(*e.*) A branch to the substance of the thalmus.

(*f.*) The direct sensitive band joining the posterior third of the posterior limb of the inner capsule.

(*g.*) A large mass of fibres which runs between the Island of Reil and the tip of the occipital lobe.

10. In the evolution of the brain it seems very probable that the functions of the thalamus and corpora quadrigemina as optic centres are transferred in man and certain mammals in great part to the cerebral cortex.

11. The cortical fibres which I have described are probably not all connected with visual centres, but are one means by which motor and other centres of the cortex are educated, and their function elicited in response to visual stimuli.

II. "On the Connexion of the Himalaya Snowfall with Dry Winds and Seasons of Drought in India." By Henry F. Blanford, F.R.S. Received April 14, 1884.

The present paper, as regards its subject-matter though not in form, is part of a general investigation of the rainfall of India, which has occupied much of my spare time for some years past, and the results of which are already partly embodied in a memoir which I hope, in the course of a few months, to issue as an official publication of the Indian Meteorological Office. The idea that the snowfall of the Himalaya exercises a direct and important influence on the dry land winds of North-Western India is not now put forward for the first time. It has been the subject of frequent reference in the annual reports on the meteorology of India since 1876, as well as elsewhere; and in a report on the administration of the India Meteorological Department lately issued, I summarised very briefly those points in the experience of the previous five years which have seemed to justify its provisional adoption as a basis for forecasting the probable character of the monsoon rains.

Relying on this experience, in the month of June last, I put forward in the Government Gazette, a note giving warning of the probability of a prolonged period of drought in the approaching monsoon season, and the result, if not in exact accordance with the terms of the forecast, has been so far confirmatory of the general idea, as to induce me to put the facts of past experience formally on record, and thereby challenge attention to the subject. If I am right in the inference that the varying extent and thickness of the Himalayan snows exercise a great and prolonged influence on the climatic conditions and weather of the plains of North-Western India,

it is probable, that with more or less modification according to the local geography, causes of a similar character will be found equally operative in other regions, and perhaps on an even more extensive scale.

Empirical Grounds of the Hypothesis.

The Year 1876 *and* 1877.—The probable dependence of dry land winds and of periods of drought on the extent of the Himalayan snowfields first occurred to me when inquiring into the meteorology of India in 1876, a year disastrously notorious for that failure of the rainfall which produced the last great famine in Madras and the Deccan; and the first reference to the subject, as far as I am aware, will be found in the official report for that year. In summing up the results of the detailed description of the meteorological features of the year, and in tracing out the apparent dependence of the drought on the remarkable and unseasonable persistence of dry north-west winds down the whole of Western India, I was led on to connect these successively with the high pressure prevailing in the Upper Provinces and Bombay, relatively to Orissa and Eastern India, and with the low temperature of North-Western India in the spring of the year, as contrasted with the abnormally high temperature of the east of the peninsula, and I remarked* that this latter fact seemed "to argue that some cooling influence more potent than usual was at work, probably in the Punjab and on the northern mountain zone, condensing the lower strata of the atmosphere and causing an unusual outflow of cooled air." A few lines further on, it was observed, "it has been shown in the foregoing description of the rainfall, that in the early months of the year, the rainfall was unusually copious over the North-Western Himalaya,† and the plains of the Punjab which border the foot of the mountains, and indeed, on the North-Western Himalaya the rainfall was above the average, more or less, throughout the greater part of the year. The rain on the outer hills is most frequently accompanied by snow on the main and higher ranges, and indeed, when I visited Rawalpindi in the early part of April, 1876, I was informed that snow lay in some thickness at Murree, a very unusual occurrence so late in the season, and the slopes of the Pir Punjal were visibly snowed down to a low level. The question is therefore naturally suggested, whether the great expanse of snow, presented under the circumstances by the southern slopes of the Himalaya, and much of which fell unusually late in the season, was not that cooling agent, to the existence of which the

* *Op. cit.*, page 96.

† As will be seen further on, this is rather overstated. The heavy unusual fall was restricted to March and April, and the total of the whole season was not above the average, except at Rawalpindi and one or two other stations.

winds, the temperature, and the pressure equally testify. That it was so seems not improbable."

The report containing these passages was written in the autumn of 1877, a second season of drought; but, in this year, most intense in the North-Western Provinces and the plateau of Rajputana and Central India, which provinces were swept persistently, up to the very close of the summer monsoon season, by parching land winds from the north-west and west. In the passage immediately following the above quotation, this fact was noticed in the following terms :—"In the early part of the present season (1877) the same phenomenon (an unusual snowfall) was repeated, and with even greater intensity, and this year the land winds have been so persistent in the upper provinces, and on the plateau south of the Ganges, as to cause an almost complete failure of the summer rains in that region; while again, those of Bengal have been up to the fall of an average season." And in a postscript to the report was given an extract from Colonel (now General) J. P. Walker's report on the operations of the Great Trigonometrical Survey, viz., a passage taken from the narrative report of Mr. E. C. Ryall, in charge of the Kumaon and Garhwal party of the Togographical Survey. It is as follows :—"The winter of 1876–1877 proved to be the severest known for many years past among these hills; the spring was wet and cold, and felt quite wintry. . . . . (The wet weather) continued with few intermissions till the 8th June, the most noticeable break, up to that time, being from the 9th April up to the 17th. . . . . Mountains which in ordinary years had their snow-line, at the end of April, at an elevation of 12,000 feet above sea-level, were mantled with snow down to 9,000 feet, and valleys which, at that time of year, used to be clear of all snow up to 10,000 feet, were literally choked with snow down to 6,000 feet; this accumulation in the valleys being caused by snowdrifts and avalanches from the mountain sides."

