NWRA NorthWest Research Associates – www.nwra.com

4118 148th Ave NE, Redmond, WA 98052 Tel: 425.556.9055 Fax: 425.556.9099

Award: USGS Earthquake Hazards Program, External Research Award G15AP00071

Title: Reports of Magnetic and Atmospheric Earthquake Precursors

Affiliation: Northwest Research Associates, 4118 148th Ave., NE, Redmond, WA 98052, USA

Author: Jeremy N. Thomas

Contact info: 1-206-947-2678; jeremy@nwra.com

Term of award: 5/1/2015 – 4/30/2016

Abstract

Earthquakes are one of the most devastating natural phenomena on earth, causing high deaths tolls and large financial losses each year. Precursory signals would provide an advanced warning of these impending disasters, possibly saving countless lives. Unfortunately, the evidence for magnetic and atmospheric precursory events has yet to be carefully and rigorously analyzed.

For USGS Earthquake Hazards Program External Research Award G15AP00071, the objective is to conduct a critical examination of existing precursor reports, focusing on satellite cloud data for an 2012 M6.0 earthquake in Italy and total electron content (TEC) observations derived from GPS data for Tohoku, Japan 2011 earthquakes. For the cloud precursor of the Italy earthquake reported by Guangmeng and Jie [2013], we find that a simple test shows no obvious statistical relationship between the occurrence of these cloud formations and earthquakes that occurred in and around Italy. All of the linear cloud formations we have identified in satellite images, including that which Guangmeng and Jie [2013] claim to have used to predict the 2012 earthquake, appear to be orographic – formed by the interaction of moisture-laden wind flowing over mountains. For the Tohoku earthquake reported by Heki [2011] and Heki and Enomoto [2013], we find that the 40 min onset of the ionospheric precursors is an artifact induced by the definition of the reference line adopted in analyzing TEC variations. By performing a Superimposed Epoch Analysis of TEC data, we show that the TEC increase reported by Heki [2011] was not particularly anomalous. We conclude that the TEC precursors reported by Heki [2011] and Heki and Enomoto [2013] are not useful for developing short-term earthquake prediction capabilities.

An undergraduate student research assistant, Jimi Huard, played an active role in this project. He developed tools in Matlab and Python to process the TEC data and presented a virtual poster at the 2015 AGU Fall Meeting. He is a coauthor on a paper to be submitted to Journal of Geophysical Research. Jimi graduated from DigiPen Institute of Technology with a BS in Computer Engineering in May 2016. He is currently enrolled in the PhD in aerospace engineering sciences program at the University of Colorado, Boulder.

Results were disseminated through Meeting presentations and publication in refereed journals. Thomas attended the AGU Fall Meeting in San Francisco, CA in December of 2015 and presented a poster “A Statistical Study of Total Electron Content Changes in the Ionosphere Prior to Earthquake Occurrences”. Six papers were published in peer-reviewed journals and two more manuscripts are in preparation.

Final Report

1. Introduction

A direct correlation between earthquake activity and changes in ionospheric properties (such as conductivity and electron density) has been observed by numerous researchers [e.g. Calais and Minster, 1995; Otsuka et al., 2006]. However, ionospherc-precursory events to earthquakes, which occur well before the seismic activity, have yet to be verified or dismissed within the scientific community. Earthquakes are a major hazard to civilization, and predicting them would benefit most of the earth's inhabitants. However, we need to be responsible in pushing ahead on this frontier, making a full exploration of alternative, and more conventional, explanations of reported precursors.

