PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Some Anomalies in the Winds of Northern India, and their Relation to the Distribution of Barometric Pressure

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XII. *Some Anomalies in the Winds of Northern India, and their Relation to the Distribution of Barometric Pressure.*

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[PLATES 19–21.]

IN the 13 years which have elapsed since Mr. BLANFORD published his paper on the Winds of Northern India,* very great additions have been made to our knowledge of the meteorology of the country. The carefully organised system of observations, commenced in Bengal and the North-Western Provinces, has been extended to include the whole of India, and placed under the direction of Mr. BLANFORD himself, aided by local officers in all the larger provinces. Verified instruments have been supplied to all the stations, and the elevations of these above sea-level have been determined by connecting them with the lines of spirit-levelling, carried inland from the coast, in various directions, by the officers of the Great Trigonometrical Survey; or, where this was impracticable, by spirit-levelling to some of the trigonometrical stations of the Survey. In this way, trustworthy and inter-comparable series of barometric observations, extending over ten years or more, have been obtained for all the more important stations. At the same time, the diurnal variations of the barometer at certain selected stations have been determined by long-continued series of hourly observations, with the object of enabling us to reduce the readings made in the ordinary way (usually at 10 A.M. and 4 P.M.) to true daily means. Simultaneously with the collection of this immense quantity of accurate and reliable barometric data, observations have been made of temperature, humidity, cloud, wind, and rain. Latterly also barometric and wind charts of the Bay of Bengal have been prepared from observations made on board ships navigating those waters.

During these 13 years, the winds prevailing over the Indian continent and the Bay of Bengal, and their relations to the distribution of pressure at sea-level, have

* "The Winds of Northern India," by HENRY F. BLANFORD, F.G.S.; 'Phil. Trans.,' vol. 164, 1874, Part II.

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been discussed from time to time, both in their normal aspects for each month or season and in their abnormal or disturbed conditions during the passage of storms. The latter conditions in particular have been very fully described by Mr. ELIOT in his numerous reports on cyclones in the Bay of Bengal, while the former have been noticed in the annual reports on the meteorology of India, in occasional papers appearing in the 'Indian Meteorological Memoirs,'* and latterly in a broad and general review in Mr. BLANFORD's great monograph on the Rainfall of India.†

There still remain several points, however, in connection with the winds of Northern and Central India, with regard to which our knowledge is very far from complete,—points in which the relation of wind direction and intensity to the distribution of pressure, as given by observation, is more or less directly opposed to what we should expect from theory; and the object of this paper is to try to find a key to the solution of such anomalies.

The chief anomalies to which I refer are the following:—

(1) The direction of the wind in the hot season, on the plains of Northern India, has often no relation to the baric gradient; instances not infrequently occurring in which the wind appears to blow directly in opposition to the gradient, *i.e.*, from a place of low pressure to one where the barometer stands higher.

(2) Over the plains of Northern India, the average velocity of the wind has little or no apparent relation to the pressure gradient, but a very obvious one to the temperature; being, on the whole, greatest when the temperature is highest; while, at this season, the local pressure gradients are extremely small.

(3) Mr. BLANFORD has shown ‡ that it is highly probable there is some connection of the nature of cause and effect between copious and late snowfall (producing low temperature) on the Himalayan ranges and the subsequent prevalence of dry winds from the north-west over northern and western India. On the strength of this relation he has for several years based forecasts of the character of the coming rainy monsoon, which have on the whole been amply verified. The anomaly here is that a low temperature to the north of India, producing high pressure, at sea-level, under the sub-Himalayan stations, gives rise to unusually strong westerly winds, whereas, according to the law usually quoted as "BUYS BALLOT's," which has been clearly deduced from the hydrodynamical principles by FERREL, COLDING, and others, such high pressure should give rise to easterly winds; the rule being that the highest pressure lies in the northern hemisphere to the right of a person travelling with the wind.

These three anomalous relations will be here discussed in the order mentioned.

* "On the Winds of Calcutta," by H. F. BLANFORD, 'Indian Meteorological Memoirs,' vol. 1, page 1; "The Winds of Kurrachee," by FRED. CHAMBERS, *ibid.*, page 249; "The Meteorology of the North-West Himálaya," by S. A. HILL, *ibid.*, page 377.

† 'Indian Meteorological Memoirs,' vol. 3.

‡ 'Indian Meteorological Memoirs,' vol. 3, Part II., and 'Proceedings of the Royal Society,' vol. 37, 1884.

Part I.—The Wind Direction Anomaly.

The hot winds of the Indian plains have been often described by travellers and writers on Meteorology, but the existence of such a condition as that mentioned above, viz., their blowing directly against the baric gradient, has been doubted by competent authorities, or at all events suspected to be only an erroneous deduction from a comparison of monthly mean pressures with the resultant wind directions. The daily weather telegraphic reports of the last few years, however, leave no room to doubt that, almost every year, there are several days in April, May, or June when this *primâ facie* impossible condition obtains over a large extent of country at 10 A.M., while, from the known character of the diurnal variations of pressure and wind direction, we may safely infer that the condition is much more frequent and more distinctly marked in the early hours of the afternoon, the diurnal fall of the barometer increasing slightly as we advance inland from Bengal, and the wind direction being steadiest from the north-west about 2 P.M.*

The following examples, selected from the 10 A.M. telegraphic reports, will prove the existence of this paradoxical condition of atmospheric circulation. The stations are enumerated in order from west to east, the general direction of the lines joining them being about W.N.W. to E.S.E. The pressures are reduced to sea-level.

TABLE I.—Instances of Wind blowing in opposition to Baric Gradient.

May 17, 1882.

Station.	Barometric pressure.	Wind direction.
	Inches.	
Meerut	29·753	NW.
Bareilly	29·758	NW.
Lucknow	29·759	W.
Gorakhpur	29·785	WNW.

May 9, 1883.

Station.	Barometric pressure.	Wind direction.
	Inches.	
Meerut	29·581	NW.
Bareilly	29·597	NW.
Lucknow	29·631	WNW.

* 'Indian Meteorological Memoirs,' vol. 1, page 353, and Plate XXX.

May 15, 1884.

Station.	Barometric pressure.	Wind direction.
	Inches.	
Roorkee	29·511	NW.
Meerut	29·545	NW.
Bareilly	29·561	NW.
Lucknow	29·560	SW.
Allahabad	29·577	NW.

May 29, 1884.

Station.	Barometric pressure.	Wind direction.
	Inches.	
Roorkee	29·466	Calm.
Meerut	29·485	NW.
Bareilly	29·484	SW.
Lucknow	29·497	W.
Allahabad	29·520	NW.

May 24, 1885.

Station.	Barometric pressure.	Wind direction.
	Inches.	
Bareilly	29·825	NNW.
Lucknow	29·845	NW.
Allahabad	29·842	NW.

May 27, 1885.

Station.	Barometric pressure.	Wind direction.
	Inches.	
Bareilly	29·766	NW.
Lucknow	29·793	NW.
Allahabad	29·805	NW.

May 20, 1886.

Station.	Barometric pressure.	Wind direction.
	Inches.	
Bareilly	29·802	SW.
Lucknow	29·829	WNW.
Gorakhpur	29·833	Calm.

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These instances abundantly prove the frequent occurrence of the condition described —the wind blowing from a place of low pressure to one where the pressure is slightly higher; but it may be objected that the places enumerated probably happen to lie nearly on an isobaric line, while the wind blows almost parallel to it, so that, if the slight disturbances of the true wind direction due to local causes were eliminated, there would be no anomaly to explain. The answer to this is that, at the season under consideration, the stations enumerated lie near the middle of a very large area of uniform low pressure (see Plate 19), while the winds are the strongest and steadiest of the year. It may be added, also, that near the equator the wind does not blow parallel to the isobars, even over the sea, but makes an angle of two or three points with them; whilst at inland stations, where the friction coefficient is greater, the angle must be still greater, as FERREL has pointed out in his works on the movements of the atmosphere. The charts prepared from the daily telegraphic weather reports for India show an average angle of something like 45° between the wind directions and the isobars. The characteristic winds of the hot season, therefore, do really blow sometimes in opposition to the pressure gradient, and the cause which sets them in motion must be sought somewhere else than in differences of pressure at sea-level, or rather at the level of the plain over which they blow.

Since, in these winds, the air-particles are not urged from west to east by any considerable difference of pressure at the ground-level, whilst they are retarded by friction, and sometimes even by an increasing pressure, as they go eastwards, their velocity must be gradually diminished as they approach the Bay of Bengal. This fact is familiarly known to residents on the plains of the Ganges. The "hot winds," which are excessively dry as well as hot—and which, therefore, serve very effectually to refrigerate the interiors of dwelling-houses by blowing through wet *tatties*, or screens of fragrant grass, placed in the door and window openings on the windward side—seldom extend as far eastwards as Monghyr, in Behar,* and their extinction takes place very gradually. It is a matter of extreme difficulty to obtain truly comparable observations of wind velocity, owing in part to slight differences in the anemometers, but chiefly to the impossibility of ensuring uniform conditions of exposure; but the following sets of stations, where the surroundings are as nearly alike as possible, show clearly a gradually diminishing velocity as we go eastwards during the hot weather, while, at other seasons there is, in some cases, a tendency for the velocity to increase as we approach the sea. The figures are taken from the Report on the Meteorology of India for 1884. They represent the averages of many years.

* For a short time at the hottest hours of the day westerly winds are felt in Bengal, and even in Assam, but they do not possess the dryness and gusty character of the winds under discussion, though when they blow they are probably due to similar causes.

TABLE II.—Comparison of Mean Wind Velocities at Places on Lines running W.N.W. to E.S.E.

Station.	Wind velocity in miles per diem.			
	January.	May.	July.	October.
Jeypore	92	181	154	92
Agra	82	144	121	72
Benares	68	119	111	61
Patna	50	113	87	47
Neemuch	168	298	284	175
Sutna	94	194	223	103
Hazaribagh	114	208	204	120
Malegaon	96	257	286	111
Akola	81	206	200	78
Raipur	58	171	275	87

The only instance in the Table, where the velocity during May increases in going eastwards, is between Sutna and Hazaribagh. The latter station is, however, the higher by nearly 1000 feet, but, being situated on a broad plateau, not an isolated peak, this would probably not make much difference. At Hazaribagh, however, we are on the border of the region over which these hot westerly winds prevail, the excess of observations in the direction of the westerly resultant being, in May, only 15 per cent., and the increase of velocity at that station is probably the effect of the frequent incursion of sea winds from the south-east.

A suggestion regarding the origin of these hot winds may be derived from their excessive dryness, above referred to; in fact, it was from this circumstance that I was first led to think of the key to their explanation, which I believe will be found in the following pages. This dryness is such that the relative humidity of the air over the Bundelkhand plateau, south of the Ganges, frequently falls in the middle of the afternoon to 5 per cent. or less. Indeed, the humidity deduced by the usual Tables, (founded on AUGUST's formula with REGNAULT's constants) is occasionally zero or apparently negative.* On the Gangetic plain it never falls quite so low, but in all

* It must be recollected that the formula is founded on the convection theory of the psychrometer. The quantity to be deducted from the tabular pressure of saturated vapour, at the temperature of the wet bulb, in order to get the vapour-pressure actually present, is $\frac{s/d\ (t-t')\ h}{L}$. The true value of the factor s/d, specific heat of air divided by relative density of vapour, is about ·38, but, to suit the formula to the usual condition of nearly still air, REGNAULT empirically increased it to ·48. Hence, during a high wind, the quantity to be deducted is too great when REGNAULT's formula is employed, and if the actual humidity be very low the result may come out negative.

the drier months of the year there is a decided diminution of vapour pressure at the hottest hours of the day, when west winds, similar to, or identical with, the "hot winds," are blowing. The following hourly values of the pressure of vapour at Allahabad will illustrate this. They are taken, with some corrections derived from subsequent observations, from a paper on the "Results of Meteorological Observations at Allahabad," published in 1881 in the first volume of the 'Indian Meteorological Memoirs.'

TABLE III.—Diurnal Variation of the Pressure of Vapour at Allahabad.

Month.	Mid-night.	2 h.	4 h.	6 h.	8 h.	10 h.	12 h.	14 h.	16 h.	18 h.	20 h.	22 h.
	″	″	″	″	″	″	″	″	″	″	″	″
January . .	·342	·334	·325	·313	·326	·355	·369	·366	·372	·384	·369	·352
May	580	·585	·588	·617	·621	·590	·557	·527	·515	·534	·552	·575
July	·928	·925	·923	·919	·943	·955	·958	·964	·956	·949	·940	·935
October . .	·656	·650	·648	·655	·683	·672	·652	·646	·654	·671	·666	·662

It will be seen that, whereas, in the month of July, the quantity of vapour in the air increases, with slight irregularities, as the temperature rises from 6 A.M. up to 2 P.M., and diminishes again steadily as the temperature falls after 2 P.M., this regular march is interrupted in the other months by a fall in the middle of the day. The fall is very slight in January, but considerable in October, making the afternoon minimum in that month slightly lower than that of the early morning. In May, however, and in the other dry hot months, the afternoon fall so completely masks the variation due to the diurnal changes of temperature, as seen in July, that the morning minimum is altogether obliterated.

Whence comes this excessive dryness in the afternoons, which is not merely a decrease of *relative* humidity, due to rise of temperature, but a diminution of the absolute quantity of vapour in the air near the ground, from an average pressure of 621 inch in May, at 8 o'clock in the morning, to ·515 inch at 4 in the afternoon? It may be caused by the wind coming from drier regions to the north-westward; but this can hardly be the true cause, for in May there is very little decrease in the mean pressure of vapour as we go north-westwards over the Gangetic plain, and there is still less in April. For example, we have for three selected stations on the plain of the Ganges, arranged in order from SE. to NW., the following values for the mean pressure of vapour.

	Allahabad.	Lucknow.	Bareilly.
	″	″	″
April	·414	·431	·421
May	·553	·565	·549

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On the plateau to the south-west of the Jumna, where the hot winds are even stronger and more persistent than over the great plain, there is a positive increase of vapour in the westward direction in the air stratum with which our observations deal. Thus we have the following mean values for May :—

Sutna.	Jhansi.	Jeypore.
·367″	·448″	·459″

The dryness characteristic of the hot winds cannot, therefore, be due to the eastward transference of air near the ground surface from the arid region of the Rajputana desert; for, if this were the cause, we should find a gradual decrease of moisture on going north-westwards, instead of which we find an increase.