Messrs. Hill and Archibald's Law.—Meantime evidence of a very important character bearing on the subject in hand, was brought to light from a different quarter. Shortly before the above report was completed and sent to press, Mr. Douglas Archibald* and Mr. J. A. Hill,† in discussing the rainfall of certain stations in Northern India in connexion with the periodical sun-spot variation, a question attracting much interest at the time, had independently arrived at a conclusion which, although reached from a very different starting point and empirical in form, obviously tended to confirm the view above set forth, and indeed, seemed to find its rational explanation in that view. This was that "the winter rains of Northern India are generally heavier when the total fall of the year is below the

* "Nature," vol. xvi, p. 339.

† Report to the North-West Provinces Government.

mean than when the summer rains are excessive." In an elaborate paper subsequently drawn up by Mr. Hill and published in 1879, in vol. i, Part 3, of the "Indian Meteorological Memoirs," he has rediscussed the subject, at considerable length, and has put forward his matured views based on much more extensive evidence. Instead, therefore, of quoting further from his or Mr. Archibald's original writings, I will take the statement of his conclusions as set forth in the postscript to his later paper. This is as follows:—*These results strongly support my original conclusion, that the winter rains are heaviest when the summer rains are defective, and *vice versâ*. They also support the idea put forward by Mr. Blanford, in his report for 1876, that an unusual amount of precipitation over Northern India and the Himalaya, in winter and spring, may, by modifying the normal distribution of pressure, cause the rainfall of the succeeding summer to be defective in the Gangetic Valley, though of course they throw no light on the question of the influence of the Himalayan snowfall on the meteorology of the Bombay Presidency.

"Thus the following twelve years had the winter rainfall excessive, and that of the summer defective, viz., 1845, 1850, 1851, 1852, 1853, 1859, 1865, 1866, 1868, 1869, 1877, and 1878; and the thirteen years 1846, 1847, 1854, 1856, 1858, 1861, 1862, 1863, 1867, 1871, 1873, 1874, and 1875, had dry winters followed by wet summers. Against these twenty-five instances in favour of the rule, we have only three years, 1855, 1870, and 1872 with the rainfall excessive at both seasons, and six years, 1848, 1849, 1857, 1860, 1864, and 1876, with a deficiency both in summer and winter."

The Contrast of the Mountain Winter Rainfall and Summer Rainfall on Plains.—Mr. Hill's conclusion, as above stated, is based on a comparison of the winter rainfall (November to April) of the North-Western Provinces, with that of the summer (May to October) in the same area, and the statistics of the former term of comparison, as well as those of the latter, are furnished therefore chiefly by stations on the plains of Northern India. In general, no doubt, precipitation on the mountain zone varies more or less *pari passu* with that on the plains. But still, this is only true as a rough generalisation. The terms involved in the hypothesis now under discussion are strictly and rigorously, on the one hand, the winter and spring snowfall on the hills, and on the other, the summer monsoon rainfall on the plains. Moreover, Mr. Hill has included in the summer rainfall that of the month of May. As regards the plains this is perhaps admissible, but in the North-Western Provinces the May rainfall is not, strictly speaking, that of the summer monsoon rains. It is either due to diurnal storms, or to what is known as the *chhota barsát*, or little rains, a burst of rainy weather, which frequently precedes the

* "Indian Met. Mem.," vol. i, p. 209.

regular rains, and is followed by a fortnight or more of dry hot weather. On the hills, as occurred in the present year (1883), it frequently takes the form of snow on the higher ranges, and when very copious is rather prejudicial to the monsoon rains.

In the following table, therefore, I have taken as representing the winter and spring rainfall, the total from January to May inclusive at twelve stations, either on the Himalaya or situated immediately at its foot. The table gives the annual precipitation since 1864 (as far as it is on record) in the form of percentages of the local averages for the same season, and the last line but one is the means of the figures in each column. The last line shows the subsequent summer rainfall of the North-Western Provinces, also in the form of a percentage of the general average of that season; the figures up to 1878 being taken from Mr. Hill's memoir.

As might have been anticipated from the stricter character of the test now applied, the results shown in the above table are even more favourable to the hypothesis than those educed by Mr. Hill. Of the eighteen years enumerated in the table, fourteen give confirmatory and only four adverse evidence. And of these four years, one (1876) is that the conditions of which originally suggested the hypothesis as already recounted above, and another (1880) apparently the most discrepant of all, I shall presently refer to, as affording in the very anomalies two of the most striking illustrative instances of its validity. The remaining two exceptional years, 1866 and 1872, I have no means of satisfactorily investigating.

The year of the heaviest winter and spring rains, shown in the table (1877), is that already referred to as one of an almost unprecedentedly heavy snowfall in the Himalaya, and it is also that of the smallest summer rainfall of the eighteen years. The two years which come next in order of winter raininess, viz., 1878 and 1865, had comparatively but a small deficiency of the summer rainfall. But it is certain that the Himalayan snowfall in the early months of 1878 was far from being comparable with that of the previous winter. Nevertheless, the rains were much retarded, so much so, as to give rise to serious anxiety. In the North-Western Provinces there was scarcely any heavy rain before the 6th or 7th of July, and after a few day's fall, a break set in which lasted up to the end of the month.*

The experience of this year, and also that of 1876, and, as will presently be shown, that of 1880, proves then, that the copiousness of the winter and spring rainfall on the outer Himalaya is by no means an exact criterion of that of the snowfall on the higher ranges; and it is only appealed to in evidence, in the absence of any regular reports on the snows, with which we are more immediately concerned. But apart from this consideration, I may here observe, that there was

* See Report on the Meteorology of 1878, pp. 135–137.

Annual Rainfall of the North-Western Himalaya from January to May as percentages of the local averages of that season, compared with the summer monsoon rainfall of the same years in the North-Western Provinces and Oudh; also as percentages of the season's average.

