Geomagnetic forcing of the lower stratospheric O_3 and surface temperature short-term variability prior to earthquakes

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Abstract This paper is focused on the short-term variations of near surface temperature (T) obtained over a period of one week prior to the earthquake occurrence (EQ). We found a systematic temperature increase in almost the entire examined area (i.e. 8˚-30˚E and 35˚-53˚N), reaching a maximum in Aegean-Balkans-Pannonia basin region. Total of 1039 EQs have been analysed, what ensures statistical significance of our results. Comparison with the spatial distribution of geomagnetic variability reveals a striking similarity between pre-EQ variations of geomagnetic diurnal amplitude and surface T variability. This result suggests that relations between lithosphere and atmosphere, detected in the latest phase of EQ preparation, are possibly connected to the corresponding changes of geomagnetic field, initiated by the stress and strain remagnetization/demagnetisation of rocks, just before their destruction.

The mechanism for such lithospheric-atmospheric relations, suggested in this paper, requires corresponding changes in the near tropopause ozone and humidity, and our further analyses confirm their synchronous variations with geomagnetic field and surface temperature. This result indicates that geomagnetic variations of a lithospheric origin could drive the temporal co-variations of meteorological variables. The physical mechanism of geomagnetic influence is briefly discussed in the paper.

Keywords: near-surface temperature, earthquakes, geomagnetic field, lower stratospheric ozone and humidity

Introduction

One of the most exciting ideas for geophysicists has always been the possibility to decode multiple signals emitted from the Earth, and the early warnings coming with them for the impending earthquake. The claim that the Earth notifies for upcoming event through a surface temperature enhancement, in the region of future epicentre, has been raised by many authors (Wang and Zhou, 1984; Gorny et al., 1988; Qiang, Xiu-Deng, and Chang-Gong, 1991; Tronin, 1996; Tramutoli et al., 2001; Ouzounov and Freund, 2004; Choudhury et al., 2006a; Panda et al., 2007; Saraf et al., 2009; Guangmeng, 2012; Qin et al., 2012). The most of these claims are based on the analysis of the Earth's thermal infrared emission (TIR), measured by satellites (Gorny et al., 1988; Qiang, Xiu-Deng, and Chang-Gong, 1991; Tronin, 1996; Tramutoli et al., 2001; Ouzounov and Freund, 2004; Choudhury et al., 2006a; Panda et al., 2007; Saraf et al., 2009). Starting with the assumption that TIR emissions are generated by the tectonics stress and strain, the attentions was focused on the "window" radiation band (i.e.8-12 μm), in which the atmosphere is almost transparent for the long-wave Earth's radiation. This wave band, however, is highly sensitive to the amount of water vapour in the lower troposphere (Kilifarska, 2012), so the "skin" temperature measured by the satellites could substantially deviates from the ground based temperature measurement. This effect has been noticed by Chinese scientists (Chen et al., 2011), who pay attention that ground-based and satellite measurements of the high frequency fluctuations (with period 10 days or less) of the surface temperature are uncorrelated. For this reason this paper is focused on analysis of ERA-Interim reanalysis, providing two near surface temperatures – the air temperature at 2 m above the surface and the soil temperature at ~3 m below the surface.

We are looking for unusual behaviour of near surface T variation in 7-day period prior to earthquakes. In addition, some other geophysical variable are investigated – i.e. ozone and water vapour near the tropopause, and the amplitude of geomagnetic Y-component diurnal variations. Results are discussed in the light of interrelation between them.

DATA and METHODS

Results described in this paper are based on the analysis of 1039 earthquakes (EQs), occurred in the period 2004-2014, in the continental area with coordinates 8^0-30^0E longitude and 35^0-53^0N latitude. The chosen events are with magnitude higher than 4 and with depth more than 2 km. The time coordinates and earthquakes' parameters are taken from the Euro-Mediterranean Seismological Centre (EMSC). The selected EQs happened in magnetically quiet periods, with Ap index below 24, what give us the confidence that observed anomalies in geomagnetic field could not be related to geomagnetic disturbances of solar and magnetospheric origin, but rather have lithospheric origin.

