AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Space Physics

COMMENT

10.1002/2014JA019896

Correspondence to:
F. Masci,
fabrizio.masci@ingv.it

Citation:
Masci, F., and J. N. Thomas (2014), Comment on "Temporal and spatial precursors in ionospheric total electron content of the 16 October 1999 M_w 7.1 Hector Mine earthquake" by Su et al. (2013), *J. Geophys. Res. Space Physics*, *119*, 6994–6997, doi:10.1002/2014JA019896.

Received 17 FEB 2014
Accepted 9 JUN 2014
Accepted article online 11 JUN 2014
Published online 8 AUG 2014

Comment on "Temporal and spatial precursors in ionospheric total electron content of the 16 October 1999 M_w 7.1 Hector Mine earthquake" by Su et al. (2013)

F. Masci[1] and J. N. Thomas[2,3,4]

[1]Istituto Nazionale di Geofisica e Vulcanologia, L'Aquila, Italy, [2]NorthWest Research Associates, Redmond, Washington, USA, [3]Department of Electrical and Computer Engineering, DigiPen Institute of Technology, Redmond, Washington, USA, [4]Department of Earth and Space Sciences, University of Washington, Seattle, Washington, USA

Abstract We review the recent paper by Su et al. (2013). Using Global Position System and Global Ionospheric Maps data, Su et al. claimed to have found ionospheric precursors a few days before the 16 October 1999 Hector Mine, California, earthquake. They proposed that this type of analysis of ionospheric data may be useful for locating forthcoming large earthquakes. In this Comment, we reexamine these data and show that ionospheric anomalies reported by Su et al. were not precursors to the Hector Mine earthquake. Therefore, their proposed analysis is not useful in the context of earthquake prediction.

1. Previous Studies

Several researchers have investigated anomalous changes in total electron content (TEC) as possible precursors of the M_w 7.1 16 October 1999 Hector Mine earthquake. The study of the ionosphere was facilitated by many ground-based GPS stations operating at that time in the southwest U.S.

Afraimovich et al. [2004] investigated TEC data from 125 GPS (Global Position System) stations in the southwest U.S. They concluded that the TEC variations near the Hector Mine region were controlled by local time and geomagnetic activity, and they were unrelated to earthquake. A few years later, *Pulinets et al*. [2007] proposed a new index that they called an "ionospheric regional variability index." This index characterizes the spatial variability of the ionosphere by means of the difference between the maximum and the minimum value of the GPS TEC observed at the stations operating within the area of analysis. According to the authors, the regional variability index is sensitive to earthquake-related TEC changes and much less sensitive to TEC variations induced by the global geomagnetic activity. *Pulinets et al*. [2007] analyzed data from 13 GPS stations operating near the Hector Mine region. They documented an anomalous increase of the ionospheric regional variability index starting 1 week before the 16 October 1999 earthquake. Without considering any other potential sources, they concluded that this was a precursor to the earthquake. A large emphasis was given to this precursor in a report by *Pulinets* [2007] published in the *EOS* newsletter of the American Geophysical Union.

In a new analysis of TEC data from the same 13 GPS stations, *Thomas et al*. [2012] showed that the increase of the regional variability index documented by *Pulinets et al*. [2007] was not an earthquake-related phenomenon. They concluded that the TEC changes were part of global-scale variations driven by solar-terrestrial interaction, and, therefore, not related to the localized seismic activity of the Hector Mine region. In a recent report, *Masci* [2013] confirmed the findings of *Afraimovich et al*. [2004] and *Thomas et al*. [2012]. By comparing the regional variability index of *Pulinets et al*. [2007] with geomagnetic *Kp* and *Dst* indices, *Masci* [2013] demonstrated that the reported Hector Mine earthquake precursor were normal variations controlled by geomagnetic activity [see *Masci*, 2013, Figure 1].

2. Discussion of Su et al. Claims

In a recent paper, *Su et al*. [2013] reported new analyses of TEC data from the 13 GPS stations near Hector Mine that were used by *Pulinets et al*. [2007] and *Thomas et al*. [2012]. In their paper, *Su et al*. [2013] discussed in detail the study of *Thomas et al*. [2012] and criticized their results. However, the authors did not reference the study of *Masci* [2013] that confirmed the conclusion of *Thomas et al*. [2012].

