diurnal variation in the wind's velocity occurring frequently also in cloudy weather. On the other hand, during the night, when terrestrial radiation is proceeding, the temperature of the surface falls greatly, and instead of an ascensional movement in the lower stratum of the air there is rather a tendency towards a descensional movement (if the wind be light there is an actual movement) of the lowest air stratum down the slopes of the country; and since the friction between the wind and the surface of the earth is thereby increased the diurnal velocity of the wind falls to the minimum during these hours (see also p. 156).

Among the most marked exceptions to the general rule of the diurnal distribution of wind force may be cited the bitterly cold furious blasts of wind encountered in narrow valleys in such mountainous regions as the Alps during clear and comparatively calm nights. These are simply the out-rush of the cold air poured into the upper basins of the valleys by the descensional currents from the slopes which the chilling effects of terrestrial radiation set in motion. On the other hand, the air of the valleys becomes heated and expands during the day, thus giving rise to a warm wind blowing up the valleys, which, on account of the vapour it carries with it from the lower levels, frequently covers the higher slopes and tops of the mountains with cloud and drizzling rain.

Diurnal Variation in the Direction of the Wind.—In all climates near seas and other large sheets of water, where the distribution of atmospheric pressure is tolerably equable, or the barometric gradient small, and the sun heat moderately strong, land and sea breezes are of daily occurrence. In such places a breeze from the sea gradually sets in in the morning, which gradually rises to a stiff breeze during the heat of the day and again towards evening sinks to a calm. Soon after this a breeze sets in from the land, blows strongly seaward during the night, and dies away in the morning, giving place to the sea breeze as before. These breezes are occasioned by the surface of the land being heated in a much higher degree than that of the sea during the day; the air over the land being thereby made lighter ascends, and its place is supplied by the cooler air of the sea breeze drawn landward, and partly also by descending currents, as shown by the humidity observations of the "Challenger," which indicate increasing dryness when the sea breeze is strongest. Again during the night the temperature of the land and of the air over it falls below that of the sea, and the air of the land thus becoming heavier and denser flows over the sea as a land breeze. As the best-marked and most frequently occurring cases of the sea breeze begin some distance out at sea and gradually approach the land, it is very probable that, as suggested by Blanford, the ascending heated air flows seaward as an upper current, and that the increased barometric gradient thus caused largely accounts for these breezes.

Sea and land breezes are thus determined by the relative positions of the land and its coasts, subject to a further modification arising from the rotation of the earth. Thus on the coast of the Gulf of Lyons the sea breeze from the south veers to south-west and dies away as a west wind, while the land breeze from the north gradually veers to north-east and dies away as an east wind. On the coast of Algeria, on the other hand, the sea breeze veers from north to north-east and dies away in the east, whereas the south land breeze veers to south-west and dies away in the west. Sea breezes also occur in such unsettled climates as that of Scotland, when the weather conditions are favourable. These conditions are presented when an anticyclone overspreads the country, with its accompanying fine settled weather, small variation in the distribution of atmospheric pressure, clear skies, and consequently strong sunshine. Under these conditions the following are the veerings of the wind off the coast of Berwickshire. In the morning the wind is north-west till about 10 A.M., when it veers to north, falling all the time till finally it sinks to a calm. A little before noon it springs up from north-east or east, veers to south-east from 2 to 3 P.M., where it continues till 7 P.M., about which time it veers to south and then south-west, diminishing in force and finally sinking to a calm. About sunset it springs up from west, veering to north-west during the night, where it continues till the following morning. The wind thus virtually makes the round of the compass, is strongest from north-west and south-east and weakest at north-east and south-west, being thus strongest when its course is perpendicular to the line of coast.

The observations made by the "Challenger" in the region of the north-east trades in 1873 show a small diurnal variation in the direction of the wind, the variation being from E. 47° 5′ N. at 2 to 6 A.M. to E. 56° N. at 10 A.M. to 2 P.M., the variation being thus 8° 55′ towards north during the hottest hours of the day. At Mauritius observatory, which is several miles from the sea, the daily period in the direction of the wind is from E. 22° 15′ S. at 4 A.M., being the most southerly point, to E. 7° S. at 1 P.M., and thence back to E. 22° 15′ S. at 4 A.M. The diurnal variation is 15° 15′, and thus the influence of the sun impresses on the wind at this observatory a more truly easterly character.

At the Austrian naval station at Pola, near the head of the Adriatic, the daily variation in the direction of the wind is well-marked. Starting from a point east of south at 5 A.M., it gradually veers round to westward, the most westerly point, almost due west, being reached at 5 to 6 P.M., after which it gradually shifts back to its starting-point in the morning. Here we have evidently a diurnal wind-system different from that of the land and the sea breeze. Pola is situated near the south-western extremity of the peninsula of Istria, and the direction in the early morning of east by south is the direction the wind would take if a small anticyclone overspread the peninsula; and the direction from the west in mid afternoon is the direction the wind would have at Pola if the peninsula were occupied by a small cyclone with the lowest pressure in the centre. Now the influence of solar radiation is to form, through the ascending current from the heated land, a diminution of pressure over the land,—in other words, what is essentially a cyclone. On the other hand, during the night the influence of terrestrial radiation is to generate, through the cooling of the land and the air resting above it, a relatively higher atmospheric pressure in the interior of the peninsula with its characteristic system of outblowing winds.

