CHAPTER VII.

On the causes of vicissitudes in climate—Remarks on the present diffusion of heat over the globe—On the dependence of the mean temperature on the relative position of land and sea—Isothermal lines—Currents from equatorial regions—Drifting of Icebergs—Different temperature of Northern and Southern hemispheres—Combination of causes which might produce the extreme cold of which the earth's surface is susceptible—On the conditions necessary for the production of the extreme of heat, and its probable effects on organic life.

As the proofs enumerated in the last chapter indicate that the earth's surface has experienced great changes of climate since the deposition of the older sedimentary strata, we have next to inquire, how such vicissitudes can be reconciled with the existing order of nature. The cosmogonist has availed himself of this, as of every obscure problem in geology, to confirm his views concerning a period when the laws of the animate and inanimate world were wholly distinct from those now established; and he has in this, as in all other cases, succeeded so far, as to divert attention from that class of facts, which, if fully understood, might probably lead to an explanation of the phenomenon. At first, it was imagined that the earth's axis had been for ages perpendicular to the plane of the ecliptic, so that there was a perpetual equinox, and unity of seasons throughout the year:—that the planet enjoyed this '*paradisiacal*' state until the era of the great flood; but in that catastrophe, whether by the shock of a comet, or some other convulsion, it lost its equal poize, and hence the obliquity of its axis, and with that the varied seasons of the temperate zone, and the long nights and days of the polar circles. When the advancement of astronomical science had exploded this theory, it was assumed, that the earth at its creation was in a state of fluidity, and red hot, and that ever since that era it had been cooling down, contracting its dimensions, and acquiring a solid crust,—an hypothesis equally arbitrary, but more calculated for lasting

popularity, because, by referring the mind directly to the beginning of things, it requires no support from observations, nor from any ulterior hypothesis. They who are satisfied with this solution are relieved from all necessity of inquiry into the present laws which regulate the diffusion of heat over the surface, for however well these may be ascertained, they cannot possibly afford a full and exact elucidation of the internal changes of an embryo world. As well might an ornithologist study the plumage and external form of a full-fledged bird, in the hope of divining the colour of its egg, or the mysterious metamorphoses of the yolk during incubation.

But if, instead of vague conjectures as to what might have been the state of the planet at the era of its creation, we fix our thoughts steadily on the connection at present between climate and the distribution of land and sea; and if we then consider what influence former fluctuations in the physical geography of the earth must have had on superficial temperature, we may perhaps approximate to a true theory. If doubt still remain, it should be ascribed to our ignorance of the laws of Nature, not to revolutions in her economy;—it should stimulate us to farther research, not tempt us to indulge our fancies in framing imaginary systems for the government of infant worlds.

In considering the laws which regulate the diffusion of heat over the globe, says Humboldt, we must beware not to regard the climate of Europe as a type of the temperature which all countries placed under the same latitudes enjoy. The physical sciences, observes this philosopher, always bear the impress of the places where they began to be cultivated; and, as in geology, an attempt was at first made to refer all the volcanic phenomena to those of the volcanos in Italy, so in meteorology, a small part of the old world, the centre of the primitive civilization of Europe, was for a long time considered a type to which the climate of all corresponding latitudes might be referred. But this region, constituting only one-seventh of the whole globe, proved eventually to be the exception to the general rule; and for the same reason we may warn the geologist to be on his guard, and not hastily to assume that the temperature of the earth in the present era is a type of that which most usually obtains, since he contemplates far

mightier alterations in the position of land and sea, than those which now cause the climate of Europe to differ from that of other countries in the same parallels.

It is now well ascertained that zones of equal warmth, both in the atmosphere and in the waters of the ocean, are neither parallel to the equator nor to each other*. It is also discovered that the same mean annual temperature may exist in two places which enjoy very different climates, for the seasons may be nearly equalized or violently contrasted. Thus the lines of equal winter temperature do not coincide with the lines of equal annual heat, or the isothermal lines. The deviations of all these lines from the same parallel of latitude, are determined by a multitude of circumstances, among the principal of which are the position, direction, and elevation of the continents and islands, the position and depth of the sea, and the direction of currents and of winds.

It is necessary to go northwards in Europe in order to find the same mean quantity of annual heat as in North America. On comparing these two continents, it is found that places situated in the same latitudes, have sometimes a mean difference of temperature amounting to 11° or even sometimes 17° of Fahrenheit; and places on the two continents which have the same mean temperature, have sometimes a difference in latitude of from 7° to 13°†. The principal cause of greater intensity of cold in corresponding latitudes of North America and Europe, is the connexion of the former country with the polar circle, by a large tract of land, some of which is from three to five thousand feet in height, and, on the other hand, the separation of Europe from the arctic circle by an ocean. The ocean has a tendency to preserve every where a mean temperature, which it communicates to the contiguous land, so that it tempers the climate, moderating alike an excess of heat or cold. The elevated land, on the other hand, rising to the

* We are indebted to Baron Alex. Humboldt for collecting together in a beautiful essay, the scattered data on which some approximation to a true theory of the distribution of heat over the globe may be founded. Many of these data are derived from the author's own observations, and many from the works of M. Prevost on the radiation of heat, and other writers. See Humboldt on Isothermal Lines, Mémoires d'Arcueil, tom. iii. translated in the Edin. Phil. Journ. vol. iii. July, 1820.