Taking the variation of humidity in the lower atmospheric strata in conjunction with the diurnal variation of cloud, which, as I have shown in the paper last quoted, attains its maximum about the time of highest temperature, as it does in most parts of the world, the idea of an interchange between the upper and lower strata by local convection currents is at once suggested. The westerly winds of the hot weather are so dry, perhaps because they descend from regions where the proportion of water vapour in the air is normally much less than at sea-level. The diurnal interchange between the lower atmospheric strata and those lying considerably higher was first suggested by Dr. KÖPPEN,* to explain the daily inequalities of wind direction and velocity—inequalities which are opposite in phase over plains and on high mountain peaks. In the sequel it will be shown that it probably suffices to clear up all the anomalies observed in the wind system of India. The explanation of the dryness of these winds by the descent of air from a higher stratum was previously suggested by MÜHRY, in a passage† quoted by BLANFORD at p. 614 of his paper on the "Winds of Northern India"; but this was under the mistaken notion of an aërial cascade pouring over the edge of the Himalaya from the elevated plains of Thibet, a notion which is quite inconsistent with the facts of observation.

A general idea of the average relations of pressure and wind direction over the Indian area will be obtained from Plate 19, on which have been charted the mean isobaric lines and the resultant wind directions at the more important observing stations, for the months of January, May, July, and October, typical respectively of the cold, the hot, and the rainy season, and the autumn transition period. The pressures used in drawing the charts are the means for ten years, published in the Report on the Meteorology of India for 1884. They have been reduced to sea-level

* 'Zeitschrift der Oesterreichischen Gesellschaft für Meteorologie,' vol. 14, 1879, p. 333. KÖPPEN's hypothesis has also been suggested by BLANFORD (*loc. cit.*) to account for the hot winds, and he adduces their dryness as a reason for believing it to be the true explanation.

† 'Untersuchungen über die Theorie und das allgemeine Geographische System der Winde,' p. 99.

and to the value of gravity at latitude 45°. The isobars have been extended across the Bay of Bengal by means of observations extracted from ships' logs, recently reduced and tabulated in the Bengal Meteorological Office. The charts given in Plate 19 are, therefore, identical with those for the same months attached to Mr. BLANFORD'S paper on the Rainfall of India,* except that the observations of one or two stations which seemed to me of doubtful validity have been rejected.

On the chart for January, the resultant wind directions, on the whole, conform to the distribution of pressure in accordance with BUYS BALLOT'S law, but there are some exceptions. For example, at Neemuch, in Southern Rajputana, south-westerly winds prevail where the law would indicate an excess of easterly components. The chief exception is in Northern Bengal, where the winds should be easterly or south-easterly according to the law, whereas there is a decided prevalence of north-westerly winds as far as Chittagong.

Elsewhere, except on the west coast, where the sea-breezes prevent observations, made only in the day time,† from giving the true resultant direction, the prevailing wind agrees closely with that given by the law; when it is borne in mind that, near the Equator, the angle between the wind direction and the isobars is larger than in higher latitudes.

In May, while there is close conformity to the law in Southern India, and near the coast generally, there is no apparent relation whatever between pressure distribution and wind direction over the very large area north of the parallel of 20° and west of the meridian of 86°. The greater portion of this area is enclosed by the very peculiarly curved isobar of 29·60″, within which are two distinct areas where the pressure is below 29·55″. One of these occupies the upper valley of the Mahanadi, in the eastern part of the Central Provinces, and the other and larger is in Upper Sindh and the Bikanir desert. Over these areas bounded by closed curves, and across the axis of low pressure connecting them, as well as across the isobar of 29·60″ which runs along the southern face of the Himalaya, the westerly winds blow without interruption as far as Behar and Chutia Nagpur, and, at a higher level, as far as Darjiling; whilst the easterly winds, which should prevail, according to the law, at all stations north of the low pressure axis, are only felt along the base of the Himalaya up to Gorakhpur. These west winds have a southerly component in the Indus Valley and Western Rajputana, as well as at most of the Himalayan stations of 6000 or 7000 feet elevation, whilst, over the rest of the region, they have usually a northerly component; but a glance at the chart for May will show that they are probably all stream lines of one continuous atmospheric flow.

The chart for July shows that the pressure gradients over the whole of India and the Bay are much steeper than in the other months, while the usual relation between the direction of the wind and the isobars holds good over nearly every part of the

* 'Indian Meteorological Memoirs,' vol. 3.

† At most stations the observations are made only at 10 A.M. and 4 P.M.

country, the most important exceptions being at Agra, Jeypore, and Multan, where the winds have a northerly component, whereas a southerly one is indicated by the distribution of pressure. At the Himalayan stations on the outermost range, as at Darjiling, Naini Tal, and Mussoorie, there is usually an easterly component in the resultant wind ; while at others, more in the interior, as at Ranikhet, Chakrata, Murree, and Leh, the resultant is westerly.

In October the pressure differences are very small, and the winds as a rule are light and irregular. The resultant directions, however, conform in most places to Buys Ballot's law; but the anticyclonic circulation of the air over South-eastern Rajputana and Central India States is apparently more regular and uniform than might be expected from the irregularly-shaped isobar of 29·85″.

Over Bengal also, from the Himalayas to the head of the Bay, the wind blows almost exactly at right angles to the isobars, instead of more or less inclined to them.

From the charts on Plate 19 it will, therefore, be seen that, when the air is moist, the sky cloudy, and the diurnal range of temperature small, the usual relation obtains between the distribution of pressure and the resultant direction of the wind. These conditions obtain over most parts of the country in July, and at many of the coast stations in the other months.

In January there are exceptions to the rule, the most important being in Bengal, which, at that season, is a region of moderately high temperature, clear skies, and a large daily range of the thermometer.

This will be evident from the following Table, in which certain meteorological conditions for January and July at several Bengal stations are contrasted :—

Table IV.—Contrast of Bengal Climates in January and July.

Station.	January.			July.		
	Mean Temperature.	Daily Range.	Cloud Proportion.	Mean Temperature.	Daily Range.	Cloud Proportion.
	°	°		°	°	
Purneah	61·9	27·9	1·2	84·0	12·9	7·1
Berhampur	64·5	25·3	2·2	83·2	10·7	8·8
Burdwan	66·0	24·4	1·7	83·5	10·9	8·1
Jessore	65·1	26·1	1·6	82·5	10·7	8·3
Dacca	66·6	22·9	1·6	83·7	9·5	8·0
Calcutta	67·3	22·4	1·3	83·1	9·6	8·0
Chittagong	66·6	21·0	1·3	80·7	9·3	7·4

The skies in this region are usually almost cloudless in January, and the daily range of temperature is between 20 and 30 degrees; while in July the average cloud proportion is high, and the daily range of the thermometer only about 10 degrees. The disturbances of thermal equilibrium by the daily transit of the sun must, therefore, presumably be nearly three times as great in January as in July, and if the distribution of pressure, at high levels, be different from that observed near the ground surface, we may, on KÖPPEN'S theory, expect to find in January a greater departure of the actual wind direction, from that given by the usual law, than we find in July.

On the Upper Gangetic plains, and in the Punjab, the range of temperature in January is quite as high as in Bengal, though the skies are somewhat more cloudy. We do not there, however, find departures from BUYS BALLOT'S law to occur so frequently in this month; probably because the disturbances of thermal equilibrium, causing convection currents, are less intense. For this there are two reasons. In the first place, whilst the diurnal range of the thermometer is but little greater on the plains than it is in Bengal, the range at the nearest hill stations is considerably greater than at Darjiling, so that the difference between high and low stations, at the hottest hour of the day, is not so considerable in North-western India as it is for the same difference of altitude in Bengal. Again, the temperature probably diminishes less rapidly with height at the North-western stations during January than it does in Bengal. Putting these two causes together, the effect is that the rate of upward decrease of temperature in the North-west is not by any means so rapid at the hottest time of the day as it is in Bengal. In the following Table, three pairs of stations are compared, so as to show the diurnal variation of the rate of temperature decrement with height during the month of January.

TABLE V.—Temperature Decrements at different times of the day during January.

	Darjiling—Goalpara.* 6555 Feet.	Chakrata—Roorkee. 6165 Feet.	Murree—Rawal Pindee. 4692 Feet.
	°	°	°
Difference of Means	21·5	13·4	8·4
Rate per 1000 feet	3·3	2·2	1·8
Difference of Maxima . . .	29·5	19·2	15·2
Rate per 1000 feet	4·5	3·1	3·2
Difference of Minima . . .	13·5	7·6	1·6
Rate per 1000 feet	2·0	1·2	0·4

The vertical decrement of temperature in North Bengal at the hottest time of the day is, therefore, 43 per cent. more rapid than at north-western stations, namely, 4·5° F. per 1000 feet, instead of 3·1° or 3·2°, according to the Table. These rates of decrement are not those which actually obtain in the free atmosphere, since they include a certain variation with latitude; and, moreover, there is reason to believe that, on mountain slopes, the decrease is considerably less rapid than that given by balloon ascents. The ratio between the rates for the two regions compared is, how-

* This column is derived from BLANFORD'S 'Indian Meteorologist's Vade Mecum,' page 57. The others are from my paper on the Temperature of North-Western India, 'Indian Meteorological Memoirs,' vol. 2.

ever, probably nearly correct, since the disturbing circumstances are similar; and this ratio shows that the diurnal convection currents, which tend to mix together atmospheric strata belonging to different altitudes, must be more active during the month of January in North Bengal than they are in the upper parts of the great plain—a relation which it is necessary to prove in order that the observed deviations of the resultant winds from their theoretical directions, in the two regions compared, may be explicable by KÖPPEN's hypothesis.

The following considerations will enable us to discuss this point a little more fully. At page 236 of his valuable work on the Meteorology of the Bombay Presidency, Mr. C. CHAMBERS, F.R.S., has shown that rapid convective movements of the atmosphere, of the kind he calls "topsy-turvy," probably extend in the day time up to the level at which the temperature is the same as that given by the law of convective equilibrium, which may be proved from thermodynamical principles to be, for dry air, a decrease of 1° F. in 183 feet. There is no reason, however, to believe that all interchange between successive layers ceases at this level, for the molecular theory of gases indicates that the ultimate distribution of temperature would be uniform in a vertical column of the atmosphere free from all disturbing causes.

It is difficult to estimate, with any exactitude, the height to which such rapid convective movements here extend, for we do not know the rate of temperature decrement in the open air over the plains of India; all our observations at high levels having been made at mountain stations, where the temperature, at least in the day time, is higher than it would be in the free atmosphere. The results of GLAISHER's balloon observations may help us, however, to obtain some idea of this height. When slightly smoothed, they may be thrown into the form of Table VI., which gives a rapid decrement of temperature in the first 2000 feet, especially with clear sky.

TABLE VI.—Rates of Temperature Decrement from GLAISHER's Observations :—

Height.	Clear sky.	Cloudy sky.
Sea-level to 1,000 feet	° 6·2	° 4·5
1000 „ 2,000 „	4·7	3·8
2000 „ 3,000 „	3·8	3·5
3000 „ 4,000 „	3·3	3·3
4000 „ 5,000 „	3·0	3·1
5000 „ 6,000 „	2·8	3·0
6000 „ 7,000 „	2·6	2·8
7000 „ 8,000 „	2·6	2·6
8000 „ 9,000 „	2·5	2·4
9000 „ 10,000 „	2·4	2·2
Sea-level to 10,000 „	33·9	31·2

This Table is represented graphically on Plate 21, which also shows the line of uniform decrement under the law of adiabatic convection. It will be seen that, according to the principles above discussed, the topsy-turvy movements extend, when the sky is clear, to an average height (in summer in England) of about 2100 feet, whilst in cloudy weather they can hardly take place at all. In India there is, in all probability, a still more rapid decrement of temperature near the ground, when the sky is free from cloud. From four years' observations made at Alipore, near Calcutta,* I find that at the hottest time of the day, about 2 P.M. during the months of greatest serenity, the temperature decreases 1·4° F. between 4 and 40 feet above the ground, or at the rate of 38·9° per 1000 feet. This we may take to be the most probable initial rate of decrease for clear weather. In the cloudy weather of July the rate is only 27·8° per 1000 feet, or 1·0° between 4 and 40 feet. Both these are very much greater than the initial rates given by GLAISHER's observations for England; which, by drawing tangents at the starting point of the curves on Plate 21, or differentiating the formulæ representing them, are found to be 7·7° and 5·2° per 1000 feet respectively; and we may infer that convective action is consequently much more energetic in India. Whilst observations made at mountain stations thus give rates of decrement which are probably different from those obtaining in the free atmosphere, at all events for the layers of the atmosphere nearest the ground, we may still, however, get an idea of the *relative* intensities of diurnal convection currents over different parts of the Indian plain by a comparison like that made in Table V.

On the Central Indian plateau, and in South Rajputana and Sindh, where there is usually but little cloud in January, and the range of temperature is very great, such convection movements doubtless take place much more frequently, and extend to a greater height than they do in the Punjab and North-Western Provinces. To the interchange thus effected may probably be attributed the anomalous wind direction observed at Neemuch.

During the hot weather, vertical convection currents are extremely active over Northern and Central India, as testified by the constant occurrence of dust-whirls, familiarly known as "devils," as well as by the frequent piling up of cumulus clouds in the afternoons and the occasional occurrence of thunderstorms. Another evidence of such action is the gradual charging of the air with dust up to a height of 8000 feet or more; so that, just before the rains set in, it may be likened in appearance to muddy water or pea-soup. At this season, the mean temperature of the 24 hours decreases rapidly on ascending; the mean rates on mountain slopes, when variations in latitude and longitude are eliminated, being the following † in the month of May :—

* 'Indian Meteorological Memoirs,' vol. 2, page 450 *et seq.*

† See 'Indian Meteorological Memoirs,' vol. 2, pages 132 to 136.

	North-Western Himalaya.	Central India and Rajputana.
	°	°
Sea-level to 1000 feet . . .	4·11	2·84
1000 „ 2000 „ . . .	3·96	3·25
2000 „ 3000 „ . . .	3·79	3·66
3000 „ 4000 „ . . .	3·61	4·06

When allowance is made for the decrease of diurnal range on ascending, these rates become, for the maxima—

	North-Western Himalaya.	Central India and Rajputana.
	°	°
Sea-level to 1000 feet . . .	6·5	6·2
1000 „ 2000 „ . . .	5·0	6·1
2000 „ 3000 „ . . .	4·0	6·0
3000 „ 4000 „ . . .	3·5	5·8

Such very rapid rates for Central India are partly confirmed by observations made during the present year (1886) in a tower at Allahabad, which for April and May give initial rates of decrement of 40° and 37·5° per thousand feet respectively at the time of diurnal maximum.

