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MARINE METEOROLOGY

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Meteorological Log kept on board the barque Mertola . **Captain** E. W. Turner **from** River Mersey **to** River Guadiana

Year 18 82 — Month X — Latitude. N. — Longitude. W. — Barometer No. 379, Height of Cistern above Sea 9 feet. — Thermometers: Dry Bulb No. 1448, Damp Bulb No. 1444.

DATE. Day. Civil Time.	Hour.	Latitude. Observed.	Latitude. Dead Reckoning.	Longitude. Observed.	Longitude. Dead Reckoning.	Course and Distance (Each four hours). True Course.	Distance by Log.	Total Compass Error. Of Compass used for Wind, being Variation and Deviation combined. State whether by Az., Amp., or otherwise.	Ship's Head. By same Compass as Wind; and Degrees of Heel to Port or Starboard. (P. or S.)	Wind (Every two hours, at the time of observation. Give the times of changes in Direction and Force in the Remark Column.) Direction. State if true, or subject to Compass Error, or only to Variation.	Force. 0 to 12. See Beaufort Scale, p. 2.	Barometer. Uncorrected Reading.	Att. Therm.	Thermometers. Dry Bulb. No. 1448	Damp Bulb. No. 1444
29	2 A.M.									SWbyW	7				
	4					N45W	10		NWbyW	"	8	29.848	66	57.7	57.7
	6									W	7				
	8					N	8		NWbyN	WbyS	7	29.830	65	55.9	55.8
	10	° ′	° ′	° ′	° ′	N	3			"	7				
	NOON		47 4	°	10 55	S45E	5	22°20′W	SbyW	"	7	29.878	67	57.9	57.0
	2 P.M.	Current in last 24 hours			mls.					W	7				
	4					S23E	10		SSW	"	7	29.912	65	57.1	57.0
	6									WbyN	7				
	8					S11E	12		SW	WNW	7	30.018	67	56.2	56.2
	10									"	7				
	MIDT					S11W	14		"	"	6	30.088	65	56.2	56.2
30	2 A.M.									W	5				
	4					S5E	20		SSW	"	"	30.086	67	57.3	57.0
	6									WbyS	5				
	8					S11E	18		SbyW	"	6	30.094	70	58.2	58.2
	10	° ′	° ′	° ′	° ′					WSW	7				
	NOON		47 34	°	10 32	S34E	18	22°20′W	S	"	8	30.036	69	57.1	57.0
	2 P.M.	Current in last 24 hours			mls.					W	7				
	4					S	10		SW	WNW	6	30.145	68	58.0	57.4
	6									WbyN	4				
	8					S	10		S	WSW	2	30.162	68	57.6	57.0
	10									SW	3				
	MIDT					S57E	12		SEbyS	SWbS	4	30.179	68	58.6	58.6
31	2 A.M.									SW	4				
	4					N85W	16		WNW	"	5	30.092	70	57.5	57.5
	6									SWbyS	5				
	8					S85W	16		WbyN	"	6	30.022	71	58.1	57.0
	10	° ′	° ′	° ′	° ′					"	6				
	NOON		47 7	°	11 16	W	8	22°30′W	"	"	6	29.935	68	58.4	57.8
	2 P.M.	Current in last 24 hours			mls.					SbyW	8				
	4					W	8		WbyS	"	9	29.721	69	58.5	57.8
	6									S	10				
	8					N67W	8		WSW	"	10	29.470	70	55.5	55.5
	10									SSW	10				
	MIDT					N45W	8		W	"	10	29.162	68	55.5	55.5
1	2 A.M.									WNW	12				
	4					N23E	8		NE	NW	11	29.444	65	51.0	51.0
	6									"	11				
	8					E	10		SW	"	11	29.800	73	53.0	51.5
	10	° ′	° ′	° ′	° ′					"	10				
	NOON		47 8	°	11 19	S45E	8	22°35′W	"	NWbyW	10	29.954	70	55.4	54.0
	2 P.M.	Current in last 24 hours			mls.					WNW	9				
	4					S45E	8		SSW	"	8	30.016	70	55.8	55.2
	6									W	7				
	8					S45E	10		S	WSW	6	30.022	66	56.4	55.2
	10									"	6				
	MIDT					S45E	10		SbyE	SWbyW	7	29.948	65	57.8	57.8
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Hour.	Clouds (When Lower Clouds do not move with the Wind, give the Direction they come from in the Remarks. (For Plates see p. 13 of Instructions.)) Lower: Names.	Upper: Names and Direction from.	Prop. of Sky Clouded. 0 to 10.	Weather. See Instructions. According to Beaufort Notation. See p. 2.	Sea Surface. Direction from. Also Record when Confused, and state when only Swell or Swells.	Disturbance. 0 to 9. See p. 2.	Temp. by No. 1446	Specific Gravity, by No. 445	Time of Remark.	Remarks. Here give any important Remarks, with the times of their occurrence; especially the times of Changes in Direction and Force of Wind, as well as the Direction, Veering or Backing, Force, and Duration of Squalls. Also note the hour at which the Ship arrives in or leaves Port. (See Instructions for further Particulars.)
2 A.M.										
4	Str		10	ogq	Confused SW and NW	7	57.5		4.30	An ugly squall for 5 minutes with r. Wind veered to West.
6										
8	Str		10	og	WSW	7	58.0		8	Wind very gusty.
10									9.30	Wore ship to Southward.
NOON	cum det str	Cir	5	bc	"	6	58.0	28		
2 P.M.										
4	Cum nim det str	Cir	8	bcq	W	7	57.1		4	Several squalls with a little rain during watch.
6										
8	nim det str		4	bcq	"	7	57.2		8	Wind gradually veering since 4 p.m. Several squalls
10										hanging about in N.W.
MIDT	det str		4	bc	WNW	6	59.0			
2 A.M.										
4	det. str	cir-s NW 3	10	o	W	6	59.0			
6										
8	Str	Cir-S	9	bc	WSW	6	59.1			
10									10	Two large whales near ship.
NOON	Str		10	ogm	"	7	58.9	28.5	Noon	Wind freshening all morning, fine misty rain at times.
2 P.M.									1	" veered a point. 1.30 veered West force 7.
4	det. str	cir Cir-S	4	bc	W	7	59.8		2.15	" " W.N.W., weather clearing up with b.
6									3.30	" moderated to force 6.
8	high str		10	og	swl "	4	59.7		8	" gradually backing and falling away since 4 p.m.
10										
MIDT	det. str	Cir-S W 3	9	bc	" " SW	4/3	59.8		Midt	" " " and increasing, tacked ship to W.
2 A.M.										
4	Str		10	og	swl. W SW	4/4	60.0		4	Wind gradually freshening at S.W.
6										
8	Str	Cir	10	o	" "	4/5	58.0			
10										
NOON	high str		10	og	" "	5/5	58.8	28		
2 P.M.									1 pm	Wind backed S by W, increasing to force 7 in hard puffs, and
4	high str		10	og	" SSW	5/7	58.9			soon after to force 8.
6									3.30	Wind increased in hard puffs to force 9.
8	nim str		10	ogd	" S	5/8	58.7		5	" " force 10.
10									8	d since 6.30. Wind gusty, lulling force 8 then up to force 10.
MIDT	det. str		2	bc	" SSW	9	58.5		9	Wind veered SSW. Midt. Sea frightfully heavy.
2 A.M.									1.15	a.m. Wind veered W force 9 but a few minutes after to WNW with hurricane
4	Str		10	ogr	swl SW NW	9	57.5			force. 2.30 ship was thrown over on starboard beam ends and we
6										had to let fly the lower topsail sheets to save ship. She righted slowly,
8	Cum nim str		6	bcq	" "	9	58.0			but both lower topsails, which were new sails, were blown to shreds
10										in a few moments, and ship was hove-to with a spare tarpaulin in
NOON	cum det str		4	bcq	" WNW	9	57.3	28		mizen rigging. 7.30 a.m. wore ship under fore topmast staysail and lee
2 P.M.										clew of foresail. Sea beyond description. During the afternoon bent
4	cum det str		5	bc	" "	8	57.5			two spare topsails and set them.
6									4	p.m. Wind gradually backing during afternoon and moderating.
8	det. str		2	bc	confused "	7	58.0		8	" " " all the watch "
10										
MIDT	Str	Cir. S	6	bc	" "	6	59.0		Midt	Wore ship to NW.
2a	17	18	19	20	21	22	23	24	25	26

A "Rough Book" is supplied with this Log. It is intended to be carried about to the different instruments, and may be retained by Commanders for future reference. It is ruled for 6 sets of observations daily. Those who observe more frequently can use 2 divisions for each day. It will be a convenience in copying if the four days on one opening of the Rough Book be copied into a similar opening of the Log

A MANUAL

OF

MARINE METEOROLOGY

FOR

APPRENTICES AND OFFICERS OF THE WORLD'S MERCHANT NAVIES.

BY

WILLIAM ALLINGHAM,

FIRST-CLASS HONOURS, NAVIGATION, SCIENCE AND ART DEPARTMENT;
PRIZEMAN, POLITICAL ECONOMY, SOCIETY OF ARTS;
JOINT-AUTHOR OF "NAVIGATION: THEORETICAL AND PRACTICAL";
AUTHOR OF "WEATHER SIGNS AND HOW TO READ THEM: FOR USE AT SEA," ETC.

SECOND EDITION.

REVISED AND ENLARGED.

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LONDON:
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EXETER STREET, STRAND.
1917

THIS LITTLE VOLUME

IS

DEDICATED TO MY FRIEND

Rear-Admiral RICHARDSON CLOVER, U.S. Navy,

WHO, DURING HIS TERM OF OFFICE AS UNITED STATES HYDROGRAPHER,
DID VERY MUCH TO MAKE MARINE METEOROLOGY
POPULAR AMONG NAVIGATORS OF
EVERY NATION.

AUTHOR'S PREFACE.

THIS little book does not lay claim to originality, nor is it exhaustive, inasmuch as the subject dealt with leaves considerable scope in either direction. Marine meteorology must, of necessity, depend upon international effort; and, at the present time, every maritime nation devotes a portion of the public funds to the investigation of matters pertaining thereto. Shipmasters in the ocean-carrying trade who co-operate with the United States Hydrographic Office, and preserve the monthly Pilot Charts of the North Atlantic and the North Pacific issued by that Department, have in their possession the very latest information, culled from every possible trustworthy source, with respect to marine meteorology. Unfortunately, only a very small percentage of the world's merchant officers are thus favourably situated. It would be difficult, if not impossible, to improve upon either the matter or the manner of these American aids to safe and rapid navigation. Hence it has seemed good to me to follow on the lines broadly marked out by the authorities at the Washington Hydrographic Office, although, perhaps, differing in minor details. Many of the diagrams are adaptations from the United States Pilot Charts; a few are kindly lent by Messrs. H. Hughes & Son, 59 Fenchurch Street; others are from various publications of the British Hydrographic Department and the Meteorological Office. My thanks are specially due to the Council of the last-mentioned office for granting me free access to their valuable original documents relating to marine meteorology. My aim is to lay before apprentices and officers of merchant ships such rudiments of marine meteorology as are necessary to ensure safety and quick passages, in the hope that they will thus be induced to follow up the subject in more mathematical treatises. Written without any pretence to what in my sea-going days we termed "high-science," this volume is but a friendly offer of assistance from a sailor on the retired list to his brethren in active service.

WILLIAM ALLINGHAM.

PREFACE TO SECOND EDITION.

It is gratifying to note the active interest that has been aroused in "Marine Meteorology" since Messrs. Charles Griffin & Co. projected their Nautical Series, in which this book finds its place, and it is evident the work has not only appealed to the imagination of sailors, but has encouraged accurate survey of the phenomena manifested in our atmosphere and the ocean, as letters to the author from various parts of the world testify. The Governments of Great Britain and the U.S.A., as well as other nations, have now realised the necessity for mariners having accurate knowledge of meteorology, and recently the subject has found place in the Examinations of the Board of Trade. This book has therefore been revised, and an Appendix given explanatory of the new departure of substituting a system of millibars in barometer readings and absolute temperatures for thermometers. The publication has been held back on account of the war; but as the book has been out of print for some considerable time, it is thought desirable to delay no longer, as students are needing a complete text-book on the subject.

W. A.

"Saratoga," Clairview Road,
Streatham, London,
April 1917.

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A MANUAL OF MARINE METEOROLOGY.

CHAPTER I.

INTRODUCTORY.

Definition.—The term **meteorology** is made up of two Greek words: μετεωρος, raised in the air, and λογος, a discourse. Hence, as the name strictly speaking implies, meteorology is the science which treats of the phenomena occurring in the vast ocean of air surrounding the globe, as well as of their causes and effects. Marine Meteorology deals with that portion of the atmosphere which overspreads the great masses of water which divide, yet connect, the land areas. It is impossible to draw a very hard and fast line between marine meteorology and the physical geography of the sea; nor has any attempt been made to effect such division throughout this elementary work intended to bring before the mariner information with respect to everything usually recorded in a meteorological logbook at sea. Meteorology is not so much a science by itself as a composite arrangement of portions of many intimately allied sciences.

Necessity for the Study.—Seafarers are, of stern necessity, proficients in weather forecasting, although all are not, of course, equally gifted; and they require to be fairly familiar, not only with the general conditions prevailing over a considerable ocean area around them, but also with the varying phenomena which precede important atmospheric changes. An acquaintance with marine meteorology helps the navigator to make a passage with the least delay and in comparative safety. No longer does the seafarer regard the moon as a disturber of the weather, acting in some ill-defined manner; neither does he expect to experience a terrible convulsion of nature upon the appearance of a comet or of a dread meteor. Climate, weather changes, the physical condition of the atmosphere; and the manifestations of heat, light, electricity and magnetism; all appertain in some measure to marine meteorology. Ocean currents and icebergs will also require consideration, as being important factors in the modification of climate and weather.

Marine Meteorology, in so far as passages and the greatest possible safety are concerned, has always been studied by sterling seamen. Yet without barometers and thermometers there would have been but little, if any, advance in weather work. Improvements in the construction of instruments, and the co-operation of seafarers, have raised Marine Meteorology out of the slough of empiricism in which it had lain neglected for centuries. Prior to Harrison's success in devising an accurate timekeeper for use at sea, there was frequently a grave difficulty experienced in determining, within a few degrees, a ship's geographical position, and even the very best kept logbooks must have introduced doubt into discussions of storms.

The development of the Subject.—A renowned American seaman, the late Commander M. F. Maury, of the United States Navy, may rightly be deemed the founder of scientific Marine Meteorology. He first gathered the strands of the subject, laid them up into a coherent whole, and eventually arranged the result so as to be useful to seafarers for all time. By force of his indomitable energy, and his "infinite capacity for taking pains," Maury induced shipmasters of the merchant navies all the world over, to co-operate with him in the good work. They supplied carefully kept observations of wind, weather, temperature of air and sea, atmospheric pressure, and other items of interest, taken at specified hours by day and by night at well-defined geographical positions during the voyage. Maury's brilliant deductions from the scattered data, obtained from thousands of observations, have seldom been equalled, and never surpassed in value. To Maury's masterly methods the world's navigators owe very much with respect to the subject of this book.

As the result of that illustrious American seaman's efforts, the United States Government convened an international maritime conference, which met at Brussels in 1853 and drew up a scheme for the record of observations of Marine Meteorology. Ever since that gathering of seamen the collection of data has been steadily proceeded with by the state-supported departments of all nations. Marine Meteorology is, therefore, naturally based upon the earnest co-operation of those that go down to the sea in ships.

Scope of the present work.—After explaining the instruments in use at sea for the purposes of Marine Meteorological Observations, the logbook itself will be described. Then, having obtained a grasp of the instruments and the method of recording, we shall pass on to consider the various facts which constitute Marine Meteorology, regarded from a loftier standpoint than that which strictly belongs to it. In this way the horizon is extended, and the student perhaps tempted to become an observer of meteorology, physiography, and natural history. Atmospheric pressure, the temperature of the air and of the sea, the salinity of the oceans, the winds, the law of storms, hurricane seasons and tracks, ocean currents, icebergs, weather charts, phenomena due to moisture, optical phenomena, and electrical indications, will all be dealt with in a popular way without requiring from the reader any considerable mathematical knowledge.

Since the first edition of this work was published, radio-telegraphy has become an accomplished fact on board many a steamship. It would appear that the steamer "Lake Champlain" was the pioneer British ship permanently fitted with radio-telegraphy apparatus; and the commencement of wireless shore stations, as a business proposition, may rightly be attributed to 1897. Radio-telegraphy, from the point of view of marine meteorology, is dealt with, in elementary form, in Chapter XX.

CHAPTER II.

INSTRUMENTS USED IN THE STUDY OF MARINE METEOROLOGY.

The Barometer. — The *barometer* is an instrument used to determine the weight, or pressure, of the superincumbent atmosphere.

A few simple experiments will convince the most sceptical that air has weight. Fill a wine-glass with water, cover its mouth with a piece of stiff paper of suitable size, hold this paper cover tightly to the mouth of the glass with one hand, and turn the glass upside down with the other hand. On removing the hand holding the paper it will be noticed that the latter remains in position. The pressure of the atmosphere prevents the water from falling out, and the paper merely serves to keep the air and water from mingling together. A circular piece of soft leather, known to schoolboys as a "sucker," is a familiar example. Moisten the leather and press it down on to a loose piece of board. In this way the air is expelled from between the sucker and the board, and the latter can then be lifted up by means of the string attached to the sucker.

A wine-glass held mouth downward over the flame of a candle for a few seconds, and then placed upon the fleshy part of the hand, will adhere thereto, and the hand will swell up, owing to the pressure of the air inside the glass being less than the air pressure outside. A partial vacuum of similar nature is supposed to exist at the centre of a cyclonic storm. During the passage of such a meteor over a West India island the windows of houses are said to have been *forced outward* into the streets by the greater pressure of the air within the houses. Atmospheric pressure also drives water up to fill the partial vacuum in pumps, syphons, and syringes. When pumping ship the student can think out for himself *why* the water rises.

About the year 1640 some pump makers, desirous of raising water from a well 50 feet deep, found that 34 feet was the maximum limit to which it would rise. The philosopher Galileo was therefore asked for an explanation. His pupil, Torricelli, came to the conclusion that the height to which water could be raised depended in some way upon atmospheric pressure. He inferred that mercury being about 13·6 times heavier than water should only rise (34 ÷ 13·6) feet, or approximately 30 inches. To prove this he took a hollow glass tube, about 6 feet long, hermetically closed at one end; filled the tube with mercury; closed the open end with his thumb; inverted the tube; and dipped the lower end into a bowl containing mercury, with water covering it, as indicated in fig. 1. On removing his thumb the mercury moved slowly down the tube, and eventually remained stationary. When the tube was raised, so that its mouth was above the mercury, but under the water, the mercury ran down the tube and the water at once took its place with a rush. This experiment proved that about 30 inches of mercury balanced the pressure of the atmosphere just as 34 feet of water did in the well. Such was the origin of the first barometer.

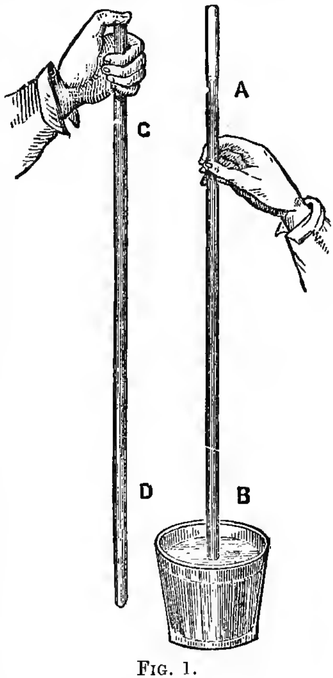


FIG. 1.

After modification in form, though on precisely the same principle, the barometer came into use half a century later on board ship. The empty space between the top of the tube and the upper surface of the mercury is known as the *Torricellian vacuum.* If any air were left in that space the barometer would be worse than useless, for it would mislead in consequence of the imprisoned air exerting a varying pressure on the mercury beneath.

Torricelli concluded that if a 30 inch column of mercury supports the atmosphere at sea level, a less lofty column would suffice for higher altitudes. Pascal carried a primitive barometer to a height of 6000 feet in order to test this opinion. Careful comparisons showed that the mercury descended the barometer tube until the mercurial column was 6 inches shorter than at the base of the mountain. A vertical ascent of 900 feet causes a difference of about 1 inch in the barometer readings at the two levels, disregarding the effect of temperature. The pressure of the atmosphere on the surface of the mercury in the cistern of a barometer maintains the mercury in the tube at a corresponding height. In 1651 Perrier noticed that the fluctuations in the height of the mercurial column of a barometer assisted in forecasting the weather.

English mercurial barometers are usually graduated to inches and decimal parts of an inch.* The average height at sea level is about 29·9 inches; but, in our latitudes, the range is nearly 4 inches, from slightly over 27 inches to a little above 31 inches.

Suppose the internal area of a barometer tube to be 1 square inch, and the height of the mercurial column 30 inches. Then the 30 cubic inches of mercury in the tube will weigh 14·7 lbs. Consequently the air pressure is a little less than 15 lbs. on every square inch. Water, glycerine, and other liquids will serve to measure the weight of the atmosphere; but mercury is preferable. It requires less length, only a 30-inch column, as against 408 inches of water and 318 inches of glycerine; it neither wets the glass tube, nor adheres thereto; and does not form vapour under normal conditions. In a water barometer the vapour pressure in the space above the water column is sufficient to depress the column 1 foot at a temperature of 75° F. Even though the Torricellian vacuum were filled with the vapour of mercury the result would be insignificant.

Small fluctuations in pressure are better shown by a glycerine barometer, having regard to the fact that a variation of an inch in the mercurial column is equivalent to about 10 inches in the glycerine column.

Barometer tubes must contain *pure* mercury; otherwise the density will vary, the mercury will adhere to the tube, and accuracy become impossible. Air and moisture are expelled by boiling the mercury in the tube, a few inches at a time, over an alcohol lamp, or a charcoal furnace. It is not an easy operation. The mercurial vapour thus formed sweeps out both air and moisture from the tube. Unless both be driven out they will get into the Torricellian vacuum space, and tend to depress the mercury. On gently inclining a barometer thus treated, the mercury will strike the top of the tube with a metallic sound as though a solid body. If the vacuum be imperfect a dull thud results, owing to the imprisoned air acting as a cushion.

Mercurial barometers may require four corrections to make the readings comparable with others. These corrections are made for capacity, capillarity, temperature, and height above sea level. Like a sextant, a barometer may also have an index error.

* See page 196.

Hence it is sometimes stated that certain barometer observations are corrected and reduced to 32° and sea level. *Capacity* error is caused by the varying level of the mercury in the cistern. It depends on the ratio between the bore of the tube and the sectional area of the cistern. The height of the barometer is the distance between the surface of the mercury in the cistern and the upper surface of the mercury in the tube. A rise or fall in the column lowers or raises the surface of the mercury in the cistern. (Compare this with the correction for tide which is made to soundings.) Liquids which adhere to glass, as water, etc., rise to a sensible height on a glass tube of small bore; liquids which do not adhere to glass, such as mercury, are depressed. This property is called *capillary* action, and depends upon the bore of the tube. Consequently the correction for capillarity, with a mercurial barometer, is additive.

The marine barometer issued to observers by the Meteorological Office is so constructed that corrections for capacity and capillarity are not required.

Corrections for Temperature.—Mercury is used, not only in the barometer for measuring atmospheric pressure, but also in the thermometer for determining temperature. The column lengthens with heat, and contracts as the temperature falls. Hence it will be inferred that a barometric reading, with the same atmospheric pressure, will be higher or lower than the truth according to the temperature. To every mercurial barometer should be affixed a thermometer, known as the *attached thermometer*. By reading this attached thermometer, and referring to the table in the Appendix, the necessary correction for temperature is directly obtainable so as to reduce the reading to what it would be at a temperature of 32° F., which is taken as the standard for comparison with other readings. Thus, if the barometer reading be 30·138, and that of the attached thermometer 80°, then the correction is − ·138, and the reading reduced to 32° F. becomes exactly 30 inches.

The pressure of the air decreases as we go aloft. Hence the necessity for a correction to reduce a reading at a given altitude to what it would be at sea level. This is the *correction for height*, and amounts approximately to ·001 inch for each foot above sea level for low altitudes. It is always additive.

Suppose that a barometer reading taken at the keel of a large sailing-ship is 30 inches, while at the same instant a barometer reading at the truck is 29·774 inches, the temperature of the air being 60° F., it is required to find the height of her mast. Turn to the table in Appendix, and under the heading of 60° find the difference between 30 inches and 29·774 inches

= ·226 inch, then the height in feet is 210. As the mercury in the barometer falls about $\frac{1}{10}$th of an inch for an ascent of 100 feet it follows that the height of a mountain can be approximately determined by its aid. An aneroid does not lend itself so readily to exactness, but will serve in the absence of a mercurial barometer.

Nautical observers need not trouble to apply any corrections to instrumental observations before entering in the logbook. In studying charts of barometric pressure, and comparing the readings on board ship with those of the chart for the same geographical position, it will be well to remember that owing to the chart values having been corrected for temperature they will be somewhat lower than the ship readings. With respect to the general run of ships the correction for height above sea level is immaterial. Some of the largest mail boats, however, carry the barometer cistern 50 or 60 feet above sea level, and then the height is more important.

How to read the Barometer.—The following explanation of the method of reading a mercurial barometer is taken from the "Instructions for Keeping the Meteorological Log" supplied to observers co-operating with the Meteorological Office, and is to be read in conjunction with fig. 2.

"To facilitate the taking of accurate readings of the height of the barometer, a small movable scale, called a vernier, is attached to the instrument.

"The general principle of this movable dividing scale is that the total number of the smallest spaces or subdivisions of the vernier are made equal, taken together, to one less or more than that number of the smallest spaces in an equal length of the fixed scale. In standard barometers the twenty-five spaces in the vernier are equal to any twenty-four spaces of the scale, which are each half a tenth or five hundredths of an inch; therefore a space on the scale is larger than a space on the vernier by the twenty-fifth part of ·05, which is ·002 inch, consequently the vernier exhibits differences of ·002 of an inch.

"The vernier is moved by a rack and pinion. Turn the milled-head of the pinion so as to bring the *lower* edge of the vernier exactly on a level with the top of the mercurial column. When set properly, the front edge of the vernier, the top of the mercury, and the back edge of the vernier should be in the line of sight, which line will thus just touch the *middle* and *uppermost* point of the column. Great care should be taken to acquire the habit of reading with the eye exactly on a level with the top of the mercury, that is, with the line of sight at right angles to the scale.

"A piece of white paper placed behind the tube, so as to reflect the light, assists in setting the vernier accurately. A small bull's-eye lamp held behind the instrument enables the observer to get a correct setting at night. When observing the barometer it should hang *freely*, not being inclined by holding, or even by a touch; because any inclination will cause the mercury to rise in the tube.

Every long line cut on the barometer scale corresponds to	– a tenth	(·100)	of an inch.
,, short ,, ,, ,, ,,	– five hundredths	(·050)	,,
Every long line cut on the vernier scale corresponds to	– one hundredth	(·010)	,,
,, short ,, ,, ,, ,,	– two thousandths	(·002)	,,

"The mode of reading off may be learnt from a study of the following diagrams, in which A B represents part of the scale, and C D the vernier, the lower edge D denoting the top of the mercurial column. The scale is readily understood ; B is 29·000 inches ; the first line above B is 29·050 ; the second line 29·100, and so on. The first thing is to note the scale line just below D, and the next is to find out the line of the vernier which is in one and the same direction with a line of the scale. In *a*, fig. 2, the lower edge of the vernier, D, is represented in exact coincidence with scale line 29·5 ; the barometer therefore reads 29·500 inches. Studying it attentively in this

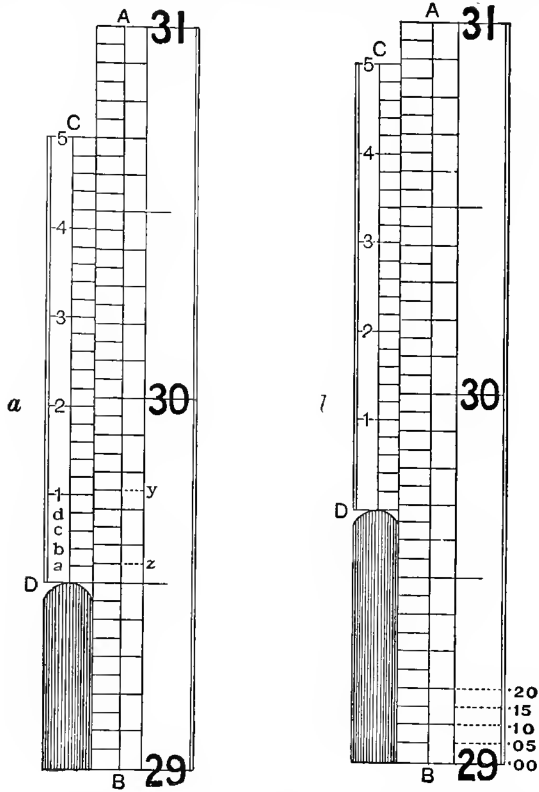


Fig. 2.

position it will be perceived that the vernier line *a* is ·002 inch below the next line of the scale. If, therefore, the vernier be moved so as to place *a* in a line with *z*, the edge D would read 29·502. In like manner it is seen that *b* is ·004 inch away from the line next above i *on the scale* ; *c*, ·006 inch from that next above it ; *d*, ·008 inch from that next above it ; and 1, on the vernier, is ·010 below *y*. Hence, if 1 be moved into line with *y*, D will read 29·510. Thus the numbers 1, 2, 3, 4, 5, on the vernier indicate hundredths and the intermediate lines the even thousandths of an inch. Referring now to *b*, fig. 2, the scale line just below D is 29·650. Looking carefully up the vernier, the third line above the figure 3 is seen to lie evenly with a line on the scale. The number 3 indicates ·030, and the third subdivision ·006 ; and thus we get, reading on scale 29·650, reading on vernier ·030 + ·006, actual reading 29·650 + ·030 + ·006 = 29·686 inches.

FIG. 3.

FIG. 4.

"Sometimes two pairs of lines will appear to be coincident ; in which case the intermediate thousandth of an inch should be set down as the reading. Thus, suppose the reading appears to be 29·684 or 29·686, the mean 29·685 should be adopted."

In the near future all barometers lent to shipmasters by the Meteorological Office will be read to hundredths only, as this degree of refinement is deemed quite near enough for marine work.

Pipette and Cistern.—In first-class barometer tubes there is a contrivance to trap any air or moisture on its way to the vacuum. It is known as the pipette, and is shown by A B in fig. 3. Air, or moisture, will generally be stopped at the shoulder A as represented by the white space. The finer bore indicated in this picture of a portion of a marine barometer tube is to check the up-and-down movement of the mercury, *pumping*, as it is termed, due to the ship's motion in a heavy sea. Should the bore be excessively contracted, on the other hand, the action of the mercurial column becomes sluggish. Occasionally a speck of dirt in the mercury stops the mercury from moving up the pipette, and the readings may then be considerably in error. The closed cistern is made of wood, or of iron. The former kind are sufficiently porous to permit of the atmospheric pressure being conveyed to the mercury ; the latter have a small aperture at the top, closed internally by a piece of leather, through which the air pressure acts, but the mercury does not escape.

Fig. 4 is a representation of a barometer, as suspended for use. For ordinary use at sea less carefully constructed instruments serve equally well whether the frames are of brass or of wood. Should the barometer "pump" it is necessary to take a mean of the highest and lowest readings. Such an understanding prevailed for many years. More recently it has been pointed out that if a barometer "pump" at the time of observation, the vernier should be set for reading when the agitated mercury has completed its downward movement. The mercury in the tube, not that in the cistern, rises and falls with the ship's motion.

Automatic aneroids, such as shown in fig. 5, are now frequently used on board ship. Very often the ship's barometer on board a sailing-ship, if mercurial, is suspended from the skylight. Consequently, when the tables beneath are spread for meals the instrument is found to be seriously in the way of those sitting around. In one large liner the mercurial barometer was fixed in a lofty companion where it could not possibly be read. Recourse was had to the aneroid. Barometers put in per specification, like compasses, are not always placed in the most suitable position for ready reference.

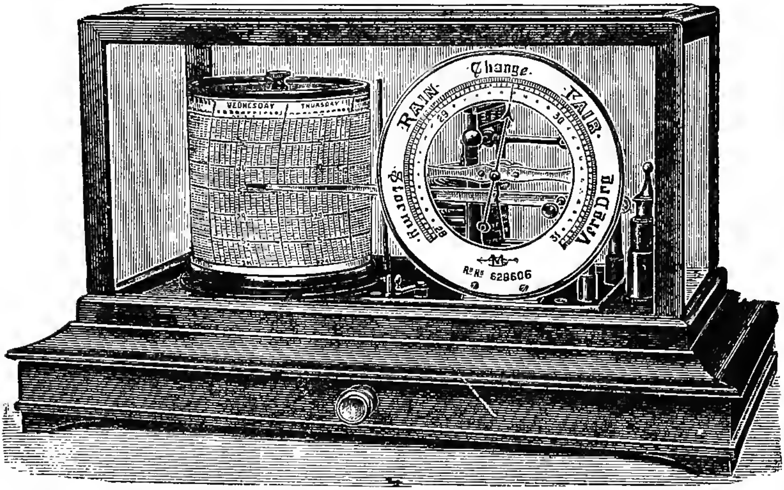


FIG. 5.

Meteorological Office Mercury Barometers have a suitably contracted tube, a pipette, a brass frame, closed cistern, and a scale of contracted inches to save the trouble of effecting the various corrections. They are tested at Kew Physical Laboratory, Teddington, to see that they are neither too sluggish, nor yet "pump" in consequence of ship's motion, and, during the testing, the pressure is varied from 27 inches to 31 inches in an air-tight chamber containing the barometer so as to allow for greatest probable range over all the oceans. Warship barometers are protected from vibration and concussion, as far as possible, by a suitable application of vulcanised india-rubber packing to the covered portion of the tube.

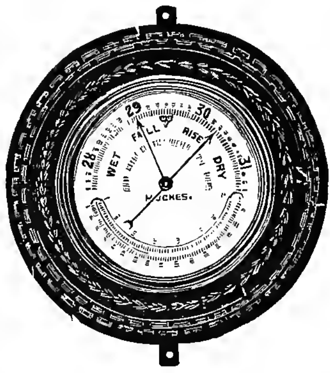


FIG. 6.

Every sailor is familiar with the external appearance of an aneroid (shown in fig. 6). Fig. 7 indicates the most improved form of aneroid mechanism, with the hand remaining attached to the stem F, the outer case and face being removed. Here we have a corrugated metal box A, which has been nearly exhausted of air through the tube J, and then hermetically sealed by soldering. The top and bottom of this box are corrugated in concentric circles, so as to yield inwardly to external pressure and return when the pressure is removed. B is a powerful curved spring, whose lower part Z is extended into two arms of which the extremities form little trunnions that work in holes in the two supports Y. These supports are firmly fixed to the frame plate P of the instrument; the upper flange is attached at X (behind F)

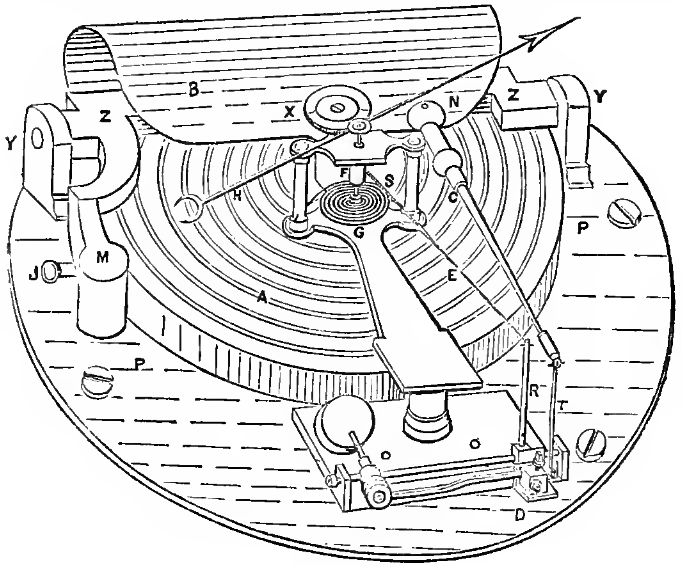


FIG. 7.

to the corrugated box A. The lever C is joined to the upper edge of the spring B at N, and by the system of rigid levers, T, D, R, and E, it is connected with the chain S. The other end of this chain is coiled around the stem F and then fastened to this stem. As the box A is compressed by the increasing weight of the atmosphere, the spring B, by means of its rigid attachment to the box A (behind F), is drawn down; the lever C is thus depressed; this motion, by the system of levers, T, D, R, and E, is so communicated to the chain S as to unwind it; the stem F, to which the chain is attached, thus turning to the right (that is, the observer's right as he looks at the page), carries with it the hand H, which turns on the graduated dial of the barometer in the direction of increased pressure. In the meantime the spiral spring G, which is coiled around F, with one extremity fixed to the frame of the barometer and the other to the stem F, is compressed. When the pressure decreases, the box A and the spring B both relax by virtue of their elasticity—the chain S slackens—the spring G unwinds—and as a consequence of all these movements the stem F turns toward the left (that is, the observer's left as he looks at the page) and carries with it the hand H in the direction of decreased pressure. M is an iron arm extending from the lower flange of the spring B. A screw works in this arm through the bottom of the plate; it is the head of this screw that is seen at the back of all aneroids; by means of this screw the spring B may be tightened or relaxed, so that its motion, conveyed to the hand H through the system of levers, C, T, D, R, E, and the chain S, may cause this hand to point to the same reading that a standard mercurial barometer indicates. The lever C is composed of brass and steel soldered together, and adjusted by repeated trials to correct it for the effects of temperature. The graduations of the aneroid scale are obtained by comparison with the correct readings of a standard mercurial barometer under normal and reduced atmospheric pressures. Reduced pressure, for comparison purposes, is obtained by placing both instruments under the receiver of an air pump.

The little thermometer attached to the aneroid is not used in the same way as the attached thermometer of a mercurial barometer, as aneroids are now, as a rule, compensated for temperature; and, in any case, correction for temperature cannot otherwise be applied with certainty. Aneroids have a bad name among scientific men; but for practical purposes at sea they have many advantages over the mercurial barometer. Aneroids must, however, be frequently compared with a correct standard mercurial instrument. Just as we get the error and rate of a chronometer, so we approximately arrive at similar corrections for an aneroid. This at least is certain. A dozen aneroid readings over an ocean area, even though the errors may not be known within ± ·1 inch, are more valuable than one mercurial reading absolutely correct to ·001. Aneroids sometimes suddenly vary their errors. Mercurial barometers occasionally act in the same way. On 16th March 1879, in lat. 21° N., long. 34° E., the barometer of the steamship "Oakdale," Captain W. F. Caborne, C.B., R.N.R., suddenly rose from 30·12 inches to 30·39 inches. It remained at that till the 19th, in lat. 17° N., long. 40° E., varying a couple of hundredths of an inch only, and then as suddenly fell to 29·94 inches. The commander had anticipated a cyclone, although this would have been opposed to experience. As a matter of fact mercurial barometers occasionally act thus owing to faulty construction. Whether aneroid, or mercurial, be used, the importance of frequent comparison is obvious; and the rules of the United States Hydrographic Office on this subject are stringent. Similar methods are adopted by the British Meteorological Office.

Comparisons of Observations.—To determine the reliability of the instrument, comparisons made by the observer himself with a standard barometer should be obtained whenever practicable. In order to make such comparisons without taking the instrument ashore, readings should be recorded, preferably at 8 a.m. or 8 p.m., 75th meridian time, in ports of the United States or Canada, but in ports where U.S. Branch Hydrographic Offices are established, observations can be made at any hour of the day. Blank postal cards, with instructions, are furnished observers on application at any U.S. Branch Hydrographic Office, the British Meteorological Office, and similar departments, for making these comparisons. The time of observation and, if the instrument is a mercurial one, the temperature shown by the thermometer attached to the barometer, should both be carefully noted; but if it is an aneroid, the temperature is not required. In the experience of weather workers it has been found best with the aneroid to take the absolute difference between its reading and the corrected height of the mercurial standard as the total correction to be applied to recorded observations for that pressure. With mercurial barometers, the readings are first corrected for temperature; the difference then found between that result and the corrected height of the selected standard is the correction to be applied to the observations. It is evident that the total correction is the algebraic sum of instrumental errors, correction for altitude, and the "personal equation" of the observer. Comparisons cannot be made too often, for it has frequently been noticed that the correction applied on an outward passage would not answer for the return one.

Another method employed in the U.S. Hydrographic Office, and elsewhere, for checking barometer readings when the reliability of an instrument is suspected or comparisons are lacking, is to make use of the isobars of the U.S. Weather Bureau Maps, or the British Daily Weather Report, or readings taken at certain shore stations. It will readily be seen that corrections are thus obtained for the barometers of vessels at that time in the immediate vicinity of any place where observations are supplied in the publications mentioned.

Thermometers.—The thermometer is a heat measurer, and consists of a glass tube of small bore closed at both ends, one of which is furnished with a bulb. For ordinary temperatures of air, water, etc., mercury fills the bulb and part of the tube; but, in cold climates, where mercury would solidify, alcohol is used instead. Spirit is also used for registering the minimum readings, should the temperature fall below $-37{\cdot}9°$. Thermometers are read

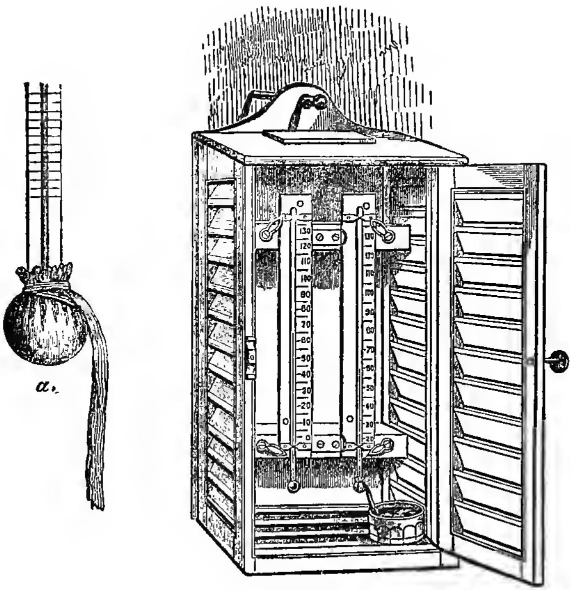


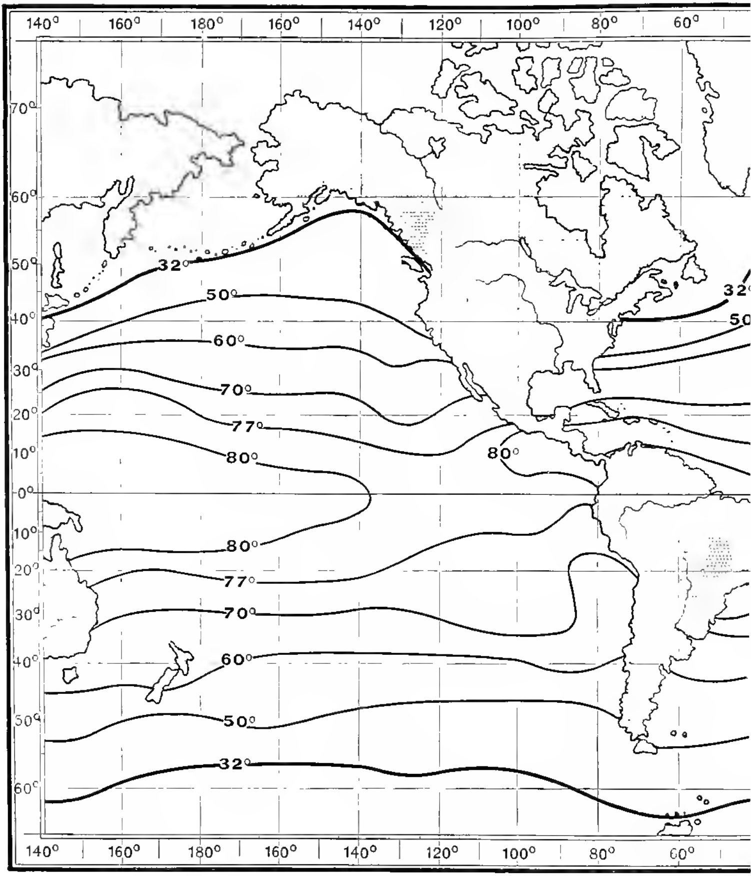
FIG. 8.

to degrees and tenths of a degree. The two fixed points on the scale correspond to the temperatures of melting ice and of boiling water, and are 32° and 212°, respectively, on the *Fahrenheit* scale. Between these two points the distance is divided into 180°. In the *Centigrade* graduation the freezing point is 0° and the boiling point 100°. In Réaumur's thermometer the same space is divided into 80°, the freezing point of water again being the zero of the scale. To obtain the temperature of the air in the shade a screen is used on board ship, as in fig. 8. Good thermometers are usually filled and hermetically sealed some months before the scale is engraved on them. With the lapse of time, the atmospheric pressure acting on the bulb's exterior surface tends to drive the mercury further up the vacuum above the column and the bulb is permanently contracted. Thermometers of any age usually require a minus correction to be applied, the readings being too high by 0°·5 or 1°.

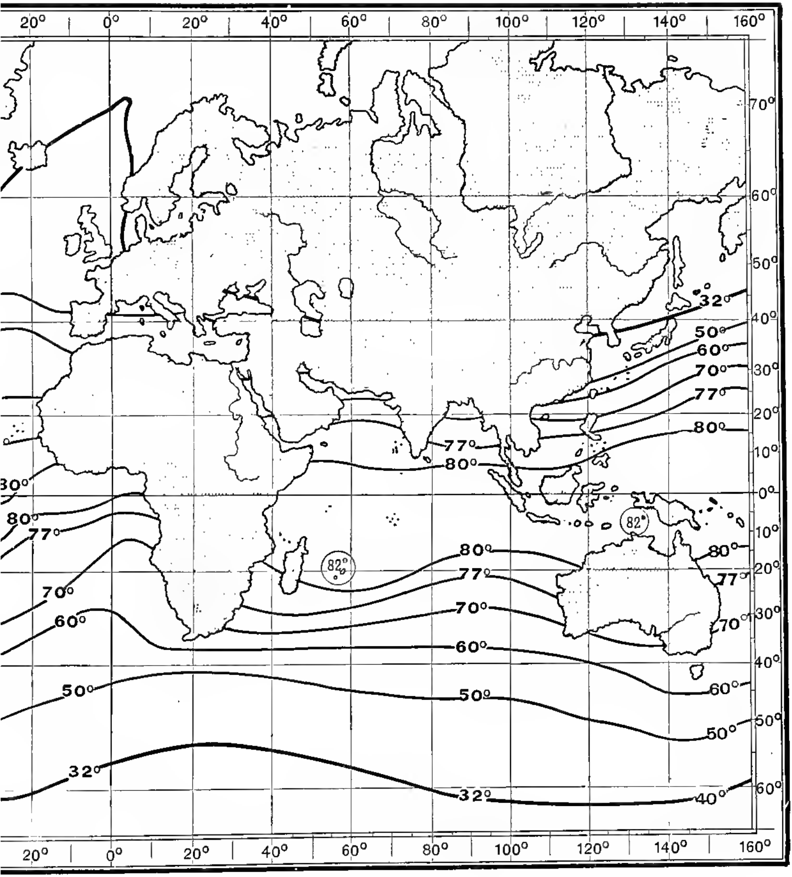
As the barometer can be used to measure the height of a mountain at different altitudes by indicating the atmospheric pressure, so the thermometer can be made to serve the same purpose. Water boils when the tension of its vapour exceeds the atmospheric pressure upon it. It has been found that the boiling point is lowered 1° F. for every 0·589 inch of barometric pressure at moderate heights. At Quito, an altitude of 9000 feet above sea level, water boils at 194°, and therefore the ship's cook on a picnic would find a difficulty in properly preparing the crew's tea. Hence, to roughly obtain the height, observe the temperature at which water boils, thence deduce the air pressure, and compare the latter with the pressure at a neighbouring place for the same instant, the height of which is known. From the difference of pressure the height can be obtained.

As a general rule, bodies expand with heat and contract as they become cooler. Both the mercury inside the glass receptacle, and the glass itself, obey this law. In the thermometer, however, the latter variation is insignificant, and may be dismissed from practical consideration. Alternations of heat force the mercury up and down the tube; a scale of equal parts is marked, either on the tube or the frame; and by noting the division of the scale against which the end of the mercurial column appears we obtain the temperature of the bulb, which may be taken to be the same as that of the surrounding medium, the air, or the liquid, in which it is placed.

Hygrometers.—Hygrometers are *moisture* measurers. Several sorts are in use to determine the dampness of the air. The easiest and most usual plan at sea, consists of utilising two thermometers close together, as in fig. 8. One of these has a piece of muslin, or cambric, tightly fitted to the bulb; and this is kept constantly damp by a few strands of cotton wick rove through the bight around the bulb with the free ends dipping into a water vessel placed near at hand. The damp bulb must not dip into the water, or otherwise the temperatures obtained will be those of the water itself, and not those due to evaporation. This thermometer is known as the damp bulb; the other is the dry bulb. To obtain the hygrometric state of the atmosphere both thermometers must be read at the same time. The damp bulb reading is useless by itself. It is usually lower than the dry bulb reading. In dry



ALLINGHAM'S MARINE METEOROLOGY. PLATE I.—LINES OF E



TEMPERATURE (ISOTHERMS) OF AIR, FOR THE MONTH OF JANUARY.

weather the difference may be from 5° to 10° at sea, or 20° on shore; in damp weather, the readings may be precisely the same, or present but a small difference either way, due to instrumental error. The greater the difference between readings of dry and damp bulb at the same instant, the drier the air. Tables are in existence which give the degree of humidity corresponding to the difference between the readings. Evaporation of the water from the muslin cover of the damp bulb lowers the temperature indicated by that thermometer. Many causes conspire to render this observation of very little use at sea. In fact it is extremely difficult to find a suitable place for the screen so that it may be in the open air and yet free from the disturbing influences of sun, rain, and spray. A thermometer screen placed in the companion, or some similar place, is utterly useless. Scientific research would be better served by leaving the screen at home. No one could then be misled by the readings.

The receptacle should contain fresh distilled or rain water by preference, in order to prevent deposition of lime and other impurity on the bulb; and it ought to be filled some little time before observing, so as to ensure the attainment of the actual temperature of evaporation. The muslin and wick have both to be kept clean. They should be washed both before use, and occasionally while in position. In frosty weather, a thin coating of ice forms on the muslin, the evaporation proceeding as usual; but if the muslin is dry and free from ice, it must be wetted, and allowed to freeze, before making observations.

Whenever it happens, as it does sometimes in high latitudes, that the temperature of the air is below 0° F., remember to place the minus sign (–) before the reading. Popular language loosely refers to 13° F. as 19° of frost, or 19° below the melting-point of ice; but 19° below the zero of the Fahrenheit scale should be entered in the logbook as –19°, and 19° of frost as 13°. Careful attention to this fact will prevent confusion.

Sea Surface Temperatures.—To obtain the temperature of the sea surface a bucket of water from alongside is drawn, and the temperature at once obtained by immersing the thermometer in use, remembering to allow sufficient time for it to adjust itself to the actual temperature of the water, say, two minutes. Ridiculous sea temperatures are sometimes recorded in ships' logbooks. When the temperature of the air in the shade is, say, 17° F., a thermometer dipped into a bucket of freshly drawn sea-surface water, and hurriedly withdrawn, may read 20° F., and this reading is given in the logbook as that of the sea-surface temperature, which is absurd. Should only one thermometer be on board, take the temperature of the air with it first, and then the sea temperature.

Unless the sea-surface water is tested on reaching the deck, it will begin to assume the temperature of the surrounding air, and the result be erroneous. Water should be drawn forward of the ejection outlet in the ship's side.

Great changes in the sea temperature will be experienced in certain parts of the ocean, notably near the Banks of Newfoundland, Agulhas Bank, River Plate, Cape Frio, and running the easting down in the Southern Ocean. Elsewhere the sea temperature approximates closely to that of the air. Reading to whole degrees is sufficiently accurate for all temperature observations at sea, whether of air or sea surface, except when hygrometric readings of both dry and damp bulb thermometers are made.

Density and Specific Gravity; Hydrometers.—When we say that anything, such, for example, as an iron belaying-pin, weighs so much, we refer to what is known as *absolute weight.* But bodies differ in *density*, and a cubic foot of water does not weigh nearly so much as the same volume of mercury. When weight is considered as the relation of equal volumes of different substances, we speak of *relative weight*, or *specific gravity.* Water is the standard, or *unit* adopted, and the weight of the substance compared with that of an equal volume of water is known as the *specific gravity* of the substance. Specific gravity is merely relative weight, and is written *S.G.* In other words, *the S.G. of a body is the number which expresses the ratio which the weight of a cubic inch of the body bears to the weight of a cubic inch of distilled water at the temperature of* 60° *Fahrenheit.*

SPECIFIC GRAVITIES OF SOLIDS AND LIQUIDS.

Fresh Water, 1. Sea Water, $\left\{\begin{matrix}1{\cdot}020\\1{\cdot}050\end{matrix}\right\}$

Platinum,	22·1	Lignum vitæ,	1·3	Mercury,	13·6
Gold,	19·4	Mahogany,	1·1	Glycerine,	1·3
Lead,	11·4	Oak,	1·1	Coal,	1·3
Silver,	10·5	Beech,	0·9	Milk,	1·03
Copper,	8·9	Elm,	0·7	Ice,	0·9
Steel,	7·8	Cork,	0·2	Olive oil,	0·9

An egg placed in a tumbler of fresh water will sink, whereas it will float if placed in brine from the harness cask. The brine is *denser*, or of *higher specific gravity*, than fresh water, and has greater buoyancy power. Sometimes hollow glass beads of different weights are used to determine specific gravity by finding which bead will remain stationary in a liquid, wherever it is placed. By taking advantage of a liquid's buoyancy we can ascertain its specific gravity. A rough test can be made by attaching a weight to the lower end of a light wooden rod, such as a treenail, and note how far it sinks in distilled water. Put salt in the water and the treenail will rise; add methylated spirit and the treenail will descend. This illustrates the principle of the hydrometer, an instrument for measuring the density of liquids.

A glass hydrometer is frequently employed, although brass instruments are also used at times. Change of form, due to rough handling and the corrosive action of salt water, introduces considerable error into the results from brass hydrometers. Fig. 9 indicates a common form of glass instrument. The bulb at the bottom is ballasted with small shot, or mercury, so that the hydrometer may float steadily in an upright position. The upper portion is a narrow stem, enclosing an ivory scale, and closed at the top. This scale is kept in position by a small spring. Between these two extremes is a larger cylindrical portion for the purpose of affording buoyancy. Several different forms of hydrometer are in use.

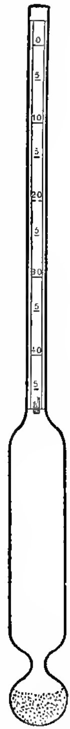


FIG. 9.

By means of this instrument the S.G. of the sea is obtained along the route. When a homogeneous body floats in a liquid the volume immersed is inversely as the specific gravity of the liquid. On this principle depends the construction of the hydrometer used on board ship. The same body in fluids of different densities floats higher in the denser than in the rarer. Hence a ship with the Plimsoll mark somewhat submerged in a fresh-water dock may rise in sea-water so as to expose it sufficiently to comply with the law.

An absolutely correct hydrometer, in distilled water at 60° F., will sink until the highest mark or point of the scale is level with the surface. The salter the water, the more the hydrometer will rise, and the scale is contrived so as to show differences of density and ranges from 1·000 to 1·040. When recording readings in a logbook, only the figures read off are entered. The front figures can be added at any time, if necessary.. Precisely the same fact is understood whether the entry be made as 28 or 1·028.

On the western side of the North Atlantic, in the Doldrums, in the Bay of Bengal, at the mouth of a large river, in the Black Sea, and around the melting ice of the Arctic and Antarctic coasts, the specific gravity is relatively low. In the Mediterranean and the northern portions of the Red Sea, the S.G. is relatively high. Guided by these general rules, and the fact that the hydrometer readings vary very little over large areas, it is easy to check such entries in a logbook. It is of interest to note in this connection that the proportion of salts in sea-water is such that if the oceans were evaporated there would be a solid crust of salt left, averaging 170 feet in thickness, all over the globe.

Water used for obtaining the S.G. of the sea surface must be drawn from over the ship's side (forward of all ejection pipes in a steamer) in a bucket or iron pail, and the temperature observed and recorded at the same instant as its specific gravity. Any dust or grease should be wiped off the hydrometer before using it to test the water. In a heavy sea the hydrometer is occasionally found extremely awkward, if not impossible, to read. Even on ordinary occasions this observation occupies considerable time at sea. Once in twenty-four hours, say at noon, is quite sufficient for the S.G. to be taken and recorded, except where large changes, in short intervals of time, are expected. Then observations should be more frequent.

Sea temperature must, as before mentioned, be tested immediately the water is drawn. For specific gravity purposes, however, the hydrometer may be read later on, provided the then temperature of the water is also taken, and both recorded in the logbook together.

Hydrometers are difficult to read on board ship under service conditions, and the opinions of two eminent authorities under this head are reproduced here in full. Captain A. S. Thomson, C.B., R.N.R., Elder Brother of the Trinity House, recommends an observer to "suspend the glass vessel, in which the hydrometer floats, by means of a tray, and at such a level that you can read the scale comfortably. The hydrometers supplied by the Meteorological Office are far too rough-and-ready instruments to be of much value for ascertaining difference of sea-water density. As a matter of fact, the capillary action on the long stem of the ordinary hydrometer is quite sufficient to vitiate all your observations, unless you wish to observe large differences of density, such as from salt water to fresh." Captain D. Wilson-Barker, R.N.R., F.R.S.E., Past-President of the Royal Meteorological Society, Captain Superintendent of H.M.S. "Worcester," Training Ship for Cadets, has pointed out that "if accurate densities are required, one of Nicholson's hydrometers should be used; the glass in which it is immersed should rest on a swinging tray, and the temperature be noted carefully." It is to be feared that a large proportion of the specific gravity observations taken at sea, with the usual form of hydrometer and a bucket, are destitute of scientific value.

CHAPTER III.

METEOROLOGICAL LOGBOOKS.

Necessity for Daily Records.—One of the most important duties devolving upon the chief officer of a ship belonging to the Merchant Navy is the proper posting up of her logbook. Every item of interest during the voyage should be clearly, yet concisely, set forth from day to day, so that a stranger, at any subsequent period, could understand exactly what the narrator intended to convey by his entries. Course and distance, direction and force of wind, the state of the weather, the sail carried, the behaviour of the ship under varying conditions, the names of helmsmen and lookouts, the times at which sidelights and masthead light are exhibited and taken in, the water in the well, the state of the sluices, the ship's position by dead reckoning, observation of heavenly bodies, and bearings of shore objects, are all carefully entered in every logbook worthy of the name. Very little extra trouble renders such a document available for all the practical purposes of weather work. As a matter of fact, the logbooks kept on board steamships owned by large firms contain much very valuable information relative to marine meteorology.

