earth's surface with the centres in the air above at greater and greater heights is called the "axis of a cyclone"; this line is inclined backward toward that high-pressure area which is usually back of it. On the west side, the air being so much colder than on the east side, the pressure diminishes more rapidly with ascent, and the centres of low pressure in successive layers must be farther and farther towards the region of cold. There is a vertical component of motion of the air in a cyclone upward, and in a high pressure motion of the air downward.

Cyclone Motion and Rainfall. — The centre of a cyclone moves approximately towards the place of greatest rainfall in the preceding 24 hours. The influence of rain, however, in directing the motion is obscure and irregular.

Cyclones and Mountains. — Mountain regions, in spite of the predominating rain, have a less number of cyclone centres passing over them than equal areas of sea or of land where there are no mountains. This shows that mountain rainfall is largely due to the relief features of the country, and not to cyclonic ascension of air.

Velocity and Depth. — The velocity of progress of the centre of a cyclone increases with the depth of pressure at the centre.

Motion of Cyclone and Circulation of Air. — The progressive motion of the centre of a cyclone is in the direction of the air current of greatest energy, or in the direction of the general circulation of the air at a place. As the condition of motion at different altitudes in the whirl is different, it is not the condition of motion in the lower air, but that of the average of all the layers of air, that determines the motion of the centre.

In the tropics the westerly progression of cyclones occurs almost wholly at a season when the westerly velocity of the air extends up to the greatest height.

There is a diurnal period in the development and progress of the low-pressure areas: the motion is more rapid toward the sun than away from it, southward if the sun is in the south, eastward during the time that the sun is in the east, and more slowly eastward when the sun is in the west. The eastward motion is, in general, greater in the morning and less in the afternoon. There is a slightly greater central depression of the barometer by day than by night. The depression increases with a temperature gradient greater than the average prevailing.

The clear air and the colder north-west wind in the rear of a cyclone, combined with the warmer southerly winds and cloudy or rainy weather on its front, are the controlling features that decide the rate and direction of its progressive motion. The colder and drier the air is on the rear the more the course turns toward the north-east.

The movements of the areas of low pressure in the United States are affected by matters that occur far outside the country. For the proper study of the atmosphere the limits of the weather-maps should be extended so as to take in the whole northern hemisphere.

A cyclonic movement 1000 miles in diameter in North America is affected by the temperatures and pressures 5000 miles away in Europe and Siberia. Such large movements in the atmosphere require a consideration of all the air in the northern hemisphere as a unit.

In northern Europe the direction of the motion of a cyclone centre for 24 hours forms an angle of 60 degrees, on the average, with a line from the centre of the low to the place of greatest preceding 24-hour temperature rise. The angle varies in winter from 34 to 90 degrees, and in summer from 30 to 110 degrees.

TROPICAL CYCLONES.

Tropical Cyclones. — The cyclones of the tropics occurring between 30° north latitude to 30° south form a special and distinctive class of low-pressure areas. They are not so great in extent as cyclones farther north. The pressures at the centres go very low, on rare occasions as low as 27.0 inches, a depth never known to be attained by cyclones in middle latitudes.

Hurricanes. — Exceedingly violent winds occur all around the centre of these cyclones, sometimes as great as 100 miles or more an hour; these winds are known as hurricanes in the West Indies. The region with hurricane winds is a circle or oval-shaped area sometimes as much as 300 miles in diameter. In the Bay of Bengal the severest are only 60 to 80 miles in diameter. The West India cyclones when moving along the United States coast produce storm winds of 50 miles an hour for a distance of 100 miles inland from the centres.

Storm Wind.—A storm wind is considered to be a wind approximating a velocity of 40 miles an hour on sea and 30 on land.

In the centre of a tropical cyclone there is at times an area of a few square miles where the air is calm and the sky clear. This is called by sailors the "eye" of the storm. Usually, however, at the centre the cloud is thickest. As the centre moves away the winds in the rear of it rage with their greatest violence. The isobars are usually oval-shaped, and the "eye" is off towards one end of the oval, in the direction of its motion.

Cirrus Cloud and Cyclone.—Cirrus clouds and halos appear on all sides around a tropical cyclone. There is not the same difference in character of cloud in rear and front in tropical cyclones that there is in the case of cyclones farther north. Cirrus clouds precede the centre of the cyclone 500 miles. Cirrus clouds in Cuba give the first indication of the position of a hurricane. Cirro-stratus stripes that appear like white and delicate feathers are the forerunners of hurricanes. Their form of divergence corresponds with the direction of the centre of low pressure. The upper clouds over the cirrus veil appear most dense in a particular part of the horizon where a whitish arc is formed. When the sun rises or sets through this it appears of an intense red.

Pressure preceding Cyclone.—Outside of a cyclone, on its border, there is a region of pressure in excess of the average, usually 30.15 inches. In the West India cyclone of September, 1875, this was observed at Havana when the centre was 1200 miles away. Without such a previous high pressure no storm of dangerous violence is apt to occur.

The ocean-swell is felt to great distances on all sides of a cyclone, and is often observed 400 miles in advance of the centre, and often 48 hours before the occurrence of the most violent winds at a place. In the West India hurricane of 1839 the swell was observed at the Bermuda Islands when the centre was at a distance of 700 miles.

Cyclone Wave.—Near the centre of a cyclone the violent winds produce a heavy sea all around the centre. The waves are sometimes as high as 40 feet, and the distance from crest to crest 500 feet. The wave becomes gradually smaller as it spreads from the origin. The law of diminution of crest height with distance from the centre of disturbance is according to the square root of the distance. A wave that is 40 feet high at a distance of 4 miles from the centre of disturbance will be 4 feet high at a distance of 400 miles.

In the case of a wave such as a tidal wave, or the wave produced by an earthquake, where all the water to the bottom of the ocean partakes of the motion, the velocity of the wave-crest is much greater than in the case of a wave where only the top layer of the ocean water is concerned. The velocity of a wave increases with the depth of the water and the length of the wave. For long waves in deep water it is equal to the velocity acquired by a body in falling through a height equal to half the depth of the water. For a depth of one mile, for instance, the velocity would be about 280 miles an hour.

Temperature in Cyclone. — In a tropical cyclone whose path is at first from east to west the temperature is lower on the west side of centre, the direction in which it is moving, than it is on the east side. The difference in temperature is slight, however, amounting only to three or four degrees. This is in marked contrast with the temperature distribution around a cyclone in middle latitudes, where it is much higher on the east than the west side, the direction in which the centre usually moves being toward the east. The difference of temperature in middle-latitude cyclones on the two sides is very great, sixty degrees or more at times in winter. The difference in temperature on the two sides of the centre would, therefore, not seem to be the cause of the motion.

Cyclones and Thunder. — Thunder and lightning are usual accompaniments of a tropical cyclone in its progress. With those of the greatest fury, however, there is no lightning. The tremendous violence of the cyclone winds destroys plantations, demolishes houses, and wrecks ships in harbour. In places subject to hurricanes, when thunder is heard people feel relieved, knowing that the storm will not be of the most destructive kind. An ever-present accompaniment of a cyclone is a heavily clouded, darkened sky, which pours down torrents of rain. Lower down than the main body of cloud there is often seen tattered masses of cloud-wrack moving from the centre of the cyclone towards the edge. The air is so filled with cloud and rain that it becomes dark in the middle of the day. On shipboard sea and sky seem to blend together.

Place of Origin. — Tropical cyclones originate at about latitude 8° or 10° on either side of the equator. The centres move toward the west, usually slightly to the north-west in the northern hemisphere.

In June and July the tropical cyclones or tracks of West India hurricanes keep well to the south, and cross the Caribbean Sea, and at times also the island of Cuba, in a west by north direction approximately. From the beginning of August to the end of September the

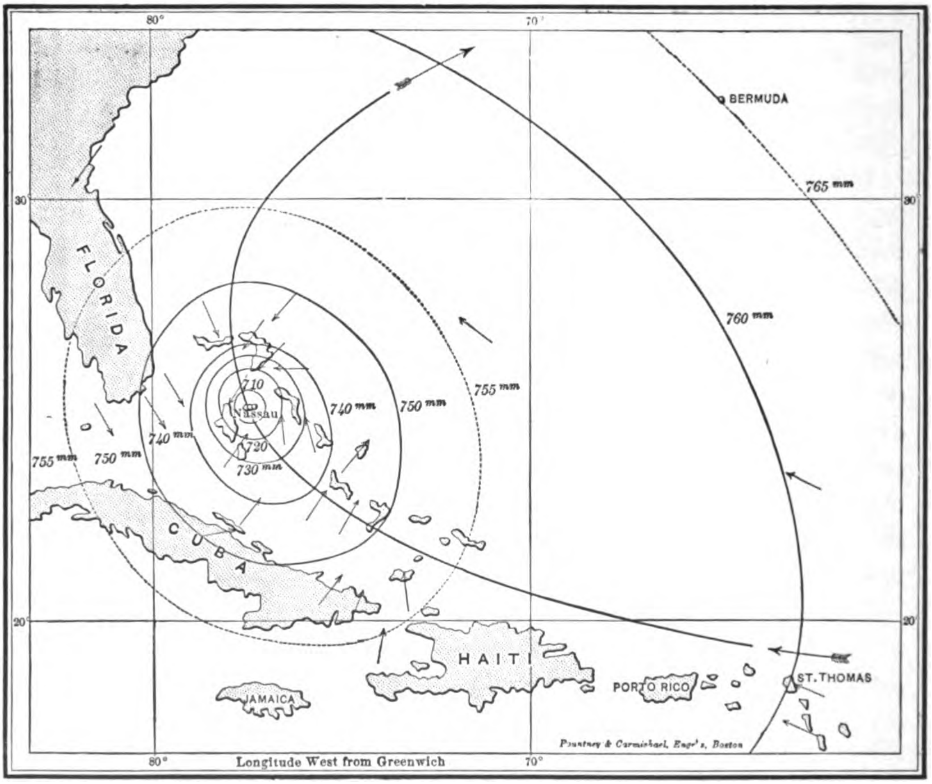


FIG. 27.

track is generally in a course between west-north-west and north-west. The paths all curve between 27° and 33° north latitude. As the season advances the directions of the tracks incline more to the westward, the hurricanes keep farther south, and the paths curve in lower latitudes. In the latter part of September and October they reach Cuba from the southern part of the Caribbean Sea, and curve at the tropic of Cancer or below it, with the peculiarity that where several come in succession each one curves in a lower latitude and farther west than the preceding one. The intervals in these cases are from 12 to 14 days.

Direction of Motion. — On reaching latitude 25° to 30° in the northern hemisphere, the direction of motion changes to north-east. When charted on a map, the path has some resemblance to a parabola. The farther north they progress the more easterly the motion becomes. The initial motion is west, and in those of the northern hemisphere, in five per cent of the cases, it is a little south of west.

In Fig. 27 is shown the track of the hurricane which passed over the Bahama Islands on the evening of October 1, 1866. The inside circle of lowest pressure, 710 millimeters, is equal to 27.95 inches.

Velocity. — The average velocity of the West India cyclone centres, in the first part of their paths, is about 15 miles an hour. The velocity diminishes as the centre approaches the turning-point in its path. At the turning-point the centre tarries, sometimes remaining stationary two or three days. After beginning to move eastward, the velocity increases as it moves north-east: the isobars also then widen out and the winds around the centre diminish in velocity.

Many West India cyclones die out before reaching the turning-point, and never describe a north-east course.

Dangerous Half. — The dangerous half of a cyclone, with the strongest winds dangerous to ships, is the northern half while moving west, and the south-eastern half while moving north-east.

In this half the wind tends to force a ship directly to the centre of the low pressure. Ships always manœuvre to avoid the centre.

Change of Wind Direction. — During the progress of a cyclone at places to the right of the centre advancing, the wind changes in the tropics, north of the equator, from the north around by the east to the south. On the left of the centre, the wind changes from the north through the west to the south. In cyclones south of the equator, these motions are reversed.

The wind directions around the centre are shown in Fig. 28.

Frequency of Cyclones. — On an average there has been one very severe hurricane in the West Indies every year. There is a record for the past four hundred years, or since the discovery of America. The percentages occurring in the various months are as follows: January, 1.4; February, 2.0; March, 3.0; April, 1.7; May, 1.4; June, 3.0; July, 11.6; August, 27.2; September, 22.5; October, 19.4; November, 4.8; and December, 2.0.

WIND DIRECTIONS AROUND A HURRICANE.

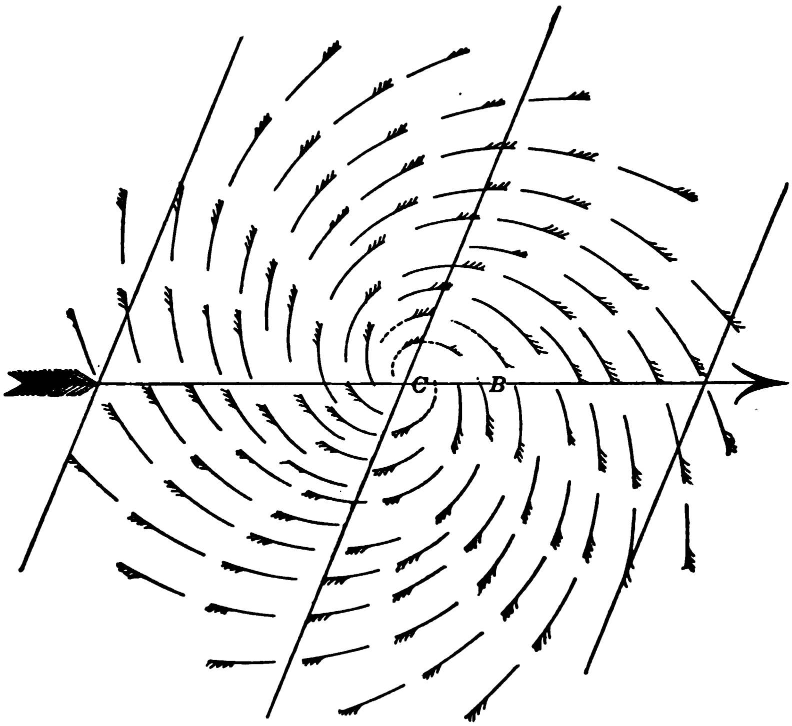


FIG. 28.

List of Cyclones. — Some of the most notable of these are as follows: —

1780. — Barbadoes hurricane; 20,000 lives lost.
Jan., 1825. — Fifty vessels driven ashore at Bermuda.
Aug. 2, 1837. — Island of St. Thomas; pressure 28.06 inches.
Oct. 5, 1844. — Cyclone moved from Cuba to Newfoundland in two days.
Sept. 6, 1865. — Guadaloupe Island; pressure 27.95.
Oct. 1, 1866. — Nassau, Bahama Island; pressure 27.72.

Aug. 14, 28, 1873. — Cyclone turned to north-east off Cape Hatteras; centre off shore; destroyed 1223 vessels; 600 lives lost.

Aug. 15, 1875. — Cyclone turned to the north-east at Indianola, Texas; 176 lives lost.

Sept. 21, 1877. — Barbadoes Island; cyclone moved along coast from Florida to Massachusetts.

Oct. 21, 24, 1878. — Havana, Cuba; cyclone entered United States on North Carolina coast.

Aug. 16, 20, 1879. — Cyclone touched the coast of North Carolina and moved along shore; at Cape Lookout the velocity of wind was 138 miles an hour (uncorrected for error of anemometer.)

Aug. 17, 18, 1880. — Hurricane at Jamaica Island.

Aug. 23, 28, 1881. — Cyclone entered the United States on Georgia coast and moved north-west to Minnesota.

Oct. 27, 1881. — Manzanilla; cyclone.

Sept. 5, 1882. — Hurricane at Cienfuegos; pressure 29.13 inches.

Oct. 8, 14, 1882. — Hurricane; Island of Cuba.

Nov. 5, 1882. — Hurricane at Manilla; pressure 27.35 inches.

Aug. 19, 20, 1886. — Indianola, Texas; overwhelmed by sea wave accompanying cyclone.

Aug. 15, 1893. — Severe off Savannah and Charleston.

Bengal Bay Cyclones. — Cyclones in the Bay of Bengal are of great intensity. The centres move north-west from the vicinity of the Andamann Islands, in latitude 12° north, to the mouth of the Ganges River in latitude 23°. In the ten years, 1877 to 1886, 18 occurred in the month of July, 17 in August, and 17 in September. These are the months of greatest frequency, Of 109 cyclones in ten years, the lowest pressure, 27.13 inches, was that observed in the False Point cyclone of September 19, 22, 1885. The velocity of the centre of this cyclone the first day was 3.5 miles an hour, the second day 8, and the third day 14. These velocities are typical of all these cyclones, gradually increasing as they advance. The average velocity of these cyclones is about 8 miles an hour, but sometimes as great as 25.

There are three well-defined regions in these cyclones; an outer area or ring of light winds, an inner area with very heavy winds, and an area of calm around the centre. In passing from the outer to the inner area, the fall of pressure is very great and sudden.

The fall of pressure in the case of the greatest of these cyclones begins to be perceptible at a place 16 hours in advance of the lowest pressure, which may be 200 miles distant. The winds are even more violent than the hurricanes of the West India cyclones. The Backergunj cyclone of October 31, 1876, was accompanied by a flood-wave 45 feet high, which covered the delta of the Ganges River, drowning 100,000 people.

These cyclones are peculiar to the water. On reaching land the meeting with a ridge of hills has the effect of breaking them up, indicating that the main part of their energy is in the lower air, and probably due to the condensation of the moisture contained.

Cyclones do occasionally originate over the land in southern India, but they are always feeble as compared with those over the water.

Typhoon. — The cyclones of the China Sea are known as typhoons; 46 have occurred in 65 years. This includes, probably, only the most violent ones. They are very similar to those of the Bay of Bengal. All this class of cyclones emanate from the belt of permanently low pressure in the region of the equatorial calms.

At Mauritius Island, in latitude 20° south, cyclones of a similar nature occur. There have been 53 in 24 years; the greatest number, 15 each, occurring in February and March. The great storm at Samoa Island, March 15, 1889, was a tropical cyclone with hurricane winds.

Signs of Cyclone. — In the tropics the approach of a cyclone is very definitely indicated by fall of pressure. The daily range of pressure in the tropics is large and very regular. The least deviation of pressure variation from its customary regularity is an indication of a cyclone in the vicinity. A close watch of the change in the direction of the wind affords a means of determining the direction of the centre. The average direction of motion of cyclones in the vicinity enables one to judge as to how the centre will pass with reference to the place, and hence what will be the probable direction and intensity of the winds accompanying it, judging by what has occurred in previous cases. This is the principle on which predictions of occurrence of cyclone and high winds are made. For the cyclones in the vicinity of the West Indies the direction of the centre from a ship can be inferred from the direction of the wind and clouds as follows: —

Clouds and winds move from	The centre will bear	Clouds and winds move from	The centre will bear
N.	E.	S.	W.
N.E.	S.E.	S.W.	N.W.
E.	S.	W.	N.
S.E.	S.W.	N.W.	N.E.

In the case of cyclones over the ocean, observations at only a single point on shipboard or on an island are usually available for purposes of prediction, making estimates very uncertain.

Management of Ship in Cyclone. — When the pressure falls 0.6 of an inch in six hours, and there has been no change in the direction of the wind in that time, it may be inferred that the place is right in the path of the centre of an advancing cyclone. The right advancing quarter has the most violent and dangerous winds in the northern hemisphere. In the case of a ship, by sailing or steaming in a proper course there is always time to avoid danger. A ship will sail away from the centre by keeping the wind on the starboard quarter in the northern hemisphere and on the port in the southern hemisphere.

This applies for the open ocean, away from the coast. In the region of the coast of the United States, from south of Florida to North Carolina, it is preferable for a vessel to be in the so-called dangerous semicircle and move to the north-east or east to get away from the centre. In the other semicircle the vessel is in a precarious position, being liable to be squeezed between the track of the hurricane and the coast without space to run. It is a bad plan to allow a ship to run with the wind. It will inevitably be carried round and round the centre and subjected to long-continued strain from the wind and waves, with danger of final destruction. The rate of pressure-fall and direction of ocean-swell, as well as the winds, are guides in estimating the direction of a cyclone centre from a ship. In most cases it is not possible to tell the true direction of centre from the one observation that can be made on shipboard. It is a good plan to have the vessel lie to for several hours in case of a great fall of pressure until the change in direction of wind can be accurately ascertained. In the northern hemisphere strong, squally winds extend a long distance from the centre towards the south-east, with very little change in the direction in many hours. This, in connection with a steady increase of pressure, would indicate that a ship was in the south-east quarter of the cyclone, and that the centre was moving away from it. The vessel could then sail or steam accordingly, so as to avoid the centre, the approximate direction of the motion of centres for the vicinity being known.

Causes of Cyclones. — Cyclones are due primarily to the unequal heating and moisture, or cooling and drying, of the air over large regions of the earth's surface, disturbing the level of the surfaces of equal density. This results in a convectional ascensional movement of the lighter air near the ground and the coming down of heavier air from above to restore the equilibrium. The light air moves spirally inward and upward, and at a greater height flows outward to the sides. This flow is similar to that of water from a basin through a hole in the bottom. The motion from opposite sides produces a couple which gives rise to the rotation.

When the upward convection extends to a height at which the temperature is lowered by dynamic cooling below the temperature of the dew-point of the air, there is condensation and cloud formation. When this occurs, the initial gyratory impulse of the air becomes of secondary consequence. The principal part in maintaining and extending the ascending motion is taken by the latent heat set free by the vapour. The reduction of pressure due to collapse of the vapour adds some to the action, but only a little. The cloud canopy in the daytime also increases the tendency of the air to ascend by transferring the point of application of the sun's heat from the ground to the top surface of the clouds at a height in the air.

Convectional ascending motion in the air is going on at all times during the day, but for the most part is not sufficient to carry the air high enough to produce any great amount of condensation, sometimes on account of the feebleness of the ascensional force, and again because of the dryness of the air requiring ascent to a very great height to reduce it to the dew-point. This condition sometimes produces a dry cyclone of feeble action, with cloud formation only, and no rain. Cyclones in middle latitudes, though they do not always cause rain, are almost invariably accompanied by cloud.

The decrease of pressure in a cyclone produced by rainfall alone is very slight. The centrifugal force developed by the gyration and the deflecting influence of the earth's rotation on the currents are the main causes of the production of low pressure at the centre of a cyclone.

Where the deflecting effect of the earth's rotation is least, near the equator, the winds blow nearly towards the centre of the cyclone, except very close to the centre, where they are nearly tangent to the isobars. In going north, the winds deviate to the right with the increase in the deflecting force of the earth's rotation due to increase of latitude, and the winds are more nearly tangential to the isobars.

Cause of Anticyclones or Highs. — Anticyclones or areas of high pressure result from convectional descending currents from the upper air produced by increased density due to excessive cooling by radiation from the upper air into space. The first effect of this process of radiation is to increase the air pressure near the ground, causing an outflow of air from the centre. The first effect of cooling is an increase in density of the air, causing a contraction and the inflow of air from roundabout to restore the level of the surfaces of equal pressure. The increased quantity and weight of air over a place produces the increase of pressure. This applies only to the great anticyclones of the middle and high latitudes. The belt of high pressure at the tropics is the result of air heaped up by its expulsion from the great permanent areas of low pressure around the poles.

The effect of convection due to radiation is, first, to make the air of a temperature throughout a great height correspond to the adiabatic rate of upward diminution, which results in a fall of temperature at the surface of the earth, and a rise of temperature in the upper air. This change of temperature alone would not produce any increase of pressure. But the upper air quickly cools by radiation to the temperature peculiar to that altitude, the small thickness of superposed air, and its freedom from moisture, offering very slight impediment to radiation. The increased pressure in a high area is solely due to the great density of the cold air of which it is composed.

In the northern hemisphere, cyclones in middle latitudes are often the result of a warm body of air coming from a southern region into a cold northern region favourable to precipitation of its moisture. A high is at times the result of air moving from the north to warmer southern regions.

The appearance of some of the greater highs is coincident with a great fall in temperature over a wide area of country. The cause of a high pressure may be partly due to radiation from the lower air, due to the absence of moisture. High areas follow after a wide-spread rainfall, and although the amount of moisture in the air in the layers nearest the earth is as great as before or during the rain, yet there is no doubt that at a considerable height there is much less than before, and the whole amount of moisture contained in the air is less. The fact that the areas are much more extensive, and the pressures greater, in winter than summer harmonizes with this view.

The circulation of the air in a high-pressure area from right to left with the motion of the hands of a watch increases the pressure in the high, the rotation of the earth deflecting the currents to the right.

That there is a great deal of the upper air brought down to the surface of the earth in a high-pressure area is shown by an analysis of the air. The percentage of oxygen contained in the air at such times is less than the average which is the characteristic of the upper air.

In winter the highs are of greatest extent and greatest frequency. The long nights of northern latitudes are favourable to great cooling by radiation from the upper air. The clear skies of the high areas, the air containing but little moisture, are favourable to the cooling of the earth by radiation during the night, and the air next to it by contact, so that the lower air becomes considerably colder than at a height above. This anomaly of temperature increase with ascent in highs is frequently observed, more especially at times when the ground is covered with snow.

It has been maintained that the cooling of the air in a high-pressure area is mainly due to cooling of the ground by radiation, and of the air by contact with it. But this can be true only of the lower strata.

Cold in Highs. — In the United States highs rarely last more than two or three days in the central part of the country. The lowest temperatures in these occur when the ground is covered with snow. The heat of the sun during the day goes largely to melting and evaporating the snow, and is so much heat disposed of that would otherwise go to raising the temperature of the air.

Conductivity of Snow. — Snow by its low conductivity prevents the passing of heat from the earth to the air. Through a layer of snow one centimetre thick, with a difference in temperature of one degree centigrade between the two surfaces, there passes through each square centimetre of surface in one minute of time 0.0304 gramme-calories of heat; through sand or loam the amount transmitted is 0.205; through iron, 9.77; through copper, 54.62.

