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STATISTICAL BEHAVIOUR OF SPORADIC E AT SODANKYLÄ 1958–1971

by

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Abstract

Data on sporadic E obtained at Sodankylä from an ionosonde between 1958 and 1971 have been analysed, and its behaviour has been studied in detail.

Maps are presented depicting the diurnal and seasonal variations, during the period of the study, in the occurrence of all the Sporadic E parameters as defined in the U.R.S.I. Ionogram Handbook. This study reveals that both auroral and middle-latitude types of Sporadic E behaviour can be seen at Sodankylä. Few of the Sporadic E parameters studied here show any definite correlation with sunspot activity. On the other hand, most of them display powerful long-term variations quite unconnected with sunspot cycle.

1. *Introduction*

Since the IGY, Sporadic E (Es) has been classified into a variety of types according to its shape on the ionogram (Annals of the International Geophysical Year, Vol. III, part 1 [1]). Under this classification the types of Es observed at Sodankylä are:

- Esl a horizontal Es trace below the normal E trace. (l for low)
- Esf a thin horizontal Es trace when no normal E trace is present. (f for flat)
- Esc an Es trace starting at the high frequency end of a normal E trace and forming an almost symmetrical cusp near the critical frequency of the E layer.(c for cusp)

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Esh An Es trace showing a discontinuity in height with the normal E layer trace at or above foE. The cusp is not symmetrical, the low frequency end of the Es trace lying clearly above the high frequency end of the normal E layer. (h for high)

Esa all types of very diffuse Es traces are combined in auroral type Es. (a for auroral)

Esr an Es trace showing group retardation at the high frequency end. (r for retardation)

Ess a diffuse Es trace which rises steadily with frequency and usually emerges from another type Es trace. (s for slant)

Of these, the l, f, c and h types of Es are found mainly on the ionograms at middle latitudes, where Es phenomena occur more often by day than at night, with a distinct and strong summer maximum in their seasonal variation. On the other hand, the a, r and s types of Es occur only in the auroral zone, where Es is more a night-time phenomenon with very little seasonal variation (THOMAS and SMITH, [5]). At Sodankylä, as elsewhere, the occurrence of the a, r and s types of Es, is clearly linked with magnetic activity (OKSMAN, [2], [3], [4]).

Ionospheric observations have been made at the Geophysical Observatory, Sodankylä, since August, 1957, by taking vertical incidence ionograms. This paper is a statistical study of the occurrence of the various types of Es observed on the ionograms at Sodankylä since 1958.

All the ionograms taken at Sodankylä during the period of the present study were scaled by the same person under the supervision of a physicist. This makes it possible to study the long-term variations of Es at Sodankylä. On the other hand our data are not comparable with those from other stations, owing to the automatic gain control used in our ionosonde.

In the present study the incidence of a parameter was first taken from monthly bulletins. No attempt has been made to correct the effect of absorption on the parameter under study because it is felt that such a correction would be inaccurate. If necessary, this effect can be estimated approximately by comparing the variations of the parameter and absorption. All the data have been smoothed using a two dimensional running average with a triangular window. This means that every point was computed from nine points over three hours and three months. It is felt to be a rather good way of processing the data available for the 14 years because it smoothes out the scatter and permits meaningful study of the long-term variations. At the same time the smoothing is not excessive for a study of diurnal and seasonal variations. The maps were drawn using manual linear interpolation between data points. The contours were drawn in steps of 10 %, and 5 %. An 0 % contour represents the occurrence of parameter with a frequency less than 1 % of the time.

2. *Presentation of the data*

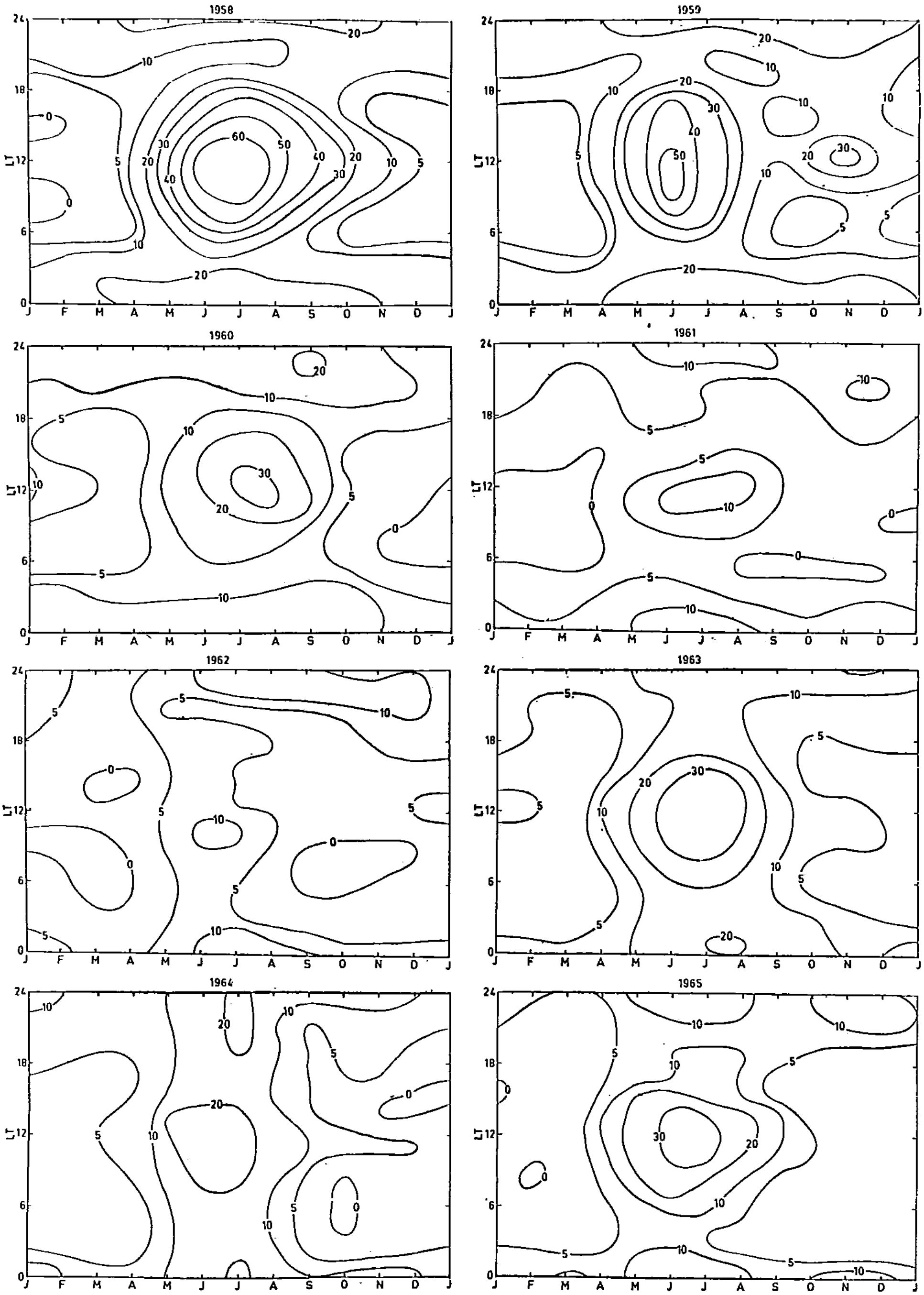
In Fig. 1 are the maps showing percentage of time in which foEs > 5 MHz. It indicates that Es occurs mostly by day and in summer months, its behaviour hardly varied during all the years studied here. However, foEs was greater than 5 MHz most often during the first three years of the studied period. We have also made similar maps for foEs > 3 MHz, but they are not presented here because there are more sources of error when the limiting values are low. The results, however, show pronounced summer maxima during daytime hours except in the first three years of the period when there were no clear diurnal or seasonal variations.

