**Earthquakes and the Ionosphere**
Carl Luetzelschwab K9LA October 2016 Bonus

Over the years I've seen more and more scientific papers discussing the impact of an earthquake on the ionosphere. Early on, these papers focused on perturbations to the ionosphere after the earthquake. This was done using ionosonde data [*note 1*] – at least when an ionosonde was in the right place! The lack of data was a major problem.

Nowadays GPS can be used to measure the worldwide TEC (total electron content – *note 2*]. TEC is a great way to see perturbations in the ionosphere due to earthquakes. The data coverage of the earthquake area is significantly better than with ionosondes. Recently, papers have emerged that talk about pre-seismic perturbations, and they use TEC data.

For example, Heki [*note 3*] reported on the March 11, 2011 earthquake that occurred in Tohoku-Oki, Japan. It was a magnitude 9.0 earthquake. It ruptured the plate boundary about 450 km in length and about 200 km in width along the Japan Trench where the Pacific Plate subducts beneath northeast Japan. The epicenter was just off the eastern coast of JA7 by the city of Sendai. The initial shock occurred at 0546 UTC.

There was lots of great data in this paper, and in my opinion the most interesting data plotted the change in TEC units (TECU, in which one TECU is 1E16 electrons per square meter) from 1 hour before the earthquake to the time of the earthquake. Figure 1 shows this data.

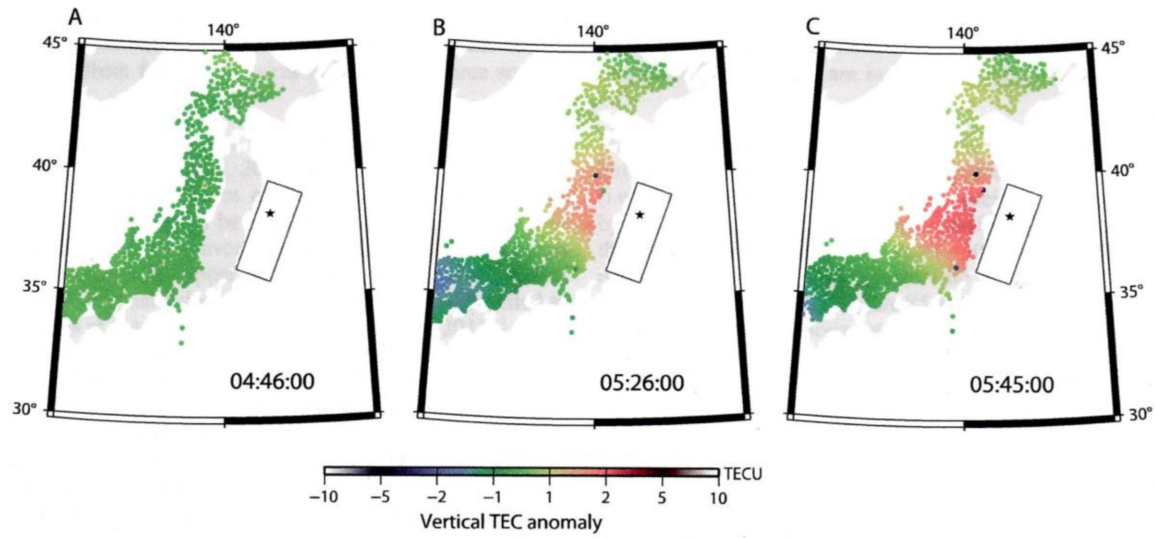


**Figure 1**

At 0446 UTC (one hour before the earthquake), no anomalies in TECU are seen. At 0526 UTC (twenty minutes before the earthquake), positive anomalies of up to almost +2 TECU are seen in the area of the epicenter. Also note small negative TECU anomalies in southwest Japan.

At 0545 UTC (within a minute of the initial shock), increased positive TECU anomalies are seen – up to about +2.3 TECU. The negative TECU anomalies, although somewhat diminished, are still present in southwest Japan. The maximum positive anomaly of +2.3 TECU corresponds to about an 8% increase in the background TEC. That's no small change!

To gain confidence in these results, the author also looked at TEC data from other recent earthquakes: the 1994 Hokkaido-Toho-Oki earthquake of 8.3 magnitude, the 2010 Central Chile earthquake of 8.8 magnitude, the 2004 Sumatra-Andaman earthquake of 9.2 magnitude, the 2003 Tokachi-Oki earthquake of 8.0 magnitude and a few magnitude 7 to 8 earthquakes. The earthquakes with magnitudes greater than 8.0 showed pre-seismic positive TECU anomalies as shown in Figure 2.