According to the law of decrement deduced from the last Table, the topsy-turvy movements described by CHAMBERS would, at the hottest time of the day, ascend the slopes of the North-Western Himalaya to an elevation of some 2600 feet; while, over the mountain tops of Central India and Rajputana, they would rise to above 11,000 feet, if the same law of temperature decrement held good.*

The heights thus computed, of course, have no pretension to exactness; in fact, the former is undoubtedly too low, for the temperature decreases much less rapidly on a broad mountain zone heated by the sun than it does in the free atmosphere. They suffice, however, to show that about midday, in the hot season, convective currents are very active up to an altitude of several thousand feet over the drier part of Northern and Central India. It is probable, therefore, that the wind direction anomalies, which are so striking at this season, may be explained by the descent, from a considerable height, of atmospheric strata which retain, for a time, the velocity acquired by them under the pressure differences prevailing at the level from which they descend.

* The temperature of the Himalayan slope may be represented by the formula $t = T - 7·5\,h + 1·0\,h^2 - 0·08\,h^3$, while according to the ultimate law of convection $t = T - 5·46\,h$; T being the sea-level temperature and h the height expressed in thousands of feet. Equating these, we get $h = 2560$ feet. For Central India and Rajputana, the formula best expressing the results in the Table is $t = T - 6·3\,h + 0·1\,h^2$, from which we find the height, where the temperature would be the same as that given by the law of convective equilibrium, to be 11,330 feet.

In Northern Bengal and Assam, at this season, the decrease of maximum temperature with height is so slow in the first three or four thousand feet, that no rapid convective action during sunshine can take place. The observations at Goalpara, 286 feet, and Darbhanga, 166 feet; at Shillong, 4794 feet, and Kathmandu, 4388 feet; and at Darjiling, 7421 feet,* give a combination from which variations in latitude and longitude are almost completely eliminated, and from the maximum temperatures of these places in May we get the following rates of decrement :—

	°
Sea-level to 1000 feet	3·0
1000 „ 2000 „	3·3
2000 „ 3000 „	3·6
3000 „ 4000 „	3·9
4000 „ 5000 „	4·2
5000 „ 6000 „	4·5

These are so much slower than those for North-Western and Central India, that there is, comparatively speaking, no disturbance of the kind above discussed, and accordingly we find that the anomalous hot winds do not usually penetrate into Bengal, or become greatly modified in character by mixing with the lower atmospheric strata, if they do.

During the earlier part of October, south-west monsoon conditions prevail over Bengal, and the wind directions are those given by the local pressure gradients; but, towards the end of the month, convection currents, induced by the high range of temperature, become active, the day winds at the same time backing from east to north and north-west, thus causing the resultant for the month to be almost due north. In Central and North-Western India, where this month is characterised by clear skies and a large temperature range, there is probably a good deal of convective action, as may also be inferred from the afternoon fall of vapour-pressure in this month (see Table III.).

In this region, the mean temperature in October decreases with height above sea-level at the following rates :—

	°
Sea-level to 1000 feet	3·91
1000 „ 2000 „	3·69
2000 „ 3000 „	3·47
3000 „ 4000 „	3·25

When these are corrected for the diminution of daily range, which is extremely rapid—the decrease, for example, between 1500 feet (the Rajputana plain) and 4000 feet (Mount Abu) being from about 30° to 15°—the figures become for the daily maxima :—

* Formerly 6941 feet, but the observatory was removed to a new site in 1882.

Sea-level to 1000 feet	6°·9
1000 „ 2000 „	6·6
2000 „ 3000 „	6·3
3000 „ 4000 „	6·0

In this region, therefore, we should expect the convective action to be even more energetic after the close of the rainy season than in the dry hot weather, though the rate of decrement falls off so rapidly that probably the action does not extend to so great a height.

If, therefore, we find, as we do, that the wind directions in October conform more closely than in May to the normal directions inferred from the distribution of pressure at sea-level, it is probably because there is less difference in the distribution of pressure at low and high levels in October than in May.* This will be investigated in the next section.

Part II.—The Velocity Anomaly.

In no part of the world is the diurnal variation of the wind velocity better marked than on the plains of Northern India. In the rainy season there is more or less wind both night and day, though the velocity at night is, as a rule, considerably less than in the day time; but during the dry season, from October to May, the nights are almost always perfectly calm, the only occasions when there is any wind at night occurring during the showery weather sometimes observed in January or February, and in occasional evening dust storms towards the end of the dry hot weather. At night, as the observations made at Alipore prove, the temperature increases for some distance with height above the ground, and under ordinary circumstances, therefore, there can be no convective interchange between upper and lower atmospheric strata. The diagrams on Plate 29 of the second volume of the 'Indian Meteorological Memoirs' show that from about 6.30 P.M. to 8.15 A.M., on the average of the year, the temperature increases with height. Between these hours, therefore, the wind movement is that due to the local pressure gradients at sea-level, whilst in the day-time, when convection takes place, the velocity is greater, owing to the descent of air from regions where the retardation by friction is much less than near the ground. This diurnal variation may be illustrated by the results of the Calcutta anemograms published at p. 23 of the first volume of the 'Indian Meteorological Memoirs,' and by three-hourly readings of a common anemometer made at Agra on four days each month for eight years, both of which are given in Table VII. For the last few years, valuable anemographic traces

* Another reason is that this rapid diminution of temperature in October obtains only during a short time each day. The temperature on the plains rises and falls so rapidly that, as will be shown in the next section, the mean rate of decrement during the six hours from 10 A.M. to 4 P.M. is only about half as great as that at the hottest time of the day.

have been obtained from three stations in Upper India—Jeypore, Roorkee, and Lucknow—but they have not been discussed yet.

TABLE VII.—DIURNAL VARIATION OF WIND VELOCITY.

Hours.	Calcutta.	Agra.
	Miles per hour.	Miles per hour.
Midnight to 3 hours.	3·28	2·87
3 ,, 6 ,,	2·96	3·33
6 ,, 9 ,,	4·51	4·25
9 ,, 12 ,,	6·12	5·71
12 ,, 15 ,,	6·55	6·82
15 ,, 18 ,,	5·65	5·19
18 ,, 21 ,,	4·36	3·49
21 ,, 24 ,,	3·87	2·95
Mean	4·69	4·33

The figures in the Table represent annual means. They prove that the velocity attains its maximum about the hottest time of the day, and its minimum about midnight at Agra and 4 A.M. at Calcutta: the exact instants of the turning points, found by taking differences, being 3 h. 31 m. and 12 h. 58 m. at Calcutta, and 0 h. 27 m. and 13 h. 13 m. at Agra. The anemograms for several years at Karachi have been discussed by Mr. F. CHAMBERS and published in vol. 1. of the 'Meteorological Memoirs,' but, as this station is on the sea-coast, where there is little frictional retardation, the hourly means do not exhibit anything like such a large variation in proportion to the mean velocity, which, at that station, is nearly 17 miles per hour. The extreme hourly distances traversed are 14·4 miles between $5\frac{1}{2}$ h. and $6\frac{1}{2}$ h., and 20·9 miles between $14\frac{1}{2}$ h. and $15\frac{1}{2}$ h.

At all the stations in North India, for which the hourly variations of the wind resultants have been computed* a double diurnal oscillation, related to that of barometric pressure, has been more or less distinctly observed; but the amplitude of this double oscillation, which may be taken to depend on the diurnal variation of pressure differences near sea-level, is extremely small in comparison with that of the single oscillation due to diurnal heating of the ground and consequent convective action. We have already seen that, in the month of May, the pressure differences over the upper Gangetic plains are often evanescent; and it will be shown below that, in this region, the differences of the mean pressures are very small at all times of the year. It must frequently happen, therefore, that any east and west pressure gradient, which may exist, is due solely to the difference in phase of the diurnal variation owing to difference of longitude; the epochs of maximum and minimum, and the range of this variation being very nearly constant through many degrees of longitude. Thus, taking two points 15 degrees apart on the parallel of Allahabad, we should find the

* 'Indian Meteorological Memoirs,' vol. 1 (Papers 1, 9, and 10).

following pressure differences on days in May when the mean pressures at sea-level are alike :—

TABLE VIII.—Pressure Differences in May dependent on Diurnal Variation only.

Hour.	Difference in 15 deg.	Hour.	Difference in 15 deg.	Hour.	Difference in 15 deg.	Hour.	Difference in 15 deg.
0 to 1	+ ·0112	6 to 7	− ·0153	12 to 13	+ ·0246	18 to 19	− ·0133
1 „ 2	+ ·0069	7 „ 8	− ·0103	13 „ 14	+ ·0275	19 „ 20	− ·0193
2 „ 3	− ·0030	8 „ 9	− ·0051	14 „ 15	+ ·0248	20 „ 21	− ·0191
3 „ 4	− ·0130	9 „ 10	+ ·0009	15 „ 16	+ ·0176	21 „ 22	− ·0127
4 „ 5	− ·0190	10 „ 11	+ ·0088	16 „ 17	+ ·0074	22 „ 23	− ·0020
5 „ 6	− ·0190	11 „ 12	+ ·0173	17 „ 18	− ·0036	23 „ 24	+ ·0077

These differences, which are taken from the 'Indian Meteorological Memoirs,' vol. 1, page 326, would produce N.W. winds, indicated by the positive sign, from about 9 h. 21 m. to 17 h. 7 m., and again from 22 h. 42 m. to 2 h. 12 m., the remaining hours having gradients for S.E. winds, indicated by the negative sign. Now, from the paper last referred to, we learn that, in the hot season, the resultant wind at Allahabad blows at all hours from points between S. 73° W. and N. 5° W., the double oscillation suggested by the Table being combined with and masked by a prevalent N.W. direction, though it is plainly indicated in the diagram formed by joining the ends of the lines representing the resultants for the several hours. The differences in the Table, in fact, are so small, not exceeding ·0275-inch in about 813 geographical miles, or ·002-inch per degree of the earth's surface, that near the ground, where the friction coefficient is large, the winds due to them would be so light as to be almost imperceptible; and, accordingly, we find that the double gyration of the wind vane, which would be produced by this cause, is almost entirely hidden by the influence of the more powerful currents of the higher atmosphere which descend in the middle of the day. The N.W. winds due to the diurnal inequality of pressure are, however, probably more than twice as strong in the afternoons as in the early mornings, the maximum pressure differences being in the ratio of 275 to 112, so that this cause combines with convective interchange between the lower and higher strata to make the velocity greatest about the hottest time of the day.

On comparing the mean pressures for each month at several stations on the Upper Gangetic plains, we shall find, as has been stated in the introductory paragraphs, that their differences have no apparent relation to the mean wind velocity; but the latter has, in the annual as in the diurnal period, a very distinct relation to the temperature. In the North-Western Provinces and Oudh there are four stations, for which we possess registers extending, with few interruptions, over nearly 18 years. When the monthly mean pressures of these are reduced to sea-level and the value of gravity at latitude 45°, we get the figures given in Table IX., the differences of which from place to place are strikingly small.

TABLE IX.—Mean Pressures at Places in the North-Western Provinces and Oudh, reduced to Sea-level and Latitude 45°.

Month.	Roorkee 17–18 Years.	Agra 16–18 Years.	Lucknow 16–18 Years.	Benares. 16–18 Years.	Jhansi 15–18 Years.
	"	"	"	"	"
January . . .	30·030	30·032	30·030	30·016	30·023
February. . .	29·949	29·957	29·949	29·943	29·951
March . . .	29·842	29·842	29·835	29·826	29·844
April	29·707	29·704	29·698	29·690	29·709
May	29·577	29·578	29·593	29·587	29·586
June	29·440	29·450	29·465	29·463	29·460
July	29·465	29·464	29·475	29·467	29·470
August . . .	29·527	29·531	29·541	29·537	29·540
September . .	29·639	29·637	29·638	29·633	29·633
October . . .	29·824	29·822	29·823	29·814	29·821
November . .	29·976	29·976	29·972	29·954	29·956
December . .	30·042	30·042	30·044	30·027	30·026
Year . . .	29·750	29·753	29·755	29·746	29·754

If we take the central station of the group—Lucknow—and measure the gradient from it towards each of the others without reference to the direction of the slope, we get the mean and extreme gradients per 60 geographical miles, which are compared in Table X. with the mean wind velocity at the same four stations, and with the mean temperature and the diurnal temperature range.

TABLE X.—Wind Velocity in the North-Western Provinces compared with Pressure Gradient and Temperature.

Month.	Mean Gradient.	Maximum Gradient.	Wind Velocity per Diem.	Mean Temperature.	Diurnal Range.
	"	"	Miles.	°	°
January . . .	·0020	·0029	58·2	59·2	27·5
February . .	·0012	·0032	73·7	64·9	27·4
March . . .	·0027	·0036	87·2	74·6	30·0
April	·0021	·0038	98·0	85·4	30·7
May	·0037	·0038	114·4	91·1	27·1
June	·0031	·0060	120·3	91·5	21·3
July	·0028	·0044	95·8	85·0	13·9
August . . .	·0024	·0034	79·6	83·7	13·1
September . .	·0010	·0020	75·0	83·0	16·0
October . . .	·0011	·0036	52·6	77·5	25·3
November . .	·0035	·0072	40·6	67·7	30·7
December . .	·0033	·0068	45·6	60·0	28·9

This Table fully justifies the statement above made as far as the monthly means are concerned. The smallest values of the gradient, both mean and extreme, are found in September, when the wind velocity does not differ much from the average. The mean gradient is steepest in May and November, the one month having a high wind velocity, and the other the lowest of the year, while the maximum value of the steepest gradient is also in November, the month of least wind movement. The suggestion, however, arises that the pressure differences of any two months may have the same small mean value, while in one month the barometer stood at a uniform height all over the country, and in the other there may have been a series of more or less violent disturbances causing strong winds; that, in short, it is useless to compare mean values instead of actual observations. In North India, however, no feature of the meteorology is more remarkable than the simultaneity of barometric movements over a large extent of country; all the usual fluctuations, which are very numerous, though of small range, even in the most settled weather, occurring with the most absolute uniformity over an extent of country often larger than France, Germany, and Austria. Small disturbances, of the nature of cyclonic storms, do occur occasionally, more especially during the rainy season and in the cold weather, during the month of January or about the end of December; but, while they, doubtless, make the mean wind velocity, for the months mentioned, somewhat greater than it would otherwise be, they do not perceptibly interfere with the regular march of its annual variation.