Fig. 2 shows percentage of time in which fbEs > 4 MHz, including total blanketing. Similar maps for total blanketing alone are presented in Fig. 3. Figs. 2 and 3 show that blanketing Es is invariably a nighttime phenomenon with little seasonal variation. The winter maxima are partly due to foF2, which is minimum during the evening hours in winter, thus increasing the probability of total blanketing. In daytime total blanketing was so rare that its probability at 1300 LT for example was less than once a year. This very striking contrast between foEs and fbEs is due to differences between the nighttime and daytime phenomena and to the sensitivity level of the sounding system. Blanketing itself is by no means limited to the evening and night hours; it only appears to be so if high limiting values are used. In similar maps for fbEs > 2 MHz, the summer maxima in the daytime and evening hours increased except during the first three years of the period studied, when there was no clear seasonal variation but there was a very strong nighttime maximum in 1958. Owing to the low limiting value and for reasons described later in this paper, the reliability of these maps is so poor that they are omitted from this report.

Fig. 4 gives percentage of time in which 'a' type Es was seen at Sodankylä as a function of local time and month. From these maps it can be seen that the occurrence of 'a' type Es is essentially a nighttime phenomenon, rising to a maximum during the winter months. The frequency of 'a' type Es at Sodankylä decreased steadily from 1958 to 1966 and then slightly increased.

In Fig. 5 similar maps for retardation Es are presented. Like 'a' type Es, 'r' at Sodankylä is essentially a night time phenomenon with winter maxima.

Es types 'f' and 'l' are added together and presented in Fig. 6. Though the diurnal variation shows that the frequency of the 'f' and 'l' types of Es is greater by day than at night, the difference is not very big. There was no clear seasonal variation in 1958 – 1967 though an occasional peak could be noted during the winter months. But from 1968 on, a well-defined pattern emerged with strong summer maxima. During the summer months, the diurnal variation exhibited two maxima around 0600 and 1800 hrs LT. In the other seasons the diurnal variation showed only one peak around 1200 hrs LT.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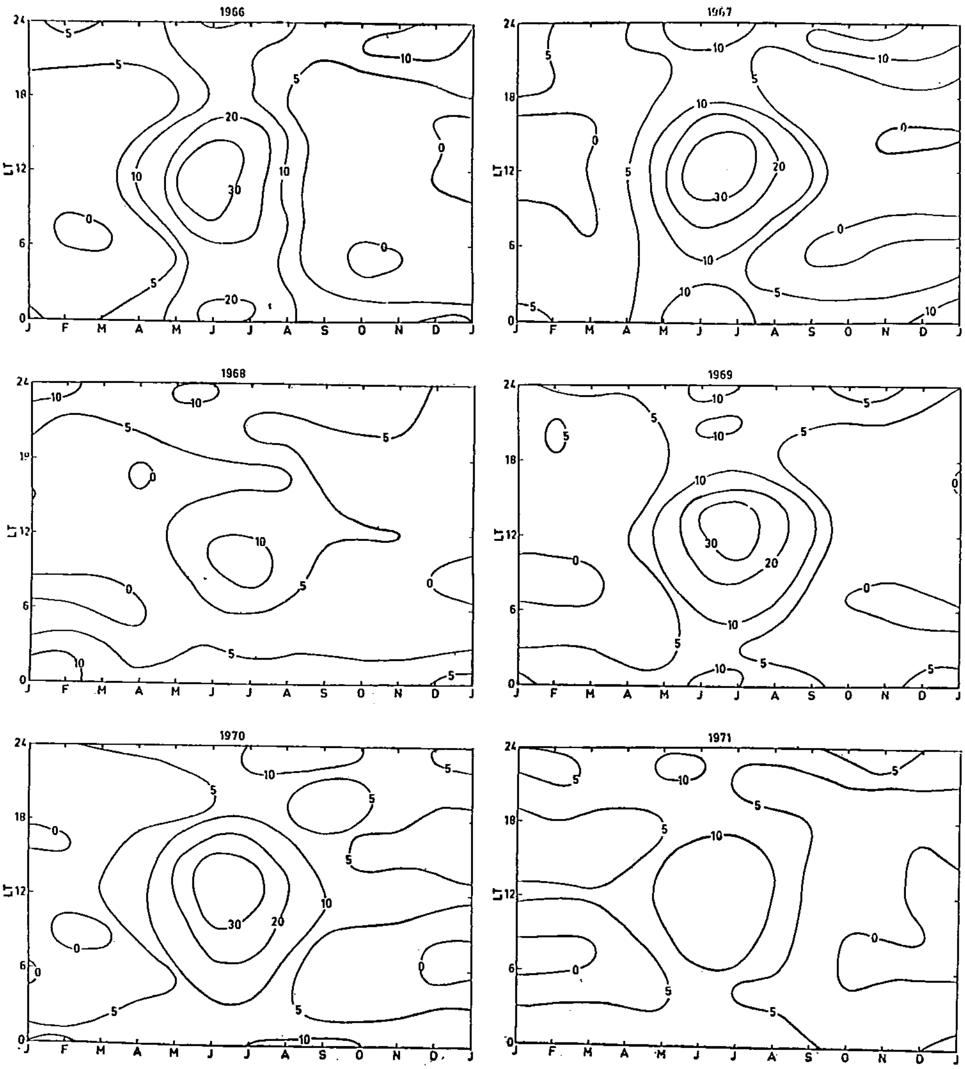
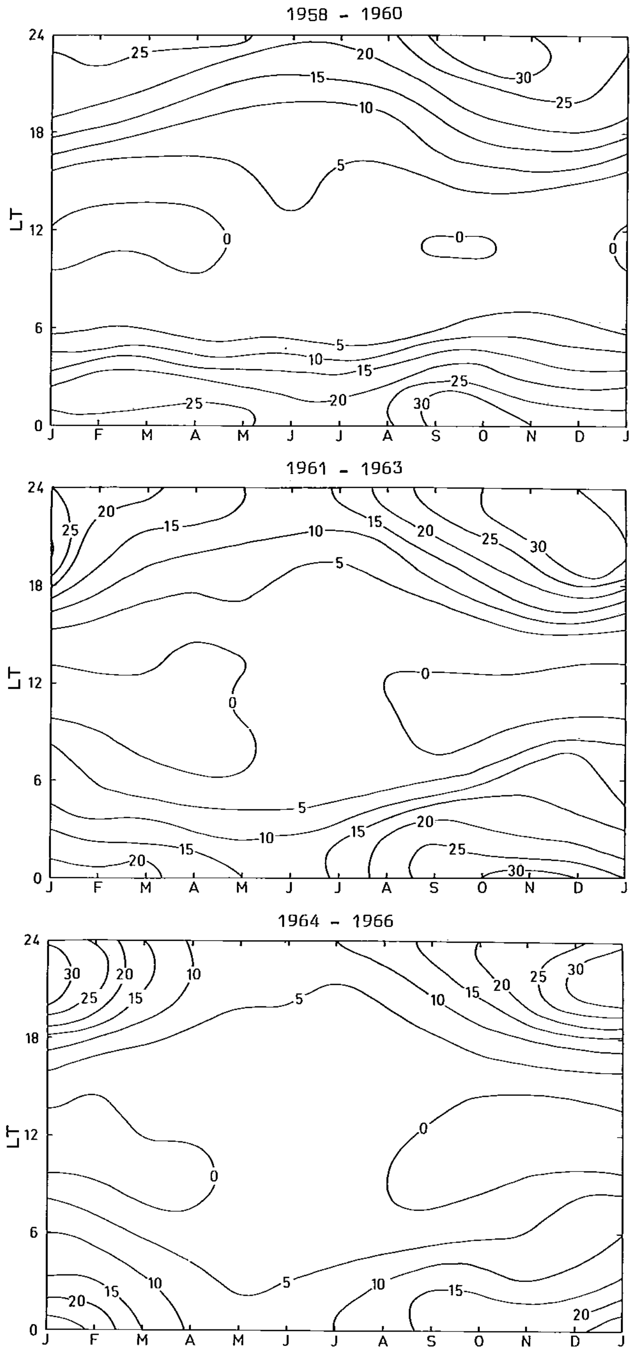


