members of the solar system moving in closed orbits. The same is by inference highly probable for most of the other meteoroids, and may be true of all of them. Permanent members of the solar system, however, if they ever fall into the sun, do so only after a long period of perturbation. If any meteoroids come from stellar spaces and have any uniform or random distribution of velocities or directions, only a very small portion of these would hit the sun's surface. The far greater portion would go on in hyperbolic orbits. But the earth receives the impact of its portion of these foreign meteoroids, both in their inward and outward course, and in addition encounters a full share of the permanent members of the solar system, of which the sun receives very few or none. It is not hard to show that a supply of meteoroids to the sun sufficient to make good its daily loss of heat would require that the twenty million meteoroids which the earth daily encounters, even if all were from stellar space, should have an average weight of hundreds of tons. The facts do not warrant the admission of any such magnitude even for the large meteors, much less for the ordinary and small shooting stars. Whatever be the source of the sun's heat, all the meteoroids of which we know anything are totally inadequate to supply the waste.

The literature of meteors and meteoroids is very much scattered. It is mainly contained in the scientific journals and in transactions of learned societies. The series of valuable *Reports* of the Luminous Meteor Committee of the British Association contains not only the record of an immense amount of original observations, but also year by year a digest of most of the important memoirs.

Meteoric science is a structure built stone by stone by many builders. In this article no attempt has been made to assign to each builder the credit for his contribution. (H. A. N.)

METEORA, a remarkable group of rock-built monasteries in Thessaly, in the northern side of the valley of the Peneus, not quite 20 miles north-east of Triccala, and in the immediate vicinity of the village of Kalabaka, Stagus, or Stagoi (the ancient Æginium). From the Cambunian chain two vast masses of rock are thrust southward into the plain, surmounted by a number of huge isolated columns from 85 to 300 feet high, "some like gigantic tusks, some like sugar-loaves, and some like vast stalagmites," but all consisting of iron-grey or reddish-brown conglomerate of gneiss, mica-slate, syenite, and greenstone. On the summit of these rocky pinnacles—accessible only by aid of rope and basket let down from the top, or in some cases by a series of almost perpendicular ladders climbing the cliff to the mouth of a tunnel—stand the monasteries of Meteora (τὰ Μετέωρα). At one time they were twenty-four in number; but Holland (1812) and Hughes (1814) found them reduced to ten; at Curzon's visit (1834) there were only seven; and in 1853 not more than four of these were inhabited by more than two or three monks. Meteora *par excellence* is the largest and perhaps the most ancient. The present building was erected, according to Leake's reading of the local inscription, in 1388 (Björnståhl, the Swedish traveller, had given 1371), and the church is one of the largest and handsomest in Greece. St Barlaam's and St Stephen's (the latter founded by the emperor John Cantacuzene) are next in importance. The decorations of the churches contain a large amount of material for the history of Byzantine art, not mueh inferior in value to the similar treasures at Athos.

Unless the identification with the Ithome of Homer be a sound one, there is no direct mention of the rocks of Meteora in ancient literature, and Professor Kriegk suggests that this may simply be due to the fact that they had not then taken on their present remarkable form. Æginium, however, is described by Livy as a strong place, and is frequently mentioned during the Roman wars; and Stagus appears from time to time in Byzantine writers.

See Holland, *Travels in the Ionian Isles, &c.*, 1815; Hughes, *Travels in Greece and Albania*, 1830; Curzon, *Visit to Monasteries in the Levant*, 1849; Leake, *Northern Greece*; Professor Kriegk in *Zeitschr. f. allg. Erdk.*, Berlin, 1858; Tozer, *Researches in the Highlands of Turkey*, 1869.

METEOROLOGY

METEOROLOGY, in its original and etymological sense, included within its scope all appearances of the sky, astronomical as well as atmospherical, but the term is now restricted to the description and explanation of the phenomena of the atmosphere which may be conveniently grouped under weather and climate. These phenomena relate to the action of the forces on which the variations of pressure, temperature, humidity, and electricity of the atmosphere depend, but in an especial sense to the aerial movements which necessarily result from these variations.

In the more exact development of meteorology, the scientific investigation of climate long preceded that of weather. Humboldt's work on *Isothermal Lines*, published in 1817, must be regarded as the first great contribution to meteorological science. The importance of this inquiry into the distribution of terrestrial temperature it is scarcely possible to overestimate, for, though the isothermals were necessarily to a considerable extent hypothetical, there cannot be a doubt that they presented a first sketch of the principal climates of the globe. Dove continued and extended the investigation, and in his great work *On the Distribution of Heat on the Surface of the Globe*, published in 1852, gave charts showing the mean temperature of the world for each month and for the year, together with charts of abnormal temperature. To this, more than to any other work, belongs the merit of having popularized the science of meteorology in the best sense, by enlisting in its service troops of observers in all parts of the civilized world.

