Rainfall.—Whatever tends to lower the temperature of the air below the dew-point is a cause of rain. It is therefore to the winds we must chiefly look for an explanation of the rainfall, and the broad principles of the connexion may be stated to be these five:—(1) when the winds have previously traversed a considerable extent of ocean, the rainfall is moderately large; (2) if the winds advance at the same time into colder regions, the rainfall is largely increased, because the temperature is sooner reduced below the point of saturation; (3) if the winds, though arriving from the ocean, have not traversed a considerable extent of it, the rainfall is not large; (4) if the winds, even though having traversed a large extent of ocean, yet on arriving at the land proceed into lower latitudes or regions markedly warmer, the rainfall is small or nil; (5) if a range of mountains lies across the onward path of the winds, the rainfall is largely increased on the side facing the winds, and reduced over the regions on the other side of the range. The reason here is that, the air on the windward side of the ridge being suddenly raised to a greater height in crossing the range, the temperature is further reduced by mere expansion, and a more copious precipitation is the result; whereas on the leeward side as the air descends to lower levels it becomes gradually drier, and accordingly the rainfall rapidly diminishes with the descent.

We have drawn attention to the diminished velocity of the wind over land as compared with the open sea (p. 125). From this it follows that an envelope of stiller air or air of less velocity than that of the prevailing wind broods over the land, and by its presence forces the prevailing wind to a greater height, thus tending to increase the rainfall. If the foreshore rises within a few miles to a height of 200 or 300 feet, the result is very striking when the wind from the sea blows straight upon it. Thus at Spittal, near Berwick, on September 1877, a N.E. wind blew straight ashore at an estimated velocity of 25 miles an hour. To eastward the sky was singularly clear down to the horizon, but te westward all the country beyond a mile from the shore was enveloped in what appeared a dense mist or fog. About 15° to eastward of the zenith of an observer on the shore, the thinnest rack of cloudlets was seen emerging without intermission from the deep stainless blue of the sky, which as they drifted landward increased so rapidly in volume and density that the zenith was three-fourths covered with clouds. A similar phenomenon was seen in September 1879 on board the Orkney steamer at the magnificent cliff of Hoy Island, Orkney. A heavy storm had just cleared away, and a strong W.N.W. wind was blowing right against the cliff. The sky was absolutely cloudless all round, except the upper 300 feet of Hoy Hill, 1570 feet high, which was enveloped in a thick mist that stretched away to windward, some distance to westward of the steamer's course, which was about 2 miles from land. The western termination of the cloud was the thinnest rack of cloud, which emerged unceasingly from the blue sky at a distance not less than 4 miles to windward of the cliff. The constituent parts of the cloud itself were in rapid motion eastward, but, owing to the fresh accessions it was constantly receiving, the cloud itself appeared stationary. Thus the wind was forced upward into the atmosphere for some considerable distance to windward of the ridge lying across its path.

It is this dragging effect of the land on the wind, and the consequences which result from it, that explain how it is that during storms of wind and rain from the north-east the rainfall over the foreshores of the Firth of Forth, the Moray Firth, and the Pentland Firth looking to the north-east is so much in excess as compared with the rest of Scotland. The same principle explains the heavy rainfall in plains at some distance from the range of hills lying across the wind's path and on the side of the rain-bringing winds.

For short intervals of time the heaviest rainfalls occur with tornadoes, waterspouts, and some other forms of the whirlwind, the reason being that not only is there rapid expansion due to the rapid ascent of the air, but also great rarefaction is produced by the extreme velocity of the aerial gyrations round the axis of the tornado. On August 1, 1846, 3·12 inches of rain fell at Camberwell, London, in two hours and seventeen minutes. Of heavy falls may be mentioned 4·60 inches in London, April 13, 1878; 6·00 inches at Tongue, September 7, 1870; 5·36 inches in Monmouthshire, July 14, 1875; 6·62 inches at Seathwaite, Cumberland, November 27, 1848; and 7·12 inches at Drishaig, Argyllshire, December 7 to 8, 1863. But it is in lower latitudes that the heaviest single showers have been recorded. The following are among the most remarkable:—at Joyeuse, France, 31·17 inches in twenty-two hours; at Genoa, 30·00 inches in twenty-four hours; at Gibraltar, 33·00 inches in twenty-six hours; on the hills above Bombay, 24·00 inches in one night; and on the Khasi Hills, India, 30·00 inches on each of five successive days.

As regards the ocean, there are no available data from which an estimate could be formed as to the amount of the rainfall, since the rainfall statistics of the ocean must be regarded as giving hardly anything more than the comparative frequency of the fall. It is, however, certain that the equatorial belt of calms in the Atlantic and Pacific between the trades is the region where the ocean rainfall reaches the maximum, and the parts of these oceans are the rainiest which are the longest within the belt of calms as it shifts its position northward and southward with season. While the cloud-screen is undoubtedly dense, and the rainfall frequent and heavy, the careful observations of the "Challenger" and "Novara" show that the statements generally made as to these points are greatly exaggerated.

