Damoiseau's revised value, viz. $65^s{\cdot}073$, of the second eccentricity of III. instead of his earlier value, viz. $116^s{\cdot}73$. From this table it appears that the mass of II. is the only one that is known with any degree of certainty: the mass of III. is doubtful to the extent of not more than 10 per cent., but the masses of I. and IV. are at present so uncertain that they may almost be looked upon as unknown. We may, however, confidently expect that much of this uncertainty will be removed by the publication of Professor Sampson's discussion of the Harvard eclipses, which is therefore anxiously awaited.

In conclusion I should like to say how grateful I am to Sir David Gill for having given me an opportunity of carrying out this piece of work: for this and many other kindnesses, too numerous to mention, I wish to offer him my most sincere thanks. It is a pleasure also to acknowledge the unfailing courtesy and kindness I received from Mr. S. S. Hough and all the staff of the Cape Observatory during the two years I spent with them.

Note on the Distribution of Sun-spots in Heliographic Latitude, 1874 to 1902. By E. Walter Maunder.

Rather more than a year ago the Astronomer Royal communicated to this Society a paper which he had desired me to prepare on the "Mean Daily Areas of Sun-spots for each Degree of Solar Latitude for each Year from 1874 to 1902 as Measured on Photographs at the Royal Observatory, Greenwich." The paper was communicated at the Meeting of 1903 May 8, and printed in vol. lxiii. No. 8 of the *Monthly Notices*. It summarised in both tabular and graphical forms the results of thirty years' work in the measurement and reduction of about 9000 photographs of the Sun, and of the latitudes and areas of about 5000 separate groups of spots, involving upwards of a quarter of a million measures made in duplicate upon those photographs.

It appeared to me, when preparing the above paper, that the results given in it could be exhibited in somewhat different aspects, and I therefore prepared other diagrams at the same time, which were not communicated to this Society, but were exhibited at the Official Visitation of the Royal Observatory on 1903 June 6. These diagrams, altered only as to scale, so as to render them suitable for reproduction in the *Monthly Notices*, I would now submit to the consideration of the Royal Astronomical Society.

At the same time I would wish to supplement them by other diagrams which the appearance of a paper by Dr. W. J. S. Lockyer in the Appendix to the last number of the *Monthly Notices* has seemed to me to render necessary. A considerable

portion of Dr. Lockyer's paper deals exclusively with the numbers and diagrams presented in the Greenwich paper referred to above, and as, in my opinion, his conclusions are entirely unsupported by the facts of the case, it appears important to show what the Greenwich record of the Sun's surface does really teach.

The diagrams here presented are eight in number; the first and the fourth, fifth, and sixth were drawn up, as already explained, more than a year ago; the seventh and eighth were specially prepared with reference to Dr. Lockyer's paper on "Sun-spot Variation in Latitude, 1861–1902." The first deals with only the areas of Sun-spots; the second to the sixth deal with both their areas and latitudes; the last two with their latitudes alone.

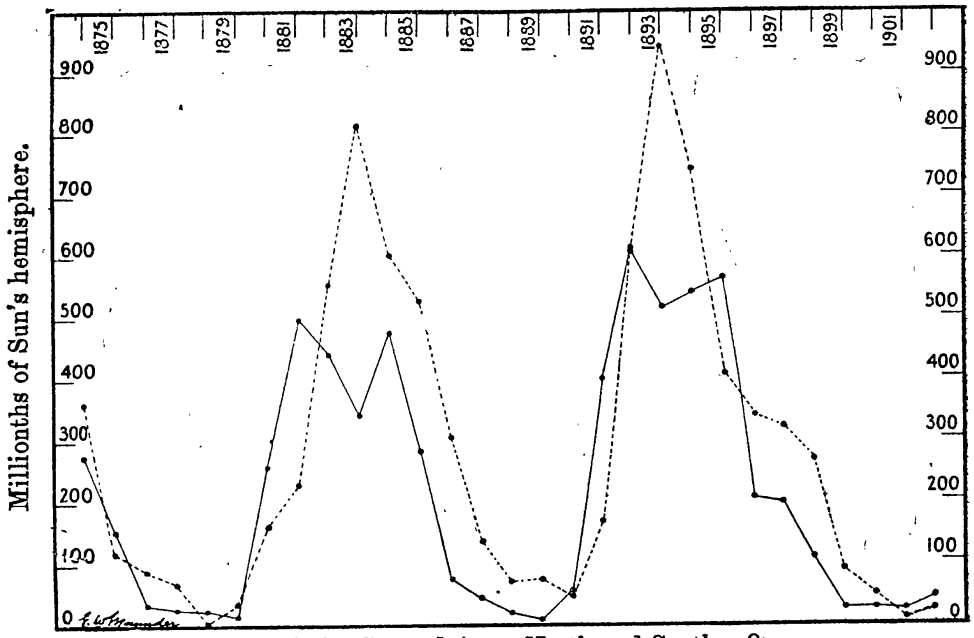


FIG. 1. Mean Daily Spotted Area, North and South, 1874–1902.
Northern Hemisphere —— Southern .....

The chief purpose of the first six diagrams is to call attention to the individuality shown by the two hemispheres of the Sun, north and south, the variations in the extent and in the mean latitude of the spotted area of the northern hemisphere being compared with the variations in the corresponding elements in the southern hemisphere. Incidentally these six diagrams serve to illustrate "Spoerer's Law of Spot-zones"; but the seventh and eighth are especially designed to bear upon it, to illustrate the fidelity with which it represents the facts of the case in general, and to suggest some additions which can now be made to it.

Fig. 1 shows the mean daily spotted area of the two hemispheres, north and south of the Sun, taken out year by year for each year from 1874 to 1902 inclusive. The points for the

areas of the northern hemisphere are joined by a continuous line, those of the southern hemisphere by a broken line. The chief facts to be gathered from this diagram are :

(*a*) The two hemispheres do not, on the whole period, differ very greatly in total spotted area ; but the southern is the more prolific of the two, the northern claiming $43\frac{1}{2}$ per cent. of all spots, reckoning by area ; the southern $56\frac{1}{2}$ per cent.

(*b*) The critical points in the progress of the solar cycle are marked earlier, in both the two cycles shown, by the northern hemisphere than by the southern ; and this on both the ascending and descending parts of the curve.