In 1868 another series of important charts were published representing by isobaric lines the distribution of the mass of the earth's atmosphere, and by arrows the prevailing winds over the globe for the months and the year. By these charts the movements of the atmosphere and the immediate causes of these movements were for the first time approximately stated, and some knowledge was thereby attained of some of the more difficult problems of meteorology. It was shown that the prevailing winds are the simple result of the relative distribution of the mass of the earth's atmosphere, in other words, of the relative distribution of its pressure, the direction and force of the prevailing winds being simply the flow of the air from a region of higher towards a region of lower pressure, or from where there is a surplus to where there is a deficiency of air. It is on this broad and vital principle that meteorology rests, which is found to be of universal application throughout the science, in explanation, not only of prevailing winds, but of all winds, and of weather and weather changes generally. One of the more important uses of the principle is in its furnishing the key to the climates of the different regions of the earth; for climate is practically determined by the temperature and moisture of the air, and these in their turn are dependent on the prevailing winds, which are charged with the temperature and moisture of the regions they have traversed. The isobaric charts show further that the distribution of the mass of the earth's atmosphere depends on the geographical distribution of land and water in their relations to the sun's heat and to radiation towards the regions of space in different seasons.

In 1882 Loomis published a map showing the mean rainfall of the globe. This map and others that have been constructed for separate countries show conclusively that the rainfall of any region is determined by the prevailing winds considered in relation to regions from which they have come, and the physical configuration and temperature of the part of the earth's surface over which they blow. The maximum rainfall is precipitated by winds which

having traversed a large breadth of ocean, come up against and blow over a mountainous ridge lying across their path, and the amount deposited is still further increased if the winds pass at the same time through regions the temperature of which constantly becomes colder. On the other hand, the rainfall is unusually small, or *nil*, when the prevailing winds have not previously traversed some extent of ocean, but have crossed a mountain ridge and advance at the same time into lower latitudes, or regions the temperature of which is markedly higher.

While the observational data for the determination of the geographical distribution of the prime elements of climate, viz., the pressure, temperature, moisture, and movements of the atmosphere and the rainfall were being slowly but surely collected, the great importance of the study of weather came gradually to be recognized. Additional impetus was given to this branch of study from its intimate bearings on the eminently practical question of storm warnings. Synchronous weather maps, showing the weather over a considerable portion of the earth's surface, were constructed, and some advance was made in tracing the progress of storms from day to day. Unquestionably one of the first problems of meteorology is to ascertain the course storms usually follow and the causes by which that course is determined, so as to deduce from the meteorological phenomena observed, not only the certain approach of a storm, but also the particular course that storm will take. The method of practically conducting this large inquiry in the most effective manner was devised by the genius of Leverrier, and begun to be carried out in 1858 by the daily publication of the *Bulletin International*, to which a weather map was added in September 1863. This map showed graphically for the morning of the day of publication the atmospheric pressure, and the direction and force of the wind, together with tables of temperature, rainfall, cloud, and sea disturbance from a large number of places in all parts of Europe. From such weather maps forecasts of storms are framed and suitable warnings issued; but above all a body of information in a very handy form is being collected, the careful study and discussion of which is slowly but gradually leading to the issue of more exact and satisfactory forecasts of weather, and to a juster knowledge of these great atmospheric movements which form the groundwork of the science.

The most cursory glance is sufficient to show that the ever-changing physical phenomena with which it is the business of meteorology to deal are all referable to the action of the sun, it being evident that if the sun were blotted out from the sky a cold lifeless uniformity would rapidly take possession of the whole surface of the globe. Meteorological phenomena naturally group themselves into two great classes,—those dependent on the revolution of the earth on its axis, and those dependent on its revolution round the sun taken in connexion with the inclination of its axis to the plane of its orbit. The science thus divides itself into two great divisions, the first comprising diurnal phenomena and the second annual phenome

Diurnal March of Phenomena.

Temperature.—Of the daily changes which take place in the atmosphere, the first place must be assigned to those which relate to temperature, seeing that on these all other changes are either directly or indirectly dependent. Observations of the temperature of the air are therefore of the first importance in meteorology. A perfectly accurate observation of the temperature of the air is unquestionably among the most difficult to make of all physical observations, the difficulty being to eliminate the effects of radiation of surrounding objects. The nearest approach yet made to the solution of this important problem of physical inquiry was made by Dr Joule in a communication to the Philosophical Society of Manchester (November 26, 1867, *Proc.*, vol. vii. p. 35). But the manipulative skill and time demanded by the method there detailed render it quite unsuitable for general adoption anywhere in collecting the observational data required in the determination of this important element of climate. It is therefore necessary to fall on some method which, while it gives results that can only be regarded as approximate, secures the essential element of uniformity among the observations.

