IV. ATMOSPHERIC ELECTRICITY AND THE IONOSPHERE

EXPERIMENTAL STUDY OF ATMOSPHERIC ELECTRICITY AND THE IONOSPHERE

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As it has been indicated in the paper entitled "The beginnings and the IGY" in this volume, the study of atmospheric electricity became the part of the observation programme of the Observatory, because its relation to the electromagnetic field of the Earth. Considering the inclusion of ionospheric measurements, it arised, when the investigation of the geomagnetic variation field necessitated the knowledge of the simultaneous variations in the ionosphere.

Atmospheric electricity

The study of atmospheric electricity can be divided on the basis of its place in the frequency spectrum into two parts. One of them is the static electric field and the other the electromagnetic field. The source of both of them is the thunderstorm activity, more precisely the charge separation in thunder-clouds. The mechanism of charge separation is not quite understood, but it is widely accepted that conditions of charge separation are the intensive lifting of air and the presence of cloudparticles. It is assumed that charge separation occurs in cloud particles in the atmospheric electric field due to the influence phenomenon. Under normal conditions, the influence charge is positive in the bottom of a cloud particle. The lighter neutral particles transported upwards by the vertical airflow, touching the heavier cloud particles floating in the airflow get positive charge decreasing at the same time the positive charge of the cloud particle. Thus, the cloud particles in the lower part of the developing thunder-cloud become more and more negative, while the lighter neutral particles after gaining positive charge are transported to the upper part of the cloud. In this way the thunder-cloud becomes an electric dipole with a positive charge centre at the top and a negative one in the lower part of the cloud.

If the thunder-clouds all over the world are taken into account, they can be considered as a generator in an electric circuit maintaining a voltage between the

Earth's surface and the so called atmospheric electric equalizing layer in the ionosphere. The system works like a space bounded by two spherical surfaces and air of high resistivity between them, i.e. as a spherical layer condenser. This condenser is a leaky condenser and the global thunderstorm activity provides for the maintenance of the voltage between the "electrodes" of the condenser.

The leakage of the condenser is due to the fact that the resistivity of the air is finite. Thus, a weak vertical air-earth current is flowing from the equalizing layer to the Earth's surface in the so-called "fine weather" areas, that is in areas without thunderstorm activity. This vertical air-earth current produces a potential difference on a column of air of unit cross section and of unit height, which is called atmospheric electric potential gradient. As it has been mentioned, the resistivity of air is finite. Consequently, the resistance of the air column is changing according to the variation of local factors (ionization by radioactive gases and galactic cosmic rays, concentration of aerosol particles, humidity, wind) determining the conductivity of the air in the vicinity of the ground, where the measurements are carried out. Because of this circumstance, the global atmospheric electric circuit can be characterized by three parameters, by the vertical air-earth current, the atmospheric electric potential gradient and the conductivity of air. If at least two of this characteristics are recorded, then the third can be computed assuming that Ohm's law is valid. However, Ohm's law is valid only under "fine weather" conditions; that is in case of absence of fog, thunder-clouds and strong wind. Otherwise convective currents can falsify the results.

Measurement of the point discharge current

As it has been mentioned in the paper entitled "The beginnings and the IGY" in this volume, the first regularly recorded atmospheric electric quantity was the point discharge current. The phenomenon and its measurement were described in that paper. Here we report on some results of these measurements.

The electric charge transported by point discharge is one component of the charge exchange between the atmosphere and the ground. Positive charge is transported to the ground (or negative charge gets to the atmosphere) by negative lightning discharges, by the vertical air-earth current, by the precipitation and point discharge in case of clouds with a positive charge centre in the lower part of the cloud. Negative charge is transferred to the ground (or positive charge gets to the atmosphere) by positive lightning discharges and point discharge in case of clouds