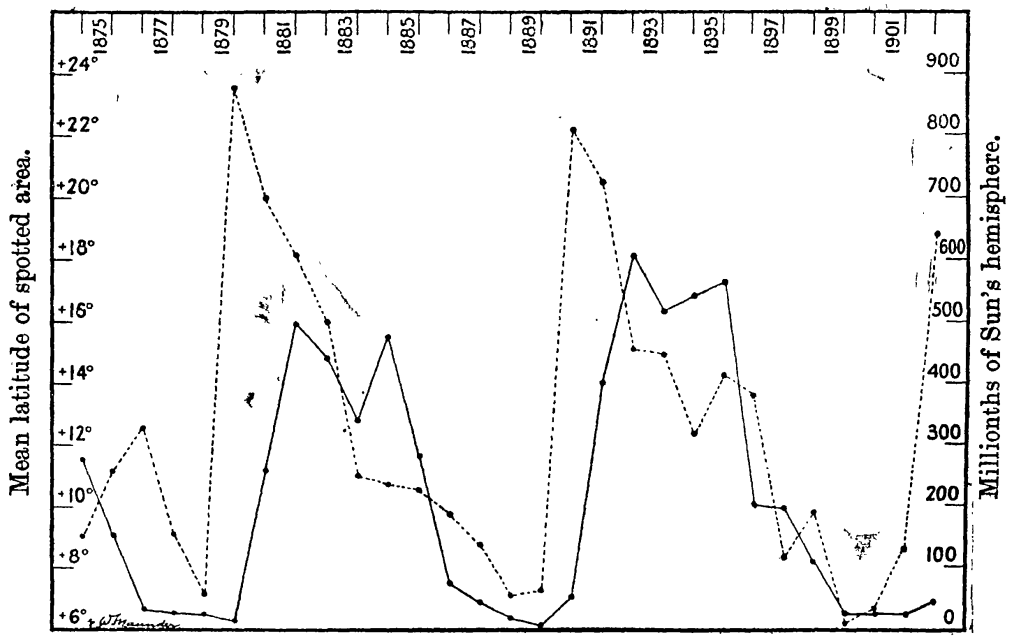


FIG. 2. Northern Hemisphere. Mean Latitude and mean Spotted Area, 1874–1902.
Latitude ..... Area ——

(*c*) The northern hemisphere shows a double maximum in both cycles, the first falling about three years before the second. The general form of the northern spot-curve, therefore, shows a long-continued but not very pronounced maximum.

(*d*) The southern hemisphere, on the contrary, shows but one very sharply marked maximum, synchronous with the slight depression between the two maxima of the northern curve.

Fig. 2 shows the mean daily spotted area for the northern hemisphere of the Sun for each year from 1874 to 1902, precisely as in fig. 1. But the mean heliographic latitude, year by year, of the spots of the northern hemisphere has also been indicated ;

the several points of the area curve being joined by a continuous line, those for the latitude curve by a broken line. The means for the latitudes are weighted means; the latitude for each separate spot-centre having been weighted in exact proportion to the area of the spot-group.

Fig. 3 shows for the southern hemisphere the same particulars as those given by fig. 2 for the northern. The following seem to be the principal relations brought out by the two diagrams:

(*e*) The rise in latitude is very abrupt in both hemispheres and takes place just as the minimum in spotted area comes to an end. The highest mean latitude is attained about three and a half years before the mean maximum* in area.

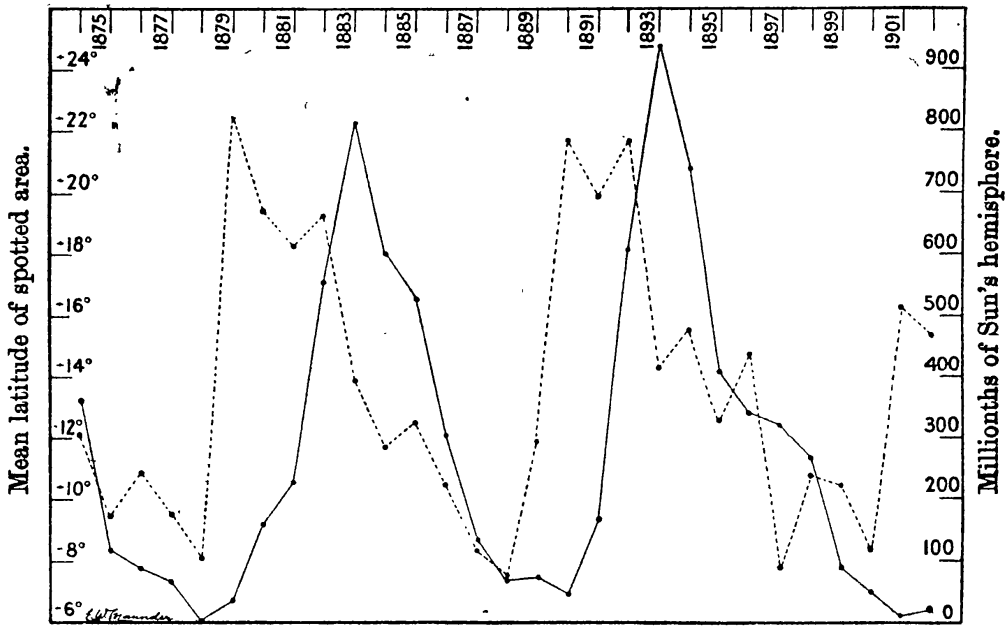


FIG. 3. Southern Hemisphere. Mean Latitude and mean Spotted Area, 1874–1902.
Latitude..... Area——

(*f*) The decline in latitude is much less rapid, and is interrupted in both hemispheres, especially in the southern, by minor rises. Of these minor rises those in 1882 and 1892 for the southern hemisphere are most striking, as they cause the form of the southern latitude curve to resemble that of the northern area curve with its double summits; whilst the more regular latitude curve for the northern hemisphere seems to reproduce the sharply defined area

* That is the maximum for the Sun as a whole. This corresponds to the maximum of the southern hemisphere, and to midway between the two maxima of the northern.

