THE LARGER OPPORTUNITIES FOR RESEARCH ON THE RELATIONS OF SOLAR AND TERRESTRIAL RADIATION[1]

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The earth is maintained at its present temperature by a balance between the solar radiation received and the terrestrial radiation emitted. The mean intensity of the solar radiation as it is at the earth's mean distance outside the atmosphere is believed to be well known. However, it appears to be variable from year to year and also irregular over short intervals of days, weeks or months. These variations, which have been discovered and to a certain extent followed for about fifteen years by the Smithsonian Astrophysical Observatory at its station on Mt. Wilson, have lately been compared with terrestrial temperatures and atmospheric pressures at different stations of the world by several meteorologists, notably by Clayton, and it appears that the effects of solar variations are important as governing changes of terrestrial temperature.

This indicates two highly desirable researches: First, to make daily observations of the sun competent to determine its variations. Second, to determine by further statistical inquiries the exact influence of the variations of the sun on the terrestrial phenomena.

In order to carry out the first research thus outlined, it requires not less than four special solar radiation observing stations in the four most cloudless regions of the earth. One such is now in existence at Calama, Chile, where it is being maintained by the private funds of the Smithsonian Institution. If there was available the necessary income of thirty or forty thousand dollars a year, the Institution would establish the required observing stations and would arrange for the daily wireless transmission of the results obtained on solar radiation so that they might be available for meteorologists in all parts of the world to use for forecasting purposes. The same could be done by international coöperation if due regard were given to making the measurements homogeneous. It is not probable that any steps of this kind will be taken within a year or two. By that time the series of measurements being made at Calama, Chile, will enable meteorologists to determine to what extent the results will be valuable for forecasting purposes.

It would promote the proposed solar investigation if there could be devised autographic recording instruments for determining the exact value of the cloudiness at all times of the day when the sun is above the horizon. Hitherto measurements of cloudiness have been made at comparatively few stations, and as they depend upon personal estimates of observers who are apt to overlook wisps of cirrus clouds especially dangerous for solar radiation work, and as they are usually taken only two or three times in the day, they are quite inadequate to enable the investigator interested in establishing solar radiation stations to select the regions of the earth best meeting his requirements of cloudlessness. It would, therefore, be a very valuable investigation if some suitable autographic method of measuring cloudiness could be devised simple enough to be employed at numerous stations reported to be cloudless.

The whole subject of the cloudiness of the earth is very important. Recent measurements of Aldrich show that a cloud surface reflects about 78% of the solar radiation incident upon it. As the cloudiness of the earth is reputed to be about 50%, it is obvious what a large part clouds play in determining the temperature. They are effective not only in cutting off incoming radiation from the sun but also outgoing radiation from the earth. If the simple autographic apparatus above mentioned were available, it should be employed at numerous stations in all parts of the world and if possible on the ocean.

The measurement of solar radiation at several stations on the earth's surface by means of the pyrheliometer has occupied observers in many countries. Several series of observations have been carried on for many years by the U. S. Weather Bureau, and are published in excellent form in the *Monthly Weather Review*. Many copies of the Ångström pyrheliometer and of the Smithsonian silver disc pyrheliometer, whose constants are both so well known as to form together a homogeneous system of pyrheliometry, have been sent out to many quarters of the world. Only a few series of regular observations are at the present time being conducted with them, and it is greatly to be hoped that a large number of such series may be conducted regularly in the future. The method of reducing the results and publishing them can hardly be improved over that which is followed by the United States Weather Bureau, and that may well be taken as a model.

The study of the outgoing radiation from the earth has lately been carried on by several observers, notably by Mr. Fowle, who has investigated the effects of water vapor in long atmospheric columns in diminishing the rays of long wave-length such as the earth sends out. His investigations extend only to a wave-length of 17 microns because no suitable optical media transparent to waves of longer wave-length are available. It appears that potassium iodide may be such a medium and it is hoped shortly to produce large crystals of the salt suitable for making prisms for the study of long wave-lengths of terrestrial radiation.

