REPORTES INTERNOS 96-12
mayo 1996

IONOSPHERIC VARIATIONS BEFORE THE STRONG EARTHQUAKES OBSERVED BY TOPSIDE SOUNDER IN THE SOLAR CYCLE MAXIMUM

S.A. Pulinets, A.D. Legen'ka, A.T. Karpachev, J . Pérez Peraza,

Instituto de Geofísica UNAM
Ciudad Universitaria
04510 México, D. F.
México

PRECIO: N$ 4.00

IONOSPHERIC VARIATIONS BEFORE THE STRONG EARTHQUAKES OBSERVED BY TOPSIDE SOUNDER IN THE SOLAR CYCLE MAXIMUM

S.A. Pulinets, A.D. Legen'ka, and A.T. Karpachev

Institute of Terrestrial Magnetism, Ionosphere an Radiowave Propagation,

Russian Academy of Sciences, (IZMIRAN)Troitsk, Moscow Region, 142092, RUSSIA.

J.Pérez-Peraza,

Instituto de Geofisica UNAM, Ciudad Universitaria, Delegacion de Coyoacan,

Codigo 04510, Mexico, D.F., MEXICO.

ABSTRACT

The Intercosmos-19 satellite was launched on elliptical orbit (490 - 960 km) with inclination 74° on 27 of February 1979 and was active until middle of 1981. There were the years of high solar activity within the falling part of 21 solar cycle maximum period. The topside sounder installed onboard the orbiting satellite gives opportunity to study the global variations of the electron density distribution from the F2 layer maximum up to the satellite altitude. Due to high solar activity the extremely wide range of critical frequency variations was observed: from 1 up to 17 MHz. This makes the critical frequency very sensitive to different influences from different sources. Among the known daily, seasonal and geomagnetically disturbed variations the new class of variations was revealed, connected with seismic activity. We demonstrate this phenomena basing on the series of strong earthquakes in June, July 1980 within the region of Australia - New Guinea and Irpinia earthquake at Italy, on 23 of November, 1980. The main effect in critical frequency variations was observed during early morning hours in the absence of solar ultraviolet radiation as a source of ionization. The diminishing of critical frequency in comparison with mean values was observed sometimes more than two days before the earthquake. Together with critical frequency diminishing the rise of the F2 layer maximum was observed, as well as the increasing of the topside electron density profile slope, what implies increasing of the light gases concentration on the height of F-2 layer maximum.

INTRODUCTION

There exist a lot of sources of the ionospheric variability. The regular variations (time and spatial dependent) such as daily, seasonal, solar cycle, latitude variations were studied during several cycles of the solar activity, and results are fixed in various (empirical and first principle) models of the Earth's ionosphere [Bilitsa et al., 1992 ; Schunk and Szuszczewicz, 1988]. But day-to-day ionospheric variability is still not understood in many its manifestations. The present paper deals with the variations of the ionospheric parameters (mainly with critical frequency f_0F2) in relation to the seismic activity. Different kinds of variations within the ionosphere connected with seismic activity were reported in may papers beginning from the great Chili earthquake, May, 1960 [Ishkova et al., 1994]. One of the first publications related to the seismo-ionospheric effects was published by Davies and Baker [1965] and was related to the Alaska earthquake on 28 of March 1964. One can find the rich list of references on this subject in [Liperovsky et al., 1992], as well as extended discussion of the seismo-ionospheric effects. A wide class of the ionospheric anomalies could be observed in plasma density, temperature and composition. Pulinets et al. [1994] made attempt to explain the different variations by chemical changes due to emanations from the earth's crust over the region of preparing earthquake.

Up to recent time the ground-based observations were the main source of information about the seismo-ionospheric effects. Their principal limitation is the one-point measurements. The experimenter can see the temporal variations but does not see the spatial distribution of the parameter under study. The advantage of the satellite measurements is a possibility of the spatial time dependent picture reconstruction over the disturbed region. In the case of topside vertical sounding it is possible to recover three-dimensional picture from the satellite altitude up to the height of F2 layer maximum [Pulinets, 1989]. We studied the electron density variations basing on the topside sounding data from Intercosmos-19 satellite for the series of strong earthquakes in June, July 1980 within the region of Australia - New Guinea and Irpinia earthquake, 120 km from Rome, on 23 of November, 1980. The main effect was observed during early morning hours in the absence of solar ultraviolet radiation as a source of ionization. The substantial diminishing of critical frequency/electron density {f_0F2 (kHz) = $9\sqrt{N}$ } in comparison with the mean values was observed sometimes more than two days before the earthquake. The disturbed ionosphere could reach the area up to 30° in latitude and up to 60° in longitude. The position of the ionospheric disturbance maximum usually is shifted from the position of the future epicenter on the earth's surface. Together with critical frequency diminishing, the elevation of the F2 layer maximum was observed, as well as the increasing of the topside electron density profile slope. The magnitude of disturbance could reach - 60% in electron density and + 70 km in the height of the F2 layer maximum.

EXPERIMENTAL DATA SET USED FOR ANALYSIS

From the data collected during 1979-1981 by INTERCOSMOS-19 satellite we selected for analysis several comparatively strong (M>6.5, depth < 60 km) earthquakes when the ground-based vertical sounding data were available simultaneously with topside sounding data over the epicenter region. The data set consist of two parts: the first one belongs to the low latitude region near Australia - New Guinea, and the second one is collected within the middle latitude European region for the Irpinia earthquake, Italy, on 23 of November, 1980. In the first case, at least for two earthquakes from 5 selected, the satellite covered the area over the future epicenter uniformly, what made possible to built the two-dimensional distribution of the critical frequency for the region of interest. The one more motivation of such selection was the similarity of ionospheric parameters variation for all cases of low latitude earthquakes, what gives us a right to consider every individual case not as a case study but as a representative from the series. For the Irpinia earthquake the satellite data were not so rich: we cannot follow the temporal development of the disturbance, the satellite did not operate continuously. But for this case we have very rich ground-based sounding data base from the European ionospheric network. So we can compare possibilities of ground-based and satellite measurements having in mind that it was the specific case of more or less dense ionospheric stations spatial distribution which we have in Europe. It is very important that all considered earthquakes took place in geomagnetically quiet conditions what give us possibility to be more courageous relating the observed variations to the tectonic activity. One can find the parameters of the low latitude series of earthquakes in the Table 1, and the list of ground-based ionospheric stations data of which were used for the Irpinia earthquake analysis in the Table 2.