In the regions of the trades the rainfall is everywhere small over the open sea, seeing that the trade-winds are essentially an outflow from anticyclonic regions, and their original dryness is to a large extent maintained because their course is directed into regions which become constantly warmer. Thus at Ascension, lat. 8° 45′ S., which is throughout the whole year within the S.E. trades, the mean rainfall for the two years 1854–55 was only 8·85 inches. At St Helena, which lies constantly within the same trades, five years give a mean rainfall of 5·36 inches on the coast; but in the same island at a height of 1763 feet the annual amount rises to 23·98 inches. Malden Island and some other islands in the Pacific, about long. 150° W., and for some distance on each side of the equator, have been pointed to by Scott as practically almost rainless, as is shown by their containing extensive guano deposits. These islands are situated somewhat similarly to Ascension with respect to the zone of calms. In Mauritius the annual rainfall on a mean of four years was 30 inches at Gros Cailloux, but at Cluny, only 16 miles distant, for the same four years it was 146 inches; in regard to which Meldrum remarks that at Cluny, which is in the vicinity of mountains and forests, in the south-east of the island, and thus directly exposed to the trade-wind as it arrives from the sea, the rainfall in almost any month is from four to six times greater than at Gros Cailloux on the north-west coast, where neither mountain nor forest exists, and where the S.E. trade arrives considerably drained of its moisture.

From what has been said it is evident that the heaviest rains will be brought by the winds which have traversed the greatest extent of ocean within the tropics, and which accordingly of all ocean winds have the highest temperature and humidity. These conditions are most completely fulfilled during the summer months of the northern hemisphere by the winds which, commencing from near lat. 30° S., blow home on southern Asia as the well-known S.W. monsoon of these regions. Accordingly it is by the winds of this monsoon that a larger rainfall is distributed over a larger portion of the earth's surface than occurs anywhere else in any season; and this large rainfall is in many regions still farther greatly increased by the mountain ranges which lie across the path of the rain-bringing winds.

It is on these winds that the rainfall of India chiefly depends. Along the whole of the west coast from the

Gulf of Cambay southward, and on the Western Ghats, the rainfall is excessive. The following are some of the more interesting annual means in inches beginning with Bombay and proceeding southwards:—Bombay, 74; Matheran, 247; Mahabaleshwar, 252; Ratnagiri, 104; Baura, 255; Goa, 102; Karwar, 115; Honawar, 139; Mangalore, 134; Cannanore, 132; Calicut, 116; and Cochin, 114. In the west of Ceylon the rainfall is also heavy, being at Colombo 87, at Galle 91, and at Ratnapura, at some distance inland among the hills, 149. Since the S.W. monsoon is drained of much of its moisture in crossing these mountains, a greatly diminished rainfall is distributed over the interior and east side of India, and on the eastern slopes of Ceylon.

If now we cross to the eastern shores of the Bay of Bengal, we again encounter an excessive rainfall along these coasts and up the slopes of the mountains looking down on them. Thus from south northward the following are among the more characteristic rainfalls in inches:—Nancowry, 102; Port Blair, 116; Mergui, 152; Tavoy, 196; Maulmain, 189; Rangoon, 100; Bassein, 98; Sandoway, 212; Akyab, 198; and Chittagong 104. On the other hand, at Thyetmio, inland on the Irawadi, the annual rainfall is only 48 inches.

We have shown how, in accordance with the peculiar distribution of pressure in India in summer, the monsoon is diverted up the valley of the Ganges as an E.S.E. wind, distributing on its way, even to the head of the valley, in a generous rainfall the moisture it has brought from the Indian Ocean and the Bay of Bengal. The rainfall does not extend farther westward than the basin of the Ganges, and the precipitation is most copious along the lower Himalayas, the largest falls being recorded at heights about 4000 feet,—being, as pointed out by Hill, near the level at which the summer monsoon is cooled just below its dew-point. The following are some of the larger rainfalls in inches, beginning with the more western:—Mussooree, 95; Naini Tal, 92; Khatmandu, 57; Darjiling, 121; Kurseong, 154; Buxa, 219; Kuch Behar, 131.

The rainfall is very large in the north-east angle of the Bay of Bengal and thence northwards towards Bhutan, or at the angle where the summer monsoon from the bay curves round to a westerly course on its way up the Ganges. Thus at Noakhally, on the coast, it amounts in inches to 109; at Tura, on the Brahmaputra, immediately to west of the Garo Hills, 129; at Silchar and Sylhet to eastward, 117 and 155; whilst at Cherrapunji, on the Khasi Hills, it rises to 493·19 inches on a mean of twenty-four years. This last rainfall is the largest known on the globe, the causes of which are the highly saturated state of the monsoon on its arrival at the lower Ganges, the high mountain range of Burmah to eastward of Bengal, which turns the monsoon to the north, and the protrusion westwards of the Khasi and Garo Hills so as to lie in the line of that branch of the monsoon which passes from the lower Ganges into the basin of the Brahmaputra above Goalpara. The consequence is that the highly saturated air of the monsoon in its passage across the Khasi Hills is suddenly raised to a height of about 6000 feet, and being thereby reduced far below the point of saturation the superabundant moisture is precipitated in unequalled deluges of rain. The amount of the annual rainfall at all these places is determined, essentially if not altogether, by the rains of the summer monsoon, the relative intensity of which over India may be taken to be fairly represented by the rainfall of July.

The rains which accompany the N.E. monsoon of the winter months may be represented by the rainfall for January. These are heaviest in Ceylon, especially on its east slopes, and in southern India, or where the N.E. monsoon arrives after having traversed a large extent of ocean. The fall for the month exceeds 6 inches over a large portion of the east coast, whilst at Colombo in the west the rainfall is only half that amount, and farther north at Pattalum the January rainfall is only 1·82 inches. In southern India the amount varies from about 1 to 2 inches. Blanford pointed out in 1873 (*Phil. Trans.*, vol. clxiv. p. 618) that, while the surface winds of northern India in winter are northerly, on the Himalayas, especially the north-west portion, southerly winds prevail during the cold months. It is these upper southerly winds which bring the winter rains to the Punjab, Upper India, and the highlands of Assam. It is further to be noted that winter rains also occur in Central India, where the prevailing surface winds are from east and north-east. The mean rainfall of January at Mussooree is 2·00 inches and at Naini Tal 2·86 inches, and in Assam, at Sibsagar, 1·13 inch. Over a large tract of the east side of southern India from Nellore southward, including Ceylon, the maximum rainfall for the year occurs in the months of October and November.