The geomagnetic data have been taken from INTERMAGNET data centre (17 observatories) and geomagnetic network of Instituto Nazionale di Geophisica e Vulcanologia, Roma, Italy, (2 observatories – Castello Tesino and Lampedusa). Data for the air temperature at 2 m above the surface (T2m), soil temperature taken at □3 m below the surface (soilT4), lower stratospheric ozone mixing ratio at 100 hPa, and the water vapour specific humidity at 150 hPa are from ERA Interim reanalysis, taken at 18:00 local time, in a grid point being at shortest distance to each of the analysed 19 geomagnetic observatories. The temperature values in all EQs epicentres, occurred in a radius of 0.3750 around a given ERA Interim data point, have values determined in that point.

For all variables the *anomalies* (i.e. different from zero deviations from the 10 year mean, calculated for each day of the year) are derived as a difference between daily values and the corresponding average for that day, taken over the period 2004–2014. The time series have been divided on two composites: "pre-EQ" – defined as 7-day averages of daily values (i.e. the day of EQ(which happened in the chosen area) and the previous 6 days), and "non-EQ"– created in a similar way from the days without EQs.

The connection between the examined variables (i.e. the diurnal amplitude of geomagnetic Y-component, near surface T, atmospheric ozone and humidity) were investigated by the use of the standard linear regression method. From the regression coefficients (calculated for the location of each geomagnetic observatory) regression maps were created, in order to gain an idea for the spatial distribution of connectivity between examined parameters.

Due to the sufficiently high length of the examined time series, practically all of the regression coefficients are statistically significant, even those reflecting a weak relation between examined variables (Kenny, 1987). The calculated power of the statistical test (i.e. the probability of rejecting the null hypothesis when it is false), given the level of significance 0.05 and sample size of 1000 measurements, is equal to 1 – even for a sample's correlation coefficient as low as 0.2. This means that conclusions derived in this analysis are highly reliable.

Results of analysis

A lot of authors (Wang and Zhou, 1984; Gorny et al., 1988; Qiang, Xiu-Deng, and Chang-Gong, 1991; Tronin, 1996; Tramutoli et al., 2001; Ouzounov and Freund, 2004; Choudhury et al., 2006a; Panda et al., 2007; Saraf et al., 2009; Chen et al., 2011, Blackett, Wooster and Malamud, 2011, Guangmeng, 2012; Qin et al., 2012; Sulçe, 2013) have found that surface air temperature increases in a close proximity to the future earthquake's epicentre. Other papers report for systematic changes of geomagnetic field prior to earthquakes (EQ) (Hayakawa et al., 1996; Mavrodiev, 2004; Kilifarska, Nedialkov and Velichkova, 2015a). Analysing the geomagnetic and temperature variation during the 7-day period prior to 1039 EQ, Kilifarska, Nedialkov and Velichkova (2015a,b) suggest that they could be related to the changes of geomagnetic field. In keeping with the methodology of analysis described in Kilifarska, Nedialkov and Velichkova (2015a), we have compared the spatial distribution of the diurnal amplitude of Y-magnetic component – measured in each geomagnetic observatory, during the 7-day period prior to the every EQ – with its corresponding values for days without EQs.

