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S.A.Pulinets, A.D.Legen'ka, A.T.Karpachev, N.A.Kochenova, V.V.Migulin,
V.N.Oraevsky, M.D. Fligel

THE EARTHQUAKE PREDICTION POSSIBILITY ON THE BASE OF TOPSIDE SOUNDING DATA

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INTRODUCTION

Coupling between the dynamics of lithospheric processes and ionospheric parameters variation is now no doubt. It is in the first term due to multitudinal data of groundbased vertical sounding (GVS) of the ionosphere showing such coupling (see for example [1-6]. A wide class of the ionospheric anomalies could be observed in plasma density, temperature and composition. The ion density anomalous variation were registered onboard the AE-C satellite [7]. But regularities of the processes are not revealed yet. It is due to complexity of processes involved and in the great extend due to limitations of ground-based observations which do not give the spatial distribution but only one-point measurements. The satellite measurements advantage is a possibility to obtain the spatial time dependent picture of the disturbed region. In the case of topside vertical sounding (TVS) it is possible to recover three-dimensional picture. The present paper is the first attempt of systematic approach to the satellite TVS data from the point of view earthquake prediction possibility.

1. EXPERIMENTAL DATA SET USED FOR ANALYSIS

The data presented are collected during 1979-1981 when INTERCOSMOS-19 satellite was on orbit with topside sounder onboard. The sounder parameters one could find in [8]. Several comparatively strong ($M > 6.5$, depth < 60 km) earthquakes were selected for analysis when the groundbased vertical sounding data were available simultaneously with topside sounding data over epicenter region. The data were selected only for geomagnetically quiet period and in the same area to exclude dependence on the geographical position and surface quality. This region is situated eastward from Australia and New Guinea and one can find in Table 1 information on the earthquakes selected and schematic representation of epicenters and groundbased ionospheric stations positions in Fig.1. The one more motivation of such selection is similarity of ionospheric parameters variation for all cases what gives a right to consider individual case not as a case study but as a representative or typical case. For this reason mainly the 16.07.1980 earthquake will be considered in further discussion as more rich in statistics of satellite passes over the region of interest.

2. THE BACKGROUND IONOSPHERIC CONDITIONS AND IONOSPHERIC PARAMETERS VARIATION

Ionosphere is undergone many kinds of influences connected with solar and geomagnetic activity. The F2 layer parameters vary with latitude and longitude, season and local time. So the task of extraction of variations connected with earthquake is in the first term good knowledge of background ionospheric conditions from which the seismoionospheric effects will be marked off. It is especially complex task in very sensitive low latitude ionosphere. The several approaches could be used: deviations from some averaged level for selected period or from model representation or from current average could be taken into account, but in any case the comparatively long series of experimental data one should have. There is no adequate model for detail representation of ionospheric parameters to account for example the longitudinal effect. Therefore we selected for extracting of anomalous variations the way of comparison with averaged distribution of electron density along longitude, latitude and height for periods before and after disturbances connected with earthquake. These distributions are based on the current satellite measurements carried out during period of interest.

3. THE LATITUDINAL VARIATIONS OF F2 LAYER CRITICAL FREQUENCY OVER SEISMO-ACTIVE REGIONS

The groundbased ionospheric measurements showing the strong anomalous disturbances in the ionosphere near the earthquake epicenter were the initial stimulus for topside sounding data analysis to look for seismo-ionospheric effects in upper ionosphere. One of the main effects is an anomalous variations of foF2 frequency 2 or 3 days before the strong earthquake which are shown on Fig.2 by solid lines in comparison with median values (hatched lines). These data are obtained at Vanimo ionospheric station (LAT = 2.70, LONG = 141.30) for 16.07.1980 earthquake. The station was situated ≈340 km from earthquake epicenter. Several days before, during and after earthquake were selected. Local time period 00-09 LT is shown on the picture. Within the narrow local time interval 03-06 LT one can observe diminishing of f_oF2 two days before the earthquake ($\Delta N_mF2 \sim -18\%$). Effect reaches its maximum one day before the earthquake (($\Delta N_mF2 \sim -55\%$) and persists during the day of earth- quake (($\Delta N_mF2 \sim -40\%$). Day after earthquake one can see slight growing of N_mF2 from median value. At the same time on the other ionospheric stations of Australian region having greater distance from epicenter any effect was not observed.

From the large quantity 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 LT. The top- side scaled values of foF2 are shown on the Fig.2 by the black spots.

To analyze the latitude variations of critical frequency the 18 passes of the satellite were selected for which 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 [9]. The results of topside measurements are shown on Fig.3 where the passes deviated eastward from epicenter longitude are marked by "-", and westward ones are marked by "+". One can see that 9-10 of June the spread of data is small and not exceeds 5%. But by 13 of June, i.e. three days before the underground 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 $\Delta N_mF2 \sim -50\%:-60\%$ is observed one day before the earthquake, i.e. 15 of June, what is supported by the groundbased 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. 3d) the shapes of latitude profiles are similar one another again but the spread is larger than on fig.3a. 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 ~04 LT when the nighttime equatorial anomaly is persisted yet. Due to this fact the shape of latitude profiles is changed in comparison with Fig.3a, and the larger spread is explained by the strong longitudinal effect in the nighttime equatorial anomaly [10].

At the end of latitude variations discussion the next conclusions could be made:

- disturbances in upper ionosphere connected with preparing of earthquake are revealed 2-3 days before the shock;
- deviations of electron density nearby the epicenter are maximal one day before the shock and reach ΔN_mF2 ~ -50%:-60% within the local time sector ~05 LT;
- latitudinal cross-section of the disturbed region is of order 15 ;
- disturbed region is shifted to the North from epicenter latitude by ~7 .

4. LONGITUDINAL VARIATIONS OF F2 LAYER CRITICAL FREQUENCY OVER THE ACTIVE REGIONS

One can see on Fig.4 the averaged longitudinal variations of f_oF2 on the epicenter latitude by the topside measurements few days before the shock (solid line) and during the days directly before the earthquake (14 and 15 of June 1980). It is obvious that on all longitudes outside the epicenter region variations of critical frequency are stable. And only on longitudes not far from epicenter 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°.

