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The Meteorological Results of the 'Challenger' Expedition in relation to Physical Geography.

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Maps, p. 192.

Twenty-one years ago, I received a letter from Sir Roderick I. Murchison, inviting me to read a paper to the Geographical Section of the British Association at Liverpool, of which section Sir Roderick was President that year, on the mean pressure and prevailing winds of the atmosphere, giving to the meeting a *résumé* of the results of the discussion of these questions which had just then been published. This was done, and immediately thereafter, the Royal Geographical Society adopted, in carrying out one of the important branches of the Society's work, one of the results of this discussion, viz. a more exact method of determining heights from barometric and thermometric observations. Previously to this time, these heights had been determined, as regards newly explored and little-known regions, by assuming a pressure of 30 inches for all localities and seasons, instead of the approximate sea-level pressure of the locality whose height was to be calculated, and for the season of the year for which observations for the purpose were available.

Other large questions, both practical and scientific, affecting the general movements of the atmosphere and of oceanic circulation, and questions dependent on these movements, began to be discussed with greater frequency and fulness, particularly in their relations to physical geography.

But a serious desideratum soon came to be felt by all workers in this department of science. It was thrust obtrusively on the attention, that discussions on the more fundamental problems of meteorology, relative to the diurnal and seasonal changes in atmospheric temperature, pressure, humidity, and wind, were really restricted to observations made on land. It was plain that data supplied exclusively by observations on land, which occupies but little more than a fourth part of the earth's surface, were altogether inadequate to a right conception and explanation of atmospherical phenomena. Accordingly, when the *Challenger* expedition was fitted out in 1872, arrangements were made for taking, during the cruise, hourly or two-hourly observations both of the atmosphere and of the surface temperature of the sea.

As you are well aware, in addition to these frequent daily observations, elaborate observations were made of sea temperatures at all depths, which gave results at once recognised to be of the first importance in terrestrial physics, inasmuch as they opened up for discussion the broad question of oceanic circulation on a sound basis of well-ascertained facts. But a right understanding of this subject demands, as an imperative preliminary, a full discussion of atmospheric phenomena. For example, one of the first requisites is an approximately correct representation of the circulation of the atmosphere on the surface of the globe in all seasons of the year. Now this can really only be attained from the geographical distribution of the mass of the earth's atmosphere, as shown by the mean monthly isobars; and these, in their turn, ultimately depend on the geographical distribution of the temperature and humidity of the atmosphere.

It is thus abundantly plain that any such discussion requires, if it is to be handled aright, maps showing for the various months of the year the mean temperature, mean pressure, and prevailing winds of the globe, with carefully prepared and extensive tables of the observational data required for the graphic representation of the results. Now the only works then available were Dove's isothermals, 1852; Buchan's isobars and prevailing winds, 1869; and Coffin and Wojekof's winds of the globe, 1875—all of which were based necessarily, when written, on defective data. A re-discussion, therefore, of all the available information regarding the different atmospheric phenomena, with a more special reference to the *Challenger* observations, was most desirable. This discussion I was asked to undertake, and after seven years' unremitting labour, and with such assistance as I could command, the report was published a year ago.

This report gives, in addition to the results proper of the *Challenger* observations, the mean diurnal variation of atmospheric pressure at 147 stations in all parts of the globe; the mean monthly and annual pressure at 1366 stations, and a similar table of mean temperatures at 1620 stations; and the mean monthly and annual direction of the wind at 746 stations. As regards the winds, other data have been utilised, which have been published with, or from, actual observations by the meteorological departments of the United States, England, France, Holland, Germany, Norway, Denmark, Italy, Mauritius, and India. In no case, as regards the all-important factor of the wind, has any wind been indicated on any one of the twenty-four maps showing the prevailing winds, which does not rest on the authority of observed facts.

Fifty-two large folding maps accompany the report, of which twenty-six show by isothermals the mean monthly and annual temperature on hypsobathymetric maps, or maps showing by shadings the height of the land and depth of the sea, first on Gall's projection, and second on north circumpolar maps on equal surface projection; and another set of twenty-six maps showing by isobars for each month and the year the mean pressure of the atmosphere, the gravity correction to lat. 45° being applied, and by arrows the prevailing winds of the globe. These data, thus elaborately and, it may be said, exhaustively represented, may be regarded as comprising all information at present existing which is required for the discussion of the broad questions dealt with in the report.

To the revolution of the earth on its axis we owe day and night; to the inclination of the earth's axis to the plane of its orbit we owe the alternation of seasons; and to its diversified surface of land and water we owe the infinite variations of climate which characterise its different regions. It is with the last of these we have here to deal. As the atmosphere everywhere overlies the land and water surfaces of the globe, and is influenced in an all-powerful manner by its simple superposition over these very different surfaces, it follows that the science of meteorology rests on the basis of physical geography. The relations of the two sciences are in truth of a greatly more intimate nature than is generally supposed.

When it is considered that three-fourths of the earth's surface is water, that the temperature of the air resting on its surface is in closest relation to the temperature of that surface, and that the latter has, through the winds, direct and all-important bearings on the temperature of the land surfaces of the globe, it is plain that it is impossible to overstate the importance of the temperature of the sea as a fundamental datum in meteorology. Steps were therefore taken to make, during the cruise, observations of sea temperatures in a manner and with a fulness not previously attempted.

Observations on the temperature of the surface were made every two hours of the day as part of the scientific work of the expedition. From 1512 observations made in the North Atlantic, the mean latitude being 30° and longitude 42°, it is conclusively shown that the daily change of the temperature of the surface of this ocean is only 0°·8. Similarly in the South Atlantic, lat. 33° and long. 20° W., it was 0°·8; in the North Pacific, lat. 37° and long. 170° W., it was 1°·0; and in the South Pacific, lat. 36° and long. 87° W., it was 0°·9. In the equatorial portions of the Atlantic and Pacific the daily variation was 0°·7; and in the higher latitudes of the Southern Ocean it was only 0°·2. Hence, in the great oceans away from land, and between lat. 40° N. and 40° S., the surface temperature nowhere shows a daily variation exceeding a degree Fahrenheit. Near the equator the daily range falls to three-fourths of a degree, and still further to one-fifth of a degree in high latitudes. The small daily variation of the temperature of the surface of the sea, shown by the *Challenger* observations, is unquestionably a most important contribution to physical science, forming, in truth, one of the prime factors in meteorology and physical geography.

Observations of the temperature of the air were made with the same frequency, with the general result that the daily range of the temperature of the air over the open sea is from three to four times greater than that of the surface of the sea over which it lies. The point is one of no little interest in atmospheric physics, from its important bearings on the relations of the air and its aqueous vapour, in its gaseous, liquid, and solid states, and of the particles of dust everywhere present, to solar and terrestrial radiation. During the seventy-six days the *Challenger* was not on the open sea, but near land, the hour of occurrence of the maximum temperature was as early in the day as noon, owing probably to the diurnal period of the sea breezes; and the amount of the daily range of temperature was considerably in excess of what is seen to occur over the open sea. Eighteen days' observations in the Southern Ocean about lat. 63° showed a mean daily range of the temperature of the air of 0°·8, being also about four times greater than that of the sea in the same region.

