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Brief communication

"Further comments on the ionospheric precursor of the 1999 Hector Mine earthquake"

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Abstract. Pulinets et al. (2007) document anomalous changes in the ionospheric total electron content (TEC) starting one week before the 16 October 1999 Hector Mine earthquake. The authors maintain that this TEC anomalous change is a precursor of the subsequent earthquake. In a previous paper, Afraimovich et al. (2004) excluded that TEC variations, which occurred before the Hector Mine earthquake, were induced by the preparation process of the seismic event. Thomas et al. (2012) reach similar conclusions by performing new analyses of the same TEC data which were investigated by Pulinets et al. (2007). They show that the TEC changes documented by Pulinets et al. (2007) are not anomalous but normal variations on global scale, and, therefore, these changes are not related to the localised seismic activity of the Hector Mine area. This paper confirms the results of Afraimovich et al. (2004) and Thomas et al. (2012). Through the use of geomagnetic indices time series it is shown that the presumed precursor of Pulinets et al. (2007) was a normal TEC variation induced by solar-terrestrial interaction.

1 Comments

As Thomas et al. (2012) point out, such similar studies to Pulinets et al. (2007) motivate the idea that earthquake prediction will one day be possible. Earthquake prediction is a controversial challenge of the scientific community but it has also a social importance because of the great benefit that could be obtained with accurate predictions. To be useful, short-term earthquake prediction requires reproducible precursors which provide information regarding magnitude, location, and time of the predicted earthquake, together with error estimates for each parameter. Thus, any potential anomaly, before it can be considered as a reliable indicator of an imminent earthquake, should be distinguishable from randomness or an anomaly of alternative cause, both natural and artificial. Recently, some researchers gave rise to a re-examination process of dubious observations of earthquake precursors. They demonstrated that there is no strong relation between the presumed precursors and subsequent seismic events (see e.g. Masci, 2010, 2011, 2012a, b; Thomas et al., 2009a, b, 2012).

Pulinets et al. (2007) propose a new ionospheric index which the authors define "regional variability index" (hereafter ΔTEC). This index describes the variability of the ionosphere by means of the difference between the maximum value and the minimum value of the GPS TEC measured in all stations within the area of the analysis. Through the analysis of data from 13 GPS stations within the preparation area of the 16 October 1999 Hector Mine earthquake, Pulinets et al. (2007) retrospectively document anomalous ΔTEC changes which the authors claim to be precursory signatures of the seismic event. According to Pulinets (2007) the regional variability index is sensitive to earthquake-related TEC changes and much less sensitive to TEC variations induced by the geomagnetic activity. As a consequence of this finding, the author maintains that "*short-term earthquake prediction based on ionospheric data may one day become as routine a technique as seismographs*". Due to the great social impact of the earthquake predictions, as required by the normal scientific process, the findings of Pulinets et al. (2007), and other similar studies, need to be seriously investigated by means of independent supporting datasets.