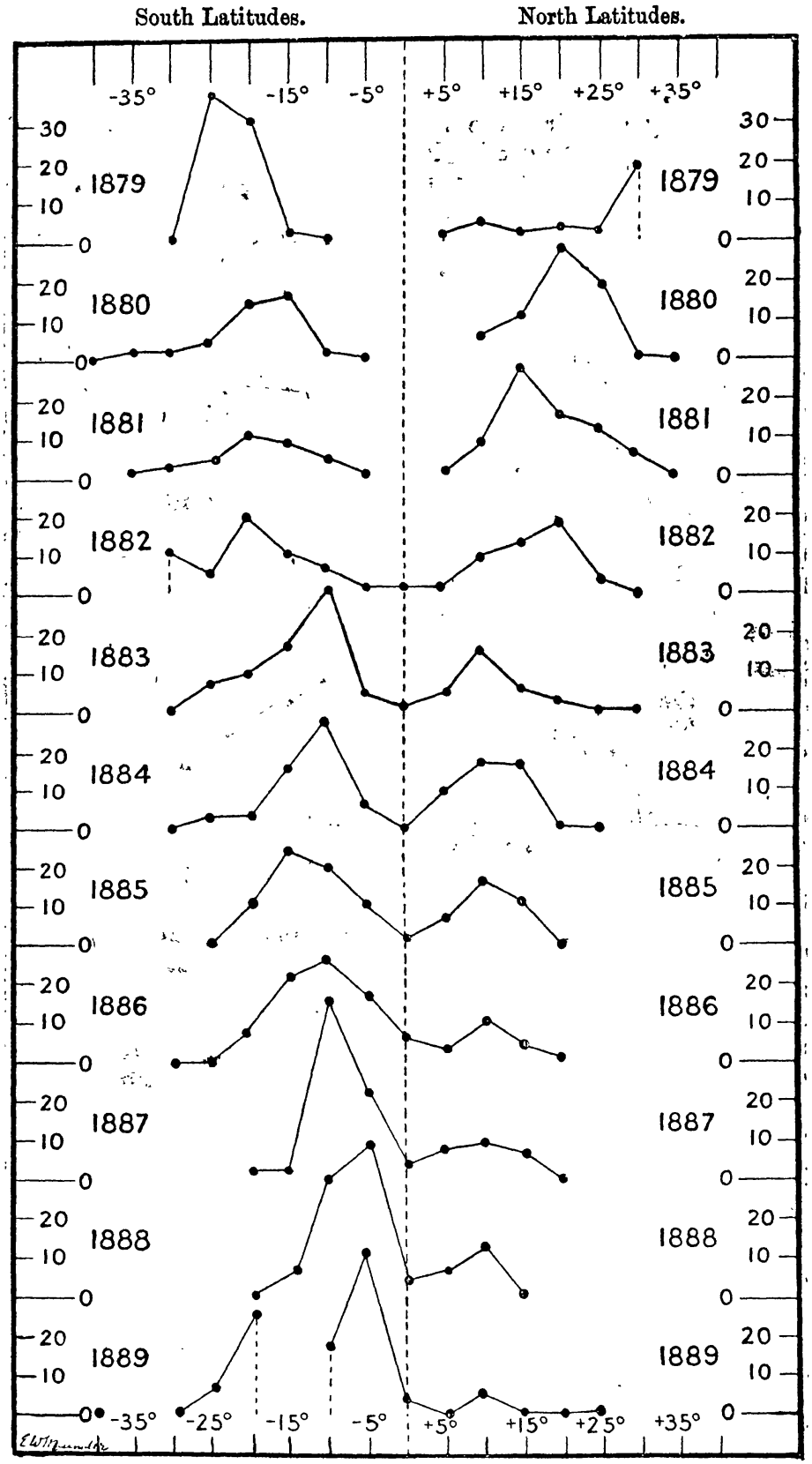


FIG. 4. Distribution of the Spotted Areas, 1879–1889.
The ordinates are percentages of the mean daily area for each several year

maxima of the south. In other words, the latitude curve attains in each cycle two maxima in the southern hemisphere, but only one in the northern.

(*g*) The mean latitude has fallen halfway to its lowest point by the time the mean maximum in area has been reached. As the decline in area after maximum takes place much more slowly than the increase in area before minimum the second half of the decline in latitude proceeds much more slowly than the first half.

(*h*) The range in latitude is greater in the northern hemisphere than in the southern, the mean position both rising higher and falling lower in the former case.

Fig. 4 shows the distribution of the spotted area, in zones of latitude 5° in breadth, for the years 1879 to 1889. The areas are expressed in percentages of the mean value for each several year, not on a uniform scale for all years of millionths of the Sun's visible hemisphere.

Fig. 5 gives the same results for the years 1890 to 1900. The two figures therefore practically give for these years the results shown in plate 15, vol. lxiii. of the *Monthly Notices*, but for 5° zones of latitude instead of 1° zones.

In some respects these two figures better represent the actual facts of spot distribution than the more detailed diagram just mentioned; and for this reason. The 5000 groups of sun-spots of the Greenwich record may be divided into three great classes. The great majority of the groups may be described as "Undeveloped." They last only a short time—sometimes only a few hours, sometimes four or five days—they are small in size and never attain a great area, and they close up and disappear without going through the regular stages which mark the long-lived groups. The second class may be described as "Normal Spot-streams." These pass through a certain sequence of changes, which varies little in general character from one group to another. They begin as a pair of small spots, develop into a stream of considerable length, the first and last spots increase in size, the middle spots die out, then the rear spot breaks up, and the leader survives as a well-defined circular spot. The members of the class not only conform to a certain life-history, they also conform to a certain standard of length, breadth, and area. This standard changes during the progress of the spot-cycle, but the range of size shown by different members of the class is at no time great. The class is fairly long-lived, being generally seen in the course of three or more rotations. The third class may be described as "Abnormal" or "Giant Spot-groups." These are of great extent, often five or six times as large as groups of the second class; they manifest some striking departures from the regular programme in the course of their development, and they vary very greatly as to their duration.

It is in the immense areas often attained by members of this third class that the explanation of the curious peaks and steeples

