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A. EGELAND AND A. OMHOLT

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CARL STØRMER'S HEIGHT MEASUREMENTS OF AURORA

A STATISTICAL STUDY

BY A. EGELAND
The Norwegian Institute of Cosmic Physics, Blindern, Norway.

AND A. OMHOLT*
The Auroral Observatory, Tromsø, Norway.

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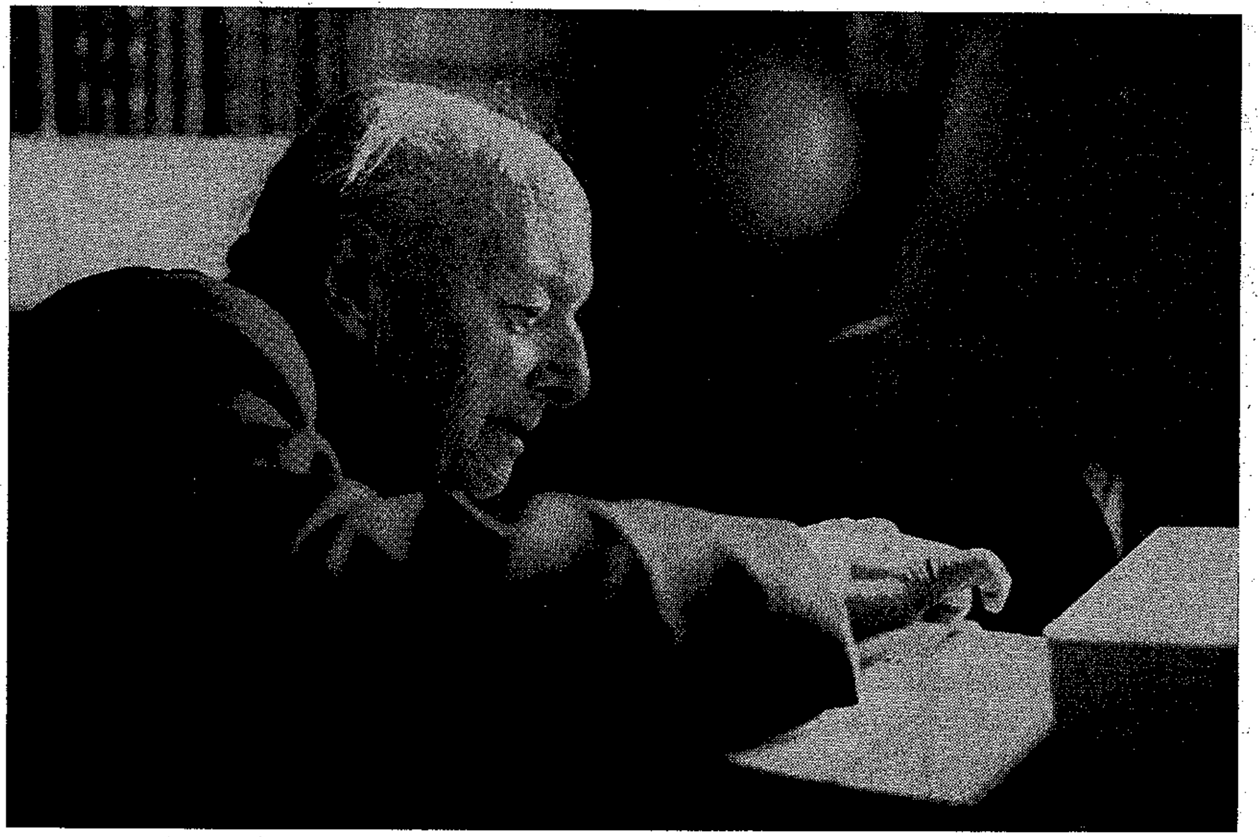

FREDRIK CARL MÜLERTZ STØRMER.
Born 3 September 1874, died 13 August 1957.
Professor of mathematics at the University of Oslo.

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* On leave from Institute of Physics, University of Oslo.

Summary. From Størmer's extensive height measurements of aurora in the years between 1911 and 1943, the heights of more than 12.000 auroral points are available for statistical studies. This paper shows the potential of this material, and presents some of the most important conclusions which may be drawn from it. The following results may be of particular interest:

A study of the geomagnetic distribution of the measured auroral points shows that visually pulsating auroral arcs and the high auroral arcs around 200 km are particular low-latitude phenomena, whereas single rays seem more dominant at high latitudes than at low latitudes.

There is some variation of height with geomagnetic latitude, particularly for draperies. Also, there is a general tendency for more low aurorae at low latitudes than at high latitudes.

A comprehensive study of the height distribution for various auroral forms and for various geomagnetic latitudes is presented. All auroral forms except rays show a pronounced peak in the height distribution around 100—110 km. There is little or no variation with latitude in the height of this peak. Rays are evenly distributed in height from about 100 km and up.

There is a small, but significant decrease in the average lower border of aurora during the later part of the night, after local midnight.

Seasonal effects in the height of aurorae seem to occur. Both sunlit and ordinary aurora show a somewhat greater average height in the autumn than in the spring. For sunlit aurora there is also a markedly greater probability of occurrence during the spring than during the autumn.

As expected, there is a good correlation between occurrence of aurora and sunsput number, except for homogeneous arcs, which show no such correlation. There is a tendency for more high aurora during the years of high solar activity, whereas for homogeneous arcs the opposite seems to be the case. Also sunlit aurora is most often observed during the solar maximum years.

1. Introduction. In a biography of FREDRIK CARL MÜLERTZ STØRMER, SYDNEY CHAPMAN (1958) writes that Størmer's photographic auroral studies have earned for him an undying name in the history of auroral science. Størmer has given a survey of his major works in his book "The polar aurora" published in 1955.

In the preface of his book, Størmer writes that in 1909 he 'found it necessary to obtain more facts about the aurora in order to compare theory and observations". He was an enthusiastic and indefatigable observer and organizer of observations. From a net of 20 well-equipped observing stations in Southern- and Middle Norway (between 59 and 64° N geomagnetic latitude) Størmer carried out the most extensive collection and analysis of auroral photographs for height and position measurements that has ever been made. From a great number of parallactic photographs (more than 40,000), he derived the heights, locations, forms etc. of the aurora. The main results of this work are described in a long series of publications, mainly in the Geofysiske Publikasjoner of the Norwegian Academy of Science (cf. STØRMER, 1955).

The height of the aurora was first established by Størmer. He published many valuable diagrams, showing the height-distribution and location of auroras in general, and for many special types of aurora. Størmer's height measurements and his discovery and studies of sunlit aurora, forms the main basis of our knowledge in this field.

In his book, STØRMER (1955) writes (cf. page 89) that the statistical study of his extensive visual auroral material is far from being completed, and that he intended to continue this work. For most of his diagrams and statistics Størmer used only a part of his numerous data collection. During the last years of his life Størmer worked hard in an attempt to complete the statistical analysis of all his observations.

For the auroral science it was a great loss that Størmer died before his statistical analyses were finished. Unfortunately, we do not know the exact program for this work. But before his death, he had marked out the most accurate material for the period 1911 to 44, which amounted to more than 12,000 auroral points derived from more than 7200 sets of pictures. This is the same material that Størmer used for the height distribution in his book, Sec. 31, Chapt. VII.

It was strongly felt that a similar collection of height measurements is not likely to be carried out again, and that a considerable amount of new statistical information on visual aurorae could be made available from this material by the use of a computer. The work presented in this paper is considered as a supplement to the results given in Størmer's book. It does not exhaust all possible use of this material, a number of detailed studies can still be carried out. This paper presents, however, some major results and demonstrates the possibilities for future work. The data compiled by Størmer and used in this study will be available to any scientist who may wish to use them for further studies in this field.

2. General remarks concerning the analysis and presentation of Størmer's data. For all 12,232 auroral points the following information has been punched on IBM cards: Year, month, time, geomagnetic co-latitude of the footpoint of the aurora, form, height, where in the auroral form the height has been measured (bottom, top and/or average), if the aurora was in sunlit position (sunlit aurora), observing stations involved, and the angles μ, ε and ρ (cf. STØRMER, 1955, Chapt. V). Unfortunately, the azimuth of the auroral point (cf. Chapt. V) is available only for approximately half of the points. Therefore it has not been possible to calculate the geomagnetic time and longitude for the measured points. As regards the geographic position of these 12,232 points, they are spread over a vast region, covering more than the whole of Norway.

The classification of auroral forms used throughout this paper is in accordance with the recommendations of 1930 of the International Union of Geophysics, which was used by Størmer. This classification is given in the Photographic Atlas of Auroral Forms by STØRMER (1930) and is also described in detail in his book. In the present paper the short symbols for the different auroral forms will be used to a large extent. A list of the auroral forms studied is given below, together with the number of measured points used in this work:

HA:	Homogeneous arcs,	1234 points
HB:	Homogeneous bands	142 „
RA:	Arcs with ray structure,	584 „
RB:	Bands with ray structure,	2269 „
R:	Rays,	5740 „
D:	Draperies,	857 „
DS:	Cloud-like aurorae or diffuse luminous surfaces,	592 „
PA:	Pulsating arcs,	390 „
PS:	Pulsating surfaces.	424 „

By means of a computer we have carried out the following analyses of more than 12,000 observed auroral points:

I. Relative frequency of occurrence and height of auroral forms as function of geomagnetic co-latitude.
II. The height distribution of various auroral forms for different geomagnetic latitudes.
III. The height of the lower border of aurorae as function of local time.
IV. Seasonal variation of occurrence and average heights for the measured auroral points.
V. Yearly variation of occurrence and average height for various auroral forms. In this study comparison with the sunspot numbers has been made.

The material obtained from this analysis will be presented in Sections 3 to 7. No elaborate interpretation or theoretical speculations will be given.

We have not included standard deviations in the given results. For the data on occurrence of aurora, the uncertainty is readily derived from the number of observations themselves. For auroral heights it is clear that standard deviations are not immediately meaningful, since the height of the aurora is a highly variable quantity. Thus, the spread in the results is mainly due to a true effect and does not obey a gaussian distribution. Also, the measured points are not always at random intervals.

Even so, it is felt that the average values give some significant information on the variability of the phenomena, but for a closer comparison with theory in the future it may be worthwhile to go more deeply into the details of the data.

3. Geomagnetic distribution of the observed auroral points and their heights.

3.1. Introduction. STØRMER (1955) has given the geographical position of several homogeneous auroral arcs, bands with ray structure and cloudlike aurorae. However, Størmer's work did not give a detailed account of the occurrence and height of aurora as function of geomagnetic latitude. In order to study this the geomagnetic co-latitude θ and height of all the measured 12,300 auroral points have been examined. The number of measured auroral points and their average height has been computed for each of the following geomagnetic co-latitude regions: $\theta < 20°$, $20 \leq \theta < 22$; $22° \leqq \theta < 24°$; $24° \leq \theta < 26°$; $26° \leqq \theta < 28°$; $28° \leq \theta < 30°$; and $\theta \geqq 30°$. The geographical location of these regions over Scandinavia is shown in Fig. 1. The center of the auroral zone over Northern Scandinavia is at approximately 22° geomagnetic co-latitude. This study also includes a detailed account of the various auroral forms listed in Sec. 2 except homogeneous bands, HB, for which the number of observations were too few to yield significant results.

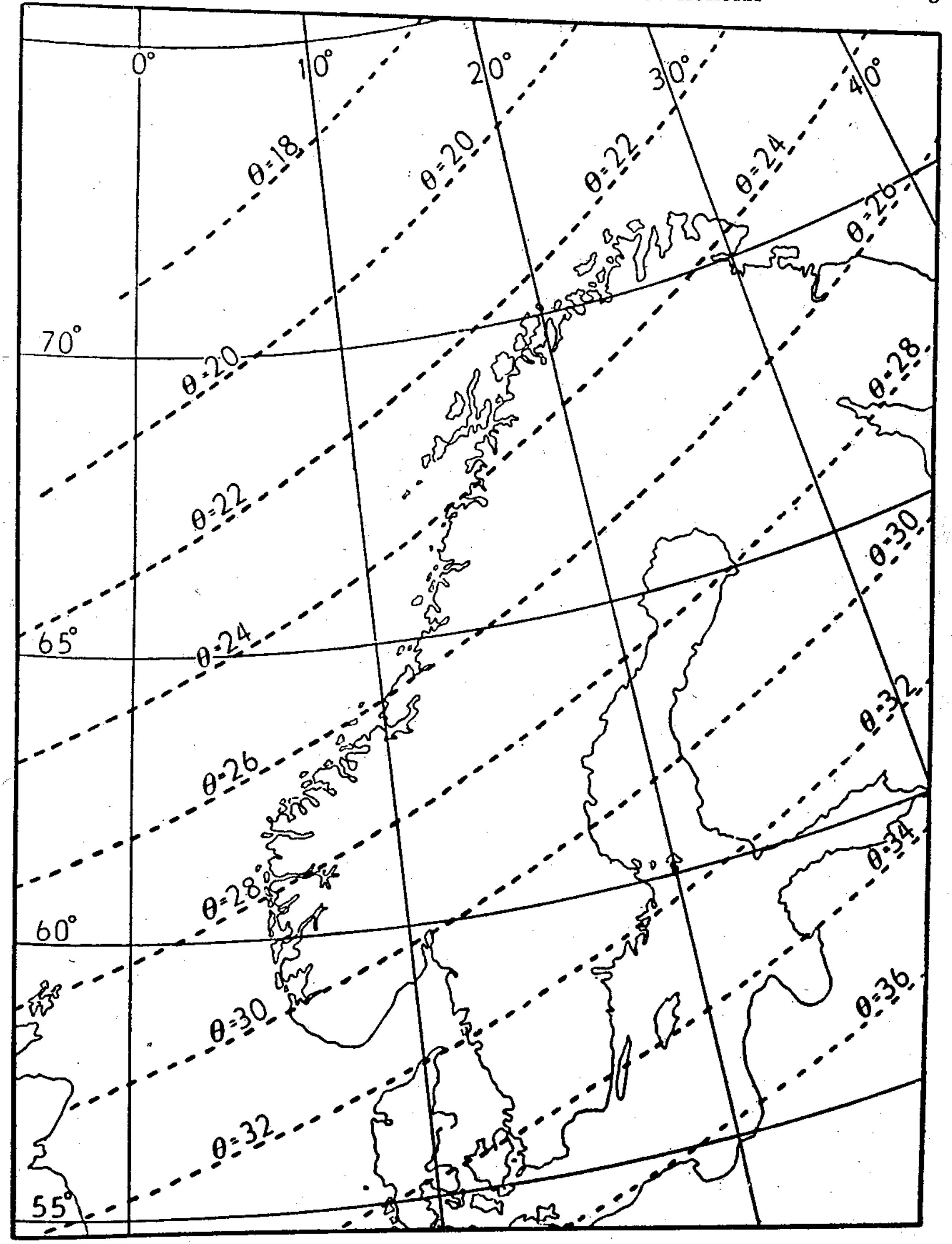


Fig. 1. Geomagnetic co-latitude circles (dotted lines) over Scandinavia.