A barometer and several thermometers are usually placed on board the majority of steamships, and a considerable number of sailing-vessels, at the owner's expense. Occasionally, hydrometers are also supplied for various purposes. Unfortunately for work where extreme precision is necessary, the instruments obtained per specification, as it is termed, are not always the best possible. Nevertheless, they are usually sufficiently accurate for use at sea, and the observations made therewith are often invaluable in the study of storm phenomena by weather workers on shore. Careful observations made with second-rate instruments afford far better information than entries of careless observations in the logbooks of ships having the most delicate instruments at command. It is essential that the errors of a ship's barometers and thermometers should be furnished by the optician in much the same way as the error of a chronometer. Any errors not exceeding 1° in a thermometer, or ·02 inch in a barometer, might safely be regarded as being immaterial. Failing such data furnished by the optician, a few readings can be taken while in port for comparison with similar readings made at the same time and which are published by authority in the daily papers; always remembering that the latter are not precisely as read off the shore instruments, as explained elsewhere. In ports of the United Kingdom, 8 a.m. or 2 p.m. is a suitable time for such observations; and in Canadian or United States ports, 8 a.m. or 8 p.m. of 75th meridian time. Never apply any corrections to readings of meteorological instruments on board ship. *Enter the observations in the logbook exactly as read from the instruments, and always bear in mind that a blank space is at least as good as an entry of doubtful value.*

It might be well to emphasise this by the yarn respecting a Yankee mate. He fell overboard while drunk, was fished up and put into dry clothes. Then he staggered to his logbook and wrote: "This day the ship went down, and all hands were drowned but me." An old down-east skipper was fond of impressing this on me.

Wind directions, and the bearings of celestial and terrestrial objects, are more useful when corrected both for deviation and variation before entering them in the logbook. Whatever method is followed, it should be distinctly indicated in a conspicuous position in the opening page of the logbook itself, so as to prevent doubt arising at some future date. Avoid erasures; rather cross out with the pen any erroneous entries. Let the master's initials appear against each day's record. When an observation of the atmospheric pressure, or any other element, is for some reason not taken as usual, it is quite unnecessary either to repeat the previous observation or to interpolate between two readings. This rule is sometimes ignored, though a doubt is thereby thrown upon the entries throughout the whole logbook. Moreover, the labour involved is wasted. If required, such interpolation and repetition can be just as well carried out by shorefolk, who were thousands of miles away, once they get possession of the logbook.

Loan of Instruments, Logs, etc.—Less than half a century ago that practical American seaman, Matthew F. Maury, introduced a plan for collecting meteorological observations from ships on every sea, and under every flag. To his boundless energy, in matters pertaining to marine meteorology, the navigator and the shipowner are deeply indebted. At weather conferences the form for a ship's weather register, or logbook, has often come up for consideration. The copy (*see Frontispiece*) of a special Meteorological Logbook, kept by an "excellent" observer for the British Meteorological Office, Captain E. Wrake Turner, on board the little barque "Mertola," then trading between

Liverpool and Pomaron, leaves nothing to desire. Young men who look upon weather registers as too much like hard work may take heart of grace after viewing this exact copy of a logbook kept in so small a vessel, in such a harassing trade. It demonstrates the praiseworthy enthusiasm of some seafarers even under most unfavourable conditions.

More than 90 per cent. of the data used for ocean weather work is supplied by masters and officers of the Merchant Navies. Masters of British ships desirous of co-operating in this good work have merely to apply in person, if possible, or by letter, to the Marine Superintendent, Meteorological Office, South Kensington, London, S.W., for the loan of meteorological instruments which are supplied at the expense of the nation, provided the shipmaster will undertake to record four-hourly observations in suitable logbooks issued for the purpose, as shown in the frontispiece, and return them, together with the instruments, either to the London central office or to an agent at an outport on completion of the voyage. Not one farthing of expense is incurred in any way by a shipmaster who thus becomes an observer co-operating with the Meteorological Office. Cost of carriage is always refunded, and various publications of the Office are presented to the master himself and the officers who assist him. One barometer; six thermometers, and a screen in which to place them, in the open air, on deck; four hydrometers; and sufficient meteorological logbooks and roughbooks for recording the observations are sent on board. The roughbooks are intended, as the name implies, to contain the observations entered up at the specified hours directly from the instruments. These rough records become the property of the observer, and are always useful for reference. The meteorological logbooks returned to the Meteorological Office are merely fair copies of the roughbooks, made when opportunity offers during the passage. Agencies exist at Cardiff, Dundee, Glasgow, Greenock, Hull, Liverpool, Southampton, South Shields, and Sunderland, at each of which ports a set of instruments is kept in working order for inspection by masters and officers. Intending observers can obtain any further information from the agents, who will supply instruments and logbooks when requested. The Marine Superintendent supplies all ships in London; and, in special cases, ships at outports where the Meteorological Office has not any accredited agent.

Specimen Page of Meteorological Logbook.—In the specimen sheet of the Meteorological Office logbook, the printed matter at the head of each column specifies its particular use. Each column is numbered at the foot for the purpose of reference. The ordinary ship's logbook is readily altered to include the most important items of this detailed official weather logbook. Sea-surface currents are deduced, as a general rule, from the difference between the observed and the dead reckoning positions at the same instant, generally noon, which are entered whenever possible in Columns 3 to 6. During the four days embraced by this specimen, bad weather prevailed. Hence the position, by observation of a heavenly body, was unobtainable, so that the set and drift of the sea-surface current could not be calculated. The course and distance given in columns 7 and 8 are obtained in the usual way. Leeway and compass error, applied to the ship's head in column 10, give the true course; the distance is either by patent log, or by ordinary log. Azimuths and amplitudes, frequently taken, supply the compass error for column 9. With a wooden ship, of which there are but few under the red ensign now, the compass deviation is small. Then the variation from the Admiralty chart, or some similar authority, is used. Beaufort's notation lessens clerical labour for wind force, weather, and sea disturbance. The wind direction should be recorded from the nearest poiut of the compass *at the instant of observing.* No matter how variable the wind may have been, during a watch of four hours, one direction will be more general than the others. Information with respect to squalls is rightly entered in the column allotted to remarks; as also the exact time of any important change in direction, or force, of the wind. Beaufort's wind scale, from 0 = a calm, to 12 = a hurricane, is fully discussed in Chapter IX.

Barometer readings are very useful. Equal care should be bestowed on this part of the logbook, in fine weather and in foul. He who watches his barometer is forearmed against impending weather changes. Looking over the barometer readings in this specimen sheet of the official weather logbook, it will be noticed how precisely the wind changes confirm them. Attached thermometer readings in column 14 are for the purpose of reducing the actual barometer readings to what they would have been had the temperature remained at 32° Fahrenheit throughout. On board the same ship two perfectly correct mercurial barometers, fixed at precisely the same height above sea level, one in a refrigerating chamber, the other in a well warmed cabin, will not give the same reading. In steaming up the Red Sea, for example, a barometer in the closed chart-room, at the temperature of 90° F., will show 30·16 inches; whereas another, at a temperature of 0° F., will indicate 29·92 inches; and a third, at 32° F., 30·00 inches.

Columns 15 and 16 are the spaces allotted to the readings of the dry and the damp bulb thermometer respectively. The next three columns are devoted entirely to the description and the amount of cloud. Column 23 is for sea-surface temperature, and column 24 for specific gravity of the sea surface. Full explanations of the entries in these columns will be found in the chapters relating to Instruments and Clouds.

The weather in column 20 is recorded according to notation as follows:—

b Blue sky.
c Clouds detached.
d Drizzling rain.
e Wet without rain.
f Fog.
g Gloom.
h Hail.
l Lightning.
m Mist.
o Overcast.
p Passing showers.
q Squalls.
r Rain.
s Snow.
t Thunder.
u Ugly appearance of weather. Threatening.
v Visibility. Objects at a distance unusually visible.
w Dew.
z Haze.

This notation is easily learnt, and remembered. The first letter of the word is used, as r = rain, s = snow; except where two or more words commence with the same letter, and then another letter of one word is used. Beginners must remember that d = drizzle, but w = dew; h = hail, s = snow, but p = (passing) showers, q = squalls, and z = haze. A few beginners have mistakenly used *h* for both hail and haze; *s* for snow, squalls, and showers; *d* for both drizzle and dew. It is always best to record the weather actually experienced at the instant of observation, not an estimate of the weather during the interval since previous observation. With fog, rain, snow, or hail, a numeral may be placed before the *f*, *r*, *s*, or *h*, to indicate the number of hours each has lasted since the previous observation. Thus $2r = 2$ hours' rain, $3s = 3$ hours' snow, and so on. More detailed information, which cannot well be put in the allotted columns, such as kinds of lightning; directions in which lightning is seen or thunder heard; the direction of the wind in squalls, their duration, and their force, should be given in the remarks. Off the west coast of Africa, and elsewhere, the apparent haze is often caused by red dust floating in the atmosphere. This fact should also be clearly specified whenever observed.

Both sea and swell, direction whence they proceed, and their heights, are also recorded. The direction should be true, if possible; that is, corrected for compass error, and by the same compass as the wind direction. In recording the disturbance of sea, or swell, it is well to use the following scale:—

0. Dead calm.
1. Very smooth.
2. Smooth.
3. Slight.
4. Moderate.
5. Rather rough.
6. Rough.
7. High.
8. Very high.
9. Phenomenal.

The young beginner will remember that the time relating to each remark is of importance, more especially with respect to wind changes of direction or force, arrival at or departure from a port, bearings, and similar items. Column 26 is devoted to remarks. It can be made to contain very interesting and useful reading by an attentive observer of natural history matters. Aurora, Zodiacal Light, Corposants, Falling Stars, Halos, Red Fog, Dust Showers, Earthquakes, Lightning, Waterspouts, Current or Tide Ripples, Discoloured or Luminous Sea, Icebergs, Field Ice, Seaweed, Drift Wood, Derelict Ships, Current Bottles, Wreckage, and similar matters, may all be carefully noted for future reference.

The Applications of the Observations.—Ships' logbooks are often of use not only to meteorological officers, but also to the hydrographers all over the world. Doubtful dangers, or vigias, have been expunged from navigating charts for reasons based upon accurate reports from masters of merchant ships. On the other hand, it must not be forgotten that entries in logbooks, or extracts therefrom, may mislead, unless care be taken by those responsible. Quite a stir was made in nautical circles in 1897 by a report of Captain Lloyd, sailing ship "Crompton," who stated he had passed a rock, in lat. 47° N., long. 37° 20′ W., right on the track of trans-Atlantic steamers. It was said to be 60 feet long, 10 feet wide, flush with the water except at the centre, and partly covered with seaweed. Although extra lookouts were perched aloft on several large liners, during subsequent passages, in the vicinity of the suspected area, nothing more was seen of the vigia. The then United States Hydrographer, Captain (now Admiral) J. E. Craig, U.S.N., in constant communication with the large majority of steamship masters in the Atlantic trade, who earnestly co-operate in providing data for the monthly Pilot Chart, was soon in receipt of important information relative to this doubtful danger, and immediately made it public for the benefit of navigators under every flag. Three different vessels passed either immediately over the spot where the rock was reported to be, or quite close thereto, without observing anything of the kind indicated by Captain Lloyd. The "Ulstermore," Captain W. H. Moore, R.N.R., by observation and by dead reckoning, was exactly over the looked-for danger. Only sea and sky were in sight, although the prevailing conditions were peculiarly favourable for discovery. Two men were stationed aloft at elevations of 98 and 50 feet, an officer was on the bridge 40 feet from the water-line, and Captain Moore remained on the chart-house just 10 feet higher. All kept a vigilant lookout, with every sense on the alert. Two days later, the R.M.S. "Aurania," Captain McKay, steamed right over the reported geographical position of the rock quite safely. Shortly afterwards the "Lucerna" passed two miles to the northward thereof, in clear weather, but not even a suspicion of danger was manifest to the eager watchers. Probably Captain Lloyd was misled by a drifting derelict ship. The "Indrani," Captain Gillies, reported to the Washington Hydrographer that she passed a small derelict, in lat. 46° N., long. 40° W., with only the stump of a mast standing, painted dark yellow, which had evidently been adrift for many days.

Four days after the "Crompton" sighted this object, the barquentine "Zoe" experienced, in the early morning, a very heavy shock of earthquake, which lasted 30 seconds, and caused her to tremble as though grating against a hard bottom. This was in lat. 44° N., long. 29° W. Seismic disturbances have occasionally led to the addition of a rock, or a shoal, where hitherto the lead had indicated deep water. Falcon Island, but a breaking reef in 1865, was pronounced to be over 150 feet high by H.M.S. "Egeria" in 1889; had sunk to 25 feet later on, according to the French warship "Duchaffault," and was reported just level with the sea surface in 1896. Some years ago, between Malta and Sicily, an island gradually rose until about 150 feet above water. The British flag was soon hoisted over this volcanic isle, which eventually disappeared whence it came. In 1868, H.M.S. "Newport" found in the known geographical position merely a shoal composed of scoriæ at a depth of 15 feet. Hence the so-called vigias, or doubtful dangers, which disfigured the navigating charts of the early days of the Victorian era, could not well be dispensed with entirely. More accurate navigation, consequent on the introduction of reliable chronometers, has clearly indicated the incorrectness of a large majority. Even now, as in the case of the "Crompton," apparently circumstantial reports of rocks and shoals reach the world's Hydrographic Offices, which may not be altogether ignored, although evidently very vague.

Necessity for Verifying Doubtful Observations.—The late Admiral Wharton has well said that, "unless the state of the sea and the weather is such as absolutely to forbid a closer examination, no seaman can be considered as having done his duty towards his brother mariners who neglects to put his suspicions beyond the shadow of doubt." Shipmasters of the British Merchant Navy have assisted considerably in improving navigating charts. At one time vessels steaming through Magellan Strait risked a great deal, owing to imperfect information. The late Captain S. T. S. Lecky, R.N.R., then in command of large steamers belonging to the Pacific Steam Navigation Company, during six years made running surveys, which were published by the

Admiralty, and served satisfactorily until superseded by the more detailed surveys of British warships under Maclear, Wharton, and others. Similar instances might be quoted relative to the pains taken by British shipmasters in this way; but, on the other hand, it must be confessed the many doubtful dangers which vex the souls of hydrographers are frequently derived from doubtful sources. Strictly speaking, nautical surveying, as now practised, may fairly be attributed to Captain James Cook, R.N., F.R.S., whose early training was obtained in a collier brig, an illustrious circumnavigator, who practically demonstrated that "honour and shame from no condition rise." In 1755 he volunteered for service in the Royal Navy; and, only four years later, while master of the "Mercury," succeeded in making some surveys of the River St. Lawrence, which assisted the landing of General Wolfe's army.

Even without earthquakes, rocks and shoals evince a disposition to crop up where least expected; and thus put to confusion the best-laid plans of nautical surveyors. It is much easier to affirm the existence of an unsuspected danger than to either confirm the statement or to demonstrate the contrary even with every modern appliance at the command of the most skilful searchers. The Avocet Rock, in the Red Sea, is an instance thereof. For a series of years steamships had navigated that increasingly important water-way. In 1887 the news reached England of the loss of a steamship, the "Avocet," by striking a rock, almost directly in the usual track, concerning which nothing had hitherto been known. Some were inclined to doubt the truth of this report. Shortly afterwards, however, the "Teddington" met her fate on the same danger. Immediately attempts were made by the British Hydrographic Office to locate so dangerous and unsuspected an obstruction. H.M.S. "Flying Fish" searched the doubtful area for several days, but found deep water everywhere. H.M.S. "Griffon" next essayed the task, without result. For a whole week she remained near the alleged position, taking numerous soundings, and dragging a chain cable after her, yet failed to locate the rock. H.M.S. "Sylvia" spent six weeks in the vicinity, hindered by bad weather while at anchor, and her soundings certainly did indicate a decreased depth of water. Consequently H.M.S. "Stork" was directed to try; and, after considerable difficulty, she succeeded in the attempt. The rock was not more than 300 yards from the spot where the "Sylvia" lay at anchor, and had only 15 feet of water over it at low tide.

Lamb's Rock, made known by a fisherman whose name it now bears, although not far from the south coast of Newfoundland, in the track of shipping, has only quite recently been placed in exact geographical position on the charts. Not long since a shipmaster made a curious mistake with respect to this rock. He erroneously imagined the symbol on his chart signified 15 feet above water, instead of 15 feet beneath; steered so as to sight the pinnacle, in order to verify his geographical position; and scraped right over the danger!

The loss of the steamship "Quetta" in Australian waters, in February 1890, seemed most mysterious at the time. She was steaming along a track traversed for years by crowded passenger steamers at full speed; not a ripple gave any indication of the coral reef some 15 feet below water, when her end came and many lives were lost. For a long interval this Quetta Rock evaded discovery, until eventually localised by the Queensland gunboat "Paluma." She subsequently examined the rock, and found only 9 feet of water over it, instead of 15 feet, as on the previous occasion. The untiring efforts of the tiny coral insects had brought the summit 6 feet nearer to the surface in a few months.

One more instance will be sufficient to show the nice discrimination necessary at Hydrographic Offices before logbook information is expunged from the charts. In 1876 a small schooner was making her way through the Inner Passage of the Great Barrier Reef, about 50 miles south of Cape York, Australia, under the command of Captain Pearn. Mrs. Pearn, the master's wife, happened to be looking over the schooner's side; and, noticing the bottom clearly visible, called out to her husband, who equally satisfied himself as to the exactness of the observation. An accurate position from such a small craft was not obtainable. Nevertheless, this rock was carefully looked for by one of H.M. surveying vessels, over a considerable area, on two occasions. Not the least indication of shoal water was obtained. Having regard to the circumstances of the case this rock was retained on the chart, though marked as position doubtful. Nineteen years later the steamship "Duke of Buckingham," while passing the spot at night, touched something harder than water, but did not receive any damage. In 1899 H.M.S. "Dart" found a very small rock, with but 10 feet of water over it, directly on the track laid down on the Admiralty Charts as the best possible, and only one mile from the approximate position allotted to it by Captain Pearn in the first instance. The terrible disaster to the "Quetta" occurred on a rock in this very passage only about 50 miles north of Pearn rock. It seems marvellous that casualties occur so seldom in parts of the ocean where coral insects are at work.

Nearly everything capable of floating has at times been deemed a solitary rock in blue water. Trees; icebergs, with earthy masses attached; whales, either dead or asleep; drifting derelict ships, almost submerged; all have combined to figure on the fair faces of navigating charts as doubtful dangers. There is a story afloat, which, if not true, is well told, of the short-sighted shipmaster who, while engaged in pricking off his ship's position on the chart, came across a vigia directly ahead. After putting about in haste, he went below, only to discover he had confounded a speck on the chart with a rock. Nevertheless, it is better to be sure than sorry. Admiral Beaufort, in 1807, was running with all sail into the River Plate when a rock was reported right ahead. Standing on, the sea was noticed breaking on this danger covered with sea-weed and barnacles. A slight flap of the ship's sails, and the vigia disappeared. It was merely a whale taking an afternoon nap!

Captain G. Evans, R.N., in 1822, while serving as master of the frigate "Owen Glendower," had a rock reported to him as distant one mile on the lee bow. Sea-weed, barnacles, fish, and breaking sea, all conspired to complete the optical illusion. Upon reaching it, by the aid of a boat, that which would have otherwise helped to harass navigators by being marked as a vigia on the chart, proved to be a huge mass of mahogany. In 1866, in the China Sea, breakers were reported from the masthead of H.M.S "Dove"; and all on board concluded an uncharted shoal had been sighted. This disturbance of the sea surface turned out to be due to a battle-royal between a whale and a thrasher. H.M.S. "Alert," in 1890, sighted supposed breakers in the Pacific, which, when closer, were found to be caused by hundreds of fish disporting themselves.

In 1861 the barque "Australia," Samarang to Singapore, observed what appeared to be an uncharted island. She steered for it; and, on drawing near, this danger was found to be a floating island made up of many trees standing upright in full verdure, many more recumbent, and a few withered stumps among them. Still more recently a similar floating island was passed by many ships in the North Atlantic. In 1886, the big sailing-ship "Thessalus," in lat. 34° N., long. 16° W., sighted what appeared to be a rock. It proved to be a dead whale, having its upper portion of a dark earthy colour 5 feet above water, and its lower part of a light colour like coral.

Waterspouts.—The following will afford an idea of the kind of remarks given in meteorological logbooks. The barque "Lillian Morris," Captain Sharp, M.M.S.A., in lat. 27° S., long. 42° W., had a critical experience. While shortening sail a waterspout was observed, bearing down upon her. As it passed clear, a terrific whirlwind took away fore-topgallant mast, main and mizen topmasts, and every stitch of canvas. One man went with the masts. The master was blown round the poop like a piece of paper, and almost went overboard. Sky and sea seemed one, resembling a smoking furnace. The base of the waterspout was about 70 or 80 fathoms in diameter. Fortunately the spout itself did not touch the ship. The schooner "Alice," in lat. 23° N., long. 61° W., was totally lost by a waterspout passing within 10 feet of her. All three masts went over the side, the chain plates were torn out, and her seams opened wide. Her crew were taken off next day. On 11th February 1888, about 300 miles west of Bermuda, the barque "Reindeer," Captain Strandt, was suddenly struck by a waterspout, and all three masts went over the side. On the 10th, in 42° N., 48° W., the Cunarder "Pavonia," Captain McKay, succeeded in avoiding a waterspout. The whirling rush of air was felt as it passed roaring terrifically, and shaped like a huge hour-glass. On 29th April 1889, off the Bahamas, the steamer "Santiago" passed through the outer edge of a waterspout having a diameter of 60 or 70 yards. It was hollow in the centre; revolved from west to east, against the sun; and the water which fell on deck was salt, with drops about the size of a two-shilling piece. Calm was not observed in the core, or heart, of the waterspout; and the water arising from it resembled an inverted fountain. The ship "Tinto Hill," Captain Docherty, on 31st December 1892, in lat. 12° N., long. 35° W., observed a large waterspout travelling about four knots from N.N.E. to S.S.W. It passed 200 feet from the stern, whirling rapidly in a right-handed direction, its wake marked by foam, and the water ascending with irregular motion.

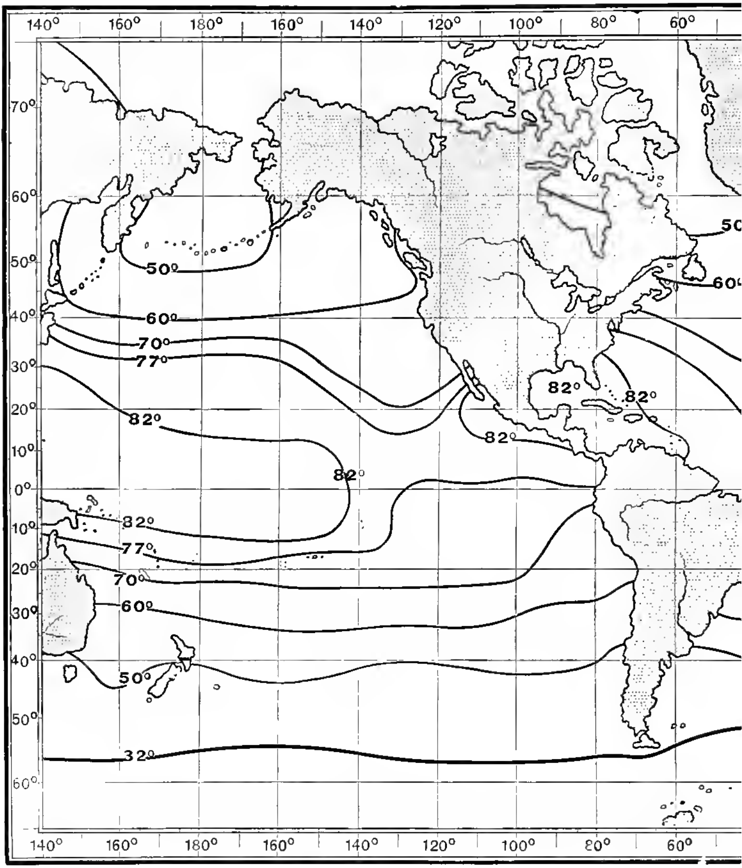
Phosphorescence.—In certain parts of the ocean the surface is covered with little microscopical creatures which emit a marvellous phosphorescent light. Sir Wyville Thomson, during the voyage of H.M.S. "Challenger," found this phosphorescent light strong enough to enable him to read the smallest print by its aid while seated in the cabin. The vessel's wake was a blaze of intensely vivid phosphorescence. Often, after a sea has broken on board, marine organisms left on deck give off radiations for all the world like a glow-worm on shore. Captain Dyke, ship "Cambrian" at Pabellon de Pica, from 12th to 20th May 1878, observed that the surface water, which was of a dirty purple colour by day, was so brilliantly phosphorescent at night that he could read the ships' names on their sterns and the time by a watch. On 19th June 1891, in lat. 3° N., long. 21° W., the "Sierra Lucena," Captain P. Murdoch, found the sea very luminous in patches. From a bucket of water drawn there was taken a substance like a strip of blubber, 8 inches long, with a hollow central canal. It emitted sufficient light in a dark room to permit of the time being told by a small clock without any other light. In the words of Shelley—

> "While the surf
> Like a chaos of stars, like a rout of death-flames,
> Like whirlpools of fire-flowing iron,
> With splendour and terror the black ship environs;
> Or like sulphur flakes hurled from a mine of pale fire,
> In fountains spurts over it."

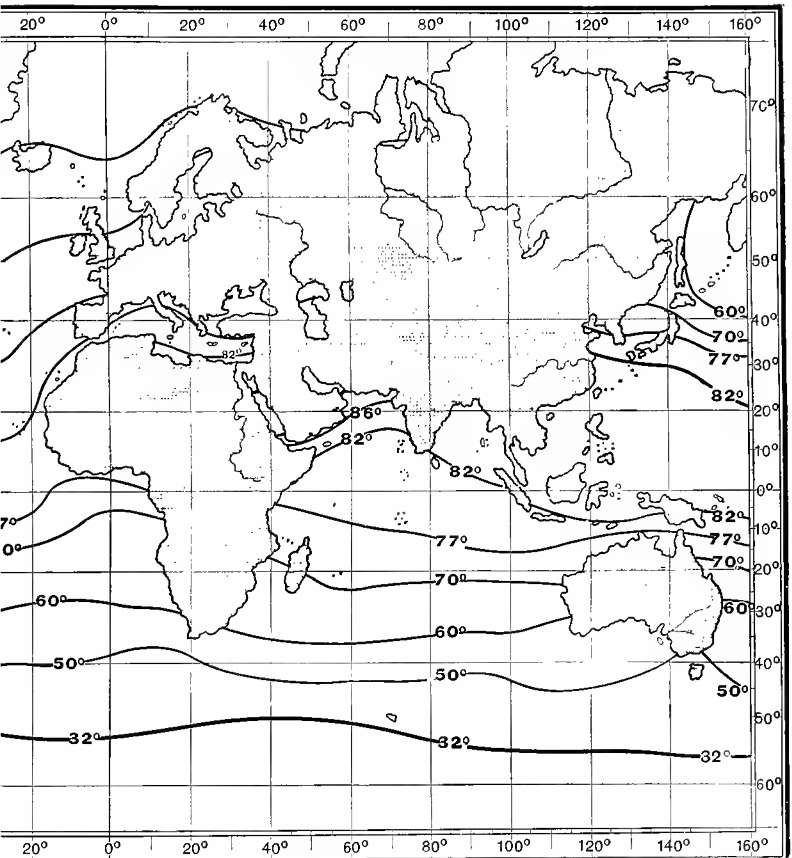
On 3rd September 1897, about 180 miles west of Colombo, the "Lusitania," Captain Veale, passed a phosphorescent area about three miles in length. The whole surface of the water was illuminated, and the appearance was similar to that of breakers on a long, shallow beach with high land behind. East of Socotra, the late Captain J. McKirdy, R.N.R., saw a long patch, which, on a dark night, looked as white as milk. The late Captain Samuels, who once brought the "Dreadnought" from Sandy Hook to Queenstown in 9 days 15 hours, has given a vivid word picture of phosphorescent sea at Java. The warship boats towed out Captain Samuel's ship, pulling together to one song with chorus of 100 voices. As the oars dipped, the sea seemed liquid silver, and, as they rose, apparently a myriad of diamonds dropped from them. To enhance the gorgeousness of the display, sharks darted hither and thither, leaving streaks in their wake, like flashes of forked lightning.

High Seas, Submarine Tremors, etc.—Admiral Fitzroy measured seas 60 feet in vertical height; Captain Kiddle some a little under 70 feet, with a velocity of 25 knots, on board the "Celtic," in January 1875, while crossing Atlantic; the Hon. Ralph Abercromby, others of 46 feet. Occasionally a solitary sea, or a couple, of exceptional height, will do much damage. Prose poets are apt to refer to these as tidal waves, but they are nothing of the sort.

In October 1881, all hands but one, a sick man below in his bunk at the time, were washed overboard from the Italian barque "Rosina" by a sea while shortening sail in the North Atlantic. On 28th March 1893, the barque "Johann Wilhelm" had a precisely similar experience. The solitary survivor, in each case, was eventually rescued by a steamer. On 18th July 1886, in lat. 40° N., long. 32° W., a tremendous solitary sea, coming along at a rapid rate, exactly like a bore in Calcutta river, rolled over the "Khyber," doing considerable damage. On 15th January 1896 the steamship "Thermopylæ" came up with three heavy swells into which she pitched the forecastle clean under. Before and after the sea was smooth as a millpond, and a light southerly breeze prevailed. On 3rd March 1896, in 48° N., 8° W., while



ALLINGHAM'S MARINE METEOROLOGY. PLATE II.—LINES O



al Temperature (Isotherms) of Air, for the month of July.

hove-to in a heavy westerly gale, the steamer "Cascapedia," Captain Kerr, was seriously damaged by a solitary sea which swept completely over her. It rose up amidships, in the hollow of the true sea, and rushed at the after part of the ship with great speed. In form it was a pyramid, fully 50 feet high, with a flat foam-crested top. On 23rd December 1896, in lat. 39° N., long. 73° W., during a north-west gale, a high and broken sea struck the steamer "Madeline," Captain Zur Nedden, which nearly threw her on her beam ends. The vessel rolled so much that the steering compass "turned right over, the lubber-point showing aft." It also gave such a jerk to the barometer as to cause the quicksilver to break the tube.

"Large sea waves," says Mr. G. W. Littlehales of the United States Hydrographic Office, "seem to be the result of a building-up process carried on by the joint action of large and small waves. If, for any cause, there be one wave larger than those surrounding it, its size will be continually increased at the expense of the smaller ones." Reports of such solitary seas should be carefully entered in the ship's logbook, bearing in mind that they cannot possibly be tidal waves. Oil is efficacious as a sea-smoother, and even soapsuds are not without utility for the same purpose.

Earthquakes, or seaquakes, as sometimes termed by seamen, are often observed in the open sea. Information in the logbook with respect thereto is useful to inquirers. On 1st November 1893, in lat. 17° N., long. 28° W., the "Crown of India" experienced a severe earthquake shock, lasting 50 or 60 seconds, and making the ship tremble as though dragging heavily over a rocky reef. The weather was fine and clear at the time. On 6th March 1897, in lat. 44° N., long. 29° W., the "Zoe" experienced a very heavy shock for 30 seconds. She trembled as though grating on a hard bottom. As with other information, care should be taken to give the ship's geographical position, the date, the hour, and the temperature and colour of the sea, when the circumstance occurred. Striking a submerged derelict, or a dead whale, might give rise to vibration, and error from this cause should be guarded against by careful inquiry before noting in the logbook. Live whales come close alongside at times. On 15th August 1895, in 39° S., 28° E., a very large whale kept close to the ship "Balmoral" and rubbed himself several times against her starboard side. This may have been done to remove parasites.

CHAPTER IV.

ATMOSPHERIC PRESSURE.

Variations of Pressure.—The pressure of the atmosphere is measured by the height to which the mercury rises in the tube of a barometer, or by an aneroid. Mercurial barometers are to be preferred to aneroids for scientific purposes requiring great accuracy; but on board ship an aneroid, when carefully compared from time to time with a standard instrument, does well enough for all practical requirements.

We live at the bottom of an ocean of air which may, for convenience, be considered as composed of two distinct atmospheres—dry air and moisture. The former is always a gas, and is constant in quantity; whereas the latter varies considerably in quantity, and is not always gaseous. Roughly speaking, the atmosphere is supposed not to extend beyond a height of about 200 or 300 miles above sea level. Our knowledge does not extend from direct evidence to much more than some 8 miles high. Mr. Glaisher, in 1862, went up in a balloon to a height of 37,000 feet, an ascent which almost had a fatal termination for the daring aeronauts; and the barometer had then fallen to 11·53 inches. At an elevation of 7 miles the density of the air is said to be reduced to one-quarter of that at the sea level, at 14 miles to one-sixteenth, and at 21 miles to merely one sixty-fourth. Breathing becomes difficult as the higher altitudes are reached, and eventually becomes impossible. Out of every 100 volumes of atmospheric air there are 77·8 of nitrogen, 20·75 of oxygen, 1·42 of aqueous vapour, and 0·03 of carbonic acid. A barometric pressure of 30 inches may be made up as follows:—nitrogen, 23·36 inches; oxygen, 6·18 inches; aqueous vapour, 0·44 inch; and carbonic acid, 0·02 inch. The traces of other gases found in air may be neglected here. Observation has proved beyond doubt that there is some connection between atmospheric pressure and the action of wind systems. Hence the force of the old adage: he who watches his barometer watches over the safety of his ship. Attention to the indications of a good barometer, the clouds, and the changes of wind, help a seafarer, remote from telegraphic stations, to form a fair idea as to coming weather. Some of the old-fashioned barometers have on their faces the words fair, change, rain, stormy, prominently placed against certain heights on the scale. Such information is likely to be more misleading than useful; at any rate for navigators, who, as we shall see later on, in making a voyage round either the Cape of Good Hope or Cape Horn, will encounter several distinct systems of barometric pressure. Even if these words were correct for one place, which cannot be admitted because the force of the wind depends on the relative pressure, not the absolute, they would be worse than useless were the barometer on a mountain or off Cape Horn.

As a general rule, in the higher latitudes, a falling barometer indicates worse weather, and a rising barometer signifies finer weather. There are not wanting exceptions. Just prior to the approach of a cyclonic storm, for example, at any given place, there may be a slight rise in the barometer calculated to lull an observer into a false sense of security. At all the government meteorological departments of the world there are drawn up daily charts of the weather conditions for several selected hours of the day. A comparison of these daily weather charts affords evidence of the paths followed by storms, and a reason why one part of the United Kingdom, for example, may have fine dry weather while it is rainy and uninviting elsewhere. Every sailor is familiar with the soundings laid down on navigating charts. Daily weather charts are on a somewhat similar principle. Information by telegraph is forwarded from chosen centres, situated both inland and on the coast; the necessary corrections applied; and the corrected results laid down on a large working chart. An isobar, or isobaric line, is drawn through all those places where the barometric pressure is the same, just as a 100 fathom line of soundings is drawn through all places where 100 fathoms of water is obtainable under specified conditions. Certain of these isobars form closed curves round places where the barometer is either lower or higher than over the neighbouring areas. We thus get cyclonic systems, and anti-cyclonic systems, respectively. Learners must remember that the term cyclone does not necessarily imply a gale of wind. Where the readings are low, but similar, for many miles around, the system may be cyclonic although the wind force is barely appreciable. Neither does the term anti-cyclone necessarily imply light winds and variables.

Owing to the alternations of cyclones and anti-cyclones, the range of the barometer in the higher latitudes is considerable. The lowest corrected and reduced barometer reading in the North Atlantic is 27·33 inches by R.M.S. "Tarifa," on 5th February

1870, in lat. 51° N., long. 24° W., when the mercury fell 2 inches in 10 hours. The fall on board the "Circassia," in February 1883, was 1·14 inches in 8 hours. The highest readings recorded for that ocean are 31·08 by the German steamer "Fulda," in lat. 50° N., long. 15° W., during January 1891; and 31 inches on another date. On 23rd January 1859, a good aneroid on board the "Victory," Captain A. Fry, gave a reliable reading of 31·01 inches. This was supported by 30·97 on board the "City of Calcutta," in lat. 41° N., long. 30° W.; and 30·93 by the "Robert Pulsford" in lat. 37° N., long. 31° W. These are probably the highest North Atlantic readings. At Trinidad, the record maximum reading is 30·13 on 25th June 1892. Greatest variations in the barometric height occur over our islands in winter. At Ochtertyre, in January 1884, the reading was 27·33 inches. The 9th January, on three occasions, has afforded the highest readings, all in Scotland. At Leith, in 1820, the record was 31·05; at Ardrossan, 31·09 in 1895; and at Glasgow, 31·12 in 1896. Probably not more than a dozen readings exceeding 30·9 have been recorded over the United Kingdom during the past 150 years. At False Point, Orissa, the barometer is said to have been 27·12 on 12th September 1885. It is sometimes said the highest readings on record are 31·8 inches at Irkutsk on 14th January 1893; and 31·72 at Semipalatinsk, in December 1877. Having regard to the height of Siberia, it must be remembered that these values do not represent the actual weight in inches of mercury of the atmosphere, but what would have been recorded had the lofty land been pared down to sea level. On 19th July 1890, in 33° S., 14° W., the "Brenda," Captain Rosseter, had her barometer up to 30·9, with a moderate S.E. breeze. At the same time, in 35° S., 25° W., the "Bracadale," Captain Peebles, recorded 30·84, wind E., light. In July 1888, in 32° S., 24° W., the "Four Winds," Captain Ritchie, had 30·72, wind N.W., light.

It can be inferred from the foregoing that the atmosphere does not always press down upon the earth, even at the same place, with the same weight; and also that the pressure varies from place to place. Areas of high pressure, and areas of low pressure, are in close touch with each other all over the globe; and in this way we may account for the irregular variations in the height of the mercurial column in the barometer. In extra-tropical regions the absolute range in barometric pressure is about 4 inches; but within the tropics it is very small, being from ·2 to ·5 of an inch.

Diurnal Range of Pressures.—In addition to these irregular changes, there are others depending upon the time of year, as we shall explain further on when referring to the average disposition of atmospheric pressure for the typical months of February and August. There are also daily changes, most marked in tropical regions, which may be classed as regular. A vessel bound across the equator from the English Channel, on board which the barometer is read at eight bells each watch, and carefully entered in the logbook, will usually experience diurnal range in her readings from lat. 21° N. to lat. 21° S. Occasionally, although rather seldom, this regular range, or barometric tide as sailors term it, is met with in higher latitudes, and continues till considerably south of the Tropic of Capricorn. By looking backward at the entries in the logbook it will be noticed that the barometer is low at 4 a.m. and 4 p.m., but high at 8 a.m. and 8 p.m. Should this diurnal range be interfered with, in tropical regions, the seafarer may either look

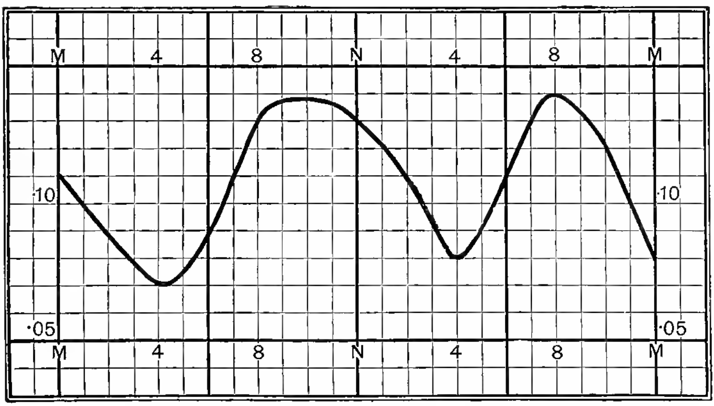


FIG. 10.

out for a cyclone or suspect an erroneous entry. In fact, so regular are the tropical barometric tides, or diurnal range, as to draw from Fitzroy, or Humboldt, the statement that by its aid a navigator may tell the time of day within a quarter of an hour or twenty minutes. About 0·10 may fairly be deemed the average diurnal range in the tropics, although the amount is not always the same. At Batavia, in lat. 6° 22′ S., the daily range is 0·11 inch; at Kingston, Jamaica, in lat. 18° 1′ N., it is 0·09 inch. As a rule, the lowest readings each day are at 4 a.m. and 4 p.m.; the highest at 10 a.m. and 10 p.m.; but may be an hour or so on either side of these hours. Fig. 10 is deduced from the meteorological log of the s.s. "Buccaneer," Captain A. S. Thomson, C.B., R.N.R., and clearly indicates the barometric tides during the period. This diurnal range, or barometric tide, is attributed by some to the changes in temperature and humidity of the air. It is greatest at the equator, decreases gradually towards either tropic, and on the polar sides of the latter is seldom distinguishable in ships' logbooks. Meteorologists sometimes assert that near the poles the diurnal range is reversed. The evidence in support of this statement is scarcely satisfactory owing to the paucity of observations made above 60° N. lat. or 60° S. lat.

Pressure and Temperature Charts.—Every seaman is familiar with the use of the deep sea lead, also with the connection between its indications and the soundings laid down on a navigating chart. Five-fathom curves, ten-fathom curves, and similar lines are equally well understood. Lord Kelvin's sounding machine has a glass tube connected with the sinker, closed at the top, and coated on the inside with chromate of silver. Chemical action of the sea-water forced up the tube by the pressure causes a white ring therein and thus enables us to determine the correct sounding by the aid of a specially constructed scale. The barometer performs a somewhat similar service for mariners with respect to atmospheric pressure; and synchronous weather charts, with their lines, are similar in principle to navigating charts setting forth soundings and various fathom curves. Just as certain corrections must be made before soundings can be compared with the chart indications, so certain corrections are applied to individual readings of barometer in order to secure comparative results among themselves.

Having gathered together observations from as many ships as possible, for a specified Greenwich Mean Time, and corrected them for errors, we lay down the resulting information on a large working chart at the corresponding geographical positions. By drawing lines through all the places having the same barometer reading, or the same temperature, we get isobars and isotherms respectively. The chart, as finished, is a graphic representation of weather conditions prevailing over the chosen area. This is a synchronous chart. In order to obtain a chart of the average conditions for each day a similar method is followed. Instead of the absolute readings at each place for a particular instant of time, we now have the daily averages with which to deal. Again, in order to arrive at a monthly chart, it becomes necessary to use the monthly averages of wind, barometer, and thermometer, at each place, and draw the lines of equal mean barometric pressure and equal mean temperature, just as though we were dealing with synchronous observations. In this way, comparing the months *inter se*, it is found that the barometer is highest during the winter months of either hemisphere. Throughout the year there is apparently very low atmospheric pressure over the Antarctic regions. Occasionally the mean annual values are used, and then the result is an annual chart of the area. For ocean spaces it is impossible to obtain a continuous record of meteorological data, and other methods have to be adopted. All the observations recorded in an area, say, of 10° of longitude by 2° of latitude, are massed together in order to obtain the average for each element, such as pressure, temperature, and wind. Probably half-a-dozen different persons would devise as many ways of determining these average values. Then having plotted on the chart, at the centre of each space, the values thus obtained for that space, the latter are utilised just as though a fixed station had been in existence during a long series of years at each of the several spots. After drawing isobars and isotherms on separate charts, the mean monthly disposition of pressure and temperature stands revealed, as in figs. 11, 12, and plates I. and II. respectively.

In consulting average monthly charts of this description, the navigator has at least one fact to bear in mind. Mercury in a barometer rises, not only for increased atmospheric pressure, but also for increased temperature; and falls for decreased pressure or decreased temperature. Hence, in order to allow for this on published pressure charts the observations are all corrected for temperature and height above sea level by the aid of special tables; and are comparable among themselves on the charts as though each had been taken at a temperature of 32° Fahrenheit and at sea level. Consequently a navigator desirous of comparing his reading with the corresponding isobar on the chart, say in lat. 5° N., with a temperature of 90°, might wonder what had happened to his barometer. If absolutely correct it would actually seem to require a minus correction of two-tenths to come into equality with the average indication on the chart for his geographical position. The seeming error would be due to the correction for temperature made to the readings before plotting on the chart. For example, suppose the mean of three or four days' barometer readings on board a ship delayed in lat. 5° N. long. 30° W. is 30·11 inches, and the thermometer attached to the mercurial barometer in question averaged 90° F., then the correction for temperature is − ·16 inch and the corrected barometer reading is 29·95 inches. Now that is the value attached to the isobar just at this point, so that the mercurial barometer is correct. An aneroid, as a rule, does not require any correction for temperature. Height above sea level is not allowed for here, as being practically unimportant. Of course, in some of the large liners, where the height of barometer cistern above sea level is as much as 60 feet, it cannot be neglected with impunity. North of lat. 20° N., or south of lat. 20° S., it is unsafe to compare the average reading of a ship's barometer with that given on the chart; except for roughly determining whether it is decidedly above or below the normal for the position of ship. In recording barometer readings in the logbook be sure to enter them as actually read off the instrument. Do not apply any corrections. Average charts might be easier for navigators were the barometric readings uncorrected for temperature. The following table gives a rough statement of the correction applied to readings of mercurial barometers in order to make them comparable *inter se* at a temperature of 32° F. The correction is in decimals of an inch :—

Temp.	40°	50°	60°	70°	80°	90°
Correction,	– ·03	– ·06	– ·09	– ·11	– ·14	– ·16

Nomenclature.—In meteorological matters not infrequently more than one term is used to express the same natural phenomenon. Thus areas where the mercury in the barometer is relatively higher than in adjacent areas are indiscriminately referred to as areas of high barometrical pressure, high pressures, or anti-cyclonic systems; whereas areas where the barometer readings are relatively lower are known as areas of low barometrical pressure, low pressures, cyclonic systems, depressions, or disturbances. High and low, cyclone and anticyclone, in this connection, it must be borne in mind, are merely relative terms. Thus we may have a barometer reading 30 inches and above at the centre of a low pressure, or 29·5 as the highest reading over a high pressure area.

Fig. 11 and fig. 12, for which I am indebted to the courtesy of the Meteorological Council, give a fair representation of the average barometrical conditions prevailing over the oceans between lat. 60° N. and lat. 60° S., during the months of February and August respectively. Similar charts have been constructed for each month of the year, but the two here given are sufficient to indicate the average disposition of atmospheric pressure during winter and summer. Above lat. 60° N., or lat. 60° S., observations are wanting.

Distribution of Pressure Areas.—Turning to the February chart, and commencing with the North Atlantic as being nearer home, we find a closed high pressure area between 20° N. and 40° N. extending from 35° W. to 55° W. The isobar of 30·25 inches indicates the highest average readings there for the month. In the South Atlantic it will be noticed that the high pressure stretches right across the ocean, from Africa to America, between the parallels of 20° S. and 40° S. The highest average readings for the month are shown by the isobar of 30·2 inches. Atmospheric pressure in the North Pacific differs slightly from the North Atlantic disposition. Between 20° N. and 40° N. will be found a distinct high pressure on either side of the ocean. In each the highest reading is 30·2 inches. Between 20° S. and 40° S., in the South Pacific, will be observed a high pressure area extending from the West Coast of South America to the 140th meridian of west longitude. The highest readings are found on the isobar of 30·2 inches. Westward is a kind of no-man's land. Evidently the arrangement of the land about the upper waters of the North Indian Ocean has something to do with the disposition of atmospheric pressure there. Both the Arabian Sea and the Bay of Bengal disclose high pressures, but 30 inches is approximately the highest average barometer reading for the month. Over the South Indian Ocean the barometric pressure is similar to that found to exist in the South Atlantic. A closed high pressure area stretches right across the lone southern ocean, between lat. 20° S. and lat. 40° S., all the way from the meridian of the Cape of Good Hope to the West Coast of Australia.

Having thus dealt with the high pressure systems, it behoves us to take note of the average conditions prevailing on either side thereof, equatorially and towards the pole. In both the Atlantic and the Pacific, low barometer readings are found in February a few degrees on either side of the equator; while, at the same time, still lower readings appear on the polar sides of the anti-cyclones in either ocean. In the Indian Ocean, however, the low barometer readings are found between lat. 10° S. and lat. 20° S., except between Ceylon and Java, where the isobar of 29·9 curves northward of the equator.

Hence, speaking generally, during the month of February the average disposition of atmospheric pressure may be readily predicted. Between the 20th and 40th parallels of latitude, in either hemisphere, there extends a zone of high barometer readings, about 30·2 inches on the average, except in the North Indian Ocean. A zone of lower atmospheric pressure is found in the vicinity of the equator, and still lower readings are generally met with on the polar sides of the high pressure systems of either hemisphere.

In August, the general disposition of atmospheric pressure is very similar to that of February, as indicated by a comparison of fig. 11 with fig. 12. Nevertheless, there will be several small differences noticed. The North Atlantic high pressure is much more marked, and the lower readings are now well north of the

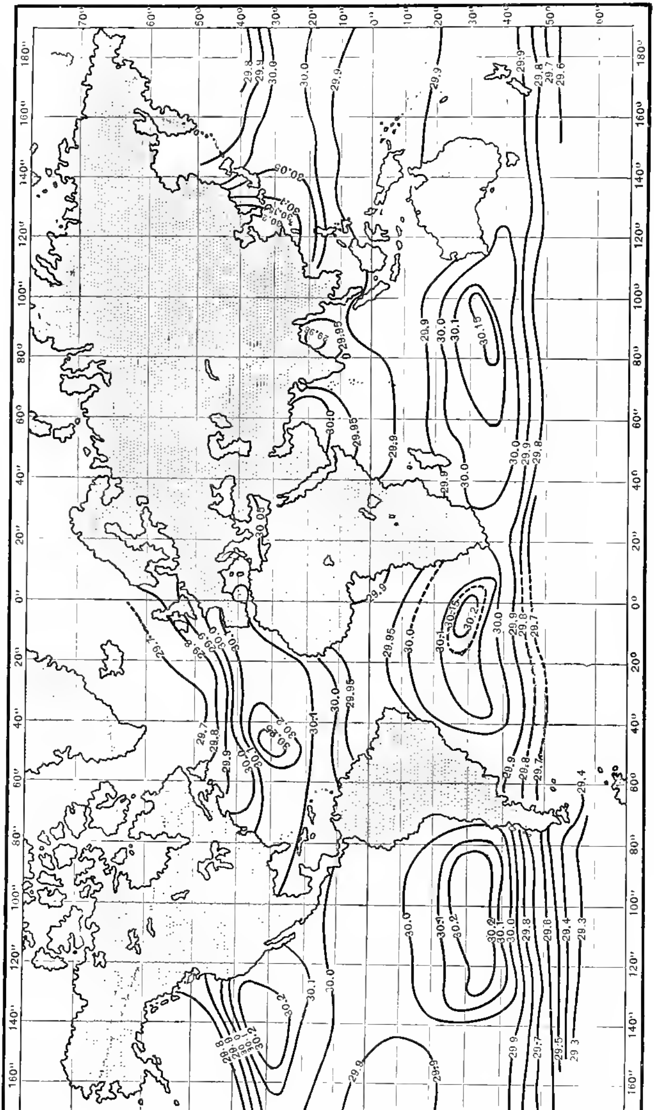


FIG. 11.—Lines of Equal Pressure (Isobars) during February.

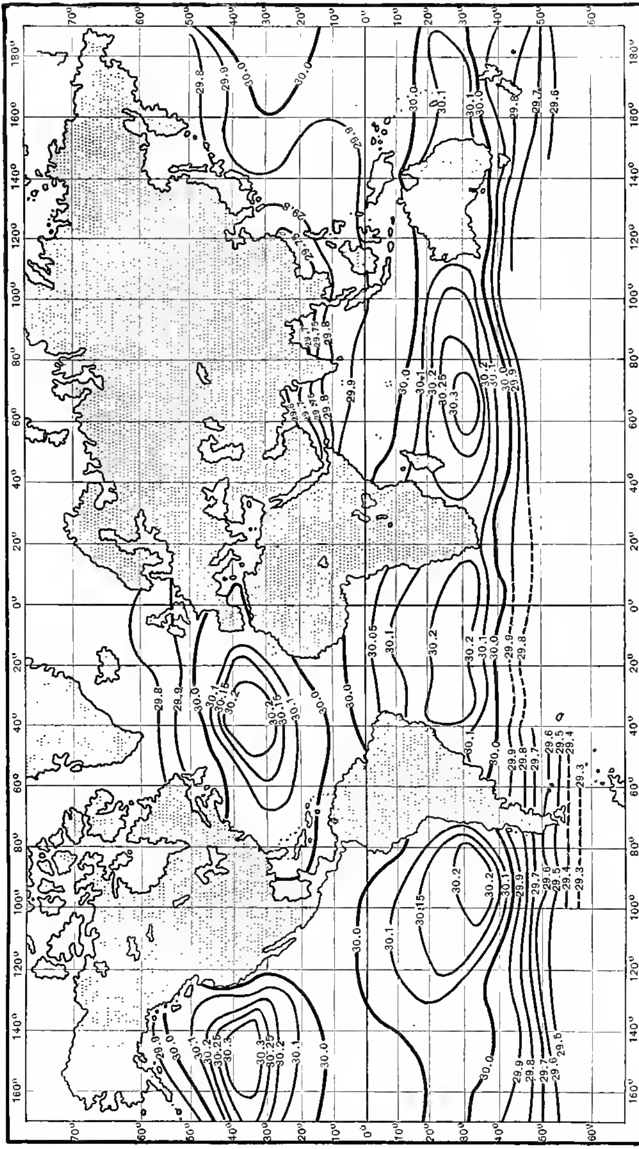


FIG. 12 —Lines of Equal Pressure (Isobars) during August.

equator. The upper portion of the February high pressure appears, as it were, to have crept northward by August, inasmuch as the 30·2 isobar of the South Atlantic Ocean extends right across from South America to Africa. In the North Pacific the highest isobar is 30·3 inches, and the high pressure system extends much further towards the coast of China, where a low pressure system of 29·75 has supplanted the February high pressure of 30·2 inches. At the same time the high pressure of the South Pacific has moved northward, and contracted in an easterly direction.

Navigators in possession of charts showing the normal distribution of atmospheric pressure over the several oceans can use them as a guide to weather forecasting for themselves. It will at once be observed that regard must be paid to the geographical position. Thus a reading of 29 inches in lat. 56° N. is usually regarded as a premonitory sign of bad weather; whereas in lat. 56° S. this is about the average height of the barometer, or comparatively equivalent in this connection to a reading of 30 inches ou an equal northerly parallel. Similar reasoning holds for other parts of the globe. Above the average, "all's well" approximately, but below the average a warning is roughly given to look out for bad weather. In the Arabian Sea, for example, a fall of three-tenths of an inch below the average is said to be an unfailing indication of the proximity of a cyclone. In other waters such a slight fall would be deemed a negligible quantity. The following table gives the average monthly values of barometer at the four places chosen:—

Place.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Scilly, . .	29·97	29·92	29·96	29·88	30·02	29·99	29·98	29·96	29·95	29·89	29·90	29·94
Gibraltar, . .	30·19	30·15	30·04	30·01	30·00	30·03	30·02	30·01	30·04	30·05	30·08	30·12
Ascension, .	29·94	29 92	29·91	29·91	29·95	30·04	30·07	30·05	30·03	30·00	29·97	29·94
Falklands, .	29·51	29 53	29·49	29·56	29·56	29·67	29·63	29·65	29·68	29·59	29·62	29·52

Corrections for Gravity.—The atmosphere is subject to the action of gravity, and this introduces another factor, a correction for which is at times applied to barometer readings before plotting them on charts. A mercurial barometer does not indicate the absolute pressure as a spring balance would, or as the aneroid might, if accurate. Gravity is not the same at all latitudes, owing to the centre of the earth being nearer to the poles than it is to points on the equator. Hence a column of mercury weighs less at the equator than it would near the poles. It would weigh, say, 192 at the equator as against 193 at the poles. Corrections have been calculated for each degree of latitude under this head, and these are applied in a few instances where extreme refinement is aimed at; but the navigator may neglect correction for gravity. It is well, however, not to lose sight altogether of this circumstance. The correction for reducing to gravity at the latitude of 45° N. or 45° S., between readings of 29·5 inches and 30·5 inches, is approximately as given in the following table, remembering that the correction is 0 at 45°, + above 45°, and – below 45°:—

Lat.	0°	10°	20°	30°	40°	45°	50°	60°	70°	80°	90°
Corr. in dec. inch	– ·080	– ·075	– ·061	– ·040	– ·014	·000	+ ·014	+ ·040	+ ·061	+ ·075	+ ·080

Occasionally the mean annual value has to be determined from a few observations per day. A slight error is thus introduced. For example, if we only had the 10 a.m. readings in the tropics the mean would be too high; or, if the 4 a.m. only, too low. In order to allow for this it is customary to determine the daily range at some adjacent place where a complete series of observations is obtainable, and then correct the imperfect average for the amount of daily range on the assumption that it is approximately the same at both places. An aneroid reading does not require any correction for gravity.

In addition to the extreme readings given on pages 25 and 26, the following are of interest. The little "Fox," under McClintock, had a barometer reading of 31·12 inches, between 70° N. and 75° N.; and another of 28·72 inches, in March, between 65° N. and 70° N. H.M.S. "Erebus," under Ross, had a maximum of 31·0 inches between 40° S. and 45° S., and a minimum of 27·40 inches between 55° S. and 60° S.; in October and March, respectively.

CHAPTER V.

AIR TEMPERATURE.

The Sun as the Source of Heat.—For all practical purposes the sun may rightly be regarded as the sole source of heat to our planet. Heat received from other sources is comparatively insignificant. Solar heat is imparted directly by somewhat warming the air in its passage through, by the remaining solar energy reaching the earth's surface, by the liberation of heat in the condensation of vapour, and by radiation from the earth's surface. Moist air does not stop solar heat very much; absolutely dry air permits its free passage, but such air is unknown in practice. Heat radiated from the earth, however, cannot force a way through the atmosphere. A cabin with closed doors, warmed through the skylight by the sun's rays, becomes insufferably hot. The heat waves from the sun are short and rapidly vibrating, whereas they have become long and sluggish after penetrating the glass. Trapped, as it were, and rendered submissive, they elect to remain below.

The sun's apparent motion round the earth causes day and night; his apparent motion in the ecliptic brings summer and winter. In the same way we get diurnal range, and annual range, of air temperature. Vertical rays produce most heating effect, because the area heated is smaller, and they have to pass through a less amount of heat-absorbing moist air. It is for a similar reason refraction is greater on the horizon than elsewhere. The lowest strata of the atmosphere are the warmer; the warmest of all being those nearest the earth on the equator. Hence there is a vertical range, and a horizontal range of air temperature. For each increase of 300 feet in the altitude there is approximately a fall of 1° in the air temperature. In tropical regions, over any given geographical position, at noon, the sun is vertical twice a year at a latitude corresponding with the declination. Latitude is a secondary consideration with respect to air temperature, as clearly shown by reference to Plates I. and II.

Disturbing Factors in the Problem.—Ocean currents and winds tend to complicate the temperature problem. Clouds reflect back the heat they receive from the earth. Consequently clouds and thick weather, as also their absence in an exceptional degree, equally affect the diurnal range of air temperature, which, at sea, is always small, with the thermometer in the shade. The ocean is slow to take up heat, and not less slow to give it up again, compared with the land. Five times as much heat is required to raise a certain quantity of water through a given number of degrees as serves to raise an equal quantity of land through the same number of degrees. The ratio of land to sea is as 1 : 4 ; and the land in the northern hemisphere is to that in the southern hemisphere as 13 : 1. England is the centre of the land hemisphere. Isotherms, or lines of equal temperature, drawn through all places having the same average air temperature, are laid down on Plate I. for January and Plate II. for July. A glance at them will suffice to show the greater irregularity of the isotherms in the northern hemisphere. South there is much more open water, and less sinuosity in the isotherms. Seasonal changes are less marked in the southern hemisphere.