In the meantime, valuable information has been obtained on terrestrial and atmospheric long wave-length radiation by Dr. A. K. Ångström by the use of the pyrgeometer or nocturnal radiation instrument devised by his father. An instrument applicable for the same purpose has also been devised by Messrs. Abbot and Aldrich of the Smithsonian Institution and is called by them the pyranometer. Neither instrument is entirely satisfactory for very long waves since both depend upon a knowledge of the absorption of blackened surfaces to long wave-lengths, and this is a matter which still lies in doubt. For satisfactory progress in this line of the measurement of nocturnal radiation, a new instrument depending upon the principle of the hollow chamber or absolutely black body ought to be devised.

The study of the effect of ozone on the temperature of the earth is one which ought not to be neglected. Next to cloudiness and atmospheric humidity, ozone is thought to play the most important part in its effect on terrestrial radiation; first, because the quantity of ozone in the atmosphere is believed to be variable, and, second, because its effect upon terrestrial radiation occurs near the wave-length 10 microns where water vapor is almost completely transparent. This research should include the determination of the variations of the quantity of atmospheric ozone and the measurement of the effect of its changes on the ozone band near 10 microns in wave-length.

A fuller discussion of the several points which have been raised above will be found in the following papers.

INVESTIGATIONS IN SOLAR RADIATION

Survey of the Present State of the Field

We may inquire: First, what is the intensity of the radiation of the sun on which all the life of the earth depends; second, is this intensity constant or variable from day to day and from year to year, and what are the effects of variability, if any?

1. *The Solar Constant.*—The question of the absolute amount of the solar radiation interests us not only for our own sake but for the sake of the future generations. What a valuable thing it would be if we knew at this time the intensity of the sun's radiation as it was in the times of the Egyptians and the Babylonians, and as it was in the intervening periods of Rome and the Middle Ages. It is plainly our duty to transmit to posterity accurate measure of the intensity of the sun's radiation as it is now, so that they will be in a better position in this branch of science than we find ourselves. We cannot expect to know the intensity of the sun's radiation as it would be in space at the earth's mean distance (that is, the so-called "solar constant of radiation") to that high degree of accuracy which we are accustomed to demand in many branches of physics. If we determine that value to one per cent, it is all we may reasonably hope for, because the intervention of the earth's atmosphere, with its changing amounts of haze and cloudiness will always interpose to the investigator an insuperable obstacle to the highest degree of accuracy. It may be that in the future apparatus can be shot up by means of rocket devices to go outside of the atmosphere altogether, but probably the sources of error of automatic apparatus for such a research will be found so large

that no greater degree of accuracy than to one per cent will be possible even with them.

The spectrobolometric investigations of this subject by the Astrophysical Observatory of the Smithsonian Institution which have been continued for the last seventeen years have yielded the general indication that the value of the solar constant of radiation is within one per cent of 1.93 calories per square centimeter per minute. This result is confirmed by experiments made with sounding balloons by the same observatory in coöperation with the U. S. Weather Bureau in 1914. Automatic recording pyrheliometers were sent to a height of about 25 kilometers. It was found that the intensity of the radiation there, at a point where 24/25 of the atmosphere was beneath the observing instrument, fell within the range of solar constant values as obtained by spectrobolometric work at the surface of the earth. The actual value obtained by the balloon work was 1.84 calories per square centimeter per minute. Allowing for the obstruction of the sun rays by the still superincumbent atmosphere a reasonable extrapolation would give 1.88 calories. This differs from 1.93 calories less than the error of the observations and is well within the range of solar constant values obtained at different days from surface observatories.

Apparently the close agreement of these widely different independent methods of obtaining the intensity of solar radiation outside our atmosphere permits us to say authoritatively that the mean value of the solar constant is at any rate between 1.9 and 2.0 calories per square centimeter per minute and most probably not greatly different from 1.93. A few men cling to the view that much higher values should be set for it—values between 3 and 4 calories per square centimeter per minute, but their arguments carry little weight, as it seems to me, and those best qualified to know are agreed that the values given above have a strong foundation.

The methods of observing the solar constant of radiation by means of the spectrobolometer have been carefully worked out and the whole subject has been published with satisfactory fullness and is in shape to be transmitted to the scientific men of the future in order to enable them to reproduce the measurements or to compare their own measurements with the results now obtained.