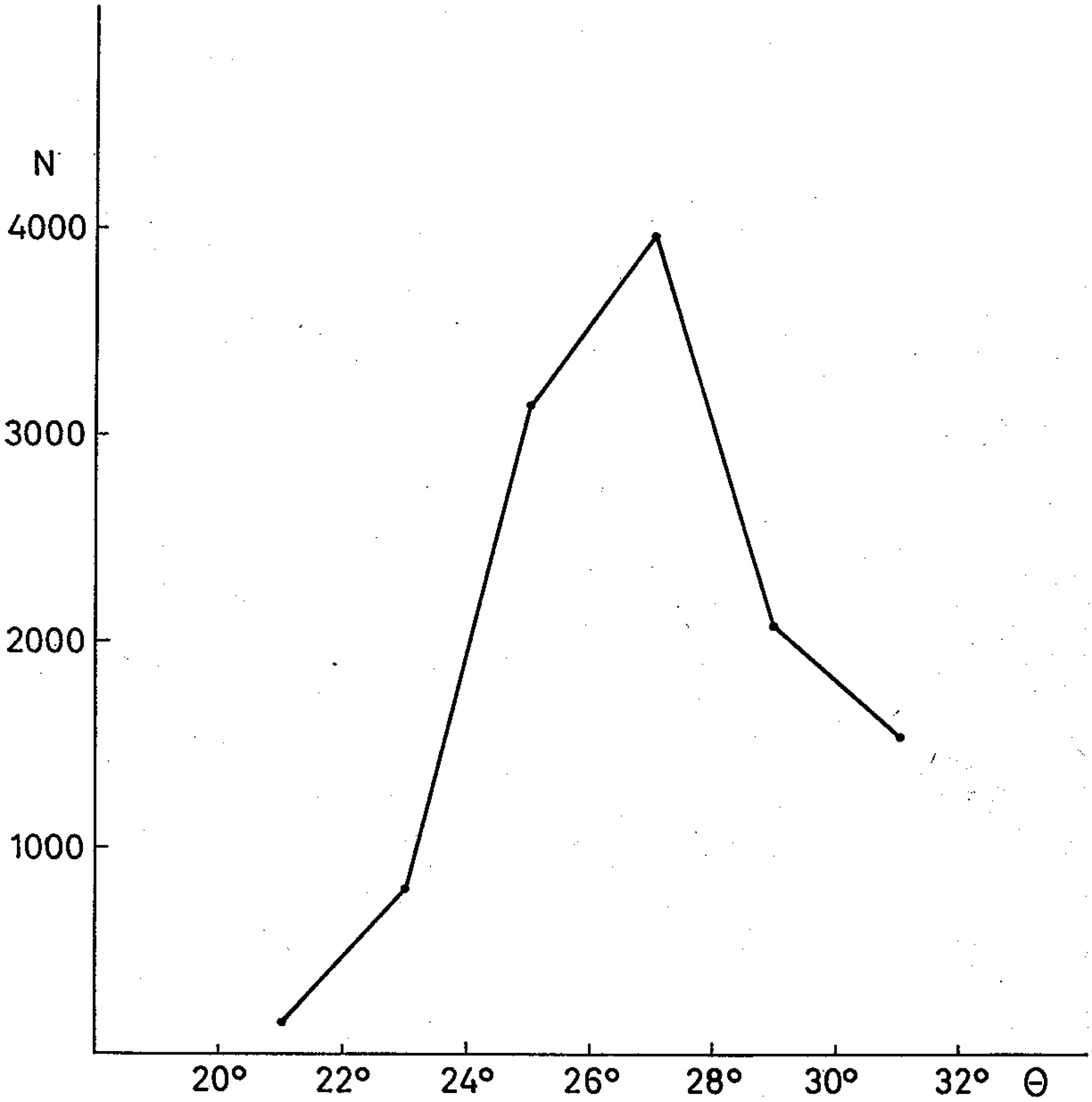
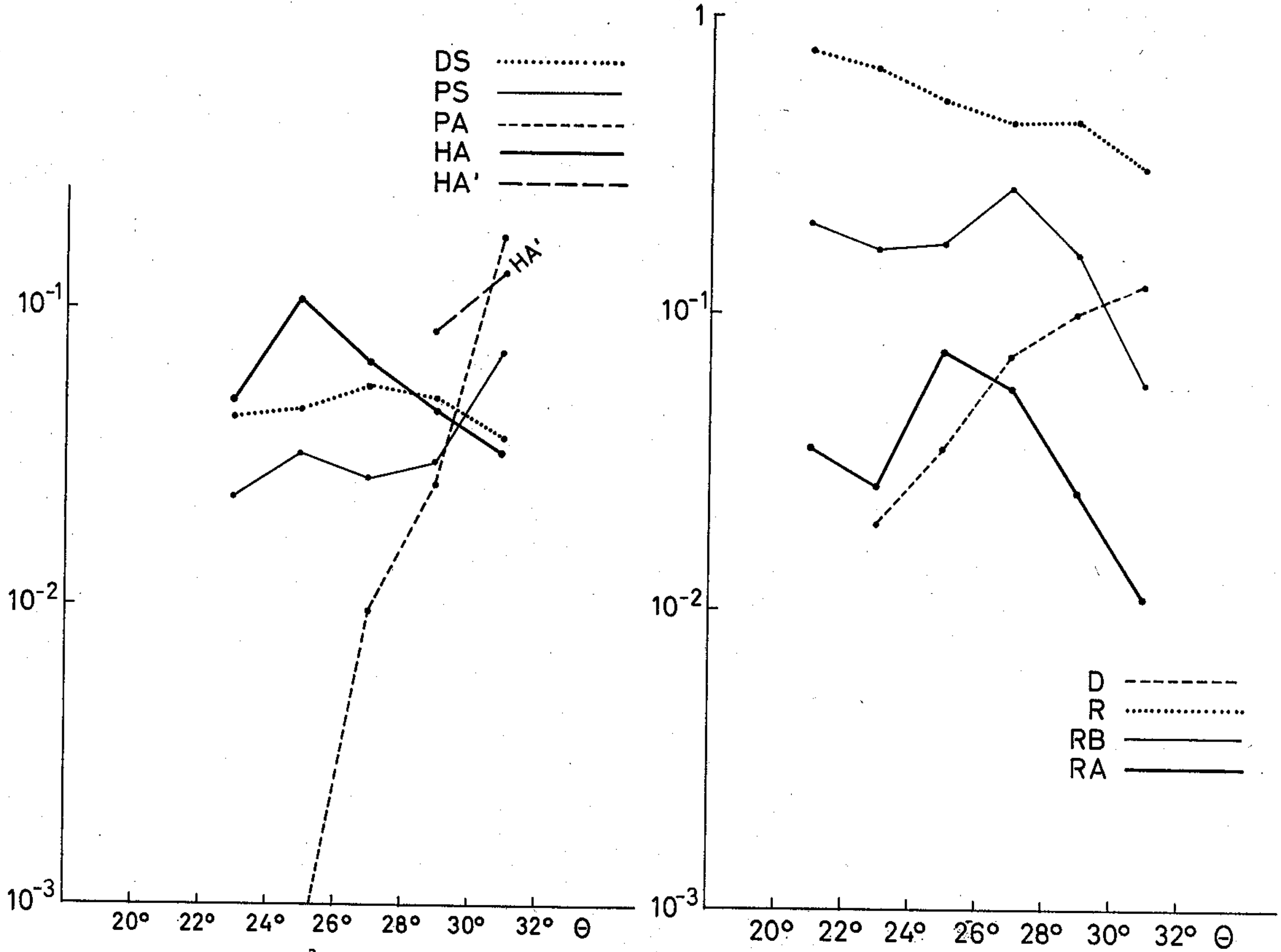


Fig. 2. Number of observed auroral points (N) as function of geomagnetic co-latitude (θ).

3.2. Geomagnetic distribution of all the observed auroral points. In Fig. 2 the distribution of all the measured points is shown as function of geomagnetic co-latitude. It appears from this figure that more than 50% of all points were observed in the co-latitude region $24^\circ < \theta < 28^\circ$ and that the number of observations decreases rapidly both southward and northward of this region. It must be emphasized that this distribution does not reflect the frequency of visual aurora for geomagnetic co-latitudes below 26°. Because there is a concentration of observing stations at co-latitudes above 26° (south of 64° N geomagnetic latitude), this part of the curve is probably reliable. From $\theta = 26^\circ$ to $\theta = 30^\circ$ the frequency of auroral occurrence decreases by more than 60%.



3a

3b

Fig. 3a and b. Relative distribution curves for the different auroral forms, showing the ratio between the number of measured points for a given auroral form and the total number of measured auroral points, as function of geomagnetic co-latitude θ. The curves for HA and HA′ are for homogeneous arcs below and above 150 km, respectively.

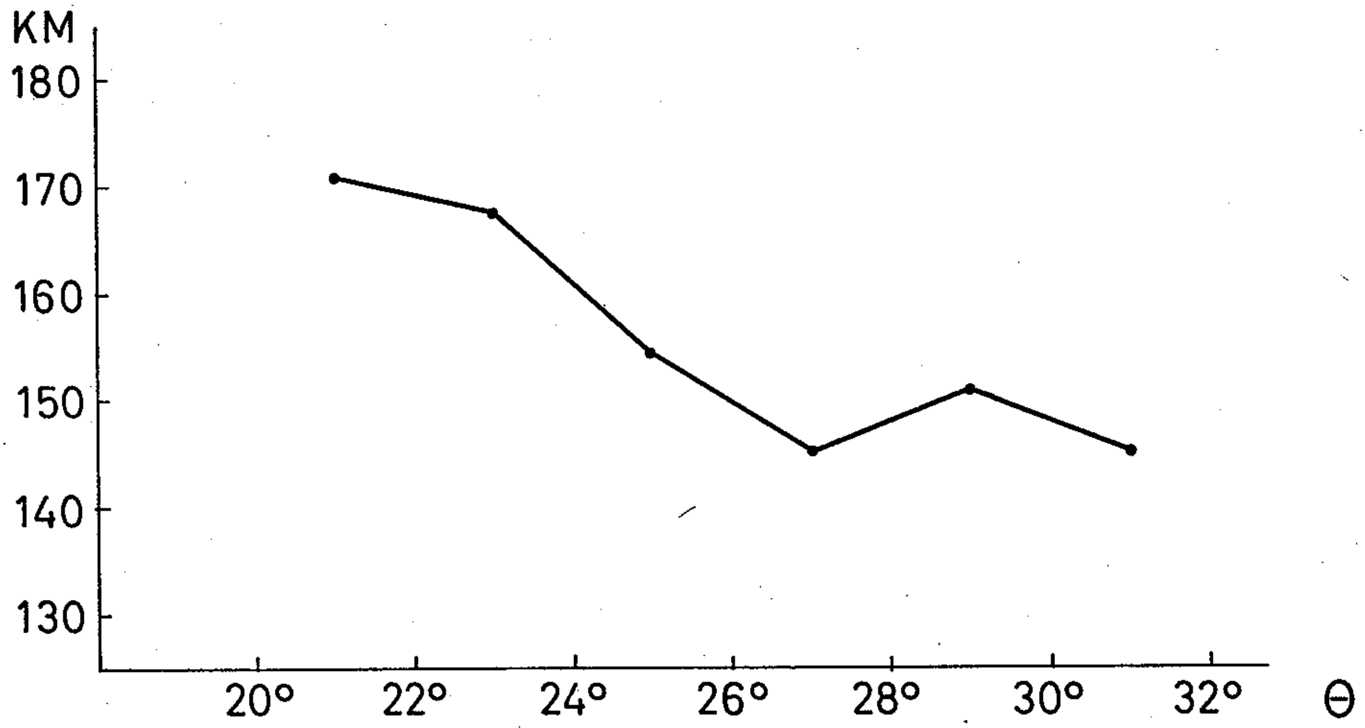


Fig. 4. Average height of all measured auroral points as function of geomagnetic co-latitude θ.

The number of observations of the various auroral forms listed in Sec. 2 relative to the total number of observed auroral points at various geomagnetic co-latitudes are shown in Fig.s 3a and 3b. Even if the distributions of absolute numbers of observations are strongly influenced by the distribution of observing sites, this is probably not the case for the relative occurrences given in Fig. 3, because it is rather unlikely that the observer's selection of auroral forms depended significantly on his position. Therefore, it is felt that significant information may be drawn from these curves, which we shall refer to as relative distribution curves. It should be stressed, however, that the data have not been collected for this particular purpose. Thus, it may be somewhat subject to selection in other criteria. For example, it is not clear whether the homogeneous arcs really contribute less than 10 % of all observed forms, counted at random times. This low percentage could reflect the fact that the heights of these are more difficult to measure accurately because they are more diffuse.