The topside ionograms were collected every 64 seconds, what is equivalent to resolution in latitude less than 5°and near 25° in longitude for neighborhood passes. Taking into account that the satellite passed over the area at the same local time, we were able to build the LT maps of the critical frequency distribution. For the European region there existed possibility to collect the topside ionograms every 8 seconds in the direct transmission mode but for the given case of the Irpinia earthquake we have only one pass of the satellite working in such regime. One can find in [Pulinets, 1989] the topside sounder description and main parameters as well as ideology of the satellite map construction.

The main features of the observed seismo-ionospheric variations will be discussed basing on the data from Australia - New Zealand region earthquakes series, and then we will look for similar variations in ground-based measurements at the European region.

THE BACKGROUND IONOSPHERIC CONDITIONS AND IONOSPHERIC PARAMETERS VARIATION

Ionosphere is undergone to many kinds of influences connected with solar and geomagnetic activity. So the task of extraction of variations connected with the tectonic activity is in the first tern the good knowledge of background ionospheric conditions from which the seismo-ionospheric effects will be marked off. It is especially complex task in very sensitive low latitude ionosphere. Usually in ionospheric research the monthly median is used as a reference level, but one should keep in mind that no monthly median could be calculated from the satellite data due to the satellite movement along its orbit. Naturally, the model values couldn't be used too: the accuracy of the existing models is of order or lower than the studied variations. So the reference level for the satellite data should be constructed from the current data. Usually it is used the averaged distribution (latitudinal or longitudinal) for the several quiet days before and after the disturbance connected with earthquake.

SPATIAL VERIATIONS OF THE CRITICAL FREQUENCY OVER THE SEISMO-ACTIVE REGIONS

LATITUDE VARIATIONS

The anomalous variations of the critical frequency f_0F2 observed at Vanimo ionospheric station (LAT - 2.70° S, LONG - 141.30° E) before the strong earthquake (№3 in Table 1) 16.07.1980 are shown on Fig.1 by solid lines in comparison with median values (hatched lines). The station was situated ~340 km from the earthquake epicenter. Several days before, during and after earthquake were selected. The local time interval 00 - 09 h LT is shown in the picture. During the early morning hours (03-06 h LT) one can observe diminishing of f_0F2 two days before the earthquake (ΔN_mF2 = -18%). Effect reaches its maximum one day before the earthquake (ΔN_mF2 = -55%) and persists during the day of earthquake (ΔN_mF2 = -40%). Day after earthquake one can observe the slight growing of NmF2 from median value. At the same time at the other ionospheric stations of Australian region, having the greater distance from the epicenter, any effect was not observed. ΔN_mF2

From the number of earthquakes this case was selected because the satellite passed over the epicenter area just within that sector of local time where the maximal deviations from median values were observed, namely at 5-7 h LT. The values of f_0F2 scaled from the topside sounding data are shown in the Fig.1 by the black spots.

18 passes of the satellite over the near epicenter area were selected for analysis of the latitude variations of the critical frequency, for which the depart in longitude from the epicenter longitude not exceeded 34°. This selection was made to exclude variations of the critical frequency due to the longitudinal effect in the ionosphere [Ben'kova et al., 1990]. The results of topside measurements are shown in Fig.2 where the passes deviated eastward from epicenter longitude are marked by "-", and westward ones are marked by "+". One can see that 9-10 of July the spread of data is small and not exceeds 5%. But by 13 of July, i.e. three days before the shock the latitude profile nearest to the epicenter differs in great extend from the previous one and deviation ΔN_mF2 from not disturbed conditions reaches 40%. The maximal deviation ΔN_mF2 = -50% ÷-60% is observed one day before the earthquake, i.e. 15

of July, what is supported by the ground-based observations. The latitude profile shape gives possibility estimate the latitude size of the disturbed region which is of order 15° and is shifted to the North from epicenter position. One can see that day after the earthquake (Fig. 2d) the shapes of latitude profiles are similar one to another again, but the spread is larger than in Fig.2a. It could be explained by the fact that local time sector of satellite orbit position is shifted by few days to the more early hours ~ 4h LT when the night-time equatorial anomaly is persisted yet. Due to this fact the shape of latitude profiles is changed in comparison with Fig.2a, and the larger spread is explained by the strong longitudinal effect in the night-time equatorial anomaly [Karpachev, 1988].

LONGITUDE VARIATIONS

The averaged longitude variations of f_0F2 on the epicenter latitude, obtained by the topside measurements few days before the shock, are shown in Fig.3 by the bold solid line, and during two days directly before the earthquake - by hatched lines. It is obvious that on all longitudes outside the epicenter region variations of critical frequency are stable, with the similar shape. And only on longitudes not far from epicenter the strong deviations from regular dependence are revealed. ΔN_mF2 reaches -60% on 15.07.80. The disturbed region cross-section is of order 35° and it is shifted to the East from epicenter by 5° ÷ 10°.

ALTITUDE VARIATIONS

The topside density profiles were calculated for quiet undisturbed and seismo-disturbed conditions. The examples are shown in Fig.4 where the undisturbed profiles are presented by solid lines. By hatched lines the disturbed profiles are shown which were measured one day before the shock i.e. 15.07.80. Two profiles present region of maximal disturbance (a) which is situated to the North from epicenter and the region directly over the epicenter (b). As one can see, the diminishing of N_mF2 in F2 layer maximum was accompanied by growing of electron density on the heights near 450 km and rising of F2 layer. On the latitude 11° N these variations are so large that the layer raised by 70-80 km (Fig.4a) and the height of transition from $-\Delta N_e$ to $+\Delta N_e$ was higher than the satellite altitude. So we can conclude that ionospheric disturbance during preparing of the earthquake spreads over the entire bulk of the ionosphere with changing of height scale. Near the epicenter F2 layer rises and the peak electron density diminishes, with growing of density at the same time in the outer ionosphere.

