and it easily results from (10) that we obtain a set of thirty formulæ, from which selecting,

$$2S\alpha\gamma\zeta S\alpha\epsilon\delta S\beta\gamma\epsilon S\beta\zeta\delta = V^2(\mu_3^2\nu_3^2 - \mu_1^2\nu_1^2 - \mu_2^2\nu_2^2) + W ;$$

$$2S\alpha\gamma\delta S\alpha\epsilon\zeta S\beta\delta\zeta S\beta\gamma\epsilon = V^2(\mu_1^2\nu_1^2 - \mu_2^2\nu_2^2 - \mu_3^2\nu_3^2) - W ;$$

we have, see (7)

$$\frac{S\alpha\gamma\zeta S\alpha\delta\epsilon}{S\alpha\gamma\epsilon S\alpha\zeta\delta} = \frac{V^2(\mu_3^2\nu_3^2 - \mu_1^2\nu_1^2 - \mu_2^2\nu_2^2) + W}{2\mu_2^2\nu_2^2V^2} ;$$

$$\frac{S\alpha\gamma\delta S\alpha\epsilon\zeta}{S\alpha\gamma\epsilon S\alpha\zeta\delta} = \frac{V^2(\mu_1^2\nu_1^2 - \mu_2^2\nu_2^2 - \mu_3^2\nu_3^2) - W}{2\mu_2^2\nu_2^2V^2} ;$$

we have thus an expression for $S\alpha\gamma\epsilon S\alpha\zeta\delta$, and by permuting we can form, in like manner, expressions for

$$S\alpha\gamma\epsilon S\beta\zeta\gamma \quad \text{and} \quad S\alpha\zeta\delta S\beta\zeta\gamma ,$$

and so obtain $S^2\alpha\gamma\epsilon$. In fact we have,

$$[\{V^2(\mu_3^2\nu_3^2 - \mu_1^2\nu_1^2) + W\}S\gamma\epsilon V\delta\zeta + \mu_2^2\nu_2^2V^2(S\gamma\zeta V\delta\epsilon + S\gamma\delta V\zeta\epsilon)]S\alpha\gamma\epsilon S\alpha\zeta\delta$$
$$= -2\mu_2^2\nu_2^2V^2F_2 .$$

It will be observed how Quaternion methods enable us to express simply forms which, without this powerful analysis, would present formidable complexities.

Report on Atmospheric Circulation, based on the Observations made on Board H.M.S. "Challenger" 1873–76. By Alexander Buchan, LL.D.

(Part I. read April 16, 1888; Part II. read May 6, 1889.)*

(Abstract.)

In these papers the meteorological observations taken during the voyage of the "Challenger" are discussed; and, from data collected from all parts of the world, fifty-two maps have been prepared, showing for each month of the year the distribution of temperature and pressure over the globe and the prevailing winds. Part I.

* These papers were submitted by permission of the Lords Commissioners of Her Majesty's Treasury. For the Report itself see "Report of the Scientific Results of the Voyage of H.M.S. 'Challenger,'" *Physics and Chemistry*, vol. ii. part vi.

deals with the diurnal, and Part II. with the seasonal phenomena of meteorology.

Diurnal Phenomena.—An examination of the temperatures observed by the "Challenger" proves that nowhere over the ocean does the mean daily fluctuation of the temperature of the surface amount to a degree Fahrenheit, the extremes being from about 0°·3 in high latitudes to 0°·9 in the tropics. Thus the atmosphere over the ocean rests on, or blows over, a surface the temperature of which is practically uniform at all hours of the day. This small variation is a prime factor in meteorology, particularly in those discussions which relate to the diurnal phenomena of atmospheric pressure and winds.

The temperature of the air over the open sea shows a daily variation of 3°·2, being four times greater than that of the sea over which it lies; but when the "Challenger" was near land, the variation rose still further to 4°·4. This larger variation in the daily temperature of the air, as compared with that of the sea, is a point of much significance in atmospheric physics, from the light it casts on the relations of the atmosphere and its aqueous vapour to solar and terrestrial radiation.