So the conclusions of previous paragraph could be supported and supplemented:

- deviations from regular longitudinal variations of peak electron density appear two days before the shock;
- deviations are maximal one day before the shock and reach -50%:-60% in ΔN_mF2 within the 05-06 sector of local time;
- longitudinal cross-section of disturbed region is of order 35 ;
- disturbed region is shifted to the East from epicenter longitude by 5-7 degrees.

5. ALTITUDE VARIATIONS OF ELECTRON DENSITY OVER SEISMO-ACTIVE REGIONS.

The topside density profiles were calculated for quiet and seismo-disturbed conditions. The examples are shown on Fig.5 where by solid lines undisturbed profiles are presented. By hatched lines the disturbed profiles are shown which were measured one day before the shock i.e. 15.07.80. Two profiles pre- sent 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 arisen by 70-80 km (Fig.5a) and the height of transition from $-\Delta N$ to $+\Delta N$ 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 electron density diminishes with growing of density at the same time in the outer ionosphere.

6. LOCALIZATION OF THE DISTURBED REGION CONNECTED WITH EARTHQUAKE PREPARING

Results of previous three paragraphs 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. Taking into account the principal importance of the information obtained for the earthquakes prediction and understanding of physical mechanisms responsible for such strong ionospheric effects, it is necessary to put forward the idea of creating the specialized space system for earthquake WARNING as a tool for localizing of region of preparing earthquake.

As an example we show two-dimensional distributions of electron density deviations over the regions of preparing earthquakes: Fig.6a and 6b. Deviations were calculated basing on the regular picture of critical frequency longitudinal-latitudinal distributions obtained for the quiet days in the same geophysical conditions and are presented on the Fig.6 in the form of isolines of deviation in MHz. Fig. 6a presents distribution obtained one day before the earthquake 16.07.80 and Fig. 6b - one day before the earthquake 19.06.80 for two different local time intervals. But the pictures are very similar: the disturbed zone is stretched to the East and to the North. The maximal cross-sections reach ~35° by latitude and ~60° by longitude. At the same time the maximal deviations are observed not over the epicenter (black spot) but ~1500 km northward. It seems that such shift is not accidental and was reported earlier in [1,2]. So except the results supporting the previous paragraphs the main conclusion is a real possibility of localizing the zone of preparing earthquakes.

7. DEPENDENCE OF SEISMO-IONOSPHERIC EFFECTS ON THE LOCAL TIME

The satellite appears over the given point of the Earth surface two times a day in different sectors of the local time with 12 hours gap. If we take into consideration the passes falling into the longitudinal band + 15° -20° near epicenter longitude we can have 4-6 passes every day for given epicenter point. For 5 earthquakes given in Table 1 we have possibility to analyze 4 intervals of local time: 05-06 h, 10-12 h, 16-17 h, and 21-23 h of LT. Results of local time effects analysis are shown in Table 2. In all five cases under analysis decreasing of electron concentration in F-layer peak and increasing of its height was observed during morning (5-6 h LT) and day (10-12 h LT) several days/hours before the main shock. What concerns the other local time sectors: afternoon (16-17 h LT) and night (21-23 h LT), the effects observed are minimal. Only for the earthquake on 14 of July 1980 (N3 in Tab.1) we succeeded in finding of effect. We had possibility to study the ionospheric situation by the data of several groundbased ionospheric stations of the region under consideration. The nearest station to the earthquake at Norfolk was in 1500 km departing from epicenter. By the data of this station the diminishing of the critical frequency was observed during nighttime hours (00-04 LT) two days before the shock already (12 of July), what is noticeable one day before (13 of July) and one day after (15 of July) the shock too. Just before and during the shock the anomalous growing of critical frequency (by 1.5-2.0 MHz) was observed at the same hours of local time. By the data of other stations of this area no effects were observed. IK-19 satellite passed over this region in 5.5-6.5 h LT and 16.5-17.5 h LT sectors. Due to the fact that satellite did not work continuously we have data one day before and during the shock for morning hours and 12 hours before and after the shock for afternoon (see Tabl.2, N3). Nevertheless groundbased effects of night and early morning hours (0-4 h LT) persisted on the topside sounding data till 5.5-6.5 h LT when satellite passed over the region.

We can make conclusion that the sector of local time when satellite passes over the seismo-active region is of great importance for the practical space system of seismic warning. But to analyze the local time dependence in detail it is necessary to have very large data base equivalent to the entire 24 hours density distribution including as quiet days so days disturbed by the seismo-ionospheric effects what equals several years of satellite continuos activity. But even now we can say that ionospheric effect of the earthquake preparing is maximal during early morning hours and practically negligible during local evening (21-22 h LT). Table 2 presents the data on number of passes over the every earthquake region, the time of advance, local time sector of satellite pass, longitude depart from epicenter longitude and some characteristics of the effects observed. As illustrations of the Table 2 the latitudinal distributions for different sectors of local time are presented on Fig.8 and longitudinal variations - on Fig.9. One can compare the effects for different local time intervals adding one more longitudinal distribution for 05 h LT presented on Fig.4.

8. TIME OF ADVANCE AND ELECTRON DENSITY VARIATIONS

The problem of ionospheric disturbances amplitude on the time of advance the shock is the same as for local time dependence: it is necessary to have continuos measurements during long time periods but basing on IK-19 topside sounding data we can conclude that:

- ionospheric effects of earthquake preparing appear two or three days in advance the main shock;
- maximal amplitude of ionospheric disturbances is reached by 1 day - 9 hours before the main shock;
- just before the shock (1 hour - 10 minutes) positive variations of critical frequency could be observed.

