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THE LONG TERM VARIATION OF Es LAYER PARAMETERS AT SODANKYLÄ 1958 – 1972

by

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Abstract

Long term variations in some Es layer parameters are studied by using the data from Sodankylä (geom lat 63.8, geom long 120.0). The yearly counts of events taken from hourly data are used. The study reveals that the occurrence frequency of the »c» and »h» types of Es increased by a factor of 100 from 1958 to 1970 after which a rapid decrease occurred. The occurrence frequency of the »a» type Es decreased roughly by a factor of 30 from 1958 to 1966 after which it increased slowly. The long term variation in the »r» type Es shows clear minimum around the sunspot minimum and seems to have double maximum at sunspot cycle maximum. Maximum in the occurrence frequency of total blanketing events was in 1960 and minimum in 1969. Similar behaviour is also seen in the occurrence frequency of total absorption events studied for purposes of comparison.

In most cases other sources than the sunspot cycle are needed to explain the observed long term variations. The periods involved are longer than 11 years except in the case of the »r» type Es. Because of the limited amount of data there are no possibilities to propose what the periods really are.

1. *Introduction*

Studies on the long term variation of the Es layer are usually made by counting events defined in some way. The most common method is perhaps to use either the critical frequency foEs or the blanketing frequency fbEs and the event is counted if some predetermined value, typically 3, 5 or 7 MHz, is exceeded. Especially in older papers the top frequency fEs is used instead of the critical frequency.

Among studies of that kind are the papers by MITRA and DASGUPTA [2], who studied the data from thirty-three stations using fEs > 5 MHz as a parameter and limiting only to noon values and by REDDY and MATSUSHITA [4], who studied fbEs data from six stations using many threshold values between 0.5 and 6.0 MHz. They studied different daytime sectors separately. A comprehensive review on the works done before IGY has been made by THOMAS and SMITH [7]. MITRA and DASGUPTA [2] concluded that in most stations the correlation between the sunspot cycle and the Es parameter they used was positive. Only at three stations it was negative and no definite correlation was found for seven stations. Among the stations which showed positive correlation were Tromsö, Kiruna and Uppsala, negative correlation was obtained for Churchill and Fairbanks and no definite correlation was found in Point Barrow and Resolute Bay. All stations mentioned here by name are in or near the auroral zone or in the polar cap region. REDDY and MATSUSHITA [4] did not include the high latitude stations in their study. They found positive correlation at all stations between the sunspot number and the mean value of fbEs, but at the same time they found that the occurrences of small fbEs values increased markedly with the decreasing sunspot number. OKSMAN [3] studied the long term variation of foEs > 5 MHz from Sodankylä data and found a positive correlation between the sunspot number and the Es parameter he used. MITRA and DASGUPTA [2] used data from 1953 – 1959, results of REDDY and MATSUSHITA [4] are based on data from 1958 – 1965 and OKSMAN [3] used data from 1958 – 1963. THOMAS and SMITH [7] summarized the early works and concluded that the sunspot cycle correlation is negative at midlatitude stations and positive in the auroral zone.

The above mentioned studies already show that there are inconsistencies in the results. This is due to many facts: *e.g.* the stations used in the studies belong to different longitude sectors, the interpretation of the ionograms may not ne uniform, the periods are not the same and, what is more important, there are great differences in the methods of analysis. Thus it seems probable that in fact different physical phenomena have been studied in different papers.

If the study is limited to the noon values as was done by MITRA and DASGUPTA [2], it has a consequence that the result obtained for a high latitude station describes mainly the long term variation of midlatitude Es seen at a high latitude station. If all events are counted without any division into time sectors the midlatitude and the high latitude type phenomena enter the same statistics and there is no possibility to see the physical background. On the other hand even when the division into time sectors is made there is mixing of the phenomena if the events cannot be separated. Before one can speak on the long term variation of Es phenomena seen at a high latitude station one must be able to separate phenomena having different physical origin. In practice this means that all those Es types which are believed to be caused by the same physical mechanism can be added together. At Sodankylä there are two clearly identified groups namely the »c» and »h» types of Es, because these are formed by widely accepted windshear theory (WHITEHEAD, [16]) and the »r» type Es which has a connection to particle E layer and is thus a direct consequence of soft particle precipitation. It is also possible to study a third family of Es layers, namely the »a» type Es, because it is certainly related to auroral processes although it may well be a big »family» of Es layers having a different origin. It is not possible to study the »l» and »f» type phenomena on the same basis because in these types at least three different Es phenomena are mixed. These are the »l» type similar to the »c» and »h» types of Es, the »l» (or »f») type caused by weak scatter and seen at high gain levels and the »f» type related to auroral processes.