In Russia the average minimum temperature of the air as compared with the daily mean temperature when there is snow on the ground is eighteen degrees lower than when there is no snow. In the United States this difference is probably not so great.

Remarks on Theory. — The commonly accepted theory of the cause of cyclones is the one just given, which attributes them mainly to condensation of vapour. It explains many facts concerning them, but it must be admitted not all. It is not very clear that it does explain the motion of the lows. Condensation of moisture can hardly be the cause of the constant procession of low-pressure areas from north of North Dakota to the Gulf of St. Lawrence. The fact that the cyclones of the Bay of Bengal are quickly broken up on reaching land by even a low ridge of hills would seem to show that the main part of the energy in that class of low pressures is in the moisture of the lower air.

It has been suggested that cyclones and anticyclones are due to the same causes that produce the general circulation of the air; that is, to the difference of temperature at the equator and the poles. The fact that the difference is greater in winter than summer, might explain the greater frequency of cyclones in winter. But as yet nothing has been developed to show just how this cause might act to produce low and high pressures. There is a good deal to indicate that rain is an incident of vertical circulation rather than a producer and sustainer of a moving area of low pressure.

The fact that the low centre moves toward the centre of the rain area, seems to favour the conclusion that in a great storm the condensation of vapour is an efficient cause which controls the winds.

There is evidence that heavy and extensive rains do not invariably precede the first formation of depression areas, and accompany their expansion. In the United States low areas do not generally begin with extensive rainfall, but the rainfall is a concomitant after the system of circulating winds has been pretty well established.

CHAPTER VIII.

WEATHER PREDICTIONS.

Basis of Predictions. — The basis of weather predictions is the approximately known direction of motion and rate of progress of areas of low pressure, and their average accompaniments as regards rain or cloud, rise or fall of temperature, and the velocity and direction of winds around them. Typical cases of low-pressure areas for different parts of the country, with the average areas of rainfall accompanying and following them, are shown in the charts on Plates No. 1 to No. 22. These charts, taken in connection with the statistics of the motions of the low-pressure areas given in the preceding pages, enable one to form some judgment as to the occurrence of rain for the case of strongly marked types of pressure distribution. Some idea can be formed as to the direction of the wind from the typical distribution of the winds around a low-pressure area, and of the strength it will attain from the pressure gradients, the rate of fall of pressure which has already occurred over the area covered by the low pressure, or from the farther fall which may be reasonably anticipated. The temperature, fall or rise, may be inferred from the contrast in the temperature of the region on the front and back side of the low-pressure area.

The typical wind directions at the surface of the earth around an area of low pressure are shown in Fig. 22.

Any area of pressure less than 29.92 inches reduced to sea-level with pressure increasing from centre is a low pressure; any area above 30.0 with pressure decreasing from centre is a high pressure.

To the side the low pressure is moving, the wind has to change approximately to the typical direction usually before rain begins. In the case of an area moving from the west, if at a place to the east of the centre, the wind is from the north-west, it will change to north-east before rain begins. When the winds are not typical the lows and highs are not persistent.

A vague irregular area of low pressure extending from Colorado east and south, if there is a high pressure to the north, with rounding convex front toward the east, is almost certain to concentrate in a definite regular low area in the region of the Great Lakes.

To the east of the centre of a low pressure, the temperature is higher than to the west. As the low pressure moves along, the temperature rises over the country to the east of it, and falls to the west of it. Cirrus-stripe clouds appear to the east of a centre of low pressure.

All around a centre of low pressure, but principally to the east of it, rain occurs.

The north and north-west winds to the north-west of a centre of low pressure, and the south-west winds to the south of the centre, are strong and about in proportion to the pressure and temperature gradients over the regions.

The area of a low pressure is considered to include all the area inside of the last rounding isobar.

To the west of a centre of low pressure, great areas of temperature fall follow, especially if there is an area of high pressure to the north, north-west, west, or south-west of the centre.

As the low pressure moves over the country, the storm winds, rain area and temperature fall areas follow along with it.

Estimate of Motion of Low. — When a low has been visible for several days, and the direction of its motion is known, the best estimate of its position at the end of the next 24 hours is, to take its path as the straight line continuation of the path just passed over, and the distance it will move in 24 hours, as one and one-third of the distance it has moved in the past 24 hours, in case the motion is towards the north-east. When the motion of a low pressure in any of the paths described is south-east, its velocity is usually retarded until it reaches the place where it turns to the north-east. At the turning-point it is usually motionless for a day or more. When it turns to move north-east its velocity increases day by day. When the centre deepens the velocity increases.

Motion of Centre towards Rain. — The centre of a low is apt to move towards the place of greatest rainfall in the preceding 24 hours to the east of it.

When the pressure gradients to the north-west of a centre are heavy as compared with those on other sides of the low pressure, the centre of the low will move in a line at right angles to the line of heaviest pressure gradient. This is nearly north-east usually.

Motion with Reference to High Dew-point.—When the approximate position of a centre of a low pressure is located 24 hours ahead, as described, or by means of an average velocity and average direction, where no path has been as yet described, the observations of dew-point in the vicinity permit of locating the future position of centre more accurately. When there is a place within two or three hundred miles of the centre, with the temperature of dew-point higher than any of the dew-points surrounding it, the centre of the low pressure after an interval of 12 hours is likely to be located at the place of the highest dew-point.

Motion by Pressure Falls.—The low-pressure areas that appear to the north and move east have certain characteristic-shaped areas of pressure fall in advance of them. The areas of 12-hour equal falls of pressure are oblong when charted by lines of equal fall through the points of 0.1, 0.2, etc., of an inch of fall and extend from south-west to north-east. The place of the centre of low pressure 12 hours ahead is apt to be on the 0.2 of an inch pressure-fall line at the end of the short axis of the area of pressure fall farthest from the centre of the low-pressure area.

In the case of double low pressures, one near the Gulf of Mexico and the other in the region of the Great Lakes, the whole system moves east just the same as a single system.

It is rarely possible to locate the centre of a low pressure more than 24 hours ahead close enough to make the estimated position of any use in forecasting weather.

Wind and Motion of Centre.—From 43 cases in the United States in which the centre of a low pressure moved 1000 miles in a day, and 52 cases in which the movement in a day was 244 miles, the velocity of the wind on the different sides of a low pressure do not seem to have any influence on the rate of motion of the centres. Low pressures moving from Texas north-east to the region of the Great Lakes, or from the Gulf of Mexico to New England, diminish in pressure at the centre about 0.3 of an inch, on the average.

Variation in Rate of Pressure Diminution.— The variation in rate of pressure decrease is valuable in indicating whether a low pressure moving east will deepen or fill up as it advances.

Places on sea or lake coast within 200 miles of a centre of a low pressure will have storm winds approximating 40 miles an hour when the pressure gradient is 0.6 of an inch or more in 500 miles and the temperature gradient at least 20 degrees in a distance of 500 miles.

A storm wind is one with a velocity approximating 40 miles an hour on sea and 30 on land.

Storm Wind and Gradients.— The greater the pressure and temperature gradients the greater the wind velocity. Hurricane winds extend no more than 100 miles from the centre of the cyclone.

With a pressure gradient as low as 0.4 of an inch and the temperature gradient as high as 40, storm winds may be anticipated. When the pressure diminishes at the centre the winds may be expected to increase in velocity.

Winds and Pressure Fall.— Storm winds need not be anticipated at a place unless there occurs to the west or to the south of it large areas of 12-hour pressure fall of 0.3 of an inch or more extending over an area at least 100,000 square miles in extent.

An area of high pressure moving to the east from the Lakes on the coast gives north-east storm winds from New Jersey to Nova Scotia. The strength of the winds depends on the pressure and temperature gradients; a pressure has usually to be at least 30.5 to give a storm wind.

High-pressure areas of 30.3 in Manitoba with considerable temperature gradient will sometimes give storm winds from the north on Lake Michigan.

A given pressure gradient in summer produces a greater wind velocity than the same gradient in winter.

The high pressures that advance to the east from the interior of the country have storm winds on their south-east front on the sea-coast.

Rain and Low.— As a rule, the appearance of a low pressure and the occurrence of rain are simultaneous over the greater part of the area inside of the last rounding isobar of the low pressure. Rain is likely to occur in 24 hours over all the area covered by the low pressure and in the area of country over which it passes as it moves along and as far as 300 miles at least from the centre to the east of it. The great downpours of rain accompanying hurricanes never extend more than 200 miles from the centre.

Quantity of Rain.— No definite estimate can be made of the depth of rainfall that will occur with a low-pressure area. In the case of a low pressure from the Gulf of Mexico, it may be taken for granted at least half an inch will fall at any place over which the low pressure will pass, and possibly two inches or more. This is especially the case with a high-pressure area to the north-east of the centre of the low pressure. This combination of pressure gradient gives rise to north-east winds extending from New England to Georgia, and constitutes the well-known north-east storm along the Atlantic coast. This, with other conditions, tends to show that rainfall is merely an incident of the circulation of which the isobars are the result. If the air contains a great deal of moisture, or the circulation extends to a sufficient height, rain follows; if but little moisture, there may be only formation of clouds. Rain occurring to the west of a centre of low pressure will show there is enough moisture to produce rain; and when this occurs, taken in connection with the typical isobars, rain to the east of the centre is tolerably sure to follow as the low pressure moves along.

Low-pressure areas that move from the Gulf of Mexico are always accompanied by great rainfalls.

When the paths of extensive low-pressure areas cross the southern part of the United States in winter, periods of cold weather will follow over the eastern part of the United States to the north of the path, and about a hundred miles south of the path.

High and Rain. — On the south-east front of an inland high-pressure area, without any definite accompanying low pressure, light rains occur at times, usually less than 0.1 of an inch.

After long-continued rains in the region from Virginia to Maine, the weather will clear within 24 hours when the pressure to the south-west from Alabama and Tennessee to Texas begins to rise.

Low pressures that first appear north of North Dakota, and move east, may have little or no rainfall, especially if the depression is only of slight depth. Long-continued wind from the ocean, 24 to 36 hours, will produce rain along the coast at times without any low pressure accompanying it.

Duration of Rain. — With low pressures from the Gulf of Mexico, cloudy weather, with occasionally rain, will last at least 1 day, sometimes 3 days. Great rainfalls are mostly over in 8 hours, and only rarely last uninterruptedly for 24 hours.

Rain Frequency in Low. — Dividing the area of a low pressure into four regions, the centre, the first, the second, and the third rings, the number of times of the occurrence of rain out of ten cases in each region, are respectively 8, 6, 4, and 3.

Dew-point and Rain. — The occurrence of rain at a place is closely related to the temperature of dew-point and its rise. Along the coast of the Gulf of Mexico, and along the south Atlantic coast, a dew-point temperature as high as 78° at 8 A.M., is sure to be followed by rain within 24 hours. In the same region, a rise in the temperature of the dew-point of only three degrees, is sure to be followed by rain. In January, in the region of the Great Lakes, a rise sometimes as great as eighteen degrees in the temperature of the dew-point occurs before there is rain. The amount of increase and the temperature of dew-point which invariably precede rain is different in different sections of the country, and varies slightly in the same section at different times of the year. Charts representing these critical values of dew-point and dew-point change for various parts of the country are of value in estimating the probable occurrence of rain in connection with the other indications given by cloudiness, pressure, and pressure change.

Frequency and Quantity of Rain. — The occurrence of rain, and more especially the quantity of rain, depends on the amount of vapour in the air, as well as on pressure gradients. When the air is nearly saturated in summer time, very slight pressure gradients, even such as are hardly perceptible on the weather-maps, are associated with great downpours of rain.

The pressure gradient in summer is, in fact, scarcely of any use in indicating a coming rain. Moist air and a barometric pressure only one-tenth, or even only a few hundredths of an inch below the average of 30.0 inches, may give numerous scattered rains over a wide area, which are usually classified and predicted as local rains.

Secondary Low Pressures. — Secondary depressions consist of a kink or loop in one or more of the isobars of a low. The secondary is a low pressure on a low pressure. Rain is very apt to occur in and around secondary low pressures, and especially thunderstorms in summer time. They occur mostly to the south or east of a centre of low pressure. In Fig. 29, thunderstorms are very apt to occur with sec-

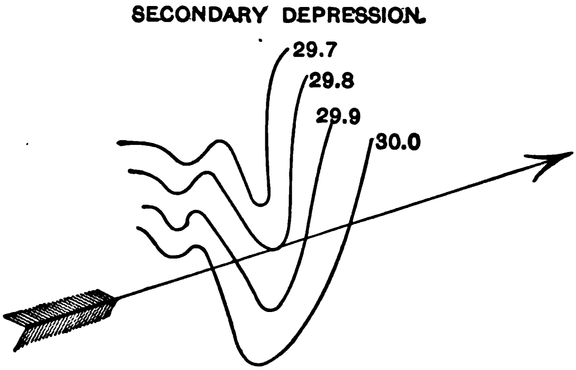


FIG. 29.

ondary low pressures. Thunderstorms are most apt to occur when the temperature is considerably above the average for the time of the year; they are most apt to occur when the pressure in its transition from a maximum to a minimum is approaching the mean pressure peculiar to the place.

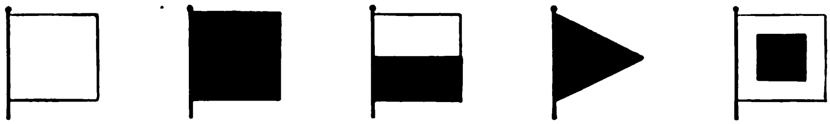
What has been said with regard to rain holds true for snow with the temperature of the air below 32°. Snow sometimes occurs with the temperature as high as 40°. In winter, when the low centre is below Washington City, it gives snow instead of rain.

Remarks on Predictions. — Predictions of rain, with the aid of weather-maps, as indicated, are on the whole far from satisfactory, and it is doubtful whether they are of any particular value in many cases. Very generally the rain begins with the appearance of a low pressure over a great area of country, both being simultaneous, and the most that can be said in the way of prediction is, that the rain will continue for some indefinite time at places where it is already raining. As much can be said on general principles, on the ground of probability, without the aid of a weather-map. Rain is, moreover, preceded by a cloudy sky, so that one can often form as good a judgment regarding the coming of rain, by means of local signs, as with the aid of the most complete weather-map. This is more especially true in summer. Tremendous downpours occur occasionally without any marked peculiarity of pressure distribution. At two places, not more than fifty miles apart, there may be a fall of 4.0 inches of rain at one, and none at the other. In winter, however, with strongly marked low pressures and high pressures of certain types, it is possible to successfully foretell for a considerable time ahead many of the great rain and snow storms.

The uncertainty of a weather prediction is greater the greater the interval of time for which it is made after the epoch of the weather-map on which it is based. For this reason the official government predictions of the Weather Bureau printed in the newspapers are not of much value, being based on the weather-map of the preceding day or even earlier. For the purpose of quick announcements signal flags are displayed at the various Weather Bureau offices throughout the country indicative of the weather expected. These flags are shown on page 186. It is difficult to remember the meanings of all the various combinations of flags in use. A system for memorizing the flags that has been found convenient for the wind-signal flags is as follows: The flag, as displayed on the page can be likened to a map; the top will be north; when the flag is white the first letter of the word "white" is indicative of west. A white pennant above the red flag then means a wind from the north-west; if below, from the south-west. The red indicates a direction opposite to the white, or from the east. A red pennant above a flag therefore indicates a north-east wind, and below it a south-east.

RAIN AND TEMPERATURE SIGNALS.

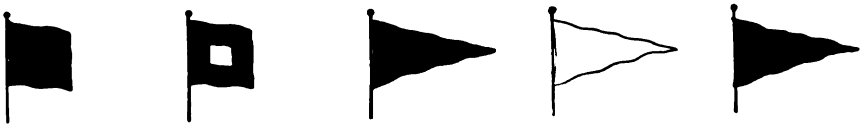
No. 1. | No. 2. | No. 3. | No. 4. | No. 5.



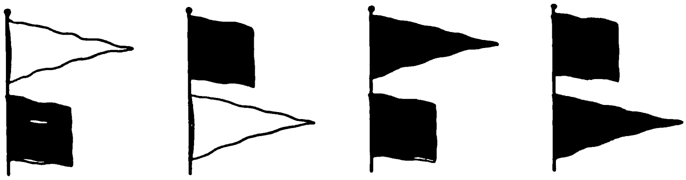
Clear or Fair. | Rain or Snow. | Local Rains. | Temperature Signal. | Cold Wave.

No. 1 indicates clear or fair weather; when displayed alone that temperature will remain stationary. No. 2 indicates rain or snow; when displayed alone that temperature will remain stationary. No. 3 indicates that local rains or showers will occur and that the rainfall will not be general; displayed alone that temperature will remain stationary. No. 4 always refers to temperature. When placed above Nos. 1, 2, and 3, it indicates warmer weather; when placed below, colder weather. No. 5 indicates the approach of a sudden and decided fall in the temperature. When No. 5 is displayed, No. 4 is always omitted.

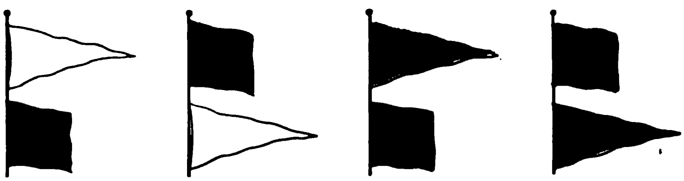
STORM, CAUTIONARY, AND INFORMATION SIGNALS.



Violent Storm. | Light Storm. | Easterly Winds. | Westerly Winds. | Information Signal.



Violent Storm, N. W. Winds. | Violent Storm, S. W. Winds. | Violent Storm, N. E. Winds. | Violent Storm, S. E. Winds.



Light Storm, N. W. Winds. | Light Storm, S. W. Winds. | Light Storm, N. E. Winds. | Light Storm, S. E. Winds.

The Information Signal denotes a storm covering a limited area, dangerous only to vessels intending to sail for certain points. Information can be had by applying to the local Observer.

Night Signals. — A red light indicates easterly winds; a white light above, westerly winds.

Spectroscope and Rain.—The indications of the twinkling of stars, supposed to be due to a great deal of moisture in the air, also red sunsets, and at times the transparency of the air, are of no value in rain prediction. When light from the sky is examined with a spectroscope, which is a prism, dispersing the light, separating it into its component colours, dark bands or lines more or less pronounced are seen in the spectrum which depend on the amount of moisture in the air. These lines known as the rainband, are of no value in indicating coming rain.

In regard to the prediction of storm winds, there are only few cases where serviceable predictions can be made, and these are for the cases of very deep and regular low-pressure areas. As a rule, the approach to a storm wind velocity is very gradual through all the lower velocities, from 15 and 20 miles an hour, up to 40. The continual increase of the wind is warning enough to sailors to seek shelter when possible, especially on the lakes, and warnings are in only rare instances of practical value.

COLD WAVES.

Cold Waves.—As a low area of pressure moves over a region, there follows west of it an area of temperature fall. As a high area of pressure moves along, falls of temperature occur to the south-east of it. When there occurs a low pressure and with it a high-pressure area to the north, north-west, west, or south-west of it, the falls in temperature are apt to be large and extend over great areas.

A fall of temperature of 20 degrees in 24 hours, extending over an area of at least 50,000 square miles, and the temperature in any part of the area going at least as low as 36° is called a "cold wave." The number of cold waves that have occurred in the United States in the ten years, 1880 to 1890, arranged according to the months and the extent of country enclosed by the 20-degree temperature-fall line, is as follows: —

NUMBER AND AREA OF COLD WAVES, 1880 TO 1890.

AREA.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	YEAR.
50,000 to 100,000 square miles . .	21	32	31	13	23	30	150
100,000 to 200,000 " " . .	13	14	30	27	26	24	134
200,000 to 300,000 " " . .	2	12	21	25	19	13	92
300,000 to 400,000 " " . .	1	10	16	29	24	11	91
400,000 to 500,000 " " . .	1	8	14	16	13	12	64
500,000 to 600,000 " " . .		5	5	13	10	1	34
600,000 to 700,000 " " . .		1	1	9	6	2	19
700,000 to 800,000 " " . .			3	4	5	1	13
800,000 to 900,000 " " . .		1	5	3	2	1	12
900,000 to 1,000,000 " " . .		2	1	1	2		6
1,000,000 to 1,100,000 " " . .				1	2		3
1,100,000 to 1,200,000 " " . .				2	1		3

Extent of Fall. — The extent of these cold waves is very great at times. The greatest in ten years occurred January 17, 1882. The area enclosed by the 10-degree temperature-fall line was 2,900,000 square miles; that by the 20-degree, 1,100,000; that by the 30-degree, 539,000; that by the 40-degree, 14,000. The greatest fall at the centre, at Denison, Tex., was 44 degrees.

The greatest fall in temperature at the centre of a cold wave varies in different cases. There have been 2 cases in ten years in which the greatest falls at the centre in 24 hours were over 60 degrees; 16 between 50 and 60; 77 between 40 and 50 degrees; 262 between 30 and 40; and 264 between 20 and 30 degrees.

The weather-map of December 31, 1884, and the cold wave that followed the next day, are shown on the adjoining page. On the upper map the red lines are the isobars, or lines of equal pressure; the blue lines are the isotherms, or lines of equal temperature. On the lower map the red lines join the points of equal 24-hour temperature fall; the 20-degree-fall area is within the 10, the 30 within the 20, and the 40 within the 30.

Cold-Wave Cone. — The areas enclosed by the temperature-fall lines are approximately elliptical. As a rule, they agree much better with this shape than in the example given. Regular ellipses will in most cases represent the falls of temperature with errors no greater than 6 degrees.

The fall of temperature in a cold wave may be considered graphically as a cone. The greatest fall in temperature at the centre of the cold wave is the altitude of the cone; the 10, 20, 30, and 40 degree temperature-fall lines are intersections of planes with the cone.

Intensity and Dimensions of Cold Wave. — The dimension of a cold wave is taken as proportional to the cubic contents of the cone or the area of the base multiplied by one-third of the altitude. The unit of area is taken as 100,000 square miles and the unit of altitude as 10 degrees of temperature fall. To find the extent of a cold wave, the areas enclosed by the temperature-fall lines are measured with a planimeter. The contents is computed as a rough cone. No allowance is made in computing the extent for any area covered by a fall of temperature less than 10 degrees.

The area of temperature fall between a 10-degree fall and the line of no fall cannot, as a rule, be measured accurately, owing to the indefiniteness of the lines of zero-temperature change. The extent of temperature fall in a cold wave, as computed, is then more accurately a cone of fall greater than 10 degrees, surmounting a cylinder of 10-degree fall. The extent of different cold waves measured in this way varies from 3.0 to 60.0.

Excess and Deficency of Pressure. — The deficiency of pressure in a low-pressure area and the excess of pressure in a high-pressure area may be estimated as cones, in the same way as the extent of a cold wave, from the measurements of the areas between the isobars on the weather-map. The unit of area is taken as 100,000 square miles, and the unit of excess or deficiency of pressure as one inch. The extent of a high or low pressure area on this basis is sometimes less than unity and at times as great as ten.

The weather and temperature-fall maps show that the extent of a cold wave depends on the extent of the low pressure preceding it, the extent of the high pressure coming after it, and the density of the isotherms in the region from the centre of the low pressure towards the high.

Fall of Temperature and Gradients. — The relation between the greatest falls of temperature in cold waves and the pressure and temperature gradients to the north-west of the centre of low pressure are as follows for the average of a number of cases: —

Number of Cases.	Greatest Fall of Temperature.	Increase of Pressure in 500 Miles.	Decrease of Temperature in 500 Miles.
16	53.6 degrees	0.66 inches	55 degrees
60	43.3 "	0.56 "	47 "
60	33.5 "	0.59 "	44 "
60	24.0 "	0.46 "	34 "
60	14.3 "	0.40 "	23 "

Predictions of cold waves are made from the weather-maps, when a low and a high pressure are shown, and the pressure and temperature gradients are sufficient to produce a fall considerably greater than 20 degrees.

Place of Greatest Fall. — The place of greatest temperature fall in a prospective cold wave can be taken at the point of highest temperature on the weather-map, within a distance of 100 miles of the centre of the low pressure. In about eight-tenths of all the cases of cold waves, this will be at a point south of the centre of the low pressure.

In the case of a high pressure to the south-west of a low pressure, the place of greatest temperature fall in many instances is farther to the south of the low pressure than 100 miles. In cases of this kind, the region of greatest temperature fall is apt to be a ridge extending from south-west to north-east rather than a point. The selection of the point of actual greatest fall in such cases cannot usually be made with great accuracy, but the point selected will at least be at a point of great fall.

In some cases the greatest fall of temperature is to the west, to the north, or to the east of the centre of the low pressure, usually about the place where the temperature diminishes most rapidly toward the north-west and at the place of highest temperature in the region about the centre of low pressure.

Fall of Temperature. — At the place of greatest prospective temperature fall in a cold wave, the temperature after the fall is the weighted mean temperature of the sections along a line drawn from the place of greatest fall, through the region of greatest diminution of temperature toward the north-west. The weight to be given to the temperature of each section is directly proportional to the length of the section, and inversely as the distance of the centre of the section from the place of greatest fall. The various sections of the line are the lengths included between the isotherms. The temperature of a section is the mean temperature of its bounding isotherms. The temperature of the first part of the line from the place of greatest fall for a distance of 250 miles is taken with a weight of unity. This rule applies only in case the pressure gradient is in excess of 0.4 of an inch in 500 miles. The computation of the temperature fall at the place of greatest fall, for the weather-map of February 11, 1887, is given below.

FEBRUARY 11, 1887.