Perturbations in ionospheric conductivity precursory to earthquakes have been reported by various researchers [e.g.; Davies et al., 1965; Datchenko et al., 1972; Chuo et al., 2002; Plotkin 2003; Krankowski et al., 2006; Hayakawa et al., 2006; Zakharenkova et al., 2006; Horie et al., 2007; Pulinets, 2007; Zhao et al., 2008; Liu et al., 2009; Heki, 2011]. Most of these studies involved changes in the ionospheric total electron content (TEC) derived from Global Positioning System (GPS) data. Other researchers observed ionospheric variations in ionosonde data, very low frequency (VLF) radio wave measurements [e.g. Horie et al., 2007], and satellite-borne in situ measurements such from the DEMETER satellite [e.g. Parrot et al., 2006]. There have been other studies that found no relationship between earthquakes and precursory ionospheric anomalies. One notable example is the work of Dautermann et al. [2007] that involved the analysis of two years of GPS TEC data in Southern California. They found no statistically significant correlation, temporally or spatially, between TEC perturbations and earthquakes, including the December 2003, M6.6 San Simeon and September 2004, M6.0 Parkfield earthquakes.

The purpose of this work was to conduct a critical examination of existing precursor reports, focusing on satellite cloud data for an 2012 M6.0 earthquake in Italy and TEC observations derived from GPS data for Tohoku, Japan 2011 earthquakes.

2. Analysis of Pre-Earthquake Clouds Reported by Guangmeng and Y. Jie [2013]

Here is a summary of my analysis of reported cloud earthquake precursors and recently published in NHESS [Thomas, J. N., Masci, F., and Love, J. J.: On a report that the 2012 M 6.0 earthquake in Italy was predicted after seeing an unusual cloud formation, Nat. Hazards Earth Syst. Sci., 15, 1061-1068, doi:10.5194/nhess-15-1061-2015, 2015].

Several recently published reports have suggested that semi-stationary linear-cloud formations might be causally precursory to earthquakes. We examine the report of Guangmeng and Jie [2013], who claim to have predicted the 2012 M6.0 earthquake in the Po Valley of northern Italy after seeing a satellite photograph (a digital image) showing a linear-cloud formation over the eastern Apennine Mountains of central Italy. From inspection of 4 years of satellite images (examples shown in Figure 1) we find numerous examples of linear-cloud formations over Italy. A simple test shows no obvious statistical relationship between the occurrence of these cloud formations and earthquakes that occurred in and around Italy. All of the linear cloud formations we have identified

in satellite images, including that which Guangmeng and Jie (2013) claim to have used to predict the 2012 earthquake, appear to be orographic – formed by the interaction of moisture-laden wind flowing over mountains. Guangmeng and Jie [2013] have not clearly stated how linear-cloud formations can be used to predict the size, location, and time of an earthquake, and they have not published an account of all of their predictions (including any unsuccessful predictions). We are skeptical of the validity of the claim by Guangmeng and Jie [2013] that they have managed to predict any earthquakes.

