The Correlation of Solar and Terrestrial Magnetic Phenomena.

By Prof. SYDNEY CHAPMAN, F.R.S.

SCHWABE'S discovery of the eleven-year sunspot cycle was soon followed by the recognition of a parallel cycle in the variations of the earth's magnetic field. Since then long series of solar and terrestrial observations have been accumulated. Magnetic observations, though still generally made in the manner introduced by Gauss, have been extended widely over the earth, while remarkable developments in the technique of solar observation have provided a wealth of detailed knowledge of solar phenomena. Yet although great advances have been made in establishing correlations between the two sets of data, some of the principal relationships remain obscure, and some important lines of investigation have yet received little attention.

The great complexity of both sets of phenomena accounts for this position of affairs. As regards the magnetic variations, observations over many years had to be collected from numbers of widely separated observatories, each contributing three distinct continuous records (for the three components of magnetic force) before it was possible to grasp the main features of the phenomena, and distinguish between what is characteristic of a general world-wide system, with its intensity waxing and waning more or less as a whole, and what is merely transient and local. As regards observation of the sun, though any terrestrial observatory has the whole solar disc at once in view, it has required the work of generations of observers to afford our present immense but incomplete knowledge of the remarkable happenings over that great surface.

In the detailed study of the relationships between the two groups of phenomena, statistical methods based on the use of the Wolf-Wolfer sunspot numbers have been very fruitful. These numbers characterise the state of the sun's surface on each day in one important respect, namely, the number and area of the dark and relatively cold regions of the surface. Daily areas of the bright patches called faculae, though available in the volumes of Greenwich observations, have been less used: there is a considerable degree of correlation between them and the sunspot numbers. Such 'daily character' figures for the sun have been compared with magnetic data chosen to represent the character of a day from the magnetic point of view. At first the magnetic data used for this purpose were generally drawn from the records of a single observatory (such as the daily range in the magnetic declination), but the need for some index less dependent on local and accidental changes at a single station gradually became felt. About twenty years ago a scheme was put into operation by which many observatories contribute data on which international daily magnetic character figures are based. These are designed to represent the degree of world-wide magnetic activity or disturbance present on each Greenwich day; they are not founded on any definite physical estimate

of the degree of disturbance, but on a general impression of the smoothness or irregularity of the continuous records at each observatory. Attempts have been made, and are continuing, to devise a practicable quantitative method of assigning such figures, but no plan has yet met with general approval.

While the present system certainly has defects, in that in different years, or even in different months of the same year, the same character figure may be used for days experiencing different amounts of disturbance, yet these magnetic figures have proved of great value in the study of solar and terrestrial relationships. The outstanding example of their usefulness is Chree's demonstration, based upon them, of the tendency for unusually quiet or unusually disturbed magnetic conditions to recur after the lapse of one or more solar rotation periods. This 27-day recurrence tendency had been recognised by Maunder (and by some earlier workers), who brought forward very strong evidence in support of it, drawn from the Greenwich records of magnetic storms; but conviction of its reality became general only when Chree's important work confirmed it in an indisputable way.

This recurrence tendency throws light on the failure to find much correlation between the *daily* magnetic character figures and the *daily* sunspot numbers, a failure which at first sight seems remarkable in view of the increase in frequency of magnetic disturbance in years of high sunspottedness. The recurrence tendency, as clearly interpreted by Maunder, shows that the solar agent that produces terrestrial magnetic disturbance must proceed from some limited region of the sun's surface, and travel outwards from the sun in a confined stream, affecting the earth only when it is swept over by the stream, which rotates with the sun (though of course lagging behind the radius through the point of emission). Magnetic disturbance is, therefore, an indication of the impingence upon the earth of some solar emission, which must be of a corpuscular nature; nothing happens when the sun is not emitting the corpuscles, but, equally, nothing happens upon the earth even when the streams are issuing from the sun, except when they chance to encounter the earth. Even if sunspots were the source of such streams, the daily sunspot numbers would not be expected to show a close correlation with the daily magnetic character figures, because a spot contributes to the sunspot number during the whole period of its passage across the visible disc of the sun, whereas the supposed streams issuing from it would appear capable of affecting the earth during at most two or three days.