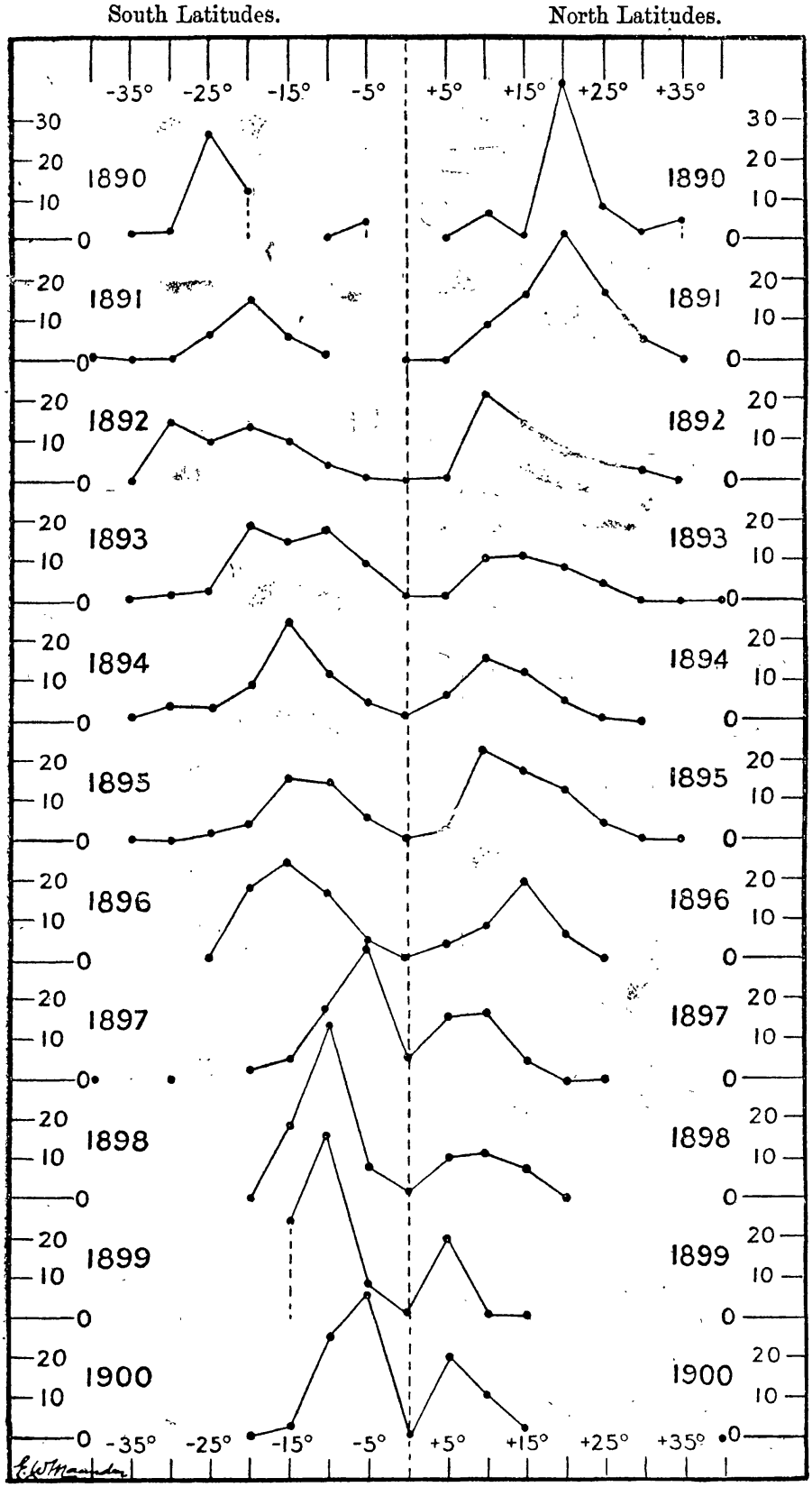


FIG. 5. Distribution of the Spotted Area, 1890–1900.
The ordinates are percentages of the mean daily area for each several year.

of the Greenwich diagram really lies; for the breadth of these groups is usually 6° or 7° of solar latitude, sometimes even 10°; but in forming the tables and diagram of the Greenwich paper of a year ago the entire area of any spot-group was referred of necessity to the 1° zone of latitude in which its "centre of gravity" was placed, inevitably causing a great apparent condensation in that zone—an *apparent* condensation which, if treated as a real one, must inevitably lead to mistaken conclusions. These peaks and spires in plate 15, vol. lxiii., are due, therefore, to isolated outbursts, not by any means to zones of activity, and are brought about by the purely computational concentration into single-degree zones of spot areas really distributed over many degrees. The feature is a feature of solar book-keeping, not of solar physics. So far is this the case that, though the plate in question represents the discussion of 5000 spot-groups, yet each one of the "Nineteen Largest Spot-groups" tabulated in my paper on the "Great Magnetic Storms" (*Monthly Notices*, vol. lxiv. No. 3) can be easily identified upon it. The majority of them stand out with an exceeding conspicuousness. More than this, so great a preponderance is exercised by some of these groups that their influence still shows out unmistakably even when the mean latitude is taken for an entire hemisphere and for a year at a time, even at solar maximum. Thus in fig. 3 the two second peaks of the latitude curve for the southern hemisphere are due to the two great groups Nos. 729 and 2421 in 1882 April and 1892 February respectively. Group No. 3412 in 1894 February creates one of the minor rises in the same curve. But their influence is not always in one direction. More usually the tendency of a great explosion is to seek a latitude a little higher than that proper to its period in the progress of the solar cycle. Occasionally, however, they appear distinctly below the average latitude, and then their influence is just as evident in producing a minor fall in the latitude curve. Thus in fig. 3 the notable drop in the latitude curve at the year 1894 is the effect of group No. 3668 of August of that year, and in fig. 4 the drop for 1897 of group No. 4497 early in January. The series of undulations in which, as Dr. Ch. Braun, of Kalócsa, pointed out, the latitude curve proceeds during its course of running down from one spot-minimum to the next is simply due to the influence of a very few of these "giant spots," which by reason of their size cannot fail, unless they chance to fall exactly on the mean curve, to drag the curve to the one side or the other.

The arrangement of spots into zones five degrees wide is, therefore, the most detailed possible if it is desired to exhibit their true distribution on the solar surface. An arrangement into zones two or three degrees wide is doubly objectionable. On the one hand it conceals the fact, so apparent when single zones are used, that the most salient irregularities are due to perfectly isolated outbursts, few in number and gigantic in scale, whilst, on the other hand, it gives rise to purely fictitious maxima, for it

concentrates into zones of two or three degrees spot-areas that on the Sun are actually spread over five, six, seven, or it may be even ten degrees of latitude. The maxima, therefore, obtained by Dr. Lockyer in the paper referred to above by taking 3° zones are not real maxima but merely apparent.

Turning to the curves shown in figs. 4 and 5, it will be seen that with 5° zones certain salient features of spot-distribution in latitude are clearly brought out.

(*i*) There is one and only one maximum, and that sharply defined, in each hemisphere in each year. This is the general rule.