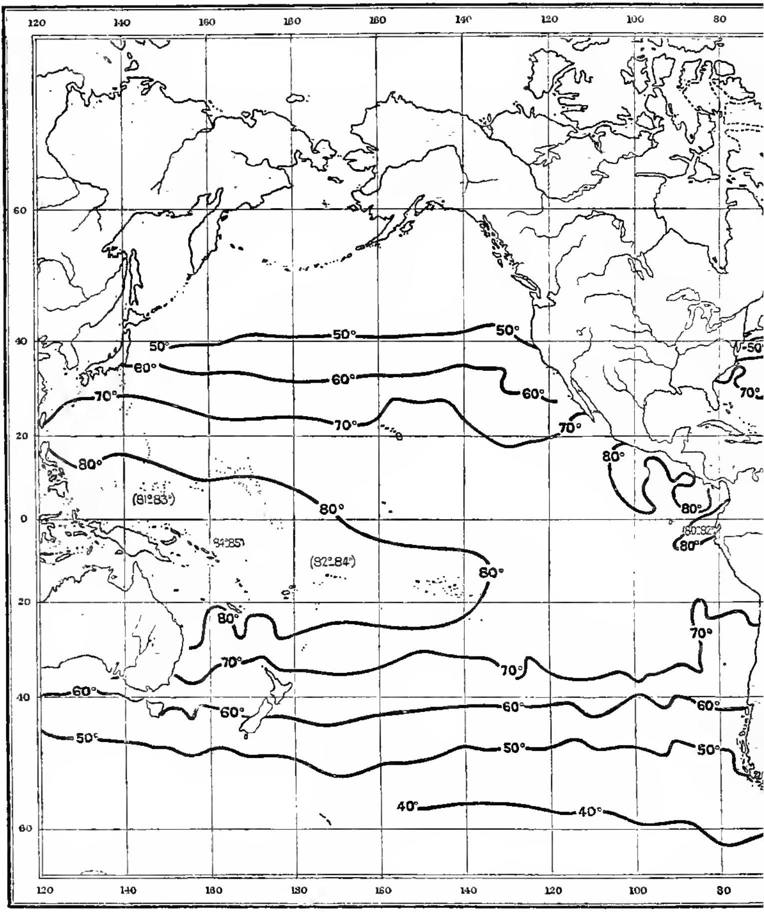
The Thermal Equator: Range of Air Temperatures.— Over the land the air may be very hot or very cold, while the air over the sea is at a fairly uniform temperature. The line along which the maximum air temperature occurs is sometimes termed the thermal equator. It travels to and fro with, but after, the sun, between the two tropics. The temperature of the sea seldom exceeds 85° ; but the *amount* of heat it contains is very great, is not easily parted with, and is carried many a mile. At Massowah, up the Red Sea, an average air temperature of 99° has been obtained, and 56° at Werchojansk in Siberia. Individual readings give a much greater absolute range of air temperature over the globe. At Mursak, an oasis of the Sahara, a vouched for reading of more than 130° has been reached; Burke and Wills at Cooper's Creek, in Australia, had a thermometer in the shade which burst at 127°. A temperature of − 81° has been reached at Werchojansk. Hence about 210° represents the maximum range of air temperature on our planet. Absolute zero, the temperature which would rule if the sun were snuffed out, and which is sometimes said to be the temperature of inter-stellar space, is variously stated as anything between 270° F. and 500° F. below the freezing point of fresh-water. At Port Jackson the air temperature in the shade has risen from 80° to 120° ; and fallen from 100° to 65° in less than fifteen minutes, and from 95° to 35° in four hours of the night. In the Arctic a ball of frozen mercury has been fired through an inch plank ; and oil of almonds, frozen in a shot mould at $-40°$ F., and fired against a target, rebounded unbroken.

The late Mr. Croll calculated that if the Gulf Stream were diverted from England, turned into the Pacific, for example, as a Captain Silas Bent once suggested, the surface of the North Atlantic would have an average temperature of 35° F. below freezing point. If it were possible to store the heat hourly given out by the Gulf Stream it might be utilised in doing the work of steam engines having a total horse power of 3,119,000,000,000. The average intellect fairly reels under such an array of figures! This much is certain, however. The Gulf Stream keeps open our harbours, while those of America's north-east coast on the same parallels are closed by ice.

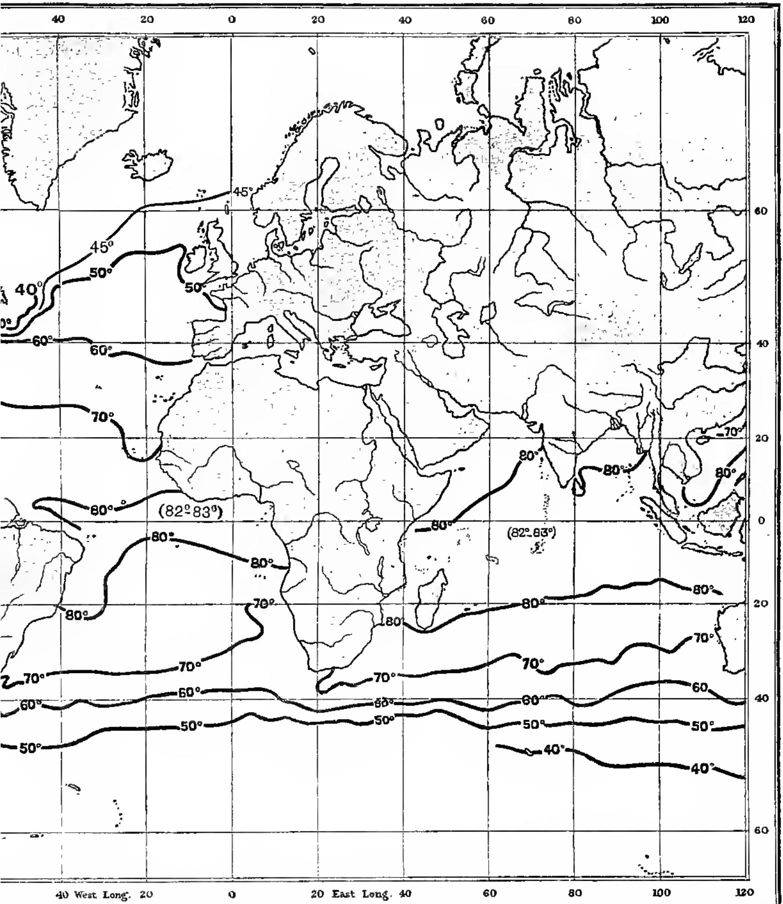
Exceptionally hot and cold winds are fallen in with over certain parts of the globe. Our own feelings are a very uncertain guide as to the actual temperature of the air. It is a question whether seafarers suffer more in the Red Sea, under a vertical sun, at an air temperature of 90°; or off New York, in a blizzard, with the mercury in the thermometer standing 12° below freezing point. Vessels trading between Japan and the United States, *viâ* Suez, occasionally record these extremes within a month.

A fairly accurate mean temperature at any one place is obtained by recording the 9 a.m. and 9 p.m. temperatures regularly, and dividing the total of the readings by the sum of the observations; or by similar treatment of the daily maximum and minimum readings. Of course a more accurate average is got by taking hourly observations in a similar way. Tables are in existence for turning the mean temperature for any given hour into the corresponding mean for the day. Such aids are of questionable accuracy. Diurnal range at sea is small, inasmuch as it principally depends on the sun's heat falling on dry land. Even on an island like Ascension, diurnal range of air temperature is fully appreciable.

Turning to January isotherms, when the sun is south of the equator, Plate I., by following the 32° line it is seen that the warmer water of the Gulf Stream has an appreciable effect even to lat 70° N. on the meridian of Greenwich. The corresponding line for the southern hemisphere keeps closely to the parallel of 60° S. The influence of the land makes the isotherms of 50° and above most irregular. On either side of the equator air temperatures of 80° or above are found. Eastern sides of the southern continents are warmer than those of the western during January, owing to winds and currents. It is mid-winter then in the north, and the air temperature at sea, as a rule, is warmer than on the same parallel over the land. By carefully following the 32° isotherm



Allingham's Marine Meteorology. P



II.—Sea Surface Isotherms (February).

we arrive at a fair idea of the effect of land and sea in modifying climate.

In July the sun is north of the equator, and thus has a greater land area to beat upon than in January. Now the sea exercises a moderating influence upon the air temperature of the northern hemisphere. The warming effect of south-west winds and north-east current is still apparent on the isotherms of Plate II. In the southern hemisphere the air temperature over the sea is rather higher than over the land on the same parallel.

The varying influences of land and sea are clearly marked on these diagrams, which are copied from the respective Pilot Charts of the British Admiralty. Other similar diagrams are in existence, of more recent date; but those here given will serve every purpose of the nautical student.

In February the Red Sea air temperature ranges from 65° in Gulf of Suez to 79° near Aden. In August the corresponding values are about 82° and 90°, with a rather sharp fall near Perim to 84°.

CHAPTER VI.

SEA TEMPERATURE.

Temperature of the Sea Surface.—Ships provided with accurate thermometers are found on every sea. With these instruments careful observations are taken of the sea surface temperature, and the results clearly entered in the logbook against the time records. Later on, at some central department to which the data have been forwarded, these temperature values are plotted in exact geographical position on large working charts. Then the isotherms, or lines of equal temperature, are drawn through the places having the same sea surface temperature, and we have a chart like that in Plate III.

Diurnal Range of Sea Temperatures.—The average daily range of sea surface temperature, in the open ocean, is generally exceedingly small, although the annual range may be considerable. When a ship is steaming rapidly over areas where cool and warm ocean currents commingle she will probably experience a very rapid alternation of high and low temperature in a few hours. In May 1861, H.M.S. "Nile," Admiral Sir Alexander Milne, on her way from Halifax to Bermuda, had a sea temperature of 70° at the bow, and 40° at the stern; or a difference of 30° in a short ship's length. Captain J. B. Kennedy once had his sea temperature fall from 76° to 45° in a few hours, when in 50 fathoms, on the parallel of Cape Charles. South of Newfoundland, off the mouth of the River Plate, running the easting down between the Cape of Good Hope and Australia, and in other parts of the ocean, there are most marked changes in sea surface temperature over short distances. In the tropics the sea surface has an average temperature which exceeds 80° all the year round. Proceeding north or south from the tropics in either hemisphere, the sea surface temperature gradually decreases. Some of the highest readings, 90°, or even slightly above that, are found in such narrow waterways as the Red Sea, where the conditions are most favourable. This excessively high reading no doubt merely holds for a shallow layer of water, below which the temperature rapidly decreases with the depth. The lowest sea surface temperatures of about 32° are found towards either pole. Sea-water freezes at approximately 28°, and the resulting ice yields much fresher water than the sea surface whence it came, as the salt is, as it were, expelled in the act of freezing.

Where the thermometer shows the sea surface to have a temperature of 70° or 80°, a specially constructed deep-sea thermometer will indicate that the temperature of the water at a depth of 400 fathoms or 500 fathoms is about 40° in every ocean. The fall is rapid in tropical regions, but more gradual as either pole is approached.

Temperatures beneath the Surface.—Except in the far north, or the far south, the temperature at the ocean bottom is considerably lower than the minimum for the year at the sea surface. This rule, however, does not hold strictly for enclosed bodies of water like the Red Sea and the Mediterranean. At the Strait of Bab-el-Mandeb, entrance to the Red Sea, is a sill which rises to within 1200 feet of the surface. On either side, both in the Red Sea and the Indian Ocean, the depth of water increases to 1200 fathoms. This sill acts as a barrier, and prevents the lower waters from mixing. The average surface temperature of the Red Sea varies from 85° in summer to 70° in winter. During the hottest period the temperature gradually decreases from 85° at the surface to about 70° in 200 fathoms, just the depth of the sill's upper edge, and thence to the bottom remains constant. In the Indian Ocean, however, the temperature is only 37° at the same depth as the bottom of the Red Sea. Were the barrier removed, the bottom temperatures in the Red Sea and the Indian Ocean would correspond. Opposite the Strait of Gibraltar, in the North Atlantic, the temperature falls from 70° at the sea surface to 37° at the bottom, a depth of about 2200 fathoms. In the Strait, on the barrier between the Mediterranean and the Atlantic, the lead reaches bottom at 200 fathoms. Consequently the Mediterranean is shut off from water the temperature of which falls below that of the lowest part of the sub-surface current setting in from the Atlantic. This is 55°. Hence the temperature of the Mediterranean falls continuously only to a depth of about 125 fathoms, which depends on the bottom of the inset. In the Caribbean Sea and the Gulf of Mexico the bottom temperature is 39°·5 at all depths exceeding 1000 fathoms. Hence, upon this fact was based an assumption that a channel with a depth of 1000 fathoms connected them with the North Atlantic. And this although every known channel was shallower. In 1884, however, between Porto Rico and Santa Cruz, one with a depth of 926 fathoms was found. By similar reasoning it is inferred that a ridge reaching within nearly 1500 fathoms of the sea surface unites South America with Asia. In the open sea, at great depths, irrespective of latitude, the temperature of the bottom strata of water is about 32°. The low bottom temperatures are said to be consequent on a slow circulation of water from the polar seas towards the equator. When this flow is comparatively unobstructed, as in South Atlantic, South Pacific, and Indian Ocean, the bottom temperature is lower than in North Atlantic and North Pacific connected to polar seas by narrow and shallow straits. This theory is supported by the observations of temperature at depths in enclosed seas.

Isothermal Lines.—February and August are the best months to indicate the distribution of sea surface temperature. Turning to Plate III., representing the sea surface isotherms for February, the first thing which strikes the eye is the peculiar way in which they crowd together south of Newfoundland; whereas on the eastern side of the ocean they widen out, just like an extended fan. The isotherm of 45° starts in lat. 40° N. long. 70° W., and trends north-easterly until the Arctic circle is almost reached on the west coast of Norway. A vessel steaming along this line as a track would have an average sea temperature of 45° all the way across, while increasing her distance from the equator by quite 1200 miles. It will also be observed that a vessel steering north-east along the American coast, from lat. 30° N. to lat. 40° N., will change her sea temperature from 70° F. to 45° F.; whereas a vessel on the eastern side of the North Atlantic must commence a northerly course on the coast of Africa near Cape Verde, in order to experience a like change. In other words, the sea temperature changes quite as much between lat. 30° N. and 40° N. on the western side as it does between lat. 15° N. and lat. 65° N. on the eastern side of the Atlantic. By carefully regarding these isotherms there is little difficulty in picturing the cold water of the Labrador current hugging the American coast all the way southward to Florida, while the relatively warm water of the Gulf Stream spreads out towards Europe. The warmest water, the temperature being 80° and above, is found to extend a few degrees of latitude both to the north and the south of the equator. In the Gulf of Guinea are fouud the highest readings.

Similarly, in the South Atlantic, the sea surface isotherms do not stretch due east and west, but make an angle with the latitude parallels. The higher temperatures, however, are now found on the western side, and the lower readings occur on the African coast. Near the River Plate, in about lat. 35° S., the isotherm of 70° commences; but it ends on the West Coast of Africa, in lat. 15° S. Here, again, the trend of the sea surface isotherms affords us fair evidence with respect to the sea surface currents. Up the West Coast of Africa flows the cool water from the lone southern ocean, which attains a higher temperature as the tropic is reached, sets westward there, and eventually this warmer water travels south along the East Coast of South America. Owing to these causes the sea surface isotherms are tilted north on the eastern side and south on the western side of the South Atlantic. Off the River Plate, where the warm water setting south meets cold water moving north, changes in sea surface temperature are very wide.

Turning to the North Pacific it will be noticed how much more nearly the sea surface isotherms coincide with parallels of latitude than in the Atlantic. There is displayed a tendency to sag by the ends on the eastern side, due to the current setting south along the West Coast of North America. The 80° isotherm does not extend right across the Pacific, on each side of the equator, to form a zone of above 80°, as in the Atlantic. Between lat. 20° N. and lat. 20° S., however, the sea surface temperature is above 75°, but below 80°. In the South Pacific there is a tendency for the isotherms to creep up the West Coast of South America, owing to the cool Humboldt or Peruvian current setting north up the coast from high southern latitudes.

In the North Indian Ocean the sea surface isotherms make an angle with the meridians of about 45°. The 80° line, starting just south of the equator on the east coast of Africa, trends to the north-eastward, and ends on the west coast of India in about lat. 20° N. A cool current setting south-westward from Cape Guardafui, the north-east corner of Africa, along the coast, keeps down the sea surface temperature there. As regards the South Indian Ocean there is little to remark, except the loop off the Cape of Good Hope in the 70° isotherm, due to the Agulhas Current. The wavy appearance of the isotherms below the parallel of lat. 40° S. may be due to the fact that the sea surface currents setting northward from high southern latitudes attain a higher northern latitude on different meridians. Near China the isotherms evince a tendency to dip southward, owing to the action of the cooler water of the Japanese Current.

The chart for August (Plate IV.) shows a marked change on that for February in certain parts. During February the Arctic sea surface was frozen over, whereas in August open water is the prevailing feature. Down south in the Antarctic similar conditions held, in an inverse order, but scarcely so well defined as in high northern latitudes. South of Newfoundland, in lat. 40° N. long. 70° W., the sea surface is nearly 30° warmer in August than in February, while the 40° isotherm is found trending almost due north and south in Davis Strait. Another branch of the 40°

line stretches from Greenland to Spitzbergen. Speaking generally, all the isotherms are considerably more to the northward, in August, in the North Atlantic, than they were during February. Of course, this might be predicted with certainty, taking into consideration the difference in seasons.

Isotherms of summer and winter do not differ nearly so much over the waters of the southern hemisphere. A swift steamer bound from the Falkland Islands to lat. 20° S. long. 40° W. would, however, experience very rapid changes in her sea surface temperature, if regularly recorded.

In the Pacific, the trend of the isotherms towards the equator, near the west coasts of North and South America, is intensified.

An interesting temperature chart, which accompanied a recent issue of the *North Atlantic Pilot Chart*, published monthly by the United States Hydrographic Office, affords an interesting example of the kinks in sea-surface isotherms, or lines of equal temperature, south of Newfoundland. It is deduced from the reports of voluntary observers from 140 vessels, representing 650 observations, between the 1st and the 25th May 1896. In addition to the isotherms there are given the outward and homeward tracks of the trans-Atlantic steamers trading to New York and Boston, arrows indicating the prevailing current and lines of equal magnetic variation. Starting at New York, for example, and running the eye along the track, the rapidity and frequency with which the sea-surface temperature changes just there, while steaming over a few degrees of longitude, are evident.

Lines of Demarcation.—In connection with this chart the following extracts from the reports of two of the observers will be sufficient to indicate the conditions at any given instant. On 19th April 1896, in lat. 40° 30′ N., long. 61° 50′ W., the R.M.S. "Etruria," Captain J. Ferguson, crossed a distinct line of division of cold from warm water running north and south from horizon to horizon. The westerly water was 62°, the other 46°. On the westerly water a moderate south-east breeze was blowing, whereas on the easterly water was an oil-smooth surface and calm. The whole eastern horizon, from one apparent end of the division line to the other, appeared raised some minutes of arc higher than the western horizon, and the break between them was quite abrupt. On 13th May 1896, the steamship "Vedamore," Captain J. Trenery, when in lat. 41° 19′ N., long. 62° 20′ W., obtained sea-surface temperatures of 40° and 64° within a few yards of each other. The meeting of the Gulf Stream and Labrador current was distinctly defined by a little "troubling of the waters," and particularly by the ascent of a dense vapour to a height of three feet. This vapour looked exactly like field-ice, and might easily be mistaken for it at night. The line of demarcation ran N.N.W. and S.S.E. as far as the eye could reach. On the cold water side the sea was quite smooth, but the warm stream was considerably disturbed. On 27th March 1890, the "Bracadale," in lat. 36° N., long. 73° W., had temperatures of air and sea 68° and 70° respectively, with beautiful weather. Next day, in lat. 38° 30′ N., long. 74° W., the air was 52° and sea 46°. On 29th, at New York, her master recorded heavy snow squalls with temperature down to freezing-point. Vessels frequently get iced up near New York and their crews frost-bitten, when they are compelled to seek the warm water of the Gulf Stream for a thaw and a refit. Bad weather is very marked where rapid changes of sea temperature are found, as south of Newfoundland and on the Agulhas Bank. Off Cape Guardafui a change of 10° is often experienced in a few hours' run. At Perim the sea temperature is often much lower than that of the adjacent ocean. Off the River Plate the sea temperature changes 15° in a few hours, and near Rio Janeiro there are also wide changes in sea temperature.

CHAPTER VII.

SALINITY.

Varying Salinity of Sea Surface.—Sea-water is salt, and has a peculiar bitter taste. A given volume of sea-water will weigh more than the same volume of pure fresh-water. If we take a cubic foot of water, at the same temperature, from the surfaces of the Black Sea, the Mediterranean, the trade-wind regions, and the tropics, they will differ somewhat in weight. The amount of solid matter dissolved, and therefore invisible, varies slightly from place to place, but its composition at sea remains almost the same everywhere. Chloride of sodium, familiarly known as common salt, accounts for rather more than three-quarters of the solid matter. The remaining portion it is that gives sea-water a bitter taste. If carefully boiled down, with proper precautions, the solids left behind would, speaking generally, be found to consist of 77·8 per cent. of common salt, 10·9 per cent. magnesium chloride, the same percentage of sulphates, and traces of nearly every known mineral. One hundred pounds of average sea-water contains about $3\frac{1}{2}$ lbs. of dissolved salts.

The density, or specific gravity, of sea-water varies not only with its saltness but also with its temperature. By measuring the density at some agreed-upon standard temperature; or, which amounts to the same thing, by measuring the density at different temperatures, and reducing each to what it would be at the standard temperature, the differences of density due to salinity are determined. Tables for carrying out these reductions have been calculated and published. A bottle holding 1000 grains of pure fresh-water at 60° Fahrenheit, the standard temperature used in the Meteorological Office and elsewhere, will contain 1026 grains of water holding 3·5 per cent. of salts in solution. With salinity percentages of 0, 1, 2, 3, 3·5, and 4, the corresponding densities are 1·000, 1·006, 1·014, 1·022, 1·026, and 1·030. By salinity is meant the ratio between the total salts and the water.

Near large rivers, the fresh-water moving seaward sometimes lowers the specific gravity of the sea surface for many miles. Off the mouth of the Amazon comparatively fresh-water, muddy and discoloured, is discovered floating on the sea surface several hundred miles from the land. The effect of the River Plate has been observed quite 1000 miles from the mouth. After heavy rain the water collected from the sea surface in mid-ocean has proved to be nearly fresh.

Percentage Salinity of Different Oceans.—Professor G. Forchhammer has determined the salinity of the several oceans. The average percentage for the Atlantic is about 3·6, for the sea between Africa and the East Indies 3·4, between the East Indies and the Aleutian Islands 3·3, and between the Aleutian Islands and the Society Islands 3·5. The corresponding value for the Mediterranean is 3·8, the Caribbean Sea 3·6, and the Red Sea 4·1. Mr J. Y. Buchanan, of the "Challenger" expedition, told the Royal Geographical Society twenty years ago that the saltness of sea-water is due to the presence of rock substance which has been disintegrated by atmospheric influence.

Disregarding the reduction for temperature—in other words, taking only the actual densities recorded by careful use of the hydrometer at sea—the young sailor will form a better conception of practical work in the determination of the specific gravity of the sea surface. Always remember, however, that for scientific purposes the temperature of the sea surface must be obtained at the same time as the specific gravity, and both entered in the logbook together.

Observed Densities of Salt-Water.—An analysis of several logbooks affords approximately the following information with respect to the specific gravity of the sea surface as observed by the hydrometer. From the Channel to 25° N., 26° W., the reading is 27; thence to 15° N., 26° W., it is 26; thence 25 to 10° N., 24° W.; 24 to 5° N., 17° W.; 25 to 5° S., 25° W.; 26 to 10° S., 25° W.; 27 thence to Melbourne and on to 30° S., 175° W.; 26 to 25° S., 165° W.; 25 to 15° S., 160° W.; 24 to 5° N., 160° W.; 23 to 10° N., 160° W.; 24 to 15° N., 165° W.; 25 to 20° N., 165° W.; and 26 to San Francisco, California. Coming down the Pacific, 26 holds to 30° N., 125° W.; 25 to 20° N., 120° W.; 24 to 10° N., 115° W.; 23 to 5° N., 115° W.; 24 to 5° S., 120° W.; 25 to 10° S., 120° W.; 26 to 35° S., 120° W.; 27 to 50° S., 105° W.; 28 to 55° S., 105° W.; 27 to 30° S., 30° W.; and 26 to 10° S., 27° W. Another vessel kept between 29 and 30 from Gibraltar to Port Said, 40 at Suez; 30 thence to Daedalus, 29 to Jebel Tier; 28 to Perim; 27 to Ras Filuk; 26 to 10° N., 70° E.; 25 to 5° S., 85° E.; 24 to 15° S., 95° E.; 25 to 20° S., 100° E.;

26 to 25° S., 105° E.; 27 to 30° S., 110° E.; 28 to 25° S., 120° E.; and 29 thence to Adelaide. Going up the Bay of Bengal from the Equator to the Sand Heads, Calcutta, the specific gravity falls from 22 to 20. When 17, 25, and 45 miles from Port Said in 1877, the sp. gr. was about 45; in Great Bitter Lake 48; and in Little Bitter Lake 35. Just about there the maximum sp. gr. is experienced. All the above readings were exactly as recorded by fairly correct hydrometers.

Excessive evaporation in the trade-wind zones tends to increase the specific gravity of sea-surface water; and the formation of ice in the regions about the poles has a similar effect. Both evaporation and congelation augment the salinity. The frequent and heavy rain common to the doldrum region causes a lower specific gravity there through dilution. Hence specific gravity and salinity are somewhat subject to seasonal changes.

In the North Atlantic the highest specific gravity is found near the Azores, Canary Islands, and Cape Verdes. The lowest readings are recorded by vessels between the equator and lat. 15° N. At the same time the specific gravities of the western side of the Atlantic, near the east coast of North America, are lower than corresponding observations on the eastern side. In the South Atlantic two areas of relatively high specific gravity exist, one near Trinidad, the other between St Helena and Ascension. Turning to the North Pacific, it is found that the specific gravity is highest about lat. 30° N.; and the minimum readings occur in about lat. 7° N., under the influence of the equatorial counter-current. Fewer observations of specific gravity have been recorded for the Indian Ocean, but there is apparently low relative density in its northern portion, together with an area of relatively high density between 20° S. and 35° S. from 60° E. to 80° E. Near Java and Sumatra, owing to the heavy rainfall, the specific gravity is lower than elsewhere.

On approaching the mouth of the Nile, the steamship "Lusitania," Captain Veale, in September 1897, observed a well-defined indication of the meeting of the Nile and the sea. The Nile water was of a muddy colour, whereas the sea water was pale green. A line of demarcation, about twelve miles from Damietta light, could be distinguished all round. With Damietta light bearing S. 3° W., distant 12 miles, the specific gravity was 1·008; and, when bearing S. 15° W., distant 13 miles, the specific gravity was 1·024. In September 1904, Captain Mullan, F.R.G.S., of the steamship "Ramsay," had specific gravity of 39·5 at the entrance to Bitter Lake, 19·5 near the Port Said Breakwater; and a current of fresh water was setting east from Damietta mouth.

CHAPTER VIII.

WINDS.

Definition; Cause of Winds.—Wind may be defined as air in sensible motion; a comprehensive definition due to Professor Laughton, R.N. Equatorial heat and polar cold, together with the earth's rotation and the relative distribution of land and sea, practically determine the wind circulation of our planet.

One portion of the earth is warmed by the sun more than the adjacent portions, thus causing the relatively warm air to expand and rise over the warmer area. Hence ensues a change both in the barometric pressure and in the specific gravity of the air, as also a surface wind which flows towards the warmed area on the principle that 'Nature abhors a vacuum.' Tropical regions are, as it were, the engine-room where the motive power for the world's wind circulation is produced and maintained. The rotation of the earth on its axis deflects the moving air from the shortest distance between any two points on the earth's surface; towards the right in the northern, and to the left in the southern hemisphere.

Since winds are due, in the first instance, to inequalities in temperature, they may conveniently be divided into three broad classes depending upon the fixity of the predisposing causes, and are either constant, periodic, or variable.

Constant winds blow *towards* the tropical regions of continuously high temperature. Periodic winds are due to unequal heating of land and sea, whether the period is annual or diurnal. Changeable winds prevail where the heating of land and sea is capricious. According to the late Professor Ferrel, a distinguished American who made the subject of the winds peculiarly his own, the earth's surface may be theoretically divided into zones which agree as a rule with those of solar climate. As indicated in fig. 17, starting at the north pole and ending at the south pole, we get calms, south-west winds, calms, north-east trades, doldrums, south-east trades, calms, brave westerly winds of Maury, and calms. This simple general distribution of wind is disturbed locally by the unequal heating of land and sea, the presence of elevated land and travelling wind systems. Sailors call the zone between 40° and 50° the 'roaring forties.' Sometimes this term is applied exclusively to the strip of south latitude, between 40° S. and 50° S., where vessels run their easting down. Occasionally, however, it is also used for the similar strip in the northern hemisphere.

The 'Doldrums.'—Near the equator, but apparently entirely to the northward thereof, is a belt of light variable breezes, calms, heavy rains, and thunderstorms, which has always been a great hindrance to sailing-ships. This area is known as the Doldrums, a name probably corrupted from the Spanish *doloroso*, or old Portuguese, *doloris*, translated as equivalent to tormenting. It varies in width from 150 to 200 miles in the North Atlantic to 300 miles in the Pacific; and travels somewhat to the northward and the southward of the average position, varying with the sun's declination. In the Atlantic the equatorial limit of this unwelcome doldrum is about 2° N. in January and 10° N. in July. Generally 5° in width, it is sometimes as much as 15°, thus tending to considerably lengthen the passages of sailing-ships. At times the two trade winds are separated by such a short space, or 'blow home,' as sailors say, that vessels pass from one trade to the other without scarcely experiencing the Doldrums' delay. In February the doldrum area is narrowest; while in August it has its greatest width. Doubtless the Pacific limits are similar, although some are of opinion that it stretches slightly south of the equator in January. Navigators in sailing-ships quite naturally aim at crossing the doldrum zone where it is narrowest in order to get over the trouble with least delay. Unfortunately this area is far from invariable either in position or in extent.

The late Captain H. Toynbee, F.R.A.S., when Marine Superintendent of the Meteorological Office, made a detailed examination of this region; yet, notwithstanding the better acquaintance with Nature thus obtained, the result is still very uncertain. A track which has proved admirable one year will probably turn out most harassing exactly twelve months later. Steamships, however, care little either for doldrums or adverse winds. December to June are the best months for crossing the Atlantic equator. The north and south swing of the doldrum area causes some places to have two rainy seasons, and other places but one.

Oceanic wind circulation is more regular than that of the land. Similarly the winds of the southern oceans are easier to understand than those north of the equator, owing to the much smaller amount of land in the south. Remembering that in the northern hemisphere the wind around a high pressure circulates with the hands of a watch, and around a low pressure in the opposite direction; whereas in the southern hemisphere the circulation in either case is exactly reversed, a glance at a diagram of the distribution of atmospheric pressure reveals the close connection between the prevailing winds and the average height of the mercurial column in the barometer at any place.

At about 30° N. lat. and 30° S. lat., as indicated on figs. 11 and 12, the highest atmospheric pressures are experienced. Surface winds blow outward therefrom towards the low pressure area on either side. If the earth were at rest the wind would be from the north in the northern portion of the torrid zone, and from the south in the southern portion. Owing to the earth's rotation from west to east on its axis, the air north of the equator is subject to a force drawing it to the westward, and therefore takes up an intermediate direction, just as a ship moves under the influence of wind and current, in agreement with the law of the parallelogram of velocities explained in the volume on *Navigation* in this series, and blows from the north-east towards the south-west. Winds are named according to the direction *from* which they blow. Similarly, south of the equator, the wind blows from the south-east to the north-west. These are the north-east and south-east trades respectively. Of the two the latter has greater strength and persistency. Both have been known to navigators for several centuries. The sailors of Columbus dreaded lest the continuous north-east wind might prevent them from returning home. He soothed the fears of his hardy toilers on an unknown sea by calling attention to the few flaws experienced. More than 150 years ago the westerly trend of the trade winds was attributed to the earth's rotation from west to east. Halley and Hadley were early observers of this phenomenon. Ferrel has more recently formulated the general law that a body moving in any direction on the earth's surface is deflected by the earth's rotation; to the right of its track in the northern hemisphere, but to the left in the southern hemisphere. The deflecting force varies in magnitude with the latitude, increasing from equator to pole; and with the velocity of the moving body. The velocity of a point on the earth's surface at the equator is 1036 miles an hour, 897 in 30° N. and 518 miles in 60° N. towards the east. Hence, if air from the parallel of 60° could be instantaneously transferred to 30°, it would have an easterly motion 379 miles per hour less than that of the air already on the parallel of 30°. In other words, it would have a relative *westerly* motion of 379 miles per hour. Hence, also, air travelling from the equator to polar regions will have a relative *easterly* motion; whereas winds from polar regions to the equator will have a relative *westerly* motion. In like manner the wind blowing out from the polar edge of the high pressure zone in each ocean is deflected. As a result we have the south-west wind on the polar side of the high pressure in the northern hemisphere, and the north-west wind on the polar side of the southern hemisphere high pressure. They are not nearly so constant as the trades, owing to the interference of travelling wind systems. Between these winds and the trades are the calms, or, as they are sometimes termed, anti-trades of Cancer and Capricorn, in the northern and southern hemispheres respectively. The calms of Cancer are also known as the "Horse Latitudes," because, in the days of long ago, so many horses were there thrown overboard from ships detained by calms.

Upper air currents flow approximately parallel to those on the surface, but towards almost exactly opposite directions. A continuous south-west wind blows at the summit of the Peak of Teneriffe. As the sun travels southward, the trade wind recedes equatorwards, and the influence of the south-west wind prevails lower down the mountain until eventually it holds sway from summit to base. Mauna Loa affords another example of the upper return currents. Sir John Herschel, in referring to the upper air currents directly over the Trades, termed them the Anti-Trades. Occasionally, however, this expression is used to indicate the south-west and north-west surface winds met with on the polar sides of the high pressure belts of the northern and southern hemispheres respectively. This amounts to much the same thing, if we assume that the upper air currents over the trades reach the surface thereabouts on their way towards the poles.

Periodic Winds.—These may be divided into seasonal and diurnal; otherwise known as *monsoons* and *land and sea breezes.* Land warms and cools faster than the ocean. Consequently in summer the land is relatively warmer than the sea, and cooler in the winter. Similarly, also, the day and night temperatures vary. The first difference causes seasonal winds with yearly periods, the second seasonal winds with periods of twenty-four hours. The monsoon derives its name from an Arabic word signifying "season," which was originally solely used for the Indian Ocean. Monsoon winds blow towards the relatively warm land in summer, and towards the relatively warm sea in winter. Here, again, as with the general circulation, the difference in temperature determines the wind direction. At different seasons the monsoon winds do not blow from exactly opposite points of the compass, the wind force varying considerably at different times, while the change of the monsoon is not restricted to any given date. Monsoons are more marked where large continents and high lands exist. Hence the special features of the monsoons experienced in the Northern Indian Ocean and the Malay Archipelago. From May to October the wind moves from the equator towards the more heated land, is deflected to the right by the earth's rotation, and becomes the south-west monsoon of the coasts of India and Arabia. A south-east monsoon prevails, at the same time, on the south-east and east coasts of Asia. In winter, October to May, the adjacent oceans are warmer than the continents. Hence the air motion is then in an almost opposite direction to that of summer. Thus we get the north-east monsoon of India, and the north-west monsoon of Asia's east coast. The summer monsoon of the North Indian Ocean is considerably stronger than the winter monsoon. It is frequently referred to as *the* monsoon, inasmuch as the north-east monsoon pales into insignificance in comparison. Steamers bound from Bombay to Aden in mid-summer suffer severely at times, owing to the gale force, and heavy sea, of the south-west monsoon. This latter monsoon commences well to the north, works its way south, and is from six to eight weeks earlier at the Tropic of Cancer than near the equator. The breaking-up of the monsoon, as the change from one monsoon to the other is termed, depends upon the sun's course. It varies with the latitude; and is marked by calms, variables, and cyclonic disturbances.

Seasonal winds are not so distinguishable elsewhere. In some parts their only effect is to modify the wind force. South America and Africa are practically without monsoons. The United States Hydrographic Office has determined a distinct monsoon effect on the east coast of Brazil during the summer, between 15° S. and 30° S. Australia has monsoons, regular but weak; and they are also found on the west coast of North America.

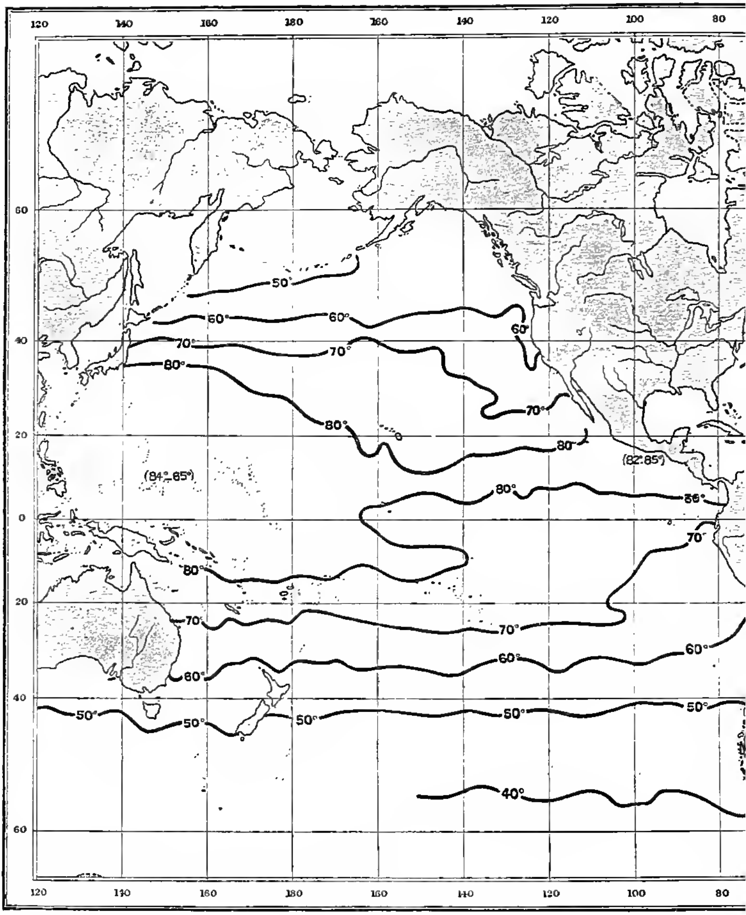
Variable Winds.—Variable winds are those which appear to blow without any regularity as to time, place, or direction. Local causes, such as the configuration of the land, the vicinity of the sea or of lakes, overpower the general atmospheric circulation, and temporary wind systems are formed. Lieut. C. H. Judd, U.S.N., has pointed out that sailors often misapply this word variable to denote an *unsteady* wind. In dealing with a ship's logbook, confusion is caused to the clerical staff of an office when they come across an entry in the wind column such as this:—"*Variable S.W. to N. force* 5 *to* 6 *to* 3." Equally glaring examples might be quoted. It is simply impossible for this to have occurred, unless the wind during the watch has been recorded. It is the wind at the instant of observation that should be specified. Never give the wind for the interval in the wind column. Meteorological departments require the wind "*at the time of observing*, and not an estimate of the direction since the last observation." Observers long ago found that the wind has a tendency to veer with the sun from N. to E. and so through S. and W. back to N. The reason for this will be found in the chapter on cyclones. A similar shift takes place in southern latitudes. The wind is usually said to veer when it changes with the sun, and to back when the changes are against the sun. Thus, in the northern hemisphere a wind veers when the shift is from east to west, say, through south; and backs when the shift is from west to east, through south. In the southern hemisphere the wind veers from east to west, through north; and backs from west to east, through north.*

Land and sea breezes are generally found in the vicinity of coasts in tropical regions. There the air over the land is warmer by day and cooler by night than over the more equable sea. These breezes are similar to monsoons in principle, only the period is a day instead of a year. With respect to small islands the analogy is almost perfect. The breeze from the sea commences in the morning and continues until night, just as the monsoon is from the sea in summer; and is replaced by a breeze from the land at night, just as the monsoon is from the land in winter. Professor J. K. Laughton has called attention to the fact that mountains in the background are necessary to ensure land and sea breezes of any strength. On the coast of Jamaica, near Port Royal, these diurnal periodic breezes are most marked. The connection between mountain ranges and monsoons is also evident. Other theories have been advanced in order to account for the fact that the sea breeze begins in the offing, not on the coast.

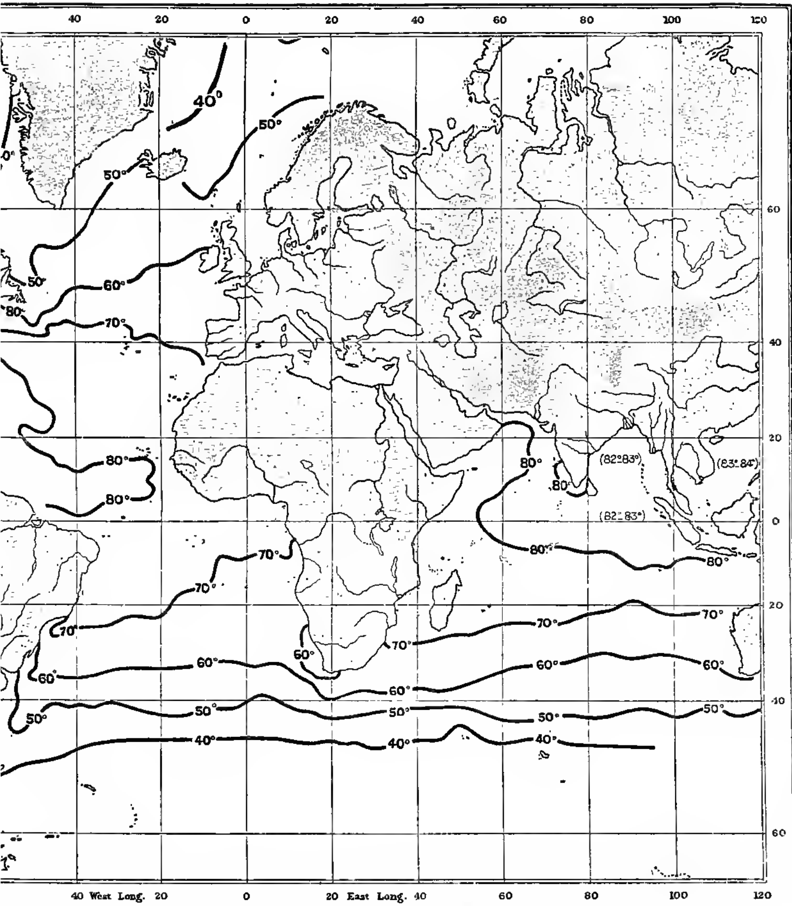
Between the parallels of 40° S. and 50° S., westerly winds are the general rule. Maury termed them the "brave west winds," and this particular belt of ocean is known to sailors as the "roaring forties." Sailing ships bound from Atlantic ports to the Pacific often find the persistent westerly gales of Cape Horn more than they can conveniently contend against. In a paper read before the Shipmasters' Society, the author has suggested that weak ships should keep away from Cape Horn altogether when outward bound for Pacific ports. By steering east as though bound for Australia they are able to utilise the very westerly wind along the "roaring forties," which so seriously militate against advance near Cape Horn.

The trade winds are strongest in either hemisphere when the sun has his greatest declination of name opposite to that of the hemisphere. In the northern winter the trades of the North Atlantic and North Pacific may extend to nearly 30° N. from about 2° N. On the eastern side of the oceans the trades are most marked. A ship sometimes holds a north-easterly wind all the way from the English Channel; partly due to the anti-cyclonic wind

* Under a more recent agreement among meteorological authorities the wind is said to veer from east to west, through south; and to back from east to west, through north; irrespective of hemisphere.



ALLINGHAM'S MARINE METEOROLOGY.



E IV.—Sea Surface Isotherms (August).

system being well north, and partly to the trades. At the same time, the south-east trades blow from the equator to a line drawn from the Cape of Good Hope to Rio Janeiro. In the eastern Pacific they extend northward to about 5° N. From May to October the north-east trades extend from 12° N. to 30° N. in the North Atlantic, while the south-east trades cross the equator and blow even as far north as 8° N. On the western side of the Pacific, the trades are interfered with by the monsoons. The monsoons of the China Seas reach to the Ladrone Islands, meeting the north-east trade; and the north-west monsoon interferes with the south-east trades during the first three months of the year, even as far east as the Low Archipelago.

A few winds known by local names are deserving of mention. Between Cape Verde and Cape Lopez the Harmattan blows in December, January, and February. It is a very dry off-shore wind, bringing with it much red dust at times, and lasting from a few hours to a fortnight. Tornadoes are violent gusts of winds experienced on the West Coast of Africa, at the beginning and end of the rainy season; and elsewhere. A fair warning of their approach is given by clouds, thunder, and lightning. Westerly winds, known as Vendavules, may be fallen in with on the coast of New Granada between July and November. So-called Northers make matters lively at times in the Gulf of Mexico, principally between September and March. Off the River Plate, between 30° S. and 40° S., as far eastward as 45° W., there are very heavy south-westerly gales, frequently attended with thunder and heavy hail, known as Pamperos. They are most severe in summer and autumn.

Squalls, termed Williwaws, blow with great force in the Straits of Magellan, at times careening a vessel almost on to her beam ends. Northers trouble the Bay of Panama from December to April. Off the Nicaraguan coast these Northers, from N.N.E. to E., are called Papagayos; and Tehuantepecs in the Gulf of that name. El Cordonazo de San Francisco, or whip of St. Francis, is a gale on the west coast of Mexico and Lower California. The prevalent winds round Australia are either cyclonic or anticyclonic. An oppressively warm wind from north-west, known as a Brickfielder, blows strongly on the south-east coast in summer; and is quickly succeeded by a southerly breeze, locally referred to as a Southerly Buster. The change in air temperature is most marked. In the Persian Gulf, the Shamál, or north-wester, blows during about three-quarters of the year in the northern half of the Gulf. It causes a dust haze like the African Harmattan. The Sharki, Kaus, or south-easter, holds from December to April. During a south-east gale, a sudden shift to north-west is probable. Winds blow generally up or down the Red Sea.

Measurement of Wind Force.—Wind force mainly depends upon the difference in barometric pressure from point to point on the earth's surface. The greater the difference of pressure over a given distance the greater is the wind force in the vicinity. Weather workers use the term gradient to express the difference in barometric pressure over a given distance. The gradients used by the British Meteorological Office are reckoned in hundredths of an inch of barometer per 15 nautical miles. On the continent of Europe, gradients are expressed in millimetres per 60 nautical miles. But ·04 inch is almost the exact equivalent of one millimetre, so that the two systems are practically identical. So far a reliable table for converting amount of gradient into force of wind is wanting.

Squalls, and curious irregularities in wind systems, are deserving of consideration. On 1st January 1859, in lat. 18° N. long. 33° W., the "Victory," Captain A. Fry, had two distinct winds at the same instant. For ten minutes the fore yard was braced up to a light breeze from east; and the main yard square to a light breeze from south-west. She was only 112 feet long. A calm followed. On 10th October 1864, at Rio, H.M.S. "Bombay" experienced a severe squall, which was soon over. The wind shifted from a strong south-east breeze to a squall from south-west, of hurricane violence. Water flooded the orlop deck through an open scuttle, but she was brought up with bower and sheet anchors, came head to wind and righted. Nine vessels in the harbour went on to their beam ends and filled. Hailstones, as large as pigeons' eggs, fell, and the damage on shore, due to this squall, was estimated at one million pounds sterling. A squall off the Isle of Wight, on 24th March 1878, caused the loss of H.M.S. "Eurydice" and many valuable lives. The ship "Candahar," Captain Russell, on 15th June 1884, in lat. 8° S., long. 15° W., had two winds at the same instant, one from S. the other from W.S.W. Her fore head-sails and main stay-sails were full from starboard side, while her sails on main and mizen were full from port side. Ship "Loch Garry," on 28th June 1887, in lat. 28° S., long. 23° E., had a strong breeze from S.W. Suddenly, without the least warning, it fell flat calm for a few minutes; and, as she was going eight knots at the time, the sails acted as though she had been taken aback. Eventually, the wind came away from the south-west again. The ship "Four Winds," on 24th August 1887, in lat. 26° S., long. 60° E., had a fresh S.E. breeze. Suddenly a very sharp gust caught her flat aback, and she stopped as suddenly as though she had run up against something solid. On 6th May 1888, in lat. 20° S., long. 30° W., the "Drumcraig" lay becalmed. Her master had the mortification of seeing the barques "Abbey Town" and

"Ivanhoe" pass only one-quarter of a mile distant, under the influence of a fine fresh breeze, going eight knots. On 21st May 1891, H.M.S. "Ringarooma," passing Cape Servat, met a fresh S.E. to S. breeze; it was warm at first, but became cold after passing Cape Bon. This wind was felt at the masthead, 100 feet high, some time sooner than on deck, where the wind was from N.E. The ship "Castle Rock," on 1st April 1893, in lat. 40° S., long. 92° E., was struck flat aback with great force. In a second the wind was right aft, with such strength that it brought the lower mizen top-sail yard down in halves. In another two seconds it burst out on her starboard beam, threw her lee top-gallant rail under water, and tore off several of the sails. On 6th June 1894, the "Loch Tay," Captain Martin, was in lat. 41° S., long. 56° E. Her sails on the foremast were aback at the same time as those on main and mizen were rap full. This lasted for about five minutes, and the wind, both before and after the flaw, was a fresh westerly breeze. On 3rd November 1894, the "Othello," Captain Price, in lat. 33° N., long. 10° W., had her fore and main top-gallant masts whipped clean out during the passage of a cumulus cloud with slight rain. The squall lasted less than two minutes, and the full force was not felt on deck. Previously the wind was light from north-west; and the squall was followed by a fresh gale for two hours. On 18th April 1897, in lat. 3° S., long. 27° W., the "Brenhilda," Captain Baxter, was struck by a squall which was not felt aft, but only forward. Jib-boom went at the cap with all head-sails, while aft all was serene. On 1st October 1898, the steamship "Amber," in lat. 36° N., long. 16° E., experienced a squall of hurricane violence lasting about six minutes. Before the squall a light breeze was blowing from E.N.E., and afterwards a breeze of similar force from the west was recorded. This squall broke over Malta with unprecedented violence, causing serious damage to shipping and shore structures, and the loss of several lives. Captain G. W. Read, of steamship "Auretta," reported that at Venice, on 10th July 1888, during a heavy squall of cyclonic nature, accompanied with heavy rain and fierce lightning, a gondola containing passengers was lifted bodily out of the water by the wind to a height of six feet, and spun round on the way. This occurred on the Grand Canal, opposite where warships anchor. At the same time, several houses in the vicinity were unroofed, the débris going straight upwards. Sailing-ships are fast passing away, as may be gathered from the fact that when Scoresby left Liverpool, in the "Baffin," for Greenland, in March 1832, there were 300 ships there, all waiting for a favourable wind. Still, a knowledge of the wind systems is not altogether useless for the navigators of steamships.

CHAPTER IX.

WIND-FORCE SCALES.

Velocity and Force of Wind.—Wind has been defined in the last chapter as air in sensible motion. Its force varies from a light air to a hurricane. Anemometers are used at many shore stations either for recording the wind velocity or wind pressure. Robinson's anemometer consists of four hemispherical cups, one at each end of two arms at right angles. The arms thus form a cross; and, being fixed to a freely rotating spindle at the crossing point, the whole system moves round, because the wind pressure is greater on the hollow side of the cup than on the rounded side. An arrangement of dials is acted upon by the lower end of the spindle, and registers the wind velocity in miles in much the same way as a patent log gives the distance run by a ship. The assumption is made that the cups will revolve five hundred times for every mile of wind velocity. As a matter of fact, the ratio between the wind velocity and the cup velocity varies with the size and inertia of the cups, the length of the arms, and also the strength and the regularity of the wind itself. Such an anemometer does not register the actual wind velocity at any given instant, but, by the aid of clockwork and photography, a continuous registration of wind force and direction is possible.

Wind pressure is often given in pounds per square foot, on the assumption that it is equal to 0·004 multiplied by the square of the velocity in miles per hour. This pressure measurement is deduced from the action of the wind on a plane surface of metal to which the wind direction is perpendicular. On the Continent of Europe the pressure is registered in kilogrammes on the square metre, hence a pressure of 1 lb. on the square foot is the same as a pressure of 4·88 kilogrammes on the square metre. The wind presses against a plate one foot square, a spiral spring having an index which permits the observer to read off the pressure. Osler's anemometer, constructed on this principle, leaves a continuous permanent pencil trace of the wind pressure.

Lind's pressure gauge is shaped like a syphon, with one end bent over at a right angle so as to face the wind. It rotates freely about a vertical axis, and the mouth is kept fully open to the breeze. Half-full of water, the zero of the scale is the level of the contained water in a calm; and the wind blowing down the tube drives the water up the other leg having a graduated scale from which to read off the pressure.

Estimation is the sheet anchor of the sailor with respect to wind force. Shore observers also depend upon estimation where anemometers are wanting, and many scales have been devised for the purpose of uniformity among observers. In some countries the limits are 0, a calm; and 4 a hurricane. The British Meteorological Office scale is from 0, a calm; to 12 a hurricane. Every variety of scale is in existence between these two extremes.

Beaufort's Scale.—The late Admiral Sir Francis Beaufort, having felt the need of a uniform system for recording the force of the wind, drew up a scale which has ever since borne his name. Very seldom, indeed, does the observer at sea trouble about what sail Beaufort's ideal frigate might be carrying, or how many knots she would be moving through the water, with a given breeze. Speaking generally, the sailor simply deals with whatever ship he may happen to be on board at the instant of observation, occasionally making an approximate allowance, should she be exceptionally fast or slow, stiff or tender. Men who have never left the land cannot have the most remote conception as to the handling of a ship. Yet sailors and shorefolk use a wind scale which ranges from 0, a calm, to 12 a hurricane; and this is known by courtesy as Beaufort's scale. Admiral Beaufort drew up his scale for use on board the "Woolwich"—a warship in the early days of the nineteenth century—about the year 1805. His scale is in strictness only applicable to vessels of her type, rig, and manning.

Probably not a single observer, on shore or afloat, uses Beaufort's scale literally. Much has happened since the period when the sailing frigate was on every sea. Bigger ships with fewer men, double top-sails and double top-gallant-sails, omission of royals, increase in the number of fore-and-aft sails, and other marked features of the modern Merchant Navy, militate against the retention of Beaufort's sailing frigate as a standard of reference. An attentive youngster at sea soon learns what is considered a fresh breeze; and so on, from a calm to a hurricane. When, as an officer, he is required to record the wind force, he first determines what the verbal description is, and then turns it into the numerical scale.

Admiral Beaufort's scale, given below, makes 12 the strongest force ever experienced. Some observers, in terrible weather, have entered 13 or 14 in their logbooks, doubtless feeling that the scale is somewhat cramped when an exceedingly heavy hurricane prevails. A cursory glance will show that the speed of Beaufort's ship is the test for forces 2, 3, and 4; whereas, for the next five units of the scale, the maximum possible sail carried on a wind is the basis for comparison. Neither speed of ship, nor sail carried, is taken into consideration with respect to forces 10, 11, and 12. It is not certain whether Beaufort's ship was hove-to or running, with the highest forces of his scale; and, with force 5, under the given conditions, a clipper ship might easily travel three times as fast as with force 4.

Force	Beaufort's Scale.*	Velocity. English Miles per hour.		
		Met. Office.	Sir W. S. Harris.	U.S. Hydrographic Office.
0	Calm, ...	3	0	0
1	Light air, or just sufficient to give steerage way, .	8	1	2
2	Light breeze, or that in which a well-conditioned man-of-war, with all sail set, and "clean full," would go in smooth water from . . . 1–2 knots,	13	3	4
3	Gentle ,, 3–4 ,,	18	6	9
4	Moderate ,, 5–6 ,,	23	10	14
5	Fresh ,, or that to which she could just carry "in chase," "full and by" . Royals, etc., .	28	14	17
6	Strong ,, Single-reefed top-sails and top-gallant sails, .	34	18	20
7	Moderate gale, Double-reefed top-sails, jib, etc., .	40	20	24
8	Fresh ,, Triple-reefed top-sails, etc., .	48	23	30
9	Strong ,, Close-reefed top-sails and courses,	56	29	40
10	Whole gale, or that with which she could scarcely bear close-reefed main top-sail and reefed fore-sail, .	65	48	67
11	Storm, or that which would reduce her to storm stay-sails, ...	75	76	80
12	Hurricane, or that which no canvas could withstand, .	90	106	100

Since Admiral Beaufort's time a modification has been made in the above scale to suit the change from deep single top-sails to handier double top-sails. Only forces 6, 7, 8, 9, and 10 are affected. For a sailing-ship fitted with double top-sails, Beaufort's scale now reads as follows:—Force 6, top-gallant sails; force 7, top-sails, jib, etc.; force 8, reefed upper top-sails and courses; force 9, lower top-sails and courses; force 10, lower main top-sail and reefed fore-sail. The wind scale below is adopted by the United States Hydrographic Office, and is in some respects more nearly in agreement with modern methods.

Methods for Ascertaining Force and Direction of Wind.—Anemometers have been used at sea on board ships under way. There is, however, a difficulty in finding a suitable position for a fixed instrument; and portable anemometers are not free from

* For revised scale see p. 191.

Force of Wind, Nautical Scale.	Nautical Designation.	Sail that a Full-Rigged Ship may carry, close-hauled by the Wind; also her Probable Speed.	Sail that a Full-Rigged Ship may carry, Wind on Quarter; also her Probable Speed.	Force of Wind in Pounds per Sq. Foot.	Velocity of Wind in Miles per Hour.
0	Calm.	All sail.	All sail.	0	0
1	Light airs.	All plain sail and stay-sails; smooth sea; 0·5 to 1 knot per hour.	All plain sail and studding - sails; smooth sea; 1 to 1·5 knots per hour.	0·004 to 0·019	1 to 2
2	Light breezes.	All plain sail and stay-sails; smooth sea; about 2 knots.	All plain sail and stud.-sails; smooth sea; 2 to 3·5 knots.	0·08	4
3	Gentle breezes.	All plain sail and stay-sails; smooth sea; 3 to 4 knots.	All plain sail and stud.-sails; smooth sea; 4 to 5 knots.	0·36	9
4	Moderate breezes.	All plain sail and stay-sails; smooth sea; 5 to 6 knots.	All plain sail and stud.-sails; smooth sea; 6 to 7 knots.	1·0	14
5	Stiff breezes.	Courses, top-sails, to'gallant sails, and stay-sails; moderate sea; 6 to 7 knots.	All plain sail and studding - sails; moderate sea; 8 to 9 knots.	1·5	17
6	Fresh breezes.	Courses, single-reefed top-sails, to'gallant sails; moderate sea; 7 to 9 knots.	Courses, top-sails, to'gallant sails, lower and topmast stud.-sails; mod. sea; 10 to 12 knots.	2	20
7	Very fresh breezes.	Courses, double-reefed top-sails, fore topmast stay-sail; moderate sea; *about* 7 knots.	Courses, single-reefed top-sails, to'gallant sails; moderate sea; 12 to 14 knots.	3	24
8	Moderate gale.	Single - reefed courses, treble-reefed fore & main top - sails, close-reefed mizen, fore topmast stay-sail: rough sea; 4 to 5 knots.	Single reefed courses, double-reefed fore & main top - sails, close-reefed mizen; rough sea; about 10 knots.	5	30
9	Strong gale.	Close - reefed courses, close-reefed fore and main top-sails, storm stay-sail; rough sea.	Close - reefed courses, close-reefed fore and main top-sails, storm stay-sail; rough sea.	8	40
10	Very strong gale.	Close-reefed fore-sail, close-reefed main top-sail, fore storm stay - sail; very rough sea.	Close-reefed fore-sail, close-reefed main top-sail, fore storm stay - sail; very rough sea.	23	67
11	Violent gale.	Storm-sails, or close-reefed main top-sail and fore storm stay-sail; very rough sea.	Close-reefed fore-sail, close-reefed main top-sail, fore storm stay-sail.	32	80
12	Hurricane, Typhoon, Cyclone.	None; lying to; drifting bodily to leeward.	Scudding under bare poles.	50 and upward.	100 and upward.

objection. Even on shore the results from anemometers are not comparable. Were it possible to use such a recorder on board ship there still remains an uncertainty as to the indications. A reliable connection between wind velocity and Beaufort's scale has yet to be devised. Moreover, for some years, the actual wind velocity was assumed to be just three times the velocity of the Robinson anemometer cups. Later inquiries have gone to show that this factor is too high. Mr. W. H. Dines, B.A., F.R.S., has proved that 2·2 is nearer the truth than 3. Taking eight different tables for converting wind velocity into Beaufort forces, the equivalent of force 7 is given as 20, 24, 25, 29, 36, 40, 41, and 49 miles per hour of wind velocity respectively. The late Captain W. Watson of the Cunard Line, and Captain D. Wilson-Barker, R.N.R., now Captain Superintendent of H.M.S. "Worcester," both obtained good results by the aid of anemometers at sea.