2. *The Sun's Variability.*—Passing now to the second branch of the subject, the investigations of the Smithsonian Astrophysical Observatory conducted at Washington, Mt. Wilson, Mt. Whitney, Bassour (Algeria), and now the investigations supported by the Smithsonian Institution from its private funds in North Carolina and Chile have all united in giving the impression that the solar radiation is not constant, but varies from day to day through a range of certainly five and possibly at times ten per cent. The conclusion that the sun is a variable star is confirmed in several ways but most notably by the results of measurements made by

the Smithsonian Astrophysical Observatory at Mt. Wilson, California, on the distribution of energy along the diameter of the solar image. These measurements indicate, as was well known before, that the edge of the sun's disc is less bright than the center, and that the contrast of brightness between the center and the edge varies according to the wave-length of light, being greater for short wave-lengths, less for long.

But the measurements of recent years have shown that not only is there a variation of contrast by wave-length, but also a variation of contrast with the time. The contrast in each wave-length is different for different days of observation and, on the average, for different years of observation. The changes of contrast have been compared with the changes of total radiation of the sun determined by the aid of the pyrheliometer and spectrobolometer, and it is found that there is a moderate degree of correlation between them. The correlation is of two kinds. For variations of long periods of years, high values of the solar constant are found associated with high values of contrast between the center and edge of the sun. On the contrary, for the short period variations of the solar radiation, occupying a few days, weeks, or months, it is found that high values of the solar radiation are associated with diminished values of the solar contrast.

The cause of this two-fold variation is reasonably explained. When the sun grows hotter and thus increases its output of radiation along with increased solar activity, as indicated by sun spots, prominences, and other visible solar phenomena, this would tend to cause a greater degree of contrast. For since if the solar temperature were zero there would be zero contrast, the higher the temperature the higher the contrast. But the sun is probably entirely gaseous, and certainly its outer layers are so, and these may become more turbid at times, just as the earth's atmosphere becomes more hazy at some times than at others. Accompanying increased turbidity of the solar atmosphere there would be found a diminished value of the solar constant of radiation. But since the path of the solar ray is oblique in the solar atmosphere near the edge of the sun, the path is longer there and the effects of the turbidity would be greater at the edges rather than at the center. Thus with the increase of turbidity the contrast of brightness would increase accompanying a diminished value of the solar constant of radiation. In this way it appears that the two-fold variations of the sun which have been found may be reasonably explained.

Investigations Required

1. *Solar Radiation Stations.*—We now pass to the applications of this discovery of the variation of the sun. What effects does it have upon the climate of the earth and upon other terrestrial phenomena? In order to cover satisfactorily this interesting and utilitarian branch of the investigation it is necessary to have good solar observations daily. Unfortunately there is no region in the world where the sky is so free from cloudiness

that a single observatory can obtain daily measurements of the intensity of solar radiation as it is outside the earth's atmosphere. The spectrobolometric investigation of the solar constant of radiation requires that the observations shall extend over several hours from the time when the sun's altitude is small to the time when it is large, so as to determine for many wave-lengths of the spectrum what increase of intensity corresponds to the diminution of the length of the path of the solar rays within the earth's atmosphere. In order to prevent error in the determination of the transparency of the earth's atmosphere, the sky must be uniformly clear during the interval just mentioned.

This is a condition very hard to fulfil. All stations in the world fulfil it well enough for certain days of the year, some stations for very many days of the year, but none for all. The experience of the Smithsonian Astrophysical Observatory in these matters indicates that probably there is no region in the world where more than 250 satisfactory days in the year can be confidently expected. Accordingly, it is highly desirable if these solar radiation changes have notable effects upon the earth's temperature and other meteorological and terrestrial phenomena, that several observatories shall join in making the measurements of the solar constant of radiation from day to day. On every day at least two values should ,be obtained strictly comparable with one another in their method of observation and with a probable accuracy as far as experimental work is concerned to the order of one per cent. The mean of two, or still better, of three or four such values, would give a probable accuracy of the final result to better than one per cent, and if a series of such observations extending over every day in the year for a course of several years were available, it would probably be possible to determine very well the effect of the changes of solar radiation on the terrestrial climate.