It is certain, however, that the streams in question do not always issue from sunspots, because magnetic storms are sometimes observed when sunspots have been absent from the sun's disc for some days. Moreover, modern theories of

the sun's atmosphere render it likely that corpuscular emissions are due to a local and temporary rise in the radiation pressure, arising from an unusually bright region of the surface. Pike has shown that a dark region or spot behaves like a centre of attraction rather than of repulsion; chromospheric matter tends to flow towards it and not away from it. This accounts for the arched forms shown by many prominences; it would seem that the apparent attraction of the dark spots, and the deflecting influence of the magnetic fields associated with them, must often prevent the ejection of chromospheric matter right away from the sun. The frequency of such complete expulsion, as judged from the records of magnetic disturbance, is somewhat difficult to explain on the basis of our present knowledge of solar atmospheric conditions; but it would seem likely that bright regions associated either with no dark spots, or with several small dark spots rather than one or two large ones, would offer the most favourable conditions. This inference seems to be in agreement with a recent examination by Greaves and Newton of the solar conditions prevailing at the time of the greatest magnetic storms observed at Greenwich.

Whatever may prove to be the local conditions causing the emission of corpuscular streams from the sun, the emitting regions have the best chance of affecting the earth when they are fairly near the centre of the sun's disc. Consequently, the magnetic character figure for any day is likely to be associated with the presence of bright regions, perhaps of some special type, near the centre of the sun's disc, not necessarily on the same day but rather at a date preceding it, by an interval equal to the time taken for the solar agent to travel from the sun to the earth. The length of this interval is unknown, but there are some grounds, both theoretical and observational, for estimating it as from two to four days. As a means to a clearer understanding of the mode of action of the sun in producing magnetic disturbance, it is desirable to have a new set of solar daily character figures having special reference to the presentation of bright solar regions towards the earth. The Solar Physics Commission of the International Astronomical Union, and the International Research Council's Committee on Solar and Terrestrial Relationships, will discuss this proposal at Leyden in July, and it is to be hoped that some simple scheme will be devised for choosing solar daily character figures which will prove to be more closely correlated than the daily sunspot numbers are with the daily magnetic character figures.

There appears to be need also for a second set of magnetic character figures, or, as it is convenient to term them (to distinguish them from those already assigned under the international scheme), daily magnetic indices. The present character figures represent the degree of magnetic disturbance, but there are daily variations which go on independently, whether disturbance is present or not; the disturbance changes are simply superposed on the other daily changes, which are seen in their pure

form on quiet days. For the sake of brevity it is convenient to refer to the two sets of changes, and the corresponding varying magnetic fields, by the symbols *D* (disturbance) and *Sq* (the solar diurnal variations seen in isolation on quiet days, though coexisting with disturbance on other days). The *D* and *Sq* fields both show a variation of average intensity in rough parallelism with the sunspot cycle, but in most respects they are strikingly different—in their distribution over the earth (and the change in this distribution throughout the year), and in their fortuitous variations of intensity from day to day. The fortuitous variations of intensity of *D* are represented by the magnetic character figures, but at present we have no index of the day-to-day variations of intensity of the *Sq* field. In the latter case the range of variation is much less than for magnetic disturbance, but the changes are both interesting and important; as yet very little attention has been given to them. They appear to be correlated only slightly with those of *D*.

In various papers I have indicated reasons for believing that the *D* and *Sq* fields are associated with different types of solar emissions, the variations of which determine the changes of intensity of *D* and *Sq*. As already stated, the *D* variations depend upon the impingence on the earth of corpuscular streams from the sun, while *Sq* appears to depend on the sun's ultra-violet radiation. In both cases the solar influence is exerted largely by the ionisation which it produces in the earth's outer atmosphere. If this hypothesis is correct, changes in the sun's ultra-violet radiation will affect the intensity of the *Sq* variations all over the earth. This appears to be the case with the eleven-year changes of average intensity of *Sq*, and is probably true also for the fortuitous variations, though this has not yet been definitely established. The difference between the nature of the solar influences which determine *D* and *Sq* renders natural the contrast between the character and changes of these two magnetic phenomena; it also indicates the desirability of a daily index of the intensity of *Sq* as well as of disturbance. One immediate application of such indices would be their comparison with the measurements of the sun's ultra-violet radiation which were commenced by Pettit at Mount Wilson in 1924; this work has shown that the radiation may vary considerably from day to day, and there is also an indication of a long period variation following the sunspot cycle. It is important to ascertain how closely the day-to-day variations of this radiation are in agreement with those of *Sq*.

Many other phenomena which, like *Sq*, are associated with the upper atmosphere, should also be compared with the variations of *Sq* as well as of *D*; among them may be mentioned the zone content, the intensity of the luminosity of the night sky in different spectral regions, and the transmissibility of radio waves of different frequencies. It will also be of interest to examine the correlation between the changes of *Sq* and *D*; it may well be that the sun's ultra-violet radiation will show a

close correlation with the sunspot numbers and the proposed new solar character figures for bright regions near the centre of the sun's disc, and that the comparative lack of association between Sq and D , and the greater range and abruptness of the changes in the latter, are due to the special feature that these depend on the conjunction of the earth with a limited solar stream.