At the end of present section we can summarize the effects of spatial variations of the electron density observed before the strong earthquakes:

- disturbances in upper ionosphere connected with preparing of earthquake are revealed 2-3 days before the shock;
- deviations of the electron density nearby the epicenter are maximal one day before the shock and reach in $\Delta N_mF2 \approx$ -50% ÷ -60% within the local time sector ~ 5 h LT;
- latitudinal cross-section of the disturbed region is of order 15°;
- disturbed region is shifted to the North from epicenter latitude by ~ 7°.
- longitudinal cross-section of disturbed region is of order 35°;
- disturbed region is shifted to the East from epicenter longitude by 5°-7° degrees.
- the peak height increases within the disturbed region by ~ 70 ÷ 80 km
- the slope of the disturbed topside profile increases

LOCALIZATION OF THE DISTURBED REGION CONNECTED WITH EARTHQUAKE PREPARING

Results of the previous paragraph have shown that it is possible by the topside sounding data to recover three-dimensional picture of electron density disturbance connected with the earthquake preparing. One can follow up in Fig. 5a the dynamics of development of two dimensional distribution of the critical frequency deviation over the region of preparing earthquake for the earthquake discussed higher. The distributions are built for the early morning hours two day before the earthquake (upper panel), one day before the earthquake (middle panel), and day after earthquake (bottom panel). Maximal dimensions of the disturbed region reach ~35° in latitude and ~60° in longitude. It should be noted that the maximal deviations are observed not over the epicenter. The complex electrodynamical, meteorological and chemical processes involved into the ionospheric disturbance development probably are responsible for the observed displacement. Nevertheless, the satellite measurements clearly indicate the region of the future earthquake, and the exact position of the epicenter should be determined by the ground-based pure seismological techniques after the satellite warning.

GEOPHYSICAL CONDITIONS AND SEISMO-IONOSPHERIC EFFECTS

All the previous discussion was related to the data collected during the quiet helio-geomagnetic conditions. The natural question arises: how to distinguish ionospheric disturbances connected with earthquake preparing and other disturbances connected with geomagnetic storms, ionospheric variability, etc. One of the answers is demonstrated on Fig.6 where daily variations of critical frequency for several ionospheric stations of Australian region are presented for period of June, 15-20 1980. The geomagnetic indices D_{st}, AE, and A_p are presented in the upper panel of the picture. Periods when the satellite measurements were carried on are shown by bars under the geomagnetic indices plots. One can see that moderate magnetic storm took place on 16 of June ($K_p \sim 4$). It is accompanied by the noticeable ionospheric activity at all ionospheric stations in the form of positive disturbance during day time, even next day it is noticeable on Christchurch and Campbell stations. At the same time only at the Norfolk station the negative deviation connected with the earthquake is observed due to the fact that this station is nearest to the epicenter. On other stations critical frequency is close to the median values. So, in contrast to geomagnetic effect which have a global scale, the seismo-ionospheric effect has a local character. The dimensions of disturbed region could be estimated basing on results of the previous paragraph (Fig.5). The satellite data support the ground-based data: meanings of topside critical frequency are shown in Fig.6 by black spots.

It's natural that ionospheric disturbances have a great diversity and could differ from the shown example (for instance, wave-like disturbances) but it is a subject of the next paper. It should be noted too that the presented results were obtained during the phase of high solar activity. One could suppose that the seismo-ionospheric effects could be different during the low solar activity, at least by its magnitude.

ON THE POSSIBILITY OF COMPLEX GROUND-SPACE SYSTEM FOR THE SEISMIC WARNING

The presented paper demonstrates the seismo-ionospheric effects revealed postfactum and for data set of the satellite which was not dedicated for applied problems. It did not work in continuos manner, had great gaps in data collection. Due to this fact only for two cases from 5 considered we have possibility to build two dimensional picture of ionospheric disturbance. But even for limited quantity of the data the main characteristics of ionospheric disturbance dynamics were determined. The technique of present data processing could lay a foundation of algorithms for extracting of ionospheric earthquake precursors from topside sounding data if the system of seismo-ionospheric patrol would be created. Naturally, that the satellite system should be supported by the ground-based measurements. We have demonstrated higher that the same variations of the critical frequency are observed by the ground-based ionospheric stations. The only problem that it is impossible to build the two dimensional distribution of the observed variations with the help of single ionospheric station data. But if the earthquake takes place within the region where the ionospheric stations are distributed close enough, one can attempt to reconstruct such distribution. It was made for the Irpinia earthquake , 23 of November, 1980, in Italy, [Legen'ka et al., 1995]. There are a lot of ionospheric stations at Europe. Their coordinates are shown in Table 2. The deviations of the critical frequency were calculated for the period of several days before the earthquake and two days after. These deviations are presented in the form of two dimensional distribution in Fig. 5b. Again, as in the case of the discussed higher Australian region earthquakes, the negative deviations are observed at early morning hours two and one days before the earthquake close to the epicenter position. These measurements were again supported by the satellite topside sounding measurements: the latitude critical frequency variations including the near-epicenter area are shown in Fig.7. This example demonstrates how it could be organized the seismic warning service.

The patrol satellites should be launched into the most effective sectors of local time on the circular solar synchronized orbit at 800 ÷ 1000 km height. The satellite should be equipped together with the topside sounder, by ELF-VLF receivers (effectiveness of this method was shown in many works, for example [Larkina et al., 1989]), *in situ* plasma parameters measurements, electric and magnetic field measurements, ion composition measurements and optical measurements. These ideas were implemented in the proposals for the special Subsatellite for Active Measurements (SAM), which will be the part of the international satellite WARNING project devoted to the study of seismo-ionospheric coupling effects [Pulinets, 1996]. Operative control and cooperation with ground-based seismo and ionospheric stations should be provided. As additional means for the global control of the ionosphere the total electron content (TEC) measurements should be noted. The global network of the stations, using signals from the satellites of Global Positioning System (GPS) makes real the current global control of the ionosphere [Lindqwister et al., 1996]. The information from this network together with topside sounding data will make the determination of the seismo-active regions more confident. One can hope that the multiparametric data procession of different kinds of measurements will let to decide the problem of earthquakes prediction.

CONCLUSIONS

By the data of ground-based and topside vertical sounding of the ionosphere the seismo-ionospheric effects were analyzed for 5 strong earthquakes which took place on 18, 19 of June and 14, 16 and 17 of July 1980 on the islands situated to the East from Australia and New Guinea, and Irpinia earthquake at Italy on 23 of November, 1980. The distinct F-layer response was discovered 2-3 days before the main shock. Especially strong reaction was observed for the earthquake on 16 of July, 1980, and practically three dimensional picture of ionosphere dynamics was recovered. For other earthquakes due to poor data statistics only separate dependencies were obtained (latitude or longitude profiles). All of them support the general picture obtained by the 16 of July earthquake data. The two dimensional distribution of the critical frequency variations was built by the data of ground-based ionospheric stations network in Europe for the Irpinia earthquake, 23 of Nov., 1980. It revealed again the negative variations of the critical frequency during the early morning hours and displacement of the maximum ionospheric effect from the vertical projection of the epicenter position.

