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On variations of $foF2$ and F-spread before strong earthquakes in Japan

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Abstract. The statistical analysis of the variations of the dayly-mean frequency of the maximum ionospheric electron density $foF2$ is performed in connection with the occurrence of (more than 60) earthquakes with magnitudes $M>6.0$, depths $h<80$ km and distances from the vertical sounding station $R<1000$ km. For the study, data of the Tokyo sounding station are used, which were registered every hour in the years 1957–1990. It is shown that, on the average, $foF2$ decreases before the earthquakes. One day before the shock the decrease amounts to about 5%. The statistical reliability of this phenomenon is obtained to be better than 0.95.

Further, the variations of the occurrence probability of the turbulization of the F-layer (F spread) are investigated for (more than 260) earthquakes with $M>5.5$, $h<80$ km, $R<1000$ km. For the analysis, data of the Japanese station Akita from 1969–1990 are used, which were obtained every hour. It is found that before the earthquakes the occurrence probability of F spread decreases. In the week before the event, the decrease has values of more than 10%. The statistical reliability of this phenomenon is also larger than 0.95. Examining the seismo-ionospheric effects, here periods of time with weak heliogeomagnetic disturbances are considered. For the $foF2$ analysis, the Wolf number is less than 100 and the index ΣK_p is smaller than 30, and in case of the F-spread study a Wolf number less than 80 and ΣK_p smaller than 17 are chosen.

1 Introduction

In a series of works, the behaviour of characteristic parameters of the ionosphere during earthquake preparation times has been studied. In this connection, the critical $foF2$-frequency – one of the parameters normally measured by vertical sounding – is often chosen. This frequency is the plasma frequency at the ionospheric F2-peak. Analyses of modifications of mean values of $foF2$ to prove if they might be precursors of sufficiently strong earthquakes were performed in a number of works. A decrease of the critical frequency $foF2$ before a few earthquakes was demonstrated by Hobara and Perrot (2005), Liperovsky et al. (1992), Ondoh (2000), Rios et al. (2004), Sing et al. (2004). On the other side, Pulinets and Boyarchuk (2004) noticed an increase of $foF2$ before an extremely strong earthquake. A statistical investigation of the $foF2$-decrease in the afternoon before Taiwan earthquakes was performed by Liu et al. (2006). These investigations were carried out for earthquakes with different ranges of magnitudes.

The aim of the present work is to prove the $foF2$-decrease statistically for Japanese earthquakes and to determine which are the magnitudes of the earthquakes yet connected with an observable modification of the mean $foF2$ frequency before a shock. Further, the pre-seismic mean temporal change of the turbulization of the F-layer, the F-spread, is studied.

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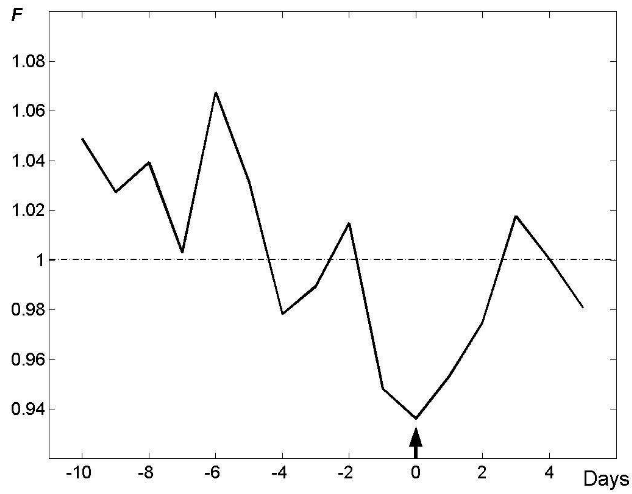

Fig. 1. Result of the superposition of epoches for earthquakes with epicenters below sea. 12 events with $M>6.5$, $R<1000$ km and $h<80$ km are analyzed.