Rainfall of the Malay Archipelago and Australia.—Under the direction of the late Dr Bergsma, systematic observations of the rainfall of the Malay archipelago were begun in 1879, the number of stations being 150. The results of the first three years show that the mean annual rainfall over the archipelago varies from about 60 inches in Timor to upwards of 200 inches at some spots among the western slopes of Sumatra. But the most important feature in the rainfall in its relations to climate is not the absolute amount that falls annually, but rather the manner of its distribution through the months of the year. Over the greater number of the islands rain falls copiously every month; but as regards some of the islands the year is divided into dry and wet seasons as marked as are seen in the climates of India. The key to this essential difference among the climates is the distribution of atmospheric pressure during the months of the year from south-eastern Asia to Australia, with the resulting prevailing winds. During the winter months atmospheric pressure is high in south-eastern Asia and low in the interior of Australia, the difference being about three-quarters of an inch. Since between these two regions the fall in the mean pressure is practically uninterrupted, the Malay archipelago lying between them is swept by northerly winds (fig. 14). As these winds have traversed a great breadth of ocean in their course, they arrive in a highly saturated state, and consequently deposit a copious rainfall, particularly on the northern slopes of the higher islands. Hence in these months the rainfall over the islands without exception is large, the mean monthly amount being in many cases more than 30 inches. These winds continue their course to southward towards the low-pressure region in the interior of Australia, and deposit along the north coasts of that continent a monthly rainfall rising generally to from 14 to 20 inches. On advancing into the interior, the mean amount gradually diminishes at the successive telegraphic stations to 3·50 inches at Alice Springs near the tropic of Capricorn. The amount of the rainfall for any particular year, and the distance from the coast to which the rains penetrate inland, depend essentially on the height of the winter pressure of south-eastern Asia as compared with the low mean pressure of central Australia, by which the strength of the northerly monsoon is regulated.

On the other hand, during the summer of the northern hemisphere pressure is high in the interior of Australia and low in China, the mean difference being about half an inch. Between the two regions the fall in the mean pressure is continuous and uninterrupted, and as a consequence southerly winds prevail over the intervening archipelago. These winds, as they advance from the continent into lower latitudes, are absolutely rainless in the north of Australia, and over Timor and the other Malay islands which are separated from Australia only by a comparatively narrow belt of sea. During the three years no rain whatever fell in Timor in July and August, and the fall in June, September, and October was small. As, however, the winds pursue their course to northward, they eagerly lick up moisture from the sea, so that by the time they arrive at Amboyna they have become so saturated that the monthly rainfall there rises to nearly 30 inches. Again at some distance to the west of Timor rain falls more or less regularly every month, the amount increasing in proportion to the extent of ocean traversed by the S.E. winds, which advance towards these islands from the direction of Australia. These marked differences among the climates of the Malay archipelago, which, since they really depend on the geographical distribution of land and sea of this part of the globe, must be regarded as permanent differences, have played no inconspicuous part in the singular distribution of animal and vegetable life which characterizes the archipelago.

In July the prevailing wind in West Australia is N.W., and the rainfall reaches the maximum for the year, whereas in January the wind is S.E., and the rainfall is the minimum. Similarly in January since the winds of the southern half of South Australia and Victoria are from the south, and thus blow towards warmer regions, the rainfall is either at the annual minimum, or it is small. But on rounding the coast and proceeding northward, the wind becomes E., then N.E., and ultimately N. in the north of Queensland. With this prevalence of oceanic and equatorial winds, the rainfall at this time of the year rapidly rises over the whole of the eastern slopes, till at Cape York it is about 20 inches. In the basins of the Murray and Darling rivers, which are shut off from the east by the mountain ranges of New South Wales, the rainfall is only about an inch and a half. On the other hand, to south of the latitude of Sydney, including Tasmania, the maximum rainfall occurs in winter over those regions which slope south towards the sea. On crossing the mountain range of Victoria into the basin of the Murray river, the rainfall rapidly diminishes. In the north of New Zealand the winter rainfall is the heaviest; but farther south, where westerly winds prevail with some steadiness through the year, the rainfall is more equally distributed through the months; and, as the prevailing winds are westerly, the heaviest rainfall is in the west of the islands. Thus at Pokitika in the west near sea-level, and not far from a lofty range of mountains to the east, the annual amount reaches 120 inches, and at Bealey inland at a height of 2104 feet it is 106 inches. At Wellington the annual rainfall is 52 inches, at Southland 46, at Dunedin 34, and at Christchurch 25, thus showing, in the rainfall of the two sides of the island, extremes nearly as great as in Scotland.