Over the open sea the humidity curve closely follows that of the temperature, being at the minimum at four in the morning, and at the maximum at two in the afternoon. But near land very different conditions prevail; here a second minimum takes place from about 10 a.m. to 2 p.m.—a feature altogether absent over the open sea. With reference to this midday minimum of the humidity curve, it is to be noted that it is at this time of the day when, the surface of the land being most highly heated, the ascending current of heated air arising from it is strongest, and the resulting breeze from the sea towards the land therefore also strongest. Now this lowering of the elastic force of the vapour of the breeze blowing over the sea towards the land points unmistakably to an intermixture, with the air forming the sea breeze, of descending air filaments or currents, to take the place of the masses of air removed by the currents which rise from the heated surface of the land. Thus, while at this time of the day ascending air currents arise over the land, descending air currents, with their characteristic greater dryness, set in over the adjoining ocean at some little distance to windward.*

Over the open sea the diurnal oscillations of the barometer are shown in their simplest and exactest form, the disturbing influence of land being wholly wanting. The remarkable result is this, though the atmosphere there overlying the ocean, and, therefore, resting on a floor whose diurnal variation of temperature does not exceed a degree Fahrenheit, yet the diurnal oscillations of the barometer are as marked, and as decided as they are over the land where the diurnal variation of temperature is great. In accounting, therefore, for these oscillations, it is virtually unnecessary to take the temperature of the surface into consideration. What is insisted on here is that while the temperature of the surface leaves its impress on the diurnal barometric curve by important modifications thereby produced, yet the barometric oscillations themselves are independent of the temperature of the earth's surface. Hence the cause must be sought in the daily changes which take place in the temperature and humidity of the air through all its height, due to solar and terrestrial radiation.

* This furnishes the explanation of the apparently erratic movements of the balloon referred to by Captain Toynbee at the meeting, p. 157.

Another important result, the *Challenger* observations have revealed, is that over the ocean, latitude for latitude, the amplitude of the barometric oscillations is larger in an atmosphere highly charged with aqueous vapour, and less in a dry atmosphere. Thus in the four anticyclonic regions of the Pacific and Atlantic, lying about lat. 36° N. and S., immediately to westward of the adjoining continents, the amount of the diurnal barometric oscillation from the morning maximum to the afternoon minimum is only about 0·025 inch, falling in summer in the anticyclonic region of the North Atlantic to 0·014 inch. Now these anticyclonic regions of the great oceans are characterised by calms, light and variable winds, and further they are little traversed by seamen, as shown by Baillie's Meteorological Charts of the ocean. These regions are shown on the accompanying isobaric charts, Plates III. and IV., where it will be seen that the surface winds outflow in every direction from the high pressure areas of the anticyclones. Since, notwithstanding the outflow from the surface, pressure remains high, it necessarily follows that the high pressure is kept up by an inflow of upper currents. As the slow descending air of the central spaces of the anticyclones connects the inflowing upper currents with the outflowing winds of the surface, it follows that the air filling the central areas of the anticyclones is relatively very dry, because every stage of the descent, increasing the pressure, thereby increases at the same time the temperature and the dryness. Hence, over anticyclonic areas, the atmosphere is less cooled by nocturnal radiation and less heated by solar radiation, and the change of the aqueous vapour from the gaseous to the liquid state, and *vice versâ*, is also greatly less than elsewhere.

The all-important bearing of these anticylonic areas on physical geography will be shown farther on, when it will be seen that to them exclusively belongs the relegation of large portions of the earth's surface to climates which result in practically rainless deserts on the one hand, and on the other to rains generous but genial in amount, and in certain regions so torrential in violence and persistency as to lay an arrest on many important industrial pursuits.

In certain situations the diurnal barometric curve exhibits a unique phase of character, which is attended with results of considerable interest to the physical geographer. Such is the barometric curve peculiar to deep valleys, of which the curves of Gries and Klagenfurt in the Alps may be cited as illustrations. In such situations, the whole surface of the region during night is cooled by radiation below the air above it, and the air in immediate contact with the ground becoming also cool, a system of descending air-currents sets in over the whole face of the country bounding the deep valley. The direction and velocity of these currents are modified by the irregularities of the ground, and, like currents of water, they converge in the bottom of the valleys, which they fill to a considerable height with the cold air they bring down the sides of the mountains. This cold and relatively dense air rises above the barometers which happen to be down in the valley, with the result that a high mean pressure is maintained during the night. In summer pressure is maintained at the coldest time of the night, 0·040 inch at Gries higher than in open situations in that country. On the other hand, during day these deep valleys become highly heated by the sun, and thus a strong ascending current is early formed, under which the barometer falls unusually low. At Gries it falls in the afternoon 0·030 inch lower than in open situations in that part of Europe. One of the many results of this abnormal distribution of the daily pressure of the atmosphere is this, that if it were attempted to use the barometric observations of Gries in determining the heights of the surrounding mountains, the height calculated from observation at 4 p.m. would be 70 feet lower than from the 4 a.m. observations. Similarly, even in two such situations in the valley of the Thames as Greenwich and Kew, the height of Greenwich above Kew would, if determined barometrically, vary six feet accordingly as calculated from observations early in the afternoon, or in the early morning in summer, in which season, owing to the larger diurnal range of temperature, the calculated differences are greatest.

It will be shown further on that there is not only an abnormal distribution of pressure as shown by the diurnal barometric curves according as the effects of solar and terrestrial radiation are practically confined to and accumulate in these valleys; but even as regards the mean annual distribution of pressure through the months of the year, substantially the same accumulations and removals of large portions of the mass of the earth's atmosphere go on, according as either solar or terrestrial radiation is in excess at that season of the year. Hence in preparing the climatological maps for the *Challenger* Report, no observations made in such situations were used.

During the cruise, observations were made on the force of the wind on 1202 days, at least twelve times daily, 650 of the days being on the open

sea, and 552 near land. The velocity of the wind is shown to be greater over the open sea than near land, the mean difference being from four to five miles an hour. Of the five great oceans, the wind's velocity is greatest over the Southern Ocean and least over the North Pacific, the rates per hour being respectively 23 and 15 miles, the difference being thus 8 miles, caused probably by the winds of the "roaring forties" which were crossed and recrossed by the *Challenger*.

With respect to the open sea, the curves for each ocean show a very small diurnal variation, but a comparison of the five curves shows there is no uniform agreement, the slight variations being different in each case. Indeed it is highly probable that, as the teaching of this large mass of observations, the true diurnal variation in the velocity of the wind is practically a uniform straight line, with the single exception of the slightest rise about midday, not quite amounting to a mile an hour.