9. GEOPHYSICAL CONDITIONS AND SEISMO-IONOSPHERIC EFFECTS ANALYSIS

All the previous discussion was connected with data collected during the quiet helio-geomagnetic conditions. The natural question is: how to distinguish ionospheric disturbances connected with earthquake preparing and other disturbances connected with geomagnetic storms etc. One of the answers is shown on Fig.10 where daily variations of critical frequency for several ionospheric stations of Australian region are presented for period of June, 15-20 1980. In the upper part of the picture the geomagnetic indices D , AE, and A are presented. Periods of satellite activity (topside sounder is on) are shown by bars under the geomagnetic indices. One can see that moderate magnetic storm took place on 16 of June (K ~ 4+). And reaction of the ionosphere is global: all ionospheric stations see growing of critical frequency during day time, even next day it is noticeable on Christchurch and Campbell stations. At the same time only on 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 paragraph 7 (Fig.6). The satellite data support the ground-based data: meanings of topside critical frequency are shown on Fig.10 by black spots.

It's natural that ionospheric disturbances have a great diversity and could differ from the example shown (for instance, wave-like disturbances) but it is a subject of the next paper.

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

The data analysis presented was made post-factum 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 seismo-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. The patrol satellites should be launched into the most effective sectors of local time on the circular orbit 800-1000 km height. The satellite should be equipped additionally to topside sounder by ELF-VLF receivers (effectiveness of this method was shown in many works, for example [11,12]), plasma temperature measurements, electric and magnetic field measurements, ion composition measurements. Operative control and cooperation with ground-based seismo-ionospheric stations should be provided. Multi-parametric data procession of different kinds of measurements will let to decide the problem of earthquake prediction.

CONCLUSIONS

By the data of groundbased 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. 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, and practically three dimensional picture of ionosphere dynamics was recovered. For other cases 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 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. 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 in evening. 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 F2. Ionospheric disturbance could engross comparatively large area: till 30 degrees in latitude and 60 degrees in longitude. Besides the disturbed region is turned out to be stretched to the North- East from the epicenter.

One should keep in mind that present conclusions were obtained for the separate region of the Earth surface and their all- embracing should be proved by the further investigations. Especially for different geographical points (middle latitudes) and different soil characteristics. The electron density measurements should be supplemented by temperature and composition measurements, sporadic E layer appearance and others. Nevertheless the discovered intensive disturbances of electron density two-three days before the main shock by the topside sounding data, possibility to built three dimensional picture of ionosphere dynamics let us to propose the technique described as a new technique for seismo-ionospheric coupling investigations and for practical use in earthquakes prediction systems.

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Table 1

N	Date	Epicenter φ (S), λ(E)		Time (h.m).		Magn.	Depth, km	Territory
				UT	LT			
1.	18.06.80г.	5.2	152.1	09.18	19.18	6.6	33	New Britain Island
2.	19.06.80г.	30.0	178.5	08.34	20.26	6.5	51	Kermadec Island
3.	14.07.80г.	29.0	184.0	16.15	4.30 (15.07)	6.7	33	Kermadec Island
4.	16.07.80г.	3.2	143.3	19.56	5.26	7.3	54	New Guinea Island
5.	17.07.80г.	13.0	166.6	19.42	6.48	7.8	33	Santa-Cruz Island