The low-latitude ionosphere reaction is manifested in the form of arising of F2 layer, what is accompanied by the diminishing of electron density in F2-layer maximum and slight growing of density in topside ionosphere, what looks as effective increasing of the topside profile slope. Thus the rebuilding of the total electron density height profile takes place. Usually the disturbance is observed during local morning and pre-noon hours and only one time was observed at evening hours. It begins 3-2 days before the main shock, reaches the maximum 1-1/2 day before the shock and sometimes persists after the shock. Its amplitude could reach -60% in N_mF2 and +70 km in h_mF2. Ionospheric disturbance could embrace comparatively large area: till 30° in latitude and 60° in longitude. Usually the disturbed region is displaced from the projected vertically future epicenter position.

One should keep in mind that in the frames of present paper we discuss only one of the many observed seismo-ionospheric effects: negative variations of the critical frequency during early morning hours. The present conclusions were obtained on the limited set of experimental data, for the period of high solar activity. The purpose of the present paper was only to demonstrate the existing possibility to build the Space-Earth system for seismic warning, based mainly on the revealed seismo-ionospheric effects. These effects have very important feature: the temporal scale of seismo-ionospheric effects dynamics (2-3 days) fills the gap between the long-term seismic predictions based on the pure seismic monitoring data and very short term predictions (few hours and minutes) based on VLF and ELF measurements data. We do not deep into discussion of the possible physical mechanisms of the observed phenomena. One can find some proposals in [Pulinets et al., 1994]. The only conclusion could be made here: the dynamics of the topside profile shape implies the appearance of the increased number of the light ions on the heights of the F-layer maximum. There were revealed the different types of emanations from the earth's crust within the region of preparing earthquake, including the light gases. The problem is how to explain the transport of the light gases atoms from the ground level to the ionospheric heights for the comparatively short time intervals, much shorter than the diffusion time. If this problem will be decided, then one can explain the observed effect by the charge exchange process between the light gases neutral atoms and O_+ ions, prevailing on the heights of F-layer maximum. During the early morning hours, in the absence of solar ultraviolet radiation, the concentration of the O_+ will decrease, what means the diminishing of the critical frequency. The appearing light ions will move further to high altitudes what will lead to the observed modification of the topside profile.

The electron density measurements should be supplemented by temperature and composition measurements, sporadic E layer appearance and others. Nevertheless the discovered intensive disturbances of the electron density on the heights of topside ionosphere two-three days before the main shock, ability to built the three dimensional picture of the ionosphere dynamics let us to propose the described technique as a new technique for seismo-ionospheric coupling investigations, and for practical use in earthquakes prediction systems.

- ***REFERENCES***

Ben'kova N.P., M.G Deminov., A.T.Karpachev, N.A.Kochenova, Yu.V Kusnerevsky., V.V.Migulin, S.A. Pulinets, M.D. Fligel Longitude features shown by topside sounder data and their importance in ionospheric mapping // Adv. Space Res. Vol.10, N8, pp.57-66, 1990

Bilitsa D., K.Rawer, L.Bossy and T.Gulyaeva, International reference ionosphere - past, present and future: I - Electron density, *Adv. Space Res.*, **13**, (3)3 -(3)13, 1992

Davies, K, and D.M.Baker, Ionospheric effects observed around the time of the Alaskian earthquake of March 28, 1964, *J.Geophys. Res.*, **70**, p.2251, 1965

Ishkova L.M., E.M.Kovalevskaya, and V.A.Morgunov, Ionospheric disturbances during the Chili earthquake on May, 1960, *Doklady, Russian Academy of Sciences*, Geophysics, **334**, No 4, pp.504-506, 1994

Karpachev A.T., The global longitudinal effect characteristics in the night-time equatorial anomaly // Geomagnetism and Aeronomy, 1988, v.28, N1, p.46-48

Larkina V.I., Migulin V.V., Molchanov O.A., Kharkov I.P., Iuchin A.S., Shevetcova V.B. Some statistical results on very low frequency radiowave emissions in the upper ionosphere over earth- quake zones // Phys. Earth Planet. Inter. 57, 1989, p.101-109.

Legen'ka A.D., S.A.Pulinets, D.S.Gregory, Reaction of the ionosphere to the Italian earthquake of November 23, 1980, IZMIRAN preprint, № 12(1081), 1995, 17p.

Lindqwister U.J., C.M.Ho, A.J.Mannucci, and B.D.Wilson, Monitoring Global Ionospheric TEC during Magnetic Storms Using GPS Networks, Personal communication, 1996

Liperovsky,V.A., O.A.Pokhotelov and. S.A. Shalimov, Ionospheric precursors of the earthquakes, Nauka, Moscow, 304 p, 1992.

Pulinets S.A.: Prospects of topside sounding, WITS Handbook, volume 2, Chapt. 3, published by SCOSTEP, Urbana, Il., edited by C.H.Liu., 1989, p.99-127

Pulinets S.A., A.D.Legen'ka and V.A.Alekseev: On the possible mechanism of the seismo-ionospheric coupling, in Noise an Chaos in Dusty and Dirty Natural and Laboratory Plasma, edited by H. Kikuchi, Plenum Press, New York, pp.532-544, 1994.

Pulinets S.A., Subsatellite for Active Measurements in the WARNING project, Geofisica International, 1996, to be published

Figure captions

Fig.1. Daily variations of f_0F2 (solid lines) and median values (dashed lines) comparison for 00-09 h LT interval at VANIMO ionospheric station few days before and after earthquake on 16.07.80. The earthquake moment is shown by arrow. f_0F2 values scaled from topside ionogram are shown by (•) when satellite passed over station.

Fig.2. Dynamics of the critical frequency (f_0F2) latitudinal variations for morning hours (05-06 LT) at different longitudes in the vicinity of the epicenter longitude for several days before and after earthquake on 16.07.80. The eastward deviations from the earthquake longitude are designated by "-", and westward ones are designated by "+"

Fig.3 Longitudinal variations of f_0F2 during the early morning hours (05 - 06 h LT) for the earthquake on 16.07.80 at the epicenter latitude.
1 - averaged distribution for the quiet conditions
2 - distribution two days before the earthquake
3 - distribution one day before the earthquake
Epicenter longitude is shown by arrow

Fig. 4. Averaged topside electron density profiles for quiet conditions (solid line) and one day before the earthquake (dashed line)
a - in the point of disturbance maximum
b - over the epicenter

Fig. 5. Two dimensional (latitude-longitude) distribution of the critical frequency deviation Δf_0F2 over the region of the preparing earthquake for the early morning hours of the local time
a - distributions obtained from the topside sounding data for the 16.07.80 earthquake at the Australian region; top panel - two days before the earthquake, middle panel - one day before the earthquake, bottom panel - one day after earthquake
b - distributions built by the ground-based vertical sounding data from European network for the Irpinia earthquake 23.11.80 for the period 19 - 24 of November, 1980

Fig. 6 Daily variations of f_0F2 (solid lines) in comparison with monthly median (dashed lines) for the period 15 - 20 of June, 1980, measured at ionospheric stations 1 - Norfolk, 2 - Christchurch, 3 - Campbell, 4 - Canberra. The earthquake moment on 09.06.80 at 08:30 UT is shown by the vertical dashed line. Dst, AE and Ap geomagnetic indices are shown in the top panel of the figure. Periods when the satellite topside sounder was on are shown by bold bars.