At Coimbra, in July 1878, the diurnal variation of the wind's direction was from W. 49° 37′ N. at 2 to 6 A.M. to W. 33° 15′ N. at 4 to 6 P.M., the amount of the variation being thus 16° 22′ in the direction of west. At Valentia, in the south-west of Ireland, during the summer months of 1878 the diurnal variation of the wind's direction was from W. by S. at 7 to 9 A.M. to S.W. by W. at 5 to 7 P.M. The variation was thus from a point nearly south to a point nearly south-west, or through nearly 45° in the direction of west. On the other hand, at Aberdeen during the same months of 1878, the diurnal variation of the wind's direction was from S.W. at 6 to 7 A.M. to S. by E. at 12 to 4 P.M., the variation being thus 56° from south-west in the direction of east through south. Attention is here drawn to the exactly opposite ways in which the diurnal veering or shifting of the wind takes places at Valentia and Aberdeen, but particularly to the important circumstance that in each case the diurnal changes in the wind's direction which actually occur are precisely those that would take place on the supposition that during the hottest hours of the day an ascensional movement of the air sets in from the heated lands of the British Islands, and that an in-draught takes place all round, which with the descending currents makes good the loss caused by the up-draught. Thus then both the diurnal increase in the wind's velocity and the change in its direction which observation shows to take place during the hottest hours of the day are traced to the same cause, viz., the heating of the surface by the sun, the heating of the lowest stratum of air resting on the surface, and the ascensional movements which are the necessary result.

It is instructive to note that at Nukuss, at some distance to the south of the Sea of Aral, where the summer direction of the wind is northerly, the north component is at the daily maximum at 4 P.M., having shifted into this direction from north-east, where it is at 9 A.M. Much or nearly everything remains to be done in working out this problem in its practical details as one of the important elements of climatology, with the view of arriving at some definite knowledge of the influence of physical configuration and different vegetable coverings of the surface on radiation and on the velocity and direction of the wind.

Diurnal Variation in the Amount of Cloud.—Mists and fogs are visible vapours floating in the air near the surface of the earth, and clouds are visible vapours at a considerable height. These forms of visible vapour are all produced by whatever lowers the temperature of the air below the dew point,—such as radiation from the molecules of the atmosphere towards the cold regions of space, the simple

expansion of the air of ascending currents, the mixing of cold air with air that is warm and moist, and the cooling of the air in contact with the surface of the earth when its temperature has been lowered by nocturnal radiation.

The forms of clouds are endless. Since clouds are subject to certain distinct modifications from the same causes which produce other atmospheric phenomena, the face of the sky may be regarded as indicating the operation of these causes, just as the face of man indicates his mental and physical states. Hence the importance of the study of clouds, and hence the necessity of a nomenclature of clouds as the basis of accurate and comparable observations. An adequate nomenclature of clouds is still a desideratum. Luke Howard's classification, which continues to hold its ground as a provisional nomenclature, was proposed by him in 1803, and by it clouds are considered as divided into seven kinds. Of these, three are simple forms, the *cirrus*, the *cumulus*, and the *stratus*; and four intermediate or compound, the *cirro-cumulus*, the *cirro-stratus*, the *cumulo-stratus*, and the *cumulo-cirro-stratus*, *nimbus*, or *rain cloud*.

The cirrus cloud consists of wavy, parallel, or divergent filaments, which may increase in any or all directions. It is the cloud of the least density, the greatest elevation, and the greatest variety of figure. It is probable that the particles composing it are minute crystals of ice or snow-flakes. The cirrus is intimately connected with the great movements of the atmosphere; and it is solely from the movements of the cirrus that we have any direct knowledge of the upper currents of the atmosphere. In recent years much has been done, particularly by Professor Hildebrandsson of Upsala and Clement Ley, in investigating the relations of this cloud to storms and other changes of weather.

The cumulus is the name applied to those convex or conical heaps of clouds which increase upwards from a horizontal base. They are generally of a very dense structure, are formed in the lower regions of the atmosphere, and are carried along by the aerial current next the earth. They form the tops of the ascending currents which rise from the heated ground, and have a diurnal period so well marked that they are often named the "cloud of the day." The form of stratus comprehends those mists and fogs which in the calm evening of a warm summer day make their appearance in the bottom of valleys and over low-lying grounds, and sometimes spread upwards over the surrounding country like an inundation; they have an equally well marked daily period, and are frequently called the "cloud of night." The cirro-cumulus is made up of small roundish masses, lying near each other, and quite separated by intervals of sky. It may be considered as formed from the cirrus by the fibres of that cloud breaking, as it were, and collapsing into roundish masses, thus destroying the texture but retaining the arrangement of that cloud. This singularly beautiful cloud is commonly known as a mackerel sky, and is of most frequent occurrence during dry warm summer weather. The cirro-stratus consists of horizontal masses thinned towards the circumference, bent downwards or undulating, and either separate or in groups. Since this cloud has great extent and continuity of substance, but little perpendicular depth or thickness, it is the cloud which most frequently fulfils the conditions for the phenomena of coronæ, solar and lunar halos, parhelia or mock suns, and paraselenæ or mock moons. The cumulo-stratus is formed by the cirro-stratus blending with the cumulus, or spreading underneath it as a horizontal layer of vapour. The cumulo-cirro-stratus, or nimbus, is the well-known rain-cloud, which consists of a cloud or system of clouds from which rain is falling. At a considerable height a sheet of cirro-stratus cloud is extended, under which cumulus clouds drift from windward; these rapidly increasing unite and appear to form one continuous grey mass from which the rain falls. The breaking up of the lower grey mass indicates that the rain will soon cease. When a rain-cloud is seen at a distance, cirri appear to shoot out from its top in all directions; and it is observed that the more copious the rainfall the greater is the display of cirri. The cirrus, cirro-cumulus, cirro-stratus, cumulo-stratus, and nimbus are connected more or less closely with the great atmospheric movements of the cyclone and anticyclone. In what follows here only the amount of sky covered will be taken into account, and not the species of cloud covering.