For these reasons it seems likely that in time international co-operation will be desirable to

assign to each day a magnetic index referring to the intensity of Sq on that day; but before such a proposal can profitably be discussed in detail, preliminary investigations of the Sq variations are necessary to ascertain how they affect different magnetic elements and different observatories. Mr. J. M. Stagg is at present co-operating with me in the first of such studies, confined to data from Greenwich and Eskdalemuir, on purely quiet days.

Obituary.

DR. JOHN HORNE, F.R.S.

IT is seldom that the death of a man more than eighty years of age can so truly be described as an irreparable loss to his science as can be said of John Horne, who has passed away with full mental powers and while completing a work on the geology of Scotland, which would no doubt have been a masterly digest of the voluminous and scattered literature, a luminous statement of the problems, and have been inspired by his contagious enthusiasm.

John Horne was born beside the Campsie Fells, near Glasgow, on Jan. 1, 1848. He was educated at the High School and University of Glasgow, but he did not graduate, as at the age of nineteen years, on the establishment of the Scottish Geological Survey in 1867, he was appointed one of the original members of the staff. His life was spent in its service, and after his retirement he often acted as its unofficial adviser.

Horne's two most important contributions to geology were his preparation of the memoir on the geological structure of the North-west Highlands of Scotland, which was written by himself and five colleagues, and the large volume, in collaboration with Peach and Teall, on the Silurian rocks of Scotland (vol. 1, 1899), which described in detail the structure of the Southern Uplands. In both cases Horne convinced Sir Archibald Geikie that Lapworth's interpretations were correct, and thus led to the abandonment of the previously accepted theory of the structure of north-western Scotland and to the scrapping of the Survey maps of large parts of the Southern Uplands.

Horne worked on all branches of Scottish geology. He was probably most interested in the pre-Palæozoic rocks and in glacial problems, and he was the author of the report of the British Association Committee supporting the direct marine origin of the high-level glacial clays at Clava. His greatest single achievement was his administration of the Geological Survey of Scotland from 1901 until 1911. He was a tactful genial chief who gained the enthusiastic support and affection of all his staff; he was an active reformer and secured the great improvement in the Scottish maps by the introduction of colour printing. His success in gaining the confidence of the Scottish coalowners secured for the Survey full and harmonious co-operation with the mining industry. In his association with others he was helped by his keen sense of

humour; he had an inexhaustible fund of racy anecdotes, which he told brilliantly. His death will be widely felt as a personal loss, for he had great gifts of friendship. He was respected and beloved by all who knew him well.

The wide recognition of the importance of Dr. Horne's work is shown by his many distinctions. He was elected a fellow of the Royal Society in 1900; he was LL.D. of three Scottish universities; he was president of the Royal Society of Edinburgh (1915-19), president of the Geological Section of the British Association at the Glasgow meeting in 1901, chairman of the council of the Royal Scottish Geographical Society, and he received the Wollaston and Murchison Medals of the Geological Society.

While on the Survey, Horne formed his beautiful and fruitful friendship with B. N. Peach. They first worked together in southern Scotland, but as Horne was dissatisfied with the official treatment of some of their results, he persuaded Peach to join him in some unofficial work; to go as far from Edinburgh as was possible in Scotland, they selected the Orkneys and Shetlands. His literary co-operation with Peach began with short papers in 1880 on the glacial geology of the Orkneys and Shetlands and on the North-west Highlands in 1883; it was continued in important memoirs on the Orkneys and Shetlands and Caithness, the Canonbie coalfield, and the volcanic rocks of the Old Red Sandstone.

According to a popular fallacy, Horne was the patient persevering plodder, whose main usefulness was as the amanuensis of his brilliant associate. Horne brought to the work keen insight, a sound, steady judgment, and powers of searching criticism which he applied remorselessly to every problem on which he worked. He was the leader in their joint work. After their retirement from the Geological Survey, Peach and Horne began together a "Geology of Scotland," which was put aside time after time because Horne would not accept some of Peach's views and could not get a satisfactory statement of his opinion for publication. The book was taken up again after Peach's death two years ago, but the interval has not been sufficient for its completion. The manuscript, it may be hoped, is sufficiently far forward for publication, for it should prove of the greatest value to geology, and a worthy monument to its author.