It is not an easy matter to obtain the wind direction and force on board a swiftly moving steamship. The indications of the vane, and the smoke from the funnel, on board a steamer under way, are good enough for the apparent direction. In daylight the ripple on the sea surface is said to point out the true direction of the wind. Having given the ship's true course, and her speed, together with the apparent direction and force of the wind, we may easily arrive at the true direction and force. Suppose a steamship in a dead calm steering west 20 miles an hour, then the observer on board of her will apparently have a wind from the westward moving about 20 miles an hour. A steamer at the same instant proceeding in the opposite direction at the same speed will appear to have an easterly wind moving about 20 miles an hour. Again, a steamer moving in the same direction as the wind, and at the same velocity of 20 miles an hour, will apparently experience a calm; while the vessel travelling in the opposite direction will have an apparent head wind of 40 miles an hour.

Between these extreme cases are an infinite number of variations. Suppose a ship steaming west, 20 miles an hour; the true wind being north, force 3. Then, the apparent wind, as shown by vane, or by smoke, is the resultant of these two velocities.

Force 3 in the Meteorological Office table is equivalent to a wind velocity of 18 miles an hour. In fig. 13, let A be ship's position; draw A B, = 20 units, to eastward, as representing the wind which the ship created by her motion to the westward, and A D, = 18 units, to south, as equivalent to the true wind. Complete the parallelogram of velocities A B C D. Then A C represents the apparent wind in direction and velocity. Enter traverse table with departure 20, difference of latitude 18, and the resultant is S. 48° E., 27 miles. Hence, by the Meteorological Office table, given above, the apparent wind is from N. 48° W., force 5.

One more example will suffice for practical purposes. In fig. 14 a ship steams N. 68° E., 20 miles, and the observer records an apparent wind N. 5° E., force 4 = 24 miles, it is required to find the true wind. From A, the ship's position, draw A B to S. 68°

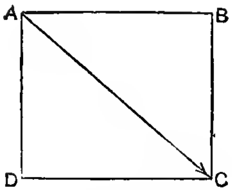


Fig. 13.

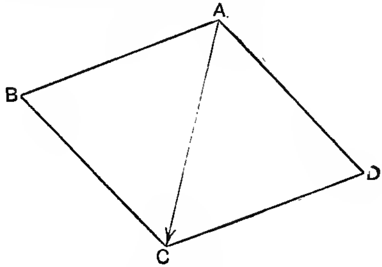


Fig. 14.

W., A C to S. 5° W. Make A B = 20, A C = 24. Join B C, and complete the parallelogram of velocities A B C D. Then A D represents true wind in direction and velocity. To find A D by traverse table we have precisely the same problem to solve as though a ship had gone from A to C and then to D, to find her course and distance made good. Here we have A C = S. 5° W. 24, C D = A B = N. 68° E. 20, to find A D.

Direction.	Velocity.	N.	S.	E.	W.
S. 5° W.	24	...	23·9	...	2·1
N. 68° E.	20	7·5	...	18·5	...
S. 45° E.	23	...	16·4	16·4	...

Hence the true wind sets *to* S. 45° E., 23 miles = force 4; or, as usually recorded *from* N. 45° W., force 4. By using elementary trigonometry we can dispense with the traverse table in solving such questions.

When the apparent direction of the wind is at an angle with the vessel's course, the true direction and velocity can be determined from that angle and the velocity of the wind and speed of the vessel as demonstrated above. The use of the following table avoids the necessity for calculation :—

Apparent Direction of the Wind from the Ship's Bow.																			
15 Points.	True Velocity, Beaufort Scale.	3	4	5	4	5	6	5	6	7	6	7	7	7	7	8	7	8	9
	True Direction, in Points.	15	15	15	15	15	15	15	15	15	15	15	16	15	15	15	15	15	15
14 Points.	True Velocity, Beaufort Scale.	3	4	5	4	6	6	5	6	6	6	6	7	6	7	8	8	8	9
	True Direction, in Points.	15	15	15	15	16	15	14	15	15	14	16	15	14	14	15	14	14	15
13 Points.	True Velocity, Beaufort Scale.	3	4	5	4	5	6	5	6	6	6	6	7	6	7	3	7	8	9
	True Direction, in Points.	14	15	15	14	15	15	14	15	15	14	14	15	14	14	14	14	14	14
12 Points.	True Velocity, Beaufort Scale.	3	4	4	4	5	5	5	5	6	5	6	7	6	7	7	7	8	8
	True Direction, in Points.	14	15	15	14	14	15	13	14	15	13	14	14	13	13	14	13	13	14
11 Points.	True Velocity, Beaufort Scale.	2	3	4	3	4	5	4	5	6	5	6	7	6	7	7	7	8	8
	True Direction, in Points.	14	14	15	14	14	14	13	14	14	13	13	14	12	13	13	12	13	13
10 Points.	True Velocity, Beaufort Scale.	2	3	4	3	4	5	4	5	5	5	6	6	0	6	7	7	7	8
	True Direction, in Points.	13	14	15	13	13	14	12	13	13	12	12	13	11	12	12	11	12	12
9 Points.	True Velocity, Beaufort Scale.	2	3	4	3	4	4	4	5	5	5	5	6	6	6	7	7	7	7
	True Direction, in Points.	13	14	14	12	13	13	11	12	13	11	12	12	11	11	12	10	11	11
8 Points.	True Velocity, Beaufort Scale.	2	3	4	3	3	4	4	4	5	4	5	5	5	6	6	6	6	7
	True Direction, in Points.	13	13	14	11	12	13	11	11	12	10	11	12	10	11	12	9	10	11
7 Points.	True Velocity, Beaufort Scale.	1	2	3	2	3	4	3	4	4	4	4	5	5	5	6	6	6	6
	True Direction, in Points.	12	13	14	11	12	13	10	11	12	10	10	11	9	10	11	9	9	10
6 Points.	True Velocity, Beaufort Scale.	1	2	3	2	3	3	3	3	4	4	4	4	5	5	5	6	6	6
	True Direction, in Points.	12	13	14	10	11	13	9	16	11	8	9	10	8	9	10	7	8	9
5 Points.	True Velocity, Beaufort Scale.	1	2	3	2	2	3	2	3	3	3	3	4	4	4	4	5	5	5
	True Direction, in Points.	12	13	14	9	11	12	8	16	11	7	8	16	7	8	9	7	7½	8
4 Points.	True Velocity, Beaufort Scale.	1	2	3	1	2	2	2	2	2	3	3	3	3	3	3	5	5	4
	True Direction, in Points.	11	13	14	8	11	12	7	9	11	6	8	9	6	7	8	5	6	7
3 Points.	True Velocity, Beaufort Scale.	1	1	2	1	1	2	2	1	1	3	2	2	4	3	3	5	4	3
	True Direction, in Points.	11	13	14	8	11	13	6	8	16	5	7	9	5	6	7	4	5	6
2 Points.	True Velocity, Beaufort Scale.	1	1	2	1	1	2	2	1	1	2	2	1	3	2	2	4	4	3
	True Direction, in Points.	12	14	15	6	11	13	4	7	16	3	5	7	3	4	5	3	3½	4
1 Point.	True Velocity, Beaufort Scale.	1	1	1	1	1	1	1	1	1	2	1	1	3	2	1	4	3	2
	True Direction, in Points.	13	15	15	4	12	14	2	5	11	2	3	5	2	2	3	1½	2	2
Speed of Vessel, Knots per Hour.		10	15	26	10	15	20	10	15	26	10	15	26	10	15	26	10	15	20
Apparent Force of the Wind.	In Miles per Hour.	8	8	8	13	13	13	18	18	18	23	23	23	28	28	28	34	34	34
	By Beaufort Scale.	1			2			3			4			5			6		

Apparent Direction of the Wind from the Ship's Bow.

Apparent Force of the Wind		Speed of Vessel, Knots per Hour.	1 Point.		2 Points.		3 Points.		4 Points.		5 Points.		6 Points.		7 Points.	
By Beaufort Scale.	In Miles per Hour.		True Direction, in Points.	True Velocity, Beaufort Scale.	True Direction, in Points.	True Velocity, Beaufort Scale.	True Direction, in Points.	True Velocity, Beaufort Scale.	True Direction, in Points.	True Velocity, Beaufort Scale.	True Direction, in Points.	True Velocity, Beaufort Scale.	True Direction, in Points.	True Velocity, Beaufort Scale.	True Direction, in Points.	True Velocity, Beaufort Scale.
	40	10	1½	5	2½	6	4	6	5	6	6	6	7	7	8	7
7	40	15	1¾	4	3	5	5	5	6	5	7	6	8	7	9	7
	40	20	2	3	4	4	6	4	7	5	8	6	9	7	10	7
	48	10	1¼	7	2½	7	4	7	5	7	6	7	7	8	8	8
8	48	15	1½	6	3	6	4	6	5½	7	7	7	8	8	9	8
	48	20	1¾	5	3½	6	5	6	6	7	7	7	8	8	9	8
	56	10	1¼	8	2½	8	3¾	8	4½	8	6	8	7	9	8	9
9	56	15	1½	7	2¾	7	4	7	5¼	8	6	8	7	9	9	9
	56	20	1¾	6	3	7	4½	7	5¾	7	7	8	8	9	9	9
	65	10	1	9	2¼	9	3½	9	4½	9	6	9	7	10	8	10
10	65	15	1½	8	2½	9	4	9	5	9	6	9	7	10	8	10
	65	20	1½	7	2¾	8	4	8	5½	8	6	9	8	10	8	10
	75	10	1	10	2¼	10	3½	10	4½	10	6	10	6½	11	8	11
11	75	15	1¼	9	2½	10	4	10	5	10	6	10	7	11	8	11
	75	20	1½	9	2¾	9	4	9	5¼	10	6	10	7½	11	8	11
	90	10	1	11	2¼	11	3¼	11	4¼	12	5	11	6½	12	8	12
12	90	15	1	11	2¼	11	3¾	11	4½	11	6	11	7	12	8	12
	90	20	1¼	10	2½	11	4	11	5	11	6	11	7	12	8	12

Apparent Force of the Wind		Speed of Vessel, Knots per Hour.	8 Points.		9 Points.		10 Points.		11 Points.		12 Points.		13 Points.		14 Points.		15 Points.	
By Beaufort Scale.	In Miles per Hour.		True Direction, in Points.	True Velocity, Beaufort Scale.	True Direction, in Points.	True Velocity, Beaufort Scale.	True Direction, in Points.	True Velocity, Beaufort Scale.	True Direction, in Points.	True Velocity, Beaufort Scale.	True Direction, in Points.	True Velocity, Beaufort Scale.	True Direction, in Points.	True Velocity, Beaufort Scale.	True Direction, in Points.	True Velocity, Beaufort Scale.	True Direction, in Points.	True Velocity, Beaufort Scale.
	40	10	9	7	10	7	11	8	12	8	13	8	14	8	14	8	15	8
7	40	15	10	7	11	8	11	8	12	8	13	8	14	9	14	9	15	9
	40	20	10	8	11	8	12	8	13	9	13	9	14	9	14	9	15	9
	48	10	9	8	10	8	11	9	12	9	13	9	14	9	14	9	15	9
8	48	15	9	8	11	9	11	9	12	9	13	9	14	9	14	10	15	10
	48	20	10	8	11	9	12	9	13	10	13	10	14	10	14	10	15	10
	56	10	9	9	10	9	11	9	12	10	12½	10	14	10	14	10	15	10
9	56	15	9	9	10	10	11	10	12	10	13	10	14	10	14	10	15	11
	56	20	10	9	11	10	11	10	12	10	13	11	14	11	14	11	15	11
	65	10	9	10	10	10	11	10	12	11	12½	11	14	11	14	11	15	11
10	65	15	9¼	10	10	10	11	11	12	11	13	11	14	11	14	11	15	11
	65	20	9½	10	11	11	11	11	12	11	13	11	14	11	14	12	15	11
	75	10	8½	11	10	11	10½	11	12	11	12½	11	13	11	14	12	15	12
11	75	15	9	11	10	11	11	11	12	12	12¾	12	14	12	14	12	15	12
	75	20	9¼	11	10	11	11	12	12	12	13	12	14	12	14	12	15	12
	90	10	8½	12	10	12	10½	12	12	12	12½	12	13	12	14	12	15	12
12	90	15	9	12	10	12	11	12	12	12	12¾	12	14	12	14	12	15	12
	90	20	9	12	10	12	11	12	12	12	12¾	12	14	12	14	12	15	12

CHAPTER X.

HISTORY OF THE LAW OF STORMS.

Early Records of Storm Occurrences.—Much has been written by all sorts and conditions of men with respect to cyclones. The late Mr. Clement Ley was of opinion that the law of storms "has often proved only too stimulating to the faculty of scientific imagination." Nevertheless, but little fresh knowledge has been added to our knowledge of the origin, development, and termination of such dreaded phenomena, since those far off days when Redfield of America, and Piddington of England, published satisfactory theories and framed reliable rules for the safe handling of sailing-ships involved in a cyclone. It has since been found that the law of storms corresponds with that of the general wind circulation.

Probably the first hurricane on record was that experienced for three consecutive days by Columbus and his hardy toilers on an unknown sea, in their tiny craft, not far from the Azores, in February 1493. Not long afterwards the Spaniards commenced to give detailed descriptions of West India hurricanes. In a recital of facts relating to a San Domingo hurricane of 1508 it is distinctly stated that this storm began operations with a northerly wind, which drove the ships from their exposed mooring; then shifted to the south, and blew just as fiercely from that direction. William Dampier, an old-time English navigator of pleasant memory, encountered a storm in the China Sea, in July 1687, which he recognised as similar in behaviour to a West India hurricane. This gale commenced with a north-east wind, which blew heavily for several hours, then a dead calm succeeded; and, eventually, the breeze came on again, with all its former fury, but from the south-west. Dampier left to posterity an excellent description of West India hurricanes, and pointed out their exceptional frequency in the months of July, August, and September. "Tho' I have never been in any Hurricane in the *West Indies*," wrote that sterling seaman, "yet I have seen the very Image of them in the *East Indies*, and the effects have been the very same; and, for my part, I know no difference between a Hurricane among the Caribee Islands in the *West Indies* and a Tuffoon on the Coast of *China* in the *East Indies*, but only the Name: And I am apt to believe that both Words have one signification which is a violent Storm." Experience has demonstrated the correctness of his views.

As navigation extended there naturally grew up quite a large amount of literature relative to storms of the North Atlantic. During the seventeenth and eighteenth centuries there was much narration, and not a few travellers' tales, with reference to storms. Generalisation had not yet been attempted. In 1698, a Captain Langford called attention to the similarity between tropical storms and whirlwinds. He also indicated the wind circulation, and the cyclone seasons. Half a century later, the American philosopher, Benjamin Franklin, wrote, "The air is in violent motion in Virginia before it moves in Connecticut, and in Connecticut before it moves at Cape Sable." Here is afforded an obscure hint as to the translation of storms. Yet the simple laws applicable to the general motions of cyclonic storms remained unexplained until the early days of the nineteenth century.

In 1780, Sir Gilbert Blane, a well-known medical man of that period, observed that the winds of a Barbados hurricane blew from every point of the compass in quick succession—"a circumstance which distinguishes the hurricane from all other gales within the tropics." He gave an elementary example of ships sailing round the centre, or core, of this storm. About twenty years later, Colonel Capper, when dealing with storms of the Bay of Bengal and elsewhere, concluded that a ship's distance from a storm centre could be inferred from observations of the changes in the force and direction of the wind. Horsburgh, the cherished guide of old-time navigators, soon afterwards described the rotatory motion of China Sea typhoons, their most marked indications, and the probable wind changes. Other writers also insisted upon the whirling nature of tropical storms.

Later Investigations.—It was, however, reserved for the late W. C. Redfield, a naval architect of New York, in 1831, to demonstrate practically what had hitherto been but assumption. He did somewhat the same for storms as Kepler did for astronomy. Modern weather workers have merely amplified his method of investigation; aided by the electric telegraph, and steam as a motive power. Redfield collated extracts from ships' logbooks relative to weather. He then laid down on large working charts, in geographical position, the data thus obtained. In this way he proved beyond cavil that the winds of a storm system have a well defined motion of revolution; while, at the same time, the whole whirl moves bodily onward in much the same way as eddies in a tidal river. On this imperishable foundation of observation he built up the "Law of Storms."

Redfield substituted solidity for supposition, and thus gained for himself the right to a prominent position on the roll of fame. Colonel Reid, R.E., some seven years later, after practical acquaintance with hurricanes when Governor of Bermuda, brought out a work confirming the views of Redfield in every particular, and extending his deductions to storms of the South Indian Ocean.

Redfield had noticed that North Atlantic storms whirled round in a direction contrary to the revolution of watch-hands. By a flash of genius he was enabled to predict an exactly opposite wind circulation for storms of the southern hemisphere. In other words, the winds of a cyclonic system, in either hemisphere, rotate contrary to the apparent course of the sun. Neither the masterly deductions of Redfield, nor his well-devised methods of discussion, have been shaken by the lapse of time. He demonstrated that North Atlantic cyclones come into being somewhere to the eastward of the West India Islands; that the wind-force increases as the centre is neared; that the rate of progression varies from ten to thirty miles an hour; that the onward motion is generally along a parabolic path having its vertex, or point where recurvature occurs, near the American coast, in about 30° N. lat.; that the wind changes recorded by ships as a cyclone passes over them vary according to their position with regard to the centre of the storm area; and he suggested that a cyclone revolved round a cylindrical axis which might be vertical, or inclined, and which by its erratic action caused the violent gusts and intervening lulls experienced by vessels not far from the cyclone centre. Redfield considered the approximately circular form quite good enough for practical purposes at sea, where undue refinement is to be deprecated. He, however, distinctly intimated that in his opinion the storm whirl need not necessarily assume the shape of a geometrical circle.

Colonel Reid soon showed that satisfactory rules might be promulgated for running, or heaving-to, when under the influence of a cyclone. He emphasised the necessity for adopting that tack on which the ship would come up to the wind, as it shifted, and bow the sea. Otherwise she was in grave risk of being caught aback and going down stern first.

Piddington was hard at work from 1839 with commendable enthusiasm. His book on the *Law of Storms* is even now regarded with favour by practical navigators of high rank. This patient inquirer demonstrated that a single storm may split up into two, or more, distinct storms, and conversely; that storms display a tendency to follow one another in quick succession; that storm waves, and storm sea-surface currents, should be guarded against; that the winds in a cyclone may be slightly incurved; and that ships should choose the coming-up tack. He also laid down rules for storm sailing, and roughly determined the average tracks of storms over several oceans. It is to Piddington we owe the expressive term *cyclone*, as applied to revolving storms, which he derived from the Greek word κύκλος, not in its limited acceptation of a strictly geometrical circle, but in its more general application as any closed curve.

Professor H. W. Dove, of Berlin, was approaching the subject from a theoretical standpoint about the same time.

In 1845, Dr. Thom, of the 86th regiment, dealt with cyclones of the South Indian Ocean. He confirmed the conclusions of Redfield, Reid, and Piddington. Four years later, a British shipmaster, Captain Andrews, pointed out that a ship would sail away from a storm centre by keeping the wind on the starboard quarter in the northern hemisphere, but on the port quarter in the southern hemisphere. In 1872, Captain Wales, harbour master at Mauritius, quite independently arrived at a similar conclusion.

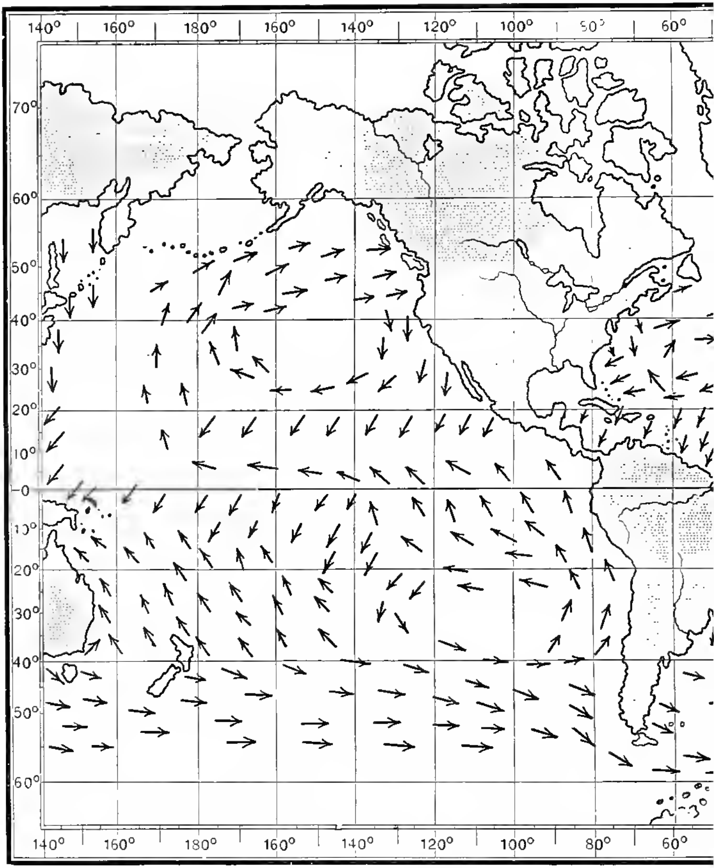
Notable Storms.—Many lives were sacrificed owing to the almost universal ignorance of the law of storms in the days of pigtails and prolonged voyages. Sir Richard Grenville, in his little "Revenge," engaged a Spanish fleet in September 1591, and went to his last sleep crying, "No surrender." Shortly afterwards, a cyclonic storm strewed the shore at Terceira with about one hundred of the Spanish ships. This storm is said to have raged with unabated vigour for a whole week. As the wind appears to have made two or three complete revolutions of the compass in that interval, probably more than one storm may have been experienced. In 1696 a single cyclone caused the loss of two hundred colliers and other coasting craft on the east coast of England. Daniel Defoe asserted that the great storm of November 1703 was the most awful concerning which history had hitherto any record. Thirteen ships of Admiral Beaumont's fleet met their fate on the treacherous Goodwins, and twelve hundred seamen perished. During a cyclone which laid waste the West India islands, in 1780, many British warships went ashore at St. Lucia; and between forty and fifty French transports foundered, taking with them not less than four thousand soldiers. On shore, thousands of lives were lost. Admiral Rodney, in his official despatch, stated that none but those actually present could form an adequate conception of this terrible war of the elements.

In 1782 there occurred one of the greatest naval disasters on record. Admiral Graves was convoying a large fleet of cargo carriers and prizes across the North Atlantic to England. A cyclone passed over the devoted ships; they were hove-to on the wrong tack; a sudden shift from south-east to north-west drove many of the merchantmen and the warships to the bottom, stern first; and three thousand seamen were lost to England.

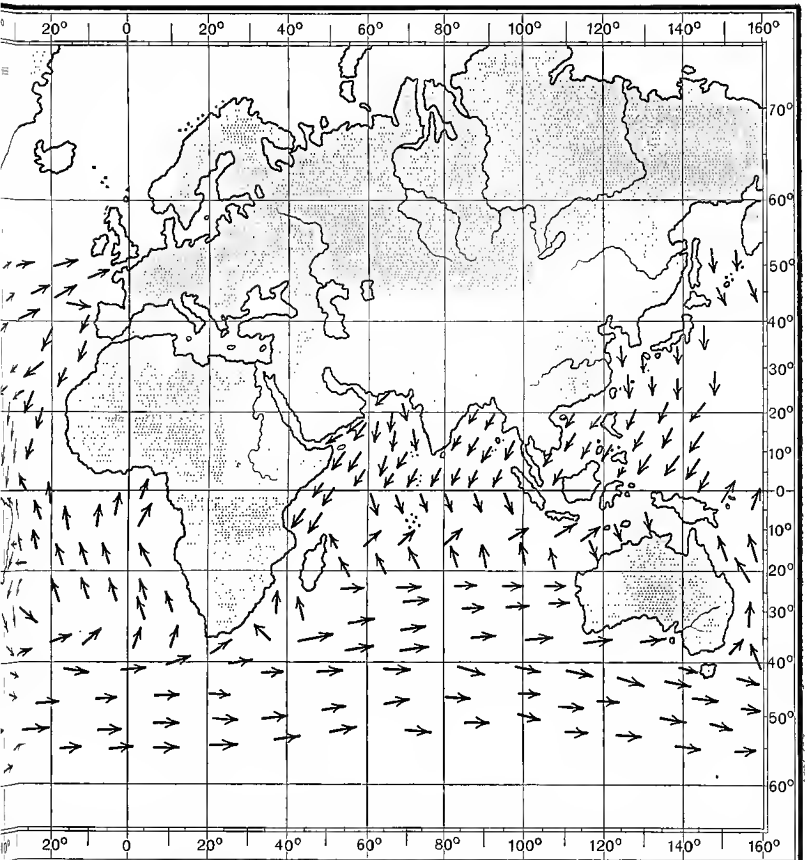
In the "Royal Charter" storm of 1859, nearly three hundred and fifty vessels were lost around our coasts. A single December cyclone of 1876 on the Banks of Newfoundland destroyed twelve schooners and ninety men, all of whom belonged to Gloucester, Massachusetts. During one day of October 1881, not fewer than one hundred and thirty vessels were posted at Lloyd's on the *Wreck and Casualty* book. The loss in nets among the Yarmouth fishermen reached the sum of £10,000. That day the Eyemouth boats put out to sea, notwithstanding warnings of danger. Many of them were overwhelmed by the cyclone which was fallen in with when far from a safe haven. One of the most destructive cyclones of recent years is the "blizzard" of March 1891, which reached the British Isles without warning. Nearly thirty coasting craft, of from thirty to three hundred tons register, were subsequently posted as missing, in consequence; and several fine ships were driven on shore along the south-west coast of England.

The 1864 Calcutta cyclone is deserving of mention as it broke the record for intensity. The bore, or gigantic storm wave, rushed onwards, a veritable wall of water quite 40 feet in height; and drove ships from their moorings, only to leave them high and dry among the trees. Just three weeks later another cyclone made matters lively there. A frigate-built East Indiaman, the "Hotspur," Captain H. Toynbee, F.R.A.S., rode out this cyclone at the Sandheads. Her three top-gallant masts were blown away, although the rigging was well set up and the yards previously sent down. The wind-force was held to be greater aloft than on deck. The pilot who took the "Hotspur" up to Calcutta had passed through the central calm of this cyclone in one of the pilot brigs. While standing by to cut away her masts there was a complete calm on deck at the same instant as a furious gale was blowing aloft!

Theories as to the Nature of Cyclones.—Modern weather workers have introduced so many curious complexities into storm sailing that a practical seaman aware of them might readily be pardoned for feeling diffident of relying implicitly upon all of them, even if he were not absolutely bewildered by some. Many shipmasters have pulled through careering cyclones by judicious use of the approximately circular theory. Probably others will



ALLINGHAM'S MARINE METEOROLOGY. PLA



…—Prevailing Winds over the Oceans for January.

be equally fortunate. An authority on Indian meteorology, the late Mr. Blanford, asserted that a cyclone centre may be from one point to five points before the port beam of a ship running dead before the wind in the Bay of Bengal. Mr. F. Chambers was of opinion that the angle of indraft varies all around the whirl, decreasing from 35° on the outside edge to a minimum scarcely worth mentioning as the dreaded centre is approached. Captain H. Toynbee, at one time Marine Superintendent of the British Meteorological Office, concluded that the angle of indraft actually increases as the cyclone centre is neared, and is greater in the front of the storm than in any other part of the affected area. Other examples of conflicting rules for finding the centre of a cyclone are not difficult to find. Sufficient, however, has been written to indicate the indeterminate nature of this problem, the solution of which would involve the proper appreciation of many variable quantities.

Angle of Indraft.—The late Mr. Clement Ley applied himself diligently to determine the average angle of indraft in well-defined cyclones by discussing a large number of observations made at various weather recording stations over the British Isles and the continent of Europe. He found that the winds, as a general rule, drew out from districts where the barometer was relatively high towards districts where the barometric pressure was relatively low. This inclination was much greater at inland stations than at well exposed stations on the sea coast. The mean angle of indraft was 20° 31′, or approximately two points for fifteen stations. Five of the more open sea coast stations afforded an average angle of 12° 49′, whereas for five inland stations the average angle of indraft was 28° 53′. It will thus be seen how intimate a connection exists between the observer's station and the departure of cyclonic rotation from an approximately circular shape. May we not, then, rightly conclude that at sea, remote from the disturbing influence of land, the indraft angle is a negligible quantity, and manœuvre accordingly?

Mr. Ley's deductions are in accordance with theory, which requires an increased indraft angle consequent on increased friction with the earth's surface. The indraft on the east side of a cyclone proved much greater than on its western side. By introducing observations from a larger number of inland stations into the discussion, Mr. Ley arrived at a larger angle of indraft, averaging 25°. The angle, however, differed considerably, not only with the distance from the cyclone centre, but also when the observer's station varied with respect thereto. It varied from about 10° to 45°, although each average angle was based upon a large number of observations. As will appear further on, there is not infrequently great difficulty in determining just where the centre of any given cyclone is. Having regard to this fact, the change in the value of the angle of indraft may be more apparent than real.

Professor Loomis, of Washington, obtained an average angle of indraft amounting to 47°, or a little more than four points, from the weather maps of the United States Weather Bureau. This difference of nearly two points between the results of Mr. Ley and Professor Loomis has been partially explained by Professor Ferrel on the ground that the former inquirer only dealt with the more violent winds near the cyclone centre; whereas Professor Loomis included many instances of insignificant wind-force. According to theory, the winds on the outer margin of a well-conditioned cyclone, where the gyratory velocity is small, have a more marked motion towards the centre than those nearer in, where the gyratory velocity is at a maximum. On the other hand, Captain Toynbee found the angle of indraft to increase as the cyclone centre is approached, and to vary with the observer's bearing and distance from the centre. Loomis's deduction was arrived at by consideration of synchronous daily weather charts embracing a long interval. Subsequent investigations of American land winds failed to alter the average angle found by Professor Loomis, but Captain Toynbee obtained a smaller angle when dealing with sea observations. In every case, Loomis found an increased angle of indraft as the centre was left behind. In all discussions relative to this important matter the student must never forget that a ship under the influence of a cyclone is not precisely a fixed observatory. She is at the mercy of wind and sea. Unexpected sea-surface currents act insidiously in vitiating a ship's geographical position by dead reckoning. Her position by observation of the heavenly bodies, and her compass error, are often only very approximately known by reason of the horizon, or the heavenly bodies themselves, or both, being ill defined. Hence very qualified reliance upon the average angle of indraft is allowable. A difference of sixty miles in the assumed and actual geographical positions of a ship is not uncommon in bad weather. This is more than sufficient, when laid down on a chart after the event, to place her in an erroneous position with respect to a cyclone centre, and thus to invalidate deductions based on observations thereon as to the angle of indraft. Occasionally a mistake of sixty miles will place a vessel on one side of a cyclone centre on a chart, whereas she was actually on the opposite side during its occurrence.

CHAPTER XI.

HURRICANES:—SEASONS AND STORM TRACKS.

West India Hurricanes.—West India hurricanes have been dealt with in greater detail than similar storms in any other part of the world. The season commences when the sun approaches his maximum northern declination, and the following old sailors' doggrel rhyme serves very well as an aid to memory: June, too soon; July, stand by; August, look out you must; September, remember; October, all over. The United States Hydrographic Office has determined the relative frequency of tropical cyclonic storms in the North Atlantic during the months of June, July, August, September, October, and November, for the twelve years 1885 to 1896. The accompanying table is based upon the information published on the monthly Pilot Charts of the North Atlantic during that period. It clearly shows that June is scarcely too soon, and that in October the cyclone season is hardly over:—

	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	Total.
June,	0	2	1	0	2	0	0	1	0	0	0	0	6
July,	1	0	0	0	1	0	2	0	0	0	0	0	4
August,	2	3	2	1	1	1	1	1	4	0	0	0	16
September,	1	1	3	3	6	2	2	1	0	2	0	3	24
October,	1	3	2	1	2	1	3	4	2	3	2	1	25
November,	0	0	2	2	2	2	0	1	1	0	0	0	10

A less reliable, but more extended, chronological list of every hurricane in the North Atlantic for several centuries, from 1493 to 1855, by Mons. A. Poey of Havannah, gives somewhat similar results, as follows:—

Months.	Jan.	Feb.	Mar.	Apr.	May.	June	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Cyclones,	5	7	11	6	5	10	42	96	80	69	17	7	355

West India hurricanes move bodily westward in the lower latitudes until near the coast of Florida, then, as a general rule, the track curves northward and north-eastward, thus forming a parabola with its vertex near Florida. Commencing, for example, in about 15° N. lat. to the eastward of the West Indies, a

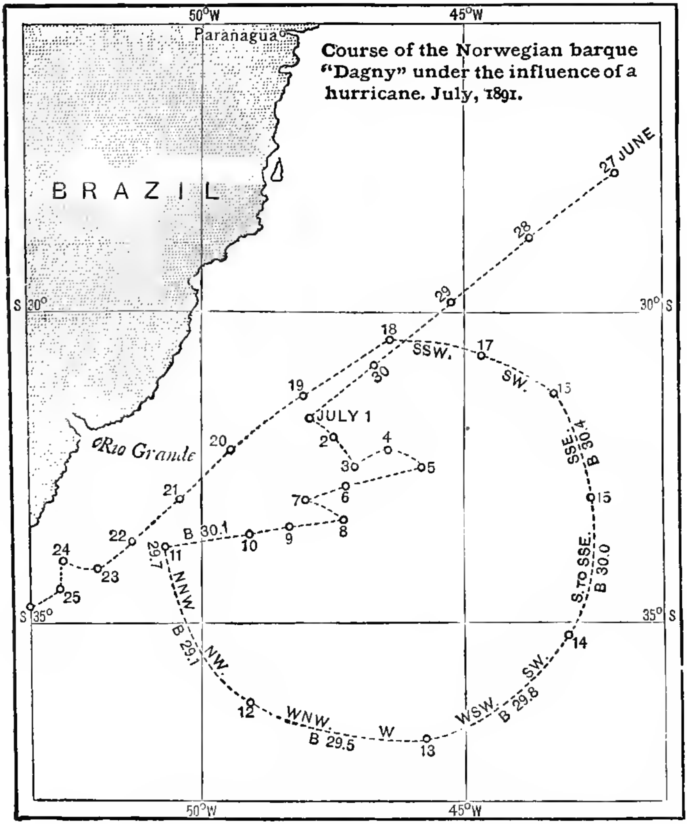


FIG. 15.

hurricane moves towards the westward, evincing a decided tendency to travel more and more northward as the meridian of 70° W. long. is approached. Between 20° N. lat. and 35° N. lat., in about 70° W. long., the cyclone is generally moving due north and developing an inclination to make some easting. From this vertex the cyclone travels north-east towards Newfoundland Banks, and making more easting, may eventually reach our shores, after having travelled over three sides of the North Atlantic, south, west, and north. The actual position of recurvature for any given storm, however, will depend upon the disposition of barometric pressures to the northward of its track. A few of these disturbances move right across the Gulf of Mexico, being prevented by the adjacent area of high barometric pressure from proceeding along the usual northerly track. West India hurricanes in June and October often recurve between latitude 20° and 23° N., in July and September between 27° and 29° N., and in August between 30° and 33° N. In low latitudes the velocity of the whirl along the track is about fifteen miles an hour, and, in high latitudes, twenty or thirty miles an hour, on an average. Particular cyclones occasionally remain almost stationary for considerable intervals, or travel rapidly onward at the rate of about sixty miles an hour.

South Atlantic Cyclones.—Very little reliable information is obtainable with respect to cyclones in the South Atlantic. Sufficient seems known, however, to confirm their existence and to show that they follow much the same laws as cyclones in the South Indian Ocean, although more remote from the equator. Fig. 15 shows the track of a Norwegian barque, the "Dagny," Captain Olsen, from 27th June 1891 to 26th July 1891, while on the passage from Leith to Buenos Ayres. On 1st July she fell in with light variable winds, which held for eleven days; then the wind came out with hurricane violence from the north, and she was run before the gale under bare poles. As the wind shifted to north-west, west, south-west, south, and south-east, little by little, her course was altered so as to bring the wind right aft. She thus ran round the circumference of a circle, and, ten days after the cyclone struck her, had arrived at the position whence she kept away before the gale. This cyclone was evidently moving to the south-east; and, by manœuvring to keep the wind aft, the vessel decreased her distance from the centre, as evidenced by the decreasing wind and rising barometer. Fig. 16 affords data of a cyclone experienced by the British barque "May Hulse," Captain H. Youlden, in November 1882, which was entered in lat. 26° 23′ S., 39° 27′ W. long., at noon of the 27th, and cleared at midnight of the 28th, in lat. 28° 30′ S., long. 41° 15′ W. The fall in the barometer reading was slight, but at 8.30 a.m. of the 28th the wind shifted suddenly to S. by W., and increased rapidly to gale force. This cyclone was also travelling south-eastward. On 16th December 1897, the "Danube," Captain Dickinson, in lat. 32° S., 51° W. long., experienced a small cyclone, although the barometer only went from 29·8 inches to 29·5 inches and back. Very heavy thunder, lightning, and rain, with wind strong from N.W., prevailed for a short time, then the rain ceased, and calm intervened, followed by a moderate gale from S.E. It would appear that the South Atlantic cyclones travel west in about 20° S. lat., recurve near the coast of Brazil, and thence proceed to the south-eastward. Captain A. P. Pinheiro, Chief of the Meteorological Service of the Brazilian Navy, Rio Janeiro, in a short paper read at the Chicago International Meteorological Congress, 1893, stated that during a period of twenty years he had noticed that South Atlantic cyclones of the higher latitudes travel from the Pacific, or Brazil, to the eastward. North Atlantic cyclones of higher latitudes not infrequently reach the ocean from the continent of North America, in a similar way. Commodore Wüllerstorft, of the Austrian frigate "Novara," kept along the polar limit of the

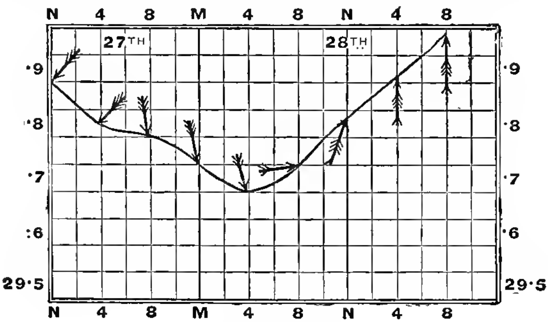


Fig. 16.

south-east trades, in 1857, for six thousand miles, and his wind changes indicated a series of cyclones travelling eastward along the polar branch of the usual parabolic track. The United States Hydrographic Office, in December 1897, investigated these South Atlantic cyclones, with somewhat similar results, as exemplified in the following quotation from the Pilot Chart for that month :—

"Returning now to the region to the south of 30°, the barometric depressions which here occur give rise to the well-known 'pampero,' a name sometimes applied to any wind of storm force, but more properly to the severe north-westerly gales, becoming later south-westerly, which prevail to the rear of the storm area. Their period of greatest frequency is the southern winter, April to August, although no month of the year is free from them, any more than the Atlantic coast of the United States may be said to be free from storms during any month of the year. Between the storms of summer and those of winter, however, marked differences exist. The pampero of summer, the 'turbonado,' is little more than the thunder storm, with its attendant features of cumulo-nimbus cloud, lightning, and abundant rain. The pampero of winter is the ordinary cyclonic storm, here setting in with light or variable northerly winds, and increase of temperature and moisture; the clouds gradually become more and more dense, and rain follows; as the storm progresses the winds gain in strength and work around either through N.W. or S.E. to S.W., where the gale blows itself out.

"The storms of the east coast of South America have recently been investigated by Dr. E. Knipping, of the Deutsche Seewarte. During the period 1890–96 inclusive, sixty-six (66) storms, all giving rise to winds of hurricane force, were reported as occurring between the parallels of 30° S. and 40° S., the latitude of the mouth of the La Plata. Forty (40) of these were encountered by outward bound vessels, twenty-six (26) by homeward bound, showing that storms are of greater frequency along a belt within 500 miles of the coast, wherein the track of outward bound vessels lies, than along the more outlying homeward bound track. The monthly distribution was as follows:

Jan.	Feb.	Mch.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
3	0	1	7	5	12	14	6	7	4	4	3	66

"A comparison of the number of easterly and westerly storms during the several months shows that during the nine months September–May inclusive, the former were just as frequent as the latter, the same number of each, viz., seventeen (17) having been reported; throughout the winter different conditions prevail, for of the thirty-two (32) storms reported as occurring during June, July, and August, four (4) were easterly, and the remaining twenty-eight (28) were westerly. The easterly storms are therefore about uniformly distributed throughout the year, while the westerly storms show a marked increase in frequency during the winter months.

"Of the sixty-six (66) storms, seventeen (17) were from the N.E., four (4) from the S.E., sixteen (16) from the S.W., and twenty-nine (29) from the N.W.

"The average shift of the wind from the beginning to the end of the storm amounted in the N.E. storms to nine (9) points, almost without exception round by the left; in S.E. storms to seven (7) points, round by the right (E.S.E. to South); in S.W. storms the wind generally held steady, the average shift being almost nothing, the record showing two cases of shifts to the left of four (4) points each, and two others of shifts to the right of like amount; in N.W. storms the average shift was six (6) points to the left. Rapid shifts, *i.e.* shifts of four (4) points or more within an hour, were noted only in N.E. storms, seven cases being reported, six of these to the left. In one instance the direction could not be determined. The maximum shift observed was fourteen (14) points in fifteen (15) minutes.

"The average duration amounted in the case of N.E. storms to 20 hours; S.E., 32 hours; S.W., 36 hours; N.W., 40 hours. It is worthy of note that the N.E. storms in this belt, between 30° S. and 40° S., exhibit by far the briefest duration, about half of that of the south-west and north-west storms; while in the belt immediately preceding 20° S. to 30° S., the N.E. storms exhibit by far the greatest persistence, lasting easily double as long as the S.E., S.W., and N.W. storms.

"The average atmospheric pressure throughout the north-east storms was 29·45 inches (748 mm.); throughout the south-west, 29·61 inches (752 mm.); throughout the north-west, 29·57 inches (751 mm.). The lowest observed values were correspondingly 29·02 (737 mm.), 29·06 inches (738 mm.), and 29·02 (737 mm.). High pressure was observed but four times, three times with south-westerly, once with south-easterly storms. The barometer then rose throughout the whole storm. The extreme values were 29·02 inches (737 mm.), and 30·47 inches (774 mm.). These values are about 0·98 inch (25 mm.) below, and 0·40 inch (10 mm.) above the mean of the place of observation.

"The north-east, south-east, and north-west storms generally set in with a falling barometer, the south-west storms more frequently with a rising than a falling. The climax was attained in the case of north-east storms more frequently with a falling barometer; in north-west storms more frequently with a rising barometer; in south-west storms, as a rule, with rising barometer."

Storms of the South Indian Ocean.—Dr. Meldrum of Mauritius is the most reliable authority for cyclonic storms of the South Indian Ocean. In 1885 he laid before that year's British Association meeting a series of cyclone track charts for that ocean from 1856 to 1884. Dr. Meldrum's more extended researches, extending over the 38 years 1848 to 1885, were published by the British Meteorological Office in 1891. An attempt was made to divide the storms into progressive and stationary cyclones. This distinction is but ill defined. The cyclone season of the South Indian Ocean is from November to May, although an occasional storm may be fallen in with in June, July, September, and October. Cyclones seldom, if ever, vex navigators in that ocean during the month of August. The maximum frequency of cyclones occurs there from December to March. Hence bad weather is most probable about the period when the sun's southern declination is greatest.

As a general rule cyclones of the Southern Indian Ocean have their vertices and recurvature between the twentieth and twenty-second parallels of south latitude, although they may extend to 8° S. and 32° S. They originate somewhere along the tenth parallel of south latitude. Proceeding thence towards the south-westward along a track trending more southerly, they eventually travel due south and south-east. Dr. Meldrum's track charts show that about ten per cent. of South Indian Ocean cyclones originate between the fourth and ninth parallels of south latitude, and generally between the eightieth and ninetieth meridians of east longitude. It is often assumed that cyclonic storms do not put in an appearance near the equator in any ocean. Dr. Meldrum, however, gives examples of so-called stationary cyclones which were experienced by vessels on, and four others within two degrees of, the equator. Mr. W. L. Dallas, when Assistant Meteorological Reporter to the Government of India, believed that he traced a cyclone from lat. 1° S., 91° E. long., on 5th December 1894, across the equator, and northward to 21° N., lat. 89° E. long., on the 16th. All these exceptions are doubtful!

Some writers imagine a higher velocity for these storms in their initial stage, but Dr. Meldrum's tracks are not in exact agreement with this view. Not infrequently the storm is moving more rapidly when several days old than it did soon after formation. The rate of travel for Southern Ocean cyclonic storms is comparatively slow throughout, and very variable. A daily advance of 500 miles is unusually rapid, while 150 to 200 miles is the average daily rate.

The following table explains the monthly frequency of cyclonic storms in the South Indian Ocean, arranged so as to bring the season in the centre.

Authority.	Period.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Season.
Piddington . .	1809–1848	1	1	4	3	9	13	10	8	4	0	0	0	53
Meldrum, Claxton	1848–1905	0	2	16	34	77	83	55	33	8	1	1	0	310

A navigator must not, however, rely implicitly upon the average cyclone track, as the following exceptions prove. In January 1855 a cyclone travelled along a right line from 15° S. lat., 58° E. long., to lat. 25° S., long. 64° E. Another in February 1861 went south-westward from 10° S. lat., 68° E. long., to lat. 32° S., long. 53° E. Twelve months later one travelled west-south-west from lat. 24° S., long. 90° E., to 25° S. lat., 84° E. long., just where a southerly or even south-easterly track might fairly have been predicted. In April 1864 a cyclone moved along a south-easterly track from 8° S. lat., 70° E. long., to 13° S. lat., 80° E. long., where the usual track is south-west. In January 1865 one travelled from lat. 13° S., long. 60° E., to 17° S. lat., 50° E. long., and next month another passed south-east from the same spot to lat. 20° S., long. 67° E., where the navigator would expect a track varying from south-west to south and south-east. In April 1866 one moved south-east from lat. 11° S., long. 81° E., to lat. 13° S., long. 83° E., where the usual track is south-east. One travelled west-south-west without recurving, in February 1876, from 19° S. lat., 60° E. long., to a position somewhat south of Tamatave. Apparently the longest track determined by Dr. Meldrum was one in February 1872, from 12° S. lat., 83° E. long. on the 9th, crossing 19° S. lat., 60° E. long. on the 15th, and terminating on the 20th in lat. 35° S., long. 85° E.

Storms and Storm Tracks in the South Pacific.—The very latest information with respect to cyclonic storms of the South Pacific is afforded by a sub-chart of the United States Pilot Chart of the North Pacific for December 1895, which was taken, with some modifications, from publications of the Deutsche Seewarte, Hamburg. Of the 55 South Pacific hurricanes, laid down with the greatest care, 32 seem to have moved in a straight line to the south-west, whereas 22 followed a parabolic track like that of the South Indian Ocean storms, and one was very irregular. Storms which move to the south-westward, west of the 160th meridian of east longitude, recurve to the south-east near the Australian coast; while storms in the more easterly regions recurve about the Loyalty, the Fiji, or the Samoan Islands. The vertex of the parabolic track is approximately in 20° S. lat., with a decided tendency to hug the groups of islands. The following table indicates the number of storms which have occurred during the hurricane season near the principal islands. This list practically includes all the storms of the region.

	Dec.	Jan.	Feb.	March.	April.	Total.
New Caledonia & New Hebrides,	1	11	9	6	0	27
Fiji Islands, ...	4	7	6	10	1	28
Tonga Islands, ...	1	2	4	5	2	14
Samoan Islands, . . .	7	10	1	8	2	28
Total, . . .	13	30	20	29	5	97

The above table is evidence that the hurricane season in the South Pacific is from December to March, with an occasional extension into April. March is the month of maximum cyclone frequency. These storms generally originate in the area bounded by a line drawn from the southern extremity of New Caledonia to the Samoan Islands, and another, almost parallel, line about 350 miles distant through the islands of Rotuma, Mallikola, and Oatafu. Within nine degrees of the equator cyclones are unknown. When the rainy season is either late, or interrupted by a persistent spell of dry weather, a hurricane may safely be predicted. Continuous heavy rain generally heralds the storm. To the right of the storm track the S.E. trades gradually freshen to gale force; whereas to the left of the track the trades shift to east and north-east, with squalls and gloomy weather. The barometer falls slowly and irregularly. A slight rise sometimes occurs before the minimum pressure which marks the passage of the cyclone centre. Nearer the equator the onward motion is about two miles an hour, whereas in higher latitudes, as 30° S., it may reach twenty miles an hour. When passing over the island groups cyclones become almost stationary.

The absolute height of the barometer, here, as elsewhere, is not much guide to the severity of a storm. With the barometer at 29·7 inches a wind force of 11 Beaufort's scale was reached, and yet 27·95 in New Caledonia, 27·56 in the Fiji Islands, and equally low readings elsewhere have been noted. On 6th April 1850, the "Favorite," in the harbour of Apia, recorded a reading of 27·05 inches. The average barometer reading during the hurricane season, after corrections have been applied for instrumental error, etc., is about 29·85 inches.

The duration and extent of these cyclones vary considerably in much the same way as they do in the North Atlantic. Near the equator they are of small radius and of few hours' duration. Further south some have blown fiercely for six days over a region having a radius of 400 miles between New Caledonia and the New Hebrides. The best known storm of those regions is that of March 1889, at Samoa, when H.M.S. "Calliope," Captain Kane, R.N., steamed out against the full force of the hurricane and reached the open sea without serious mishap, while the fleets of the United States and of Germany were swept ashore by the northerly gale and heavy seas making into the unprotected anchorage of Apia. Mr. Everett Hayden, U.S.N., the then Marine Meteorologist of the United States Hydrographic Office, investigated this cyclone in detail. The wind blew with hurricane force for twenty-four hours. In January 1854, however, at the New Hebrides, a hurricane raged thirty-six hours; and another for full five days as reported by the

"Æolus" in March 1891, in 17° S. lat., 159° E. long. It was during the Samoan hurricane of March 1889 that were witnessed "those scenes of heroism, self-sacrifice, and devotion, that for months made the wreck-strewn ledges and beaches of Apia harbour the focus of public attention, and that must for centuries elicit the praise and admiration of mankind."

During September and October, off the coast of Lower California, when the wet season gives way to the dry, local storms of cyclonic nature are common. They are known as El Cordonazo de San Francisco (the whip of St. Francis), develop energy rapidly, and are very dangerous to vessels anchored in the open roadsteads. Hence it is desirable to get an offing should one threaten. Heavy southerly swells, a rise in air temperature, and the fall of rain, denote the approach of one of these storms. The barometer falls slowly at first; later the change is rapid, and a fall of six-tenths in forty minutes has been recorded. The duration of these disturbances varies from a few hours to four days, and they generally travel towards the north. As a general rule, starting somewhat south of Acapulco, in about 15° N. lat., the centre crosses 20° N. lat. between Cape Corrientes and the 110th meridian of west longitude, thence curving towards Mazatlan. Some reach Guaymas, and even San Diego, California. The wind is occasionally of hurricane force, 12 by Beaufort's scale; and has been known to uproot trees on shore, and to dismast ships at sea.

Typhoons.—Dr. W. Doberck, Director of the Hong-Kong Observatory, is the highest authority on typhoons in the East Asiatic waters of the Pacific Ocean. The following table shows the relative frequency of typhoons over the western part of the Pacific during the thirteen years 1883 to 1896, and for a longer interval of eighty-five years, apparently less reliable.

Months.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
13 years, .	1	0	1	4	10	24	45	43	57	31	22	6	244
85 years, .	5	1	5	5	11	10	22	40	58	35	16	6	214

Typhoons appear to originate within the area bounded by the Philippines, the Carolines, and the Ladrones; or in the China Sea. At the centre of a fully-developed typhoon, the minimum barometer reading may be as low as 28·5 inches, but the barometric change over small areas is large. In low latitudes the typhoons travel westward. Some keep on and pass over the mainland of Cochin-China; others recurve towards the north-east, and skirt the shores of Japan; a few eventually reach California by way of Kamtschatka and the Aleutian Islands. In fact, the tracks of storms on the western side of the North Pacific are similar to those on the western side of the North Atlantic. In the former case Formosa is about the vertex of the parabolic track.

Cyclones in the Arabian Sea are few in number, and precise information not always obtainable. In the Bay of Bengal, however, they are more frequently experienced, and more especially strong on the western side of the Bay. In either case the most dangerous period is the changing of the monsoons. They are more marked in October, November and the beginning of December, when the north-east monsoon sets in, than when the south-west monsoon becomes manifest in April, May, and June.

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Bay of Bengal,	2	0	2	9	21	10	3	4	6	31	18	9	115
Bombay, .	1	1	1	5	9	2	4	5	8	12	9	5	62
Arabian Sea,	0	0	1	2	1	2	0	0	1	1	5	2	15

Variations in Cyclone Tracks.—Beginners are apt to assume a uniformity in onward motion for cyclones, which does not always square with Nature. Unfortunately, the determination of a ship's geographical position is liable to various errors during a heavy gale, so that implicit reliance may not be placed upon it by those investigating the storm problem by the aid thereof. Fig. 17 is a synoptic chart which clearly shows the erratic path of a cyclone near the Azores, between the 24th November and the 30th November 1896, as indicated by the heavy line, the circles marking position of centre at Greenwich mean noon of attached date. It also affords a graphic representation of barometric pressure, winds and weather, at noon G.M.T., on the 26th. The symbols have the usual significance. Arrows fly with the wind, feathers show force; the shading of arrowhead varies with the amount of cloud. Occasionally near the Azores, both outward and homeward bound vessels between the English Channel and the Equator have very bad weather for several consecutive days. A cyclone adopting such an erratic track as is herein indicated is sufficient to account for the prolonged rough weather. At such times there is generally an area of high barometric pressure central over, or to the west of, our islands; and another on the opposite side of the Atlantic. A cyclonic system in the intervening space is likely to split into two. One part moves northward, up the furrow as it were, while the other

SYNOPTIC CHART showing storm in the vicinity of the Azores; NOVEMBER, 1896. G.M.N.

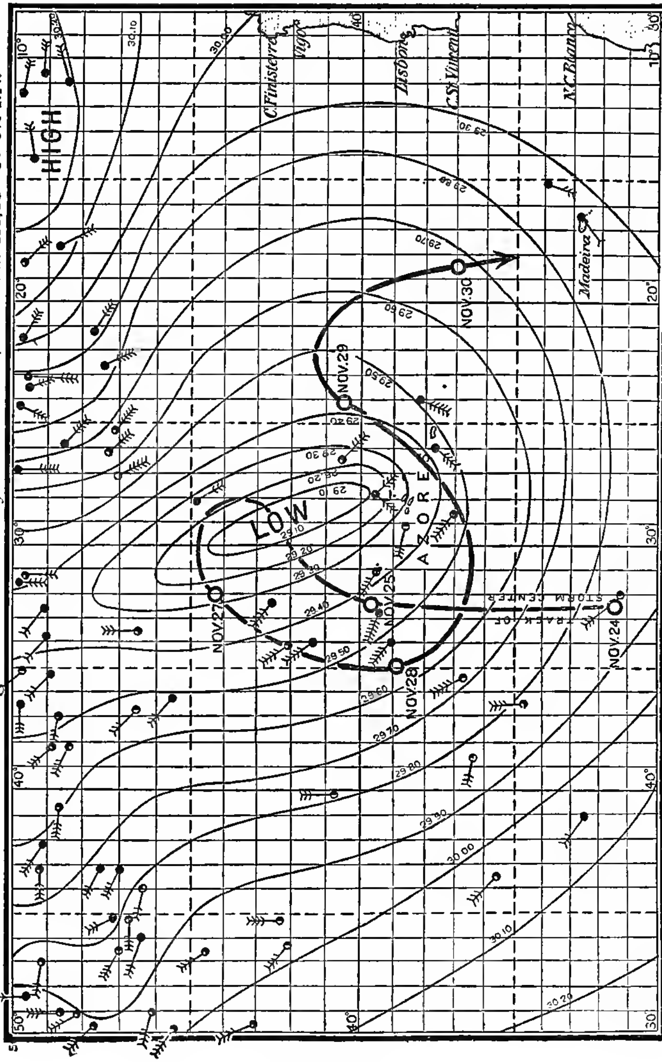


FIG. 17.

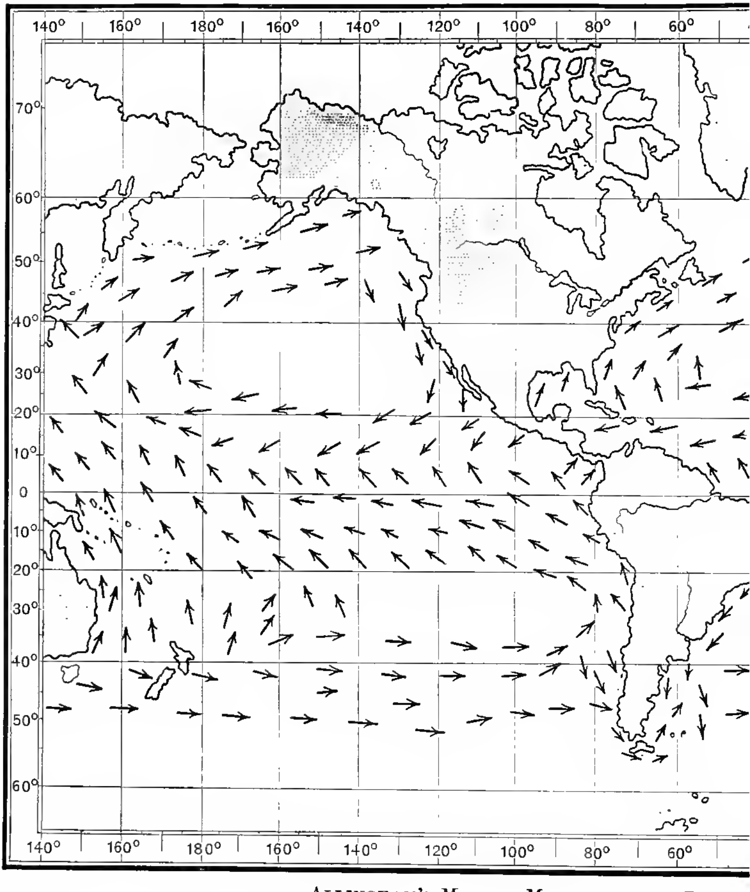
moves eastward towards the Mediterranean, or south-east towards Africa, in agreement with the tendency of cyclones to move round anti-cyclones. The latter portion will often carve out for itself an erratic track similar to that given on the chart. Apparently the high barometric area acts as a fender in some way and prevents it making easting. A feature of this particular class of cyclone is the interference with the trade winds. In this instance, on 29th November, the trades were wanting as far as 40° W., and southward to the 14th parallel of north latitude. They were replaced by light westerly and south-westerly breezes. Sailing-vessels bound for the English Channel from the equator, in the winter months, may find it advantageous to make directly for the Channel from the point where the failure of the trades and the fall of barometer are first noted, inferring that there is a cyclonic system between the Azores and Madeira which will permit them to profit by the southerly winds on its eastern side, whereas, following the usual diverging track to the westward, they would fall in with the northerly gales of the western half of the cyclones.

