CHAPTER XVIII.

TERRESTRIAL TEMPERATURES AND WINDS.

267. Temperature of the Air.—By the *temperature of a place* meteorologists commonly understand the *temperature of the air* at a moderate distance (5 or 10 feet) from the ground. This element is easily determined when there is much wind; but in calm weather, and especially when the sun is shining powerfully, it is often difficult to avoid the disturbing effect of radiation. Thermometers for observing the temperature of the air must be sheltered from rain and sunshine, but exposed to a free circulation of air.

268. Mean Temperature of a Place.—The *mean temperature of a day* is obtained by making numerous observations at equal intervals of time throughout the day (24 hours), and dividing the sum of the observed temperatures by their number. The accuracy of the determination is increased by increasing the number of observations; as the mean temperature, properly speaking, is the mean of an infinite number of temperatures observed at infinitely short intervals.

If the curve of temperature for the day is given, temperature being represented by height of the curve above a horizontal datum line, the mean temperature is the height of a horizontal line which gives and takes equal areas; or is the height of the middle point of any straight line (terminated by the extreme ordinates of the curve) which gives and takes equal areas.

Attempts have been made to lay down rules for computing the mean temperature of a day from two, three, or four observations at stated hours; but such rules are of very limited application, owing to the different character of the diurnal variation at different places; and at best they cannot pretend to give the temperature of an individual day, but merely results which are correct in the long run. Observations at 9 A.M. and 9 P.M. are very usual in this country; and

the half-sum of the temperatures at these hours is in general a good approximation to the mean temperature of the day. The half-sum of the highest and the lowest temperature in the day, as indicated by maximum and minimum thermometers, is often adopted as the mean temperature. The result thus obtained is usually rather above the true mean temperature, owing to the circumstance that the extreme heat of the day is a more transient phenomenon than the extreme cold of the night. The employment of self-registering thermometers has, however, the great advantage of avoiding errors arising from want of punctuality in the observer. The correction which is to be added or subtracted in order to obtain the true mean from the mean of two observations is called a *correction for diurnal range*. Its amount differs for different places, being usually greatest where the diurnal range itself is greatest.

The *mean temperature of a calendar month* is computed by adding the mean temperatures of the days which compose it, and dividing by their number.

The *mean temperature of a year* is usually computed by adding the mean temperatures of the calendar months, and dividing by 12; but this process is not quite accurate, inasmuch as the calendar months are of unequal length. A more accurate result is obtained by adding the mean temperatures of all the days in the year, and dividing by 365 (or in leap-year by 366).

269. Isothermals.—The distribution of temperature over a large region is very clearly represented by drawing upon the map of this region a series of *isothermal lines;* that is, lines characterized by the property that *all places on the same line have the same temperature.* These lines are always understood to refer to mean annual temperture unless the contrary is stated; but isothermals for particular months, especially January and July, are frequently traced, one serving to show the distribution of temperature in winter, and the other in summer. The first extensive series of isothermals was drawn by Humboldt in 1817, on the basis of a large number of observations collected from all parts of the world; and the additional information which has since been collected has not materially altered the forms of the lines traced by him upon the terrestrial globe. They are in many places inclined at a very considerable angle to the parallels of latitude; and nowhere is this deviation from parallelism more observable than in the neighbourhood of Great Britain, Norway, and Iceland—places in this region having the same mean annual temperature as places in Asia or America lying from 10° to 20° further south.

270. Insular and Continental Climates.—We have seen that the specific heat of water, the latent heat of liquid water, and the latent heat of aqueous vapour are all very large. The presence of water accordingly exerts a powerful effect in moderating the extremes both of heat and cold, and a moist climate will in general have a smaller range of temperature than a dry climate. Moreover, since earth and rock are opaque to radiant heat, while water is to a considerable extent diathermanous, the surface of the ground is much more quickly heated and cooled by radiation than the surface of water. This difference is increased by the continual agitation of the surface of the ocean. Large bodies of water thus act as equalizers of temperature, and the most equable climates are found on oceanic islands or on the ocean itself; while the greatest difference between summer and winter is found in the interior of large continents. It is common to distinguish in this sense between *continental* climates on the one hand, and *insular* or *marine* climates on the other.