Distances between Isotherms.	Mean Temperature of Section.	Length of Section.	Centre of Section from Point of Greatest Fall.	Assigned Weight.	Mean Temperature × Weight.
Degrees. Miles.		Miles.	Miles.		
– 30 to 60, 1100 .	——	——	——	——	——
– 20 to 60, 800 .	– 25°	300	950	0.32	– 8.0
10 to 60, 690 .	– 15°	110	750	0.15	– 2.2
0 to 60, 500 .	– 5	190	590	0.32	– 1.6
10 to 60, 380 .	5	120	440	0.27	+ 1.4
20 to 60, 270 .	15	110	360	0.31	+ 4.7
(20–63)	42	——	——	1.00	42.0
Sums				2.37	36.3
Mean temperature					15.3
Fall of temperature					– 47.7

The temperature on February 11, 1887, at Lamar, Mo., the place of greatest fall, was 63°. The next day it was 9°. The computed fall is 48 degrees. The fall that actually occurred was 54 degrees.

Position of Long Diameter of Fall Area. — The long diameter of a 20-degree temperature-fall area usually lies in a direction from south-west to north-east, or in the direction of the long axis of the low pressure area. This corresponds to the average direction of the isotherms to the west and south-west of the centre of the low. The long diameter of a temperature-fall area always extends in the direction of the open isobars of a low. The 20-degree temperature-fall areas on two successive days rarely overlap. This never occurs except in cases where one of the areas exceeds 400,000 square miles, and even then the overlap is only throughout a narrow strip of country scarcely more than 50 miles in width.

The limits of the 20-degree temperature-fall area to the north-east, or to the south-west, can be fixed somewhat nearly by comparison of the temperatures on weather-map with the lowest temperatures for the time of the year occurring in those particular regions. There is usually no 20-degree fall to be anticipated, when it would carry the temperature below the average lowest temperature for the month, as derived from a number of years, unless the conditions are very strong, for instance, proximity to the place of greatest fall.

Of 211 cold waves, the above rule for computing the amount of temperature fall at the place of greatest fall gave, in 14 cases, the actual fall of temperature with an error of less than one degree; in 36 cases ± 1; in 24 cases ± 2; in 22 cases ± 3; in 14 cases ± 4; in 18 cases ± 5; in 19 cases ± 6; in 10 cases ± 7; in 15 cases ± 8; in 8 cases ± 9; in 5 cases ± 10; in 4 cases ± 11; in 3 cases ± 12; in 7 cases ± 13; in 3 cases ± 14; in 1 case ± 15; in 4 cases ± 16; in 1 case ± 17; and in 2 cases ± 18. The errors are commonly greater in large temperature falls than small ones. The probable error for falls between 20 and 30 degrees is ± 2.5; between 50 and 60 it is ± 5.0.

Frost Predictions. — At periods of the year when frost may be anticipated harmful to growing crops, with the temperature in the evening about 50°, a rough estimate of how low the temperature will go during the night can be made from the readings of a wet and dry bulb thermometer; the difference between the two readings multiplied by 2.5, and subtracted from the dry-bulb reading will give the temperature approximately. This condition of the air occurs only when the sky is clear and the air pressure prevailing is 30.1 inches or more. When it is a matter of only a few degrees to prevent a frost, protection may be afforded in preventing radiation by covering tender plants with a light cloth or layers of straw, or even by producing a cloud of smoke.

LONG-TIME PREDICTIONS.

Long-time predictions of any value — that is, for several days, weeks, months, or a year — are impossible. Some of the most interesting features of the weather, and of the greatest value to know, such as droughts, heated terms, and wet periods, cannot be foreseen.

The only approach to success that has been made in this direction is for the rainfall in India. Some success it seems is attained in long-time predictions of the amount of rain for several months ahead in the middle Ganges valley of northern India. Unusually heavy and late snowfall to the north-west of the Himalaya Mountains exercises a retarding influence on the summer monsoon by keeping down the temperature of the region, which is one of the goals toward which the monsoon blows. The pressure gradients in the upper air producing westerly winds are intensified by this, and, in consequence, the easterly winds which prevail in India as far south as the Ganges valley, and ordinarily extend up to the level of the lower cirrus clouds in the rainy season, are greatly restricted in depth, in horizontal extent, and also in duration. The result is, a diminution of rainfall to a disastrous degree, causing the failure of crops and sometimes famine. The observed depth of snowfall in the Himalayas thus permits of forming some idea of the quantity of rainfall to be expected in the succeeding rainy season in the lower Ganges valley. In five great famines between 1782 and 1877, a year of very sparse rainfall in southern India was succeeded the next year by a sparse rainfall in northern India. Coincidence is too improbable to be fortuitous, but the cause of the connection is not known.

The dry periods and heated terms that occur at times in the United States are associated and dependent upon the passage of low-pressure areas moving from west to east across the northern part of the country, inducing southerly winds over a wide stretch of country to the south of them without any accompanying rain. There is no known cause why the low-pressure areas occur at such times only over the northern part of the country. All attempts to show a seasonal occurrence of these phenomena, or to prove that a deficiency or excess of rainfall or temperature in one season is made up in the next following season or some other season, have proved futile.

The heated terms always occur in connection with droughts. When the rainfall for two months in succession is only one-half the average amount, the result is a drought; the intensity of the drought is greater the less the rainfall and the longer the dry period continues. The excessive heats of August, 1876, from Maine to Virginia and west to Ohio, were coincident with a rainfall of only one-fourth to one-half the amount for August over the region, averaging only about one inch. Temperatures of near 100° and over occurred on several successive days from Jacksonville and Montgomery northward to Pittsburg and New York. In connection with the unparalleled heated term of July to September, 1881, which affected the entire country east of the Mississippi, there occurred the most extensive, prolonged, and disastrous drought ever known in the United States. In July and August the drought was also severe in Kansas and Arkansas. During August less than one-eighth of the usual amount of rain fell in the Ohio valley, and less than one-third along the Atlantic coast.

In 1886 a severe and prolonged drought prevailed in part of Dakota and Minnesota from about the middle of June to the end of October. In July it included Nebraska, Iowa, and parts of Wisconsin and Kansas. During this time there was only 2.85 inches of rainfall from June 26 to September 16, a period of 81 days.

In some parts of the west the variations of rainfall from year to year are very variable. Some years there is rain enough for the growth of crops, and others are so dry that any crop is impossible.

The climate of the whole interior of Australia is excessively variable as to rainfall, rendering the larger part of it uninhabitable at most times.

In the matter of the prediction of the beginning, continuance, and cessation of droughts and heated terms, nothing can as yet be done. It is, however, not entirely hopeless that it may be possible some time in the future to predict these occurrences. When the general circulation of the air in the northern hemisphere is understood in relation to the distribution of the air pressure, it may be possible to predict the weather with an approach to accuracy for some considerable time ahead.

At present very important points have been developed in regard to weather in Europe, extending over two or three weeks, in relation to the positions of the permanent low-pressure areas over the north Atlantic Ocean and the permanent high pressure that extends from Bermuda to the Azores and the high pressure of Siberia in the winter time. The shifting boundaries of these areas are associated with very profound modifications of the weather over a great part of Europe.

There are three principal places of low pressure in the northern hemisphere, — one south-west of Iceland, one near Davis Strait, and one in the Polar Sea. Around these the circulation takes place, and as one or the other is deeper, it has an important bearing on the weather prevailing in western Europe.

When the high-pressure area of the south Atlantic extends very far east, the south-west winds from it bring ocean air over Europe, and a milder winter than in the case where the high pressure moves off north-east and access of ocean air is cut off.

In Siberia in winter there is ordinarily a high-pressure area which extends unbroken for a distance of 3800 miles from north to south and 4900 miles from east to west. When there is a division in this, which sometimes occurs along the drainage basin of the Obi River, the western half of the high-pressure area is farther west than usual, and produces or is associated with severe winters in Russia and sometimes Germany.

The idea prevails very extensively, that weather is dependent very largely on mere local influences, but it is not so. Proximity to sea and mountains are important and have their influence, but for the most part lakes, valleys, and forests have scarcely any perceptible effect. Würtemberg, Bavaria, and Switzerland, where the characteristics of the country are so different, are nevertheless dry or rainy at the same time, and this is because weather is the result of the general circulation of the air.

CHAPTER IX.

RIVERS AND FLOODS.

Kinds of Floods. — Floods are produced as follows: By sea waves accompanying earthquakes, by storm waves accompanying cyclones, by seiche waves overflowing lake shores, by the slow rise of lake surfaces, by the bursting of glacier lakes, by the giving way of ice dams, earth embankments, or levees, by the choking of river channels due to the luxuriant growth of vegetation, by avalanches and landslides, by the overflow of river banks due to great rainfall or a rapid rate of rainfall, and by a river cutting its banks and changing its course. Overflows due to great rainfall are mainly treated of here.

Earthquake Floods. — A wave from the ocean produced by earthquake shock sometimes causes great destruction. The greatest recorded example of an earthquake wave was that at Lisbon, Portugal, November 1, 1755. More than 4000 persons were swallowed by the yawning earth, and 60,000 were drowned by the wave 80 feet high which advanced from the sea. The shock of this earthquake was felt over an extent of 12,000,000 square miles of the earth's surface, or four times the area of the United States.

Cylone Floods. — Floods from storm waves are sometimes very disastrous. The storm wave accompanying the Backergunge cyclone inundated the delta of the Ganges, destroying more than 100,000 persons; it was 40 feet in height. Many disastrous floods have occurred in Holland due to storms breaking the dykes which protect a great part of the country from being covered by the sea. A great catastrophe of this kind occurred in the year 1230, and a still greater one November 1 and 2, 1570, when 40,000 lives were lost.

Seiches. — A seiche is a sudden increase in the height of the surface of a lake. Seiches occur on the Great Lakes of the United States and also on the lakes of Switzerland. They are sometimes called "swashes." The increased height of water surface lasts but a short time, and is sometimes as great as six feet. The cause of a seiche wave is not known. They often occur in calm weather. A notable case of seiche occurred at Cleveland, Ohio, at 6.20 A.M., June 23, 1882, which was associated with the funnel-shaped cloud of a tornado moving over Lake Erie. The wave came with a change of wind from the south to the north-west.

Lake Floods. — Floods from steady rise of lake surface, due to long-continued great rainfall over a drainage basin, are not of any very great importance. Floods of this kind occur on the shores of some Asiatic lakes. The Great Lakes of the United States and Canada are not subject to such overflows.

Reservoir Floods. — The giving way of reservoir dams often produces disastrous floods. A notable instance of this kind was the breaking of the dam of the South Fork reservoir in western Pennsylvania, on June 1, 1889, which caused the loss of 2500 lives at Johnstown. The reservoir was 3½ miles long, 1 mile to 1¼ wide, and 100 feet deep in some places. All this water was precipitated on Johnstown, 18 miles below, by the giving way of a dam 1000 feet wide, which caused the stupendous fatality.

Ice-Dam Floods. — Great floods occur when temporary lakes are released by the breaking of ice dams caused by the advance of a glacier blocking a stream. The flood from a jam of floating ice is not of much importance except in a flat country. The Missouri River flood of 1881 was largely an ice-jam flood, caused by a series of ice dams. The peculiar case of an advancing glacier blocking a stream occurs frequently in Switzerland. In 1818 in the valley of Bagnes south of Martigny, the winter being very severe, the Gintroz glacier advanced and blocked the Dranse River, making a lake a mile long, 700 feet wide, and 200 deep. The ice was pierced artificially and the water about half drained off, when the barrier broke, causing a great flood below. No lives were lost, as the break had been anticipated for a long time. Nearly the same thing occurred in 1595, but with great loss of life.

Indus Floods. — In the region of the north-west Himalayas, the upper tributaries of the Indus are often held back in this way, and finally precipitated as floods. A notable case of this kind occurred in 1835, when whole villages were swept away for a distance of 300 miles along the stream. The wave crest moved with a velocity of 25 miles an hour.

The greatest example of the bursting of a glacier lake known was that on the Shyok River, a branch of the Indus, which occurred in 1841, on the south slope of the Karakorum Mountains, caused by the Biafo glacier. The length of the lake was 12 miles, its width 2.5 miles, and its depth 200 feet. When the barrier broke, the flood came down the Indus, and at Attock, 300 miles distant, part of the Sikh army under Golab Singh, encamped on its bank, was destroyed.

Floods from Dams caused by Vegetation. — Floods caused by luxuriant vegetation in tropical rivers are of no very great consequence. Floods of this kind occur on the Nile above Sobat, in the Lualaba, a tributary of the Congo in Africa, and on the Parana in South America.

Rainfall Floods. — Floods that arise from excessive rainfall gorging a river channel can be foretold along the lower courses of rivers from the progressive character of flood waves when the water stages along the upper courses are known and observations of the stages of water in previous floods have been made along the river course.

Floods by Channel Changes. — No predictions can be made of earthquake or storm-wave floods, nor of river floods, where they arise from a river changing its course. These latter are the most tremendous and disastrous of all floods. No region of the world is subject to such great floods of this kind as the parts of China traversed by the Hwangho River. The place where this river empties into the sea has varied in historical times a distance of 350 miles along the sea-coast. At every change enormous loss of life occurs. In the fifteen years, from 1851 to 1866, it has been estimated that the changes in the bed of the Hwangho have caused by drowning and by destruction of crops the loss of 30,000,000 to 40,000,000 lives.

RAINFALL FLOODS.

Rivers. — Rivers and lakes are products of rainfall. Of the rain that falls, a great part sinks into the earth, a small part enters into the structure of plants and animals, and part runs directly into the rivers and lakes and to the sea. Of the rain that sinks into the earth a part is evaporated into the air and part runs out of the earth as springs at lower levels than it entered. About one-fourth of all the rainfall at a place attains a depth of three feet under the surface of the ground; the remainder is evaporated from the top layers of the earth or runs out in springs.

Inland Drainage Areas. — In landlocked areas the rivers run to the lowest part of the drainage area and form a lake. A region of this kind is called an "inland drainage area." All the rainfall in such an area is evaporated. Rivers are slightly charged with salt and other minerals from the ground through which they run. The constant concentration of the minerals by evaporation of water from the surface of the lake renders it salty. Great Salt Lake, Utah, contains 17 per cent of salt and other minerals. Of lakes of this kind, the Caspian Sea, with an area of 180,000 square miles, is the largest in the world.

Amount of Inland Areas. — The amount of land surface of the earth consisting of closed basins or inland drainage areas is: in Australia, 52 per cent of the whole country; in Africa, 31 per cent; in Europe and Asia, 28 per cent, mainly in Asia; in South America, 7.2 per cent; and in North America, 3.2 per cent.

Lake Rivers. — In drainage areas, almost landlocked, where the rainfall exceeds the evaporation, there is a rise of its lake waters until the lowest point of the enclosing ridge is reached, when it begins to overflow as a river to the sea. The stages of water in rivers flowing from large lakes is nearly uniform all the year round. The St. Lawrence River, which rises in Lake Ontario, is subject to no more than three-feet fluctuation along any part of its course. The connecting rivers of the Great Lakes, the Niagara, the Detroit, and the St. Mary's oscillate only a few feet, and even a great part of this oscillation is due to the effect of wind on the water surface, and the level is very nearly constant.

Total Rainfall. — The total rainfall over the land surface of the earth in a year is estimated to be 28,000 cubic miles of water, and the amount flowing yearly into the sea about 7000 cubic miles. Twenty-two hundred cubic miles of the rainfall falls on inland drainage areas.

The periodicity of rainfall over a country is reflected in the oscillation of its rivers, sometimes dry and at times overflowing their banks.

RIVER COURSES.

Thalweg. — Slope of the ground determines the way in which water runs. It collects in the valley bottoms, which are called the "thalweg," and moves along like a ball rolling down an inclined plane.

The amount of rainfall that sinks into the earth depends on the permeability of the soil, on the slope of the ground, and on the rate of rainfall. The degree of permeability of ground is highly important in estimating river flow from rainfall. All ground is more or less permeable to water, but soils are classified broadly as permeable or impermeable. The ground above granite or lower cretaceous bed rock is impermeable. The impermeable prevails largely in hilly and mountainous regions.

Characteristics of Impermeable Ground. — A marked feature of impermeable ground is the great frequency of streams. In a valley over granite bed rock, there will scarcely be ten acres without a rivulet or a ravine at the bottom of it. In ground classified as permeable, streams are infrequent: there is neither rivulet nor ravine in the vicinity of the thalweg, and cultivation of the soil is carried on to the very bottom. When at great intervals a creek does appear, the flow of water is often found to diminish as the stream progresses, due to the water sinking into the earth. This difference in number of streams over permeable and impermeable ground is sufficiently marked to be noticeable on the maps of two such regions.

In permeable ground the thalweg is almost free of water even in the heaviest showers. In impermeable ground the water runs along the smallest furrows. When it rains, every furrow becomes a rivulet, every fold of the ground a torrent, and the bottom of every valley a creek or river. The rapid motion of the water carries soil with it, and the streams of such a region are heavily loaded with silt. In some cases silt comes from the rapid current cutting the banks of a stream; so that silting is not always an indication of impermeable soil.

Rivers and Rainfall. — The amount of water contained in permeable ground to the bed rock is about one-third of the depth of the soil. The amount of rainfall that runs off in rivers varies widely at different times and in different places. This quantity is called the "run-off." In Australia the Darling River drains, on the average, only 1.5 per cent of the rainfall over its drainage basin. In different years it varies from 0.1 per cent to 6 per cent. In Europe the river drainage is about one-fourth of the rainfall; in the Ohio valley it is one-fourth; in the Missouri valley only one-eighth. When ground is frozen the amount of rainfall drained may be as much as 90 per cent.

Rise of Rivers. — The rivers in impermeable ground rise with great rapidity at first and then more slowly. They fall as rapidly as they rise. In permeable ground the rise and fall of rivers is always slow.

River Basin. — The basin of a river is the tract of country which it drains. This is also called the drainage area, the catchment basin, and the watershed.

The boundaries separating drainage basins are called water-partings or divides. These vary from the sharp ridge of a mountain range to a slight roll in the plain imperceptible to the eye.

Where the ridge is worn down so that two adjoining basins connect, the water-parting is called "quaquaversal" as in the Cassiquiare River which connects the Orinoco and Rio Negro.

The vertical height of a river surface in feet above low water at a place is called the "stage of the river." In some localities the channel depth is called the stage.

As the water of a river moves, it is joined by water from other rivers; these rivers are called tributaries and affluents; the place of meeting with the main stream is the confluence.

River Slope. — The slight inclination of a river surface, in the direction in which the water flows, is called the "slope." The greater the volume of a river, usually, the less its slope. In small rivers and mountain streams the slope is in some cases as much as 4 to 7 feet per mile. In great rivers, like the Mississippi, it is not more than 0.23 of a foot in a mile, on the average. For a rising stage at a place, the slope increases; with a falling stage it diminishes.

The velocity of water in a river is greater the greater its slope, the greater the area of its cross-section, and the greater the depth of the water.

There is not a close connection between river slope and velocity, such that the velocity can be computed from the slope. All the attempts to derive formulæ for velocity in natural channels from observed slope have proved futile. This is in large measure due to the very variable cross-section of a river even at points very close together. In fact it is sometimes observed that the inertia of the water will sometimes carry it against a slope. The velocity is approximately proportional to the square root of the slope and also to the square root of the mean hydraulic depth.

Wetted Perimeter. — The length of a line from one margin of a river to the other, measured along the bottom, is called the "wetted perimeter."

The area of a cross-section divided by the wetted perimeter is called the "mean hydraulic depth."

Great slope and shallow water produce a riffle.

An abrupt lowering of a river surface produces a "falls" or a cataract.

Regimen. — The characteristics of a river as to its customary rise and fall, greatest and least discharge of water, character of slope and area of cross-section at different stages and in different parts of its course constitute its regimen.

Flood Line. — The danger line or flood line of a river is an arbitrarily selected stage, farther rise beyond which it is presumed may cause damage.

Low-water stages of rivers are mainly of interest to boatmen. High stages are a matter of great concern to the population along river courses, in localities where the banks are apt to be overflowed at a high stage and the country inundated.

Different Classes of Flood Streams. — The way in which high water occurs in rivers is very various in different parts of the world. In the rivers of Siberia and British America that flow into the Arctic Ocean, high water is the result of snow melting in spring in the lowlands up to a height of about 3000 feet above sea level and flowing north over ice and frozen ground. The Obi and Yenisei in Siberia are of this type. The rivers flow from south to north. Along the upper courses the snow melts first, and as the water flows down it is met by the water from the snow farther north, melting later, and the consequence is excessively high water along the lower courses of the rivers.

In some Siberian rivers high water occurs only in mid-winter and is due to the choking of the channel by the formation of ice during the excessive cold of 60° or lower that often prevails for a considerable length of time. This does not produce a flood.

Along the Mackenzie River, floods are caused by the head waters flowing over the lower river while frozen, covering great areas of land.

While not more than 25 per cent of the amount of rainfall over a drainage area runs into the rivers, the amount of melted snow that runs off in the case of frozen ground may be as much as 72 per cent. (Measured at Moscow, Russia.)

Rivers from Snow. — There is a class of rivers that derive their high waters from snow melting in the mountains. The melting is a slow process, and high water occurs very gradually and with great regularity. The rivers that take their rise in the mountains of central Asia are of this type, — the Indus of India, for example.

Tropical Rivers. — Another class of rivers receive water from rain only, and have high water in summer. These are tropical rivers, and high water depends on the rains of the belt of calms and the monsoon. The greatest rivers of the world belong to this class, the Amazon, the Congo, the Ganges, the Brahmaputra, the Yangtse-Kiang, and the Nile. Rivers near the equator have two high waters in a year, corresponding to the two periods of rain when the sun passes the zenith in moving from south to north, and again in moving from north to south.

Nile. — The Nile, a tropical river, is the greatest irrigating stream in the world. A rise less than the average causes great distress among the inhabitants of Egypt, from failure of crops for want of irrigating water. A rise much beyond the average is destructive from the inundation it causes. The lowest high water in 30 years at Cairo, Egypt, was 14.4 feet in 1864; the highest, 26.2 feet in 1878, when the whole delta to Alexandria was flooded. The lowest water occurs in June, and the highest in the latter part of September. The rise is due to the monsoon rains in Abyssina between latitude 5° and 15° north. The great fertility of lower Egypt is due to the alluvium deposited by the flood waters of the Nile. The water is loaded with black earth, and contains traces of nitre.

Yangtse-Kiang. — The Yangtse-Kiang rises regularly in mid-summer about 50 feet at Hwangho near the middle of its course. Sometimes the rise is as great as 56 feet, and a vast area of country is flooded. The floods in this river are especially disastrous, occurring at a time of the year when the crops are growing. The rains that cause the rises continue from May to July. The flood of 1849 lasted from July to December. The Chinese do not consider that any great part of the flood water is from the melting of snow in the mountains. Records have been kept of all the floods that have occurred in this river, extending back to 922 B.C. The summer rises of the Yangtse-Kiang, the Amur, and Hwangho show that the monsoon winds penetrate Asia to a considerable distance inland.

Amazon. — The Amazon River, of South America, receives most of its water from rainfall, a very little coming from melting snow in the Andes Mountains. It has the largest drainage basin of any river in the world. In some parts of the basin the yearly rainfall is 280 inches. There is, however, no very great variation in the stages of the Amazon. When the northern tributaries are in flood, those from the south are at a low stage, and when the southern tributaries are in flood those from the north are low. The Orinoco has greater fluctuations than any other river in the world, the average annual variation being 70 feet.

Temperate-Zone Rivers. — Another class of rivers receive their water from rain and have high water in winter or spring. The Mississippi and Ohio belong to this class, and also the rivers of Europe, the Rhine, the Seine, and the Elbe. In this class the heaviest rains producing high water occur in winter and spring, and are specially efficient in filling the rivers more, because they occur at a time when the evaporation is small or the soil frozen and more of the rain goes into the rivers.

In the summer, after long-continued dry weather, the top layer of the ground becomes so dry that it takes about three inches of rain to soak it, before much of the water will run off. Floods do sometimes occur in these rivers in summer. The main cause of floods is great quantity and rapid rate of rainfall. A slow rainfall of two inches extending over three days may produce only a very slight rise in a river, while the same amount in two hours may produce a very great one. A rapid rainfall forms a water surface over the ground, which promotes a rapid transfer of a great part of it to the streams.

Snow-water Rivers. — Some rivers receive a great part of their water from rain, but high water is due to additional water coming from melted snow. Where the water from melted snow is even only as great as one-fifth of the amount of rainfall, yet so much of it goes to the rivers when melted, the ground being frozen, that, added to the ordinary rainfall, it produces very high water. The rivers of New England, and sometimes the Ohio River, belong to this class of streams.

Sub-tropical Rivers. — Another class of rivers receive their waters from rain and are much higher in winter than summer, even going nearly dry in summer. This class of rivers is peculiar to southern Europe and the high waters are related to the sub-tropical rains, that is, little or no rainfall in summer. The Arno and Tiber in Italy, the Loire, Rhone, and Garonne in France, the Tagus, Mancanarez, and Guadalquivir in Spain are of this class. The rivers of California and Oregon are of this class also, but receive some water from melting snow in the mountains.

Along the lower course of the Rhone is a district subject to great floods. The loss of life and property was very great in the flood of November 10 to 20, 1840, and in the overflow of 1860 even greater.

Intermittent Streams. — There is a class of intermittent streams which, on account of dryness of climate and irregularity of rain, flow only when rain falls. Temporary creeks and rivers form and vanish soon after the rain is over.

Gulches. — The beds of such streams are known as ravines; in California they are called "gulches." Some rivers flow for a distance and are lost in the ground, to reappear farther on or not at all. These are sometimes known as "lost rivers."

Desert Streams. — The great deserts like the Sahara, the Kalahari, and the Gobi are regions without rivers, though there is considerable rainfall. In the desert of Sahara, however, there are some continuous streams in the mountains. Sometimes such regions are traversed by rivers that bring water from a long distance. The Rio Grande, the

Nile, and the Indus are types of this class, also the Colorado from latitude 36° to the mouth of the Gila river in Arizona.

