The study of ionospheric anomalies in Japan area during 1998-2010 by Kon et al.: an inaccurate claim of earthquake-related signatures?

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Abstract

The problem of identify earthquake-related precursory signals is a very important topic in the hope of mitigate the seismic hazard, but false precursor claims decrease the credibility of this field of research. The statistical study by Kon et al. (2011) show that positive total electron content (TEC) anomalies occurred 1-5 days before 52 M>6 earthquakes which struck Japan during 1998-2010. Kon et al. (2011) also report in detail three selected case studies claiming the occurrence of TEC anomalies possibly related to large and destructive earthquakes. This paper casts doubts on the possibility that in the three cases variations of TEC values could be undoubtedly induced by seismic events suggesting that the TEC changes could be actually part of normal global geomagnetic activity. As a consequence, also the results of the statistical analysis by Kon et al. (2011) could be seriously influenced by global magnetospheric signals.

Keywords: Ionospheric anomalies; Total electron content; Earthquake-related ionospheric anomalies; Short-term earthquake prediction.

1. Introduction

Many studies claim the observation of different types of pre-earthquake seismogenic anomalies. The motivation for the research of earthquake precursors is to realize short-term deterministic earthquake prediction. This field of research is very important because of the great benefit which could be related to accurate prediction, but false alarms could have negative consequences. Ouzounov et al. (2011) affirm that: "*the costs to human life by such events are another indication that development of an earthquake hazard mitigation scheme requires an interdisciplinary effort*". In addition, I would like to emphasize that the mitigation of seismic hazard needs of reliable and reproducible earthquakes precursors.

Several papers report the observation of pre-earthquake signals, but also show the lack of any firm correlation with the seismic activity. In addition, even if these anomalous signals have been retrospectively related to seismic events, several researchers consider these pre-earthquake signatures a new way towards the possibility of developing earthquakes prediction capabilities (e.g., Uyeda et al., 2009; Hayakawa and Hobara, 2010). On the contrary, many in the scientific community doubt the reliability of anomalous signals claimed to be precursors of pending earthquakes. These researchers criticize the retrospective validation of earthquake precursors, the lack of validation and reproducibility of the precursory signals, and the observation of precursors without expected co-seismic related larger signals (see e.g. Geller, 1997; Pham and Geller, 2002; Johnston et al., 2006). Recently, some studies have cast serious doubts on the authenticity of well-known earthquake precursors (e.g. Campbell, 2009; Thomas et al., 2009; Masci, 2010, 2011a, 2011b, 2012a, 2012b). Obviously, it's likely that an ''anomalous variation'' can happen before the occurrence of an earthquake, but is rather incorrect to relate the anomaly and the seismic event without further validations. If the anomaly occurs simultaneously or at least shortly prior/after the earthquake, chances are good that it is linked to the seismic event. On the contrary, it is very difficult to associate the precursor with the earthquake if they are separated in time. In this case, the appearance of the anomalies before the earthquakes occurrence could be a chance event. In light of this, a closer inspection of the real presence of seismogenic signals in geophysical data sets is required.

Many papers claim the observation of ionospheric phenomena which could be possibly associated with strong seismic events (e.g. Liu et al., 2009; Le et al., 2011; Liu et al., 2011) suggesting also possible mechanisms to account for their generation (e.g. Pulinets et al., 1994). On the contrary, other authors question the anomalous behaviour of the ionosphere considered as earthquake precursor (e.g. Rishbeth et al., 2006a). They maintain that in some cases pre-earthquake anomalies, such as TEC variations, may be actually related to changes in solar and geomagnetic activity which cause not only global alteration of the ionosphere, but also may control local perturbations of ionospheric parameters such as the regional TEC variations (see Afraimovich et al., 2004; Afraimovich and Astafyeva 2008; Rishbeth et al., 2006b). In addition, other studies report the observation of pre-earthquake TEC anomalies but also the lack of any significant statistical correlation, both in time and in space, between these anomalies and the seismic events (e.g. Dautermann et al., 2007) showing that some ionospheric precursors are artefacts caused by enhanced space weather activity. In summary, since the influence of the seismic activity on the ionosphere remains an open question, and many points remain unclear regarding the detection of pre-earthquake effects, a real caution should be adopted before claiming the observation of seismogenic ionospheric precursory signals.