CHAPTER XII.

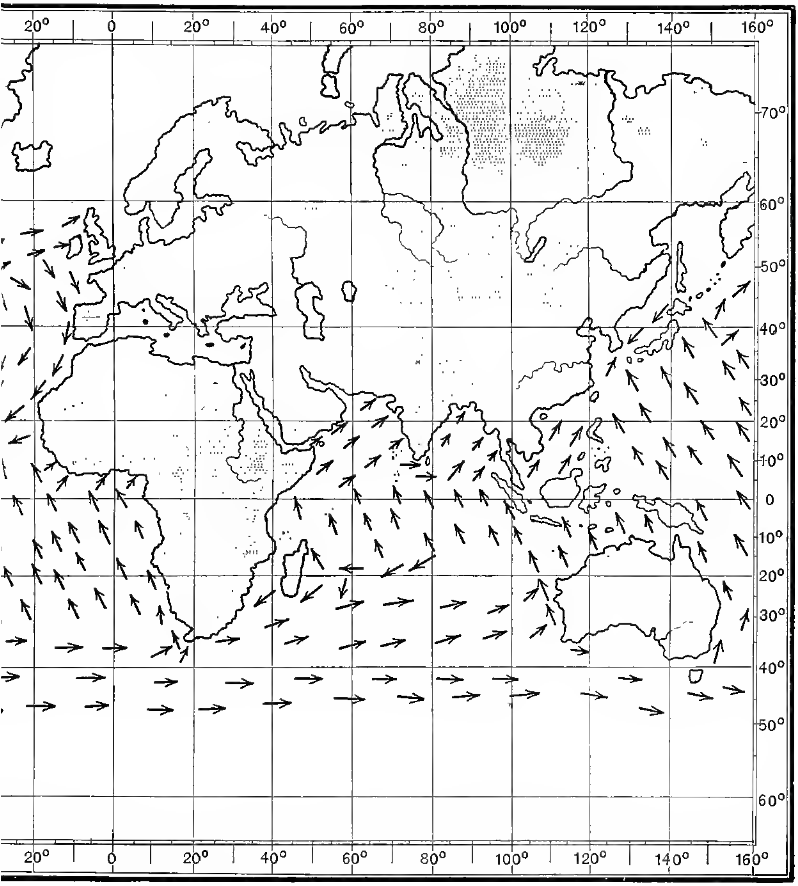
SOLUTION OF THE CYCLONE PROBLEM.

Theoretical Considerations.—In a cyclone, hurricane, typhoon, or revolving storm—call this particular class of disturbance what you will—the wind, regarded from a strictly theoretical point of view, revolves in an approximately circular system around a central area of calm and low barometer. At the same time, the whole system moves bodily onward, somewhat like a spinning-top dragged by a string looped over its peg. It is not easy to determine just what serves the purpose of the string, when the question relates to a cyclonic storm; either as to the motion of rotation, or that of translation. The diameter of a cyclonic system may, and often does, vary from a few miles, in tropical regions, to 1000, or even to 1500 miles, between the parallels of 40° N. and 60° N. Such an atmospherical disturbance has been clearly demonstrated to exist right across the North Atlantic, from Newfoundland to Ireland, with heavy westerly gales blowing all along the margin nearer to the equatorial regions. One cyclone may split up into two or more distinct storms, each moving independently. On the other hand, two or more cyclones may coalesce at some point on their converging tracks, and merge in a single storm. The onward progress of a cyclonic storm is also a very variable quantity. At times almost stationary, and again travelling over other parts of the track at the rate of sixty miles an hour, these meteors occasionally put to confusion the best laid plans of navigators remote from land and the electric telegraph, and falsify the predictions of shore weather-workers in telegraphic communication with numerous reporting stations.

Information extending over a sufficiently long series of years enables us to lay down on a chart the average tracks of cyclones over the several oceans with a moderate degree of accuracy. Nevertheless, the path followed by any particular cyclone may diverge widely from the average track. A cyclone does not always proceed along a straight line, but appears to follow the path of least resistance. Neither is the velocity of rotation or of translation invariable



Allingham's Marine Meteorology. Plate



PREVAILING WINDS OVER THE OCEANS FOR JULY.

throughout a cyclone's career from origin to dispersal. Little is known even now as to the birth and the death of a cyclone.

In either hemisphere the wind travels round a cyclone's centre in a direction contrary to the apparent course of the sun. For the northern hemisphere, the cyclonic wind revolution is from east to west through north. In the southern hemisphere, the rotation is from east to west through south. It is absolutely necessary for a student to obtain a clear conception of the wind's rotatory motion in a cyclonic system. Another method of expressing cyclonic circulation is by reference to the revolution of the hands of a watch placed face upwards. In the northern hemisphere the cyclone wind rotates in a direction contrary to watch-hands; whereas in the southern hemisphere the revolution is with watch-hands. A much simpler, but equally useful aid to memory, is the fact that in either hemisphere the westerly wind of a cyclone is always on that portion of the storm whirl which is nearest to the equator. Hence, as in Fig. 18, draw a straight line, AB, in an east and west direction, to represent the equator; then describe a circle, ever so roughly if in haste, and mark the westerly wind arrow as indicated, on that portion of the circumference which is nearest the equator. Thus the whole circulation of a cyclone is perceived at a glance without burdening the memory by mastering cumbrous verbal rules. A rough diagram of this elementary description will assist us considerably in understanding the wind changes which a ship experiences at sea, and also the action of the barometer. Here it may be well to remark that the wind-force of a cyclonic system does not always reach that of a gale. Provided the wind rotates as above, the resulting system is a cyclone, no matter what the wind force may be. The term cyclone includes both small and large whirls.

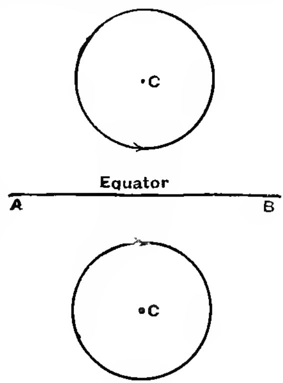


Fig. 18.

The most violent revolving storms occur in the vicinity of the West India Islands and Mauritius; in the Bay of Bengal and in the China Sea. All round the globe, within a zone of about 10° on either side of the equator, cyclonic storms are exceedingly rare, although not unknown. On 20th August 1874 the "Ardgillus," Captain Brett, had a day's curious weather in 7° N. lat., 28° W. long. For the first four hours a moderate gale blew from

W.S.W., then eight hours of light N.E. breeze, followed by eight hours of W.S.W. moderate gale, and four hours S.W. strong breeze to strong gale. At 8 p.m. there were nasty cross seas from N.E., S.W., and N.W. A cyclone may have been brewing here. Very few cyclones are met with in the South Atlantic, from the equator to 25° S.; or over the eastern side of the Pacific.

Origin of Cyclonic Disturbances.—Cyclonic circulation was formerly assumed to be set up by the collision of winds from different directions, in much the same way as a top is spun round with the hands. This view is incorrect, inasmuch as a cyclone often originates where there is little, if any, wind motion. Then it was supposed that the gyratory movement commenced in the upper regions of the atmosphere, and worked downward to the earth's surface. Variation in temperature is a more probable cause. Hot air rises, tends to form an ascending current, and in this way the barometric pressure is decreased at that point. Local ascensional currents are most marked where evaporation and cousequent changes occur readily. Hence the most destructive cyclones originate over the ocean. After the whirl is formed, in some way not easy of explanation, near the limits of calms and equatorial rains, it moves onward with the normal air current like an eddy in a tidal stream. The late Professor W. Ferrel first called attention to this curious circumstance, and meteorology is indebted to that illustrious American enquirer for some extremely interesting researches into matters connected with the movements of the atmosphere. In low latitudes, in either hemisphere, a cyclonic circulation travels to the westward with the surface air current. Near the tropics the westerly motion diminishes, the cyclone track curves gradually away from the equator, and eventually trends eastward in the higher latitudes. As a cyclone speeds onwards, the diameter increases, while the wind force diminishes somewhat, until the storm finally dies out, or disappears beyond the limits of observation. The same air is not necessarily acted upon all through the life of a cyclone. Part is probably left behind during its passage, and a fresh supply attracted.

Storm Path.—The storm path, track, axis line, or trajectory, is the line along which the cyclone centre travels. If the cyclone centre be bearing down directly on a ship hove-to in front of the storm, the wind direction will not change until the calm centre passes over her. Then the wind will come upon the ship again, with equal fury, but from an almost exactly opposite direction. The calm area is not always clearly defined. Suppose, in the northern hemisphere, a ship has the barometer falling rapidly with the wind blowing steadily from the northward and increasing in force to that of a hurricane. Then the cyclone is travelling westward along a path which joins the ship and the storm centre. She will probably experience a lull for a short interval, followed by a southerly wind of hurricane violence. Approaching the centre from any other direction, the wind changes become more pronounced and vary with the angle between the ship's track and the cyclone track. A ship hove-to at A in fig. 19 with a cyclone moving down on her along the track D C B A, will first experience a northerly wind, then a calm or a lull, as the centre, C, passes over her; and eventually a southerly wind. A glance at the diagram shows this sequence of events. In fig. 20, however, a vessel hove-to at A will escape the central portion of the cyclone. Her wind will change from north-east to east and south-east, while her maximum wind force occurs at B when nearest the centre. A vessel hove-to at E will have the wind change from north-west to south-west, through west. The slower a cyclone travels the less rapid will be the wind changes experienced by a ship in the toils. Should the storm stand still or travel very slowly, and the ship

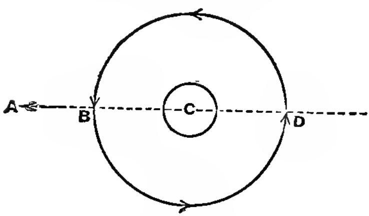


FIG. 19.

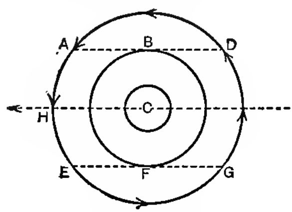


FIG. 20.

herself steam onward, the vessel's motion may cause an apparent series of wind changes contrary to those she would have had if hove-to. As a matter of fact, whenever a ship is overtaking a cyclonic storm the effect upon the wind changes is much the same as though the cyclone were actually advancing in the opposite direction to that of the ship at a rate equal to the difference between the ship's speed and that of the cyclonic disturbance.

Fig. 21, devised by the United States Hydrographic Office, goes far to explain the most modern views held with respect to the wind circulation in a West India hurricane. The wind revolves around a central area of relatively low barometric pressure, in a direction contrary to that of watch-hands, with an angle of indraft of about two points towards the centre. At the same time the whole whirl moves onward. Very often a calm prevails at the centre, while all around, within a radius of a few miles, ships are battling with a furious hurricane. When this central calm has passed over a vessel the wind will come out from a direction different to that prior to the calm, but with equal energy. Hence a ship is liable to be taken aback, gather stern-way, and founder in the heavy confused sea. Consequently the centre is avoided, as far as possible, at any rate by sailing-ships, for there the wind changes are sudden, and the seas from every point of the compass.

Form of Cyclonic Area.—Were every cyclonic system

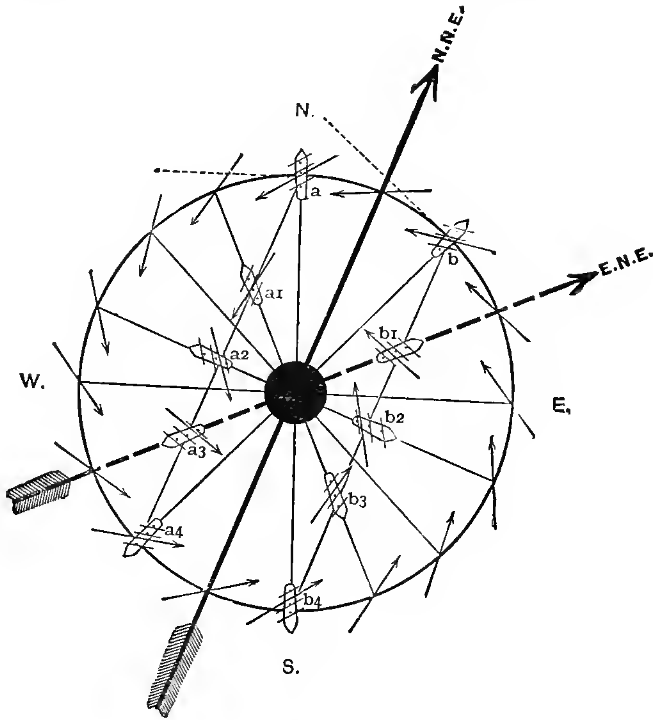


Fig. 21.

circular in shape, as in fig. 23, then the bearing of the centre would always be exactly eight points, or 90°, to the left of an observer standing with his back to the wind in the northern hemisphere. Unfortunately for the navigator, this simple geometrical figure does not always accommodate itself readily to the recorded facts, and there has grown up a tendency to assume that the centre bears, on an average, about ten points to the left in the northern hemisphere. Even with this academical allowance for the assumed drawing in of the wind towards the centre, known as

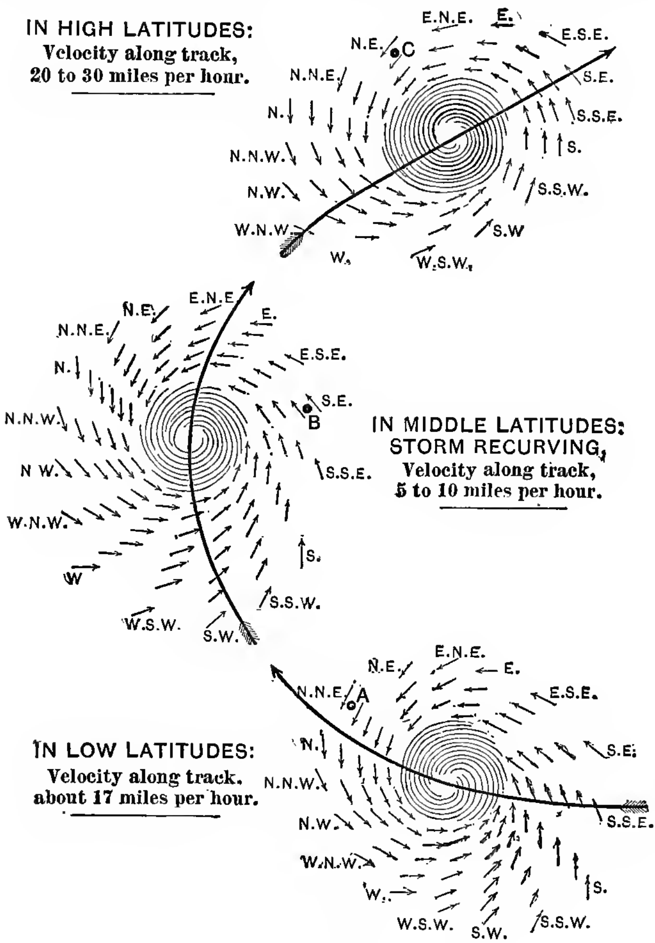


FIG. 22.

the incurvature, the indraft, or the angle of indraft, the navigator is not much more certain in his deductions than he would be by adopting the circular theory. The angle of indraft is said to vary from point to point around the storm system, with the distance from the storm centre, and also with the latitude. My friend Commander S. T. S. Lecky, R.N.R., in his invaluable *Wrinkles in Practical Navigation,* has well said that "As a fact, no rule is possible for determining more than approximately the position of the vortex of a cyclone by observations confined to a single ship." When laid down on a Mercator chart, storm systems are generally elliptical in shape, with the major axis along the direction in which the cyclone is moving. The lowest barometer is generally found at one end of the ellipse, and evinces a tendency to shift from end to end of the major axis.

A first-rate exercise in storm sailing can be carried out by copying one of these diagrams on a piece of tracing paper, and moving the whirl, thus formed, over a spot on a sheet of white paper or on a chart, which shall represent a ship hove-to in north latitude. For example, in the northern tropic, with threatening, squally weather, falling barometer, and N.N.E. wind, a ship at A, in fig. 22, will have the wind shift rapidly to N.E., E., and S.E., as the storm centre travels westward. When the hurricane recurves, a ship with wind from S.E., shifting to S., will probably be at B. In higher latitudes, storm centre moving north-east, a vessel with steady barometer, and wind shifting from N.E. to N. and N.W., will be somewhere near C. A vessel directly on the track will not experience any wind change prior to the calm, although its force will increase and the barometer fall. This is a position of extreme danger.

Fig. 21 represents a northern hemisphere cyclone, in the North Atlantic, say. To simplify matters, suppose the storm area is circular, and the winds inclined to the centre at a two-point angle of indraft. The cyclone is advancing towards the N.N.E. as indicated by the thick arrow. A ship at a has the wind E.N.E.; and another, at b, has the wind E.S.E. As the cyclone advances, the vessels, if hove-to and practically stationary, will take up the successive positions, a_1, a_2, a_3, a_4; and b_1, b_2, b_3, b_4, respectively. The first ship's winds shift to the left as indicated by the arrows. Consequently, hove-to on the starboard tack, in the left-hand semicircle, she risks being taken aback. Moreover, the sea direction changes after the wind, so that even should she break off in time, the sea comes from more aft in her new position, and it is always dangerous to be stern-on to a heavy sea in such a plight. In the left-hand semicircle she should be on the port tack, if possible, so that the wind shall draw aft as it changes, and the ship in coming up will bow the old sea. She must also be kept under low sail on the port tack lest she make headway towards the centre.

Cyclonic Semicircles.—Every cyclonic system is divided into two approximately equal portions by the storm track. Looking towards the point of the horizon whither the cyclone is proceeding, the portion on the right side of the storm track is termed the right-hand semicircle; the other half is the left-hand semicircle. That semicircle in which the motions of rotation and translation are similar is known as the dangerous semicircle, the other is the navigable semicircle. The dangerous semicircle is so called, not

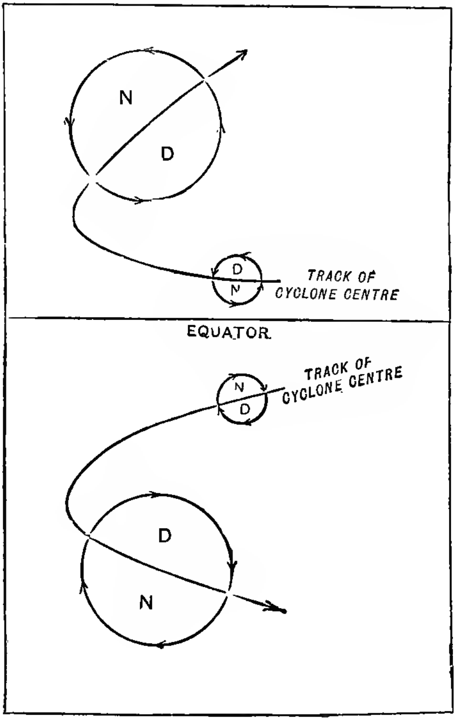


Fig. 23.

only because a ship running before the wind in that semicircle will cross the storm track ahead of the advancing centre, but also because the weather is decidedly worse there. A ship running in the navigable semicircle will cross the storm track increasingly to the rearward of the centre. In fig. 23 these dangerous and navigable semicircles are marked D and N respectively. The long curved arrows represent the average storm tracks of the two hemispheres. As will be noticed, the D semicircle is on the eastern side of the track, and the N semicircle on the western side, in either hemisphere. In other words, the D semicircle is to the right, and the N semicircle to the left of the storm track, in the northern hemisphere; whereas the N semicircle is to the right, and the D semicircle to the left of the storm track in the southern hemisphere, taking into consideration the direction in which the storm is travelling in both cases. In either hemisphere the D semicircle is on that side of the storm towards which the curvature of the track occurs.

In the right-hand semicircle the wind changes will be to the right; from north towards east, east towards south, and so on. In the left-hand semicircle the change of wind will be to the left; from north towards west, from west towards south, and so on. Hence the change of wind will indicate in which semicircle the ship happens to be. In the right-hand semicircle, if compelled to heave-to, put the ship on the starboard tack; but in the left-hand semicircle put her on the port tack. This rule for the determination of the semicircle, and the heaving-to tack, is applicable to all parts of the world. By following it, when possible, the ship will come up as the wind shifts. She will thus avoid being taken aback at a critical moment. An aid to memory is afforded by the fact that the direction of the wind change, the name of the semicircle, and the heaving-to tack, all three correspond to the same side of a given line. All we have to do is to remember six words: *right*, *right*, *right*; *left*, *left*, *left*; which signify that if the wind changes to the right, the ship is in the right-hand semicircle, and should be hove-to on the right hand, or, in other words, the starboard tack. If the wind shifts to the left, the ship is in the left-hand semicircle, and should be hove-to on the left-hand or port tack. If, however, by the change in the wind, running is deemed advisable, then keep the wind well on the starboard quarter in the northern hemisphere, but well on the port quarter in the southern hemisphere. Running with the wind right aft, a ship may be brought directly iuto the storm centre; and running with the wind on the quarter introduces a risk of broaching-to, so there is merely a choice of evils at times. If a ship is immediately on the path of an advancing storm centre, the wind direction will not change perceptibly; although the barometer will fall, and the wind force increase rapidly. By running before the wind for a few hours the wind changes will approximately reveal into which semicircle she has advanced. When a ship is on the storm centre line of advance, in either hemisphere, she must run, but always on a course which will increase her distance from the dreaded centre. The reference to shift of wind implies that the ship is stationary, hove-to, or anchored, as the case may be. Should she be going ahead this motion may interfere with a proper appreciation of the wind's direction and force.

When a storm is at hand the barometer will generally give fair warning by the restlessness of its mercurial column, or by a sudden *rise* of greater magnitude than those oscillations. A very rapid fall in the barometer, once a ship is under the influence of a storm, will indicate that its area is of small diameter, but that it is one of great violence. A gradual fall would imply a more extensive storm of less intensity. The lowest reading of the barometer in a cyclone will be at the central core or heart of the storm. Hence we have the "law of storms" for the northern hemisphere, expressed in terms of the barometer, which is commonly known as Buys Ballot's law: "Put your back to the wind and the lowest pressure is on your left hand." This is the old circular theory, without making any allowance for incurvature of the wind towards the cyclone centre. Very often the rule is stated as though the observer were facing the wind. An original aid to memory for this law, northern hemisphere, is to associate it with the name of the one-time Secretary of the Meteorological Office, "R. H. Scott, F.R.S.," thus:—Right Hand Shows Centre On Turning To Face Revolving Storm. The initial capital letters give the name and title of the weather authority above mentioned, while the words express the law. For the southern hemisphere Buys Ballot's law runs as follows: "Put your back to the wind and the lowest barometric pressure is at your right hand." In other words, the wind blows along the isobars with less pressure on the left of its course in the northern hemisphere, and on the right in the southern hemisphere. The barometer falls until the ship is at her minimum distance from the centre, and rises again as the distance from the centre is increased. In the northern hemisphere the barometer will also rise when the ship is on the starboard tack, and fall when she is on the port tack; in the southern hemisphere it will rise on the port tack. Hence in the northern hemisphere, as a general rule, a rising barometer on the starboard tack is not an infallible indication that better weather is at hand. A rising barometer on the port tack is a favourable omen, while a falling barometer on the starboard tack indicates more mischief to come. This order of events is reversed in the southern hemisphere. Fig. 24 clearly shows why this is.

Buys Ballot's law, for north latitudes, tells us that the lowest barometer is on the left, with back to the wind, and then a ship on the starboard tack advances to the higher barometer. A change in the absolute barometric pressure during the interval will tend to complicate this rule. The high barometer may be receding faster than the ship travels, or an area of low barometric pressure may be overtaking her. In the tropics, where the mercury rises and falls in the barometer tube with the regularity of the tides around our coasts, any departure from the normal rise and fall must be regarded as an indication that a cyclone is not far distant. The intimate connection between the progressive motions of ship and cyclone is explained fully in Chapter XV.

Data necessary for solving the Problem.—The cyclone problem, in so far as it bears on the safe navigation of a ship at sea, demands the location of the cyclone centre; the ship's position in the cyclone area, relative to its centre; the storm track; and the readiest manœuvre to be adopted. Unless there

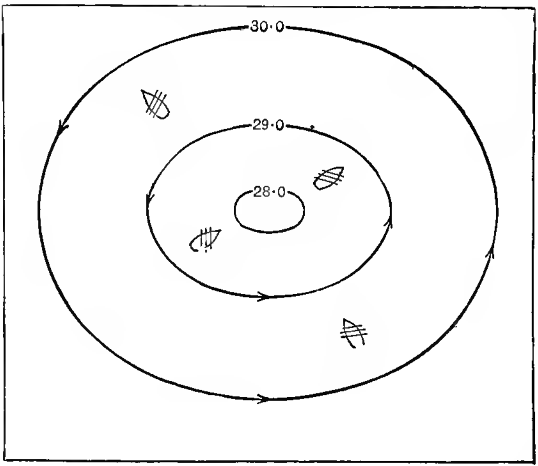


FIG. 24.

is plenty of sea-room, and the ship is under command, the very best rules in theory avail but little in practice. This is almost self-evident.

An approximate storm track is arrived at by plotting on a chart the positions of the ship and the cyclone centre on two or more consecutive bearings. Just here arises a grave difficulty in practice. The distance on the first bearing must be by estimation, for exactitude is precluded; the ship's position may be by dead reckoning, and therefore probably in error, and an accurate account of the ship's course during the interval between the consecutive bearings is necessary. In order to obtain the greatest possible precision the ship should be hove-to. The accompanying storm card, fig. 25, derived from the United States Pilot Charts, embodies the latest suggestions for storm sailing in the northern hemisphere, and a similar card can be constructed for the southern hemisphere.

When a hurricane is proceeding along the equatorial verge of a trade-wind region there is a belt of intensified trade-wind on the windward side of the storm track. It is unsafe to assume, because

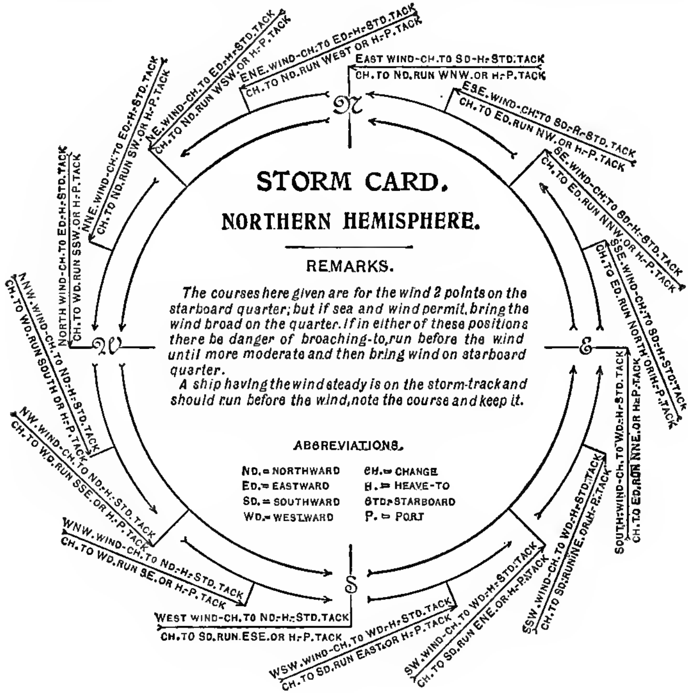


FIG. 25.

the trade wind grows stronger to gale force, and remains steady in direction, that a ship is on a storm track, until the barometer has fallen about ·6 of an inch. Should an attempt be made to cross the track too early, by running as the wind freshens, a ship may be steering directly for the storm centre. It is impossible to determine the distance from the centre, either by the absolute height of the mercury in the barometer tube, or by the rate of fall. If the barometer rise, however, while the wind decreases, the storm is passing away; but if the fall continues, while wind and sea increase, the cyclone may be either approaching or becoming more severe.

One of the most severe Atlantic cyclones on record is that of the early days of February 1899, of which fig. 26 affords an interesting bird's-eye view. Many vessels were seriously damaged,

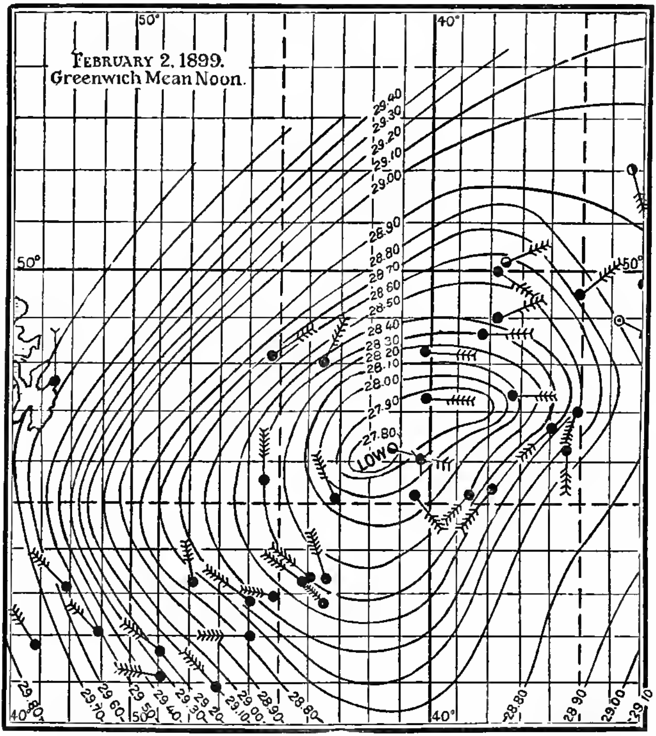
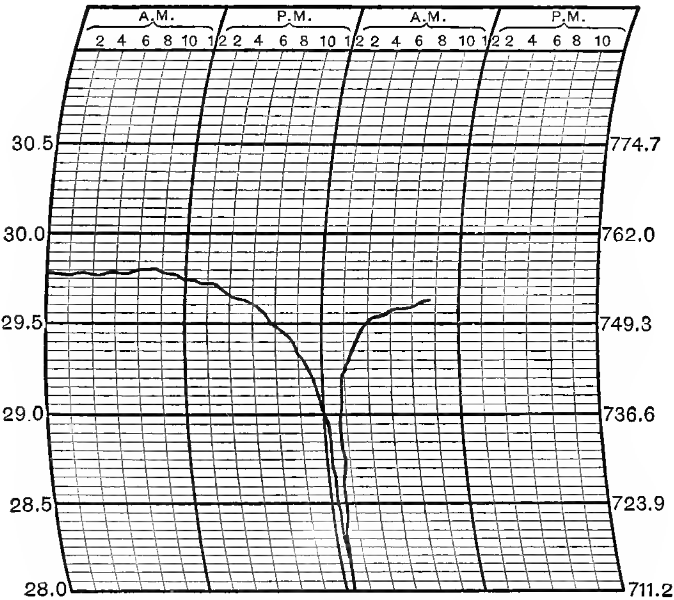


FIG. 26.

among them the Cunarder "Pavonia" and the Hamburg-American "Bulgaria," both of which had to be towed to St. Michael's, Azores, for repairs; and a dozen large steamers, worth, with their cargoes, over half a million sterling, were posted as missing. In some instances wind of hurricane force was experienced for thirty-six hours without intermission, and the most powerful liners hove-to for twelve or eighteen hours. Snow, hail, thunder, lightning, squalls, and terrific seas, joined in the general disturbance. At 2 p.m. on 2nd February, in 44° 58′ N. lat., 39° 7′ W. long., the lowest barometer reading of the cyclone was recorded. It was 27·57 in., corrected and reduced, and is within about two-tenths of the lowest ever known in the North Atlantic. The following reports made to the Washington Hydrographic Office will give the young beginners a fair idea of these dread occurrences. Captain C. O. Allen, of British steamer "Platea," says:—"The storm of February 1 and 2 was the worst I have ever experienced in any part of the world. I thought I had seen it blow in the China Sea typhoons and in West India hurricanes, but they were nothing to the lasting severity of this gale and the fearful seas that ran. February 1, at 8 p.m., being in latitude 46° 30′ N., longitude 38° 30′ W., the wind, which had been blowing hard from N.W., hauled into E.S.E. with snow, and blew furiously until 3 a.m. of February 2, when it lulled down and cleared off nicely overhead, the moon coming out beautifully and the clouds showing a slight motion from N.E. In the meantime, the barometer, which had stood at 29·60 inches at the time of preceding noon, had fallen to 27·65 inches (corrected), 0·75 inch lower than I had ever seen it during the thirteen years I have had it. At 7 a.m. the wind sprang up from N.E., backing into north by 9 a.m. and blowing a perfect hurricane which lasted without any let up for eleven hours, by which time it had reached W.N.W., and then settled into a heavy gale lasting another twenty-four hours. During the hurricane the barometer quickly rose to 28·50 before wind eased off any. After it had been blowing for twenty-four hours our oil, which we had been using from all closets fore and aft, was exhausted. A tremendous sea struck boat by after-hatch, smashing in weather bulwarks, breaking No. 4 derrick, going over to leeward, and starting our lee bulwarks outboard. Considering that we were flying light—18 feet of freeboard—I think that the chances of a deeply laden ship were rather slim."

The Fourth Officer's report from s.s. "Spaarndam," Capt. G. Stenger, is not less impressive. "The barometer rose until 8 o'clock in the evening (of February 1) and then stood at 755·1 mm. (29·73 inches); hard squally weather until evening, with snow and hail; the wind then moderated considerably and became variable, finally shifting to E.S.E. During the night the surface of the sea was brilliant with phosphorescent light. In the middle watch the wind increased to force 9, and then again diminished, the barometer falling steadily, with continuous rain. In the morning watch the weather was terrible; the wind increased to 11, sky overcast with rain, and much lightning along the whole horizon. A waterspout drifted over the ship. Wind shifted at 5.30 a.m. to S.W.; sea very high and wild. In the morning at 8 o'clock we suddenly got a very heavy squall from N.W., which lasted only an hour. Force of wind was more than 11. Then the wind went again to S.W. Position at Greenwich mean noon (9·26 a.m. local time) of February 2, 45° 15′ N., 38° 35′ W., wind S.W., 11, barometer 712·4 mm. (28·05 inches). The barometer continued to fall and the wind fell calm, became variable, and went to S.S.W. At noon, February 2 it was about force 2, baro-

BAROGRAM, SEPTEMBER 8-9, 1897.
S.S. "EMPRESS OF INDIA".



The full depth of the depression is not shown as it exceeded the limits of the tracing paper.

Fig. 27.

meter 27·75 inches; continued to fall and stood at 1 p.m. 703·5 mm. (27·70 inches), and at 2 p.m. reached its lowest, 700·2 mm. (27·57 inches). The sky was most of the time overcast with much rain, but now and then we got a fine sky with cirro-stratus and alto-cumulus clouds. After 2 p.m. the wind went to the west, the barometer rose, and the wind increased very fast; went to W.N.W.

and became so strong and sea so high that in the evening it was like hurricane weather. The air was thick, the sky lead-coloured, with now and then hail and rain. The barometer rose and at midnight stood at 731 mm. (28·78 inches), and remained there. The wind blew steadily W.N.W., force 12, till 10 p.m. of February 3."

This cyclone left the United States coast near Cape Hatteras on 31st January, and by noon of 3rd February the centre had travelled to about 48° N., 34° W., at the rate of 40 miles an hour.

The barogram, fig. 27, is from the noon G.M.T. report of s.s. "Empress of India," Captain O. P. Marshall, R.N.R., and is a graphic representation of the facts disclosed by a perusal of the special report furnished by Second Officer H. Mowatt. The barometer used is said to have been an excellent aneroid, its monthly corrections having varied from − ·01 inch in October 1896, to + ·08 inch in September 1897. This correction has been applied to the readings given below. On 8th September 1897, in lat. 33° 31′ N., long. 136° 8′ E., at 9 p.m., the wind was E.S.E., 9; barometer 29·56; temperature of air 78°, sea surface 76°; overcast, rain; sea from south-west.

Date.	Hour.	Wind.	Barometer.
8th Sept.	10 p.m.	S.E. 9	29·48
,,	11 p.m.	S. by E. 11	29·28
,,	Midnight	S. by E. 12	29·18
9th Sept.	1 a.m.	S. by E. 12	28·28
,,	1.15 a.m.	S.W. 12	27·88
,,	1.25 a.m.	W. by S. 12	28·08
,,	2 a.m.	W. by S. 12	29·15
,,	4 a.m.	W. by S. 11	29·56
,,	8 a.m.	W. by S. 7	29·70

Centre passed north of ship at 1·15 a.m. when she was in 33° 52′ N. lat., 137° 5′ E. long., and travelled from 40 miles an hour to about 60 miles. Winds of full hurricane force appear to have extended 62 miles ahead of the storm centre, and 95 miles in its rear. Fig. 28 shows the disposition of barometric pressure and the track of this storm centre, as determined by the Central Meteorological Observatory of Japan. The arrows fly with the wind; the number of tail feathers gives the wind force by Beaufort's scale, and the head appearances indicate the weather; absence of shading representing fine weather; partial shading, cloudy weather; and a wholly shaded head, an overcast sky. Absence of arrow shaft indicates calm. The small circles containing a cross, along the heavy-lined storm track, give position of storm centre at the designated hour. Rainfall was exceptionally heavy in the front of the storm. The sky cleared almost immediately after the lowest barometer reading had been recorded.

Another good example for the student is afforded by the experience of the P. and O. s.s. "Valetta," Captain Gadd, on 25th

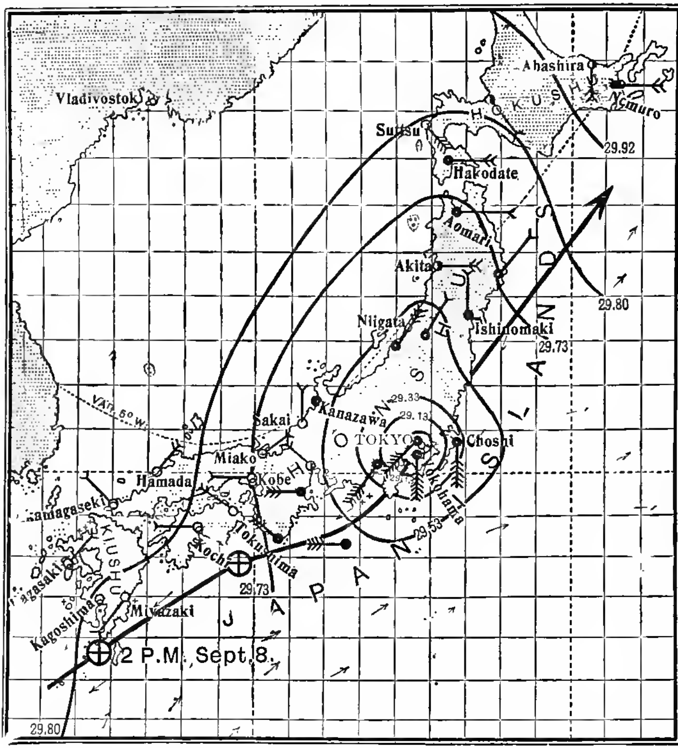
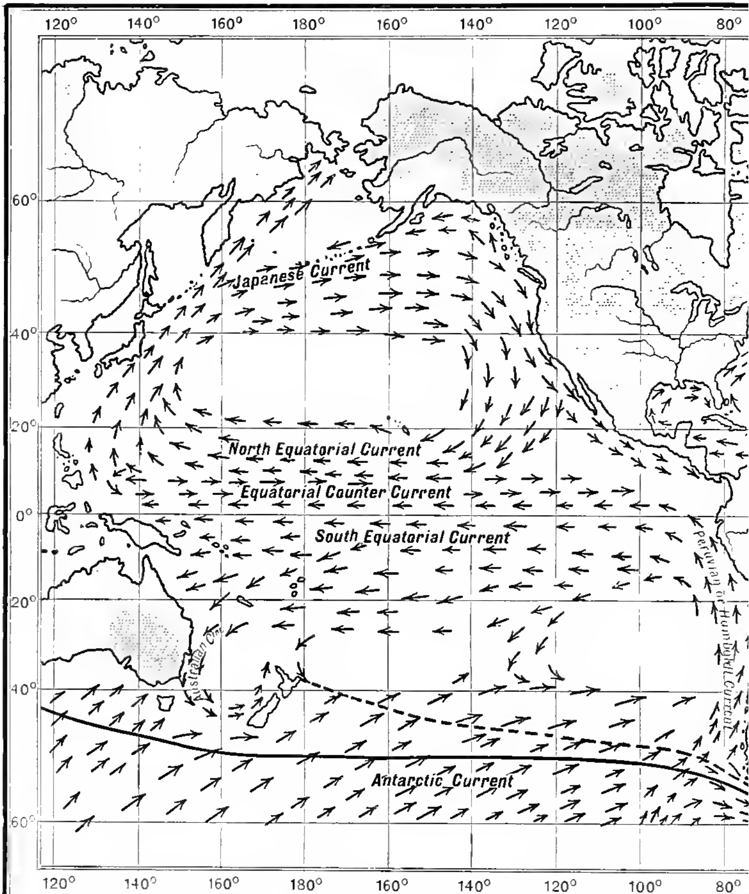
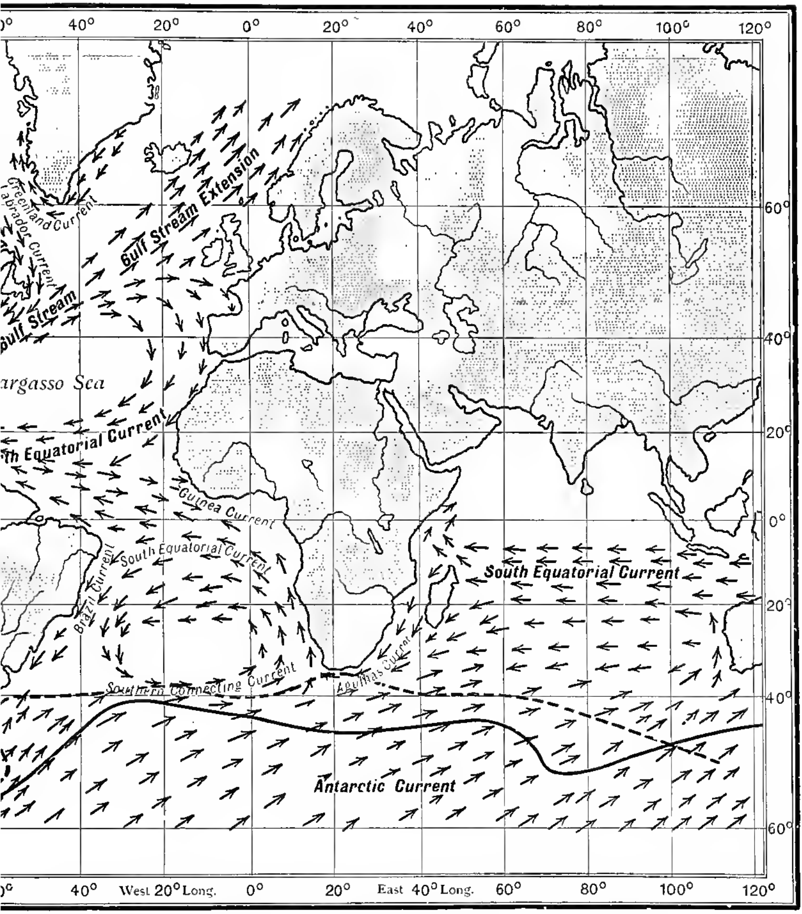


FIG. 28.

June 1897, in 29° S. lat., 110° E. long. At 0.50 p.m. a hard N.E. gale was blowing, with heavy rain and thick mist. Ten minutes later the sky cleared, sun shone, and barometer commenced to rise. For about two minutes there was an absolute calm. Then, in a squall of hurricane violence, the wind came out from S.W. A high N.E. sea was running at the time; but so strong was the



ALLINGHAM'S MARINE METEOROLOGY. PLATE VII.—GENERAL S



FACE CURRENTS AND LIMITS OF ICEBERGS IN SOUTHERN HEMISPHERE.

S.W. wind opposed to the N.E. sea that the tops of the waves were simply cut off and driven up into the air like vapour. Here the calm centre was clearly defined, although the fall and rise of the barometer during the passage of this cyclonic disturbance was only about ·5 of an inch.

On 15th November 1898, in 16° N. lat., 60° E. long., the "Britannia," Captain Turner, was under the influence of a cyclonic disturbance, and apparently near the centre. The wind shifted suddenly from S.E. to N.W., the sea was very confused, and numbers of land birds were around the ship.

The following extract from the log of the ship "St. Lawrence," Captain C. Johnson, London to Madras, in November 1871, gives an excellent word-picture of a cyclone. "Sunday, 5th. Noon; 12° 3′ N. lat., 80° 44′ E. long. Current for previous twenty-four hours, S. 24° W. 77 miles. 6 p.m. Weather beginning to look dirty, with a heavy confused sea. 8 p.m. Strong increasing breeze and squally. 9 p.m. In mainsail, jib, and driver. 10.30 p.m. Kept away S.E. Squalls very heavy. Wind hauling to N.W. Stowed courses, not liking the look of the weather. Monday, 6th, 1 a.m. Sea heavy. Very heavy squalls with heavy rain. Steering S.E.; wind about N. by W. 2 a.m. A peculiar light in the heavens like light brick dust. Wind N.N.W., steering S.E. 3 a.m. Stowed upper topsails. Wind N. by W. Steering S.E. by S. 4 a.m. Wind north, steering S.E. Strong gale, with heavy rain at times. 5 a.m. Wind N.N.E., steering S.S.E. 5–7 a.m. Wind unsteady from N. by W. to N.N.E.; heavy squalls, glass rising a little. 8 a.m. Wind N., steering S. by E. Squalls less frequent and not so strong. Very heavy sea at times. Leaden appearance to eastward, and very dirty-looking weather. 9 a.m. Wind N. by W., steering S.S.E.; heavy sea, squalls and rain. 10 a.m. Increasing. Down fore and mizen topgallant yards. Wind N. by W.; steering S.S.E. Fearfully heavy sea. 11 a.m. Wind N.N.W.; steering S.E. by S. A paddy bird and a flight of curlews tried to settle, but could not. Noon. Blowing a perfect hurricane and such a tremendous sea. I was afraid to run any longer, having had the cuddy, main-deck, and forecastle filled. In lower topsails and hove-to under bare poles with a small boat-sail in mizen rigging. 1 p.m. Wind N.W., ship's head N.E. At 1.30 p.m. mizen stay parted; preventer stay held the mast. Increasing every minute; could not get along the deck except on hands and knees. Ship lay-to beautifully with the water just washing over the lee poop covering boards. 2 p.m. Blowing a furious hurricane, wind W.N.W. Starboard quarter boat washed away, also the whole of the starboard mainrail and hammock nettings. Jib-boom and fore-topgallant mast gone. 3 p.m. Still blowing a romping, roaring, vicious hurricane. How the masts stand I can't think. 3.30 p.m. Glass commenced to rise. Wind W. 5 p.m. More moderate; wind S.W. but still blowing a thundering hard gale; obliged to cut away the wreck of jib-boom to save the ship's bows. Mizen topsail and upper foretopsail blown from the gaskets. 5.30 p.m. A great deal of lightning to the westward, but gradually getting fainter. 8 p.m. Hard gale, but fine weather.

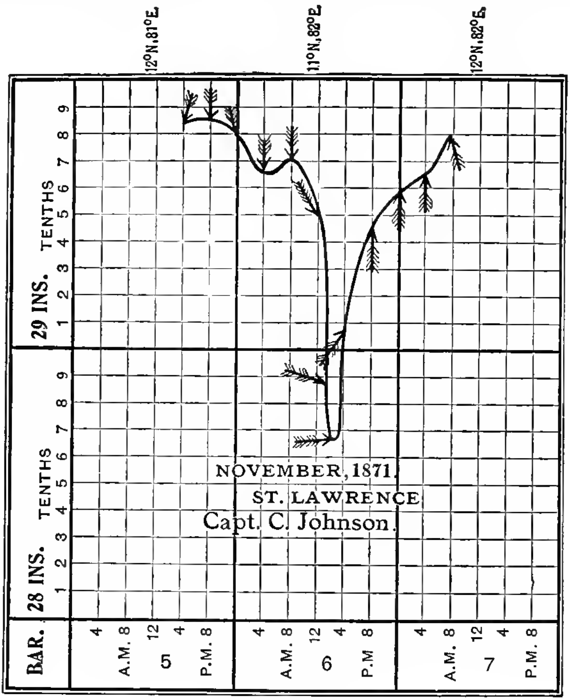


FIG. 29.

Wind about S.S.W. 7th, 4 a.m. Frightfully heavy sea. 8 a.m. Wind moderating. During the hurricane observed a peculiar glare in the heavens every now and then when there was a lull; but for nearly three hours, when the hurricane was at its height, nothing could be seen on board, and our eyes and ears suffered for it afterwards. Could not see a man two yards from us." Fig. 29 is a graphic representation of the action of wind and barometer during this hurricane.

CHAPTER XIII.

OCEAN CURRENTS.

Universality of Currents.—Stagnation is unknown, in so far as the sea surface is concerned, inasmuch as many causes combine to disturb the equilibrium of old ocean's upper layers. Were it otherwise, existence on our planet would soon become impossible, and death would brood over a slimy sea. In this elementary work an ocean current can be best defined as a body of water in motion. Tides due to the attraction of the moon and the sun must not be confounded in any way with what are strictly known as ocean currents. Nevertheless it must be freely confessed that just where current ceases to affect a floating body, and tidal action commences, does not seem quite clear. That old-time navigator blessed with keenly observant faculties, Dampier of pleasant memory, pointed out that currents are scarcely ever felt except on the open sea, remote from the land; and tides only upon the coasts of continents. Tidal influence, then, is principally confined to the coasts, and within the one hundred fathom curve of soundings which is generally indicated on navigating charts.

Causes of Ocean Currents.—Ocean currents depend upon many and various causes. The wind, however, is perhaps the most important and the most constant factor in the problem of sea-surface motion. Evaporation, precipitation, outsets from large rivers like the Amazon, the rotation of the earth on its axis, differences of temperature and salinity, and variation of atmospheric pressure, are some of the most powerful disturbing influences which assist not only in giving rise to ocean currents, but also in maintaining them. Going a step farther back, we arrive at some form of solar energy as the prime mover. The earth's rotation, and the trend of the land, merely modify the flow. Movements of the sea surface may be divided into two principal classes: drift currents and stream currents. Sub-surface currents are also known to exist in some parts of the hydrosphere.

The wind does not glide frictionless and imperceptibly over the ocean's upper layers. Even a light breeze will cause a ripple.

The air in motion drags the sea surface onward to leeward with, but after it. In this way is produced a *drift current.* Benjamin Franklin, the great American philosopher, was apparently the first to discover in the trade winds of either hemisphere the principal cause of the marked westerly set of the sea surface in tropical regions where, as explained in Chapter VIII., the wind is generally from the eastward. As the wind impels the upper layers of the ocean's surface onward, there arises a *compensating stream* which serves to remove the inequality in the windward portion of the affected region due to the drifting to leeward of its upper layers. Dr. Murray, of "Challenger" fame, by observations of Loch Ness temperatures, clearly proved how rapidly this wind action alters the distribution of water in a deep lake. On a calm day the loch temperature decreased from 60° at surface to 40° at 100 fathoms. A strong wind drove the surface water to one side. The extra pressure of this heaped-up water forced the lower layers along the bottom and up the other side, thus completing a circuit which, after a sufficiently long interval, mixed the water thoroughly and made its temperature the same throughout.

Should a drift current be obstructed by a coast, a shoal, or even another current, it will be deflected into a *stream current.* Major Rennell, of England, first divided sea-surface currents into drift and stream. *Sub-surface* currents include all ocean currents the upper layers of which do not reach the surface.

Current Charts.—Current charts are compiled from information afforded by a scrutiny of well-kept logbooks of carrying craft and warships. The action of an ocean current upon a ship when she is remote from a fixed terrestrial object cannot be directly observed by those on board of her. Hence it becomes necessary to use indirect methods of determining ocean currents. These rivers in the ocean vary in breadth up to 250 miles, as the Gulf Stream; have sufficient depth to be interfered with by banks 60 to 80 fathoms below the surface, as the Agulhas; and occasionally running from 100 miles to 120 miles in twenty-four hours, are but little influenced by an adverse wind of great strength. At noon each day, or oftener if deemed desirable, whenever the horizon is defined and the heavenly bodies visible, the geographical position of a ship on the waste of waters is deduced from astronomical observations by the aid of the sextant. As explained in Chapter VII. of the work on *Navigation* of this series, the courses and distances run from the last-observed position are carefully estimated by compass and log respectively. Compass error, and error of log, are supposed to be known, and the necessary correction made. In these ways the nearest approximation to a ship's geographical position is obtained, for the same instant, both by observation of celestial bodies and by estimation. These two results seldom agree exactly under the actual conditions of navigation. Occasionally, however, the position by estimation is cooked, so as to agree nearly with the position by observation, before entry in the log. This is a reprehensible practice in so far as the current chart is concerned, as it may lead the compilers thereof widely astray. Logbook keepers should remember that the very logs coming under their charge may be used for current chart compilation at some future date.

The difference between a ship's estimated position and her observed position, expressed as a course and distance, is usually attributed to current. Should the two results for the same instant happen to agree, then there is assumed to be an approximately stationary condition of the sea surface. Beginners should never forget that currents are named after the compass point *towards* which they flow, whereas winds are named according to the direction *from* which they blow. Bearing this convention in mind, it will be readily inferred that a northerly current is a body of sea-surface water setting *to* the northward; but a northerly wind is air in sensible motion *from* the north. Currents set *to*, winds blow *from*. The *set* of a current is indicated by that point of the compass whither the water proceeds; and the *drift* of a current is the rate per hour stated in miles.

Suppose, for example, we have found, by the true course steered, and distance run by log, that a ship in the North Atlantic is in 10° N. lat., 25° W. long., but astronomical observations show she is actually in 11° N. lat., 25° W. long., then it is evident some force acting upon the vessel, of which we had not any knowledge, must have carried her just 1° north of the spot where she was erroneously estimated to be. The best possible allowances having been made for leeway, compass error, bad steering, and similar items, the resulting difference in a ship's estimated and observed positions, at the same instant, is attributed to current. Exact estimation is out of the question where fallible human beings are concerned. Certainty is also lacking as to the geographical position by observation. Even the number of watch officers introduces personal peculiarities. Hence currents are convenient scapegoats for all sorts of errors, whether of estimation, observation, or calculation. The latitude is more easily and accurately obtained than the longitude, by observation of a heavenly body; so that the east or west components of a current are more likely to be in error than north or south. Strongly marked rivers in the ocean, such as the Gulf Stream and the Agulhas current, have been fairly determined by combining the informa-

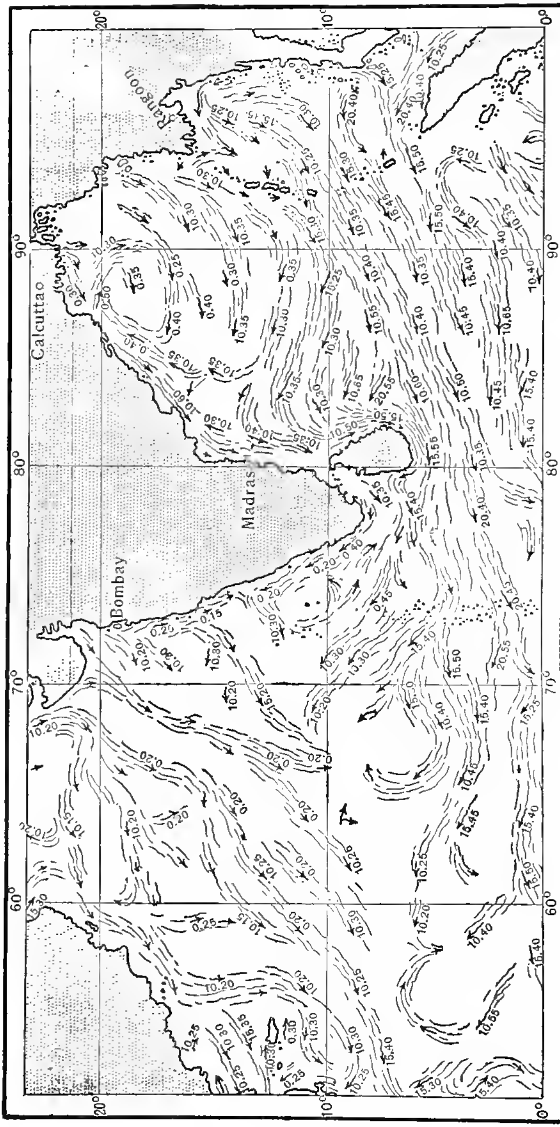


Fig. 30.

tion obtained from many ships spread over a sufficiently long series of years. Where information is scarce, little reliance should be placed upon the generalised currents laid down on charts. Probably no two persons, working independently, would deduce precisely the same general currents from the same batch of individual experiences laid down in position on a large working chart.

The loss of the sailing-ship "Sierra Parima," in June 1896, affords an object-lesson in sea-surface current problems. At noon of the 19th she was in lat. 2° 9′ S., long. 71° 30′ E., and the difference between her estimated and observed positions gave a current of N.W. by N. 10 miles. At midnight her course was altered, to allow for a strong *easterly* current indicated on her navigating chart, and also for the north-west wind acting on her in ballast trim. The sequel showed that she was actually experiencing a *westerly* current; for, a few hours later, she became a total loss on Sudiva Atoll. Turning to the current charts of the Indian Ocean, recently issued by the Admiralty, the June chart shows a north-west set, and the July chart has a well-defined westerly set from 80° E. to 60° E., just where the "Sierra Parima" met her fate, lulled into false security by erroneous indications on her chart. Even the most recent charts, although giving the more correct direction, do not help much as to the velocity, for 10 to 70 miles in the twenty-four hours allow a large margin of insecurity. Figs. 30 and 31, copied from the above-mentioned Admiralty Charts, show the different directions of the currents in the Arabian Sea and Bay of Bengal during the north-east and south-west monsoons. "All currents," wrote Admiral Wharton, "even the most permanent, such as the Agulhas, being exceedingly variable in both direction and velocity, the actual currents experienced by the navigator may sometimes differ considerably from the generalised current arrows shown on the chart." Many a navigator has proved this to his cost. Coming round a nasty corner he has allowed for a landward drift of 20 or 30 miles, only to find his vessel set out to sea in the opposite direction, and his passage lengthened. Next time, bearing this fact in mind, he allows the same amount, and she drifts ashore.

Chief Ocean Currents.—The principal ocean currents are the Gulf Stream, the Labrador Current, and the Guinea Current, in the Atlantic; the Agulhas Current in the Indian Ocean; the Kuro Siwo, or Japan Stream, and the Oya Siwo, in the Pacific Ocean. It is usual to refer to the Gulf Stream and the other powerful ocean currents, as apart from the general oceanic circulation; but this is merely for facility of reference. They are not separate phenomena, but parts of one great system, as indicated in Plate VII.