Rainfall of Europe.—As regards rainfall, Europe may be conveniently divided into two distinct regions,—western and northern Europe, extending in a modified degree through the interior of the continent into Siberia, and the countries bordering on the Mediterranean. A vast ocean on the one hand, a great continent on the other, and a predominance of westerly winds are the determining circumstances in the distribution of the rainfall over western Europe. Hence the rainiest regions are to be found in the west, where mountain ranges stretch north and south. The annual rainfall exceeds 80 inches over a considerable district, including the greater part of Skye and portions of the counties of Inverness and Argyll to the south-east, in the lake district of England, and in the more mountainous parts of North Wales,—these three districts being the wettest in Europe. As Ireland presents no continuous range of mountains opposing the westerly winds of the Atlantic, no Irish rain-gauge shows a mean rainfall of 80 inches. A point of some interest is suggested by the rainfall of the counties of Kirkcudbright and Dumfries in Scotland. These counties offer to the westerly winds a series of valleys sloping south to the Solway Firth, which show successively a diminished rainfall on advancing eastward till at several places in Nithsdale and Annandale it does not exceed 40 inches. But in Eskdale, farther to the east, the rainfall instead of falling increases to about 60 inches. The reason is that the westerly winds are obstructed in their onward course by the range of hills by which Eskdale is bounded on the east, in surmounting which the winds are much reduced in temperature, and their superabundant moisture falls in copious rains immediately to westward of the ridge. The cause of the larger rainfall of Eskdale is thus analogous to that of the large rainfall of the coast in the north-east of the Bay of Bengal immediately under the Assam range of mountains. In England the largest annual rainfall is 146 inches at Seathwaite in the Lake district, in Scotland 128 inches at Glencroe in Argyll, whilst in Ireland the largest is only 76 inches. The driest part of the British Islands is an extensive district to south-south-west of the Wash, with a rainfall of about 21 inches. A large extent of England, and all the more important agricultural districts in Scotland, have a rainfall under 30 inches: the greater part of England, and nearly the half of Scotland, have a rainfall not exceeding 40 inches; but in Ireland it is isolated patches only that show a rainfall less than 40 inches.

In the west of Norway the rainfall in inches is 72 at Bergen, 51 at Aalesund, 46 at the Naze and in the Lofoten Isles, falling to 10 at the North Cape. At Christiania, Upsala, and a large part of the east of Scandinavia the rainfall is about 21 inches, falling to 16 inches on the north coast of the Gulf of Bothnia. In Russia and Siberia it rises only at a few places to 20 inches, several districts of this extensive region having an annual rainfall of 10, 5, 3, or even 2 inches. The rainfall of Spain presents great extremes—from 68 inches at Santiago to 13 inches at Saragossa. In France and the plains of Germany the average varies from 35 to 20 inches, but in mountainous regions these figures are greatly exceeded, rising through all gradations to upwards of 100 inches at some points in the Alps.

An important distinction between the manner of distribution of the rainfall in the west of Europe and at more inland places is that the greater part of the annual quantity of the west falls in winter, whilst in the interior the amount in summer is greater than in winter. The rainfall of January and July shows this in a very forcible manner. The summer climates of the extreme south of Europe and North Africa are rainless, and over extensive regions in the south of Europe adjoining the July rainfall does not amount to an inch. Over these dry regions the prevailing winds of summer are northerly, and hence the drought which characterizes them. On the other hand, the rainfall in the interior of the continent is large. In January the maximum rainfall occurs on the mountains and high grounds overlooking the Atlantic, and the minimum on the plains of Russia.

Owing to the way in which Europe is broken up by the seas which diversify its surface, the time of the year when the rain attains the maximum differs greatly in, different regions. This phase of the rainfall occurs, indeed, according to locality, in all months except February, March, and April. The month of occurrence of the annual maximum rainfall over Europe is shown by fig. 18. A similar map

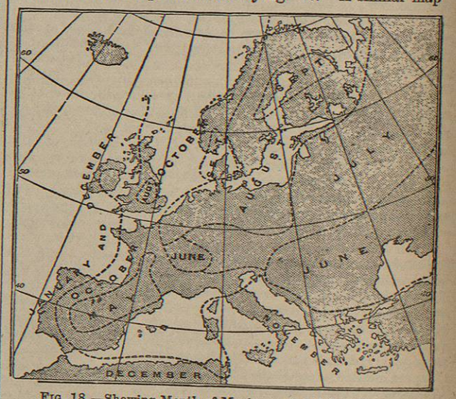

FIG. 18.—Showing Month of Maximum Rainfall in Europe.

representing the month of least rainfall shows still greater uniformity in a regular succession of the months in passing from region to region. Thus the month of least rainfall is January on the lower Volga, February in western Russia and the greater part of central Europe, March in the north of France and south of Great Britain, April farther to the north,

May in Scotland north of the Grampians, June in Orkney, Shetland, Iceland, the west of Ireland, and the north-west of France, and July over the whole of the south of Europe. The driest month occurs nowhere in Europe in any of the five months from August to December.

Rainfall of North America.—West of the Rocky Mountains the rainfall is very unequally distributed, the annual amounts varying from 86 inches at Astoria, near the mouth of the Columbia river, to 8 inches at San Diego on the coast, and 3 inches at the head of the Gulf of California. Over the whole of the region between the Cascade and Rocky Mountains the rainfall at all seasons is extremely small, this being indeed that feature in the climate to which the formation of the cañons of that region is chiefly to be referred. On the other hand, in the United States and Canada to east of long. 100° W. the distinguishing feature of the rainfall is the comparative equableness of its distribution, an annual rainfall exceeding 50 inches occurring only over restricted districts, and a rainfall as low as 20 inches being scarcely met with anywhere. The regions where the rainfall exceeds 50 inches are Florida, the lower basin of the Mississippi, and the Atlantic seaboards of Nova Scotia and Newfoundland.