2. Kon et al. claims

Kon et al. (2011), hereafter cited as KON, is part of the studies presented at the international workshop VESTO (Validation of Earthquake Precursors by Satellite, Terrestrial, and other Observations) organized in March 2009 at Chiba University, Japan (Ouzounov et al, 2011). Twelve selected papers, including KON, were published in a special issue of Journal of Asian Earth Sciences (volume 41, issues 4-5). KON using GIM-TEC, that is TEC data derived from Global Ionospheric Maps, investigate the occurrence of pre-earthquake ionospheric anomalies before strong seismic events which struck Japan during the period 1998-2010. The authors calculate the normalized GIM-TEC (hereafter TEC*) by means of the 15-day backward running mean and the corresponding standard deviation. Refer to KON for further details. In order to reduce the effect due to strong geomagnetic activity, such as magnetic storms, which can perturb TEC from few hours to 2 days after the onset of magnetospheric disturbances, KON removed 2 days TEC data after the beginning of the perturbed periods. The criterion adopted by the authors to define an ionospheric perturbed period is when the global geomagnetic Dst index exceeds -60nT.

As examples of case studies, KON report TEC* time-series in correspondence of four selected strong earthquakes: 2004 mid-Niigata Prefecture Earthquakes (M6.8, M6.1), 2007 offshore mid-Niigata Earthquake (M6.8), and 2008 Iwate–Miyagi Nairiku Earthquake (M7.2). Figures 1, 2, and 3 show TEC* time-series in correspondence of these seismic events as reported by KON. The original views also show Kp index, Dst index, and F10.7 solar radio flux index time-series. Vertical green lines refer to the earthquakes dates and grey areas highlight geomagnetic disturbed period (Dst<-60nT). The authors define an ionospheric anomaly when TEC* exceeds 2σ. More precisely, positive anomalies appear when TEC* exceeds +2σ, and negative anomalies appear when TEC* exceeds -2σ. KON, taking into account the results of the three case studies, affirm: "*it is highly suggestive that possible positive and negative TEC* anomalies before and after large earthquakes occur*". As a consequence, they performed a statistical study by means of Superimposed Epoch Analysis (Hocke 2008) claiming that positive TEC* anomalies appear 1-5 days before M>6 earthquakes occurrence within an area having a radius of 1000 km around Japan.

3. Discussion

The results of Kon et al. (2011) are investigated in order to verify the real nature of their claims. In figures 1, 2, and 3 green arrows refer to the TEC* anomalies described by KON, whereas yellow arrows refer to other cases of TEC* values exceeding 2σ which are not considered by KON. The authors, referring to the three case studies, claim that: "*Although there are some positive and negative TEC anomalies before and after the four earthquakes, there is a tendency that positive TEC anomalies appear 1–5 days before all the above earthquakes even during the quiet geomagnetic condition.*" According to my opinion, the original views show that there is a reasonable positive correlation between TEC* and Kp over the whole period of time: on average the behaviour of TEC* and Kp time-series are rather similar. Obviously, we should expect this correspondence between TEC* and Kp because the ionosphere is strongly influenced by solar-terrestrial interaction (see Afraimovich et al., 2004, 2008; Hocke 2008).