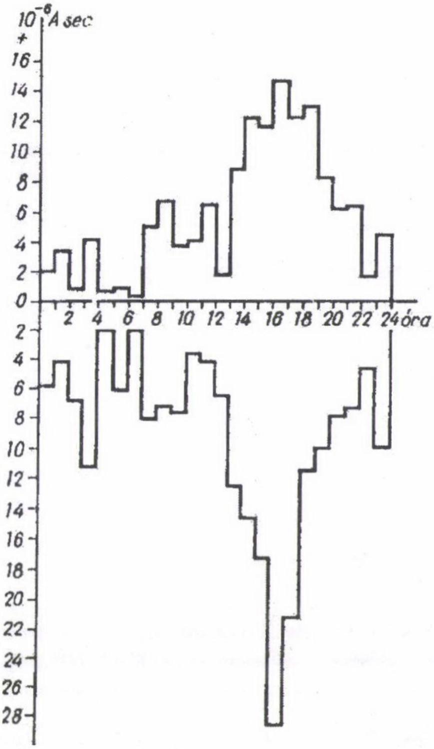

Fig. 1. Annual average daily variation of the charge transported by point discharge plotted for charges of both signs observed in the Geophysical Observatory Nagycenk

of a lower negative charge centre. According to the investigations, there is an equilibrium in the charge exchange between the atmosphere and the ground.

The charge transported by point discharge can be obtained by the determination of the area between the recorded curve and the straight line indicating zero current (Bencze and Märcz 1967a). This procedure gives the charge in As, since the vertical scale of the record is calibrated in Ampere (A), the horizontal scale is time fixed by the recording paper or film transport. The evaluation of the records can be made in the simplest case by means of a planimeter. However, the digital recording enables also the determination of the charge, if the sampling interval is small enough. The periods without point discharge can be eliminated by prescribing a threshold value. In this case only those periods are recorded, when point discharge occurred during the day.

Our results have shown that the charge transported by point discharge indicates the dominance of the negative charge transport (Fig. 1) (Bencze and Märcz 1963). The daily variations of the charges of both signs show a minimum in the morning hours and a broad maximum in the afternoon and evening hours. This type of the daily variation is similar to that of the thunderstorm activity confirming the connection of the point discharge with the thunderstorm activity. Accordingly, the occurrence of point discharge is limited mainly to the summer months.

The recordings of the point discharge currents enable also the recognition of the electrical structure of thunder-clouds (Bencze 1966). As it is known, the thunder-clouds can be approximated by a vertical electrical dipole. Thus, if a thunder-cloud is approaching the site of observation, first the effect of the upper pole is dominant. In course of the further advance of the cloud the effect of the lower pole becomes determinant. After the cloud passed the place of observation, the effects appear in the opposite order. In this way a thunder-cloud, the upper pole of which is positive, appears on a point discharge current recording in the form of positive current followed by negative current and then repeatedly positive current due to the change of the increased positive potential gradient to a negative one and then again to the original positive potential gradient (Fig.2). In case of a thunder-cloud of opposite polarity, the order of the changes of the current direction is the opposite according to the sign of the charge centers.

It is interesting to note that the sensitivity of the equipment can be increased and already fleecy clouds can be registered in case of passing through its surroundings. This experience was obtained in connection with the restoration of the liberty statue at the top of mountain Gellért in Budapest. The provision for the safety of the people working on the platform surrounding the monumental statue necessitated the thunderstorm forecast. This task was solved by us mounting to the top of the platform a point made of rust-proof steel and connecting it with a sensitive recording galvanometer. The sensitivity of the equipment could be increased by changing the resistances in the circuit of the galvanometer until it registered also isolated fleecy clouds.

Measurement of the atmospheric electric potential gradient

After starting the registration of the point discharge currents, the next step was the realization of the measurement of the electric potential gradient. In the study of atmospheric electricity the expression potential gradient is generally used, because of the variation of the potential difference within the space ranging from the ground

Fig. 2. Change of the point discharge current coresponding to the electrical structure of the thunder-cloud and due to the increased potential gradient, which is caused by the approach of the charge centers of different signs measured in the Geophysical Observatory Nagycenk

to the height of 1 m. The expression field strength could be used in case of the linear increase of the potential moving off the ground under fine weather conditions.

As it has been described in the previous paper, the radioactive collector method has been applied for the measurement of the atmospheric electric potential gradient. The study of the literature has shown, namely that this method is mostly used at atmospheric electric stations because of its reliability. The disadvantage of the radioactive collector, however is its relatively great time constant (the careful choosing of the activity of the radioactive material has already been mentioned before). The sensitivity of the recording was set to 10 mm/100 Vm^{-1} following international recommendations and a recording speed of 20 mm/hour was chosen as in case of other measurements carried out in the Observatory. The measurement of the atmospheric electric potential gradient was aimed first of all at the investigation of the global atmospheric electric circuit. Thus, the measurements could be confined to the range ± 250 V/m. If the potential gradient exceeds this limits, the recorded grid current of the valve working as an electrometer gets to saturation. In course of the evaluation of the recordings hourly averages are computed.