Fig. 1. Maps showing percentage of time in which foEs exceeded 5 MHz at Sodankylä from 1958 to 1971.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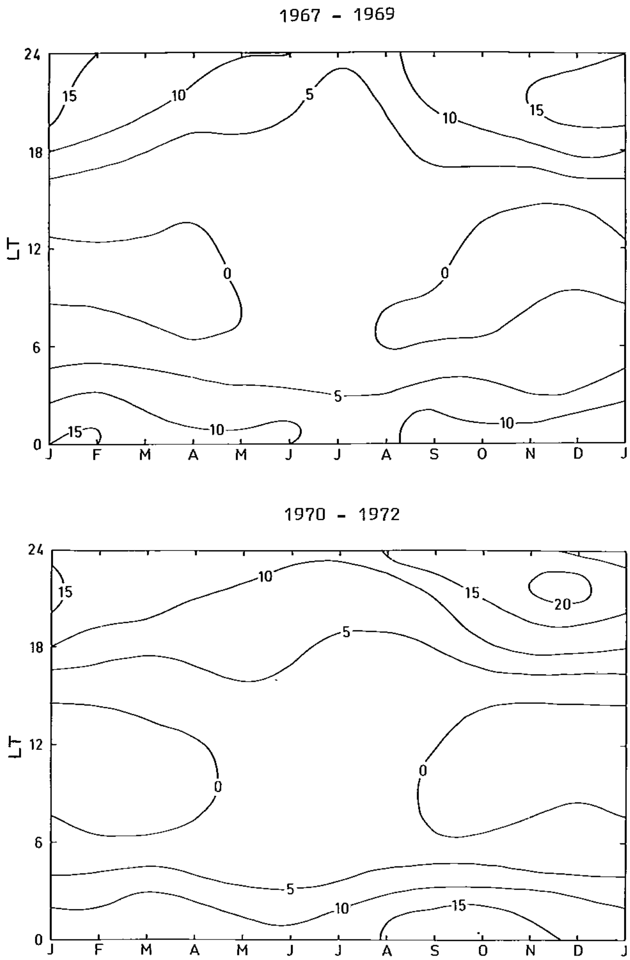
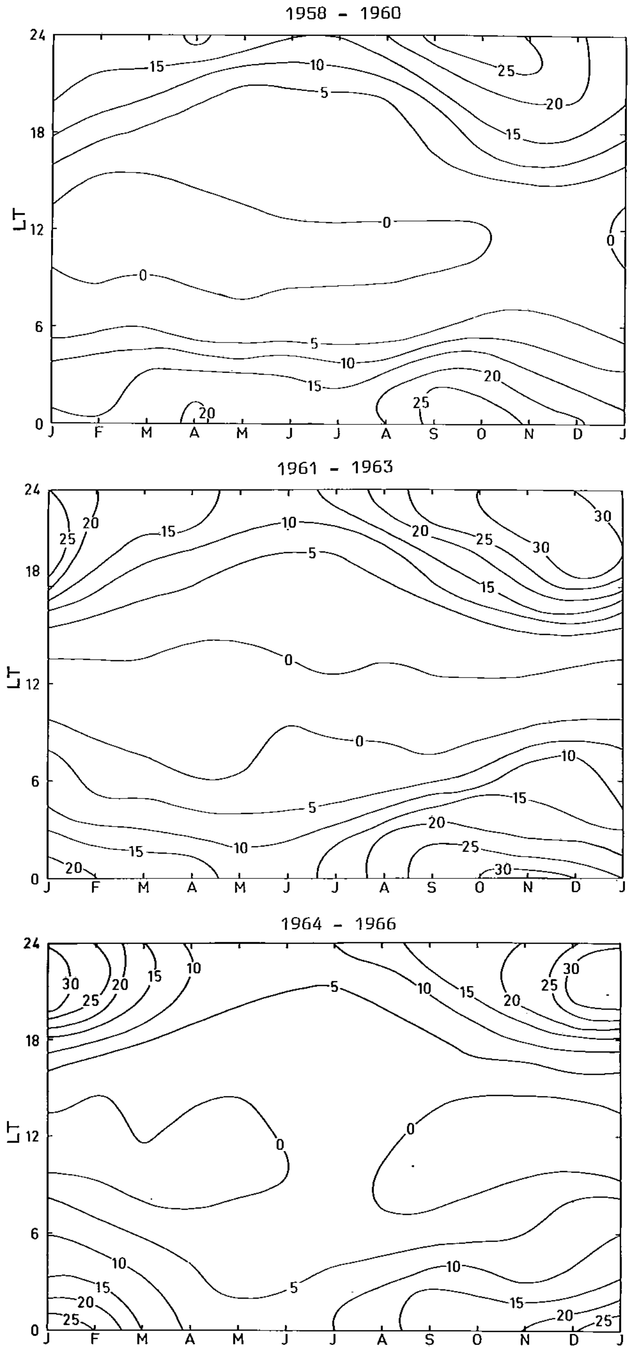