To better investigate the real nature of the earthquake-related ionospheric anomalies reported by KON, Kp time-series is superimposed onto the TEC* original views. According to my opinion Figs. 1, 2, and 3 show that:

(1) on average a close correspondence between TEC* and Kp exists not only during disturbed periods (grey areas in Fig. 1) but also during periods of moderate geomagnetic activity;

(2) TEC* values exceeding 2σ are present during all the period of time;

(3) the majority of positive and negative TEC* peaks exceeding 2σ correspond respectively to high and low values of Kp; the correspondence fails in very few cases; as a

consequence, TEC* peaks exceeding 2σ seem to be related to changes of the global geomagnetic activity level both before and after the earthquakes occurrence;

(4) TEC* increases which occur 1-5 days before the earthquakes actually correspond to Kp increases; there is one exception on 13 June 2008;

(5) the delay between Kp changes and TEC* peaks is less than 2 days as, according to KON, is expected for ionospheric perturbations induced by geomagnetic activity.

Concerning to the points (3) and (4), since the Kp index is representative of the geomagnetic field average disturbances over planetary scale caused by magnetosphere-solar wind interaction, it must be considered that we should not always expect a strong correspondence between TEC* and Kp.On the other hand, a close correspondence between Kp and TEC* variations indicates that these changes are part of normal global magnetic field variations driven by solar-terrestrial interaction (see also Masci, 2010, 2011a, 2011b).

In summary, in the three case studies reported by KON the regional TEC* variations seem to be controlled by geomagnetic activity changes. This suggests that the criterion adopted by KON for reducing the effect of the geomagnetic activity on the ionosphere may not completely eliminate solar and magnetospheric influence. Thus, simply related TEC* values which exceed the threshold of 2σ to the earthquakes occurrence seems to be an inaccurate assumption. In addition, I would like to emphasize that in the three case studies the duration of the majority of the ionospheric anomalies is more than 10 hours. Pulinets and Boyarchuk (2004) affirm that "*The duration of a seismically induced deviation of a given sign is comparatively short about 4–6 h (relative to magnetic storm effects). Only in cases of very strong earthquakes (such as before the large 1964 Good Friday earthquake, Alaska) can the duration of a seismically induced deviation reach about 12 h*" (see also Pulinets et al., 2003).

In conclusion, according to Pulinets and Boyarchuk, in the three case studies the seismogenic origin of TEC* changes is rather dubious.

4. Conclusions

Kon et al. (2011) report a statistical investigation of the occurrence of possible earthquake-related ionospheric GIM-TEC anomalies in the Japan area during 1998-2010 claiming the presence of positive ionospheric anomalies 1-5 days before M>6 earthquakes. The author also report details of three selected case studies. This paper shows that in the three cases no firm evidence of earthquake-related ionospheric anomalies really exists. On the contrary, a close correspondence between total electron content changes and the geomagnetic activity level has been shown. This correspondence is also evident in the days just before the earthquakes occurrence. As a consequence, also the Superimposed Epoch Analysis performed by KON could be influenced by global geomagnetic activity. Thus, the tendency of positive TEC* variation to appear 1-5 days before the earthquakes occurrence could be simply a coincidence. In summary, the results of KON seem to be not completely reliable.

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References

Afraimovich, E. L., Astafyeva, E. I., Gokhberg, M. B., Lapshin, V. M., Permyakova, V. E., Steblov, G. M., Shalimov, S. L., 2004. Variations of the total electron content in the ionosphere from GPS data recorded during the Hector Mine earthquake of October 16, 1999, California. Russian Journal of Earth Sciences, 6(5), 339–354. doi:10.2205/2004ES000155.

Afraimovich, E. L., Astafyeva, E. I., 2008. TEC anomalies – local TEC changes prior to earthquakes or TEC response to solar and geomagnetic activity changes?. Earth Planets and Space, 60, 961–966.

Campbell, W. H., 2009. Natural magnetic disturbance fields, not precursors, preceding the Loma Prieta earthquake. Journal of Geophysical Research, 114, A05307. doi:10.1029/2008JA013932.

Dautermann, T., Calais, E., Haase, J., Garrison, J., 2007. Investigation of ionospheric electron content variations before earthquakes in southern California, 2003–2004. Journal of Geophysical Research, 112, B02106. doi:10.1029/2006JB004447.

