Polarian.	*Procyonian.*
Predominant. — Proto-calcium, proto-titanium, hydrogen, proto-magnesium, proto-iron, and arc lines of calcium, iron, manganese, silicium (I). *Fainter.*—The other proto-metals and metals occurring in the Sirian genus.	Same as Polarian.
Aldebarian.	*Arcturian.*
Predominaut.—Proto-calcium, arc lines of iron, calcium, manganese, proto-strontium, hydrogen, silicium (I). *Fainter.*—Proto-iron and proto-titanium.	Same as Aldebarian.
Antarian.	*Piscian.*
Predominant.—Flutings of manganese. *Fainter.*—Arc lines of metallic elements.	*Predominant.*—Flutings of carbon. *Fainter.*—Arc lines of metallic elements.

It will be seen that the conclusions arrived at in the former part of the paper as to the different conditions under which the different groups of silicium lines become prominent verify the order in which the stars were placed on a scale of ascending temperatures. Thus those stars in which Group I occurs prominently are at the bottom, those in which Groups II and III predominate occupy intermediate positions, and those in which the lines of Group IV are a special feature appear high up in the classification.

The photographs of the silicium spectra were taken by Mr. Butler. Their discussion has devolved upon Mr. Baxandall, who has also traced the silicium lines through the stellar spectra, and assisted in the preparation of the paper.

"On Solar Changes of Temperature and Variations in Rainfall in the Region surrounding the Indian Ocean." By Sir NORMAN LOCKYER, K.C.B., F.R.S., and W. J. S. LOCKYER, M.A. (Camb.), Ph.D. (Gött.). Received October 26,—Read November 22, 1900.

The fact that the abnormal behaviour of the widened lines in the spectra of sunspots since 1894 had been accompanied by irregularities in the rainfall of India suggested the study and correlation of various series of facts which might be expected to throw light upon the subject.

The conclusions already arrived at from bringing together the results of several investigations undertaken with this view may be stated as follows:—

(1.) It has been found, from a discussion of the chemical origin of lines most widened in sunspots at maxima and minima periods, that there is a considerable rise above the mean temperature of the sun around the years of sunspot maximum and a considerable fall around the years of sunspot minimum.

(2.) It has been found, from the actual facts of rainfall in India (during the S.W. monsoon) and Mauritius, between the years 1877 and 1886,* as given by Blanford and Meldrum, that the effects of these solar changes are felt in India at sunspot maximum, and in Mauritius at sunspot minimum. Of these the greater is that produced in the Mauritius at sunspot minimum. The pulse at Mauritius at sunspot minimum is also felt in India, and gives rise generally to a secondary maximum in India.

India, therefore, has two pulses of rainfall, one near the maximum and the other near the minimum of the sunspot period.

(3.) It has been found that the dates of the beginning of these two pulses on the Indian and Mauritius rainfall are related to the sudden remarkable changes in the behaviour of the widened lines.

(4.) It has been found, from a study of the Famine Commission reports, that all the famines therein recorded which have devastated India during the last half-century (we have not yet carried the investigation further back) have occurred in the intervals between these two pulses.

(5.) It has been found, from the investigation of the changes in (1) the widened lines, (2) the rainfall of India, and (3) of the Mauritius during and after the last maximum in 1893, that important variations from those exhibited during and after the last maximum of 1883 occurred in all three.

It may be stated at the same time that the minimum of 1888–1889 resembled the preceding minimum of 1878–1879.

(6.) It has been found, from an investigation of the Nile curves between the years 1849 and 1878, that all the lowest Niles recorded have occurred between the same intervals.

(7.) The relation of the intervals in question to the droughts of Australia and of Cape Colony, and to the variations in the rainfall of extra tropical regions generally, has not yet been investigated. We have found, however, a general agreement between the intervals and the rainfall of Scotland (Buchan), and have traced both pulses in the rainfalls of Córdoba (Davis) and the Cape of Good Hope.

* This period was selected because the Kensington observations of widened lines only began in 1879, and the collected rainfall of India has only been published to 1886.

(8.) We have had the opportunity of showing these results to the Meteorological Reporter to the Government of India and Director-General of Indian Observatories, John Eliot, Esq., C.I.E., F.R.S., who is now in England, and he allows us to state his opinion that they accord closely with all the known facts of the large abnormal features of the temperature, pressure, and rainfall in India during the last twenty-five years, and hence that the inductions already arrived at will be of great service in forecasting future droughts in India.

Addendum. Received November 16, 1900.

Since Meldrum and one of us called attention, in 1872, to a possible connection between sunspots and rainfall, there has been a large literature upon the subject which it is not necessary for us to analyse; it may be simply stated that, in spite of the cogent evidence advanced since, chiefly by Meldrum, and in later years by Mr. Hutchins,* it is not yet generally accepted that a case for the connection has been made out.

What has been looked for has been a change at maximum sunspots only; the idea being that there might be an effective change of solar temperature, either in excess or defect, at such times; and that there would be a gradual and continuous variation from maximum to maximum.

At the same time, it is possible that the pressure connection, first advanced by Chambers, is now accepted by meteorologists as a result of the recent work of Eliot.

The coincidence, during the last few years, of an abnormal state of the sun with abnormal rain in India, accompanied by the worst famine experienced during the century, suggested to us the desirability of reconsidering the question, especially as we have now some new factors at our disposal. These have been revealed by the study, now extending over twenty years, of the widened lines in sunspots, which suggested the view that two effects ought to be expected in a sunspot cycle instead of one.

The Widened Lines.

It will be gathered from previous communications to the Royal Society† that, on throwing the image of a sunspot on the slit of a spectroscope, it is found that the spectrum of a spot so examined indicates that the blackness of the spot is due not only to general but to selective absorption,‡ and that the lines widened by the selective absorption vary from time to time.

* 'Cycles of Drought and Good Seasons in South Africa,' 1889.

† 'Roy. Soc. Proc.,' vol. 40, p. 347, 1886; vol. 42, p. 37, 1887; vol. 46, p. 385, 1889; vol. 57, p. 199, 1894.

‡ 'Roy. Soc. Proc.,' Lockyer, October 11, 1866.