The diurnal variation in the amount of cloud in the sky on the open sea is very small. The following are the means of two hundred and seventy-seven days' observations on board the "Challenger," stated in percentages of sky covered:—

2 A.M.	59	10 A.M.	58	6 P.M.	57
4 ,,	59	Noon	56	8 ,,	57
6 ,,	62	2 P.M.	58	10 ,,	57
8 ,,	62	4 ,,	59	Midnight	57

Two maxima are here indicated, the one about or shortly after sunrise and the other in the early part of the afternoon; and two minima, the one at noon and the other from sunset to midnight. The difference between the extremes is only 6 per cent. of the sky.

At Batavia the daily maximum is from 6 to 11 P.M., and the minimum from 8 to 11 A.M., the extremes being 52 per cent. at 9 A.M. and 69 per cent. at 7 P.M.,—a difference of 17 per cent. Of four daily observations at Mauritius, the maximum is 50 per cent. at 1 P.M. and the minimum 38 per cent. at 6 A.M. At Coimbra, observations of clouds have been made five times daily, and six years' results give the maximum 63 per cent. at 9 P.M. and the minimum 52 per cent. at 9 A.M. At this place, during July and August, the greatest amount of cloud occurs at 6 P.M., and in these months the rainfall at Coimbra is very small. The minimum is more pronounced at 9 A.M. than at any other period; in winter this phase occurs about four hours later. At the continental situation of Vienna, during the warm months of the year the maximum is at 2 P.M., with a secondary maximum about 6 A.M., and the minimum from 10 P.M. to 2 A.M.; but during the cold months the maximum is at 6 A.M. and the minimum during the evening and night. In the Rocky Mountains, the chief maximum, 57 per cent., is at 3 P.M., with a secondary one 30 per cent. at 5 A.M.; and the chief minimum 20 at 3 A.M. and a secondary one 29 at 11 P.M. At Helsingfors the maximum of cloud occurs from 10 A.M. to 2 P.M., and the minimum from 10 P.M. to 2 A.M.

Much yet remains to be done with regard to the determination of the diurnal variation of cloud, but from the above one or two deductions of a general character may be drawn. A maximum occurs in the morning and continues till shortly after the sun has risen, and this maximum is more decidedly pronounced over the open sea than over land. Its appearance is without a doubt due to the general cooling of the atmosphere through its whole height by terrestrial radiation, and its disappearance to the heating of the air, which commences about sunrise. Then follows one of the diurnal minima, which continues till midday, or a little later; in other words, it continues till, owing to the diurnal heating of the air by the sun, the ascending current has fairly set in. The period of this ascending current marks the second maximum, which during the warmer months is larger than the morning maximum over land. The cumulus is the characteristic cloud of this maximum. These clouds are merely the summits of the ascending currents which rise from the heated land, where the aqueous vapour is condensed in cloud by the expansion which takes place with increase of height.

These cumulus clouds throw a not unimportant light on the behaviour of the ascending currents which rise from the surface when heated by the sun,—inasmuch as they point to the fact that the current ascending from the surface is broken up and thereafter grouped into separate well-defined ascending currents, which are marked out and overtopped by these cumuli; and further it is probable, from their well-defined position, that the air composing the ascending currents is not only warmer but also more humid than the air in the clear interspaces at the same heights. It may also be regarded as highly probable that it is down through these clear interspaces that the descending air-filaments shape their course in their way to take the place of the air-molecules that ascend from the heated surface of the earth.

The secondary minimum occurs from about sunset onwards during the time of the P.M. maximum of atmospheric pressure. In a highly saturated atmosphere, which is so characteristic a feature of many tropical climates at certain seasons, this time of the day is remarkable for the amount of cloud; and it is during those seasons and hours that heat-lightning, or lightning without thunder, attains its annual and diurnal maximum period, which is from six to eight hours later than that of thunderstorms. The morning maximum, shortly before and after sunrise, has two quite distinct and characteristic clouds accompanying it. One of these is the cumulo-stratus, which is a consequence of the cooling of the atmosphere through all its height by nocturnal radiation. As the colouring of the cloudlets is often singularly fine, it has been a favourite theme with poets of all ages and climes. The other, which results from the cooling of the surface of the earth by terrestrial radiation and thence of the lower stratum of the atmosphere, is quite different, being a low creeping mist, appearing first in low-lying situations, and gradually extending upwards as the temperature falls. Fog is a well-known form of this cloud, having its diurnal maximum in the morning and early part of the day.