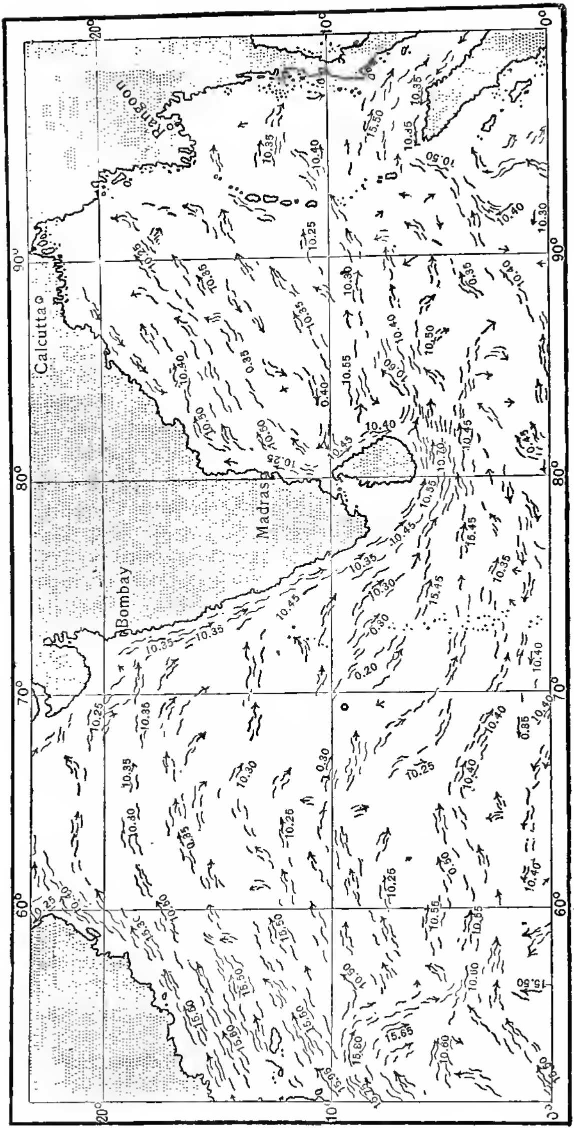


FIG. 31.

The Gulf Stream.—The Gulf Stream, a warm, relatively superficial layer flowing over an ocean of cold water, is probably the best known of all the currents. It has been studied in great detail by officers of the United States Navy, and the Coast Survey. Commander J. E. Pillsbury, U.S.N., is the most recent and reliable authority; and his results, published by the American Hydrographic Office, leave little to desire. A current from the south-east trade winds divides into two branches near Cape St. Roque; one flows towards Brazil, the other towards the West Indies. The current from the north-east trade winds joins forces with the last-mentioned portion of the south-east trade current, flows through the Caribbean Sea, round the Gulf of Mexico, and finds an outlet through the Strait of Florida, which, being narrow and shallow, causes the velocity of the current to increase. This oceanic river of relatively warm and salt water is 50 miles wide, 350 fathoms deep, and has a velocity of five miles an hour at the Strait. Thence it sweeps northward for about 300 miles, growing broader and decreasing in depth. Its width off Hatteras is 120 miles; and, on a line joining Bermuda and Halifax, about 250 miles. The portion of the equatorial current which passes north of the Bahamas bears down on the eastern side of the Gulf Stream, and thus compresses the latter between itself and the cooler Labrador current flowing southward inshore. In this way the stream is prevented from spreading, its velocity is increased, and its high temperature maintained. Near the Banks of Newfoundland the Gulf Stream proper loses velocity; but its warmer water is borne towards the British Isles, Norway, and Iceland, by the prevailing westerly wind of that region. Irregularities in velocity and direction of the Gulf Stream occur in consequence of varying wind and barometric pressure. The average velocity is greatest at the axis, which rarely coincides with the centre of the current. Even at the Strait of Florida the velocity is affected by the tides which cause it to vary as much as one-half its maximum rate during the twenty-four hours. The thermometer is not a sure guide with respect to the point where the Stream is reached. High temperature indicates tropical origin, but current may be wanting.

The Labrador Current. — This flows southward from Davis Strait, over the Banks of Newfoundland, and hugs the Atlantic coast of North America, inside the Gulf Stream, even as far to the south as the orange groves of Florida. A part of this relatively cold current is said to flow through the Strait of Belle Isle, and along the west coast of Newfoundland. It is the Labrador current which brings icebergs from Arctic regions. Some suppose the Banks of Newfoundland to have been formed by rocks and earthy matter deposited by such drifting masses as they dissolve under the influence of higher temperature. The line of separation between the cool Labrador Current and the warm Gulf Stream is known as the "Cold Wall." The deep blue of the salter Gulf Stream, and the green colour of the fresher Labrador Current, aided by a ripple in fine weather, indicate this margin. A blockade runner, under Captain "Roberts," otherwise the Hon. Augustus Hobart, afterwards "Hobart Pasha," left Wilmington one foggy night. Next morning a Federal cruiser was observed bearing down on her in chase. A northern prison seemed not far distant from the blockade runner's crew; but the ripple was observed, and Captain Roberts, aware of its import, edged away into the favourable current. He thus distanced his pursuer, retarded by the other current.

Some authorities imagine the Gulf Stream to disappear, as such, soon after passing south-east of Newfoundland. Westerly winds prevail in the higher latitudes of the North Atlantic, thus ensuring a general easterly set of the sea surface in any case. At one time the southern portion of this easterly current was supposed to strike the land between Cape Finisterre and Cape Ortegal. Part of it followed the trend of the coast to the southward; the remaining portion, known as Rennell's current, proceeding along the north coast of Spain, the west coast of France, and thence across the entrance to the English Channel. Of late years, however, this view has been held to be erroneous. Instead of the easterly current, or southern edge of the Gulf Stream, striking near Cape Ortegal, it is now supposed to hit Ushant. Consequently the circulation around the Bay of Biscay, according to the latest research, is from Ushant to Ortegal, hugging the French and Spanish coast, and is so laid down on charts; and not, as hitherto assumed, from Ortegal to Ushant. Landward of the 100-fathom line, however, tidal influence comes into play. This fact must not be ignored by navigators.

Between the parallels of 10° and 30° N. latitude, the surface water is drifted slowly westward by the north-east trade wind. A portion of it passes among the West India Islands and merges with the Equatorial Current.

The Guinea Current flows to the eastward along the African coast, into the Bight of Biafra, and extends southward to 2° N. lat. As a rule this current is found as far west as 25° W.; and from July to November may be fallen in with even to the 50th meridian, between 5° N. and 10° N. Off Cape Palmas the velocity is about 3 knots. It is warmer than the Equatorial Current, and has a maximum velocity of 3 knots off Cape Palmas. A sterling seaman and skilful navigator, the late Captain Alfred Fry, once told the Liverpool Mercantile Marine Service Association a true tale with respect to the effect of this current upon the plans of a thoughtless shipmaster. The latter sailed from a port on the coast washed by this current, the breeze died away, and the land began surely to disappear below the horizon. Day after day the vessel drifted in the current. Badagry was seen in the distance; the next land sighted was Prince's Island, and then Cape Lopez. Thence she steered along the equator with the south-west monsoon, and eventually reached the place of departure. Her master, ignorant of the current, had set out for a port nine miles distant, went 3000 miles, was away seven weeks, and yet was no nearer his destined haven. Captain Fry, in cloudy weather, desirous of getting out of the adverse Guinea Current into the favourable Equatorial Current, has felt his way out with the hydrometer.

An example of this easterly set, more to the westward, is afforded by the experience of Dr. Mann. He left Cayenne for Paranahyba, on 26th July 1862, in the brigantine "Monte Christo." She steered due north for four days, and was then in 7° N. lat., 52° 14′ W. long., by dead reckoning. On 7th August she spoke an Austrian brig, the "Rarita," and her longitude was 27° 14′ W. as against 42° 14′ W. by dead reckoning of the "Monte Christo," which had thus drifted fifteen degrees to the eastward. On the 15th, another vessel was spoken, giving her observed longitude 27° 8′ W. as against 44° W. by the dead reckoning of the "Monte Christo." This confirmed the previous speaking, and indicated that in eight days she had drifted nearly two degrees to the eastward. It must be remembered, however, that a passenger on board ship does not necessarily have access to the ship's logbook, but must depend upon information supplied by those responsible for the navigation of the ship.

Surface Currents of the North Atlantic. — Speaking generally, the surface water circulation of the North Atlantic agrees with that of the wind. In mid-Atlantic there is an almost permanent system of high barometer around which the wind circulates in the same direction as the hands of a watch. The sea surface follows much the same rule. At the centre of this whirl, the winds are often light and irregular, so also are the currents; and immense quantities of weed hang about there continually. Mr. A. W. Clayden has devised an instructive model of North Atlantic surface currents which clearly shows the connection between winds and currents. This weed-strewn area is known as the Sargasso Sea; and Mr. Julius Chambers of New York City quite recently utilised it as the field of action for an original and entertaining work of fiction. Most Sargasso weed is found over an elliptical area between 25° N. and 35° N., from

40° W. to 70° W. It has been passed in 55° N., in mid-Atlantic; and within 15° of the equator. This Sargasso weed, gulf weed, or *Fucus natans*, as it is sometimes termed, thrives even when broken off from its place of origin. The little berries, somewhat similar to small grapes, led the Portuguese navigators in olden times to christen this part of the Atlantic the Sargaçao Sea, from *sarga*, a grape, now Anglicised to Sargasso. There is an old story, which if not true is well told, of the experience of Columbus at this place, where he is said to have been compelled to cut a way with axes through the matted Gulf weed for his slow ships.

Owing to the perpetual circulation of the sea surface, life is made more worth living over our islands. At the same time, however, the Atlantic coast of North America has very low temperatures from the same cause. The sea-surface currents carry nearly half the sun's heat at the tropics to higher latitudes, and temper the climate of western shores of continents by cool currents from the higher latitudes.

South Atlantic Currents.—Just as the general circulation of sea surface in the North Atlantic agrees with the prevailing wind direction, so in the South Atlantic the currents tend to move round the area of high barometric pressure. In the southern hemisphere, however, the direction of revolution is contrary to that of watch hands. Along the West Coast of Africa there is a cool current, flowing towards the equator, known as the South African, South Atlantic, or Benguela Current. After reaching the 6th parallel of south latitude, this current, having previously kept parallel with the coast, moves out a little towards the westward. A little further north it meets the south equatorial current, unites therewith, and the combined currents move due westward, the south-east trade winds assisting in this movement. Part of the current travels north-west, the remainder goes south-west, bifurcating somewhat eastward of Cape St. Roque. The south-seeking portion follows the trend of the coast of South America, at any rate as far as the River Plate, curves eastward, and so eventually completes the South Atlantic circuit. Comparatively fresh water setting out of the Plate joining forces with the westerly wind helps forward this easterly diversion, between 35° S. lat. and 40° S. lat.; the Antarctic drift also sets eastward just about here. Occasionally the influence of the Brazil Current is traceable right down the east coast of South America almost to Cape Horn. Near the land this current is not felt to any extent worth mentioning, but depends greatly on the prevailing wind.

The Pacific Ocean.—Currents of the Pacific Ocean are not nearly so well known as those of the Atlantic, owing to the smaller number of ships traversing it compared with those on the great ocean highway between the Old World and the New. The general circulation, however, is similar to that prevailing in the Atlantic. This similarity holds for both the northern and southern oceans, although more markedly with respect to the former. Here, again, we have a fairly permanent area of high barometric pressure in each ocean around which both wind and currents circulate, while about the equator are sea-surface drifts forming a kind of doldrums. On opposite sides of the zone of calms and variables the sea surface flows to the westward, impelled thither by the persistent action of the trade winds of either hemisphere. In both Atlantic and Pacific the southern equatorial current exceeds the northern, not only in breadth but also in velocity. It extends from 15° S. lat. to 5° N. lat. in the Pacific, and is most marked on the northern limit, where a westerly current of 100 miles in the twenty-four hours has been experienced. The main branch divides at New Guinea. Part finds a way into the Indian Ocean through Torres Strait, or down the east coast of Australia; but the major portion reaches the Philippines.

North Equatorial Current.—The north equatorial waters are driven westward by the north-east trades, between latitudes 9° and 20° north, thus forming the north equatorial current. This current only attains to about half the velocity of its southern counterpart. On reaching the Philippines one part sweeps northward to form the Kuro Siwo; the other portion recurves, unites with waters of the southern equatorial current also recurving, and together they travel eastward as the equatorial counter current which results from the tendency to preserve a condition of equilibrium of the waters heaped up on the shores of Asia and Australia by the action of the north-east trades and the south-east trades. From July to December it is aided at its western extremity by the south-west monsoon then prevailing. After passing the 150th meridian, on its eastern course, the south-west winds which blow in the region of calms from July to October also assist in driving the surface water eastward. During the winter season the equatorial limits of the trades approach each other very closely, and steady easterly winds weaken or even reverse this counter current, but directly the easterly winds cease, the counter current reasserts itself between the 5th and 8th parallels of north latitude.

South Equatorial Current.—During the north-east monsoon the south equatorial current is diverted through the passage between Formosa and Luzon down the China Sea into the Indian Ocean, at the same time mixing with a cool current flowing equatorwards from the Yellow Sea. When in summer the south-west monsoon prevails, a reverse action takes place. The China Sea waters are aided by those of the Indian Ocean making their way northward between Luzon and Formosa. As this stream passes the east coast of Japan, it widens out, and is known as the Kuro Siwo, or Black Stream, so called by reason of the deep colour of the water. A branch also passes into the Japan Sea during the south-west monsoon.

The Japan Stream.—Kuro Siwo, Japan Stream or Black Stream, is to the western part of the North Pacific what the Gulf Stream is to the North Atlantic, but is scarcely so well marked as the latter, owing to the influence of islands and the monsoons. Near the east coast of Formosa this stream is 200 miles wide, and proceeds to the north-east with a maximum velocity of about 4 knots. After washing the south-east coast of Japan, the Kuro Siwo comes under the influence of south-west winds; and, like the Gulf Stream, moves eastward across the ocean, merges into a general surface drift, and eventually reaches the coasts of Alaska and British Columbia. Following the example of the Gulf Stream it becomes fan-shaped. Part flows north; the remainder sets southward along the west coast of North America, and is known as the Californian current, which gradually recedes from the coast and joins with the north-east trade drift setting westward, thus completing the general circulation of the North Pacific. This relatively cool Californian current affects the ports on the coast with fog.

Between the Kuro Siwo and the mainland is a cold current setting southward, known as the Oya Siwo. It is similar to the Labrador Current of the North Atlantic. The line of demarcation of the two streams is equally noticeable, as the warmer water is of a deep blue, and the cooler water a pale green colour. The Gulf Stream and Labrador Current should be studied together with these two streams. Changes of sea surface temperature are very marked at the mingling of the water in both oceans.

The Peruvian Current.—The sea-surface water setting northward from high southern latitudes strikes the coast of Patagonia. Part proceeds northward along the west coast of South America; the remainder, assisted by the prevailing winds, assumes an easterly direction off Cape Horn. Hence on both the west coast of Africa and the west coast of South America, we find a cool stream of water setting north. Either the low temperature is due to the off-shore wind skimming off the warmer water continuously, or to the fact that the water originates far to the southward. Probably both causes operate together. The Humboldt, or Peruvian Current, washes the west coast of South America from about 50° S. almost right up to the equator. This, at any rate, is principally due to the northern advance of a large body of Antarctic water. Deflected westward by the coast line, it merges into the above-mentioned south equatorial current, part of which finds a way south anywhere between the 140th meridian of west longitude and the coast of Australia. The many islands on the western side of the South Pacific interfere with the free onward motion of the waters. The cooler north-easterly drift from the Antarctic meeting with the south-seeking portion of the south equatorial current is deflected to the eastward, they unite forces, and thus complete the general circulation of the South Pacific.

Currents of the Indian Ocean.—The Indian Ocean, north of the equator, has currents depending upon the prevailing monsoon. At times the monsoon influence is felt as far south of the equator as 10° S. latitude. In the South Indian Ocean, however, the general circulation of the sea surface is much the same as it is in the South Atlantic and the South Pacific Oceans. From about 10° S. to 30° S. the sea surface is driven westward by the trades towards Madagascar. There the current begins to move between south-west and south-east, having opened out fanwise. The south-easterly portion moves eastward, towards Australia, travels northward parallel to the Australian coast, and eventually merges into the south equatorial current, thus completing the South Indian Ocean circuit under normal conditions.

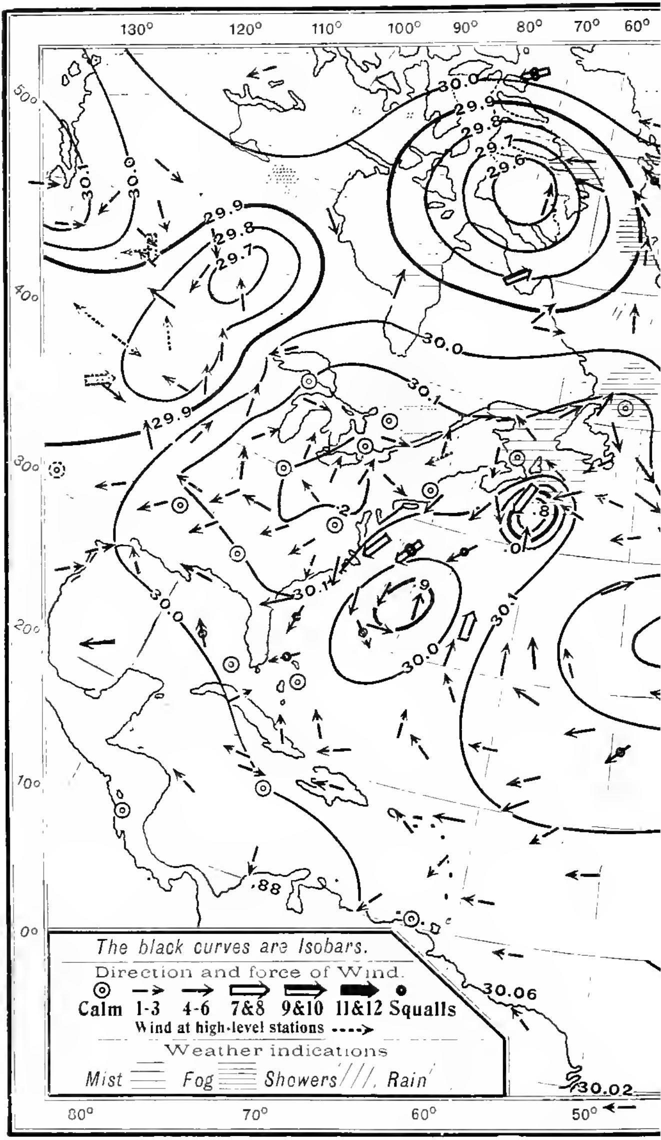
Agulhas Current.—Eastward of Rodriguez the westerly drift divides into two, which curve round the north and south end of Madagascar respectively. Meeting the mainland, about Cape Delgado, this northern portion also splits into northern and southern branches. A strong current of warm water passes southward through the Mozambique Channel; about the parallel of Natal it joins the current from the south end of Madagascar, and the combined stream is known as the Agulhas Current. It attains at times a velocity of 5 knots; and ships have been carried by it dead to windward against a gale at the rate of 3 or 4 knots. As a rule the Agulhas Current sets along the edge of the great Agulhas bank; and, about the meridian of the Cape of Good Hope, is split up into portions, some of which may round the Cape, while others, after crossing, proceed to the eastward. The width of the Agulhas is about 50 miles.

Westerly winds prevail over the lone Southern Ocean where sailing-ships run down their easting. These are the "brave west winds" of the illustrious Maury. Consequently the surface drift all round the world in that unobstructed belt is in an easterly direction. Icebergs drifting from Antarctic regions towards the equator afford evidence of a north-easterly drift, although very little is known of it. Apparently there is a well-marked flow of surface water from a position south of Cape Horn towards the Cape of Good Hope.

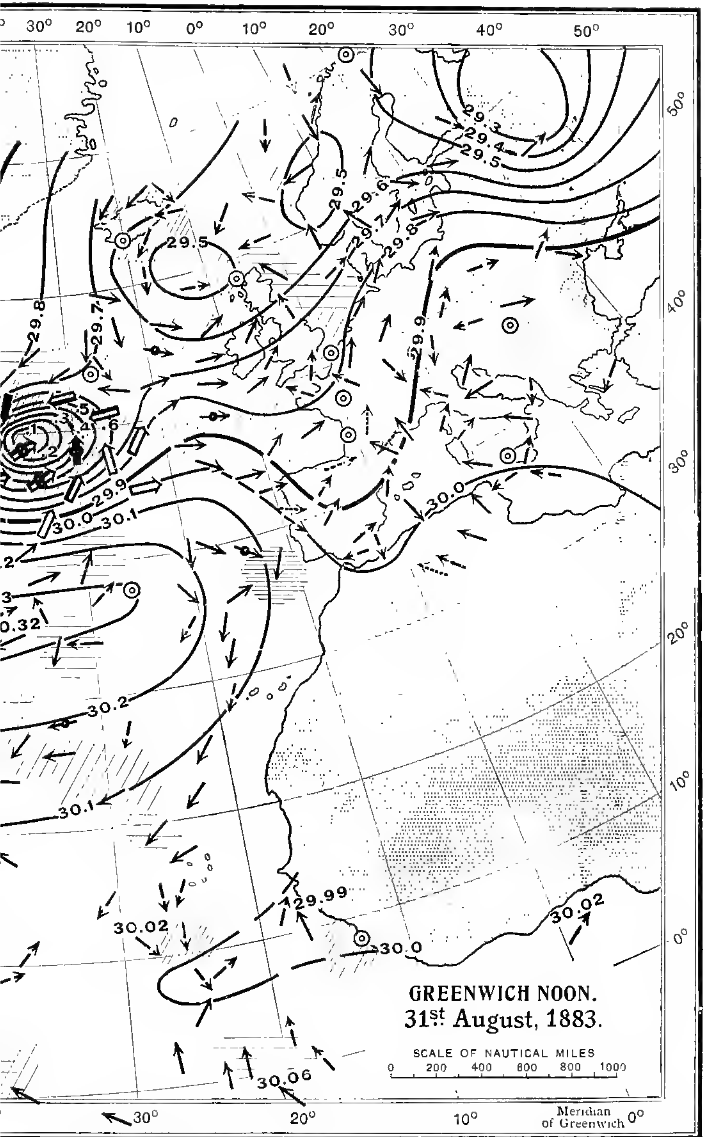
The monsoons exert a powerful influence over the direction of sea-surface currents in the Arabian Sea and Bay of Bengal. The north-east monsoon which sets in over the northern portion in January is a dry off-shore wind; evaporation is rapid, and the sea surface becomes salter and heavier. Wind friction drives this water south-west towards the Doldrums, and thence westward to the coast of Africa near the equator. There this current falls in with the northerly current from Cape Delgado, and the resultant is a well-marked Indian counter current, from Zanzibar to Sumatra, setting eastward with a velocity of from 1 to 3 knots, depending on the strength of the north-west monsoon blowing at the time. During the prevalence of the damp south-west monsoon the currents in the northern part of this ocean are reversed in direction. They then flow eastward round the Arabian Sea and Bay of Bengal; thus strengthening the counter equatorial current of the north-east monsoon, and eventually increasing the strength of the Kuro Siwo. A glance at figs. 30 and 31 will explain the peculiarities of these monsoon circulations.

The direction of currents as indicated by drifting objects.—For many years mariners have sent adrift bottles containing papers, setting forth the date of despatch, the corresponding geographical position, the ship's name, and other particulars, in order to test the direction of sea-surface currents. Captain A. B. Becher, R.N., the then Editor of the *Nautical Magazine*, in the volume of 1843 published a chart delineating the assumed tracks of many bottle messages in the North Atlantic. Of recent years the United States Hydrographic Office has issued several most interesting bottle-drift charts based on more natural principles. Prince Albert of Monaco, assisted by Professor Pouchet, made a series of current experiments from his yacht "Hirondelle," with casks, copper spheres, and bottles. Very few bottle messengers fulfil their mission. Some shipmasters send off one every day at noon, between England and the Antipodes, and hear nothing more of them. The direction of the sea-surface current is approximately ascertained by drifting objects, but not the velocity; for the time of departure is accurately known, whereas the bottle may lie neglected on some lonely beach for months. Bottles follow almost exactly the tracks which would be predicted for them after a study of generalised wind and current charts.

A bottle messenger despatched from the "Kent" East Indiaman, in March 1825, was picked up near Barbados, in September 1826. The East Indiaman caught fire in the Bay of Biscay, during a gale, while carrying troops to India, and succour seemed beyond belief. Major M'Gregor, the father of "Rob Roy" M'Gregor, wrote a farewell to his relatives on a scrap of paper,



Allingham's Mar


GREENWICH NOON.
31st August, 1883.
SCALE OF NAUTICAL MILES
0 200 400 600 800 1000
Meridian of Greenwich

enclosed this in a bottle, and committed it to the deep. This messenger drifted south for a time, and then to the westward. A bottle from the "St Enoch," sent off on 30th July 1893, in 8° 29′ N., 24° 20′ W., was picked up on 20th March 1896, in 60° 15′ N., 1° 15′ W. In the opinion of the United States authorities this messenger first travelled eastward in the Guinea current, then somehow got into the south equatorial current, by which it was swept westward through the passages of the Windward Islands, and thence onward to its last resting place at Totaborough Walls, Shetland Islands. North of the Azores, along the parallel of 50° N., the easterly drift spreads out like a fan, and bottles thrown overboard just there may be picked up anywhere between the North Cape of Norway and Gibraltar according to which branch of the stream they follow. Bottle drifts, currents, and wind circulations tend to confirm each other's indications.

Columbus is said to have placed a parchment record of his eventful voyage in a cask, which he threw overboard, fearing lest the angry sea would swallow up his nutshell caravels. This cask messenger has not been heard of since. Articles from the "Jeannette," the frail vessel engaged in Arctic exploration under the gallant but ill-fated Commander De Long, U.S.N., which was crushed by ice in 1881 in Behring Sea, drifted to the coast of Greenland, presumably on a mass of ice, and thus pointed out the way to Nansen and the crew of the "Fram."

Several derelict vessels have drifted right across the North Atlantic. A few have completed the circuit. The schooner "Twenty-one Friends" was left to her fate close to the Capes of Chesapeake Bay on 24th March 1885; and, after having been reported more than twenty times, she disappeared near Cape Finisterre on the Spanish coast. Her solitary drift of 3525 miles occupied eight months and ten days. Another American schooner, the "W. L. White," was abandoned in the awful blizzard of March 1888 somewhat to the eastward of Delaware Bay, and eventually, towards the close of January 1889, drifted ashore at Haskeir Island, one of the Hebrides. She had passed over 5910 miles of sea in 310 days, and was reported forty-five times. A still more lengthy drift was that of the schooner "Wyer G. Sargent," abandoned on 31st March 1891 with a valuable cargo of mahogany, close to Cape Hatteras, and last sighted on 6th December 1892 midway between that American Cape of Storms and the Strait of Gibraltar. Her track laid down on the chart forms a veritable maze, and during this interval of 615 days she travelled at least 5500 miles. Two similar schooners, the "Ethel M. Davis" and the "David W. Hunt," were abandoned in November 1888 within a few hours during a heavy cyclonic storm near Cape Hatteras.

The former, reported twenty-seven times, was last sighted in December 1889 about 800 miles west of Cape Finisterre, after a drift of 4400 miles in 370 days. The "David W. Hunt" was last reported as passed in November 1889 not far from Madeira. She had travelled 4800 miles in 347 days, and had been reported forty-one times to the United States Hydrographer. Of course in thick weather, and during dark nights, a derelict ship might be hidden from the view of those on board a passing vessel, even though close alongside. The three-masted schooner "Fannie E. Wolston" was abandoned in October 1891 near Cape Hatteras, drifted 3460 miles in 426 days, and was last observed in mid-Atlantic, where she probably fell to pieces. An Italian barque, the "Vincenzo Perrotta," abandoned in September 1887 about 600 miles northeast of Bermuda, drifted to the south-west, passed close to the southward of that island; and in April 1889, having travelled 2950 miles in 536 days, she drove ashore at Watling Island, otherwise known as St. Salvador, in the West Indies, where Columbus is supposed by some to have made the land on his first voyage in quest of Far Cathay. A Norwegian barque, the "Telemach," left by her crew in October 1887, nearly 450 miles west of the Azores, appears to have broken up in April 1889, some 10° nearer the American coast, after having drifted 3150 miles in 551 days.

Iron vessels seldom become derelicts. There are, however, a few exceptions worth mentioning. The "Ada Iredale" was abandoned in the South Pacific, with her coal cargo on fire, about 1900 miles east of the Marquesas Islands, in October 1876. She drifted westward in the south equatorial current, and the burning wreck was eventually towed into Tahiti by a French cruiser. She passed over 2400 miles in eight months. After the fire died out, in May 1878, she was repaired, and is now under the American flag as the "Annie Johnson." The iron ship "Oriflamme," abandoned under similar conditions in June 1881, about 850 miles west of Lima, on the coast of Peru, came ashore eight months later at the island of Raroia, after drifting 2840 miles.

CHAPTER XIV.

ICEBERGS.

Origin of Icebergs.—Icebergs brought by ocean currents from the Polar regions towards the equator are hindrances to the safe navigation of certain latitudes in either hemisphere. Such drifting dangers are frequently veiled from view of passing ships by fog, mist, falling snow, or heavy rain. The Hydrographic Department, London, issues general charts of the world setting forth the equatorial limits of icebergs; and the Hydrographic Office, Washington, affords the most recent information for the North Atlantic on its monthly Pilot Chart of that ocean. In high northern latitudes, glaciers move slowly seaward; their extremities are eventually broken off by the upward pressure of the water into which they protrude, and the resulting icy masses, after a few convulsive somersaults, drift many a league towards the equator until dissolved under the influence of a more vertical sun, assisted by the increasing temperature both of the air and the sea surface. All round the icy fastnesses adjacent to the South Pole there is a vast barrier of land ice which dwarfs into comparative insignificance the glaciers of North Polar regions. "The upper surface of these tabular barriers," said Sir James Ross, "is like an immense plain of frosted silver; gigantic icicles depended from every projected point of its perpendicular cliffs, proving that it sometimes thaws, which otherwise we could not have believed." This impenetrable barrier of ice is supposed to be formed by the deposition of moisture on the surface from fog and snow. The slope of the land towards the sea is probably very gentle; but the mass of ice presses bodily onward to the lowest level, and the outer edge is wrenched off from the parent body. Icebergs vary in extent from a few yards to many miles in length and breadth. Their height above the sea surface ranges from a few feet to 1700 feet. Tabular icebergs of the southern hemisphere are very much larger than the more irregularly-shaped icebergs of the northern hemisphere. After drifting for some distance to sunnier climes, the submerged portion of an iceberg having melted considerably, the centre of gravity of the whole mass gradually shifts, and the iceberg topples over to assume a new position of equilibrium. A cubic foot of ice at 32° weighs 57·5 lbs.; while a cubic foot of sea water weighs 64 lbs.; and a cubic foot of fresh water 62·4 lbs., at 62°, with the barometer at 30 inches. Hence icebergs are only about one-eighth of their whole mass above the sea surface. It does not, however, necessarily follow that an iceberg has only one-eighth of its vertical height exposed to view. Bergs coming from the north in the Labrador Current carrying stones and earthy matter, may ground on the Banks of Newfoundland, and help to decrease the depth of water there by leaving behind a portion of the adhering matter.

Records of Icebergs.—From the highest point of Whalefish Islands in 69° N., 53° W., no fewer than one thousand icebergs were once observed drifting south; and Admiral Markham, in his whaling cruise to Baffin's Bay, saw quite 700 or 800 bergs at one time. Some of these were very large. In the North Atlantic such dangers are most dreaded in the late spring and early summer months. They vary considerably in number from year to year, and have been met with even in December. The "Maria" on 15th December 1842, and the "Wabeno" on 5th December 1868, both received serious damage by collision with icebergs. On 28th January 1890 the steamer "Colina," in lat. 48° N., 49° W. long., was fast in the ice for twelve hours with engines stopped. Next day, 300 miles to the southward, the steamer "Mineola" passed an iceberg 700 ft. high and one mile long. On 10th February, in 43° N. lat., 49° W. long., the steamer "Lepanto" sighted an iceberg 500 feet high. In May, the steamers "Parisian," in 48° N. lat., 40° W. long., the "Beacon Light," in 44° N. lat., 48° W. long., and the "Thingvalla," in 47° N. lat., 43° W. long., all collided with icebergs. In July an iceberg broke into three pieces alongside the barque "Portia." One piece came up directly beneath her, lifted her five feet, and nearly capsized her. Icebergs were specially numerous in the North Atlantic during 1890, and the master of the German steamer "Slavonia" reported to Commander Richardson Clover, U.S.N., the then United States Hydrographer, that his vessel had passed the last remnants of an iceberg on 10th July, in 49° N. lat., 24° W. long. Probably this is the nearest approach of icebergs towards the British Isles since the glacial period.

Practical experience in the North Atlantic and elsewhere has demonstrated that sea-surface temperature is not the least indication as to the presence or absence of ice. A cold current of water may be bringing icebergs along. Nevertheless, the drifting bergs are not the cause of the low temperature. There is not any appreciable difference in sea-surface temperature even when close alongside an iceberg. This is what might be expected, having regard to the poor heat-conductivity possessed by water. Moreover, icebergs have been observed in the warmer water of the Gulf Stream, and to the southward thereof, impelled thither probably by an under current. A vigilant lookout may, perchance, hear the echo of a steam whistle, or the wash of the waves, or see the ice-blink; but the thermometer will not help the navigator to locate an iceberg.

The steamer "Gulf of Taranto," Captain Hudson, passed two pieces of detached ice 30 feet high, 300 feet to 400 feet long, on 11th September 1895, in 36° 35′ N. lat., 71° 36′ W. long., and much field ice covering a distance of two miles. Captain Hudson, when asked for confirmation of this report by Captain (now Admiral) C. D. Sigsbee, U.S.N., the then American Hydrographer, pointed out that this ice was noticed by all on board the steamer. The United States North Atlantic Pilot Chart for June 1891 has the report of a doubtful iceberg passed somewhat to the south of Cape Hatteras, and nearly in the same longitude as that above given. These icy masses are probably the nearest towards the equator of any on record. They had drifted southward in the cold Labrador current that washes the east coast of North America all the way down to Florida, inside the warmer waters of the Gulf Stream.

The late Mr. J. T. Towson impressed upon shipmasters the saving of distance effected by following the great circle track along the lone Southern Ocean to the Antipodes. It became necessary to determine the frequency of icebergs along this route, inasmuch as the nights in winter were long, the air temperature low, and fogs far from infrequent. He collated every possible item of information with respect to these drifting dangers, and his detailed investigations were published in 1859. They showed that ice was unusually prevalent in the Southern Ocean from November 1854 to April 1855; that icebergs might be met along any parallel between the Cape of Good Hope and Australia; that from Australia to Cape Horn ice is most frequently met with in the higher latitudes to the meridian of 80° W., that all over the Southern Ocean ice is in evidence during the southern summer, and that a very dangerous ice area lies north-east of Cape Horn. He thought that sea temperature changes, together with a vigilant lookout, would give sufficient warning of icebergs in the vicinity.

The author has for some years past kept a careful record of Southern Ocean ice. From hundreds of reports by ships of every nation it follows that icebergs must be guarded against south of 45° S. lat. in the South Pacific, and 40° S. lat. for the remaining portion of the Southern Ocean. Occasionally bergs drift north of the 40th parallel of south latitude, particularly near the east coast of New Zealand, north-east of the Falklands, and off the Cape of Good Hope. Mr. Towson was not aware of ice near New Zealand, and the views he set forth as to sea temperature indications are, as we have seen, unsound.

Recorded Altitudes of Lofty Bergs.—Some of the estimated heights of Antarctic bergs are almost beyond belief. Yet mariners are fairly accurate in their reports concerning heights and distances, and independent observers confirm each other, while sextant measurements do not fall much below those obtained by estimation, where imagination and awe might have had place. The following table sets forth some of the extreme heights of icebergs in the Southern Ocean from water-line to summit. The "Curzon" had 50 bergs in sight at the same time, having altitudes above sea level varying from 500 feet to 1000 feet; and the "Loch Torridon," in addition to a record berg of 1500 feet, sighted several of 1000 feet at the same time. It will be noticed that several of these "floating rocks," as that illustrious circumnavigator, Captain James Cook, termed such icy masses, were apparently seen on different dates in various geographical positions. An objection may be raised to these estimated altitudes that they exceed the heights of prominent landmarks. Ailsa Craig is 1098 feet, the South Foreland 380 feet, Gomara Island 1440 feet, Cape of Good Hope 800 feet, and Cape Horn 500 feet. Nevertheless the following list tends to prove that bergs 1000 feet in height are not uncommon.

Year.	Month.	Ship's Name.	Feet above Sea Surface.	Position.	
				Lat.	Long.
1840	August	Gen. Baron v. Geen	1000	38° S.	15° E.
1884	June	Emil Julius	1700	44° S.	49° E.
1890	October	Noel	1000	50° S.	118° W.
1891	February	Marianna	1000	53° S.	141° W.
1892	April	Cromdale	1000	46° S.	36° W.
,,	May	Strathdon	1000	45° S.	26° W.
,,	September	Loch Eck	1000	44° S.	2° W.
,,	October	Curzon	1000	44° S.	31° W.
1893	January	Loch Torridon	1500	51° S.	46° W.
,,	February	Cutty Sark	1000	50° S.	43° W.
,,	March	Turakina	1200	51° S.	47° W.
,,	April	Brier Holme	1000	49° S.	51° W.
,,	May	Charles Racine	1000	50° S.	52° W.
1896	December	,,	1500	45° S.	50° E.
1901	September	Loch Katrine	1000	50° S.	130° W.
1902	,,	Sokoto	1000	56° S.	67° W.
1904	November	Zinita	1500	52° S.	44° W.
1906	May	Belen	1000	57° S.	64° W.
,,	July	Bossuet	1000	56° S.	67° W.
1908	August	Cognati	1300	49° S.	42° W.
1909	December	Walden Abbey	1000	50° S.	47° W.
1910	February	Invertay	1000	57° S.	133° W.
,,	August	Halewood	1000	52° S.	57° W.
1911	,,	Metropolis	1000	50° S.	63° W.

A similar list for the North Atlantic, though much shorter, includes sufficient instances to show that occasionally lofty icebergs are also passed in that ocean.

Year.	Month.	Ship's Name.	Feet above Sea Surface.	Position.	
				Lat.	Long.
1892	May	Hafis	600	46° N.	47° W.
1896	,,	Maryland	600	43° N.	49° W.
1899	April	St. Andrew	600	43° N.	50° W.
1903	March	Energia	600	41° N.	47° W.
1906	May	Marie	1000	48° N.	45° W.
,,	June	Paolo Madre	700	42° N.	49° W.
,,	July	Norden	700	52° N.	54° W.
,,	,,	Puritan	600	53° N.	51° W.

The late Admiral Fitzroy in his weather book stated that "immense islands, rather than icebergs, have been passed thereabouts, eight hundred to one thousand feet above the sea." In January 1833 Captain Boulton of the "Arethusa" passed many bergs in lat. 55° S., long. 149° W. One was not less than 20 miles long. "Some of these masses," said he, "I had the curiosity to measure, and found the height of one 840 feet above the level of the sea; and as I have seen some of them from the deck at the distance of 29 miles by log, I am led to believe that they may be higher." In lat. 57° S., long. 80° W., he saw an ice island, fully 800 feet high, turn completely over. The "Hesperus," in May 1892, passed an iceberg, in lat. 44° S., long. 39° W. Its altitude by sextant was 450 feet. A Dutch warship, the "De Ruyter," in 47° S., 18° E., January 1894, passed a number of bergs. Several measurements by sextant gave the mean height of one at 350 feet. In April 1895 the "Lowther Castle" had over a hundred bergs in sight, in 45° S., 25° E. One was 635 feet above sea level by sextant measurements. Mr. Gascoigne, Resident Magistrate at the Chatham Islands, east of New Zealand, where icebergs had been strangers for many years, reported that in October 1892 several icebergs had been seen from the island. Some stranded among the rocks. One of these was 500 feet high. An iceberg deemed "colossal" in 40° S. lat. would be but of average height twenty degrees nearer the Antarctic ice cap.

Ice Islands.—From December 1854 to April 1855, between 44° S. 28° W. and 40° S. 20° W., many ships passed an ice island 300 feet high. It was hook-shaped, with the longer shank stretched in an unbroken line for 60 miles. The shorter was forty miles in length. Situated between these two icy promontories was a broad bay, quite 40 miles from side to side. An emigrant sailing ship, the "Guiding Star," on her way to Australia, was entrapped in this bay, and lost with all on board. Two similar ships, the "Cambridge" and the "Salem," although embayed and imperilled, were headed back into safety and the open sea, by dint of sterling seamanship.

Icebergs in the Southern Ocean during 1892–95.—During the four years 1892 to 1895 the height, area, and numbers of icebergs in the Southern Ocean probably exceeded all previous records.

The "Invercargill" sighted 200 icebergs, in lat. 46° S., long. 38° W., in May 1892; the "Alice," in June, passed a solid body of ice composed of not less than 300 icebergs, extending 35 miles without a break; the "Kinfauns" passed 100 icebergs during one forenoon, and sailed over 400 miles in the presence of ice; and in December the "Drumcraig" observed an ice island nearly 30 miles in length. In January 1893 the "Wasdale" was surrounded by icebergs in lat. 47° S., long. 42° W. At sunrise she was found to be in a horseshoe-shaped bay, 20 miles deep, 10 miles across the middle, and 4 miles at the entrance. The ship "Stracathro" was in company. The "Loch Torridon" sailed for 50 miles along one side of an immense ice island; its extent could not be determined exactly, but, in the direction of the width, ice was visible as far as the eye could reach from aloft. The bays and indentations along its coast-line swarmed with icebergs and detached ice. The "Ariadne" sailed 30 miles along one side of an iceberg, in lat. 50° S., long. 45° W., and the "Ethel" encountered an icy barrier 50 miles long, about four degrees further to the westward. In March the "British Isles" passed fully 1000 icebergs while sailing 200 miles in about 48° S. lat., 46° W. long. The "Lodore," steering east along the 45th parallel of south latitude, during January 1897, did not lose sight of icebergs from 20° E. to 40° E. In November 1894 the "Antarctic," in about 58° S. lat., 175° W. long., sighted an immense body of ice about 60 to 80 m es in length. It was 60 feet high, quite flat on the top, and looked like land. The "Ladas," in March 1895, in 53° S. lat., 29° W. long., got into a continuous series of icebergs during the morning, and by nightfall came up with an icy barrier stretching from right ahead to 45 degrees on the bow without an opening. She sailed at least 600 miles round it. In April, the "Earnock" fell in with her first icebergs in 46° S., 20° E. For several days she sailed between long rows of them. At one time no fewer than 100 were in sight from the deck, and her master, Captain Yates, is of opinion that she passed quite 900 icebergs, some of which were 600 feet high and three miles long. In December 1 96 the steamer "Damascus," in about this position, passed 954 bergs in three days. Of these, 708 were sighted in one day and 236 in four hours. Numerous large bergs were seen aground on the rocks at Kerguelen Island. The above are only a few out of several hundred reports at command.

Very many of these huge masses of ice were barely distinguishable from land, by reason of their dark colour and adhering earth. Doubtless the vigias of the early navigators in the Southern Ocean, the existence of which has since been disproved, are directly traceable to such a source of error. Captain Ross, R.N., the renowned Antarctic explorer, some years ago observed an iceberg in those inhospitable regions which was nearly covered with mud and stones. There were also large pieces of rock upon it weighing many tons. Fragments of these were procured, and proved to be of volcanic origin. In December 1859 the "Edmond" passed an iceberg 580 feet high, in 51° S., 41° W., and her master was so misled by its earthy appearance that he reported this danger as a rocky islet. About a fortnight earlier, almost in the same geographical position, the "Gleaner" sighted a smaller iceberg, equally difficult to distinguish from dry land until she sailed quite close thereto. The "Hesperus" passed an iceberg in May 1892, which was brown and black, and exactly resembled an island. An iceberg, in 45° S. lat., 31° W. long., at first mistaken for land by the "Parsee," in June 1892, was apparently thickly coated with earthy matter and stones. A week later the "Gladys" seems to have sighted the same danger. Thick kelp in the vicinity assisted to deceive. In October 1892, in 49° S. lat., 43° W. long., the "Roderick Dhu" had forty icebergs in sight, some brown, others dirty green. They would not have been distinguishable from islands had not white ice been also nigh. In January 1893, not far from the above-mentioned position, the "Wasdale" was close to an iceberg in which a great quantity of sand was noticed in seams, thus giving the iceberg an appearance similar to variegated marble. One of the icebergs sighted by the "Loch Rannoch" in February 1893 had a large brown rock firmly fixed in it. The land-like nature of these icy masses is a peculiar feature of the icebergs seen in the Southern Ocean during the four years, 1892 to 1895.

Commencing with the meridian of Greenwich, the northern limit of icebergs in the Southern Ocean, laid down on the Admiralty ice chart, runs along the 44th parallel till 60° E. is reached, then dips down to the 50th parallel in 70° E., rises again to the 44th parallel south of Australia, thence dips again to 50° S. in 160° E., and runs along that parallel up to 110° W. Thence it dips gradually to Cape Horn, and then proceeds to the 40th parallel in 30° W., following that parallel to the meridian of Greenwich. During the iceberg interval, 1892 to 1895, icebergs were met on the equatorial side of this limit, from 300 to 600 miles farther north, nearly all around the Southern Ocean. Curiously enough, not an iceberg was sighted to the southward of Australia, although the Admiralty ice chart indicates that some years back such dangers were well in evidence just there. On the other hand, there is no mention of icebergs to the east of New Zealand either by the Admiralty, Fitzroy, Maury, or Towson, yet they formed a remarkable feature of the years above mentioned. Icebergs are seldom seen between the Falkland Islands and South America. The current setting round Cape Horn drifts them to the north-eastward of the Falklands; and, just there, icebergs are most dangerously prevalent. In June 1893 the steamer "Titania," however, passed an iceberg 250 feet high and two miles long, in 44° S. lat., 59° W. long. It was apparently aground. Just twelve months later, H.M.S. "Garnet," in 46° S. lat., 61° W. long., about 330 miles north of the Falklands, sighted an ice island ten miles in length which also seemed to be aground. This is probably the record for that part of the world. The United States Hydrographic Office recently issued a small chart for the guidance of navigators, on the Pilot Charts for January 1896, based on reports received from the numerous shipmasters co-operating with that Department, which contains much valuable information with respect to the South Atlantic ice limits of 1893–94. Captain C. D. Sigsbee, U.S.N., the then hydrographer, pointed out that the "Dochra," in April 1894, passed quite close to a piece of ice in 26° 30′ S. lat., 25° 40′ W. long. It was 12 feet long, 4 feet wide, 4 feet high, and was clearly distinguished by several of those on board. This is the record for equator-seeking ice in the South Atlantic. In January 1850, an iceberg was seen from the Cape of Good Hope. On 6th August 1895, however, this record was broken, for on that date, only about fifty-five miles south-east of Cape Agulhas, the "Queen Mab" passed seven icebergs varying in height from 70 feet to 200 feet. Authentic instances of southern icebergs so far north are extremely rare. The broken line, Plate VII., represents the northern limit of the 1892–95 icebergs. The thick line is the Admiralty limit.

For many years it was erroneously assumed that a fall in the sea-surface temperature was always experienced in the vicinity of ice. A well-known text book in popular science has a statement that icebergs "cool the water sensibly to the distance of 40 or 50 miles around, the thermometer sinking 17° or 18° in their neighbourhood." Another work on physical geography asserts that the presence of icebergs "can very generally be told in the Atlantic by steady observations with the thermometers." As a matter of fact very many navigators have sailed quite close to huge icebergs, exercised the greatest care in determining the temperature of the sea surface, yet were quite unable to discern the slightest fall in the readings of the thermometer. The late Captain S. T. S. Lecky, R.N.R., in his *Wrinkles in Practical Navigation*, first called attention to the danger courted, should implicit reliance be placed on so untrustworthy an indication of the presence or absence of ice. A vigilant lookout is the only safeguard.*

The origin of these southern icebergs is to be found at the Antarctic ice-cap. Why they are more frequent at irregular intervals is not so easy to explain satisfactorily. An interesting paper, dealing with icebergs in the Southern Ocean, was read quite recently before the Royal Society of New South Wales by Mr. H. C. Russell, B.A., C.M.G., F.R.S., in which the author suggested that these icebergs are set free by the action of the Antarctic continent's volcanoes which "burst forth in eruption and earthquake, and so shake the foreshore, that the icebergs are broken off from the glaciers and set adrift to float we know not where." The size and shape of Antarctic icebergs differ very considerably from those broken off the Arctic glaciers, and therefore Mr. Russell's view may be approximately correct. Careful records of southern ice throughout the next five or ten years will tend to show whether the outbursts are irregular in frequency, or whether they are better reported than formerly.

Northern Icebergs.—At the British Association meeting of 1842 it was asserted that the cool summers over the British Islands experienced during the four preceding years were due to the extraordinary prevalence of icebergs in the North Atlantic. For fifty years, according to some of those present, ice had not put in an appearance to the westward of our islands until the autumn. Professor Archibald, not long since, put forward a similar suggestion as to a connection between the frequency of North Atlantic icebergs and the coolness of British summers. An unbiassed examination of reliable records for a long series of years would doubtless disprove any such theory.

Icebergs are not known in the North Pacific. Maury called attention to the fact that there is no nursery for icebergs to the northward of that ocean. The water of Behring's Strait is too shallow to let them pass thence into the open ocean; and, moreover, the climate does not favour the formation of large icebergs.

One of the most interesting ice reports of the nineteenth century is from the brig "Renovation," Captain E. Coward. On 20th April 1851, when near the eastern edge of the Bank, in 45° 30′ N. lat., two icebergs were sighted in clear weather. One of these bergs was of exceptional size, with field-ice attached, on

* See p. 192.

which were two three-masted ships, high and dry, the larger one on her beam ends. With masts and yards sent down, they appeared to have been abandoned after being made snug for wintering together. The *Nautical Magazine* made diligent inquiry into this matter, and many persons were erroneously of opinion that these two vessels were the ill-fated "Erebus" and "Terror," drifted out of Melville Sound and Baffin's Bay. On 1st July 1894, in 43° S. lat., 33° W. long., the barque "Gladys," Captain B. H. Hatfield, was completely surrounded by icebergs. For three days she sailed along in sight of huge icebergs and detached pieces. On the 4th, in 40° S. lat., 32° W. long., while passing close to a berg, saw signs of human beings having been on it. A beaten track was on one side, an apparent sheltering place was formed in a hollow on the top of the ice, and five dead bodies of men were stretched out in the vicinity. Night coming on, and a gale blowing, there was no possibility of detailed search.

CHAPTER XV.

SYNCHRONOUS CHARTS.

Careful Observations essential.—There is not much difficulty in being wise after an event has taken place. A navigator, far distant from shore and telegraphic communication, must of dire necessity depend upon his own observations to determine the best possible means of keeping clear of a storm centre. Sea and sky, barometer and thermometer, wind and weather, are all carefully observed and recorded by the seafarer mindful of his reputation. After an atmospheric disturbance has passed over, weather workers on shore may gather together copious extracts from the logbooks of ships which fell in with the gale in various geographical positions, and in this way lay down its track with much more accuracy than was within the power of the solitary shipmaster and his officers. This fact must always be borne in mind; for so many causes conspire together to put to confusion the best-laid plans of a shipmaster in actual navigation. Hence the apprentice and the junior officer will find it decidedly advantageous to become familiar with the normal meteorological conditions prevailing over the several oceans from month to month. Pilot Charts for the several oceans issued by the United States Hydrographic Office, the British Meteorological Office, and the Deutsche Seewarte, for each month, afford this necessary information in a handy form.

British Meteorological Office Charts.—In Plate VIII. we have a bird's-eye view of the meteorological phenomena, prevailing over the whole North Atlantic Ocean at Greenwich noon, 31st August 1883. The head of each arrow laid down on the water-space of this instructive chart points out the most probable geographical position of some ship at that instant, the commander of which was co-operating with the British Meteorological Office in an endeavour to solve the intricate problem of Atlantic weather. A detailed record of wind, weather, barometer, temperature of the open air in the shade and also of the sea surface, and other items pertaining to marine meteorology, was kept by shipmasters whose ships happened to be anywhere on the North Atlantic. These records were forwarded to the London central office at the first favourable opportunity. The series of synchronous observations continued thirteen months, from 1st August 1882 to 31st August 1883, and a similar chart to that here given was drawn up for every day of this period. Not fewer than 11,236 returns were received from about 3000 steamships and sailing-vessels, merchantmen and warships, affording data from about 400 ships at sea daily. On either side of the North Atlantic, in addition, shore stations sent in their observations to the number of about 300, so that the average number of observations used for any given day's chart does not fall far short of 700.

This information, after undergoing the necessary corrections for instrumental errors, was laid down in geographical position upon large working charts. Then isobars, or lines of equal barometric pressure, were drawn through the similar barometer readings; and isotherms, or lines of equal temperature, were also drawn through the temperatures of the same value at different points. There is nothing mysterious in the method of constructing an isobar or an isotherm, once anyone has grasped the method followed by makers of navigating charts when laying down, for example, the fifty fathom or the one hundred fathom line of soundings. We shall gather more definite views on marine meteorology by a close study of Plate VIII. than, perhaps, by any other way,

On this chart, for the 31st August 1883, we find, first of all, an area of high barometric readings in mid-Atlantic which extends from latitudes 20° to 40° N. between the meridians of 10° and 60° W. We are at once struck by the fact that the prevailing winds there, as indicated by the arrows, which fly with the wind, are generally light and circulate in the same direction as the hands of a watch around the central portion enclosed by the isobar of 30·3 inches. Let us suppose this area of high barometer remains constant in shape and geographical position while we sail together in some good ship along a track indicated by the isobar of 30·2 inches, starting in 40° N. lat., 20° W. long., and eventually returning thither familiar with the wind changes of this anti-cyclonic system. The arrows drifting before the gentle breeze clearly show how our initial northerly wind shifts slowly, but surely, as we sail onward. It becomes north-east, east, south-east, south, south-west, west, north-west, and back again to north, as we go round the 30·2 inch isobar on a fine weather cruise in the same direction as the hands of a watch. Our barometer readings, corrected for temperature, height above sea-level, and errors of instrument, kept at 30·2 inches without a break. Such an anti-cyclonic wind system and area of high barometric pressure readings is fairly stationary in that part of the North Atlantic, and a similar system obtains in the North Pacific.

Hence it is that the master of a ship bound under sail for England does not attempt, after crossing the equator, to make directly towards his destined haven. He knows full well the persistency with which the wind blows from the northward on the eastern side of this almost permanent area of high barometer readings; and, acting on this knowledge, stands boldly along its western and northern limits in order to utilise the fairer winds found there. The longest way round is the quickest way home, in this instance at any rate. Should, however, this anti-cyclone be northward of its usual position, the homeward-bounder may be detained considerably by easterly winds at the entrance to the English Channel. When this is the case, cyclonic storms skirt the northern edge of the anti-cyclone on their way across the Atlantic and pass well to the northward of our islands.

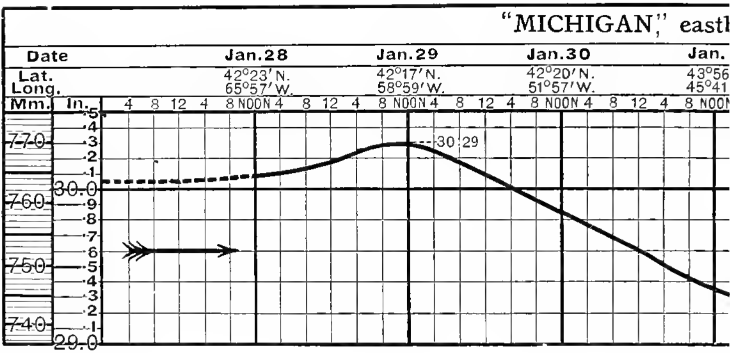
Description of the Chart.—The chart alluded to also indicates the reason for another departure from the shortest distance between two ports. A weak sailing-ship bound from Europe to Canada, in ballast, high out of the water, occasionally avoids pile-driving against the strong westerly winds generally encountered on the 50th parallel of north latitude. She steers southward, as though bound across the equator, until 30° N. lat., 20° W. long., is reached. Thence she gradually trends to the westward, before the prevailing easterly breezes, along the 25th parallel, till in 60° W. long., and then turns more and more directly towards her destination.

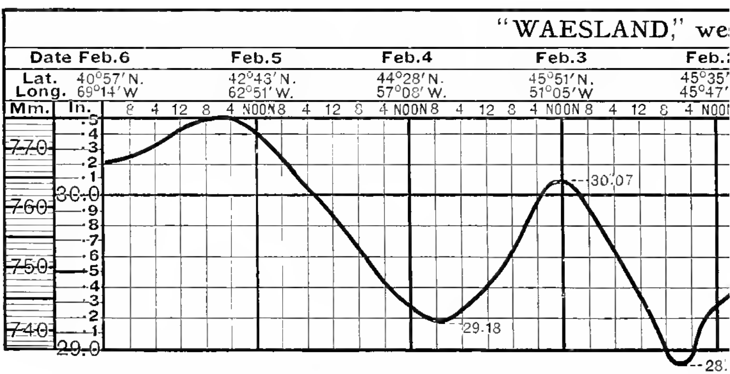
Vessels attempting to reach ports on the north-east coast of America, under sail, by the northern route from Europe, have been longer on the passage than sailing-ships from California to Queenstown with cargoes of golden grain. An iron barque, the "Viola," sailed from London for St. John, Newfoundland, in January 1894, and occupied 103 days on the passage. About the same period, the iron barque "Broomhall" was striving to reach New York from Hamburg. Cyclone after cyclone passed over her in quick succession; she was driven up between Greenland and Iceland, had decks swept, lost a man overboard, and eventually arrived at New York after a tempestuous and eventful passage of 113 days.

Returning to Plate VIII. it will be seen that there are eight distinct cyclonic systems in existence at the same instant, Greenwich noon, 31st August 1883. Two of these are over the continent of North America. The remaining six lie almost equidistant from each other along a straight line drawn from 35° N.

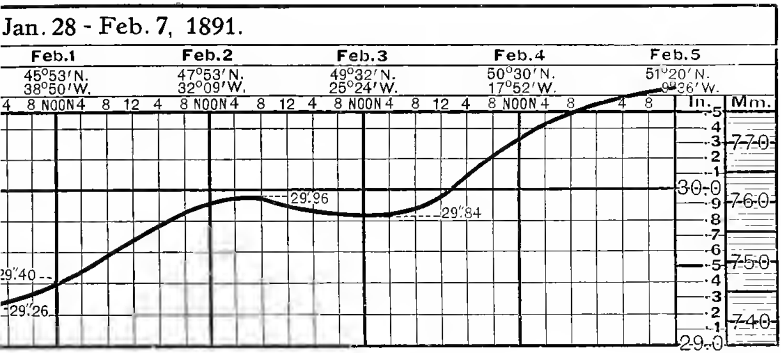
lat., 70° W. long., to 60° N., 40° E. And this very line points out approximately the track affected by a large number of cyclones when proceeding eastward across the North Atlantic. Even a cursory glance is sufficient to show all who are studying the chart that a cyclonic circulation of wind does not necessarily imply the absolute existence of a gale over the region concerned. Truly the barometer readings are lower than elsewhere in the vicinity, and decrease towards the central portion of the cyclone. Nevertheless, it cannot be too often impressed upon the beginner that the force of the wind depends on the relative height of neighbouring barometer readings, not on the absolute height of one. We may have a gale of wind with a comparatively high barometer, provided there is a large difference in the readings over small areas, or light breezes with a low barometer, if the atmospheric pressure does not vary much over large areas. We readily notice how strong the winds are where the isobars are closely packed together, and also how light the winds are just where the isobars are widely separated. And this law holds, no matter whether the wind circulation is cyclonic or anti-cyclonic.