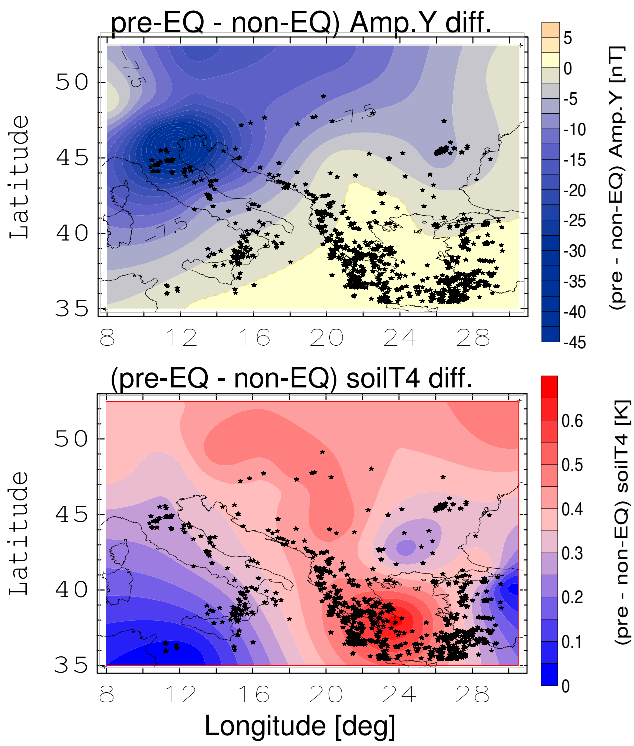

Fig.1 Spatial distribution of anomalous behaviour (relative to the days without EQs) of Y-magnetic component diurnal amplitude, and soil temperature, observed within 7-days prior to EQ. Black stars designate the all 1039 earthquakes.

Results are shown in Fig.1 (top). The figure presents difference between pre-EQs and non-EQs composites of geomagnetic Y-component's daily amplitude, averaged over the period 2004-2014. The upper panel in Fig. 1 shows that in the most of examined area (more specifically – Tyrrhenian Sea, the Eastern Alps and Carpathians) the amplitude of diurnal variability of magnetic Y-component is substantially reduced for the period of one week prior to EQ. Only over the Agean-Anatolian region and Balkan Peninsula is observed a slight increase of the geomagnetic diurnal variability.

Quite strikingly, a similar difference between pre-EQ and non-EQ episodes has been found in the spatial distribution of the near surface temperature anomalies (i.e. the deviation of daily temperature values, measured at 18:00 local time, from the 10-year average, calculated for the same day). The bottom panel in Fig.1 illustrates fairly well that soil temperature is increased everywhere, but the strongest rise is detected in Aegean Sea – Balkans – Pannonia basin area.

The similarity between spatial distribution of geomagnetic Y-component diurnal variations and the near surface temperature anomalies, obtained prior to EQs (compare top and bottom panels in Fig.1), suggests that they are possibly interrelate or influenced by a third unknown factor. Considering the relationship between geomagnetic field and climate variations, described in (Kilifarska, 2015; Kilifarska, Bakhmutov and Melnyk, 2015), we decided to check whether there is a statistically meaningful connectivity between changes in magnetic field and relevant temperature anomalies observed prior to EQ.