The »l» type Es related to the weak scatter is especially important in Sodankylä data because of automatic gain control, which in practice means the highest possible gain. A more detailed discussion on this subject is given elsewhere (TURUNEN, [8], [12]). For details on the »auroral f» the reader is referred to SHAEFFER [6]. For these reasons the »l» and »f» types of Es are omitted in this study.

This study is based mainly on the data concerning Es types. That data are in many respects the best data to describe the Es phenomena seen at a high latitude station, because it allows the separation of physical processes, gives a correct answer in case of multiple Es phenomena and is simple to use. Thus in this study no weight is given on the strength of an event but it is always counted if it has been clear enough in order to allow type identification. One must keep in mind that though in any long term variation both change in the number of events and in the strength of events is present this method gives no weight to the possible changes in the strength of events, *i.e.* to foEs and fbEs.

It is worth noting that in many long term studies the method of using integral counts of foEs or fbEs and high threshold values is very sensitive to changes in foEs or fbEs distributions. That such changes exist is in fact verified in the study of Reddy and Matsushita mentioned earlier.

The only frequency parameter studied here is the blanketing frequency. The occurrence frequency of total blanketing cases was used and also the occurrence frequency of the fbEs $>$ 3 MHz including the total blanketing. For purposes of comparison the absorption variation was studied by counting the events of total absorption and the cases when fmin exceeded 3 MHz.

Regardless of the method used in a long term study on Es phenomena the data must be checked and the basic properties of the sounding system must be known. Related to this study a series of experiments were made in 1973 and 1974 in order to get a full understanding of possible sources of errors in the data. That study ruled out the use of the foEs and small fbEs values. It also showed the impossibility to use the »l» and »f» types of Es. Some details about the results of these experiments are published elsewhere (TURUNEN, [8], [12], [13]).

The selection of basic parameters demands that the main morphological features of the studied phenomena are known. The seasonal and diurnal variations of Es at Sodankylä (TURUNEN, [8]), the relations to auroral substorms (TURUNEN and M.M. RAO, [9], TURUNEN, [14]) and the sequential Es phenomenon were studied (TURUNEN and RAO, [10]) before this work was undertaken.

2. *Results and discussion*

2.1. The midlatitude types of Es

The long term variation of the »c» and »h» types of Es is presented in Fig. 1. It shows that during the first years of the studied period only some tens of Es layers belonging to these types were seen, but in 1970 about 4000 layers were measured. The change in the yearly counts was thus roughly two orders of magnitude. The diurnal and seasonal variation of these layers has been the same all the time (TURUNEN, [8]).

The first explanation, which comes to mind, is an error in the interpretation of the ionograms or a systematic change in the ionospheric sounding. The equipment at Sodankylä has been, however, all the time the same, the interpretation has been carried out by the same person and all the data have been controlled by a physicist.

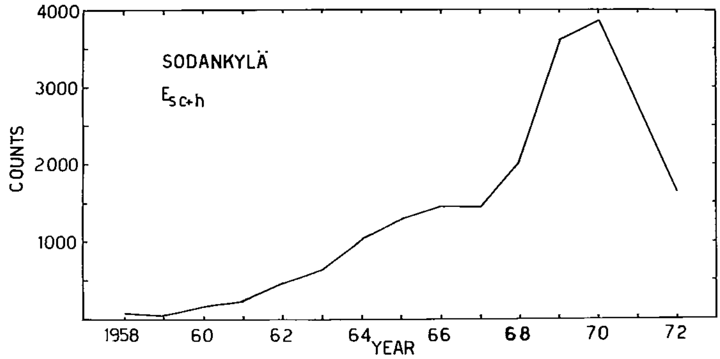

Fig. 1. Yearly counts of the »c» and »h» types of Es layers taken from hourly data.