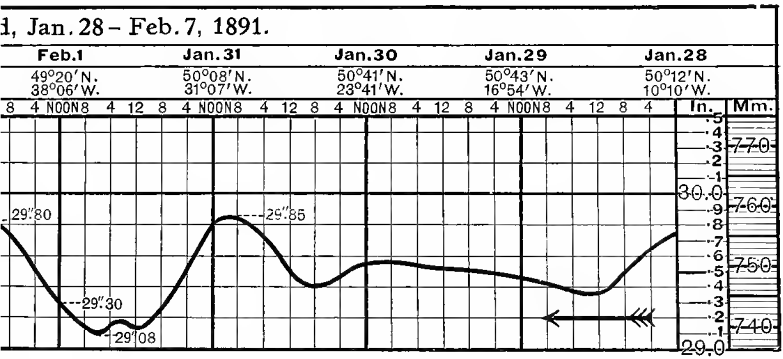
Squally weather, indicated by the black ball on the wind arrows, and strong winds, will be observed to prevail over the small low pressure area having its centre in about 35° N. lat., 70° W. long. If this cyclone remained stationary, a swift steamer proceeding across it to the westward along the 35th parallel would have her southerly wind shift to the northward as she travelled from the eastern side to the western side of the isobar of 29·9 inches. A vessel bound the opposite way would experience a shift of wind from north to south. In either case the barometer would rise when the wind changes within a short interval. Similar results would ensue if the ship were stationary and the cyclone travelling onward from west to east, or from east to west. The data on the chart are not sufficiently numerous for us to determine whether the wind changes were sudden in this instance, or whether a calm of short duration intervened. Curiously enough the symbol for calm does not appear at, or near, the central portion of any one of these six cyclones all in a row. Theoretically there ought to be an interval of calm as the cyclone centre passes over a ship. Practically, however, this central calm is not always present. Following the track of the Gulf Stream, the great "storm-breeder," we come to another small cyclonic system, central in about 42° N., 60° W. Here we have the wind circulation approximately like that of the cyclone in 35° N. lat., 70° W. long., though the wind arrows do not fit in nicely either with the circular or with the in-draft theory. This disturbance affords a good example of the very appreciable effect an error of a few miles in a ship's geographical





ALLINGHAM'S MARINE METEOROLOGY. PLATE IX.—RELATION BETW





URSE AND SPEED OF SHIPS AND CYCLONIC SYSTEMS IN NORTH ATLANTIC.

position will have upon the apparent bearing of the cyclone centre. The arrow to the south seems directed towards the centre. One degree more eastward it would agree admirably with the circular theory. For our purpose, as students desirous of arriving at the truth, it would be better on all such charts to express by some suitable symbol whether the ship's geographical position was by dead reckoning or by observation.

North-eastward of the last mentioned wind system is a cyclone worth mentioning. Its centre lies in about 50° N. lat., 35° W. long. Like the large majority of such cyclones, it is elliptical in shape. The major axis, or longest diameter, is some 1900 miles in length, stretching in an east-north-east and west-south-west direction, and the minor axis is 900 miles long from north-north-west to south-south-east. The barometric gradient is steep. In less technical terms the readings of the barometer vary very considerably over the small storm-area. A glance at the arrows clearly indicates that wind of hurricane violence was experienced by ships all around the central isobar of 29·1 inches, that the winds all appear to draw in towards the centre, while at the same time there is an outdraft from the anti-cyclonic area to the southward. The extent of the earth's surface under the influence of a cyclone is continually varying. Sometimes expansion of the cyclonic disturbance takes place, and this in turn gives way to contraction.

Still further to the north-eastward we observe three cyclonic circulations in which the isobars are wide apart, and the corresponding wind force does not exceed a moderate breeze. The first cyclone is central in about 60° N. lat., 15° W. long., the next in 65° N. lat.,10° E. long., and the third in 60° N., 40° E. Over North America are two other low-pressure systems, neither of which demands detailed explanation, except that the cyclone central in 65° N. lat., 70° W. long., is based upon a few scattered observations.

The general movement of the atmosphere between the parallels of 30° N. and 50° N. is from west to east. Cyclonic systems also move eastward in this pronounced air current, in much the same way as eddies in a tidal river. If not deflected to the northward, not an uncommon occurrence ; or to the southward, which is less frequent, they require from four to eight days to cross the Atlantic from the New World to the Old. Hence a steamer proceeding westward may meet a series of cyclones following each other like the six shown in Plate VIII. If, on the other hand, the steamer is bound from America to Europe she may keep up with a cyclone going the same way for several successive days. A little thought, aided by a glance at the diagram, shows that the westward-bound vessel will have her barometer readings undergo more rapid fluctuations, and her wind shifts far more sudden than they would be if she were travelling in the opposite direction. In consequence of the eastward advance of cyclones along the trans-Atlantic steamer tracks, the mercury in the barometer of a steamer within its influence, bound westward, will indicate more rapid alterations of pressure than an equally reliable barometer on a steamship in the vicinity steering eastward. The change in a given interval of time increases, or decreases, according to the velocity with which the cyclone centre is approached. In the first case this velocity is equal to the sum of the velocities of ship and cyclone; in the second case to their difference. Suppose, for example, that the "Lucania" or the "Paris" is steaming westward at the rate of twenty-five miles an hour and meets a storm travelling eastward with the same velocity, then the result will be precisely the same with respect to the changes of wind and barometer as though the storm was stationary, and the ship advancing towards it at the rate of fifty miles an hour; or the ship hove-to and the storm travelling eastward fifty miles an hour.

Another way of regarding this question is from the point of view of barometric fluctuation. Suppose the barometer readings fall as the centre of a cyclone is approached at the rate of one-tenth of an inch for thirty miles, while at the same time the whirl is moving eastward twenty miles an hour. A vessel due east of the cyclone centre, standing west, ten miles an hour, draws near the centre at the rate of $(20 + 10) = 30$ miles an hour, and her barometer will fall one-tenth of an inch in that interval of time. A ship in the neighbourhood, steering east at a similar speed, will be overtaken by the cyclone centre at the rate of $(20 - 10) = 10$ miles an hour, and the fall in her barometer readings will be only one-tenth of an inch in three hours. Two vessels west of the cyclone centre will experience a rise in their barometers, the rate of change depending on the direction in which they are travelling with reference to the cyclone centre.

Plate IX., taken directly from one of the monthly United States Pilot Charts, serves to illustrate the two cases by a comparison made between the barometer readings of two ships proceeding in opposite directions. The upper curve represents the action of the barometer on board the steamship "Waesland," Captain C. H. Grant, during her westward passage from 28th January 1891 to 7th February 1891, and shows plainly the rapid alternations of high and low barometer readings. The lower curve gives similar information respecting the steamship "Michigan," Captain S. Walters, eastward bound, during the same period. Its greater smoothness exhibits the less rapid changes in barometer readings of an eastward-bound ship. These two vessels passed each other on 1st February, when the barometer of the "Waesland" stood at 29·3 inches, and that of the "Michigan" 29·4 inches. The mercury was rising in both barometers, although at very different rates. Readings from the former rose steadily from 29·08 inches at 6 a.m. on 1st February to 29·8 inches at 10 p.m., or about 0·045 inch per hour. Readings from the latter rose slowly from 29·26 inches at 2 a.m. on 1st February to 29·96 inches at 5 p.m. on the 2nd, or at the rate of only 0·018 inch per hour. This difference was due to the fact that the "Michigan" was running along with the storm system to the eastward, whereas the "Waesland" was proceeding westward directly away from the disturbance. The former ship had only two storms; while, as the diagram shows, the latter vessel fell in with five. Hence it will rightly be inferred that the onward movement of a ship must not be disregarded when dealing with the question of cyclonic storms.

Anti-Cyclonic Systems.—Very seldom does the corrected barometer reading reach 31 inches. Hence Plate X. will be found especially interesting in this connection. A glance at this chart reveals two areas of high barometric pressure or anti-cyclonic systems, existing over the North Atlantic at noon, G.M.T., on 27th December 1894, central respectively in about 52° N. lat., 18° W. long., and over Newfoundland. The large system on the east governed the wind circulation from 30° to 60° N. lat., between Western Europe and 45° W. long. As a rule, the highest barometer readings over the North Atlantic are experienced during the winter months. Once reached, they may persist for days. This graphic representation clearly indicates the large number of vessels at any given moment along the tracks between our islands and the United States. Overcast weather and moderate winds prevailed all the way across. A cyclonic system is shown with a central isobar of 29·9 in the south-west corner of the chart. The arrows flying with the wind indicate the changes a vessel would experience in passing from one system to the other. When the sailing-ship bound up the English Channel is kept beating about for weeks, within a few miles of her destination, the disposition of barometric pressure may probably be on similar lines to those laid down on this chart. If only the centre travelled a few miles to the southward, the wind would change to the westward. A cyclonic system, with its centre between Ushant and Finisterre, for example, would similarly hinder the homeward-bounder. This can easily be grasped by imagining the centre of the cyclonic system in 50° W. long., to move along a straight line joining its present position with Bordeaux. A more northerly track would have brought the westerly winds of the southern segment of the cyclone directly over the Channel. A little thought expended over suppositions of this nature will assist us materially in mastering the elements of marine meteorology.

CHAPTER XVI.

DEW, MISTS, FOGS, HAZE, CLOUDS.

Dew: its formation; Hoar Frost.—Dew may be defined as moisture deposited when visible cloud is absent. The heat of a vessel's rail, for example, is radiated into space, and its temperature falls. Should the night be clear, the wind but a zephyr, and the air comparatively dry, that portion of the air resting on the rail is cooled by contact therewith. At this lower temperature the air concerned is not able to hold as much moisture as at the higher temperature, and begins to deposit the surplus in the form of dew. The exact temperature at which this takes place is known as the dew-point, and may be 10°, or even 30°, below the actual temperature. Mr. J. Aitken has pointed out that only a proportion of the dew is derived from the air. Water vapour rises from plants and the earth, and this also is condensed. Wind, by renewing the air on the rail, hinders deposit of dew. A cloudy sky acts similarly, because the heat from the rail is then reflected back by the clouds, thus keeping up the temperature. Mr. Dines gives 1·5 inches per annum as the amount of moisture deposited as dew.

A similar deposit of moisture is formed on the outside of a glass of cold water brought into a warm room. The cold glass "saps" the air of its aqueous vapour. It is related of a person in India, who was puzzled by the behaviour of his iced whisky and water, that, on tasting the deposit of moisture referred to above, he concluded that the water somehow made its way between the molecules of the glass, whereas the whisky elected to remain inside.

At the outlet of a steam whistle the steam is not apparent. A few inches from the opening, however, the cool external air condenses the steam into vapour like a cloud made up of particles of water. Often quite large drops of water fall on deck. A sponge holds a certain amount of water, and is then saturated. By squeezing, it is made to give up a portion of the water. The air acts similarly with respect to moisture; and when squeezed, as it were, by a fall of temperature, we get dew, rain, mist, fog, hail, snow, and hoar frost. Here it may be well to state that hoar frost is merely frozen dew. The moisture is deposited on bodies having a temperature below 32° F. Either dew or frost may be prevented, or at any rate checked, by anything that lessens the radiation of heat from the object. The heat, rendered latent or non-apparent in vapour, is given off again when the vapour is condensed. The damp-bulb hygrometer, or psychrometer, is used at sea for indirectly determining the amount of moisture in the air.

Fogs.—Aqueous vapour is generally invisible. Once the temperature falls below the dew-point a proportion of this aqueous vapour is condensed and becomes visible in consequence. Fog is frequently due to the intermingling of air currents having different temperatures, but occasionally it is formed in other ways. Sailors frequently refer to fog, mist, or haze, as one and the same phenomenon. Writers on meteorology, however, find distinctions between them. The rule-of-the-road at sea also seems to be based on this latter view. Clear definitions seem wanting. Apparently, if the condensed aqueous vapour is of about the same density as the air, and hangs low, it is called fog. If the density be slightly in excess of the air, thus causing a persistently fine rain, then we have mist. Haze, on the other hand, is an especially dry fog. Sailors often jokingly refer to the weather as "Scotch mist which wets an Irishman through to the skin." Very often in crossing the North Atlantic the fog is dense to about the height of the mastheads, while above that the sun is visible in a vault of blue.

Fog is often met with just about where cold and warm ocean currents meet. Off the Banks of Newfoundland and the Agulhas Bank, danger from fog is most marked. Yet large steamships seldom obey the rule enjoining upon them moderate speed in fog, mist, heavy rain, or falling snow. On 7th August 1860, the "Sultana," in 44° 30′ N. lat., 50° 30′ W. long., was in a thick fog. It cleared up suddenly, and her master was surprised to find his vessel surrounded by quite twenty fishing schooners at anchor. The barque "Glen Grant," on 1st June 1897, in 45° N. lat., 51° 30′ W. long., during a thick fog, passed dangerously close to the stern of a French fishing schooner at anchor in neglectful silence. The barque broke off the end of the schooner's main boom, and tore adrift some of her dorys. On 27th January 1898, in 38° N. lat., 68° W. long., the four-master "Buckingham," Captain Scott, had air temperature of 43° and sea temperature of 69°. The latter had risen 17° in four hours. A heavy fog, just like steam condensing from boiling water, rose from the sea surface. During part of the time the lower part of the mizen-mast was not visible from the poop. A similar formation of fog was noticed at Halifax, N.S., by the steamship "Minia," on 14th December 1898, when the air temperature was 8° and the sea 33°. A very dense fog prevailed for about three feet above the water. Sitting in an open boat the moisture was deposited on the clothes in the form of fine snow. The weather was fine and clear.

Admiral Smyth related an amusing yarn with respect to fog, which shows it is not without an admirer. Captain Fothergill, R.N., who had been for some years in Indian waters, came on deck one November morning in the Channel, while homeward bound, during foggy weather, and said to the lieutenant of the watch, "Ha! this is what I call something like; none of your cursed eternal blue skies here; a fellow can see his breath now." Fog is occasionally so dense near Newfoundland, that, as the story runs, a Yankee schooner once ran into one so solid as to break short off her jib-boom. Some sailors and others imagine that fog adversely affects the compass needle. It does nothing of the sort. Captain D. Galloway told a court of inquiry into the loss of ship "James Russell" in 1855, that fog made the compass sluggish. In May 1856 the master of steamer "Princess Royal," stranded on the Wigtown coast, told the court a similar fairy tale. A shipbuilder called as a witness thought such a fog as caused her loss was sufficient to interfere with the deviation more than a point. Falling snow has also been seriously put forward as a disturbing influence under this head. In 1837 the compasses of the wooden steamer "Robert Napier" are said to have acted erratically in snow showers, and Sir J. South attributed the effect to electricity descending with the snow. In 1873–4 the late Professor Tyndall found that fog, rain, hail, and snow do not sensibly stop sound, although fog had been deemed an obstacle. Clouds are acoustically more disturbing. Scoresby found that some fogs in the Arctic regions neither wet a vessel's rigging nor her decks.

Range of Sound in Fogs.—Range of sound in fog is capricious. Disregarding the winds, large areas of silence have been found in different directions and at different distances from the shore sound signal. Consequently the Board of Trade has warned mariners not to assume a ship to be far off a syren because the latter is not heard, or only heard faintly; nor that she is near the sound signal because it is plainly heard on board. Neither is the experience of one voyage any guide as to the next with the same sound signal. The steamer "Rhode Island" was wrecked in a fog on Bonnet Point, and an investigation proved that the Beaver Tail fog signal, two miles distant, was in full operation. The experiment showed that the sound signal could not be heard with the expected intensity or at the expected place; it would be heard just the opposite of what was expected, loud instead of faint, and *vice versa*; it could not be heard at some points near, although quite distinct further away; it could be heard and lost and heard and lost again all within reasonable ear-shot; although the signal was going strong without intermission. Fig. 32 indicates the results of observations made from a sail boat by Commander, now Captain Chadwick, U.S.N., on the doubted Beaver Tail fog signal. Thermometer at beginning was 58° F.; ending 67° F. Wind was westerly, moderate; weather, clear and cold with bright sun. Beginning time was 11.15 a.m. The width of the line of his course exhibits the varying intensity of the sound of the fog signal. Whistles have been heard at 20 miles distant, and yet not at

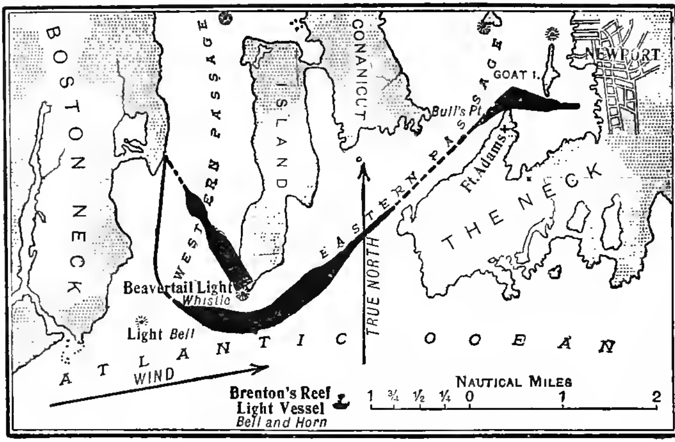


FIG. 32.

a distance of two miles. Fog makes life much less worth living for the navigator, inasmuch as sound signals are then unreliable.

Haze due to Suspended Dust.—Haze due to drifting dust is often encountered by vessels on the eastern side of the North Atlantic, over an area bounded by the West Coast of Africa and the 40th meridian of west longitude, between the parallel of 40° north and the equator. Dust haze is more especially noticeable west of the Sahara during the first four months of the year. The illustrious Darwin recorded instances thereof in 1833 while at St. Jago, where a fine reddish-brown dust fell during the whole three weeks the "Beagle" was at anchor there. Apparently 1898 was a record year for this dust haze. On 14th February the "Roslin Castle," Captain Travers, ran into a dense haze of this nature. For over 900 miles the heavenly bodies were hidden, and the vessel coated with red dust. Captain Travers was subsequently presented with an address and a purse of gold in recognition of his seamanlike services on that occasion. The "Carl Woermann" left Teneriffe on the 15th, and was two days and three nights before arrival at Las Palmas. A Currie liner, the "Tintagel Castle," outward bound for the Cape, was detained by the same dust haze for thirty hours. On the morning of the 16th, at Las Palmas, the sun was hidden, and a dense haze, caused by fine red dust, prevented terrestrial objects from being distinguished at a distance of one hundred yards. Many instances of a similar nature might be quoted, but sufficient has been written to indicate the peculiarity of this so-called dust haze. Smoke fogs, if we may use this term, are also met with. In the American schooner "Legal Tender," the author was once six weeks behind Coos Bay bar, on the Oregon coast, prevented from getting out by reason of dense fog caused, or helped, by the woods being on fire all round us.

In 1835 a volcanic eruption at Coseguina, Central America, threw dust into the upper currents of the atmosphere sufficient to darken the sky for thirty-six hours. During twelve days the daylight was interfered with by a fine dust that fell incessantly even at places 50 miles from the erupting volcano. Some of the dust was carried 1200 miles by the upper currents dead against the direction of the surface wind. During the Krakatoa eruption of August 1883, dust from that volcano fell 1100 miles away. The British ship "Charles Bal," within ten miles, found the darkness so intense owing to fall of pumice stone and dust that she was compelled to shorten sail and await the issue. The ship "G. G. Loudon," 45 miles north-west, in the bay of Lampong, underwent a mud rain, accumulating on deck at the rate of 6 inches in ten minutes. The crews of the "Sir Robert Sale" and the "Norham Castle" were employed for hours in endeavours to keep the vessels free from falling pumice dust.

Origin of Clouds.—Clouds, like mist and fogs, are due to mixture of cold air with air which is relatively warm and moist. Unlike mists and fogs, clouds float at high altitudes. Air laden with moisture due to evaporation rises during the warmer part of the day, loses heat in expanding, and is cooled below the dew-point. Condensation takes place, cloud is formed, and this continues until the supply of vapour is no longer equal to the demand. As night approaches evaporation diminishes, and the air contracts; the clouds sink to a warmer lower level and dissolve there. Thus clouds are continually being made and unmade. At different heights the clouds are often drifting in different directions.

The peaks of mountains being cold, the temperature of the air around them falls, and thus clouds form. Table Mountain, and similar elevations, often have a cloud apparently attracted to their summits. Going up a mountain, or ascending in a balloon, several alternate layers of cloud and clear spaces are frequently passed through. Probably the highest clouds are about ten miles above the earth's surface, and the average height of the lower forms of clouds in the temperate zone is about half a mile. Clouds have been defined as mists, or fogs, at high altitudes.

Classification of Clouds.—Luke Howard's classification of clouds held for many years, but is gradually giving way to other systems. He divided all clouds into three simple classes, cirrus, cumulus, and stratus; and four compound forms, cirro-cumulus, cirro-stratus, cumulo-stratus, and nimbus. Cirrus signifies "a curl" in the Latin; and the cirrus clouds are thinner and higher than any other sort. They are made up of minute ice crystals. Sometimes cirrus clouds are in parallel lines; sometimes in tufts or curls of white hair, "mares' tails"; sometimes a delicate network. They are often a precursor of wind, and move in a direction opposed to that of lower clouds. *Cumulus*, also from the Latin, means "a heap." Cumulus clouds are heap clouds, as the name implies. They are usually very solid-looking, and heaped up on a horizontal base. The base may be a mile above the sea, with invisible ascending vapour between; and the summit three miles. Thunder-clouds are of this shape. *Stratus* means "a layer," hence clouds forming an extended sheet or layer, of fairly uniform thickness, at low altitudes, the lower surface often resting on earth or sea, are termed stratus. Being so low they are usually seen edgeways, and thus seem to be in long layers parallel to horizon. They are generally fine-weather clouds. Cumulus is sometimes referred to as the day cloud, and stratus the night cloud. *Cirro-cumulus* is a high cloud made up of small round masses close together, yet separated from each other by blue sky. This forms the well-known "mackerel" sky, the height being about three miles. *Cirro-stratus* is solid-looking in the middle, but thin at each end; either separate or in groups. It usually results from a cirrus which is compelled to sink consequent on increased condensation to a somewhat lower plane. Halos and other refraction phenomena afford proof that cirro-stratus is an ice cloud. *Cumulo-stratus* is, as it were, cumulus surrounded by small fleecy clouds, and is similar to cirro-cumulus. As defined by Luke Howard, it is cirro-stratus mixed with cumulus. *Nimbus* is the rain cloud, apparently a mixture of cumulus and stratus, and forms at an altitude of about a mile. The motion of cirrus clouds affords evidence of coming weather; and the lower clouds, cumulus and stratus, tend to prevent the sun's heat being excessive by day, and check the loss of heat by radiation from the earth's surface at night. In ship's logbooks it is usual to follow certain contractions adopted by weather authorities in order to save clerical labour. Thus for the several forms we write cir., cum., str., cir.-c., cir.-s., cum.-s., and nim. When several forms occur at the same time they are separated from each other in logbooks by a vertical line. Thus, cum.|str. represents two forms, cumulus and stratus, but cum.-s. is merely one form, *i.e.*, cumulo-stratus. Care is required to carry out this convention in entering up the logbook, otherwise workers on shore are likely to be misled in discussing the observations at a later date. Difficulty will be experienced in determining cloud motion by an observer on the bridge of a swiftly-moving steamship. The amount of cloud is roughly estimated according to a scale of 0 to 10, where 0 represents a perfectly clear blue sky, and 10 the sky entirely overcast.

In 1897, under the superintendence of Captain (now Admiral) C. D. Sigsbee, U.S.N., the Washington Hydrographic Office issued a small book of plates illustrative of cloud classification based on the International Cloud Atlas published at Paris in 1896. Under this scheme, clouds are divided into ten distinct forms as follows:—Upper clouds, cir., cir.-s.; intermediate clouds, cir.-c., alto.-cum., alto.-str.; lower clouds, strato-cumulus, nimbus; clouds of diurnal ascending currents, cum., cum.-nim.; and high fogs, stratus. Six other forms are also illustrated: (1) fracto-stratus, (2) fracto-cumulus, (3) a second example of cumulus, (4) mamato-cumulus, (5) a second example of strato-cumulus, and (6) fracto-nimbus or scud.

The names given to clouds must often be open to serious objection. Equally keen-sighted observers would probably describe the same cloud by different names. One of the greatest authorities on clouds, the late Mr. Clement Ley, was of opinion that inaccuracy in cloud observation is the rule and not the exception. Clouds which tend to form horizontal layers are clouds of the night, of winter, or of the sea, while those of spherical or hemispherical shape are clouds of the day, of summer, and of the land.

CHAPTER XVII.

RAIN, SNOW, HAIL.

Rain Formation.—Rain, snow, and hail are merely three different forms of condensed moisture, due to the cooling in some way of a relatively warm and saturated current of air. Occasionally rain falls from a cloudless sky, and is then known as "serein." This is due to the mingling of two air currents of different temperature, both nearly saturated. As a general rule, however, rain falls from clouds. Rainfall is measured by a specially constructed rain-gauge, fig. 33, a hollow metallic cylinder with a funnel at the top, to prevent evaporation, the amount being expressed by the number of inches which would accumulate in a day, a month, or a year.

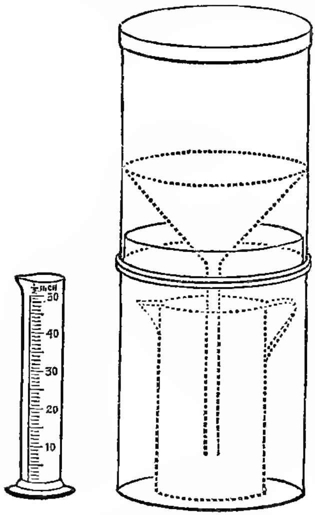


Fig. 33.

Invisible vapour rises into the air from the water. Hence absolutely dry air is unknown. There is always a certain amount of moisture mixed with the nitrogen, oxygen, dust, and other items, which go to make up the air. Representing by 100 the maximum amount of moisture in air, 6 is about the least ever recorded. This was at Ben Nevis. Vapour rises from the ocean, and drifts hither and thither with the air, but only a definite quantity of vapour can be thus absorbed at any given temperature. Warm air will take up a greater quantity than cold air. When the air will not receive any more invisible water vapour, it is said to be saturated. The hotter the air, the more vapour is required to saturate it. Once saturated the surplus vapour is condensed and rain falls. Air at a temperature of 32° F. can take up about ·01 of its own weight of vapour, and its capacity is doubled for every addition of about 27° to the temperature. For example, a cubic foot of saturated air at 92°, and another at 32°, mixed together, will have a temperature of 62°. Now the first mentioned air would hold 15·7 grains of invisible vapour, and the second 2·1 grains, but the mixture will only hold 12·4 grains. Consequently, as the air at 62° will contain but 12·4 grains, whereas the amount in the components of the mixture taken together is 15·7 + 2·1 = 17·8 grains, it follows that from the two cubic feet of the mixture there must fall 17·8 grains − 12·4 grains = 5·4 grains of rain. Again, suppose that saturated air at a temperature of 60° contains 5·9 grains of moisture in each cubic foot, and air at 80° similarly saturated, 10·8 grains; then if the air of 80° is suddenly cooled down to 60°, about 4·9 grains of water must be deposited in the form of rain, because air at 60° will only hold 5·9 grains, whereas it previously held 10·8 grains at 80°. Rain is formed in this way. Warm air takes up considerable moisture, and subsequently becoming cooled, is no longer able to contain the same amount of vapour. If the temperature is above the freezing-point the deposition takes the form of rain. Rise in barometric pressure, or decrease of temperature, may result in precipitation.

Conditions governing Rainfall.—Speaking generally, the causes of rain may be divided into three broad classes:—the ascent of damp air chilled by expansion as it rises, the contact of warm damp air with a colder surface, and the mixture of hot and cold air. Each grain of water in the form of vapour takes up sufficient heat to raise 966 grains of water 1° Fahrenheit. This heat is not appreciable by the thermometer, but is employed in keeping the water in a state of vapour. The whole heat, latent in vapour, is again rendered appreciable when the vapour is condensed into rain. This is one reason why rain often brings warmer weather. Professor Haughton has calculated that one gallon of rain water gives out during its formation latent heat sufficient to melt 75 lbs. of ice, or 45 lbs. of cast iron. Hence every inch of rainfall is capable of melting a layer of ice 8·2 inches thick.

The Red Sea is a narrow rainless, riverless channel. An undercurrent takes away the heavier salt water left by evaporation. Sir J. Fayrer has pointed out that the small accession of moisture caused by the Suez Canal has brought some rain into the desert. For nine years prior to the opening of the Canal, according to the experience of a local pilot, he had never known rain to fall. At Aden, on 28th May 1870, serious damage was done by exceptionally heavy rain in a short interval. Eight inches of rain fell between

11 p.m. of 27th, and 7 a.m. of 28th. On the coast of Peru heavy dews take the place of rain. Other rainless regions are the Sahara and the Gobi Deserts. In the Doldrums there is almost constant rain. The trade winds rising over the equatorial calms are saturated with moisture; they cool down, and rain falls in torrents. There is said to be a rainfall of 100 inches per annum near the equator. Rainfall is greater near the coasts, especially where they are washed by a sea-surface current from lower latitudes. Cool currents, on the other hand, tend to prevent precipitation. As a result of the sun's motion two wet seasons and two dry seasons frequently occur in the torrid zone. Except near the equator these two rainy seasons occur simultaneously, and form but one wet and one dry season. The south-west monsoon brings rain to the west coast of India, and the north-east monsoon to the east coast. Mountains tend to condense moisture, as the air rises up the slopes to higher altitudes. The least rain falls inland, especially to leeward of mountain ranges which sap the air.

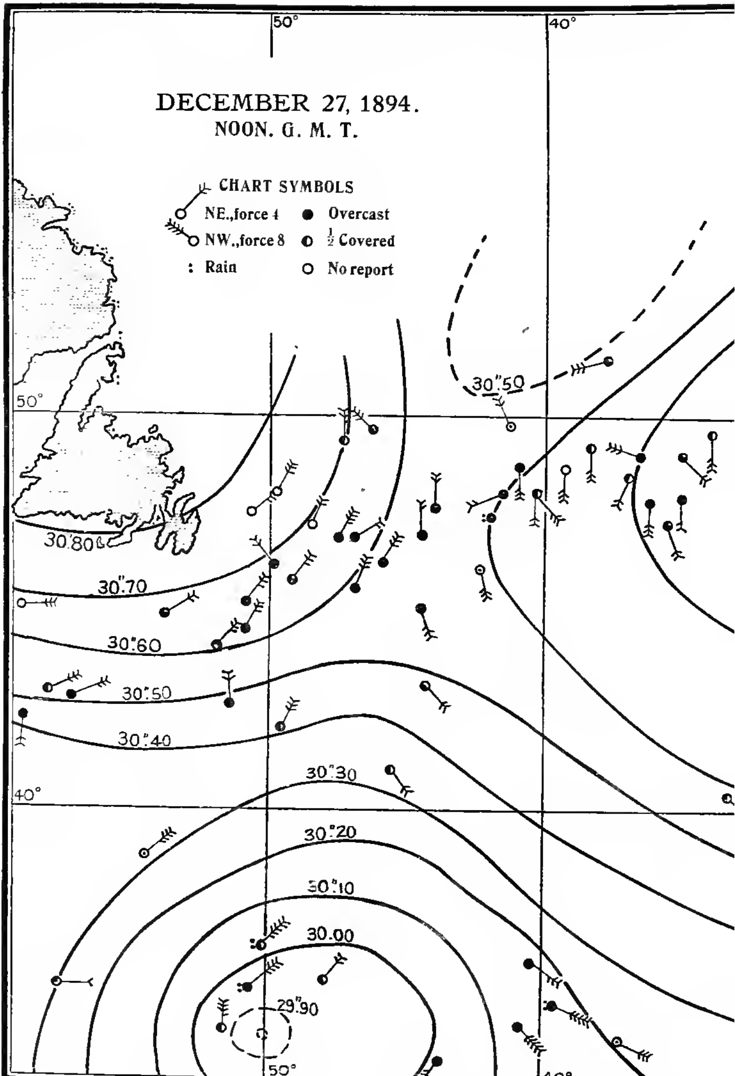
Seathwaite, at the south end of Derwentwater, has a rainfall of 140 inches per annum; a little above it, Stye Head has 175 inches on an average, but more than 200 inches as a maximum annual rainfall. On the Khasia Hills, north-east of Calcutta, the annual rainfall is 610 inches. Near Karachi, in the north-west of India, however, under different conditions the average annual fall is only 7 inches.

Rain does not always fall regularly from month to month. At Bombay, out of an annual fall of $70\frac{1}{4}$ inches, all but $3\frac{1}{4}$ inches fall between June and September, or in four months. In the United Kingdom, we have an occasional drought, giving rise to pessimistic predictions as to the water supply, but the fall is fairly equally distributed over each of the twelve months. Large daily falls are principally due to storms. On 6th August 1857, over 10 inches fell at Scarborough. At Bombay over 15 inches, and at Cherraponji over 25 inches of rain fell in one day. Some rain showers are very local. In 40° N., 34° W., on board the "Cassandra," Captain Cromarty, passing showers drenched the fore part of the ship, yet left the after part quite dry. The resistance of the air prevents rain-drops from attaining a greater velocity than about 30 feet per second.

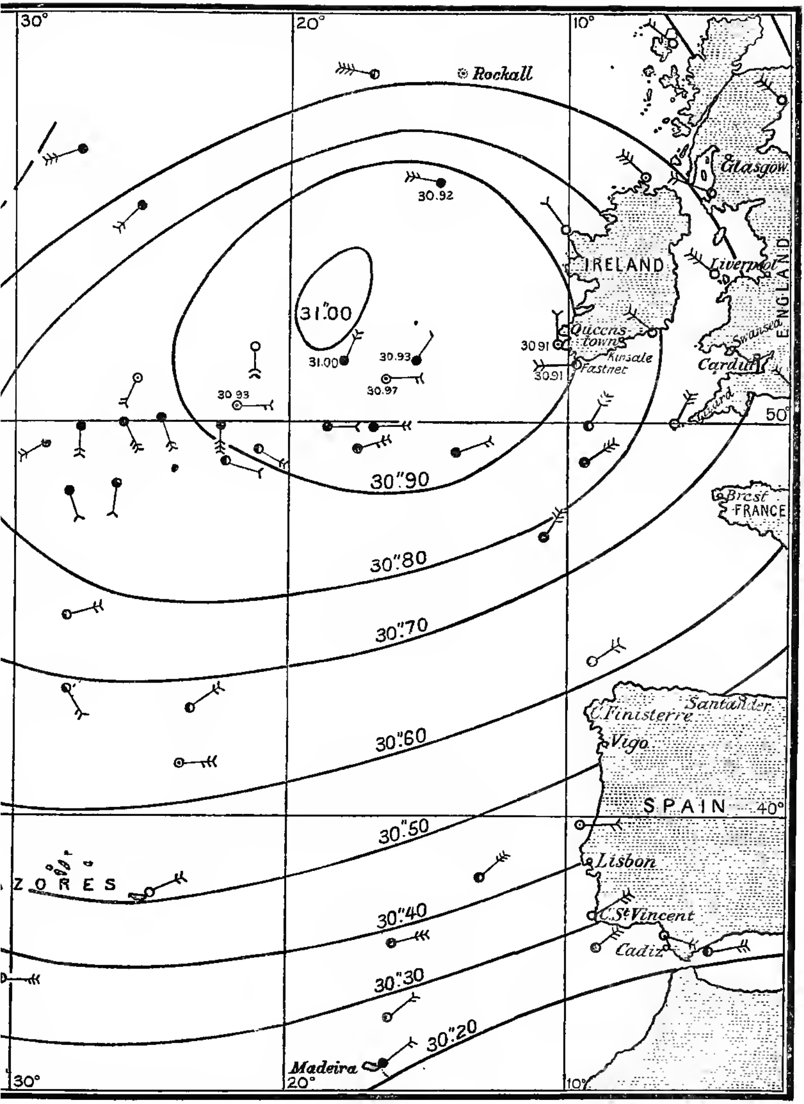
Snow and Hail.—At a low temperature water solidifies. Ice is a familiar example. Hence when the air's aqueous vapour is condensed to a temperature of 32° or below, it freezes, and falls as snow, or hail. In steamers carrying frozen meat from New Zealand, or elsewhere, snow forms in part of the apparatus. Similarly, snow has fallen at St. Petersburg inside a heated ball-room when the cold air was suddenly let in from the outside. Snow falls when the air temperature is several degrees above the freezing-point, the snow having been formed up aloft. At some places snow never falls, while at others the deposit of moisture is nearly always in the form of snow. At certain altitudes moisture is always deposited as snow, and never entirely disappears throughout the year. This limit of constant snow is termed the snow-line. Its height varies from the sea-level at Spitzbergen in 78° N. lat., to an altitude of 19,560 feet in the Northern Himalayas in 29° N. The fall is heavier and more frequent when the temperature is near the freezing-point than when it is much colder. Snowflakes are of infinite variety, but always six-sided. One inch depth of water is obtained by thawing one foot depth of snow, as a general rule. Very large snowflakes are made up of smaller flakes, and are only to be observed when the air is damp. In very dry weather, the snow falls in small pellets, something like pop-corn in size and shape, and is known as *graupel*. This is a kind of compromise between snow and hail. Sleet is a mixture of snow and rain; another compromise.

Ships on the United States coast come at times under the influence of terrible snowstorms known as "blizzards." During the blizzard of 11th to 14th March 1888, New York, Philadelphia, and Boston were isolated. The only advices possible for a couple of days from Boston were by way of England. About 100 miles east of Cape Henry the American schooner "Kensett" had continual snow throughout the 12th and 13th, with air temperature down to 23° F. On the 12th the "Annie M. Smull" experienced a terrific gale, the ship being covered with snow, and ice making fast. Five men had hands and feet frostbitten. It snowed throughout 12th and 13th, when she ran for the Gulf Stream to thaw. The New York pilot-boat "Charles H. Marshall" had a similar experience about 12 miles E.S.E. of Sandy Hook. In two hours she was so much iced up with snow and water that she resembled an iceberg. Iron bars and huge hammers had to be used to beat the ice off the ropes and mast in order to lower the foresail. Impossible to look to windward by reason of the heavy snow. She drifted 100 miles to leeward in the two days, using oil as a sea-smoother all the time. During the blizzard of 8th February 1898, the s.s. "Wydale," Captain Gibson, was five miles east of Hoy Island. She had not less than 75 tons of ice on her rigging which was carried to within 10 feet of the crosstrees.

Hail is made up of ice pellets falling in showers. They may vary in size from small shot to hen's eggs, or apples. Sometimes they are made of clear ice; but usually each has a core of hard snow, and is built up in layers. Large masses of ice which fall at times are probably formed by the stones adhering and freezing together, either on the way down or afterwards. Hail is supposed to be formed by a sudden uprush and cooling of moist air; or, according to Volta, by electric action, inasmuch as hail is most frequently experienced in connection with thunderstorms. On 24th February 1887 the barque "Elissa" had a heavy squall, lasting twenty minutes, during which a heavy fall of pieces of ice occurred, compelling the men to seek shelter. These pieces were said to be as "large as apples."



ALLINGHAM'S MARINE METEOROLO



LATE X.—A RECORD HIGH PRESSURE.

CHAPTER XVIII.

MIRAGE, RAINBOWS, CORONAS, HALOS, AND METEORS.

Refraction and Reflection: Mirages.—Refraction is the deflection caused in a ray of light by its passing through the earth's atmosphere, and every navigator has to make allowance for this in his calculations. Its general effect is to increase the apparent altitude, and varies from a maximum at the horizon to a minimum at the zenith. Owing to unequal heating, or varying amounts of moisture, layers of air in close proximity have unequal densities, and then the refraction is most irregular. Such exceptional refraction and total reflection of light rays in passing through air layers of unequal density often gives rise to images of distant objects out of all proportion to the originals. In some instances the image in the air is inverted. A ship may be seen, as it were, sailing along the sky with her mastheads where her keel ought to be. This phenomenon is known as mirage. In July 1891, in 30° 30′ S. lat., 49° 50′ W. long., with heavy banks of haze all round the horizon, the coast line was raised by mirage; and, apparently within a few miles, a steamer was inverted in the air. In October 1891, the new American barquentine "Steadfast" was wrecked on the Island of St. Croix while bound with asphalte from Trinidad for Philadelphia. Her loss is alleged to have been due to mirage, which caused the island to appear as though many miles away although the vessel was actually close to the reefs.

Rainbows.—A sunbeam breaking through a rift in the clouds is but an example on a large scale of a ray of light let into a dark room through a small hole. In either case the path is rendered visible by the light reflected by particles of various kinds along it. Sailors term this phenomenon "the sun drawing up water."

A rainbow is the arc in the celestial concave displaying all the colours of the spectrum, red, yellow, orange, green, blue, indigo, and violet. It is usually seen in shower or mist upon which the sun is shining from a point behind the spectator. White light on entering a raindrop at a certain angle is split up into its constituents. The coloured rays suffer total reflection within the drop, to emerge eventually on the same side of the drop as that which they entered, and reach the observer's eye. Sometimes a double bow is visible. Then the outer one is less vivid, and the order of the seven colours is reversed. A glance at fig. 34 affords an explanation of the single bow. The outer arc of the double rainbow is similarly formed, but the coloured rays are twice reflected inside the drop. Hence the primary bow is caused by refraction, reflection and refraction; and the secondary bow by refraction, two reflections, and refraction. As a general rule the angle between the sunbeam of white light and the reflected coloured rays is 42°. Portions of bows are known as wind-dogs. A white rainbow may be seen on a thick fog, and at times an

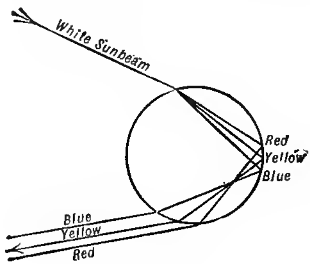


FIG. 34.

ordinary rainbow does not show all the prismatic colours. Lunar rainbows are formed in a similar way; but they are scarcer, and less marked. If the sun is on the horizon, the bow will be a semicircle; if his altitude is 42°, the bow touches horizon; and for greater altitudes of the sun there will not be any bow. Circular bows have been seen from the summit of a mountain under certain conditions.

The Corona; Halos.—A corona is the coloured ring often visible round the moon or the sun, when seen behind fleecy clouds. Only lunar coronæ are generally visible to the naked eye, as the sun's glare demands the use of smoked glass or reflection from a mirror. The sextant shades moderate the intensity. Coronæ show prismatic colours after the manner of the rainbow. When the corona is large, there is sometimes but a single ring of whitish appearance visible. Coronæ are due to what is termed *diffraction*. The rays of light are deflected in passing between the tiny drops of water, of nearly equal size, which form the intervening cloud; and the corona has a greater diameter in proportion as the droplets of water are smaller. Hence a contracting corona indicates that the droplets are uniting, and that rain is probable shortly.

Halos are circles around the sun or moon, differing from coronæ, and of larger size. They are due to refraction through the minute ice crystals of cirrus cloud, and are of complicated form. Generally white rings, they are occasionally coloured, but with the red *inside* instead of blue, as with coronæ. Halos usually have a radius of 22°, less seldom of 46°. Supernumerary circles are not uncommon, and at the points of intersection of the circles of the halo the concentrated light may form images of the sun or the moon. These images of the sun are *parhelia*, or mock-suns; those of the moon are *paraselenæ* or mock-moons. A common position for them is on the same level as the sun or moon, distant 22° east or west.

Shooting Stars and Meteors.— Shooting stars and other meteors of various descriptions are often observed by seafarers during the lonely night watches. Starshowers are common on the 10th August and the 13th November. A star apparently detaches itself from the celestial concave, and makes for earth, leaving an evanescent track of light to indicate the change. The November shower is said to occur every thirty-three years, 1866, 1899, and so on. Popularly speaking, these meteors are stars shooting hither and thither. Scientifically, they are nothing of the sort. Small solid bodies enter the earth's atmosphere with enormous velocity, catch fire owing to their energy of motion being converted into heat by friction with the air, and are rapidly consumed, while the product falls as a fine dust upon our planet. Meteors, otherwise shooting stars, commence to glow about seventy miles above the earth's surface, and cease to be seen, as a rule, at half that height. Doubtless other planets have like experiences. Occasionally a meteoric mass, or ærolite, of considerable size, actually reaches the earth.

CHAPTER XIX.

LIGHTNING, CORPOSANTS, AURORAS.

Lightning.—Franklin demonstrated the connection between lightning and electricity in a simple way. He flew a kite under a thunder-cloud and succeeded in drawing sparks from a key attached to the kite string. His experiment failed, however, until a shower wet the string, and made it a conductor. There is always free electricity in the atmosphere; positive electricity when the sky is cloudless, but either positive or negative when clouds are present. The earth's surface is always negative. On either hand the intensity is variable. Sir J. Herschel was of opinion that to condensation of vapour may rightly be attributed the principal source of atmospheric electricity. During heavy snowstorms the lower air strata afford indications of the presence of electricity of considerable intensity. Dry air, it must be remembered, is a poor conductor, whereas moisture is a good conductor of electricity.

When an electrified cloud approaches another, or the earth, there is likely to be a disturbance in the form of thunder and lightning. The lightning flash is generally white, but in the upper regions it is violet at times. There is only a difference of degree between the spark of an electrical machine and the lightning flash. Thunder is due to the sudden expansion and contraction of the affected air, and is not audible for more than fifteen miles. Inasmuch as the flash may be several leagues in length, the sound proceeds from unequal distances and becomes a roll. Echoes contribute to enhance this effect. Lightning prefers the line of least resistance, and the flash is therefore very often zigzag as it picks out the easiest way. Here, again, the longest way round is often the shortest way home. In a vacuum the electric spark affects a straight line. The flash is instantaneous, and it cannot be accurately determined from which direction it starts.

Sheet lightning is merely the reflection of lightning at a distance, frequently from clouds below the horizon, the thunder being inaudible. Occasionally the whole sky is overspread in this way, owing probably to the moisture in the air allowing electricity to escape without sound, but resisting sufficiently to cause a glow.

Globe or ball lightning is, as the name implies, somewhat in the shape of a fire-ball descending from the heavens to the earth. A luminous ball of this nature may be visible for ten seconds.

In 1840 the packet-ship "Poland" was burnt at sea. A large ball of fire descended from a cloud, ran down her chain topsail sheets, and exploded. Soon afterwards the cotton cargo in her lower hold was discovered to be on fire. The revenue cruiser "Chichester," off the west coast of Ireland, had a ball of fire pass right through her, tearing off the copper on emerging. It is said to have crossed the dining table, shattering the glasses but sparing the diners.

It is sometimes assumed that lightning and thunder do not become manifest in Arctic regions. This is a mistake; for instances thereof, although rare, are not wanting.

The vicinity of lofty objects, such as masts, trees, spires, and high buildings, is dangerous in a heavy thunderstorm. They attract the electricity from clouds overhead, and the discharge which at times results, destroys animal life, shatters masts, and inflames combustible substances. It has been known to magnetise bars of iron, and invert the poles of the compass needle. Conductors are fitted to the masts of many ships in order to avoid accident. On 31st May 1896, in 3° S., 87° E., the steamer "Victoria," Captain Worcester, R.N.R., experienced a terrific thunderstorm with lightning and rain. After it had passed away the standard and wheel-house compasses differed 6° from former comparisons. An azimuth confirmed this, and on swinging her the deviation did not exceed $1\frac{1}{2}°$ on any course, whereas previously the deviation was as much as 7° E. on north. It is presumed that the lightning affected the needle, as afterwards the forward lightning conductor was found to be fused. Probably the conductor was too thin for its work. A conductor must be continuous, of sufficient section to permit of a free path for the electric current, and in connection with the sea. Copper is the best substance in use. Iron ships are not nearly so often struck as the old-time wooden vessels. In September 1889 the steel steamship "Tainui" was struck by lightning in the Royal Albert Dock, London. Large holes were burnt through the bridge deck, near the mainmast; and a block aloft was much charred.

The efficacy of a lightning conductor depends upon the power of points. Electricity collects on the surface, cannot be retained on the point, and flows off to equalise the potential of the ship and the clouds, thus tending to prevent a disruptive discharge and casualty.

St Elmo's Fire.—Corposants, or St Elmo's Fires, on yardarms and trucks are not uncommon. They are due to electric discharge. Atmospheric electricity of low intensity induces electricity on the ship, which escapes from pointed objects inaudibly, but with a luminous brush discharge. At Cay Lobos Lighthouse, the keeper, on holding out his hand, saw a corposant on each finger. On 3rd June 1856, during a hail squall, in 39° S., 54° E., a ball of fire struck the ship "Aden," carrying away topgallant and topsail ties. It burst near the deck with the report of a cannon, passed through the coat of the mainmast, and filled the cabin with smoke. On 19th August 1862, in 42° S., 105° E., the "Blanche Moore," Captain Smith, had a curious experience. Corposants were on the yardarms, and lightning appeared to play around masts and decks in every direction. Her master seemed surrounded by fire. One of the passengers received a severe shock in the legs, and a strong smell of burnt gunpowder prevailed throughout the ship for ten minutes. Ten days later, in 43° S., 160° E., the "Nelson," Captain Meiklejohn, had corposants about her when something fell from the heavens, as bright as a moon, which illuminated the whole ship. It fell into the water about twenty yards to leeward, and a phosphorescent glow is reported to have illuminated the spot for five or ten minutes. Something similar happened to the R.M.S. "Kaikoura," Captain W. C. Crutchley, R.N.R., in 36° S., 50° W., on 6th May 1890. A small "ball of electricity" struck the bridge between an officer and a quartermaster. It exploded with the report of a small pistol, and showed a blue light for four seconds. In September 1896 the German steamer "Heligoland" had a curious experience. A gigantic ball of fire, illuminating the whole heavens, came so close to the ship that the heat could be felt by the crew on deck. As it struck the water, a report occurred like the explosion of dynamite, and the sea was sufficiently disturbed to roll the steamer. The steamer "Don," on her way from Barbadoes, on 8th October 1896, a week before arrival had a "thunder-bolt" strike and break her fore-topgallant mast. The meteor exploded near the vessel's bow. The ship "Belford," on 5th March 1899, in 3° S., 24° W., had her fore-royal yards struck and broken by a "thunderbolt." On 10th January 1899 the steamship "Sardinian" experienced a severe electrical storm. What seemed to be a huge ball of fire burst close to the deck with a terrific explosion. An officer was partially blinded and stunned by the shock. The steamer "Galileo" on 20th October 1898, in 12° N., 58° W., observed a large "aerolite" fall into the sea close alongside. The splash wetted her deck.. About the same time a flash of lightning struck and split the main deck. The "Seven-Stones" light-vessel was struck by a meteor, rendering the watch insensible. The decks were covered with cinders which crushed underfoot, but were swept overboard by wind and sea. On 21st May 1895, ten miles west of Gun Cay, the sailing tanker "Carrie E. Long," laden with petroleum and acids from Philadelphia to Havannah, was struck by lightning and destroyed by fire, together with several of her crew.

Auroras.—The aurora is a singularly beautiful phenomenon seen in the sky, most frequently in high latitudes; and supposed to be due to electric action between the earth and the atmosphere. It is a luminous display in the form of an arch, or arches like curtains one behind the other. In northern latitudes it is known as the *aurora borealis*, northern lights, or merry dancers; while in southern latitudes it is called the *aurora australis.* The term aurora covers both hemispheres, but beginners must be careful not to apply the adjectives borealis (northern) and australis (southern) to the wrong hemispheres. From the arches which are at right angles to the magnetic meridian, luminous streamers dart towards a point 90° from the magnetic pole known as the magnetic zenith. The *aurora borealis* has been observed at Christiania in the form of an almost complete oval; and on other occasions, at the same time, both in the Old World and the New. Its height above the earth is said to vary between the limits of 45 miles and 500 miles; it is more frequent at the equinoxes, less so at the solstices; is rarely seen within the tropics, and is most frequent along the 60th parallel of either hemisphere. Between that parallel and the poles auroras are seldom seen. The light is generally of a pale yellow colour, or white; but sometimes various colours are visible simultaneously. Attempts have been made to trace a connection between sun-spots and auroras. Both certainly influence the working of the electric telegraph and the magnetic needle.

CHAPTER XX.

OCEANIC WEATHER FORECASTING BY RADIO-TELEGRAPHY.

MANY of the trans-Atlantic steamships are now fitted with radio-telegraphy apparatus; and this system of communication is in course of extension to the other oceans, along the shores of which are rising radio-telegraphy stations after the manner of those already in existence on either side of the North Atlantic. Apparently about two hundred miles is the effective radius for radio-telegraphy messages emanating from the majority of ships; albeit such ships are able to receive messages, of like kind, despatched from shore stations situated at a much greater distance. Not infrequently, to-day, large liners are in touch, through the medium of radio-telegraphy, with a considerable number of ships that are similarly fitted; and also with stations along the coasts of the several continents. Hence their officers can, if they will, make a serious study of marine meteorology, more especially of the prevailing weather conditions; and construct a Daily Weather Chart such as is issued by the official weather authorities of the United Kingdom, the United States, and other countries. At the same time, on board the world's palatial floating hotels, thanks to radio-telegraphy, a newspaper is not infrequently published, day by day, throughout each passage. Marconi and his rivals have thus enabled the seafarers of the twentieth century to keep themselves posted with precision in many an item, either of navigational importance or of social interest, such as was impossible prior to the advent of radio-telegraphy on board ships at sea.

Consequent on the fact that much of the weather of the United Kingdom, if this popular term be permitted me, comes from the vast oceanic area to the westward, it follows that weather-messages, from ships between Europe and the United States, or Canada, provided they arrive well ahead of the weather sequences travelling the same way, are useful for incorporation in the data used by the forecasters of the Meteorological Office, London, in the compilation of daily weather charts. Similar advantage is taken of radio-telegraphy weather-messages by other nations. A shipmaster in communication with a number of ships, suitably separated by a sufficient distance, may readily draw up, or have drawn up by one of his officers, with the data thus obtained by co-operation, a weather chart of a type similar to those issued by shore weather authorities remote from the tumult of wind and of wave. A simple telegraphic code has been devised, for such a purpose, by Sir Napier Shaw, Sc.D., LL.D., F.R.S., Director of the Meteorological Office, London, which not only saves time but also lessens trouble. A Mercator chart of the North Atlantic is divided into 10° rectangles; and these, again, are subdivided into rectangles of 1° side, latitude and longitude, respectively. To each area of position a distinguishing code number is allotted, as in fig. 35. Having determined the geographical position of his ship by one of the methods usually employed at sea, for a given instant of time, the officer entrusted with the special duty of weather forecasting will first pick out the number of the corresponding position-rectangle from the key-chart in his possession. The barometer reading for the adopted instant having been duly corrected for height above sea level, and for instrumental error; and also reduced to 32° Fahrenheit by the aid of a special table, similar to that on p. 185; is at once mentally coded by the omission of the initial figure of the inches. Thus, corrected readings of 29·87 inches and 30·02 inches become 987 and 002, respectively, for transmission by code. Correction of mercury barometer readings for gravity, or for latitude, as it is sometimes termed, may be neglected in this class of work. An aneroid reading only requires correction for height above sea level, and for index error, if any, in either case. Code numbers for wind-direction and wind-force are taken out of the table given below, which is similar in arrangement to the time-honoured traverse-table of navigation.

Force.		Wind Code. Direction and Force.															
Verbal Description.	Beaufort Scale.	N.N.E.	N.E.	E.N.E.	E.	E.S.E.	S.E.	S.S.E.	S.	S.S.W.	S.W.	W.S.W.	W.	W.N.W.	N.W.	N.N.W.	N.
Light breeze .	1–3	01	07	13	19	25	31	37	43	49	55	61	67	73	79	85	91
Moderate breeze	4–5	02	08	14	20	26	32	38	44	50	56	62	68	74	80	86	92
Strong wind	6–7	03	09	15	21	27	33	39	45	51	57	63	69	75	81	87	93
Gale . . .	8–9	04	10	16	22	28	34	40	46	52	58	64	70	76	82	88	94
Storm .	10–11	05	11	17	23	29	35	41	47	53	59	65	71	77	83	89	95
Hurricane .	12	06	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96
Calm . .	00	Direction is to be referred to *true* meridian.															

The prevailing weather is indicated by one figure, in agreement with the accompanying table.

Weather or State of the Sky Code.

No.	Description.	No.	Description.	No.	Description.
0	Cloudless	3	$\frac{3}{4}$ Clouded	6	Snowing
1	$\frac{1}{4}$ Clouded	4	Entirely clouded	7	Haze *or* mist
2	$\frac{1}{2}$ Clouded	5	Raining	8	Fog
				9	Thunderstorm

The rectangle determining the ship's position on the code chart is that immediately north of the parallel of the degree of latitude and immediately west of the meridian of the degree of longitude. Such a convention ensures accuracy and rapidity. The key-chart, fig. 35, shows that if a ship be in, say, 52° N., 12° W., it would be equally correct, in the absence of a definite understanding, to quote 312, 322, 311, or 321, as the number of the one degree rectangle appropriate to the ship's geographical position at the given instant. The above convention, however, strictly limits the observer to but one out of the four conterminous areas. For coding the day of the month, a nought is prefixed to the dates from 1 to 9, inclusive; so that the coded dates shall run consecutively, each with two figures, from 01 to 31; in other words, from 1st to 31st when necessary. The date will not be required for meteorological communication between ships for weather forecasting. A similar artifice to that of the dates is adopted for radio-telegraphy purposes when dealing with wind-direction and wind-force. This coded weather information can then be despatched to all similarly fitted ships within the effective radius of the sender's apparatus; and thence passed on, in like manner, to ships that are more remote from the original sender.

During the course of a paper by the writer, which was read at the International Meteorological Congress held at Washington, D.C., in 1894, it was suggested that the swiftest trans-Atlantic steamers of the several nations, on arrival at Queenstown, for example, should immediately send an urgent telegram to the Meteorological Office, London, for the use of the weather forecasters of that Department, who, under certain conditions, might thus receive information with respect to a slowly moving storm that had been outstripped on its way east by the reporting steamer which was travelling in the same direction at a much higher rate.* Radio-

* *Forecasting of Ocean Storms and the best Methods of making such Forecasts available to Commerce.* By William Allingham.