Fig. 2. Maps showing percentage of time in which fbEs exceeded 4 MHz at Sodankylä from 1958 to 1972. Cases of total blanketing are included.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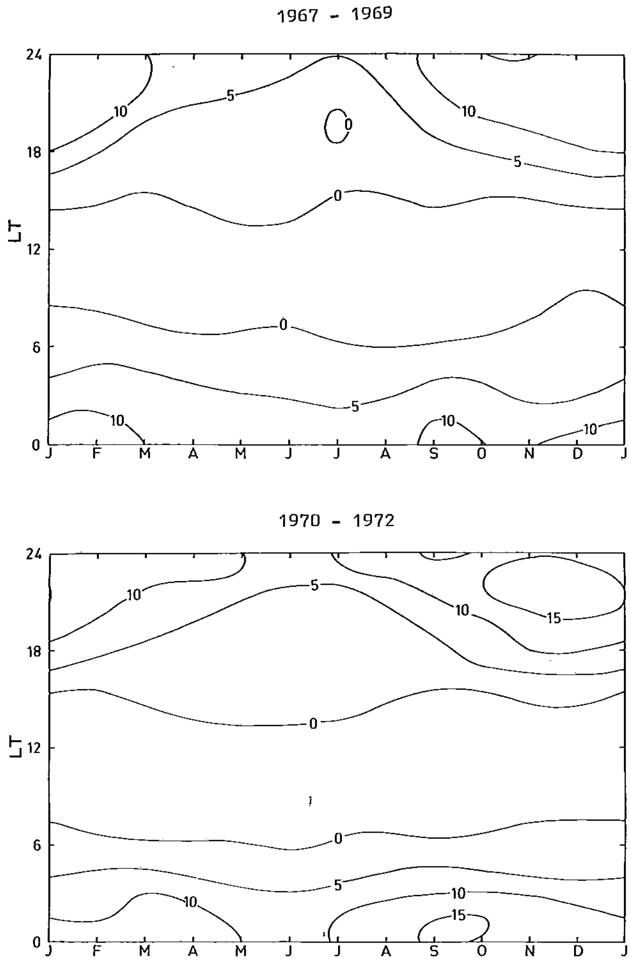
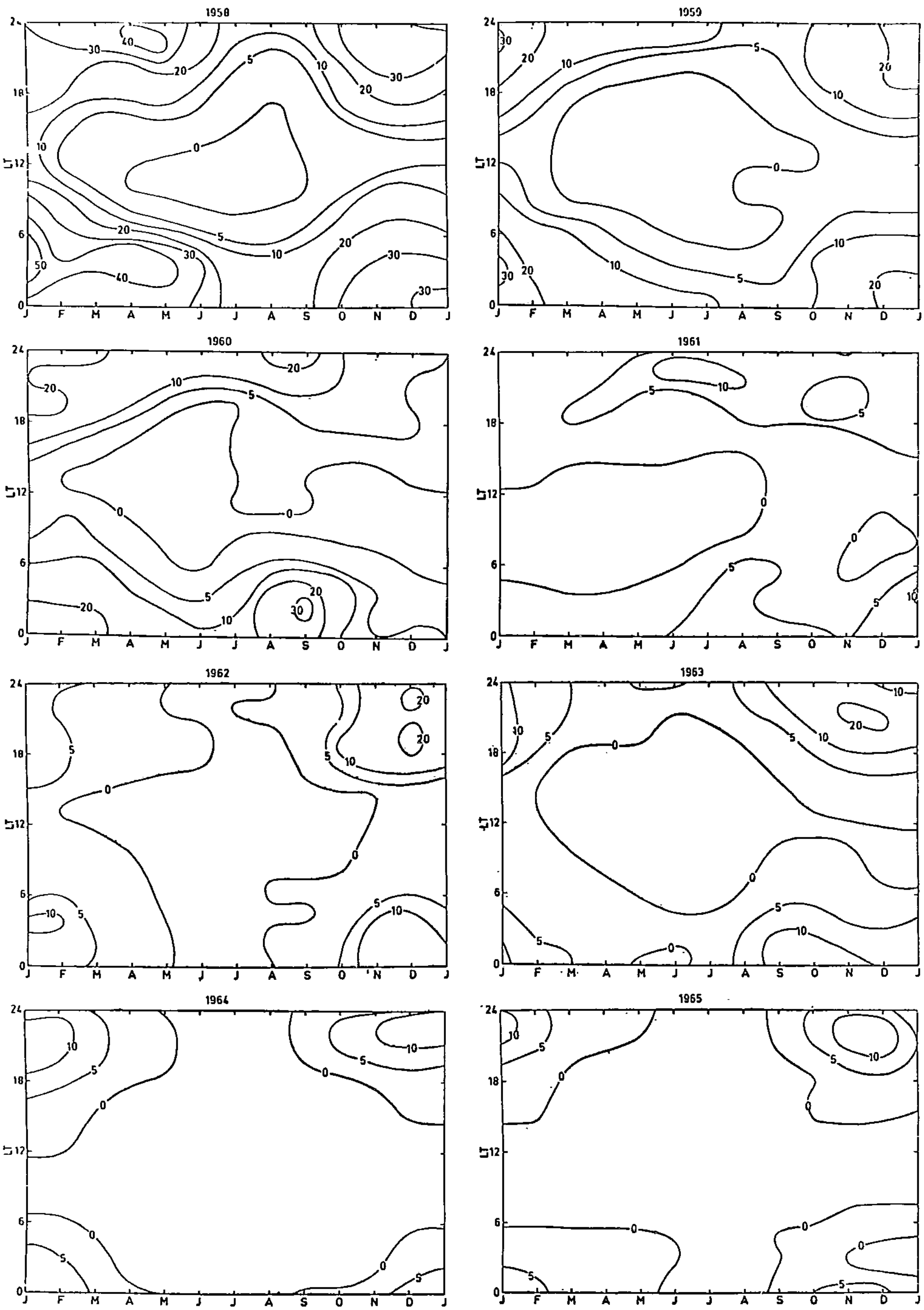


Fig. 3. Maps showing percentage of time in which total blanketing was seen at Sodankylä from 1958 to 1972.

Note: The method used for Figs. 2 and 3 were similar to those for Figs. 1 and 4...7 except that the data were grouped into 3-year period for better statistical significance.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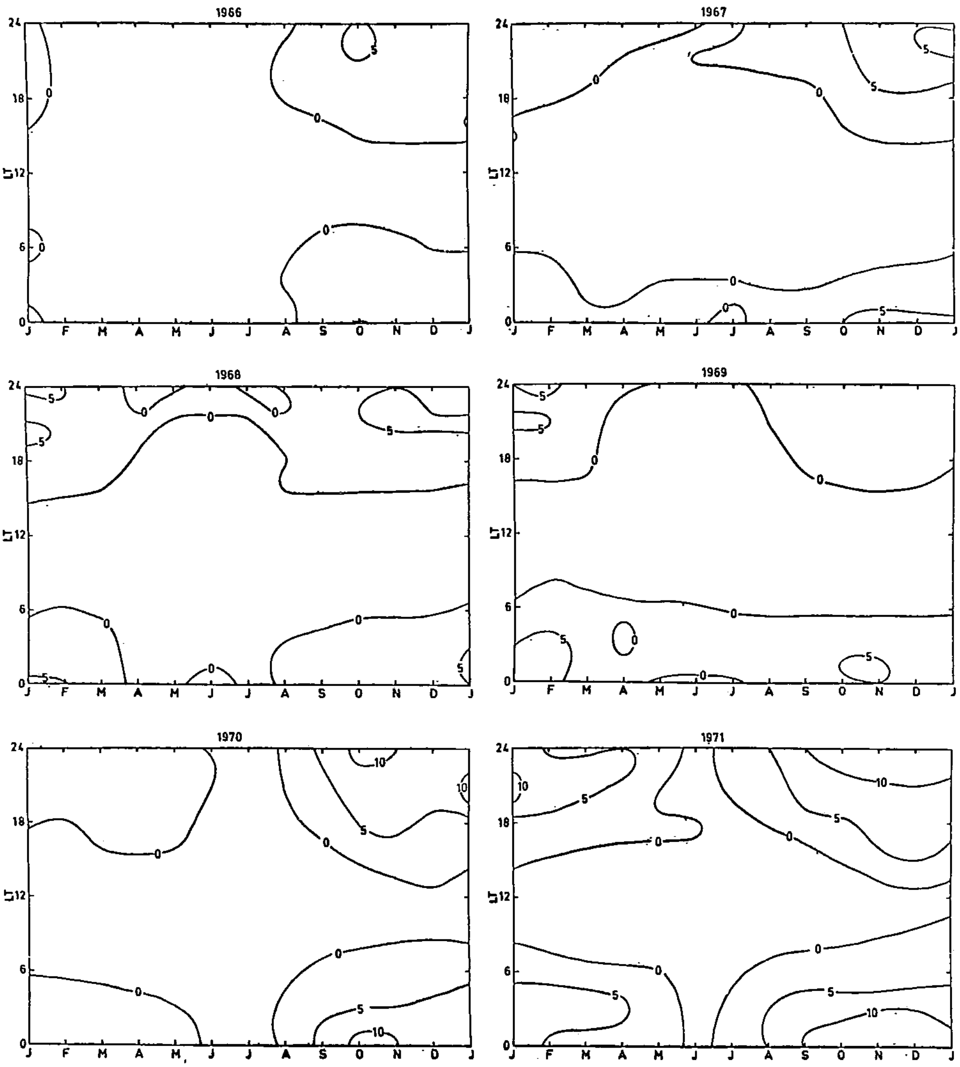
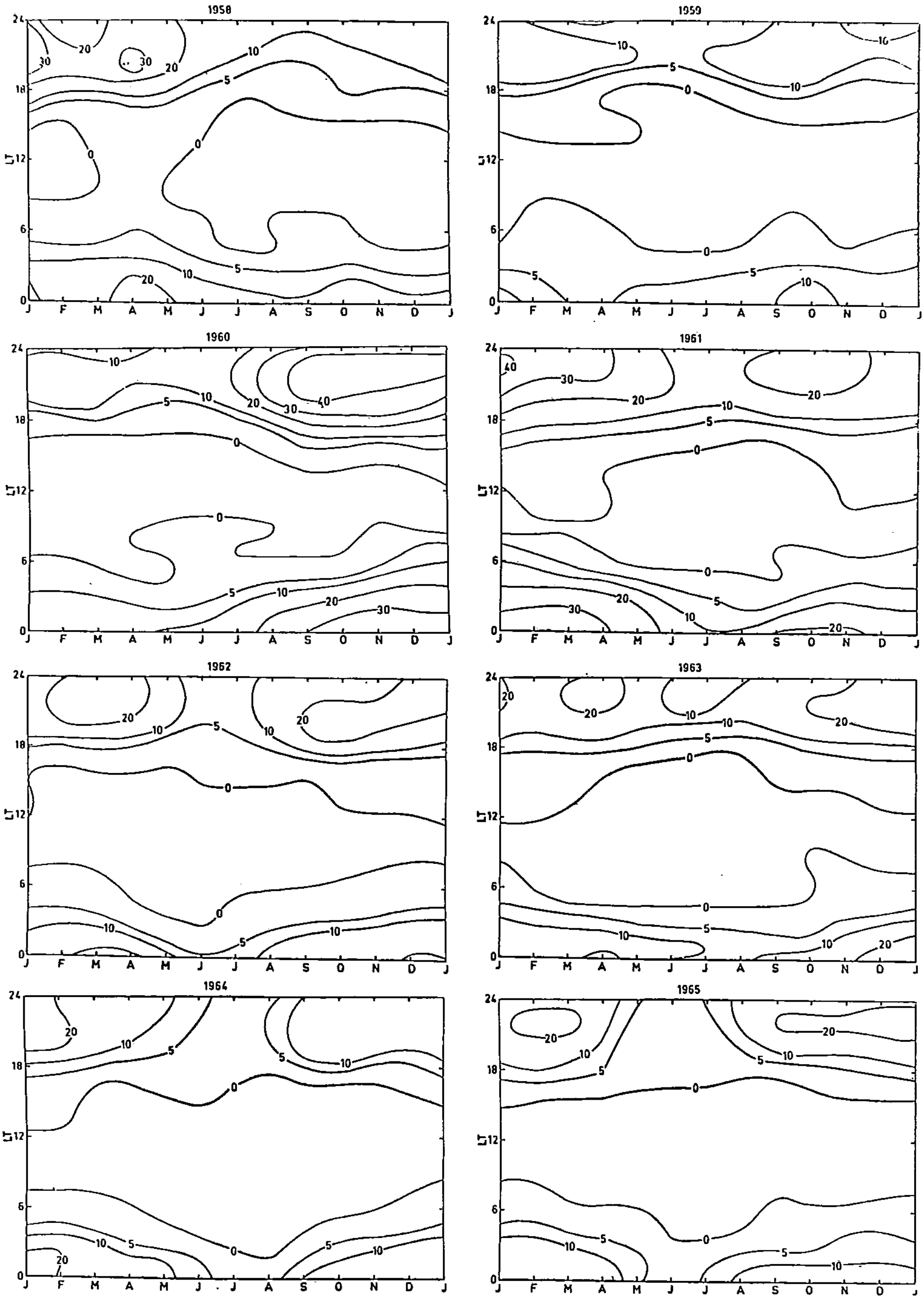


