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SEQUENTIAL ES AT SODANKYLÄ

by

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Abstract

Nine sequential Es events which occurred in the moths of May, June and July, 1973, at Sodankylä are analyzed in detail in the present study. All the events occurred during the afternoon hours and they generally lasted 4—7 hours. During a sequence the disturbance starts in the upper E region and lower F 1 region and gradually descends to low E region altitudes. The time during which the blanketing frequency and top frequency of the disturbance were maximum seems to correspond quite well with the time at which the disturbance reached the lowest altitude during the sequence. It is suggested that sequential Es is caused by the downward movement of ionized layers, which is due to a »corkscrew» mechanism. The persistence of these layers at low altitudes is attributed to the abundance of metallic ions at these latitudes.

1. *Introduction*

Attention was first drawn to the existence of a sequential type of Es in the ionosphere by SKINNER *et al* [12] at Ibadan; they termed it »ridges» in the F 1 layer. SAHA and RAY [10] observed a E2 layer at Haringhata and this E2 layer seemed to be part of a sequential Es.

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MATSHUSITA [7] was the first to investigate the phenomenon in detail from ionograms obtained at various latitudes. He classified sequential Es into three types: a 'morning type' which appears in the early morning and apparently descends and then rises; an 'evening type' which appears in the evening and gradually descends while the maximum frequency decreases; and a type of sequential Es that seems to move generally downwards and to persist more than three hours.

It is reported in the *Annals of the I.G.Y.* [1] that sequential Es develops from an E2 layer and occurs frequently at medium and low latitudes. It has been observed to start as an E2 layer or F1 stratification with a critical frequency near 4 MHz and a mean virtual height between 140 and 210 km. The layer then decreases in virtual height and increases in critical frequency until a height of about 100 km is reached. This development is normally reported to take several hours. It is suggested that this could be due to the downward motion of an ionized cloud.

SHAPLEY in the *Atlas of Ionograms* [11] discusses the development of sequential Es. He feels that it is formed by a redistribution of the normal E and F region ionospheric structure. Though the sequence he studied lasted several hours he considers that a typical event may be much faster. In his sequence, the layer seems to have formed between the E peak and F region and descended through the E region with time. When it became sporadic E, it was of the 'h' type and later it was of the 'c' type. He suggests that the redistribution of ionization, which causes sequential Es, is the result of vertical drifts of ionization.

2. *Analysis and results*

Analyzed here are nine examples of sequential Es observed at Sodankylä during the summer of 1973. The ionograms showing the presence of sequential Es on 7 June 1973 are presented in Fig. 1. In Fig. 2 the parameters measured from the ionograms obtained during the occurrence of sequential Es on 7 June are plotted as a function of time. As can be seen from Fig. 1 the sequence develops in the form of a disturbance in the F1 heights and then it gradually descends. In the following description we will use the word 'disturbance' to refer to the sequential Es on a particular ionogram because the term sequential Es means the entire event, which may last several hours, as can be seen from the ionograms for this time. The virtual height of this disturbance is plotted