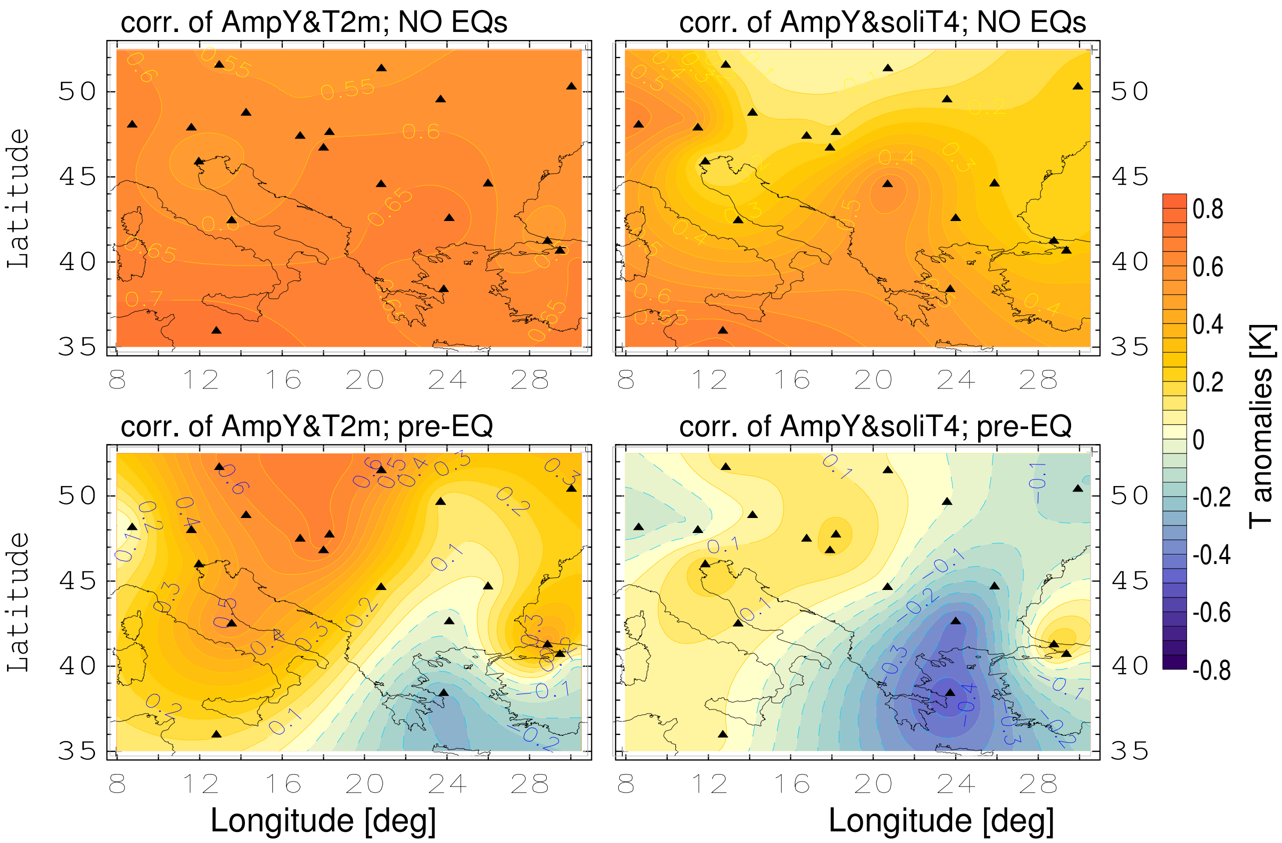

Fig. 2 Regression maps of connectivity between geomagnetic diurnal amplitude (Y component) and near surface air T (left column), and soil T at ~ 3 m below the surface (right column), calculated over the period 2004-2014. Top panel shows connection of non-EQs, while bottom panels – of pre-EQ composites.

For this purpose, we examined the correlation coefficients of the magnetic field diurnal amplitude (Y-component) with surface and soil temperature anomalies (i.e. at ~ 3 m below the surface), calculated in each of the surveyed 19 magnetic observatories. From the resulting correlation coefficient we built correlation maps of connectivity between magnetic field and temperature variations – for the periods without earthquakes, and for the 7-day period prior to each earthquake. The results are presented in Fig.2. An overall weakening of the connection between magnetic field and temperature prior to EQ is well noticeable in Fig.2. Over Aegean Sea, the Balkans and Anatolia region the correlation becomes even negative (especially pronounced in the soil temperature; Fig.2, right column). The comparison with Fig.1 reveals that at the same region is observed a weak amplitude enhancement of the magnetic field diurnal variation, unlike the overall decrease before the earthquake occurrence. This result implies that temperature anomalies, observed by many researchers before earthquakes (Wang and Zhou, 1984; Gorny et al., 1988; Qiang, Xiu-Deng, and Chang-Gong, 1991; Tronin, 1996; Tramutoli et al., 2001; Ouzounov and Freund, 2004; Choudhury et al., 2006a; Panda et al., 2007; Saraf et al., 2009; Blackett, Wooster and Malamud, 2011; Guangmeng, 2012; Qin et al., 2012), are probably related to changes in geomagnetic field.