Fig. 4. Maps showing percentage of time in which auroral Es was seen at Sodankylä from 1958 to 1971.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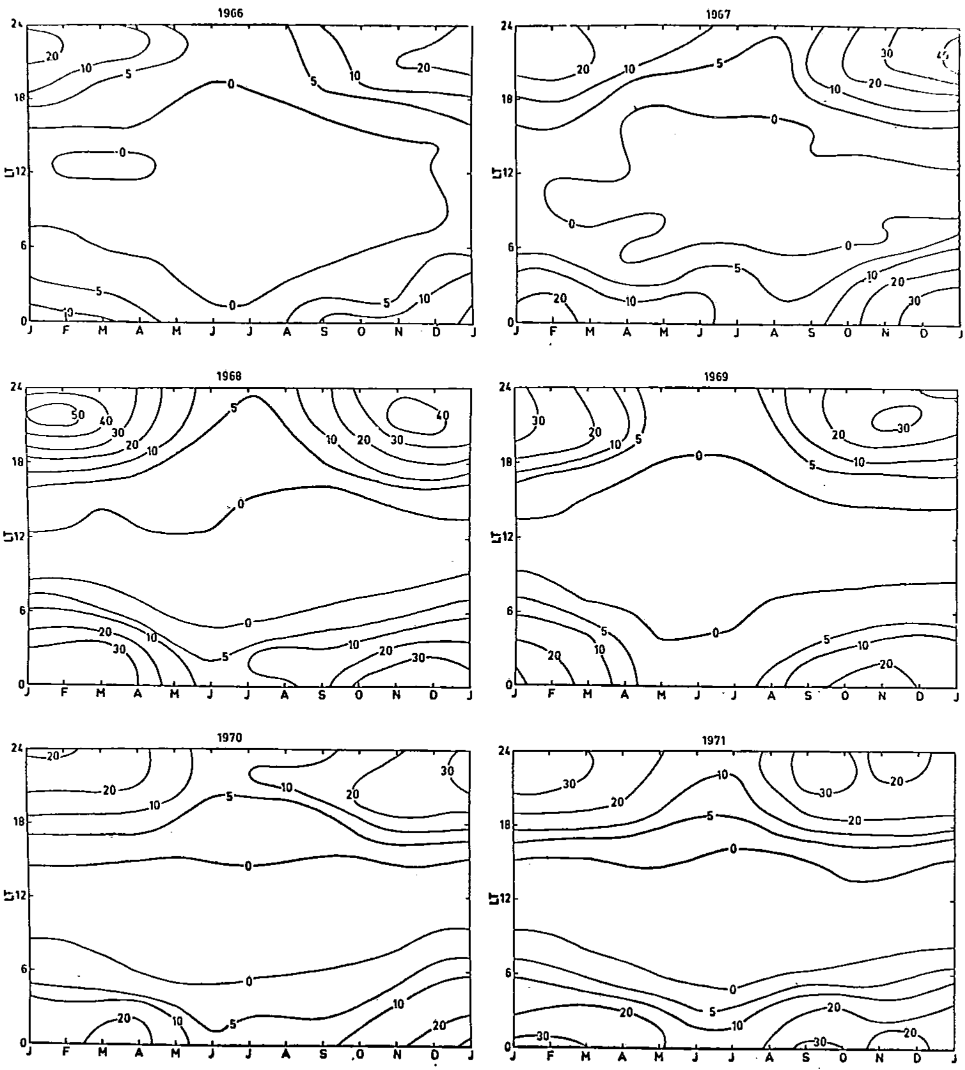
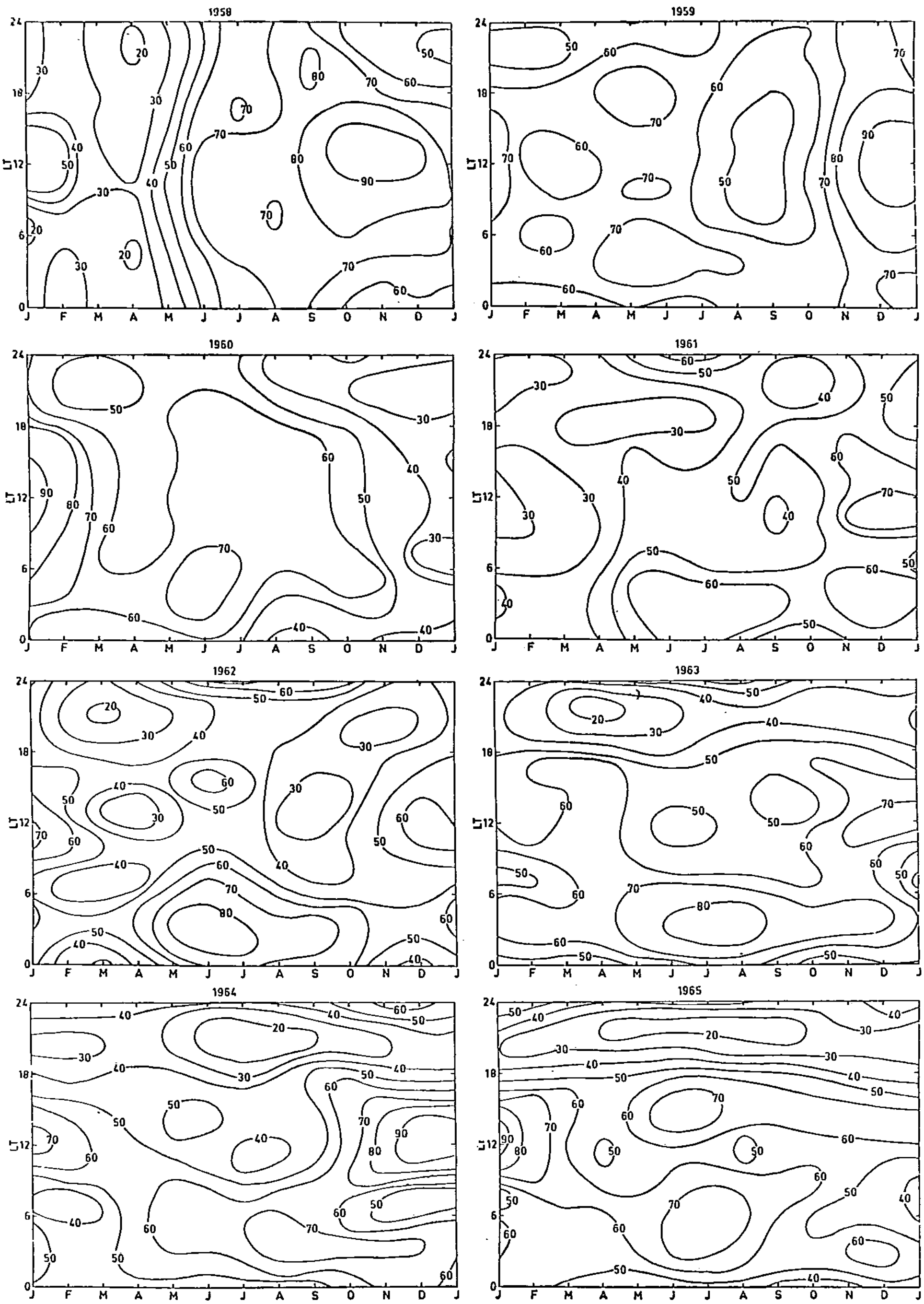