The most striking feature in Fig. 3a is the relatively high frequency of pulsating arcs and draperies at low magnetic latitudes. This is also partly the case with pulsating surfaces. However, the pulsating forms measured by Størmer were necessarily those which pulsations were visual. From recent measurements it appears that pulsations are much more frequent than previously believed, but that the puslations very often are too weak to be noticed through visual observations (cf. Iyengar and Shepherd, 1961; Johansen and Omholt, 1966). It is, therefore, premature to draw conclusions on the occurrence of pulsating aurora, although one may conclude from Størmer's observations that strong pulsations are relatively more frequent for $\theta > 30°$ than for lower values of θ.

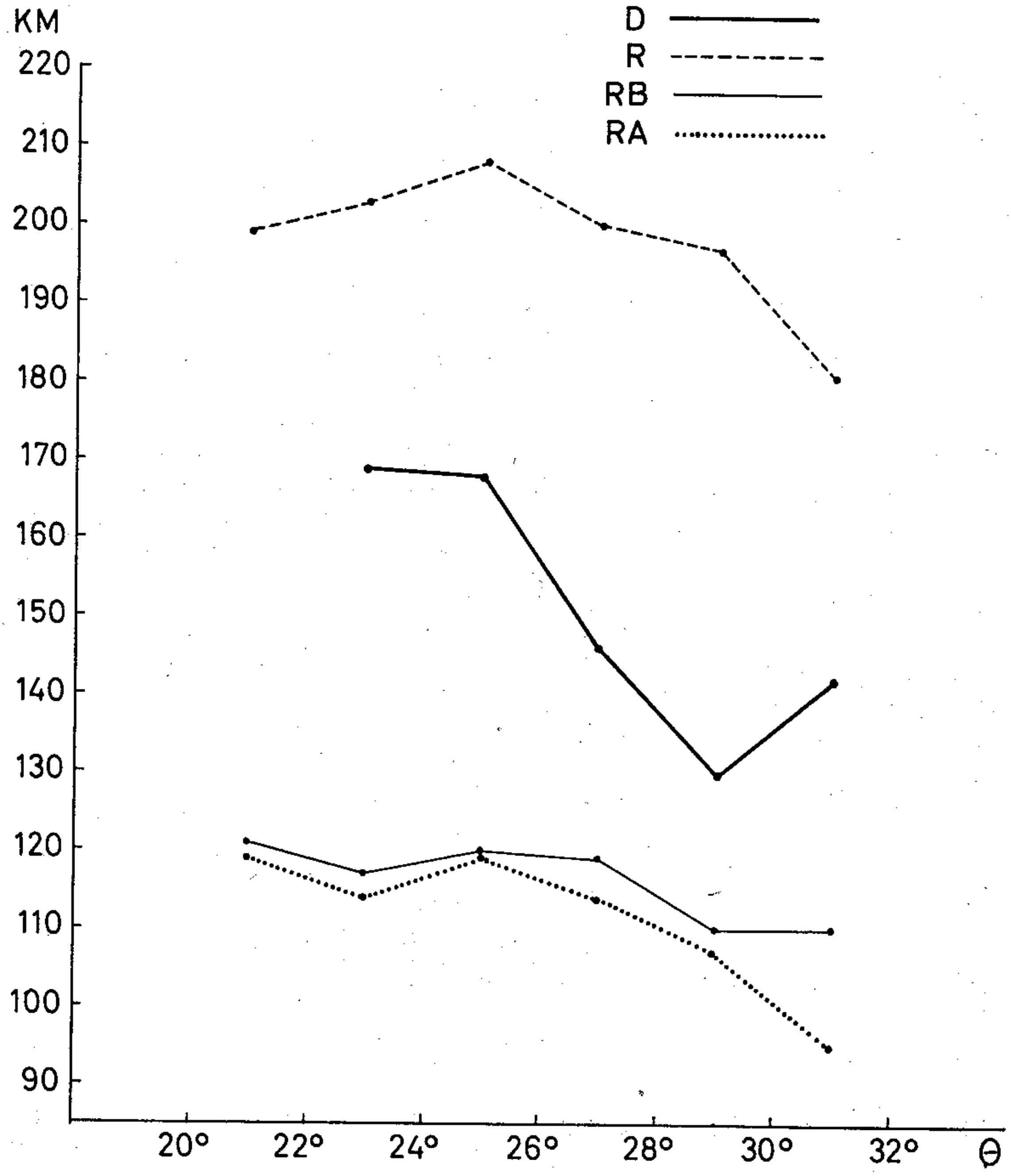


Fig. 5a. Average height of measured points in the different auroral forms, as function of geomagnetic co-latitude θ.

The homogeneous arcs at heights below 150 km show a relative distribution curve which is somewhat similar to those of most other forms. Homogeneous arcs at heights above 150 km seem to be a phenomenon distinctly different from other arcs. This is evident from Fig. 7, Sec. 4. The high arcs occur exclusively at low latitudes, for $\theta > 28°$, where they are measured in much greater numbers than the low ones. Another puzzling

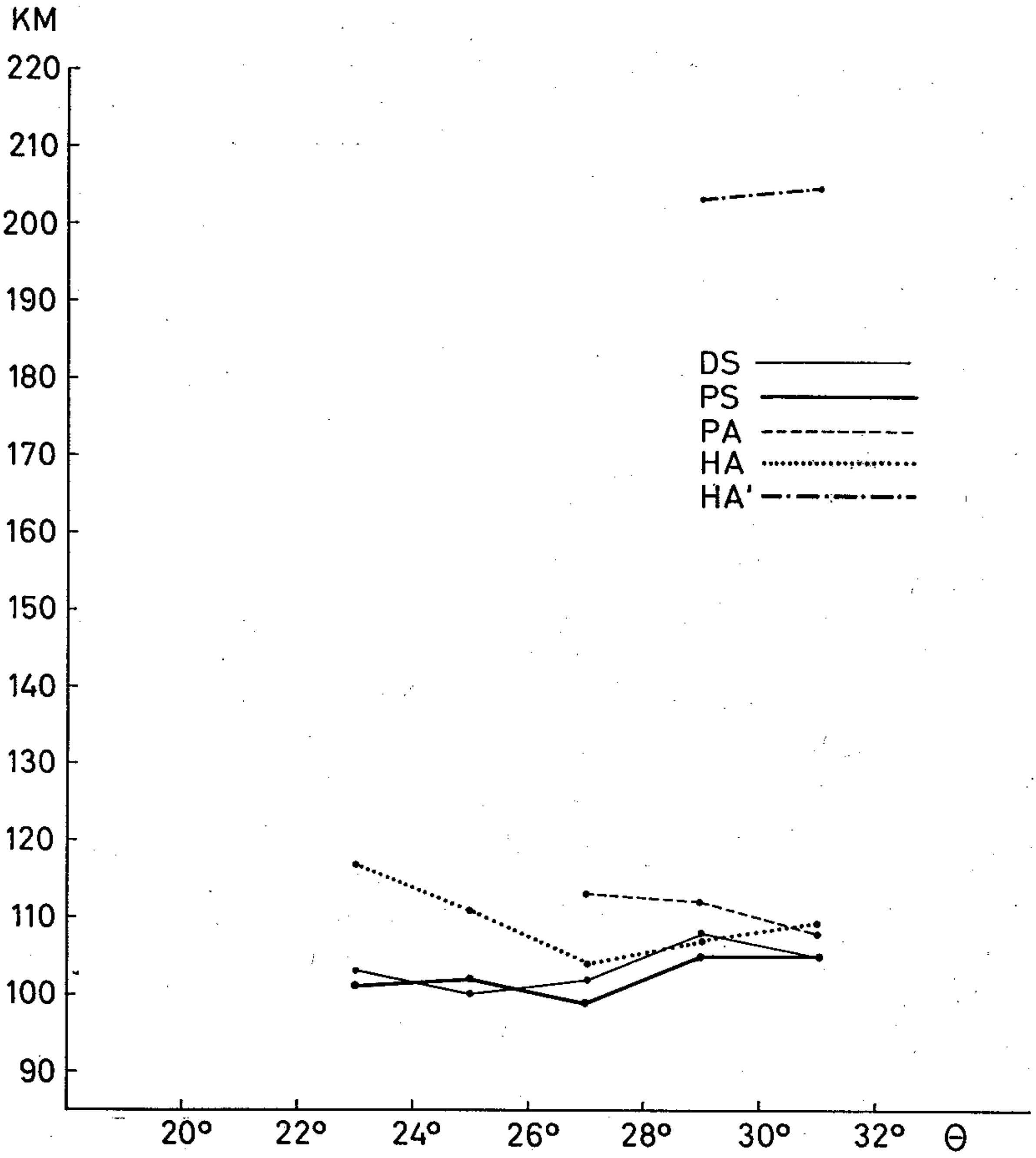


Fig. 5b. Average height of measured points in the different auroral forms, as function of geomagnetic co-latitude θ.

feature with these high arcs is that the largest fraction of observations arises from two single years, 1930 and 1932.

3.3. Variation of the average height with geomagnetic co-latitude. STØRMER (1955) discussed the geomagnetic distribution of the average height for three different auroral forms. In this study, however, he used only a small fraction of all his observations. Using all the 12,232 points measured, the variation of average height with geomagnetic co-latitude was derived. The result, which is shown in Fig. 4, indicates strongly that the height of all observed points, averaged over the given co-latitude intervals, decreases systematically with increasing co-latitude from 20° to 30°.

It should be stressed that the points measured are structures which can be recognized on simultaneous photographs from at least two stations, and that the measurements include points from the higher as well as the lower part of the aurora. Even so, we feel that the observed variation reflects a significant variation in the energy distribution of the auroral primary particles, particularly in the low-energy end of the spectrum.

In Fig.s 5a and 5b the distribution, similarly derived, is shown for the various auroral forms. Sunlit aurorae are included, but this affects only the height distribution of auroral rays (R) significantly. The auroral forms, D, RB and RA (Fig. 5a) show height variations with latitude which are similar to that for the average of all forms, even if the actual heights are very different. The height for rays shows a decrease at small values of θ, which is probably significant.

From Fig. 5b it appears that DS, PS, PA as well as the ordinary HA show little or no significant height variation with latitude. The high arcs, HA′, have an average height of 204 km.

The results given here are in general consistent with those given by Størmer. The selection of the material and the number of points included in the statistics necessarily makes the detailed shape of the curves somewhat different.

4. The height distribution of the measured points as function of geomagnetic co-latitude.

4.1. Introduction. In the preceding section the average height of all measured points as function of geomagnetic co-latitude was presented. In this section a more detailed account of the distribution of heights will be given.

Størmer (1955) gave the distribution of the heights of all auroral points measured from 1911 to 44 for heights between 70 and 1100 km. Also for some particular forms he has plotted on a diagram the measured points at their appropriate heights, thus giving a typographic density impression of the height distribution.

In this section a more complete analysis is presented for the height interval 65 to 300 km. The curves in Fig.s 6 to 14 display the number of measured auroral points per 5 km height interval and per 2° latitude interval. We believe that the actual height distribution as function of geomagnetic latitude may be of special interest for detailed comparison with auroral theories. The homogeneous bands have been excluded here, since the number of measured points are few. It should again be stressed that the points used lie partly at the bottom of the forms and partly higher up.

4.2. The height distribution of all measured points. Fig. 6 shows the height distributions of all the measured auroral points, regardless of auroral form, for the various geomagnetic

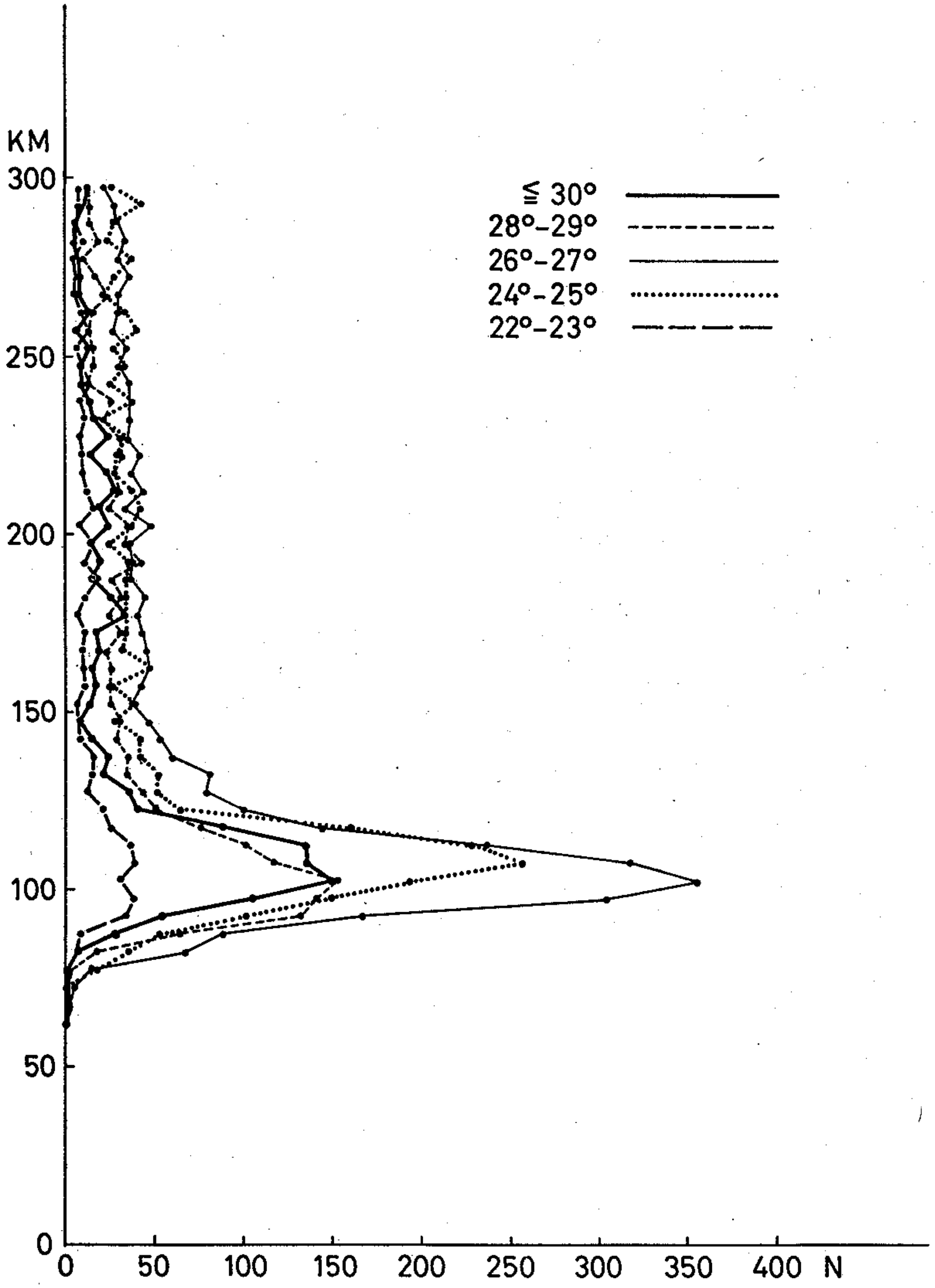


Fig. 6. Height distribution of all measured auroral points for various intervals of geomagnetic co-latitude θ. N is the number of measured points per 5 km height interval and 2 degrees co-latitude interval.