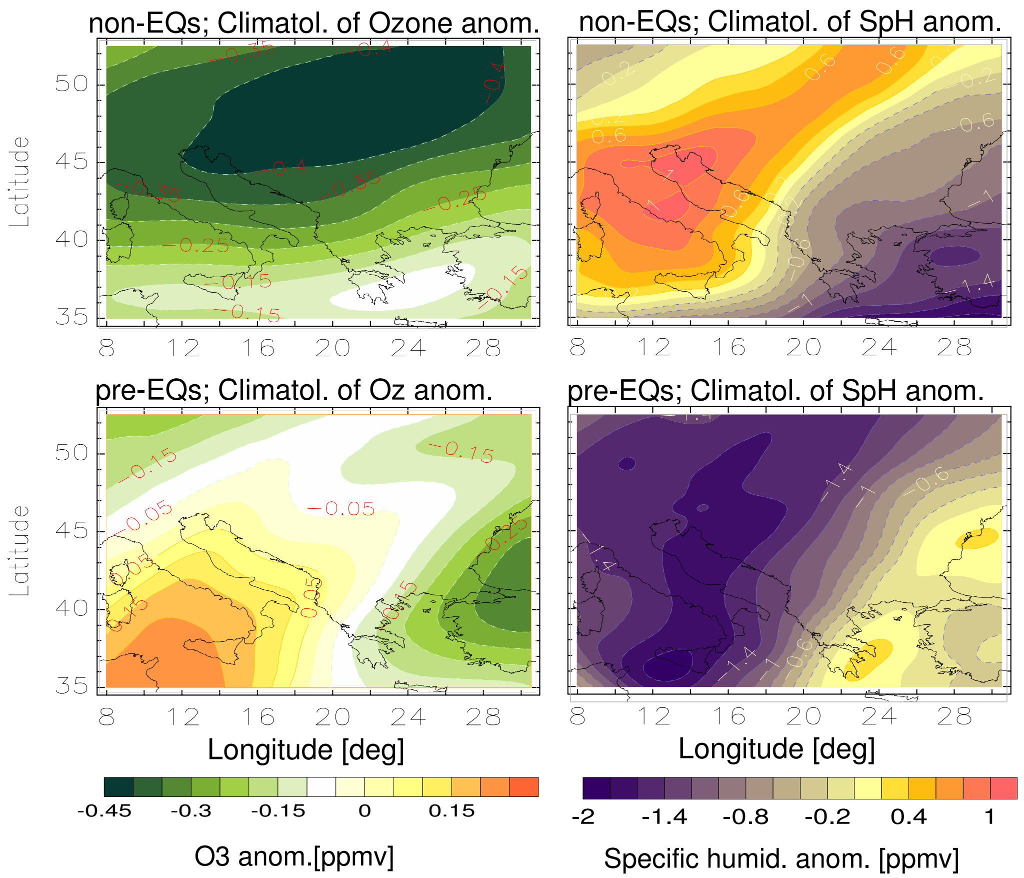

Fig. 3 Spatial distribution of the O_3 **anomalies** found at 100hPa and specific humidity – at 150hPa, calculate from non-EQs (top) and pre-EQs composites (bottom) panels.