Glacier Rivers. — In the regions of perpetual snow and ice the place of rivers is supplied by glaciers which carry to the sea or warmer regions the surplus of snow which is not evaporated. The melting of glaciers is the origin of some rivers. Such rivers have a milky appearance from the great amount of pulverized rock carried.

Ice-jam Floods. — Ice is carried along in streams at the time of breaking-up of the frozen rivers in the spring. At times, narrow parts of the channel, or sections obstructed by bridge piers, become gorged and produce floods back of them; when the barrier yields, floods ensue below them. A flood of this kind occurred in the Maumee River at Toledo, Ohio, February 11 to 14, 1881; and one at Washington City, February 12, 1881, by an ice gorge at Long Bridge.

Snow Floods. — With great depth of snow on frozen ground great floods are occasionally produced in rivers not otherwise subject to overflow. About once in a century the river Somme in France overflows from this cause. The flood of 1658, which was preceded by six weeks of excessively cold weather, was due entirely to melting snow which lay on the ground to the depth of six feet. Preceding the great flood of 1740 the conditions were similar.

Weather and River Rises. — Very little has as yet been discovered in the way of dependence between meteorological laws and river floods, more than what is known about high waters produced by the monsoons in the tropics, and the locking of waters by frost in the winter in northern latitudes.

In some streams dependent on water from the melting of snow in mountains, there is a perceptible variation in the stage of the water having the period of a day, due to the fact that more snow is melted during the warm than the cold part of the day. The time of highest stage depends on the distance of place from the snow field. In the temperate zone floods occur without any very noticeably great rainfalls. Floods in a river are apt to be due to a peculiar sequence of rainfalls over a river basin rather than to any one great downpour. Intermittent light rains may cause a river to rise slowly and steadily until it is nearly bank-full, and then a moderate rain but little greater than the others will carry the water over the banks.

Flood Combinations. — Floods depend largely on the topographical features of a country, in combination with sequence of rainfall over its various parts. A succession of rainfalls over a basin, so occurring that the flood waters from a number of tributaries reach some part of the main river at the same time, will give a high stage for all the places along its lower course. A difference of some hours in the times of rainfall may cause the floods from the various tributaries to pass in succession through the main river, producing a medium stage of water extending over a long time, but no very great high water. For any particular river basin the number of combinations capable of producing a flood or high water is large, but the probability of any one of them occurring is small in the case of many rivers. The occurrence of many floods may therefore be considered as due to a combination of favourable circumstances or as purely fortuitous. Care must be taken in drawing conclusions from flood records of a river with regard to changes in its regimen.

Forests and Rivers. — The clearing of forests from land, the extension of cultivation, and the introduction of subsoil drainage, may have some effect on river regimen, tending to increase or diminish the highest water stages occurring during floods, but these are far outweighed by other accidental circumstances. The forests of Maine are growing in ground covered with boulders filled in with leaf mould and moss. When this permeable soil is burned, there is left a very impermeable soil, which may change river regimen without any change of rainfall.

Ploughed ground is more permeable to water than prairie sod, and must act to restrain and store up the water which will then in great part be evaporated or will run to the rivers more slowly than would otherwise be the case. Forests have no direct restraining effect in diminishing the heights of floods. This has been shown by the gauging of two rivers from two similar areas of land side by side in France, when both were covered with forest and after the trees had been cleared from one of them. The maximum stage showed no dependence on the forest.

Effect of Forests. — Forest growth over the drainage basin of a river diminishes the amount of silt carried to the streams, especially forest on hillsides. Bushes serve equally well, and preserve the soil from being washed away to the streams. In this way, plant growths diminish the flood heights of a river, by diminishing the amount of sediment thrown down in river beds in places where the current slackens. The gradual rise of the bottom of a river in this way, by slow sedimentation, may cause overflows of the banks finally, which otherwise would not have occurred. The sedimentation of rivers in south-eastern France after the clearing away of the forests from the hillsides was so great that many disastrous floods occurred. In recent years, since reforestation, the rivers have cleared the channels of much of the deposit, and the former regimen has been in a measure restored.

Mining Silt. — The bed of the Sacramento River in California at Sacramento City is 20 feet higher than it was in 1849, owing to the débris from gold-mining washed down, especially that from hydraulic mining. The river water consequently rises 20 feet higher than formerly. Now that hydraulic mining has stopped, being forbidden by law, the bed of the river will probably be scoured out some and its former regimen at least partially restored. Part of the silting of the Sacramento River is due to the diminished tidal flow through the river, owing to the reclamation of swamp land by building of levees.

Cultivation Silt. — The Chattahoochee River in Georgia is an example of a stream that has become silted by the extension of cultivation, so that lands are now overflowed which formerly were not.

At Augusta, Ga., where the Savannah River is notable for its floods, there has been no great increase of high waters, even though there has been a great extension of cultivation in the drainage basin in the past century.

In the Savannah River the Yazoo flood of 1796, and the Harrison flood of 1840, with a stage of 37.5 feet, were nearly as high as the great high water of September 11, 1888, which was 38.7 feet.

River Records. — From the most ancient times a gauge, called a "nilometer," has been maintained on the Nile for indicating the stages of water.

River gauges are now maintained at many places, and a record of the daily stages of water kept in the interest of navigation and for the purpose of giving warning of floods. It is only within recent times that much attention has been given to the matter of river-gauge records in the United States. Since 1871 a number of river gauges have been maintained at places on the Mississippi River and its tributaries, and records of the water stages have been kept up under the auspices of the government. These records are published by the Mississippi and Missouri River Commissions and the United States Weather Bureau. Records previous to 1871 have been kept at only a few places by interested individuals, corporations, or city governments.

Weather-map and Flood. — No sufficiently satisfactory estimate of the amount of a coming rainfall over a drainage area can be made from a weather-map to be of any use in making a flood prediction. It is impossible to tell just where the rainfalls attending a storm will occur, or in what quantity the rain will fall. In case the rivers of a region are already high, as shown by the gauge-readings, and there is a storm of the first order over the region, important conclusions can be drawn. At Augusta, Ga., for instance, with a stage of 20 feet in the Savannah River and the centre of a West India hurricane within 200 miles of the basin, a farther rise in the river of at least 10 feet may be anticipated. For a rise of 20 feet at Augusta there is required an average of 2.2 inches of rainfall in the three days preceding at Augusta, Atlanta, Chattanooga, Knoxville, and Charlotte. The least rainfall producing such a rise has been 1.6 inches. For a 24 to 28 foot rise requires a three-day rainfall at the same places of 2.5 to 6.4 inches. The 34.5-foot stage on July 31, 1887, was preceded by a rainfall of 5.4 inches at Atlanta and Augusta. The rainfall preceding the 38.7-foot stage of September 11, 1888, was 3.7 inches.

Predictions without Gauges. — Flood predictions are rarely made for rivers not provided with gauges. Unless something is known about the customary stages of water in a river, no prediction of a river stage of any value can be made, on the basis of an approaching cyclone, nor even from rainfall already on the ground as observed by rain gauges.

For the purpose of forming a rough estimate of the effect of rainfall on the river stages at a place, the rainfalls are entered on a chart showing lines of equal time of travel from the various parts of a drainage basin to the place by the river routes. A map of this kind for St. Louis, Mo., is shown on page 244, the heavy lines representing the points from which water reaches St. Louis in one, two, three, etc., days. These lines are for medium stages of water, and based only on the distance from St. Louis by river, regardless of the varying velocity of the water in different parts of the river courses. In reality, these lines vary a good deal for different stages of water, the velocity of the current being greater the deeper the water. Such maps, however, though not very accurate, serve to show approximately what volumes of water may be expected to flow by a place when the rainfalls over different parts of the drainage area are known.

Floods in rivers in the United States from a single rainfall, causing a river to rise from a low stage to the flood line in a single day, are very rare. This does, however, occur occasionally, as in the case of the Black Warrior River at Tuscaloosa, Ala., when there was a rise of 65 feet in one night, on March 25, 1881.

Rainfall and Rise. — From a lack of knowledge of the nature of the ground over drainage areas, and from the uncertainty in the factors that determine what part of a rainfall runs into the rivers, even the observed depth of rain after it has fallen, is not of any very great service in determining a river rise, except in cases where the rainfall is excessive. When the ground is very much below the temperature of freezing-point in winter and a slow rain occurs, the ground becomes covered with glare ice, and a subsequent heavy rainfall goes almost wholly to the rivers, and may produce a rise seemingly very disproportionate to the observed depth of rainfall. Moreover, the rainfall differs so much in neighbouring places, that observations at only a few points over a drainage basin are not of great value in river-stage prediction. One place may have a fall of three inches, and at a place 20 miles away there may be only a fraction of an inch, or none whatever. While great river rises may occur with less than one inch of rainfall in twenty-four hours, in general, no trustworthy conclusions with regard to rises can be drawn from rainfalls alone, unless in excess of two inches in 24 hours for at least two stations in a drainage basin, which may enable one to form an idea of the area covered by the rainfall. This applies to areas of not more than 5000 square miles.

Course of Rise. — In a small drainage basin the river rise after a rainfall is very rapid, and the water subsides as quickly as it rises.

The larger the drainage basin, the slower and more regular the rise and fall.

There is a motion of a flood wave down stream. The crest of the wave moves with a velocity dependent on the slope of the river and the mean hydraulic depth, and does not differ a great deal from the velocity of the water. A flood wave is apparently retarded as compared with the water velocity, due to the water having to fill the empty river channel as the stage increases. A flood wave from the Yellowstone River takes ten days to reach St. Louis. From Cincinnati to Cairo the time of a flood wave is 6 days; from Cairo to Vicksburg, 7 days; and from Vicksburg to New Orleans, 4 days.

Flood Crest. — After rain falls and flows into a river, it has the velocity peculiar to the slope and hydraulic depth of the stream where it enters. The first additions of water proceed down stream at a uniform velocity. As more water is added from the same area, the hydraulic depth being increased, the velocity becomes slightly greater, and in the course of time the water catches up with the first. As water continues to be added, the hydraulic depth and the velocity continues to increase, and the water overtakes that ahead always at a point farther down stream. In this way a wave crest is formed and reaches its greatest development some distance down stream from the region of rainfall. In the case of widely extended rainfalls over large drainage basins, the waters from the various tributaries produce the flood-wave crest in the main river. After the mean hydraulic depth stops increasing, there is a gradual spreading out of a flood wave and a lowering of its crest, as it moves down stream, when there are no further additions from tributaries.

Velocity of Water. — The velocity of the water in mountain streams or torrents is very different from that in streams through comparatively level country. In torrents, on account of the greater steepness of the banks, the hydraulic depth increases faster with the stage than it does in rivers with very sloping banks. While the ordinary increase in the velocity of a river from a low to high stage is not usually more than double, in torrents it may be four or five times greater. But this is very variable in different streams. The Missouri River from low to high water increases in velocity (at Omaha) from 2.3 miles to 5.3 miles per hour for the average of the cross-section. The average velocity of the Ohio River (at Paducah) near its mouth varies from one mile an hour at low water to three miles at high water. The current of a river is swiftest in the middle of a stream at some distance below the surface, depending slightly on the velocity and direction of the wind. The average velocity of water in a river from bottom to surface throughout a depth is equal to 0.87 of the mid-depth velocity. Sometimes the average velocity is considered to be at six-tenths of the depth.

With a rising stage of river the velocity is greater than for the same stage when the river is falling. In gauging a river, by measuring the velocity with a current meter, a coming rise is often indicated on the lower Mississippi 48 hours in advance by an increase in the velocity of the water.

Torrent Velocity. — In torrents the velocity of the water is sometimes as great as 50 feet a second, or 34 miles an hour. The tremendous ravining effect of such a current can be understood from the fact that the energy of impact in water is proportional to the sixth power of the velocity. A current of ten feet a second is sufficient to move a stone weighing four pounds; when the velocity is doubled it is capable of moving a stone sixty-four times as heavy, or 256 pounds. In the valley of the Ardèche, one of the tributaries of the Rhone in southeastern France, a torrent has transported a rock which is estimated to weigh 450 tons.

Rise of Torrents. — In a torrential river there are two rises in a flood; the first quickly after the rainfall, which as quickly subsides; the second a slow and steady rise from the water oozing out of the ground from numerous springs.

In every great valley there is a point where floods cease increasing. This is where the flood of the principal stream passes without meeting the floods of affluents already past. This point is the farther from the source of a river, the more mountainous the country, because, on account of the greater slopes of the thalwegs, the floods pass over more space in a given time than in a nearly level country.

In a torrential stream a great flood may be produced by a single rainfall over only a part of its basin, and not necessarily the part about its source. The floods in small torrents do not usually last longer than 24 hours.

The tranquil flow which follows the torrential flood increases at every confluence, since it is of some duration. The flood then goes on increasing at each confluence until it reaches one where all the flood has passed, from which point the height begins to diminish.

In permeable ground, floods of the affluents concur in increasing the flood in the principal stream. The duration of floods in such streams does not increase notably as they progress. In torrents, the duration of floods being very short, a flood most always passes before another comes on. Two succeeding floods are usually independent of each other.

River Discharge. — A knowledge of the quantity of water passing in a river in a given time, or the river discharge, is needed in estimating the relative importance of streams in producing floods. The discharge is commonly given in cubic feet per second passing. The discharge depends on the stage of water, being greater the higher the stage. The discharge in cubic feet in a second is equal to the area of the cross-section of a stream in square feet multiplied by the velocity of current in feet per second.

There are four methods of measuring the velocity of a river current:

First, The Weir Method. This method depends on measuring the height of a surface of water running over a weir; this can be done with very great accuracy by means of a gauge constructed specially for the purpose. The method is only applicable to small streams and is the most accurate of any method of stream gauging.

Second, The Meter Method. This method consists in ascertaining at different depths in the different parts of a stream, the number of revolutions made in a given time by an immersed propeller wheel, an electrical break-circuit being used to record the number of turns. The velocity corresponding to the number of revolutions is ascertained by dragging the meter at a known velocity through the quiet water of a pond. This is the most satisfactory method of measuring velocity in large streams, and the one commonly used. By means of a cable stretched across a stream a meter can be carried on a pulley to any desired point and readily lowered to any part of the river channel. The insulated wires connecting the wheel with a register on shore record the number of turns; the interval of time for which the turns are taken is usually five or ten minutes for each point where a measurement is made. In the case of navigable streams, the stretching of a cable not being permissible, the meter has to be lowered from a boat anchored in the stream for the purpose.

Third, The Float Method. This method consists in observing the velocity of water by means of an object floating down a stream. This is done by observing it from two stations on shore, the distance between them being known. The float consists of a keg or tin vessel attached to a rod and loaded so as to leave a little of the stick projecting above the water surface. The rod takes the velocity of the water at the place of the vessel. This method is cumbersome and at the present time rarely used where extensive gaugings of a river are to be made.

Fourth, The Slope Method. This method consists in computing the velocity by means of the measured slope of the water surface and the mean hydraulic depth of the stream. The formula depends on observations made by the methods described above. The slope of water surface is determined by means of simultaneous gauge readings at two places a number of miles apart, the difference in elevation of the marks being known by means of accurate levellings.

The method gives only a general approximate result. The constant of the formula is very uncertain, depending on the friction of the water on the bed of the river and its various irregularities and also on the magnitude of the stream. It is applicable only to a straight stretch of river without bends or curves. It is uncertain what length of river should be used in deriving the slope of surface.

In the following tables are given the river discharges and the amount of rainfall in cubic miles for each of the years 1881 and 1882, and for each of the drainage areas of the upper Mississippi River, the lower Mississippi, the Ohio River, and the Missouri. There was a flood in the Missouri River in 1881, and in the Mississippi in 1882. The discharges are mainly derived from measurements with a propeller-wheel meter.

A discharge of one cubic mile in a month of thirty days corresponds to an average discharge of 56,790 cubic feet per second during the time.

River Discharge and Rainfall in Cubic Miles of Water.
Year 1881.

Month.	Whole Mississippi River.		Ohio River.		Missouri River.		Upper Mississippi River.	
	Disch'ge.	Rainfall.	Disch'ge.	Rainfall.	Disch'ge.	Rainfall.	Disch'ge.	Rainfall.
January	6.8	33.5	3.9	11.4	0.6	9.6	0.9	3.2
February	14.5	58.3	7.5	16.0	1.2	10.8	1.1	8.7
March	22.2	36.0	7.1	12.0	3.1	8.7	2.3	5.5
April	22.2	40.4	8.9	12.5	4.7	10.9	4.8	3.9
May	22.2	73.6	4.9	9.6	4.7	26.5	4.6	9.5
June	17.7	72.2	3.3	17.6	3.1	26.9	3.1	15.3
July	11.5	45.9	2.2	8.6	2.7	17.1	3.1	10.6
August	5.1	34.2	1.1	4.6	1.0	13.0	1.2	9.1
September	4.2	71.6	1.1	11.2	0.8	21.4	1.3	19.2
October	5.4	69.7	1.6	14.4	1.7	16.5	4.3	16.1
November	9.9	45.1	3.2	15.1	1.6	6.7	6.2	7.2
December	12.9	33.7	4.9	18.1	1.1	2.4	2.8	3.5
Sums	154.6	614.2	49.7	151.1	26.3	170.5	35.7	111.8

River Discharge and Rainfall in Cubic Miles of Water.
Year 1882.

Month.	Whole Mississippi River.		Ohio River.		Missouri River.		Upper Mississippi River.	
	Disch'ge.	Rainfall.	Disch'ge.	Rainfall.	Disch'ge.	Rainfall.	Disch'ge.	Rainfall.
January	19.0	56.0	16.7	26.8	0.8	4.7	1.8	2.6
February	22.1	58.9	17.6	21.7	1.2	6.4	1.9	4.9
March	29.6	45.2	16.2	16.7	1.6	7.4	2.9	7.3
April	28.4	54.1	6.9	10.0	1.7	20.5	3.9	8.5
May	24.8	98.4	8.5	21.0	2.0	29.3	5.0	13.4
June	22.9	74.0	8.0	15.1	2.8	27.6	5.4	17.9
July	21.7	67.8	4.2	13.8	3.4	19.7	4.8	9.6
August	12.1	52.1	2.8	20.6	1.3	7.0	1.8	7.8
September	6.1	38.7	2.5	11.3	0.6	9.9	1.2	3.5
October	4.9	48.1	1.4	6.4	0.6	14.6	1.0	10.1
November	5.1	37.2	1.3	8.9	0.7	5.8	1.3	5.4
December	6.2	25.5	2.1	7.9	0.4	7.0	1.0	4.3
Sums	202.9	656.0	88.2	180.2	17.1	159.9	32.0	95.3

CHAPTER X.

RIVER-STAGE PREDICTIONS.

Freshet Waves in Rivers. — A high-water wave in a river being progressive, some idea can be formed in advance, as to the stages of water that will occur along the lower course of a river, when the stages at points along the upper course are known. The judgment is based on what has been observed to have occurred in preceding cases of high waters. Hence the value of a record of water stages, to determine the relation between the wave crests along a river course. The relation of wave crests is not identically the same in all cases of high water. It depends on the distribution of rainfall over the drainage basin of a river. The average of a great many cases, however, gives a result which, though sometimes in error, yet in many or most cases is very nearly right. The result is uncertain by the amount of water entering the river between gauges, which goes to swell that passing the lower gauge without affecting the stage at the upper one.

When the relation of the high-water stages at two places is known the observed stage at the upper one can be used to predict the stage that will occur at the lower one. The prediction will be the more accurate the more of the drainage basin there is above the upper gauge, and the nearer the two gauges are together.

If, however, the upper gauge is close to the lower one, a prediction loses in value, on account of the slight interval of time between the prediction of a stage and its occurrence.

In a river draining a very great area and without any affluents, stages can be predicted several days ahead accurate to within a few inches. When a rise at a place is the result of rises in several tributaries, a stage cannot be predicted with as great an accuracy. It may be in error in some cases two or three feet or even more, depending on the extent of drainage basin and the number of tributaries.

Methods of Predicting Stages. — To derive rules or methods for predicting river stages requires a long-continued record of the stages of water at two or more points on a river. In order to derive a rule for rivers with many tributaries, a record extending over several years is necessary, with rises occurring sometimes in one tributary and sometimes in another, in order that the effects of the various tributaries in producing a rise in the main river may be disentangled.

A theoretical determination of a river rise as a problem in dynamics or hydraulics is entirely out of the question. The complexity of such a problem is very great, involving the varying depth, slope, and cross-section of a river in different parts of its course and the tortuousness of its channel. Moreover, a precise result is not to be expected, because of the water entering the river between gauges.

Where there are two gauges on a river, without any large tributary entering the river between them, the method of finding the relation between stages is, to take the mean of all the high-water crests about a certain stage for the upper gauge, and compare it with the mean of the corresponding highest stages that are found to follow at the lower gauge. From these means a table can be derived, giving the corresponding stages at the two places, proceeding by differences of one foot from the highest to the lowest for the upper gauge. These corresponding stages will differ in time one day, or several days, as the case may be, depending on the distance of the gauges apart.

The method of finding the relation between crests on rivers with tributaries coming in between gauges varies with the nature of the tributaries and on the records available for deriving a rule. Various suppositions are made as to the relation of the rises, until something is found that satisfies tolerably well all the observed high waters. An examination of the rainfall records is made, and the rises excluded, which are found to be dependent mainly on rainfall above the upper station or in the drainage area between the two gauge stations. When the record of gauge readings for a place extends over a number of years, and the rises are numerous, some idea can be formed of the accuracy of a predicted stage. The method of comparative crests used for rivers without great tributaries is also available for rivers with them to a limited extent when no better method is available, the number of rises to work with being small.

Where a gauge record is kept usually at least one reading is taken daily at the same hour every day.

Gauge Readings at a Single Place. — Gauge readings at a single point on a river, when made daily or hourly during a rise, are of value in many cases in forming an idea of what a stage will be in the near future. Usually something is known as to the average duration of rises at a place. At Cincinnati, for instance, important rises continue at least six days. The variation of rise where the gauge is of such a character that the stages can be accurately observed, is of great service in estimating a coming stage of water a short time ahead. By means of observations at intervals of two or three hours it can be ascertained whether the rate at which the water surface is rising is increasing or diminishing. When the rate of rise is diminishing, the high-water crest cannot be far distant. If, for instance, the gauge readings at a place at intervals of four hours show rises of four feet, three feet, and two feet: then it may be inferred that the rise in the next four hours will not be more than one foot, when the crest will be reached and the stage will begin to diminish.

Gauge readings at a single place can only be used to advantage in predicting stages when the area of drainage basin above the place is very considerable, at least 30,000 square miles. Even with such a large area there is often much irregularity in the rises, so that any rules that may be derived, based on observed rates of rise alone, are of limited value.

The average daily rises at Cincinnati are as follows, for six days preceding the high-water crests as derived from 59 cases since the year 1858, where the rise was at least 15 feet, and the highest water as great as 40 feet: —

Days before crest,	6 to 5	5 to 4	4 to 3	3 to 2	2 to 1	1 to crest
Rise in feet,	2.2	3.2	3.8	4.0	2.8	1.3

For St. Louis the rises for like intervals before a crest are as follows: —

Rise in feet,	0.3	0.4	0.6	0.9	1.0	0.5

The rate of rise increases, on the average, from the sixth to the third day before a crest, and diminishes from the third day to the day of the crest. At St. Louis the greatest rate of rise is only one-fourth as great as at Cincinnati. The rate of rise is more apt to be irregular in the case of great rises than small ones.

Floods at Paris, France. — The rises in the Seine River at Paris are predicted three days in advance, from gauge readings made at seven places on streams in the upper part of the drainage area of the Seine: at Clancy on the Yonne, at Avallon on the Courson, at Aisy on the Armancon, at Chaumont on the Marne, at Vraincourt on the Aire, and at Sainte Menehould on the Aisne. The last two places are not in the part of the Seine basin above Paris, but are so close to the Marne, and the rain conditions over the drainage areas are so similar, that the rises are indicative of rises in the upper Seine. These stations are representative of the impermeable area of the Seine basin which is the most important part of the drainage area in flood production. The stations probably also represent country of high average slope. Either cause, impermeability or great slope, will explain Belgrand's observations on the wetted perimeters of the stone-arch bridges of the Seine valley.

When the torrents at these seven places show a rise, and at the same time the river at Paris is in a rising stage, the average of the seven rises divided by the number 1.99 gives the rise that may be expected in the next three days at Paris. The error in the stage computed in this way is never greater than two feet. When the river at Paris is in a falling stage, the mean rise in the torrents divided by 1.46 gives the three-day rise at Paris. The maximum error of a computed stage in this latter case is somewhat greater than in the first.

The average duration of a rise at Paris is 3.4 times that of a rise at the upper points. The number of days a flood continues is usually three or four. In five cases out of eighty-one, floods have lasted five days. The duration of a rise at Paris depends on the number of affluents in flood. When the rise lasts six to eight days it is the result of floods in two affluents; when it lasts nine to twelve days there are floods in three affluents; for thirteen to fifteen days there are floods in four affluents. The number of affluents participating in a flood in different cases varies from one to four.

There is a record of high waters that have occurred at Paris since the year 1615. On July 11th of that year the water reached a height of 29.3 feet above low water, a stage that has never since been equalled.

The gardens of the Tuileries were flooded. In January, 1658, a stage within half a foot of the highest was reached. Stages of water as high as 23 feet occur, on the average, about once in 25 years.

The combinations of flood waves from the tributaries of the Seine that produce the greatest floods at Paris are due to a peculiar distribution of rainfall over the various drainage areas that may be considered as purely accidental. Great floods may occur at intervals of a few years and not in a thousand years.

This method of predicting high stages of water at Paris was devised by Belgrand, and has been in use since 1854.

Regular predictions of water stages are now made in France for many places along the Saone, the Loire, and the Garonne rivers. For some points where there are no tributaries coming in between gauges, the predicted stages are never in error more than four inches. The rules for making predictions are in some cases based on observed rises, and in others on comparison of corresponding stages at two or more places.