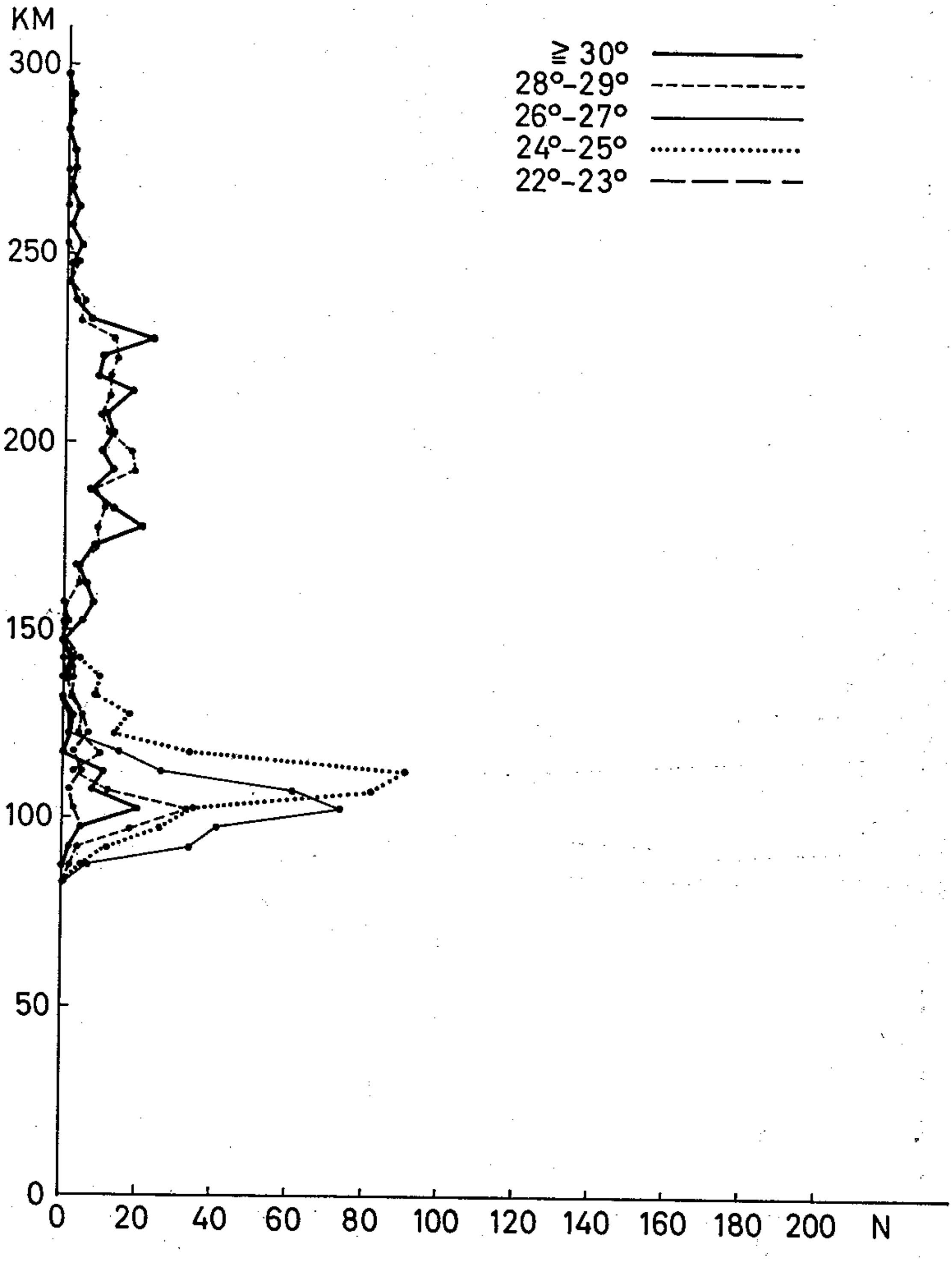


Fig. 7. Height distributions for homogeneous arcs (HA).

Fig.s 7—14. Height distribution of measured auroral points in the different auroral forms for various intervals of geomagnetic co-latitude *θ*. *N* is the number of measured points per 5 km height interval and 2 degrees co-latitude interval.

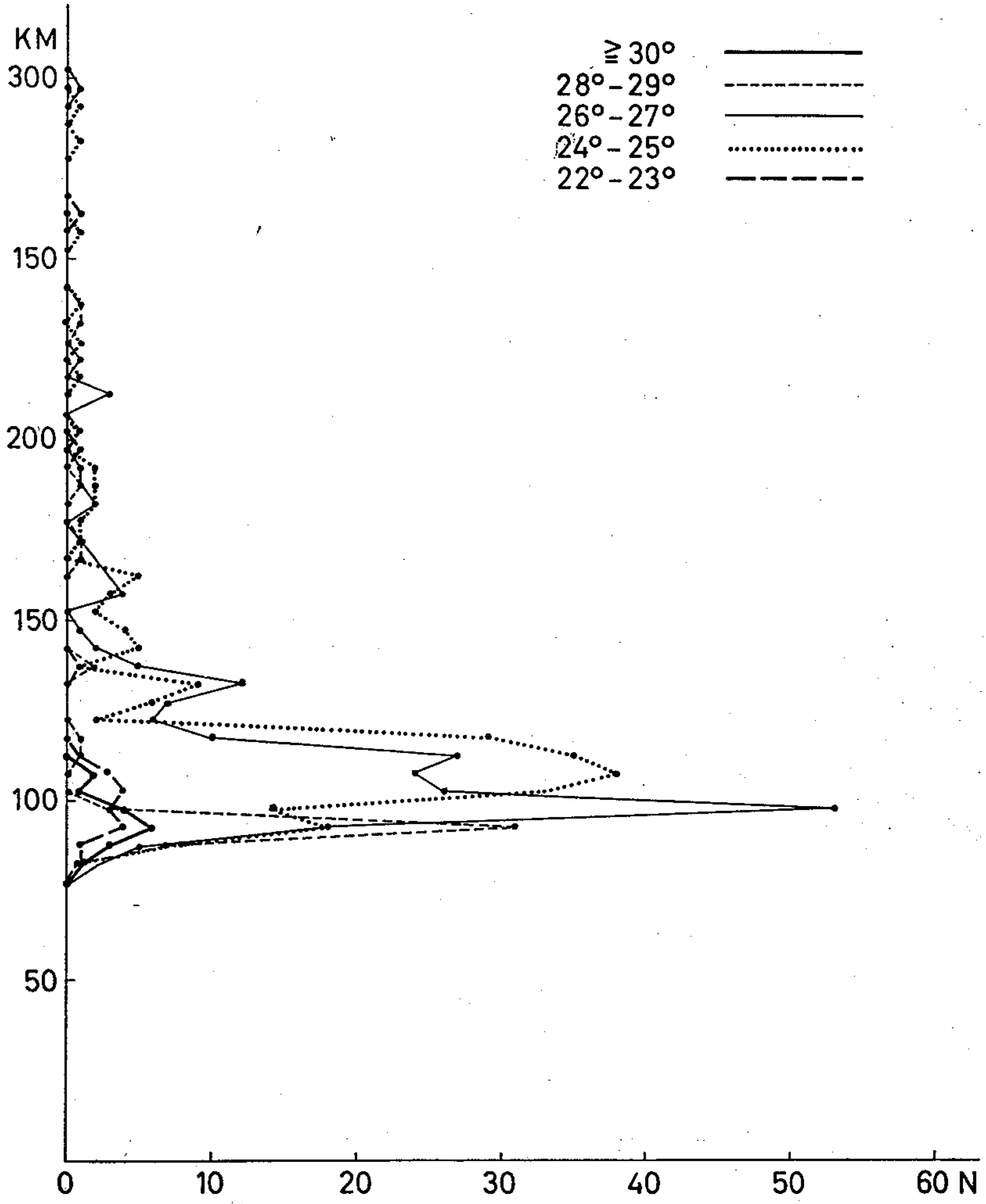


Fig. 8. Height distributions for rayed arcs (RA).

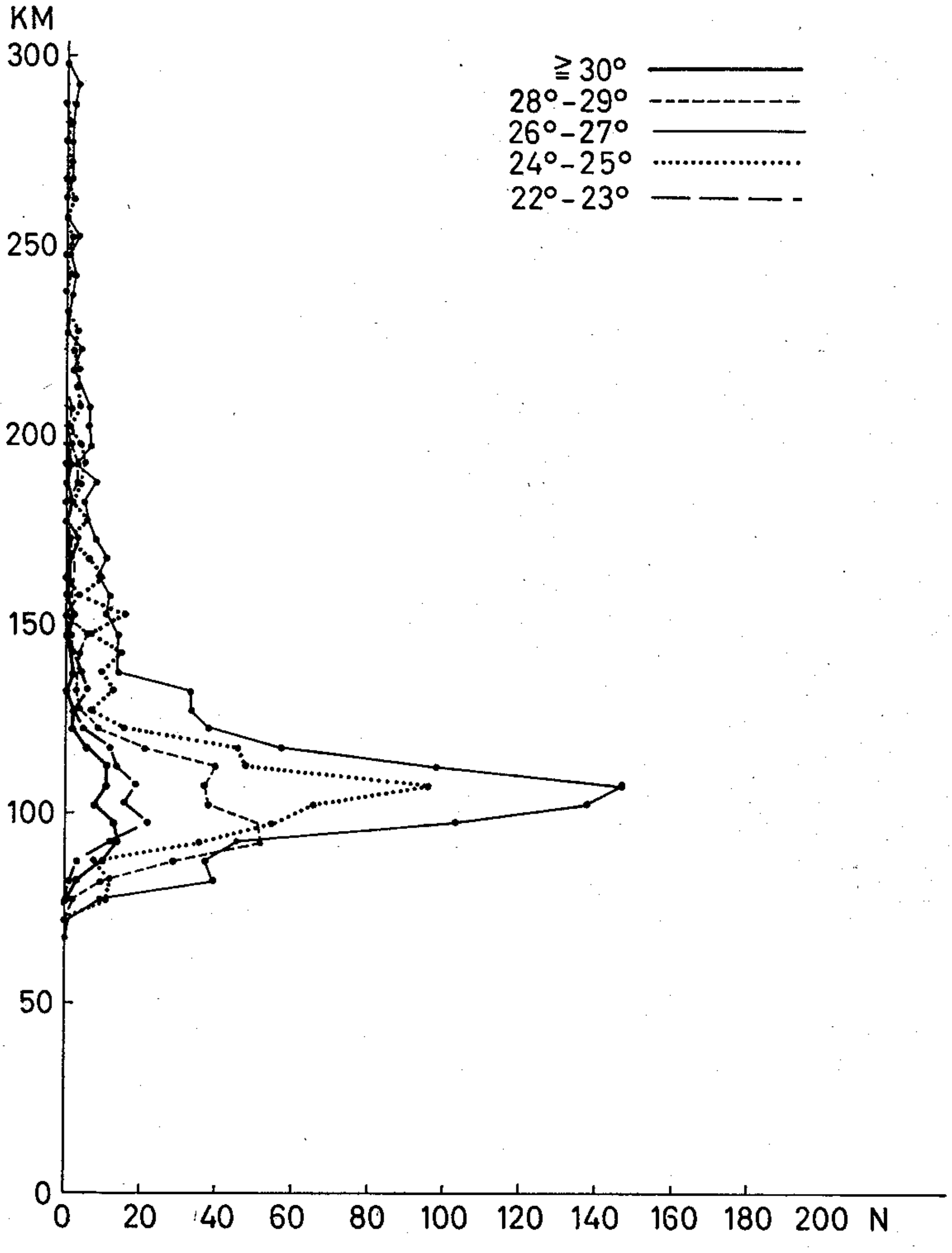


Fig. 9: Height distributions for rayed bands (RB).