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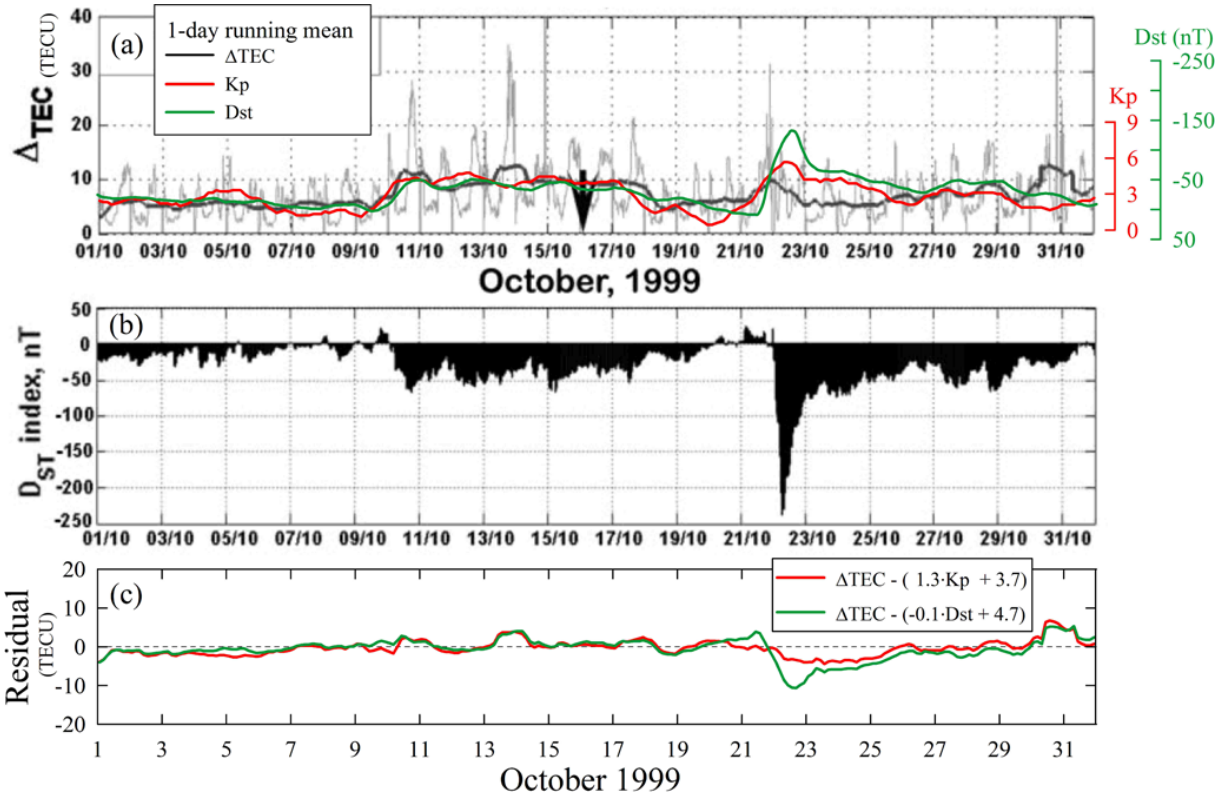

Fig. 1. (a) and **(b)**: a reproduction of Fig. 6 by Pulinets et al. (2007). Ionospheric regional variability index ΔTEC **(a)** and Dst geomagnetic index **(b)** during October 1999. The black arrow indicates the date of the Hector Mine earthquake. Geomagnetic Kp and Dst indices time series are superimposed onto panel **(a)**. **(c)** Residual time series of the linear relationship between the 1-day running average of the geomagnetic indices and that of ΔTEC. The TEC units are TECU, where 1 TECU $= 10^{16}$ electrons m^{-2}. See text for details.

Many papers by means of statistical methods put in evidence anomalous behaviour of TEC, which the authors believe to be related to the subsequent earthquakes (see e.g. Le et al., 2011). On the contrary, other studies document the observation of pre-earthquake ionospheric disturbances but no statistically significant correlation between these anomalies and the seismic events (see e.g. Dautermann et al., 2007; Rishbeth, 2006) showing that some ionospheric precursors are artefacts related to changes in solar and geomagnetic activity, which influences the ionospheric parameters such as the regional TEC variations (see Afraimovich and Astafyeva, 2008; Masci, 2012c). Thus, it is evident that the consideration of the geomagnetic activity level is a key parameter for the interpretation of the observed ionospheric disturbances. In this brief report I compare the regional variability index by Pulinets et al. (2007) with the geomagnetic indices Kp and Dst. The 3-h Kp index is representative of geomagnetic activity changes over planetary scale, while the 1-h Dst index monitors the world wide magnetic storm level. In any case the two indices give us indications about global geomagnetic disturbances.