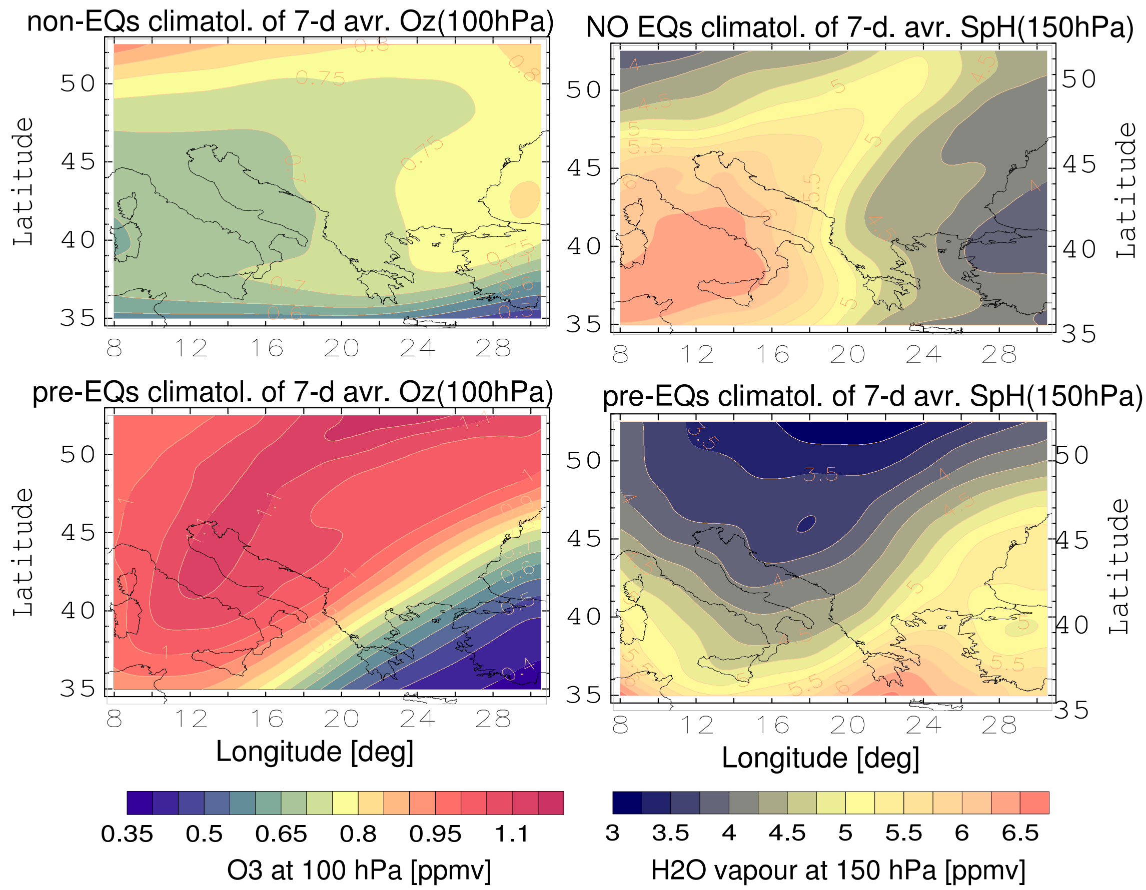

Fig.4 Spatial distribution of the **mean** O_3 and H_2O **values**, taken correspondingly at 100 and 150 hPa, derived for days without EQs (top panels) and for 7 days prior to EQs (bottom panel).

The mechanisms of geomagnetic influence on the climatic scales surface temperature variations (Kilifarska, 2015) suggests geomagnetic modulations of the intensity and depth of galactic cosmic rays (GCR) penetration in the Earth's atmosphere, and consequently – their absorption at different atmospheric levels. In turn GCR excite ion-molecular reactions at the level of their maximal absorption (usually near the tropopause), leading to the destruction or generation of ozone therein. Moreover, it is well-known that ozone influences the temperature near the tropopause, and respectively the transmission of water vapour between the troposphere and the stratosphere (Kilifarska, 2012). For example, the ozone reduction in the lower stratosphere leads to systematic cooling of the tropopause and facilitates the vertical transfer of water vapour to the lower stratosphere (Kilifarska, 2012; Kilifarska, Bakhmutov and Melnyk, 2015). On the other hand, the ozone enhancement has the opposite effect – increasing the tropopause temperature, it raises the static stability of the upper troposphere. In a stable atmosphere, however, the upward mass movements are greatly suppressed, reducing in such a way the already small amount of water vapour in the lower stratosphere.

On the other hand, the water in the upper troposphere provides 90% of the greenhouse effect of the Earth's atmosphere (Inamdar, Ramanathan and Loeb, 2004). So the enhancement of humidity leads to an increase of the greenhouse effect, rising in such a way the surface temperature. Oppositely, the reduction of water vapour weakens the greenhouse effect and correspondingly decreases the surface temperature.

If the mechanism of magnetic field influence is similar to the above-described, this implies differences in the spatial distribution of ozone in the periods without and prior to earthquake (due to changes of geomagnetic field). Moreover, synchronous antiphase variations of ozone and water vapour near the tropopause could be expected. To check whether the pre-EQ spatial distribution of O_3 at 100 hPa differs from its distribution in periods without earthquakes, we have analysed the deviations of daily values, measured at 18:00 local time, from their respective 10-year averages. The results are presented in Fig.3 (left column) and indicate that the well-defined negative anomaly in the Alpine-Carpathian region, change its sign within the 7-day period before the earthquake.