The results of the measurement of the atmospheric electric potential gradient indicate that the recordings correspond to that of undisturbed continental area. The diurnal variation of the potential gradient in summer months shows the increase of the potential gradient already in the morning hours differing from the diurnal variation of the global thunderstorm activity (Carnegie curve). This circumstance indicates that the radioactive collector is already located at that time in the exchange layer characterized by turbulence dispersing the ionizing radioactive decay products (radon, thoron) in a thicker layer. Hereby, the conductivity of the air is decreased and the potential gradient increased. In the winter months the effect of the exchange layer is considerably reduced and the diurnal variation of the potential gradient is much more similar to that corresponding to the global thunderstorm activity. In Fig. 3 the diurnal variation of the potential gradient recorded in the Geophysical Observatory Nagycenk is presented constructed on the basis of data measured in the period from 1964 to 1976 (Märcz and Bencze 1981). The analysis of the data shows that the potential gradient displays also a seasonal variation with a minimum in summer and a maximum in winter.

The recordings of the potential gradient indicate also short period fluctuations, which are called atmospheric electric agitation. These short period fluctuations are due to local effects influencing the conductivity of the air. The conductivity of the air can be affected by the changing concentration of aerosol particles transported by the wind from various directions. The concentration of aerosol particles changes the conductivity by modifying the ion composition and hereby the resultant mobility of the ions. According to various investigations, the parameters of the atmospheric electric agitation depend not only on the speed and direction of the wind but also on the sky cover and on the type of the airmass related to the change of the weather (Bencze 1965). Concerning the sky cover, its effect might be connected with its influence on the illumination intensity and thus, also on the turbulent intensity. The types of airmasses can have qualities advantageous or disadvantageous in the point of the development of the atmospheric electric agitation. Advantageous can be the Atlantic cold airmasses in summer, the continental cold and polar cold airmasses both in summer and in winter showing large vertical temperature gradient

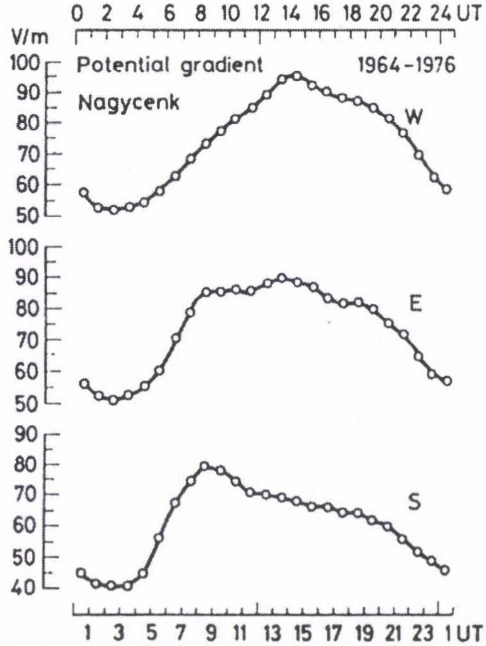

Fig. 3. Diurnal variation of the atmospheric electric potential gradient in different seasons (W=winter, E=equinoctial month, S=summer) recorded in the Geophysical Observatory Nagycenk

favourable for the development of the agitation. Disadvantageous can be subtropic, continental warm, Mediterranean mild and Atlantic mild airmasses indicating only small vertical temperature gradient, which is not favourable for the production of agitation.

The diurnal variations of the fluctuations of different period (0–6, 6–12, 12–24 and 24–60 min) show a maximum about midday in case of the first two period ranges in the summer months, but variations in the winter months more similar to that of the potential gradient (Bencze 1964). Considering the third and fourth period ranges, the diurnal variations are more similar to that of the potential gradient. These daily trends prove the above mentioned role of turbulence in the development of the atmospheric electric potential gradient and that of the atmospheric electric agitation indicating a maximum about midday in case of the shorter period fluctuations in summer, but a variation more resembling that of the potential gradient in case of the longer fluctuations in both summer and winter months. These conditions determine also the seasonal variation of the atmospheric electric agitation. In Fig. 4 the seasonal variations of the four period ranges and that of the potential gradient are shown. It can be seen that the seasonal variation of the fourth period range is the most similar to that of the potential gradient displaying increased values in winter as compared with the summer months. Generally, it has been found that the amplitude of the atmospheric electric agitation is proportional to the magnitude of the potential gradient.