	1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	1881.
Peshawar	67	144	106	81	102	76	39	103	123	105	102	82	105	194	182	53	15	119
Abbottabad	150	136	88	119	148	123	47	94	159	66	87	86	81	165	157	44	39	127
Murree	..	..	..	..	..	..	54	96	138	72	92	86	99	182	143	35	34	171
Rawalpindi	130	97	96	94	82	168	17	61	137	74	107	57	140	182	190	31	43	92
Dharmsala	108	184	67	90	151	106	53	89	74	81	107	75	86	178	149	66	79	101
Simla	207	161	56	75	114	68	82	79	105	72	91	96	89	153	150	48	101	123
Chakrata	..	..	..	..	..	101	86	51	65	64	58	94	106	200	183	68	125	100
Dehra	100	259	109	94	164	124	108	67	157	56	133	151	49	177	185	59	114	86
Ranikhet	..	..	..	..	..	..	..	..	..	..	..	..	94	87	247	60	84	130
Naini Tal	80	158	95	77	146	111	71	102	105	82	53	105	40	180	113	64	84	92
Almora	64	156	100	86	131	122	88	116	122	80	96	112	100	147	185	67	85	122
Paori	85	161	83	67	146	92	81	110	135	78	67	73	58	204	129	54	89	85
Means January to May	110	162	89	87	131	101	66	88	120	75	90	99	84	171	168	54	74	112
Mean monsoon rainfall in the N.W. Provinces.	69	95	92	135	66	97	121	131	111	101	131	14	93	45	90	134	69	98

another condition which influenced, in a very important degree, the meteorology of the years 1876 to 1878, which may indeed have originated in conditions more or less similar to the above, but was of far wider incidence, and must have been determined by circumstances operating far beyond the limits of our area. This condition was that excessive atmospheric pressure which, from August, 1876, to August, 1878, prevailed continuously over India, and which I have noticed at length in the Report on the Meteorology of India in 1878.* In India this was at its maximum from July to September, 1877, and its disappearance in Northern India in August, 1878, about coincided with the abundant influx of the monsoon rains of that year. In Southern India it had disappeared earlier, viz., in May. During the northern summers of 1876 and 1877 it was even more excessive in extra-tropical Asia on the one hand, and in Australia (in the southern winter) on the other, than in India. It was probably the presence of this condition in the monsoons of 1876 and 1877 and its absence in the latter part of that of 1878 which in part, at least, determined the differences in the rainfall of these years. Still, this is no argument against the local influence of the Himalayan snows, for which there is ample independent evidence. It only shows that the latter were not the sole cause operating in those years.

To return to the consideration of the facts shown by the table. The two years with the smallest winter rainfall, viz., 1879 and 1870,† when it amounted respectively to only 54 and 66 per cent. of the general winter average, were years of very plentiful summer rains, that of 1879 being one of the highest on record, and one-third in excess of the average, while that of 1870 was as much as 21 per cent. in excess. In three other years, in which the excess of the summer rains amounted to as much or nearly as much as in 1879, the winter rainfall on the North-Western Himalaya had been from 10 to 13 per cent. below the general average.

Evidence of the Exceptional Year, 1880.—The facts of the deficient rainfall of 1880, both in the winter and summer seasons, are of especial interest in relation to the present discussion. In this year the winter rainfall was on the whole considerably below the average, but in February there was a heavy fall of snow on the North-Western Himalaya, when according to a report received from the Commissioner of Kumaon, General Sir H. Ramsay, " the fall of snow in Almora came down to a lower altitude than it had been known to do for many years."‡ Further, with respect to the mountains around

* *Op. cit.*, pp. 53–58.

† It is noteworthy that Mr. Hill adduces 1870 as a year of winter rainfall above the average, and therefore as affording adverse evidence. This is, of course, due to the different method in which he has treated the data.

‡ Report on the Meteorology of India in 1880, p. 166.

the sources of the Ganges, the report states "The winter has been an exceedingly severe one; snow fell at Srinagar (in the Ganges valley), Ramri, Palinda (a few miles north of Katawara), places where it was seldom seen." The months of March and April which followed were of excessive dryness. Scarcely a drop of rain fell in these two months on the plains of the North-Western Provinces, the Punjab, Rajputana, or Central India, and in May, June, and July, except in the Punjab and the most northerly of the adjacent districts of the North-Western Provinces, the fall was considerably below the average. But in June and July there was heavy rain in the Eastern Punjab and on the North-Western Himalaya. In July, "on the hills the rain was almost continuous; at Dharmsala, there was but one day in the month on which no rain was registered, and at Simla but seven days."* The rain was equally heavy in the hills of Kumaon and Garhwal, and as appeared from information subsequently received the precipitation extended far into the heart of the mountain zone. Major Biddulph, then stationed at Gilgit, in the north-west of Cashmere, wrote to me to the effect that the weather was unusually stormy in Northern Cashmere throughout July, and that "the rain and snowfall on the mountains have been such as are unprecedented at this season." Also a letter from the Reverend Mr. Heyde, stationed at Kailong in Lahoul, reported "such weather as Major Biddulph experienced in July of this year . . . . we certainly had also in Lahoul, about the same time. It commenced on the 1st July with heavy rain, which, after a few hours, changed to snow, and lasted till the 6th. The snow fell heavily for three successive days, doing much harm. Ponies, cattle, sheep, and goats grazing on the higher hills perished in large numbers in the snow, &c." This unseasonable snowfall was followed, in August, by an almost entire suspension of the rains on the plains of North-Western India. As described in the official report on the meteorology of the year, "August was conspicuously a dry month in India, and to some extent in Burmah. Indeed the last half of the month was almost rainless in Northern India; and dry westerly winds set in, which recalled, for the time, the disastrous seasons of 1876 and 1877, and seemed to justify the most gloomy forebodings." In the Western Punjab there was no rain, and in the Eastern Punjab and the North-Western Provinces, except in the eastern districts and in Kumaon, it was practically rainless after the 12th or 14th. In Rajputana and the States of Central India, although the rainfall of the month was very deficient, the deficiency, except in the eastern States, was much less than on the Gangetic plain and in the Punjab. Even in the Central Provinces, with one or two exceptions, the fall was very deficient.