Table X. also shows, contrary to what might be expected from the preceding part of this Paper, that the velocity is much more distinctly related to the actual temperature of each month than to the daily range of the thermometer. The explanation of this probably is that in the interior of Northern India the daily range at all seasons is sufficient to set up convection currents, while the velocity, of the winds which descend from a considerable elevation over the plains is dependent upon the pressure gradients prevailing at high levels. Now these gradients are doubtless subject to a distinct annual range, depending on the temperature; for, if the plains be heated more than usual relatively to the Himalayan slope, the result will be to raise the planes of equal pressure and make them incline towards the mountains, thus giving rise to westerly upper currents, the velocity of which will, *cæteris paribus*, be proportional to the temperature difference between plains and mountains.

Now, if we compare the mean temperature for stations on the plains of the North-Western Provinces and Oudh, given in Table X., with that of the mountain slope at a height of about 5700 feet, as computed from the observations of Chakrata, Ranikhet, Pithoragarh, and Kathmandu, we find the following differences, which are subject to a very distinct annual variation, nearly coincident in phase with that of wind velocity on the plains:—

Month :—	January.	February.	March.	April.	May.	June.
Temperature difference . . .	$13^\circ\!\cdot\!4$	$17^\circ\!\cdot\!1$	$18^\circ\!\cdot\!1$	$22^\circ\!\cdot\!1$	$24^\circ\!\cdot\!2$	$21^\circ\!\cdot\!3$
Month :—	**July.**	**August.**	**September.**	**October.**	**November.**	**December.**
Temperature difference . . .	$16^\circ\!\cdot\!1$	$15^\circ\!\cdot\!3$	$15^\circ\!\cdot\!4$	$15^\circ\!\cdot\!3$	$12^\circ\!\cdot\!0$	$10^\circ\!\cdot\!0$

A similar relation obtains to the greatest elevation at which observations have been made on the mountains. The temperature difference, between Leh (11,503 feet) and the Punjab plains, is greatest in May and June and least in November; so that, if we may assume the temperature decrement in the free atmosphere over the plains to be less variable than on the mountain slope, as seems *à priori* probable, there must be a greater pressure gradient for westerly winds at high levels in May and June than in November.

The proper way to verify this and various other deductions, which have been made from the hypothesis that convective interchange is the cause of the observed wind anomalies, is to find the distribution of pressure over India at a considerable height in the atmosphere, say 10,000 feet. For this purpose I have selected some 40 stations out of the large number in India and Ceylon for which 10-year averages of pressure are published in the Meteorological Report for 1884, and have tried to reduce their mean pressures for January, May, July, and October to the proposed elevation. The majority of stations selected are those on mountain tops or high plateaux, but, in order to complete the maps on Plate 20, fourteen stations situated at levels below 1500 feet have had to be added.

Table XI. gives the stations, with their elevations and the mean pressures of the months selected. Two of the stations mentioned, Dodabetta and Shillong, are not now on the list of meteorological observatories, but their pressures and temperatures have been taken from old reports. In the case of Dodabetta, the published barometric heights had first of all to be corrected for the temperature of the mercury. The elevations given have been found by levelling to Great Trigonometrical Survey stations, or other datum levels, in every case except Pithoragarh and Shillong. The elevation of the last-mentioned has been found by comparing barometric observations at the station with those made simultaneously at Darjiling and Silchar, which places are on opposite sides of Shillong, and are respectively considerably higher and lower than that station. The error in the determination cannot amount to more than two or three feet. The elevation of Pithoragarh has been computed by comparing, month by month, the barometric observations of four years at that station with those of Ranikhet and Kathmandu, and taking the mean of the results. The error of this mean must be very small.

The pressure observations of two stations in Southern India, Wellington and Mercara, have had to be rejected, as, when reduced to a common level, they did not agree with those of neighbouring stations, such as Coimbatore, Dodabetta, and Bangalore, while the latter agreed very fairly with one another. The assigned elevation of Wellington appears to be about 200 feet too high, and that of Mercara 135 feet too low. These elevations have been deduced trigonometrically or by spirit-levelling from points fixed in the early days of the Survey, when the uncertainties of terrestrial refraction were not sufficiently allowed for.

The observations made at Simla have also been rejected, as there is some uncertainty about the true elevation of the barometer.

TABLE XI.—Observed Pressures used in constructing Table XIV.

Station	Elevation in feet.	Pressure (corrected for temperature, &c.).			
		January.	May.	July.	October.
Newara Eliya	6,240	24·010	23·994	23·984	23·996
Kandy	1,696	28·226	28·137	28·165	28·187
Coimbatore	1,348	28·609	28·451	28·466	28·523
Dodabetta	8,644	22·045	22·018	21·946	22·019
Bangalore	2,981	27·013	26·863	26·857	26·931
Bellary	1,455	28·505	28·285	28·295	28·400
Belgaum	2,550	27·437	27·285	27·255	27·362
Secunderabad	1,787	28·192	27·959	27·914	28·080
Poona	1,849	28·131	27·939	27·872	28·046
Chikalda	3,656	26·433	26·217	26·109	26·345
Pachmarhi	3,528	26·533	26·319	26·193	26·461
Raipur	960	29·043	28·679	28·601	28·897
Indore	1,823	28·168	27·896	27 791	28·074
Hazaribagh	2,007	27·984	26·683	27·568	27·869
Sutna	1,040	28·977	28·593	28·484	28·823
Nimach	1,639	28·367	28·054	27·937	28·258
Mount Abu	3,945	26·146	25·961	25·818	26·092
Ajmere	1,611	28·412	28·075	27·954	28·294
Quetta	5,501	24·684	24·546	24·397	24·688
Peshawar	1,110	28·955	28·547	28·366	28·783
Leh	11,503	19·646	19·689	19·604	19·727
Murree	6,344	23·882	23·789	23·701	23·918
Chakrata	7,052	23·263	23·196	23·108	23·302
Ranikhet	6,069	24·113	24·013	23·928	24·113
Pithoragarh	5,363	24·758	24·624	24·534	24·729
Kathmandu	4,388	25·714	25·492	25·383	25·633
Darjiling	7,421	22·964	22·915	22·859	23·018
Shillong	4,794	25·272	25·118	25·058	25·255
Sibsagar	333	29·739	29·430	29·281	29·570
Dacca	35	30·015	29·698	29·571	29·845
Akyab	20	30·005	29·763	29·666	29·856
Diamond Island	41	29·972	29·772	29·727	29·845
False Point	21	30·031	29·684	29·558	29·848
Vizagapatam	31	30·005	29·688	29·596	29·824
Madras	22	30·000	29·733	29·728	29·850
Bhuj	395	29·639	29·311	29·162	29·491
Karachi	49	30·016	29·646	29·490	29·862
Multan	420	29·639	29·189	29·030	29·444
Delhi	718	29·316	28·904	28·780	29·143
Lucknow	369	29·674	29·264	29·152	29·498

In the formula connecting barometric pressure with height above sea-level, the most important variable is the temperature of the air. The chief object of this paper being to find out the cause of the anomalous *day* winds, the temperature of the air, in the day time when these winds blow, is that which should be adopted in the reduction to a height of 10,000 feet, which is now attempted. For the several observing stations this is obtained with sufficient accuracy by combining the maximum temperature with that of the usual hours of observation, 10 A.M. and 4 P.M., or where observations have not been made at these hours, as at the Ceylon stations, by applying to the daily mean a correction derived from some similarly situated station which is not too far off, this correction being made proportional to the daily range. These day temperatures are given in the 2nd, 3rd, 4th, and 5th columns of Table XII.

TABLE XII.—Temperatures used in constructing Table XIV.

Station.	Temperature at Station.				Temperature at 10,000 Feet.			
	January.	May.	July.	October.	January.	May.	July.	October.
	°	°	°	°	°	°	°	°
Newara Eliya	65·6	68·8	63·6	65·2	58·2	61·4	56·2	57·8
Kandy	79·9	85·1	81·3	81·3	55·8	61·0	57·2	57·2
Coimbatore	82·1	88·1	82·3	82·5	56·1	62·6	56·8	57·0
Dodabetta*	57·5	62·9	55·6	57·4	54·3	59·9	52·6	54·4
Bangalore	75·5	86·6	77·7	77·9	56·3	67·4	58 3	58·5
Bellary	82·8	97·3	87·1	85·1	57·5	72·0	62·3	60·3
Belgaum	79·5	87·2	73·2	79·0	58·5	66·2	52·2	58·0
Secunderabad	78·7	97·5	81·9	81·8	54·7	73·5	58·2	58·1
Poona	79·9	94·6	78·5	82·8	56·2	70·9	55·0	59·1
Chikalda	69·9	88·7	72·3	74 9	52·9	71·7	55·1	57·9
Pachmarhi	67·9	90·1	73·4	74·3	50·4	72·6	55·7	56·8
Raipur	77·7	105·0	83·1	84·3	49·8	77·1	56·2	56·4
Hazaribagh	70·3	94·2	82·2	80·7	47·3	71·2	59·3	57·8
Sutna	71·0	100·5	86·4	86·1	43·3	72·8	59·7	58·4
Indore	76·3	96·9	81·0	85·6	52·6	73·2	57·4	61·9
Nimach	72·2	98·1	83·4	87·4	47·9	73 8	59·3	63·1
Mount Abu	65·1	85·1	74·9	75·7	49·0	69·0	58·6	59·6
Ajmere	69·3	98·2	87·5	89·7	46·1	75·0	64·5	64·3
Quetta	47·2	78·4	87·3	71·3	35·8	66·3	75·2	59·2
Peshawar	60·1	91·8	96·2	82·0	33·8	64·5	68·9	54·7
Leh	25·7	58·1	70·0	50·7	31·8	60·5	70·9	54·9
Murree	45·0	71·8	73·9	66·7	36·0	62·6	64·9	57·5
Chakrata	47·7	70·7	67·5	63·4	40·3	63·3	60·4	56·0
Ranikhet	51·5	73·5	71·1	66·9	41·5	63·5	61·3	56·9
Pithoragarh	55·3	75·5	74·9	70·6	43·3	63·5	62·9	58·6
Kathmandu	58·1	75·0	78·5	74·3	43·4	60·1	63·6	59·6
Darjiling	42·6	59·9	64·5	58·5	36·5	53·8	58·4	52·4
Shillong	56·5	72·4	73·1	67·9	43·0	58·8	59·5	54·4
Sibsagar	68·0	81·9	87·5	82·4	38·3	52·2	57·8	52·7
Dacca	74·6	88·2	86·7	85·7	40·9	57·1	53·6	52·0
Akyab	76·2	87·4	82·1	85·2	42·5	56·3	51·0	51·5
False Point	75·5	90·2	87·2	88·4	42·8	56·5	56·1	54·7
Vizagapatam	81·9	93·5	89·6	88·8	48·2	59·8	58·5	55·1
Madras	81·9	93·9	90·7	85·7	48·2	60·2	59·6	54·6
Diamond Island	79·8	87·0	83·0	84·4	46·1	55·9	51·9	53·3
Bhuj	75·6	96·0	87·8	90·1	44·2	64·6	58·4	60·7
Karachi	71·8	89·0	87·6	87·6	38·2	58·0	56·6	54·0
Multan	64 0	99·5	98·7	88·4	32·6	68·1	67·3	57·0
Delhi	65·4	98·4	90·2	86·9	35·8	68·8	62·2	57·3
Lucknow	68 3	100·1	90·3	87·8	36·9	68·7	60·9	56·4

* The temperature of this station appears to be about 3° too low in comparison with Coimbatore, near which it lies. Coimbatore, is, however, in the dry region to the lee of the mountains, and when Dodabetta is compared with the west coast stations it appears warm in comparison. Thus the mean day temperatures of Cochin and Mangalore when reduced to 10,000 feet are:—

January.	May.	July.	October.
51·4°	55·6°	49·8°	51·6°

The pressures given in Table XI. do not need any special correction for daily range, because in every part of India the mean height of the barometer between 10 and 16 hours does not differ by more than a few thousandths of an inch from the mean of the twenty-four hours, and it will be seen immediately that, with the unavoidable uncertainty there is as to temperature, it is unnecessary to take such small differences into account.

It has already been pointed out, in discussing the probable height to which convection currents extend at the hottest time of the day, that nothing accurate is known regarding the decrease of the day temperatures with height above the sea in the free atmosphere. But, by taking the differences between the day temperatures given in Table XII. for stations in North-Western and Central India and the sea-level values of the mean temperatures of the same places, published in vol. 2 of the 'Indian Meteorological Memoirs,' pages 137–141, and combining the results into groups for stations below 2000 feet, between 2000 and 5000 feet, between 5000 and 8000 feet, and above 8000 feet, we can construct a set of curves giving the variations of temperature on mountain slopes, unaffected by changes of latitude or longitude. By graphic interpolation we can, then, get from these the rates of decrement. The results for the four months in the Table are shown in Table XIII. They exhibit a considerable diversity of character, and a tendency in the summer to an increase of temperature with height at the greatest elevations, owing to the greater diurnal range of the thermometer at Leh than at the stations on the outer ranges about 7000 feet elevation, whilst it is practically certain that there is no such tendency in the free atmosphere.

TABLE XIII.—Vertical Decrement of Day Temperature on the Mountains of Central and North-Western India.

Height.	January.	May.	July.	October.
	°	°	°	°
0 to 1,000 feet . . .	4·4	7·3	6·0	4·6
1,000 „ 2,000 „ . . .	3·4	6·1	5·3	4·1
2,000 „ 3,000 „ . . .	2·7	5·1	4·6	3·8
3,000 „ 4,000 „ . . .	2·2	4·1	4·0	2·8
4,000 „ 5,000 „ . . .	1·8	3·2	3·4	2·4
5,000 „ 6,000 „ . . .	1·6	2·3	2·8	1·7
6,000 „ 7,000 „ . . .	1·6	1·5	2·3	1·5
7,000 „ 8,000 „ . . .	1·7	0·8	1·9	1·4
8,000 „ 9,000 „ . . .	1·9	0·1	1·5	1·5
9,000 „ 10,000 „ . . .	2·1	0·5	1·1	1·6
0 to 10,000 feet . . .	23·4	30·0	32·9	25·4

The total decrement between sea-level and 10,000 feet is less in every month than that found by GLAISHER in the free atmosphere over England and France, as was to be expected. The difference is not very great in the summer months, but amounts to 10° or more in January. At this season, however, the decrement in Bengal is, as we have seen, much more rapid, and such appears also to be the case in Southern India, when we compare the temperature of Dodabetta with that of Coimbatore and the nearest stations on the west coast.