Since the year 1879, the *selective* absorption in spots has been observed for every spot that was large enough to be spectroscopically examined, the method adopted being as follows :—

The regions of the spectrum investigated lie between F—*b* and *b*—D, and an observation consists in observing the six most widened lines in each of these regions. These lines are then identified on the best solar spectrum maps available and their wave-lengths determined.

An examination of many years' records of these widened lines has shown that at some periods they are easily traceable to *known* elements, while at others their origins have not been discovered, so the latter have been classed as "unknown" lines. If we compare these two periods with the sunspot curve as constructed from the measurements of the mean spotted area for each year, it is found that when the spotted area is greatest the widened lines belong to the "unknown" class, while when the spotted area is least they belong to the "known" class.

The majority of the lines traced to some terrestrial origin belong to iron, but the lines of other elements, such as titanium, nickel, vanadium, scandium, manganese, chromium, cobalt, &c., are also represented in a less degree.

It is quite likely that some of the "unknown" lines are higher temperature (enhanced) lines of known chemical elements.

In our laboratories we have means of differentiating between three stages of temperature, namely, the temperature of the flame, the electric arc, and the electric spark of the highest tension. At the lowest temperature, that of the flame, we get a certain set of lines; a new set is seen as the temperature of the electric arc is reached. At the temperature of the high tension spark we again have many new lines, called enhanced lines, added, while many of the arc lines wane in intensity.

It is found that at sunspot minimum, when the "known" lines are most numerous, the lines are almost invariably those seen most prominent in the arc. Passing from the sunspot minimum towards the maximum the "unknown" lines gradually obtain the predominance. As said before, they may be possibly "enhanced lines"—that is, lines indicating the action of a much higher temperature on *known* substances.

Unfortunately the records of enhanced lines at South Kensington, having been obtained from photographs, are chiefly confined to a region of the spectrum not covered by the visual observations of widened lines in sunspot spectra.

We can only point to the evidence acquired in the case of one metal —iron, for which photographs of the enhanced lines, in the green and yellow parts of the spectrum, have been obtained.

This evidence quite justifies the above suggestion, for the enhanced

lines of iron can be seen revealing themselves as the number of unknown lines increases.

We are, therefore, quite justified in assuming a very great increase of temperature at the sunspot maximum when the "unknown" lines appear alone.

The curves of the "known" and "unknown" lines have been obtained by determining for each quarter of a year the percentage number of known and unknown lines and plotting these percentages as ordinates, and the time elements as abscissæ. Instead of using the mean curves for all the known elements involved, that for iron is employed, as it is a good representative of "known" elements, and has been best studied. When such curves have been drawn they cross each other at points where the percentage of unknown lines is increasing, and that of the iron or known lines are diminishing, or *vice versa*.

We seem, therefore, to be brought into the presence of three well-marked stages of solar temperature.

When the curves of known and unknown lines cross each other, that is, when the number of known and unknown lines is about equal, we must assume a mean condition of solar temperature. When the unknown lines reach their maximum we have indicated to us a + pulse or condition of temperature. When the known lines reach their maximum we have a – pulse or condition of temperature.

The earliest discussion showed that, generally speaking, the unknown-lines curve varied directly, and the iron-lines curve varied inversely with the spot-area curve. The curves now obtained for the whole period of twenty years not only entirely endorse this conclusion, but enable more minute comparisons to be drawn.

The "widened line" curves are quite different from those furnished by the sunspots. Ascents and descents are both equally sharp, changes are sudden, and the curves are relatively flat at top and bottom. The crossings are sharply marked.

During the period since 1879 three such crossings have occurred, indicating the presence of mean solar temperature conditions, in the years 1881, 1886–7,* and 1892. It was expected that another crossing with the known lines on the rise would have occurred in 1897, indicating thereby the arrival of another mean condition of solar temperature, but as yet no such crossing has taken place.

The following tabular statement shows the years of those crossings, together with the probable dates, in brackets, of the two previous crossings, as determined by the time of occurrence of the preceding sun-spot maximum.

* According to the observations the mean was reached in December, 1886, or January, 1887.

Rise of	Years.		
Unknown lines ..	(1869)	1881	1892
Known lines	(1876)	1886–7	?

Comparison of Solar and Terrestrial Weather.

It has long been known that a cycle of solar weather begins in about lat. 32° N. and S., and in a period of eleven years ends in about lat. 5° N. and S.

Just before one cycle ends another commences. The greatest amount of spotted surface occurs when the solar weather-changes produced in the cycle reach about lat. 16° N. and S.

It becomes, therefore, of the first importance to correlate the times of mean solar temperature, and of the + and − heat pulses, with the solar weather cycle, in order to arrive at the temperature-history of the sun during the period which now concerns us. This may be done as follows :—

Solar cycles.				→				→		→
Lat. of spots	19°		12°		18°		10°		19°	
Heat condition	mean	+	mean	−	mean	+	mean	−	mean	+
Years ..	1869	1870–5	1876	1877–80	1881	1882–6	1886–7	1888–91	1891–2	1892

Connection of the Spots with Prominences.

In 1869, when a sunspot maximum was approaching, the prominences were classified by one of us into *eruptive* and *nebulous*; the former showing many metallic lines, the latter the hydrogen and helium lines chiefly. This conclusion, which was published in 1870, was subsequently confirmed and adopted by Secchi, Zöllner, Spörer, Young, and Respighi.

In the same year prominences on the sun's disc were also observed by one of us by means of the C and F lines.*

The eruptive prominences, unlike the nebulous ones, were not observed in all heliographic latitudes; but, according to the extended observations of Tacchini and Ricco, had their maxima in the same

* 'Roy. Soc. Proc.,' vol. 17, p. 415.

latitude as the spots. This is especially well shown by the diagrams illustrating the distribution of spots, faculæ, eruptions, and protuberances which are given by Tacchini for 1881—1887 in the 'Memorie della Soc. degli Spettroscopisti Italiani,' 1882—1888. These curves show in the most unmistakable manner that the spots, faculæ, and eruptive or metallic prominences have their maximum frequency in the same solar latitudes while the nebulous or quiet prominences are more uniformly distributed, and even have maxima in zones where spots are rarely observed. This is corroborated by what Professor Respighi many years ago stated:

"In correspondence with the maximum of spots, not only does the number of the large protuberances increase, but more than this—their distribution over the solar surface is radically modified."

