covering essentially the same departments as those of the sections of the American association, and Professor Thurston accepted the charge of the department of engineering. His contributions to the pages of this JOURNAL have been many and are well known to our readers. His work, which never flagged, continued to the last, for on the day of his death an article signed R. H. T. was in type and it appeared in the issue which contained the obituary announcement.

It is yet too early to speak with accurate judgment regarding the final value of the scientific and engineering work of Professor Thurston. There can be no doubt, however, that it was of great benefit to mankind, for he made engineers better scientists, promoted engineering education, helped to put engineering upon a higher professional plane, and constantly was on the watch to dispel the fogs of prejudice by help of the truths of science. His alma mater conferred upon him the degree of LL.D., and Stevens Institute devised the degree of doctor of engineering to do him special honor. In personal disposition he was quiet and retiring, but yet affable and kindly. His work was done with method and precision, and he was always most untiring to serve the interests of the educational institution with which he was connected. It is announced that the authorities of Cornell University propose to commemorate his services by the erection of a costly laboratory as a memorial, the same to be called Thurston Hall.

*SIMULTANEOUS SOLAR AND TERRESTRIAL CHANGES.**

THERE are very many cases recorded in the history of science in which we find that the most valuable and important applications have arisen from the study of the ideally useless. Long period weather forecasting, which at last seems to be coming into the region of practical politics as a result of the observation of solar changes, is another example of this sequence.

The first indications of these changes on the sun, to which I have referred, are matters of very ancient history, and so also is the origin of some of the branches of observation on which the study of them depends.

I will begin by referring to these and to the conclusions arrived at in relation to simultaneous solar and terrestrial changes previously to the last 25 years.

The facts that there are sometimes spots on the sun, and that there is a magnetic force which acts upon a needle, seem to have been known to the ancient Chinese. In more modern times the enquiries with which we are now concerned, date from the times of Galileo (1564–1642) and Kepler (1571–1630).

To Galileo, Fabricius and Scheiner we owe the first telescopic observations of the spots on the sun; to Kepler, the basis of spectrum analysis, which has not only revealed to us the chemistry of the sun and of its spots, but enables us to study daily other phenomena, the solar prominences, which will in all probability turn out to be more important for practical purposes than the spots themselves.

It is only quite recently that the importance of the study of the prominences in this direction has been indicated, so that we have to deal, in the first instance, with a long period of years in which only the spots and their terrestrial echoes were in question.

According to Professor Wolf (as quoted by Professor Köppen), Riccioli, in 1651, shortly after the first discovery of sun spots, surmised that some coincidence

* Report, International Committee, Southport, 1903.

might exist between them and terrestrial weather changes.*

In the first year of the last century, Sir Wm. Herschel drew attention to this subject.† He wrote:

The first thing which appears from astronomical observations of the sun is that the periods of the disappearance of spots on the sun are of much greater duration than those of their appearance.

With regard to the contemporary severity and mildness of the seasons, it will hardly be necessary to remark that nothing decisive can be obtained. An indirect source of information, however, is opened to us by applying to the influence of sunbeams on the vegetation of wheat in this country. I do not mean to say that this is a real criterion of the quantity of light and heat emitted by the sun, much less will the price of this article completely represent the scarcity or abundance of the absolute produce of the country.

On reviewing the period 1650–1713, it seems probable, from the prevailing price of wheat, that some temporary scarcity or defect of vegetation has generally taken place when the sun has been *without* those appearances which we surmise to be symptoms of a copious emission of light and heat.

To those acquainted with agriculture who may remark that wheat is well-known to grow in climates much colder than ours, and that a proper distribution of rain and dry weather are probably of much greater consequence than the absolute quantity of light and heat derived from the sun, I shall only suggest that those very circumstances of proper alternations of rain and dry weather and wind, etc., favorable to vegetation, may possibly depend on a certain quantity of sunbeams being supplied to them.

Herschel's suggestion was a daring one, for however perfect our national statistics may have been in relation to the price of wheat, there was nowhere kept up a continuous record of the changes observable on the sun's surface, nor had there been any serious attempt made to determine the law underlying them.

In 1825 this serious attempt was made, and by Schwabe of Dessau, who discovered a cycle of about eleven years in the solar changes. Wolf afterwards took up the question.

Herschell had associated the variation in the number of spots with that in the price of corn, the connecting link being sunshine or weather. It was to him a question of meteorology.

A year after the publication of Herschel's papers, Wollaston extended the early spectrum work of Kepler and Newton by discovering that in the solar spectrum there were many dark lines; these were for the first time mapped by Fraunhofer in 1814.

Soon after 1850 it became a question of the connection of sun spots with terrestrial magnetism as well as with meteorology. A new idea was introduced.