Attempts that have been made in France to use discharge measurements in predicting river stages have not as yet proved successful. By discharge measurements is meant the rate of flow in cubic feet per second, as dependent on the varying stage of a river. The best method of predicting stages has been found to be by comparison of dependent rises at different places.

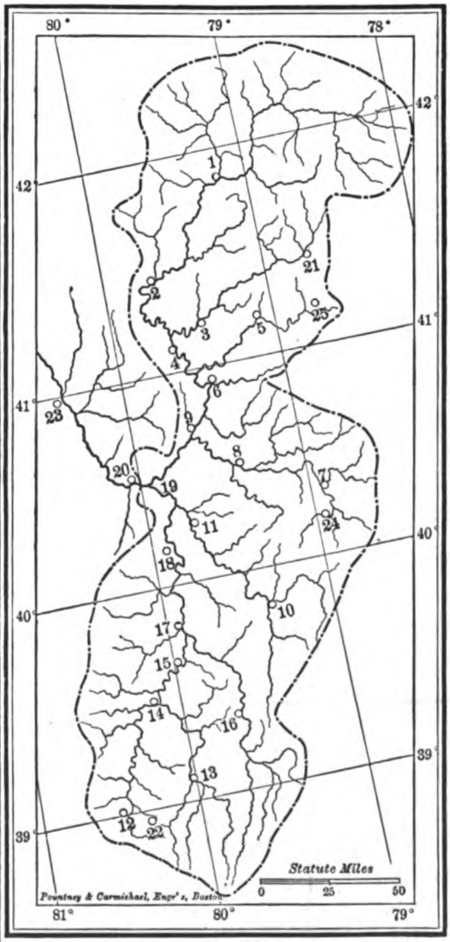
Very little has been done as yet in any country, except France, in the way of developing methods of predicting river rises.

River-Stage Predictions at Pittsburg. — For the drainage area above Pittsburg, the observations of rainfall cannot be used to any great advantage to foretell with any accuracy to what stage the river will rise. The rainfalls over the drainage area, which is 17,000 square miles, are not uniform in depth, nor do they occur simultaneously over the various parts of the area. Inasmuch as the variations in depth of rainfall over the different parts are so great, and the time of travel of the water to Pittsburg so short, a discussion of the relation of rainfall to river stage would only be of small value. This is especially so, since the observations of rainfall preceding the occurrence of great rises are not very plentiful, and the volume of river discharge for different stages of the river is not known.

The most that can be inferred from rainfall observations is about as follows: When the rainfall on three successive days for the average of 20 stations in the drainage basin, as shown on map accompanying, is 1.0 inch, the stage reached will be 22 feet; for a three-day rainfall of 2.5 inches on the average at 20 stations, the stage attained will be 31 feet.

The most satisfactory method of estimating a high stage at Pittsburg is by means of the rises at stations on the rivers above it. For this purpose the rises at Oil City, Brookville, Confluence, Rowlesburg, Wes-

RIVER GAUGE AND RAINFALL STATIONS ABOVE PITTSBURG, PA.



Number.	Stations.	
1	Warren,	Pa.
2	Oil City,	"
3	Clarion,	"
4	Parker's Landing,	"
5	Brookville,	"
6	Mahoning,	"
7	Johnstown,	"
8	Saltsburg,	"
9	Freeport,	"
10	Confluence,	"
11	West Newton,	"
12	Weston,	W. Va.
13	Philippi,	"
14	Fairmont,	"
15	Morgantown,	"
16	Rowlesburg,	"
17	Greensboro,	Pa.
18	Lock No. 4,	"
19	Pittsburg,	"
20	Davis Island Dam,	"
21	Ridgway,	"
22	Buchannon,	W. Va.
23	New Castle,	Pa.
24	Scoyestown,	"
25	Du Bois,	"

ton, and Johnstown, are used because of the greater lengths of record available at those places for deriving the relation of stages. The drainage areas above these places are respectively 4526, 400, 782, 886, 140, and 711 square miles. Rises at these places have different power to produce rises at Pittsburg. The power to produce a rise at Pittsburg will be assumed to be in proportion to the square root of the areas above them. Taking the unit of area as 1000 square miles, the relative weights of the rises at the different places in producing a rise at Pittsburg will be for Oil City, 2.1; Brookville, 0.6; Confluence, 0.9; Rowlesburg, 0.9; Weston, 0.1; Johnstown, 0.8.

Rises at any one or all of these places have different power to produce rises at Pittsburg depending on the stage at Pittsburg; the higher the stage at Pittsburg the less will be the rise, the rises at upper stations being the same in both cases. It is assumed that the rise multiplied by the mean stage during the rise is comparable throughout different stages for Pittsburg.

In accordance with these assumptions, the table below is derived, in which is given the stage that will be reached at Pittsburg when the rises at places above it are known. The horizontal argument 6, 8, 10, 12, etc., is the stage at Pittsburg at the beginning of a rise; the vertical argument 15, 20, 25, etc., is the sum of the weighted rises at six stations, that is, the rise at Oil City multiplied by 2.1, Brookville by 0.6, Confluence by 0.9, Rowlesburg by 0.9, Weston by 0.1, and Johnstown by 0.8, and all the products added together. The figures in the body of table are the highest stages to be expected at Pittsburg.

Crest Stages at Pittsburg.

Weighted Sum of Rises at Six Stations.	Pittsburg Stage at Beginning of Rise.								
	6	8	10	12	14	16	18	20	22
15	18	19	20	21	22	23	25	27	28
20	21	22	22	23	24	26	27	29	30
25	23	24	24	25	26	28	29	30	31
30	25	26	26	27	28	29	30	32	33
35	27	28	28	29	30	31	32		
40	29	30	30	31	31				
45	30	31	32						

No predictions should ever be made of a stage higher than 33 feet.

Examples of the use of the table, February 6, 1893: The stage at Pittsburg was 10.0 and rising. The stages, February 6 and 7, were, at Oil City, 6.8, 11.0; Brookville, 3.3, 7.1; Confluence, 4.8, 10.0; Rowlesburg, 4.5, 9.6; Weston, 5.5, 6.0; and at Johnstown, 1.5, 2.5. The weighted sum of rises is: —

$$\begin{aligned}&4.2 \times 2.1\\&3.8 \times 0.6\\&5.2 \times 0.9\\&5.1 \times 0.9\\&0.5 \times 0.1\\&1.0 \times 0.8 = 21.2\end{aligned}$$

At the intersection of 10 in the horizontal heading, and at one-fourth of the way from 20 to 25 in the vertical column, the stage of 22+0.5 is found, or 23 may be taken as the highest stage to be expected. The stage reached was 23.1.

At Pittsburg, February 16, 1891, the stage was 9.3 feet. February 16 and 17 the stages were, at Oil City, 3.5, 16.2; at Brookville, 2.5, 10.0; at Confluence, 6.9, 12.3; at Rowlesburg, 5.0, 5.7; at Weston, 3.5, 3.0; and at Johnstown, 7.3, 17.1.

The weighted sum of rises is 44.5. At the intersection of the vertical column 45, and the horizontal heading 9, half-way between 8 and 10, the tabular number 31+0.5 is found, or the highest stage to be expected may be considered as 32 feet. The stage was 31.3 feet.

The agreement in all cases will not be as good as in the examples given. The stages estimated in this way may at times be in error by as much as 4 or 5 feet.

Ohio River, Wheeling, W.Va. — A high-water crest at Pittsburg is followed one day later by a crest at Wheeling. The flood line is at 36 feet. The highest water, that of February 7, 1884, was 52 feet.

Ohio River, Parkersburg, W.Va., and Marietta, Ohio. — A high-water crest at Pittsburg is followed two days later by a crest at Parkersburg, 243.5 miles below. The stages at Marietta, 12.5 miles above Parkersburg, and at Parkersburg are nearly identical.

The flood line at Marietta is at 25 feet. The highest water, that of February 9, 1884, was 55 feet.

Pittsburg.	High-Water Crests.	
	Wheeling.	Parkersburg.
10		16.7
15	21.3	21.6 ± 1.5
20	28.4 ± 1.4	28.7 ± 3.0
25	25.6 ± 1.4	37.5 ± 2.2
30	44.5	45.7
32	49.0	48.7

Ohio River, Cincinnati, Ohio. — For predicting rises of the river at Cincinnati there are available the stages of water at Parkersburg, 286 miles above; at Charleston, W.Va., on the Great Kanawha River, 235 miles above; and at Louisa, Ky., on the Big Sandy River, 178 miles above. The stage of water at Circleville, Ohio, on the Scioto River is also observed, but it bears no important part in the high waters that occur at Cincinnati. The relation of the gauges is shown on the map.

There is a record of the daily river stages at Cincinnati, beginning in 1858; at Marietta, beginning 1873; at Charleston, beginning 1873; and at Louisa, beginning 1883.

The drainage area of the Ohio River above Cincinnati is 78,000 square miles. Of this there is above Parkersburg 36,000 square miles; above Charleston, 12,000; and above Louisa, 4000. The drainage areas in the mountainous region of Pennsylvania, West Virginia, and Kentucky are the important ones in the production of flood stages at Cincinnati. Over these areas there is great average slope of the ground, and it is mainly impermeable on Belgrand's classification.

The dominating cause of a rise at Cincinnati is a preceding rise at Parkersburg. In 103 cases since 1873 the wave crest at Cincinnati occurred with respect to the crest at Parkersburg as follows: In 1 case 6 days after, in 6 cases 4 days, in 39 cases 3 days, in 25 cases 2 days, in 18 cases 1 day, and in 10 cases on the same day. The wave crest occurred earlier than at Parkersburg, in 2 cases 1 day, in 1 case 2 days, and in 1 case 3 days. The difference in wave time between the two places on different occasions is due to the compounding of wave crests from the tributaries in different ways.

The best that can be done will be, to use the rises and stages after a crest has occurred at Parkersburg in predicting the rise and the stage three days later at Cincinnati.

Nothing is known about the cross-sections of the rivers at the various places, or about the velocity or discharge at different stages. The

same stage on different rivers corresponds to very different quantities of water passing. For like stages at two places, the quantity of water passing a place probably has some relation to the area which the water drains.

A rise of ten feet at Parkersburg when the stage is high will cause a greater rise at Cincinnati than ten feet when the stage is low, the stage at Cincinnati being the same in both cases. A rise at Parkersburg will have a greater effect in producing a rise at Cincinnati, the less the Cincinnati stage, and a less effect the greater the stage at Cincinnati.

For the purpose of deriving the relation between the rises at the upper gauges and at Cincinnati, the following proceeding was adopted: The rise at Cincinnati in the three days preceding a crest multiplied by the stage three days before the crest, and also by an unknown factor, is placed equal to the sum of the products of the rises at Parkersburg, Charleston, and Louisa from the sixth to the third day before the Cincinnati crest, multiplied by the mean stages at the places during the time. Separating these products, as derived from the various high waters, into groups arranged according to the magnitude of the stage of water at Cincinnati, the unknown factor is derived for a number of stages. The factor is considered as applying to the mean of all the Cincinnati stages from which it is derived. The factors found for the various stages are subjected to an adjustment for the purpose of smoothing out irregularities.

The rule thus derived for finding the highest stage of water for a flood wave at Cincinnati, or a three-day rise near the time of a flood wave, is as follows: When the river is in a rising stage at Cincinnati, and has been rising for at least three days, and a crest has occurred at Parkersburg, then the rise at Cincinnati in the next three days will be equal to the previous three-day rise at Parkersburg multiplied by the mean stage at Parkersburg on the day and the third day preceding, plus the rise at Charleston in the preceding three days multiplied by the mean stage, plus the three-day rise at Louisa multiplied by the mean stage, the sum divided by the stage at Cincinnati and multiplied by the factor given below, depending on the Cincinnati stage.

Cincinnati.		Cincinnati.	
River Stage.	Factor.	River Stage.	Factor.
Feet.		Feet.	
		40	0.43
26	0.97	41	0.42
27	0.87	42	0.41
28	0.83	43	0.39
29	0.79	44	0.38
30	0.75	45	0.37
31	0.71	46	0.36
32	0.67	47	0.35
33	0.63	48	0.34
34	0.59	49	0.34
35	0.55	50	0.34
36	0.51	51	0.34
37	0.48	52	0.34
38	0.46		
39	0.44		

In case there is a fall at any of the three places, it enters the sum with a minus sign.

The rule can still be used for deriving the approximate rise at Cincinnati, even when the crest at Parkersburg is three days past, provided the stage at the other places is very high, as much as 46 feet and rising. The following shows some of the important rises at Cincinnati computed according to this rule: —

Date.	Cincinnati River Stage.	Rise in Three Days.	Computed Rise.	Error.
	Feet.	Feet.	Feet.	
February 11, 1884 . . .	66.8	4.3	3.0	− 1.3
March 14, 1884	48.3	1.3	0.7	− 0.6
January 17, 1885	41.1	4.9	6.7	+ 1.8
April 6, 1886	54.2	1.6	3.3	+ 1.7
January 18, 1890	40.3	3.5	3.5	0.0
February 26, 1890 . . .	49.4	7.4	7.7	+ 0.3
March 23, 1890	52.0	7.1	7.4	+ 0.3

It is not to be expected that the stage of water given by this method will always be exactly correct. The area from which water drains passing Cincinnati, but which does not pass Parkersburg, Charleston, or Louisa, is 26,000 square miles. In case most of a rainfall is above these places, the computed stage will be too high; in case most of it is below the places the computed stage will be too low. As a general thing, rainfall is distributed nearly uniformly, and the method represents the average of rises somewhat nearly. There is also some uncertainty in a predicted stage from the rainfall that may occur, in the three days after the prediction, in the immediate vicinity of Cincinnati.

The flood line at Cincinnati is at 45 feet. The highest water, that of February 14, 1884, was 71.1 feet. This high stage was due to heavy rainfall over frozen, ice-glazed ground, most of the water passing immediately to the streams.

The following is the method of using the rule to compute a river stage. March 23, 1890, the river at Cincinnati was at a stage of 52.0 feet, and had been rising for more than three days. At Parkersburg, where the river was at a crest on March 23d, there was a rise in three days from the stage of 19.0 to 31.0 feet. At Charleston there had been a rise from 16.3 to 30.9 feet. At Louisa there had been a rise from 24.7 to 40.0 feet. Hence the rise to be expected at Cincinnati according to the rule is:—

$$0.34 \frac{[25 \times 12.0 + 24 \times 14.6 + 32 \times 15.3]}{52} = 7.4.$$

The number 0.34 is taken from the table of factors corresponding to 52 feet. The observed rise was 7.1 feet.

Ohio River, Louisville, Ky.; Evansville, Ind.; Mount Vernon, Ind. — The time of a flood wave from Cincinnati to Louisville is one day; the distance is 132 miles. The Kentucky River is the only important stream entering the Ohio between Cincinnati and Louisville.

By taking the heights of crest waves at Cincinnati, and the corresponding heights at Louisville, arranging them according to the magnitude of the stage at Cincinnati, and taking the average of groups from 15 feet to 20, 20 feet to 25, etc., and then interpolating to the nearest five feet 25, 30, 35, etc., the corresponding crest stages at the two places are found to be the following. The numbers with plus or minus prefixed are the probable errors. The error of a stage will rarely be greater than three times the probable error.

The stages of water at Louisville are those given by the city gauge at the foot of Fourth Street.

The flood line is at 24 feet. The highest water, that of February 16, 1884, was 46.6 feet.

The time of a flood wave from Cincinnati to Evansville, Ind., is about four days. The distance is 316 miles.

The flood line is at 30 feet. The high water of February 19, 1884, was 48.0 feet.

The time of a flood wave from Cincinnati to Mount Vernon, Ind., distance 352 miles, is about four days.

HIGH-WATER CRESTS.

Cincinnati River Stage.	Louisville.		Evansville.		Mount Vernon.	
Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
10			5.2	± 0.8		
15	7.4	± 0.5	10.0	± 1.4		
20	8.7	± 0.3	14.4	± 1.5		
25	10.2		19.4	± 1.4	17.7	± 1.8
30	11.8	± 1.0	24.0	± 1.6	22.5	
35	13.8		28.6	± 1.7	27.7	± 2.1
40	16.9	± 1.1	32.8	± 1.7	35.6	
45	20.4		37.0	± 1.0	40.7	
50	26.0	± 1.4	41.2	± 1.2	43.3	
55	31.5		44.6	± 1.7	44.9	
60	38.2		47.0		46.4	
65	43.4		48.0			
70	46.4		48.1			

The method of using the table is as follows: For a stage of 50 feet at Cincinnati, the stage to be expected one day after at Louisville is 26.0 feet, at Evansville four days after 41.2, and at Mount Vernon 43.3. When the exact value of the Cincinnati stage is not in the first column, a proportional part of the differences of corresponding crests is to be used in finding the computed crests. The stage at Cincinnati being 53 feet, for instance, the stage at Evansville will be three-fifths of the way from 41.2 to 44.6, or 43.2 feet.

Ohio River, Cairo, Ill. — For predicting river stages at Cairo six days ahead, the stages used are observed at St. Louis on the Mississippi

River, at Cincinnati on the Ohio, at Nashville on the Cumberland, and at Chattanooga on the Tennessee. These places are shown on the map. Besides the water passing these places, large contributions of water are received by the Ohio from the Wabash, the Kentucky, and the Green rivers. Besides the water passing the places mentioned, there is water passing Cairo which drains from 108,000 square miles of additional drainage area below the places.

The distance from Cairo to St. Louis is 200 miles; to Cincinnati, 499 miles; to Nashville, 227 miles; to Chattanooga, 488 miles. A high-water crest at Cairo usually follows in from six to eight days after a crest at Cincinnati. In 76 cases the intervals between crests were as follows: 3 days in 1 case, 4 days in 4 cases, 5 days in 5 cases, 6 days in 41 cases, 7 days in 9 cases, 8 days in 5 cases, 9 days in 3 cases, 10 days in 4 cases, 11 days in 2 cases, 12 days in 1 case, and 14 days in 1 case.

The six-day rise at Cairo, multiplied by the stage at Cairo on the day of the Cincinnati crest, being placed equal to the sum of the products of the preceding six-day rise at Cincinnati, the three-day rise at Nashville, the six-day rise at Chattanooga, and the four-day rise at St. Louis, by the mean stages at the places, and each product by an unknown factor, and being grouped according to the magnitude of the Cairo stage, the following factors were derived for the various places and for Cairo as dependent on the stage: for Cincinnati, 0.69; for Nashville, 0.62; for Chattanooga, 0.42; and for St. Louis, 0.32.

Cairo River Stage.	Factor.	Cairo River Stage.	Factor.	Cairo River Stage.	Factor.
Feet.		Feet.		Feet.	
20	0.353	30	0.308	40	0.237
21	0.352	31	0.304	41	0.227
22	0.347	32	0.300	42	0.216
23	0.343	33	0.294	43	0.204
24	0.337	34	0.287	44	0.194
25	0.334	35	0.283	45	0.182
26	0.329	36	0.276	46	0.171
27	0.324	37	0.270	47	0.159
28	0.319	38	0.258	48	0.150
29	0.314	39	0.248		

The rule for deriving the Cairo rise is as follows: When the river has been rising at Cincinnati for at least six days, and has reached a crest, then the rise at Cairo in the next six days will be equal to the preceding six-day rise at Cincinnati multiplied by the mean stage of water at Cincinnati on the day of the crest, and six days before, and by the factor 0.69, plus the three-day rise at Nashville multiplied by the mean stage and the factor 0.62, plus the six-day rise at Chattanooga multiplied by the mean stage and the factor 0.42, plus the four-day rise at St. Louis multiplied by the mean stage and the factor 0.32, the whole divided by the stage at Cairo and multiplied by the factor given on page 233 for the Cairo stage.

The following is an example of the method of computation: March 1, 1890, the stage of water at Cincinnati was 56.8 feet and at a crest; on February 23 the stage was 43.0 feet. At Nashville the stage on March 1 was 47.2 feet, and on February 26, 37.3 feet. At Chattanooga the stage on March 1 was 40.2 feet, and on February 23, 7.2. At St. Louis the stage on March 1 was 8.6, and on February 25, 8.4. The stage at Cairo on March 1 was 42.1. Hence the rise to be expected at Cairo in the next six days according to the rule was:—

$$\begin{aligned} 0.204\,[(13.8 \times 50 \times 0.69) \\ + (9.9 \times 42 \times 0.62) \\ + (33.0 \times 24 \times 0.42) \\ - (0.2 \times 8 \times 0.32)] \div 42 = 5.2. \end{aligned}$$

The observed rise by March 7 was 5.1 feet. The crest, however, did not occur until March 11, when there was an additional rise of 1.6 feet.

The following are some of the important rises at Cairo computed according to the rule:—

Date.	Cairo River Stage.	Observed Rise in Six Days.	Computed Rise.	Error.
	Feet.	Feet.	Feet.	Feet.
April 17, 1881	44.8	0.3	1.1	+0.8
February 21, 1882	47.4	4.3	1.9	−2.4
February 14, 1884	48.2	3.3	1.8	−1.5
April 9, 1886	47.8	2.4	−0.4	−2.8
March 31, 1888	43.8	1.4	2.6	+1.2
January 21, 1890	43.7	−1.1	1.8	+2.9
March 1, 1890	42.1	5.1	5.6	+0.5
March 26, 1890	46.7	1.8	2.2	+0.4

Cairo Rise, Three Days Ahead.—The rises at Cairo, Ill., can also be estimated three days ahead from the rises at St. Louis, Mo., on the Mississippi; Mount Carmel, Ill., on the Wabash; Evansville, Ind., on the Ohio; Nashville, Tenn., on the Cumberland; and Johnsonville, Tenn., on the Tennessee; all about the same distance by river above Cairo, Ill. A rise at any of these places has its full effect three days after in producing a rise at Cairo in the same time. The following tables give the relations of the rises at these places to the subsequent rises at Cairo, as deduced from the cross-sections, discharges, and slopes of the river at the various places throughout all the stages, at the various places taken in connection with the rises as observed at some of the stages. Corresponding rises have not been observed at all the stages.

The Wabash River comes into the Ohio below Evansville, Ind. The effect of a rise at Mount Carmel, Ill., on the Wabash, is estimated most conveniently in terms of the rise at Evansville. In using the tables, therefore, a rise or fall at Mount Carmel should be applied to the rise or fall at Evansville during the same time, and then with the Evansville rise the effect estimated on Cairo by means of the Evansville table.

The Nashville three-day rise in the Cumberland River, divided by subsequent three-day rise at Cairo, equals the following fractions. Nashville, 215 miles above Cairo.

Cairo Stage. Ft.	5	10	15	20	25	30	35	40	45	50
Nashville Stage. Ft.										
5	.16	.16	.14	.11	.08	.07	.06	.04	.04	.04
10	.21	.18	.18	.13	.09	.07	.07	.06	.06	.04
15	.25	.23	.21	.17	.11	.08	.07	.07	.06	.06
20	.28	.25	.25	.19	.12	.11	.07	.07	.07	.06
25	.30	.28	.28	.21	.14	.13	.08	.10	.08	.07
30	.32	.30	.30	.23	.15	.13	.10	.10	.08	.08
35	.35	.32	.30	.25	.18	.14	.11	.10	.10	.08
40	.46	.41	.41	.34	.23	.18	.14	.14	.13	.13
45	.48	.46	.41	.34	.24	.21	.15	.15	.13	.13

The Evansville, Ind., three-day rise in the Ohio River, divided by subsequent three-day rise at Cairo, equals the following fractions. Evansville, 183 miles above Cairo.

CAIRO STAGE.	5	10	15	20	25	30	35	40	45	50
EVANSVILLE STAGE.										
5	.23	.21	.18	.17	.14	.12	.09	.07	.06	.05
10	.33	.29	.26	.24	.20	.17	.14	.10	.09	.07
15	.41	.36	.34	.31	.26	.25	.20	.15	.13	.10
20	.51	.45	.44	.38	.33	.28	.25	.21	.16	.14
25	.64	.57	.56	.50	.41	.36	.28	.24	.19	.18
30	.65	.64	.57	.56	.48	.37	.36	.28	.24	.21
35	.74	.65	.64	.63	.50	.43	.37	.33	.28	.22
40	.75	.74	.65	.64	.56	.49	.43	.37	.30	.26
45	.98	.86	.84	.83	.74	.63	.54	.48	.40	.35

The St. Louis, Mo., three-day rise in the Mississippi River, divided by the subsequent three-day rise at Cairo, equals the following fractions. St. Louis, 168 miles above Cairo.

CAIRO STAGE.	5	10	15	20	25	30	35	40	45	50
ST. LOUIS STAGE.										
5		.78	.71	.57	.36	.31	.25	.20	.15	.13
10		.87	.87	.65	.44	.36	.29	.22	.19	.15
15			1.00	.80	.66	.53	.45	.36	.28	.22
20				1.03	.87	.71	.60	.49	.36	.30
25						.73	.66	.58	.41	.34
30						.78	.75	.68	.52	.44
35								.77	.54	.46
40								.78	.60	.51

The Johnsonville, Tenn., three-day rise in the Tennessee River, divided by the subsequent three-day rise at Cairo, equals the following fractions. Johnsonville, 140 miles above Cairo.

CAIRO STAGE.	5	10	15	20	25	30	35	40	45	50
JOHNSONVILLE STAGE.										
5	.39	.35	.30	.24	.15	.11	.08	.07	.04	.04
10	.46	.44	.39	.30	.20	.15	.11	.08	.07	.06
15		.48	.44	.34	.23	.17	.13	.11	.10	.07
20			.53	.38	.26	.21	.17	.13	.11	.10
25				.44	.30	.22	.18	.15	.13	.11
30					.35	.27	.24	.18	.17	.14
35						.31	.24	.21	.20	.15
40							.28	.25	.21	.18
45								.27	.24	.21

The Mount Carmel, Ill., rise in the Wabash River, divided by the corresponding rise in the Ohio, as measured by gauge at Evansville, Ind. equals the following fractions. Mount Carmel, 178 miles above Cairo.