† Humboldt's tables, Essay on Isothermal Lines, &c.

colder regions of the atmosphere, becomes a great reservoir of ice and snow, attracts, condenses, and congeals vapour, and communicates its cold to the adjoining country. For this reason, Greenland, forming part of a continent which stretches northward to the 82nd degree of latitude, experiences under the 60th parallel a more rigorous climate than Lapland under the 72nd parallel.

But if land be situated between the 40th parallel and the equator, it produces exactly the opposite effect, unless it be of extreme height, for it then warms the tracts of land or sea that intervene between it and the polar circle. For the surface being in this case exposed to the vertical, or nearly vertical rays of the sun, absorbs a large quantity of heat, which it diffuses by radiation into the atmosphere. For this reason, the western parts of the old continent derive warmth from Africa, " which, like an immense furnace," says Malte-Brun*, " distributes its heat to Arabia, to Turkey in Asia, and to Europe." On the contrary, Asia in its north-eastern extremity, experiences in the same latitude extreme cold, for it has land on the north between the 60th and 70th parallel, while to the south it is separated from the equator by the North Pacific.

In consequence of the more equal temperature of the waters of the ocean, the climate of islands and coasts differs essentially from that of the interior of continents, the former being characterized by mild winters and less temperate summers; for the sea breezes moderate the cold of winter, as well as the summer heat. When, therefore, we trace round the globe those belts in which the mean annual temperature is the same, we often find great differences in climate; for there are *insular* climates where the seasons are nearly equalized, and *excessive* climates as they have been termed, where the temperature of winter and summer is strongly contrasted. The whole of Europe, compared with the eastern parts of America and Asia, has an insular climate. The northern part of China, and the Atlantic region of the United States, exhibit " excessive climates." We find at New York, says Humboldt, the summer of Rome and the winter of Copenhagen; at Quebec, the summer of Paris and the winter of Petersburgh. At Pekin, in China,

* Phys. Geog. Book xvii.

where the mean temperature of the year is that of the coasts of Brittany, the scorching heats of summer are greater than at Cairo, and the winters as rigorous as at Upsal *.

If lines be drawn round the globe through all those places which have the same winter temperature, they are found to deviate from the terrestrial parallels much farther than the lines of equal mean annual heat. For the lines of equal winter in Europe are often curved so as to reach parallels of latitude 9° or 10° distant from each other, whereas the isothermal lines only differ from 4° to 5°.

Among other influential causes, both of remarkable diversity in the mean annual heat, and of unequal division of heat in the different seasons, are the direction of currents and the accumulation and drifting of ice in high latitudes. That most powerful current, the Gulf stream, after doubling the Cape of Good Hope, flows to the northward along the western coast of Africa, then crosses the Atlantic, and accumulates in the Gulf of Mexico. It then issues through the Straits of Bahama, running northwards at the rate of four miles an hour, and retains in the parallel of 38°, nearly one thousand miles from the above strait, a temperature 10° Fahr. warmer than the air. The general climate of Europe is materially affected by the volume of warmer water thus borne northwards, for it maintains an open sea free from ice in the meridian of East Greenland and Spitzbergen, and thus moderates the cold of all the lands lying to the south. Until the waters of the great current reach the circumpolar sea, their specific gravity is less than that of the lower strata of water; but when they arrive near Spitzbergen, they meet with the water of melted ice which is still lighter, for it is a well known law of this fluid, that it passes the point of greatest density when cooled down below 40°, and between that and the freezing point expands again. The warmer current, therefore, being now the heavier, sinks below the surface, so that in the lower regions it is found to be from 16° to 20° Fahrenheit, above the mean temperature of the climate. The movements of the sea, however, cause this under current sometimes to appear at the surface, and greatly to moderate the cold †.

* On Isothermal Lines.

† Scoresby's Arctic Regions, vol. i. p. 210.

The great glaciers generated in the valleys of Spitzbergen, in the 79° of north latitude, are almost all cut off at the beach, being melted by the feeble remnant of heat retained by the Gulf stream. In Baffin's Bay, on the contrary, on the east coast of old Greenland, where the temperature of the sea is not mitigated by the same cause, and where there is no warmer under-current, the glaciers stretch out from the shore, and furnish repeated crops of mountainous masses of ice which float off into the ocean *. The number and dimensions of these bergs is prodigious. Capt. Ross saw several of them together in Baffin's Bay aground in water fifteen hundred feet deep! Many of them are driven down into Hudson's Bay, and, accumulating there, diffuse excessive cold over the neighbouring continent, so that Captain Franklin reports, that at the mouth of Hayes river, which lies in the same latitude as the north of Prussia or the south of Scotland, ice is found every where in digging wells at the depth of four feet!