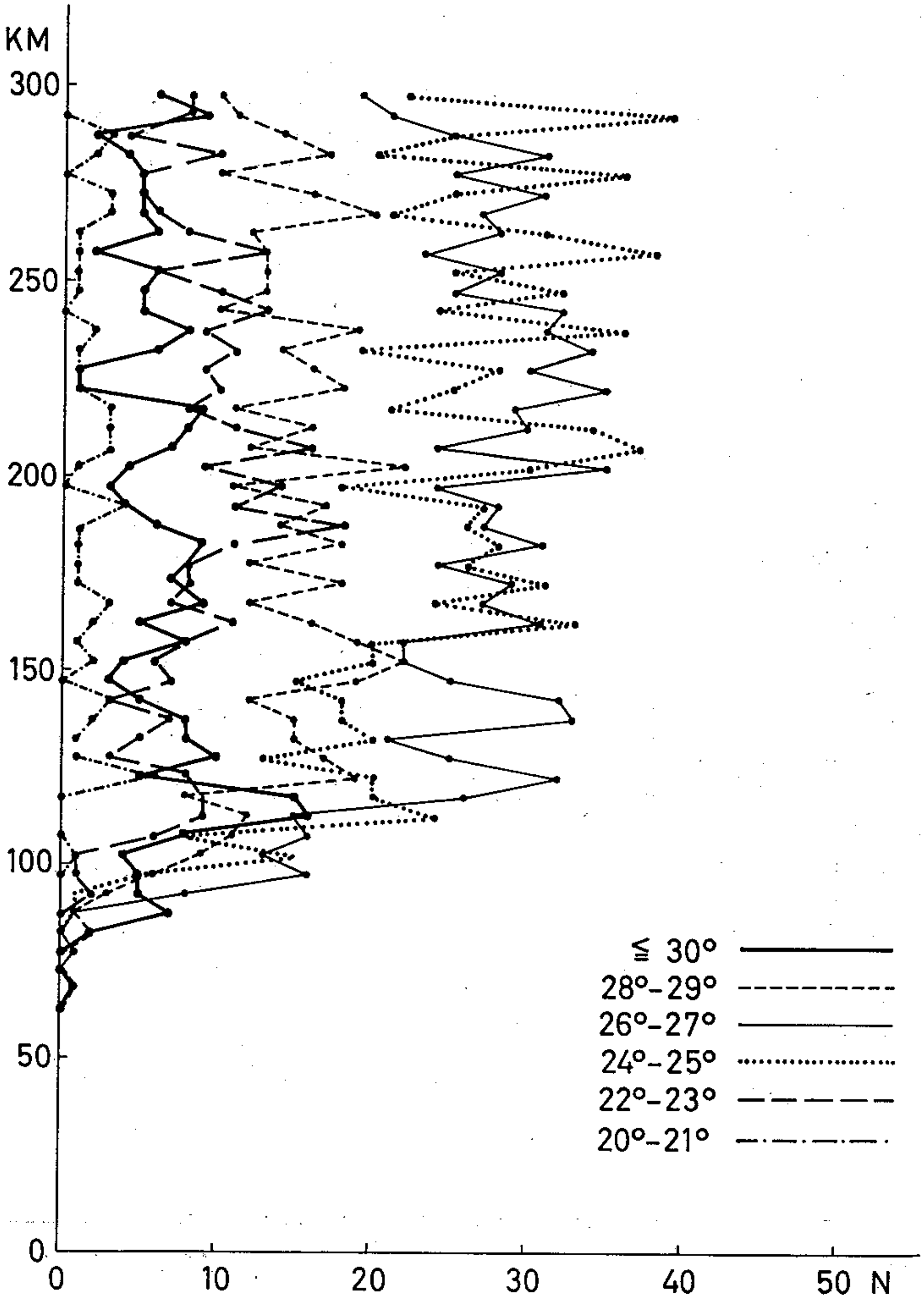


Fig. 10. Height distributions for rays (R).

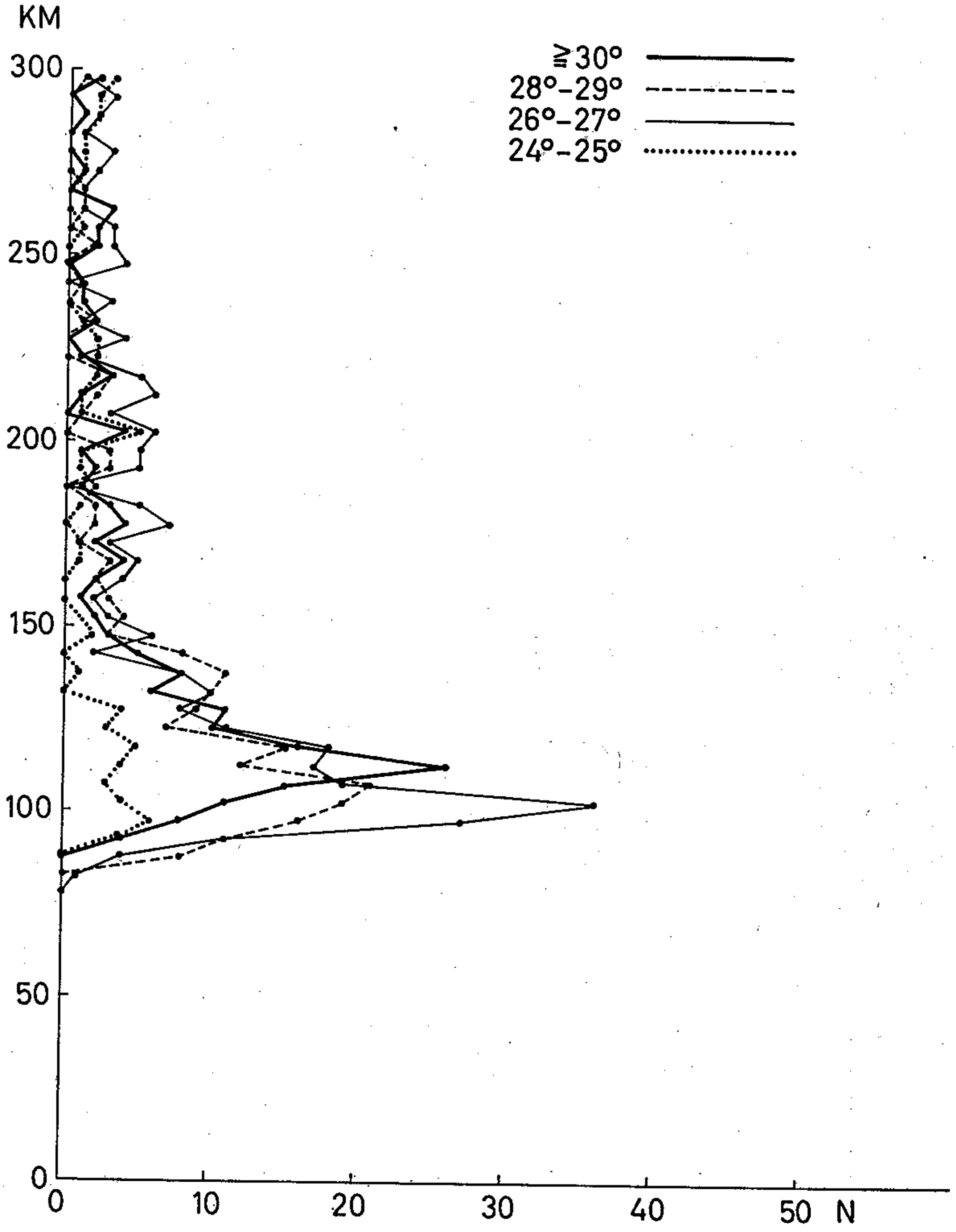


Fig. 11. Height distributions for draperies (D).

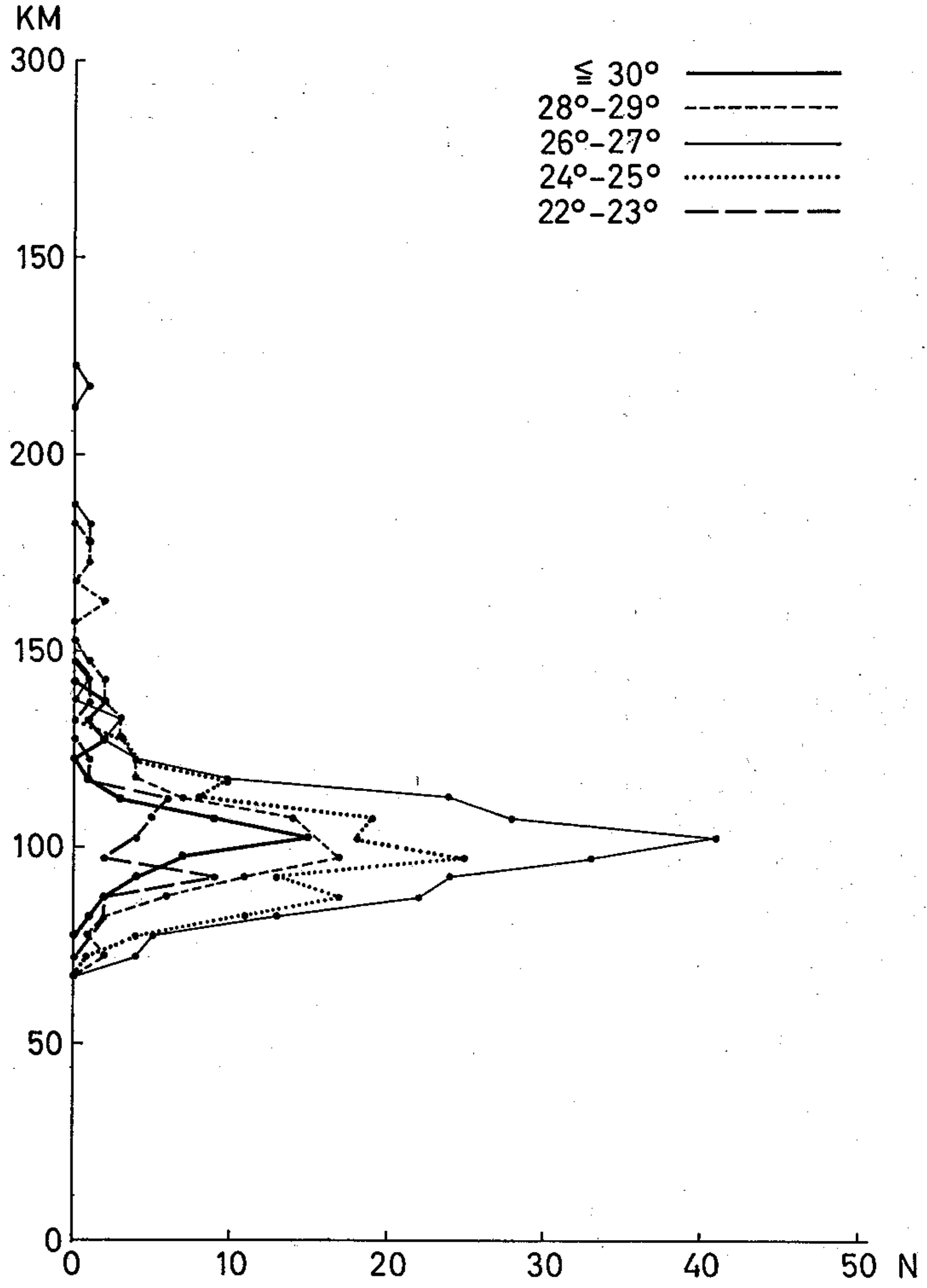


Fig. 12. Height distribution for diffuse surfaces (DS).

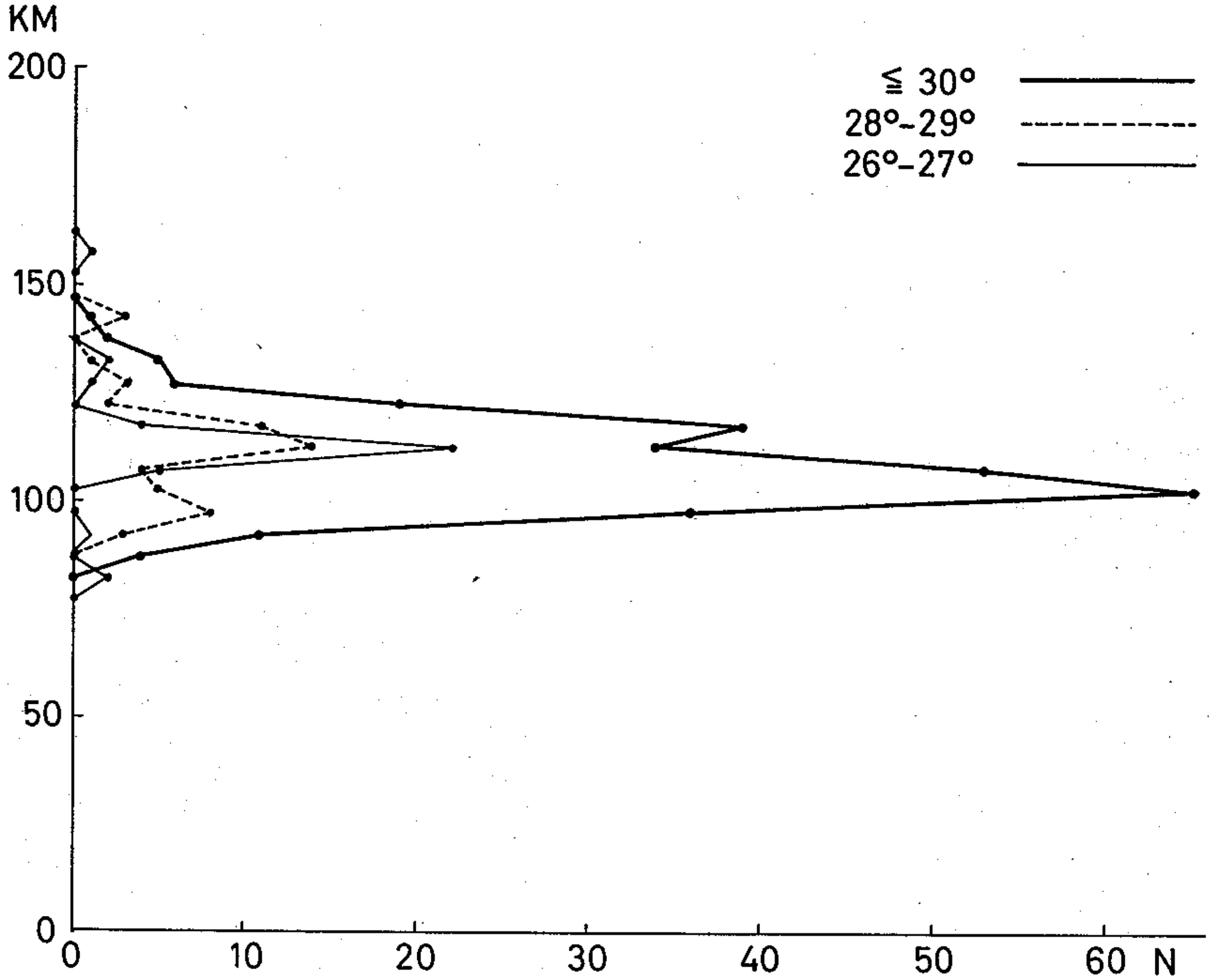


Fig. 13. Height distribution for pulsating arcs. (PA).

latitude ranges. The most characteristic features of these curves may be summarized as follows:

a. For all geomagnetic co-latitude intervals between 30 and 22°, a very pronounced maximum of auroral occurrence is observed between 90 and 120 km.

b. The peak height of maximum occurrence frequency is found between 100 and 110 km for all latitude intervals. Although there is a slight tendency for the peak to vary with latitude, it does not appear to be very significant.

c. The half-width of the height distribution curves seems to vary with latitude, increasing with increasing θ above 24°. This, together with the curve given in Fig. 2, may indicate that the average energy as well as the energy spread of the primary particles is larger at high values of θ than closer to the auroral zone.