It is not then too much to say that this very exceptional year (as

* Report on the Meteorology of India in 1880, p. 149.

tried by the rough test of contrasting the winter rainfall on the hills with the summer rainfall on the plains) affords some of the most striking evidence in support of the hypothesis that the snows favour the production of dry land winds on the plains, and is eminently one of those exceptions that tend to prove the rule.

Negative Evidence of the Years 1881 *and* 1882.—I may pass rapidly over the years 1881 and 1882, which presented no feature of striking importance. The winter of 1880–81 was one of light snowfall. There was a moderate fall in March, 1881, and the succeeding April and May were dry and seasonable, characterised chiefly in Rajputana and Central India by hot land winds of somewhat more than usual steadiness.* The rains set in and came to an end somewhat earlier than usual, but the rainfall, with merely local exceptions, was well up to the average, and in some parts of Northern India somewhat above it.

The winter of 1881-82 also was on the whole dry and mild. In Kumaon, Sir H. Ramsay reported it as "unusually mild;" and Mr. Ney Elias, writing from Leh, on the 5th April, stated that, "the snow has been extraordinarily light this year in Ladak, and the winter altogether unusually mild . . . . . Even high altitudes are much less covered than usual." But he adds, "I hear from Dias that the snow on the outer range (at and near the Yogi pass) is as heavy as ever. In fact, the snowfall is very partial and irregular in these mountains." The rains set in early and copiously on the Bombay side; and up to the end of July, in Western and North-Western India, were even excessive; but a change took place in August, and though there was no period of actual drought, the fall during a part of August was light throughout the north-west of India, and notwithstanding the recurrence of heavy rain in the latter part of the month, the total fall of the season was somewhat below the average in the North-Western Provinces, and more so in the eastern than in the western districts.

The Year 1883. *Forecast of Drought and the Result.*—In previous years, the available information respecting the snowfall had been meagre, and had had reference to only one or two districts in the Himalaya. But having now been convinced of the high importance of the subject, I took steps, by private correspondence, and officially with the aid of the local governments, to obtain more numerous and detailed reports. In December, 1882, and the early part of January, 1883, the season was fine and warm; but on the 10th the ordinary cold weather rains set in in the upper provinces, and snow fell at Taini-Tel and some other stations. During the remainder of the month the falls were frequently repeated on all parts of the North-Western Himalaya, and from the night of the 24th to that of the

* Report on the Meteorology of India in 1881, pp. 85, 86, 111, 171, 175, &c.

27th snow fell almost without intermission, and down to levels at which it has rarely been known. At Simla it accumulated to a thickness of 5 feet, on surfaces free from drifts, and even at Rawalpindi, at a distance from the mountains, on the plain of the Patwar, and only 1700 feet above the sea, it lay to a depth of 4 inches on the night of the 27th, an occurrence stated to be without precedent in the memory of the inhabitants. At Murree, the Deputy Commissioner reports the total aggregate fall of January to have been 26 feet, but this seems to require confirmation, if by this statement it is implied that the measurement was made in undrifted snow. At Chamba it was stated to be 9 or 10 feet.

The falls were repeated frequently in February and March, though less heavily, and these additions to the unmelted residue of the previous accumulation caused the mountains to retain their snow mantle down to low levels at a time when, in years of less abundant precipitation, it is restricted to the greater altitudes and occasional hollows at 12,000 or 13,000 feet. The area of the unusual fall was very extensive. It included Kumaon and Garhwal, Sirmoor, and a portion of Bissahir, Kangra, and Hazara. But in the valleys and passes to the north-east and south-east of Wangtu (in the Sutlej valley) the fall was small as compared with former years.* So also at Sultanpur and Plach in the Kulu valley, the fall was considered to be below the average, and in Lahoul and Spiti it was unusually light. In Chamba the fall was abnormally heavy on the first snowy range between the Ravi and Chenab, but on the north-east of the range it was light, and "the Pangi men complained that they had not had enough snow."† In Hazara, the Deputy Commissioner reported that "the snowfall is unprecedented since 1877 (the winter previous to the scarcity of 1877–78);" and Colonel Sir Oliver St. John, writing from Jamu on the 28th February, informed me "there was a heavy fall of snow in the Kashmir valley, and over the Pir Punjal range at the end of last month, but I do not learn that it was anything out of the common." Also Mr. Ney Elias, writing from Leh, states that "last winter was a very open one in Ladak, and both ranges and valleys were unusually lightly covered till the beginning of May."

These reports show that the abnormal snowfall was restricted to the outer Himalaya and the first snowy range; but over this region it was very thick and lasting. During the latter part of January and in February and March, the weather over a great part of Northern India was exceptionally cold. But the temperature rose in April, and May was a hot and remarkably dry month up to the 21st. The dryness was greatest on the North-Western Himalaya; the relative

* As reported by Mr. G. G. Minniken, Assistant Superintendent of the Hill States.

† In a letter from Major C. H. Marshall, Superintendent of the Chamba State.

humidity of the air at Chakatra on the 19th and 20th, at 10 A.M., being only 8 per cent. of saturation (according to the telegraphic report), or 45 per cent. below the general average of the month of May. Great heat and dryness prevailed also with the westerly winds over the whole of extra-tropical India, with the exception of Bengal and Assam.

In Ladak, however, very bad weather set in in the beginning of May, and lasted nearly a month. This thickened the snows, and for a time brought the snow-line down to about the ordinary March level. In the last week in May the weather again became clouded over Northern India and the outer Himalaya; the temperature fell, and on the 28th and 29th another heavy fall of snow took place on the mountains, whitening their sides down to 10,000 or 11,000 feet.

In was under these circumstances that the following notes were published in the "Gazette of India" (2nd June). The first was written on the 18th May, when the dryness of the air was about at its maximum, and a day or two before the change set in that culminated in the snowfall of the 28th and 29th May. The second was written on the 31st May, immediately after the fall.