When we compare the climate of the northern and southern hemispheres, we obtain still more instruction in regard to the influence of the distribution of land and sea on climate. The dry land in the southern hemisphere, is to that of the northern in the ratio only of one to three, excluding from our consideration that part which lies between the pole and the 74° of south latitude, which has hitherto proved inaccessible. The predominance of ice in the antarctic over the arctic zone is very great; for that which encircles the southern pole, extends to lower latitudes by ten degrees than that around the north pole †. It is probable that this remarkable difference is partly attributable, as Cook conjectured, to the existence of a considerable tract of high land between the 70th parallel of south latitude and the pole. There is, however,

* Scoresby's Arctic Region, vol. i. p. 208.—Dr. Latta's observations on the Glaciers of Spitzbergen, &c. Edin. New Phil. Journ. vol. iii. p. 97.

† Captain Weddell, in 1823, reached 3° farther than Captain Cook, and arrived at 74° 15′ longitude, 34° 17′ west. After having passed through a sea strewed with numerous ice-islands, he arrived, in that high latitude, at an open ocean; but even if he had sailed 6° farther south, he would not have penetrated to higher latitudes than Captain Parry in the arctic circle, who reached lat. 81° 10′ north. The important discovery, therefore, of Captain Weddell, does not destroy the presumption, that the general prevalence of ice, in low latitudes in the southern hemisphere, arises from the existence of greater tracts of land in the antarctic, than in the arctic ocean.

another reason suggested by Humboldt, to which great weight is due,—the small quantity of land in the tropical and temperate zones south of the line. If Africa and New Holland extended farther to the south, a diminution of ice would take place in consequence of the radiation of heat from these continents during summer, which would warm the contiguous sea and rarefy the air. The heated aërial currents would then ascend and flow more rapidly towards the south pole, and moderate the winter. In confirmation of these views, it is stated that the cap of ice, which extends as far as the 68° and 71° of south latitude, advances more towards the equator whenever it meets a free sea; that is, wherever the extremities of the present continents are not opposite to it; and this circumstance seems explicable only on the principle above alluded to, of the radiation of heat from the lands so situated.

Before the amount of difference between the temperature of the two hemispheres was ascertained, it was referred by astronomers to the acceleration of the earth's motion in its perihelium; in consequence of which the spring and summer of the southern hemisphere are shorter, by nearly eight days, than those seasons north of the equator. A sensible effect is probably produced by this source of disturbance, but it is quite inadequate to explain the whole phenomenon. It is, however, of importance to the geologist to bear in mind, that in consequence of the procession of the equinoxes the two hemispheres receive alternately, each for a period of upwards of 10,000 years, a greater share of solar light and heat. This cause may sometimes tend to counterbalance inequalities resulting from other circumstances of a far more influential nature; but, on the other hand, it must sometimes tend to increase the extreme of deviation which certain combinations of causes produce at distant epochs. But, whatever may now be the inferiority of heat in the temperate and arctic zones south of the line, it is quite evident that the cold would be far more intense if there happened, instead of open sea, to be tracts of elevated land between the 55th and 70th parallel; for, in Sandwich land, in 54° and 58° of south latitude, the perpetual snow and ice reach to the sea beach; and what is still more astonishing, in the island of Georgia, which is in the 53° south latitude, or the same parallel as the central counties of England, the perpetual snow descends to the level of the ocean. When

we consider this fact, and then recollect that the highest mountains in Scotland do not attain the limit of perpetual snow on this side of the equator, we learn that latitude is one only of many powerful causes, which determine the climate of particular regions of the globe. The permanence of the snow, in this instance, is partly due to the floating ice, which chills the atmosphere and condenses the vapour, so that in summer the sun cannot pierce through the foggy air. The distance to which icebergs float from the polar regions on the opposite sides of the line, is, as might have been anticipated, very different. Their extreme limit in the northern hemisphere appears to be the Azores (north latitude 42°), to which isles they are sometimes drifted from Baffin's Bay *. But in the other hemisphere they have been seen, within the last two years, at different points off the Cape of Good Hope, between latitude 36° and 39° †. One of these was two miles in circumference, and 150 feet high ‡. Others rose from 250 to 300 feet above the level of the sea, and were, therefore, of great volume below, since it is ascertained, by experiments on the buoyancy of ice floating in sea-water, that for every solid foot seen above, there must at least be eight feet below water §. If ice islands from the north polar regions floated as far, they might reach Cape St. Vincent, and, then being drawn by the current that always sets in from the Atlantic through the Straits of Gibraltar, be drifted into the Mediterranean, where clouds and mists would immediately deform the serene sky of spring and summer.