On the other hand, as regards the winds observed near land, the velocity at the different hours of the day gives a curve, for the five oceans, as clearly and decidedly marked as the diurnal curve of temperature. The minimum occurs from 2 to 4 a.m., and the maximum from noon to 4 p.m., the absolutely highest being at 2 p.m. The differences between the hours of least and greatest velocity are, for the Southern Ocean, 6½ miles; South Pacific, 4½ miles; South Atlantic, 3¼ miles; and the North Atlantic and North Pacific, 3 miles per hour. The higher velocities of the southern hemisphere were doubtless occasioned largely by the persistently low pressure at all seasons in Antarctic regions, and the time of the cruise during which the *Challenger* was within the sphere of that influence.

Over each ocean the velocity of the wind over the open sea is considerably in excess of that near land, and it is particularly to be noted that in no case does the maximum diurnal velocity near land reach the velocity over the open sea. The nearest approach, at any hour of the day, of the maximum velocity near land to the velocity over the open sea is 2·5 miles for the North Atlantic; 3·8 miles for the South Atlantic; 4·6 miles for the North and South Pacific; and 5·1 miles for the Southern Ocean. The difference is greatest at 4 a.m., when it is about six miles an hour, but diminishes as temperature rises, till at 2 p.m. it is a little less than three miles an hour. These facts bring before us, in an impressive manner, the extraordinary effect of the land in reducing, by friction, the velocity of the winds blowing over it; and further, that the heating of the surface of the land by the sun is in some way counteractive of friction.

The observations show that as regards the occurrence of rain over the open sea, there is one maximum of 130 instances at 2 a.m., and one minimum of 95 at 4 p.m.; and that while, for the twelve hours ending 8 a.m., the number of cases was 706, for the twelve hours ending 8 p.m. the number was 635, thus indicating that the occurrence of rain over the open sea is inversely as the temperature. Putting it otherwise, rain falls more frequently over the sea when the effects of terrestrial radiation are at the daily maximum than when solar radiation is in excess; thus corresponding, as will immediately appear, with the hours of the day when the occurrence of thunderstorms is at the maximum on the ocean.

Of the forty-five thunderstorms recorded during the cruise, twenty-six occurred over the open sea, and nineteen near land. Of those over the open sea, twenty-two occurred during the ten hours from 10 p.m. to 8 a.m., whereas during the other fourteen hours of the day only four occurred. Hence the important conclusion that over the open sea thunderstorms are essentially phenomena of the night, and occur mainly during the time of the morning minimum of pressure. On the other hand, as regards the thunderstorms which were recorded near land, they are pretty evenly distributed during the twenty-four hours, being thus intermediate as regards the hours of their occurrence between the thunderstorms of the ocean and those of the land, whose climates are more or less continental in character. In these climates the time of maximum occurrence is in the early afternoon, or when the barometer is at the afternoon minimum, and the minimum occurrence in the early morning, or when the barometer is at the other minimum of the day—the diurnal phases over the land being thus exactly the reverse of what takes place over the open sea.

Over the open sea the diurnal curve for the occurrence of lightning is on the other hand closely congruent with the evening maximum of pressure; and thus the relations of the maximum of lightning to that of thunderstorms over the open sea are essentially different from what obtains over land. Thus while on land surfaces the maximum of lightning occurs from five to six hours later than that of thunderstorms, it occurs four hours earlier than over the ocean. The order of occurrence of these phenomena in the summer months is thus:—thunderstorms over land 2 to 6 p.m.; lightning over land 8 p.m. to midnight; lightning over the open sea 8 p.m. to 4 a.m.; and thunderstorms over the open sea 10 p.m. to 8 a.m.

If it be assumed—and all observation seems to warrant the assumption—that thunderstorms occur during those abnormal distributions in the atmosphere when temperature falls with height much more rapidly than the normal rate, it follows that on land this abnormal distribution of temperature is brought about by the superheating of the lowermost strata of the air by strong insolation; but over the open sea the abnormal arrangement is brought about by the relatively great cooling of the upper strata by the direct effect of terrestrial radiation. On the other hand, lightning without thunder, or silent lightning, reaches its daily maximum at those hours when the upper atmosphere contains the greatest amount of aqueous vapour in its different forms, thus favouring the occurrence of silent electric discharges, and at the same time furnishing the means of making these discharges better seen.

Of the annually recurring phenomena of the atmosphere, the distribution of atmospheric pressure, temperature, and the prevailing winds of the globe are the most important. In truth, charts showing by isobaric lines the mean pressure of the atmosphere through the months of the year, may be considered as furnishing the key to the more fundamental problems of meteorology, since it is only by the information thereby obtained that questions relating to the prevailing winds, the varying temperature, cloud, and the rainfall of different regions can be satisfactorily handled. Accordingly, fifty-two maps have been constructed from all the data available for the purpose, of which twenty-six show, by isothermals, the mean monthly and annual temperature on hypsobathymetric maps, or maps showing by shading the height of the land and the depth of the sea, first on Gall's projection, and second on north circumpolar maps on equal surface projection; and twenty-six show, by isobars, for each month and the year, the mean pressure of the atmosphere, the gravity correction to latitude 45° being applied, and by arrows the prevailing winds of the globe. The isothermals have been drawn from mean temperatures calculated for 1620 stations, and the isobars from mean pressures from 1366 stations. We reproduce here the maps showing the distribution of temperature for January and July, Plates I. and II.; and the distribution of pressure and the prevailing winds, Plates III. and IV.; and refer to the report itself for fuller details and for a description of the methods adopted in discussing and charting this large mass of material, nearly the whole of which has been prepared expressly for this report. One or two points, however, may be noted.

The correction for the rate of the diminution of temperature with height, or technically the reduction of the temperature observations to sea-level, has been the uniform rate of one degree Fahrenheit for each 270 feet of ascent, as deduced from the observations at the two Ben Nevis observatories, the one at the top and the other at the foot of the mountain. From the horizontal proximity of these two stations and the success with which the local disturbance from the effects of solar and terrestrial radiation have been minimised, the above may be regarded as by far the best data yet available for the determination of this important factor in the physics of the atmosphere.

From the same double set of observations, a vitally important modification has been made, in reducing barometric observations to sea-level, of Laplace's formula, which has necessitated a serious change in the figures for reduction especially in climates such as Africa and Central Asia, where the mean temperature of the months differs greatly from 45°.