4.3. The height distribution of the various auroral forms. In Fig.s 7—14 are shown the height distributions within the various latitude ranges for the auroral forms HA, RA, RB, R, D, DS, PA and PS, respectively.

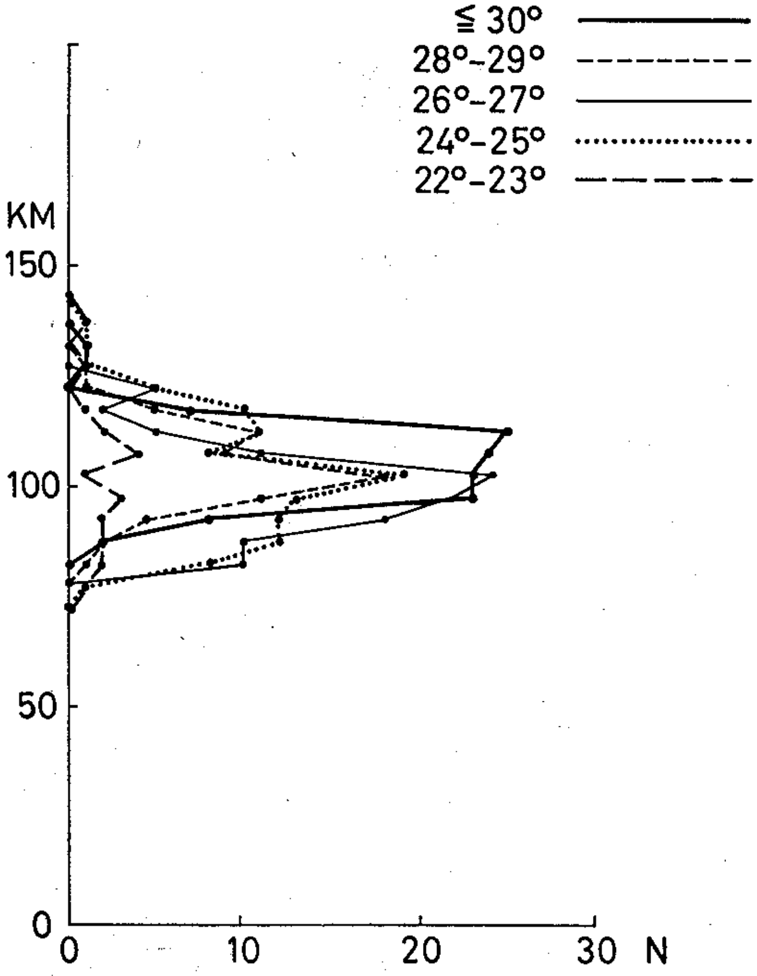


Fig. 14. Height distribution for pulsating surfaces (PS).

Here we shall give only some brief comments to the figures in the order in which they appear.

Fig. 7, homogeneous arcs (*HA*): Størmer (1955) discussed in some detail the height distribution of auroral arcs, but no detailed information concerning the latitude variation of heights was derived. He remarks that "very high narrow arcs generally appear isolated near the zenith in Oslo". This is easily verified by these curves, which show that high arcs (h > 150 km) appear exclusively for $\theta > 28°$, and there they even seem to be the dominating form. It is striking that homogeneous arcs hardly ever occur at heights around 150 km.

This minimum in the curves at 150 km strongly suggests that two distinctly different types of arcs occur, the high ones and the low ones. For the low arcs there is a shift in the peak towards lower heights with increasing θ. Thus, it seems justified to extend Størmer's conclusion regarding homogeneous arcs at low geomagnetic latitudes, ($\theta > 28°$) and state that these are either observed at markedly greater altitudes or at lower altitudes than what is the average for higher geomagnetic latitudes ($\theta < 28°$).

Fig. 8, rayed arcs (*RA*): Rayed arcs also exhibited a marked decrease in the distribution peak with increasing θ. Contrary to the curve for all forms in Fig. 6, the width of the distribution curve seems to decrease with increasing θ.

Fig. 9, rayed bands (*RB*): These show distribution curves which are very similar to those for all forms given in Fig. 6.

Fig. 10, rays (*R*): As expected, no pronounced height maxima are found. The figure gives a slight indication that rays may be observed relatively more frequently at very low heights at lower geomagnetic latitudes ($\theta > 30°$) than at higher latitudes.

Fig. 11, draperies (*D*): For these there seems to occur a shift in the peak of the distribution curves which is opposite to that for homogeneous arcs and rayed arcs, e.g., there is an increase in the height of the peak with increasing θ.

Fig. 12, diffuse and cloudlike aurorae (DS) : Aurorae between 150 and 200 kms are very rare, and the peaks in the distribution curves as well as the average height (cf. Fig. 5b) are low. There is no pronounced shift in the peak with θ. However, this analysis does not include auroras above 300 km, and it turns out from the data available that this kind of aurora actually does occur at great heights.

Fig. 13, pulsating arcs (PA) : Pulsating arcs are very rare above 150 km. There is some shift in the peak of the distribution curve, decreasing in height with increasing θ.

Fig. 14, pulsating surfaces (PS) : Also these are particularly low-lying forms, with their average height close to 100 km (cf. Fig. 5b). However, they seem to be distributed over a broader height interval than pulsating arcs. Størmer (1955) has given a closer description of some of these auroras, having diffuse contours and often resembling clouds. He used, however, only a fraction of his observations (up to the year 1922) in his own statistical analysis.

5. The height of the lower border as function of local time. For this study we have used only the auroral points that Størmer stated refer to the lower border or the base of the aurora. In Fig.s 15a and b the average values of these heights, for each whole hour, are given for all forms for which more than about a hundred measurements

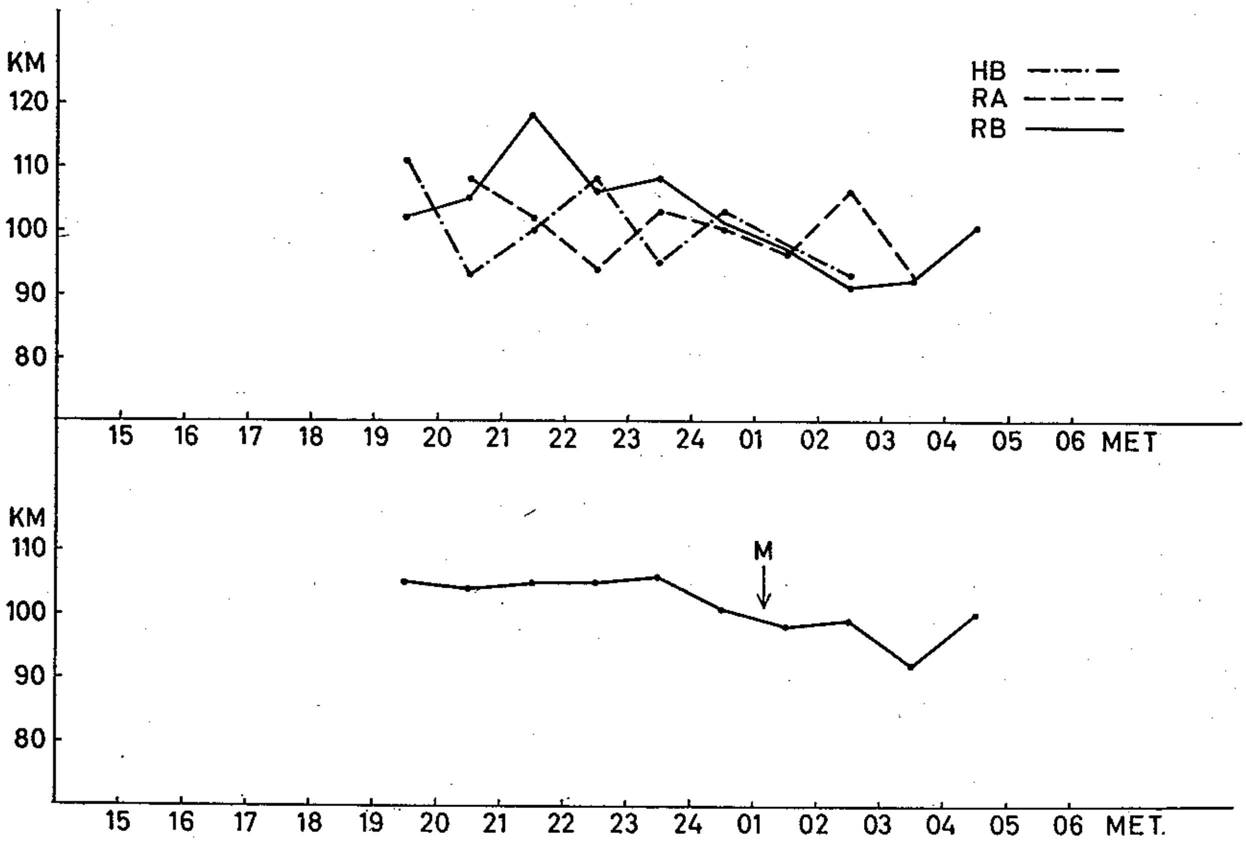


Fig. 15a. Average height of measured lower limit for some auroral forms.
Curve M is the average curve for homogeneous bands (HB), rayed arcs (RA) and rayed bands (RB), the curve for which are also drawn separately.

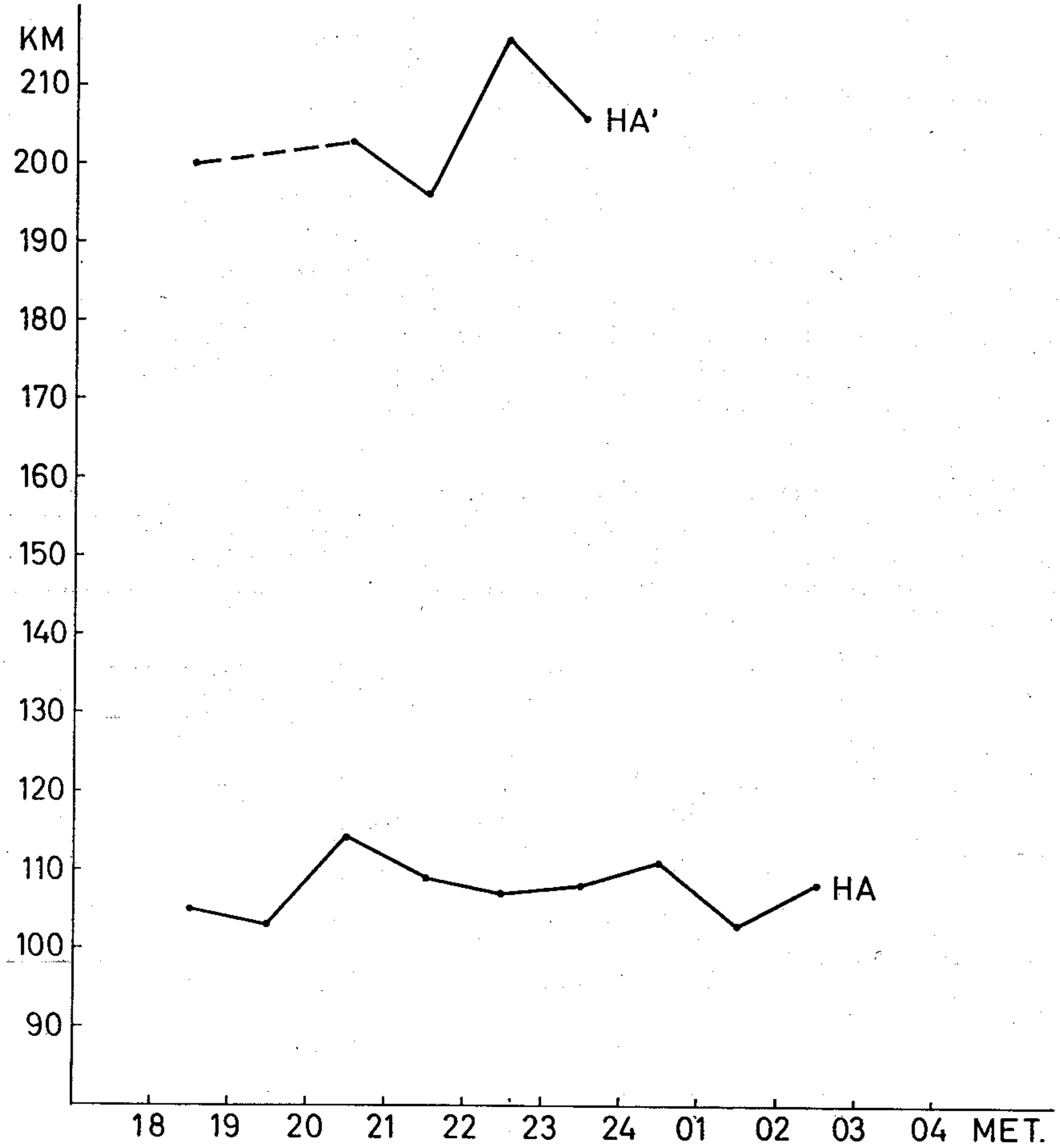


Fig. 15b. Average height of measured lower limit for homogeneous arcs.
The curve HA refers to arcs below 150 km, while HA' represents arcs above 150 km.

were available. These are the homogeneous arcs (HA), homogeneous bands (HB), rayed arcs (RA) and rayed bands (RB).