The great extent of sea gives a particular character to climates south of the equator, the winters being mild, and the summers cold. Thus, in Van Dieman's land, corresponding nearly in latitude to Rome, the winters are more mild than at Naples, and the summers not warmer than those at Paris, which is 7° farther from the equator ||. The effect on vegetation is very remarkable:—tree ferns, for instance, which require abundance of moisture, and an equalization of the seasons,

* Examples will be given in Major Rennell's forthcoming work on Currents.

† On Icebergs in low Latitudes in the Southern Hemisphere, by Captain Hosburg, Hydrographer to the East India Company; read to the Royal Society, February, 1830.

‡ Edin. New Phil. Journ. No. xv. p. 193; January, 1830.

§ Scoresby's Arctic Regions, vol. i., p. 234. || Humboldt, ib.

are found in Van Dieman's land in latitude 42°, and in New Zealand in south latitude 45°. The orchideous parasites also advance towards the 38° and 42° of south latitude *.

Having offered these brief remarks on the diffusion of heat over the globe in the present state of the surface, we shall now proceed to speculate on the vicissitudes of climate, which must attend those endless variations in the geographical features of our planet, which are contemplated in geology. In order to confine ourselves within the strict limits of analogy, we shall assume, 1st, That the proportion of dry land to sea continues always the same. 2dly, That the volume of the land rising above the level of the sea, is a constant quantity; and not only that its mean, but that its extreme height, are only liable to trifling variations. 3dly, That both the mean and extreme depth of the sea are equal at every epoch; and, 4thly, It will be consistent, with due caution, to assume, that the grouping together of the land in great continents is a necessary part of the economy of nature; for it is possible, that the laws which govern the subterranean forces, and which act simultaneously along certain lines, cannot but produce, at every epoch, continuous mountain-chains; so that the subdivision of the whole land into innumerable islands may be precluded. If it be objected, that the maximum of elevation of land and depth of sea are probably not constant, nor the gathering together of all the lands in certain parts, nor even perhaps the relative extent of land and water; we reply, that the arguments which we shall adduce will be greatly strengthened, if, in these peculiarities of the surface, there be considerable deviations from the present type. If, for example, all other circumstances being the same, the land is at one time more divided into islands than at another, a greater uniformity of climate might be produced, the mean temperature remaining unaltered; or if, at another era, there were mountains higher than the Himalaya, these, when placed in high

* These forms of vegetation might perhaps be developed in still higher latitudes, if the ice in the antarctic circle did not extend farther from the pole than in the arctic. Humboldt observes, that it is in the *mountainous, temperate, humid,* and *shady* parts of the equatorial regions, that the family of ferns produces the greatest number of species. As we know, therefore, that elevation often compensates the effect of latitude in plants, we may easily understand that a class of vegetables which grow at a certain height in the torrid zone, would flourish on the plains far from the equator, provided the temperature throughout the year was equally uniform.

latitudes would cause a greater excess of cold. So if we suppose, that at certain periods no chain of hills in the world rose beyond the height of 10,000 feet, a greater heat might then have prevailed than is compatible with the existence of mountains thrice that elevation.

However constant we believe the relative proportion of sea and land to continue, we know that there is annually some small variation in their respective geographical positions, and that in every century the land is in some parts raised, and in others depressed by earthquakes, and so likewise is the bed of the sea. By these and other ceaseless changes, the configuration of the earth's surface has been remodelled again and again since it was the habitation of organic beings, and the bed of the ocean has been lifted up to the height of some of the loftiest mountains. The imagination is apt to take alarm, when called upon to admit the formation of such irregularities of the crust of the earth, after it had become the habitation of living creatures; but if time be allowed, the operation need not subvert the ordinary repose of nature, and the result is insignificant, if we consider how slightly the highest mountain chains cause our globe to differ from a perfect sphere. Chimborazo, although it rises to more than 21,000 feet above the surface of the sea, would only be represented on an artificial globe, of about six feet in diameter, by a grain of sand less than one-twentieth of an inch in thickness *. The superficial inequalities of the earth, then, may be deemed minute in quantity, and their distribution at any particular epoch must be regarded in geology as temporary peculiarities, like the height and outline of the cone of Vesuvius in the interval between two eruptions. But, although the unevenness of the surface is so unimportant, in reference to the magnitude of the globe, it is on the position and direction of these small inequalities that the state of the atmosphere and both the local and general climate are mainly dependent.