The report by *Su et al*. [2013] is clear evidence of how part of the scientific community places great importance on TEC related precursory studies. They proposed that ionospheric measurements would soon be used to predict earthquake locations [see *Su et al*., 2013, conclusion]. However, short-term deterministic prediction requires real and reproducible precursors in order to obtain information regarding location, time, and magnitude of the coming earthquake. Thus, there is a need for scientists to provide strong evidence of the observation of reliable seismic precursors. In this perspective, we review the findings of *Su et al.* [2013].

In order to separate out local effects (e.g., earthquake-related signals) from global effects, *Su et al*. [2013] investigated temporal and spatial TEC changes over the Hector Mine region during October 1999. They also examined TEC data from two reference regions in Japan and Europe having similar magnetic latitude of the Hector Mine region [see *Su et al*., 2013, Figure 1]. GPS TEC time series and spatial gradients above the three regions were investigated. TEC data derived from Global Ionospheric Maps (GIM) were used to investigate the spatial distribution of ionospheric anomalies. *Su et al*. [2013] claimed to have found ionospheric precursors a few days before the Hector Mine earthquake.

Here we will discuss the main findings of *Su et al*. [2013] taking into account, as they pointed out, that (i) multismall storms occurred during October 1999, (ii) geomagnetic activity was relatively disturbed during 10–17 October, and (iii) an intense geomagnetic storm occurred during 21–24 October.

The analyses performed by *Su et al*. [2013] include GPS TEC temporal analysis, GPS TEC spatial analysis, and GIM TEC spatial analysis. GPS TEC precursors were observed on 10 October, and GIM TEC precursors were found on 11 October.

2.1. GPS TEC Temporal Analysis

Su et al. [2013] by using the "quartile method" [see, e.g., *Liu et al*., 2009], investigated GPS TEC changes over the Hector Mine region and two references regions in Japan and Europe. According to them [see *Su et al*., 2013, Figure 2], the many TEC anomalies that were present over the three regions during October 1999 demonstrated that TEC is very sensitive to solar radiation and geomagnetic activity. We would like to point out that Figure 2 by *Su et al*. [2013] clearly shows that the TEC changes that occurred on October 1999 were more intense over Europe and Japan than over the Hector Mine region. The 10 October TEC change is more intense over the two references regions as well. In addition to that, we would like to note that 10 October is characterized by an increase of the global geomagnetic activity (see *Kp* and *Dst* index time series in *Su et al*. [2013, Figure 2a]) that could have induced the intense TEC changes over the three regions. The quartile analysis by *Su et al*. [2013] does not seem to be a reproducible method for identifying ionospheric precursors to earthquakes. Many studies that used the quartile method [see, e.g., *Liu et al*., 2009, 2010, 2011] documented the observation of ionospheric anomalies before strong earthquakes. However, these reports did not provide strong evidence that the anomalies were induced by the seismic activity, nor have the authors carefully taken into account non-earthquake-related explanations for the anomalies. We note that one event occurring before another does not imply that the events are correlated. Correlation requires a statistical basis to be established through an independent data set that was not used in the original identification of the correlation. Moreover, a new data set should be collected after predicting a correlation of the same type as seen in the original data set [e.g., *Feynman*, 1998, pp. 80–81].

2.2. GPS TEC Spatial Analysis

Based on the investigation of the TEC spatial distribution suggested by *Pulinets et al*. [2007], *Su et al*. [2013] calculated eastward and northward GPS TEC gradients over the Hector Mine region and the two reference regions [see *Su et al*., 2013, Figure 3]. Anomalous TEC spatial changes, more evident in the northward direction, were present over the three regions during 10 October. Since the northward negative gradient is bigger over the Hector Mine region, the authors claimed that this was possibly related to the coming earthquake.