But the greatest change has been occasioned by the rigid exclusion from the maps of all observations of temperature and pressure at places situated in valleys, more or less steep and confined, as previously referred to. The result is a considerable change in the representation of the geographical distribution of temperature, and pressure over particular regions, as hitherto generally given by meteorologists and climatologists. Plates V. and VI., showing the pressure for a large portion of Europe, illustrate this point. On Plate V. the actual mean pressures at sea-level, and corrected to the gravity of lat. 45°, are engraved, the mean pressures at Röros and Tönset in Norway, and at Klagenfurt and Gries in the Alps, being printed in red ink. It is very plain that these red figures stand out as clear exceptions from every surrounding average of atmospheric pressure. The most striking contrast is presented by the means for Tönset and Dovrè, which are respectively 29·95 and 29·87 inches, the two places being nearly the same height, but separated by a broad mountainous range. It will be observed from Plate V. that if the red figures be omitted, mean pressure rises from the west coast of Norway uninterruptedly in every direction on advancing inland into the continent. The higher pressure at Tönset and Röros is simply confined to the lower parts of the deep valleys where these places are situated, and as suggested by the mean pressure at Dovrè adjoining, to no very great heights in these valleys. Probably the extent to which the high pressure obtains in these valleys, would be diagrammatically represented on a map of isobars by no more than a rather broadish stroke of the pen in these valleys.

Plate VI. shows the distribution of the January pressure over this part of Europe as given in Berghaus's recently issued Physical Atlas, where the mean pressures at Tönset and Röros are practically made to overrule the other pressures over the region to east and north-eastward. Similarly, the mean pressures at Klagenfurt and Gries stand equally out as exceptions from neighbouring stations and are worse than useless in drawing the isobars, particularly in the summer and winter months, when the local effects of solar and terrestrial radiation result in marked diminutions and excess of pressure in deep valleys. To these places may be added many others, such as several of the stations in the Caucasus, at Irkutsk and other Siberian stations, and in South America. A similar remark is also applicable in drawing the isothermals.

It also follows that such stations are eminently unsuitable to be used in the barometric determination of heights, it being evident that the heights of the hills between Dovrè and Tönset, if determined from the mean pressures of January, would be 70 feet lower if calculated from the Dovrè observations than they would be if calculated from the observations at Tönset.

In this connection the winds at Röros are remarkably instructive. For the ten years 1879 to 1888, the following are the averages for the month of January.

Days on which the various winds were observed:—

N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
2	0	1	3	4	1	2	6	12

Hence neither in direction nor force are the winds at Tönset controlled by the lie and proximity to each other of the isobars in this part of Europe; but, with the abnormal pressure, they stand alone. On twelve of the thirty-one days calms prevail, and during the other nineteen days the movement of the air is simply down and up the valley. A considerable outflow from these valleys takes place, resulting from the higher pressure there; and as this higher pressure is maintained from the effects of terrestrial radiation, a character is impressed on the general wind system of this region, which is readily misunderstood and misinterpreted.

Isothermal, isobaric, and wind maps accompany this paper for January and July as the representative months of the seasonal extremes. As January is the time of the year when the sun's heat is least felt, and the effects of terrestrial radiation attain the maximum, the greatest cold occurs over the largest land surfaces in high latitudes. Hence the lowest mean temperature that occurs anywhere or at any season on the globe, $-61°·2$, occurs in January at Werkojansk, lat. 67° 34′ N., and long. 133° 51′ E., in North-eastern Siberia, at a height of 460 feet above the sea. At this place temperature fell in January 1886 to $-88°·8$, being absolutely the lowest temperature of the air yet known to have occurred. The lowest mean temperature in America is nearly $-40°$, over the region situated a little to the north of the magnetic pole. For obvious reasons no such low temperatures occur in the southern hemisphere at any season.

In the northern hemisphere the ocean maintains a higher temperature than the land in regions open directly or indirectly to its influence, as is seen not only in the higher latitudes to which the isothermals push their way as they cross the Atlantic and Pacific, but in their irregular courses over and near the Mediterranean, Black, Caspian, and Baltic Seas, Hudson's Bay, the American Lakes, and all other large sheets of salt and fresh water. The influence of the ocean and ocean currents in keeping up the temperature during the winter months is most strikingly seen in the North Atlantic, where the isothermal of 35° reaches a much higher latitude in midwinter than anywhere else on the globe.

In the southern hemisphere the highest isothermals are 90° in Australia and South Africa, and 85° in South America. It is to be noted that in January, the summer of this hemisphere, the lowest isothermal is 25° in the Antarctic Ocean to the east of South Victoria; whereas in July, the corresponding summer month of the northern hemisphere, the lowest isothermal is only 35°, or 10° higher than in the Antarctic Ocean. The difference is due to the icebergs and icefields of Antarctic regions. In Antarctic and sub-Antarctic regions the change of temperature through the months of the year is comparatively small, the annual range being only about 10°.

In January the mean pressure of Central Asia rises to about 30·50 inches, which is absolutely the highest mean pressure for any month anywhere over the globe. Now, since the prevailing winds in this great anticyclone, which virtually overspreads nearly the whole of Asia and Europe, flow outwards in all directions, bringing south and south-west winds over Russia and Western Siberia, it follows that the temperature of these inland regions is considerably higher than would otherwise be the case. On the other hand, since the prevailing winds are north-west, north, and north-east on the east and south of Asia, the temperature of these regions is thus abnormally depressed. Indeed, so strong is this influence of wind direction and ocean combined, that the isothermals run, roughly speaking, north and south in the west of the Europeo-Asiatic continent, and do not assume an east and west direction till about 70° or 80° long. E.

Since in Siberia light airs and calms prevail, and the general drift of the atmosphere is N.N.E. towards the higher latitudes of the Arctic regions, the temperature continues rapidly to fall in that direction, with the result that the lowest mean temperature is not coincident with the centre of greatest pressure to the south of Lake Baikal, but occurs at Werkojansk, about thirty degrees of latitude to the N.N.E.

The other anticyclonic regions are North America, in the centre of which pressure rises to 30·20 inches; two in the Pacific to the west of California and of Chile respectively; in the south Atlantic to the west of Cape Colony; and in the Indian Ocean to the west of Australia. Such regions, and they are well marked, are found in all months and in all oceans about lat. 30° to 40° N. and S., immediately to the westward of the continental masses in these latitudes. The only apparent exception to this is in the North Atlantic in January, and the isobars of this part of the ocean for the months immediately following suggest that this is a true exception. Lieut. Baillie's isobaric and current charts of the ocean show in an instructive manner that the central spaces of these anticyclonic regions are nearly always avoided by seamen, and therefore practically long known to them. It is scarcely necessary to add that the prevailing winds blow out of them in all directions; and since these winds have the temperature of the upper regions whence they have come increased only by the increasing pressure to which they are subjected as they descend, their temperature often differs considerably from that of the surface of the sea over which they blow, but the precise temperature relations have yet to be worked out.

The lowest isobar, 28·90 inches, is in the Antarctic regions to the east of New Victoria. The observations of all months for which we have observation show that there is a permanently low pressure over these regions, lower than is to be found anywhere else on the globe. On all the maps pressure is drawn to the isobar of 29·30 inches, since observations appear to warrant this; but during the summer months of the southern hemisphere lower isobars have been drawn for the portions of Antarctic regions for which observations have been furnished by the various expeditions which have been made into these southern seas.