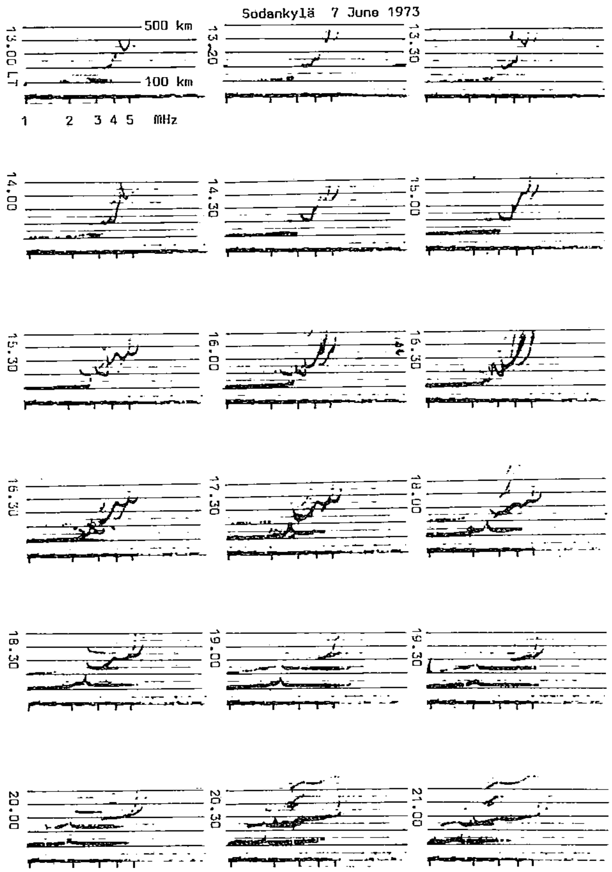

Fig. 1. Ionogram sequence showing the presence of sequential Es.

as a function of time in Fig. 2. It can be seen from this graph that the height variation with time has four distinct stages in which the disturbance has different rates of descent. During the first hour of the sequence the height decreases by as much as 60 km (from 255 to 195 km). After that the decrease is less rapid: the height descends from 195 km at 1400 hrs. L. T. to 125 km at 1730 hrs. — i.e. at a rate of approximately 20 km per hour. Again at 1730 hrs. L. T. the rate of decrease abruptly changed to a lower pace. It decreased from 125 km at 1730 hrs. to about 110 km at 1900 hrs. L. T., which means that the rate of decrease was about 10 km per hour during this period. From 1900 hrs. L. T. on the

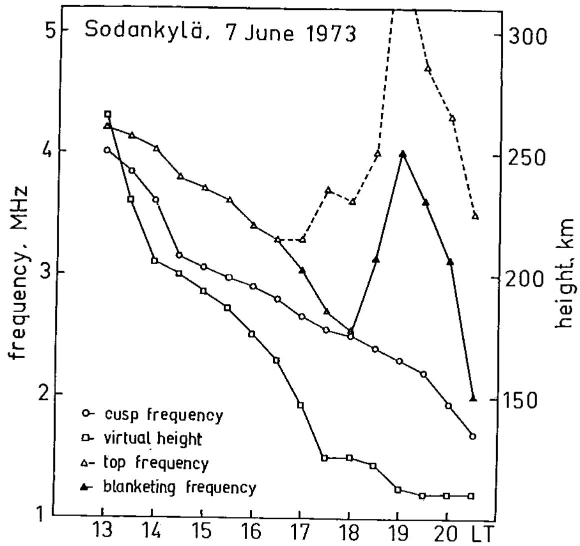

Fig. 2. Parameters measured from the ionograms shown in Fig. 1. All values are scaled from the o-component.

change in the height was very small and the reflection remained stationary at 110 km.

The bottom and top frequencies of the disturbance are plotted in this graph on the same time scale. Also shown is the blanketing frequency. From these plots it can be seen that both the top and bottom frequencies of the disturbance gradually decrease with time. At 1700 hrs. L. T. the disturbance begins to be partially transparent. By this time it had also reached E region altitudes (about 150 km), so from then on it could technically be referred to as an Es layer. At 1730 hrs. L. T., the time at which the rate of descent of this isturbance underwent an abrupt change, the foEs began to increase. From 1800 hrs. L. T. on the blanketing frequency also began to increase very steeply, reaching a maximum value of 4 MHz at 1900 hrs. L. T., foEs also reached its maximum at the same time. At 1900 hrs. L. T., the altitude of the disturbance reached 110 km, after which it remained static. This period corresponds to the stage of decrease in foEs and fbEs values.

In the present investigation we have analyzed eight more sequences of this nature observed in May, June and July of 1973. The virtual heights of these events are shown in Fig. 3.