Before we consider the effect which a material change in the distribution of land and sea must occasion, it may be well to remark, how greatly organic life may be affected by those minor mutations, which need not in the least degree alter the

* Malte-Brun's System of Geography, book i. p. 6.

general temperature. Thus, for example, if we suppose, by a series of convulsions, a certain part of Greenland to become sea, and, in compensation, a tract of land to rise and connect Spitzbergen with Lapland,—an accession not greater in amount than one which the geologist can prove to have occurred in certain districts bordering the Mediterranean, within a comparatively modern period,—this altered form of the land might occasion an interchange between the climate of certain parts of North America and of Europe, which lie in corresponding latitudes. Many European species would probably perish in consequence, because the mean temperature would be greatly lowered; and others would fail in America because it would there be raised. On the other hand, in places where the mean annual heat remained unaltered, some species which flourish in Europe, where the seasons are more uniform, would be unable to resist the great heat of the North American summer, or the intense cold of the winter; while others, now fitted by their habits for the great contrast of the American seasons, would not be fitted for the *insular* climate of Europe*. Many plants, for instance, will endure a severe frost, but cannot ripen their seeds without a certain intensity of summer heat and a certain quantity of light; others cannot endure the same intensity of heat or cold. It is now established, that many species of animals, which are at present the contemporaries of man, have survived great changes in the physical geography of the globe. If such species be termed modern, in comparison to races which preceded them, their remains, nevertheless, enter into submarine deposits many hundred miles in length, and which have since been raised from the deep to no inconsiderable altitude. When, therefore, it is shewn that changes of the temperature of the atmosphere may be the consequence of such physical revolutions of the surface, we ought no longer to wonder that we find the distribution of existing species to be *local*, in regard to *longitude* as well as latitude. If all species were now, by an exertion of creative power, to be diffused uniformly throughout those zones where there is an equal degree of heat, and in all respects a similar climate, they would begin from this moment to

* According to Humboldt, the vine can be cultivated with advantage 10° farther north in Europe, than in North America.

depart more and more from their original distribution. Aquatic and terrestrial species would be displaced, as Hooke long ago observed, so often as land and water exchanged places; and there would also, by the formation of new mountains and other changes, be transpositions of climate, contributing, in the manner before alluded to, to the local extermination of species.

If we now proceed to consider the circumstances required for a *general* change of temperature, it will appear, from the facts and principles already laid down, that whenever a greater extent of high land is collected in the polar regions, the cold will augment; and the same result will be produced when there shall be more sea between or near the tropics; while, on the contrary, so often as the above conditions are reversed, the heat will be greater. If this be admitted, it will follow as a corollary, that unless the superficial inequalities of the earth be fixed and permanent, there must be never-ending fluctuations in the mean temperature of every zone, and that the climate of one era can no more be a type of every other, than is one of our four seasons of all the rest. It has been well said, that the earth is covered by an ocean, and in the midst of this ocean there are two great islands, and many smaller ones; for the whole of the continents and islands occupy an area scarcely exceeding one-fourth of the whole superficies of the spheroid. Now, on a fair calculation, we may expect that at any given epoch, there will not be more than about one-fourth dry land in a particular region; such, for example, as the arctic and antarctic circles. If, therefore, at present there should happen in the only one of these regions which we can explore, to be much more than this average proportion of land, and some of it above five thousand feet in height, this alone affords ground for concluding, that in the present state of things, the mean heat of the climate is below that which the earth's surface, in its more ordinary state, would enjoy. This presumption is heightened, when we remember that the mean depth of the Atlantic ocean is calculated to be about three miles, and that of the Pacific four miles*; so that we might look not only for more than two-thirds sea in the frigid zones, but for

* See Young's Nat. Phil. Lect. 47. Laplace seems often to have changed his opinion, reasoning from the depth required to account for the phenomena of the tides; but his final conclusion respecting the sea was "que sa profondeur moyenne

water of great depth, which could not readily be reduced to the freezing point. The same opinion is farther confirmed, when we compare the quantity of land lying between the poles and the 30th parallels of north and south latitude, and the quantity placed between those parallels and the equator; for it is clear, that at present we must have not only more than the usual degree of cold in the polar regions, but also less than the average quantity of heat generated in the intertropical zone.

In order to simplify our view of the various changes in climate, which different combinations of geographical circumstances may produce, we shall first consider the conditions necessary for bringing about the extreme of cold, or what may be termed the winter of the "great year," or geological cycle, and afterwards, the conditions requisite for producing the maximum of heat, or the summer of the same year.

To begin with the northern hemisphere. Let us suppose those hills of the Italian peninsula and of Sicily, which are of comparatively modern origin, and contain many fossil shells identical with living species, to subside again into the sea, from which they have been raised, and that an extent of land of equal area and height (varying from one to three thousand feet) should rise up in the Arctic ocean, between Siberia and the north pole. In speaking of such changes, we need not allude to the manner in which we conceive it possible that they may be brought about, nor of the time required for their accomplishment,—reserving for a future occasion, not only the proofs that revolutions of equal magnitude have taken place, but that analogous mutations are still in gradual progress. The alteration now supposed in the physical geography of the northern regions would cause additional snow and ice to accumulate where now there is usually an open sea; and the temperature of the greater part of Europe would be somewhat lowered, so as to resemble more nearly that of corresponding latitudes of North America; or, in other words, it might be necessary to travel about 10° farther south, in order to meet with the same climate which we now enjoy. There would be no compensation derived from the disappearance of land in the Mediterranean countries; for, on the contrary, the mean heat of

est du même ordre que la hauteur moyenne des continens et des îles au-dessus de son niveau, hauteur qui ne surpasse pas mille mètres (3280 ft.)." Mec. Céleste. Bk. 11. et Syst. du Monde, p. 254.