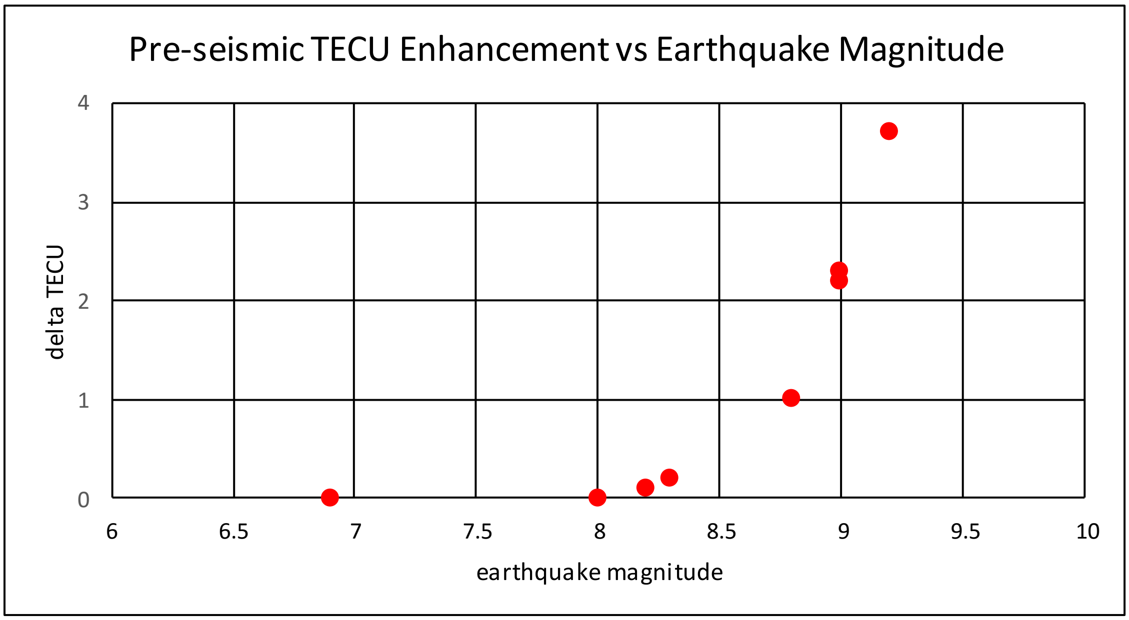


**Figure 2**

In summary, total electron content data from GPS has allowed scientists to analyze the impact of earthquakes on the ionosphere. In the grand scheme of things, this is good news, as one of the three causes of the day-to-day variability of the F2 region of the ionosphere is events in the lower atmosphere coupling up to the ionosphere (the other two are solar radiation and geomagnetic field activity – see *note 4*). This day-to-day variability prevents us from having a daily model of the ionosphere – at the moment we have a statistical model over a month's time frame.

Of course earthquakes don't occur in the lower atmosphere – they happen at and below ground level. But it shows that this coupling does exist. As we learn more about this coupling (which likely involves several different physical mechanisms) for earthquakes and other events, maybe someday we'll have a true daily model of the ionosphere for our propagation predictions.

*Notes*

1 – Ionosondes are low power pulsed radars looking straight up. They are looking for the highest frequencies that can be returned to Earth from the E region, F1 region and F2 region of the

ionosphere. These frequencies are called critical frequencies, and can easily be translated to maximum useable frequencies (MUFs) for oblique propagation.

2 – For more information on TEC, read my June 2016 Monthly Feature.

3 – Kosuke Heki, *Ionospheric electron enhancement preceding the 2011 Tohoku-Oki earthquake*, **Geophysical Research Letters**, Vol 38, doi:10.1029/2011GL047908, 2011

4 – Of the total day-to-day variability of the F2 region, solar radiation contributes the least. Yes, solar radiation instigates the ionization process, but nonetheless it contributes the least in terms of the day-to-day variability. The biggest contributors of the day-to-day variability are geomagnetic field activity and events in the lower atmosphere coupling up to the ionosphere (they contribute about equally). We have a decent understanding of geomagnetic field activity through the STORM time empirical ionospheric correction model (**http://www.swpc.noaa.gov/products/storm-time-empirical-ionospheric-correction**), which uses the past 33 hours of geomagnetic field activity – not just a single 3-hour value as in our current propagation predictions. As for events in the lower atmosphere coupling up to the ionosphere, scientists in the past several years have just begun to investigate these events to the depth necessary to improve our propagation predictions.