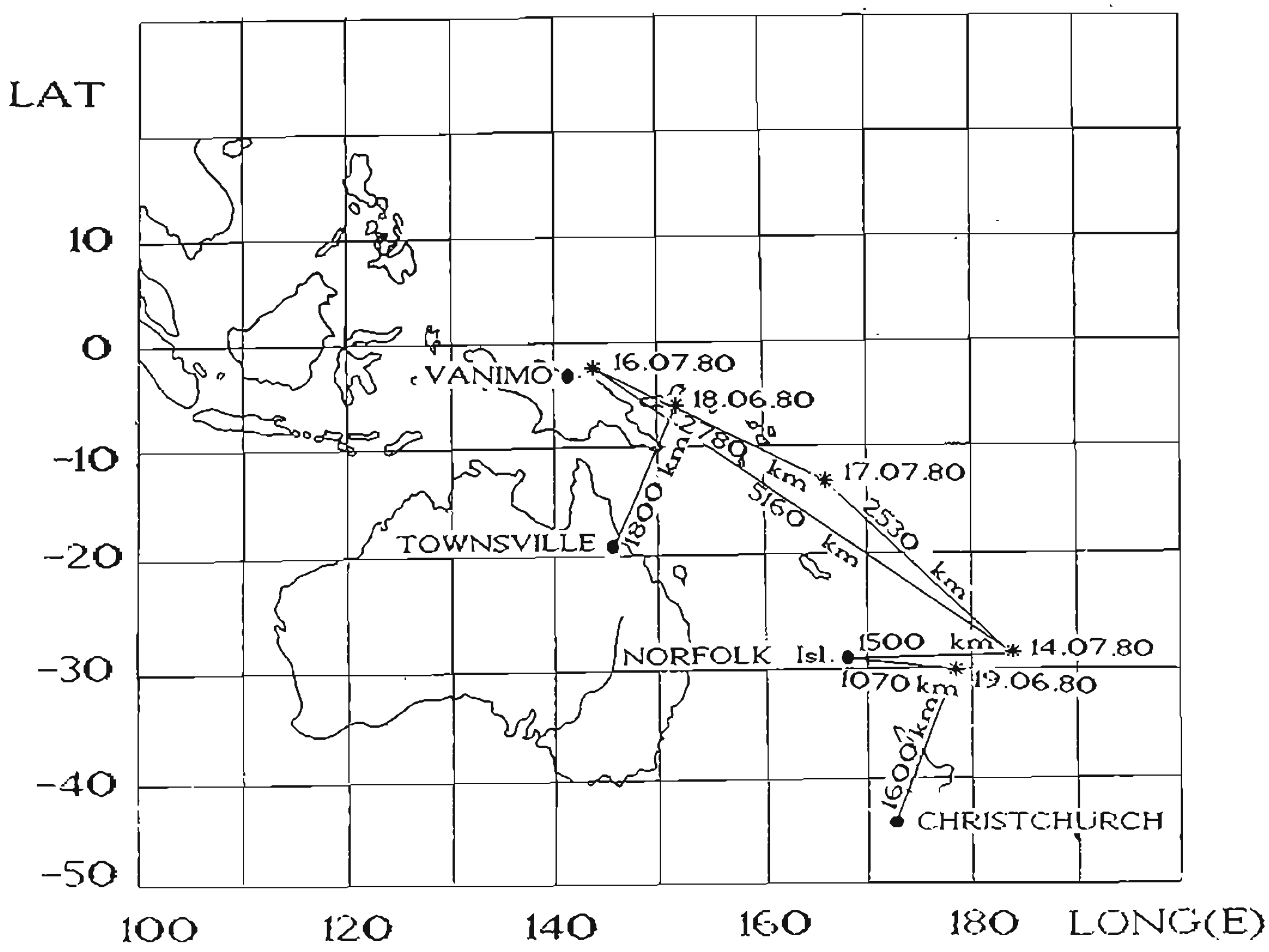
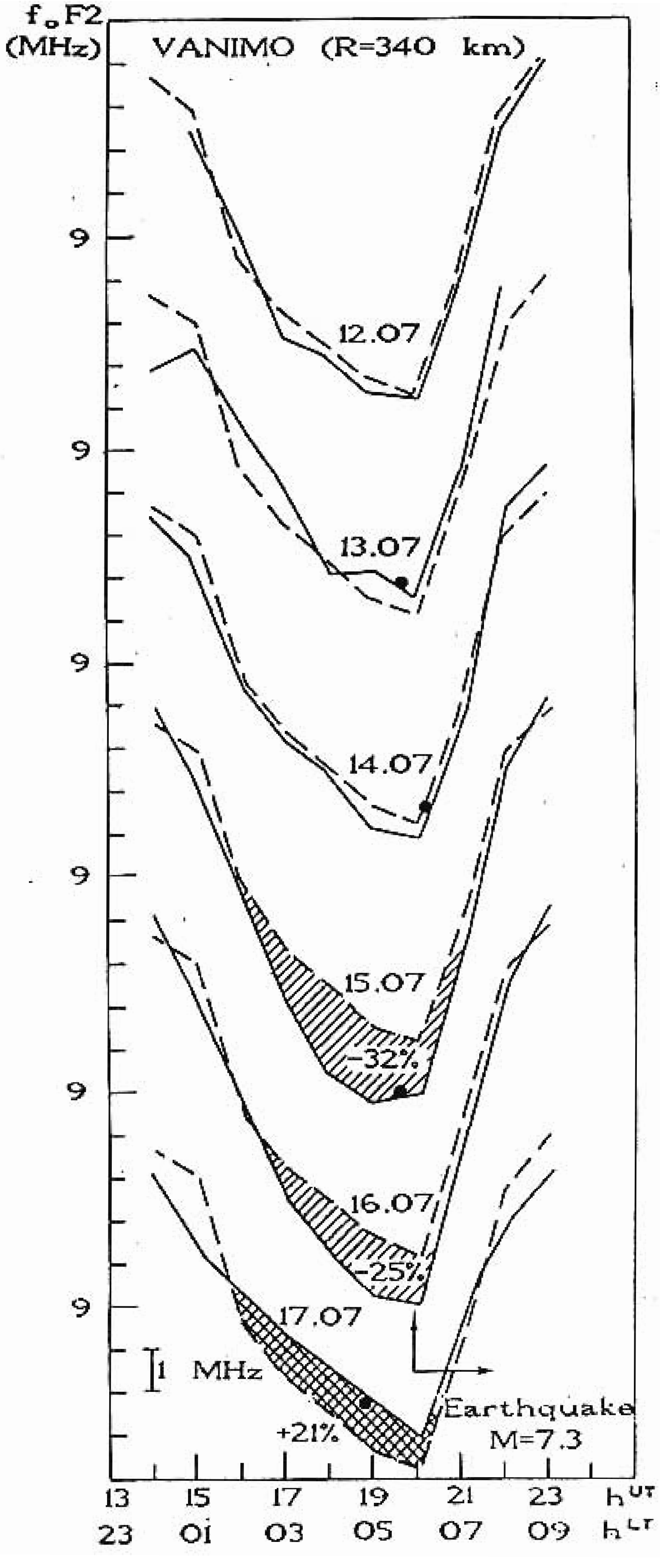


Fig. 1 Schematic presentation of earthquake epicenters (*) and ionospheric stations positions (closed circles) in Australian region for June-July 1980



Daily variations of f_oF2 (solid lines) and median values (hatched lines) comparison for 00-09 h^{LT} period at VANIMO ionospheric station few days before the earthquake 16.07.80. The earthquake moment is shown by arrow. Scaled topside f_oF2 values (●) when satellite passed over station.