Study of the ionosphere

It has been mentioned in the introduction that ionospheric measurements were initiated for the support of the investigation of the geomagnetic variations. As it is known, the diurnal variation of the geomagnetic variation field is due to an equivalent ionospheric current system located in the lower part of the E region of the ionosphere, where the electrical conductivity of the atmosphere is greatest. This part of the lower ionosphere can also be observed in a simple way by the determination of the ionospheric absorption of LF, MF radio waves, that is by oblique incidence called A3 method. However, it is to be noted that the study of the lower ionosphere was also motivated by the circumstance that at that time the upper ionosphere (F region) was observed by the vertical sounding of the ionosphere in the meteorological station Békéscsaba of the Meteorological Institute. The data of these measurements were mainly used for the preparation of the forecasting of radio wave propagation. This ionosonde was transferred to the Geophysical Observatory Nagycenk in 1991.

Variations of the ionospheric absorption of radio waves

The determination of the ionospheric absorption of radio waves was carried out in the beginning by recording the sky (reflected) waves of two transmitters, as it has been mentioned in the paper entitled "The beginnings and the IGY". However, it shortly turned out that the power of the transmitter Budapest (539 kHz) is changing and hereby the field strength of the sky wave is also subject to artificial variations. Thus, the determination of the ionospheric absorption was continued using only the transmitter Ceskoslovensko (272 kHz); though, meanwhile the recording of the sky waves of other transmitters being in operation in the LF and MF ranges and located in proper distance from the Observatory was also attempted.

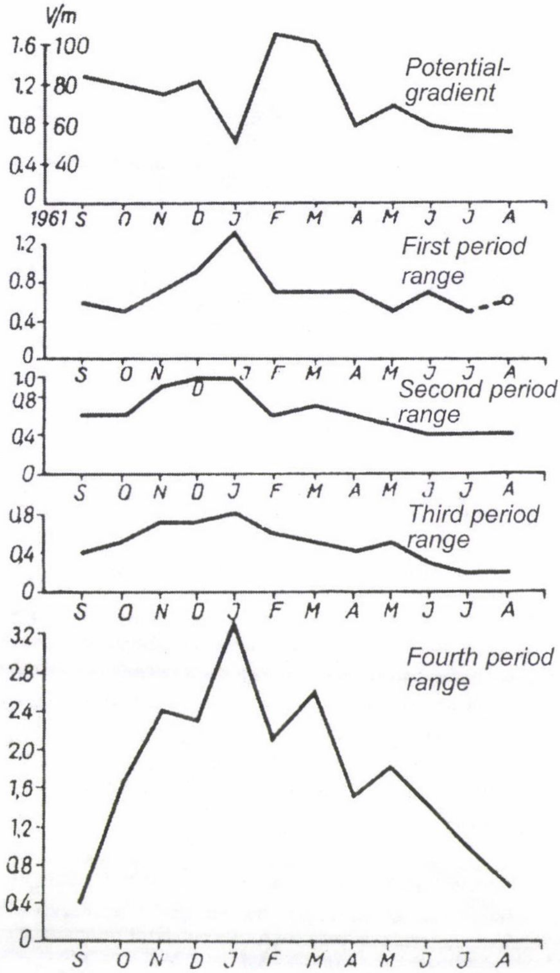

Fig. 4. Seasonal variation of the atmospheric electric agitation referring to the four period ranges and that of the potential gradient observed in the Geophysical Observatory Nagycenk

The absorption of radio waves in the lower ionosphere is determined partly by the absorption taking place in the medium traversed by the waves in course of their path to the point of reflection and back to the receiver, partly by the absorption directly in the vicinity of the reflection point. The first type of absorption is called non-deviative, the latter type is called deviative absorption. It is the non-deviative absorption, which decreases the field strength of the sky wave by day due to the