Diurnal Variation in the Amount of the Rainfall.—From the sixteen years during which hourly observations of the rainfall were made at Batavia Dr Bergsma has given a table showing the diurnal variation, of which the following shows how much per cent. of the total daily amount fell every two hours:—

Midt. to 2 A.M.	8·7	8 A.M. to 10 A.M.	5·5	4 P.M. to 6 P.M.	13·5
2 A.M. ,, 4 ,,	6·4	10 ,, ,, Noon	6·3	6 ,, ,, 8 ,,	10·5
4 ,, ,, 6 ,,	6·1	Noon ,, 2 P.M.	9·5	8 ,, ,, 10 ,,	7·4
6 ,, ,, 8 ,,	5·2	2 P.M. ,, 4 ,,	12·2	10 ,, ,, Midt.	8·7

The diurnal curve of rainfall is thus very distinctly marked at Batavia. The minimum is from 6 to 10 A.M. and the maximum from 2 to 6 P.M.,—10·7 per cent. falling during the four hours ending 10 A.M., but 25·7 per cent. in the four hours ending 6 P.M.

The observations were arranged and averaged by Dr Bergsma with the view of seeing how far the phases of the moon influence the rainfall. The results for the eight phases of the moon, beginning with new moon, showing the mean amount of rain in twenty-four hours during the seventeen years ending 1880, are these:—0·243, 0·236, 0·193, 0·181, 0·212, 0·183, 0·189, and 0·203, and daily mean 0·205 inch. The influence of the moon's phases on the rainfall at Batavia is thus quite decided from these seventeen years; for, while the mean daily rainfall is 0·205 inch, it rises at full moon to 0·243 inch, from which time it gradually falls to 0·181 inch at the third octant, rises to 0·212 inch at the fourth octant, falls again to 0·183 inch at the fifth octant, and finally rises to the maximum at the time of new moon.

At Coimbra, where the rainfall has been observed every two hours for the six years ending 1881, the means show a minimum of 3·08 inches from midnight to 2 A.M., a maximum of 4·03 inches from 2 to 4 A.M., a second minimum of 3·20 inches from 10 A.M. to noon, and a second maximum from 2 to 4 P.M. These four phases of the rainfall are pretty nearly accordant with the four phases of the barometric pressure, the maximum periods being near the times of minimum pressure, and the minimum periods near the times of maximum pressure. The rainfall at Philadelphia shows a decided maximum at 6 P.M. and minimum at 3 A.M. At Vienna during the summer half of the year there are three maxima and three minima in the curve of the daily rainfall, the chief maximum, which is nearly double of each of the other two, occurring from 2 to 4 P.M., and the chief minimum from 3 to 6 A.M. At this place the number of hours of rain has been recorded, showing two maximum periods, the first from 2 to 8 A.M. and the second from 4 to 7 P.M. Since the time of maximum amount indicates a number of hours for the fall under the mean of the day, it follows that the showers from 2 to 4 P.M. are often very heavy. At Prague the chief maximum is from 2 to 6 P.M. and the minimum from 1 to 6 A.M. At Zechen the maximum is from 2 to 7 P.M., with a secondary maximum from 5 to 8 A.M., and the minimum from midnight to 4 A.M. At Bern the maximum fall is from 7 P.M. to midnight. Twenty-one years' observations at Calcutta show the maximum occurrence of rainfall during the rainy season from June to October to be from 11 A.M. to 6 P.M., the absolute maximum being from 2 to 3 P.M. and the minimum from 9 P.M. to 1 A.M.; and during the hot dry season from March to May the maximum is from 5 to 9 P.M., and the minimum from midnight to 9 A.M.

The data already collected show the general occurrence of a diurnal maximum from about 11 A.M. to 6 P.M., and this feature of the curve is particularly well seen in the rainfall of continental climates during the summer half of the year. A marked diminution of the rainfall is very generally observed from about sunset to midnight, when the diurnal amount of cloud in many climates falls to the minimum, and the evening maximum of atmospheric pressure takes place. The time of the morning minimum pressure from about 2 to 6 A.M. is, curiously, strongly marked in some places with an increase, while in others it is as strongly marked with a diminution, in the rainfall. The "Challenger" observations show that the occurrence of rain on the open sea is inversely as the temperature, 684 days' observations giving 96 cases from 9 to 4 P.M., and 135 from midnight to 2 A.M., these being the minimum and maximum periods.

Diurnal Variation of Thunderstorms.—It has just been remarked that a prominent feature of the diurnal rainfall in continental climates during the summer months is the increased rainfall from about 11 A.M. to 6 P.M., and the Vienna observations point to unusually heavy falls occurring at these hours. This is caused by the rains which accompany the thunderstorms of these regions. The following table gives for the hours of the day the times of occurrence of thunderstorms at Ekaterinburg in the Ural Mountains during the fourteen years ending 1872:—