Fig.2

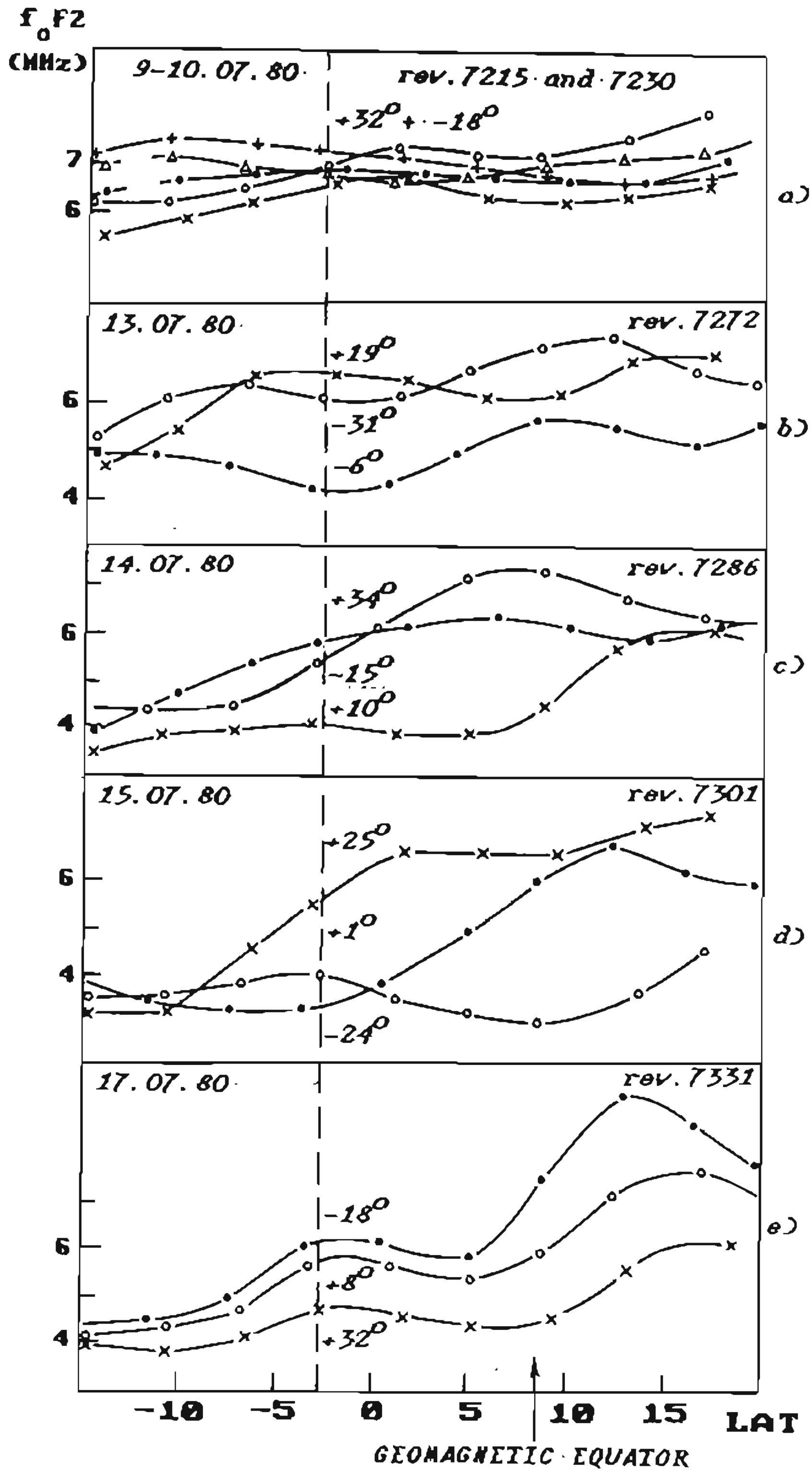


Fig.3 Latitudinal foF2 variations dynamics for morning hours (05-06 LT) at different longitudes nearby earthquake epicentef longitude for several days before and after earthquake 16.07.80. By "-" the eastward deviations of satellite pass from epicenter longitude are nominated amd by "+" - the westward ones.

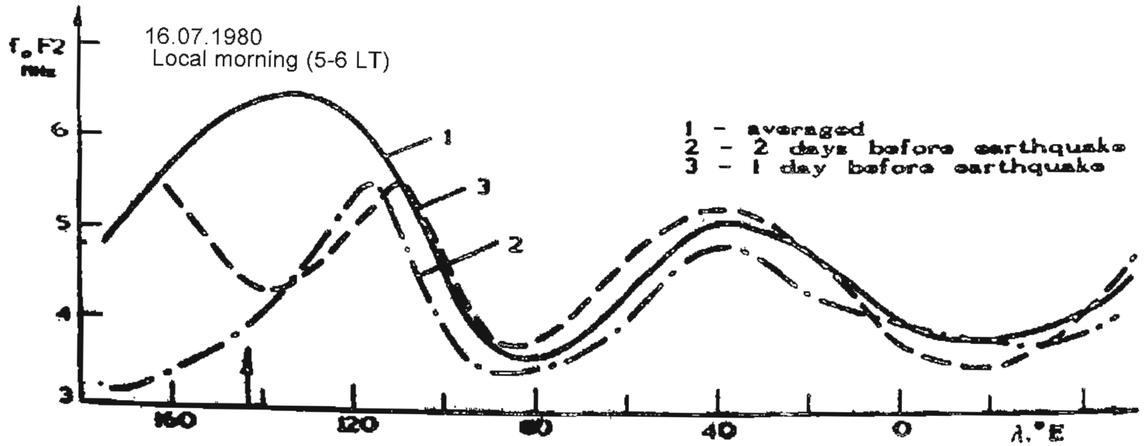


Fig.4 Longitudinal variations of f_oF2 during morning hours (05-06 h LT) for earthquake 16.07.80 on the earthquake epicenter latitude:

1 - averaged dependence for quiet conditions;

2 - two days before the earthquake (14.07);

3 - one day before the earthquake (15.07);

Epicenter longitude is shown by arrow.