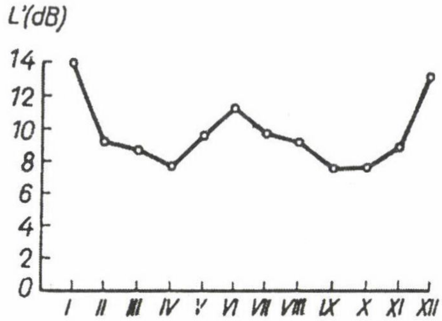

Fig. 5. Seasonal variation of the ionospheric absorption of radio waves in case of the transmitter Budapest (539 kHz) measured in the Geophysical Observatory Nagycenk

presence of the D layer and the non-deviative absorption determines the observed field strength by night after the almost complete disappearance of the D layer. Thus, the daily variation of the ionospheric absorption of LF and MF waves shows increased values by day as compared with the night values, since the effect of the non-deviative absorption is greater than that of the deviative absorption. The electron density in the D region is due to the extreme ultraviolet (EUV) radiation of the Sun, consequently the absorption of these radio waves can be expressed in day-time by the solar zenith angle.

It has been mentioned before that the variation of the ionospheric absorption of LF and MF waves depends on the solar zenith angle. If it is so, then one would expect that the seasonal variation of the absorption shows large values in summer and small values in winter. However, the data show besides large values in summer, after a minimum in autumn large values in winter, too (Fig. 5) (Bencze and Märcz 1967b). This phenomenon is called winter anomaly and it is due to the seasonal variation of the vertical component of the wind in the lower thermosphere (corresponding to the lower ionosphere) indicating downward flow in winter. This means that the downward wind transports additional easily ionizable nitrogen-oxide (NO) from the source region above to the vicinity of the reflection height, hereby increasing the ion production and the absorption of the radio waves. This is the reason why the seasonal variation of the ionospheric absorption of LF, MF radio waves does not follow the zenith angle rule at mid-latitudes.

Another anomaly of the ionospheric absorption of LF and MF waves is the so called geomagnetic after effect, or post-storm effect. This phenomenon is related to geomagnetically disturbed periods and it appears as increased absorption 3-4 days after the end of the geomagnetic disturbance. It has been found using data of the level of atmospheric radio noise measured at 27 kHz in high mid-latitudes that the appearance of the effect indicated by the enhancement of the level of atmospheric radio noise, is delayed in case of a station located at a lower latitude as compared with the time of the appearance of the effect observed by a station of higher latitude (Fig. 6) (Bencze and Szemerédy 1973). The increased level is due to the improvement of the reflection conditions of the VLF waves in the vicinity of the reflection height (70–90 km) because of the increased electron density there. This phenomenon leads to the conclusion that the post storm effect is also related to the transport of easily ionizable nitrogenoxide from high to low latitudes. This conclusion is also supported by the increase of the post storm effect in winter as compared with the post-storm effect in summer, in accordance with the latitudinal variation of the concentration of the nitrogen-oxide and its change with season showing winter maximum at high latitudes.

Vertical incidence sounding of the ionosphere

After ceasing the ionospheric investigations in the Central Institute for Atmospheric Physics of the Meteorological Service because of the reduction of the staff in 1990, the ionosonde operated at the meteorological station in Békéscsaba was offered to the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences. The Institute could assure place for the instrument in its Geophysical Observatory Nagycenk. However, not every condition could be fulfilled at that time for the installation of the ionosonde. Though, the building and the infrastructure was available, it was necessary to set up a tower made of steel for the placing of the transmitting and receiving antennas. For the preservation of the undisturbed conditions, it was necessary to locate the tower in a given distance from the site, where the absolute values of the components of the geomagnetic field are measured; thus, the area of the Observatory had to be increased. The area by which the area of the Observatory had to be increased was determined by the dimensions of the antenna.