Fig. 5. Maps showing percentage of time in which retardation Es was seen at Sodankylä from 1958 to 1971.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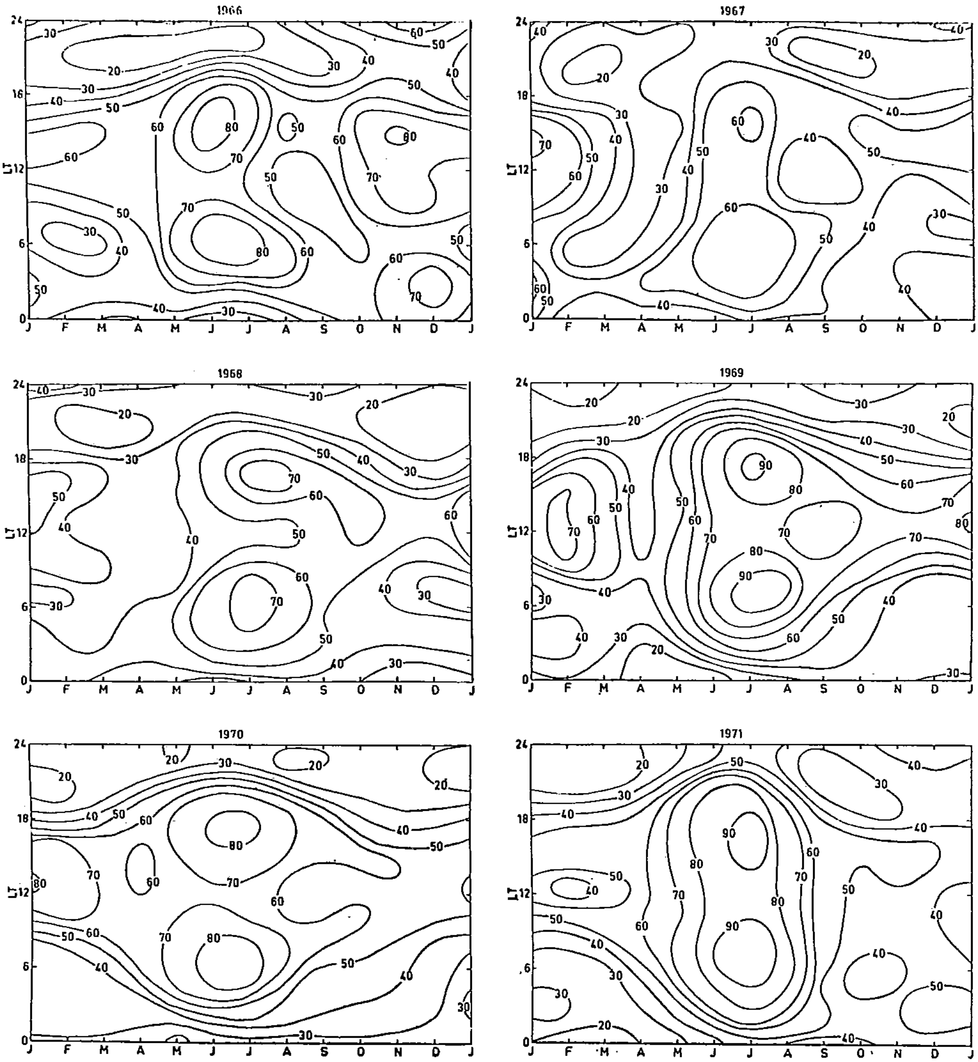
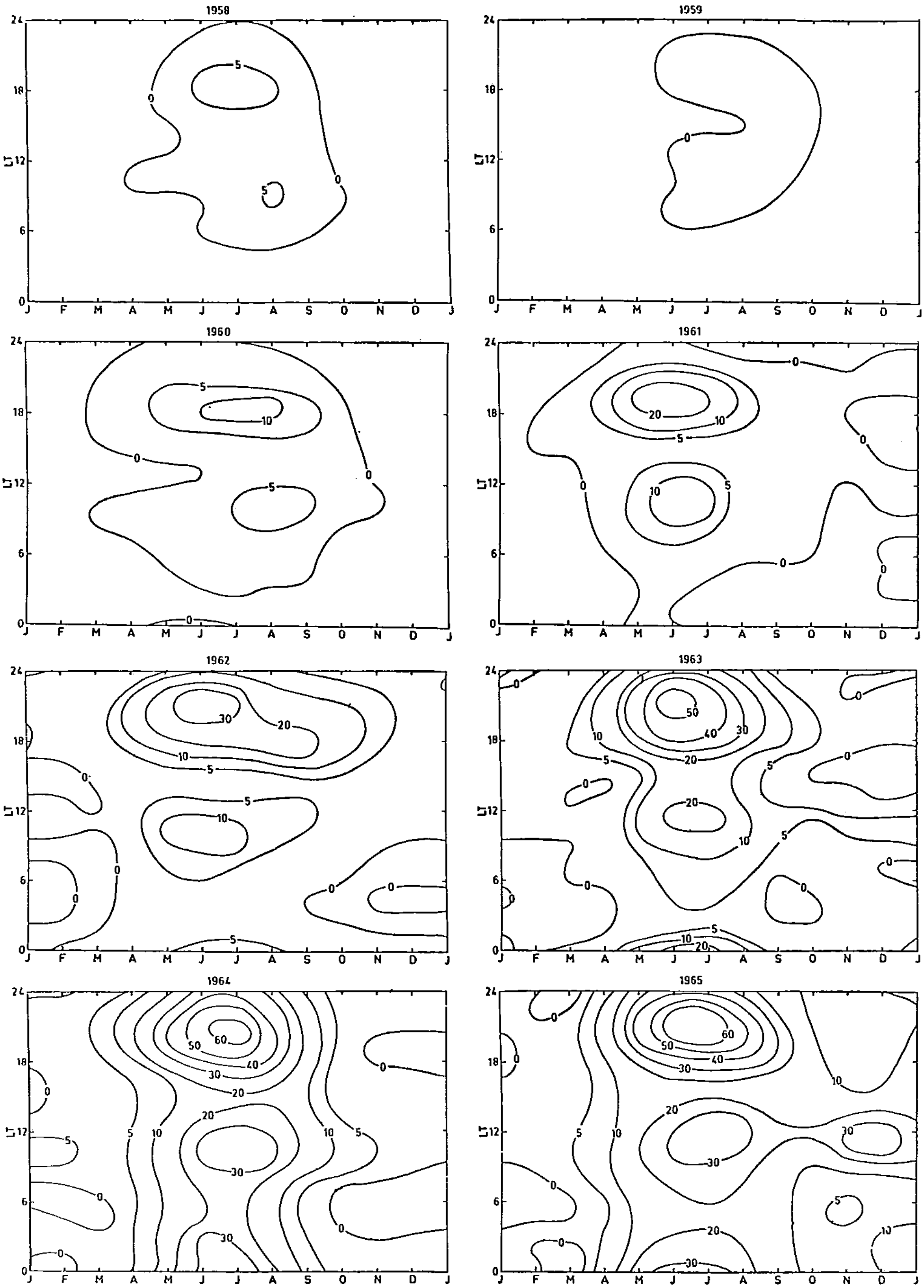