Lamont, Sabine and Allan Broun discovered that there was a well marked coincidence between the variations of magnetic effects, as observed on the surface of our planet by delicately suspended magnets, and the quantity of spotted area observed on the sun. This in later telegraphic days is not merely a pious opinion which does not interest anybody, because, when the magnetic changes are very considerable and the disturbances arrive at a maximum, it is very difficult to get a telegram from London to Brighton.

The period around the year 1860 was rendered ever memorable by a still further extension of Kepler's and Newton's work, which at once explained the dark lines observed in the solar spectrum by Wollaston and Fraunhofer.

Hitherto undreamt-of attacks on the nature of the sun became possible. The names of Kirchhoff, Bunsen, Angström, Stokes, Balfour Stewart will go for very long down the stream of time, because they showed us that in spectrum analysis we had the power of practically conversing, chemically, with the distant worlds in

* Blandford, Bengal, *Asiat. Soc. Journ.* 65; Part II., 1875, p. 22.

† *Phil. Trans.*, 1801, p. 265.

space, and these distant worlds, of course, included the sun, although it is practically our neighbor.

It was now established that the solar radiation came from the incandescence of metallic vapors and gases in the sun's atmosphere, the metals and gases being for the most part those with which we are familiar on the earth. Not only was a high temperature demonstrated in this way, but it was further shown that above the sun's apparent surface there was an absorbing atmosphere, consisting of vapors cooler than those below, but yet hot enough to be composed of the steam of iron and other metals.

In 1865, De la Rue, Stewart and others, in an attempt to get the periodicity of the solar phenomena still more accurately determined, started work at Kew; while the former observations were carried on by Schwabe and Wolf by the eye, photography, which was then being introduced into astronomical work by the labors of Warren De la Rue, was for the first time now utilized, and a picture of the sun was taken each day.

In 1866 a new method of observing solar changes, which consisted in throwing an image of the sun on the slit plate of a spectroscope, revealed the fact that the spectra of spots differed from that of the photosphere generally; certain lines were widened in the spot spectrum.*

In 1867 a connection between changes in spotted area and in terrestrial temperatures was pointed out by Baxendell.† He noticed a distinct and very striking relation between the number of sun spots and the ratio which exists between the difference of the mean maximum temperature of solar radiation and the mean maximum air temperature on the one hand, and that of the mean temperature of the air and of evaporation on the other.

* Lockyer, *Proc. Roy. Soc.*, October 11, 1866.

† *Memoirs of the Manchester Lit. and Phil. Soc.*, Third Series, Vol. IV., pp. 128 et seq.

In 1868 a spectroscopic method was discovered of observing in full daylight the 'prominences' or 'red flames' which hitherto had only been glimpsed during eclipses, and it was established that, closely surrounding the sun ordinarily seen, there was an envelope, named the chromosphere, of incandescent gases and vapors, hydrogen and a new substance named helium chief among them.*

Many spectroscopic observations made on the spots and prominences about this time indicated great changes in the solar temperature in different regions, and possibly, therefore, changes in the amount of heat radiated earthwards. From the changes thus actually seen it was easy to imagine that there might be a cycle of terrestrial changes depending no longer on the sun's presentation to us in its daily and yearly rounds, but on physical changes in the sun itself, requiring, perhaps, many years to accomplish.

In 1869, Janssen showed† that by a special arrangement of the spectroscope an image of the sun, showing the prominences both on the disc and surrounding it, might be obtained.

It was not very long before it was found that the reaction of these solar changes on the earth was not so limited as had formerly been thought. This was an idea started by Dr. Stone of the Royal Observatory at the Cape of Good Hope, Piazzi Smyth of the Royal Observatory of Edinburgh, and others, about the years 1870 and 1871, but the most striking imperial contribution to the matter we owe to the labors of a distinguished meteorologist, Dr. Meldrum, director of the observatory at Mauritius, which has since become the Royal Alfred

* Lockyer, *Proc. Roy. Soc.*, October 20, 1868.

† *Comptes Rendus*, Vol. LXVIII. (1869), pp. 367 et seq.

Observatory. He showed that the number of wrecks which came into the harbor of the Mauritius and the number of cyclones observed in the Indian Ocean could enable any one to determine the number of spots that were on the sun about the time. The Mauritius is most admirably suited for the making of these observations, because the Tropics are really the right region in which to try and estimate the possibilities of this solar action. Meldrum found, in fact, that the maximum number of cyclones was associated with the maximum number of sun spots. He wrote:*

> During the period 1847–72 it is found that some years have been remarkable for a frequency, and others for a comparative absence of cyclones.
> 1847–51 were characterized by cyclone frequency.
> 1852–57 were characterized by comparative calm.
> 1858–63 were characterized by cyclone frequency.
> 1864–68 were characterized by decrease.
> 1868–72 were characterized by great increase.
>
> It will be seen that the years correspond with the maxima and minima epochs of sun spots. It appears to me that there is more than a mere coincidence as to time.
>
> The numbers of wrecks during these periods also show a similarly regulated frequency.