Fig. 1 represents Stevenson's louvre-boarded box for the thermometers, which is now very widely used for temperature observations. The box is made of wood, and louvred all round so as to protect the thermometers inside from radiation, and at the same time secure as free a circulation of air as is consistent with a satisfactory protection from radiation. The box is painted white, both inside and outside, and screwed to four stout wooden posts, also painted white, firmly fixed in the ground. The posts are of such a length that when the thermometers are hung in position the bulbs of the minimum thermometer and hygrometer are exactly at the same height of 4 feet above the ground, the maximum thermometer being

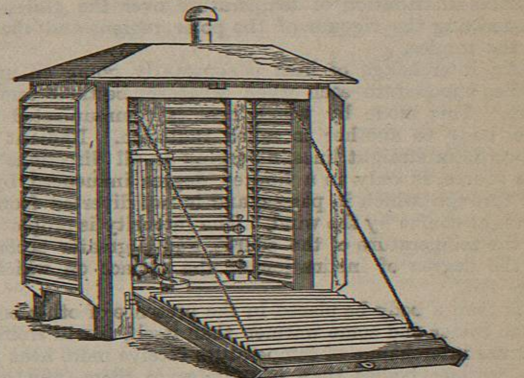

Fig. 1.—Thermometer Box.

hung immediately above the minimum thermometer. This thermometer box is placed over a plot of grass, and in a free open space to which the sun's rays have free access during as much of the day as surrounding conditions admit of. It will be observed that the thermometers are suspended on cross-laths in the centre of the box and face the door, which should always open to the north. It is not possible to overestimate the importance of seeing that uniformity of height above ground and method of protecting the thermometers is secured, since in no other way is it possible to obtain results from different places which shall be comparable with each other and thus supply satisfactory materials for the investigation and development of comparative climatology.

A desired uniformity is yet far from being attained among the meteorological systems of different countries. Thus in Russia the box for the protection of the thermometers is made of zinc, on the supposition that such a box follows more closely the changes of temperature of the air than a box of wood. Owing to these international diversities of observation, it is extremely desirable that steps were taken to ascertain, by Joule's method of observing, the approximate errors peculiar to each sort of thermometer box, in order that the temperatures of different countries may be compared together in a more satisfactory manner than has yet been possible.

Interchanges of temperature among bodies take place by conduction, convection, and radiation. In meteorology the most important illustrations of conduction are the propagation downwards through the earth's strata of the changes of the temperature of the surface as it is heated during the day and cooled during the night, and the propagation of the same changes of temperature through the lowest stratum of the air which rests on the surface. Since sand and light loose soils are much worse conductors of heat than clay and dense soils, it follows that loose soils and tracts of sand are subject during the day to higher temperature and during the night to lower temperature near the surface than dense soils, and that frosts and extreme temperatures do not penetrate so far into loose as into dense soils. It is on these differences that some of the more striking features of climates depend. As snow is one of the worst conductors of heat, owing to the quantity of air filling the interstices among the ice crystals, it protects the soil it covers by setting a limit to the depth to which the severe frosts of the surface penetrate, and by arresting the escape of the heat of the soil upwards to the air.

The communication of heat from one part of the earth to another by convection is seen on a grand scale in the winds and in the currents of the ocean. It is seen also in the ascending and descending currents of the atmosphere everywhere, which have their origin in the daily and unequal changes of temperature to which the surface of the earth is subject. The direct and beneficial effect which results from atmospheric and oceanic circulation is a more equable distribution of temperature over the globe, thus moderating the rigours of the polar regions and the heat of the tropics.

An interchange of heat is constantly going on among bodies exposed to each other, whatever be their temperature. This mode by which heat is communicated from one body to another is called radiation. Radiant heat proceeds in straight lines, diverging in all directions from the source, is only in a limited degree influenced by the air through which it passes, and is not diverted from the straight course by the wind. The intensity is proportional to the temperature of the source, and is greater according to the degree of inclination of the surface on which the rays fall.

If then a body be placed in the presence of other bodies, some colder and some warmer than itself, it will from this mutual interchange of temperature receive more heat from the warmer bodies than it radiates to them, and consequently becomes warmer; but it will receive less heat from the colder bodies than it radiates to them, and its temperature consequently falls. This is precisely the condition in which the earth is placed in space. When a part of the surface is turned towards the sun, that part of the surface receives more heat than is radiated from it; and the temperature consequently rises most in that region which for the time is perpendicular to the sun's rays, and least round the annulus where the inclination of the surface is greatest. On the other hand, since the hemisphere turned from the sun radiates more heat than it receives from the cold regions of space, the temperature there falls. Owing to the essentially distinct conditions under which the earth is placed with respect to radiation, the subject falls naturally to be divided into two heads, solar radiation and terrestrial radiation.

Solar Radiation.—Of the sun's rays which arrive at the earth's surface, those which fall on the land and solid bodies generally are wholly absorbed by the thin surface layer exposed to the heating rays, the temperature of which consequently rises. Whilst the temperature of the surface increases, a wave of heat is propagated downwards through the soil. The intensity of the daily wave of temperature rapidly lessens with the depth at a rate depending on the conductivity of the soil, until at about 4 feet below the surface it ceases to be measurable. Part of the heat of the surface layer is conveyed upwards through the air by the convection currents which have their origin in the heating of the lowermost stratum of air in direct contact with the heated surface of the land.