Geller, R. J., 1997. Earthquake prediction: a critical review. Geophys. J. Int., 131, 425-450, doi:10.1111/j.1365-246X.1997.tb06588.x.

Hayakawa, M., Hobara, Y., 2010. Current status of seismo-electromagnetics for short-term earthquake prediction. Geomatics, Natural Hazards and Risk, 1, 2, 115–155, doi: 10.1080/19475705.2010.486933.

Hocke, K., 2008. Oscillations of global mean TEC. Journal of Geophysical Research , 113, A04302, doi:10.1029/2007JA012798.

Johnston, M. J. S., Sasai, Y., Egbert, G. D., Muller, R. J., 2006. Seismomagnetic effects from the long-awaited 28 September 2004 M 6.0 Parkfield earthquake. Bull. Seism. Soc. Am., 96(4B), S206-S220, doi:10.1785/0120050810.

Kon, S., Nishihashi, M., Hattori, K., 2011. Ionospheric anomalies possibly associated with M ≥6.0 earthquakes in the Japan area during 1998–2010: Case studies and statistical study. Journal of Asian Earth Sciences, 41, 410-420. doi:10.1016/j.jseaes.2010.10.005.

Le, H., Liu, J. Y., Liu, L., 2011. A statistical study of ionospheric anomalies before 736 M6.0+ earthquakes during 2002-2010. Journal of Geophysical Research, 116, A023203. Doi:10.11029/2010JA015781.

Liu, J.Y., Chen, Y.I., Chen, C.H., Liu, C.Y., Chen, C.Y., Nishihashi, M., Li, J.Z., Xia, Y.Q., Oyama, K.I., Hattori, K., Lin, C.H., 2009. Seismoionospheric GPS total electron content anomalies observed before the 12 May 2008 Mw7.9 Wenchuan earthquake. Journal of Geophysical Research 114, A04320. doi:10.10292008JA013698.

Liu, J. Y., Le, H., Chen, Y. I., Chen, C. H., Liu, L., Wan, W., Su, Y. Z., Sun, Y. Y., Lin C. H., Che, M. Q., 2011. Observation and simulations of seismoionospheric GPS total electron content anomalies before the 12 January 2010 M7 Haiti earthquake. Journal of Geophysical Research, 116, A023202. Doi:10.11029/2010JA015704.

Masci, F., 2010. On claimed ULF seismogenic fractal signatures in the geomagnetic field. Journal of Geophysical Research, A10236. doi:10.1029/2010JA015311.

Masci, F., 2011a. On the seismogenic increase of the ratio of the ULF geomagnetic field components. Physics of the Earth and Planetary Interiors, 187, 19-32. doi:10.1016/j.pepi.2011.05.001.

Masci, F., 2011b. On the recent reaffirmation of ULF magnetic earthquakes precursors. Natural Hazards and Earth System Sciences, 11, 2193–2198. doi:10.5194/nhess-11-2193-2011.

Masci, F., 2012a. Comment on "Ultra Low Frequency (ULF) European multi station magnetic field analysis before and during the 2009 earthquake at L'Aquila regarding regional geotechnical information" by Prattes et al. (2011). In press, Natural Hazards and Earth System Sciences.

Masci, F., 2012b. Comment on "Possible association between anomalous geomagnetic variations and the Molise Earthquakes at Central Italy during 2002" by Takla et al. (2011). Submitted to Physics of the Earth and Planetary Interiors .

Ouzounov, D., Hattori, K., Liu, J. Y., 2011. The validation of earthquake precursors-VESTO. Journal of Asian Earth Sciences, 41,369-370. doi:10.1016/j.jseaes.2011.04.008.

Pham, V. N., Geller, R. J., 2002. Comment on "Signature of pending earthquake from electromagnetic anomalies" by K. Eftaxias et al. . Geophys. Res. Lett., 29(18), 1871, doi:10.1029/2002GL015328.