For the whole country, therefore, after due consideration, I have decided to adopt the rates of decrement found by GLAISHER, and given above in Table VI. These include an allowance for diminishing diurnal range, since the observations were made in the day time only. Though considerably more rapid for some months than those in the last Table, they are, perhaps, too slow on the whole, the decrement in India being probably greater near the ground than in England, where insolation is not so powerful. The last four columns of Table XII. give the probable temperatures at 10,000 feet, deduced by means of Table VI., the rate for cloudy skies being used when the average cloud proportion for the month amounts to half the expanse or more, and the rate for clear skies in the other months.

The formula adopted for the barometric reductions is the simple one :—

$$\log p = \log \mathrm{P} - \frac{h}{60{,}360\left(1 + \frac{\mathrm{T} + t - 64}{986}\right)}.$$

With the values of T and t in Table XII., and the mean value of p, about 21 inches, it can be shown, by differentiating, that for a difference of elevation of 10,000 feet, an error of 1° in estimating t would give an error in the resulting value of p lying between ·008 and ·010 inch. As the margin of possible error in many of the values of t may amount to several degrees, there is evidently nothing to be gained by using a more complicated formula, in which the variations of gravity and of density, owing to the presence of more or less water vapour, are taken into account.

The computed results, which have been reduced to the standard value of gravity, are given in Table XIV. Considering the uncertainty of the adopted rates of decrease of temperature, and the widely different altitudes of the base stations, these results are remarkably consistent. Even apparent exceptions to this consistency, such as the low pressure over Dodabetta compared with the neighbouring station Coimbatore, or of Chikalda compared to Poona, or Mount Abu to Neemuch, serve to confirm the probable correctness of the rates of temperature decrement adopted; for these are instances of the mid-day distribution of pressure which gives rise to the diurnal mountain winds, observed in all the warmer regions of the world.

TABLE XIV.—Mid-day Pressures at 10,000 Feet (corrected to Gravity of Latitude 45°).

Station.	Pressure.			
	January.	May.	July.	October.
	"	"	"	"
Newara Eliya	20·922	20·924	20·888	20·906
Kandy	20·953	20·950	20·882	20·947
Coimbatore	20·996	20·958	20·901	20·945
Dodabetta	20·934	20·919	20·836	20·909
Bangalore	20·979	20·969	20·901	20·959
Bellary	21·014	21·021	20·886	20·966
Belgaum	21·017	20·978	20·809	20·955
Secunderabad	20·992	21·031	20·825	20·949
Poona	21·039	21·035	20·806	20·977
Chikalda	20·997	20·988	20·757	20·972
Pachmarhi	20·959	20·993	20·740	20·962
Raipur	20·947	21·037	20·719	20·946
Hazaribagh	20·925	20·958	20·746	20·956
Sutna	20·894	20·982	20·740	20·981
Indore	20·985	21·012	20·755	21·018
Neemuch	20·941	21·009	20·758	21·067
Mount Abu	20·951	20·964	20·764	20·999
Ajmere	20·925	21·013	20·805	21·070
Quetta	20·837	20·919	20·844	20·993
Peshawar	20·815	20·914	20·835	20·970
Leh	20·792	20·767	20·654	20·820
Murree	20·800	20·863	20·799	20·950
Chakrata	20·818	20·858	20·766	20·922
Ranikhet	20·816	20·856	20·768	20·906
Pithoragarh	20·839	20·863	20·784	20·920
Kathmandu	20 889	20·846	20·784	20·958
Darjiling	20·811	20·835	20·801	20·923
Shillong	20·832	20·822	20·779	20·902
Sibsagar	20·847	20·825	20·773	20·931
Dacca	20·882	20·865	20·741	20·920
Akyab	20·880	20·888	20·743	20·904
False Point	20·892	20·854	20·737	20·941
Vizagapatam	20·965	20·902	20·803	20·936
Madras	20·940	20·929	20·899	20·950
Diamond Island	20·923	20·903	20·815	20·919
Bhuj	20·917	20·973	20·754	21·022
Karachi	20·842	20·852	20·722	20·970
Multan	20·794	20·955	20·828	20·985
Delhi	20·811	20·947	20·764	20·975
Lucknow	20·822	20·964	20·767	20·967

The pressures given in this Table are charted on Plate 20, which is headed "Mid-day Pressures at 10,000 Feet." These charts deserve some study in detail.

In January, the region of lowest pressure, bounded by the isobar of 20·80 inches, covers a considerable part of Afghanistan and the Punjab, and extends through Kashmir into Ladakh and Thibet. The north-east corner of the Punjab and the region of the Hindu Kush have probably a slightly higher pressure. The isobar of

20·80 inches sends a long loop down the valley of the Ganges to the north of Delhi. The next two isobars are very similarly curved, but they extend further to the east over known regions, and are seen to curve southward again over Bengal and the head of the Bay. The others probably form closed curves of a roughly triangular form round a centre lying in the western Deccan near the town of Sholapur.

The system of winds, pertaining to this distribution of pressure at a height where the friction coefficient is very small, would be S.W. over the Bombay coast, Sindh, and Rajputana, S. or S.W. at most of the Himalayan stations, N. or N.E. at Murree, S.E. along the foot of the Central Himalaya, N.W. in Bengal, W. over Central India and the Gangetic plains, N.E. over nearly the whole of the Madras Presidency, and E. or S.E. in Travancore and Cochin. Now in almost every instance where the observed prevailing wind direction for this month is inconsistent with the distribution of pressure at sea-level it is in accordance with this upper system of wind currents.

A possible solution of another question of great interest is suggested by the chart. The cause of the disturbances which produce the winter rainfall of the Punjab, North-Western Provinces, and Rajputana, and the snows of the North-west Himalaya, is not yet fully understood. Mr. F. CHAMBERS has suggested that these precipitations may be due to disturbances of the same nature as the winter storms of high latitudes entering India from the west,* while Mr. BLANFORD attributes their origin to the disturbance of atmospheric equilibrium by the upward diffusion and condensation of water vapour formed locally.† It is difficult to understand how a cyclonic storm, if it be of the same nature as those formed in the Bay of Bengal at the turn of the seasons, can cross a mountainous country like Afghanistan ; but that whirling storms do cross the Rocky Mountain region is a common experience in America.

Without presuming to dogmatise, therefore, about a subject which I have not sufficiently studied, I would suggest that it is possible such storms may be formed in more than one way, and that some of them at least may travel for long distances if they do not originate in a region of relatively low pressure in some upper stratum of the atmosphere. Such whirling storms, crossing the Indus in the month of January, might travel along the axis of lowest pressure directly into Kashmir, or they might pass along the V-shaped depression in the Valley of the Ganges as far as Behar ; but, owing to the higher pressure in West Bengal and Nepal, they could seldom penetrate to Assam, except by the roundabout way of Thibet, in which case their chance of survival after twice crossing the Himalayas would be infinitesimal. Now these possible paths suggested by the form of the isobars are precisely those most frequently taken by the disturbances which bring the winter rains.

The chart for May shows that the distribution of pressure at 10,000 feet elevation during this month is extremely simple if we leave out of consideration local minima

* 'Nature,' vol. 23, page 400.

† 'Journal of the Asiatic Society of Bengal,' vol. 52, Part 2, and 'Indian Meteorological Memoirs,' vol. 3, page 93.

in the Nilgiris and Satpuras, such as cause the diurnal mountain winds above referred to. The high pressure region in the Deccan is much enlarged, and the centre shifted northwards to Berar. Round this the isobars curve in a nearly triangular form, following closely the outline of the country as bounded by the sea, the Hála and Suleiman ranges and the Himalayas; the most important exception to this rule being a recurvation of the lines of equal pressure round a low-pressure area extending obliquely across Bengal from Balasore to Assam. The wind system, induced by this distribution of pressure, would be S. or S.W. in the valley of the Indus and Rajputana, W. or N.W. over the rest of Northern India, as far east as Lower Bengal and as far south as Berar, S.W. in Eastern Bengal and Burma, N.E. along the eastern side of the Peninsula from Orissa to Negapatam, and S.E. or S. on the Malabar coast. That is to say, over the interior of Northern and Central India the upper currents in this month have exactly the same direction as the anomalous hot winds which we have reason to suppose may be caused by their descent under the convective action set up by the daily passage of the sun.

The steepest gradient on the map is that to the west of the Orissa coast. Disturbances originating at the head of the Bay would therefore, according to the usual experience that the line of least resistance is that of lowest pressure, experience much difficulty in proceeding westwards, but would meet with less resistance in the northward direction over Bengal. As a matter of fact, the majority of such storms as are formed in this region during May do proceed northwards,* and those which turn westwards across the plain of Orissa do not survive to reach the Central Provinces. Mr. ELIOT attributes their rapid break-up to the comparatively small height to which they extend in the atmosphere, and the resistance they experience from the hills west of Orissa; but, while this may be one reason for their disappearance, the rapidly increasing pressure in a westward direction at moderately great elevations is doubtless another.

The low-pressure area extending obliquely across Bengal and Assam is the scene of frequent local storms, known as "Nor'-Westers," in the hot season, and the area of maximum "spring storm rainfall" on Mr. BLANFORD'S charts† coincides very closely with it. At page 105 of the work cited, Mr. BLANFORD gives a clear and interesting description of these storms and their origin, which he attributes to the mixing, by convective action, of the southerly sea winds with the north-west winds, which blow over the Chutia Nagpur plateau, and probably continue their course eastwards over the low plains of Bengal at nearly the same level. The line of maximum rainfall in May, according to Mr. BLANFORD'S Table, passes through or near the following places, the rainfall gradually increasing as the distance from the sea increases and the Khasia Hills are approached :—

* "Account of S.W. Monsoon Storms generated in the Bay of Bengal during the years 1877 to 1881," by J. ELIOT, 'Indian Meteorological Memoirs,' vol. 2.

† "The Rainfall of India," 'Indian Meteorological Memoirs,' vol. 3.

Balasore	4·78 inches
Midnapore	5·08 ,,
Krishnaghar	6·62 ,,
Jessore	7·56 ,,
Faridpur	8·33 ,,
Dacca	9·26 ,,
Mymensingh	11·74 ,,
Sylhet	21·64 ,,
Cherra Punji	51·46 ,,

The line joining these places coincides almost exactly with the axis of lowest pressure at 10,000 feet on the chart for May.

In July the triangular area of high pressure in the Deccan has retreated to the extreme south-east of the Peninsula, and occupies those parts of the Carnatic where the rainfall at this time of the year is very light.

Along the foot of the Himalayas there is a zone of relatively high pressure, 20·80 inches, or slightly less, which widens out in the west, so as to include the western Punjab and Afghanistan. Parallel to this, and south of it, from the head of the Bay of Bengal to Sindh, extends a region of lower pressure, below 20·75 inches; which is, however, interrupted along the line of the Aravalis by a belt of higher pressure, exceeding 20·80 inches in the vicinity of Ajmere.

As regards the country south of the parallel of 24°, there can, therefore, be but little difference in direction between the winds prevailing at high and low levels, and, except for the diminution of frictional retardation on ascending, the upper currents have probably no greater velocity than those at the ground surface, since the gradients of 10,000 feet are no steeper than those at sea-level. In Bengal the winds at this elevation should be easterly or north-easterly, while those deduced from the distribution of pressure at sea-level by BUYS BALLOT'S Law would be southerly. The prevailing winds are south-easterly, or in Cachar north-easterly, the average angle between the wind and the isobars being about 60°, an effect which is possibly due in part to convective interchange; though, as we have already seen, the activity of such interchange at this season is not great. The northerly winds at Multan, Jeypore, and Agra, to which attention was directed in the first part of this Paper, are evidently the effects of the high pressure in the upper strata over Afghanistan and the Aravali region respectively, these stations being all in the drier part of North-western India, where clear skies and a high temperature range, with their accompaniment of active convection currents, are not infrequent even in July.

The extensive belt of low pressure, at high altitudes, stretching across the Central Provinces and the head of the Bay, is doubtless connected with the fact, brought prominently to notice in Mr. ELIOT'S paper last referred to, that cyclonic storms formed during the prevalence of the S.W. monsoon usually pass inland across the Orissa coast, meeting with little obstruction from the ranges of low hills they have to surmount,* and often passing right across India to Sindh, the Rajputana desert, or the western Punjab; while those formed at the spring and autumn transition periods, which either do not extend to so great a height or meet with increasing pressures at moderate elevations as they go westwards, very seldom succeed in crossing from Orissa to the Central Provinces.

From the charts attached to Mr. ELIOT'S paper it appears that, during the five years 1877–1881, inclusive, 30 cyclonic storms crossed the coast near the head of the Bay in the months of June, July, August, and September. Of these, 23 proceeded westwards at first, and the remaining seven went northward into Bengal. Only five storms occurred in the month of July, all of which crossed the Orissa coast in the westward direction. The majority of such storms either proceed almost due west towards Gujerat and Sindh, or turn off northwards to the valley of the Ganges, doubtless owing to the obstruction presented by the high-pressure region in Eastern Rajputana. Of the 23 above enumerated, 9 turned off towards the Ganges Valley, 2 succeeded in crossing the Aravali range near Ajmere and ultimately reached the Indus Valley, and the remainder either proceeded *viâ* the Narbada Valley to Gujerat and Sindh, or died out during the trans-continental passage. To the frequent passage of such storms over the Central Provinces and Malwa is doubtless to be attributed the fact of these regions having a heavier and less variable rainfall than any other part of the interior of the Indian Peninsula.

In October, the highest pressure is over Rajputana and Malwa, and the lowest in Arakan and Upper Burma, and in the Trans-Himalayan regions of Ladakh and Thibet. The general appearance of the isobars is that of a system of more or less wavy loops surrounding the high-pressure centre in Rajputana, and extending to an unknown distance westwards over the Arabian Sea. The system of winds due to this distribution of pressure must be E. or S.E. in the extreme south of the Peninsula, S.W. in the Indus Valley as well as in Lower Burma and Tenasserim, W. in the Punjab, N.W. in the Ganges Valley, N. over the Bengal delta, and N.E. over the rest of the country. Except in Bengal and on the western side of the Indus Valley, this is not dissimilar to the system due to the pressure distribution at sea-level, and accordingly, we find it is only in these parts of the country that there are any marked anomalies in the direction of the wind observed on the plains.