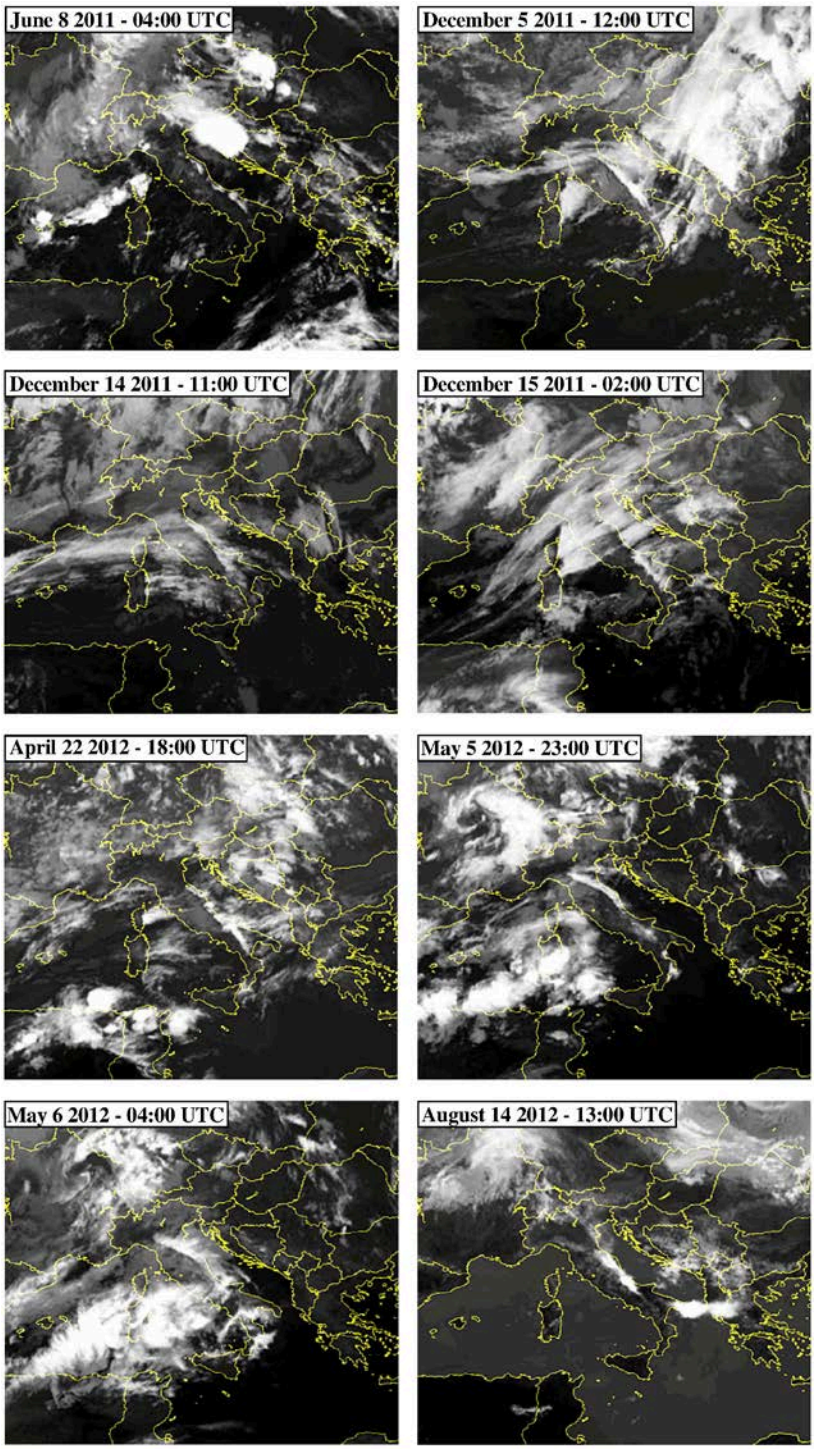

Figure 1. Eight separate examples of linear-cloud formations over Italy, including the instance for 22 April 2012 that Guangmeng and Jie (2013) claim led them to predict the M6.0 Earthquake on 20 May 2012.

3. Analysis Ionospheric Precursor to Tohoku Earthquake Reported by Heki et al.

Here is a summary of my analysis of reported cloud earthquake precursors and recently published in JGR [Masci, F., J. N. Thomas, F. Villani, J. A. Secan, and N. Rivera, On the onset of ionospheric precursors 40 minutes before strong earthquakes, J. Geophys. Res. Space Physics, accepted article, doi: 10.1002/2014JA020822, 2015.]

Heki [2011] and Heki and Enomoto [2013] claimed that anomalous, yet similar, increases of ionospheric total electron content (TEC) started ~40 min prior to the 2011 Tohoku-Oki, as well as before other Mw > 8 earthquakes. The authors concluded that the reported TEC anomalies were likely related to the pending earthquakes,

suggesting also that TEC monitoring may be useful for future earthquake prediction. Here we carefully examine the findings of Heki [2011] and Heki and Enomoto [2013] by performing new analyses of the same TEC data. Our interpretation is that the 40 min onset of the ionospheric precursors is an artifact induced by the definition of the reference line adopted in analyzing TEC variations. We also discuss this repeatability in the tectonic and geodynamic context of the earthquakes. By performing a Superimposed Epoch Analysis of TEC data, we show that, however, the TEC increase reported by Heki [2011] was not particularly anomalous (see Figure 2). We conclude that the TEC precursors reported by Heki [2011] and Heki and Enomoto [2013] are not useful for developing short-term earthquake prediction capabilities.