Fig. 7 Latitudinal variations of f_0F2 measured by the Intercosmos-19 topside sounder for the passes close to the Irpinia earthquake 23.11.80 epicenter longitude. □ – pass N 9127 19.11.80, O – pass N 9142 20.11.80, ▼ – pass N 9156 21.11.80, ● – pass N 9165 22.11.80, Δ – pass N 9199 24.11.80. Epicenter latitude is shown by arrow.

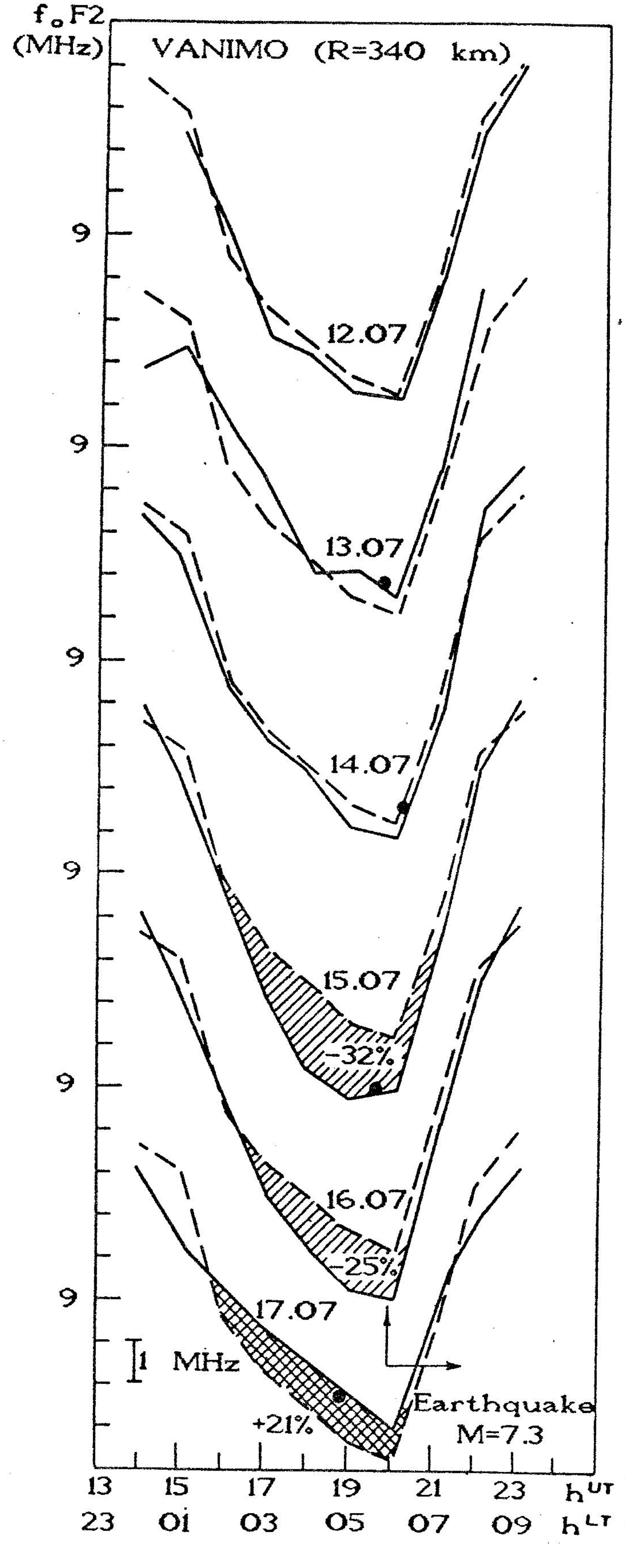

foF2 (MHz)
VANIMO (R=340 km)
9
9
9
9
9
9
12.07
13.07
14.07
15.07
-32%
16.07
-25%
17.07
+21%
1 MHz
Earthquake M=7.3
13 15 17 19 21 23 hUT
23 01 03 05 07 09 hLT

Fig. 1.