Altogether different is the influence of the sun's rays on water. In this case the sun's heat is not all, indeed very far from all, arrested at the surface, but penetrates to a considerable depth. The depth to which the influence of the sun is felt has been shown by the observations made during the cruise of the "Challenger" to be, roughly speaking, about 500 feet below the surface of the sea. The rate at which, in perfectly clear water, this heat is distributed at different depths is a problem that has not yet been worked out. Since water is a bad conductor, the heat thus distributed does not, as takes place with respect to land, penetrate to still lower depths by conduction, but only by different densities prevailing at the same depths, whether these different densities be due to different temperatures or different degrees of salinity. Thus one of the more important distinctions between land and water surfaces in their bearings on climate is that nearly all the sun's heat falling on land is arrested on the surface, whereas on water it is at once diffused downwards to a great depth. In examining temperatures of the sea taken at different depths, it is surprising to note the rapidity with which changes of temperature are felt at considerable depths, especially in cases when the temperature of the air rises rapidly, accompanied with strong sunshine.

In shallow water the sun's heat raises the temperature much higher than that of deep water, this being obvious from the consideration that nearly the whole of the sun's heat which falls on the surface is utilized in raising the temperature of the shallow layer of water; in other words, it is, so to speak, concentrated through a small depth of water instead of being diffused through a great depth.

Surface Temperature of the Sea.—The importance of a knowledge of this datum of meteorology will be at once recognized when it is kept in view that three-fourths of the earth's surface is water, that the temperature of the air resting on this surface is in close relation to the temperature of the surface, and that the latter has, through the intervention of the winds, direct and important bearings on the temperature of the air over large portions of the land surfaces of the globe. During the years 1859–63 Captain Thomas, while engaged on the survey of the islands on the north-west of Scotland, made observations of the temperature of the surface of the sea every hour of the day at all seasons, and with sufficient frequency for the determination of the diurnal range of the temperature of the surface. The daily minimum, 0°·17 below the mean, occurred near 6 A.M.; the mean was reached about 11 A.M., the maximum, 0°·13 above the mean, between 3 and 4 P.M., and the mean again shortly before 2 A.M. Thus the daily oscillation of the temperature of the surface of the sea amounted on the north-west of Scotland only to 0°·3. In lower latitudes the amount of the daily fluctuation is somewhat larger, but everywhere it is comparatively small, if care be taken to make the observations properly, or at a distance from land, where the influence of the heated or cooled land is not allowed to vitiate the results.

During the voyage of the "Challenger" a complete system of meteorological observations, including the temperature of the surface of the sea, was made every two hours as part of the scientific work of the cruise. These are now being discussed, and the writer of this article is, by permission of the Lords Commissioners of H.M. Treasury, allowed to use such of the results as have been already arrived at.

The diurnal march of the temperature of the surface of the North Atlantic has been determined from observations made on one hundred and twenty-six days from March to August 1873 and in April and May 1876, the mean latitude of all the points of observation being nearly 30 N., and the longitude 42° W. The following variations from the mean show the phases of this diurnal oscillation:—

2 A.M.	−0°·24	10 A.M.	0°·06	6 P.M.	0·26
4 ,,	−0·33	Noon	0·24	8 ,,	0·02
6 ,,	−0·29	2 P.M.	0·47	10 ,,	−0·19
8 ,,	−0·12	4 ,,	0·47	Midnight	−0·35

Thus in mid Atlantic, about 30° N. lat., where the sun's heat is strong, and at the time of the year when the sun is north of the equator, the diurnal fluctuation of the temperature of the surface is only 0°·80. It is highly probable that nowhere over the ocean does the mean daily fluctuation of the temperature of the surface quite amount to a degree. This small daily fluctuation is a prime factor in meteorology, particularly in discussions relating to atmospheric pressure and winds.

Temperature of Air over the Open Sea.—The following shows the daily march of the temperature of the air over the North Atlantic on a mean of the same one hundred and twenty-six days for which the temperature of the sea has been given:—

2 A.M.	−1°·13	10 A.M.	0°·78	6 P.M.	0°·73
4 ,,	−1·40	Noon	1·45	8 ,,	−0·30
6 ,,	−1·41	2 P.M.	1·80	10 ,,	−0·80
8 ,,	−0·21	4 ,,	1·56	Midnight	−1·02

The amplitude of the daily fluctuation of the air is thus 3°·21, or nearly four times greater than that of the sea over which it lies. During the same months the "Challenger" was lying near land on seventy-six days. The observations made on these days show a greater daily range of temperature of the air than occurred out in the open sea. The minimum, −2°·05, occurred at 4 A.M., and the maximum, 2°·33, at noon, thus giving a daily range of 4°·38. The occurrence of the maximum so early as noon is doubtless occasioned by the greater strength of the sea breeze after this hour, this maintaining a lower temperature. Part of the increased range of the temperature of the air as compared with that of the sea was no doubt due to the higher temperature during the day and the lower during the night on the deck of the "Challenger" as compared with that of the air. But, after making allowance for this disturbing influence, it is certain that the temperature of the air has a considerably larger daily range than that of the sea on which it rests. The point is one of no small interest in atmospheric physics from the important bearings of the subject on the relations of the air and its aqueous vapour to solar and terrestrial radiation.