Poey, investigating shortly afterwards the cyclone condition in the West Indies,† found that the greater number of years of maxima of storms fall from six months to two years, at the most, after the years of maxima of solar spots.

Out of twelve maxima of storms, ten coincide with maxima periods of spots. Out of five minima of storms, five coincide with minima of spots.

It will be seen that the results from both the East and West Indies are the same. Next came the question of a rainfall cycle corresponding to the solar spots.‡

When I was preparing to go to India, in 1871, to observe the eclipse, Mr. Ferguson, the editor of the *Ceylon Observer*, who happened to be in London, informed me that everybody in Ceylon recognized a cycle of about thirteen years or so, in the intensity of the monsoon—that the rainfall and cloudy weather were more intense every thirteen years or so. This, of course, set one, interested in solar matters, thinking, and I said to him: "But are you sure the cycle recurs every thirteen years, are you sure it is not every eleven years?" adding, as my reason, that the sun spot period was one of eleven years or thereabouts, and that in the regular weather of the Tropics, if anywhere, this should come out.

It afterwards turned out that the period in Ceylon was really of eleven years, five or six years dry, and five or six years wet, and that a longer period of about thirty-three years was recognized.

Mr. Meldrum passed from cyclones to rainfall by a very obvious step, because cyclones are generally accompanied by torrential rains. A study of the rainfalls of Port Louis, Brisbane and Adelaide led him to the conclusion that a case had been made out for a supposed periodicity.

On my return from India I looked up the Cape and Madras records for the periods available, and found that they followed suit, hence I quite agreed with Dr. Meldrum that investigations were desirable, and I wrote as follows:*

> Surely in meteorology, as in astronomy, the thing to hunt down is a cycle, and if that is not to be found in the temperate zone, then go to frigid zones, or the torrid zones and look for it, and if found, then above all things, and in whatever manner, lay hold of, study it, record it, and see what it means. If there is no cycle, then despair for a time if you will, but yet plant firmly your science on a physical basis, as Dr. Balfour Stewart long ago suggested, before, to the infinite detriment of English science, he left the Meteorological Observatory at Kew; and having got such a basis as this, wait for results. In the absence of these methods, statements of what is happening to a blackened bulb in vacuo, or its

* *Nature*, Vol. VI., p. 357, 1872.

† *Comptes Rendus*, November 24, 1873, p. 1222.

‡ 'Solar Physics' (Lockyer, 1874), p. 425.

* 'Solar Physics, pp. 424–5.

companion exposed to the sky, is, for research purposes, work of the tenth order of importance.

With reference chiefly to Dr. Meldrum's paper, I added:

Surely here is evidence enough, evidence which should no longer allow us to deceive ourselves as to the present state of meteorology. A most important cycle has been discovered, analogous in most respects to the Saros discovered by the astronomers of old, indeed, in more respects than one, may the eleven yearly period be called the Saros of meteorology, and as the astronomers of old were profoundly ignorant of the true cause of the Saros period, so the meteorologists of the present day are profoundly ignorant of the true nature of the connection between the sun and the earth.

What, therefore, is necessary in order to discover the true nature of this nexus? Two things are necessary, and they are these. In the first place, we must obtain an accurate knowledge of the currents of the sun, and secondly, we must obtain an accurate knowledge of the currents of the earth. The former of these demands the united efforts of photography and spectrum analysis, and the second of these demands the pursuit of meteorology as a physical science, and not as a mere collection of weather statistics. When these demands are met—and in spite of the Mrs. Partingtons who are endeavoring to prevent this, they will soon be met—we shall have a science of meteorology placed on a firm basis—the meteorology of the future.*

At this time the Indian authorities were quite alive to the importance of such investigations as these. India is in the tropics, India is a child of the sun, the inhabitants depend almost entirely upon the beneficent rains which seemed, in some way or another, to depend upon solar action. India also had then the germs of one of the best equipped meteorological organizations which exist on the surface of the planet, and the meteorologists felt that there was something behind their meteorological registers which might be assisted by taking a very official step and going to headquarters, headquarters being the sun. When I was in India, in 1872, Lord Mayo, the then Viceroy, did me the honor to ask me to go to Simla with a view of choosing a site for a proposed Solar Physics Observatory. That is thirty years ago! Unfortunately, I was secretary of the Duke of Devonshire's Commission, which was then sitting, and I could not get leave, and, therefore, could not go; the scheme, which was then before the Indian authorities—which, if I may say so, was altogether grandiose and extravagant—fell through.

In 1873, the idea of the possible connection of solar and magnetic changes had got so far that the magnetic and meteorological department of the Royal Observatory at Greenwich, which had been established in 1838, received an important addition. A photo-heliograph was set up in order to continue the daily photographic record of the sun's surface, begun at Kew in 1865.

In the same year Köppen found that the maximum temperature occurs in the years of sun spot minima and the reverse, years with many spots are cool years.*

Of special importance for the connection between the temperature on the earth's surface with the sun's spotted area is the fact that the temperature curve (mean number for the whole earth) and the curve representing the sun-spotted area is identical in all the irregularities.