In his observations, Professor Young found that the H and K lines of calcium were reversed in the chromosphere as constantly as *h* or C, and the same lines "were also found to be regularly reversed upon the body of the sun itself, in the penumbra and immediate neighbourhood of every important spot."* This result was confirmed by the early (1881) attempts of one of us to photograph the spectra of the chromosphere and spots, and also by eclipse photographs. In the photographic spectrum, the H and K lines are by far the brightest of the chromospheric lines, and this fact has been utilised by Hale and Deslandres, acting on a suggestion due to Janssen, for the purpose of photographing at one exposure the chromosphere and prominences, as well as the disc of the sun itself, in the light of the K line.

These photographs thus give us in K light the phenomena which one of us first observed by the lines C and F of hydrogen, and thereby present a record of the prominences across the whole disc of the sun as well as at the limb.

In such photographs near sunspot maximum, the concentration of the prominences in zones parallel to the equator is perfectly obvious at a glance. Eruptive or metallic prominences are thus seen to cover a much larger area than the spots, so that we have the maximum of solar activity indicated, not only by the increased absorption phenomena indicated by the greater number of the spots, but by the much greater radiation phenomena of the metallic prominences; and there seems little doubt that in the future the measure of the change in the amount of solar energy will be determined by the amount and locus of the prominence area.

Spots are, therefore, indications of excess of heat, and not of its defect, as was suggested when the term "screen" was used for them. We know now that the spots at maximum are really full of highly heated vapours produced by the prominences, which are most numerous when the solar atmosphere is most disturbed.

* 'Catalogue of Bright Lines in the Spectrum of the Chromosphere,' 1872.

The Indian meteorologists have abundantly proved that the increased radiation from the sun on the upper air currents at maximum is accompanied by a lower temperature in the lower strata, and that with this disturbance of the normal temperature we must expect pressure changes. Chambers was the first to show that large spotted area was accompanied by low pressures over the land surface of India.*

Passing, then, from the consideration of individual spots to the zones of prominences, with which they are in all probability associated, it is of the highest interest to note the solar latitudes occupied when the crossings previously referred to took place, as we then learn the belts of prominences which are really effective in producing the increased radiation. The area of these is much larger, and therefore a considerable difference of radiation must be expected.

The greater disturbance of certain zones of solar latitude seems to be more influential in causing the + pulse than the amount of spotted area determined from spots in various latitudes.

It is all the more necessary to point this out because the insignificance of the area occupied by the spots has been used as an argument against any easily recognised connection between solar and terrestrial meteorological changes.†

Assuming two belts of prominences N. and S. 10° wide, with their centres over lat. 16°, the sixth of the sun's visible hemisphere would be in a state of disturbance.

Indian Rainfall. S.W. Monsoon, 1877–1886.

It will be clear from what has been stated that our object in studying rainfall was to endeavour to ascertain if the + and − temperature pulses in the sun were echoed by + and − pulses of rainfall. The Indian rainfall was taken first, not only because in the tropics we may expect the phenomena to be the simplest, but because the regularity of the Indian rains had broken down precisely when the widened line observations showed a most remarkable departure from the normal.

It was also important for us to deal with the individual observations as far as possible, because it was of the essence of the inquiry to trace the individual pulses if they were found. Hence the S.W. monsoon was, in the first instance, considered by itself, because although Eliot holds that the winter rains (N.E. monsoon) are due to moisture brought

* 'Abnormal Variations,' p. 1.

† "So far as can be judged from the magnitude of the sunspots, the cyclical variation of the magnitude of the sun's face free from spots is very small compared with the surface itself; and consequently, according to mathematic principle, the effect on the elements of meteorological observation for the whole earth ought also to be small" (Eliot, 'Report on the Meteorology of India in 1877,' p. 2).

by an upper S.W. current,* their incidence is very different and their inclusion might mask the events it was most important to study.

The first investigation undertaken was the study of the rainfall tables published by the Meteorological Department of the Government of India. These were brought together by Blanford down to the year 1886.† As the widened line observations were not begun at Kensington till 1879, the discussion was limited in the first instance to the period 1877–1886 inclusive, embracing the following changes in solar temperature, occurring, as will be seen, between two conditions of mean solar temperature:—

Mean.	− pulse.	Mean.	+ pulse.	Mean.
1876	1877—1880	1881	1882—1886	1886—1887

Bearing in mind that the intensity of the + pulse may in some measure be determined by the solar disturbances, which for the present are registered by spotted area, it is important to point out that the preceding maximum in 1870 was remarkable for obvious indications of great solar activity.‡

It soon became evident that in many parts of India the + and − conditions of solar temperature were accompanied by + and − pulses producing pressure changes and heavy rains in the Indian Ocean and the surrounding land. These occurred generally in the first year following the mean condition, that is in 1877–8 and 1882–3, dates approximating to, but followed by, the minimum and maximum periods of sun-spots.

* 'Report,' 1877, p. 125.

† 'Indian Meteorological Memoirs,' vol. 3.

‡ "The year 1870 was characterised by an exuberance of solar energy, which is without parallel since the beginning of systematic observations (*i.e.*, since 1825). The number of observed groups far exceeds that of any previous year, and it appears also from a cursory comparison with the maximum year's observations, as recorded by Hofrath Schwabe, that the magnitude of the different groups, as well as the average amount of spotted surface during any period of the year, is unprecedented." ('Monthly Notices,' vol. 31, p. 79, Warren de la Rue, B. Stewart, B. Loewy.)

The table which the authors of this paper give shows that during the year, although observations of the sun were made on 213 days out of the 364, there was no day without spots recorded. In fact, during the whole year no less than 403 new groups of spots were noted, thus showing us that on the average there was more than one new group per diem.

The authors further remark. "A very remarkable feature of the groups observed during the year appears to be their extraordinary lifetime . . . an exceedingly large number of groups completed three, four, and even more revolutions before finally collapsing."