Fig. 6. Maps showing percentage of time in which flat or low Es was seen at Sodankylä from 1958 to 1972.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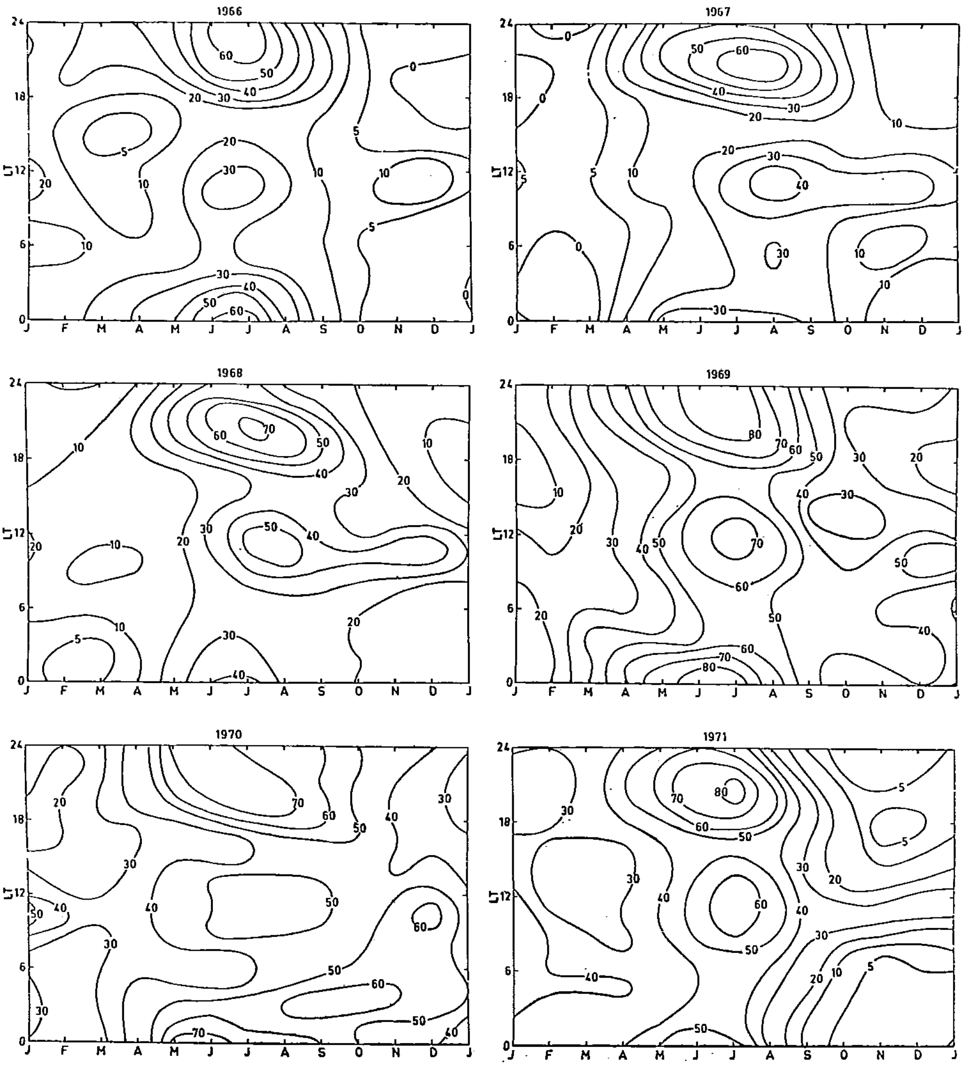

Fig. 7. Maps showing percentage of time in which cusp or high Es was seen at Sodankylä from 1958 to 1972.

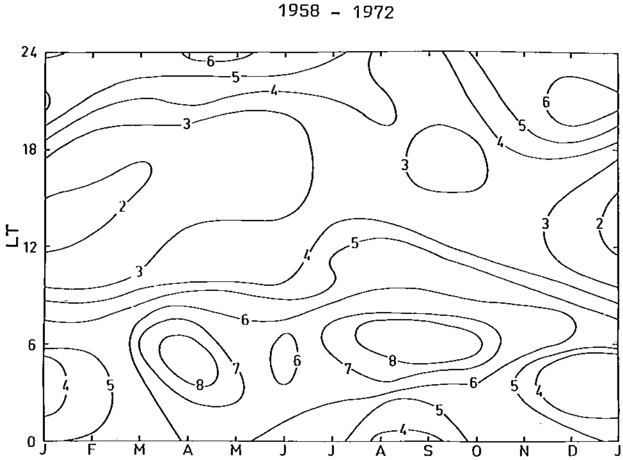

Fig. 8. Map showing percentage of time in which total absorption occurred at Sodankylä. Data from 1958 to 1972 are added together.

Fig. 7 contains the maps for the diurnal and seasonal variation of the frequency of 'c' and 'h' types of Es. These two types are added together in the same way as the 'f' and 'l' types reported in the previous paragraph. In 1958 and 1959 'c' and 'h' types of Es were very rare at Sodankylä but then they increased gradually but steadily in frequency reaching a maximum in 1970. In ten years the yearly sum of the Es of these types increased by a factor of a little more than 100. There was a distinct summer maximum in the seasonal variation in all the years. During the summer months, the diurnal variation rose to a strong maximum between 1800 and 2400 hrs LT.

Fig. 8 shows the probability of total absorption at Sodankylä. This figure can be used for estimating the effects of absorption on the maps depicting the diurnal and seasonal behaviour of the Es parameters. It indicates that less than 8 % of the data was lost owing to total absorption, but the effects of lesser absorption must be also taken into account. For this reason we have made maps for fmin > 2 MHz similar to those depicting the behaviour of the Es parameters. These showed that the probability of fmin > 2 MHz is nearly always below 20 %; the probability rose to 30 % only by day in equinoctial months during sunspot peaks.