In January the annual maximum rainfall occurs over the whole of the west coast from Sitka to lower California; but in the interior between long. 120° and 95° W. the amount is everywhere small, and over a considerable part in the south-west of this region no rain falls. The region of largest rainfall extends from Louisiana to West Virginia, where the mean varies from 4 to 6 inches. Over nearly the whole of the Dominion of Canada, by much the greater part of the winter precipitation is in the form of snow, which has been carefully measured and recorded by the Meteorological Service. The average snowfall for January exceeds 30 inches at St John's, Newfoundland, in Anticosti, Prince Edward Island, and in many other regions.

In July the rainfall is everywhere small in the west, a large part of this extensive region being absolutely rainless. The remarkable dryness of the climate at this season is due to the N.W. winds that set in towards the low pressure of the interior, which thus blow towards warmer regions. The rainfall to the east of the Rocky Mountains is distributed by the winds which are connected with the low-pressure region of the interior and with the high-pressure region of the Atlantic. The result is two regions of larger rainfall, the one in the south-east of the States and the other to the west of the lakes. The summer winds of the south-eastern coasts are southerly, and as they are anticyclonic in their origin and have in their course traversed some extent of ocean, they arrive well- but not super-saturated, and pour down a rainfall in July of 6 inches and upwards along the coasts and for some distance inland from Louisiana to Chesapeake Bay. Further, since in July these winds attain their maximum force and persistency, the rainfall at the same time reaches the maximum along the whole coast from Boston to some distance west of New Orleans. Since the summer winds blow in the line of the Alleghany mountains and not across them, the rainfall diminishes in ascending their slopes. The comparative equableness of the rainfall over the eastern States is the necessary result of the winds' passing into higher latitudes, and, therefore, cooler regions. A broad region where the rainfall is less than on each side of it, extends from Michigan to the south-west as far as Canadian River. To the west of the lakes the rainfall rises above 4 inches, and, since over this region the winds become somewhat easterly as they flow towards the low-pressure area, it is probable that the larger rainfall of this prairie region has its origin in no small degree in the evaporation of the lakes. On ascending the higher reaches of the Mississippi, the amount diminishes, but scarcely falls lower than 2 inches, being thus analogous to the summer rains of the Upper Ganges. On crossing the water-parting into the basin which drains into Hudson Bay, we encounter E. and N.E. winds laden with vapour licked up in their passage over Hudson's Bay, which they distribute in a generous rainfall of probably 3 to 5 inches over the rising colonies of Manitoba and Saskatchewan. An important point in the climate of the States is that over nearly the whole of the extensive region stretching between Alleghanies and Rocky Mountains, except the south coast already referred to, the annual maximum rainfall does not occur in summer but in spring, the month of largest rainfall in the great majority of cases being May. In the basin of Hudson's Bay July is the month of largest rainfall.

Rainfall of Central and South America.—The following are, in inches, the larger and more interesting annual rainfalls round the coasts:—Vera Cruz, 182; Belize, 75; Maracaibo, 163; Caracas, 155; Georgetown, 95; Paramaribo, 142; Cayenne, 140; Para, 71; Pernambuco, 109; Buenos Ayres, 34; Bahia Blanca, 19; Puerto Montt, 102; Valdivia, 109; Valparaiso, 100; Serena, 93; Lima, 9; and a large part of Peru, nil. A remarkable feature of the rainfall of South America is the large amounts that fall in the basins of the Orinoco and Amazon; the fall is 91 inches in the upper basin of the Madeira, and 112 inches at Yquitos (lat. 3° 40′ S., long. 72° 57′ W.). The reason is that this immense region, where pressure appears to be almost constantly low, is open to the highly saturated winds that blow from the equatorial Atlantic. Quite different is the distribution of the rainfall over the La Plata basin. The annual falls, in inches, are 92 at Joinville, 58 at Corrientes, 44 at Monte Video, 36 at Parana, 24 at Santiago, 22 at San Luis, and only 6 at Mendoza. The fall rapidly rises in ascending the eastern slopes of the Brazil mountains facing the South Atlantic; thus, while the amount at Rio Janeiro is 45 inches, on the hills to northward it is 116 inches.

In January northerly winds prevail on the south coasts of the Gulf of Mexico and the Caribbean Sea, and as they have their origin in the high pressure of the American continent, and in crossing the sea pass into lower latitudes, the January rainfall of these coasts is comparatively small. In July, however, the prevailing winds are easterly, and as they have traversed a large extent of the equatorial waters of the Atlantic they are highly saturated, and consequently the July rainfall of these coasts is everywhere very large. The following are, in inches, the January and July rainfalls:—Caracas, 1·00 and 14·04; Guatemala, 0·28 and 10·79; Vera Cruz, 5·10 and 35·90. The seasonal distribution of the rainfall in the basin of the Amazon is the reverse of this. In January the position of the belt of calms is about lat. 3° N., and as pressure is relatively low over the basin of the Amazon, especially its southern slopes, the trades and the west portion of the region of calms unitedly spread their highly saturated air over the whole region as far as the Andes, resulting in one of the most widespread heavy rainfalls anywhere to be met with. On the other hand, since in July the belt of calms is about lat. 10° N., the saturated atmosphere of the tropical regions no longer flows up the Amazon, but is carried westward into the Caribbean Sea and Gulf of Mexico. Hence at this season the rainfall of the Amazon valley is small. The following are, in inches, the January and July falls:—Para, 6·51 and 3·26; Manaos, 7·33 and 1·82; upper Madeira, 15·90 and 0·30; and Yquitos, 10·24 and 4·26. On the La Plata in January pressure is low, and as winds consequently blow from the ocean in upon the region of low pressure the rainfall is large; but as pressure is high in the interior in July the rainfall in that month is small. The following are, in inches, the January and July rainfalls:—Buenos Ayres, 2·37 and 1·70; Parana, 4·63 and 1·32; Corrientes, 5·24 and 2·67; Joinville, 14·26 and 3·55; and San Luis, 2·63 and 0·00.