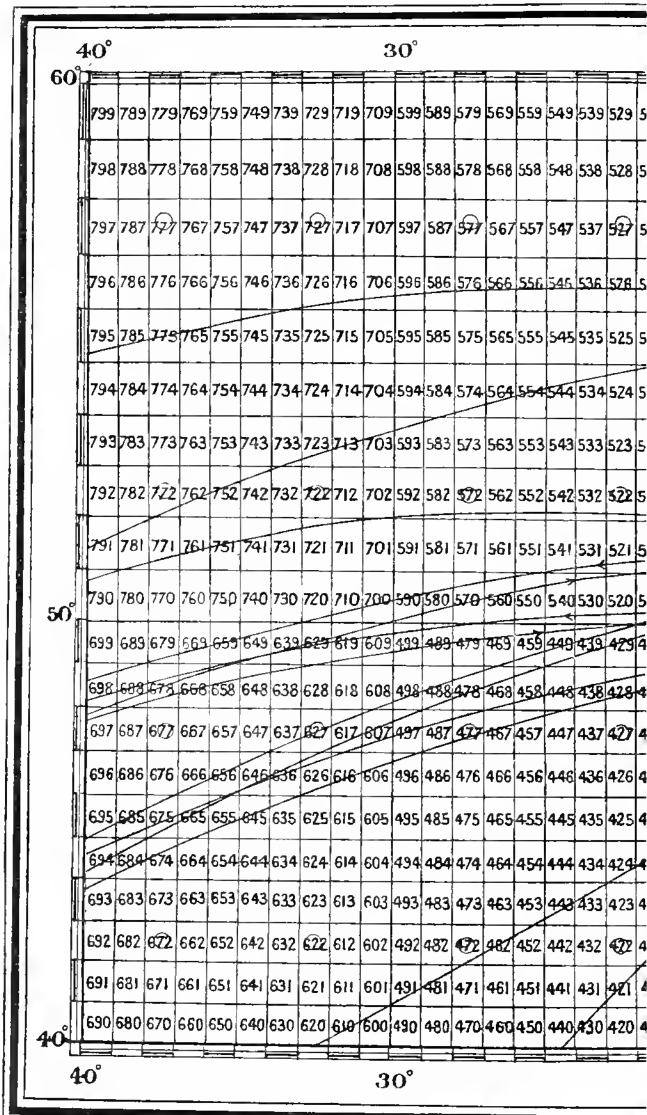
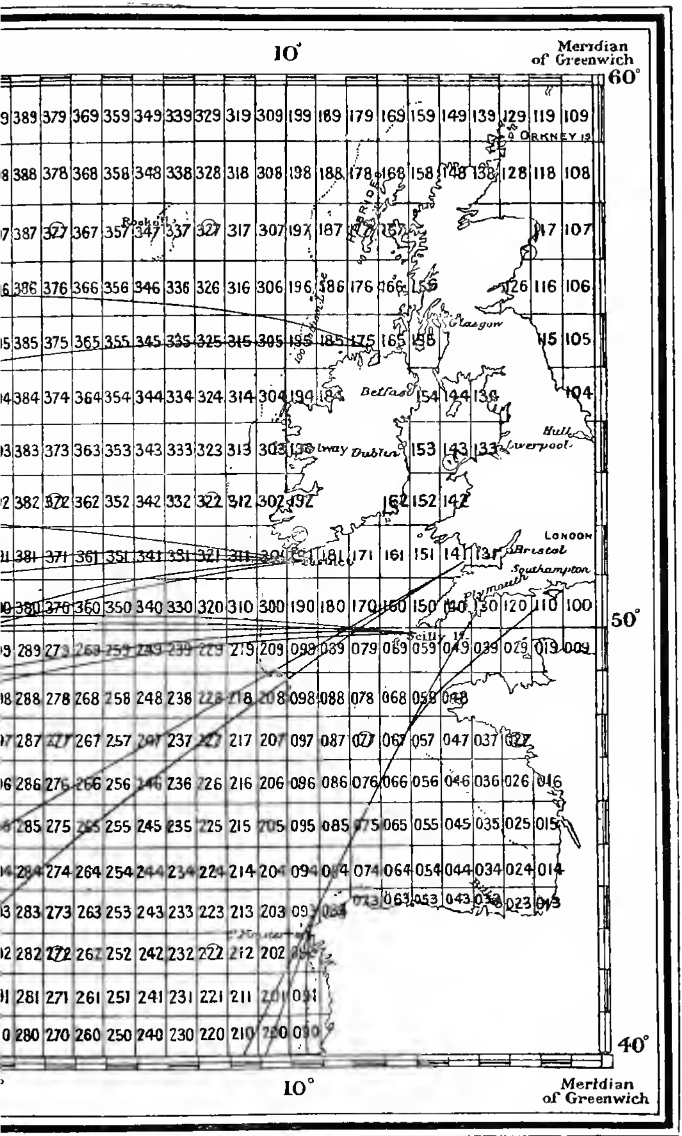


FIG. 35.—Degree squares for indicating



sitions of ships at the times of observations.

telegraphy, however, enables a weather forecaster, in London, for example, remote from the North Atlantic tumult of wind and of wave, to be in communication with steamships much farther seaward than the westernmost verge of Ireland. Forecasting by the aid of specially arranged weather charts—whether they be synchronous or synoptic matters but little in practice—on board ships at sea, can be easily brought to a successful issue by the officers of vessels fitted with radio-telegraphy apparatus. Reference to a special weather-code document is only necessary to find the code numbers, of the ship's position-rectangle, and of the wind. The code-figures for weather can be mentally fixed in a few minutes. A glance at the accompanying key-chart, fig. 35, affords a grasp of the ship's radio-rectangle; and the table of wind-force and wind-direction is even slightly less difficult. A *memoria technica* for the wind data is right at hand. Beaufort's scale of 0 to 12 is subdivided so that there are six divisions of wind-force in the table, with vertical columns; and the wind-directions, running horizontally, are given to each two points, commencing with N.N.E. and working round the compass through E. to North. Thus the radio-telegraphy numbers run from 01 to 96, six in each of the sixteen vertical columns; and a calm, 00, makes up the table. Even this aid to memory may become unnecessary by practice. The rectangle-number invariably consists of three figures. From left to right, the first defines the 10° area, the second is the last in the degrees of longitude, and the third is the last in the degrees of latitude. The initial numbers, 0, 2, 4, 6, 8, apply to the 10° areas between the parallels of 40° N. and 50° N., working westward from the meridian of Greenwich; and 1, 3, 5, 7, 9, apply, in like manner, to the 10° areas between the parallels of 50° N. and 60° N. West of 45° W., the numbers are repeated; but such repetition does not militate against the code scheme for ships at sea where the effective radius of communication is limited. Take area 553, for example, of ship "Nineteen," mentioned on p. 172. The figure 5 points out that she was in the third 10° area west of Greenwich, between 50° N. and 60° N.; the second figure, in this instance also a 5, is the last figure in the longitude; and the third figure, here a 3, is the last figure in the latitude. The hour is represented by its proper figure from 1 to 9 inclusive; but T, E, W, respectively, must be used for ten, eleven, and twelve.

One example of this combination of radio-telegraphy and weather-codes should suffice to impress the elementary student with the utility and the simplicity of the method employed. On the 10th January, 1913, in 52° N., 26° W., the master of the steamship "Nineteen" may be assumed to have received coded meteorological data for Noon, G.M.T., of that date, from twenty-seven other ships, from Scilly, and from Roche's Point. In Table A are grouped the essential data from each ship and shore-station, as specified in code-form; and the corresponding conversions into everyday language are shown in Table B. The observing officer at once proceeded to plot the given data from Table B, in geographical position, on a chart of suitable dimensions, by the aid of convenient symbols. Next he drew lines through those points on the chart at which the barometer readings were the same. These curves of equal barometric pressure are technically known as "isobars." Should the precise isobar value be wanting it may be found, approximately, by interpolation. Thus if 30·50 inches be the value of the isobar under consideration, and two neighbouring ships give readings, respectively, of 30·58 inches and 30·40 inches, then the required reading of 30·50 inches may be assumed to lie between the two at a point eight equal divisions from the higher reading and ten like divisions from the lower reading. Should the barometer values from several ships, in close proximity, apparently differ among themselves, at the same instant, the officer concerned must make the best of a bad job. He may use a mean of the batch, or select what seems to be the most reliable. It is impossible to lay down an absolute rule for guidance. Wind-arrows fly with the wind; the number of feathers indicates the force of the wind; and the point of each arrow-head is placed at the centre of the position rectangle. Such a weather-chart should not take long to construct! It would keep the officers in close touch with atmospheric phenomena—past, present, and future; and might be brought to the notice of passengers through the medium of the daily journal now common on many large liners from shore to shore. A code group is made up of five figures, as indicated below. Hence two groups complete the weather message from ship to ship.

<table>
<tr><th colspan="5">Code Group s.s. "Nineteen."</th></tr>
<tr><td>Position.</td><td>Hour.</td><td>Weather.</td><td>Barometer.</td><td>Wind.</td></tr>
<tr><td>553</td><td>N.</td><td>2</td><td>772</td><td>35</td></tr>
<tr><td colspan="3">553N2</td><td colspan="2">77235</td></tr>
</table>

January, 1913, was a peculiarly stormy month over the North Atlantic; in fact the United States Weather Bureau authorities regarded it as probably the stormiest month on record for that ocean. On the back of the Meteorological Chart of the North Atlantic for May, 1913, issued by that Weather Bureau, special attention was devoted to the most severe of the series of storms that crossed the Atlantic during the first half of the preceding January. At one o'clock on the morning of the 10th, in 52° N., 25° 30′ W., a reading of 26·96 inches was registered by an aneroid on board the British steamer "Manchester Inventor." "This is probably the lowest reading," in the opinion of the United States Weather Bureau, "ever made on the North Atlantic." Doubtless

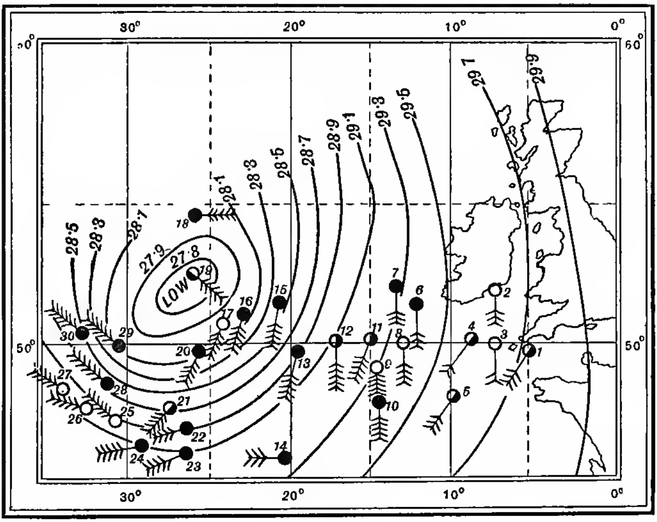
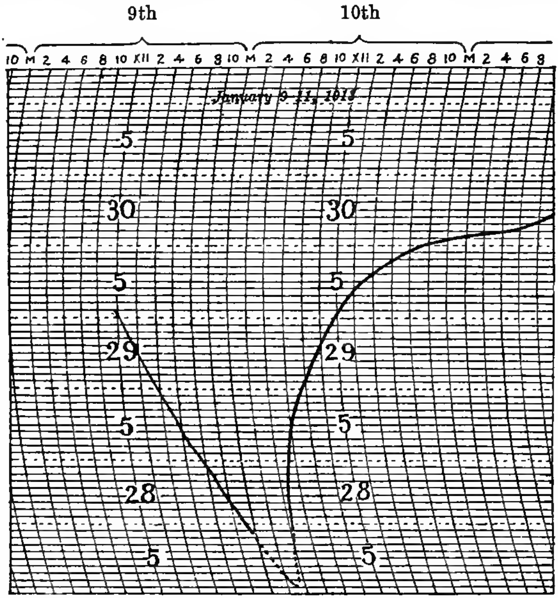


Fig. 36.

this conclusion is absolutely true; but, unfortunately, the reading was not from a mercury barometer of approved type, the error of which had been accurately determined throughout the scale. The "Manchester Inventor," however, was not far remote from the cyclone's centre when this phenomenally low atmospheric pressure was recorded, so that it is probably not much, if anything, in error. Moreover, the wind was then of hurricane force, and a mountainous sea was running. Inasmuch as the diagrams, set forth by Mr. Ralph E. Harris on the above-mentioned charts of the United States Weather Bureau, are especially interesting, and probably unique under some heads, it has been deemed advisable to use three of them for the purposes of illustrating the statements in this chapter. Fig. 36 is an adaptation of one of the American diagrams; while fig. 37 and fig. 38 are reproductions of two from the same source. Assuming that the meteorological data, indicated on the chart drawn up by Mr. Harris, had been laid down in geographical position on a large working sheet by each of the observing officers of the twenty-eight co-operating steamers, and that the isobars were drawn, then each of that number would have before him a picture of the weather for the specified oceanic



(No barometer readings taken between midnight of the 9th and 4 a.m. of the 10th.)

Fig. 37.—S.S. "Kansas City."

area at Noon, G.M.T., of 10th January, 1913, similar to fig. 36. In the ensuing tables there are given the series of observations, thirty in number, approximately as first coded, and also as eventually charted, after the necessary corrections had been made, from which fig. 36 was constructed. On the large working charts the barometer reading, corrected and reduced, would be written against the head of the wind-arrow to which it refers; and the shading of the circular extremity of each arrow indicates the proportion of the sky clouded at that position on a scale of from 0 = clear to 4 = overcast.

Table A.

Data as Coded.

Ship's Name.	Position Rectangle.	Hour.	Weather.	Barometer.	Wind.
One	Scilly	N.	2	972	57
Two	Roche's Pt.	N.	0	962	45
Three	170	N.	0	962	43
Four	180	N.	2	956	56
Five	098	N.	2	955	57
Six	311	N.	4	936	45
Seven	332	N.	4	928	45
Eight	320	N.	0	933	46
Nine	249	N.	0	930	47
Ten	248	N.	4	935	47
Eleven	350	N.	2	925	53
Twelve	370	N.	2	912	47
Thirteen	289	N.	4	890	53
Fourteen	405	N.	4	926	69
Fifteen	501	N.	4	842	53
Sixteen	531	N.	4	805	53
Seventeen	548	N.	0	800	59
Eighteen	554	N.	4	805	23
Nineteen	553	N.	2	776	35
Twenty	459	N.	4	808	59
Twenty-one	477	N.	2	870	59
Twenty-two	466	N.	4	888	64
Twenty-three	465	N.	4	912	64
Twenty-four	495	N.	4	912	65
Twenty-five	605	N.	0	892	84
Twenty-six	617	N.	0	900	83
Twenty-seven	648	N.	0	900	83
Twenty-eight	608	N.	4	870	84
Twenty-nine	609	N.	4	810	84
Thirty	730	N.	4	850	83

Table B.

Data prepared for Plotting on Working Chart.

Ship's Name.	Position.		Hour.	State of Sky.	Barometer Corrected and Reduced.	Wind.	
	Lat.	Long.				True Direction.	Force Beaufort.
One	Scilly		N.	c.	29·72	S.W.	6
Two	Roche's Pt.		N.	b.	29·62	S.	6
Three	50	7	N.	b.	29·62	S.	3
Four	50	8	N.	c.	29·56	S.W.	4
Five	48	9	N.	c.	29·55	S.W.	6
Six	51	11	N.	o.	29·36	S.	6
Seven	52	13	N.	o.	29·28	S.	6
Eight	50	12	N.	b.	29·33	S.	8
Nine	49	14	N.	b.	29·30	S.	10
Ten	48	14	N.	o.	29·35	S.	10
Eleven	50	15	N.	c.	29·25	S.S.W.	10
Twelve	50	17	N.	c.	29·12	S.	10
Thirteen	49	19	N.	o.	28·90	S.S.W.	10
Fourteen	45	20	N.	o.	29·25	W.	6
Fifteen	51	20	N.	o.	28·42	S.S.W.	10
Sixteen	51	23	N.	o.	28·05	S.S.W.	10
Seventeen	50	24	N.	b.	28·00	S.W.	10
Eighteen	54	25	N.	o.	28·05	E.	10
Nineteen	53	25	N.	c.	27·76	S.E.	10
Twenty	49	25	N.	o.	28·08	S.W.	10
Twenty-one	47	27	N.	c.	28·70	S.W.	10
Twenty-two	46	26	N.	o.	28·88	W.S.W.	8
Twenty-three	45	26	N.	o.	29·12	W.S.W.	9
Twenty-four	45	29	N.	o.	29·12	W.S.W.	10
Twenty-five	46	30	N.	b.	28·92	N.W.	12
Twenty-six	47	31	N.	b.	29·00	N.W.	10
Twenty-seven	48	34	N.	b.	29·00	N.W.	10
Twenty-eight	48	30	N.	o.	28·70	N.W.	12
Twenty-nine	49	30	N.	o.	28·10	N.W.	12
Thirty	50	33	N.	o.	28·50	N.W.	11

Inasmuch as the barometer was not read on board the "Kansas City" at midnight of the 9th, and at 4 a.m. of the 10th, the barogram of that ship (fig. 37) may be slightly in error at those critical hours. Having due regard to the experience of the "Michigan" (fig. 38), and of other ships in the vicinity, the estimated values for the "Kansas City," as adopted by Mr. Harris on the diagram, may be accepted as correct. The following notes,

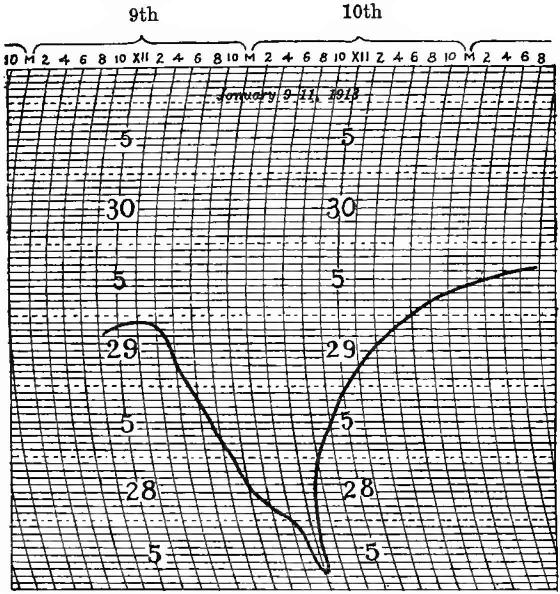


FIG. 38.—S.S. "Michigan."

unavoidably condensed from reports furnished to the United States Weather Bureau by the masters of co-operating steamers, are sufficient to show the exceptional severity of this atmospheric disturbance. On the 9th, in 46° N., 39° W., the "Assyria" experienced waves of "enormous" height, lost three boats, sustained much deck-damage, and put back to Fayal for repairs. Next day several steamers were endangered. The "Matoppo," in 35° N., 22° W., was visited by heavy seas varying in height from thirty feet to forty feet, albeit 1000 miles from the storm centre; the "Ivernia" recorded seas of "phenomenal" height, in 51° N., 23° W., and a fall in the barometer, from 29·34 inches to 27·80 inches, in twelve hours; the "Manchester Inventor," in 52° N., 26° W., and the "Montana," in 49° N., 25° W., each reported a "mountainous" sea; and the "Virgil," in 47° N., 27° W., laboured heavily among seas having a height of not less than thirty feet. Some of the seas observed by Captain H. David, of the "Megantic," while she was hove-to in 50° N., 27° W., were "fully sixty feet high" in his opinion. Captain David used oil, as a sea-smoother, with satisfactory results. A "mountainous" sea was observed from the "Elswick Manor" in 45° N., 29° W. Her master reported that at 3 a.m. he deemed the gale to be at its maximum. During his seventeen years' sea-service he had never experienced such bad weather, or seen so high a sea. Being in light trim, the "Elswick Manor" was run before the storm, with her engines going at a little over quarter speed, and "behaved splendidly." In 47° N., 30° W., the liner "Orotava" became unmanageable, consequent on engine-room troubles, and was without steerage way. She laboured heavily in a "mountainous" sea, which frequently came on deck. The "Michigan," in 50° N., 32° W., used oil as a sea-smoother, with good effect, when the sea was "one mass of foam"; the "Venango," in 41° N., 33° W., rolled heavily, and occasionally fell off into the trough of the sea against her helm. In 46° N., 35° W., the "Kansas City" fell in with a "tremendous" sea; four degrees to the westward, the "Chicago" reported seas having a height of from 36 feet to 55 feet; and the "Menominee" a sea of like height, in 44° N., 40° W. The "Canada" and the "Armenian" experienced a "mountainous" sea, in 48° N., 44° W., and 45° N., 46° W., respectively.

The "Cedric," in 44° N., 49° W., had her radio-telegraphy aerial blown down, and her emergency boats lifted bodily by the wind. During the twenty-five hours and 40 minutes, ended 8 p.m. on the 10th, her barometer rose from 27·49 inches to 30·29 inches, averaging about a tenth of an inch each hour. This may perhaps be rightly regarded as a record rise in the barometer for parallels of latitude north of 35° N. Between 6 a.m. and 7 a.m., of that date, the barometer on board the "Idaho" rose from 27·83 inches to 28·69 inches.

Weather forecasting, on board ships at sea that are fitted with radio-telegraphy apparatus, by the aid of synchronous or synoptic charts, will probably take the place of the old-fashioned rule-of-thumb methods once so prominent afloat and ashore. A reference to weather charts similar to fig. 36, the originals of which were given by the American Weather Bureau, for Greenwich Mean Noon of the 8th, 9th, 10th, and 11th, shows that this severe storm, of great area, travelled from New York City's environs to a position in 56° N., 15° W., during the three successive days. The minimum barometric pressure, at the storm centre, at each noon, was 29·60 inches, 28·72 inches, 27·76 inches, and 28·60 inches, respectively. A number of ships reported hail or snow, terrific squalls, and thick weather. As indicated above, there were lower readings reported by several ships, but they were at hours other than the instant adopted for fig. 36. This cyclonic disturbance was remarkable for the extreme force of the wind; the abnormal height attained by the sea; and more especially, for the great defect in atmospheric pressure, as indicated by the barometer readings of 26·96 inches and 27·20 inches.

QUESTIONS.

METEOROLOGICAL INSTRUMENTS.

1. Explain the use of the thermometer attached to the barometer, known as the "attached thermometer."

2. What instrument is used in determining the specific gravity of the sea surface. How is this instrument read? Give a rough diagram of it, clearly indicating the markings on the stem.

3. What precautions do you take in making observations for specific gravity on board a steam vessel?

4. Give a definition of the term "specific gravity" of sea water?

5. What corrections are applied to the readings of marine barometers? Explain why it is necessary that they should be applied. Is it usual to apply such corrections on board ship?

6. Make a sketch of the hydrometer, showing the graduation on the scale.

7. What precautions do you take when drawing surface sea water from over the side of a steamer, in a bucket, to obtain the correct temperature of the sea surface?

8. Explain briefly the construction of the mercurial barometer, as used at sea. What is the "pumping" action of some barometers?

9. When a barometer "pumps," how do you obtain an approximately correct reading? In marine barometers, what is done to prevent or obviate this so-called pumping?

10. Explain how you would fit up the damp bulb and dry bulb in order to obtain the hygrometrical state of the atmosphere. Is a damp bulb reading of any use without the corresponding dry bulb reading? What must be specially regarded in choosing the wick and the water used for the damp bulb?

11. Show by means of a sketch how the marine mercurial barometer is graduated.

12. Do the barometer readings taken on board your ship

require any corrections to be applied to them? If so, what are they, and by whom are they usually applied?

13. What is a thermometer? Explain clearly the three principal thermometer scales in use, and give a rough diagram indicating the essential features of the three scales.

14. Why is mercury generally adopted in the ordinary thermometer? Occasionally spirit of wine is used. Why?

15. To what error are all thermometers liable? Explain the cause thereof.

16. How should thermometers be placed so as to show the air temperature on board ship? Would the readings from a thermometer kept in a ship's companion be any safe guide as to the temperature of the external air in the shade? If not, why not?

17. Describe the pipette in a marine barometer, as supplied to ships by the Meteorological Office, and explain its use. What effect may a pipette be expected to have if there happens to be an impurity in the mercury of the barometer tube?

18. What is the principle of the aneroid barometer? Why is a mercurial barometer preferred to an aneroid barometer?

19. In obtaining the air temperature, what precautions must be taken with the screen? Explain the bad effect of heavy spray wetting the bulb.

METEOROLOGICAL LOGBOOK.

1. What are synchronous observations? Explain their use in marine weather work.

2. In Beaufort's notation for recording the weather, explain the meaning of *h*, *w*, *d*, *s*. What other significations are erroneously allotted to these symbols?

3. Write down as much of Beaufort's weather notation as you can remember.

4. Explain the method of recording the force of the wind by what is known as "Beaufort's Scale." What modifications have been introduced since Admiral Beaufort's time?

ATMOSPHERIC PRESSURE.

1. What is the difference between periodical and non-periodical barometrical fluctuations?

2. Describe the diurnal range of the barometer, and state where it is greatest and least.

3. What are isobars and isotherms?

4. Why does a vessel in the winter months generally experience

more rapid changes in barometrical pressure when proceeding from England to New York, than when going in the opposite direction?

5. How may the changes of pressure shown by the barometer be classified? Which of these is the most important to the sailor?

6. How does the presence of vapour in the atmosphere affect the barometer? Explain the mode in which great wind storms affect the mercury in the barometer tube.

7. Explain what is meant by the weight of the air, and describe how the pressure of the air is measured.

8. Is the barometer high over great continents in winter or in summer, and on what does such difference depend?

WINDS.

1. When a westerly wind is blowing in the English Channel, what would the relative heights of the barometer be over England and France?

2. State Buys Ballot's law for the northern and southern hemispheres.

3. What changes of wind would a vessel experience in sailing round areas of high pressure in the northern and southern hemispheres respectively?

4. Does the force of the wind depend on the mere height of the barometer at the place where it is blowing? Explain fully.

5. Two ships are in the northern hemisphere; one is directly north of the other, and the wind is strong from the eastward. Which ship has the higher barometer, and why?

6. What changes of wind would a vessel experience in sailing round areas of low pressure in the northern and southern hemispheres respectively?

7. Describe the nature and causes of the land and sea breezes that blow within the tropics.

8. Explain the cause of periodical winds and the special phenomena of the trade winds.

9. How are winds produced? What modifications of the trade winds occur in the Indian Ocean? What are the horse latitudes?

10. How far are occasional and periodical winds dependent on changes in the pressure of the air?

11. Can you give any reason why, in making a passage from the Cape to St. Helena, the prevailing winds are southerly?

12. Why does a vessel experience south-easterly winds when proceeding from St. Helena to Ascension?

CYCLONES.

1. A vessel in a cyclone is hove-to on the starboard tack; in which semicircle is she, and why?
2. In what months are hurricanes most common in the West Indies?
3. In tropical cyclones give the rule for lying-to in the right hand semicircle.
4. Which is the dangerous semicircle in cyclones of each hemisphere? and explain why.
5. You are in a hurricane in northern hemisphere, and in the "dangerous semicircle"; on which tack should you heave-to, and why?
6. In a tropical cyclone, how would you know that you are hove-to on the right tack?
7. How would you know when your ship lies in a direct line of advance of a tropical cyclone?
8. What is meant by "angle of indraft," and what is the average value of this angle?
9. What is the "coming-up tack"? Give the rules for heaving-to in a revolving storm.
10. You are in a West India hurricane and the wind is north-west. What is the bearing of the centre?
11. What peculiarity is there in the north-easterly and easterly winds in cyclones of the South Indian Ocean?
12. Describe briefly the course of a cyclone or circular storm in the northern hemisphere.
13. You are hove-to in a cyclone, and the ship is "falling-off" as the wind shifts. What do you learn from this?
14. How do the winds circulate around areas of low pressure in the southern hemisphere?

QUESTIONS on the LAW OF STORMS formerly given at the Board of Trade Examinations of Candidates for Masters' and Mates' Certificates of Competency. The candidate had to answer in writing, on paper supplied to him, the following questions, numbering the answers to correspond with the questions.

Question 1. The direction of the wind in a cyclone being * state the probable bearing of its centre from the ship in the* hemisphere.

* These spaces to be filled in by the Examiner, and frequently varied.

2. And suppose that the wind during the passage of the same cyclone was found to change towards the * , what would be the ship's position with reference to the line of progression of the centre of the cyclone, and what action would you take?

3. Under what conditions would the change in the direction of the wind in the cyclone be the reverse of the above?

4. What are the usual indications of a ship being on the line of progression of the centre of a cyclone?

5. What are the usual indications that a ship is (*a*) approaching the centre of a cyclone; (*b*) receding from it?

6. Describe the track usually taken by cyclones in the † , and state the seasons of the year in which they most frequently occur in that region.

CURRENTS.

1. How are surface currents determined at sea?

2. Mark on a diagram of the North Atlantic Ocean the chief surface currents, the known instances of deep counter currents, and the position of the Sargasso Sea.

3. Describe the sea-surface currents round the coasts of North America.

4. What are the three varieties of currents?

5. Describe the ocean currents of the South Atlantic, the North Pacific, and the South Pacific.

6. Describe the surface currents of the Arabian Sea and the Bay of Bengal. Explain the cause of any remarkable seasonal change they may experience.

7. Compare the sea-surface currents of the South Atlantic and those of the South Indian Ocean.

8. Explain why there is a marked difference between the climates of places in similar latitudes on the European and American shores of the North Atlantic.

ICEBERGS.

1. What are the usual limits of icebergs in the northern and the southern hemispheres respectively? Give the extreme equatorial limit of icebergs in each case, also the easternmost ice ever reported in the North Atlantic.

* This space was filled in by the Examiner, and frequently varied.

† The Examiner filled in whether North Atlantic, Bay of Bengal, China Sea, Indian Ocean, etc.

2. Which ocean has the most massive and most numerous icebergs? Give the maximum dimensions of icebergs reported in the several oceans.

3. What proportion of the volume of an iceberg is exposed above the sea surface?

4. It is sometimes asserted that the temperature of the air, or of the sea, affords a sure guide to the anxious navigator when in the vicinity of icebergs. Explain the objections urged against the adoption of such a view.

5. Write out a short account of the frequency of ice in the South Atlantic and the North Atlantic, stating the years of maximum frequency and minimum frequency.

SYNCHRONOUS CHARTS.

1. What do you understand is meant by the term "synchronous chart"?

2. Of what use are synchronous charts in weather discussion?

3. At times charts are published, setting forth the geographical position of a storm centre from day to day. Explain fully how these positions are determined in the first instance.

4. On some synchronous charts isobars are drawn with either very little information at hand, or on purely imaginary details. Explain why such a use of the imagination is likely to lessen the value of the charts to an enquirer, or mislead him, when determining the track of a cyclone.

5. Explain how synchronous charts are constructed. How are the data obtained on which are based the isotherms, isobars, and the other features of such charts?

CLOUDS.

1. Describe (*a*) Cumulus clouds; (*b*) Cirrus clouds.

2. Mention the different kinds of clouds, and explain the phenomena of fog, mist, and dew.

3. Name the various forms of upper and lower clouds according to Luke Howard.

OPTICAL PHENOMENA.

1. Explain, with diagram, the theory put forward to account for the formation of a rainbow.

2. How are halos, coronæ, and parhelia formed?

3. Explain the curious phenomenon of nature known as mirage.

APPENDIX I.

Table for reducing Barometric Observations to 32° F.

Temp. Faht.	English Inches. 27·0	28·0	29·0	30·0	31·0	Temp. Faht.
	–	–	–	–	–	
35°	·016	·016	·017	·018	·018	35°
40	·028	·029	·030	·031	·032	40
45	·040	·041	·043	·044	·046	45
50	·052	·054	·056	·058	·060	50
55	·064	·066	·069	·071	·073	55
60	·076	·079	·082	·085	·087	60
65	·088	·091	·095	·098	·101	65
70	·100	·104	·108	·111	·115	70
75	·112	·116	·120	·125	·129	75
80	·124	·129	·133	·138	·143	80
85	·136	·141	·146	·151	·156	85
90	·148	·153	·159	·164	·170	90

Table for reducing Barometric Observations to Sea Level.
Correction additive.

Height in Feet.	Temperature of External Air—Degrees Fahrenheit. Barom. Reading at Sea Level 27 Inches.			Barom. Reading at Sea Level 30 Inches.			Height in Feet.
	30°	60°	90°	30°	60°	90°	
10	·010	·010	·009	·012	·011	·010	10
20	·021	·019	·018	·023	·022	·020	20
30	·031	·029	·027	·034	·032	·030	30
40	·041	·039	·036	·046	·043	·040	40
50	·052	·049	·046	·058	·054	·051	50
60	·062	·058	·055	·069	·065	·061	60
70	·072	·068	·064	·081	·076	·071	70
80	·082	·078	·073	·092	·086	·081	80
90	·093	·087	·082	·104	·097	·091	90
100	·103	·097	·091	·115	·108	·101	100
200	·206	·194	·182	·229	·215	·202	200
500	·513	·481	·453	·570	·535	·503	500
1000	1·016	·953	·898	1·129	1·059	0·998	1000

Table for converting Millimetres into English Inches and Decimals.

mm.	in.	mm.	in.	mm.	in.	mm.	in.
686	27·01	713	28·07	739	29·10	765	30·12
687	27·05	714	28·11	740	29·13	766	30·16
688	27·09	715	28·15	741	29·17	767	30·20
689	27·13	716	28·19	742	29·21	768	30·24
690	27·17	717	28·23	743	29·25	769	30·28
691	27·21	718	28·27	744	29·29	770	30·32
692	27·25	719	28·31	745	29·33	771	30·36
693	27·28	720	28·35	746	29·37	772	30·39
694	27·32	721	28·39	747	29·41	773	30·43
695	27·36	722	28·43	748	29·45	774	30·47
696	27·40	723	28·47	749	29·49	775	30·51
697	27·44	724	28·50	750	29·53	776	30·55
698	27·48	725	28·54	751	29·57	777	30·59
699	27·52	726	28·58	752	29·61	778	30·63
700	27·56	727	28·62	753	29·65	779	30·67
701	27·60	728	28·66	754	29·69	780	30·71
702	27·64	729	28·70	755	29·73	781	30·75
703	27·68	730	28·74	756	29·76	782	30·79
704	27·72	731	28·78	757	29·80	783	30·83
705	27·76	732	28·82	758	29·84	784	30·87
706	27·80	733	28·86	759	29·88	785	30·91
707	27·84	734	28·90	760	29·92	786	30·95
708	27·88	735	28·94	761	29·96	787	30·99
709	27·91	736	28·98	762	30·00	788	31·02
710	27·95	737	29·02	763	30·04	789	31·06
711	27·99	738	29·06	764	30·08	790	31·10
712	28·03						

Comparison of Fahrenheit Thermometer with Centigrade and Réaumur.

Faht.	Cent.	Réau.	Faht.	Cent.	Réau.	Faht.	Cent.	Réau.
	−	−		+	+		+	+
16	8·9	7·1	43	6·1	4·9	70	21·1	16·9
17	8·3	6·7	44	6·7	5·3	71	21·7	17·3
18	7·8	6·2	45	7·2	5·8	72	22·2	17·8
19	7·2	5·8	46	7·8	6·2	73	22·8	18·2
20	6·7	5·3	47	8·3	6·7	74	23·3	18·7
21	6·1	4·9	48	8·9	7·1	75	23·9	19·1
22	5·6	4·4	49	9·4	7·5	76	24·4	19·6
23	5·0	4·0	50	10·0	8·0	77	25·0	20·0
24	4·4	3·6	51	10·6	8·4	78	25·6	20·5
25	3·9	3·1	52	11·1	8·9	79	26·1	20·9
26	3·3	2·7	53	11·7	9·3	80	26·7	21·3
27	2·8	2·2	54	12·2	9·8	81	27·2	21·8
28	2·2	1·8	55	12·8	10·2	82	27·8	22·2
29	1·7	1·3	56	13·3	10·7	83	28·3	22·7
30	1·1	0·9	57	13·9	11·1	84	28·9	23·1
31	0·6	0·4	58	14·4	11·6	85	29·4	23·6
32	0·0	0·0	59	15·0	12·0	86	30·0	24·0
	+	+						
33	0·6	0·4	60	15·6	12·4	87	30·6	24·4
34	1·1	0·9	61	16·1	12·9	88	31·1	24·9
35	1·7	1·3	62	16·7	13·3	89	31·7	25·3
36	2·2	1·8	63	17·2	13·8	90	32·2	25·8
37	2·8	2·2	64	17·8	14·2	91	32·8	26·2
38	3·3	2·7	65	18·3	14·7	92	33·3	26·7
39	3·9	3·1	66	18·9	15·1	93	33·9	27·1
40	4·4	3·6	67	19·4	15·6	94	34·4	27·6
41	5·0	4·0	68	20·0	16·0	95	35·0	28·0
42	5·6	4·4	69	20·6	16·4			

Pressure Values.

Equivalents in Millibars of Inches of Mercury at 32° and Latitude 45°.

Mercury Inches.	·00	·01	·02	·03	·04	·05	·06	·07	·08	·09
	Millibars.									
27·0	914·3	914·6	915·0	915·3	915·7	916·0	916·3	916·7	917·0	917·4
27·1	917·7	918·0	918·4	918·7	919·0	919·4	919·7	920·1	920·4	920·7
27·2	921·1	921·4	921·8	922·1	922·4	922·8	923·1	923·4	923·8	924·1
27·3	924·5	924·8	925·1	925·5	925·8	926·1	926·5	926·8	927·2	927·6
27·4	927·9	928·2	928·5	928·9	929·2	929·5	929·9	930·2	930·6	930·9
27·5	931·2	931·6	931·9	932·3	932·6	932·9	933·3	933·6	933·9	934·3
27·6	934·6	935·0	935·3	935·6	936·0	936·3	936·7	937·0	937·3	937·7
27·7	938·0	938·3	938·7	939·0	939·4	939·7	940·0	940·4	940·7	941·1
27·8	941·4	941·7	942·1	942·4	942·8	943·1	943·4	943·8	944·1	944·4
27·9	944·8	945·1	945·5	945·8	946·1	946·5	946·8	947·2	947·5	947·8
28·0	948·2	948·5	948·8	949·2	949·5	949·9	950·2	950·5	950·9	951·2
28·1	951·6	951·9	952·2	952·6	952·9	953·2	953·6	953·9	954·3	954·6
28·2	954·9	955·3	955·6	956·0	956·3	956·6	957·0	957·3	957·7	958·0
28·3	958·3	958·7	959·0	959·3	959·7	960·0	960·4	960·7	961·0	961·4
28·4	961·7	962·1	962·4	962·7	963·1	963·4	963·7	964·1	964·4	964·8
28·5	965·1	965·4	965·8	966·1	966·5	966·8	967·1	967·5	967·8	968·1
28·6	968·5	968·8	969·2	969·5	969·8	970·2	970·5	970·9	971·2	971·5
28·7	971·9	972·2	972·6	972·9	973·2	973·6	973·9	974·2	974·6	974·9
28·8	975·3	975·6	975·9	976·3	976·6	977·0	977·3	977·6	978·0	978·3
28·9	978·6	979·0	979·3	979·7	980·0	980·3	980·7	981·0	981·4	981·7
29·0	982·0	982·4	982·7	983·0	983·4	983·7	984·1	984·4	984·7	985·1
29·1	985·4	985·8	986·1	986·4	986·8	987·1	987·5	987·8	988·1	988·5
29·2	988·8	989·1	989·5	989·8	990·2	990·5	990·8	991·2	991·5	991·9
29·3	992·2	992·5	992·9	993·2	993·5	993·9	994·2	994·6	994·9	995·2
29·4	995·6	995·9	996·3	996·6	996·9	997·3	997·6	997·9	998·3	998·6
29·5	999·0	999·3	999·6	1000·0	1000·3	1000·7	1001·0	1001·3	1001·7	1002·0
29·6	1002·4	1002·7	1003·0	1003·4	1003·7	1004·0	1004·4	1004·7	1005·1	1005·4
29·7	1005·7	1006·1	1006·4	1006·8	1007·1	1007·4	1007·8	1008·1	1008·4	1008·8
29·8	1009·1	1009·5	1009·8	1010·1	1010·5	1010·8	1011·2	1011·5	1011·8	1012·2
29·9	1012·5	1012·8	1013·2	1013·5	1013·9	1014·2	1014·5	1014·9	1015·2	1015·6
30·0	1015·9	1016·2	1016·6	1016·9	1017·3	1017·6	1017·9	1018·3	1018·6	1018·9
30·1	1019·3	1019·6	1020·0	1020·3	1020·6	1021·0	1021·3	1021·7	1022·0	1022·3
30·2	1022·7	1023·0	1023·3	1023·7	1024·0	1024·4	1024·7	1025·0	1025·4	1025·7
30·3	1026·1	1026·4	1026·7	1027·1	1027·4	1027·7	1028·1	1028·4	1028·8	1029·1
30·4	1029·4	1029·8	1030·1	1030·5	1030·8	1031·1	1031·5	1031·8	1032·2	1032·5
30·5	1032·8	1033·2	1033·5	1033·8	1034·2	1034·6	1034·9	1035·2	1035·6	1035·9
30·6	1036·2	1036·6	1036·9	1037·2	1037·6	1037·9	1038·2	1038·6	1038·9	1039·3
30·7	1039·6	1039·9	1040·3	1040·6	1041·0	1041·3	1041·6	1042·0	1042·3	1042·6
30·8	1043·0	1043·3	1043·7	1044·0	1044·3	1044·7	1045·0	1045·4	1045·7	1046·0
30·9	1046·4	1046·7	1047·1	1047·4	1047·7	1048·1	1048·4	1048·7	1049·1	1049·4

Pressure Values.

Equivalents in Mercury Inches at 32° and Latitude 45° of Millibars.

Millibars.	0	1	2	3	4	6	6	7	8	9
	Mercury Inches.									
910	26·87	26·90	26·93	26·96	26·99	27·02	27·05	27·08	27·11	27·14
920	27·17	27·20	27·23	27·26	27·29	27·32	27·35	27·38	27·41	27·44
930	27·46	27·49	27·52	27·65	27·58	27 61	27·64	27·67	27·70	27·73
940	27·76	27·79	27·82	27·85	27·88	27·91	27·94	27·97	28·00	28·03
960	28·05	28·08	28·11	28·14	28·17	28·20	28·23	28·26	28·29	28·32
960	28·35	28·38	28·41	28·44	28·47	28·50	28·63	28·56	28·59	28·62
970	28·65	28·67	28·70	28·73	28·76	28·79	28·82	28·85	28·88	28·91
980	28·94	28·97	29·00	29·03	29·06	29·09	29·12	29·15	29·18	29·21
990	29·24	29·26	29·29	29·32	29·36	29·38	29·41	29·44	29·47	29·60
1000	29·63	29·66	29·69	29·62	29·65	29·68	29·71	29·74	29·77	29·80
1010	29·83	29·86	29·89	29·92	29·94	29·97	30·00	30·03	30·06	30·09
1020	30·12	30·15	30·18	30·21	30·24	30·27	30·30	30·33	30·36	30·39
1030	30·42	30·45	30·48	30·51	30·63	30·56	30·59	30·62	30·65	30·68
1040	30·71	30·74	30·77	30·80	30·83	30·80	30·89	30·92	30·95	30·98
1050	31·01	31·04	31·07	31·10	31·13	31·16	31·18	31·21	31·24	31·27

Differences for tenths of a millibar :—

mb.	·1	·2	·3	·4	·5	·6	·7	·8	·9
in.	·003	·006	·009	·012	·015	·018	·021	·024	·027

Table for the Conversion of Temperature Readings on the Fahrenheit and Centigrade Scales to the Absolute Scale.

Fahr.	Cent.	Abs.	Fahr.	Cent.	Abs.	Fahr.	Cent.	Abs.
0	−17·8	255·2	40	+ 4·4	277·4	80	+26·7	299·7
1	17·2	255·8	41	5·0	278·0	81	27·2	300·2
2	16·7	256·3	42	5·6	278·6	82	27·8	300·8
3	16·1	256·9	43	6·1	279·1	83	28·3	301·3
4	15·6	257·4	44	6·7	279·7	84	28·9	301·9
5	15·0	258·0	45	7·2	280·2	85	29·4	302·4
6	14·4	258·6	46	7·8	280·8	86	30·0	303·0
7	13·9	259·1	47	8·3	281·3	87	30·6	303·6
8	13·3	259·7	48	8·9	281·9	88	31·1	304·1
9	12·8	260·2	49	9·4	282·4	89	31·7	304·7
10	12·2	260·8	50	10·0	283·0	90	32·2	305·2
11	11·7	261·3	51	10·6	283·6	91	32·8	305·8
12	11·1	261·9	52	11·1	284·1	92	33·3	306·3
13	10·6	262·4	53	11·7	284·7	93	33·9	306·9
14	10·0	263·0	54	12·2	285·2	94	34·4	307·4
15	9·4	263·6	55	12·8	285·8	95	35·0	308·0
16	8·9	264·1	56	13·3	286·3	96	35·6	308·6
17	8·3	264·7	57	13·9	286·9	97	36·1	309·1
18	7·8	265·2	58	14·4	287·4	98	36·7	309·7
19	7·2	265·8	59	15·0	288·0	99	37·2	310·2
20	6·7	266·3	60	15·6	288·6	100	37·8	310·8
21	6·1	266·9	61	16·1	289·1	101	38·3	311·3
22	5·6	267·4	62	16·7	289·7	102	38·9	311·9
23	5·0	268·0	63	17·2	290·2	103	39·4	312·4
24	4·4	268·6	64	17·8	290·8	104	40·0	313·0
25	3·9	269·1	65	18·3	291·3	105	40·6	313·6
26	3·3	269·7	66	18·9	291·9	106	41·1	314·1
27	2·8	270·2	67	19·4	292·4	107	41·7	314·7
28	2·2	270·8	68	20·0	293·0	108	42·2	315·2
29	1·7	271·3	69	20·6	293·6	109	42·8	315·8
30	1·1	271·9	70	21·1	294·1	110	43·3	316·3
31	− 0·6	272·4	71	21·7	294·7	111	43·9	316·9
32	± 0·0	273·0	72	22·2	295·2	112	44·4	317·4
33	+ 0·6	273·6	73	22·8	295·8	113	45·0	318·0
34	1·1	274·1	74	23·3	296·3	114	45·6	318·6
35	1·7	274·7	75	23·9	296·9	115	46·1	319·1
36	2·2	275·2	76	24·4	297·4	116	46·7	319·7
37	2·8	275·8	77	25·0	298·0	117	47·2	320·2
38	3·3	276·3	78	25·6	298·6	118	47·8	320·8
39	+ 3·9	276·9	79	+26·1	299·1	119	+48·3	321·3

Alternative Wind Specification.

Admiral Beaufort's Numbers.	Average of Velocity in Statute Miles an Hour.	Limits of Velocity in Statute Miles an Hour.	Equivalent Pressure in Pounds upon a Circular Disc one Square Foot in Area.	Description of Wind.	Mode of Estimating on Board Sailing Vessels.	Criteria for Steamships.
0	0	Less than 1	Less than ·01	Calm	...	Special consideration is required for the specification of the scale for use on board steamships. For this purpose it is recommended that as opportunity occurs use be made of the equivalents given in Col. 2. Thus, when the ship is steaming in a calm at 15 knots, the wind felt in an exposed position on board will be a moderate breeze, which, according to the table, is force 4 on the Beaufort scale, and, if a similar breeze is felt when the ship is steaming at 15 knots *right before the wind*, the actual speed of the wind will be 30 knots, 7 on the Beaufort scale, according to the table of equivalents. Other opportunities occur from time to time for comparing the speed of the wind with the speed of the ship. A hand anemometer may be employed if used judiciously and if proper allowance be made for the motion of the ship.
1	2	1 to 3	·01 to ·04	Light breeze	Sufficient wind for working ship.	
2	5	4 ,, 7	·05 ,, ·16			
3	10	8 ,, 12	·17 ,, ·44			
4	15	13 ,, 18	·45 ,, ·96	Moderate breeze	Forces most advantageous for sailing with leading wind and all sail drawing.	
5	21	19 ,, 24	·97 ,, 1·75			
6	27	25 ,, 31	1·76 ,, 2·88	Strong wind	Reduction of sail becomes necessary even with a leading wind.	
7	35	32 ,, 38	2·89 ,, 4·43			
8	42	39 ,, 46	4·44 ,, 6·45	Gale force	Considerable reduction of sail necessary even with wind quartering.	
9	50	47 ,, 54	6·46 ,, 9·00			
10	59	55 ,, 63	9·01 ,, 12·16	Storm force	Close reefed sail when running; or hove-to under storm sail.	
11	68	64 ,, 75	12·17 ,, 15·97			
12	Above 75	...	15·98 and above	Hurricane	No sail can stand even when running.	

APPENDIX II.

SEA SURFACE TEMPERATURE AS A GUIDE TO ICE.

Professor H. T. Barnes, D.Sc., F.R.S., Director and Professor of Physics at McGill University, Montreal, has recently made a study of the temperature changes in the ice-bearing waters of the St. Lawrence River. During the course thereof he developed a delicate resistance thermometer which records automatically temperature changes to an accuracy of one-thousandth of a degree. He asserts that approach to an iceberg is always indicated by a *rise of temperature above the surrounding sea temperature.* This rise is always followed by a rapid fall of temperature when a ship is abeam of an iceberg from half a mile to a quarter of a mile. An iceberg, he says, melting in salt water produces a zone of higher temperature about it, which has been traced as far as twelve miles! The individual effect of an iceberg, or of a group of icebergs, is to increase the temperature of the sea water, says Professor Barnes, two or three degrees Centigrade. This he terms the "iceberg effect." Can an iceberg, or a group of icebergs, be definitely located by means of the micro-thermometer of Professor Barnes? This is the condition of importance to the navigator. "In general," he is of opinion, that "it may be said that *an iceberg will make itself felt in the first place by a rapid rise of temperature as it is approached.* In the immediate vicinity of the berg the temperature falls quickly. The first warning will be when the temperature begins to mount up the scale above the surrounding sea temperature. . . . The actual temperature of the water in the ice track is no guide to the proximity of even the largest iceberg. . . . It is to the small variations of temperature we must look for the infallible guide, and *by means of the character of these variations we can determine the presence of ice, land, or currents.*" Professor Barnes has found that the temperature of the sea falls rapidly on approach to the coast. In June 1912, shortly after the lamentable loss of the palatial "Titanic" with many of her passengers and crew, a party of three members of the Bureau of Standards, Washington, D.C.—Messrs. G. W. Waidner, H. C. Dickinson, and J. J. Crowe—were granted every facility for determining the proximity of ice from temperature records on board the U.S. S. *Chester* and the U.S. S. *Birmingham* while those vessels were engaged on ice-patrol duties in the vicinity of the Banks of Newfoundland. Their conclusions, published by the United States Hydrographic Office, were most interesting, as the following quotation will show :—

"The temperature records published by Professor Barnes very generally show a rise in temperature as a berg is approached, occasionally accompanied by a slight fall in temperature very near the berg. Professor Barnes regards the rise of temperature as the 'characteristic iceberg effect,' and attributes any drop in temperature to cold currents. His records show the normal variations of sea-water temperature in the localities of his observations to be very much smaller than were observed in the parts of the ocean where our observations were made. Although many of the small temperature variations which appear significant in his records would be completely masked by the large and sudden temperature changes which our records show, nevertheless the magnitude of the so-called iceberg effect observed by Professor Barnes being often 0·5° to 2° C., such changes would be very evident on our records where changes of a few hundredths of a degree are readily discernible.

"Our records do not corroborate Barnes's characteristic iceberg effect. Twelve of the fourteen curves, as well as the mean curve, certainly show no such rise in temperature. Most of these curves indicate the opposite effect.

"As Professor Barnes's and our own records are matters of observation which unquestionably represent conditions that were actually encountered, it would seem that the effects due to bergs, if such effects can yet be regarded as established, must be different under different conditions. Indeed, that such is the case is shown by the different temperature records obtained in approaching a given berg along different courses.

"Enough data are not yet at hand to formulate a theory to account for the variations of temperature observed in the vicinity of icebergs. Indeed, the question is still in doubt as to whether they influence to any measurable extent the temperatures of sea water at any considerable distance (a mile or so).

"An examination of the temperature records, which were obtained under a variety of conditions, at once impresses one with the difficulty of separating the large and sudden variations of sea-water temperature, so frequently met with, from any variations that may be caused by the proximity of icebergs. The authors have obtained records in some parts of the ocean in which the temperatures were practically constant to a few tenths of a degree for many hours. On the other hand, some of the sample records submitted show that the temperature variations in other parts of the ocean, where no ice is near, are as great and as sudden as any observed in the neighbourhood of bergs. Having established the existence of such variations in sea-water temperatures, it follows that it will be very difficult and often impossible to draw definite conclusions as to the proximity of ice from temperature records.

"In approaching or leaving a berg, the temperature of the sea water may rise or fall or remain practically constant.

"Barnes's records so uniformly show a rise of temperature as the berg is approached that he has termed this observed rise 'the iceberg effect.' This effect is not characteristic of our records. Indeed, on the average, the authors observed a fall in temperature from a distance of several miles up to the bergs. In view of the erratic variations of the temperature of these parts of the ocean when no ice is near and of the fact that in approaching a given berg along different courses the temperature variations are quite different (being nearly constant over some courses and falling very appreciably over other courses) we would not deem it justifiable to conclude that the observed variations were certainly connected with the presence of the bergs.

"It is interesting to inquire a little further into the question whether any cooling action of the berg could be expected to make itself felt at any considerable distance from the berg. If the berg is constantly drifting into new waters such effect would obviously be impossible from the consideration of the fact that it would require the melting of about a million tons of ice to cool one square mile of the ocean to a depth of only 25 feet by 1° C., hence the possibility of any significant cooling action would require that the berg and the water in which it is immersed drift together for a considerable period of the time—*i.e.* that the relative motion be small. This is probably true under some conditions, but by no means always. Considerations, such as these, of the enormous mass of ice required to produce a cooling action distinguishable from temperature variations due to other causes, the slowness of melting of the berg, etc., render it doubtful whether any such effect could be distinguished with certainty at distances of a mile or so. To account for the observed rise in temperature or 'iceberg effect,' Barnes has advanced an ingenious theory. He assumes that in regions of the ocean at some distance from the berg the surface layer, heated by solar radiation, is mixed with the colder water below by the 'normal vertical circulation.' While near the berg there is a current set up toward the berg due to the combined effects of the melting and cooling action of the berg. This current toward the berg, it is assumed, interferes with 'the normal vertical circulation' so that the warm water remains on the surface. It is difficult to understand how a sufficiently strong current toward the berg could be set up by the melting and cooling action of the berg to interfere with the 'normal vertical circulation' at a distance of a mile or two. That there is no very strong current toward the berg seems to be indicated by the drifting apart of the fragments of a berg from the berg itself or of the larger parts of a berg after breaking up. Difference of wind action may, however, complicate any conclusions based on such observations.

"CONCLUSIONS.

"The records of sea-water temperatures obtained by means of an electrical resistance thermometer and a Leeds and Northrup temperature recorder, installed on the U.S. S. 'Chester' and 'Birmingham' in their patrol of the North Atlantic Ocean in June and July 1912, show that the temperature variations in parts of the ocean far removed from ice are often as great and sudden as in the neighbourhood of icebergs.

"For a majority of the courses of the ship in the vicinity of icebergs there was a fall in temperature from a fraction of a degree to 3° in the distance of 4 or 5 miles on approaching the berg. Records were obtained, however, in which the character of the temperature variation varied with the direction of approach to the berg, the temperature being nearly constant over one course, while over other courses the temperature rose or fell as the berg was approached. So far as our records go, therefore, it does not seem possible to draw positive conclusions as to the absence or proximity of ice from the temperature records of sea water. This is not a condemnation of the use of suitable recorders on ships. As Barnes has shown, the temperature record may give valuable information on the approach to shore and shallow water, on the identification of characteristic ocean currents; and, as his records seem to show, even of the proximity of icebergs in some parts of the ocean where the variations are less erratic than in the regions in which our observations were made.

"If the 'characteristic iceberg effect' observed by Barnes, *i.e.* rise of temperature on approaching icebergs, had been present around the bergs observed by us and of the same or even much less magnitude, our records would have rendered such an effect evident, notwithstanding the irregular variations of temperature usually found to exist. In view of the differences in the character of the records obtained by Barnes and the authors, it is very desirable that further observations be made in different parts of the ocean, and under as varied conditions as possible, before attempting to draw final conclusions."

So far as the observations of these three experts went, the air temperature in the shade did not furnish any evidence of value as to the proximity of a berg.

APPENDIX III.

A NEW DEPARTURE IN BAROMETER GRADUATION.

Barometric Pressure in Pressure Units.

In their Eighth Report to the Lords Commissioners of His Majesty's Treasury, the Meteorological Committee intimated their intention to use Absolute Units for pressure in the Daily Weather Report of the British Meteorological Office from 1st May 1914.

The absolute unit of pressure on the Centimetre-Gramme-Second system is the dyne per square centimetre. As this unit is exceedingly small, a practical unit one million times as great has been suggested. This unit, the megadyne per square centimetre, is called a "bar." In the British Meteorological Office Daily Weather Report the centibar and the millibar, respectively the hundredth and the thousandth part of the "bar," are adopted as working units. The relation between the millibar and the inch of mercury is given in a table on page 188.

One of the principal reasons for this change is that it is a step towards the adoption of a system of units which may become common to all nations.

The system was approved by the Meteorological Council in 1904, and by the Gassiot Committee of the Royal Society in 1910. Upon the initiative of Professor V. Bjerknes, formerly Professor at Christiania, and later of the Geophysical Institute at Leipzig, it was used in important publications of the Carnegie Institution of Washington, and was adopted by the International Commission for Scientific Aeronautics for the international publication of the results of the investigation of the upper air. Since 1907 the system has been used in the Meteorological Office for the upper air, and since 1911 for the data from the Observatories where Centimetre-Gramme-Second units have been used for many years in connection with magnetism and electricity. The Weather Bureau of the United States has adopted *millibars* and *absolute temperatures* on the Centigrade Scale for the issue of daily charts of the Northern Hemisphere, which began on 1st January 1914; the Royal Meteorological Society has decided to use *millibars* for the expression of the series of pressure normals for the British Isles, which it is now preparing; and the British Meteorological Office has followed the example of the Weather Bureau in using absolute units for the daily maps in the Weekly Weather Report, but its isobars are figured in centibars, as they were in the specimen issued with the Eighth Annual Report of that Office.

The ground of scientific appeal to all nations to adopt the bar, centibar, and millibar is that these units fall naturally into place as members of the Centimetre-Gramme-Second system of units, which has already become universal for Magnetism and Electricity and most branches of Physics. Its principles are, therefore, well known. The inch and the millimetre are really units of length, and to estimate the effect of a pressure measured in terms of height of a column of mercury, it is necessary to introduce the value of the density of mercury at some particular temperature and the value of the acceleration due to gravity at a particular place. It is well known that the atmospheric pressure at sea level in Britain varies between $13\frac{3}{4}$ and $15\frac{1}{4}$ lbs. weight per square inch. The pound weight per square inch is often used by engineers, but it is not a convenient unit, because its value depends upon latitude.

The past fifteen years have witnessed the collection of extensive meteorological observations in the upper air, made by means of kites and balloons, from which important results have already been deduced. The absolute system of units is the most convenient for the discussion of the data so collected, and it is being generally adopted for the purpose. The rapid development of aviation makes it impossible to draw a line between the academic study of the meteorology of the upper air and the practical meteorology of the British Daily Weather Report. The use of two systems of units, one for observations made at the surface, and the other for observations taken at higher levels, could only retard progress.

It is acknowledged that an accuracy of one-thousandth of an inch is not really attainable in practice. For many years the Inspectors of the British Meteorological Office have had to be satisfied with agreement within ·003 inch, and now the National Physical Laboratory has ceased to certify barometers of the Kew pattern to the thousandth of an inch. Consequently, with an instrument graduated to ·001 inch, observers are being asked to read to an accuracy which is acknowledged to be unattainable. On the other hand, an accuracy of the hundredth of an inch is not good enough for scientific purposes.

The practical degree of precision for a mercury barometer of the Kew type is *one-tenth of a millibar*. Graduation in centibars and millibars, with a simple vernier scale for estimating to tenths of a millibar, thus brings the demand for accuracy made upon the observer into harmony with that actually attainable. The new graduation does away with the complications of the conventional vernier scale in use on barometers graduated in inches, and consequently the risk of errors of observation is reduced.

Another advantage is that the Bar, or Centimetre-Gramme-

Second atmosphere, differs but little from the standard atmosphere. The equivalent of the adopted normal value at sea level of 29·92 mercury inches is 101·32 centibars, or 1013·2 millibars. The lowest barometer value ever observed for sea level in the British Isles is 925·5 millibars, the equivalent of 27·33 inches. This value was recorded at Ochtertyre on 26th January 1884. The highest value is 1053·5 millibars, the equivalent of 31·11 mercury inches. It was recorded at Aberdeen on 31st January 1902.

A reading at 100 centibars, or 1000 millibars, is equivalent to 29·53 mercury inches. It will be remembered that the word "change" is placed opposite the sea level reading 29·5 in the conventional descriptions engraved on dial barometers. Thus in a barometer graduated in centibars the reading 100 would occupy the position conventionally marked "change."

Practical Course to be Pursued.

It is evidently impossible at one operation to change all the barometers in use in the various services, and even in the most favourable circumstances there must be for many observers a time when the readings are taken on one scale, and the results quoted or published in another. Tables of equivalents are given on pp. 188, 189 for making the necessary conversion.

The above explanation is almost identical with a circular issued by Sir Napier Shaw, F.R.S., Director of the British Meteorological Office, which recently appeared on several issues of the Meteorological Chart of the North Atlantic over his signature.

THE SAILOR'S RULE-OF-THREE.

In a storm at sea there's a rule of three
Which every sailor knows,
And all but fools observe these rules,
No matter how hard it blows.
(1) Always lie-to on the coming-up tack,
For if you don't you'll get taken aback,
And for ever thereafter regret it.
(2) Many a man his vessel saves,
By using oil to calm the waves,
And don't you ever forget it.
(3) Look out for the first rise after low,
When the wind will shift and stronger blow
—Well, follow these rules, and let it!

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