The hourly deviations from the mean daily temperature of the air at two places, one near the equator and the other in the north temperate zone, and both near the sea, viz., Batavia (6° 8′ S. lat., 106° 48′ E. long., mean temperature 78°·7) and Rothesay (55° 50′ N. lat., 5° 4′ W. long., mean temperature 47°·3), are these:—

Batavia.		Rothesay.	Batavia.		Rothesay.
1 A.M.	−3°·2	−1·7	1 P.M.	+5°·7	+2°·4
2 ,,	−3·6	−2·0	2 ,,	+5·6	+2·7
3 ,,	−4·0	−2·1	3 ,,	+5·2	+2·8
4 ,,	−4·3	−2·2	4 ,,	+4·3	+2·6
5 ,,	−4·7	−2·2	5 ,,	+3·3	+2·1
6 ,,	−4·9	−2·0	6 ,,	+1·9	+1·5
7 ,,	−4·3	−1·5	7 ,,	+0·6	+0·9
8 ,,	−2·2	−0·9	8 ,,	−0·4	+0·2
9 ,,	−0·5	−0·2	9 ,,	−1·2	−0·4
10 ,,	+2·8	+0·5	10 ,,	−1·8	−0·8
11 ,,	+4·4	+1·2	11 ,,	−2·3	−1·2
Noon	+5·4	+1·9	Midnight	−2·8	−1·5

The times of the four phases of the daily temperature at Batavia are—minimum about 5.50 A.M., mean 8.45 A.M., maximum 1.20 P.M., and mean 7.40 P.M.; while for Rothesay the same times are 4.30 A.M., 9.15 A.M., 3 P.M., and 8.20 P.M. At Batavia, where the days and nights are nearly equal during the year, there is little variation in these times through the months; but at Rothesay, where the days are much longer in summer than in winter, there is considerable variation in the times of occurrence of these phases. The following table shows the times of the phases for a number of selected places in the northern hemisphere for the two extreme months, January and July:—

	January.				July.			
	Min.	Mean.	Max.	Mean.	Min.	Mean.	Max.	Mean.
	A.M.	A.M.	P.M.	P.M.	A.M.	A.M.	P.M.	P.M.
Sitka........	6.0	9.40	1.30	6.35	3.40	7.40	0.50	7.30
Toronto........	6.20	10.0	1.50	9.40	3.50	8.15	3 45	8.10
Philadelphia..	6.50	10.0	2.40	8.45	5.0	8.40	3 10	8.0
Havana....								
Archangel......	6.0	10.40	1.30	9.0	2.40	8.36	2.50	8.50
Rothesay.... ..	5.30	10.10	2.30	8.0	3.30	9.0	3.15	8.50
Oxford..	7.20	10.10	2.0	7.0	3.40	8.45	3.10	8.25
Madrid........	6.50	10.5	2.40	8.35	4.40	8.50	2.50	8.35
Geneva	6.0	10.0	2.0	8.0	3.15	8.15	2.50	8.10
St Bernard....	4.30	8.25	0.55	6.45	3.0	8.10	1.20	7.50
Bogoslovsk....	5.30	9.25	1.30	8.15	3.40	7.35	2.5	8.4
Petroalexan-drovsk.....	6.50	9.50	2.35	7.45	4.30	8.20	2.40	8.25
Tiflis...........	7.10	9.50	2.25	7.50	5.0	9.5	3.10	8.15
Calcutta........	6.30	9.35	2.30	8.20	5.30	8.45	0.40	7.30
Bombay........	6.0	9.10	2.10	8.5	5.30	9.0	1.30	6.30
Madras........	5.40	8.0	0.40	6.45	5.0	8.45	1.25	6.50

During the night in summer the temperature falls continuously from the effects of terrestrial radiation till the earliest dawn, when the daily rise in the temperature sets in owing to the heat reflected from the upper strata of the atmosphere, which have begun to be heated and lighted up by the rays of the morning sun. It will be observed that the time of the daily minimum temperature occurs earliest in high latitudes and latest in low latitudes. During winter, on the other hand, the minimum temperature takes place in several regions some time before dawn. At this season the two chief causes on which changes of temperature depend are the sun and the passage of cyclones and anticyclones; and it is probable that those cases where the minimum occurs markedly before the dawn are, where not occasioned by purely local disturbing causes, due to the mean diurnal times of occurrence of the changes of temperature which accompany the great atmospheric disturbances of cyclones and anticyclones.