It was also necessary to make up-to-date the recording of the ionograms. The ionosonde was operated in Békéscsaba with analog recording unsuited to the processing of the obtained ionograms by a computer. The problem was solved by

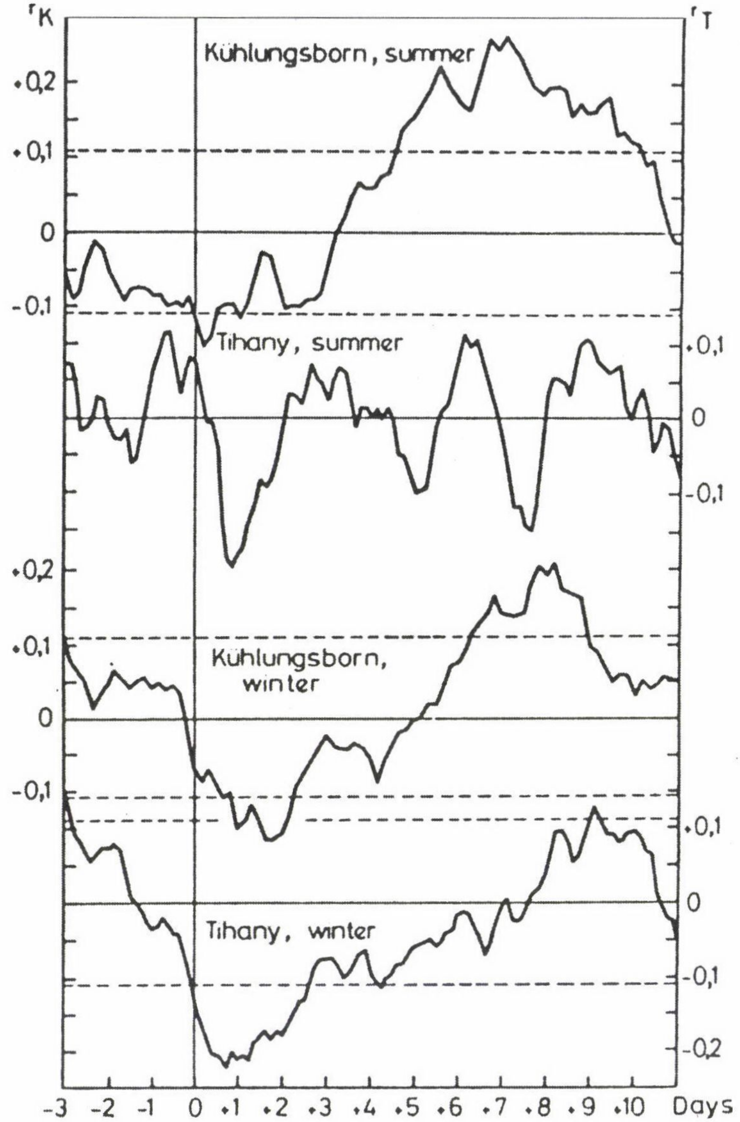

Fig. 6. Cross correlation function of the three hour (in case of Kühlungsborn four hour) averages of differences between hourly values and the corresponding monthly medians of atmospheric noise level and Kp referring to the stations Kühlungsborn (54°07′N, 11°46′E) and Tihany 46°54′N, 17°54′E). Positive shift means that Kp is delayed as compared to the level of atmospheric noise. Dashed line indicates the 99 % level of significance

mounting the proper interface in the ionosonde insuring the safe passing of the ionogram in digital form to the computer and by using the proper software. The ionosonde is operated by K. Kovács.

The temporal and spatial variations of the six frequency and three height parameters usually read from the ionograms are already known, furthermore the electron density profiles for the subpeak region of the ionosphere can also be determined, since the computation of them is enabled by computers. However, the ionosphere indicates also anomalies, that is a variation of the ionospheric regions departing from their usual behaviour. The anomalies are partly regularly returning phenomena, partly changes related to geomagnetically disturbed periods. These offer further possibilities for the research. Special phenomena are also the solar eclipses, like the last one observed as a total solar eclipse the 11th August 1999 in Hungary. The vertical incidence sounding of the ionosphere was carried out every minute during this eclipse in the Geophysical Observatory Nagycenk starting the measurement with this frequency before the day of the eclipse and continuing them also the day after the eclipse. In Fig. 7 the variation of the critical frequency foE of the E layer proportional to the maximum electron density in the E layer is plotted showing the considerable decrease of the electron density at a height of about 110 km in the period from 11^h26^m to 14^h08^m LT . The totality of the eclipse occurred at 12^h28^m LT. The change of foE in the same period of the following day is also indicated enabling the demonstration of the effect of the eclipse. In Fig. 8 the variation of the critical frequency foF1 of the F1 layer proportional to the maximum electron density in the F1 layer is presented indicating the significant decrease of the electron density at a height about 180 km in the period about the eclipse. For comparison the change of foF1 in the same period of the following day is also shown making possible the illustration of the effect of the eclipse. The decrease of the electron density could be expected, if it is taken into account that the ionization is produced in the E and F1 regions of the ionosphere by the solar extreme ultraviolet radiation. Thus, the source of the ionizing radiation was eclipsed by the Moon causing night conditions and an eclipse also in the ionosphere.