I. "That the unusually dry weather now prevailing over the North-Western Himalaya, and that which, though less abnormal, characterises the whole of North-Western India at the present time, is an effect of the unusual accumulation of snow, is a conclusion justified by the experience of the last few years; and were it not that the snow is rapidly decreasing under the unobstructed radiation of the sun, there might be some reason, judging from the present limited experience, to anticipate some retardation of the rains in the upper provinces, and possibly even in Western India generally. But, on the other hand, the fact that during the months of April and May the atmospheric pressure over the greater part of the country has been below the normal average of the season, is one which . . . . portends favourably for the timely influx of the monsoon. In Bengal it may be said the prospects are wholly favourable."

II. "Since the above was written there has been heavy rain for many days on the outer hills, and more or less on the plains of the Punjab, and apparently a very heavy fall of snow on the higher ranges . . . . If, therefore, the mountains of Lahoul, Spiti, and other more distant ranges have shared this fall, if it is as extensive as it is apparently heavy on the visible ranges, and if the views which the experience of recent years seem to justify, viz., that an unusual extent and thickness of snow on the Himalaya is productive of dry north-west and west winds in North-Western India are valid, we must be prepared for a long spell of dry weather and a retarded rainfall in the upper provinces."

June was a very dry month in the upper provinces and Rajpu-

tana. In Bengal the rains set on in the 13th, which is a day or two in advance of the average date, but they extended inland only as far as Behar, with a moderate fall up to Allahabad. Further westward there were occasional thunderstorms, but no heavy rain fell before the 26th, nor in the Punjab before the 29th, and even then it was not continuous. On the 2nd or 3rd July, in writing a summary of the weather of the previous month, Mr. Dallas remarks:—"In parts of the North-Western Provinces and the Punjab continuous rain has hardly yet set in."

In Rajputana there was scarcely any rain in June, but the month was decidedly cool; and in Bombay and Gujarat also the temperature was below the average. In Bombay the monsoon did not set in steadily before the 24th, and the rainfall was light throughout the month. This coincidence of deficient rainfall, and a temperature below the average, is unusual.

During the first half of July rain was frequent and heavy on the North-Western Himalaya; but, according to my own observations at Simla, this rainy period presented one or two noteworthy features. In the first place, thunderstorms were repeated day after day; and, secondly, the rain was frequently accompanied with hail. These accompaniments are characteristic of the storms that precede the rains, and are exceptional in a rainy season of the normal character. As far as my experience goes, they indicate an unsteady monsoon or its approaching termination, and the existence of a dry current at no great elevation above the rain clouds. Certain it is, that at frequent intervals during this rainy period the existence of such a current was rendered evident by the drift from the north-west of small broken cloud tufts, or by the inclination and movement of the tops of the rain clouds, when the lower current was from some southerly direction, generally up-valley.

About the 19th July the rains ceased, except for occasional thunderstorms, and from that time to the end of August this north-west current held full sway, frequently down to the surface of the hills (7,000 feet), but more generally perhaps 2,000 or 3,000 feet higher. This same current prevailed also throughout the monsoon season of 1877, and during the drought of August, 1880; and it is also characteristic of the spring months. It appears to me to be the feeder of the westerly and north-westerly winds (the land winds of North-Western and Western India, as I shall presently explain more at length).

On the plains of the Punjab (except in the eastern districts, between the 6th and 18th July) there was no continuous rain, but heavy falls, for the most part very local, occurred at intervals up to the 19th. After this date, up to the end of August, save on two days, there was no fall amounting to 1 inch in any part of the province; and the districts east and south of Ludhiana, and all to the west of

Lahore and south of the salt range, were absolutely rainless. In Rajputana there was no rain of any importance from the 18th July to the 29th August, and the absolutely rainless interval was from the 6th to the 17th August. In the North-Western Provinces all the western districts were rainless from the 26th July to the 20th August; and in Oudh and the eastern districts, except in Mirzapur, there were only rare and insignificant showers. Still further east, in Behar, showers were somewhat more frequent, but still only occasional, and for the most part light. In Gujarat, Khandish, and Berar, the drought was equally great and prolonged; lasting from the 18th July to the 26th August, and at some stations up to the 31st. And even in Hyderabad and the Deccan there was no general rain, and but few heavy showers locally, for the space of an entire month, from the 20th July. In the Konkan light showers fell daily up to the 7th August; but even here and on the Ghats the rainfall was very light, and the interval from the 8th to the 16th August was almost rainless.

The extent of the drought was therefore very great, including the whole of Western and North-Western and the greater part of Central India. It began earlier and ended later in the Punjab and Northern Rajputana than further to the south and east, and was most severe during eight or ten days in the middle of August. It affected nearly the whole of the country in which the land winds prevail most regularly and persistently during the spring months; and the winds during the drought were identical in character and direction with those which are normal in the spring season.

During the period here dealt with, the barometric features, though subject to considerable variation, were less anomalous than might perhaps have been anticipated. In April there had been, on the whole, a slight excess of pressure above the average on the Punjab Himalaya, about an average pressure on the plains of the greater part of the province, and a slight deficiency on the Gangetic plains and the adjacent hills, from the Jamna eastwards, greater on the plains than on the hills. In May, save in the north of the Bombay Presidency during the first week, and generally on the last three or four days, the pressure was below the average throughout Northern India, the deficiency averaging, on the mean of the whole month, $-\cdot038''$ on the North-Western Himalaya, $-\cdot041''$ on the Punjab plains, and $-\cdot056''$ on the Gangetic plain down to Benares. To the south of the Ganges, in Central India, Rajputana, and the Central Provinces, it was less, averaging from $-\cdot020''$ to $-\cdot030''$. With the snowfall at the end of May the pressure rose greatly above the average both on the hills and plains, and so remained nearly a week. About the 4th June it fell again, and remained unduly low over the whole of Northern India till after the middle of the month. Between the 18th and 20th, that is, a few days after the rains had set in

in Bengal, it again rose above the average, and except for another fall on the 27th and 28th, just before the rain, it remained excessive during the latter part of the month (save, indeed, in the Western Punjab), the excess culminating on the 21st and 25th. On the plains of the Western Punjab the temperature was very high; at Rawalpindi, on some days, as much as 10° or 12° above the average of the month; which fact probably explains the local anomaly of the average pressure in that region.