Meldrum, as far back as 1881,* referred to "the extreme oscillations of weather changes in different places, at the turning points of the curves representing the increase and decrease of solar activity."

It was especially in regions, such as Malabar and the Konkan where the monsoon strikes the west coast of India, that the sharpness and individuality of these pulses was the most obvious.

One method of study employed has depended upon Chambers's view† that the S.W. monsoon depends upon the oscillations of the equatorial belt of low pressure up to 31° N. lat. at the summer solstice. The months of rain-receipt on the upward and downward swing will therefore depend on the latitude, and these months alone have been considered.

We began by taking elevated stations in high and low latitudes.

Leh Lat. 34° N. 11,500 feet	The 1881 pulse (in July) was the heaviest recorded (1·77 inches) save one in 1882; the rainfall was nearly as high. The pulse felt in 1878 was the highest of all.
Murree Lat. 33° N. 6,344 feet	The 1881 pulse (August) is high, but is followed by a higher next year. The 1878 pulse (August) is highest of all.
Newera Eliya Lat. 7° N. 6,150 feet	Taking the fall in July and August. The 1881 pulse occurs in 1882, and is highest. Next comes the pulse in 1878.

It must also be stated that if we take the sun-spot maximum, including the period we have chiefly discussed (1877–1886), as normal, it is found that there are variations in rainfall accompanying the preceding and succeeding maxima of 1870 and 1893. This variation indicates the existence of a higher law, but there has not been time to discuss them thoroughly enough to justify any definite statements about them.

The Rainfall of "Whole India."

The next step was to work on a longer base, and for this purpose Eliot's whole India table of rainfall, 1875–1896,‡ embracing both the S.W. and N.E. monsoons, being at our disposal, was studied.

It was anticipated that such a table, built up of means observed over such a large area and during both monsoons, would more or less conceal the meaning of the separate pulses observed in separate

* "On the Relations of Weather to Mortality, and on the Climatic Effect of Forests."

† 'Indian Meteorological Memoirs,' vol. 4, Part V, p. 271.

‡ 'Nature,' vol. 56, p. 110.

localities; this we found to be the case. But, nevertheless, the table helped us greatly, because it included the summation of results nine years later than those included in Blanford's masterly memoir. Predominant pulses were found in 1889 and 1893, following those of 1877–8 and 1882–3. So that it enabled us to follow the working of the same law through another sun-spot cycle, the law, that is, of the mean solar temperature being followed by a pulse of rainfall.

Mean sun.	Rain pulse.
1876	– 1878
1881	+ 1882
1886–7	– 1889
1892	+ 1893

The main feature of this table is the proof of a tremendous excess of rainfall in 1893—by far the greatest excess of all (percentage variation, + 22). This was far greater than the excess in 1882.

The next remarkable excess occurs in 1878 (percentage variation, + 15).

The pulses in the period stand as follows :—

	Percentage variation.	Heat pulse.	
Min. 1878	+ 15	–	Years after rise of iron lines.
Max. 1882	+ 6	+	Years after rise of unknown lines.
Min. 1889	+ 6	–	Years after rise of iron lines.
Max. 1893	+ 22	+	Years after rise of unknown lines.

The variations in the intensities of the pulses of rain at the successive maxima and minima are very remarkable, and suggest the working of a higher law, of which we have other evidence. But, putting this aside for the present, it should be pointed out that even normally we should not expect the same values for the rainfalls in 1882 and 1893, because the amount of spotted area was so different, 1160-millionths of the solar surface being covered with spots in 1883, and 1430 in 1893.

The very considerable variation in the quantity of snowfall on the Himálayas has often been pointed out by the Indian meteorologists. We have, therefore, used the "whole India" curve between 1875 and 1896, to see whether the sun pulses, which we have found to be bound up with the Indian rainfall, are in any way related to the snowfall as might be expected.

The Himálayan snowfall beyond all question follows the same law as the rain, the value occurring at the + and – pulses, as under, being among the highest :—*

* 'I.M.M.,' vol. 3, p. 235.

	Inches.
− 1867–8.........	134
+ 1871–2.........	110
− 1877–8.........	207
+ 1882–3.........	81

From these tables it follows that both in rainfall and snow the quantity is increased in the years of the rise both of the unknown and iron lines.

Other Rainfalls.

Being in presence of pulses of rainfall in India during the south-west monsoon, corresponding with pulses of solar change, it became necessary to attempt to study their origins. We may add that other pulses were traced, especially one in 1875, but the simplest problem was considered alone in the first instance.

The rainfalls at the Mauritius, Cape Town, and Batavia, were collated to see if the pulses felt in India were traceable in other regions surrounding the Indian Ocean to the south and east.

The Mauritius Rainfall.

The rainfall of Mauritius has been obtained by utilising the results that have been published in the Blue Books* issued by the Royal Alfred Observatory since the year 1885. The volume for 1886 gives the yearly total rainfall for every station that was then in use from 1861 up to the year 1885, and these values have been employed; since then, the yearly values have been obtained direct from each of the yearly volumes subsequently published, *i.e.*, to the end of the year 1898.

It was at first thought that the total Mauritius rainfall could be fairly obtained by employing for the period between 1861 and 1886 the means of several stations as given by Meldrum,† and continuing the values from the observations published in the more recent yearly volumes.

It was found, however, that from 1861–1880 the rainfall was obtained from the observations of four stations, while from 1871–1886, the observations from eight stations were employed.

As a study of all the published data showed that more stations

* "Mauritius Meteorological Results."

† 1861-1880. 'Relations of Weather to Mortality, &c.,' 1881, p. 36. 1871–1886. 'Annual Report of the Director of the Royal Alfred Observatory for 1886,' p. 18.

might be utilised in determining the total rainfall of Mauritius, it was decided to discuss all the observations afresh, and make use of as many as possible.