The right column of Fig.3 compares the spatial distribution of the water vapour anomalies at 150 hPa (i.e. its deviations from the 10-year averages, calculated for each day of the year) – in periods without EQs (top) and prior to them (bottom). It is clear that the positive anomalies in the Apennines-Carpathian region in the days without earthquakes changes to negative anomalies within 7 days prior to the earthquake (Fig.3, right column). The comparison between the left and the right columns of Fig.3 shows in addition, an out of phase synchronization between O_3 and H_2O vapour anomalies' variations, in both periods – without and prior to earthquakes.

Similar synchronicity between ozone and water vapour near the tropopause is observed in their average values (Fig.4). Statistical analysis of differences between *pre-EQ* and *non-EQ* ozone's and surface temperature's mean values (calculated in each magnetic observatory) confirms their significance at 2σ level in the greatest part of the observatories. This result, as well as the analysis of the covariance between geomagnetic field and lower stratospheric O_3 prior to EQs (Kilifarska, Nedialkov and Velichkova , 2015b), allows us to conclude that the mechanism of the magnetic field influence on the near surface temperature includes geomagnetic control over the intensity of GCR, which in turn affect the density of ozone.

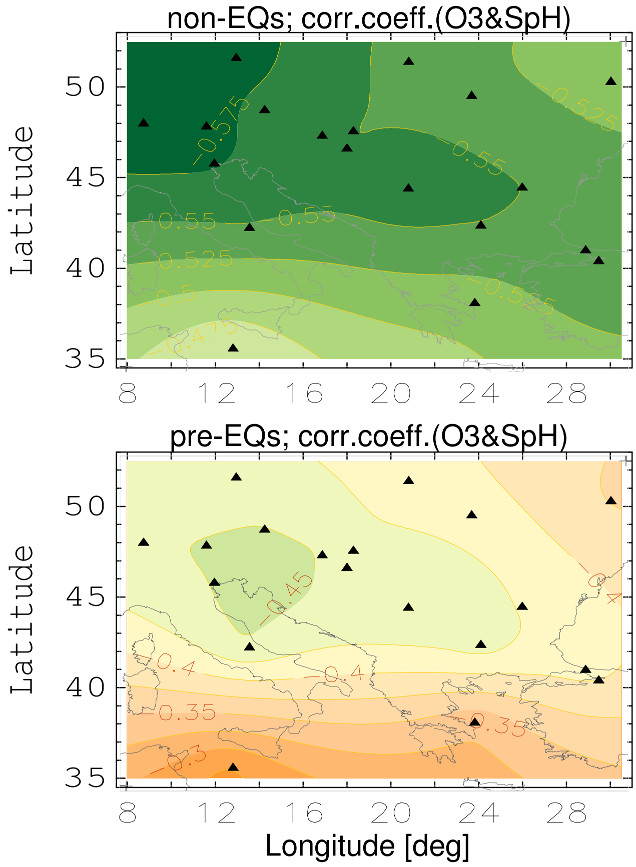

Fig.5 Spatial distribution of correlation coefficients between ozone at 100 hPa and specific humidity at 150 hPa calculated for days without earthquakes (top) and during the 7-day period prior to EQs (bottom).

The complementary analysis of ozone-water vapour relation, shown in Fig. 5, illustrate fairly well the connectivity between near tropopause O_3 and H_2O densities – in periods with and without EQs. Although the O_3 influence on the near tropopause humidity is weakened during the pre-EQ period (due to the tight magnetic control over the ozone's density), the relation between them remains strong enough. This relation supports the mechanism suggested by us for geomagnetic influence on the surface temperature through the mediation role of near tropopause ozone and water vapour.