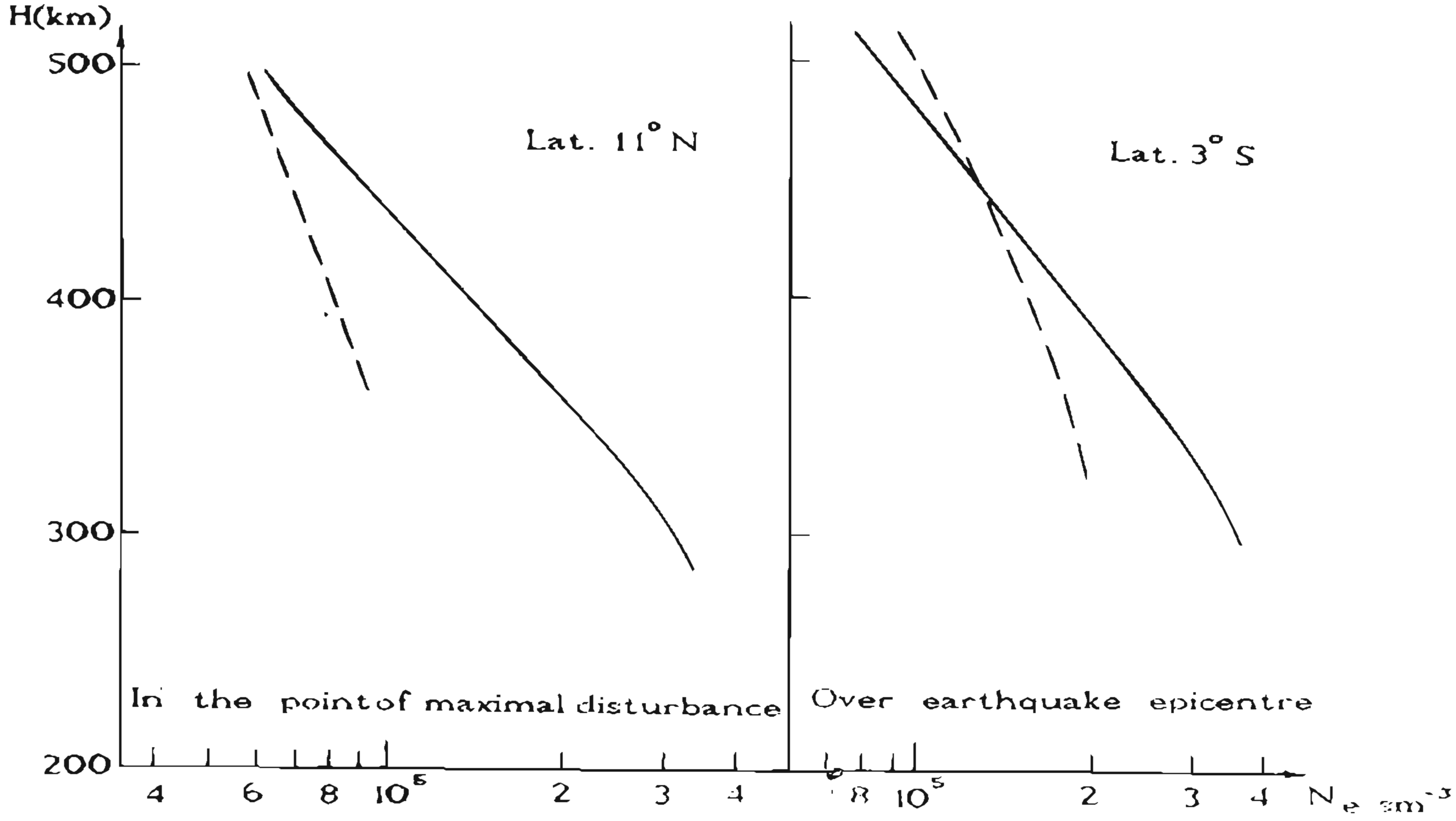


Fig. 5 Electron concentration topside vertical profiles for quies averaged conditions (solid lines) and one day before the earthqauke 16.07.80 (hatched lines) in the point of maximal disturbances (left) and over earthquake epicenter (right)

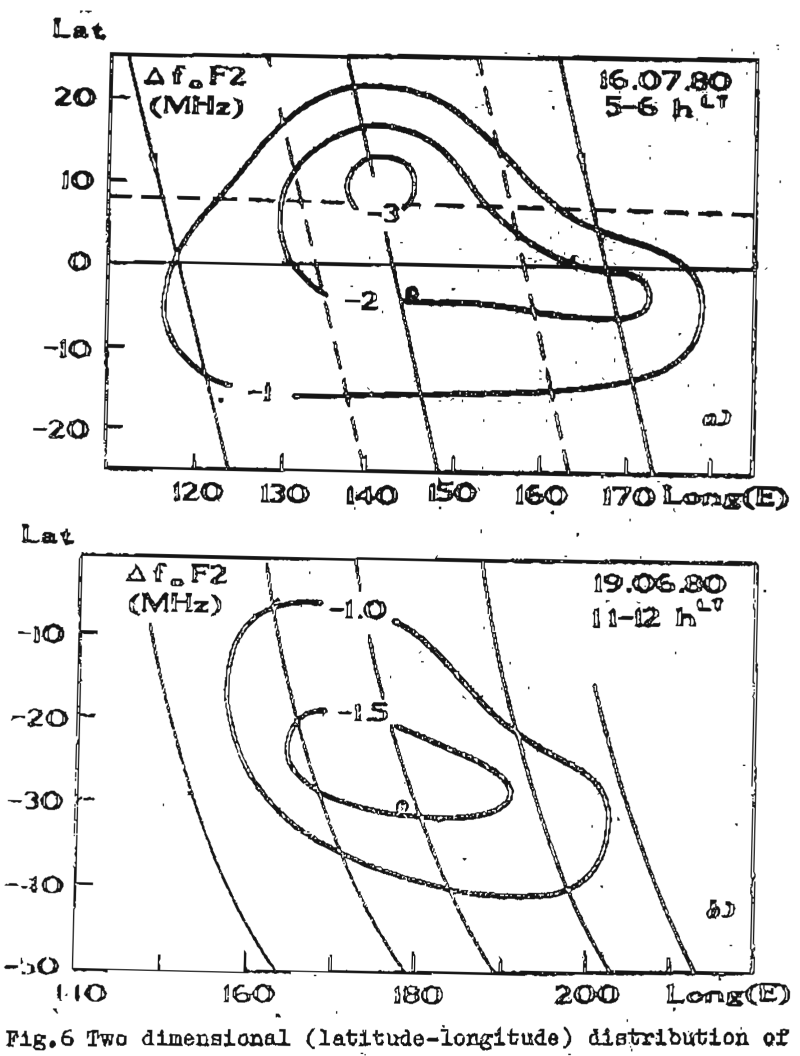


Fig.6 Two dimensional (latitude-longitude) distribution of f_0F2 deviations from the quiet averaged values in the maximal phase of disturbances before the earthquake 16.07.80 (a) and 19.06.80 (b). The earthquake epicenter positions is shown by black dots.