On the other hand these types of Es are relatively easy to interpret. However, two sources of error are present. The definition of the »c» and »h» types of Es layer demands that the normal E layer is seen in the ionogram and thus a small sunspot cycle dependence follows from the sunspot cycle dependence of the normal E layer. This is a totally unimportant source of error. A much more serious error is caused by technical reasons. Because the gain used in the receiving system has been very high there has been practically always some kind of scatter covering roughly a frequency range of one megacycle or even more just above foE and a height range of several hundred kilometers starting from 100 km. Under some conditions this scatter (which has nothing to do with the »a» type Es) can saturate the receiver and when this occurs it is very difficult to see any echoes, which are within the range of scatter. Thus the »c» and »h» types of Es layers having low critical frequencies can remain unnoticed. Furthermore this scatter seems to have a maximum coinciding with the lower boundary of E layer. This together with the differentiating circuit in the recording unit causes that if the interpretation is not very careful a blanketing »l» type Es enters the data the apparent blanketing being only a receiver effect. When this difficulty was realized the ionograms from 1962 were rescaled. There was an error in the number of the »c» and »h» types of Es but it was smaller than by a factor of two. Because the result obtained in this study remains the same even when the data is in error by a factor of five the original data were accepted and the results are based on it. The reader must, however, be aware of this error.

Because the long term variation of the »c» and »h» types of Es is so peculiar and does not follow the sunspot cycle some comparisons were made with the results found in the literature together with some study on Kiruna and Lycksele data. MAEHLUM [1] got a result that the probability for the »h» type of Es was 0.1 % and for the »c» type of Es was 0.7 % in Tromsö. He used data from 1957 – 1958. This fits well with the results from Sodankylä at the same time and gives an indication that the low occurrence frequency around 1958 is a fact at Sodankylä. At the same time Maehlum notes that the occurrence frequency of these types was roughly 20 times higher at Kjeller. This means that a great change in the occurrence frequency of midlatitude types of Es can occur in a relatively narrow latitude interval. In 1962 when the occurrence frequency of these types had increased in Sodankylä already by a factor of 10 the data from Kiruna and Lycksele were studied. The value from Kiruna was the same within some percent. Thus the real number of the »c» and »h» types of Es was either lower in Kiruna by a factor of two compared with Sodankylä or there was a similar error in interpretation as at Sodankylä. The Lycksele data showed an occurrence frequency, which was about ten times higher than the one seen at Sodankylä. If the data were correct it again shows that the decrease was very rapid when the auroral zone was approached. In the 1970 data the yearly count of the »c» and »h» types of Es at Sodankylä was roughly four times higher than in Kiruna but it was also more than two times higher than in Lycksele. It would be possible to explain this behaviour, too, by assuming that just before the latitude where a steep decrease occurs a maximum is reached. This is, however, too complex an explanation although it can explain the data. It is much more probable that such details are far beyond the reliability of the data.

The result which seems to be valid is that in the neighbourhood of the auroral zone the number of the »c» and »h» types of Es decreases rapidly with increasing latitude. The latitude where the decrease occurs has a long term variation which does not have a period of eleven years. At least another period, which is much longer, is strongly dominating. As a consequence a station having a proper position like Sodankylä can have a change in the number of the »c» and »h» types of Es well exceeding one order of magnitude.

2.2. Auroral zone types of Es

The auroral zone types »a» and »r» were studied separately because the long term variation of these two turned out to be very different, although these types of Es have similar seasonal and diurnal variation at Sodankylä (TURUNEN, [8]) and both are clearly connected to auroral processes. On the other hand the »r» type of Es is easy to interpret from the ionograms and the data is thus quite reliable. The same is not true when the »a» type Es is concerned. The difficulties with the »a» type Es are caused by a great variety of forms, which this special Es can take, sensitivity to technical properties of the ionosonde and aerials and weaknesses in the international definitions of this Es type. In any case it is certain that data from different stations are inconsistent, and it also seems doubtful that a homogeneity in the data can be maintained at any station over long periods.

The long term variation of the »r» type Es is presented in Fig. 2. The occurrence frequency of the »r» type Es is highest during the sunspot maximum years but the variation clearly exhibits two maxima around the sunspot maximum. The variation does not have any trend similar to the one found in case of the »c» and »h» types of Es. Thus the long term variation seen in the »r» type Es can be explained in terms of sunspot cycle, although the dependence is not linear.

The »r» type Es is believed to be an oblique reflection from a particle E layer (formerly known as night E layer) having a horizontal gradient. It was found that the data used in this study is interpreted in such a way, that also layers which could have been scaled as a particle E are in most cases scaled as an »r» type Es.