In the tropics in the

Year before the sun spot *Min.*, the temperature is 0.41° higher than the mean.

Year before the sun spot *Max.*, the temperature is 0.32° lower than the mean.

The variation is thus 0.73°.

* I very much regret that, in the article quoted, my reference to Carlyle's German 'Dry as dust,' as a patient enquirer who would eventually apportion credit to all meteorological workers, has been misunderstood by some of my German friends. Relying on imperfect dictionaries, which have told them that a mere 'bookworm' was meant, they have missed the high compliment I intended to pay them.

* W. Köppen, 'Uber mehrjährige Perioden der Witterung,' *Zeitschrift f. Meteorologie*, Bd. VIII., 1873, pp. 241–248 and 257–268.

By this time spectroscopic observations of the solar changes had proved that the sun was hottest when there were most spots, thereby upsetting the old idea that the spots acted as screens and reduced the radiation at sun-spot maximum. Köppen's result, therefore, was a paradox, and was thus explained by Blanford.*

The temperatures dealt with by Professor Köppen are of course those of the lowest stratum of the atmosphere at land stations, and must be determined *not by the quantity of heat that falls on the exterior of the planet, but on that which penetrates to the earth's surface, chiefly to the land surface of the globe.* The greater part of the earth's surface being, however, one of water, the principal immediate effect of the increased heat must be the increase of evaporation, and therefore, as a subsequent process, the cloud and the rainfall. Now a cloudy atmosphere intercepts the greater part of the solar heat, and the re-evaporation of the fallen rain lowers the temperature of the surface from which it evaporates and that of the stratum of air in contact with it. The heat liberated by cloud condensation doubtless raises the temperature of the air at the altitude of the cloudy stratum; but at the same time we have two causes at work, equally tending to depress that of the lowest stratum. As a consequence, an increased formation of vapor, and therefore of rain, following on an increase of radiation, might be expected to coincide with a low air-temperature on the surface of the land.†

The next important advance had to do with atmospheric pressure. In 1875, Mr. C. Chambers, the director of the Bombay Observatory, found that

The variation of the yearly mean barometric pressure at Bombay shows a periodicity nearly corresponding in duration with the decennial sun-spot period.‡

The years round 1875 were rendered very important by the number of new organizations established to record and demonstrate various classes of observations with which we are concerned in this short history. Meteorological enquiries on a large scale were organized at home and in India, and observatories were established at Potsdam, Paris and London, with the main object of studying solar changes. At the same time steps were taken to resume observations in the tropics. It is not out of place here to make a brief reference to what was done in Britain and India.

The government took this action in consequence of a strong recommendation of the Royal Commission on Science, presided over by the late Duke of Devonshire, of the establishment by the state of an Observatory of Solar Physics in which enquiries relating to the nature of the sun and its changes should be fostered and various investigations which were necessary should be carried on.

The commission also proposed that similar institutions should be established in various parts of the empire.

The ground on which the Royal Commission, and subsequently a memorial presented to the government by the British Association, urged this new departure was that, in the opinion of a considerable number of scientific men, there was a more or less intimate connection between the state of the sun's surface and the meteorology of the earth; and they called attention to the fact that recent independent investigations on the part of several persons had led them to the conclusion that there was a similarity between the sun-spot period, periods of famine in India, and cyclones in the Indian Ocean. The memorialists concluded by saying:

We remind your lordships that this important and practical scientific question can not be set definitely at rest without the aid of some such institution as that the establishment of which we now urge.

The Lords of the Committee of Council on Education referred this memorial to a

* Blanford, Bengal, *Asiat. Soc. Journ.*, 1875.

† See also Blanford, *Nature*, April 23, 1891, Vol. 43, p. 583.

‡ 'Meteorology,' Bombay Presidency, August, 1875, S. 26, p. 12.

committee, consisting of Professor Stokes, Professor Balfour Stewart and General Strachey, for their opinion as to whether a commencement might not be made to give effect to the proposals of the memorialists by utilizing the chemical and physical laboratories at South Kensington, as the proposed observatory must be more chemical and physical than astronomical. The following paragraph appeared in the terms of reference:

Although we are not at present in a position to consider the establishment of a physical observatory on a comprehensive scale, we believe that some advantage can be gained if a new class of observations can be made with the means at command, since the best method of conducting a physical observatory may thus be worked out experimentally, and an outlay eventually avoided which, without such experience, might have been considered necessary.

While the discussion as to the establishment of a solar physics observatory in this country was going on, Lord Salisbury, who was then Secretary of State for India, permitted me to send him a memorandum on this subject. In it I pointed out that what we wanted, especially in reference to solar enquiries, was to learn, day by day, what the sun was really doing, which India and other tropical countries always could tell us, while it seemed almost impossible that we should ever get sufficiently continuous records in England.