Pulinets, S.A., Legen'ka, A.D., Alekseev, V.A., 1994. Pre-earthquake ionospheric effects and their possible mechanisms. In: Kikuchi, H. (Ed.), Dusty and Dirty Plasmas, Noise, and Chaos in Space and in the Laboratory. Plenum Publishing, New York, pp. 545–557.

Pulinets, S. A., A. D. Legen'ka, T. V. Gaivoronskaya, and V. Kh. Depuev, Main phenomenological features of ionospheric precursors of strong earthquakes, *J. Atmos. Sol. Terr. Phys.*, 65, 1337–1347, 2003. doi:10.1016/j.jastp.2003.07.011.

Pulinets, S. A., Boyarchuk, K. A., 2004. Ionospheric Precursors of Earthquakes. Springer, Berlin, Germany, p. 315. doi:10.1016/j.jastp.2005.03.017.

Rishbeth, H., Ionoquakes: Earthquake Precursors in the Ionosphere?, *EOS*, **87**(32), 316–317, 2006a. doi:10.1029/2006EO320008.

Rishbeth, H.: F-region links with the lower atmosphere?, J. Atmos. Sol.Terr. Phys., 68, 469–478, doi: /10.1016/j.jastp.2005.03.017, 2006b.

Thomas, J. N., Love, J. J., Johnston, M. J. S., Yumoto, K., 2009. On the reported magnetic precursor of the 1993 Guam earthquake. Geophysical Research Letters, 36, L16301, doi:10.1029/2009GL039020.

Uyeda, S., Nagao, T., Kamogawa, M., 2009. Short-term earthquake prediction: Current status of seismo-electromagnetics. Tectonophysics, 470, 205-213, doi:10.1016/j.tecto.2008.07.019.