Some examples of both kinds are given in the following table. The temperatures are Centigrade:—

MARINE CLIMATES.	Winter.	Summer.	Difference.
Faroe Islands,	3°·90	11°·60	7°·70
Isle of Unst (Shetland),	4 ·05	11 ·92	7 ·87
Isle of Man,	5 ·59	15 ·08	9 ·49
Penzance,	7 ·04	15 ·83	8 ·79
Helston,	6 ·19	16 ·00	9 ·81
CONTINENTAL CLIMATES.			
St. Petersburg,	− 8°·70	15°·96	24°·66
Moscow,	−10 ·22	17 ·55	27 ·77
Kasan,	−13 ·66	17 ·35	31 ·01
Slatoust,	−16 ·49	16 ·08	32 ·57
Irkutsk,	−17 ·88	16 ·00	33 ·88
Jakoutsk,	−38 ·90	17 ·20	56 ·10

271. Temperature of the Soil at Different Depths.—By employing thermometers with their bulbs buried in the earth, and their stems projecting above, numerous observations have been made of the temperature from day to day at different depths from 1 inch to 2 or 3 feet; and at a few places observations of the same kind have been made by means of gigantic spirit-thermometers with exceedingly strong

bulbs, at depths extending to about 25 feet. It is found that variations depending on the hour of the day are scarcely sensible at the depth of 2 or 3 feet, and that those which depend on the time of year decrease gradually as the depth increases, but still remain sensible at the depth of 25 feet, the range of temperature during a year at this depth being usually about 2° or 3° Fahrenheit.

It is also found that, as we descend from the surface, the seasons lag more and more behind those at the surface, the retardation amounting usually to something less than a week for each foot of descent; so that, at the depth of 25 feet in these latitudes, the lowest temperature occurs about June, and the highest about December.

Theory indicates that 1 foot of descent should have about the same effect on diurnal variations as $\sqrt{365}$ that is 19 feet on annual variations; understanding by *sameness of effect* equal *absolute amounts* of lagging and equal *ratios* of diminution.

As the annual range at the surface in Great Britain is usually about 3 times greater than the diurnal range, it follows that the diurnal range at the depth of a foot should be about one-third of the annual range at the depth of 19 feet.

The variations of temperature at the surface are, as every one knows, of a very irregular kind; so that the curve of surface temperature for any particular year is full of sinuosities depending on the accidents of that year. The deeper we go, the more regular does the curve become, and the more nearly does it approach to the character of a simple curve of sines, whose equation can be written

$$y = a \sin. x.$$

Neglecting the departures of the curve from this simple character, theory indicates that, if the soil be uniform, and the surface plane, the annual range (which is equal to $2\,a$) goes on diminishing in geometrical progression as the depth increases in arithmetical; and observation shows that, if 10 feet be the common difference of depth, the ratio of decrease for range is usually about $\frac{1}{2}$ or $\frac{1}{3}$.

To find a range of a tenth of a degree Fahrenheit, we must go to a depth of from 50 to 80 feet in this climate. At a station where the surface range is double what it is in Great Britain, we should find a range of about two-tenths of a degree at a depth and in a soil which would here give one-tenth.

These remarks show that the phrase "stratum of invariable temperature," which is frequently employed to denote the supposed lower boundary of the region in which annual range is sensible, has no precise significance, inasmuch as the boundary in question will vary its depth according to the sensitiveness of the thermometer employed.

272. Increase of Temperature Downwards.—Observations in all parts of the world show that the temperature at considerable depths, such as are attained in mining and boring, is much above the surface temperature. In sinking a shaft at Rose Bridge Colliery, near Wigan, which is the deepest mine in Great Britain, the temperature of the rock was found to be 94° F. at the depth of 2440 feet. In cutting the Mont Cénis tunnel, the temperature of the deepest part, with 5280 feet of rock overhead, was found to be about 85° F.