I gave the following extracts:

Solar research is now being specially carried on in Europe at—

1. Potsdam, in the new Sonnenwarte.
2. Paris, in the new physical observatory.
3. Rome and Palermo.
4. South Kensington, in connection with the Science and Art Department.
5. At Greenwich, Wilna, and other places it is carried on in a less special way.

In these European observatories, however, especially in the more northern ones, we are attempting to make bricks without straw, that is, the climate is such that the observations are often interrupted, at times for weeks together, while, in addition to this, in winter the sun's altitude is so small that fine work is impossible.

While this state of things holds in Europe, in India, on the other hand, one has an unlimited and constant supply of the *raw material*, by which I mean that here one can, if one chooses, obtain observations of the finest quality in sufficient quantity all the year round. I may even go further, and say that, limiting my remark to English ground, we have in India a *monopoly* of the raw material.

The prayer of the memorandum was granted, and shortly afterwards I had the pleasure of sending out one of my assistants to India. Unfortunately, he died soon after the first series of daily photographs of the sun had been commenced, but eventually the Trigonometrical Survey Department took the matter up, an observatory was built at Dehra Dun, and India began its work, and I am thankful to say that it has gone on continuously ever since.

It was not till 1879, and after a letter from the Duke of Devonshire, that a sum of £500 was taken on the estimates to replace the assistance formerly obtained by myself from the Government Grant Fund administered by the Royal Society, and to allow of more research work being undertaken. At the same time, the Solar Physics Committee was appointed. The object sought was to make trial of methods of observation, to collect and discuss results, to bring together all existing information on the subject, and to endeavor to obtain complete series of observations along the most important lines.

This state action was taken because the sun has to be studied, if studied at all, continuously, because it is ever changing, and the more we study it the longer are the cycles which we find to be involved; hence, all enquiries into its nature must be on an imperial basis. Individuals die, nations remain. Nor is this all. Observatories are not only wanted in the centers of intellectual activity where research can be conducted in a scientific atmosphere, but there must be others to obtain the necessary observations in those favored regions of our planet in which the maximum of sunshine can be depended upon.

The then astronomer royal, Sir George Airy, was most sympathetic, and as a result of this state action, the little observatory at South Kensington was shortly afterwards enlarged; it has considerably grown since then, but it is still in the experimental stage. Although, perhaps, I am not the one to say it, I am prepared to take the responsibility of stating that it is now one of the best equipped for its special work in the world. It certainly is the shabbiest to look at. Irreverent comparisons have been made even in the House of Commons; the general appearance of its wood and canvas huts having been likened to that of a more or less disreputable looking traveling menagerie, but, at all events, it is instrumentally efficient, and that for the present must be sufficient.

During the last quarter of a century a great deal of work has been going on, and the colonies and dependencies of Britain have also been doing yeoman service; very little has been said about it, because not all departments are in the habit of advertising themselves, and Blue Books are not as a rule light reading. In the first place, the Indian daily photographic record, which was weak during a month or two during the S.W. monsoon, was supplemented by the erection of a duplicate instrument at the Mauritius; and I am again thankful to say that the work has gone on at the Mauritius continuously since. Thus we have now two tropical records, which, taken together, may be described as absolutely continuous, of solar changes sent to us in the most imperial fashion by two observatories. Another appeal was made to Australia. For a time records were sent us, but I am sorry to say that after a time they ceased.

These records are sent regularly with every precaution against loss, to the observatory at South Kensington; and for the days when no photographs have been taken at Greenwich the necessary photographs are transmitted there, where they are reduced in continuation of the record commenced in 1873 there, in succession to Kew.

What has been the result of this? The late astronomer royal took up this work at Greenwich in 1873. In 1874, 1875, 1876, 1877, 1878, the average number of days on which it was possible to obtain photographs in each year was a little over 160, the exact figures being 159, 161, 167, 171, 149. This was Greenwich working alone, national work.

Next, we come to the imperial work. Selecting years at random, and dealing with 1889 to 1893, I find that we obtained photographs of the sun in 1889 for every day in the year except five, in 1890, for every day except four, in 1891, for every day except two. It is easy to understand that with such a magnificently complete record as this the study of solar physics was enormously improved.

Very fortunately for science, even before these steps were being taken to secure a continuous record of the spotted area, Professor Respighi (1869) and Professor Tacchini (1872) had commenced at Rome a daily record of the solar prominences and of the latitudes at which they appeared at different times.

I pass on to some of the most important work done during the last quarter of a century, only referring to the results obtained which bear upon the connection between solar and terrestrial changes.

Many important advances were made in 1878.