In confirmation of the general direction of the circulation of the atmosphere at 10,000 feet elevation, we have the evidence of the winds at the hill-stations in the Himalayas and in Southern India. On the whole, though these stations, with the exception of Leh, are only at elevations between 6,000 and 7,000 feet, the accordance of the actual wind directions with those given by the distribution of

* Instances have been known to occur in which such storms, after crossing the Orissa coast, gave little or no indication of their existence on the charts of sea-level isobars, but after a day or two reappeared in the Narbada valley. This seems to prove that, unlike the cylones of October, they are high-level disturbances.

pressure at 10,000 feet is very fairly exact, as may be seen by comparing the wind directions on Plate 19 with the isobars on Plate 20. For greater elevations I have only the evidence of the Allahabad nephescope, by means of which the directions of movement of the cirrus clouds has been observed for eight years. These observations were recorded and originally tabulated to 16 points, but in giving them here I have reduced the number of points to 8. The total number of observations, during the eight years 1878–1885, inclusive, with the resultants computed by LAMBERT's formula, are given in Table XV.

TABLE XV.—Observed Movements of Cirrus Clouds at Allahabad during the years 1878–85.

Month.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Resultant.	
									Direction.	Percentage.
January	1	..	..	..	..	27	44	20	S. 87° W.	84
February	2	..	1	..	3	18	55	9	S. 85° W.	83
March	1	..	2	3	3	28	58	8	S. 77° W.	79
April	2	..	..	1	1	10	31	15	N. 86° W.	80
May	..	..	..	..	..	8	22	7	S. 89° W.	88
June	..	6	6	4	2	15	24	7	S. 77° W.	43
July	..	4	10	3	4	6	8	3	S. 6° E.	14
August	2	6	10	2	1	7	9	4	N. 33° W.	5
September	2	4	11	5	3	6	9	3	S. 28° E.	8
October	..	1	1	1	..	7	5	1	S. 63° W.	58
November	1	..	..	..	1	4	6	2	S. 82° W.	73
December	..	..	..	..	1	21	17	3	S. 68° W.	88

The resultants for January, May, and October are consistent with the distribution of pressure at 10,000 feet, but that for July has too large a southerly component. The very small percentages of steadiness for the three rainy months of July, August, and September, however, indicate that the pressure gradients of the rainy monsoon are evanescent at the level of the cirrus clouds.

As regards the country north of the parallel of 24° and west of the meridian of 86° E. longitude, the distribution of pressure in October is strikingly similar to that which obtains in May, but the gradients are much less steep. Therefore, although on account of the large diurnal range of temperature, convective interchange may be quite as active in October as in May, the winds which blow in the afternoons are not nearly so strong. In Table XVI., the maximum gradient through Lucknow, at 10,000 feet above sea-level, is compared with the gradient at sea-level and with the mean wind velocity at North-Western Provinces stations, for each of the four months under review.

TABLE XVI.—Comparison of Wind Velocities with Pressure Gradients over the Gangetic Plains.

Month.	Velocity in miles per diem.	Maximum gradient for 60 geographical miles.	
		At sea-level.	At 10,000 feet.
	Miles.	Inch.	Inch.
January	58·2	·0029	·028
May	114·4	·0038	·035
July	95·8	·0044	·012
October	52·6	·0036	·019

It seems probable from this Table that the high velocity for July may be attributed, partly at least, to the higher pressure gradient at sea-level in that month than in any of the others, and that the lower velocity in October than in May is the result of the lower gradient prevailing at high levels. The relation between the wind velocity and the gradients at high and low levels may be investigated as follows :—

If v be the velocity of the wind near sea-level in miles per hour, and v' that prevailing in a higher stratum where the gradients are the same as at 10,000 feet in the Table, and if x be the number of hours during which the wind from this high level descends to the earth's surface, then the total distance traversed daily will be $v'x + v(24 - x)$. Should the wind not descend from a level where the gradients are so high as those given in Table XVI., x will not represent the true time during which the upper current descends, but will be longer or shorter in inverse proportion to the gradient.

From FERREL's formula for the relation between the wind velocity and barometric gradient, given in his work on the Movements of the Atmosphere, we get, on reducing to English measure, and taking the unit of distance to be one degree of the earth's surface, $\Delta B = \cdot 00607 (\cdot 525 \sin \phi + u) v$; or, taking ϕ equal to the mean latitude of the Gangetic plain (about 26°), and neglecting the angular velocity u, we get $v = 714 \Delta B$. In arriving at this result, however, frictional retardation has been neglected ; but, if the ratio between the actual and the theoretical velocity for a given gradient be called f, we may put for the actual velocity $v = 714 f \Delta B$. Substituting for v and v' in the previous formula their values thus expressed in terms of the barometric gradients for each of the four typical months, and assuming the probable values $f = \cdot 4$ and $f' = \cdot 7$ since the equations are indeterminate, we get the following results :—

Month.	x.
January	2·9 hours.
May	5·4 ,,
July	13·9 ,,
October	3·3 ,,

These results, for the three dry months, are consistent with the variations of the length of the day, and the probable rates of decrease of temperature near the ground; but the result for July is much too large, and implies either that the convective action does not extend to so great a height as in the other months, or that, owing to the frequency of small cyclonic disturbances in July, the mean of the gradients actually obtaining from day to day is considerably steeper than that deduced from the chart of monthly mean pressures. Both reasons, doubtless, concur in producing the result just found.

The hypothesis of diurnal interchange between atmospheric strata lying at low and high levels, brought about by convection currents during the hours when the sun is shining, having thus been shown to account for the observed anomalies of the winds of Northern and Central India, both in direction and velocity, I shall now proceed to enquire whether the same hypothesis will suffice to explain the effect of unusual snowfall on the Himalaya in producing extraordinarily powerful and persistent N.W. winds over the Indian plains.

Part III.—The Anomalous Effect of Heavy Snow in the Himalayan Region.

In the year 1877, remarkable for the almost total failure of the summer rains, I pointed out, in a letter to the Government of the North-Western Provinces, the probability of a rule that when the winter rains of Northern India are light those of the summer are heavy, and *vice versâ*. About the same time Mr. E. D. ARCHIBALD arrived independently at the same empirical law. The investigation which led up to this law was continued and extended, and two years afterwards I published a paper on the subject in the 'Indian Meteorological Memoirs,' vol. 1. At page 209 of that volume it is shown that out of a total number of 34 years of which the rainfall statistics are discussed 25 tell in favour of the rule that, in the North-Western Provinces, the winter rainfall and that of the succeeding summer vary in inverse directions, and only nine are against it. Mr. BLANFORD has since investigated the subject further, and shown that if, instead of the rainfall during the winter and spring months over the plains, we take the precipitation on the North-West Himalaya (which usually, but not always, varies, *pari passu*, with the rainfall on the plains), and compare it with the rainfall of the succeeding summer monsoon, the unfavourable instances, with one or two exceptions, due to special temporary causes, all disappear.

The way, in which unusually heavy and late snowfall on the mountains exercises a retarding and weakening influence on the summer monsoon, is doubtless by keeping down the temperature of those regions, which constitute one of the goals towards which the monsoon winds blow. In such dry years, the westerly winds, which usually prevail over northern and western India during April and May, are strongly reinforced, and continue to blow far into June or July; or even, as in 1868 and 1877, right on through the months of the summer monsoon until September or October. In his earliest writings on this subject Mr. BLANFORD seemed to incline to the notion that these north-west winds were a nearly direct effect of the cold to the north of India, their immediate cause being the (apparent) high pressure of the mountain region when the actual pressures observed were reduced to sea-level. It has been pointed out in the introductory paragraph, however, that the result of such a distribution of actual pressure would be to cause easterly instead of westerly winds, in accordance with the usual deflecting influence of the earth's rotation. In his last paper ('Proceedings of the Royal Society,' vol. 37, 1884) this idea that the north-west winds are a direct effect of Himalayan cold has been dropped, as will be seen from the following quotation, and he anticipates the explanation on the hypothesis of convective interchange, which I now attempt to give. At page 18 he says: "The question then presents itself, 'What is the origin of the dry westerly current?' The supposition that the indraught from the south-west furnishes more than a small portion of the stream is at once negatived by the fact that, even at Karachi and Bhuj, southerly winds do not preponderate over northerly until May, and even then almost inappreciably—at Rajkot not before June; and the very fact of the great dryness of the west and north-west winds militates against the idea that any considerable portion of their air-mass can be drawn from the sea. Neither is it derived to any considerable extent from the valleys and lower slopes of the surrounding hills. There is no permanent drainage of air from these hill-slopes, and strong winds blowing outwards from the larger valleys, like the *dadu* of Hurdwar, are local and exceptional phenomena, restricted to certain hours of the day. At all the hill-stations of the outer North-West Himalaya, as far as the existing registers show, southerly winds preponderate over northerly all through the year; and, although this is probably due in some measure to the fact that the night winds have not hitherto been registered, it suffices to show that, up to a level of 7000 feet, there is no steady outflow of air from the hills to the plains.

"There remains then only the supposition that these winds are fed by the descent of air from an upper stratum, viz., from a current moving at a considerable elevation from west to east. And that this is their true explanation several facts seem to testify. In the first place, they are characteristically winds of the day time, their movement being at a minimum (almost or quite a calm) in the morning hours, and indeed up to 9 or 10 o'clock in the forenoon—then increasing with temperature, and falling again towards evening; and, secondly, such observations as have been made on the decrease of temperature with elevation show that, in the dry weather, the vertical decrement is such as is incompatible with the vertical equilibrium of an air column, being considerably more than 1° in 183 feet. The diurnal variation of the movement is then probably to be accounted for on KÖPPEN'S hypothesis, viz., the interchange of the higher and lower air strata, by convective movements which do not affect the existing horizontal movement of the higher atmosphere, so that the air of the latter, after its descent, preserves for a time its original eastward motion. The hypothesis of convective interchange receives further support from the character of the diurna variation curve of vapour-tension in a dry atmosphere near the earth's surface, which is the same in all parts of India. This shows a rapid fall of the absolute humidity of the air after 8 or 9 o'clock in the forenoon, reaching its minimum about the time of greatest heat, and a more or less sudden rise before sunset, which it is difficult to account for on any other supposition than that it coincides with the cessation of the convective movement." Having given thus clearly and concisely the evidence that the explanation of the diurnal hot winds is probably to be found in KÖPPEN's hypothesis, Mr. BLANFORD does not go on to explain how the abundance or paucity of the snowfall on the mountains will affect their intensity. From what has gone before, however, it will be evident that their intensity is likely to be affected only by two causes: (1) the intensity of the convective action which brings about an interchange between the higher and lower atmospheric strata; and (2) the pressure gradients and consequent intensity of the winds prevailing at high levels. The former, which depends on the rate of variation of temperature with elevation, is doubtless affected by rainfall over the plains in what is ordinarily the dry season; for such rainfall invariably lowers the temperature at the ground surface, though, from theoretical reasons, it would appear to raise it by the liberation of latent heat at the level where precipitation occurs, the double effect being a decrease in the rate of vertical decrement. The cooling effect of occasional showers over the plains is, however, a transient phenomenon, compared with that of the snows on the mountain slopes; hence it is probably by an increase of the baric gradient at high levels, owing to the sinking of the planes of equal pressure over the cold mountain zone, that the westerly winds are intensified to the extent observed in dry years.

A thorough investigation of this part of the subject would demand the preparation of charts of the distribution of pressure at a high level for each of a considerable number of years, a comparison of the gradients on which, month by month, with the rainfall and the prevailing wind directions over the plains, would enable us to completely verify or disprove the hypothesis. It is to be hoped that, in future, such high-level* charts may be prepared for the monthly mean pressures, as regularly as the charts at sea-level now published in the Annual Reports on the Meteorology of India. Such charts could not fail to be instructive. The labour of preparing such a series would, however, be very great, and all that can be attempted now is to ascertain as nearly as possible what were the high-level gradients prevailing over the Gangetic valley in the typical months of a few years of marked characteristics as regards rainfall.

During the last eight years for which the Meteorological Reports have been published, the rainfall of the Punjab, Rajputana, Central India, the North-West Provinces,

* The elevation, 10,000 feet, adopted in the charts attached to this paper, has been chosen only because it is expressed by a convenient round number, and because it lies above all the mountains in India except the snowy ranges. It may be found in practice more convenient to adopt some other level.

and Oudh—a region comprising between one-third and one-half of the plains of India—has varied from the average as follows :—

Year :—	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.
Rainfall variation per cent.	− 35	− 2	+ 5	− 20	+ 2	+ 4	− 17	+ 16

These are the variations computed on the total rainfall of the year, which averages 31·26 inches. Owing to the opposition in sign of the variations for the winter and summer months, the summer rainfall alone would give larger departures from the average, the defect in 1877,* for example, being 55 instead of 35 per cent. The totals for the separate seasons are not given in the summaries† from which the above figures are taken ; but, as those of the summer nearly always vary in the same direction as the annual totals, the latter will suffice for our purpose, which for the present has reference only to direction and not to extent of variation.

Leaving out of account the two years 1878 and 1881, for which the variations lie within the limits of possible error, and also 1882, the barometric data for which at one of the stations given below are incomplete, there remain five years of distinctly marked positive or negative variations in the rainfall. Table XVII. gives the observed pressures and day temperatures, for the four typical months of these years, at three stations on the outer Himalayas, and three others in a nearly parallel line on the plateau to the south of the Ganges valley ; and in Table XVIII. are given the computed pressures at an elevation of 10,000 feet. In making the computations for this Table, the same rates of temperature decrement have been assumed as in constructing the Table of normal values, though there is reason to believe, as above stated, that these rates may be different for dry and showery months of the winter and spring ; but, then, we have at present no means of estimating exactly what the variations from month to month of this element of our calculations may be. Some of the apparently anomalous results worked out below would, doubtless, disappear if the true rates of decrement were known and used.

* Owing to the heavy rainfall of the winter and spring months of 1877, the total rainfall of the N.W. Punjab that year was considerably over the average.

† Near the end of the letter-press of each Annual Report on the Meteorology of India.

TABLE XVII.—Pressures and Temperatures at North Indian Stations in Certain Years.