Rainfall of Africa.—As regards the rainfall, Africa presents the greatest diversity in its climates. The following are the annual amounts in inches at various points on or near the coast:—Port Said, 2; Alexandria, 8; Tunis, 12; Algiers 31; Oran, 17; Mogador, 50; mouth of the Senegal, 17, Goree, 21; Sierra Leone, 126; Christiansborg, 23; St Thomas, 40; Gaboon, 106; Loanda, 11; Cape Town, 23; Mossel Bay, 15; Port Elizabeth, 24; Durban, 43; Zanzibar, 58; and mouth of the Zambezi, 61. In the north of the continent, the rainfall rapidly diminishes inland, and over the great desert of Sahara practically none falls. In the interior of Algiers it diminishes, the amount at Laghouat being 17 inches, and at Biskra 9. In Egypt the rainfall is limited to a narrow strip along the coast; at Cairo the annual fall scarcely amounts to an inch. The January and July rainfalls are, in inches, as follows:—Port Said, 0·46 and 0·00; Alexandria, 1·25 and 0·20; Algiers, 4·43 and 0·04; Biskra, 0·56 and 0·03; St Louis (Senegal), 0·28 and 3·00; Goree, 0·00 and 4·06; Sierra Leone, 0·69 and 24·20; Christiansborg, 0·50 and 2·00; Katunga, 0·11 and 4·76; Gaboon, 9·35 and 0·43; Cape Town, 0·28 and 3·83; Durban, 5·00 and 1·70; Pretoria, 6·07 and 0·71; and Zanzibar, 2·02 and 2·35. At Zanzibar the heaviest rains occur about the equinoxes, the mean for April being 14·55 inches, and for October 6·80 inches.

In the case of this, as the other continents, the explanation of the different amounts is to be had in the seasonal changes of wind. In the north the winter rains are to a very large extent the accompaniment of the Mediterranean storms of that season, but in summer pressure is diminished in the interior and increased in the Atlantic to the north-west, resulting in strong steady northerly winds, which as they advance into hotter regions are unaccompanied with rain. The heavy summer rains from Senegambia to the Gold Coast are due to the strong monsoonal winds which set in towards the interior, thus drawing over these coasts the highly saturated air of the belt of calms and of the trades immediately to the north and south of it. Since in winter the belt of calms is removed 3° of latitude farther to the south, and the temperature of the interior is greatly reduced, it follows that the winds blowing on these coasts from the sea are drier and less strong, and consequently the rainfall is small. At Sierre Leone the absolutely driest month is February, 0·31 inch, and the wettest September, 29·15 inches. On the other hand, at Gaboon (lat. 0° 25′ N.) the dry season is from June to August, when the belt of calms is farthest to the north; and the absolutely rainiest about the equinoxes, the mean of March being 14·70 inches and October 19·52 inches. At Loanda (lat. 8° 49′ S.) the annual amount is only a tenth of what falls at Gaboon, and it

falls wholly during the summer months of the southern hemisphere. In South Africa pressure in January is lowest in the interior, towards which prevailing winds from the ocean blow, and as these advance into regions becoming rapidly hotter the rainfall all round the coast and for some distance inland falls to the annual minimum. But in more strictly inland districts which are at a considerable elevation the rainfall reaches the maximum at the same season. Thus the amounts in inches for January and July are—for Pretoria, 6·07 and 0·71: Maritzburg, 4·23 and 0·21; Graham's Town, 2·89 and 1·51; Lower Nel's Poort, 1·33 and 0·49; and Aliwal North, 1·55 and 0·00. In the winter months pressure in the interior is high, and the rainfall consequently small. Though on the coast winds from the arid interior frequently prevail, yet the storms that sweep eastward past South Africa precipitate over large portions of the southern slopes of this part of the globe what must in the main be regarded as a generous rainfall. It follows that the climates of these important colonies range themselves into two perfectly distinct classes,—the climates of the inland regions and the Natal coast, where the rains occur during the hottest months, and the climates of the other regions, where the annual rains occur during the coldest months. Little is accurately known regarding the rainfall of the interior of Africa. It is certain, however, that it is small, or nil, over the extensive region of the Sahara, and that it is large from about 15° N. lat. to some distance south of the equator. Probably the rainiest part of Africa is the region extending from the Victoria Nyanza northwards to and including the gathering grounds of the two great tributaries of the Nile.

Snow.—Snow takes the place of rain when the temperature is sufficiently low to freeze the condensed moisture in the atmosphere. Snow is composed of crystals, either six-pointed stars or hexagonal plates, which exhibit the greatest variety of beautiful forms, one thousand different kinds having been observed. These numerous forms Scoresby reduced to five principal varieties:—(1) thin plates, comprising several hundred forms of the most exquisite beauty; (2) a nucleus or plane figure, studded with needle-shaped crystals; (3) six-sided, more rarely three-sided, crystals; (4) pyramids of six sides; (5) prismatic crystals, having at the ends and middle thin plates perpendicular to their length. In the same snowfall the forms of the crystals are generally similar. The flakes vary from 0·07 inch to an inch in diameter, the smallest occurring with low temperatures and the largest when the temperature approaches 32°. If the temperature is a little higher, the snow-flakes are partially thawed in falling through it, and fall as sleet. The white colour of snow is caused by the combination of the different prismatic colours of the minute snow-crystals. The density of snow is far from uniform; it is generally from ten to twelve times lighter than an equal bulk of water, but varies from eight to sixteen times lighter than water.