The most widespread low-pressure area is in tropical regions, where pressure, except in the eastern half of the Pacific, falls below 29·85 inches. In this extensive region, which covers about two-fifths of the whole surface of the globe, there are three areas where pressure falls still lower. These are the north-west of Australia, Southern Africa, and South America. A line drawn round the globe along the path of least pressure of this zone separates the north and south "trades," indicating the belt or still narrower zone towards which these great aerial currents blow. In the Atlantic and eastern half of the Pacific, where the barometric gradient is well marked, these winds are mapped out with equal distinctness; but in the western part of the Pacific, where the gradient is low and indistinctly marked, the direction of the prevailing winds is irregular and obscure, and it is probable that increased observation will the more strongly illustrate this remark.

It will be observed that the path of least pressure lies north of the equator in the Atlantic and Pacific Oceans. But in the Indian Ocean it is, at this season, south of it, lying in a line from Seychelles to the north of Australia. In this restricted region the winds are especially interesting as illustrating Buys Ballot's law of the wind in the southern hemisphere.

The next most important low-pressure system overspreads the northern part of the Atlantic and regions adjoining, the lowest mean pressure being 29·50 inches from Iceland to the south of Greenland. It is this region of low pressure which gives to Western Europe its prevailing south-westerly winds and to North America its north-westerly winds in winter. By these the temperature of Western Europe is abnormally raised by its prevailing winds coming from the ocean and from lower latitudes, and the temperature of North America is abnormally lowered by its prevailing winds coming from Arctic regions and from land in the season when the effects of terrestrial radiation are at the maximum. The opposite action of these winds, which are component parts of the same atmospheric disturbance about Iceland, is shown by the temperature on the coast of Labrador being only —13°, whilst in the same latitude, in mid-Atlantic, it is 45°, or 58° higher. This low-pressure region extends eastwards beyond Nova Zembla, and from the resulting winds which follow that extension the rigours of the winter climate of the north of Russia and Siberia, as far east at least as Cape Severo, are materially counteracted.

The remaining cyclonic centre is in the North Pacific, the lowest isobar being 29·55 inches south of Alaska. The effects of this low pressure on the prevailing winds, and through these on the temperature and rainfall of the north-east of Asia and the north-west of America, is exactly similar to the effects of the low pressure of the Atlantic on the climates of Europe and the United States.

The influence on the pressure of the Spanish and Italian peninsulas on the one hand, and on the other the influence of the Mediterranean, Black, and Caspian Seas is strongly marked; and equally so do the Arabian Sea, India, and the Bay of Bengal leave their mark on the isothermals, isobars, and the winds.

July.—This is the typical month of the summer of the northern and of the winter of the southern hemisphere. The three regions in Asia, Africa, and North America, enclosed in June with the isothermal of 95°, and marking off the hottest regions of the globe in that month, cover now a wider extent, and include maximum temperatures a few degrees higher, indicating absolutely the highest mean temperatures that occur anywhere or at any season.

Among the most interesting features of the climates of restricted regions shown by the isothermals may be enumerated the relatively low temperature of Nova Scotia, the coast of Morocco, Burmah, and Victoria in Australia; and the relatively high temperature of the eastern division of India sheltered from the summer monsoon, and the inland regions of Scandinavia, Spain, Italy, and Greece. In these months the influence of the Red Sea, the meteorology of which has recently been contributed to science by the Meteorological Council, is conspicuously seen in maintaining a low temperature, and thereby breaking the continuity between Asia and Africa of the isothermals of 90° and 95°. The crowding together of the lines in California, and from the Bay of Biscay to the south of Algiers is very remarkable.

The more important changes of the distribution of the pressure are an increase over the southern hemisphere generally, with very slight exceptions in South Africa, New Zealand, and the south of South America; India, except the north-west; Japan; a patch of Europe, extending from the north of Spain to Hungary; the south-western half of the North Atlantic, and the continental portions of North America from the Gulf of Mexico north-westward to lat. 55°. Elsewhere pressure has diminished, but particularly over Asia and Europe, except the regions mentioned above, the northern half of the North Atlantic, and nearly the whole of British America.

In this month the pressure of the northern hemisphere, taken as a whole, falls to the annual minimum. If 29·95 inches be accepted as the mean pressure of the atmosphere over the globe, which is very near the truth, then the whole of this hemisphere, excepting the anticyclonic regions of the Atlantic and Pacific, has a mean pressure below the average. This great seasonal depression has its centre marked off by the isobar of 29·40 inches, extending from Mooltan to Muscat, and is absolutely the lowest continental pressure occurring anywhere or at any season. This great depression, which may be roughly regarded as coterminous with the land of the northern hemisphere, may be justly considered as ruling the climate and weather of this half of the globe during the summer months.

Subordinate centres of low pressure are to be seen in North America, between South Greenland and Hudson Bay, south of Iceland, in Scandinavia, in Spain, and in the valley of the Po, the last four being, however, comparatively slight. In America the lowest isobar is 29·75 inches. In Africa the increased heat seems to result in a widening apart of the isobars from the Red Sea to Sierra Leone, rather than in the formation of any distinct cyclonic centre.

In addition to the four anticyclones in the Atlantic and Pacific, anticyclones appear also to the west of Australia, in South Africa, and in Australia, in the last case reaching the maximum for the year. In the southern hemisphere, about lat. 30°, pressure rises over long stretches to or above 30·20 inches; and nowhere, except in the comparatively short distance from long. 170° E. to long. 140° W., does it fall below 30·00 inches. It is to this belt of high pressure that the part of the air which has been removed from the continents of the northern hemisphere has no doubt been transferred.

In January the highest mean pressure in Asia is a little more than 30·50 inches in the upper valley of the Amur and the region to the south-west of it; whereas in July the lowest pressure, 29·40 inches, is at a considerable distance from the above, being located in the valley of the Indus and south-westwards to Muscat. The difference of pressure between these two extreme months is thus 1·10 inch, or fully a thirtieth part of the entire barometric pressure, nearly the whole of the difference being occasioned by the difference of temperature of the two months, the rainfall being so small that it may be regarded as practically nil at these times of the year. In North America and in Australia the difference of pressure of January and July is only 0·45 inch.

In the remarks on January it was pointed out that the centres of maximum pressure and minimum temperature, which are respectively these maximum and minimum data for the globe for any season, are far from occupying the same geographical area. But in July the regions of minimum pressure and maximum temperature are virtually coincident. In this region the climate is remarkably dry and rainless, or nearly so, and substantially the same climatic characteristics distinguish the more restricted regions of low pressure in the United States, Scandinavia, Spain, and North Italy. The point is of considerable importance in atmospheric physics, as showing that when the sun's heat is strongest cyclonic areas of low pressure are generated in dry climates; whereas in winter, in the higher latitudes, cyclonic areas are formed in humid and rainy climates.