Year.	Station.	Elevation in feet.	Observed mean pressure.				Day temperature.			
			January.	May.	July.	October.	January.	May.	July.	October.
			"	"	"	"	°	°	°	°
1877	Ajmere . . .	1632	28·444	28·111	27·992	28·305	69·9	97·4	94·9	89·0
	Sutna	1040	29·022	28·654	28·523	28·857	69·0	98·1	91·4	86·2
	Hazaribagh . .	2010	28·042	27·737	27·606	27·942	68·0	91·2	84·5	81·7
	Chakrata . . .	7052	23·305	23·221	23·117	23·334	44·4	70·3	68·8	61·6
	Ranikhet . . .	6069	24·167	24·035	23·926	24·153	47·2	71·2	72·7	64·5
	Darjiling . . .	6912	23·503	23·361	23·291	23·506	46·8	63·0	66·9	61·5
1879	Ajmere . . .	1632	28·366	28·013	27·931	28·252	74·6	105·3	91·6	88·9
	Sutna	1040	28·951	28·546	28·506	28·806	74·4	104·4	83·1	83·0
	Hazaribagh . .	2010	27·970	27·648	27·600	27·851	72·4	98·5	82·1	79·0
	Chakrata . . .	7052	23·261	23·119	23·088	23·292	49·7	75·2	65·9	63·3
	Ranikhet . . .	6069	24·116	24·006	23·905	24·108	53·3	79·7	68·6	65·2
	Darjiling . . .	6912	23·426	23·349	23·288	23·460	47·8	65·4	66·5	63·8
1880	Ajmere . . .	1611	28·373	28·069	27·969	28·301	73·4	97·7	85·5	88·8
	Sutna	1040	28·916	28·584	28·501	28·837	72·9	101·6	84·6	88·8
	Hazaribagh . .	2007	27·920	27·674	27·576	27·889	71·1	90·6	82·2	81·3
	Chakrata . . .	7052	23·245	23·196	23·090	23·321	51·7	68·0	65·3	64·1
	Ranikhet . . .	6069	24·077	24·000	23·912	24·130	54·0	71·4	69·6	67·0
	Darjiling . . .	6912	23·389	23·345	23·301	23·475	47·9	62·6	65·3	60·4
1883	Ajmere . . .	1611	28·382	28·058	27·961	28·334	68·8	96·7	85·3	87·1
	Sutna	1040	28·975	28·561	28·477	28·869	69·9	103·2	85·1	84·1
	Hazaribagh . .	2007	27·987	27·633	27·588	27·911	67·9	98·4	81·0	82·2
	Chakrata . . .	7052	23·226	23·115	23·088	23·322	43·9	73·1	67·7	63·8
	Ranikhet . . .	6069	24·089	23·975	23·908	24·134	48·5	74·3	71·7	66·8
	Darjiling . . .	7421	22·974	22·895	22·860	23·048	40·9	61·1	65·4	58·1
1884	Ajmere . . .	1611	28·462	28·084	27·953	28·338	71·2	99·7	89·3	84·0
	Sutna	1040	29·015	28·589	28·493	28·878	71·8	103·0	83·7	81·8
	Hazaribagh . .	2007	28·014	27·660	27·559	27·902	69·8	96·0	81·3	73·8
	Chakrata . . .	7052	23·290	23·175	23·100	23·311	45·6	73·9	67·3	60·1
	Ranikhet . . .	6069	24·138	23·997	23·928	24·134	52·5	75·4	71·1	63·1
	Darjiling . . .	7421	23·025	22·903	22·869	23·057	45·1	58·8	64·6	57·2

TABLE XVIII.—Mid-day Pressures for certain Years, reduced to 10,000 feet and Gravity of lat. 45°.

Station.	1877.				1879.			
	January.	May.	July.	October.	January.	May.	July.	October.
Ajmere	20·977	21·077	20·933	21·105	20·964	21·058	20·848	21·059
Sutna	20·900	21·003	20·829	21·006	20·921	20·994	20·719	20·932
Hazaribagh	20·939	20·974	20·799	21·019	20·938	20·981	20·767	20·974
Chakrata	20·840	20·878	20·780	20·944	20·825	20·879	20·742	20·913
Ranikhet	20·836	20·861	20·777	20·927	20·831	20·935	20·734	20·891
Darjiling	20·918	20·865	20·820	20·988	20·852	20·865	20·815	20·956

Station.	1880.				1883.			
	January.	May.	July.	October.	January.	May.	July.	October.
Ajmere	20·951	21·003	20·793	21·075	20·899	20·938	20·789	21·084
Sutna	20·876	20·993	20·728	21·022	20·880	20·994	20·716	20·983
Hazaribagh	20·881	20·914	20·747	20·977	20·895	20·968	20·745	20·999
Chakrata	20·820	20·847	20·739	20·943	20·713	20·795	20·748	20·942
Ranikhet	20·800	20·833	20·746	20·921	20·777	20·828	20·756	20·925
Darjiling	20·821	20·848	20·820	20·956	20·814	20·820	20·805	20·948

Station.	1884.			
	January.	May.	July.	October.
Ajmere	20·989	21·039	20·829	21·052
Sutna	20·935	21·009	20·709	20·964
Hazaribagh	20·939	20·962	20·728	20·902
Chakrata	20·833	20·851	20·759	20·965
Ranikhet	20·844	20·855	20·768	20·902
Darjiling	20·877	20·820	20·810	20·953

These Tables suffice to prove that, even at a height of 10,000 feet, the pressure is subject to very considerable variations from year to year, both on the mountains and over the plains. The actual pressures observed were most variable at Ajmere, (allowance being made for the change in the elevation of the barometer), whilst on the mountains, as a rule, the variations were less than on the plains; but the great variations at Ajmere, especially in January, are partly discounted by reduction to 10,000 feet; high pressure at low levels being usually accompanied by, and doubtless the result of, low temperature. Accordingly, we find that the greatest range of the pressure at 10,000 feet, in January, is shown by Chakrata, and the next greatest by Darjiling; and this indicates that if, as we have seen good reason to believe, the direction of the wind is powerfully influenced by the distribution of pressure at high levels, it is more important, as far as the weather of the winter months is concerned, to know the variations of pressure from the normal at the highest hill-stations than at any place on the plains. In May there are considerable fluctuations over both regions, the greatest range being shown by Ajmere and the next greatest by Ranikhet; but in July the variations over the mountains, which are always more or less moist and equable in temperature at this season, are very small, the ranges not exceeding ·043 inch in the five years compared, while at Ajmere and Sutna they amount to ·144 and ·120 inch. In October, as we should expect from the fact of the mean temperature of the month being about the average of the year, and the normal distribution of pressure very uniform at all levels, the range of the variation is less than in any of the other three, and is greatest at Hazaribagh, which, during the first half of the month, is on the border of the region where the rains still penetrate after they have ceased in Upper India, while it also lies near the track of some of the October cyclones.

The great variability of pressure at 10,000 feet over Central India and Rajputana during the rainy season, which depends chiefly upon the still greater variability of temperature in the same region, is a good instance of the general tendency for any established set of meteorological conditions to persist by the interaction of cause and effect. An unusually high pressure in the upper atmosphere over this region in the months of May and June probably produces, as we have seen, westerly and north-westerly winds; these, being dry winds, neither cool the earth's surface by precipitation and subsequent evaporation, nor, by the interposition of a screen of clouds, prevent its temperature from rising high in the day-time; then, in consequence of the high day temperature in this region as compared with the Himalayas, which are more or less cloudy and moist, the pressure at 10,000 feet or other high levels remains relatively excessive; and again, in consequence of the high baric gradient thus conserved, the westerly winds continue to blow on, until some disturbance originating at a distance supervenes, or, as in 1877, until after the autumnal equinox, when the night begins to exceed the day in length, and the loss of heat by radiation to the clear sky over-balances the gain.

The mean gradients or pressure differences, measured more or less directly across the Gangetic plain, in each of the months compared in Table XVIII., are given in Table XIX., the figures representing thousandths of an inch, and the positive sign indicating a gradient for westerly winds, *i.e.*, meaning that the higher pressures belong to the southern stations, such being the most frequent condition.

TABLE XIX.—Pressure Differences over the Gangetic Valley in Thousandths of an Inch.

Year.	Ajmere—Chakrata.				Sutna—Ranikhet.			
	January.	May.	July.	October.	January.	May.	July.	October.
1877 . .	+137	+199	+153	+ 61	+ 64	+142	+52	+ 79
1879 . .	+149	+179	+106	+146	+ 90	+ 59	−25	+ 31
1880 . .	+131	+156	+ 54	+132	+ 76	+160	−18	+101
1883 . .	+186	+143	+ 41	+142	+103	+166	−40	+ 58
1884 . .	+156	+188	+ 70	+ 87	+ 91	+144	−59	+ 62

Year.	Hazaribagh—Darjiling.				Mean of the three Pairs of Stations.			
	January.	May.	July.	October.	January.	May.	July.	October.
1877 . .	+ 21	+109	−21	+31	+ 74	+150	+61	+57
1879 . .	+ 86	+116	−48	+18	+109	+118	+11	+65
1880 . .	+ 60	+ 66	−73	+21	+ 89	+127	+12	+85
1883 . .	+ 81	+148	−60	+51	+123	+152	−20	+84
1884 . .	+162	+142	−88	−51	+136	+158	−26	+33

On comparing this Table with the figures given above for the variations of rainfall, it will be seen that, in the worst years, 1877 and 1880, the mean gradients for January were least, indicating the probable existence, for a considerable number of days in the month, of moist south-easterly currents, bringing the snowfall, which, according to Mr. BLANFORD's theory, was the cause of the subsequent drought. These moist winds were observed in January, 1877, on the plains; but in 1880, as Mr. BLANFORD has pointed out in the paper above quoted, they were confined chiefly to the higher valleys and slopes of the Himalaya. In May, the variations of the pressure differences are less evidently connected by any rule, and in July there apparently is in the mean of the three pairs of stations a nearly uniform decrease in the gradients for westerly winds or an increase in those for easterly ones during the eight years from 1877 to 1884.

It does not seem right, however, to group the Hazaribagh-Darjiling pair with the others, as the character of the rainfall of any season in Bengal is usually different from and often opposite to that which obtains in Upper India. Thus, in 1883, in which the gradients over West Bengal appeared rather favourable for rainy winds, the defect of rainfall in that province was only 4 per cent., as against 17 per cent. in the upper provinces, and this small defect may possibly be explicable by other causes;* whilst in 1880, during which the gradient between Hazaribagh and Dar-

* For example, the diminished absolute humidity of the air, owing to the temperature being below the average. The mean temperature of the whole of India in 1883 was 0·48° below the average, and the vapour tension was ·013 inch in defect.

jiling was still more favourable for easterly winds, there was an actual excess of rainfall over the Bengal provinces, amounting to 10 per cent., against a defect of 20 per cent. in Upper India.

The character of the Ajmere observations for accuracy, moreover, is not nearly so high as that of the work of the Sutna observer, and the barometer at Ajmere has been several times changed, while there has also been a change in its position during the years compared. Hence, though every care has been taken to correct the observations for such changes, it is possible that there may be some residual errors undetected, which, though negligible, or nearly so, in the mean of a long term of years, many of which were anterior to the changes mentioned, may introduce some confusion in comparing the observations of single years. For these reasons, it is probable that the best criterion of the pressure gradients, prevailing over Bundelkhand, Rajputana, and the North-West Provinces, will be a comparison of the observations of Sutna and Ranikhet.

Thus estimated, the gradient for westerly winds was relatively high in May, July, and October, 1877. It was low in May and October, 1879, and in July there was a considerable gradient for easterly winds. In 1880, the gradient for westerly winds was high in May and October, and there was a small gradient for easterly ones in July; thus, on the whole, the upper winds were such as to make the rainfall less than usual. In the dry year, 1883, the gradients for westerly winds were greater, or for easterly ones less, than in the wet year 1884, both in May and July; but in July, 1883, there was nevertheless a rather high gradient for easterly winds, contrary to what might be expected. It was in August, 1883, however, not in July, that the principal deficiency of rain occurred.

The verification of theory by means of the deductions from observations embodied in Table XIX. being thus less definite than is desirable, it will be worth while to work out the pressure gradients between Sutna and Ranikhet for the other months of the rainy season in each of the years compared. Table XX. gives the pressures at 10,000 feet for the months of June, August, and September.

TABLE XX.—Pressures at 10,000 feet for the other Months of the Rainy Season in certain Years.

Year.	Sutna.			Ranikhet.		
	June.	August.	September.	June.	August.	September.
	"	"	"	"	"	"
1877 . . .	20·907	20·836	20·968	20·832	20·810	20·892
1879 . . .	20·857	20·730	20·824	20·772	20·718	20·829
1880 . . .	20 881	20·811	20·911	20·765	20·781	20·842
1883 . . .	20·875	20·801	20·858	20·782	20·785	20 840
1884 . . .	20·903	20·752	20·828	20·793	20·779	20·851

Combining the differences of these figures with those for the same pair of stations in Table XIX., we get the following results for the whole summer half-year, that is to say, for the six months May to October inclusive, during which almost the whole rain of the year falls on the Gangetic plain.

TABLE XXI.—Pressure Differences between Sutna and Ranikhet for the Summer Half-Year.

Year.	May.	June.	July.	August.	September.	October.	Mean.
1877 . .	+142	+ 75	+52	+26	+76	+ 79	+75
1879 . .	+ 59	+ 85	−25	+12	− 5	+ 31	+26
1880 . .	+160	+116	−18	+30	+69	+101	+76
1883 . .	+166	+ 93	−40	+16	+18	+ 58	+52
1884 . .	+144	+110	−59	−27	−23	+ 62	+34

In Table XXI. the relation between the pressure differences and the rainfall variation becomes quite clear. The driest years, 1877 and 1880, had the largest gradients for westerly winds, that is to say, in those years, easterly winds at high levels over the plains of Northern India were probably infrequent, or restricted to an unusually narrow belt along the Himalayas; on the other hand, the wet years, 1884 and 1879, had the smallest gradients, or in those years the easterly upper currents were steadiest, and reached their widest extension; while in the moderately dry year, 1883, there was a considerable gradient for westerly winds, but nothing like so great as in 1877 and 1880. If the month of May be left out in striking the mean for the season, the relation indicated becomes still more distinct; thus—

Year.	1877.	1879.	1880.	1883.	1884.
Mean gradient for 5 months . .	+62	+20	+60	+29	+13
Rainfall variation per cent. . .	−35	+ 5	−20	−17	+16

It appears, therefore, from this analysis of the observations, that the theoretical deductions from KÖPPEN's convection hypothesis are fairly substantiated by experience; that in years of unusually heavy snowfall, and consequent cold, over the North-West Himalaya the pressure gradients producing westerly winds in the upper atmosphere are intensified, and that in consequence of this the easterly winds, which prevail as far south as the Ganges up to the level of the lower cirrus clouds in the rainy season of average years, are greatly restricted in horizontal extent, and doubtless also in height as well as in time, the result being a diminution of the rainfall, sometimes to a disastrous degree.

Though these conclusions are substantiated by the average of the observations of five or six months, they are not completely borne out by those of any single month, except September, and from Table XXI. it would appear impossible to predict in May or June what will be the prevailing pressure difference later on in the year. The irregularities in the pressure differences deduced from the observations of single months may, however, as already pointed out, be due in great part to the uncertainty of the assumed rate of decrease of temperature, which, while probably nearly true, or at all events giving consistent results when applied to the average of many years' observations for any calendar month, or even to the mean for five or six consecutive months of a single year, may be very considerably in error when applied to the observations of one month standing by itself.