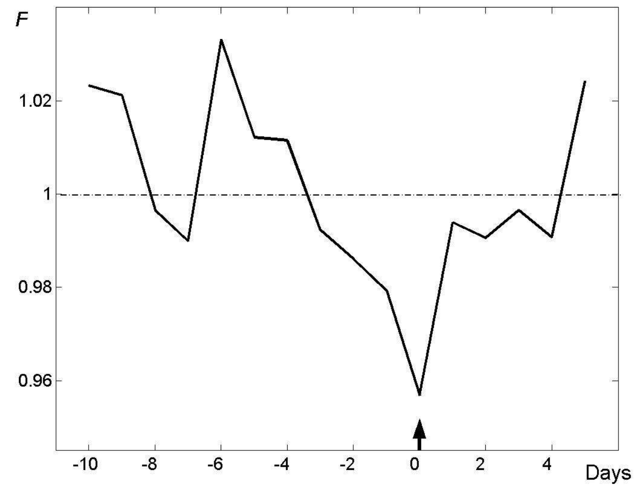

Fig. 2. Result of the superposition of epoches for earthquakes with epicenters below sea. 43 events with $6.5>M>6$, $R<1000$ km and $h<80$ km are analyzed.

2 Method of analysis of $foF2$ frequency

In the present work earthquakes with depths of $h<80$ km and distances R to the sounding station smaller than 1000 km are divided into two groups, earthquakes with epicenters under the bottom of the sea (marine earthquakes) and with epicenters below land (land earthquakes). Each of these groups is again divided into three parts – events with magnitudes $M>6.5$, with $6.5\geq M>6.0$, and with $6.0\geq M>5.5$. The ionospheric data were obtained by the station Kokubunji (φ=35.7° N, λ=139.5° E, years 1957–1990, http://www.rl.ac.uk.wdcc1/data.html). Ionospheric effects of earthquakes are usually superposed by solar and geomagnetic disturbances. Thus, only days with not too large solar and geomagnetic disturbances are taken into account. What means "not too large" is interpreted differently by different investigators. Here only days with Wolf numbers less than 100 and $\Sigma K_p<30$ are used in the study. Making such an assumption, more than half of the available experimental data are analysed.

In the present work, dayly-mean values $\langle foF2\rangle$ of $foF2$ are analysed. For any earthquake, a time interval from 10 days before the event up to 5 days after the event is taken into account. If a few earthquakes happened on one day, the day is treated as a day with one event. Further, earthquakes are excluded from the statistics, if the number of "quiet" days of the total time interval of 16 days was less than 8 days (less than half of the whole time interval). Then, the value $\langle foF2\rangle$ of every of the 16 days is normalized by the mean value of the whole time interval of 16 days. Thus, for any earthquake i a series of undimensional numbers $F_i=\langle foF2\rangle_i/\langle foF2\rangle_{\text{total}}$ is calculated for all the considered 16 days separately. Further, the method of superposed epoches for earthquakes of each group of events is applied, i.e. the normalized values F_i are averaged over the whole set of earthquakes for each day. As result a time-dependend function $F(t)$ is found, which is presented in corresponding figures.

3 Decrease of $foF2$ for earthquakes with epicenters below sea

Twelfe events with magnitudes $M>6.5$ occurred in the years 1957–1990, two of them even at the same day. In Fig. 1, $F(t)$ for earthquakes with $M>6.5$, $h<80$ km and $R<1000$ km are considered. Indeed, the dayly-mean values of $foF2$ statistically decrease. This phenomenon starts one week before the event, and the minimum occurs on the day of the earthquake. This result is in agreement with the findings of the works by Sing et al. (2004) and Hobara and Parrot (2005). An analogeous result, we find for somewhat weaker marine earthquakes with $6.0<M<6.5$ (43 events, see Fig. 2). On the other hand, for earthquakes with lesser magnitudes $6.0>M>5.5$, $R<1000$ km and $h<80$ km (225 events) no decrease of $\langle foF2\rangle$ is found for the day of the shock.