The high pressure thus established in the latter part of June lasted in the Eastern Punjab and the North-Western Provinces, with but slight intermission, throughout the first half of July, being very excessive at the beginning and end of that period. To the eastward in Bengal, and to the south-east and south in the Central Provinces and Bombay, as well as in the Western Punjab, the oscillations were similar in phase, but the average excess was either less pronounced or altogether nullified and reversed, the pressure being above the average only for a few days at the beginning and after the 15th of the month. An abnormal excess of pressure relatively to the remainder of Northern India was therefore existent in the Eastern Punjab and the North-Western Provinces.

In the latter part of the month, after the cessation of the rain, the pressure fell generally below the average in Northern India, and especially in the Punjab and North-Western Provinces, but the northern part of Bombay formed an exception to the rule. A great deficiency of pressure both on the hills* and plains characterized also the first days of August, and on the plains and at the western-most hill station, Murree, this was associated with an excessive temperature; but at Simla, Chakrata, and Ranikhet, the latter was more or less considerably below the average. After the 6th the pressure rose again, and smaller oscillations, lasting five or six days, followed during the remainder of the month. In the Punjab, the North-Western Provinces, and Bengal, the mean pressure of the month was slightly below the average of many years. In Rajputana, Gujarat, Sind, and Western and Central India generally, such was not the case, since in this region an excessive pressure prevailed throughout the middle of the month for seventeen or eighteen days after the 6th. This coincided with the period of the greatest and most extensive drought.

At the hill stations the oscillations of pressure were similar to those on the plains, though less in amount. At Simla and Murree the mean pressure of the two months, July and August, scarcely deviated from the normal average. But at Leh in both months there was a decided deficiency, and it was but slightly less at Chakrata and Ranikhet.

* That is at levels of about 7,000 feet.

The barometric features of the season may then be summed up as follows:—With local and more or less temporary exceptions the pressure of the atmosphere over India was below the average throughout the first eight months of the year, the greatest depression being in May, when it was universal in India. But this was only the general average of a series of oscillations of pressure (somewhat greater than usual at most stations in May, June, and July), which succeeded each other throughout the period. These oscillations were closely connected with great variations of temperature, and were to some extent an effect of the latter, each fall of rain (or snow on the hills) being accompanied with a rise of pressure and a temporary excess which speedily diminished, and was followed by a fall below the average, with the return of dry, fine weather.

Meteorology of the Land Winds.

The Westerly Winds of the Winter and Spring.—The land winds from west and north-west are the characteristic winds of the winter, spring, and early summer throughout the greater portion of Northern India, and of Western India from February to May. In the Punjab indeed, the atmosphere is most frequently calm, or agitated only by light movements of very variable direction,* and especially so in the winter months. But down the Gangetic plain (save in the neighbourhood of the hills), and on the plateau of Rajputana and Central India, light and steady winds from between north-west and west are those most characteristic of the whole of the dry season. During the winter months these winds are cooler, from March onwards warmer, than those from the opposite quarters; and in April and May they constitute the well-known hot winds of Northern India. At both seasons they are dry winds, and the striking change in their temperature is due, as was long ago pointed out by Sir Joseph Hooker, to that of the land surface swept by them. *Pari passu* with the rise of temperature they undergo certain partial changes of direction, and also in the region of their prevalence. From November to February, when, as a rule, an axis of maximum pressure runs from the Punjab and Sind across Rajputana, Central India, and the Central Provinces towards Orissa, with lower pressures over the Gangetic valley and Bengal on the one hand, and over the peninsula, and especially on its south-west coast, on the other, the current of which they form part tends to circulate anticyclonically around the ridge of high pressure above defined, and thus the directions are northerly on the eastern portion of the Central India plateau and easterly to the south of the Satpura chain in Nagpur, the Deccan and Hyderabad. But when in March a barometric minimum is established over the

* See "Winds of Northern India," "Phil. Trans." for 1874, vol. 164, p. 563.

Bellary and Hyderabad plateau, which speedily extends to the eastern half of the Central Provinces, Chutia, Nagpur, and the Gangetic plain, the winds, in accordance with the law of cyclonic circulation, become northerly or north-westerly in the Deccan, and the western half of the Central Provinces and Central India, and almost due west on the plateau south of the Ganges and Jamna, and on the plain along the course of those rivers. On the other hand, in accordance with the same cyclonic law, the winds of the east coast and maritime plains of the peninsula and Bengal are chiefly from south; and as the season advances, the current from the sea creeps up the northern margin of the Gangetic plain as a south-east wind under the lee of the hills and intermittently sweeping the crests of the outer Himalaya.

This distribution of the winds explains that of the spring rains, which fall, chiefly in thunderstorms, on the southern and eastern districts of the peninsula and in Bengal; whereas, westward from Nagpur, in the Deccan, Berar, Khandesh, Gujarat, and even the Konkan, Kátywár, and Cutch, indeed the whole of Western India, southwards to Belgaum and northwards to the confines of the Punjab, the season from November to May is practically rainless. This latter is the realm of the dry land winds, or, as regards the coast, northerly long-shore winds; this being the local phase of the general current, and equally unfavourable to precipitation.