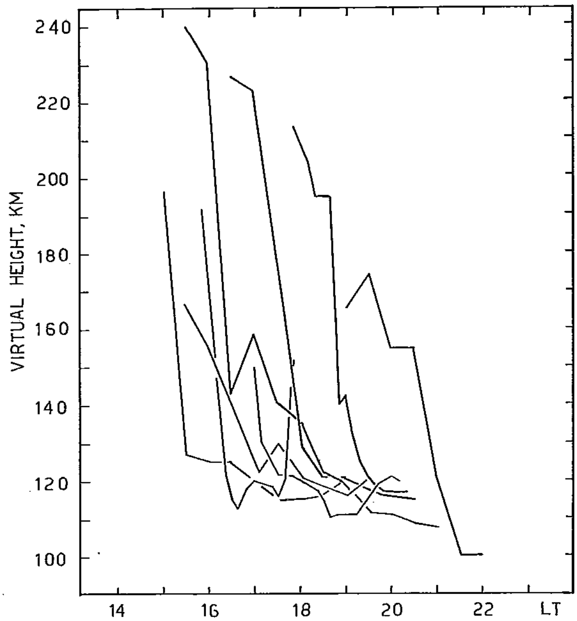

Fig. 3. Virtual heights of eight sequential Es events which occurred at Sodankylä in the months of May, June and July 1973.

The following broad features were found to be common to all the sequences analyzed:

a) The sequences occurred during the afternoon hours at Sodankylä
b) The entire sequence generally lasted 4 . . .7 hours
c) The disturbance was first noticed in the upper E region or F1 region altitudes and then gradually descended
d) The rate of decrease was maximum at the start of the sequence and almost zero at the end of the sequence
e) foEs and fbEs were maximum at the time the disturbance reached the height range of 110—120 km
f) When the sequence reached its lowest height and became static, both foEs and fbEs began to decrease.

3. *Discussion*

Sequential Es occurred at Sodankylä in the afternoon hours and lasted 4 . . . 7 hours in all cases analyzed here. As suggested by Matsus-

HITA [7], it was found to descend and then sometimes to reascent again (see Fig. 3). Matsushita suggests that sequential Es occurs mostly in summer at high latitudes. This seems to be true for Sodankylä and the authors feel that the occurrence of sequential Es at Sodankylä is connected with the summer afternoon peak in the occurrence of 'c' and 'h' types of Es observed at this station. The times at which the sequences started at Sodankylä also agreed well with Matsushita's results.

It is worth considering, what type of ionization distributions in the E and F1 regions could cause sequential Es in the ionograms. SMITH [13] obtained electron density profiles during the night of 22nd February 1968 with a series of five rocket launchings starting at midnight and continuing at intervals of one-and-a-half hours. From these profiles it can be seen that the sporadic E layer, which lay initially at an altitude of 140 km, descended at a rate of few hundred meters per second. As it descended, it tended to become thinner and sharper. This could well be what happens during a sequential Es. The lowest frequency of the disturbance decreases continously with time. This is understandable because the disturbance layer descends to regions of ever decreasing ambient electron density. When the layer moves downwards during the initial stages of the sequence, the top frequency of the disturbance, indicating perhaps the peak electron density in the layer, does not increase much. At 1700 hrs. L. T. (see Fig. 2) the virtual height of the disturbance dropped below 150 km and it became partially transparent. It is conceivable that at this time the real height of the lower part of the layer was already at an altitude where the atmosphere is partially turbulent. This could have produced irregularities in the lower part of the layer and the presence of such irregularities might in turn have produced the non-blanketing sporadic E reflections in the ionogram (RAO and SMITH, [8]. DERBLOM [4] obtained electron-and ion-density profiles from a rocket launching at Kiruna. Around the time of the launch a sequential Es was noticed in the ionogram. The time of launching coincided almost exatly with that at which the sequence was at its lowest altitude. The electron density profile reveals enhanced ionizations at 92 and 96 km, corresponding to the sporadic E layers observed in the simultaneous ionosonde records.

Incoherent scatter observations at Arecibo have shown that night time electron density enhancements are formed in the upper E2 region and move down to merge with a stable Es layer lying between 105 and

110 km (Rowe, [9]. Rowe also reports that this phenomenon is strongest in winter and is accompanied by an underlying Es layer near 90 km. From contour plots of electron density he has noticed that the electron density enhancements descend from an altitude of over 140 km to 105—110 km where they merge with sporadic E layers. This seems to correspond quite well with the sequential Es noticed at Sodankylä. However we believe that when the layer descends, it becomes sporadic E when it reaches the E region altitudes instead of merging into already existing sporadic E layers, as suggested by Rowe [9].