the soil so situated, is probably far above that which would belong to the sea, by which we imagine it to be replaced. But let the configuration of the surface be still further varied, and let some large district within or near the tropics, such as Mexico for example, with its mountains rising to the height of twelve thousand feet and upwards, be converted into sea, while lands of equal elevation and extent are transferred to the arctic circle. From this change there would, in the first place, result a sensible diminution of temperature near the tropic, for the soil of Mexico would no longer be heated by the sun; so that the atmosphere would be less warm, as also the Atlantic, and the Gulf stream. On the other hand, the whole of Europe, Northern Asia, and North America, would feel the influence of the enormous quantity of ice and snow, now generated at vast heights on the new arctic continent. If, as we have already seen, there are some points in the southern hemisphere where snow is perpetual to the level of the sea, in latitudes as low as central England, such might now assuredly be the case throughout a great part of Europe. If at present the extreme limits of drifted icebergs are the Azores, they might easily reach the equator after the changes above supposed. To pursue the subject still farther, let the Himalaya mountains, with the whole of Hindostan, sink down, and their place be occupied by the Indian ocean, and then let an equal extent of territory and mountains, of the same vast height, stretch from North Greenland to the Orkney islands. It seems difficult to exaggerate the amount to which the climate of the northern hemisphere would now be cooled down. But, notwithstanding the great refrigeration which would thus be produced, it is probable that the difference of mean temperature between the arctic and equatorial latitudes would not be increased in a very high ratio, for no great disturbance can be brought about in the climate of a particular region, without immediately affecting all other latitudes, however remote. The heat and cold which surround the globe are in a state of constant and universal flux and reflux. The heated and rarefied air is always rising and flowing from the equator towards the poles in the higher regions of the atmosphere, and, in the lower, the colder air is flowing back to restore the equilibrium. That this circulation is constantly going on in the aërial cur-

rents is not disputed *, and that a corresponding interchange takes place in the seas, is demonstrated, according to Humboldt, by the cold which is found to exist at great depths between the tropics; and, among other proofs, may be mentioned the great volume of water which the Gulf stream is constantly bearing northwards, while another current flows *from* the north along the coast of Greenland and Labrador, and helps to restore the equilibrium †.

Currents of heavier and colder water pass from the poles towards the equator, which cool the inferior parts of the ocean; so that the heat of the torrid zone, and the cold of the polar circle, balance each other. The refrigeration, therefore, of the polar regions, resulting from the supposed alteration in the distribution of land and sea, would be immediately communicated to the tropics, and from them would extend to the antarctic circle, where the atmosphere and the ocean would be cooled, so that ice and snow would augment. Although the mean temperature of higher latitudes in the southern hemisphere is, as we have stated, for the most part lower than that of the same parallels in the northern, yet for a considerable space on each side of the line, the mean annual heat of the waters is found to be the same in corresponding parallels. When, therefore, by the new position of the land, the generating of icebergs had become of frequent occurrence in the temperate zone, and when they were frequently drifted as far as the equator, the same degree of cold would immediately be communicated as far as the tropic of Capricorn, and from thence to the lands or ocean to the south. The freedom, then, of the circulation of heat and cold from pole to pole being duly considered, it will be evident that the mean quantity of heat

* The trade wind continually blows with great force from the Island of St. Vincent to that of Barbadoes; notwithstanding which, during the eruption of the volcano in the Island of St. Vincent, in 1812, ashes fell in profusion from a great height in the atmosphere upon Barbadoes. This apparent transportation of matter against the wind, confirmed the opinion of the existence of a counter-current in the higher regions, which had previously rested on theoretical conclusions. Daniell's Meteorological Essays, &c., p. 103.

† In speaking of the circulation of air and water in this chapter, no allusion is made to the trade winds, or to irregularities in the direction of currents, caused by the rotatory motion of the earth. These causes prevent the movements from being direct from north to south, or from south to north, but they do not affect the theory of a constant circulation.

which at two different periods visits the same point, may differ far more widely than the mean quantity which any two points receive in the same parallels of latitude, at one and the same period. For the range of temperature in a given zone, or in other words, the curves of the isothermal lines, must always be circumscribed within narrow limits, the climate of each place in that zone being controlled by the combined influence of the geographical peculiarities of all other parts of the earth. But, when we compare the state of things as existing at two distinct epochs, a particular zone may at one time be under the influence of one class of disturbing causes, as for example those of a refrigerating nature, and at another time may be affected by a combination of opposite circumstances. The lands to the north of Greenland cause the present climate of North America to be colder than that of Europe in the same latitudes, but they also affect, to a certain extent, the temperature of the atmosphere in Europe; and the entire removal from the northern hemisphere of that great source of refrigeration would not assimilate the mean temperature of America to that now experienced in Europe, but would render the continents on both sides of the Atlantic much warmer.