To this end the records of twenty-eight stations, situated in six different districts, were chosen, and the total rainfall for each year obtained. It is only natural that the number of rain-gauge stations in the early year of 1860 was not so numerous as that of more recent years; the facts may be stated as follows:—

Years.	Mean yearly rainfall variation from normal.	Number of stations used.	Years.	Mean yearly rainfall variation from normal.	Number of stations used.
	Inches.			Inches.	
1861	+26·6	1	1880	−19·3	23
1862	−10·2	4	1881	− 7·3	25
1863	+ 9·6	6	1882	+16·6	25
1864	−12·2	8	1883	+ 1·8	26
1865	+22·6	10	1884	−12·4	25
1866	−18·2	10	1885	− 9·8	26
1867	− 6·6	11	1886	−35·3	26
1868	+27·1	11	1887	− 4·2	27
1869	− 3·3	12	1888	+22·3	26
1870	− 3·6	12	1889	+18·4	24
1871	−18·9	13	1890	+ 1·2	25
1872	− 7·0	13	1891	+ 1·4	26
1873	+10·3	13	1892	+ 5·1	19
1874	+17·4	17	1893	− 7·4	24
1875	+ 3·0	15	1894	− 0·6	24
1876	− 6·5	17	1895	+10·0	21
1877	+31·4	19	1896	+17·6	22
1878	− 3·8	22	1897	−19·6	24
1879	− 5·2	22	1898	− 2·1	24

With regard to the general rainfall of Mauritius throughout the year, it may be stated that on the average the most rainy months are from December to April, both months inclusive.

The months of November and May are those in which the daily rainfall is increasing and diminishing respectively. Sometimes in July or August there is a slight tendency for a small increase.

The Mauritius Rainfall Curve for the period 1877–1886.

In plotting the Mauritius rainfall curve for the period 1877–1886, it was observed that the curve is of a fairly regular nature, showing alternately an excess and deficiency of rainfall.

The highest and lowest points of the curve will be gathered from the following table:—

Year.	Maximum.	
	Excess.	Deficiency.
1877	31·4	—
1880	—	19·3
1882	16·6	—
1886	—	35·3

Comparing the times of occurrence of the two pulses of rainfall at Mauritius with the times of the crossings of the known and unknown lines, it is found that the Mauritius maximum rainfall of 1877 occurs about a year after the rise of the known lines in 1876. The next Mauritius pulse of rainfall in 1882 follows the succeeding crossing, when the unknown lines are going up, also about a year later.

Comparison of the Mauritius Rainfall with those of Leh, Murree and Newera Eliya for the period 1877–1886.

The most prominent feature of the Mauritius rainfall for this period was the great excess in the years 1877 and 1882.

Both of these pulses have corresponding maxima in the curves for the rainfalls of Leh, Murree and Newera Eliya, the dates of these in all three cases being 1878 and 1882.

The delay of about a year in the effect of the Mauritius pulse being felt in Ceylon and India, is exactly what would be expected if the rain at sun-spot minimum comes from the south, as has been surmised.

The fact that the pulses at Mauritius, Ceylon, and India in 1882 occur simultaneously, is very strong evidence in favour of an origin in the equatorial region itself for the Indian rain at sun-spot maximum. The pulse at maximum in the Indian south-west monsoon may depend to a large extent upon the action of the excess of solar heat on the equatorial waters to the south of India, and not on an abnormal effect on the south-east trade.

We have found that there was a defect of the usual rainfall at Mauritius in 1892–93, and yet the rain supply in India was in excess.

Result of the Comparison of Rainfall.

The + and – Pulses.

It seems quite certain that we are justified in associating the 1878 pulse of rainfall during the south-west monsoon in India with the rainfall common to Mauritius, Batavia, and the Cape at that date; that in

all cases the rain has been associated with some special condition connected with the south-east trade in the Indian Ocean.

The rainfall of Córdoba suggests that the same trade wind in the Atlantic Ocean was similarly affected at the same time.

The Cause of the – Pulse.

Mr. Eliot long ago conjectured that the rainfall of India was profoundly modified by events taking place from time to time in the Southern Ocean. In his "Annual Summary" for 1896 he wrote as follows:—

"It has apparently been established in the discussion that the variations of the rainfall in India during the past six years are parallel with, and in part, at least, due to variations in the gradients, and the strength of the winds in the south-east trade regions of the Indian Ocean. The discussion has indicated that there are variations from year to year in the strength of the atmospheric circulation obtaining over the large area of Southern Asia and the Indian Ocean, and that these variations are an important and large factor in determining the periodic variations in the rainfall of the whole area dependent on that circulation, and more especially in India. It has also been indicated that these variations which accompany, and are probably the result in part of abnormal temperature (and hence pressure) conditions in the Indian Ocean and Indian monsoon area, may be in part due to conditions in the Antarctic Ocean, which also determine the comparative prevalence or absence of icebergs in the northern portions of the Antarctic Ocean."

We have begun an investigation into the pressure changes which have been recorded in this region, but it will be some time before it is finished. The idea underlying the inquiry is that the reduced solar temperature may modify the pressure so that the high pressure belts south of Mauritius may be broken up and thus allow cyclonic winds from a higher latitude to increase the summer rains, as they certainly were increased at the normal minima of 1877 and 1888.

It has been shown that the – pulse is felt in India about a year later than it commences action in the Southern Ocean; while in some cases the + pulse is felt almost simultaneously in India and at the southern stations.

The Rainfall at the Cape, Batavia, and Córdoba, for the period 1877—1886.

Each of the curves (fig. 1) illustrating the rainfall for the Cape and Córdoba (Arg.) for this period shows two prominent maxima in the years 1878 and 1883; these correspond nearly with the + and – pulses

of solar temperature. Comparing them also with the Bombay and Mauritius curves for the same period, it is found that the pulses indicated at Bombay occur simultaneously with those of 1878 and 1883, but in the case of Mauritius the effect of each of the pulses is felt about a year or so earlier, namely, 1877 and 1882.

The rainfall curve for Batavia for this period has its most prominent maximum in the year 1882, like that of Mauritius, thus preceding by a year the pulse felt at the Cape, Córdoba, and Bombay in 1883.

The Time Conditions of the Pulses.

The various curves which we have drawn for the purposes of study have been compiled from yearly means, and so far, in these curves the rainfall in months has not been considered. That will have to come later. Hence if the rainfall which most influences the yearly mean occurs in the last three months at one place, and in the first three months of the next year at another, they are shown as being a year apart, whereas they have actually been continuous.