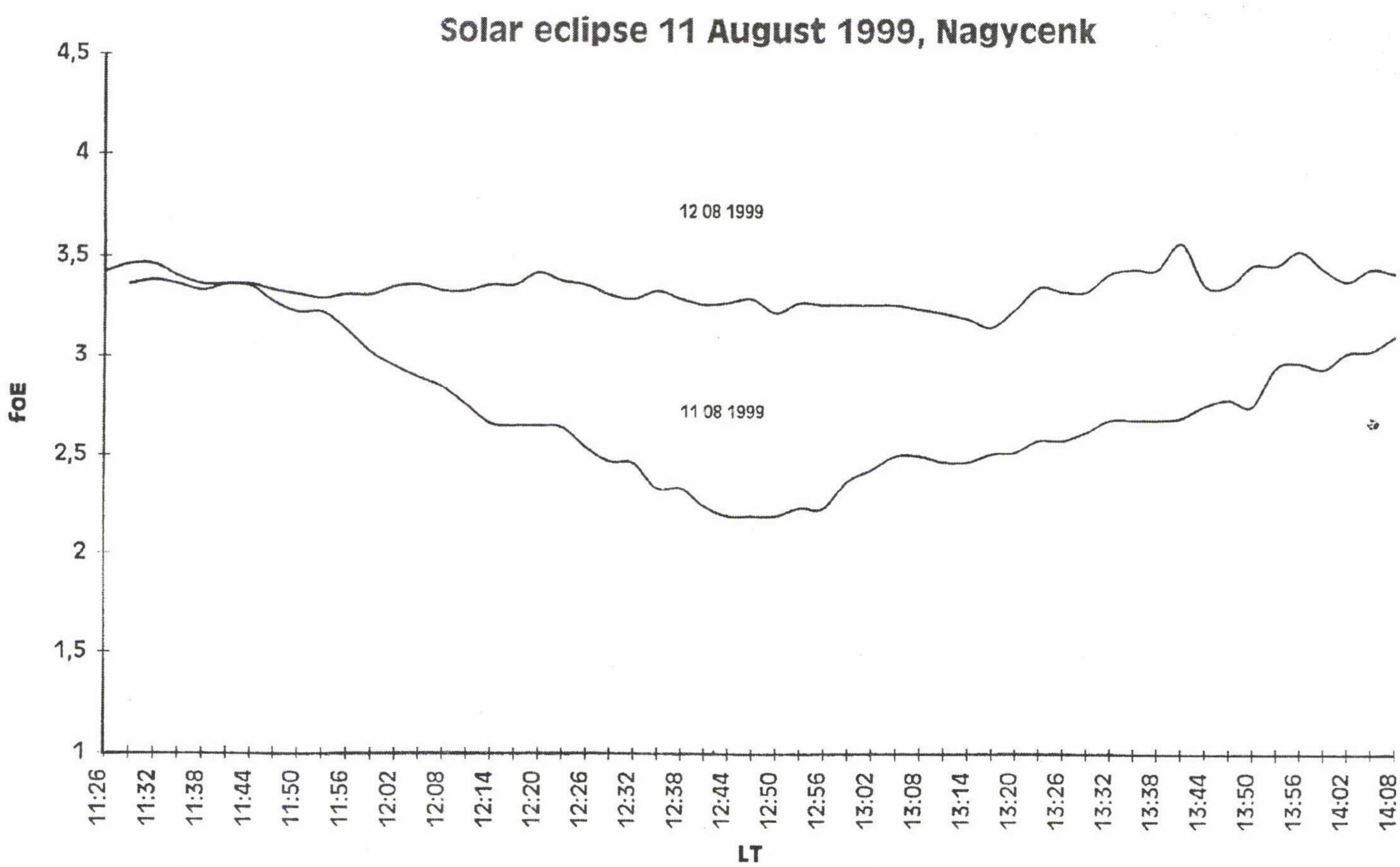

Fig. 7. Variation of the critical frequency foE of the E layer on the 11th and 12th August 1999