As seen from Fig. 15a there is no large variation in the height of the lower border of HB, RA and RB. To increase the significance, we have also plotted the mean curve for these three forms. This shows a fairly constant height around 105 km until local midnight, followed by a slight drop, to well below 100 km. The corresponding change in the necessary energy of the primary electrons is significant; it amounts to at least a factor 2.

For the homogeneous arcs below 150 km (HA) no drastic changes occur with time (Fig. 15b). It appears that these are scarce in the early morning hours. The high arcs are observed exclusively before midnight, but there is no significant change in their heights with time. It is peculiar though, that no such arcs are observed in the time interval 19—20 hr local time, whereas a few are observed before 19 hr and many after 20 hr.

6. Seasonal variations in the frequency and height of aurora. In this section we shall present a study of seasonal variations, based on all the measured points. Again it should be emphasized that the material was not originally intended for studies of auroral occurrence frequencies so that the distribution may be somewhat influenced by the circumstances under which the observations were made. For example, the low number of auroral points observed in the month of February seems rather peculiar, but on the other hand we find no particular reason why February should be so badly represented through more than 20 full years of observations.

Fig. 16 shows the number of measured auroral points per month in the dark atmosphere, as well as the average height of these points for each month. The seasonal variation in the occurrence of aurora is in general agreement with other observations (CHAMBERLAIN, 1961), except for the peculiar low number for February, for which no explanation is readily available.

There seems to be a significant tendency for the auroral points to lie at greater heights in the fall months than during the rest of the year. This may be due to systematic changes in the primary particle spectrum, but one may also speculate that it reflects seasonal changes in the atmospheric structure. In this connection one must remember that the relatively low number of auroras at heights above 200 km may dominate the variations in average heights. Again, if other evidence favours a closer inspection of the data from one or the other point of view, this should be done with the particular problem in mind.

The corresponding results for sunlit aurora are given in Fig. 17. For these, a significant difference is apparent both in occurrence and height between spring and autumn. The average height for the months November through February are certainly of low significance, because of the very few sunlit aurorae observed in this period. The height difference between spring and autumn is about the same as for aurorae in the dark (≈ 50 km), whereas the heights themselves are about 200 km greater. In this connection it should be mentioned that 92 per cent of all measured sunlit aurorae are rays, which thus constitue the dominating form of sunlit aurora.

7. Occurrence and average height of the measured auroral points between 1917 and 1942 averaged over the sunspot cycle.

7.1. Introduction. As observed long time ago (cf. e.g. STØRMER, 1955), the occurrence of visual aurora has an eleven year periodicity like the sunspot numbers. However, no

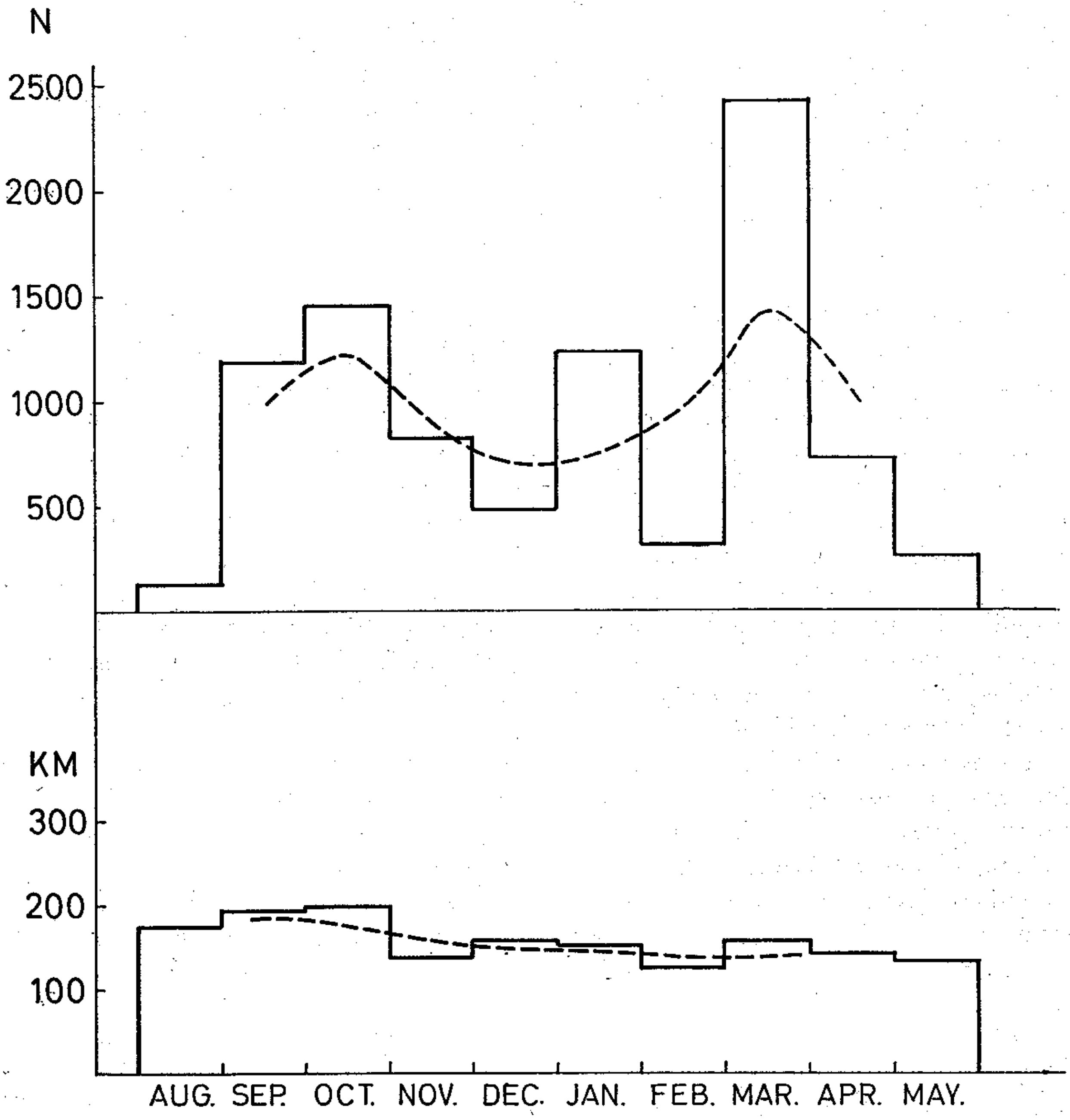


Fig. 16. The number of observed auroral points (N) in the shadow and their average height in km for the months August through May. The smoothed curves give the value of $Y_s = \frac{1}{4}Y_{-1} + \frac{1}{2}Y_0 + \frac{1}{4}Y_{+1}$.

detailed investigation has been made to determine whether the different auroral forms show the same periodicity. It should also be pointed out that there is a systematic tendency for the maximum occurrence of aurora to follow the sunspot peak by a year or two.

Although more than 12,000 auroral points have been measured during the 26 years period, there is not enough data to give a significant picture of the year to year variation of the auroral activity during the whole period. For this reason, all data have been used

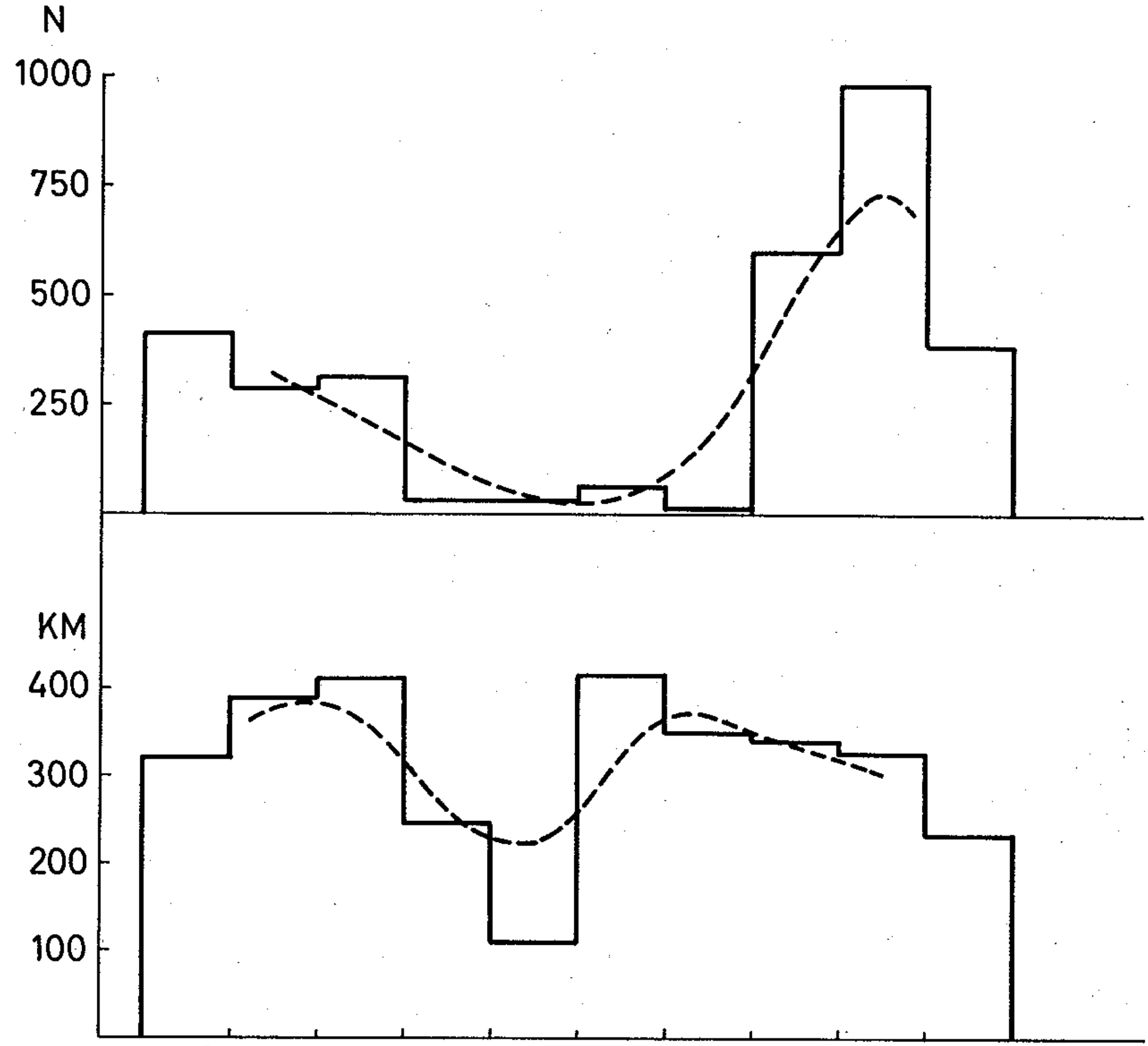


Fig. 17. The number of observed auroral points (N) in the sunlight and their average height in km for the months August through May. The smoothed curves give the value of $Y_s = \frac{1}{4}Y_{-1} + \frac{1}{2}Y_0 + \frac{1}{4}Y_{+1}$.

to draw average sunspot cycle curves. By this method some of the irregularities in this data collection (i.e. yearly variations in hours of observations, number of observing stations and meteorological conditions etc.) have been somewhat smoothed out.

7.2. Variation in occurrence and average height of aurorae in shadow during the 11 year sunspot cycle. As the sunlit aurora will be discussed separately in Section 7.3, all the curves and figures given in this section refer to aurora in shadow.