One of the most remarkable illustrations of the respective influences of land and water on the courses of the isobars is seen at this season in the higher pressure maintained from the Straits of Gibraltar, eastwards to the Sea of Aral by the extensive sheets of water for which this region is so remarkable. The crowding, widening, and deformation of the isobars in the different parts of the region are curious and highly instructive. On the other hand, the diminution of the pressure shown by the isobar of 29·80 inches immediately to the north in eastern Russia, where there are no water surfaces, is equally striking.

As Australia is an island sufficiently large to show the climatic features of a continent, it is interesting to note in connection with the anticyclone overspreading it at this time, that on all coasts the winds blow out from the land seawards. This, therefore, is the dry season of Australia.

One striking feature of the oceanic anticyclones deserves attention. The isobars crowd more together on their eastern sides, where they press closely upon the continents adjoining, than on their western sides, where they are prolonged westwards through their respective oceans. The prevailing winds of continental coasts adjoining the central and southern portions of anticyclonic regions are usually dry for two reasons; they advance from higher to lower, and therefore warmer latitudes, and they have traversed the evaporating surface of the ocean but a comparatively short way since their descent from the higher regions of the anticyclones. The arid climates of California, Peru, Morocco, and south-west of Africa at this time may be referred to as illustrations.

The July isobars of India are of more than ordinary interest, implying, as they do, the utmost practical advantages to the empire. From Cutch southward pressure is everywhere higher in the west than in the east of the same latitudes, represented by the south-easterly slant of the lines as they cross India. The difference is about half a tenth of an inch, and the same difference also holds good in Ceylon. The consequence of this peculiarity in the distribution of the pressure is that the summer monsoon blows more directly from the ocean than would have been the case if the isobars had lain due west and east. A much more important consequence, however, follows from the location of the region of least pressure in the valley of the Indus, so that in the valley of the Ganges, and in the north of India generally, pressure diminishes steadily from east to west—from Assam, up the Ganges, and westward to Jacobabad on the Indus. The inevitable result of this inversion in the manner of the distribution of the pressure is that the winds are no longer south-westerly, but they become southerly over the Bay of Bengal, and thereafter deflected into E.S.E. winds blowing up and filling the whole valley of the Ganges, and distributing in their course a generous rainfall over this magnificent region. If winds there had been south-westerly, the rainfall would have been meagre and inadequate, owing to the intervention of the Western Ghauts between the sea and the Ganges.

It will be observed that the low-pressure system of Asia and the anticyclonic system of high pressure of the Atlantic are connected by what is virtually an unbroken broad belt of westerly winds over Europe and western Asia, bearing with them much vapour from the Atlantic to which is due the summer rainfall of these parts of the old continent.

It has been explained that the centres of anticyclones are occupied with a vast column of descending air, which as it descends becomes continually warmer and drier; and also that the limiting isobarics of the anticyclones press close together on the west coasts of the adjoining continents out of which the air currents spread over these continents. Now an examination of the surface winds of the anticyclones in their middle and southern portions in the northern hemisphere, and in their middle and northern portions in the southern hemisphere, show clearly that they traverse but a small part of the ocean before reaching the adjoining continent, and further as they thereafter pass in lower latitudes they become still drier as they advance. The inevitable result is that the parts of North and South America, and of the north and south of Africa where these anticyclonic winds prevail, are virtually rainless barren deserts; and they will remain so as long as the present geographical distribution of land and water remains substantially as it is. On the other hand, as the winds which blow in upon the continents on the side farthest from the equator, must arrive at the land after traversing a considerable portion of the ocean, and thereafter advance into higher latitudes and therefore colder climates, the rainfall over such regions is generous in amount, and in many cases, in even undue excess. In illustration may be cited, the arid climate of Lower California as contrasted with the west coast of British Columbia, the annual rainfall of San Diego being only 10 inches, whereas that of Fort Simpson is 100 inches.

Or stating more generally the relation of the isobaric lines to the rainfall, which, from the hygrometric conditions it involves, impresses on climates their more characteristic and beneficial features, the greater the distance the winds have traversed the ocean before they strike the coast, the more copious is the rainfall; and the less the space so traversed, in the same proportion do the climates of the land surfaces approach a rainless aridity, even though the winds arrive direct from the ocean. Thus the isobaric lines and winds for July show that among the regions of the globe where the rainfall is large are India, the winds there having really traversed the ocean from near latitude 30° S.; the United States, the prevailing winds arriving there after having traversed nearly the whole breadth of the Atlantic, and the Gulf of Mexico; and Japan, to which the prevailing winds arrive after traversing more than half the breadth of the Pacific to the south-eastward. Again, in January, the winds of the British Islands and Norway have previously passed over a large portion of the Atlantic; and as regards the East India Islands, the prevailing north-easterly winds of winter bring a heavy rainfall gathered during the long course they have pursued over the Pacific. Where the continental masses of land are of comparatively small extent, as in Australia and South Africa, and the isobaric systems therefore less likely to be fully developed year by year, there the most serious droughts occur from time to time.

The desert of Gobi is caused by quite a different set of meteorological conditions. During winter, the wind system of this region is part of the general atmospheric movement of Asia, which proceeds from the centre of the continent in all directions towards the surrounding ocean. Hence the region at this season is practically rainless; and during summer the winds in this part of the continent become northerly as they follow the general atmospheric movement in upon the low pressure system in north-western India, and hence in this season also the climate is rainless. The point to be insisted on here is that these regions are made deserts by the meteorological conditions of pressure and the resultant prevailing winds, which in their turn are the inevitable result of the present distribution of land and water over the face of the globe.

The isobaric maps show in the clearest and most conclusive manner, that the distribution of the pressure of the earth's atmosphere is determined by the geographical distribution of land and water, in their relations to the varying heat of the sun through the months of the year; and since the relative pressure determines the direction and force of the prevailing winds, and these, in their turn, the temperature, moisture, and rainfall, and in a very great degree the surface currents of the ocean, it is evident there is here a principle applicable, not merely to the present state of the earth, but also to different distributions of land and water in past times. In truth it is only by the aid of this principle that any rational attempt, based on causes having a purely terrestrial origin, can be made in explanation of those glacial and warm geological epochs through which the climates of Great Britain and other countries have passed. Hence the geologist must familiarise himself with the nature of those climatic changes, which necessarily result from different distributions of land and water, especially those changes which influence most powerfully the life of the globe.