3. *The reliability of the results*

All the observations were made with the same equipment and all the data were checked by a physicist. So wide long-term variations due to the equipment or the human factor seem unlikely, and we believe that the long-term variations found in some of the parameters are real.

Our data are not fully comparable with data from other ionospheric stations. This is due mainly to the automatic gain control used at Sodankylä. Most stations have fixed gain; at Sodankylä the gain is controlled by the noise level. Though this is a very effective method of obtaining the lowest possible fmin values, it has serious drawbacks. As the noise level has a diurnal and a seasonal variation due to corresponding variations in the propagation conditions, some spurious diurnal variations are probably present in parameters that are highly sensitive to gain. During the daytime, in particular, the gain is much higher than is really needed for ionospheric soundings. This, together with the differentiation used in the recording system, causes difficulties when scattered echoes occur. The most important effects of the automatic gain control used at Sodankylä can be summarized briefly as follows:

1) Echo is seen on the film if it is slightly above the noise level. Thus echoes are found even when the absorption is quite high. Though overhead absorption is not reflected in the noise level, the automatic gain control tends to compensate the effects of absorption if the overhead absorption does not differ much from the absorption controlling the interference level.
2) Very weak echo from the bottom side of the E layer is seen, specially in daytime during the summer months. This echo forms a pattern that resembles 'l' type Es, and it is interpreted as an Es layer. However it does not resemble the 'l' type Es that occurs in the last stage of sequential Es or the 'f' type Es often seen at night. The weak echo seen at Sodankylä is probably a gradient reflection from the E layer. It never blankets and it never shows clear multiples. In daytime it dominates our foEs statistics because it occurs practically the whole time. But it is seldom seen when a low fixed gain is used (TURUNEN,[7]).
3) Scattered echoes are nearly always seen above 100 km, especially near foE. When the noise level is low and the gain high, these echoes can cause saturation of the receiver. When this happens, strong echoes are sometimes lost if they are within the same height range as the weak scattered echoes. This causes error in fbEs.
4) For the same reasons, h and c types of Es may be hidden by scattered echoes if the critical frequency of those layers is not high. This causes error in the Es type statistics. Scaling is difficult if the cusp in the c type Es is small. In this case the scatter or gradient reflection from the E layer prevents the cusp from beeing seen in the first order. If higher orders are not seen, there is no indication whatever of occurrence of c type Es and an l type Es enteres the Es type data.

The effects of the automatic gain control and differentiation are discussed in greater detail elsewhere (TURUNEN, [6]).

Another source of error in Es statistics is due to absorption, because the parameters are gain-sensitive. Though it is theoretically possible to correct for absorption we have not done so for the following reasons. The automatic gain control compensates to the changes in absorption to some extent and in any case the physical conditions at high latitudes are so different when high absorption occurs that any extrapolation of Es behaviour based on quiet-time conditions is hazardous. It is possible to estimate the amount of probable error from absorption statistics. Fig. 8, showing the frequency of total absorption, indicates that 8 % of data are lost under the worst conditions during morning hours in equinoctial months. This means to say that the minimum error on our maps is about 8 %. However our study of fmin > 2 MHz has shown that the probability of that parameter is always less than about 30 %, which is the most pessimistic estimate for maximum error in absolute values. The errors in the diurnal and seasonal variation are less than the values shown. They may be higher due to other reasons than absorption. But the other sources of errors are impossible to estimate without extremely laborous rescaling of large amounts of data, and without a very detailed investigation of the properties of the equipment.

4. *Results*

Without going into details the statistical Es behaviour at Sodankylä measured by an ionosonde equipped with automatic gain control, a high-quality receiver with a tuned front end, a transmitter delivering 10 kW output of peak power and high-quality rhombic antennas can be summarized as follows:

1) The parameter foEs > 5 MHz shows that Es's have pronounced daytime maxima in summer months. On the other hand the frequency of Es when fbEs > 4 MHz, including cases of total blanketing shows a winter maxima at night, and the probability of strongly blanketing layers at noon is extremely small. The real seasonal variation in strongly blanketing Es is even smaller than that indicated by the maps because foF2 values are small during the evening in winter so total blanketing occurs at lower blanketing frequencies than in summer.
2) Auroral and retardation types of Es are nighttime phenomena with winter maxima, but the overall seasonal variation is not very pronounced. A comparison between the frequency of these types and that of fbEs > 4 MHz suggests that these types, particularly the r type of Es account for the majority of strongly blanketing Es layers at Sodankylä.

3) Cusp and high types of Es have very pronounced seasonal variation. The main maxima are seen during the late evening hours in summer. Although these layers are often partly blanketing, they are not reflected in blanketing statistics when a high limit is used for counting the events. If a low limit is used (e.g. 2 MHz) there is a maxima which is clearly related to the cusp and high types of Es. The maps for this are not, however, presented in this paper. Cusp and high Es usually have rather low foEs values, because they are not clearly seen in the maps depicting the variation of foEs > 5 MHz. This, however, only holds when very sensitive sounding is used. With insensitive sounding the weak phenomena (see 4, below) masking the effects of these types disappear and a clear evening maximum is seen at times when cusp and high types of Es are common (TURUNEN, [7]).

4) Low and flat types of Es are dominant in the foEs > 5 MHz statistics in a sensitive sounding system, specially by day and in summer. Most of the layers classified as low type Es are in fact weak gradient reflections from the E layer; they are not Es similar to the low type Es forming a part of sequential Es, for example. As some of the layers shown in the maps depicting f +1 behaviour belong to the »auroral flat» type, there are at least three different layers included in those maps: weak gradient reflections, Es layers similar to cusp and high types of Es, and layers which may have connection with auroral phenomena, namely the flat type seen at night.

5) There were some strong long-term variations, which are summarized below:
   a. The yearly amounts of cusp and high types of Es increased by a factor of more than a hundred from 1958 to 1970.
   b. The amount of auroral Es decreased from 1958 to 1966.
   c. The yearly amount of foEs > 5 MHz decreased from 1958 to 1963.
   d. The diurnal and seasonal variations of most of the parameters were much clearer and more stable during the later part of the period studied.

   There were also long-term variations that were not so pronounced as to be directly visible on the maps presented in this paper. The most interesting of these was a retardation Es, whose maxima occurred before and after the sunspot maxima. A more detailed study about the long-term variations has been published in a separate paper (TURUNEN, [8]).

The maps give far more information than has been summarized above. However, the reliability of such details in this kind of map is questionable.

5. *Summary*

Some 10^6 Es measurements were used for making the maps depicting the diurnal and seasonal variations of Es phenomena at Sodankylä. The main finding is, that three different Es phenomena can be seen at Sodankylä: the high latitude types of

Es are seen in the evening and at night, with maxima during the winter months. They are also the layers with the highest blanketing frequencies at Sodankylä. The mid-latitude types of Es are seen mainly during the late evening hours in summer. They often blanket but both the blanketing and critical frequencies are usually so small that they do not appear in the statistics on frequency parameters when high limits are used. This is true only if the sounding system is very sensitive; with insensitive sounding these types almost totally dominate the behaviour of the frequency parameters during the daytime. At the sensitivity level used at Sodankylä, a weak reflection from the E layer, probably a gradient reflection, is almost invariably seen in daytime ionograms. Although this echo, which is interpreted as low Es, dominates our daytime foEs behaviour, it has no effects on the blanketing statistics when high limits are used. Whether this weak echo is seen at other stations systematically in or outside the auroral zone is not known. The reflection is not seen with insensitive sounding.

Long-term variations were found in all the parameters, the most pronounced variation was the increase in the frequency of c and h types of Es by a factor of more than 100 between 1958 and 1970. Few of our long-term variations reflect the sunspot cycle.

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