The phases of the elastic force of vapour over the open sea occur at the hours of the maximum and minimum temperatures of the sea and the air. On nearing land, however, this no longer holds good; but owing to the influence of the land breeze, the time of minimum humidity is delayed from 4 to 6 A.M., and owing to the sea breeze and its effects, the amount of the aqueous vapour falls to a secondary minimum from noon to 2 P.M. As regards the relative humidity, the maximum occurs from midnight to 4 A.M., and the minimum about 2 P.M., this curve being thus inverse to that of the temperature; and it may be added, that this is substantially the curve of the relative humidity for all climates and seasons.

The phenomena of the double diurnal barometric tide appear in their simplest form in the centre of the Pacific, or in the midst of the largest water surface of the globe. The following are the variations of pressure from September 1 to 12, 1875, in mean lat. 1° 8′ S. and long. 150° 40′ W., the mean pressure for the time being 29,928 inches :—

	Inch.		Inch.
2 A.M.	−0·012	2 P.M.	−0·043
4 „	−0·022	4 „	−0·055
6 „	0·003	6 „	−0·028
8 „	0·028	8 „	0·004
10 „	0·032	10 „	0·013
Noon,	0·006	Mid.	0·012

from which it is observed that the amplitude of the range from the morning maximum to the afternoon minimum amounts to 0°·087 inch.

Latitude for latitude, the smallest variations over the open sea occur in the anticyclonic regions of the different oceans. Thus about lat. 36°, and the time of the year when the sun is highest in the heavens, the amounts are—for the South Pacific, 0·036 inch; North Pacific, 0·025 inch; South Atlantic, 0·024 inch; and North Atlantic, 0·014. It thus appears that these amplitudes diminish as the ocean is more land-locked with continents.

In the open ocean the morning minimum of pressure is largest in equatorial regions, and it diminishes with latitude; but the rate of diminution with latitude, through anticyclonic and other regions, is generally less, and is more uniform than is the case with the afternoon minimum. Further, in high latitudes over the open sea, the diurnal barometric tide shows only one maximum and one minimum; and also in continental situations in high latitudes there occurs in summer only one maximum and one minimum, but the phases of their occurrence are the reverse of each other.

In middle and higher latitudes in summer, proximity to the sea, conspicuously so when the places are situated on the west coasts of continents and islands, delays the time of occurrence of the morning maximum and the afternoon minimum; whilst in continental situations the morning maximum occurs much earlier than in lower latitudes, and the afternoon minimum nearly as late as at places near the sea. But, as seen from the "Challenger" observations, these peculiarities of the curves do not occur over the open sea in the higher latitudes. The retardation of the time of occurrence of the morning maximum is greatest in situations which, while strongly insular in character, are at the same time on, or not far from, an extensive tract of land to eastward or south-eastward. A table was given showing, for fourteen stations, a gradual retardation of this phase of the diurnal pressure in June, from 7 A.M. at Culloden, to 11 A.M. at St Petersberg, and finally to 3 P.M. at Sitka.

As regards the land surfaces of the globe, the great range hitherto observed between the morning maximum and the afternoon minimum is nearly two-tenths of an inch in the arid climate of Jacobabad. At Aden, where the climate at all seasons is dry, it is 0·084 inch in January, whereas in August it amounts to 0·163 inch, or nearly double that of January, when the sun occupies a much lower place in the sky. On the other hand, at Bombay, during the dry season in January, the range is 0·119 inch, but during the wet season in July, though the sun's position is then nearly vertical, the range is only 0·067 inch.