	April.	May.	June.	July.	Aug.	Sept.	Year.
Midnight to 1 A.M.	...	...	5	5	5	...	15
1 A.M. ,, 2 ,,	...	...	1	5	2	...	8
2 ,, ,, 3 ,,	...	...	1	4	1	...	6
3 ,, ,, 4 ,,	...	...	1	2	3	...	6
4 ,, ,, 5 ,,	...	...	2	1	1	...	4
5 ,, ,, 6 ,,	...	...	3	3	...	...	6
6 ,, ,, 7 ,,	..	...	2	3	...	...	5
7 ,, ,, 8 ,,	1	...	5	2	2	...	10
8 ,, ,, 9 ,,	1	...	4	4	1	..	10
9 ,, ,, 10 ,,	1	...	6	7	5	...	19
10 ,, ,, 11 ,,	1	...	8	12	4	...	25
11 ,, ,, Noon.	1	2	14	30	5	1	53
Noon ,, 1 P.M.	3	4	19	25	5	4	60
1 P.M. ,, 2 ,,	2	8	21	29	12	2	74
2 ,, ,, 3 ,,	3	10	22	35	15	4	89
3 ,, ,, 4 ,,	3	6	26	45	20	1	101
4 ,, ,, 5 ,,	2	5	24	33	9	..	73
5 ,, ,, 6 ,,	1	6	25	30	11	2	75
6 ,, ,, 7 ,,	2	7	15	20	10	..	54
7 ,, ,, 8 ,,	2	5	16	20	9	...	52
8 ,, ,, 9 ,,	2	6	14	14	6	...	42
9 ,, ,, 10 ,,	2	3	8	10	5	1	29
10 ,, ,, 11 ,,	...	1	6	6	5	...	18
11 ,, ,, Midnight...	...	1	7	6	8	...	22
Sums	27	64	255	351	144	15	856

Hence the thunderstorms at this place have a diurnal period as strongly marked as any other meteorological phenomena, and in this respect Ekaterinburg is fairly representative of extratropical continental climates during summer. For the fourteen years no thunder occurred

during the six months from October to March. The mean of the six hottest months shows the maximum to take place from 3 to 4 P.M. and the minimum from 4 to 5 A.M., these being the times of occurrence of the two minima of pressure. At this season, however, the morning minimum pressure is but faintly marked in such climates as those of Siberia. During the twelve hours from 9 A.M. to 9 P.M., when the temperature is above the daily mean, 717 of the whole number occurred, thus leaving only 139 for the twelve hours when the temperature is below the daily mean. The great majority of the thunderstorms occur during the part of the day when the ascensional movement of the air from the heated ground takes place, and they attain the maximum when the temperature and this upward movement are also at the maximum. Owing to the westerly winds from the Atlantic which prevail over Europe and western Siberia during summer, the maximum rainfall of the year occurs over this extensive region in this season; and the importance and significance of the inquiry into this element of climate lie in the fact that the greater portion of the summer rains is discharged over these regions by the thunderstorm. The "Challenger" observations on the open sea show the maximum occurrence of thunderstorms to be from 10 P.M. to 8 A.M., 22 being observed during these ten hours and 10 during the other fourteen hours of the day,—a result which suggests that over the ocean terrestrial radiation is more powerful than solar radiation in causing vertical disturbances in the equilibrium of the atmosphere.

Atmospheric vapour and ascending currents thus play an important part in the history of these thunderstorms. Where the climate is dry and rainless, like that of Jerusalem in summer, thunder is altogether unknown. On the other hand, where during a particular season an anticyclone with its vast descending current in the centre remains over a region, as happens over the centre of the old continent during the winter, over that region thunder is equally unknown during that season. Further, in such places as Lisbon and Coimbra, where the summer rainfall is small and its occurrence infrequent, thunderstorms become less frequent, and the hours of their occurrence are later in the day than they are before and after the dry season.

The thunderstorms at Mauritius call for special notice. There are two maxima in the diurnal curve, the larger from noon to 4 P.M. and the smaller from 3 to 6 A.M., which are near the times of the barometric minima; and two minima, from 9 P.M. to 1 A.M. and from 8 to 10 A.M., these being near the times of the barometric maxima. But the important point as regards the thunderstorms of Mauritius is that for twelve years none were recorded in June and July, one only in August, one in September, and three in October. The annual period of the thunderstorms of this island extends from near the end of October to the middle of May, or during the time of the greatest rainfall, practically none occurring during the rest of the year. But rain continues to fall during the four months of no thunder, the mean monthly rainfall being then about 2 inches, falling, however, in September to 1·37 inches. During these four months, therefore, there is in the air the aqueous vapour, and, these being dry months, there is the condition of ascending currents. There appears, however, to be then wanting another element which seems essential to the electrical manifestations of the thunderstorm, viz., the conditions which give masses of descending cold air along with the ascending current of warm moist air. During the months when thunder is of no unusual occurrence the high pressure of Asia repeatedly advances, as Dr. Meldrum has pointed out, close on Mauritius; and so frequently is this the case that he considers the belt of calms between the two trade winds to stretch in a slanting direction from Madagascar to Ceylon. As long as this state of things occurs with more or less frequency, the conditions of a descending cold current of large volume are provided, and thunderstorms occur. But during June, July, August, and September, when atmospheric pressure is low in Central Asia, and there is an unbroken increase of pressure from Asia southwards to Mauritius, and while Mauritius remains in the heart of the south-east trades, the conditions of descending cold currents of any considerable volume are not present, and thunder is there unknown at that season.

Now in situations which afford the three conditions of aqueous vapour, ascending currents, and descending cold currents, whilst the diurnal and annual periods are quite distinctly marked, the phenomena are more uniformly distributed through the hours of the day and months of the year than elsewhere. Pola and Fiume, at the head of the Adriatic, being shut in and encompassed by lofty Alps, are illustrations. At Fiume the greater maximum occurs from 11 A.M. to 4 P.M. and the smaller from 2 to 4 A.M., and the minima from 10 P.M. to 1 A.M. and 5 to 9 A.M. While during the twelve hours the temperature is above the mean of the day from May to September the number of the thunderstorms here was 245 for the nine years ending 1879, the number during the twelve hours the temperature is under the mean was 185. The comparatively large number during the colder hours of the night is no doubt due to the warm moist atmosphere of this confined sea and the close proximity of the Alps.