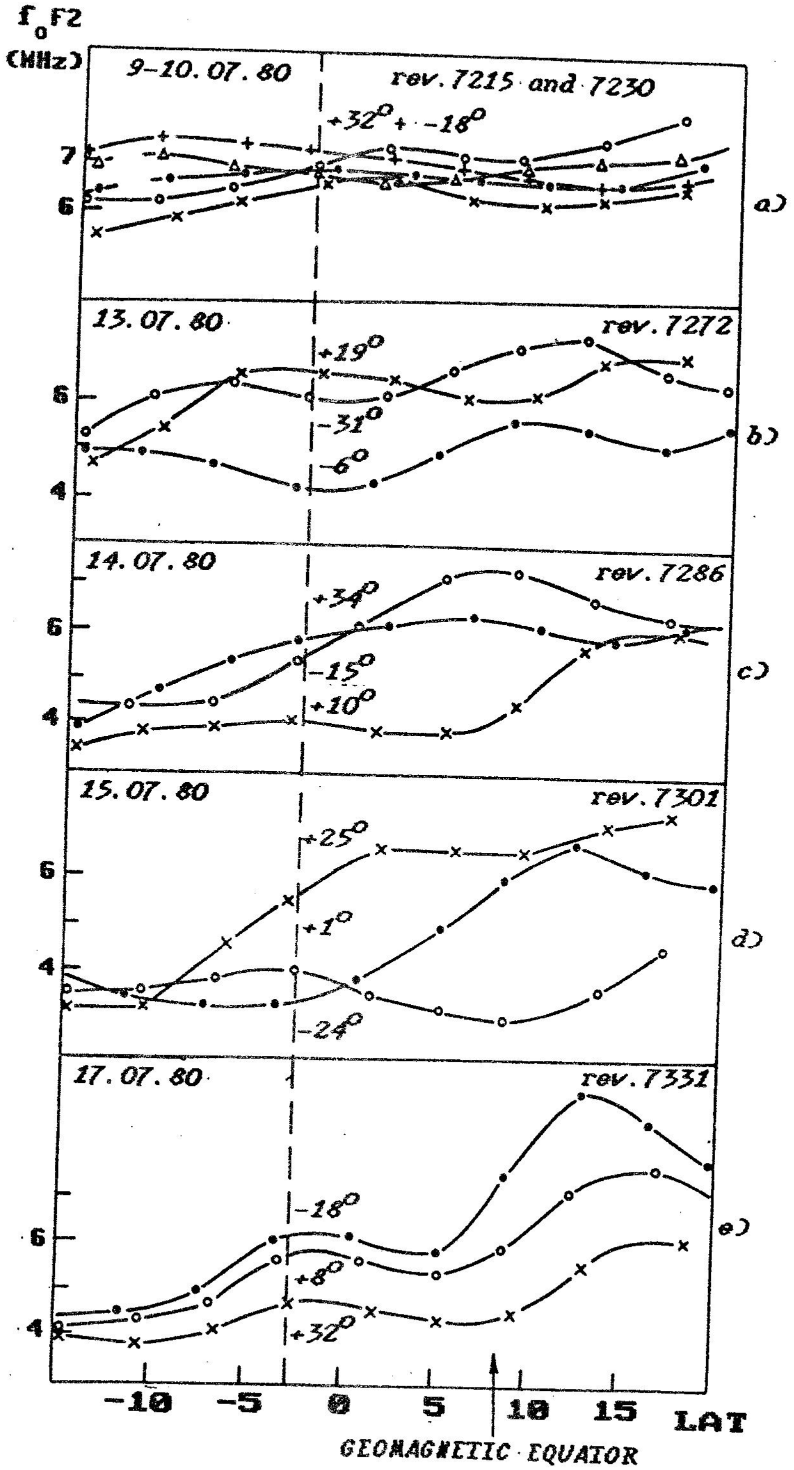
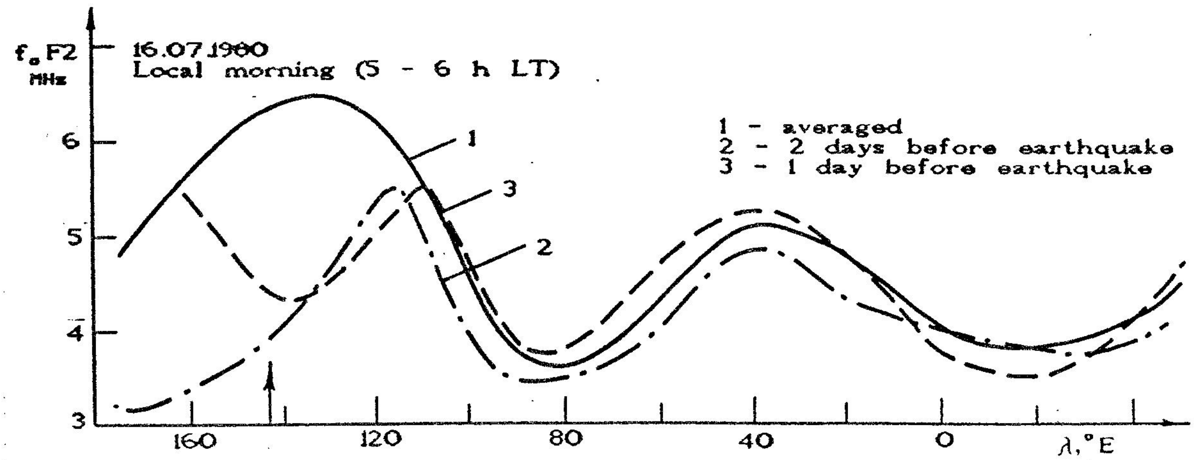

f₀F2 (MHz)
9-10.07.80
rev.7215 and 7230
+32° + -18°
a)
13.07.80
rev.7272
+19°
-31°
-6°
b)
14.07.80
rev.7286
+34°
-15°
+10°
c)
15.07.80
rev.7301
+25°
+1°
-24°
d)
17.07.80
rev.7331
-18°
+8°
+32°
e)
-10 -5 0 5 10 15 LAT
GEOMAGNETIC EQUATOR

Fig. 2.



f_oF2
MHz
16.07.1980
Local morning (5 - 6 h LT)
1 - averaged
2 - 2 days before earthquake
3 - 1 day before earthquake
6
5
4
3
160
120
80
40
0
λ,°E

Fig. 3.