The "Challenger" observations show that the atmosphere over the open sea rests on a floor or surface, subject to a diurnal range of temperature so small as to render the temperature practically constant both day and night, and also that the diurnal oscillations of the barometer occur over the open sea equally as over the land surfaces of the globe. This consideration leads to the all-important conclusion that the diurnal oscillations of the barometer are not caused by the heating and cooling of the earth's surface by solar and terrestrial radiation, and by the effects which follow these diurnal changes in the temperature of the surface, but are primarily caused by the direct heating by solar radiation, and cooling by nocturnal radiation of the molecules of the air and its aqueous vapour, and the dust particles suspended in it, these changes of temperature being instantaneously communicated through the whole mass of the atmosphere, from its lowermost stratum resting on the surface to the extreme limit of the atmosphere. The all-important bearing of these considerations of the theory of the diurnal oscillations of the barometer was explained at length.

The peculiarities of the diurnal barometric tides in deep valleys, and those at high-level observatories, such as Obirgipfel and Ben Nevis, were described and discussed.

During the cruise, observations of the force of the wind were made on 1202 days, at least twelve times each day, 650 of the days being on the open seas and 552 near land. As regards the open sea, the diurnal variation of the force of the wind is exceedingly small, the difference between the hour of least and greatest velocity being less than a mile per hour; and as the hours of occurrence of these very small maxima and minima vary with the different oceans, they cannot be regarded as true maxima and minima.

Quite different is it with the winds observed by the "Challenger" near land, the force of the wind there giving a curve as pronouncedly marked as the diurnal curves of temperature, pressure, or humidity. The minimum occurs from 2 to 4 A.M. and the maximum from noon to 4 P.M., the highest velocity being at 2 P.M. The curves from each of the five great oceans give one and the same result, viz., a curve closely congruent with that of the diurnal temperature. The differences between the hour of least and greatest velocity are these:—Southern Ocean, 6½ miles; South Pacific, 4½ miles; South Atlantic, 3½ miles; and North Atlantic and North Pacific, 3 miles per hour. Another point of considerable importance is that in no case does the maximum velocity, attained near land about or shortly after noon, reach the velocity of the wind on the open sea.

The diurnal variation in the amount of cloud is very small. There are, however, indicated two maxima, one about sunrise and the other early in the afternoon; and two minima, one at noon and the other from sunset to midnight, the differences not exceeding 6 per cent. of the whole sky. The observation of the diurnal occurrence of rain on the open sea is inversely as the temperature, 684 days' observations giving 96 cases in the seven hours, from 9 A.M. to 4 P.M., but 135 in the two hours from midnight to 2 A.M., these being respectively the times of minimum and maximum occurrence.

Of the forty-five thunderstorms recorded, 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., but during the remaining fourteen hours of the day only four were recorded. Hence, the important conclusion is arrived at, that over the open sea thunderstorms are essentially phenomena of the night, and occur mostly during the morning minimum of temperature and pressure, squalls reaching the daily maximum at the same time; the phases of the curve of distribution during the twenty-four hours being thus the reverse of what obtains over the land surfaces of the globe. On the other hand, the maximum in the diurnal curve of lightning over the open sea is closely coincident with the evening maximum of pressure. The phases of the diurnal curves of the electric phenomena are these:—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.

Monthly, Annual, and Recurring Phenomena.—The following among other tables have been published with the Report:—Table IV., showing the Mean Diurnal Variation of Atmospheric Pressure at 147 Stations; Table VI., the Mean Monthly Height of the Barometer at 1365 Stations; Tables VII. and VIII., the Mean Monthly Direction of the Prevailing Winds at 746 Stations; and Table IX., the Mean Monthly Temperature at 1620 Stations. The results of these data are represented on fifty-two large maps, giving for the months and the year the distribution over the globe of the temperature and pressure of the atmosphere, and the prevailing winds. These results were stated in some detail, from which the following broad conclusions were drawn:—This investigation shows 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 received from 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, rainfall, and in a very great degree the surface currents of the ocean, it is plain there is here a principle applicable not only 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.