EVANSVILLE STAGE.	5	10	15	20	25	30	35	40	45
MOUNT CARMEL STAGE.									
5	.61	.52	.51	.48	.46	.44	.44	.44	.37
10	.72	.62	.59	.57	.54	.52	.52	.52	.43
15	.78	.67	.64	.61	.58	.56	.56	.56	.47
20	1.05	.91	.86	.83	.79	.76	.76	.76	.63
25	1.44	1.24	1.18	1.12	1.08	1.04	1.04	1.04	.87
30	1.56	1.33	1.28	1.22	1.17	1.12	1.12	1.12	.93

The rise at Cairo in three days is the sum of the rises at the various places in the preceding three days after being multiplied by the fractions given in the tables. This always gives a very close approximation to the Cairo stage three days ahead. In deriving the rule, some distinction should have been made between the rises occurring suddenly and those that occur more slowly. A rise that takes place, for instance, in one day, and persists at the high stage for the next two days, has a greater effect in producing a rise at points below it than the same rise extending over three days. For the important factors, however, in producing a rise at Cairo, St. Louis, and Evansville, the volumes of water for high stages are great, and the rises are slow and gradual.

The drainage area above St. Louis is 699,000 square miles; above Mount Carmel, 26,300; above Evansville, 99,700; above Nashville, 11,600; and above Johnsonville, 36,700. The water from additional drainage area passing Cairo, but not passing those places, is 37,600 square miles.

Cumberland River, Carthage, Tenn.; Nashville, Tenn.; and Eddyville, Ky. — The time from a high-water crest at Burnside, Ky., on the Cumberland River, to Carthage, Tenn., 177 miles, is two days; to Nashville, 259 miles, three days; to Eddyville, 394 miles, five days. The comparative crests at these places are as follows: —

HIGH-WATER CRESTS, CUMBERLAND RIVER.

BURNSIDE.	CARTHAGE.	NASHVILLE.	CARTHAGE.	NASHVILLE.	NASHVILLE.	EDDYVILLE.
Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
10	9.9 ± 2.2	11.3 ± 1.7	10	13.1 ± 1.1	10	10.0 ± 1.8
15	14.0 ± 2.4	16.5 ± 2.3	15	17.9 ± 1.4	15	16.7
20	17.6 ± 1.6	20.5 ± 1.4	20	21.0 ± 2.3	20	23.0
25	21.6 ± 2.2	24.8	25	27.3 ± 1.8	25	29.4 ± 1.8
30	25.8	31.4 ± 0.5	30	33.4 ± 2.8	30	36.7
35	28.3 ± 2.2	36.6	35	36.9 ± 1.8	35	44.2
40	31.5 ± 2.3	39.9	40	41.0 ± 0.8	40	49.8
45	35.0 ± 0.2	42.6	45		45	53.0
50	39.1 ± 0.5	44.6	50		50	55.5
55	44.0	46.5				60.3
60	48.4	48.6				
62	50.0	49.4				
74	64	55.2				

The flood line at Burnside is at 30 feet. The stage has been as high as 74 feet.

The flood line at Carthage is at 30 feet. The water sometimes rises as high as 64 feet.

The flood line at Nashville is at 40 feet. The highest recorded stage of water is 55.2 feet.

The flood line at Eddyville is at 31 feet. The highest water, 60.3 feet, occurred in 1882.

Tennessee River, Chattanooga, Tenn.; Decatur, Ala.; Florence, Ala.; and Johnsonville, Tenn. — The stages of water at Chattanooga are the result of the stages two days preceding at Knoxville on the Tennessee, 158 miles above, and at Clinton on the Clinch River, 148 miles above. Some water is also added to the Tennessee by the Hiawassee, which enters the river 35 miles above Chattanooga.

When the river is rising at Chattanooga the approximate rise two days after a crest at Clinton or Knoxville is obtained as follows: Multiply the two-day rise at each of the places by the mean stage and the sum of the products by the factor given below, and divide by the stage at Chattanooga.

Chattanooga River Stage.	Factor.	Chattanooga River Stage.	Factor.
Feet.		Feet.	
10	0.90	35	0.28
15	0.82	40	0.24
20	0.67	45	0.21
25	0.45	50	0.18
30	0.35		

Example. — At Clinton, February 26 to 28, 1890, the river rose from a stage of 23.8 to 35.5 feet, and at Knoxville from 12.9 to 23.0. The stage at Chattanooga on February 28 was 34.8. Hence the rise at Chattanooga by March 2d, according to the rule, was: —

$$\frac{0.28(11.7 \times 30 + 10.1 \times 18)}{35} = 4.3.$$

The rise observed was 7.7 feet.

The wave-crest time from Chattanooga, Tenn., to Decatur, Ala., 160 miles, is two days; to Florence, Ala., 208 miles, three days; to Johnsonville, Tenn., 360 miles, five days. A large volume of water is added to the Tennessee by the Duck River at a short distance above Johnsonville, which renders computed crests for that place less accurate than for points farther up the river. The record at Columbia, on the Duck River, has not yet been kept long enough to make the stages of use for lower points.

In the following table are given the comparative crest for the various places on the Tennessee River: —

HIGH-WATER CRESTS, TENNESSEE RIVER.

CLINTON.	CHATTANOOGA.	CHATTANOOGA.	DECATUR.	FLORENCE.	JOHNSONVILLE.
10	12.0	10			
15	17.0	15	12.2 ± 0.7	11.1 ± 0.8	
20	21.6	20	14.4 ± 0.9	13.8 ± 1.3	
25	27.3	25	16.5	16.6	
30	34.0	30	18.5 ± 0.8	19.6 ± 2.3	
35	41.5	35	20.4	22.4	33.6
40	47.3	40	22.7	26.4	37.1
45	52.2	45	24.6	27.6	39.9
		50	26.0	27.8	41.4
		52	26.7	28.0	41.8

The flood line at Clinton is at 25 feet.

The flood line at Chattanooga is at 33 feet. The highest water, 58.0 feet, occurred March 11, 1867.

The flood line at Decatur is at 21 feet.

The flood line at Johnsonville is at 21 feet.

Missouri River and Upper Mississippi River. — High-water crests in the Missouri River pass Omaha, Neb., one day and a half later than at Sioux City, 135 miles above.

The flood line at Omaha is at 18 feet.

High-water crests pass Kansas City two and a half days after Omaha, 282 miles above.

The flood line at Kansas City is at 21 feet. The high water of 1844 was 37 feet.

The flood-wave time from Kansas City to Jefferson City, Mo., 240 miles below, is three days.

The flood line at Jefferson City is at 20 feet. The high water of 1844 was 28.5 feet.

High-water crests in the upper Mississippi River pass from Dubuque, Ia., to Davenport, Ia., a distance of 99 miles, in one day.

The flood line at Davenport is at 15 feet. The high water of 1868 was 20.9 feet.

The comparative crests at these places are shown in the following table: —

HIGH-WATER CRESTS, MISSOURI RIVER AND UPPER MISSISSIPPI.

DUBUQUE.	DAVENPORT.	SIOUX CITY.	OMAHA.	OMAHA.	KANSAS CITY.	KANSAS CITY.	JEFFERSON CITY.
Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
5	4.2 ± 0.8						
6	4.7						
7	5.3						
8	5.8 ± 0.7	8	9.0				
9	6.7	9	9.8				
10	7.6 ± 0.6	10	10.8 ± 0.8	10	14.8 ± 1.4		
11	8.6	11	11.8	11	15.3		
12	9.7	12	12.8	12	15.8		
13	10.5	13	13.8	13	16.6	13	10.3
14	11.3	14	14.6	14	17.3	14	11.0
15	12.0 ± 0.3	15	15.4 ± 0.6	15	18.1 ± 1.2	15	11.7 ± 1.3
16	12.7	16	16.0	16	18.7	16	12.3 ± 0.6
17	13.6	17	17.5	17	19.4	17	13.2
18	14.5	18	19.0	18	20.4	18	13.9
19	15.5	19	20.5	19	21.4	19	14.7
20	16.4	20	22.0	20	22.4	20	15.5
21	17.3	21	23.2	21	23.3	21	16.3
		22	23.8	22	24.3	22	17.0
				23	25.3	23	17.6
				24	26.3	24	18.0
						25	18.4
						26	18.7

Missouri River Flood.—The great flood along the lower Missouri River in 1881 was preceded by a very severe winter. The ice at the mouth of the river was 2 to 3 feet thick, and at Sioux City and Vermillion, 4 to 5 feet. Warm weather set in on the eastern slopes of the Rocky Mountains in February, while it was still cold in the East. The ice was tumbled east by the floods, and the rivers gorged and the barriers across the valleys flooded the country back of them. The lower rivers were at a low stage when the great flood came after April 17, entirely from above Sioux City, Ia., and was all snow water. The valley between the bluffs, averaging 5 miles in width for 376 miles from Sioux City, Ia., to Glascow, Mo., was submerged. Much of the water did not pass the gauge at Omaha, but passed around it through sloughs and low places. The river left its bed and went down the centre of the valley, leaving deposits 6 to 12 feet in depth in various places. After the river got out of its banks from Omaha to Kansas City, the velocity slackened and the rate of rise increased. In a few hours it slackened so skiffs could go about with ease, although before it left its banks, and after its return, the current was so swift that steamboats could not stem it.

Contrary to what usually happens, the crest of the flood wave was greatly retarded. The front lengthened out, while the rear shortened up. At the same time the total length, from hollow to hollow, remained nearly constant, but the crest was shifted from front to rear in its progress down the valley.

Ordinarily, gauge readings will show with unobstructed condition of flow as the surface rises the sectional area, velocity and discharge increase at a rate proportional to the increase of gauge reading. As the water surface rises the velocity increases, and the mass of water moving forward more rapidly tends to overtake and run upon that which precedes it, so that the crest advances more rapidly than the front of the wave, and the front slope steepens. The reverse occurs on the rear slope. Crests usually take 6½ days from Sioux City to St. Charles at the mouth. That of 1881 took 12 days, and was 7 feet higher than any previous one at Sioux City.

The heights reached by the flood of 1881 were abnormal for the quantity of water passing solely, because the river was out of its banks and the progress of the water was so retarded by frictional resistance being transferred from its normal section to one of small depth and miles in width. The slope by this was doubled, but not enough to offset increased resistance, and water in rear piled up on that in front, causing an abnormal rise at St. Charles, of 5 to 8 feet.

Mississippi River at St. Louis, Mo. — A rise of the Mississippi at St. Louis, Mo., amounting to several feet, can be estimated with some accuracy four days ahead of its occurrence. The basis of the estimates are the river-gauge readings at St. Louis, and the readings of the gauges at places above it on the Missouri and Mississippi rivers, and the observations of rainfall in the drainage area of 130,000 square miles immediately above St. Louis. The back records of stages during great rises, and the observations of rainfall, furnish the means of deriving a rule for estimating the stages. The record of stages at St. Louis begins in 1861.

The situation of the various river gauges above St. Louis are shown on the accompanying map.

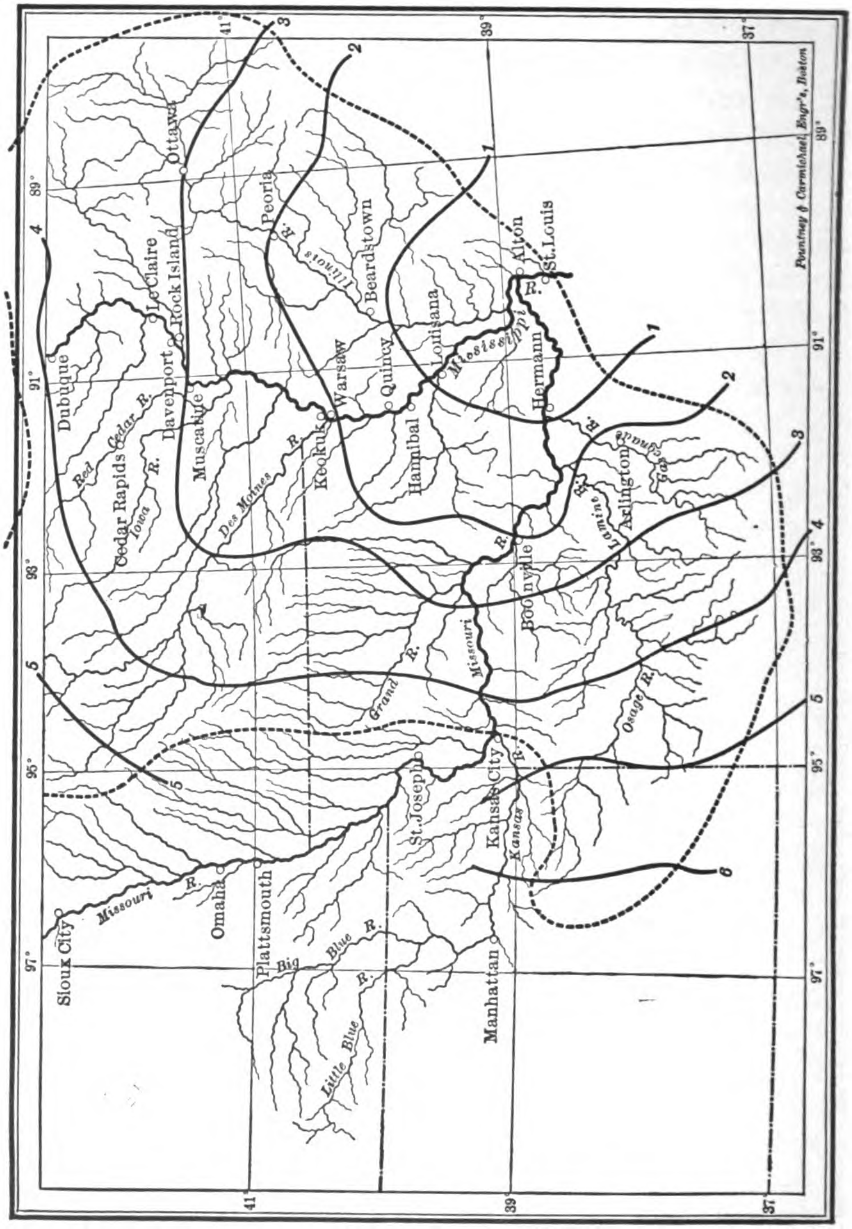
The principal rise of the river, which occurs in May or June, and is popularly known as the June rise, is due to rainfall in the lower part of the drainage area mainly, and not to a rise from the upper Missouri River and the melting snow in the mountains, as commonly supposed.

The highest water of which the record is certain was 41.4 feet on June 27, 1844. There is said to have been a stage of 42.0 feet in April, 1785. There was a stage of 33.6 feet in March, 1828; 32.4 feet, June 27, 1845; 30.0 feet, May 7, 1853; 37.0 feet, June 14, 1858; 31.4 feet, April 26, 1862; 32 feet, May 10, 1876; 33.6 feet, May 5, 1881; 32.2 feet, July 5, 1882; 34.8 feet, June 26, 1883; 36 feet, May 19, 1892; and 31.5 feet, May 3, 1893.

The average of the annual highest water is 26.3 feet, the lowest being 18.0 feet in 1863. The height of 30 feet has been exceeded seven years of the thirty-three years during which time there are records.

The average date of highest water of the year is May 27; the earliest, March 4; the latest, July 28.

The greatest number of days above the danger line in a year, the


Sioux City
Omaha
Plattsmouth
St. Joseph
Kansas City
Manhattan
Dubuque
Cedar Rapids
Davenport
Muscatine
Le Claire
Rock Island
Ottawa
Peoria
Beardstown
Keokuk
Warsaw
Quincy
Hannibal
Louisiana
Alton
St. Louis
Hermann
Boonville
Arlington
Missouri R.
Mississippi R.
Illinois R.
Des Moines R.
Iowa R.
Red Cedar R.
Grand R.
Kansas R.
Osage R.
Big Blue R.
Little Blue R.
Gasconade
Lamine R.
Pountney & Carmichael, Engr's, Boston

stage of 30 feet, were 36 days in 1892, 17 in 1883, 12 in 1881, 7 in 1876, and 9 in 1862.

The average lowest water of the year is 3.0 feet, and the average time of its occurrence, December 27. The greatest number of days below a stage of 3 feet was 33 in 1864. The extreme lowest water, 0.0 feet at the zero of the gauge, occurred December 21, 1863.

The annual stage at St. Louis from 32 years' observations is 12.97 feet. The ten-year means show a slight progressive increase, being 12.30 feet for 1860–1870, 12.61 for 1870–1880, and 14.0 for 1880–1890.

Although the water that flows by Kansas City and Dubuque comprises the drainage from 568,900 square miles of the total drainage area above St. Louis, yet the rises of the rivers at those places have a relatively small effect in producing rises subsequently at St. Louis and the river stages at the places are not closely dependent. This is due to the great rainfall in the drainage area of 130,000 square miles immediately above St. Louis being so much greater than in the part of the drainage basin higher up.

The drainage area above Kansas City, Mo., is 491,800 square miles; the distance to St. Louis is 401 miles; the zero of the gauge is 337.2 feet higher than the zero of the gauge at St. Louis. The drainage area above Dubuque, Ia., is 77,100 square miles; the distance to St. Louis is 437 miles; the zero of the gauge is 104.3 feet above the zero of the gauge at St. Louis.

The time of water travel from Kansas City and Dubuque to St. Louis is four to five days.

The rises to high water at Kansas City and Dubuque are very slow and regular.

At Kansas City, in the cases of crests to 16 feet, the average daily rises are: —

Days . . .	6 to 5	5 to 4	4 to 3	3 to 2	2 to 1	1 to crest
Feet . . .	0.0	0.6	1.0	1.1	0.8	0.7

and for crest above 16 and to 26 feet, they are: —

Days . . .	6 to 5	5 to 4	4 to 3	3 to 2	2 to 1	1 to crest
Feet . . .	0.3	0.4	0.4	0.9	0.8	0.5

At Dubuque, in cases of crests to 20 feet, the average daily rises are:—

Days . . .	6 to 5	5 to 4	4 to 3	3 to 2	2 to 1	1 to crest
Feet . . .	0.6	0.5	0.5	0.4	0.5	0.5

The highest water at Kansas City, 37 feet, occurred June 20, 1844. The next highest was 26.3 feet, April 30, 1881. The greatest rise in a day is rarely as much as 4 feet.

The highest water at Dubuque was 22.7 feet, June 24, 1880. The greatest rise in a day is rarely as much as 3 feet.

The rise of river at St. Louis is usually slow and regular. The average rises for six days before crests are:—

Days . . .	6 to 5	5 to 4	4 to 3	3 to 2	2 to 1	1 to crest
Feet . . .	0.3	0.4	0.6	0.9	1.0	0.5

Some of the greatest rises in a day have been,—

February 9 to 10, 1881, when there was a rise of 6.8 feet in the river at St. Louis, from the stage of 10.9 to 17.7. The day before there was a rise of 1.7, and the day after a rise of 0.3. February 6 and 7 the rainfall was 1.24 inches at Des Moines, Ia., 2.12 at Leavenworth, Kan., 2.28 at Boonville, Mo., and 1.41 at Hermann, Mo.

February 20 to 21, 1882, there was a rise of 9.3 feet at St. Louis, from the stage of 18.2 to 27.5; the day before there was a rise of 7.0 feet, and the day after a rise of 0.7 of a foot. The rainfalls, February 19 and 20, were: 0.95 of an inch at Keokuk, 5.12 at Boonville, 4.93 at Hermann, 4.00 at Jefferson City, and 6.71 at St. Louis.

February 15 to 16, 1883, there was a rise of 9.7 feet, from a stage of 10.3 to 20.0 feet; the day before there was a rise of 2.9, and the 18th an additional rise of 5.8 feet. February 16, the rainfall at Davenport was 3.90 inches; at Keokuk, 3.56; at St. Louis, 1.06; at Chicago, 1.94. The main reliance in predicting a rise at St. Louis must be the use of observed heavy rainfalls above it.

Only the great rises of river at St. Louis, due to heavy rainfalls, can be estimated with any accuracy. The method of estimating a rise is by means of the heavy rainfalls in the vicinity of St. Louis and above it, using the back records of rainfall and rises to find the relation with an allowance for the rise or fall in the four days preceding, at Kansas City and Dubuque. In this way the stage for St. Louis can be estimated four days ahead, with some accuracy in the case of the heaviest rainfalls.

In deriving a rule for predicting the stage at St. Louis, it is necessary to have some knowledge of the relative quantity of water passing St. Louis, Kansas City, and Dubuque, at different stages, from low to high water. Discharge measurements have been made under the auspices of the Engineer Corps at St. Louis, for different stages, from 0 to 36 feet, and at Kansas City from 0 to 23 feet. No measurements of discharge have been made at Dubuque, but some have been made at Clayton, Ia., 48 miles above it, for different stages, from 4 to 18 feet above low water, which presumably would not differ very much from discharges at Dubuque. Nothing is known definitely about the high-water discharge at Dubuque. It is safe to say, however, it cannot be as great as the flood discharge of Keokuk below it, which, in the flood of 1851, was 265,000 cubic feet of water per second. During this high water the Des Moines River was high, and was pouring out 65,000 cubic feet per second.

The discharge of a river is, in general, not very closely dependent on stage; that is to say, for the same stage at different times there may be different quantities of water passing in the river depending on whether it is on a rising or a falling stage, and also on the rapidity of the rise or fall, the cutting or filling of the channel, and the slope of the water surface below and above the place. It is therefore not possible to assign a definite and exact discharge for each stage. An approximate estimate, however, can be made which will be of use in calculating the relative effects of rises or falls at Kansas City and Dubuque in producing a rise at St. Louis. The estimated discharges for stages four feet apart are given in the following table:—

River Discharges in Cubic Feet per Second.

Stage Feet.	St. Louis.	Kansas City.	Dubuque.
0	48,000	20,000	20,000
4	81,000	36,000	39,000
8	127,000	62,000	80,000
12	188,000	107,000	124,000
16	274,000	183,000	168,000
20	390,000	285,000	212,000
24	526,000	400,000	
28	683,000		
32	878,000		
36	1,146,000		

The two tables following show the gauge relations between rises or falls at St. Louis, Kansas City, and Dubuque:—

Ratio of Rises at St. Louis and Kansas City.

Kansas City Stage.	St. Louis Stages.									
	0	4	8	12	16	20	24	28	32	36
0	0.5	0.5								
2	0.8	0.7	0.5							
4	0.9	0.9	0.6	0.4						
6	1.2	1.1	0.8	0.6	0.4	0.3				
8		1.5	1.0	0.7	0.5	0.4	0.3			
10			1.1	0.8	0.6	0.4	0.4	0.3	0.3	0.3
12				1.0	0.7	0.6	0.5	0.4	0.3	0.3
14				1.2	0.8	0.7	0.6	0.5	0.4	0.3
16					0.9	0.8	0.6	0.6	0.4	0.3
18					1.0	0.8	0.7	0.6	0.5	0.4
20						0.9	0.8	0.7	0.6	0.4
22						0.9	0.8	0.7	0.6	0.4
24							0.8	0.7	0.6	0.4

RATIO OF RISES AT ST. LOUIS AND DUBUQUE.

DUBUQUE.	St. Louis Stage.									
	0	4	8	12	16	20	24	28	32	36
6 to 22			0.8	0.6	0.4	0.3	0.3	0.3	0.2	0.1

The method of estimating the effect of rainfall in producing a rise at St. Louis was to select a number of cases of heavy and extensive rainfall and compare the amount with the subsequent rise.

On the map, page 244, is shown the drainage area immediately above St. Louis and below Kansas City and Dubuque, and some of the rainfall stations within the area. The heavy dotted line on the map marks the southern and eastern boundary of the drainage basin above St. Louis. The heavy continuous lines show the lines of equal time of water travel by river in days from various points in the drainage area to St. Louis, taking the rate of travel for average stages as 3.5 miles per hour, or 84 miles a day.

Of the rain that falls, a part goes directly into the rivers, and part sinks into the ground. Of this latter, a part is fed out slowly to the rivers from springs, but a greater part evaporates.

Of all the rain that falls, the part of it that runs off through the rivers is, on the average, 25 to 45 per cent for most drainage areas. It varies greatly with the slope of the ground, the hardness of the soil, and the rate of rainfall. In a heavy rain a greater proportion of the water goes into the rivers than in a light one. The run-off for the whole Missouri valley is not, on the average, more than one-eighth of the rainfall. For the lower part of the drainage area, where the rains are much heavier than in the upper part, the run-off must be much larger.

In estimating rises at St. Louis, only the rainfalls greater than 1.0 inch have been considered. In most cases the great rises are associated with rains of 2.0 to 5.0 inches in 24 hours.

In the region of St. Louis, the rainfalls as regards the amount of rainfall in 24 hours, is about as follows, derived from 20 years' observations at St. Louis, Springfield, Ill., Kansas City, Des Moines, Keokuk, Davenport, and Dubuque. The table gives the number of heavy rainfalls for any place in the region.

NUMBER OF HEAVY 24-HOUR RAINFALLS IN 20 YEARS.

INCHES.	JAN.	FEB.	MAR.	APR.	MAY.	JUNE.	JULY.	AUG.	SEPT.	OCT.	NOV.	DEC.	SUMS.
1 to 2	5	5	6	10	18	20	14	11	14	12	8	6	130
2 to 3		1	1	2	4	5	5	4	4	2	1	1	30
3 to 4				1	1	1	1	1	1	1			7
4 to 5						1			1				2
5 to 6							1						1

Of all the rain that falls in the immediate drainage area above St. Louis, in the cases of rains of 1.0 inch or more in 24 hours, it will be assumed that 45 per cent of it reaches the rivers on the day of the fall and two days after, and the proportion of the rainfall each day reaching the streams will be taken as 0.25 of the rainfall, 0.13, and 0.07.

In the cases of rainfall on successive days in the various areas above St. Louis, marked by the lines of water travel on the map, 1, 2, 3, and 4 days from St. Louis, the following is the distribution of water passing through the river at St. Louis on successive days:—

PARTS OF RAINFALL PASSING IN THE RIVER BY ST. LOUIS.