The rate of increase downwards is by no means the same everywhere; but it is seldom so rapid as 1° F. in 40 feet, or so slow as 1° F. in 100 feet. The observations at Rose Bridge show a mean rate of increase of about 1° in 55 feet; and this is about the average of the results obtained at other places.

This state of things implies a continual escape of heat from the interior of the earth by conduction, and the amount of this loss per annum can be approximately calculated from the absolute values of conductivity of rock which we have given in Chap. xii.

There can be no reasonable doubt that the decrease of temperature upwards extends to the very surface, when we confine our attention to mean annual temperatures, for all the heat that is conducted up through a stratum at any given depth must also traverse all the strata above it, and heat can only be conducted from a warmer to a colder stratum. Professor Forbes found, at his three stations near Edinburgh, increases of 1°·38, 0°·96, and 0°·19 F. in mean temperature, in descending through about 22 feet, that is, from the depth of 3 to the depth of 24 French feet. The mean annual temperature of the surface of the ground is in Great Britain a little superior to that of the air above it, so far as present observations show. The excess appears to average about 1° F.

273. Decrease of Temperature Upwards in the Air.—In comparing the mean temperatures of places in the same neighbourhood at different altitudes, it is found that temperature diminishes as height increases, the rate of decrease for Great Britain, as regards mean annual temperature, being about 1° F. for every 300 feet. A decrease of temperature upwards is also usually experienced in balloon ascents, and numerous observations have been taken for the purpose of determining its rate. Mr. Glaisher's observations, which are the most numerous as well as the most recent, show that, upon the whole, the decrease becomes less rapid as we ascend higher; also, that it is less rapid with a cloudy than with a clear sky. The following table exhibits a few of Mr. Glaisher's averages:—

	Decrease of Temperature Upwards.	
Height.	With clear sky.	With cloudy sky.
From 0 to 1000 feet, . . .	1° F. in 139 feet.	1° F. in 222 feet.
From 0 to 10,000 ft. . . .	1° F. in 288 feet.	1° F. in 331 feet.
From 0 to 20,000 ft. . . .	1° F. in 365 feet.	1° F. in 468 feet.

These rates may be taken as representing the general law of decrease which prevails in the air over Great Britain in the daytime during the summer half of the year; but the results obtained on different days differ widely, and alternations of increase and decrease are by no means uncommon in passing upwards through successive strata of air. Still more recent observations by Mr. Glaisher, relating chiefly to the first 1000 feet of air, show that the law varies with the hour of the day. The decrease upwards is most rapid soon after midday, and is at this time, and during daytime generally, more rapid as the height is less. About sunset there is a uniform *decrease* at all heights if the sky is clouded, and a uniform *temperature* if the sky is clear. From a few observations which have been taken after sunset, it appears that, with a clear sky, there is an *increase* upwards at night.

That an extremely low temperature exists in the interplanetary spaces, may be inferred from the experimental fact recorded by Sir John Herschel, that a thermometer with its bulb in the focus of a reflector of sufficient size and curvature to screen it from lateral radiation, falls lower when the axis of the reflector is directed upwards to a clear sky than when it is directed either to a cloud or to the snow-clad summits of the Alps. The atmosphere serves as a protection against radiation to these cold spaces, and it is not surprising that, as we increase our elevation, and thus diminish the thickness of the coating of air above us, the protection should be found less complete. But probably the principal cause of the diminution of temperature upwards is the cooling of air by expansion, which we have discussed in § 223.

274. Causes of Winds.—The influences which modify the direction and intensity of winds are so various and complicated that anything like a complete account of them can only find a place in treatises specially devoted to that subject. There is, however, one fundamental principle which suffices to explain the origin of many well-known winds. This principle is plainly illustrated by the following experiment, due to Franklin. A door between two rooms, one heated, and the other cold (in winter), is opened, and two candles are placed, one at the top, and the other at the bottom of the doorway. It is found that the flame of the lower candle is blown towards the heated room, and that of the upper candle away from it.