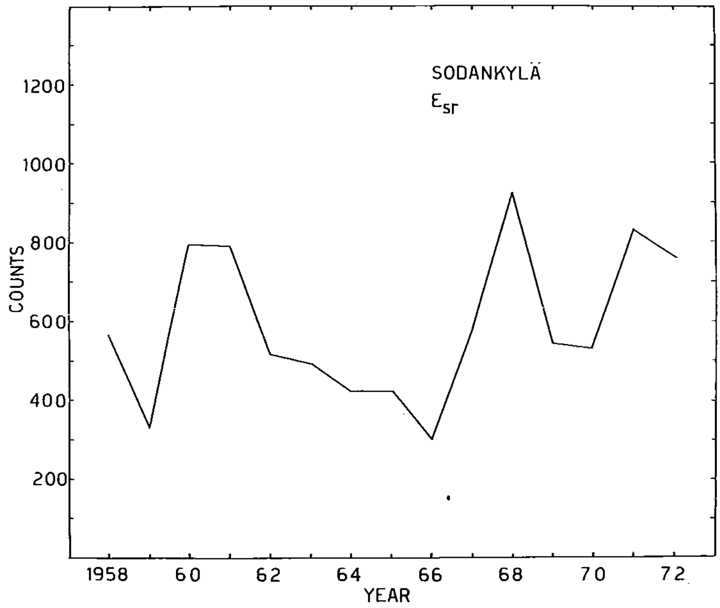

Fig. 2. Yearly counts of the »r» type Es layers taken from hourly data.

Thus it can be assumed that the »r» type Es statistics used in this study describe closely the behaviour of the particle E layer and the event enters the data if the particle E layer is somewhere in the antenna pattern of the ionosonde. Because the particle E layer on the other hand has connections to particle precipitation in the keV energies, the physical background of the »r» type Es is perhaps better understood than in any other Es layer type. The existence of a proper particle E layer in the antenna pattern of the ionosonde is, however, only a necessary but not sufficient condition for the »r» type Es. The »r» type Es can be seen in the ionogram only if there is not too much scatter, *i.e.* there are not so many irregularities in the lower ionosphere that the other auroral zone type of Es, the »a» type, enters the data instead of the »r» type Es. Another condition, which must also be fulfilled is that the particle precipitation is soft enough, *i.e.* there is not too much absorption to cause fmin > foEs.

The long term variation seen in the »r» type Es is thus related to the long term variation in the occurrence frequency of events of soft particle precipitation under low absorption conditions and there is also a demand that any mechanism causing irregularities is not too strong. In principle a change in any of these three conditions, which must be fulfilled, could cause the observed long term variation. Since, however, there are no features in the long term variations of the »a» type Es and absorption (see Figs. 3 and 5) clearly opposite to the behaviour seen in the long term variation of the »r» type Es, it can be assumed that the main contribution in the long term variation is caused by the occurrence frequency of soft particle precipitation events in the antenna pattern of the station.

There are two different ways to explain the variation seen at Sodankylä. Either the number of events has the variation when all latitudes of interest are taken into account or the zone where the events mainly occur has a long term movement. Probably both are true. It is impossible to give an answer, which is certainly valid, because it demands a study of many stations properly situated in the auroral zone. Furthermore it may well be that the data homogeniety is not good enough at different stations for that kind of study. We must assume that at Sodankylä the main contribution in the long term variation comes from the latitudinal movement of the main zone although this assumption is strictly speaking not justified at all. After this assumption it is possible to explain the long term variation of the »r» type Es by a mechanism which is the same as the one used to explain the observed dependence of the »r» type Es on magnetic activity. It is well stated (MAEHLUM, [1], OKSMAN, [3], TURUNEN, [15]) that there is a zone roughly coinciding with the auroral zone where the »r» type Es occurs even during magnetically quiet periods. This zone moves towards the lower latitudes when the activity increases. As a consequence an auroral zone station has a negative correlation between the »r» type Es and magnetic activity, a station near the auroral zone like Sodankylä has a positive correlation at low levels of magnetic activity and negative at high levels, the turning point being at Sodankylä around the Q-index value 3 and at lower latitudes the correlation is positive all the time. It was also shown (TURUNEN, [15]) that there are no significant differences between sunspot minimum and maximum years in this respect at Sodankylä. If we assume that the long term change in the amount of the »r» type Es is caused by a similar mechanism we still have many possibilities. The change may be a long term change in the quiet time position of the zone along which the »r» type Es occurs, or the statistical movement is a consequence of different magnetic activity levels in different years. In any case the increase in the number of the »r» type Es is caused by a movement of the zone towards the station, which here means towards the lower latitudes. It is, however, difficult to explain the minima around the sunspot maxima because it demands either a movement towards the higher latitudes just after the sunspot maximum and backward movement in a couple of years or that the statistical position of the »r» type Es zone is at lower latitudes than Sodankylä during the sunspot maximum years. The first explanation does not fit in with the overall morphology of events of any nature related to auroral zone processes and it is thus very doubtful, although there is in the Es data from Sodankylä nothing, which would be against this possibility. The second explanation is possible but it is difficult to understand why the diurnal variation has not changed and why the response to magnetic activity is the same both during the minimum around sunspot minimum and during the minimum around the sunspot maximum. Thus, in spite of the peculiarity, the backward movement at the sunspot maximum for a short period is at least worth considering. The final answer between these two explanations is beyond the possibilities of this study and the data used. It is not ruled out that there are totally different mechanisms causing the long term variation in the »r» type Es from those discussed above. On the other hand the variation in the yearly counts of the »r» type Es events is within a factor of three, which is not a very significant variation when considering the overall inaccuracies found in the Es data. One must keep this in mind. It is obvious that a study covering all latitudes of interest is needed.