FROM AREA ABOVE ST. LOUIS.	SUCCESSIVE DAYS.					
DAY'S TRAVEL.	1	2	3	4	5	6
0 to 1	.25	.13	.07			
1 to 2		.25	.13	.07		
2 to 3			.25	.13	.07	
3 to 4				.25	.13	.07

The method of estimating the water from the rainfall which, after reaching the rivers, passes St. Louis, is as follows: On a map for each day, the rainfall in inches is entered that fell in 24 hours at each place where there are observations. The absence of any figure indicating rain at a place does not necessarily mean that no rain fell. At the time there may have been no observations taken.

Blue lines on the map are drawn through the places having equal depth of rainfall of 1.0 inches, 2.0 inches, etc. For later years the observations of rainfall at the numerous voluntary rainfall stations in existence permit of forming a somewhat accurate idea of the extent of country over which the heavy rainfalls extend. For the earlier years previous to 1890, observations of rainfall are very few.

The unit of area in estimating the quantity of rainfall is taken as a rectangle one degree of latitude and one degree of longitude on a side, called a degree square.

A degree square comprises an area of 3600 square miles of the earth's surface. The unit of quantity of water is taken as 1.0 inch over an area of one degree square. This quantity of water corresponds to 96,000 cubic feet of water per second, passing a place for one day.

The extent of area covered by different depths of rainfall can be estimated with the eye with sufficient accuracy for the purpose in view, in terms of degree squares or parts of a square it covers on the map. The parallels and meridians on the map are two degrees apart. There is no need of resorting to very accurate measurement of the areas by a planimeter, as it would involve a great deal of labour which in most cases would be labour wasted, as the rainfall data is very incomplete, and the blue lines through places of equal depth are more or less inaccurate.

By the method described, the quantity of water flowing from the drainage area just above St. Louis, on successive days, was derived for selected cases of great rises. By comparing the maximum in each series with the corresponding rise, the following table was derived, which gives the rise at St. Louis in terms of the inch-degree squares of water computed to be flowing from the area.

RISES AT ST. LOUIS IN FEET.

RAINFALL IN INCH-DEGREE SQUARES ABOVE ST. LOUIS.	STAGES AT ST. LOUIS.															
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
0.5	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.0	1.0	1.0	1.0				
1.0		4.5	4.0	3.0	2.5	2.0	2.0	2.0	2.0	2.0	1.5					
1.5		6.5	5.5	4.5	3.5	3.0	3.0	3.0	3.0	2.5	2.0	1.5	1.0	0.5		
2.0		9.0	7.5	6.0	5.0	3.5	3.5	3.5	3.5	3.0	2.5	2.0	1.5	1.0		
2.5		11.0	9.0	8.0	6.0	4.5	4.5	4.0	4.0	3.5	3.0	2.5	2.0	1.5	0.7	
3.0		13.0	11.0	9.0	7.0	5.5	5.0	5.0	4.5	4.5	4.0	3.0	2.5	2.0	1.0	
3.5		15.0	13.0	11.0	9.5	7.5	7.0	6.0	5.5	5.0	5.0					
4.0		16.5	15.0	13.0	11.5	10.0	8.5	7.0	6.0	6.0	6.0					
4.5		18.0	16.5	15.0	13.5	12.0	10.0	8.0	6.5	6.0	6.0					
5.0		19.0	17.0	16.0	14.0	12.5	10.5	8.5	7.0	6.5	6.5					

The date of computed maximum number of inch-degree squares of water passing in the river by St. Louis, occurs as follows in 40 cases that have been examined:—

Maximum on same day as St. Louis crest, 6 times.
Maximum 1 day before St. Louis crest, 18 times.
Maximum 2 days before St. Louis crest, 7 times.
Maximum 3 days before St. Louis crest, 1 time.
Maximum 1 day after St. Louis crest, 5 times.
Maximum 2 days after St. Louis crest, 3 times.

In the table following the stages at St. Louis are given for the day of highest stage, and for the three days preceding. The stages at Kansas City and Dubuque are also given for four days preceding the period of rise at St. Louis. The table gives also the quantity of water in inch-degree squares computed to be passing St. Louis on successive days from the area just above it.

River Stages — Heights in Feet and Tenths.

St. Louis.				Kansas City.		Dubuque.		Inch-degree Squares of Water.	
Date.	Stage.	Observed Rise.	Computed Rise.	Date.	Stage.	Date.	Stage.	Date.	Number.
				26	12.8	26	4.6		
1875.				28	13.2				
July 30	24.0			30	12.9	30	3.8	30	0.1
31	23.0							31	0.9
Aug. 1	25.6							1	1.9
2	28.4							2	3.2
3	29.8	5.8	4.6					3	1.9
1876.				2	10.9	2	15.4		
May 6	25.4			6	14.1	6	16.0	6	0.2
7	27.8			8	15.4			7	1.6
8	30.0							8	2.2
9	31.8							9	2.5
10	32.0	6.6	3.2					10	2.1
								11	0.9
				18	16.2	18	10.8		
June 22	24.5			22	16.6	22	10.0		
23	24.0					27	11.3		
24	23.9								
25	24.0							25	0.5
26	27.2	2.7	2.8					26	0.9
								27	1.6
								28	1.8
								29	1.0
				29	16.2	29	10.8		
						2	11.1		
July 3	24.3			3	16.3	3	11.0	3	
4	24.5			5	16.8			4	0.1
5	25.5							5	1.7
6	28.7							6	2.9
7	30.1	5.8	4.3					7	2.4
								8	1.6
								9	0.6
1878.				4	7.0	4	3.0		
March 8	16.4			8	6.6	8	3.3	8	0.2
9	15.8			9	6.8			9	1.2
10	17.2							10	2.0
11	21.8							11	1.8
12	22.8	6.4	3.5					12	1.3
								13	0.4
				17	8.5	17	4.3		
April 21	16.2			21	8.8	21	5.3	21	
22	16.8							22	
23	18.5							23	1.2
24	21.4							24	2.2
25	22.0	5.8	3.9					25	2.0
								26	1.1
								27	0.5

St. Louis.				Kansas City.		Dubuque.		Inch-degree Squares of Water.	
Date.	Stage.	Observed Rise.	Computed Rise.	Date.	Stage.	Date.	Stage.	Date.	Number.
				14	5.0	14	6.0		
1882.				16	6.0				
Feb. 18	10.4			18	5.7	18	6.3	18	
19	11.2							19	1.7
20	18.2							20	3.7
21	27.5							21	4.5
22	28.2	17.8	16.5					22	2.9
								23	1.3
1883.				10	4.6	10			
Feb. 14	7.4			14	6.0	14		14	0.2
15	10.3							15	0.4
16	20.0							16	0.9
17	24.0							17	0.8
18	25.8	18.4	4.1					18	0.6
1885.				9	13.3	9	8.5		
June 13	20.6			13	16.7	13	7.9	13	0.6
14	22.0			19	19.1			14	1.4
15	24.1							15	1.7
16	26.4							16	1.4
17	27.1	6.5	3.2					17	1.0
1886.				21	14.6	21	5.0		
June 25	15.7			25	14.9	25	5.7	25	
26	15.4			27	15.2	1	6.1	26	0.4
27	16.2							27	1.2
28	20.4	4.7	4.7					28	2.2
								29	2.6
								30	1.7
1889.									
May 27	16.7			24	9.8	24	6.3		
28	16.3			28	10.4	28	7.1	28	
29	16.5			29	10.6	30	7.4	29	1.2
30	21.8							30	3.0
31	24.4							31	3.2
June 1	24.6	7.9	5.7					1	3.4
								2	1.6

St. Louis.				Kansas City.		Dubuque.		Inch-degree Squares of Water.	
Date.	Stage.	Observed Rise.	Computed Rise.	Date.	Stage.	Date.	Stage.	Date.	Number.
1892.				31	13.7	31	4.8	3	0.7
April 4	19.3			4	14.0	4	5.6	4	1.3
5	23.4			6	14.8			5	3.1
6	25.1							6	3.6
7	26.5							7	2.6
8	26.8	7.5	6.6					8	1.1
								9	0.1
				14	15.4	14	9.3	17	0.4
18	21.8			18	14.4	18	10.5	18	0.4
19	22.5			21	14.8			19	0.8
20	24.1							20	0.8
21	25.5							21	1.2
22	26.4	4.6	2.4					22	1.1
								23	0.9
								13	1.0
				11	19.9	11	8.8	14	2.2
May 15	34.4			15	23.2	15	9.6	15	2.7
16	34.9			21	24.9	19	11.2	16	2.7
17	35.3							17	1.9
18	35.6							18	1.3
19	36.0	1.6	0.8						
				28	17.6	28	13.9		
				30	16.6				
June 1	32.3			1	17.5	1	16.9		
2	32.6			3	18.1	2	17.8		
3	33.2							3	1.1
4	34.0							4	1.9
5	34.7	2.4	0.9					5	1.3
								6	0.4

The following is an example of the method of estimating a rise at St. Louis in terms of the rainfall over drainage area immediately above it, and the changes of stage preceding it at Kansas City and Dubuque.

On April 4, 1892, the stage at St. Louis was 19.3 feet, and on the 8th, 26.8 feet; at Kansas City the stages were, March 31 and April 4, 13.7 and 14.0, and at Dubuque, on the same dates, 4.8 and 5.6 feet. The rises at St. Louis due to these rises are, for Kansas City, as shown by table on page 248, 0.2. and for Dubuque 0.3, and the sum of the two, 0.5.

The rainfalls on April 3, 4, and 5 were as follows:—

APRIL 3, 1892.

Areas.	Inches. 1.5	2.5	3.5	Sums, Inch-Degree Squares.
	Degree Squares.			
0 to 1	0.8	0.3	0.2	2.7
1 to 2	0.4			0.6
2 to 3	1.4	0.4		3.1
3 to 4	1.3	0.3		2.8
4 to 5	0.5	0.4	0.1	2.2

APRIL 4, 1892.

Areas.	Inches. 1.5	2.5	3.5	Sums, Inch-Degree Squares.
	Degree Squares.			
0 to 1	0.7	0.6		2.6
1 to 2	1.2	1.6		5.8
2 to 3	1.8	1.2		5.7
3 to 4	0.9			1.4
4 to 5	0.4			0.6

APRIL 5, 1892.

AREAS.	INCHES. 1.5	2.5	3.5	SUMS, INCH-DEGREE SQUARES.
	DEGREE SQUARES.			
0 to 1	0.2			0.3
1 to 2	0.2			0.3
2 to 3				

The last column is the sum of the products of the degree squares by the inches at the top of each column. The area between the 1.0 inch and 2.0 inch rainfall line is considered to have a rainfall of 1.5 inches; between 2.0 and 3.0 inches the rainfall is 2.5 inches, etc.

The parts of rainfall passing St. Louis being taken according to table on page 250, the following results as the quantity of water passing St. Louis on successive days in inch-degree squares of water.

RAINFALL OF	SUCCESSIVE DAYS.—APRIL. 3	4	5	6	7	8	9	10
April 3	0.7	0.4	0.2					
		0.2	0.1	0.0				
			0.8	0.4	0.2			
				0.7	0.4	0.2		
					0.5	0.2	0.1	
April 4		0.7	0.4	0.2				
			1.5	0.8	0.4			
				1.4	0.7	0.4		
					0.4	0.2	0.1	
						0.1	0.0	0.0
April 5			0.1	0.0	0.0			
				0.1	0.0	0.0		
Sums . . .	0.7	1.3	3.1	3.6	2.6	1.1	0.2	0.0

The maximum number of the series is 3.6, and from the table on page 252, the rise corresponding to it for a stage of 19.3 feet, is 6.8 feet. This, added to the rise of 0.5, due to the rises at Kansas City and Dubuque, gives the total rise at St. Louis as 7.3. The observed rise was 7.5. Such a good agreement, however, is not to be expected for every rise.

For a rainfall of 1.0 inch in a day over the whole of the drainage area between St. Louis and the line of water travel four days above it, the estimated number of inch-degree squares of water passing St. Louis on successive days from the area, are: 0.5, 1.5, 2.3, 2.3, and 1.0, which correspond to a rise at St. Louis in four days of 8.4 feet with the stage 10 feet, and 2.8 with the stage 26 feet.

For a rainfall of 1.0 inch on each of two successive days over the whole area, the number of inch-degree squares of water passing St. Louis, would be: 0.5, 2.0, 3.8, 4.6, 3.3, and 1.0, corresponding to a rise of 16.6 with the stage 10 feet, and 6.1 with the stage 26 feet.

The above method of predicting a river rise based on observations of rainfall gives very satisfactory results, and is a great improvement on anything that has heretofore been done in the way of predicting river stages based mainly on rainfall observations. The official United States Weather Bureau prediction, made according to this method for St. Louis on May 26, 1893, when the stage was 22.5 feet, was that there would be a rise of 5 feet in the next four days at St. Louis, when the water would reach its highest. The stage attained on May 30, was 28 feet, which was the highest reached during the rise.

Mississippi River. — The country bordering the Mississippi River, below the mouth of the Ohio, is subject to overflows. The districts liable to overflow at high water are: The St. Francis bottom, on the west side, from Cairo to Memphis, area 6000 square miles; the Yazoo bottoms, on the east side, from Memphis to Vicksburg, area 6600 square miles; the Tensas basin, on the west side, from Vicksburg to the Red River, 5000 square miles; the Atchafalaya basin, on the west side, from the Red River to the Gulf of Mexico, about 6000 square miles. The area of country flooded at one time or another is 30,000 square miles, inhabited by more than one million people. The area, which varies from 30 to 50 miles in width from Cairo to New Orleans, is shown on the map.

The country from the Gulf to Cairo is protected by levees except the St. Francis front. Great floods occurred in 1828, 1844, 1849, 1850, 1858, 1859, 1863, 1867, 1882, 1884, 1890, 1892, and 1893. Flood time is from February to May. It begins on rare occasions in December. It is almost a proverb along the Mississippi that a full river in January portends a flood in the spring. Floods in the lower Mississippi are due mainly to the coincidence of freshets from the Missouri, the upper Mississippi, and the Ohio, coming into the lower river at the same time. The Arkansas and Red rivers are the next important in flood production. From the way the waters of the lower Mississippi are assembled, it is possible to foresee the occurrence of high stages along the lower river a considerable time ahead. The river gauge at Cairo is the key to all the gauges along the lower river. Slight modifications to predictions have to be introduced for the stages of the Arkansas, as shown by the gauge at Little Rock, the stages of the White River, as shown by the gauge at Jacksonport, or Newport, and the Red River at times, as shown by the Shreveport gauge. In great floods of the Mississippi, the discharge of water is about 2,000,000 cubic feet per second.

The map shows the positions of gauges. The crest of a high water for Cairo can be foreseen 7 days ahead. The wave-crest time from Cairo to Vicksburg, 599 miles, is 7 days when the river is within banks. The wave-crest time from Little Rock to Vicksburg, 374 miles, is 5 days. From Vicksburg to New Orleans, the wave-crest time is 4 days. The wave-crest times are very different in different floods, being much longer when the river is out of its banks and the country along the stream is overflowed. The Cairo stage is the key to the stages along the lower river.

For a stage of 41 feet at Cairo, the St. Francis bottoms begin to be overflowed. The bottoms act as a reservoir from which the water flows slowly, returning to the Mississippi River through the St. Francis River. While the time of wave-crest travel from Cairo to Helena, distance 303 miles, is only 4 days, while the river is within banks, yet when the St. Francis is overflowed, the time is on the average 12 days, when the crest at Cairo approximates 50 feet. In 1893 it was 15 days. Helena, Ark., is just below the mouth of the St. Francis River. It takes 37 days to fill the swamps above Cairo to a depth of 5 feet.

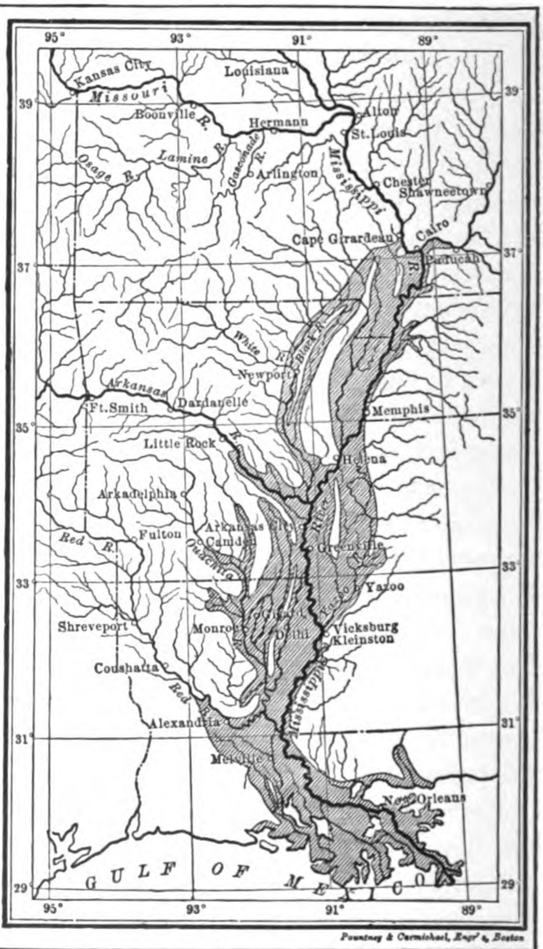
The same retarding influence on the time of wave crests from Cairo to Vicksburg is caused by the Yazoo basin when overflowed. The crest time from Cairo to Vicksburg has been as high as 31 days; on the average for the river out of its banks it is 17 days. The time is

AREAS OF OVERFLOW.

Locality.	States.	Sq. Miles.	Total Sq. Miles.
St. Francis Basin, from Commerce, Mo. to Helena, Ark.	Miss. Ark.	2874 3216	6090
Left Bank, from Commerce, Mo. to Memphis, Tenn.	Ill. Ky. Tenn.	65 125 426	616
White and Arkansas Basins, from Helena, Ark. to Arkansas City, Ark.	Ark.	956	956
Yazoo Basin, from near Memphis, Tenn. to Vicksburg	Tenn. Miss.	27 6621	6648
Macon Bœuf and Tensas Basins, from Ark. City, Ark. to Red River.	Ark. La.	480 4475	4955
Left Bank, from Vicksburg, Miss. to Baton Rouge, La.	Miss. La.	305 110	415
Atchafalaya Basin, from Red River to Bayou La Fourche.	La.	6085	6085
Pontchartrain Basin, from Baton Rouge La. to the Gulf of Mexico.	La.	2001	2001
LaFourche Basin from Donaldsonville, La. to the Gulf of Mexico.	La.	2024	2024
Total,	..	..	29700

AREAS BY STATES.

Locality.	Square Miles.	Locality.	Square Miles.
Illinois, Missouri, Kentucky, Tennessee,	65 2874 125 453	Arkansas, Mississippi Louisiana,	4652 6926 14695
		Total,	29790



greatly dependent on the breaks or crevasses there may happen to be along the river above Vicksburg. When the Tensas basin is overflowed, the river at New Orleans may steadily rise for a month after the fall at Vicksburg has set in.

Were it not for the levees a great part of the flood plain of the lower Mississippi would be overflowed every year, preventing cultivation. In most cases of ordinary high water levees prevent the country from being flooded. When the water overtops the levees or the wave wash causes a break, it rapidly widens and may become miles in width unless the ends of the break are secured by driving piling or throwing in stones. The effect of a break is to lower the water along the river immediately below it. The stages of water along the stretches of river lower down where the overflow water returns to the river are higher than when there is no overflow. At all high waters there are more or less breaks, and they modify the stages so largely that it is impossible to lay down rules for stage prediction along the lower course of the river, that will give accurate results in all cases. The continual levee building that is going on changes the relative flood heights along the lower river somewhat. There has been such a great increase in the extent of levees since 1886, that the record of rises previous cannot be used to determine what the rises will be at the present time at the highest stages.

The following are, on the average, the corresponding stages for Cairo and a number of places on the lower river as long as the river remains within its banks.

COMPARATIVE STAGES.

Cairo.	Memphis, 3 Days after.	Helena, Ark., 4 Days after.	Arkansas City, 5 Days after.	Greenville, 6 Days after.	Vicksburg, 7 Days after.
Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
20	14.1	21.0	23.9		
25	18.3	25.7	27.7	24.2	25.4
30	22.5	31.5	32.5	29.7	32.4
35	26.7	36.2	37.5	34.2	37.3
40	30.7	40.4	41.5	38.7	41.5

Helena, Ark. — For the highest stage reached at Cairo, 49 to 52 feet, the rise at Helena, Ark., continues for twelve days after, and the average rise in the time is 4.0 feet when the stage at Helena on day of Cairo crest is 43.5 feet. The successive daily rises at Helena from the day of Cairo crest are as follows, on the average: —

Day . .	1st	2d	3d	4th	5th	6th	7th	8th	9th	10th	11th	12th
Feet . .	+.1	+.1	+.2	+.25	+.33	+.6	+1.0	+.6	+.3	+.2	+.1	+.05

The average number of days from the day of crest at Cairo to the day of maximum rise at Helena is eight, and the rise continues on the average four days after that. The greatest maximum daily rise in any case is 1.2 feet.

For the highest stage reached at Cairo, 46 to 49, the rise at Helena, Ark., continues fourteen days after the Cairo crest, and the average rise in that time is 2.6 feet. The successive daily rises at Helena from the day of the Cairo crest are as follows, on the average: —

Day,	1st	2d	3d	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th
Feet,	+.05	+.1	+.1	+.1	+.2	+.2	+.3	+.3	+.3	+.3	+.2	+.2	+.1	0

The greatest daily rise is 0.5 foot, and occurs ten days after the Cairo crest. The rise continues four days after it.

For the highest stage reached at Cairo, 45 to 46 feet, the rise at Helena, Ark., continues for eleven days after, and in that time rises, on the average, 2.2 feet.

Vicksburg, Miss. — For finding a rule to determine the rise of the river at Vicksburg there are available the records of stages of water observed at Cairo, Ill., on the Ohio River, at Little Rock on the Arkansas River, at Newport, Ark., on the White River, and at Madison, Ark., on the St. Francis River. The wave-crest time from Cairo to Vicksburg, distance 599 miles, is from seven to eight days; from Little Rock to Vicksburg, 374 miles, five days. As yet records have not been kept long enough at Newport and Madison to make the stages of any service in computing the Vicksburg stage.

Besides the water passing Cairo and Little Rock there is also water passing Vicksburg from 78,000 square miles of additional drainage area below those places. The Cairo stage is, however, the main and dominating influence in producing high stages of water at Vicksburg.

With the record of river stages since 1872, proceeding in the same manner as for Cairo, the following rule is derived for finding the rise in the river at Vicksburg in terms of the rises at Cairo and Little Rock.

When the river has been rising at Cairo for seven days, and has reached a crest, the rise at Vicksburg in the next seven days will be equal to the rise in the preceding seven days at Cairo multiplied by the mean stage on the day of the crest and seven days before, plus one-third of the rise at Little Rock in the five days preceding, multiplied by the mean stage at Little Rock on the day of the Cairo crest and five days before, the sum multiplied by a factor depending on the Vicksburg stage, and divided by the stage at Vicksburg on the day of the Cairo crest. When there is a fall at Little Rock its product is to be taken with a minus sign. The following are the factors: —

FACTORS FOR VICKSBURG STAGE FROM CAIRO, ILL.

VICKSBURG STAGE.	FACTOR.	VICKSBURG STAGE.	FACTOR.
Feet.		Feet.	
25	0.76	35	0.46
26	0.75	36	0.42
27	0.73	37	0.37
28	0.72	38	0.33
29	0.71	39	0.29
30	0.69	40	0.25
31	0.65	41	0.21
32	0.61	42	0.17
33	0.56	43	0.13
34	0.51	44	0.09

The following is an example of the application of the rule: The stage of water at Cairo rose from 31.0 feet on April 21, 1885, to 38.2 on April 28. From April 23 to 28 the Arkansas River at Little Rock rose from 10.6 to 28.6 feet. The stage of water at Vicksburg, April 28, was 35.4 feet. The rise to be expected at Vicksburg by May 5 was then: —

$$\frac{0.46(7.2\times 35+0.33(18.0\times 20))}{35}=4.9.$$

The observed rise was 4.6 feet.

This rule only applies while the river is within its banks, and the stage of river at Cairo is not greater than 42 feet.

The flood line at Vicksburg is at 41 feet. The high stage of April 25, 1890, was 49.1 feet. When the flood water coming out of the St. Francis and Yazoo bottoms coincides with a rising stage in the main Mississippi River, the stage may possibly go as high as 51.7 feet, as occurred in the flood of 1862.

The rise of the Arkansas River at Little Rock, Ark., can be anticipated two days ahead from the rises at Fort Smith, 194 miles above it. The corresponding crests are as follows:—

COMPARATIVE STAGES.

Fort Smith.	Little Rock, 2 Days later.	Fort Smith.	Little Rock, 2 Days later.
Feet.	Feet.	Feet.	Feet.
15	17.7 ± 1.2	22	24.7 ± 0.7
16	18.8	23	25.5
17	20.2	24	26.4
18	21.0	25	27.3
19	22.0	26	28.1
20	22.8	27	28.7
21	23.8	28	29.6

The flood line at Little Rock is at 23 feet. The highest water, 31 feet, occurred in 1844.

The corresponding wave-crest stages for Vicksburg, Baton Rouge, and New Orleans are as follows:—

COMPARATIVE STAGES.

Vicksburg.	High-water Crests.	
	Baton Rouge, 3 Days after.	New Orleans, 4 Days after.
Feet.	Feet.	Feet.
20	12.6	6.3
25	14.8	7.6
30	19.6	9.5
35	25.6	11.5
40	28.4	13.1
45	32.6	14.5
49	36.0	15.7

While the river is within its banks the rise at New Orleans in four days is, on the average, one-fourth of the preceding four-day rise at Vicksburg.