Discussion

Most of the authors, reporting for a temperature increase prior to EQs, have based their conclusions on the satellite measurements of the Earth's thermal infrared emissions (TIR). As mentioned in the introduction, the TIR measurements are designed to detect the Earth's long-wave radiation in the "window" radiation band (i.e.8-12 μm), in which the atmosphere is *almost* transparent. Detailed measurements of the outgoing long-wave radiation (OLR) have shown that Earth's emission in the "window" band is, however, influenced by the amount of water vapour in the lower troposphere (Inamdar, Ramanathan and Loeb, 2004). Thus the reduction of the boundary layer H_2O vapour, due to the enhanced radon emission and aerosol formation (Pulinets et al., 2015), should increase the intensity of measured TIR by the satellites, simply as a result of reduced humidity. However, the impact of the "window" radiation band in the total OLR is only ~10% (Inamdar, Ramanathan and Loeb, 2004). The strongest impact in the Earth radiation balance (i.e. the rest ~90%) belongs to the upper tropospheric H_2O vapour (Inamdar, Ramanathan and Loeb, 2004). Consequently, the regional increase of near surface T (described above) could hardly be explained by the mechanism of aerosol formation – drying regionally the boundary layer (Pulinets et al., 2015) – because the impact of the "window" Earth's radiation in total OLR is very small.

Moreover, we have shown that these T variations are synchronised with similar variation of the geomagnetic field, as well as with the near tropopause ozone and H_2O vapour. These covariances could not be explained in the framework of the aerosols induced reduction of water vapour near the surface (Pulinets et al., 2015). This is a hint that another mechanism of lithospheric influence on the surface T should exist, which affect the amplitude of geomagnetic diurnal variation (particularly its Y-component) and near tropopause ozone and water vapour.

The mechanism for lithospheric-atmospheric interactions, suggested in this paper, relates geomagnetic field variations with intensity of energetic particles' precipitation in the Earth's atmosphere. The latter influence the near tropopause ozone and humidity, which in turn impact the atmospheric greenhouse effect, and correspondingly the near surface temperature (Inamdar, Ramanathan and Loeb, 2004; Kilifarska, 2012, Kilifarska, Bakhmutov and Melnyk, 2015). Thus the synchronous pre-EQ variations of geomagnetic field, temperature and atmospheric variables near the tropopause become easily understandable.

The various spatial pattern of geomagnetic variations prior to EQs, on turn, may be related to the geomagnetic strengthening or weakening, due to the rocks' remagnetization or demagnetisation, when accumulated stress and strains approach the structural failure, at the vicinity of a future EQ (Revol, Day and Fuller, 1977). This means that the sign of regional geomagnetic anomaly depends on the specific characteristics of rocks, as well as on the mechanism and depth of occurrence of each EQ – determining the regional thermal characteristics of lithosphere (Revol, Day and Fuller, 1977; Kilifarska, Nedialkov and Velichkova , 2015a). This hypothesis is indirectly supported by our analysis, because we have found that the difference between non-EQ and pre-EQ diurnal amplitude of magnetic Y-component becomes maximal when averaging its values for 7 days prior to EQ. This is a hint for an accumulative character of the pre-EQ geomagnetic field changes. Similarly, we have found a well pronounced systematic increase of the near surface (air, skin and soil) temperatures, when pre-EQ composite has been determined as 7-day averages, and did not find any signal, when averaging over the interval of two weeks.

Conclusions

Results from this study are based on the analysis of 1039 earthquakes, occurred in the region with coordinates: 8^0–30^0 E and 35^0–53^0 N, which ensures the reliability of our statistical tests.

Analysis of the near surface temperature deviations (measured at 18:00 local time) from their 10-year climatology (calculated for every day of year) reveals systematic increase of the pre-EQ near surface temperature, especially well pronounced in Aegean – Balkans and Pannonia basin regions.

Examination of the spatial distribution of the diurnal amplitude of geomagnetic Y-component (Fig.1), as well as its correlations with near surface air and soil temperatures (Fig.2) showed very good conformity with the anomalous behaviour of ozone and water vapour before the earthquake (Figs.3-5). This allows us to conclude that: 1) pre-EQ changes observed in the surface temperature are likely connected to relevant regional changes of geomagnetic field; 2.) the mechanism of geomagnetic influence on surface temperature should be a chain of consequences, which includes the synchronous variability of near tropopause ozone and water vapour (Kilifarska, Bakhmutov and Melnyk, 2015).

The mechanism proposed in this paper consists of geomagnetic control on the intensity of GCR, which in turn influences the amount of ozone and water vapour near the tropopause. The powerful greenhouse effect of the latter (reaching up to 90% of the total greenhouse effect) influences the near surface temperature of the Earth.

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