In order to carry on the work in this way, a considerable income is required. The experience of the Smithsonian Institution in its several expeditions to Africa and to South America, and to the western part of North America, indicates that an income of between five and ten thousand dollars, preferably as much as eight thousand dollars per year, for each station would be requisite. If four stations should be considered competent to carry out the problem, it would, therefore, require a yearly income of from thirty to forty thousand dollars for the whole series. It would be preferable that the work should be under a central direction so that the various measurements might be strictly comparable and homogeneous. If the Smithsonian Institution, with its long experience in these matters, had available for this purpose an income of the amount specified, that would offer a good way of dealing with the problem.

On the other hand, it may be that support for the project would be more easily obtained if the several governments of the regions where the observatories for this purpose might be favorably located should be approached and asked to take over the work. The establishment of such new observatories seems not to be urgent for another year, until the results obtained in Chile by the Smithsonian Expedition shall have been compared with the climate of Argentina, as is now being done by Mr. Helm Clayton, so as to see if there is a well-justified expectation that solar observations of this kind will be useful in meteorology.

2. *Autographic Cloud Observers.*—Looking to the possible establishment of such solar constant observing stations, the most important preliminary investigation relates to the choice of the most favorable situations. Experience hitherto has shown that the reported results of observations of cloudiness by meteorological services do not give a sound index of the availability of situations for this exacting work. In all of our experiments we have invariably been disappointed in not observing as many days as the reports of the cloud observations have led us to expect. Certain portions of the earth, it is true, have the reputation of being cloudless, among them the Chilean Desert, the Central and Western Provinces of Australia, some parts of South Africa, Upper Egypt, the Desert of Sahara, the Desert of Arabia, regions in British India, and possibly others. What would facilitate the establishment of solar observing stations more than anything else, in case they should seem desirable, would be to have a long series of cloud observations obtained by strictly automatic processes, independent of the judgment of observers, for a considerable number of the most promising regions, such as those I have mentioned. Such observations should cover the whole period when the sun is above the horizon.

Dr. Humphreys has proposed to me an instrument for such a preliminary investigation of cloudiness. It is based on the principle of photographing a reflecting ball from above. The sensitive surface would be that of a moving film or plate which would be exposed for an instant once in a quarter or half an hour, as would be most convenient, and would, therefore, give a series of photographs of all the clouds which occurred in the sky at the instants of observation. If this or some other suitable automatic device for photographing the whole sky could be prepared and employed by the meteorological services of the world which operate in the most cloudless regions, the work of establishing solar constant stations, if these should be needed, would be materially advanced. Otherwise, there is no method except to go to a region that is recommended and be disappointed and sorry that the region was chosen but without knowing where else to go, just as has occurred before. This is a disheartening, costly and time-consuming process, and might, perhaps, be avoided in the way above suggested.

3. *Pyrheliometric Observations.*—While the measurement of the solar radiation by means of spectrobolometric work is the only thorough way available in which to determine the variation of the sun, situated as the observer must necessarily be beneath an atmospheric sea full of haze and

other obstructing materials, yet it is highly important to have measurements of the radiation of the sun made at the earth's surface in many parts of the world. A series of measurements of this kind is being conducted by the U. S. Weather Bureau at its stations in Washington, Madison, Lincoln, and Santa Fe. This work, in charge of Professor Kimball, has gone on now for about ten years, and is being published in excellent form in the *Monthly Weather Review* of the U. S. Weather Bureau. Observations were also undertaken in Egypt and a report was published several years ago by Dr. Shaw. Observations were carried on for a number of years by the Harvard College Observatory at Arequipa, in Peru, but about a year ago the instrument was accidentally broken. The Arequipa series was then discontinued, partly because the Smithsonian Institution has its spectrobolometric and pyrheliometric station in Chile not far from Arequipa. Some measurements are being made also in Argentina, Brazil and elsewhere. There are also pyrheliometric instruments at the Island of Teneriffe which were in use before the war, but whether the measurements are being conducted there regularly now I am not aware. Dr. Dorno, of Davos, Switzerland, has made such measurements with many others of related subjects for a long time, and has just published a great volume of valuable results.