To one portion of this region, viz., Sind, Cutch, Kátywár, and the adjoining portion of Western Rajputana, the above description of the winds is applicable only with some modification. In this part of Western India, north-east is the prevailing direction from November to February, and in the subsequent months south-west winds are frequent even if they do not preponderate. But these latter bring no rain. They appear to be an indraught from the coast, and as they penetrate the country they coalesce with the general stream and contribute their quota to the dry winds of Eastern Rajputana and Gujarat. They become merged and lost in the prevailing current.

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 Kurrachee 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 longer valleys, like the

dâdu 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 7,000 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 the 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 diurnal 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.*

Systematic observations on the movement of the clouds, and more especially the higher clouds in the upper provinces during the dry season, are unfortunately as yet wanting, but according to such casual observations as I have myself made when on inspection tours in the cold season and during the spring months or hot season at Simla, go to show that the movement is generally, if not always, from some westerly quarter, and most frequently from the north-west.

* See, for instance, Plates II, VIII, and XXVI of vol. i of these memoirs. The curves of Yarkhand and Allahabad show that this type of variation is characteristic of the months in which the range of temperature is greatest.

The North-West Winds after Winter Rainfall.—A phenomenon which almost invariably follows a fall of rain and snow on the North-Western Himalaya in the winter and early spring months, and which has been repeatedly described in the Annual Reports on the Meteorology of India,* is a wave of high pressure advancing eastward from the valley of the Indus, accompanied with steady cool north-west winds on the plains. Charts illustrating this phenomenon have been given in several of the Annual Reports on the Meteorology of India, from which I select that of February 26th, 1881, as a very characteristic example (fig. 1). At this season, the snow falls at comparatively low levels (occasionally, though rarely, as in the present year, to below 2,000 feet), and below the snow limit the hill slopes and valleys are cooled by the rainfall.

In these cases it can hardly be questioned that the north-west wind is simply an outflow of cold air from the hills, the high density of which is the chief cause of the rise of the barometer. On the plains, in the neighbourhood of the hills, it rarely lasts more than a few days; not longer indeed than it requires to melt the low lying snow and to evaporate the fallen rain, but the phenomenon is of great interest in the bearing that it has on the main topic of this paper, affording an illustration at a low level of that which I conceive to operate at a high level on a more lasting and extended scale, later on in the season.

Summary and Conclusion.

The principal facts and conclusions set forth in this paper are as follows:—

1st. The experience of recent years affords many instances of an unusually heavy and especially a late fall of snow on the North-Western Himalaya being followed by a prolonged period of drought on the plains of North-Western and Western India.

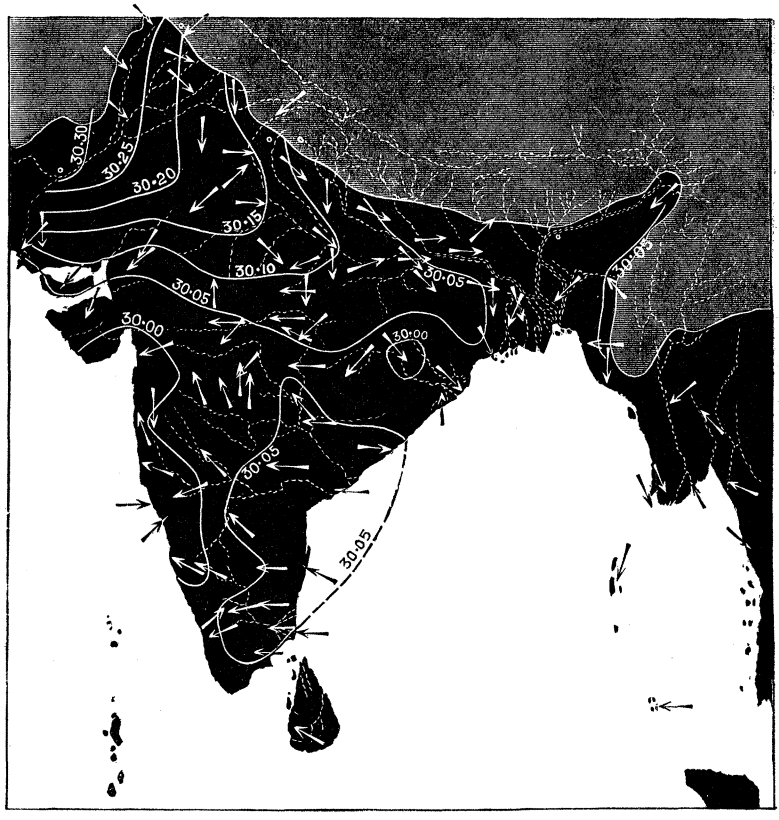
2nd. On tabulating the average rainfall of the winter and spring months at the stations of the North-Western Himalaya, year by year, for the last eighteen years, and comparing it with the average rainfall of the North-Western Provinces in the ensuing summer monsoon, it is found that with four exceptions an excessive winter precipitation on the hills is followed by a deficient summer rainfall on the plains, and *vice versâ*. Of the four apparent exceptions, two are found to afford a striking support to the first proposition.

3rd. The west winds which, in Western and Northern India, are characteristic of seasons of drought as abnormal winds, are identical in character with the normal winds of the dry season, and appear to

* See, *e.g.*, Reports for 1878, pp. 129, 130; 1879, pp. 136, 154; 1880, pp. 143, 144, 171; 1881, pp. 151, 152.

be fed by descending currents from the North-Western Himalaya and possibly the western mountains generally.

4th. It is a common and well-known phenomenon of the winter months that a fall of rain and snow on the North-Western Himalaya is immediately followed by a wave of high pressure advancing eastwards from the western mountains, accompanied with dry cool north-west winds.



Baric and Wind Chart for 10 A.M. of February 26, 1881.

5th. The conclusion is that an unusual expanse of snow on the North-Western Himalaya, whether due to the unmelted residue of an unusually copious winter snowfall, or to an unusually late fall in the spring months, acts, at high levels, in the summer months, in somewhat the same way as the ordinary falls of snow and rain on the Lower Himalaya do at low levels in the winter season, and favours

the production of dry north-west winds on the plains of Western India.