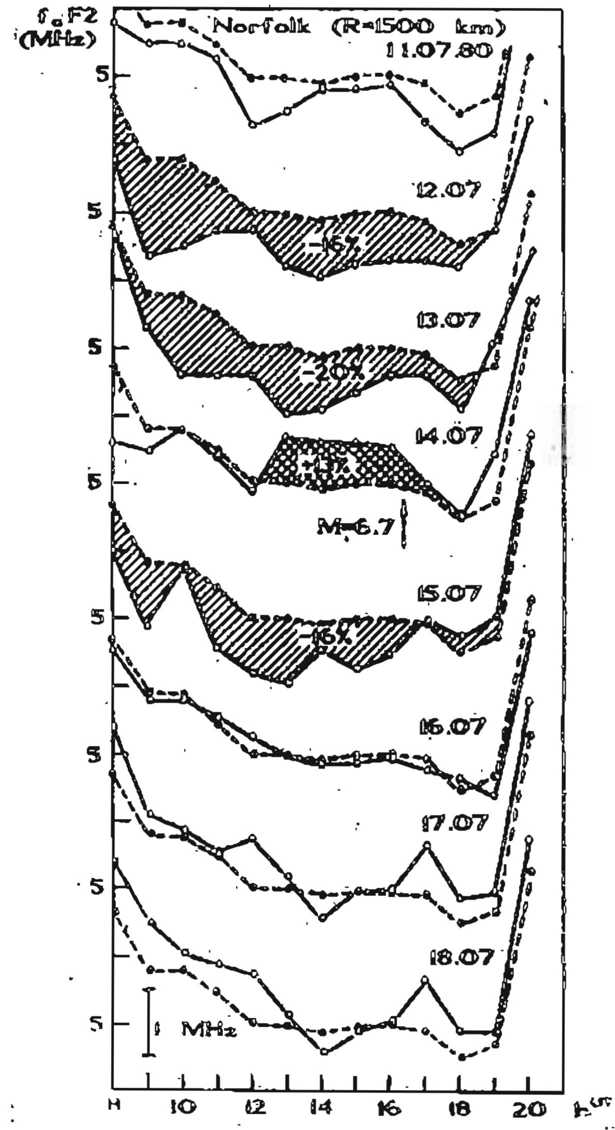


Fig.7 Comparison of daily variations f_oF2 (solid lines) with median values (hatched lines) at NORFOLK station for 08-20 h UT few days before, during and after the earthquake 14.07.80. It is by arrow.

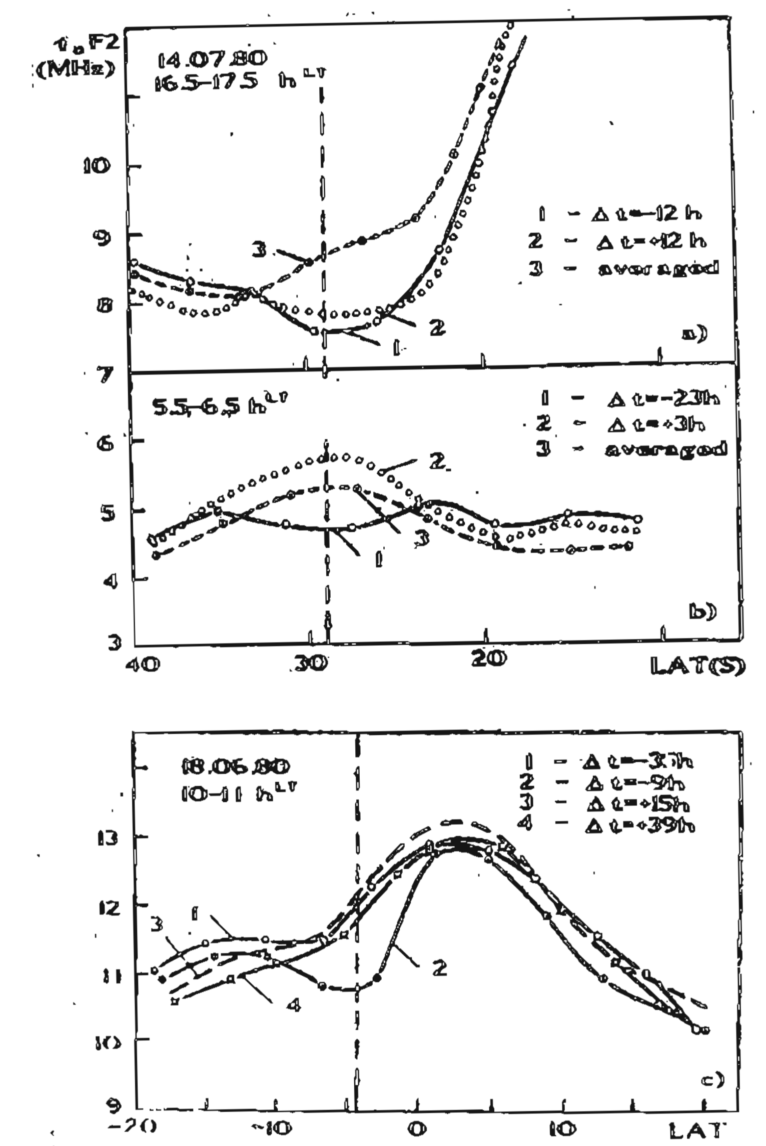


Fig.8 Latitudinal variations of f_oF2 for different local time sectors. The epicenter latitude is shown by hatched line.