It would be very desirable if work of this kind could be carried on regularly at favorable stations employing strictly comparable instruments. There are about thirty copies of the Smithsonian silver disc pyrheliometer distributed to a number of different parts of the world but as stated above it is not probable that during the period of war they have been in regular use. Many of them are in very cloudy localities.

4. *Distribution of Radiation over the Solar Disc.*—As stated above, it has been found at the Smithsonian observing station on Mt. Wilson, in California, that the distribution of radiation along the diameter of the solar disc is subject to variability of two kinds—one of a long period of years, and the other of a short period of days, weeks, or months, and that these two kinds of variation are fairly closely correlated with the variations of the total radiation of the sun. The work of observing the radiation along the solar diameter requires the use of a long focus telescope and a spectrobolometer, and may very readily be carried on nearly simultaneously with measurements of the solar constant of radiation. Such investigation is going on regularly at Mt. Wilson during the summer season when the Smithsonian observers are working there. Perhaps it would not be necessary to set up other stations since the main object of this work was accomplished when it was shown that it confirmed the existence of the solar variability shown by the measurements of the solar radiation itself.

The method of observing the distribution of brightness along the solar diameter which we have adopted is to stop the clock-work of the coelostat which reflects the solar beam into the long focus telescope, so that the solar image drifts across the slit of the spectrobolometer in an east and west fashion. The question was, therefore, open for some time whether the distribution at right angles to this, that is, along the north and south diameter of the sun, would be substantially the same. In 1918, Mr. Aldrich investigated this matter by the aid of special mechanism associated with the coelostat and was able to show that if any difference in distribution exists between the north and south and the east and west diameter of the solar image, respectively, it is too small to recognize by this method and, indeed, is less than one per cent.

INVESTIGATIONS OF THE RELATIONS OF TERRESTRIAL CLIMATE TO RADIATION

Survey of the Present State of the Field

1. *Kinds of Radiation Concerned.*—The temperature of the world is maintained by the balance between the income of solar radiation and the outgo to space of terrestrial radiation. The former is principally included between the wave-lengths 0.3 and 3.0 microns. The latter is principally included between the wave-lengths 5.0 and 50 microns. Substances which are transparent for the one may be opaque for the other, though in these long ranges of wave-lengths substances may pass through several minima or maxima of opacity and transmissibility. Apart from cloudiness, which is the principal factor, the radiation of the sun is principally hindered in its passage to the surface of the earth by the water vapor of the terrestrial atmosphere and by the scattering of the molecules of the air and by the dust which the air carries. The losses of the direct solar beam by scattering from air molecules and dust are largely compensated for by the indirect solar radiation received from the whole hemisphere of the sky. On the other hand the rays lost from the direct beam by absorption in the water vapor of the earth's atmosphere, while they go to warm the atmosphere itself, are very differently applied to maintain the heat of the earth as a planet than they would be if they reached the earth's surface.

2. *Absorbents of Terrestrial Radiation.*—Apart from cloudiness, which is the principal hindering factor, the outgoing radiation of the earth's surface to space is hindered mainly by water vapor, ozone, and carbon dioxide. Of these the principal obstruction is water vapor which absorbs powerfully over great ranges of spectrum. The other two absorbents are each confined in their absorbing regions to comparatively narrow ranges of spectrum, but the ozone absorption band, at about 10 microns, occurs in a region where water vapor absorbs scarcely anything while the carbon dioxide absorption band at about 14 microns occurs in a region where water vapor is also powerfully absorbing. The atmospheric proportion of carbon dioxide is sensibly constant, while water vapor and ozone are variable. Accordingly, while water vapor is certainly the most important of the three,

probably ozone, although much less plentiful in the atmosphere, and certainly not more powerful as an absorber for the spectrum of a perfect radiator than carbon dioxide, is yet entitled to be regarded as second in importance on account of this peculiar posture of affairs.