The Fig. 3 shows a long term variation of the »a» type Es. The main feature is a decrease by roughly a factor of 30 in the occurrence frequency of this type of Es from 1958 to 1966. After 1966 a small increase occurred. The details seen in the variation are too small to be significant.

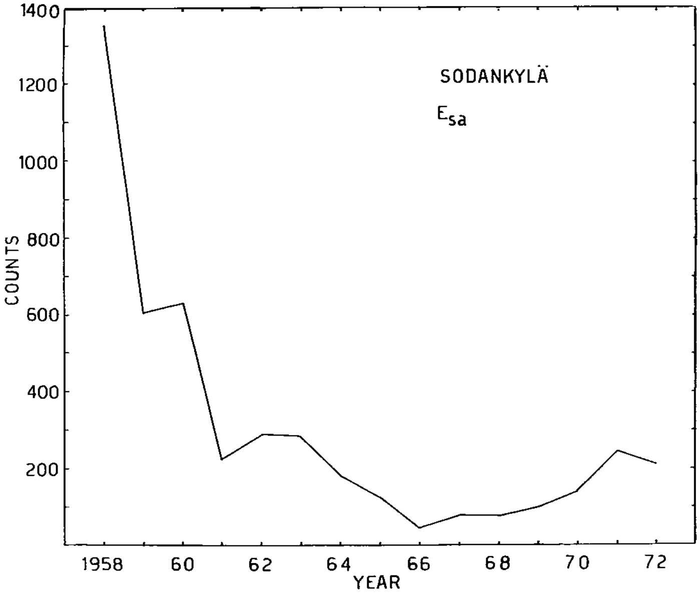

Fig. 3. Yearly counts of the »a» type Es layers taken from hourly data.

It is very dangerous to rely on any statistics on the »a» type Es. The only result, which probably is valid in the Fig. 3, is that the sign of the trend is correct. Formally this leads to positive correlation with the sunspot number. There may be some physical connections between the decrease in the occurrence frequency of the »a» type Es and the corresponding increase in the occurrence frequency of midlatitude types of Es.

2.3. Long term variation of fbEs

Two parameters were used in a long term study on the blanketing power of the Es, namely the yearly count of total blanketing cases and the yearly count of fbEs > 3 MHz including total blanketing cases. The results are shown in Fig. 4. In the long term variation of total blanketing cases the maximum is reached in 1960 and the main minimum in 1969. The variation is very smooth. The year 1958 shows a very low number of total blanketing cases but 1959 is almost as high as the following maximum year. The period of the variation remains a puzzle. There may be an 11-year component but certainly no relationship to the sunspot numbers. The anomalous long term variation is limited only to the strong, *i.e.* total blanketing events because the parameter fbEs > 3 MHz shows a clear sunspot cycle dependence. The physical explanation of that is, however, not straightforward.