With regard to the travel of the pulses over large areas under the influence of the S.E. trade, it may be gathered from the pressure charts that the + and − conditions of pressure are apt to lie over the centres of land and water areas, and not generally over coast lines. In the case of water surfaces, the effect of a sudden change in the solar radiation on the pressure might be expected to be felt not at the point where the pressure is least or greatest at the time, and of the most general type, but where the equilibrium is most unstable. On the other hand, more time would be required for the new pulse to establish itself where the conditions are more complicated.

Hence we should expect the pulses to be felt first in the eastern part of the Southern Ocean, and this seems generally to be the case. Thus after the mean solar temperature of 1876, the − pulse was felt first at Mauritius, then in India, and the Cape. After the mean of 1881, the + pulse was felt first at Mauritius, then in India, and the Cape. Córdoba felt both pulses in the same year as India and the Cape.

Subsidiary Pulses.

In a normal sun-spot curve we find a sharp rise, generally taking three or three-and-a-half years, to maximum, and a slow decline to minimum, on which the remaining years of the cycle are spent.

The curve on the upward side rises generally regularly and continuously; on the downward portion the regularity of the curve is very often broken by a "hump" or sudden change of curvature. There has not yet been a complete discussion of the number and character of the prominences associated with the spots during the cycle;

we have found, however, that the "hump" in the sun-spot curve in 1874 was accompanied by a remarkable increase in the number of eruptive prominences.

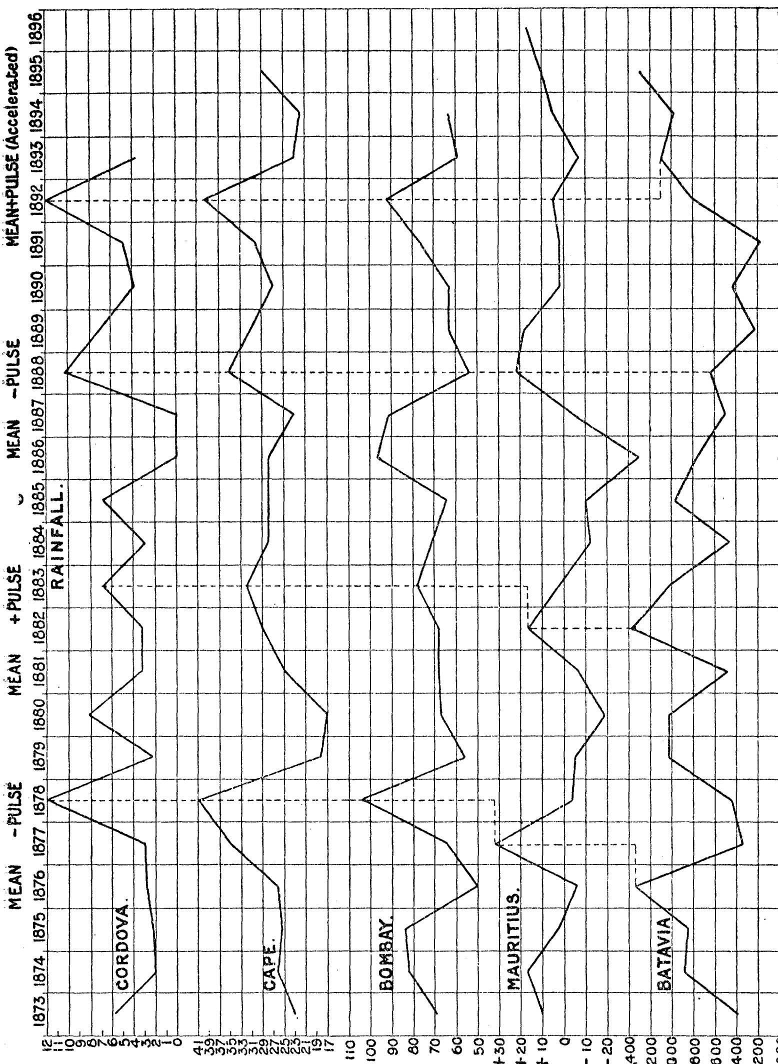

FIG. 1.

We have already referred, in discussing the Indian rainfall, to a remarkable intensification of the south-west monsoon in 1874–75, the effect of which is especially noticeable in the rainfalls of the Konkan and North-west Provinces, and we have come to the conclusion that we must consider all these events as due to a common cause—that is, to