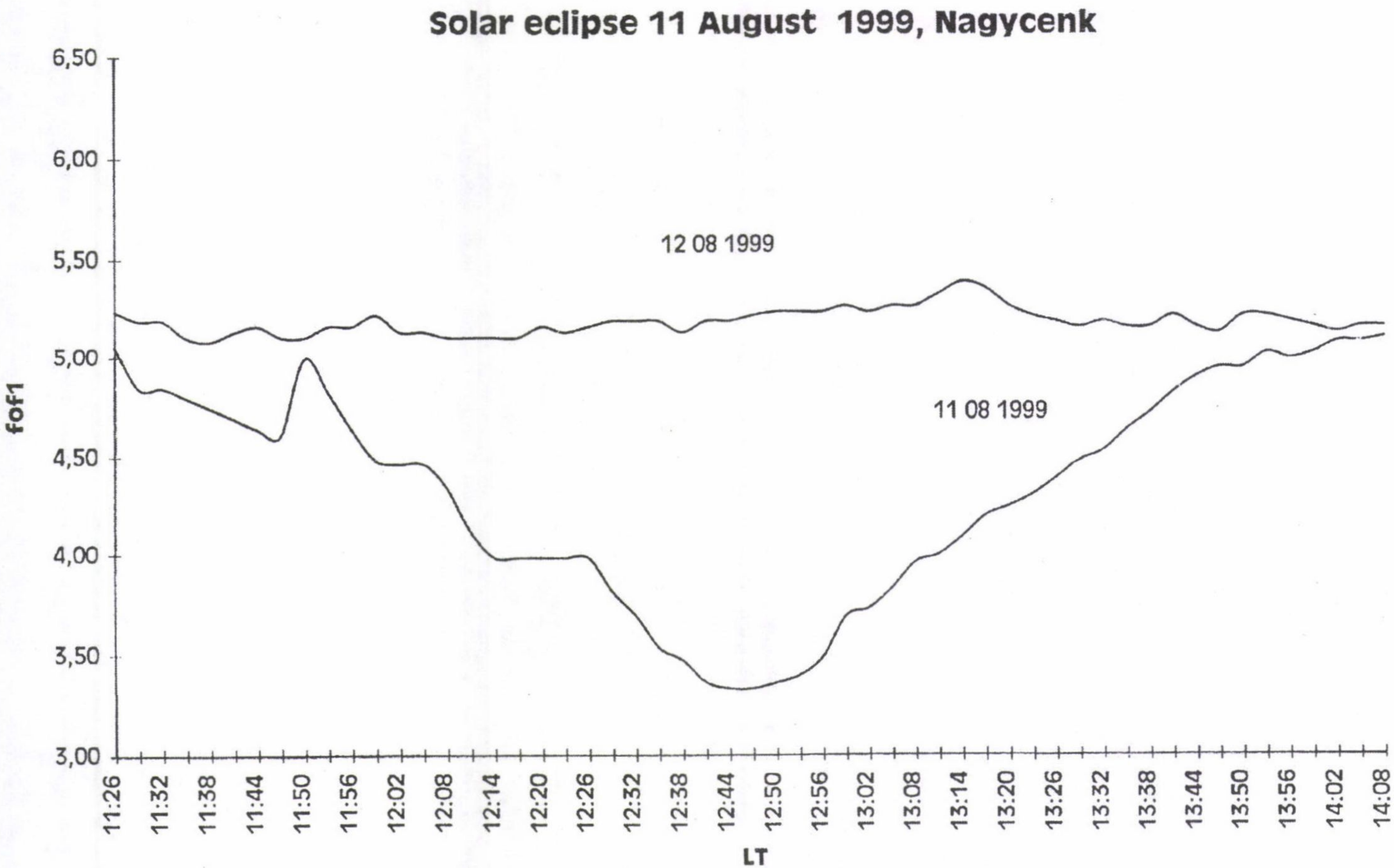

Fig. 8. Variation of the critical frequency foF1 of the F1 layer on the 11th and 12th August 1999

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