Mr. R. H. Scott (Meteorological Office): I think the Society may congratulate Mr. Buchan on being able to lay before it the results of investigations upon which, to my knowledge, he has been engaged for the last quarter of a century. Mr. Buchan commenced to make his charts of the distribution of barometric pressure and wind, which were published about twenty-two years ago, somewhere about the year 1865; and now in the year of grace 1891 he comes to lay before you the conclusions to which his ripened judgment has led him. Of course, owing to the number of questions which Mr. Buchan has dealt with, it is impossible to discuss any one of them; he has merely lightly touched on the subjects leading to the conclusions he has arrived at. However, this is not the place or the time to enter into a discussion, because there may be some slight differences of opinion; but I think we are exceedingly obliged to him for having taken the trouble to put all these results together. In bringing forward these remarks he has talked about the distribution of land and water which has produced the climate that exists. There is one question I should have liked to have heard him take up; that is, the subject discussed by some foreign physical geographers as to what is required to reproduce the glacial epoch in England. They say what is wanted is merely to submerge Germany and Russia, which could be done by lowering the level of the land some 200 feet; so, really, it does not require any very great disturbance in the distribution of land and water to produce this phenomenon. As regards the question of the work of the *Challenger*, it is exceedingly interesting to me to hear that Mr. Buchan has found that we never on land get anything like the wind which is met with on the open sea. Of course I know myself, from experience in the interior of the continent of Europe, that the wind there is nothing like what it is on our own west coast. We have heard from ships of tremendously strong winds in the Atlantic and we certainly in our office never believed the reports, as the observers had not instruments on board to prove that the wind actually reached the amount of violence reported in the logs; but it appears from the observations of Mr. Buchan that, on nearing the coast, a very considerable diminution in the force of the wind is found. However, with reference to the whole of the subject, I think that till Mr. Buchan's paper is in print and condensed, it is hardly time to discuss it, or to give any opinion upon it until one has had time to consider carefully the conclusions at which he has arrived. I congratulate him most sincerely on being able to bring the paper before this Society.

Mr. F. Galton: The only point to which I would draw attention is the extraordinary advance that Europe has made during this century in meteorology, an advance parallel to that made in the science of geography, with which we are more especially concerned here. Not many years back it would have been totally impossible to have constructed a map with these isobars and isotherms indicating the distribution of meteorological phenomena over the face of the globe, as all the necessary information for doing this has been collected in comparatively recent years. Again, although people may justly say that our predictions of the weather issued by Mr. Scott are by no means as perfect as they might be, and though we cannot even roughly anticipate more than thirty-six or even twenty-four hours, still a very great advance has been made from what was formerly possible. Therefore we ought not to be discouraged by the length of time it may take to approach to perfection, considering how very much has been done in this one century. The great thing we now want to know is the state of the air above us, for we are at the bottom of an aërial ocean and all we know is what takes place at the bottom. Imagine how little a marine animal that lived at the bottom of the sea, having the same intelligence as ourselves, would know of the currents above. That is precisely our position; we understand only one horizontal section of this superincumbent mass. Mr. Buchan has done a great deal in endeavouring to add, as far as the geography of England and Scotland will permit, to our knowledge in this respect, by his advocacy of the construction of an observatory on Ben Nevis, and I should like to take this opportunity of saying how much it would add to the interest of the daily returns from that observatory now published in the *Times*, if returns from Fort William were given at the same time, so that we should be easily able to compare the results obtained from these high and low-level stations.

Admiral Sir Erasmus Ommanney: I should like to ask one question, Sir, as to the great contrast of readings of the barometer in the Arctic as compared with the Antarctic zones, which differ we know from observations made. The barometer stands about an inch lower in the Antarctic than in the Arctic regions. I do not know whether you have considered the matter, but if you have, it will be of great interest.

Mr. Douglas Freshfield: Mr. Galton has spoken of the importance of knowing what is above us in the atmosphere. It is a common observation of weather-prophets in the mountains, that great changes of weather are preceded by changes in the upper sky, which do not precede minor local disturbances. It would be of interest if Mr. Buchan could tell us what is the force of the wind as observed at the different high stations in Europe, not only at Ben Nevis, but at those of double the height, on Etna, in the Pyrenees, on the Pic du Midi, and in the Alps, at the St. Bernard, on the Säntis, the Sonnblick, and elsewhere; whether the winds at these stations are of the same force as they are on the great oceans. I would point out that there is now an opportunity for meteorologists, which I hope they will avail themselves of, in the new cabin at the height of 14,000 feet on Mont Blanc, where undoubtedly an observer could live for six months, and an enthusiast might conceivably stay the whole year. The general opinion is that the wind is very much stronger at such heights, but I do not think this is necessarily true, as a little extra cold in a gale makes it appear much stronger, and of course at these elevations the winds are often icy. At the beginning of the greatest of the storms which characterised last summer, a party of men, perfectly capable of taking care of themselves, were swept off one of the ridges of the mountain by the force of the wind. M. Janssen's observations of the force of this gale at this cabin proved that it was not equal in violence to the great tornado he experienced in Hong Kong. The relatively high temperatures noted by mountaineers on Alpine summits during winter ascents, seemed to demand more explanation than they had yet received.

Mr. Buchan: As regards the force of the wind at Ben Nevis we have little idea here, save perhaps in great storms, which I do not believe at all equal what is often felt there. They have drawn up a scale 0–12 in Mr. Scott's style that is used throughout the whole of the world; what is registered as eight at Ben Nevis would be registered here as twelve. Twelve would equal about 120 miles an hour, and such is the great strength of the wind, that in making observations all three men have to go out roped together, and creep along on hands and feet. There are many important things which there is not time to go into; for instance, it not infrequently happens, looking at the isobars issued by the Meteorological Office of the surface winds, that the winds at the top are opposite to the isobars. It repeatedly occurs that when the wind all round the British Isles is light, exceedingly strong winds are experienced on Ben Nevis, winds that lasted on one occasion a fortnight, with force of from ten to eleven, equal to about 112 miles an hour. At the level of the top of Ben Nevis we have a totally different distribution of the earth's atmosphere from that below, and we should be delighted if the information Mr. Galton desires appeared in the newspapers—it is a matter of expense, as it would mean a great deal more for the daily telegraph. We are very desirous of bringing it about, and perhaps by and by may be able to do so.

Captain H. Toynbee: Having spent thirty-three years at sea, chiefly on voyages to India, I have passed many times through the areas of high and low barometric pressure which are depicted on Mr. Buchan's charts. After that time I was twenty-three years in the Meteorological Office examining the logs of ships, so that I am able to say that these areas and their corresponding winds are confirmed by experience. It would have been a great advantage to me had I possessed such charts during my voyages. With regard to Mr. Galton's remark on the importance of observing the upper currents of air, I think that any further advance in meteorology depends on such observations. For instance, our present weather is related to the fact that an area of high barometric pressure has existed for some time over our islands, and has warded off the cyclonic systems which generally pass over us on their way to the north-eastward or eastward, especially in winter. This year most of those systems have passed to the northward of us on their way to Norway. We should like to know the peculiar circumstances which caused the upper air to settle down over our islands, instead of passing further east towards central Europe, where an area of very high pressure is generally constant in winter. On these grounds I have ever pressed upon the captains and officers of ships, who have undertaken to observe for the Meteorological office, the importance of noting the direction from which cirrus-cloud is moving. It seems possible that cheap balloons might be used to advantage where upper clouds are not seen. This is proved by the following anecdote told me by my old friend, the late Mr. W. H. Bayley, who was then secretary to the Revenue Board of Madras. An aeronaut came to Madras and advertised an ascent, fixing an hour when the sea breeze had set in, with the object of his being driven over the land. There were no upper clouds to show the motion of the upper current of air, but Mr. Bayley thought the man might have made a mistake, so he took his binoculars to the top of his office and watched the balloon. At first it drifted quickly to the westward over the land, but it soon gave a peculiar twist and then moved seaward so quickly that, although the man pulled the string of the valve so hard that it jammed open, allowing the gas to escape very freely, he fell into the sea two or three miles from the land, and the boats of ships in the harbour raced out and saved him. I have always held Mr. Buchan's opinion that currents of the sea are produced by the action of wind, which is well shown by Mr. Clayden's model about to be exhibited in the Royal Naval Exhibition. Mr. Buchan's paper has interested me much, and I hope he may enjoy another twenty-five years of work with equally good results.