6th. That this dependence of dry winds on the Himalayan snow-fall affords a criterion for forecasting the probabilities of drought in North-Western and Western India.

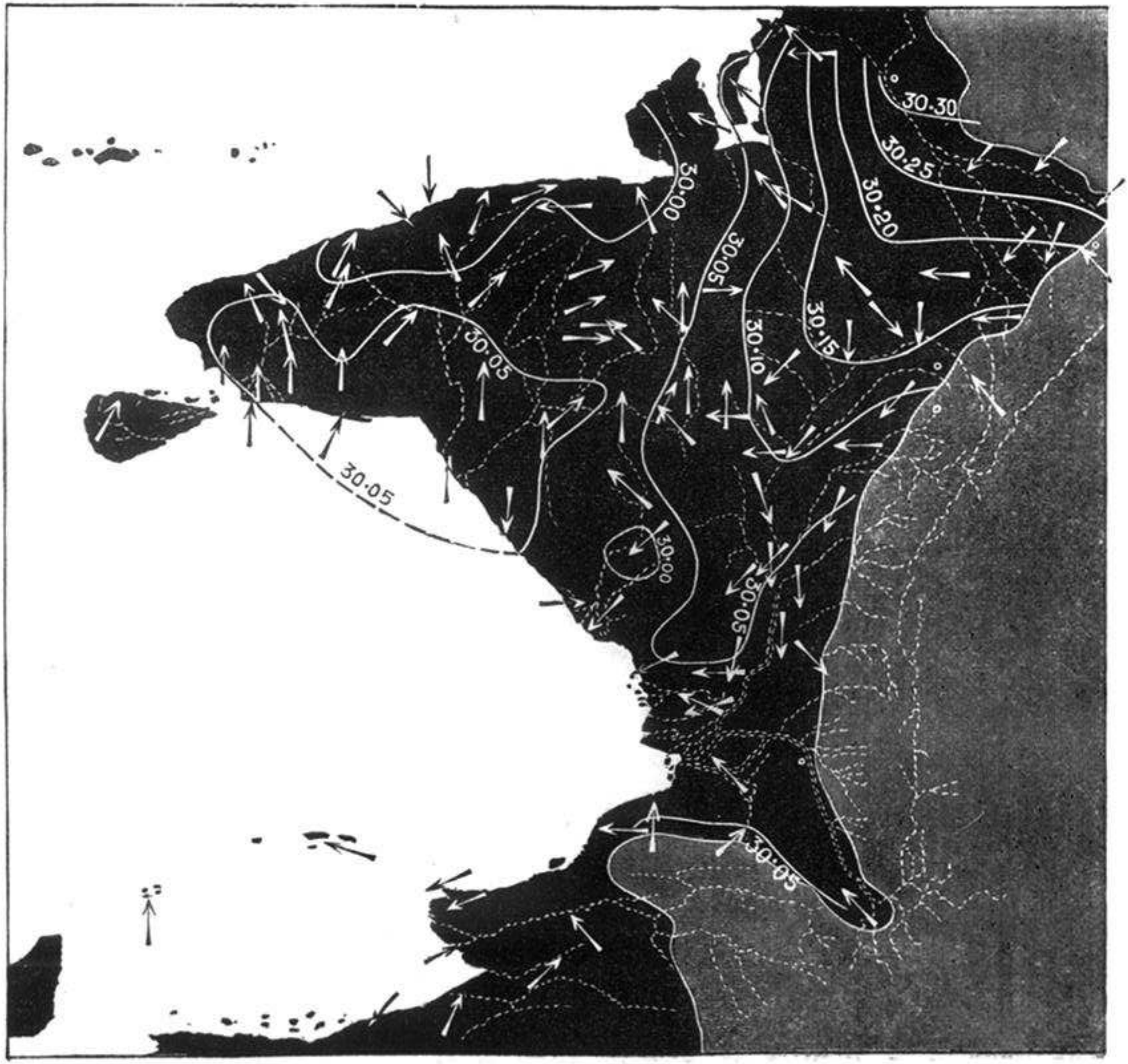
In setting forth the above conclusions, it is, however, necessary not to ignore the fact that there other conditions besides those here considered which exercise a very great influence on the prevalence of dry winds and drought. During the last famine period in India (the years 1876 and 1877; in the former year in Southern India, in the latter in the North-Western Provinces and Rajputana), the pressure of the atmosphere was persistently and abnormally high, and this was due, as I showed in the reports on the meteorology of those years, to the condition, probably the high density, of the higher atmospheric strata. Moreover this excessive pressure was shown to affect so extensive a region, that it would be unreasonable to attribute it to the condition of any tract so limited as a portion of the Himalayan chain; and if dependent on the thermal conditions of the surface, which may indeed have been the case, this land must rather have been the major portion of the Asiatic continent than merely a relatively small portion of its mountain axis. This question must remain for future inquiry. It is referred to here to guard against too wide an application being assigned to the action of the Himalayan snows.

III. "Report to the Solar Physics Committee on a Comparison between apparent Inequalities of Short Period in Sun-Spot Areas and in Diurnal Temperature-Ranges at Toronto and at Kew." By BALFOUR STEWART, M.A., LL.D., F.R.S., and WILLIAM LANT CARPENTER, B.A., B.Sc. Communicated to the Royal Society at the request of the Solar Physics Committee. Received April 21, 1884.

(Abstract.)

It has been known for some time that there is a close connexion between the inequalities in the state of the sun's surface as denoted by sun-spot areas and those in terrestrial magnetism as denoted by the diurnal ranges of oscillation of the declination magnet; and moreover the observations of various meteorologists have induced us to suspect that there may likewise be a connexion between solar Inequalities and those in terrestrial meteorology.

This latter connexion, however (assuming it to exist), is not so well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