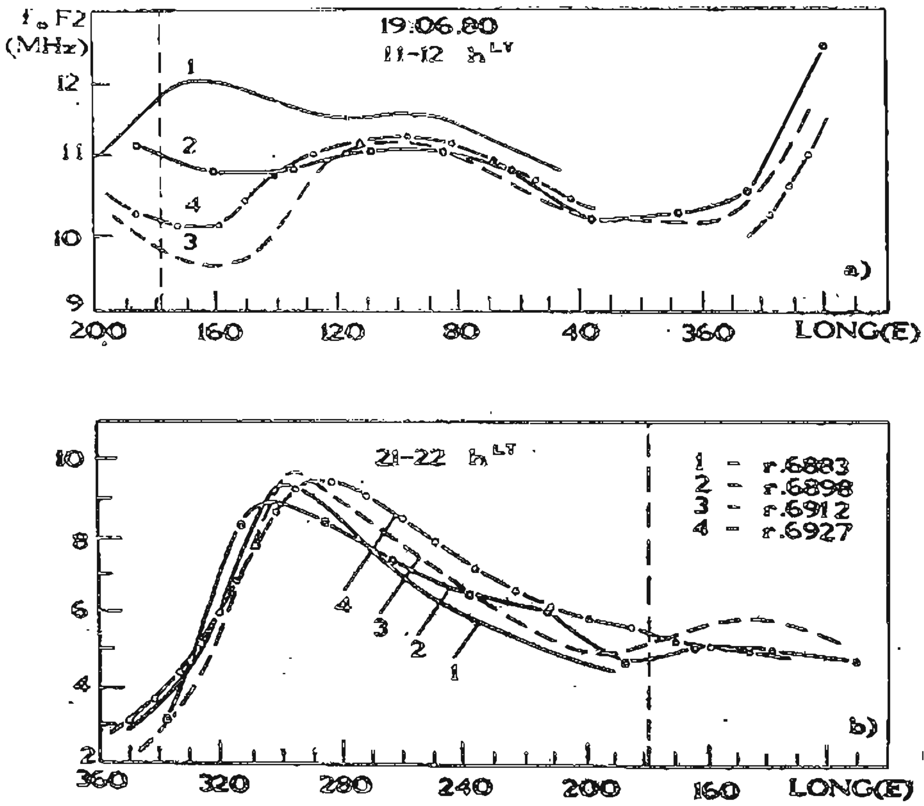


Fig.9 Longitudinal variations of f_oF2 for different local time sectors. The epicenter longitude is shown by hatched line.

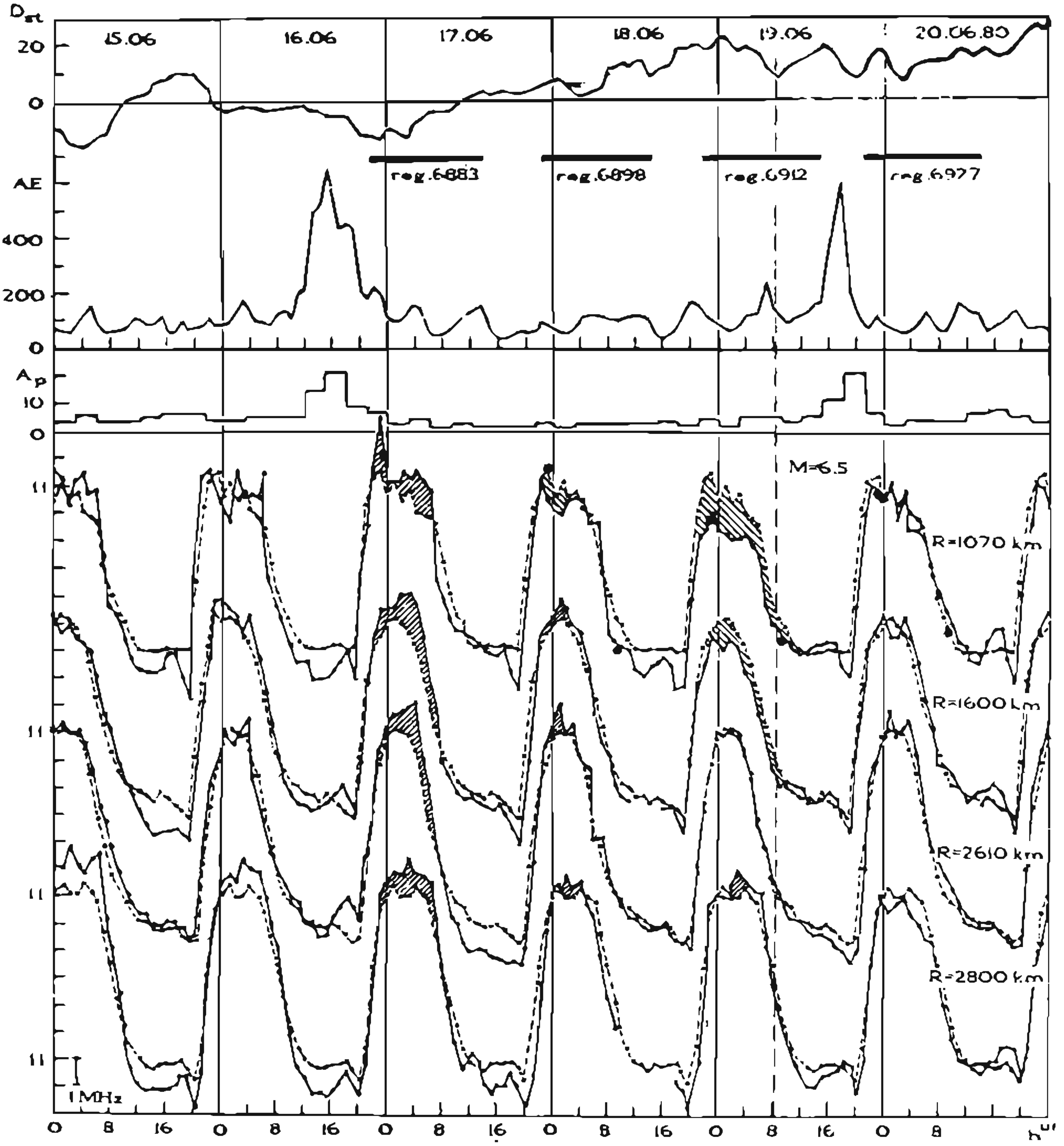


Fig. 10 Comparison of daily foF2 variations (solid lines) with medisn values (hatched lines) for several ground based ionospheric stations 1 - NORFOLK, 2 - CHRIST-CHURCH, 3 - CAMPBELL, 4 - CANBERRA for June 15-20 period. The earthquake moment (19.06.80; 8:30 UT) is marked by vertical dash line. Dst, AE and ap indices are shown in upper part of the figure. Periods of satellite records (topside sounder is on) are shown by bars