4 Decrease of $foF2$ for earthquakes with epicenters below land

In Japan strong earthquakes with epicenters below land happen less frequently than below sea. During the considered period of time 1957–1990 under "quiet" heliomagnetic and geomagnetic conditions, only one event with $M>6.5$ and six events with $6.5>M>6.0$ occurred. Fig. 3 shows the result of the superposition of epoches for this 7 earthquakes. Further, for less strong earthquakes with $6.0>M>5.5$ (30 events), an

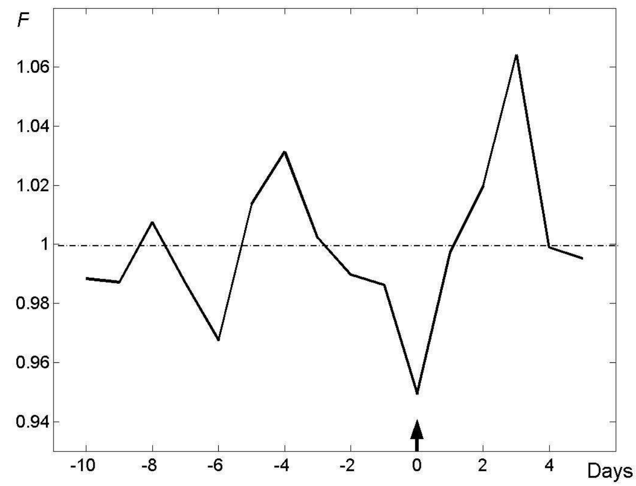

Fig. 3. Result of the superposition of epoches for earthquakes with epicenters below land. 7 events with $M>6$, $R<1000$ km and $h<80$ km are analyzed.

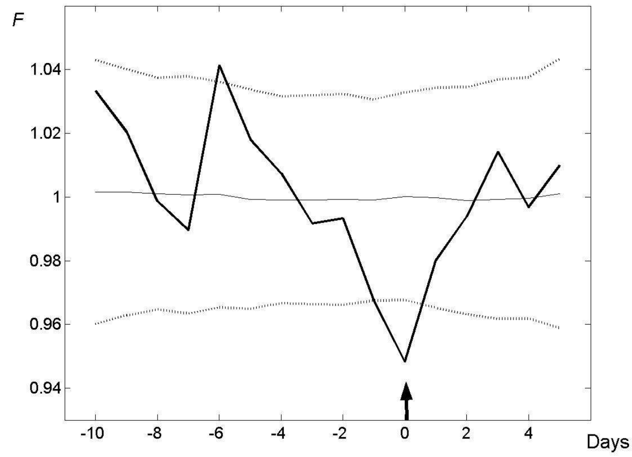

Fig. 4. Result of the superposition of epoches for earthquakes with epicenters below sea and below land. 62 events with $M>6$, $R<1000$ km and $h<80$ km are analyzed. Solid line – temporal behaviour of F. The dashed line gives the mean value of F and the dotted lines show the interval of reliability 2σ (2 standard deviations), which is calculated by random process modelling.

analogeous decrease of $\langle foF2 \rangle$ towards the day of the shock is not found. Summarizing the earthquakes with epicenters below sea and below land, which meet the condition $M>6.0$, into one group, one obtains a statistically reliable result: The dayly-mean values of $foF2$ decrease about one week before the earthquake.

Now, one has to investigate if the obtained seismo-ionospheric effect is casual or not. To answer this question, one has to calculate the probability P_{casual} that the effect is casual. If this probability is small enough, e.g. $P_{\text{casual}}<0.05$, then the effect is not casual with probability $P=1-P_{\text{casual}}>0.95$. In such a case the effect may be treated as a seismoionospheric one.