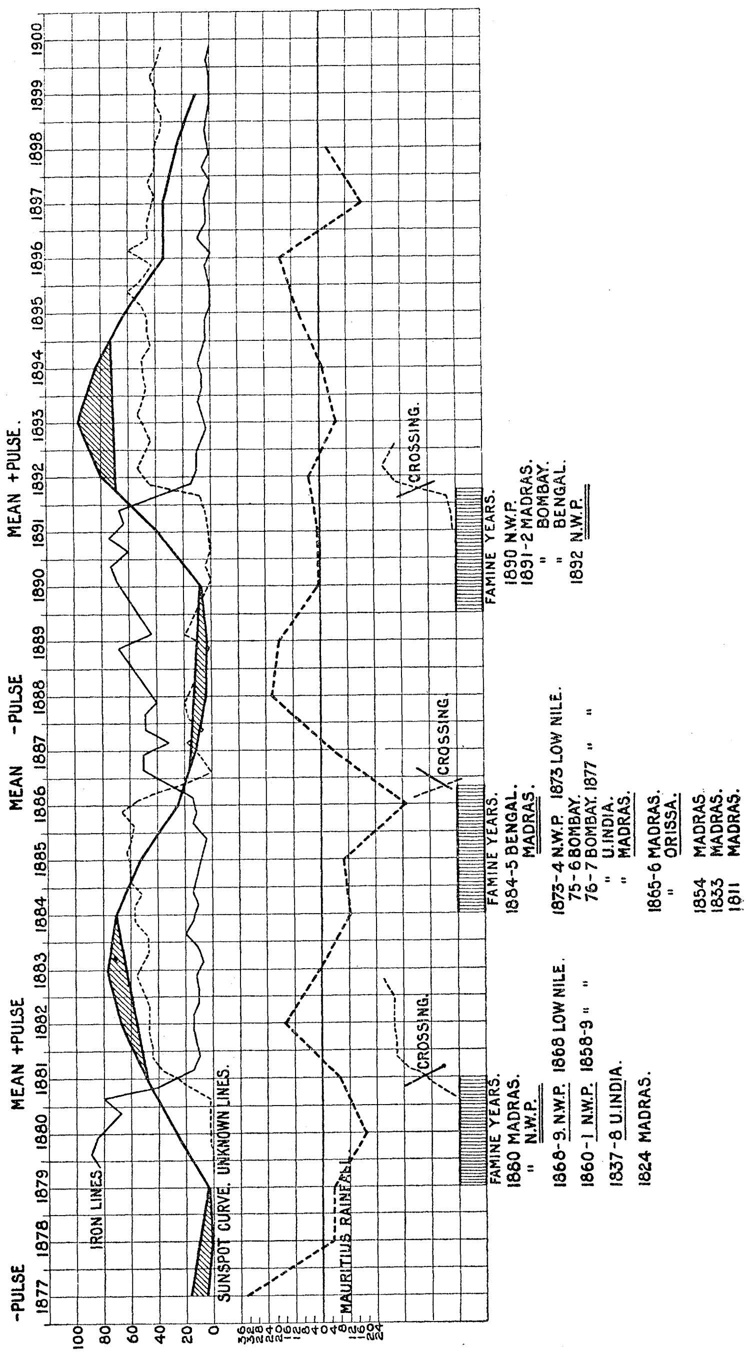
-PULSE
MEAN +PULSE
MEAN -PULSE
MEAN +PULSE.
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
100
80
60
40
20
0
IRON LINES.
SUNSPOT CURVE.
UNKNOWN LINES.
MAURITIUS RAINFALL.
CROSSING.
CROSSING.
CROSSING.
FAMINE YEARS.
1880 MADRAS.
" N.W.P.
1868-9 N.W.P. 1868 LOW NILE.
1860-1 N.W.P. 1858-9 " "
1837-8 U.INDIA.
1824 MADRAS.
FAMINE YEARS.
1884-5 BENGAL.
MADRAS.
1873-4 N.W.P. 1873 LOW NILE.
75-6 BOMBAY.
76-7 BOMBAY. 1877 " "
" U.INDIA.
" MADRAS.
1865-6 MADRAS.
" ORISSA.
1854 MADRAS.
1833 MADRAS.
1811 MADRAS.
FAMINE YEARS.
1890 N.W.P.
1891-2 MADRAS.
" BOMBAY.
" BENGAL.
1892 N.W.P.

Fig. 2.

a subsidiary solar pulse. We propose to return to this subject in a subsequent communication, after inquiries have been completed relating to 1885–86 and 1896–97.

The Intervals between the Pulses.

There will obviously be intervals between the ending of one pulse and the beginning of the next, unless they either overlap or become continuous.

The + and − pulses, to which our attention has been chiefly directed, are limited in duration; and when they cease the quantity of rain which falls in the Indian area is not sufficient without water storage for the purposes of agriculture; they are followed, therefore, by droughts, and at times subsequently by famines (fig. 2).

Taking the period 1887–89 we have—

Rain from − pulse	77
	78
	79 (part)
No rain pulse	79 (part)
	80 (central year)
	81 (part)
Rain from + pulse	81 (part)
	82
	83
	84 (part)
No rain pulse	84 (part)
	85 } (central years)
	86 }
	87 (part)
Rain from − pulse	87 (part)
	88
	89

The duration of these + and − pulses of rainfall was determined in the first instance by the Mauritius rainfall, which shows both pulses: and later from the Malabar rainfall, which perhaps shows the effect of the south-west monsoon in its greatest purity.

All the Indian famines since 1836 (we have not gone back further) have occurred in these intervals carried back in time on the assumption of an eleven-year cycle.

The following tables show the result for the two intervals :—

The Interval between the Pulses, taking 1880 as the Central Year, on the Upward Curve.

		1880, Madras famine.
		N.W.P. famine.
1880 − 11	=	1869, N.W.P. famine (1868–9).
1869 − 11	=	1858, N.W.P. famine (1860).
1858 − 11	=	1847.
1847 − 11	=	1836, Upper India famine (1837–8). (Great famine.)

The Interval between the Pulses, taking 1885–6 as the Central Years, on the Descending Curve.

1885–6		Bengal famine, Madras famine (1884–5).
1885–6 − 11	=	1874–5, N.W.P. famine (1873–4).
		Bombay famine (1875–6).
		Bombay famine, Upper India famine (1876–7).
1874–5 − 11	=	1863–4, Madras famine, Orissa famine (1865–6).
1863–4 − 11	=	1852–3, Madras famine (1854).

It is clear from the above table that if as much had been known in 1836 as we know now, the probability of famines at all the subsequent dates indicated in the above tables might have been foreseen.

The region of time from which the above results have been obtained extended from 1877 to 1886. The next table will show that if the dates, instead of being carried back, are carried forward, the same principle enables us to pick up the famines which have devastated India during the period 1886–97.

Same intervals, going Forward.

	1880.
+ 11	1891, N.W.P. famine (1890).
	Madras famine, Bombay famine, Bengal famine (1891–2).
	1885–6.
+ 11	1896–7, General famine.

This result has arisen, so far as we can see, from the fact that the + and − pulses included in the period 1877–1886 were normal; that is, were not great departures from the average.

Nile Floods.

After we had obtained the above results relating to the law followed by the Indian famines, we communicated with the Egyptian authorities with a view of obtaining data for the Nile Valley.

We have since found, however, from a memorandum by Eliot,* that Mr. Wilcocks, in a paper read at the Meteorological Congress at Chicago, remarked that "famine years in India are generally years of low flood in Egypt."

It remains only for us, therefore, to point out that the highest Niles follow the years of the + and – pulses. Thus:—

1871, one year after + pulse 1870.
1876, two years after subsidiary pulse of 1874.
1879, two years after – pulse 1877.
1883–4, one and two years after + pulse 1882.
1893–4, after + pulse 1892 (India excess rainfall, 1892–3–4).