To return to the state of the earth, after the changes before supposed by us, we must not omit to dwell on the important effects to which a wide expanse of perpetual snow would give rise. It is probable that nearly the whole sea, from the poles to the parallels of 45°, would be frozen over, for it is well known that the immediate proximity of land, is not essential to the formation and increase of field ice, provided there be in some part of the same zone a sufficient quantity of glaciers generated on or near the land, to cool down the sea *. Field ice is almost always covered with snow, through which the sun's rays are unable to penetrate †, and thus not only land as extensive as our existing continents, but immense tracts of sea in the frigid and temperate zones, would now present a

* See Scoresby's Arctic Regions, vol. i. p. 320.

† Captain Scoresby, in his account of the arctic regions, observes, that when the sun's rays "fall upon the snow-clad surface of the ice or land, they are in a great measure reflected, without producing any material elevation of temperature; but when they impinge on the black exterior of a ship, the pitch on one side occasionally becomes fluid, while ice is rapidly generated at the other." vol. i. p. 378.

solid surface covered with snow, and reflecting the sun's rays for the greater part of the year. Within the tropics, moreover, where we suppose the ocean to predominate, the sky would no longer be serene and clear, as in the present era; but the melting of floating ice would cause quick condensations of vapour, and fogs and clouds would deprive the vertical rays of the sun of half their power. The whole planet, therefore, would receive annually a smaller proportion of solar influence, and the external crust would part, by radiation, with some of the heat which had been accumulated in it, during a different state of the surface. This heat would be dissipated into the spaces surrounding our atmosphere, which, according to the calculations of M. Fourier, have a temperature much inferior to that of freezing water.

At this period, the climate of equinoctial lands might resemble that of the present temperate zone, or perhaps be far more wintery. They who should then inhabit the small isles and coral reefs, which are now seen in the Indian ocean and South Pacific, would wonder that zoophytes of such large dimensions had once been so prolific in those seas; or if, perchance, they found the wood and fruit of the cocoa-nut tree or the palm silicified by the waters of some mineral spring, or incrusted with calcareous matter, they would muse on the revolutions that had annihilated such genera, and replaced them by the oak, the chestnut, and the pine. With equal admiration would they compare the skeletons of their small lizards with the bones of fossil alligators and crocodiles more than twenty feet in length, which, at a former epoch, had multiplied between the tropics; and when they saw a pine included in an iceberg, drifted from latitudes which we now call temperate, they would be astonished at the proof thus afforded, that forests had once grown where nothing could be seen in their own times but a wilderness of snow.

As we have not yet supposed any mutations to have taken place in the relative position of land and sea in the southern hemisphere, we might still increase greatly the intensity of cold, by transferring the land still remaining in the equatorial and contiguous regions, to higher southern latitudes; but it is unnecessary to pursue the subject farther, as we are too ignorant of the laws governing the direction of subterranean forces,

to determine whether such a crisis be within the limits of possibility. At the same time we may observe, that the distribution of land at present is so remarkably irregular, and appears so capricious, if we may so express ourselves, that the two extremes of terrestrial heat and cold are probably separated very widely from each other. The globe may now be equally divided, so that one hemisphere shall be entirely covered with water, with the exception of some promontories and islands, while the other shall contain less water than land; and what is still more extraordinary, on comparing the extra-tropical lands in the northern and southern hemispheres, the former are found to be to the latter in the proportion of thirteen to one*! To imagine all the lands, therefore, in high, and all the sea in low latitudes, would scarcely be a more anomalous state of the surface.

Let us now turn from the contemplation of the winter of the "great year," and consider the opposite train of circumstances, which would bring on the spring and summer. That some part of the vast ocean which forms the Atlantic and Pacific, should at certain periods occupy entirely one or both of the polar regions, and should extend, interspersed with islands, only to the parallels of 40°, and even 30°, is an event that may be supposed in the highest degree probable, in the course of many great geological revolutions. In order to estimate the degree to which the general temperature would then be elevated, we should begin by considering separately the effect of the diminution of certain portions of land, in high northern latitudes, which might cause the sea to be as open in every direction, as it is at present towards the north pole, in the meridian of Spitzbergen. By transferring the same lands to the torrid zone, we might gain farther accessions of heat, and cause the ice towards the south pole to diminish. We might first continue these geographical mutations, until we had produced as mild a climate in high latitudes as exists at those points in the same parallel where the mean annual heat is now greatest. We should then endeavour to calculate what farther alterations would be required to double the amount of change; and the great deviation of isothermal lines at present

* Humboldt, on Isothermal Lines.

seems to authorize us to infer, that without an entire revolution of the surface, we might cause the mean temperature to vary to an extent equivalent to 20° or even 30° of latitude,—in other words, we might transfer the temperature of the torrid zone, to the mean parallel, and of the latter, to the arctic regions. By additional transpositions, therefore, of land and sea, we might bring about a still greater variation, so that, throughout the year, all signs of frost should disappear from the earth.