Mr. F. Chambers, in continuing his studies on the Indian barometer, found* a remarkable degree of resemblance in the progression of barometric pressure during

* *Nature*, Vol. XVIII., p. 567.

summer, winter and year, and sun spots from year to year; but he noticed that the barometric curve *lags* behind the sun-spot curve, particularly in the years of maxima of sun spots. The winter curve is more regular than the summer one, probably because the weather generally in India is more settled in the winter than in the summer; but on the whole the two curves support each other in having a *low pressure* about the time of *sun-spot maximum*, and a high pressure about the time of sun-spot minimum. We may, therefore, conclude that the *sun is hottest* about the time when the *spots are at a maximum*. He added, that these results appear to harmonize well with the decennial variations of the rainfall in India, and to throw light upon the inverse variation (compared with the sun spots) of the winter rainfall of northern India.

Dr. Allan Broun also, in a discussion of Indian barometric readings, found that the years of greatest and least pressure are probably the same for all India, and that, therefore, the relation established by Mr. Chambers for Bombay holds for all India.*

I next pass to rainfall. Dr. Meldrum, returning to his rainfall studies, found that †

> There is a remarkable coincidence between the rainfall and sun-spot variation at Edinburgh, much more remarkable than that at Madras. The years of maximum and minimum rainfall, and sun spots for the mean cycles, coincide, and on the whole there is a regular gradation from minimum to maximum, and from maximum to the next minimum.

The minimum rainfall occurred, on an average, in the year immediately preceding the year of maximum sun spots.

The results of these investigations show that the rainfall of 54 stations in Great Britain from 1824–1867 was .75 inches *below mean* when sun spots were at a minimum, and .90 inches *above mean* when sun spots were at a maximum.

For the 34 stations in America, the corresponding numbers were .94 inch in 1.13 inches.

In the report of the Meteorological Department of the government of India, published this year (1878), the following reference to solar action occurs:

> The following are the main important inferences that the meteorology of India in the years 1877–1878 appears to suggest, if not to establish: There is a tendency at the minimum sun-spot periods to prolonged excessive pressure over India, and to an unusual development of the winter rains, and to the occurrence of abnormally heavy snowfall over the Himalayan region. * * * This appears also to be accompanied by a weak southwest monsoon.

In 1880 the relation of India famines and the barometer was first fully treated by Mr. F. Chambers, the meteorological reporter for western India.* He concluded from his enquiry that there is some intimate relation between the variations of *sun spots, barometric pressure* and *rainfall;* and as famines in general are induced by a deficiency of rain, it is probable that they also may be added to the above list of connected phenomena.

Commencing with the daily abnormal variations observed at several stations in western India, it was found that as the time over which an abnormal barometric fluctuation extended became longer and longer, the range of the fluctuation became more and more uniform at the various stations, thus leading to the conclusion that the '*abnormal variations of long duration affect a very wide area.*' For testing this, the conditions of Batavia were compared with those at Bombay, and the results showed a striking coincidence, the curves obtained for the two places being almost identical in form, but with this remarkable difference: the curve for Batavia was

* *Nature*, Vol. XIX., p. 6.

† *Nature*, Vol. XVIII., p. 565.

* *Nature*, Vol. XXIII., p. 109.

found *to lag* very persistently about one month *behind* the Bombay curve.

Similar results were then worked out for other stations. St. Helena, Mauritius, Madras, Calcutta and Zi-ka-wei. On comparing the curves obtained for these various places, though a strong resemblance in form betwen all the curves is observed, there is also strong evidence of a want of simultaneity in the barometric movements at different stations, and that as a rule the changes take place at the *more westerly stations* several months *earlier than* at the more *easterly ones.*

Thus, on comparing the curves for St. Helena and Madras from 1841–1846, the latter sometimes lagged behind the former as much as six months, and for Bombay and Calcutta the corresponding difference was often upwards of six months.

The facts suggested to him long atmospheric waves (if such they may be called) traveling at a very slow and variable rate round the earth, from *west to east,* like the cyclones of the extra-tropical latitudes.

With special reference to famines, he remarked that, on comparing the dates of all the severe famines which have occurred in India since 1841, widespread and severe famines are generally accompanied or immediately preceded by waves of high barometric pressure. He suggested, therefore, that intimation of the approach of famines might be obtained in two ways:

(*a*) By regular observations of the solar spotted area, and early reductions of the observations, so as to obtain early information of current changes going on in the sun.

(*b*) By barometric observations at stations differing widely in longitude, and the early communications of the results to stations situated to the eastward.

In the same year, Dr. H. F. Blandford discovered that*:

Between Russia and Western Siberia on the one hand, and the Indo-Malayan region on the other, there is a reciprocating and cyclical oscillation of barometric pressure, of such a character that the pressure is at a maximum in *Western Siberia* and *Russia* about the epoch of maximum sun-spots, and in the *Indo-Malayan* area at that of minimum sun-spots.

* *Nature,* Vol. XXI., p. 480.

Up to 1881, the general idea had been that there was a great difference between the meteorological conditions at the maximum and minimum of the sun-spot curve, but the more numerous and more accurate series of observations available in the year in question revealed to Meldrum 'extreme oscillations of weather changes in different places at the turning points of the curves representing the increase and decrease of solar activity.'