Figure 1a and b shows the regional variability index ΔTEC and the Dst geomagnetic index during October 1999 as reported by Pulinets et al. (2007). The authors claim that the ΔTEC increase, which occurred during the week before the Hector Mine earthquake, has a seismogenic origin. However, by a simple visual investigation of Fig. 1a and b, we can see an evident correspondence between ΔTEC and Dst, i.e. the ΔTEC increase corresponds to an increase of the geomagnetic activity. In my opinion, this correspondence was to suggest to the authors that the presumed precursor was not a real seismogenic signature. Here the 1-day running averages of Kp and Dst were superimposed onto Fig. 1a. If we focus our attention to the period before the Hector Mine earthquake, we can see a strong correlation between the running average of the geomagnetic indices and that of ΔTEC. This fact suggests us that during the period before the Hector Mine earthquake, the regional TEC variability was induced by global geomagnetic disturbances and was not related to preparatory phase of the subsequent earthquake. However, I should point out that after the earthquake, or more precisely during the period of 22–26 October, the correlation between ΔTEC and the geomagnetic indices is weak. Since this period includes a strong geomagnetic storm ($Dst_{max} = -237$ nT), the lack of a good correlation between ΔTEC and the geomagnetic indices obviously does not support the idea that seismogenic

Table 1. Mean values of ΔTEC and residuals during the period before the Hector Mine earthquake and during the month of October 1999.

	$\overline{\Delta TEC}$	$\overline{\lvert Res_{Kp} \rvert}$	$\overline{\lvert Res_{Dst} \rvert}$
1–15 October	7.03	1.36	1.09
1–31 October	7.14	1.51	1.95

ionospheric disturbances, which may be consequential to earthquakes, occurred during the period of time after the Hector Mine earthquake. As Thomas et al. (2012) point out, we should not expect that a good correlation always exists between ΔTEC and the geomagnetic indices since the regional variability index of Pulinets et al. (2007) was not designed to investigate global geomagnetic activity changes. More specifically, Fig. 1 shows that while the index of Pulinets seems to be generally well correlated with low to moderate levels of geomagnetic activity, it is not a good measure of magnetic storms. In addition to that, since the Kp index is representative of the geomagnetic field average disturbances over planetary scale, we should not expect that a close correlation between the index of Pulinets and Kp will exist always and everywhere over long time range. On the other hand, a good correlation during a period of time indicates that during this period the TEC variability is part of normal global magnetic field variations driven by solar-terrestrial interaction and cannot be related to a seismic activity (see also Masci, 2010, 2011, 2012c). As further investigation, I digitized the ΔTEC 1-day running average from the original view of Pulinets et al. (2007). The digitized values have a resolution of 3 h as the Kp index. Secondly, the 1-day running average of both the geomagnetic indices Kp and Dst were calculated with a resolution of 3 h. Finally, I calculated the linear relationship between ΔTEC and the two geomagnetic indices. ΔTEC data during the period of time which includes the magnetic storm were excluded in the estimation of the two linear relationships. The two linear residual time series are plotted in Fig. 1c. We can see that, before the Hector Mine earthquake, the residuals are much smaller than the values of the variability index ΔTEC and do not show any anomalous signature that may be attributed to lithospheric processes preceding the earthquake. Table 1 shows the mean values calculated for ΔTEC and for the absolute value of the two residuals time series during October and before the Hector Mine earthquake. We can see that the mean of the residuals are smaller than the ΔTEC mean.

2 Conclusions

This brief report confirms the results of Afraimovich et al. (2004) and Thomas et al. (2012), which demonstrated that before the Hector Mine earthquake, the TEC variations are controlled by geomagnetic activity changes and then they cannot be related to the preparation process of the seismic event. In addition to that, even if an external triggering (e.g. by seismic processes) may induce the release of a great amount of energy accumulated in the system ionosphere-atmosphere, the study of Pulinets et al. (2007) does not shows any clear evidence of the effect of mutual influence between the Earth and the ionosphere that Popov et al. (1989) define "terrogenic effect in the ionosphere" and in recent literature it is called Lithosphere–Atmosphere–Ionosphere Coupling (LAIC) mechanism (see e.g. Pulinets and Ouzounov, 2011). In summary, this paper definitively shows that the regional variability index by Pulinets et al. (2007) is not a good predictor of earthquakes.

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