The plane of congelation would rise in the atmosphere in all latitudes; and as our hypothesis would place all the highest mountains in the torrid zone, they would be clothed with rich vegetation to their summits. We must recollect that even now it is necessary to ascend to the height of 15,000 feet in the Andes under the line; and in the Himalaya mountains, which are without the tropic, to 17,000 feet before we reach the limit of perpetual snow. When the absorption of the solar rays was unimpeded, even in winter, by a coat of snow, the mean heat of the earth's crust would augment to considerable depths, and springs, which we know to be an index of the mean temperature of the climate, would be warmer in all latitudes. The waters of lakes, therefore, and rivers, would be much hotter in winter, and would be never chilled in summer by the melting of snow. A remarkable uniformity of climate would prevail amid the numerous archipelagos of the polar ocean, amongst which the tepid waters of equatorial currents would freely circulate. The general humidity of the atmosphere would far exceed that of the present period, for increased heat would promote evaporation in all parts of the globe. The winds would be first heated in their passage over the tropical plains, and would then gather moisture from the surface of the deep, till, charged with vapour, they would arrive at northern regions, and, encountering a cooler atmosphere, would discharge their burden in warm rain. If, during the long night of a polar winter, the snows should whiten the summit of some arctic islands, and ice collect in the bays of the remotest Thule, they would be dissolved as rapidly by the returning sun, as are the snows of Etna by the blasts of the sirocco.

We learn from those who have studied the geographical distribution of plants, that in very low latitudes, at present,

the vegetation of small islands remote from continents has a peculiar character, and the ferns and allied families, in particular, bear a great proportion to the total number of other vegetables. Other circumstances being the same, the more remote the isles are from the continents, the greater does this proportion become. Thus, in the continent of India, and the tropical parts of New Holland, the proportion of ferns to the phanerogamic plants is only as one to twenty-six; whereas, in the South Sea Islands, it is as one to four, or even as one to three*. We might expect, therefore, in the summer of the "great year," which we are now considering, that there would be a great predominance of tree-ferns and plants allied to palms and arborescent grasses in the isles of the wide ocean, while the dicotyledonous plants and other forms now most common in temperate regions would almost disappear from the earth. Then might those genera of animals return, of which the memorials are preserved in the ancient rocks of our continents. The huge iguanodon might reappear in the woods, and the ichthyosaur in the sea, while the pterodactyle might flit again through umbrageous groves of tree-ferns. Coral reefs might be prolonged beyond the arctic circle, where the whale and the narwal now abound. Turtles might deposit their eggs in the sand of the sea beach, where now the walrus sleeps, and where the seal is drifted on the ice-floe.

But, not to indulge these speculations farther, we may observe, in conclusion, that however great, in the lapse of ages, may be the vicissitudes of temperature in every zone, it accords with our theory that the general climate should not experience any sensible change in the course of a few thousand years, because that period is insufficient to affect the leading features of the physical geography of the globe. Notwithstanding the apparent uncertainty of the seasons, it is found that the mean temperature of particular localities is very constant, provided we compare observations made at different periods for a series of years. Yet, there must be exceptions to this rule, and even the labours of man have, by the drainage of lakes and marshes, and the felling of extensive forests, caused such changes in the atmosphere as raise our conception of the important

* Ad. Brongniart, Consid. Générales sur la Nat. de la Végét., &c. Ann. des Sciences Nat., Nov. 1828.

influence of those forces to which even the existence in certain latitudes of land or water, hill or valley, lake or sea, must be ascribed. If we possessed accurate information of the amount of local fluctuation in climate in the course of twenty centuries, it would often, undoubtedly, be considerable. Certain tracts, for example, on the coast of Holland and of England, consisted of cultivated land in the time of the Romans, which the sea, by gradual encroachments, has at length occupied. Here an alteration has been effected; for neither the division of heat in the different seasons, nor the mean annual heat of the atmosphere investing the sea is precisely the same as that which rests on the land. In those countries also where the earthquake and volcano are in full activity, a much shorter period may produce a sensible variation. The climate of the once fertile plain of Malpais in Mexico must differ materially from that which prevailed before the middle of the last century; for, since that time, six mountains, the highest of them rising 1700 feet above the plateau, have been thrown up by volcanic eruptions. It is by the repetition of an indefinite number of local revolutions due to volcanic and various other causes, that a general change of climate is finally brought about.