The occurrence of all measured points averaged over one 11 year sunspot cycle is shown in Fig. 18, Curve A, while Curve B shows the relative sunspot numbers averaged

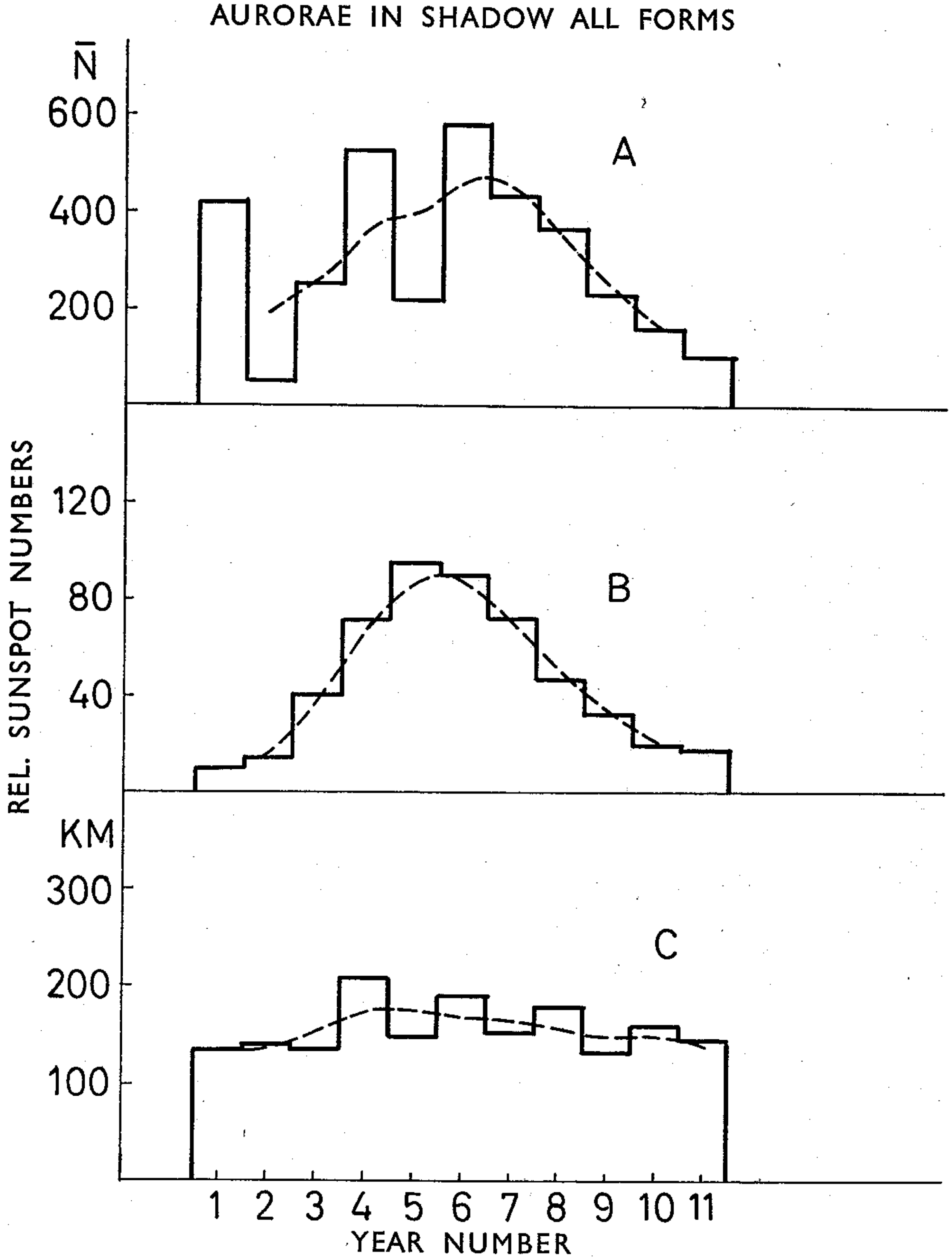


Fig. 18. The average occurrence of aurora (A), sunspot number (B) and average auroral heights (C) for each year in the solar cycle. Sunlit aurorae are excluded. The smoothed curves are derived in the same way as on Fig.s 16 and 17.

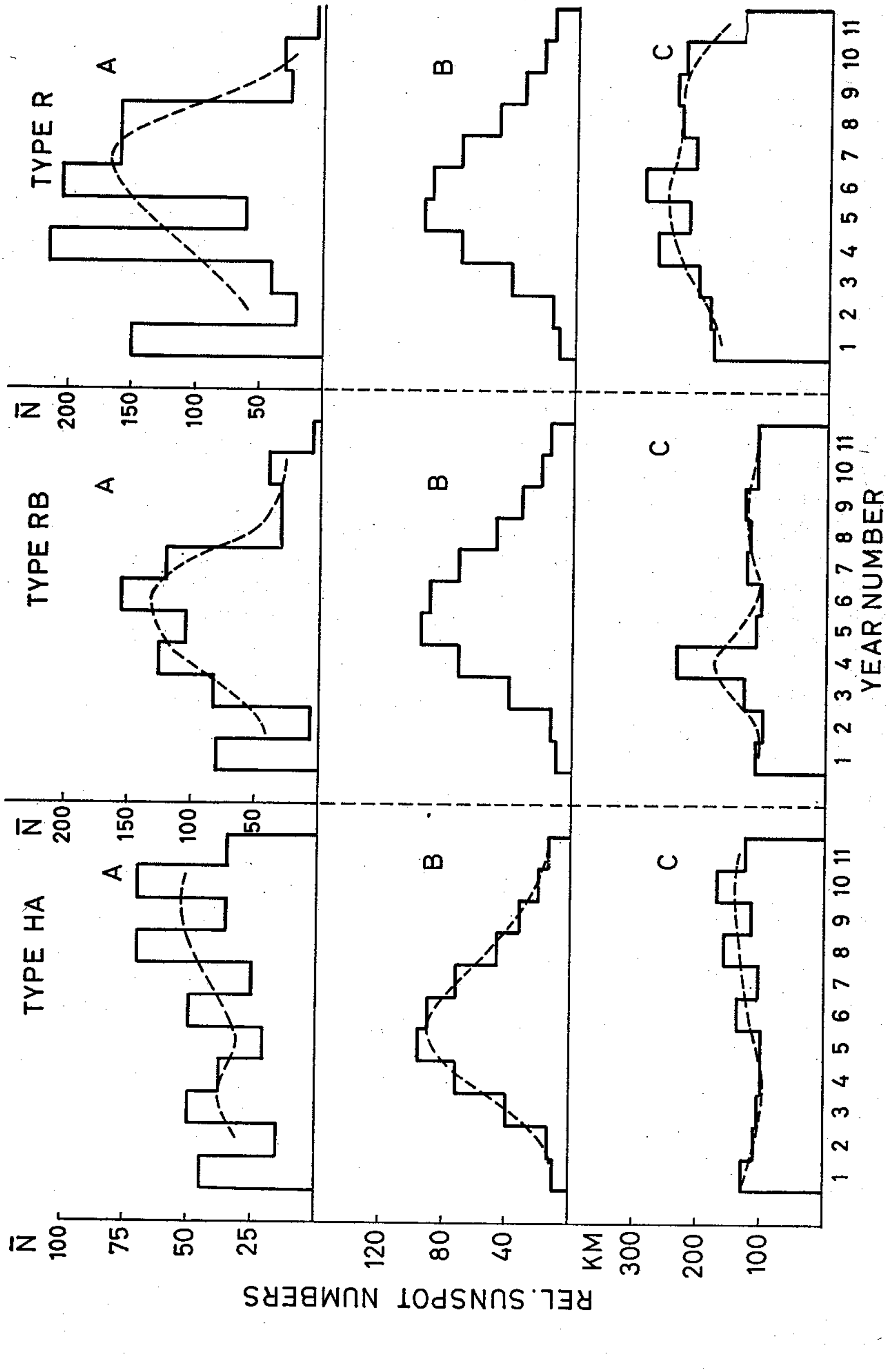


Fig. 19a, b and c: The average occurrences (A), average sunspot number (B) and average heights (C) for respectively homogeneous arcs (HA), rayed bands (RB) and rays (R) for each year in the solar cycle. The smoothed curves are derived in the same way as on Fig.s 16 and 17.

over the same period. By comparing these two curves, a high correlation between auroral occurrence and the solar activity is found. Furthermore, the auroral activity reaches its maximum one year after the sunspot maximum. (The peak in the first year of the cycle is due to the extremely high observing-activity during the second polar year, 1932/33. This peak is also found in the yearly variation of particular auroral forms, as shown in Fig.s 19 and 20.)

The average auroral heights for the same 11 year period is drawn in Fig. 18, Curve C. As this curve shows the average altitudes vary from more than 200 km down to 120 km. The significance of the apparent variation with the sunspot cycle, is uncertain, but it appears as though the average altitudes are somewhat higher during years of high solar activity.

In Fig.s 19a, b and c, the three different auroral forms HA, RB and R have been plotted in the same way. While the occurrence of RB and R is rather closely correlated with the 11 year sunspot cycle, this is not the case for HA. (As the statistical material is relatively small, some irregularities are seen for R and RB). Homogeneous arcs, on the other hand, show no correlation with the sunspot activity. In fact, HA's are probably observed more often during years of low solar activity.

It may be pointed out that the unusual high arcs discussed in Sections 4 and 5, were observed during relatively strong local magnetic disturbances.

The average 11 year height curves, which are also seen in Fig. 19, show some variations, but there is no correlation with the solar activity. (As pointed out earlier, these peaks are probably due to observations and selection of points). For homogeneous arcs the average heights seem to be somewhat lower during solar maximum than during years of low solar activity, but it is not certain if this change in height is significant. As already seen from Fig. 5a, the average heights of rays are more than 100 km greater than for HA and RB, for example.

7.3. Variation in occurrence and average height of sunlit aurora during the 11 years sunspot cycle. The average 11 year sunspot cycle curve for 3064 measured sunlit auroral points is shown in Fig. 20, Curve A, while curve B shows the variation in sunspot number. By comparing these two curves, it is found that sunlit aurora occurs mostly during years of high solar activity. The correlation coefficient is not too high, but this may be due to:

1) a realtively small statistical material, and
2) irregularities in observations. (The peak during the first year of the cycle is due to the extremely high observing activity during the second polar year).

The average 11 year height curves of sunlit aurora is shown in Fig. 20, Curve C. Also for sunlit aurora no correlation between the height variations and the solar activity is found. It should be pointed out that the average height of all 3064 points is 330 km. This means that the average height of sunlit aurora is approximately 200 km higher than for aurora in shadow.

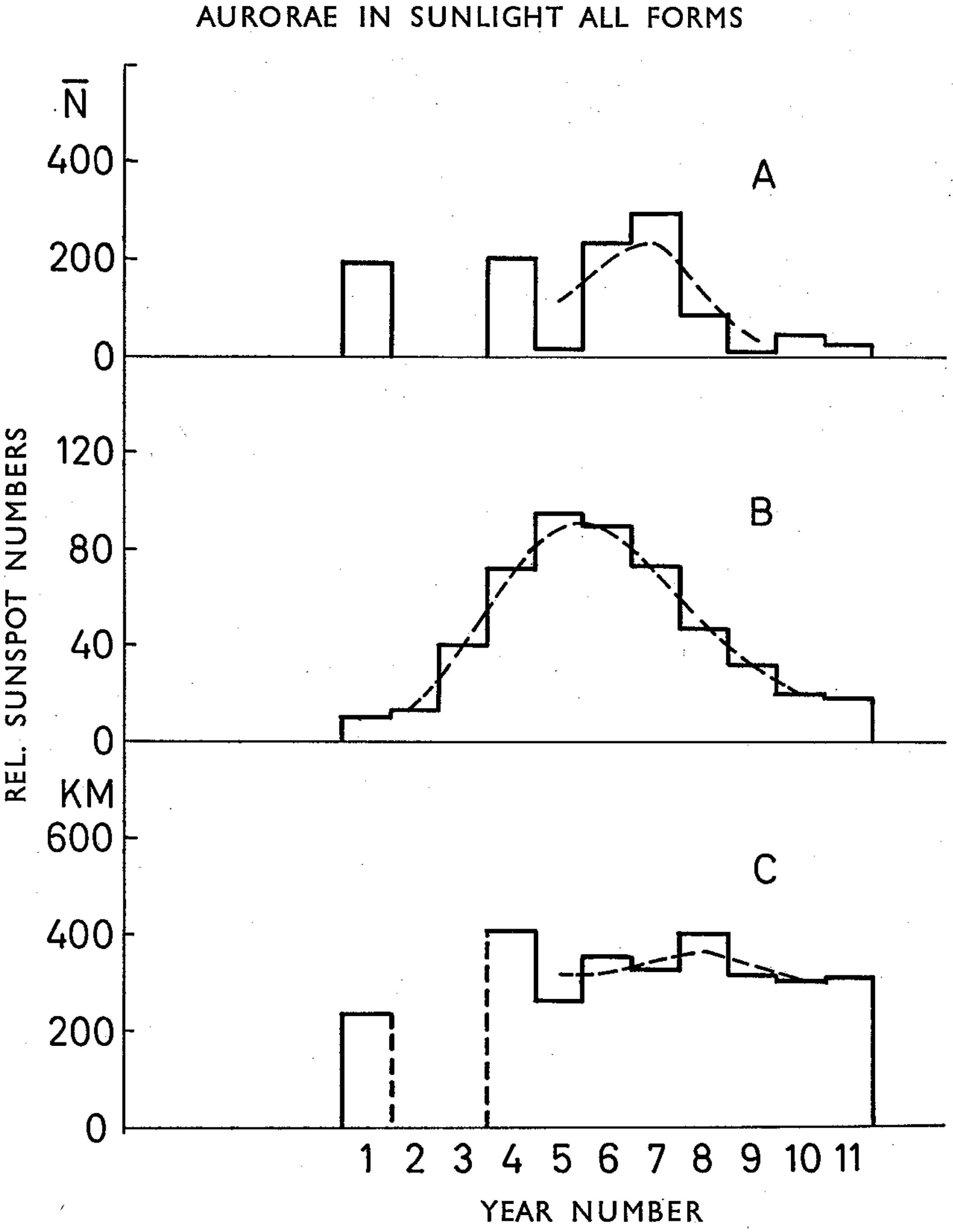


Fig. 20. The average occurrence (A), average sunspot number (B) and average height (C) for sunlit aurora, for each year in the solar cycle. The smoothed curves are derived in the same way as on Fig.s 16 and 17.

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