There is still another set of conditions favouring the development of thunderstorms in certain climates which the observations made at Stykkisholm in the north-west of Iceland illustrate. During the fourteen years ending 1879 there occurred here twenty-three thunderstorms, but there was only one in the six warm months from April to September; in other words, the thunderstorms of this climate are essentially winter phenomena. Further, of the twenty-three hours in which they occurred, only three were at a time of the day when the sun was above the horizon, viz., twice in March and once in September; in other words, the thunderstorms of Stykkisholm are nocturnal phenomena. It is instructive to observe that in the north and north-west of Scotland thunder occurs most frequently during the night and in winter, whereas in central, southern, and eastern districts it occurs most frequently during the day and in summer,—the thunderstorms in the former case approximating in type to those of Iceland and in the latter to those of Ekaterinburg. A little reflexion shows that in north-western Europe it is during winter and during night that warm moist ascending and cold dry descending currents are most frequently brought into close proximity during the great Atlantic storms of the season; and it is at the changes of wind, humidity, and temperature accompanying the passage of the centres of the cyclones that the thunder peals are heard. On the other hand, in the east and south of Scotland it is during the hot months of the year that these ascending columns of warm moist air and descending columns of cold dry air are most frequently brought together, and there, accordingly, thunder with the heavy rains which accompany it is of most frequent occurrence from 11 A.M. to 5 P.M. from May to September. These essentially different types of thunderstorms have been classed by Mohn as heat thunderstorms and cyclonic thunderstorms.

Given an initial difference of electric potential, it is easy to understand from the effects which follow the sudden extraordinary condensations of the aqueous vapour that take place how the most violent thunderstorms are produced. The difficulty is to account for the production of the initial difference of electric potential,—how, for example, in the same great aerial current of the south-west monsoon, this difference of potential is produced in the molecules of aqueous vapour at Calcutta but not in the aqueous vapour at Mauritius. It is to the physicist that meteorologists still look for the explanation.

Diurnal Period in the Occurrence of the Whirlwind, Waterspout, Dust Storm, and Tornado.—Whirlwinds, waterspouts, dust storms, and tornadoes are essentially the same, differing from each other only in their dimensions, their intensity, or the degree in which the moisture is condensed into visible vapour, while the hailstorm and the rainstorm are simply the manner and degree of the precipitation accompanying them. In several important respects they differ widely and radically from cyclones (see ATMOSPHERE, vol. iii, p. 33). The largest tornadoes are of so decidedly smaller dimensions when compared with the smallest cyclones as to admit of no shading of the one into the other. Cyclones occur at all hours of the day and night, whereas whirlwinds and tornadoes show a diurnal period as distinctly marked as any in meteorology. Finally, cyclones take place under conditions which involve unequal atmospheric pressures or densities at the same heights of the atmosphere, due to inequalities in the geographical distribution of temperature and humidity; but whirlwinds occur where for the time the air is unusually warm or moist, and where consequently temperature and humidity diminish with height at an abnormally rapid rate. Cyclones are thus phenomena resulting from a disturbance of the equilibrium of the atmosphere considered horizontally, but whirlwinds and tornadoes have their origin in a vertical disturbance of atmospheric equilibrium.

Among the most remarkable of the tornado-swept regions of the globe are certain portions of the United States: and to the examination of these the meteorological service of the States has given special attention by a systematic, careful, and minute observation of the attendant phenomena and the destructive effects. The tornadoes of the last eighty-seven years, numbering about six hundred, have been classed under the different States where they are reported to have occurred, and fig. 5 shows this relative distribution over the States. The areas of greatest frequency are at long distances from each other. That part of the great basin lying west of the Mississippi, including the States of Iowa, Missouri, Kansas, and Nebraska, is the region in which tornadoes are most frequent. Tornadoes occur at all seasons, being most frequent, however, from April to September, and least frequent in December and January.

The hour of occurrence of one hundred and sixty-two of the tornadoes is given in the official report as follows:—

Midt. to 2 A.M.	2	8 A.M. to 10 A.M.	1	4 P.M. to 6 P.M.	52
2 A.M. ,, 4 ,,	5	10 ,, ,, Noon	7	6 ,, ,, 8 ,,	17
4 ,, ,, 6 ,,	3	Noon ,, 2 P.M.	13	8 ,, ,, 10 ,,	7
6 ,, ,, 8 ,,	4	2 P.M. ,, 4 ,,	47	10 ,, ,, Midt.	4