3. *Studies of Terrestrial Radiation and Its Atmospheric Absorption.*—The study of these absorbing elements and their influence upon the spectrum has been carried on to a considerable extent by several investigators, notably by Paschen, Rubens and his collaborators, Miss Eva von Bahr, and lately by Mr. Fowle of the Astrophysical Observatory of the Smithsonian Institution. Mr. Fowle's researches[2] comprised the examination of the spectrum of the Nernst Glower up to a wave-length of about 17 microns, particularly as it is affected by the absorption occurring in long columns of atmospheric air containing known amounts of humidity and carbon dioxide. The experiments deal with quantities of from 0.003 to 3.0 centimeters of liquid water disposed in the atmosphere as water vapor. Owing to the lack of a suitable transparent refracting medium for optical purposes beyond the wave-length 17 microns, the important region of the terrestrial spectrum extending from 17 to 50 microns could not be investigated by Mr. Fowle. Somewhat later, Mr. Aldrich of the Astrophysical Observatory of the Smithsonian Institution made a long series of experiments (as yet unpublished) with crystals both natural and artificial and with other available substances, endeavoring to discover one which would be suitable for making a prism transparent to these rays. The only substance found which seemed to be notably superior to rock salt is potassium iodide, and this material has hitherto been available only in very minute crystals. Promising experiments made at the General Electric Company indicate that large crystals of potassium iodide for prisms may soon be available. If so, it will be possible to carry on this valuable spectrum investigation over a region hitherto very little explored. The dependence of terrestrial radiation on water vapor has been investigated to a considerable extent in another way by Dr. A. K. Ångström, who made observations in Algeria, Southern California, and lately in Sweden with the pyrgeometer, a nocturnal radiation measuring instrument invented by K. Ångström. Dr. Ångström's measurements were conducted during several months at a considerable number of stations varying in altitude from near sea level to that of Mt. Whitney, 4,400 meters, and in dryness from desert conditions to those of considerable humidity. At the same time measurements were made of the humidity prevailing in the air, partly at the surface by means of psychrometers and partly in the free air by means of kites and sounding balloons under the management of the United States Weather Bureau. This valuable investigation was supported by the Hodgkins Fund of the Smithsonian Institution, and was published as Vol. 65, No. 3, of the Smithsonian Miscellaneous Collections.

Investigations Required

1. *Ozone and Radiation.*—Very little is known concerning the influence of ozone on the earth's radiation. It is certain that a conspicuous band of this substance occurs at the wave-length of about 10 microns, where water vapor is almost completely transparent. It is a little hard to see how the investigation of the influence of ozone can be best undertaken. The region of 10 microns is very difficult to work with in the solar spectrum. All terrestrial surroundings give out waves of this wave-length. It is as if the investigator of the visible spectrum were troubled with stray light from every direction upon his photographic plates or other means of observation. Furthermore, and still more serious, the more intense rays of the solar spectrum, coming from regions of much shorter wave-length, are continually encountered as stray light in the spectrum, even hundreds of fold greater in intensity than the rays of the spectrum at the region in question. Rock salt must be employed for the optical train and its hygroscopic character is a serious difficulty. Finally the measurements ought to be quantitative in terms of energy. Something can be done to avoid stray light by reflecting the solar beam by means of several silvered ground glass mirrors. In this way the shorter wave-lengths are scattered, while the longer wave-lengths desired are reflected by virtue of the greatness of their wave-length, compared with the roughness of the mirrors. Yet the prospects of getting good bolographic representations of this region of spectrum day after day are not good. Perhaps the quantity of ozone existing in the air could be determined daily by measurements made in the ultra-violet spectrum by the aid of photography and these results could bè compared with measurements of the nocturnal radiation made after the method of Ångström. Allowance being made for variations of temperature and water vapor, the influence of variations of the ozone might then appear. At all events, determination of the effects of ozone on the terrestrial radiation is a desirable investigation though so extremely difficult.

2. *Cloud Observations.*—The effect of clouds on terrestrial temperature is extremely important. Recent measurements by Mr. Aldrich of the Smithsonian Institution, made from a military balloon, show that a smooth layer of clouds reflects about 78% of the total direct and indirect solar radiation incident upon it from the sun and sky. Investigations of the quantity and distribution of the cloudiness of the surface of the earth have been published by Tisserenc du Bort, and Arrhenius. They depend, however, on very imperfect material. Cloud observations are much more fragmentary than temperature observations, and besides are not based upon standardized instruments in general, even if there be such, but are based on observers' estimates of the proportion of the sky obscured. The matter is so fundamental to the proper understanding

of the temperature of the world and its dependence on the balance of radiations of the sun and earth that it warrants careful attention. Some simple autographic means, theoretically satisfactory and instrumentally accurate, ought to be provided for estimating cloudiness, and this should be installed with the least possible delay at all first-rate meteorological stations in the world, and indeed as extensively as possible. The instrument should not be merely applicable to land conditions, but ought to be available for ships. It is hardly possible to overestimate the importance of this neglected branch of meteorology.