In July the daily maximum temperature occurs generally from 2 to 4 P.M. At places, however, near the sea, which are within the immediate influence of the sea breeze, and in places at some distance from the sea, such as Calcutta, where the wind, being essentially a sea wind, attains its greatest daily velocity and the sky at the same time is much clouded, the maximum occurs nearly two hours earlier. In high situations, such as the St Bernard hospice, the highest daily temperature also occurs nearly two hours sooner than on the plains below. In the winter months the maximum is about an hour earlier than in the summer.

In investigating the daily curves of temperature, Sir David Brewster drew several interesting conclusions from them. By dividing the daily curve of temperature, deduced from the mean of the year, into four portions, at the points representing the two daily means and the two extremes, he showed that the four portions approximate to parabolas, in which the temperatures are the abscissæ and the hours the ordinates. The correspondence between the observed and calculated results is so close that the difference did not in any case exceed a quarter of a degree Fahrenheit. This interesting result is true for places at which the horizon is open all round, so that no shadows of hills, trees, or buildings fall on the places where the thermometers are kept during the day. If a hill rises to the north of the place, by which the sun's rays are never obstructed, it exercises little, if any, influence on the observations; but if one or more hills obstruct the rays of the sun after it has risen above the horizon, such obstruction affects the temperature while, and for some time after, the position in which the thermometer is placed is shaded from the sun.

Brewster further made the important remark that the mean of observations made at any pair of hours of the same name, such as 8 A.M. and 8 P.M., 9 A.M. and 9 P.M., &c., does not differ much from the mean temperature of the day. The pairs of hours which approximate closest to the true daily mean are 9 A.M. and 9 P.M., 10 A.M. and 10 P.M., 3 A.M. and 3 P.M., and 4 A.M. and 4 P.M. The mean of four hours at equal intervals from each other gives a result still closer to the true mean temperature.

In organizing any system of meteorological observation, by which it is intended to develop the climatology of the country, the determination of the hours of observation is a question of the first importance. If only two observations be made daily the best hours are 9 A.M. and 9 P.M., or 10 A.M. and 10 P.M.; and if there be four observations the best hours are 3 and 9 A.M. and 3 and 9 P.M., or 4 and 10 A.M. and 4 and 10 P.M. If there be three observations the best hours are 9 A.M. and 3 and 9 P.M., or 10 A.M. and 4 and 10 P.M.; but in these cases it is essential that the observations of a minimum thermometer be added to the temperature observations. These hours are further strongly recommended by the consideration that they are approximately coincident with the diurnal phases of atmospheric pressure, an exact knowledge of which lies at the root of nearly all climatological inquiries. The three equidistant hours which have been adopted in several countries, viz., 6 A.M. and 2 and 10 P.M., are only good as regards the temperature, not as regards atmospheric pressure. With respect to two daily observations, the hours 8 A.M. and 1 P.M., which have been adopted in some countries, are singularly unsuitable for the furnishing of the observational data required in the development of the climatologies of these countries; and, what is still more serious in a science where international co-operation is so imperatively demanded, these observations cannot be used with any satisfaction in such deeply important inquiries as the comparative climatologies of Europe.

The times of occurrence of the highest, lowest, and mean daily temperatures, and the amount of the daily range of temperature, are in a great degree influenced by the covering or want of covering of the earth's surface on which the air rests. When the ground is covered with vegetation, the whole of the solar heat falls on the vegetable covering; and, as none falls immediately on the soil, its temperature does not rise so high as happens where there is no vegetable covering to shade the surface from the sun. The temperature of plants exposed to the sun is not so high as that of exposed soil in the vicinity. As regards forests, the four diurnal phases of temperature occur later than in the open country, and the maximum and minimum are less decided; and, since the maximum temperature of the air in forests falls short of the maximum in the open to a considerably greater extent than the minimum under trees is above the minimum in the open, it follows that the mean temperature of the air in forests is less than that of the open country adjoining. The reason of the difference is that the chilling effects of nocturnal radiation penetrate lower down among the trees than do the heating effects of solar radiation; and as the soil is not heated directly by the sun its temperature is lower, and consequently that of the air over it is also lower. A cleared space in a forest, sheltered by the surrounding trees, but open to the sun, has a warmer and moister atmosphere in spring and summer and very much moister in autumn than prevails in the open country adjoining, and has also the diurnal differences of range peculiar to a warmer and moister atmosphere.

One of the most important elements of climate is disclosed by the difference between the hour of lowest and the hour of highest mean temperature respectively, or, as it is usually expressed, by the daily range of temperature. We have seen that as regards the sea in the north-west of Scotland the difference is only 0°·3 and in the Atlantic about 30° N. lat. 0°·8, and that probably the diurnal range of temperature of the surface of the sea nowhere amounts to a degree. In the same part of the Atlantic the daily range of the temperature of the air resting on the ocean is 3°·2, and on the sea near land 4°·4. On advancing on the land, the daily range of temperature rapidly increases, and the rate of increase is greatly augmented when an inland position is arrived at to which any sea breezes that may prevail do not extend.