Thus the diurnal period of tornadoes is analogous to the period

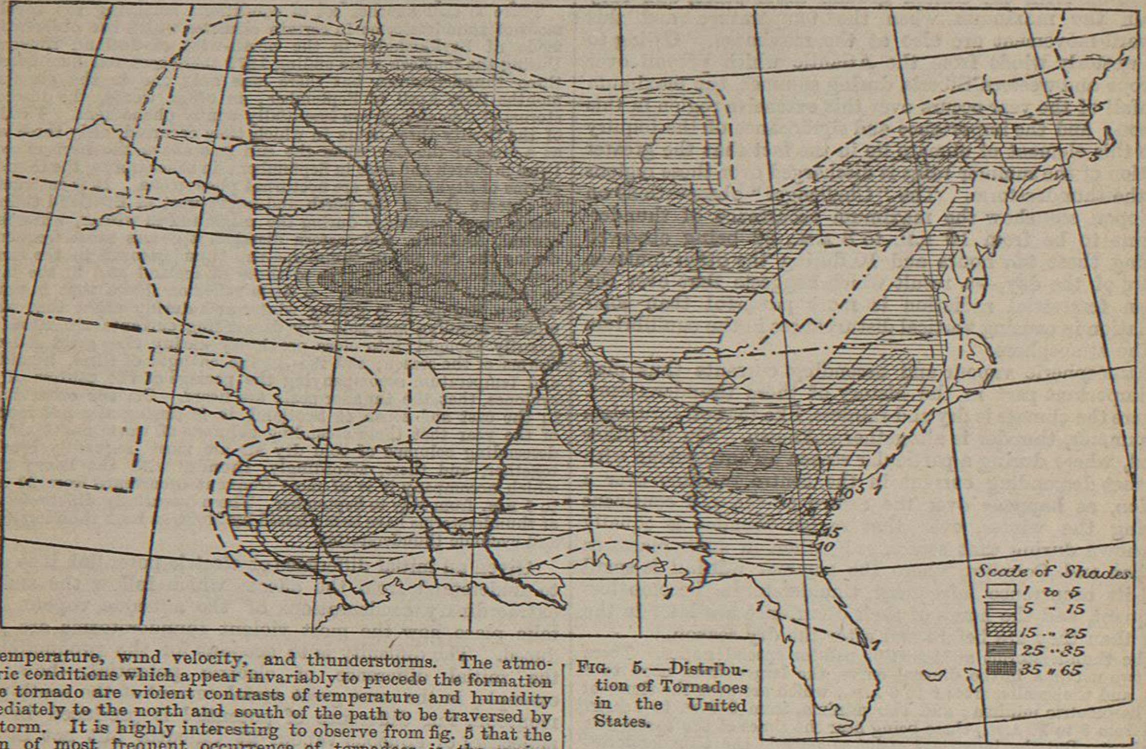

FIG. 5.—Distribution of Tornadoes in the United States.

for temperature, wind velocity, and thunderstorms. The atmospheric conditions which appear invariably to precede the formation of the tornado are violent contrasts of temperature and humidity immediately to the north and south of the path to be traversed by the storm. It is highly interesting to observe from fig. 5 that the region of most frequent occurrence of tornadoes is the region where a large number of the cyclones of the United States appear to originate (and the same region Loomis has shown to be remarkable for violent contrasts of temperature occurring within limited spaces and times), and that, as appears in the regions of the Alleghanies, they decrease in frequency with height.

Fig. 6 shows the waterspout in different aspects. A black cloud covers the sky, from which a projection is let down in the form of an inverted cone, as at A, which continues to increase and extend downwards. The sea immediately beneath is soon thrown into violent agitation, showing that the whirling movement which began in the clouds has extended to the sea, and is doubtless continuous throughout, though the portion of the column from A downwards is not yet made apparent by the condensation of its contained vapour into cloud. As the whirling movement of the column becomes more intensely developed, the increased rapidity of the gyrations brings about increased rarefaction of the air within, with the inevitable result of increased condensation of the vapour into cloud downward. The protrusion of the cloud and its extension downwards are thus not due to the descent of vapour from the clouds, but to the visible condensation of the vapour of the spirally ascending air-currents arising from an increasing rarefaction due solely to the accelerated rate of the gyrations, the condensation being analogous to that of the cloud seen in exhausting an air-pump.

Under each of the columns of fig. 6 the surface of the sea is seen to be more or less heaped up, as well as in violent agitation, showing that atmospheric pressure immediately under the gyrating columns is less than it is all round. On land, when the tornado passes directly over a dwelling house or other closed building, it often happens that the whole building, walls and roof, is thrown outward with great violence, the wreckage presenting the appearance of a sudden explosion, proving that atmospheric pressure outside the building was instantaneously and largely reduced, and the building shattered to fragments by the expansion of the air within. It is in this way that the tornado does some of its most dreadful work.

The wind of the tornado reaches a velocity probably never equalled in cyclones. During the Ohio tornado of February 4, 1842, large buildings were lifted entire from their foundations, carried several rods through the air, and then dashed to pieces, some of the fragments being carried distances of 7 and 8 miles; and large oaks nearly 7 feet in girth were snapped across like reeds. This tornado swept on its course at the rate of 34 miles an hour, and at one

place did its fearful work in the brief space of a minute. The tornado which passed over Mount Carmel (Illinois), June 4, 1877, swept off the spire, vane, and gilded ball of the Methodist church, and carried it bodily 15 miles to north-eastward. The velocity of the ascending currents which kept this heavy object suspended in the air for 15 or 20 miles must have been very great.