The Great Indian Famine of 1899.

When, in a sun-spot cycle, the solar temperature is more than usually increased, the regularity of the above effects is liable to be broken, as the advent of the – pulse is retarded.

This, as we have already pointed out, is precisely what happened after the abnormal + heat pulse of 1892, following close upon the condition of solar mean temperature.

The widened line curves, instead of crossing, according to the few precedents we have, in 1897 or 1898, have not crossed yet—that is, the condition of ordinary solar mean temperature has not even yet been reached.

We have shown that, as a matter of fact, in a normal cycle India is supplied from the Southern Ocean during the minimum sun-spot period, and that this rain is due to some pressure effect brought about in high southern latitudes by the sun at – temperature.

As the – temperature condition was not reached in 1899, as it would have been in a normal year, the rain failed (fig. 3).

We may say then that the only abnormal famine recorded since 1836 occurred precisely at the time when an abnormal effect of an unprecedented maximum of solar temperature was revealed by the study of the widened lines.

We desire to tender our acknowledgements to Dr. Buchan, F.R.S., and Mr. Shaw, F.R.S., for their kindness in so promptly replying to our appeal for rainfall tables. We wish also to thank Mr. H. Shaw, one

* Forecast of S.W. Monsoon rains of 1900.

of the teachers in training at the Royal College of Science, for assistance in bringing together rainfall data and plotting numerous curves.

Fig. 3.

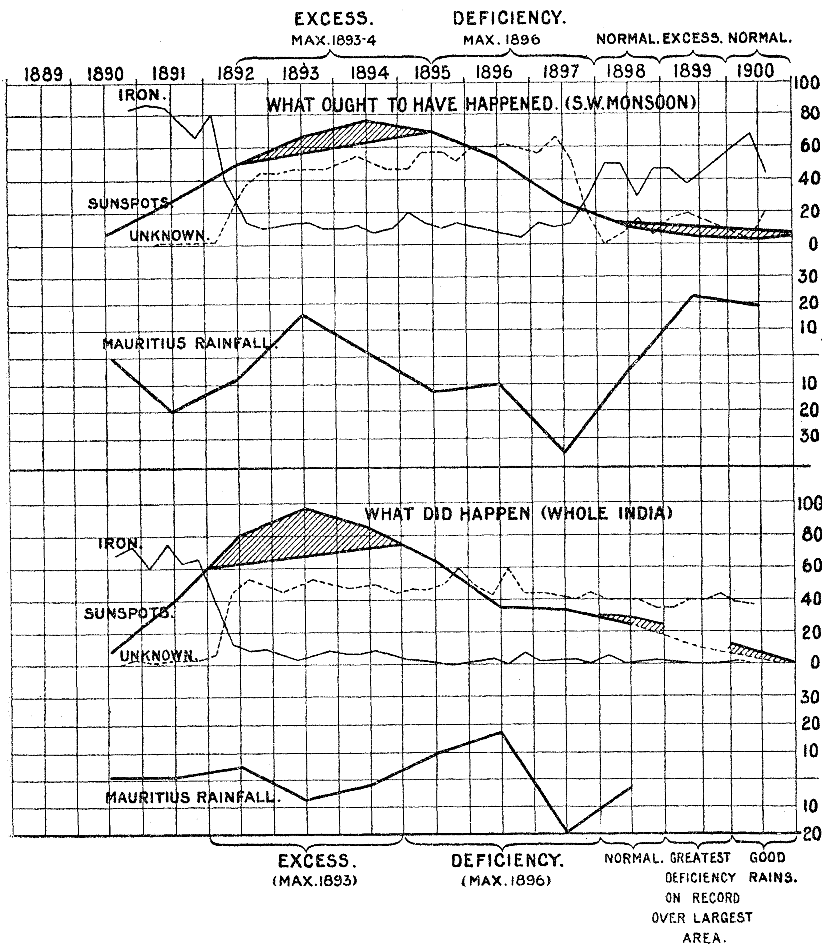

Table showing the Occurrence of the + and − Rainfall Pulses in other Parts of the World.

	+ 1870.	− 1877.	+ 1882.	− 1886.	+ 1892.
Batavia	—	1876	1882	1883	(?)
Mauritius	—	1877	1882	1888	1892
Catherinenburg (Russia)	—	1877	abs.	1887–8	1892
Scotland	—	1877	—	—	1892
Copenhagen	1872–3	1877	1882	1888	1891
Adelaide	1870	1877	1883	1889	1892–3
Tiflis	1870	1878	1881	1886–90	1893
Archangel	1872	1878	1881–2	1887–8	1892
Brussels	—	1878	1882	1888	1892
Hobart Town	—	1878	1882	1887	1893
*Malabar	1871	1878	1882	1888	1892
Toronto	1870	1878	1883	1886	1893
Córdoba (Arg.)	—	1878	1883	1888	1892
Cape	—	1878	1883	1888	1892
Java	1872	1879	1882	—	1893
Barnaul (Russia)	1872	1879	1882–3	1887	1894
St. Petersburg	1871	1879	1883	1888–9	1893
Nile	1871	1879	1883–4	—	1893–5

* For comparison.

"On the Restoration of Co-ordinated Movements after Nerve Crossing, with Interchange of Function of the Cerebral Cortical Centres." By ROBERT KENNEDY, M.A., D.Sc., M.D., Assistant Surgeon to the Western Infirmary, Glasgow. Communicated by Professor McKENDRICK, F.R.S. Received October 11,—Read November 22, 1900.

(Abstract.)

I.—*Experiments on Nerve Crossing.*

The experiments on nerve crossing were undertaken in order to ascertain whether, after division and cross union of the entire nerve supply of two antagonistic groups of muscles, the animal can regain the power of performing voluntary co-ordinated movements with the affected muscles, and also to ascertain the effects on the cerebral cortical centres affected by the crossing.

The object of this was to ascertain if the organism has the power to compensate for a change whereby nerve centres are brought into connection with peripheral endings, not by nature belonging to them.

The experiments were made on the right fore-limb of dogs, and