The limit of the fall of snow near sea-level coincides roughly with the winter isothermal of 52°, since in places where the mean winter temperature is no higher than 52° that of the air falls occasionally to 32° or lower during the winter months. As regards Europe, the southern limit is about Gibraltar, in North America it is Savannah, New Orleans, the mouth of the Rio Grande, the head of the Gulf of California, and San Francisco. In Europe, north of lat. 60°, snow falls generally on an average of from 80 to 110 days in the year. At Upsala the number of days is 61, at Warsaw 45, Aberdeen 42, Oxford 18, Ostend 15, Brussels 27, Tarum (in the south-west of Jutland) 12, Copenhagen 23, Vienna 33, Odessa 19, Sebastopol 12, Milan 11, Trieste 6, Saragossa 5, Madrid 3, and Lisbon 1. In Greenland the number of days exceeds 80, and this figure is nearly reached in Newfoundland and the north-east seaboard of Nova Scotia. At Quebec the mean days of snow are 66, Halifax 64, Winnipeg 54, Detroit 34, Cape Henry 13, St Louis 11, mouth of the Columbia River 7, and Charleston 2. In Russia the time of the year when snow falls most frequently is December and January, except in the south of the empire, where February is the month of the most frequent occurrence of snow. But to the north of a line drawn from the entrance of the Gulf of Finland through Warsaw, Cracow, Salzburg, and Santiago March is the month of maximum occurrence in the great majority of instances; while to the south of this line it is January and in several cases December.

The largest falls of snow occur in the Antarctic regions, as is well attested by the magnificent icebergs of solidified snow which break off all round from the lofty walls of ice that engirdle the Southern Ocean. Excepting perhaps in the Dominion of Canada, no data have been anywhere collected from which even a rough estimate could be formed as to the mean annual amount of snow that falls in different parts of the globe.

Snow-Line.—The snow-line marks the height below which all the snow that falls annually melts during summer. No general rule can be stated for this height in different climates owing to the many causes determining it. These are the exposure of mountain slope to the sun (and hence, other things being the same, it is higher on the south than on the north sides of mountains), exposure to the rain-bringing winds, the steepness of the mountains, and the degree of dryness of the air. Hence the position of the snow-line can be known by observation only. It falls only little on either side of the equator to lat. 20°; from lat. 20° to 70° it falls equably, but from lat. 70° to 78° much more rapidly. To this general rule there are many exceptions. It is 4000 feet higher on the north than the south side of the Himalayas, owing to the larger snowfall on the south, and the greater dryness of the climate of the north side, and therefore the greater evaporation from the snow there. It is higher in the interior of continents than near the coasts, because the precipitation is less and summer heat greater. In the Caucasus it is 11,063 feet high, but only 8950 in the Pyrenees. In South America it rises from the equator to lat. 18°, and more on the west than on the east slopes of the Cordilleras, owing to the large precipitation on the east and small precipitation and arid climate of the west side of that chain of mountains. It is as high in lat. 33° S. as in 19° N., but south of that latitude it rapidly sinks owing to the heavy rains brought by the moist N.W. winds of these regions. In the south of Chili it is 3000 feet lower than in the same latitudes in Europe, and 6000 feet lower than in the extremely arid climates of the Rocky Mountains.

Storms.—If weather charts representing a large part of the northern hemisphere be examined, two distinct systems of pressure are seen which change their forms and positions on the earth's surface from day to day. The one set are systems of low pressure marked off by concentric isobars enclosing pressures successively lower till the centre is approached; and the other systems of high pressure marked off by concentric isobars enclosing pressures becoming successively higher towards the centre. The former of these are called cyclones, and the latter anticyclones. These areas of low pressure are the distinguishing characteristics of the hurricanes and typhoons of tropical regions, and of the ordinary storms of higher latitudes, and they may all be conveniently grouped under the general name of cyclones. Fig. 19 shows a storm which was passing across north-western Europe on the morning of November 2, 1863, and it may be taken as fairly representing the general features of cyclones. In the figure the arrows fly with the wind, and the force of the wind is indicated by the number of feathers on the arrows.

It will be seen that the winds indicate, not a circular movement round the centre of lowest pressure, but a vorticose motion inwards upon that centre, the motion being opposite to that of watch-hands. In other words, the wind follows Buys Ballot's law, already explained. The winds are strongest where the isobars are closest together; or they are generally proportioned to the "baro-

metric gradient,"—a term introduced by Stevenson in 1867. Cyclones have diameters seldom less than 600, and they occasionally exceed 3000 miles; the cyclone of fig. 19 had a diameter of about 1200 miles. The cyclones of the Mediterranean are usually of smaller dimensions than those of north-western Europe and America. The rates at which cyclones advance over the earth's surface vary greatly, the average in America being 24 miles an hour, in the Atlantic 20 miles, and in Europe 26 miles. A rate as high as 70 miles an hour has occurred in the British Islands; sometimes they remain stationary, and more rarely their course is for a time retrograde. The temperature and humidity increase at those places towards and over which the front part of the storm is advancing, and fall at those places over which the front part of the storm has already passed. In other words, the temperature and humidity rise as pressure falls and fall as pressure rises. This is the important climatic significance of cyclones. Thus a succession of low pressures passing eastwards in courses lying to northward of the British Islands are the essential conditions of open winters; whereas, if the cyclones follow courses lying to southward, the winters are severe. In a cyclone the broadest feature of weather is an area of rain about or rather somewhat in front of the centre, surrounded by a ring of cloud, outside which the sky is clear. The precise form and position of these areas have been shown by Abercrombie to vary with the type of pressure distribution, with the intensity of the cyclone, and with the rate of its progress, and they are also influenced by local, diurnal, and seasonal variations.