Two classes of apparent exceptions are to be noted. In four instances, even taking the spots of a year, and grouping them in 5° zones, a single spot-group still succeeds in standing out. These are all in the southern hemisphere and are the following :—

Group	No. 729, 1882 April,	Lat.	−28°·5
,,	,, 2421, 1892 February	,,	−28·3
,,	,, 3106, 1893 August	,,	−17·6
,,	,, 3281, 1893 November	,,	− 5·1

The other instances are just after minimum, and are illustrations of "Spoerer's Law of Spot-zones"; for, as Spoerer pointed out, at this stage of the spot-cycle the first members of the new spot-cycle begin to appear in high latitudes, whilst the last members of the expiring spot-cycle have not yet wholly died out in the low latitudes to which they are confined. Thus in 1879 and in 1889 two clearly defined maxima are seen in both hemispheres, separated, as the more detailed diagram in plate 15 of the former Greenwich paper shows, by a broad zone absolutely free from any spots at all. In 1880 the old cycle-spots in low latitude have completely disappeared, and only a single maximum, and that sharply defined, is seen in each hemisphere. In 1890 the process of elimination of the old cycle spots is not quite complete, and they still show feebly; but the new spots in high latitudes are in a most overwhelming preponderance. It is possible to consider two or three very small spots of the following year as being survivors of the old cycle, but there is no possible question of a double maximum.

(*j*) The real exceptions to (*i*) occur, therefore, only immediately after the sun-spot minimum, precisely in accordance with "Spoerer's Law."

Some time ago Dr. Lockyer stated to this Society that "the curves of Spoerer are very misleading, for by taking the mean position of several spot-zones you arrive at a latitude in which spots may not exist at all" (*Observatory*, 1903 June, p. 236). This statement is true only respecting the commencement of the new cycle. Then, and only then, are there definite and distinct zones of spots in either hemisphere. But so far from

this being an exception to Spoerer's Law it is a relation which is especially brought out and insisted on by it.

At all other times there is practically but one spot-zone * in each hemisphere, and necessarily the mean latitude for the hemisphere falls not where spots do not exist at all, but where they are largest and most numerous. This can be seen at once to be the case from a comparison of figs. 2 to 5 inclusive, but is brought out again in a slightly different manner in fig. 8 (Plate 16). It is sufficient to state here that the careful examination of the photographic record of the last thirty years fails to show any fact to give the slightest support to the above statement of Dr. Lockyer.

Referring again to figs. 4 and 5 two other relations appear evident :—

(*k*) During the rise to maximum the spots avoid the equatorial region, but after maximum they gradually abandon the higher latitudes, and close in towards the equator.

(*l*) There is a strong tendency for the curves of any year in fig. 5 to reproduce the curves of the corresponding year in fig. 4—that is to say, eleven years earlier.

The reproduction is not quite exact, for, as the sun-spot cycle is not precisely eleven years, but varies from time to time, the cycle attaining its maximum in 1883 being shorter, whilst the following cycle was longer than the average, years separated by an undecennial period do not in this case represent precisely the same phases of the cycle. But even as it is the chief characteristic differences between the curves of the northern and southern hemispheres seen in the earlier cycle reappear in the later.

Fig. 6 exhibits the numbers of figs. 4 and 5 in a different manner. Here the areas for each zone 5° wide are treated separately, the annual means for that particular zone being shown in one and the same line, from 1874 to 1901. The areas are given in millionths of the Sun's visible hemisphere. Since, as already seen, the spots of either hemisphere form but a single zone this division is not a natural one, and conclusions must not be drawn from it without reference to the manner in which it has been formed. But certain relations do appear to be presented by it :—

(*m*) As pointed out in the Greenwich paper of a year ago, "spots in a higher latitude than 33° are at all times rare, and when seen are never large or long-lived. Taking them as a class by themselves they are seen irregularly, appearing at times which do not seem to bear any fixed relation to any one of the four chief stages of the sun-spot cycle—minimum, increase, maximum, and decline."

* I trust to be permitted in a future paper to deal with the distribution of spots both in latitude and in longitude. The above statement is absolutely correct, but I shall then be able to treat of certain restricted senses in which it is possible to speak of minor spot-zones.

