

## Statistical and case studies of TEC anomalies associated with large earthquakes in Sumatra region, Indonesia

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In order to investigate earthquake-related ionospheric total electron content (TEC) anomalies, statistical and case studies have been examined in Sumatra region, Indonesia. The analyzed period is about 10 years from May, 1998 to May, 2008. Earthquakes with magnitude greater than or equal to 6.0 and focal depth less than or equal to 40 km have been selected from USGS earthquake catalog. Eventual examples are the 2004 Sumatra-Andaman EQ (Dec. 26, 2004, M9.2) and the 2007 Southern Sumatra EQ (Sept. 12, 2007, M8.5).

We use the IGS (International GNSS Service) and SuGAR (Sumatran GPS Array) data for TEC computation, and GIM (Global Ionosphere Maps) for GIM-TEC computation in this paper. In order to minimize possible confounding effects of consecutive earthquakes and properly identify the abnormal signals, we computed the mean TEC ( $TEC_{mean}$ ) and GIM-TEC ( $GIM-TEC_{mean}$ ) values for the previous 15 days, and the associated standard deviation ( $\sigma$ ) as a reference at specific times. Then, we derived the normalized TEC ( $TEC^*$ ) and GIM-TEC ( $GIM-TEC^*$ ) values by the following equations.  $TEC^*(t) = (TEC(t) - TEC_{mean}(t)) / \sigma(t)$ , where the  $TEC^*$  is derived every 2 min. and averaged every 60 min.  $GIM-TEC^*(t) = (GIM-TEC(t) - GIM-TEC_{mean}(t)) / \sigma(t)$ , with using linearly interpolations. The correlation of TEC and GIM-TEC variation at Sumatra found to be very good and it is confirmed we can use the GIM-TEC data in the 10-year statistical analysis. In this paper, to ensure that an observed TEC anomalous depression is earthquake related, we require that the reduction of the geomagnetic index Dst does not exceed -70 nT, otherwise it is considered to be geomagnetic storm related.

The result of the statistical analysis with superposed epoch analysis shows that the decrease anomaly of  $GIM-TEC^*$  observed at Sumatra in 12-4 days before the earthquakes with R (epicentral distance) 0-1000 km. In particular, the anomaly in day 6-4 before the earthquakes are the most significant. Moreover, the anomaly of  $GIM-TEC^*$  observed at Sumatra in 2 weeks before the earthquakes with R 1000-2800 km.

The result of the 2004 Sumatra-Andaman EQ (M9.2) shows that the decrease anomaly of  $TEC^*$  observed in day 24-21, 19-17, 15, 13-11, 9, and 5 before the EQ and that of  $GIM-TEC^*$ , in day 24, 22, 21, 19-17, 15-12, 9, and 5 before the EQ around the Sumatra island. The spatial analysis of the day 5 before the EQ (Dec. 21, 2004) suggests that the extent of these reduction anomaly reaches to the 30 degrees in latitude and 40 degrees in longitude.

The result of the 2007 Southern Sumatra EQ (M8.5) indicates that the decrease anomaly of  $TEC^*$  observed in day 10-7 and 3 before the EQ and that of  $GIM-TEC^*$ , in day 8 and 3 before the EQ around the epicenter. The spatial analysis of the day 3 before the EQ (Sept. 9, 2007) shows that the extent of these reduction anomaly reaches to the 10 degrees in latitude and 40 degrees in longitude.

These statistical and case studies suggest that the decrease anomalies of  $TEC^*$  and  $GIM-TEC^*$  around epicenter are possibly affected by the earthquakes with magnitude greater than or equal to 6.0.