The true daily range of temperature is stated by observations made with maximum and minimum thermometers. Generally speaking, the amount of the range increases as the latitude is diminished, and as the distance from the sea is increased, but above all it increases in proportion to the dryness of the climate.

The differences of this vital element of climate are strikingly shown in the meteorology of India. In the *Report* for 1880 the following are the mean daily ranges of March of that year at a few places: at Goa 5°·4, Bombay 11°·2, Kurrachee 23°·5, Jacobabad 37°·4, and Pachbudra (lat. 25° 55′ N., long. 72° 18′ E.) 41°·3. In the last case, undoubtedly one of the greatest mean daily ranges of temperature meteorology has yet recorded, the mean of the days was 103°·4 and of the nights 62°·1. As March is altogether within the season of the north-east monsoon, the general drift of the wind over western India, where these are situated, is from the interior towards the sea, subject as regards Bombay and Goa to the influences of the land and the sea breeze. On the other hand, in June, when the south-west monsoon has fairly set in, the following are the mean daily ranges of temperature at the same places: at Goa 5°·6, Bombay 8°·2, Kurrachee 10°, Jacobabad 27°·6, and Pachbudra 24°·1. These show in a striking manner the powerful influence of the moister atmosphere spread over India by the south-west monsoon, under which the daily range of temperature falls at Kurrachee from 23°·5 to 10°, and in the excessively arid climate of Pachbudra from 41°·3 to 24°·1. In these dry climates of the basin of the Indus, whilst the rainfall both in March and in June is practically nil, yet the relative humidity of the atmosphere is widely different. Thus the humidities for March and June respectively at 4 P.M., when the temperature is nearly the maximum for the day, are 48 and 77 for Kurrachee, 18 and 30 for Jacobabad, and 11 and 36 for Pachbudra. It is not so much the amount of cloud that determines the degree of fierceness of the sun's heat in these climates as the relative humidity, or the dryness of the air, as pointed out by Strachey in 1866. Thus at Jacobabad less than half the amount of cloud appears in the sky in June as compared with March, but the relative humidities are 30 and 18, and the daily range of temperature 27°·6 and 37°·4. If we except the dry arid wastes of Persia and Arabia, there is perhaps no other region of the globe where the daily range of temperature approaches that of the valley of the Indus. Thus in the dry climates of such places as Sacramento (California) in summer it amounts only to about 30°, at Madrid to 27°, and Jerusalem 24°. In central districts in the south of England it is about 20°; farther north it falls to 15°; and in the islands in the north, whose climate is strictly insular in its character, the summer daily range is only 10°. In Arctic regions, such as Spitzbergen and Boothia Felix, the range in winter varies from 0°·0 to 1°·0; in May, when the sun has reappeared and continues to rise and set, it rises to 14°; but in July, when the sun does not set, the range sinks to 10°.

But maximum and minimum thermometers not only show the mean daily range of temperature, they are also of great utility in giving observations for the determination of mean temperature. The mean temperature may be accepted as the mean of the twenty-four hourly observations of the day. If with such a system of observation daily readings of the maximum and minimum thermometer be compared, the value of the latter observations in questions of mean temperature may be arrived at. Double series of observations of this description have been made at many places. The following shows a comparison of the mean of maximum and minimum daily temperatures with means from observations made twenty-four times daily, the former exceeding the latter means in nearly all cases:—

	Spring.	Summer.	Autumn.	Winter	Year
Batavia	0·3	−0·2	0·2	−0·2	−0·2
Calcutta	1·0	0·7	0·7	0·9	0·8
Peking	0·6	0·6	0·6	0·7	0·6
Nertchinsk	0·1	0·3	0·6	1·0	0·5
Barnaul	0·5	0·5	0·7	0·8	0·6
Ekaterinburg	0·5	0·7	0·7	0·6	0·6
Tiflis	0·5	0·5	0·5	0·4	0·5
St Petersburg	0·6	0·6	0·3	0·1	0·4
Valentia	0·4	0·5	[illegible]	−0·1	0·2
Greenwich	0·7	0·8	0·6	0·0	0·4
Rothesay	0·4	0·3	0·3	0·3	0·3

These results show remarkable uniformity, and it may be inferred from them that mean temperatures deduced from maximum and minimum observations are about half a degree above the true mean temperature. In general climatological inquiries, observations with these thermometers have the strong recommendation of supplying from observations taken once a day the data for the determination of the mean temperature and mean daily range of localities; to which falls to be added the further advantage of giving results more uniformly comparable for different places than could be afforded by observations made with a common thermometer at any single hour or pair of hours daily.