In our opinion, and as already mentioned for the GPS temporal analysis, the main issues are (i) the 10 October TEC anomaly was present simultaneously over all three regions, not just the Hector Mine region, and (ii) the anomaly was coincident with an increase in geomagnetic activity. This suggests that the TEC change that occurred on 10 October over the Hector Mine region is not local, but instead was part of global-scale variations induced by the geomagnetic activity.

2.3. GIM TEC Spatial Analysis

Su et al. [2013] using TEC derived from Global Ionospheric Maps investigated the spatial distribution of anomalous TEC increases and decreases in various persistency periods during 10–11 October 1999. According to the authors, the investigation of the persistence of these anomalies should discriminate possible local earthquake-related effects from global effects. *Su et al*. [2013] claimed that on 11 October 1999 two anomalies (positive and negative) were persistent for several hours southwest and northeast the epicenter, respectively. We would like to point out that the persistent anomalies documented by *Su et al*. [2013] were localized very far from the Hector Mine region [see *Su et al*., 2013, Figure 5]. These persistent TEC changes cover an area that extends for several thousand kilometers and is always greater than about 1000 km away from the earthquake epicenter. According to *Su et al*. [2013], the theoretical formula proposed by *Dobrovolsky et al*. [1979], which estimates the so-called preparation zone of an earthquake, would explain the distance between the two anomalies and the epicenter. Note that Figure 5 by *Su et al*. [2013] shows that the persistent anomalies barely extend to the earthquake preparation zone calculated by the Dobrovolsky formula. More importantly, we point out the Dobrovolsky formula for calculating the preparation zone is not supported by experimental evidence. For instance, recent studies [see, e.g., *Wang et al*., 2009; *Marshall et al*., 2013] using GPS and other satellite measurements have shown that the area involved in the preparation of an earthquake is much lower than that estimated by the theoretical calculation of Dobrovolsky. Moreover, *Jónsson et al*. [2002] found no observable surface fault offset or surface slip at a distance of few tens of kilometers from the epicenter of the 1999 Hector Mine earthquake [see *Jónsson et al*., 2002, Figure 11]. Thus, a preparation zone radius of 1100 km for the Hector Mine earthquake, as given by the Dobrovolsky formula, is not realistic. Therefore, we conclude that the Dobrovolsky formula cannot support the seismogenic origin of TEC anomalies documented by *Su et al*. [2013].

We note that the temporal and spatial anomalies from GPS TEC data occurred on 10 October [see, *Su et al*., 2013, Figures 3b and 4b], whereas the persistent anomalies from GIM TEC data occurred on 11 October [see *Su et al*., 2013, Figures 5]. This suggests that the identification of ionospheric anomalies is sensitive to the method adopted to extract them and may also depend on the TEC data set under investigation. Finally, we would like to point out that examining 1 month of data (October 1999) is not enough to claim that the observed ionospheric changes were induced by the preparatory phase of the 16 October earthquake. A longer duration of data should clarify whether these TEC changes were exclusive for the period before the Hector Mine earthquake, or if they usually occur independently to earthquake activity. In addition, the authors did not identify any physical mechanism for the generation of the presumed earthquake-related TEC anomalies.

3. Conclusions

We find that the temporal and spatial analyses performed by *Su et al*. [2013] do not show any clear relationship between the documented ionospheric anomalies and the 16 October 1999 Hector Mine earthquake. The temporal analysis of GPS TEC by *Su et al*. [2013] over Europe, Japan, and the Hector Mine region shows similar and simultaneous TEC changes over the three regions. This means that the TEC changes reported by *Su et al*. [2013] are part of global-scale variation and are not related to local events such as the Hector Mine earthquake. Additionally, the temporal analysis shows that the TEC anomalies that occurred on 10 October 1999 are more intense over Europe and Japan than over the southwest US. The spatial analysis of GIM TEC shows positive and negative persistent anomalies that occurred on 11 October 1999 very far from the Hector Mine region. Since the ionosphere is disturbed by solar radiation, solar wind, magnetic storms, and other sources, we conclude that TEC anomalies documented by *Su et al*. [2013] had a non-seismogenic origin. As a consequence, temporal and spatial analyses of ionospheric TEC as proposed by *Su et al*. [2013] cannot be used for short-term earthquake prediction.