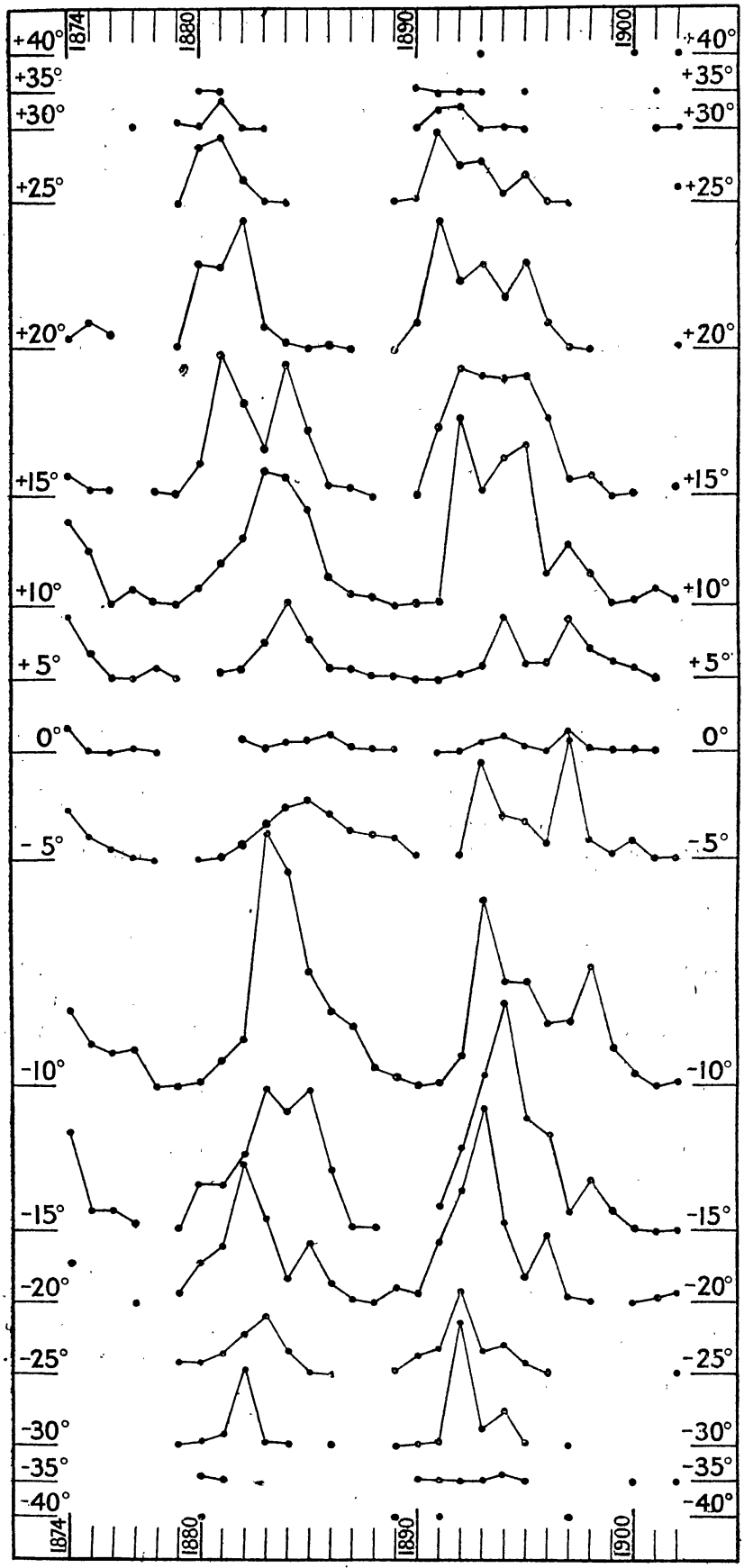


FIG. 6. Spotted Areas, 1874–1902, for each Zone of five degrees breadth in Latitude.

(*n*) Equatoreal spots are not, as is often stated, absent at maximum, but are fairly numerous. They commence to appear at, or a little before, maximum, and decline irregularly until their extinction early in the next cycle.

(*o*) The years of the maximum spot activity of the Sun taken as a whole are, broadly speaking, the years of maximum activity in every latitude, and not only in the zone of 15°. But the maxima for latitudes higher than 15° tend on the whole to fall earlier, and those for latitudes lower than 15° later, than the maxima for the 15° zone itself.

(*p*) The tendency of the northern hemisphere to reach the critical stages of the sun-spot cycle earlier than the southern is not only seen when the two hemispheres are treated as wholes, but, broadly speaking, is seen in every latitude.

Referring again to Dr. Lockyer's paper on "Sun-spot Variation in Latitude," the question arises whether even if the numerous maxima which he supposed in either hemisphere really existed, he would be justified in joining them together from year to year in the way he has done. Whilst it must be remembered that a spot of 150-millionths—and this is almost the smallest size for a group of the second class, the "Normal Spot-streams"—will have a breadth of 2° of solar latitude, and that a circular spot 1° in diameter will only have an area of 38-millionths, and will be only a small spot of the "Undeveloped" class, yet, on the other hand, immense as is the area of some spot-groups, the proportion of the solar surface covered by spots at any one time is quite insignificant. The mean daily area during the last maximum was one-seventh of 1 per cent., at minimum one-four-hundredth of 1 per cent. On no single day since the Greenwich record was commenced has the total spotted area reached 1 per cent., whilst the average for the whole period is about $\frac{1}{250}$ of 1 per cent. Further, the number of groups visible at any one time is, on the average, only slightly over one group for the southern half of the visible hemisphere, and a little less for the northern half. This being so, the barren areas between group and group must necessarily be very great as compared with the groups themselves, especially in the early days after a minimum, when the total spotted area is extremely small. Under such circumstances the linking together of certain selected spot-centres to form a "spot-activity track" can only be regarded as a matter of personal predilection, not as one of solar physics.

Fig. 7 will serve to indicate an example of this. It shows the distribution in heliographic latitude and in date of appearance of all the spot-centres in the northern hemisphere during the four years 1878 to 1881. The centres of 1878, eleven in number, all lie between +16° and the equator. A period of more than five months followed without any spots at all, and then in 1879 May a new group, No. 281, appeared in latitude +14°; a second, No. 283, in latitude +28°; and a third, in

latitude +6°, broke out in July ; and nine others followed before the end of the year. Following Spoerer's enunciation, the group at +28° was clearly the first of the new cycle, whilst that at 6° was as clearly a survivor of the cycle that had just passed ; but in which category should the first group, at +14°, be classed ?

Of the other groups of the year one at +18°, No. 289, may be mentioned. This and the group already referred to at +28° are considered by Dr. Lockyer as commencing two "spot-activity tracks." He writes : "Considering the curves relating to the Sun's northern hemisphere, it will be seen that in 1879, the year following a sun-spot minimum, when the spots were ending a cycle near the equator, two new outbreaks occurred in latitudes about 20° and 30°. These two centres of activity moved towards the equator next year, and by 1881 the former had disappeared, while the other rapidly grew in intensity and reached latitude 15°. During this year a new outbreak in latitude 30° made its appearance, and this in the two following years had an equatoreal trend."

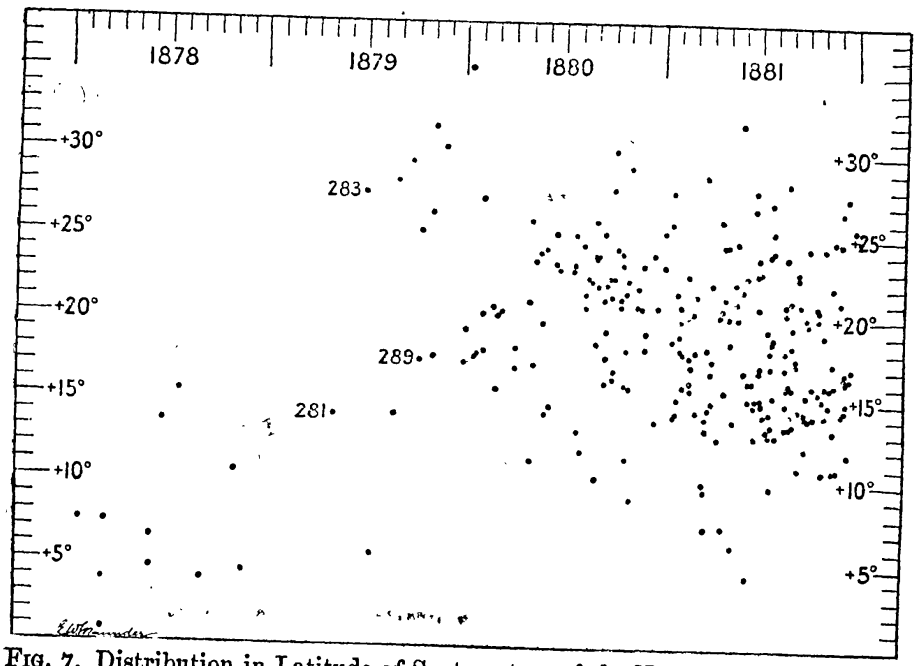


FIG. 7. Distribution in Latitude of Spot-centres of the Northern Hemisphere, 1878–1881.