3. *Standard Instruments for Nocturnal Radiation.*—As mentioned above, Dr. Ångström has employed the pyrgeometer for an extensive and valuable research on nocturnal radiation and the determination of atmospheric re-radiation at different temperatures and under various other meteorological conditions. There has also been devised at the Smithsonian Institution, by Messrs. Abbot and Aldrich, an instrument called the pyranometer, which is applicable for the same purpose. Neither of these instruments, however, is thoroughly satisfactory, for this reason: They both present blackened flat surfaces which radiate towards the atmosphere and space, and it is assumed in the theory of the instrument that the absorbing and radiating properties of the blackening upon these strips is known. Experiments, however, seem to show that the materials used for the blackening purposes become less and less satisfactory for the longer wave-lengths, so that for rays beyond 15 microns there is a strong chance that the instruments are very imperfect. In order to really cover the objection it is necessary to produce a nocturnal radiation instrument which employs the well-known hollow receiver principle of the "black body." This is a matter of some difficulty because the intensity of the radiation to be considered is small, and it must be emitted and received at all angles within a hemisphere. There are very formidable difficulties in the way of a satisfactory solution of this requirement, but in order to give really definite information as to the nocturnal radiation of the earth and atmosphere they must be overcome. Associated with this problem is a definitive solution of the question of the constant of the fourth power radiation formula of Stefan. The measurements hitherto made by physicists on this constant, usually called σ, are in considerable disaccord. The margin of possible error is, perhaps, not very large, but it cannot be allowed as certain that we know this constant within 2%.

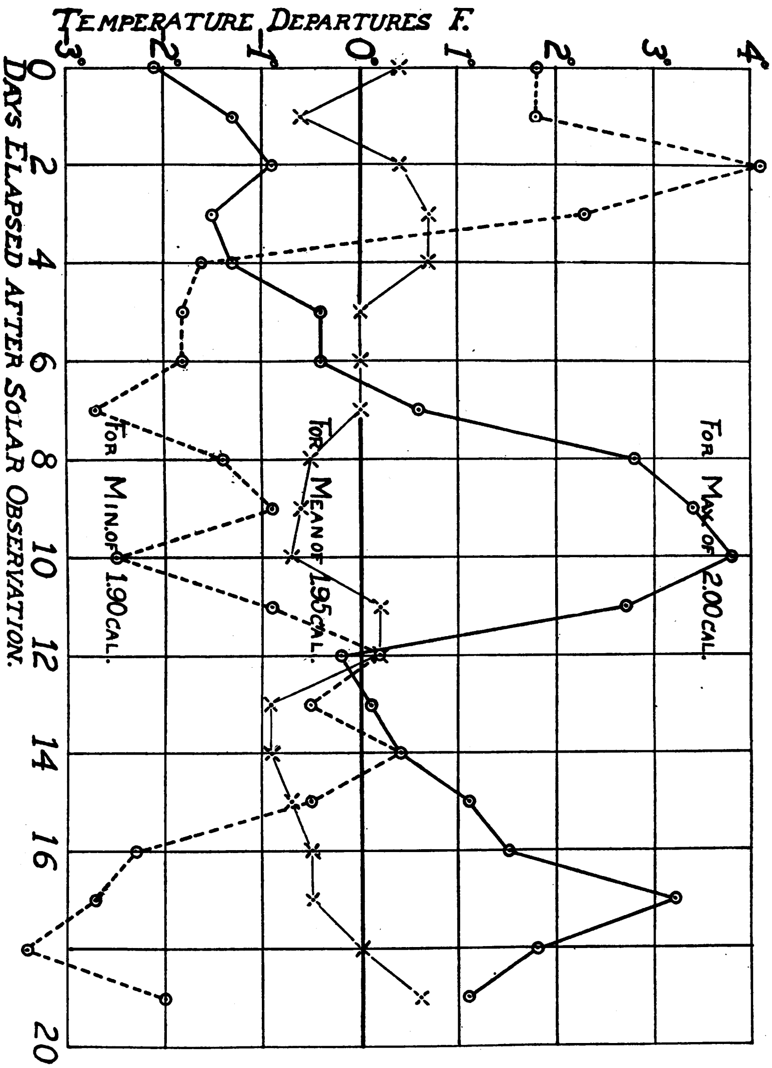
4. *Statistical Studies.*—As already stated, the sun is known to be a variable star. The effect of its variations on the terrestrial climate has lately been investigated to a considerable extent by Mr. H. H. Clayton[2] of Buenos Aires. Investigations of a similar kind have been made also by Dr. Arctowski of New York and by Dr. Helland-Hansen and Dr. Nansen[3] of Norway. These investigators have all reached the conclusion that the variations of the sun reported by the Smithsonian observers