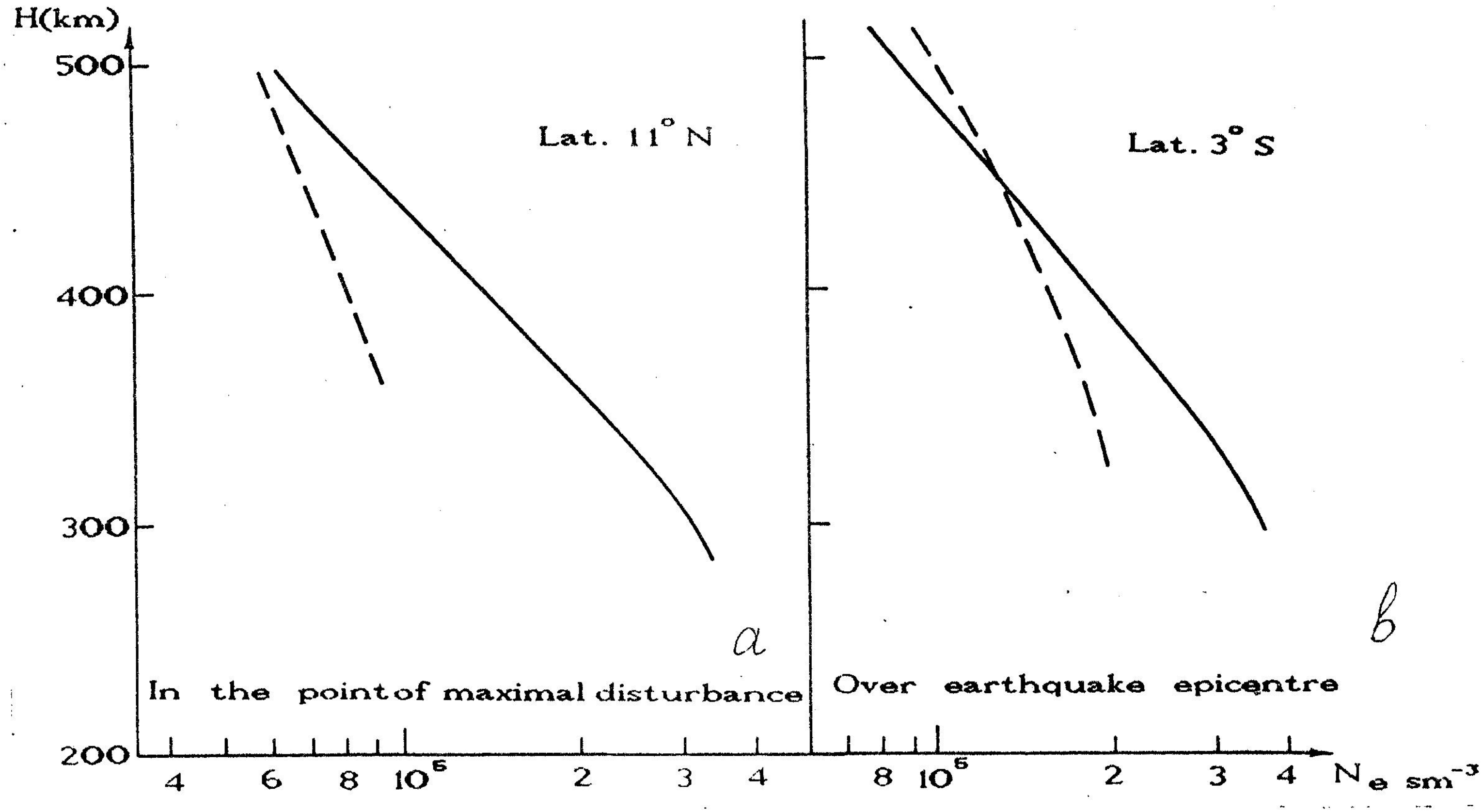
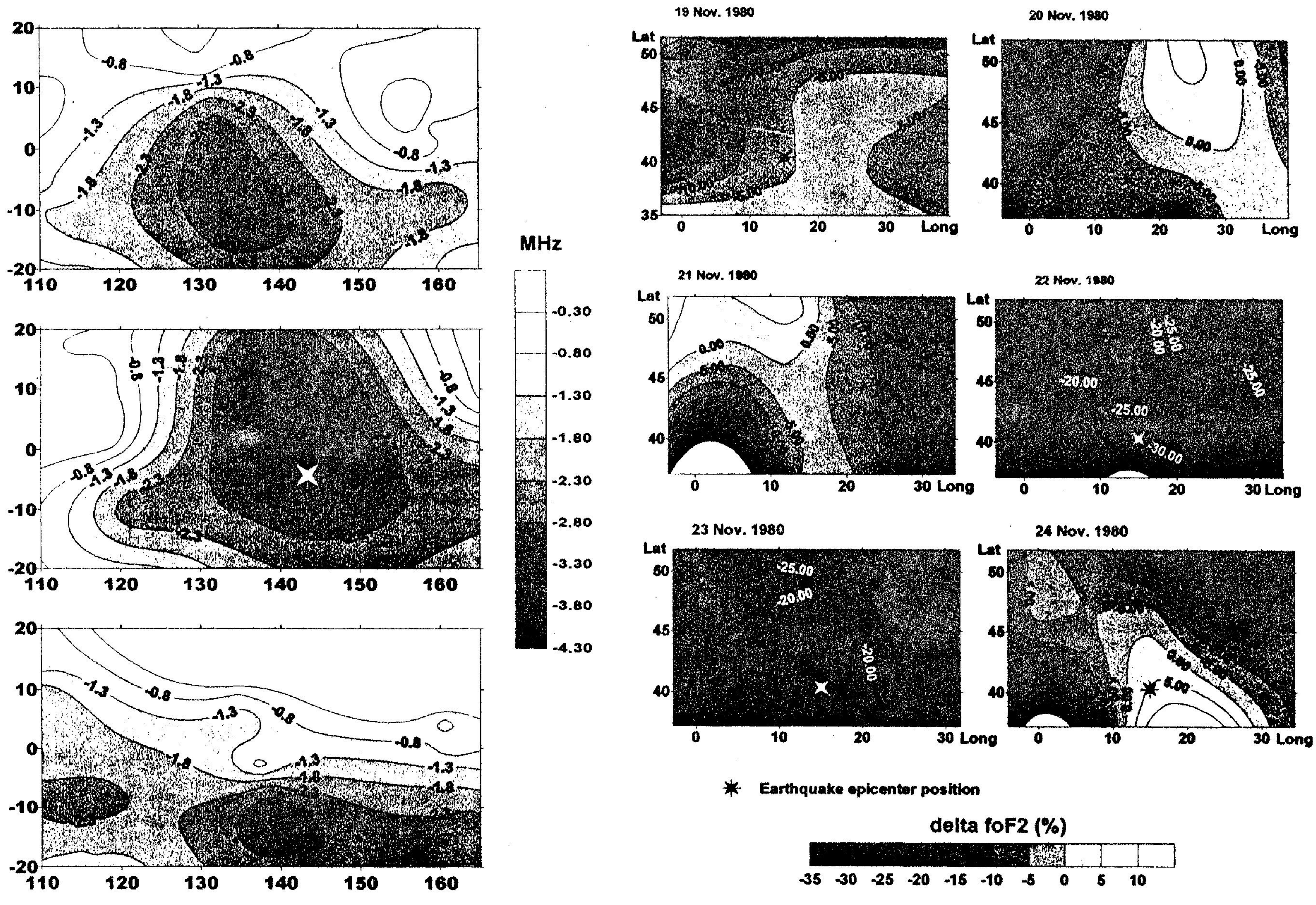

H(km)
500
400
300
200
Lat. 11° N
Lat. 3° S
a
b
In the point of maximal disturbance
Over earthquake epicentre
4
6
8
10⁶
2
3
4
8
10⁶
2
3
4
Ne sm⁻³