An examination of the diagram (fig. 7) shows that this association of groups Nos. 283 and 289 with a downward moving current is purely arbitrary. The groups succeeding group No. 283 in or near the same latitude tend very markedly on the whole towards a higher latitude, not towards a lower. So with group No. 289. The first ten groups succeeding it in order of date are all either at the same or at higher latitudes, and it is not until five months after its appearance that another spot forms in

a slightly lower latitude. There is even some slight evidence of an actual movement upward of group No. 289, for in the next rotation group No. 293 forms in the same longitude, but very slightly higher in latitude. Other groups early in 1880 show the same tendency. Group No. 308 is an actual return of group No. 301 with an increase of 0°·8 in latitude; group No. 320 a second return of group No. 314, with an increase of 0°·7 in latitude. A careful examination of the diagram shows, in fact, that the real phenomenon that was in progress in 1880 and 1881 was by no means the setting up of downward moving "spot-activity tracks," but a general multiplication of spot activity in all latitudes consequent upon and concurrent with the general increase in the spotted area.

There is, therefore, no satisfactory evidence in favour of the existence of Dr. Lockyer's downward moving "spot-activity tracks." The last diagram gives positive evidence against it.

Fig. 8 (Plate 16) displays for the entire period 1877–1902 the same features shown in fig. 7 for the four years 1878–1881. But in this case, in order to bring the facts within reasonable compass, instead of the individual spot-centres being represented, the spot-distribution for each synodic rotation of the sun has been given. Wherever a spot-centre has fallen on one or more days during a given rotation in a particular degree of latitude a line has been drawn across that particular degree. The diagram, therefore, like fig. 7, represents distribution in latitude, but takes no account of area. In assigning a spot-centre to any particular degree of latitude all latitudes from, say, 6°·5 to 7°·4 have been reckoned as 7°, and similarly with others.

An examination of the diagram brings out Spoerer's Law with remarkable clearness. There is but a single movement in either hemisphere, the general trend of which is downward from immediately after minimum to immediately before minimum. During the years of great spot-activity almost every degree of latitude is affected. The interruptions are perfectly irregular and sporadic. The indications of subordinate zones, which would be shown, if present, by continuous barren tracks, through the middle of the vertical lines, are quite wanting. Nothing can be more striking than the contrast between the very fair approach to continuity of the distribution lines, during the greater part of the solar cycle, and the definiteness with which they are limited, both on the side of the equator and on that of high latitudes, by barren belts descending towards the equator. The general form of spot-distribution in both cycles is that of a hollow wedge.

But there are some minor details which are worth notice. A comparison of both cycles and in both hemispheres shows that though the outbreak after minimum occurs quite suddenly in high latitudes it does not at once start in the highest latitude, and then run down. There is a short time, in length about a year or a year and a half, during which the outer boundary of the