To evaluate P_{casual}, here a study of the variations of the ionospheric parameter F is performed using a random background process model. The random background process is constructed to check, if the variations of F_{virtual} found with the help of a set of "virtual events" (the number of "virtual" events must be equal to the number of real events) is of less amplitude than $F(t)$ obtained for the real events. Therefore $k=200$ series of events are constructed, each consisting of 62 virtual earthquakes. In each series of events the days of the earthquakes are chosen by a random number generator. Thus, an F_{virtual} is found for each set of "virtual" events. For every day, e.g. the day (-7) or the day (+2), F_{virtual} possesses a Gaussian distribution. Thus it is possible to determine the standard deviation $\hat{F}_{\text{virtual}}$ and the reliability σ for every day for all $k=200$ sets. The number 200 was chosen for k as for such large k-values, $\hat{F}_{\text{virtual}}$ and σ do not depend on k and may be calculated with proper accuracy. Then, for each day, F of the real earthquakes is compared with the variations of $\hat{F}_{\text{virtual}}$ using $\hat{F}_{\text{virtual}}\pm 2\sigma$. In Fig. 4, $\hat{F}_{\text{virtual}}$ (dashed line) and $\hat{F}_{\text{virtual}}\pm 2\sigma$ (dotted line) are presented, and it is to be seen that F exceeds $\pm 2\sigma$ on the days (-1) and (0). Hence, the decrease of $foF2$ is not casual with a probability P larger than 0.95.

5 Variability of the turbulization of the F-layer before earthquakes

As characteristic parameter of the turbulization of the F-layer, the F-spread phenomenon may be used. F-spread is observed as diffusivity of the traces of the F-layer on ionograms. The most important characteristic of F-spread is its occurrence probability which is studied here. The occurrence probability of F-spread equals the ratio of the number of F-spread observations to the number of observations of F2-layer tracks on the ionograms. Sometimes F-spread is comparatively weak and the observers can determine an exact value of $foF2$. At other times F-spread can be so intensive that an $foF2$-value cannot be found. Using data obtained every hour, one can calculate the occurrence probability of F-spread for some time interval.

F-spread is mainly observed at night. As illustration, Fig. 5 shows the number of F-spread observations as function of the local time for the years 1969–1990. Thus it is reasonable to investigate F-spread only for nighttime. Data of the station Akita ($\varphi=39.7°$ N, $\lambda=140.1°$ E.) are used, because man-made activity is powerful around the station Kokubunji (Tokio), and this may disturb the F-spread. Here the occurrence probability of F-spread is calculated for each night. For the night a time interval from 23:00 LT until 05:00 LT is chosen. Besides, only F-spread on days with comparatively weak solar and geomagnetic disturbances is considered, but

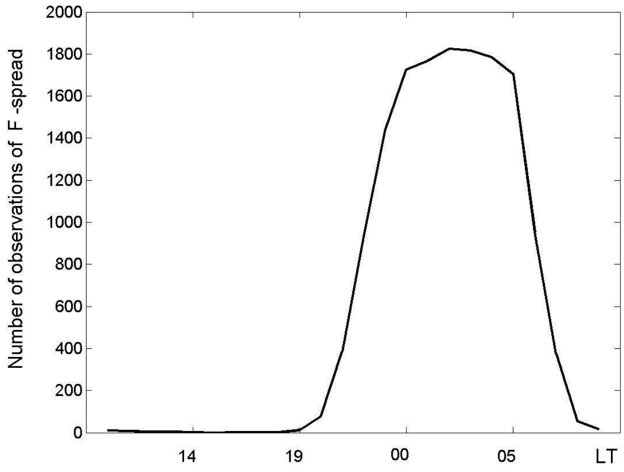

Fig. 5. Number of F-spread observations in the years 1969-1990 as function of the local time.