This was a most important change of front. Not the maximum only, but both the maximum and minimum had to be considered.*

In relation to these pressure changes he wrote as follows:†

Among the best established variations in terrestrial meteorology which conform to the sun-spot cycle, are those of tropical cyclones, and the general rainfall of the globe, both of which imply a corresponding variation in evaporation and the condensation of vapor. Now the variation of pressure with which we have to deal evidently has its seat in the higher (probably the cloud-forming) strata of the atmosphere. This is not only illustrated in the present instance by the observed relative excess of pressure at the hill stations as compared with the plains, but also follows as a general law from the fact established by Gautier and Köppen, viz., that the temperature of the lowest stratum varies in a manner antagonistic to the observed variation of pressure. It is then a reasonable inference that the principal agency in producing the observed reduction of pressure at the epoch of sun-spot maximum is the more copious production and ascent of vapor, which may operate in three different ways. First, by displacing air the density of which is three eighths greater; second, by evolving latent heat in its condensation; and thirdly, by causing ascend-

* 'Relations of Weather and Mortality, and in the Climatic Effect of Forests.'

† *Nature,* XXI., p. 482.

ing currents, and thus reducing dynamically the pressure of the atmosphere as a whole. The first and second of these processes do not indeed directly reduce the pressure but only the density of the air stratum while they increase its volume. In order, therefore, that the observed effect may follow, a portion of the higher atmosphere must be removed, and this will necessarily flow away to regions where the production of vapor is at a minimum, viz., the polar and cooler portions of the temperature zones, and more especially those where a cold dry land surface radiates rapidly under a winter sky. Such an expanse is the great northern plain of European Russia and Western Siberia north of the Altai.

In 1886 we got the first fruits of the observations of the widened lines in sun spots, which had been obtained on a definite plan, since 1879. The changes which occurred from a spot-minimum to a spot-maximum, and some distance beyond, had therefore been recorded. The changes were most marked, showing a great change in the chemistry of the spots at these times. At minimum the lines chiefly widened were those of iron and some other metals, but at the maximum the lines widened were classed as 'unknown,' because they had not been recorded in the spectra of the terrestrial elements. It was reasonable to suppose, therefore, that the sun was not only hotter at maximum, but hot enough to dissociate iron vapors.*

In 1891 Janssen's suggestion of 1869 was brought into a practical shape for observatory work, by Hale and Deslandres,† and the prominences on the sun's disc, and surrounding it, were photographed in full daylight by using only the light radiated by the calcium vapor, which they always contain.

By the year 1900 we had accumulated, at South Kensington, observations of the widened lines for a period of over 20 years. There was a curious break in the regularity of the results obtained after 1894, and the Indian meteorologists reported contemporaneous irregularities in the Indian rainfall.

I determined, therefore, to make a connected enquiry into both these classes of phenomena. Thanks to the establishment of the Indian Meteorological Department in 1875 we had rainfall tables extending over a quarter of a century, and in the tropics, where the problems might be taken as of the simplest, to compare with the new solar data.

I have already stated that in the preliminary discussion of the most widened lines observed in the sun spots up to the year 1885, a most remarkable difference was observed in the lines observed at sun-spot maximum and minimum. This continued till about 1895, another ten years. As the curve of iron lines went up, the curve of 'unknown' lines came down; there were therefore *crossings* of the curves which might, on the hypothesis before referred to, be taken as the times at which the temperature of the solar system had a mean value. These crossings turned out to be about half-way between the maxima and minima of the spotted area which had to be considered as the times at which the sun was hotter and colder than the mean.

We were then brought into the presence of three well-marked stages of solar temperature—it was no longer a question merely of spots and no spots, but of heat pulses.

The next point was to study these heat pulses in relation to the Indian rainfall, and it was found that in many parts of India the plus and minus heat pulses on the sun, which, of course, occurred immediately after the time of mean temperature, when the sun was getting either hotter or colder, were accompanied by pulses of rain in the Indian Ocean and the surrounding land. It was next found, from a study of the Indian Famine Committee's reports,

* *Proc. Royal Soc.*, 1886, p. 353.

† *Comptes Rendus*, August 17, 1891.

that the famines which have devastated India during the last half century have occurred in the intervals between the pulses.

In 1902, with a view of getting more light on the important issues raised by the comparison of the solar heat pulses and the Indian rainfall, I determined to reduce the observations of prominences made by Tacchini at the Observatory of the Collegio Romano since 1874, and compare the Indian meteorological conditions with them. The reason for this step was that the admirable photographs of the prominences on the solar disc, published by Hale and Deslandres, showed the extensive area over which they were distributed. An argument which has been used against the possible connection between solar and terrestrial changes was based upon the small area covered by spots. In 1877 Eliot wrote as follows:*

> So far as can be judged from the magnitude of the sun spots, 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 mathematical principle, the effect on the elements of meteorological observations for the whole earth ought to be small.