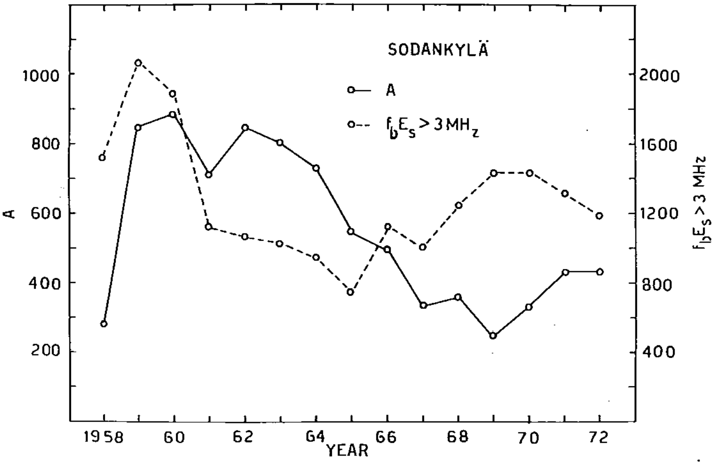

Fig. 4. Yearly counts of cases of total blanketing and fbEs > 3 MHz including total blanketing cases taken from hourly data.

The total blanketing as a parameter has two advantages. It is so simple to interpret that it is practically free from human errors, and because it is a night time and evening time phenomenon with only small seasonal variation (Turunen, [8]) it is related to Es layers having origin in the auroral zone processes. The parameter also has one serious drawback especially if long term variation is concerned. It depends on foF2 which has a well-established positive correlation with the sunspot cycle. If there were no changes in the blanketing power of Es layers or in the number of blanketing Es layers the relation between foF2 and the sunspot cycle would cause negative correlation between total blanketing cases and the sunspot number. This is clearly not so. If there were no long term trend in the data there should be in any case a symmetrical behaviour between the sunspot maxima. Neither is this so. Thus it can be concluded that an anomalous long term variation is present in strongly blanketing Es layers. This method does not allow any conclusion concerning the sunspot cycle dependence of the variation, but it must have smaller amplitude than the dominating variation.

The sunspot cycle dependence in the parameter fbEs > 3 MHz is extremely clear. One must remember, however, that this parameter no longer is physically simple, because there are both auroral zone events and midlatitude type phenomena counted together. Furthermore the fbEs values from Sodankylä in those years are very unreliable near foE because of high gain and scatter. There is really no reason to believe that the result is correct. There are no Es layers, which have that type of long term variation. The only parameter, which varies like the sunspot cycle, is the foE, and in some years foE can be even higher than 3 MHz around noon hours. It is better to make no conclusions.

The blanketing power is dependent on the maximum electron density in the Es layer (Reddy *et al.*, [5]). Because the layers, which strongly dominate in the total blanketing statistics, are related to the auroral phenomena, it is clear that the ionization is caused by the precipitating electrons of the energy of some keV. Thus the long term variation seen in the occurrence frequency of total blanketing is at least partly caused by the long term variation in the occurrence frequency of soft electron precipitation events of very high fluxes.

2.4. Long term variation of absorption

There is a parameter in the ionograms, which is certainly related to the particle precipitation at a high latitude station, namely fmin, and it is thus interesting to compare the long term variations of the fbEs with the long term variation seen in the fmin. In Fig. 5 the long term variation in total absorption is presented. Also

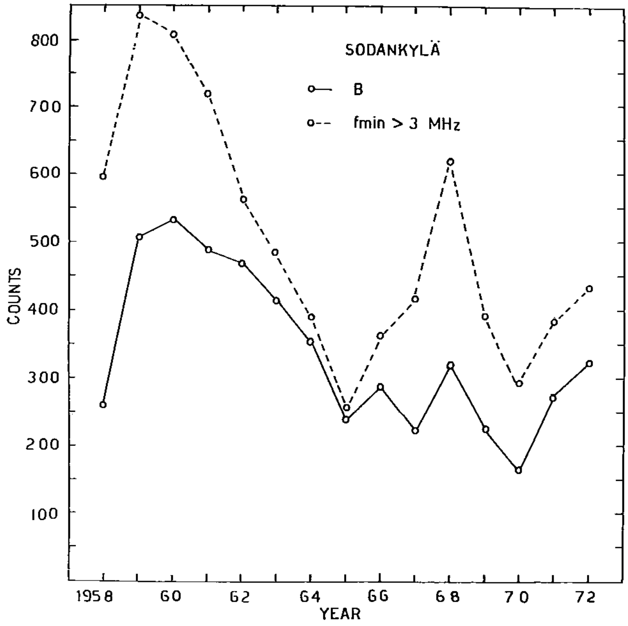

Fig. 5. Yearly counts of cases of total absorption and fmin > 3 MHz including total absorption taken from hourly data.