Daily Variation of the Humidity of the Air.—The gaseous envelope surrounding the earth is composed of two atmospheres, quite distinct from each other,—an atmosphere of dry air and an atmosphere of aqueous vapour. The dry air, which consists of oxygen and nitrogen, is always a gas, and its quantity remains constant; but the aqueous vapour does not continue permanently in the gaseous state, and the quantity present in the air is, by the ceaseless processes of evaporation and condensation, constantly changing. If the aqueous vapour remained permanently and unchanged in the atmosphere, or were not liable to be condensed into cloud or rain, the mixture would become as complete as that of the oxygen and nitrogen of the air. The equilibrium of the vapour atmosphere, however, is being constantly disturbed by every change of temperature, by every instance of condensation, and by the unceasing process of evaporation. Since dry air further materially obstructs the free diffusion of the aqueous vapour, it follows that the law of the independent pressure of the vapour and of the dry air of the atmosphere holds good only approximately. The aqueous vapour, however, constantly tends to approach this state. Since, then, the independent and equal diffusion of the dry air and the aqueous vapour is, owing to these disturbing causes, never reached, the important conclusion follows that the hygrometer can never indicate more than the local humidity of the place where it is observed. Hygrometric observations can therefore be regarded only as approximations to a true indication of the quantity of aqueous vapour in the atmosphere over the place of observation. It is, however, to be added that, while in certain cases the amount of vapour indicated is far from the truth, yet in averages, particularly long averages, a close approximation to the real amount is reached if the hygrometer be at all tolerably well exposed and carefully observed.

Aqueous vapour is constantly being added to the air from the surfaces of water, snow, and ice, from moist surfaces, and from plants. The rate of evaporation increases with an increase of temperature, because the capacity of the air for vapour is thereby increased. The atmosphere can contain only a certain definite amount of vapour, according to the temperature; when therefore the air has its full complement of vapour, or when, in other words, it is saturated, evaporation ceases. Thus the rate of evaporation is greatest when the air is driest or freest from vapour, and least when the air is nearest the point of saturation. Since currents of air remove the moister and substitute drier air over the evaporating surfaces, evaporation is much more rapid during wind than in calm weather. As air expands under a diminished pressure, its temperature consequently falls, and it continues to approach nearer to the point of saturation, or become moister; and, as it contracts under an increased pressure, its temperature rises and it recedes from the point of saturation or becomes drier. Hence ascending currents of air become moister with every addition to the ascent, and descending currents drier as they continue to descend. Thus as winds ascend the slopes of hills they become moister, but when they have crossed the summit and flow down the other side they become drier in proportion to the descent, and all the changes may be experienced from extreme dryness to saturation in the same mass of air, which all the time has practically had its amount of aqueous vapour neither added to nor diminished.

In an atmosphere of air and aqueous vapour perfectly mixed, the elastic force of each at the surface of the earth is the pressure of each. In this case the elastic force of aqueous vapour would be the pressure of the whole vapour in the atmosphere over the place of observation. This pressure is expressed in inches of mercury of the barometer. If we suppose the total barometric pressure to be 30·000 inches, and the elastic force of vapour to be 0·745 inch, the pressure or weight of the dry air, or air proper, would be 29·255 inches, and of the aqueous vapour 0·745 inch. From this it follows that the elastic force of vapour may be regarded as indicating the quantity of aqueous vapour in the air at the place of observation, or it may be designated the absolute humidity of the air.

The diurnal variation in the elastic force of vapour in the air is seen in its simplest form on the open sea. Grouping together all the hygrometric observations made on board the "Challenger" on the North Atlantic at a distance from land, from March to July 1873 (eighty-four days), we have for that time a mean elastic force of 0·659 inch, and the following diurnal variation:—

	Inch.		Inch.		Inch.
2 A.M.	−·015	10 A.M.	+·004	6 P.M.	+·007
4 ,,	−·020	Noon	+·017	8 ,,	+·002
6 ,,	−·016	2 P.M.	+·020	10 ,,	−·005
8 ,,	−·007	4 ,,	+·017	Midnight	+·003

Hence the minimum (−·020 inch) occurs at the hour when the temperature of the surface of the sea and air resting over it falls to the daily minimum; it then rises to the mean a little after 9 A.M., and to the daily maximum (+·020 inch) at 2 P.M., when the sea and air are also near the daily maximum, and falls to the mean shortly before 9 P.M.

Treating the observations made near land by the "Challenger" during the same months, the following is the diurnal variation disclosed:—

	Inch.		Inch.		Inch.
2 A.M.	−·003	10 A.M.	+·014	6 P.M.	·000
4 ,,	−·009	Noon	+·011	8 ,,	−·004
6 ,,	−·010	2 P.M.	+·007	10 ,,	−·005
8 ,,	−·003	4 ,,	+·015	Midnight	−·007

The disturbance induced by proximity to land in the distribution of the aqueous vapour in the lower strata of the atmosphere is very striking. The maximum and minimum no longer follow the corresponding phases of the temperature of the surface of the sea and of the air. The disturbing agents are the sea and land breezes and their effects. Under the influence of the land breeze the time of the minimum humidity is delayed till about 6 A.M.; and under the influence of the sea breeze and its effects the amount of the aqueous vapour shows a secondary minimum from noon to 2 P.M. It is to be here noted that this midday