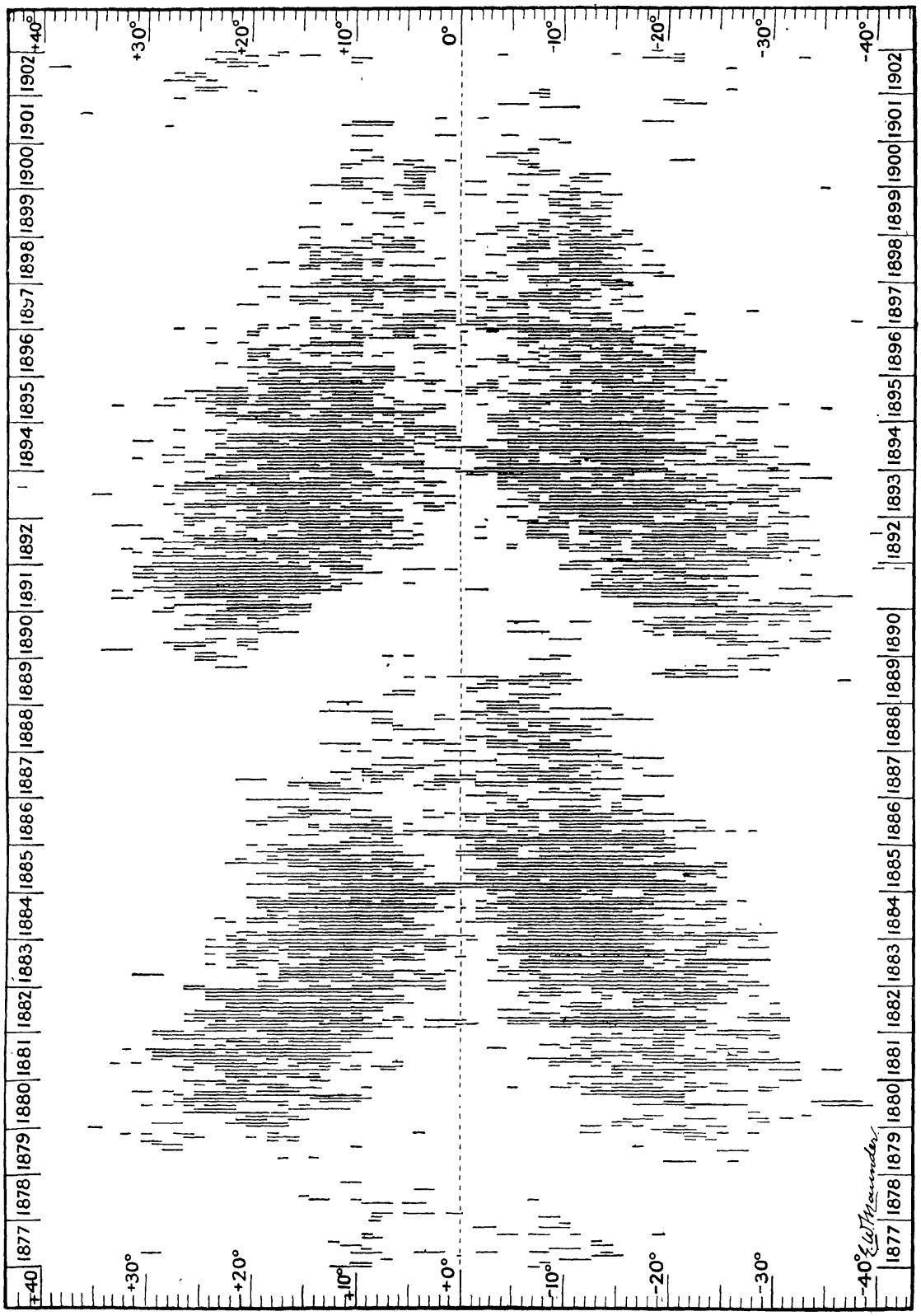
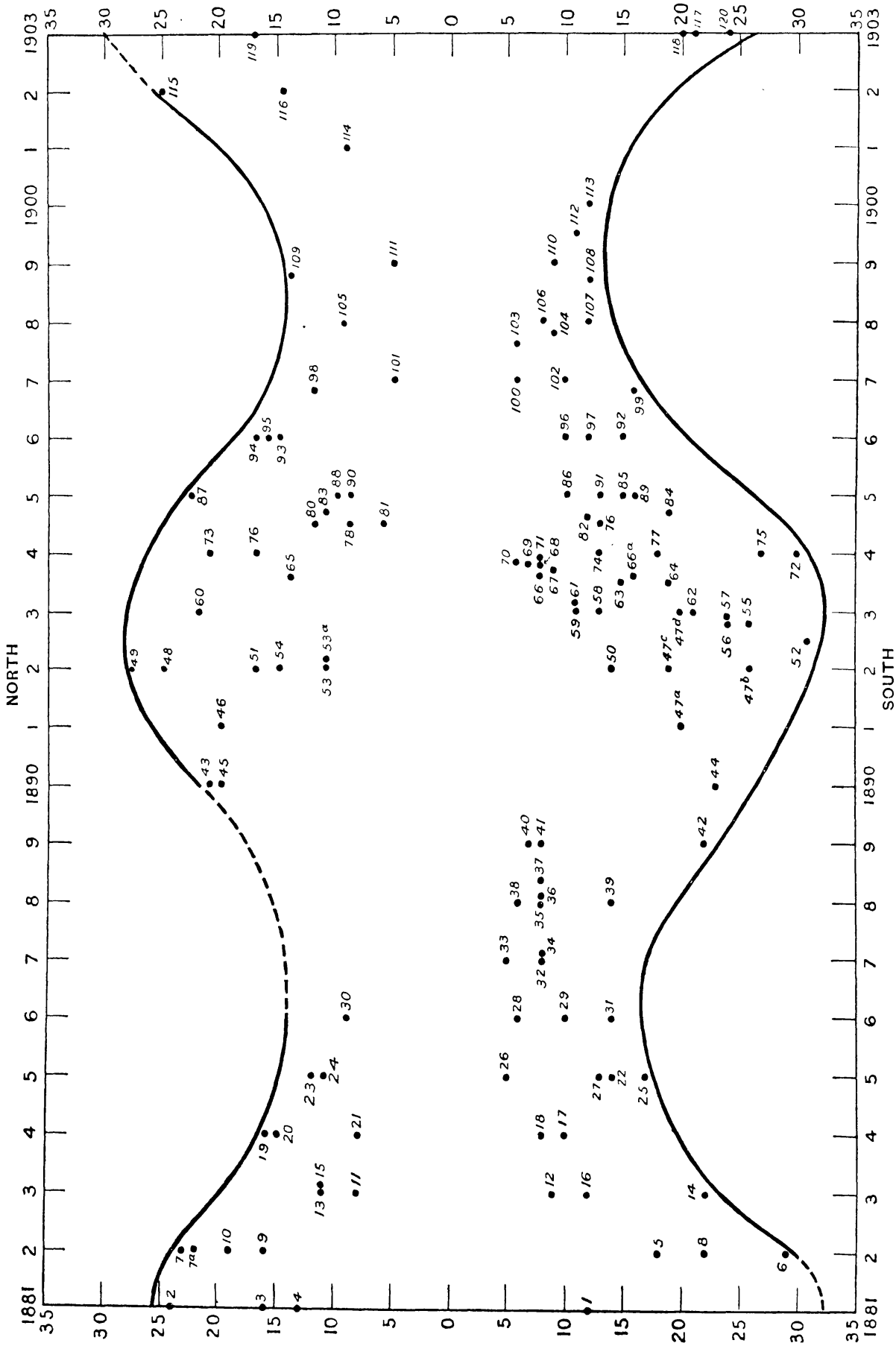


FIG. 8.—DISTRIBUTION OF SPOT-CENTRES IN LATITUDE, ROTATION BY ROTATION, 1877–1902.



HELIOGRAPHIC-LATITUDE CHART OF THE GREATER SOLAR SPOTS, 1881–1903.

spot-distribution is steadily and continuously mounting. Fig. 7 shows this in detail for the northern half of the first cycle, group No. 283 and its successors moving steadily upwards. Inasmuch as the general increase in spot activity is eventually seen in all zones there must be a broadening of the general area of disturbance, and therefore it might be expected there would always be a few spots which could be selected in order to favour the idea of short-lived downward currents. In 1889 in the southern hemisphere, however, the current moved upwards, and upwards only. There were no spots for a year to offer any excuse for the idea of a downward moving "spot-activity track." In the previous cycle a similar feature was presented, but was not quite so strongly marked. The limit, therefore, of spot-distribution in latitude varies in precise analogy with the variation in area—that is to say, it shows a swift run up to maximum, a slow and undulating movement down to minimum.

Though the diagram shows clearly that there is but a single spot-zone in either hemisphere in each of these two cycles, a zone which moves in general accordance with Spoerer's curves, it reveals a striking and unexpected fact—namely, that the southern current not only reaches the equator, but crosses it. The limit which bounds spot-distribution in the southern hemisphere on the equatorial side can be traced not only as far as the equator, but beyond it.

Fig. 8 therefore shows :

(*q*) That Spoerer's Law is completely true within the limits of its enunciation.

(*r*) That there is only one spot-zone—a very broad one—in either hemisphere except during the brief period just after minimum, when two cycles overlap.

(*s*) That Spoerer's Law is defective in so far as it does not take note of the short period during which the limit of spot-distribution moves upward at the beginning of a new cycle.

(*t*) That it is also defective in not taking note that the downward movement of the limits of spot-distribution may, as in 1886 *et seq.*, lead one of the two spot-zones right across the equator.

On the whole the results of the Greenwich record for the twenty-nine years 1874 to 1902, briefly summarised on pp. 452 and 453 of the *Monthly Notices*, vol. lxiii., fully confirm and bear out "Spoerer's Law of Spot-zones," whilst indicating some important additions to it.

86 *Tyrwhitt Road, St. John's, S.E.:*
1904 *June* 9.