When the Tensas basin is overflowed from breaks in the vicinity of the Arkansas River, the water subsequently returning to the river lower down, through Bayou Mačon and the Red River, may cause a rise to continue in the lower river long after a fall has set in at Vicksburg; in such a case the river at New Orleans may go as high as 17.9 feet.

When the lower Mississippi River is very high, near the tops of the levees, rules for estimating the rises are almost useless, on account of the disturbances of the regimen due to the water escaping from the main channel through crevasses and returning again to the river at a lower level. The best method of estimating rises when the river is high is to compare what has occurred along the upper course in recent great rises, when the circumstances as to number of crevasses and regions overflowed were somewhat similar. Accordingly the records of stages for the rises since 1886 are given in the following tables. In the 1891 rise there were no breaks in the levees, and no areas were flooded. In 1890 the Yazoo and Tensas basins were flooded. In 1892 and 1893 the Tensas basin was flooded.

Comparative River Stages.

Date.	Cairo.	Memphis.	Helena.	Arkansas City.	Green-ville.	Vicks-burg.	New Orleans.	Little Rock.
1886.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
April 4	44.2							
5	45.2							
6	46.0							
7	46.6							
8	47.2							
9	47.8		41.2					
10	48.3		41.8					
11	48.8		42.1					
12	49.3		42.4					
13	49.7		42.6					
14	50.0		43.0					
15	50.2		43.2					
16	50.4	34.0	43.4					
17	50.7	34.0	43.6					
18	50.9	34.1	43.8					
19	51.0 c	34.4	44.0	43.4	38.7	41.2		16.1
20	50.8	34.6	44.2	43.8	39.0	41.4		15.0
21	50.5	34.6	44.4	44.1	39.2	41.6		16.1
22	50.0	34.8	44.6	44.4	39.4	41.9		16.1
23	49.3	34.8	44.9	44.6	39.6	42.1		14.7
24	48.2	34.8	45.2	44.9	39.8	42.2		13.4
25	46.6	34.7	45.9	45.2	40.0	42.4		12.2
26	44.5	34.7	47.1	45.4	40.2	42.8		10.9
27	41.6	34.7	47.8	45.6	40.3	43.0		10.2
28		34.8 c	47.9	46.0	40.5	43.3		10.4
29		34.7	48.0	46.3	40.7	43.5		10.6
30			48.1 c	46.4	40.8	43.7		10.6
May 1			48.0	46.4	40.8	43.7		
2			47.6	46.6	40.8	43.8		
3			47.6	46.6	41.0	43.9		
4			46.1	46.8	41.1	44.0		
5			45.0	46.9 c	41.1	44.0	13.3	
6			43.8	46.85	41.0	44.1	13.3	
7						44.25	13.4	
8						44.25	13.4	
9						44.25	13.4	
10							13.4	
11							13.4	
12							13.4	
13							13.4	
14							13.5	
1887.								
Feb. 22	45.9							
23	46.0							
24	46.2							
25	46.4							
26	46.7							
27	46.9							
28	47.0							
Mar. 1	47.1	34.8	43.4					
2	47.0	34.8	43.5					

COMPARATIVE RIVER STAGES. — *Continued.*

DATE.		CAIRO.	MEMPHIS.	HELENA.	ARKANSAS CITY.	GREENVILLE.	VICKSBURG.	NEW ORLEANS.	LITTLE ROCK.
1887.		Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Mar.	3	46.9	34.9	43.6					
	4	47.0	34.8	43.6					
	5	47.0	34.9	43.7					
	6	47.3	35.0	43.9					
	7	47.8	35.2	44.3					
	8	48.3	35.2	44.4		39.6	43.1		
	9	48.5	35.3	44.5	44.8	39.7	43.2		12.5
	10	48.5	35.3	44.7	45.0	39.8	43.3		11.6
	11	48.3	35.2	44.9	45.2	39.9	43.5		10.7
	12	47.9	35.2	45.1	45.4	40.0	43.6		10.0
	13	47.4	35.2	45.3	45.5	40.1	43.7		9.6
	14	46.8	35.2	45.5	45.6	40.2	43.8		9.3
	15	46.3	35.2	45.6	45.8	40.3	43.9		8.9
	16	45.9	35.2	45.8	45.8	40.4	44.0		8.4
	17	45.4	35.2	45.9	46.0	40.5	44.0		7.9
	18	44.9	35.2	46.0	46.2	40.5	44.1		7.4
	19			46.1	46.2	40.6	44.2		6.9
	20			46.2	46.5	40.7	44.4		6.8
	21			46.3	46.5	40.8	44.4		6.5
	22			46.3	46.6	40.8	44.5		6.0
	23			46.2	46.6		44.6	13.6	5.9
	24				46.6		44.6	13.6	5.7
	25				46.6		44.6	13.6	
	26						44.7	13.8	
	27							13.8	
	28							13.9	
	29							14.0	
	30							14.0	
	31							14.0	
1888.									
Mar.	28	37.6							
	29	40.8							
	30	42.7							
	31	43.8							
April	1	44.5							
	2	45.0							
	3	45.2					35.6		9.5
	4	45.2	32.7	40.4	38.8	34.4	36.6		8.8
	5	45.2	33.0	40.8	39.3	34.9	37.3		8.5
	6	45.2	33.3	41.3	39.8	35.3	37.9		8.1
	7	44.8	33.3	41.4	40.3	35.7	38.5		7.7
	8	44.2	33.6	41.8	40.7	36.1	39.0		7.4
	9	43.4	34.0	42.2	41.1	36.4	39.4		7.3
	10	42.6	34.1	42.4	41.6	36.8	39.8	12.4	7.7
	11	41.6	34.2	42.5	42.0	37.2	40.2	12.5	12.2
	12	40.5	34.2	42.6	42.4	37.6	40.6	12.6	14.8
	13		34.0	42.7	42.8	38.0		12.7	
	14		33.8	42.8	43.3	38.4		12.9	
	15			42.8	43.8	38.8		12.9	
	16			42.7	44.2	39.2		13.0	
	17			42.6	44.6	39.5		13.1	

Comparative River Stages. — *Continued.*

Date.		Cairo.	Memphis.	Helena.	Arkansas City.	Greenville.	Vicksburg.	New Orleans.	Little Rock.
1888.		Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
April	18				44.8	39.9		13.2	
	19				45.2	40.2		13.3	
	20				45.3	40.4		13.5	
	21				45.3	40.5		13.6	
	22				45.4	40.6		13.7	
	23							13.6	
	24							13.8	
	25							13.9	
	26							14.4	
	27							14.1	
1890.									
Mar.	1	42.4							
	2	43.6							
	3	44.6	32.4						
	4	45.5	32.9						
	5	46.3	33.2	42.4	46.8	41.7	46.4		16.2
	6	46.9	33.6	42.6	47.0	41.8	46.5		14.6
	7	47.4	33.8	42.8	47.4	42.1	46.6		13.2
	8	47.7	34.2	43.0	47.5	42.4	46.7		12.0
	9	47.9	34.3	43.2	47.6	42.5	46.9		11.0
	10	48.0	34.5	43.3	47.6	42.5	47.0		10.2
	11	48.3	34.8	43.5	47.6	42.6	47.1		9.6
	12	48.8 c	35.0	43.8	48.0	42.8	47.2		10.1
	13	48.6	35.2	44.0	48.1	43.0	47.5		22.1
	14	48.3	35.4	44.1	48.2	43.0	47.7		22.3
	15	48.2	35.5	44.2	48.4	43.1	48.0		21.9
	16	48.2	35.6	44.3	48.6	43.3	47.9		21.4
	17	48.3	35.6	44.4	48.8	43.4	47.6		20.1
	18	48.2	35.5	44.5	48.8	43.4	47.5		18.2
	19	48.0	35.5	44.7	48.8	43.1	47.4		16.0
	20	47.5	35.5	44.9	48.9	43.1	47.2		
	21	47.0	35.5	45.1	49.0	43.1	47.1		
	22	46.8	35.5	45.4	49.0	43.2	47.0		
	23	46.7	35.6	45.8	49.0	43.2	46.9		
	24	46.6	35.6	46.2	49.1	43.2	46.9		
	25	46.6	35.6	46.7	49.2	43.3	46.8		
	26	46.7	35.5	47.2	49.4	43.4	46.8		
	27	46.8	35.4	47.5	49.5	43.4	46.7		
	28	47.1	35.3	47.7	49.3	43.3	46.6		
	29	47.4	35.3	47.7	49.0	43.0	46.5		
	30	47.8	35.2	47.7	48.8	42.9	46.4		
	31	48.2	35.3	47.6	48.7	42.8	46.4		
April	1	48.5	35.4	47.6	48.7	42.8	46.4		
	2	48.5	35.4	47.5	48.6	42.7	46.4		
	3	48.6	35.5	47.5	48.6	42.8	46.6		15.1
	4	48.6 c	35.6	47.4		42.6	46.7		19.9
	5	48.6	35.6	47.3	48.0	42.2	46.8		20.2
	6	48.6	35.5	47.2	48.0	42.2	47.0		20.6
	7	48.3	35.5	47.1	48.0	42.2	47.1		20.6
	8	47.7	35.5	47.1	48.0	42.2	47.3		19.7
	9	46.8	35.5	47.1	48.0	42.2	47.4		18.3

Comparative River Stages. — *Continued.*

Date.		Cairo.	Memphis.	Helena.	Arkansas City.	Greenville.	Vicksburg.	New Orleans.	Little Rock.
1890.		Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
April	10	45.8	35.5	47.0	48.0	42.1	47.6		16.4
	11		35.4	47.0	47.9		47.7		14.6
	12		35.3	47.1	47.9		47.9		13.1
	13		35.2	47.1	47.8		48.0		12.0
	14			47.2			48.1		11.2
	15			47.4			48.2		10.8
	16			47.4			48.3		12.0
	17			47.4			48.5		18.1
	18			47.3			48.6	15.1	21.7
	19			47.0			48.6	15.2	22.3
	20			46.6			48.7	15.2	21.6
	21			45.9			48.7	15.4 c	20.6
	22			45.2			49.0	15.2	19.5
	23						49.0 c	15.0	
	24								
1891.[1]									
Feb.	26	44.7							
	27	45.1		41.9					
	28	45.5		42.0					
Mar.	1	45.8	33.0	42.0					
	2	46.0	33.3	42.2					
	3	46.1	33.4	42.2					
	4	46.2	33.5	42.4	44.4		44.4		10.4
	5	46.2	33.6	42.5	44.7		44.5		9.7
	6	46.2	34.0	42.7	44.9		44.8		9.1
	7	46.1	34.2	42.9	45.2		45.5		9.8
	8	45.9	34.5	43.1	45.4		45.7		11.6
	9	45.5	34.8	43.3	45.6		45.9		12.5
	10	45.3	34.9	43.4	45.8	40.7	46.1		12.7
	11	45.0	34.8	43.4	46.0	41.0	46.3		12.0
	12	44.8	34.7	43.6	46.2	41.2	46.5		11.1
	13	44.7		43.7	46.5	41.4	46.8		10.5
	14	44.7		43.8	46.6	41.6	47.0		10.0
	15	44.6		43.8	46.7		47.2		10.1
	16	44.5		43.9	46.8	44.9	47.4		10.3
	17	44.5		44.0	46.9	42.0	47.6		10.4
	18	44.5		44.0	47.0	42.0	47.6		10.2
	19	44.5		44.0	47.1	42.1	47.7		9.9
	20	44.5		44.1	47.2	42.2	47.7		9.5
	21	44.4		44.2	47.3	42.4	47.8		9.2
	22	44.2		44.4	47.4		47.8		9.1
	23	44.1		44.4	47.5	42.6	47.7		9.2
	24	44.0		44.5	47.5	42.6	47.7		9.2
	25	43.6		44.6	47.6	42.7	47.8		9.0
	26	43.3		44.7	47.7	42.8	47.8		8.8
	27	42.9		44.7	47.8	42.9	47.8		8.6
	28	42.5		44.6	47.8	43.0	47.8		8.5
	29	42.0		44.6	47.9		47.8		9.0
	30	41.9		44.6	47.9	43.1	47.9	15.7	10.3
	31	42.2		44.6	48.0	43.1	48.0	15.7	11.3

[1] No breaks in levees this year.

Comparative River Stages. — *Continued.*

Date.		Cairo.	Memphis.	Helena.	Arkansas City.	Greenville.	Vicksburg.	New Orleans.	Little Rock.
1891.		Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
April	1	42.8		44.6	48.0	43.2	48.0	15.7	12.8
	2	43.4		44.5	48.1	43.2	48.1	15.8	15.5
	3	44.0		44.4	48.1	43.2	48.1	15.6	16.2
	4	44.4	33.5	44.4	48.2		48.1	15.5	15.3
	5	44.7	33.3	44.2			48.0	15.6	14.0
	6	44.8	33.4	44.1			48.0	15.6	12.6
	7	44.7	33.5	44.0			48.0	15.5	11.3
	8	44.5	33.6	44.0			48.0	15.5	10.2
	9	44.3	33.6	44.0			48.0	15.5	
	10	43.9	33.8	44.0				15.6	
	11	43.5	33.9	44.0				15.5	
	12	43.3	33.9					15.4	
	13	43.3	33.9					15.5	
	14	43.4	33.9					15.4	
1892.									
April	4	36.2							
	5	38.0							
	6	39.8							
	7	41.7							
	8	43.2							
	9	44.4							
	10								
	11	45.8	31.7	40.3			39.3	13.4	19.6
	12	45.8	32.2	40.7			39.9	13.5	17.1
	13	45.6	32.7	41.1			40.5	13.5	15.4
	14	45.5	33.2	41.5			41.2	13.8	13.4
	15	45.3	33.5	42.0			41.9	14.0	12.4
	16	45.2	33.5	42.2			42.4	14.2	11.2
	17								10.3
	18	44.8	33.7	42.6			43.4	14.7	9.4
	19	44.3	33.8	42.7	44.9	39.4	43.8	14.9	9.1
	20	43.9	33.7	42.9		39.8	44.1	14.9	8.7
	21	44.3	34.2	43.3	45.6	40.2	44.5	14.9	10.0
	22	45.3	34.3	43.3	46.0	40.5	44.8	15.5	10.7
	23	46.3	34.2	43.4	46.3	40.8	45.0	15.4	11.8
	24	47.0							11.9
	25	47.7	34.2	43.5	46.9	41.5	45.8	15.9	12.0
	26	48.1	34.1	43.6	47.1	41.8	46.2	15.8	12.3
	27	48.2	34.2	43.6	47.2	42.0	46.4	15.8	12.0
	28	48.2	34.2	43.7	47.4	42.2	46.6	16.0	11.0
	29	48.2	34.4	43.9	47.6	42.5	47.0	16.0	10.1
	30	47.9	34.5	44.0	47.7	42.6	47.2	16.0	9.5
May	1	47.4							10.3
	2	46.8	34.6	44.3	48.0	42.9	47.5	16.1	12.4
	3	46.0	34.5	44.5	48.0	43.0	47.6	16.2	14.1
	4	44.7	34.6	44.6	48.1	43.2	47.5	16.3	13.6
	5	43.0	34.4	44.8	48.2	43.3	47.8	16.4	13.0
	6	40.9	34.4	44.8	48.4	43.4	47.9	16.4	11.0
	7	38.7	34.4		48.5	43.6	48.0	16.5	9.4
	8	37.7				43.7			10.4
	9	36.7	33.9	45.4	48.7	43.8	48.2	16.6	17.4

Comparative River Stages. — *Continued.*

Date.		Cairo.	Memphis.	Helena.	Arkansas City.	Greenville.	Vicksburg.	New Orleans.	Little Rock.
1892.		Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
May	10	36.5	33.6	45.7	48.7	43.8	48.4	16.8	17.5
	11	36.6	33.0	45.8	48.8	43.8	48.4	16.7	20.2
	12	36.8	32.5	45.7	48.9	43.9	48.3	16.8	21.8
	13	37.4	31.8	45.5	49.1	44.0	48.3	16.8	22.0
	14	38.4	31.4	45.2	49.2	44.1	48.4	16.7	21.5
	15		31.3				48.4	16.7	21.2
	16	41.2	31.2	44.7	49.1	43.9	48.4	16.7	24.3
	17	41.8	31.4	44.9	49.1	43.9	48.3	16.7	25.6
	18	42.5	31.7	44.5		43.9	48.4	16.9	26.4
	19	43.0	32.0	44.5	49.1	43.9	48.3	16.8	27.3
	20	43.6	32.2	44.4	49.2	44.0	48.2	16.9	27.9
	21	44.2	32.5	44.4	49.3	44.0		17.0	27.8
	22	45.0	32.7					17.0	27.5
	23	45.6	32.9	44.4	49.4	44.1	48.2	17.1	27.1
	24	45.9	33.1	44.3	49.4	44.1	48.2	17.1	26.6
	25	46.0	33.3	44.3	49.5	44.2	48.2	16.9	25.9
	26	46.0	33.5	44.3	49.6	44.1	48.2	16.8	25.0
	27	45.9	33.6	44.3	49.6	44.2	48.3	16.9	24.2
	28	45.6	33.8	44.4	49.7	44.2	48.2	16.9	23.5
	29	45.5	34.0				48.2	16.9	22.6
	30	45.4	34.1		49.8	44.4	48.3	16.9	21.2
	31	45.0	34.2		49.8	44.4	48.3	17.0	20.0
June	1	44.6	34.3	44.7	49.9[1]	44.5[1]	48.3	17.1	19.8
	2	44.2	34.4	44.8	49.8	44.4	48.4	17.2	21.2
	3	43.8	34.4	44.7	49.8	44.3	48.4	17.2	23.6
	4	43.7	34.2	44.6	49.6	44.2	48.4	17.3	24.9
	5	43.7	34.2				48.4	17.3	25.6
	6	43.9	34.1	44.6	49.5	44.0	48.3	17.3	25.8
	7	44.0	34.0	44.6	49.4	43.9	48.2	17.2	25.7
	8	44.0	33.9	44.7		43.9	48.2	17.4	25.5
	9	43.9	33.9		49.4	43.9	48.1	17.4	25.0
	10	43.7	33.9	44.8	49.4	43.9	48.1	17.4	
	11	43.5	33.8	44.8	49.4	43.9	48.0	17.6	
	12	43.1	33.8				48.0	17.5	
	13	42.8	33.8	45.0	49.4	43.9	48.0	17.5	
	14	42.5	33.7	45.0	49.4	43.9		17.5	
	15	42.2	33.5	45.1	49.4	43.9	47.9	16.9	
	16	41.8	33.5	45.4	49.4	43.8	47.9	16.9	
	17	41.3		45.1	49.3	43.8	47.9	16.8	
	18	40.5		45.0	49.2	43.7	47.9	16.8	
1893.									
April	17	40.6	26.4	32.2			30.0	10.3	
	18	41.8	27.9	34.6			30.2	10.0	
	19	42.5	28.9	36.2			31.7		
	20	43.0	29.9				33.4	10.0	
	21	43.1	30.8	38.4			34.7	10.0	

[1] Arkansas City would have gone to 51 and Greenville to 46 had not the levees broken. A great part of the high water of Arkansas and White rivers never reached the Mississippi, but escaped over banks and around the head of Arkansas levees in Amos Bayou ridge. — WILLIAM STARLING.

Comparative River Stages. — *Concluded.*

Date.		Cairo.	Memphis.	Helena.	Arkansas City.	Greenville.	Vicksburg.	New Orleans.	Little Rock.
1893.		Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
April	22	43.5	31.3	39.2			35.8	10.2	
	23								
	24	43.7	32.0	40.3			37.6		
	25	43.2	32.3	40.6			38.3	11.5	8.7
	26	42.6	31.9	41.0			38.8	11.6	12.3
	27	42.1	32.8	41.3			39.4	11.8	13.6
	28	41.8	32.8	41.6			39.9	11.9	13.5
	29	41.9	32.8	41.7			40.4	11.9	15.1
	30								
May	1	44.6	33.1	42.0			41.4	12.4	23.4
	2	45.9	33.2	42.1		38.2[1]	41.8	12.6	25.1
	3	46.8	33.3	42.2	44.8[1]	38.8	42.4	12.8	25.2
	4	47.6	33.4	42.3	45.4		43.0	12.8	25.1
	5	48.2	33.6	42.4	46.0	40.0	43.4	13.8	24.9
	6	48.8	33.8	42.5	46.6	40.7	44.0	13.7	24.0
	7	49.1	34.0	42.7			44.6		22.4
	8	49.2	34.3		48.0	42.4	45.2	14.1	21.4
	9	49.3	34.5		48.4	42.9	45.8	14.2	20.9
	10	49.3	34.7	43.3	48.7	43.4	46.2	14.3	20.8
	11	49.3	34.9	43.5	48.9	43.6	46.8	14.6	21.1
	12	49.3	35.0	43.7	49.1	43.7	47.1	14.8	20.6
	13	49.2	35.0	43.8	49.2	43.8	47.3	15.0	19.9
	14	49.1		44.0					
	15	49.0	35.2	44.2	49.5	44.1	47.8	15.5	17.5
	16	48.6	35.2	44.4	49.6	44.1	48.0	15.7	16.1
	17	47.9	35.2	44.6	49.6	44.1	48.1	15.7	14.8
	18	47.0	35.1	44.9	49.6	44.1	48.2	15.7	13.6
	19	45.8	35.1	45.2	49.6	44.1	48.2	15.6	13.0
	20	44.3	35.1	45.7	49.6	44.0	48.2	15.6	13.1
	21			46.4					
	22	40.0	34.9	47.0	49.6	44.0	48.3	15.7	12.1
	23	37.9	34.7	47.5	49.7	44.1	48.3	15.9	11.6
	24	36.2	34.6	47.8	49.8	44.2	48.1	15.9	11.0
	25	34.9	34.2	48.0	49.9	44.2	47.8	16.0	10.4
	26	34.3	33.4	47.9	50.0	44.2	47.5	16.0	9.9
	27	34.6	32.4	47.7	50.0	44.2	47.2	16.0	9.5
	28			47.7					
	29	36.7	31.2	47.2	50.3	44.3	47.0	16.0	14.8
	30	37.9	31.0		50.0	44.0	47.0	16.0	16.7
	31	38.7	31.0	46.0	49.8	43.9	46.8	16.0	16.7
June	1	39.5	31.6	46.0	49.7	43.7	46.7	16.1	20.6
	2	40.3	31.8		49.6	43.6	46.5	16.1	21.4
	3	41.4	32.1	45.6	49.6	43.5	46.4	16.2	21.5
	4								
	5	43.2	32.5	45.3	49.6	43.5	46.2	16.1	20.8
	6	43.3	32.9	45.2	49.6	43.5	46.2	16.2	19.6
	7	43.1	33.1	45.5	49.5	43.4	46.1	16.4	18.0
	8	42.7	33.2	45.0	49.5	43.4	46.1	16.5	16.5
	9	42.7	33.4	44.9	49.3	43.3	46.9	16.5	15.0
	10	43.0	33.4	44.8	49.2	43.2	45.9	16.5	14.2

1 *May* 10. — Top of levees east bank of river are up to 47 feet Greenville or 52 feet Arkansas City gauge, except a few short stretches, which are one foot lower. Top of levees west bank 51 feet Arkansas City or 45.5 Greenville gauge. — William Starling, *Chief Engineer*.

CREVASSES IN 1893.

(1) May 11, 6 A.M. — Break 50 feet, 1½ miles below Lakeport, Ark. Latitude 33° 12'.
(2) May 14. — Break 75 feet wide at Millport, Ark., 15 miles south of Lakeport.
(3) May 15, 8 P.M. — Levee broke 3 miles north of Grand Lake, Ark., 300 feet wide, 8 to 10 deep.
(4) May 17, morning. — Levee broke ½ mile south of Grand Lake. Crevasse on Arkansas side, all within 12 miles, 3000 feet of breaks.
(5) May 23. — Levee broke at Wylies, 4 miles below Lake Providence, May 25, 1200 feet wide; May 28, 2100 feet wide.
(6) May 29. — Amos Bayou levee, below Arkansas City, broke this morning 300 feet wide at noon. May 30, Amos crevasse, 700 feet wide. June 1, 3400 feet wide. June 2, Wylies crevasse, 4000 feet wide.
(7) June 19 or 18. — Break on east side, 47 miles above New Orleans. Break near Baton Rouge. Baton Rouge break closed June 15. June 24, Rescue crevasse, at 10.30 A.M., 500 feet wide, 89 miles above New Orleans. June 27, 748 feet wide.

The methods of prediction described for the lower Mississippi River give very good results in practice. As an example, the official predictions of the United States Weather Bureau, made in accordance with the methods, and issued in the special river bulletin of April 21, 1892, are as follows, and will serve to show the accuracy that may be attained by the method: —

"The river at Cairo will rise 5.5 feet in the next 7 days, making the stage 50 feet by April 28 (the actual highest, April 28, was 48.2 feet)."

"At Helena the stage will rise to 47 feet by May 10 (the actual highest was 45.8, May 11)."

"At Arkansas City the stage will rise to 49.5 by May 15 (the actual highest was 49.2, May 14)."

"At Vicksburg the stage will reach 48 feet by May 15 (the actual highest, 48.4, was May 15)."

"At New Orleans the stage will reach 16.5 feet about May 20 (the actual highest, 17.1, occurred May 23)."

Without levees a great deal of country bordering the lower river would be overflowed at every high water, and would be untenable by population. Levees cannot entirely prevent floods in the lower Mississippi valley. Such great volumes of water as were poured from the Ohio and the upper Mississippi into the lower river in 1882 and 1890, would have gone over the tops of the most economical system of levees that the country could construct. Levees diminish the frequency of overflows, but cannot entirely prevent them. Even when not overtopped accidental breaks are liable to flood great areas.

The whole system of levees, originally built by the states bordering the river, and in some cases by private landowners, are now under the control of the General Government and the management of the Mississippi River Commission. Floods in the future will doubtless be less frequent and less disastrous than in the past.

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