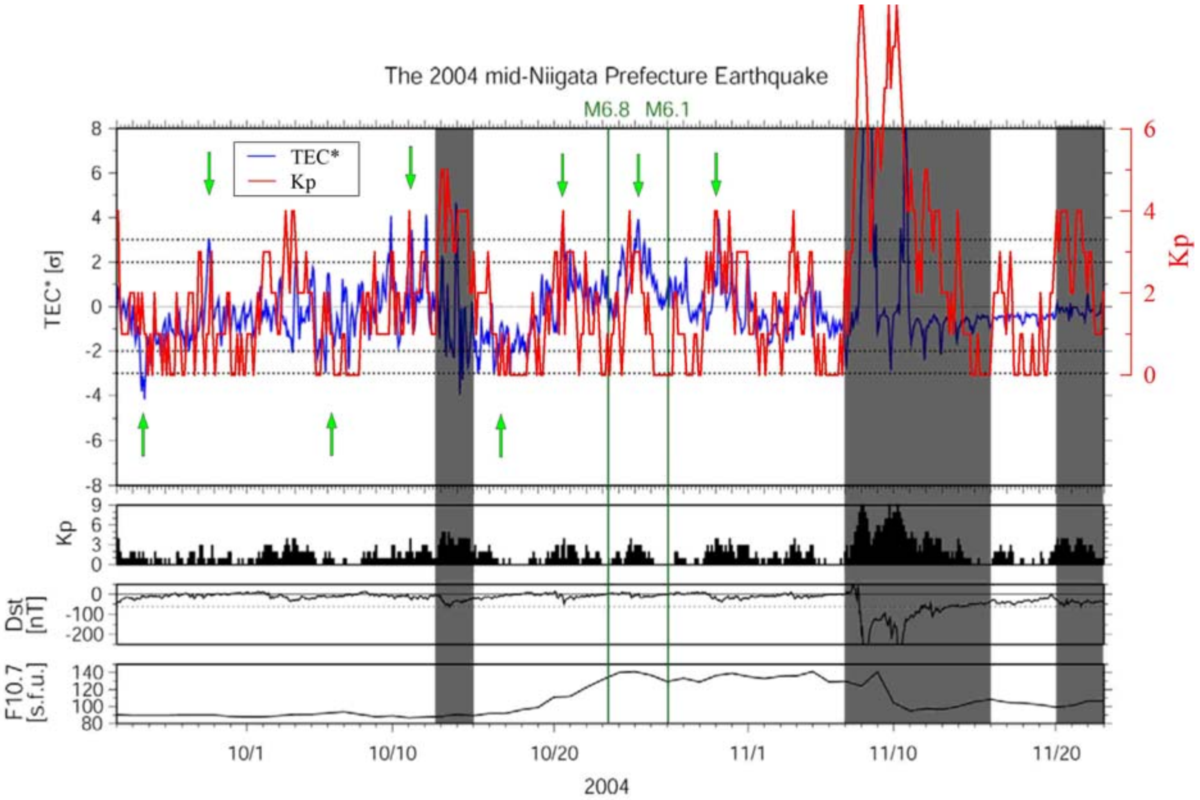

Fig. 1. A reproduction of Fig. 3 by Kon et al. (2011). From the top: TEC* variation, Kp index, Dst index, and F10.7 solar flux. Vertical green lines refer to 2004 mid-Niigata Prefecture earthquakes. Grey areas refer to disturbed periods according to the criterion adopted by KON (Dst<-60nT). Kp index time-series is superimposed onto the upper panel of the original view.