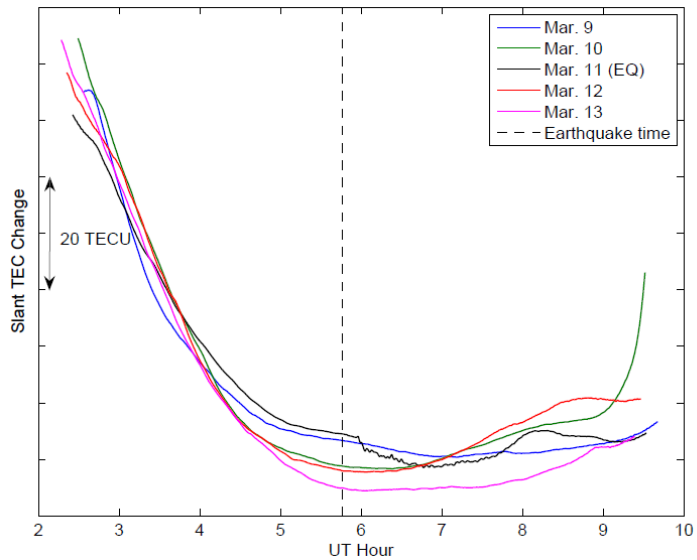

Figure 2. Slant TEC for 9-13 March 2011 for GEONET GPS station 3009 in Japan and satellite 15. The time of the earthquake (5:46 UT) on 11 March is shown as the black vertical dashed line. A co-seismic ionospheric disturbance is clearly seen on 11 March (black curve) starting a few minutes after the earthquake. *Heki* [2011] reported that the enhancement of the slant TEC curve starting at 5:00 UT 11 March is a possible precursor.

4. Student Training

An undergraduate student research assistant, Jimi Huard, played an active role in this project. He developed tools in Matlab and Python to process the TEC data and presented a virtual poster at the 2015 AGU Fall Meeting. He is a coauthor on a paper to be submitted to Journal of Geophysical Research. Jimi graduated from DigiPen Institute of Technology with a BS in Computer Engineering in May 2016. He is currently enrolled in the PhD in aerospace engineering sciences program at the University of Colorado, Boulder.

5. Dissemination

Thomas attended the AGU Fall Meeting in San Francisco, CA in December of 2015 and presented a poster “A Statistical Study of Total Electron Content Changes in the Ionosphere Prior to Earthquake Occurrences”. As indicated in the bibliography below, six papers were published in peer-reviewed journals and two more manuscripts are in preparation.

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2. In-progress

- Thomas J.N., J. Huard, and F. Masci, A statistical study of earthquakes and ionospheric TEC changes, to be submitted to Journal of Geophysical Research - Space Physics.
- Masci, F. and J. N. Thomas, A reanalysis of two reports of changes in magnetic and ionospheric data prior to the 6 April 2009 L'Aquila earthquake, to be submitted to Nat. Hazards Earth Syst. Sci.

3. Conference Presentations

- Thomas J.N., J. Huard, and F. Masci, A Statistical Study of Total Electron Content Changes in the Ionosphere Prior to Earthquake Occurrences, American Geophysical Union Annual Meeting, San Francisco, CA, December 2015.
- Huard, J. E., J. N. Thomas, and F. Masci. Analysis of Methods for Identifying Anomalous Pre-seismic Total Electron Content (TEC) Changes from Global Ionosphere Map (GIM) Data, American Geophysical Union. AGU Virtual Poster showcase, 2015.