shown is the variation in fmin > 3 MHz. The same discussion about the foF2 dependence of these parameters as given for total blanketing is valid but not exactly in the same way because the diurnal variations of total blanketing and total absorption are very different. The occurrence frequency of total absorption is peaked in the morning (TURUNEN and RAO, [8]). The electron energies are roughly ten times higher than those causing the total blanketing events. Again it is clear that there is an anomalous long term variation in strong absorption events, *i.e.* in the occurrence frequency of energetic electron precipitation events of very high fluxes and the variation is exactly the same as in the total blanketing related to the precipitation events of lower energies. It also comes out that the anomalous variation is limited only to strong events because fmin > 3 MHz has a clear sunspot cycle correlation, a result, which could not be verified for blanketing because of limitations in the data. The correlation coefficient between the total absorption and the total blanketing variations is as high as 0.9. It is perhaps worth noting that the total absorption and total blanketing never occur in the same ionogram and the data are in this respect independent.

The anomalous long term variations in blanketing and absorption are based on reliable parameters. They show that variations not following the sunspot cycle occur at high latitudes thus giving in a way an indirect verification that the other long term variations not correlating with the sunspot cycle are not impossible in principle in spite of their peculiarities.

3. *Summary*

The long term variation of the Es layer at a high latitude station cannot be defined with one parameter but many parameters are needed, which must be defined in such a way that as good a separation as possible between the different physical processes controlling the Es layer formation is obtained. In this study the long term variation in the midlatitude types of Es was studied by adding the »c» and »h» types of Es together and taking the yearly counts of events from Es type data. The maximum appeared in 1970 when the occurrence frequency was about 100 times higher than in 1958 – 1960. The change can be explained by a systematic movement of the highest latitude where the midlatitude type Es layers are formed. The period of the movement is longer than 11 years. Possible period is 22 years although it is hard to understand why the period of 22 years could be much more important than the period of 11 years. Other periods may be important, too. Before any discussion about the possible mechanism causing the observed long term variation can be given the period must be accurately known.

The long term variation in the »r» type Es exhibits double maxima around the sunspot maximum years and the minimum at the sunspot minimum. The connection to the sunspot cycle is clear but not linear. The explanation that the variation is caused by a movement of the »r» type Es zone is very promising although strictly speaking not verified. The long term variation of the »r» type Es has connections to soft particle precipitation events under special conditions described in the text.

A long term variation seen in the »a» type Es shows a decrease in the occurrence frequency from 1958 to 1966, after which a slow increase occurred.

A very peculiar long term variation is seen in the occurrence frequency of Es layers having high blanketing power. These layers are related to auroral zone processes, and the soft particle precipitation is at least partly responsible for the blanketing power. The occurrence frequency of cases of total blanketing was very low in 1958 but reached a maximum in 1960. The minimum was reached in 1970 and there was no significant structure in the variation between the maximum and the minimum. If there is any variation related to the sunspot cycle it is in any case out of phase by several years.

Exactly the same behaviour is seen in the total absorption, which is related to particle precipitation, too, but in a higher energy range. This indicates that there is a peculiar long term variation in strong particle precipitation events both in the energy range causing ionization in the E layer and in the energy range causing ionization in the D layer.

In all cases a comparison to the sunspot cycle was made and it was found inadequate to try to explain the variations with the sunspot cycle alone except perhaps the case of the »r» type Es. It would be much better to try to find relationships with magnetic activity than with sunspot cycle but the periods involved are so long that the data are inadequate in any case.

The sporadic E phenomenon is at a high latitude station so complex that it is very difficult to see physical relations to the other processes. It is clear that both the atmospheric processes and the auroral zone or magnetospheric processes must be taken into account. The long term variations of different types of Es phenomena seem to be in most cases quite independent and thus it is not possible to use a parameter common to all, for example low foEs and fbEs values.

It was also seen that it is not worth attempting a long term study on Es without a careful examination of possible sources of error, both in the interpretation and in the measuring system. This part of the work took in fact much more time than the long term study itself after it was known what was possible to study and what the possible methods were.

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