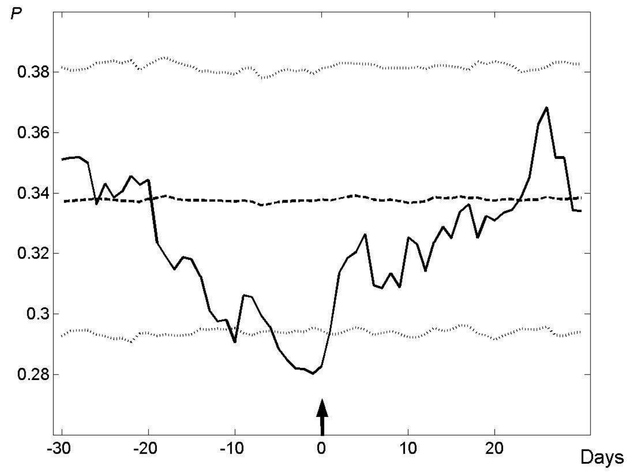

Fig. 6. Mean occurrence probability of F-spread P (thick solid line) during the time interval from 30 days before the earthquake until 30 days after the event. The dashed line gives the mean value of the occurrence probability calculated using the random process modelling. The dotted lines show the interval of reliability 2σ (2 standard deviations) found by random process modelling. Earthquakes with $M>5.5$, $R<1000$ km, $h<80$ km are considered.

in this case stronger conditions are chosen, there are taken Wolf numbers <80 and $\Sigma K_p<17$. The chosen boundary values are median values for 1969–1988. More than 1/3 of the days of this time interval are "quiet" ones.

The occurrence probability of F-spread is calculated for each day (i) in the vicinity of each earthquake using time intervals from the day $(i-3)$ to the day $(i+3)$. For these 7 days, the number of F-spread observations $N_{F-\mathrm{spread}}$ and the number of F-layer observations $N_{F-\mathrm{layer}}$ are determined, and the F-spread occurrence probability $P=N_{F-\mathrm{spread}}/N_{F-\mathrm{layer}}$ are calculated. Using the method of superposition of epoches, the mean occurrence probability of F-spread for the set of earthquakes with $M>5.5$, $R<1000$ km, $h<80$ km is calculated. During the considered time interval, 226 of such earthquakes are registered. For every earthquake, a time interval from 30 days before the shock to 30 days after the event is taken into account. Figure 6 shows the mean occurrence probability P of F-spread for all 61 analysed days. Almost one week before the earthquakes, a decrease of P is observed. The minimum of P is found in the time interval between the days (-3) and (+1). The decrease of P amounts to more than 10%. To prove this result statistically, again the method of modelling of random processes, described above, is applied. Here, 200 series of events are constructed, each consisting of 226 virtual days of earthquakes. Then, the mean value P_{virtual} and the standard deviation σ of the 200 virtual sets are calculated. The interval of reliability 2σ is also presented in Fig. 6. It is to be seen that P exceeds the $(\pm 2\sigma)$ interval and hence the statistical reliability of the decrease of the F-spread observation probability is larger than 0.95.

6 Conclusions

In the present work, ionospheric effects connected to 62 strong earthquakes with $M>6.0$, which took place in Japane, are analysed. The epicenters of the earthquakes were situated below sea and below land. It is shown that about 7–5 days before the events, the dayly-mean values of $foF2$ decrease. The relative minimum of the $foF2$ value occurs on the day of the earthquake.

The observed decrease of the $foF2$ values seems to be a consequence of a specific heating of the ionosphere by specific currents, which are excited by earthquake preparation processes during their last phase.

Further, $foF2$-variations of more than 260 less strong earthquakes with $6.0>M>5.5$ are studied. For these events no decrease of the dayly mean $foF2$ values during the earthquake preparation phase is obtained. This is valid for earthquakes with epicenters below sea and below land separately.

On the other hand, for the weaker earthquakes with $M>5.5$, $R<1000$ km, a decrease of the turbulization of the ionospheric F-layer (that means of F-spread) is found a week before the shock. This effect has a maximum in the imminence of the day of the shock.

The statistical reliability of both investigated seismo-ionospheric phenomena, the decrease of the $foF2$ values and the decrease of the F-layer turbulization is larger than 0.95.

Thus, considering earthquake precursors, it is more reliable to analyse the turbulization of the F-layer, because the turbulization of the F-layer may be registered already for rather weak earthquakes.

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