Of the tornadoes the progressive courses of which were recorded, 310 advanced towards N.E., 38 towards S.E., 16 towards E.N.E., 14 towards E., 7 towards N.N.E., 5 towards E.S.E., and 3 towards S.S.E. The course is thus always

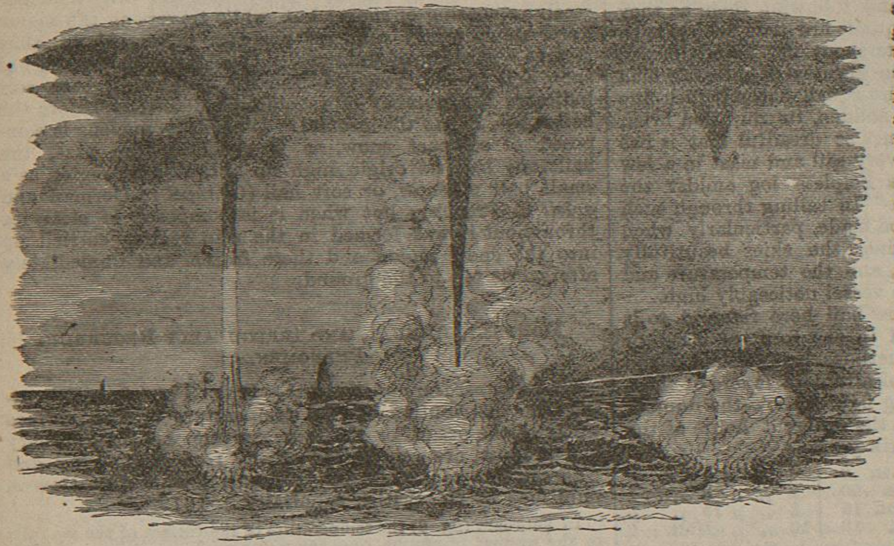
FIG. 6.—Forms of Waterspouts.

towards some easterly direction, the great majority being towards the north-east. The velocity of their onward movement varied from 12 to 60 miles an hour, the average being 30 miles an hour. The time occupied in passing a particular spot varied from 10 seconds to half an hour, the mean time being nearly six minutes and a half. The width of the path of destruction marked with debris and other relics of the violence of the tornado varied from 40 to 10,000 feet, the average being 362 yards. The direction of the whirling movement of the tornado was invariably from right to left, or the opposite of the movement of the hands of a watch, resembling in this respect the vorticose movement of cyclones in the northern hemisphere. The passage of the tornado cloud is often described as accompanied with remarkable noises, which observers variously characterize as terrible, deafening, a terrific crash, the roar of a thousand trains of cars, or the uproarious din of innumerable pieces of machinery.

The usual position of the gyrating columns of cloud is vertical; but occasionally a curving form or slanting direction is assumed. It is probable that to these latter forms many stationary or slowly moving dangerous squalls are to be referred, which spring up with unexpected suddenness in lakes and arms of the sea in mountainous regions.

The dust storm of India, Arabia, and Africa is a well-marked type of the whirlwind. Previous to the outbreak of a dust storm the air is unusually calm and sultry, just as happens in the case of the tornado. The simplest form of the dust storm is that of a tall aërial column of sand moving onwards, and drawing into itself, as it whirls round in its course, dust and other light bodies within the sweep of the strong air-currents which blow along the surface of the ground and converge vorticosely round the base of the column. A form commonly seen is shown in fig. 7, which represents several dust columns grouped together, each whirling independently round its own axis with incurving air-currents at the base, while the whole group of columns is borne bodily forward, and presents striking aspects as the forms and relative positions of the columns are changed. The importance of the observations made on dust storms as leading to a correct understanding of the whirlwind consists in this that it affords conclusive evidence that there is a strong inflow of the air along the surface of the ground all round vorticosely towards the base of the whirlwind, and that these same inflowing air-currents afterwards ascend through the air along the central axis of the whirlwind, carrying with them the evidence of their ascent in the visible solid particles of dust, sand, and other light objects they whirl up with them in their ascending course.

Owing to the extreme dryness of the air-currents involved in the dust storm, the rarefaction generated by the rapidity of the gyrations is insufficient to produce condensation of the aqueous vapour in the interior of the column. Quite different, however, is it with waterspouts and tornadoes, where, in the great majority of cases, the air near the surface before being drawn into the ascending vortex is of a high temperature and near the point of saturation. From the extreme rarefaction to which these air-currents are subjected, owing to their sudden ascent in a rapidly gyrating column, excessive condensation follows, with an aqueous precipitation at times so astonishing that it can only be fittingly described as an aerial torrent of solid water, or an aerial avalanche of hail and ice.

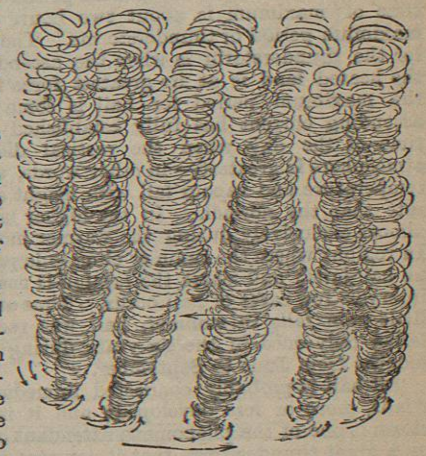
FIG 7.—Dust Storm.

Certain tracts of the ocean included within what may be called permanent anticyclones, or where atmospheric pressure is higher than all round, are characterized by an absence or comparative absence of rain. These regions are also remarkable for clear skies and strong sun heat. Similarly small anticyclonic areas occurring between or in the vicinity of cyclones are characterized by dry air and clear skies, and it is under these conditions that the strongest sun heat is felt. When, as repeatedly