Acknowledgments
F.M. would like to thank Michele Carafa and Fabio Villani for helpful discussions. This work was supported by the USGS Geomagnetism Program and the USGS Earthquake Hazards Program through external research grant G11AP20177 to J.N.T.

Michael Liemohn thanks the reviewers for their assistance in evaluating this paper.

References

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

Dobrovolsky, I. P., S. I. Zubkov, and V. I. Miachkin (1979), Estimation of the size of earthquake preparation zones, *Pure Appl. Geophys.*, *117*, 1025–1044, doi:10.1007/BF00876083.

Feynman, R. P. (1998), *The Meaning of It All: Thoughts of a Citizen-Scientist*, pp. 1–133, Perseus Books, Reading, Mass.

Jónsson, S., H. Zebker, P. Segall, and F. Amelung (2002), Fault slip distribution of the 1999 *Mw*7.1 Hector Mine, California, earthquake, estimated from satellite radar and GPS measurements, *Bull. Seismol. Soc. Am.*, *92*, 1377–1389, doi:10.1785/0120000922.

Liu, J. Y., Y. I. Chen, C. H. Chen, M. Nishihashi, J. Z. Li, Y. Q. Xia, K. I. Oyama, K. Hattori, and C. H. Lin (2009), Seismoionospheric GPS total electron content anomalies observed before the 12 May 2008 Mw7.9 Wenchuan earthquake, *J. Geophys. Res.*, *114*, A04320, doi:10.1029/2008JA013698.

Liu, J. Y., Y. I. Chen, C. H. Chen, and K. Hattori (2010), Temporal and spatial precursors in the ionospheric global positioning system (GPS) total electron content observed before the 26 December 2004 M9.3 Sumatra–Andaman earthquake, *J. Geophys. Res.*, *115*, A09312, doi:10.1029/2010JA015313.

Liu, J. Y., H. Le, Y. I. Chen, C. H. Chen, L. Liu, W. Wan, Y. Z. Su, Y. Y. Sun, C. H. Lin, and M. Q. Chen (2011), Observations and simulations of seismoionospheric GPS total electron content anomalies before the 12 January 2010 M7 Haiti earthquake, *J. Geophys. Res.*, *116*, A04302, doi:10.1029/2010JA015704.

Marshall, S. T., G. J. Funning, and S. E. Owen (2013), Fault slip rates and interseismic deformation in the western Transverse Ranges, California, *J. Geophys. Res. Solid Earth*, *118*, 4511–4534, doi:10.1002/jgrb.50312.

Masci, F. (2013), Further comments on the ionospheric precursor of the 1999 Hector Mine earthquake, *Nat. Hazards Earth Syst. Sci.*, *13*, 193–196, doi:10.5194/nhess-13-193-2013.

Pulinets, S. A. (2007), Natural radioactivity, earthquakes, and the ionosphere, *Eos Trans. AGU*, *88*(20), 217, doi:10.1029/2007EO200001.

Pulinets, S. A., N. Kotsarenko, L. Ciraolo, and I. A. Pulinets (2007), Special case of ionospheric day-to-day variability associated with earthquake preparation, *Adv. Space Res.*, *39*, 970–977, doi:10.1016/j.asr.2006.04.032.

Su, Y. C., J. Y. Liu, S. P. Chen, H. F. Tsai, and M. Q. Chen (2013), Temporal and spatial precursors in ionospheric total electron content of the 16 October 1999 Mw7.1 Hector Mine earthquake, *J. Geophys. Res. Space Physics*, *118*, 6511–6517, doi:10.1002/jgra.50586.

Thomas, J. N., J. J. Love, A. Komjathy, O. P. Verkhoglyadova, M. Butala, and N. Rivera (2012), On the reported ionospheric precursor of the 1999 Hector Mine, California earthquake, *Geophys. Res. Lett.*, *39*, L06302, doi:10.1029/2012GL051022.

Wang, H., T. J. Wright, and J. Biggs (2009), Interseismic slip rate of the northwestern Xianshuihe fault from InSAR data, *Geophys. Res. Lett.*, *36*, L03302, doi:10.1029/2008GL036560.