Now the photographs, to which I have referred, exhibited broad bands of prominences extending almost across the whole disc, and if we assume two belts of prominences, N. and S., 10° wide, with their centers over latitude 16°, a sixth of the sun's hemisphere would be in a state of disturbance. Hence it followed that the prominence effect, when fully studied, might be much more striking and important than that produced by spots.

The prior work in connection with the Indian rainfall had shown not only that there was a close connection between pressure and rainfall, but that the pressure was much the more constant element over the different areas. The comparison with the prominences obtained from the discussion of Tacchini's results was in the first instance compared with the Indian pressure curve.

The result was magnificent. In addition to the well-marked prominence maximum at the maximum of the spotted area, there were others corresponding approximately with the 'crossings' of the widened lines, and all were re-echoed by the Indian barometers!

The sun-spot cycle of eleven years gave way to a prominence cycle of about 3.7 years, and by this interval, as a rule, are the Indian pressures separated.

To see whether such a striking and important result as this was limited to Indian ground, the magnificent series of pressure obtained at Cordoba in South America were studied. Here the same effect was also most marked, but with the important difference that the curves were inverted: that is, high pressure years in India were represented by low pressure years in Cordoba. In order to extend the Indian and Cordoba areas and see how far these conditions prevailed, the pressure variations of stations as widely distributed as possible were examined. The result of this inquiry showed that the world might be divided roughly into two portions. The Indian area was found to extend to Australia, East Indies, Asiatic Russia, Mauritius, Egypt, East Africa and Europe, while the Cordoba region might be said to include not only South and Central America, but the United States and Canada, extending further west than Honolulu.

This discovery of this barometric surge, which has been corroborated since by Professor Bigelow, was an important advance, and will enable the investigator to connect up regions that undergo similar pressure changes.

In addition to the two periods, namely, 11 and 3.7 years, mentioned above, Brück-

* 'Report on the Meteorology of India,' 1877, p. 2.

ner* has pointed out that there is a long period weather variation. His discussion of all the available data of pressure, rainfall, temperature, etc., led him to conclude that there is a periodical variation in the climates over the whole earth, the mean length of this period being about 35 years.

Since this work, a recent discussion of the sun-spot data by Dr. W. J. S. Lockyer† has brought to light a similar long period, and this has taught us that each eleven-year cycle is different from the one immediately preceding and that following it.

A further inquiry into the distribution of the solar prominences, as observed by Respighi, Secchi Tacchini, Ricco, and Mascari,‡ has resulted in increasing our knowledge of the circulation of the solar atmosphere. The centers of prominence action, or the centers of the prominence belts, have a tendency to move from low to high latitudes, the opposite of spots; generally speaking, two belts in each hemisphere exist for some time, then they couple up and move towards the solar poles, while in the meantime a new belt begins to form in low latitudes.§

The existence of prominences in the polar regions is coincident with great magnetic disturbances on the earth, just previous to or about the time of sun-spot maxima.‖ Further, these polar prominences are responsible for the existence of large coronal streamers near the solar poles, as seen during solar eclipses about the time of sun-spot maximum. In fact, recent research seems to indicate that this prominence circulation is intimately associated with all the different forms of the corona.*

There seems little doubt, therefore, that we must look to the study of the solar prominences not only as the primary factors in the magnetic and atmospheric changes in our sun, but as the instigators of the terrestrial variations.

In dealing with solar phenomena, especially from a meteorological point of view, it is of great importance that the solar disc be treated in zones and not as a whole.

Just as it has been shown that the prominences sometimes exist in these zones in one hemisphere at one time, so is this the case with spots, but unfortunately, it is only until very recently that the phenomena occurring in each hemisphere have been treated in this manner.

It has already been pointed out that a possible connection existed between changes in the spotted area of the sun and terrestrial temperatures. Quite recently this question has been studied by Charles Nordmann † who finds that—

> The mean terrestrial temperature exhibits a period sensibly equal to that of solar spots; the effect of spots is to diminish the mean terrestrial temperature, that is to say, that the curve which represents the variations of this is parallel to the inverse curve of the frequency of solar spots.

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* 'Klimaschwankungen,' Eduard Brückner (Vienna, 1890).

† *Proc. Roy. Soc.*, Vol. 68, pp. 285–300.

‡ 'Memorie della Societa degli Spettroscopisti Italiani.'

§ *Proc. Roy. Soc.*, Vol. 71, pp. 446–452.

‖ *Ibid.*, pp. 244–250.

* *Monthly Notices R. A. S.*, Vol. LXIII., 1903.

† *Comptes Rendus*, No. 18, May 4, 1903, Vol. 136.

THE GERMAN ANTHROPOLOGICAL ASSOCIATION.

THE German Anthropological Association is just as old as the German Empire. The thirty-fourth meeting of the society, held at Worms, August 9–13, 1903, was the first to take place since the death of its most distinguished founder, the late Ru-