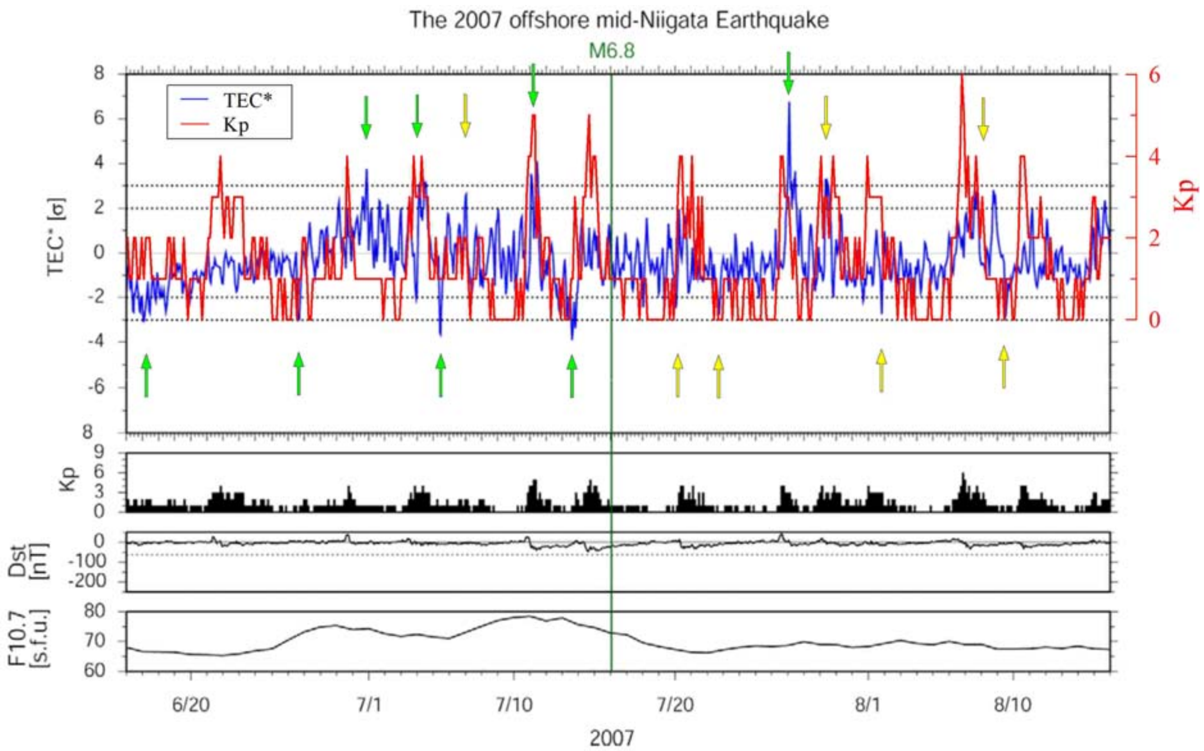

Fig. 2 A reproduction of Fig. 4 by Kon et al. (2011). As Fig. 1 but for the case of 2007 mid-Niigata Prefecture earthquake.

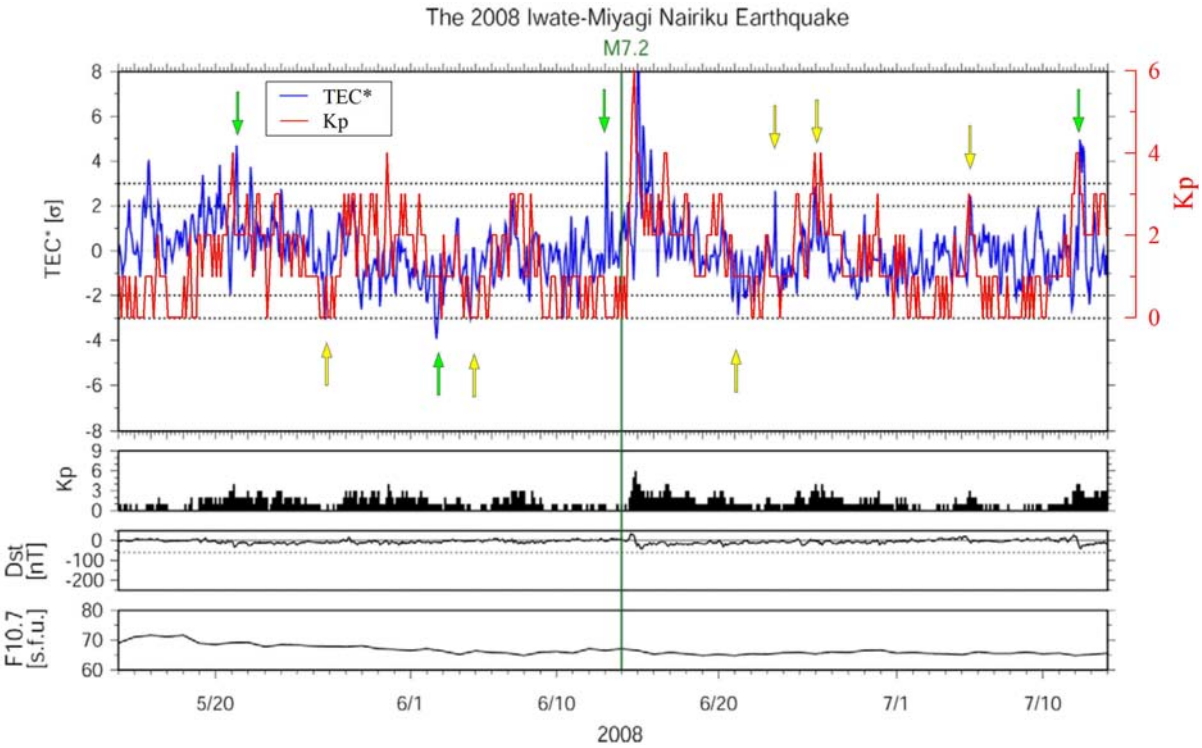

Fig. 3. A reproduction of Fig. 5 by Kon et al. (2011). As Fig. 1 but for the case of 2008 Iwate-Miyagi earthquake. As Kon et al. (2011) pointed out, the TEC* enhancement of 14 June is caused by disturbed geomagnetic conditions (Kp=6) which occurred 1 day after the earthquake.