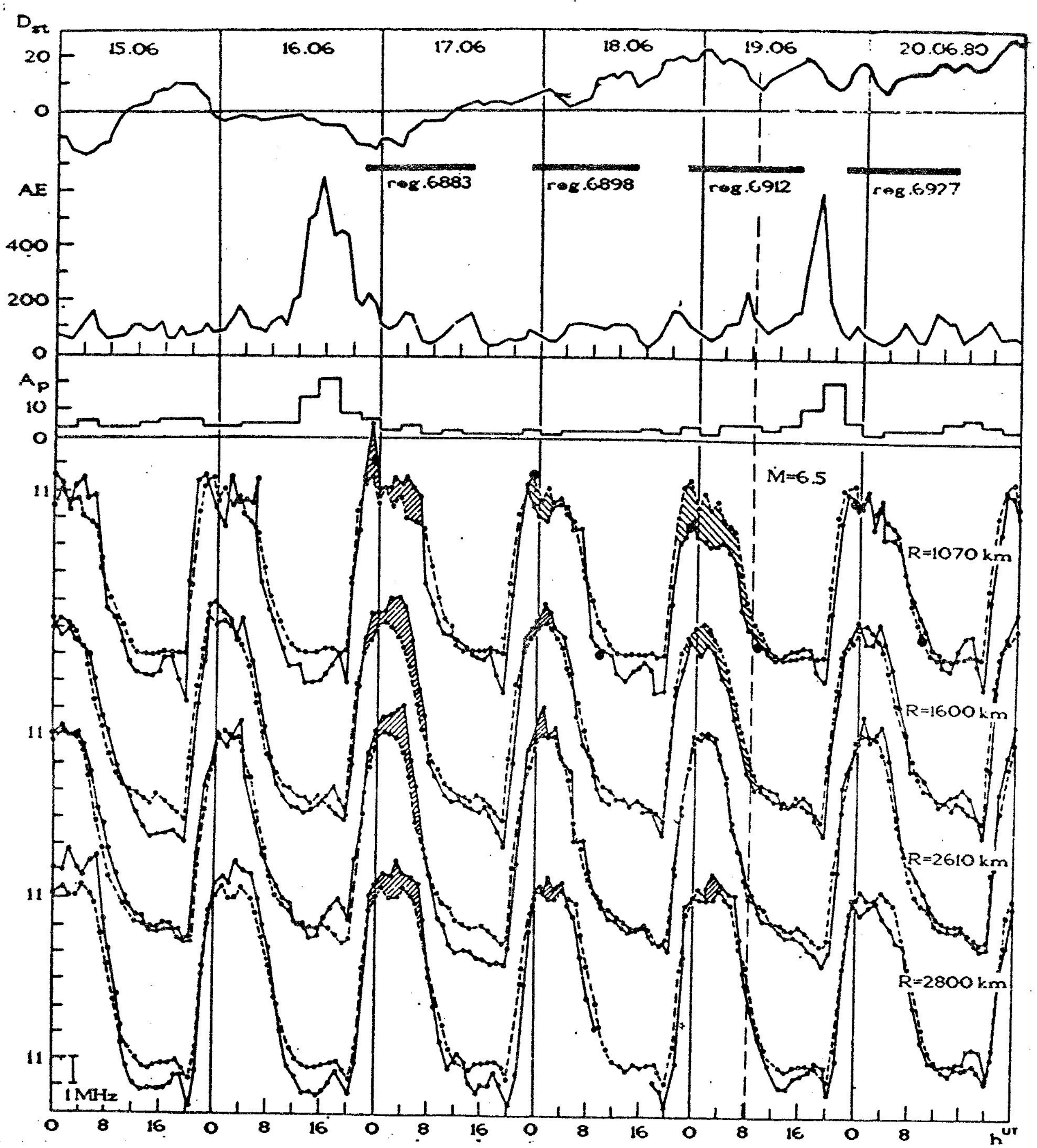
Fig. 4.


MHz
-0.30
-0.80
-1.30
-1.80
-2.30
-2.80
-3.30
-3.80
-4.30
19 Nov. 1980
20 Nov. 1980
21 Nov. 1980
22 Nov. 1980
23 Nov. 1980
24 Nov. 1980
Lat
Long
Earthquake epicenter position
delta foF2 (%)

(a)

(b)

Fig. 5



Dst
20
0
15.06
16.06
17.06
18.06
19.06
20.06.80
reg.6883
reg.6898
reg.6912
reg.6927
AE
400
200
0
Ap
10
0
M=6.5
11
R=1070 km
R=1600 km
11
R=2610 km
11
R=2800 km
11
1MHz
0
8
16
0
8
16
0
8
16
0
8
16
0
8
16
0
8
h^UT

Fig. 6.

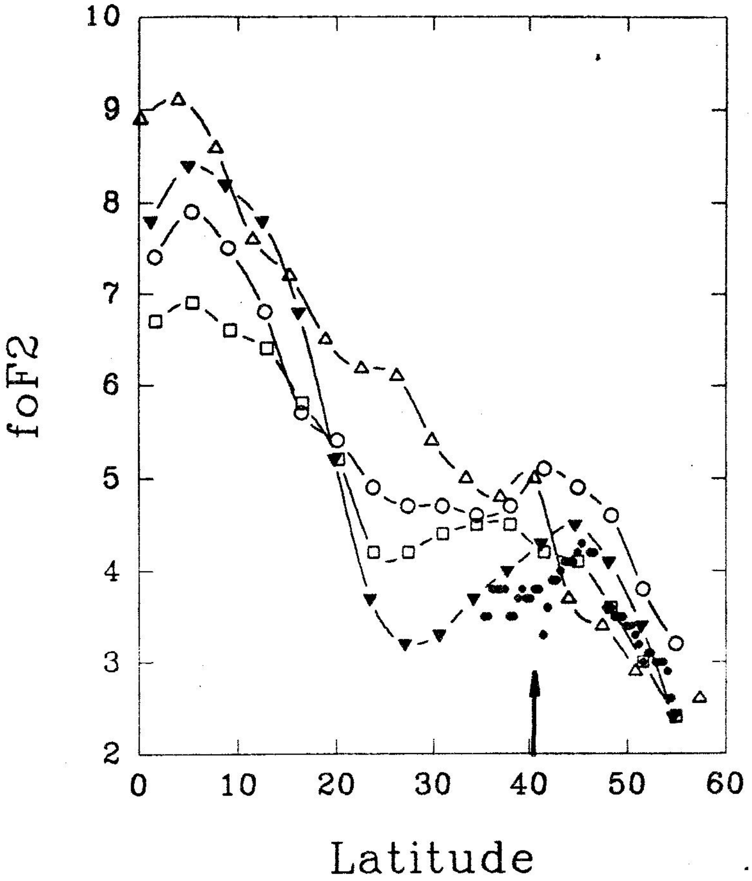


Fig. 7.