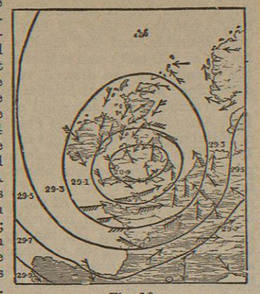

Fig. 19.

The chief point of difference between American and European storms is essentially the result of the mean winter pressures to the west and north-west of their respective storm-tracks. Owing to the high winter pressure in the interior of America, the barometer rises in the wake of the storms of the United States more rapidly, the wind veers round more quickly and more uniformly to N.W., N.N.W., and N. and keeps longer in these directions, and the temperature and humidity fall to a greater degree, than happens in Europe. In the New England States and Canada the easterly winds of the storms, coming as they do from the Atlantic, are disagreeably cold, damp, and misty in a degree and with a frequency much greater than occurs with the same winds in the British Islands.

The chief points of difference between the hurricanes and typhoons of the tropics and the cyclones of higher latitudes are these:—tropical cyclones are of smaller dimensions, show steeper barometric gradients and therefore stronger winds, and advance at a slower rate over the earth's surface. Another point of difference is that a large number of the hurricanes of the West Indies and the typhoons of eastern Asia first pursue a westerly course, which gradually becomes north-westerly, and on arriving at about lat. 30° they recurve and thereafter pursue a course to north-eastwards. The tropical cyclones of the Indian Ocean south of the equator also first pursue a westerly course, which gradually changes to south-west, and often on arriving about lat. 30° recurve to the south-east. Many of the cyclones of India have their origin to westwards of the Nicobar Islands, pursue a course to north-westward, and die out in the valley of the Ganges; and, similarly, a considerable number of the cyclones of the West Indies pursue a westerly course through the Gulf of Mexico, and several die out in the States.

The most dreadful attendant on tropical cyclones is the storm-wave, caused by the in-blowing winds and the low pressure of the centre of the storm. When this wave is unusually high and is hurled forward on a low-lying coast at high water it becomes one of the most destructive agents known. The Bakarganj cyclone of October 31, 1876, was accompanied by a wave which flooded the low grounds to the east of the delta of the Ganges to heights varying from 10 to 45 feet, by which more than 100,000 human beings perished.

Tracks of Cyclones of North America, Atlantic, and Europe.—In the *Physical Atlas of the Atlantic Ocean*, issued under the direction of Dr Neumayer of the Deutsche Seewarte, plate 28 shows by shadings the mean positions of the centres of cyclones and by lines their mean tracks. The following are the regions where the lowest barometer of storms has been most frequently found:—the region to west-south-west of the lakes of the United States; the Gulf of St Lawrence; mid-Atlantic about lat. 35° long. 52°; to the south-west of Greenland; to the south-west of Iceland, which is by far the most important of the whole; to the south-west of the Lofoten Isles; the region embracing Denmark, the south of Scandinavia, and Finland; and, as secondary centres of frequency, the south of the British Islands, Corsica and part of Italy adjoining, and the north-east of the Adriatic. The great importance of these centres, where the lowest barometers are most frequently found, consists in the indication they give of the precise regions either where many storms originate or where they are either retarded or arrested in their course. As regards the origin of storms, the centre west of the Mississippi is the region where most of the United States storms originate, the centre in the Gulf of St Lawrence is where many of the great Atlantic storms have their origin, and the centres in mid-Atlantic and to the south-west of Iceland are the regions where the storms of north-western Europe chiefly originate. The centres on the south-west of Greenland, the Lofoten Isles, Denmark, and the south of the British Islands, all appear to suggest that storms are retarded in their onward courses on coming up against large masses of land,—which may, in part at least, be occasioned by the heavy rainfalls that mark these parts of their courses.

Of all storm tracks the most frequently taken is that by the storms of the United States, which pursue an easterly course through the lakes to the Gulf of St Lawrence. A considerable number of storms follow a course from Nova Scotia to Davis Straits; but the larger number take a north-easterly course through the Atlantic towards Iceland and thence past the north of Norway. Among the less frequent but important tracks are these:—from near New Orleans along the east coast of the States towards Nova Scotia; from mid-Atlantic to south of Ireland and thence through France to the north of the Mediterranean; and from the Atlantic about lat. 42° long. 40° in a north-easterly course quite outside but at no great distance from the British Islands, and thence towards the North Cape. Of the tracks more immediately affecting British weather are one from Iceland in a south-easterly direction through the North Sea and Germany, and four tracks which start from near Scilly:—(1) to the south-east as already described; (2) eastward through the north of Germany; (3) north-east to Christiania; and (4) north through Ireland and the Hebrides. These are the storm tracks which chiefly give the United Kingdom its easterly and northerly winds.