On making a retrospective survey of all the evidence put forward in the preceding pages, it will, I think, be generally admitted that the hot winds of Northern and Central India cannot be satisfactorily explained by the distribution of pressure at the earth's surface, and that Köppen's hypothesis of convective interchange between the upper and lower strata is probably the true explanation of them, (1) because the vertical distribution of temperature is such that convective action must take place; (2) because the diurnal variation of the intensity of these winds and their characteristic dryness suggest such an origin for them; and (3) because the distribution of pressure at 10,000 feet above sea-level in May is such as to produce winds of the observed direction.

The distribution of the upper currents as suggested by the charts also elucidates many other obscure points in the wind system of India, and the same hypothesis of the origin of the westerly winds gives a rational explanation of the law worked out by Mr. Blanford connecting the spring snowfall of the North-west Himalaya with the rainfall over the plains during the succeeding summer monsoon.

If these conclusions have not been all completely established, as I am by no means desirous of asserting, they have, I think, been shown to be sufficiently probable to warrant a more complete examination in detail by the determination, if possible, of more trustworthy rates of temperature decrement with height than those assumed in this paper, and by the systematic preparation of high-level pressure charts for the whole of India, month by month.

Description of the Plates.

Plate 19 shows the isobars or lines of equal pressure at sea-level over India and the Bay of Bengal for the months of January, May, July, and October; typical respectively of the cold, the hot, and the rainy season, and the autumn transition period. The pressure, indicated by each line, is represented by the figures attached to it, those for successive lines differing by ·05 inch. The pressures have all been corrected for variations of gravity with latitude. The charts also give the prevalent wind directions at the more important stations, these "resultant" directions having been computed by means of Lambert's formula from the observations of many years.

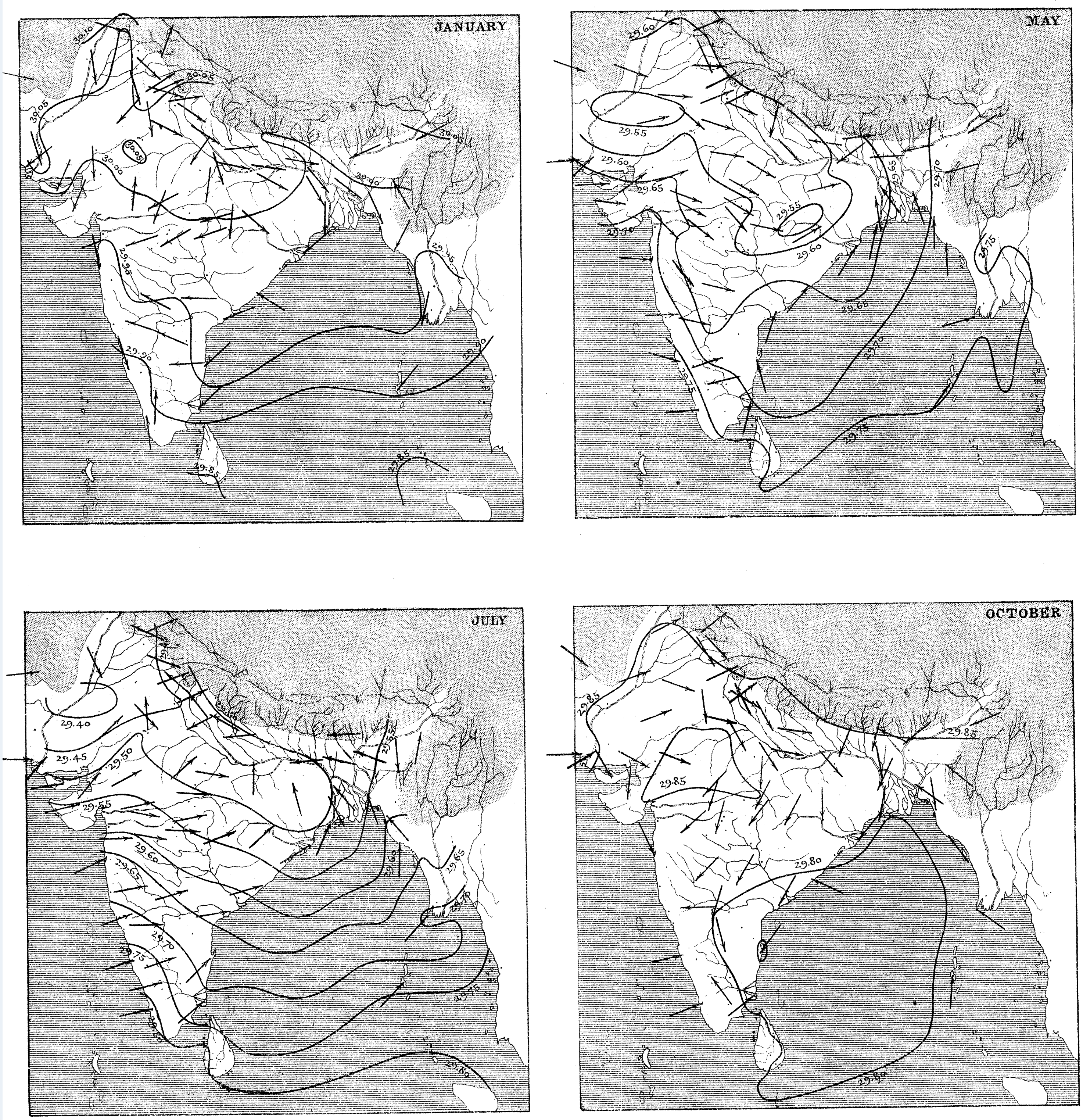
Plate 20 gives the isobars for a stratum of the atmosphere 10,000 feet above sea-level.

The pressures represented are not, however, mean pressures, but those prevailing in the middle of the day, between 10 A.M. and 4 P.M. They have been computed from the observations made at 40 stations (including nearly all those above 1500 feet) by assuming the temperature to decrease at the rates represented on Plate 21, and applying a Table computed by Major ALLAN CUNNINGHAM, R.E., on the basis of Professor RANKINE's modification of LAPLACE's formula.

Plate 21 shows the probable rate of decrease of temperature, on ascending, in the day time, through the atmosphere over a plain; the form of the curves, which are slightly different for clear and cloudy skies, being deduced from Mr. GLAISHER's observations made during balloon ascents. The straight line shows the theoretical rate of temperature decrement in a mass of air carried upwards without gain or loss of heat.

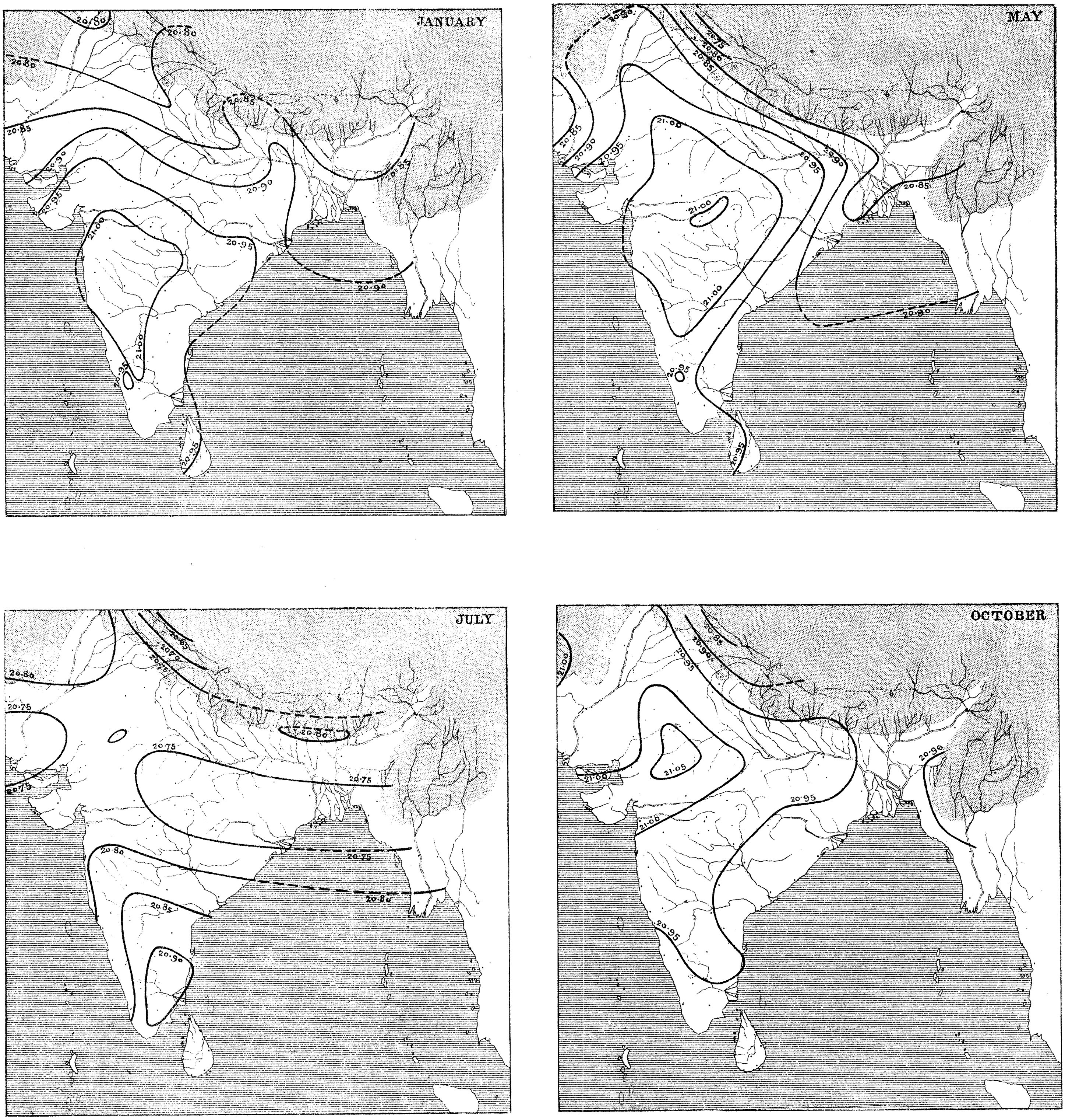
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

MEAN PRESSURES AT SEA-LEVEL



West, Newman & Co. lith.

MID-DAY PRESSURES AT 10,000 FEET



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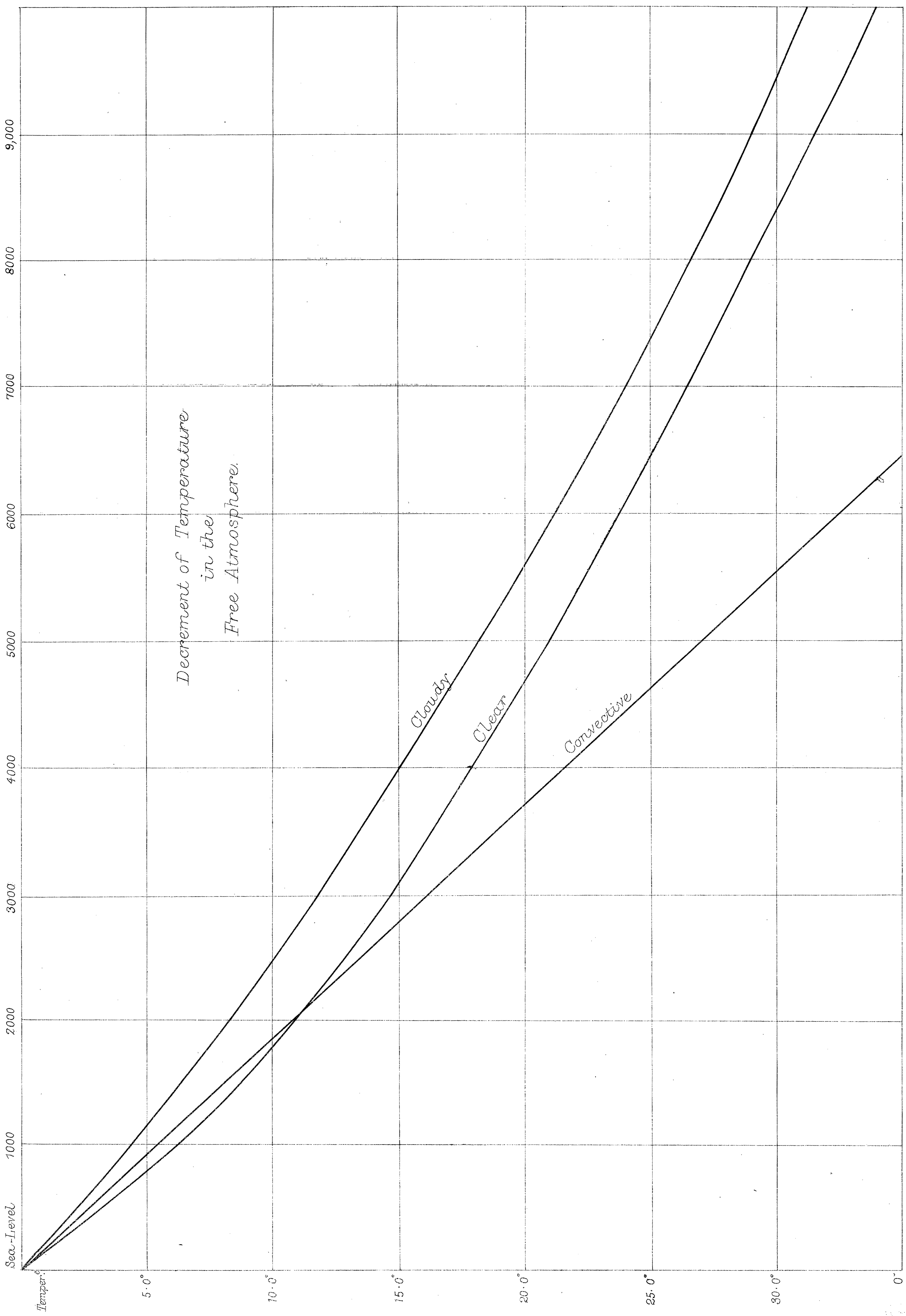
Decrement of Temperature in the Free Atmosphere.
Cloudy
Clear
Convective
Sea-Level
1000
2000
3000
4000
5000
6000
7000
8000
9,000
Temper.e
5·0°
10·0°
15·0°
20·0°
25·0°
30·0°