at Mt. Wilson affect terrestrial temperatures to a considerable extent and also induce variations of terrestrial atmospheric pressure. Mr. Clayton's investigations have led him to the conclusion that the tropical and the polar regions of the earth are made warmer by temporary increases of solar radiation, while the temperate regions both north and south of the equator are made cooler by the same increase of radiation. Dr. Nansen, however, is of the opinion that when more thorough studies of the matter have been made, it will be found that the effects are not thus zonal, but rather are associated with the great action centers of atmospheric circulation. Dr. Nansen's view is that since a considerable portion of the sun's radiation is absorbed by the clouds, dust and water vapor in the atmosphere, a change in the amount of solar radiation may produce notable changes in the atmospheric circulation, and these, by altering the direction of the prevailing winds, may alter indirectly the temperature of meteorological stations. Hitherto the amount of investigation of the variation of the sun has been inadequate to give very satisfactory data to work with in determining these correlations. The present expedition of the Smithsonian Institution to Chile, it is hoped, will be continued for several years and will enable meteorologists to trace this relation much more thoroughly. Mr. Clayton, from the studies he has made and is making, is very sanguine about the value of solar radiation observations such as are being made by the Smithsonian observers.

The accompanying illustration, prepared from Clayton's studies, shows the remarkable courses of temperature departures at Buenos Aires, following high, intermediate and low values of the solar constant of radiation.

A very great deal of additional statistical inquiry is already possible in view of the series of solar constant observations reported by the Smithsonian observers on Mt. Wilson. There is now a much more continuous series of results available extending from July 27, 1918, as obtained at Calama, Chile. Meteorologists should be in a position to study these observations in connection with the temperature, pressure, cloudiness and wind at a very great number of stations distributed as well as possible over the earth's surface. It is only by such laborious investigation that a sound basis can be laid for the improvements in forecasting which Mr. Clayton thinks are now possible.

If it shall appear from such statistical investigations that the variations of the sun are really important for forecasting purposes, and if it shall prove possible to establish three or four additional solar radiation stations, widely scattered in the most cloudless regions in the world, then we may contemplate the possibility that from each such solar radiation station the results of each day might be sent out by wireless telegraphy, to be employed by the meteorological stations of the different countries for forecasting purposes. Experience in Calama, Chile, indicates that with a staff of three industrious and energetic persons it is possible to compute and send out the result of morning observations of a given day before night-fall. A brief empirical method for the determination of solar



THE GREAT AND PROLONGED INFLUENCE OF SOLAR CHANGES ON TERRESTRIAL TEMPERATURE

Average march of the mean temperature of Buenos Aires for 19 days following high, mean and low values of the solar constant of radiation for the years 1913, 1914, 1915 and 1918, in the months May to November. Solar radiation determined at Mount Wilson, California; temperatures by Argentine Weather Service.

radiation has lately been devised at Calama and seems satisfactory, so that it is possible that the result of a morning of observation may be telegraphed to the world by noon.

[1] This is issued as the second of a series of research surveys prepared under the auspices of the National Research Council. Reprinted in *Reprint and Circular Series of the National Research Council,* Number 7.

[2] *Smithsonian Misc. Coll. Washington,* **68,** No. 3, 1917.

[3] Now in course of publication by the Smithsonian Institution.