Dr. Rae: Might I be allowed to say a few words in regard to the centre of cold in North America. In 1850–1 I wintered in latitude 67′. We had cold 73° below zero. My thermometer was tested by the Meteorological Office, and the mercury was frozen six to seven days continuously, and I think this is colder than has been recorded in any other part that I know. This was at the north-east end of Great Bear lake; the lake, of course, might affect the temperature, but it was completely covered by ice. I think this temperature is the same as that registered by Captain Nares in Smith's Sound. I believe that Captain Ross's party, when as near as possible to the magnetic pole, never registered so great a degree of cold.

Mr. Buchan: Of course in my paper I have been dealing not with single temperatures, but with averages. Might I ask if you took this observation in a valley with high ground round you?

Dr. Rae: The ground was rather low; my instruments would be 10 to 12 feet above the lake, and the lake is about 300 to 400 feet above sea-level.

The President: There is a thought which I am convinced passed through the minds of a great many people when Mr. Scott was speaking, and it was this, that although there was nothing in the evening papers about the submergence of Germany or Russia, there was some reason to think that the glacial period had returned already. However that may be, we are all very much obliged to Mr. Buchan for having come here to-night in such dreadful weather, and from a long distance, and for having given us the result of his observations and reflections hived up through so many years. I trust that he will not be a sufferer for having done so. I know that Mr. Buchan is in somewhat infirm health, and that his throat is a weak point. I was pleased, however, to observe that his voice showed no faltering as he proceeded, and I trust and hope that to-morrow he will not have to regret the great amount of pleasure and instruction he has given to a large company of this Society.

Notes on a Botanical Trip in Madagascar.

By G. F. Scott Elliot.

I landed at Madagascar in December, and, after a few days at Tamatave, proceeded to Antananarivo. After a fortnight's stay in the capital, I then started on my journey south-eastwards, and after six weeks' almost continuous travelling, I arrived at Fort Dauphin, the extreme south eastern corner of the island. Most of this route is over very well-known ground, and Messrs. Baron, Grandidier, Hildebrandt and others have very thoroughly described the character of the country. The first part of my journey was to Lake Itasy, which is about two days' journey west of the capital. This district deserves notice, as the geological structure is peculiar. I passed over two rather extensive basalt flows, which appear to be of rather recent date, though the absence of any overlying rock renders it impossible definitely to fix their age. On this basalt there is a distinct change in the vegetation. *Lysimachia parviflora* and a few other species are more common, and *Clematis anethifolia, Kniphofia palladiflora*, and others appear almost confined to it. The whole district near Lake Itasy is volcanic; the country is studded with small cones of scoriæ, rising (in the neighbourhood of the lake) out of a level, marshy plain, and one is tempted to assume that the lake lies in a hollow due to the subsidence of the land through volcanic action. From Lake Itasy I went to Mr. MacMahon's station at Ramainandro, and near here I saw the celebrated subterranean river. It is a very simple formation. The strike of the strata is east and west nearly, and the river, running in the same direction, has burrowed its way underneath a harder layer of rock, which latter has subsequently broken off in large boulders and covered the stream.

I next passed through the Ankaratra Mountains, which rise to about 10,000 feet, and appear to be of rather a different rock to the ordinary monotonous gneiss and granite of Imerina and the Betsileo. These mountains are very misty, and never suffer, so far as I could see, from the drought prevalent over most of the country.

Corresponding to this climatic change, there is a distinct change in the vegetation. The higher mountain plateaux and hillsides are covered with luxuriant grass, amongst which there is a profusion of flowers. Orchids—especially such forms as Eulophia, Habenaria, Satyrium—are especially abundant. Gentians of various species are also common, and many kinds of *Stachys* and *Salvia* also grow in this part.

The ravines of these mountains are often filled with patches of forest, and it is interesting to see how these woods are strictly confined to the more sheltered places. The trees along the outside edge of a ravine, and which are therefore exposed to the wind and sun, show a stunted and branched condition. This exposure to wind and drought explains the absence of trees over the parched, steppe-like plains of Imerina, where all the vegetation consists of very small shrubs with a prostrate, much-branched, wiry habit, more like heather than any other English plant.

The rest of my journey to Fianarantsoa, and south of that town to the border of the forest at Angalampena, lay over these low, broken, gneissose hills, intersected by numerous rivers and with green rice-fields lying in every valley. The plants become sometimes taller and more luxuriant by the riversides, and in the rice-grounds one finds many common weeds of cultivation, but the rest of the country is almost wholly covered by the indigeneous forms, such as Hypericums, Indigoferas, Desmodiums, Otiophoras, Phaylopsis, Commelyna, and many others.

There is an interesting mountain lying to the east of the road near Fianarantsoa. According to Malagash tradition, its misty summit is inhabited by the ghosts of the dead. When the cannon are fired in the capital at the feast of the new year answering salvos of ghostly artillery are said to be heard from the mountain top. Mr. Shaw told me he had once managed almost to reach the summit, and he found the valleys had a peculiar bend and shape which might form an echo, so that this may really be a fact.

The most interesting part of my journey began at Angalampena, about 50 miles south of Fianarantsoa. This is the inner limit of the forest, and, as nearly as I could calculate, the mountains are at this place about 4000 feet high. There are two parallel ridges, running nearly north and south, and separated by a river of considerable breadth. The river seems a branch of the Mangoky, and apparently turns to flow westwards a few miles inland. After crossing the river, and a rather dangerous morass which covers about two miles of the road, one has the second mountain ridge to traverse. This is the watershed of the island, the rivers on its seaward side draining into the east coast, while those on the inland side eventually fall into the sea on the western coast. The whole of these mountain ridges and their valleys is covered with a well-grown and dense forest. It is difficult, in fact, to get a good idea of the country until one emerges on the eastern flanks of the second ridge. The view from this side is very beautiful. Below one's feet lies a long, very deep valley, with a broad river running eastwards. Little villages are placed on flanking spurs of the hills, while the mountain ranges to the westward, rising one behind another, are covered with forest. Every here and there an abrupt granite precipice appears amongst the trees. The level of the valley is 1000 feet below that of the river flowing west. The forest is here very narrow.