The windshear theory of the formation of middle latitude sporadic E, developed by Whitehead [14], might well account for many of the features observed in the sporadic E phenomenon. It is, however, found that low altitude (below 110 km) sporadic E layers occur at places that reveal no clear relationship with simultaneously observed neutral wind profiles (*e.g.* Wright *et al*, [15]). Observations of neutral winds by Wright *et al* [15], however, suggest that the profile of horizontal velocities descends. This is consistent with the theory of internal gravity waves (Hines, [5]), according to which the phase velocity of the waves is directed downwards, whereas the group velocity is directed upwards. Chimonas and Axford [2] showed that a downward propagating wind profile eventually produces low-lying layers of ionization in positions that are not obviously related to the instantaneous profile. They postulated a 'corkscrew' mechanism for the vertical transport of long-lived ions from higher to lower altitudes. It is quite probable that such a mechanism is at work during sequential Es.

One of the difficulties in the explanation given above is to account for the fact that sequential Es lasts several hours. This means that even though the layer descends to high collision-frequency regions, it has a capacity for survival. The presence of metallic ions reduces the recombination coeffient, thus prolonging the life of the layer (Lehman *et al*, [6]). From an analysis of the experimental mars-spectrometer data, Danilov [3] concludes that the half width of Fe^+ and Mg^+ layers increases with decreasing altitude at altitudes of 80—120 km. The (Mg^+) / (NO^+) ratio also increases with decreasing altitude. Thus the persistence of the layer for several hours during a sequential Es as it comes down in altitude can probably be explained by the presence of metallic ions.

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REFERENCES

1. *Annals of the International Geophysical Year, Vol. III, Part I*, 1957: Editors W. J. G. Beynon and G. M. Brown. Porgamon Press, p. 104.
2. CHIMONAS, G. and W. I. AXFORD, 1968: Vertical movement of temperate zone sporadic E layers. *J. Geophys. Res.*, **73**, 11—117.
3. DANILOV, A. D., 1973: *Meteoric Ions in the D- and E-regions.* Paper presented at the Cospar Sixteenth Plenary Meeting, Konstanz, FRG, 1973.
4. *Derblom, H.*, 1971: Prelimary report on the electron- and ion-density profiles from twilight high-latitude rocket experiment. *Proceedings of the SAR symposium held in Kiruna. KGO Report No. 714.*
5. HINES, C. O., 1960: Internal atmospheric gravity waves at ionospheric heights. *Can. J. Phys.*, **38**, 1441—1480.
6. LEHMAN, H. R., and C. U. WAGNER, 1966: Meteoric ions in the lower ionosphere *J. Atmos. Terr. Phys.*, **28**, 617—625.
7. MATSUSHITA, S., 1955: Sequential Es and Lunar effects on the equatorial Es. *J. Geomagnet. Geoelec.*, Kyoto, **7**, 91—95.
8. MUKUNDA RAO, M., and L. G. SMITH, 1968: Sporadic E classification from rocket measurements. *J. Atmos. Terr. Phys.*, **30**, 645—550.
9. ROWE, J. F., 1973: *Night-time E-region incoherent scatter measurements at Arecibo.* Paper presented at the Cospar Sixteenth Plenary Meeting, Konstanz, FRG, 1973.
10. SAHA, A. K., and S. RAY, 1955: Some features of the E 2 layer observed at the Ionosphere field station, Haringhata, Calcutta. *J. Atmos. Terr. Phys.*, **7**, 107—108.
11. SHAPLEY, A. H., 1970: *Atlas of ionograms, Report UAG-***10** *of World Data Center A, Part III*, **11**.
12. SKINNER, N. J., BROWN, R. A., an R. W. WRIGHT, 1954: Multiple stratification of the F layer at Ibadan. *J. Atmos. Terr. Phys.*, **5**, 92—100.
13. SMITH, L. G., 1970: A sequence of rocket observations of nighttime sporadic E., *Ibid.*, **32**, 1247—1257.
14. WHITEHEAD, J. D., 1970: Production and prediction of sporadic E. *Rev. Geophys.*, **8**. 65—114.
15. WRIGHT, J. W., MURPHY, C. H., and G. V. BULL, 1967: Sporadic E and the wind structure of the E-region. *J. Geophys. Res.*, **72**, 1443—1460.