The principle which this experiment illustrates may be stated as follows:—*When two neighbouring regions are at different temperatures, a current of air flows from the warmer to the colder in the upper strata of the atmosphere; and in the lower strata a current flows from the colder to the warmer.* The reason is that variation of pressure with height is greater in the cold than in the hot region; so that if there be one level at which the pressure is the same in both, the pressure in the cold region will preponderate at lower and that in the hot region at higher levels. We proceed to apply this principle to the land and sea breezes, the monsoons, and the trade-winds.

275. **Land and Sea Breezes.**—At the sea-side during calm weather a wind is generally observed to spring up at about eight or nine in the morning, blowing from the sea, and increasing in force until about two or three in the afternoon. It then begins gradually to die away, and shortly before sunset disappears altogether. A few hours afterwards, a wind springs up in the opposite direction, and lasts till nearly sunrise. These winds, which are called the sea-breeze and land-breeze, are exceedingly regular in their occurrence, though they may sometimes be masked by other winds blowing at the same time. Their origin is very easily explained. During the day the land grows warmer than the water; hence there results a wind blowing towards the warmer region, that is, towards the land. During the night the land and sea both grow colder, but the former more rapidly than the latter; and, accordingly, the relative temperatures of the two elements being now reversed, a breeze blowing from the land towards the sea is the consequence.

Monsoons.—The same cause which, on a small scale, produces the diurnal alternation of land and sea breezes, produces, on a larger scale, the annual alternation of monsoons in the Indian Ocean, and the seasonal winds which prevail in some other parts of the world. The general direction of these winds is towards continents in summer, and away from them in winter.

276. **Trade-winds: General Atmospheric Circulation.**—The trade-winds are winds which blow constantly from a north-easterly quarter over a zone of the northern hemisphere extending from a little north of the tropic of Cancer to within 9 or 10 degrees of the equator; and from a south-easterly quarter over a zone of the southern hemisphere extending from about the tropic of Capricorn to the equator. Their limits vary slightly according to the time of year, changing in the same direction as the sun's declination. Between them is a zone some 5° or 6° wide, over which calms and variable winds prevail.

The cause of the trade-winds was first correctly indicated by Hadley. The greater power of the sun over the equatorial regions causes a continual ascent of heated air from them. This flows over to both sides in the upper regions of the atmosphere, and its place is supplied by colder air flowing in from both sides below. If the earth were at rest, we should thus have a north wind sweeping over the earth's surface on the northern side of the equatorial regions, and a south wind on the southern side. But, in virtue of the earth's rotation, all points on the earth's surface are moving from west to east, with velocities proportional to their distances from the earth's axis. This velocity is nothing at the poles, and increases in approaching the equator. Hence, if a body on the earth's surface, and originally at rest relatively to the earth, be urged by a force acting along a meridian, it will not move along a meridian, but will outrun the earth, or fall behind it, according as its original rotational velocity was greater or less than those of the places to which it comes. That is to say, it will have a relative motion from the west if it be approaching the pole, and from the east if it be approaching the equator.

This would be true, even if the body merely tended to keep its original rotational velocity unchanged, and the reasoning becomes still more forcible when we apply the principle of conservation of angular momentum, in virtue of which the body tends to increase[1] its absolute rotational velocity in approaching the pole, and to diminish it in approaching the equator.

Thus the currents of air which flow in from both sides to the equatorial regions, do not blow from due north and due south, but from north-east and south-east. There can be little doubt that, notwithstanding the variable character of the winds in the temperate and frigid zones, there is, upon the whole, a continual interchange of air between them and the intertropical regions, brought about by the permanent excess of temperature of the latter. Such an interchange,

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[1] The tendency is for velocity to vary inversely as distance from the axis of rotation.