The New Characteristics of Ionospheric Total Electron Content (TEC) Disturbances prior to Four Large Earthquakes

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Outline

- Introduction
  - Earthquake and earthquake prediction
  - Ionospheric disturbances prior to earthquake
  - Four large magnitude earthquakes
  - Database
- Characteristics of 5 new parameters
  - $dTEC$
  - $\Delta dTEC$
  - $TECR$
  - Percentage of the variation
  - Power of the $TECR$
- Detection for disturbances
  - Existing method
  - New method
  - Reference values
  - Results
- Discussion and Summary
Outline

Introduction

• Earthquake and earthquake prediction
• Ionospheric disturbances prior to earthquakes
• Four large magnitude earthquakes
• Database

Characteristics of 5 new parameters
Detection for disturbances
Discussion and Summary
Earthquake

Earthquake (EQ) is one of the leading natural disasters causing loss of human lives and property. More people are killed by earthquakes than any other form of weather hazard.

The Wenchuan earthquake killed more than 67,000 people, and 20,000 more were missing, resulting in ¥845.1 billion loss.

It's essential to study and build up an earthquake prediction system.

There are two major methods of predicting earthquake: statistical analysis and geophysical precursors.

2008 Wenchuan EQ

2011 Tohoku EQ
EQ and EQ Prediction

• There are a variety of geophysical precursors:
  – ground uplift and tilt
  – radon emissions increase
  – electric resistivity of rocks decrease
  – underground water level fluctuation

• Recently, many research indicate that ionospheric variations exist associated with the seismic activity and appearing a few days (1-15 days) or hours before the seismic shocks of large intensity (M>5) [Pulinets et al., 2003].
Ionospheric disturbances prior to EQ

• Many researchers were concerned on the ionospheric anomaly in 1-30 days before the EQ, based on the ground-based ionosondes, satellite and ground-based GPS observations.

• The results show that ionospheric F₂ peak electron density NₘF₂, the critical frequency of F₂ layer f₀F₂ and the Total Electron Content (TEC) anomaly increased or reduced on 1-12 days before the earthquake [Liu et al., 2004].

• More study of the characteristics of the ionospheric variations prior to EQ are needed.
## Four large EQs

<table>
<thead>
<tr>
<th></th>
<th>Date</th>
<th>Time</th>
<th>Location</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sumatra</td>
<td>26 Dec. 2004</td>
<td>00:58 UT</td>
<td>3.3°N 95.95°E</td>
<td>9.3</td>
</tr>
<tr>
<td>Wenchuan</td>
<td>12 May 2008</td>
<td>06:28 UT</td>
<td>30.986°N 103.364°E</td>
<td>8.0</td>
</tr>
<tr>
<td>Chile</td>
<td>27 Feb. 2010</td>
<td>06:34 UT</td>
<td>35.909°S 72.733°W</td>
<td>8.8</td>
</tr>
<tr>
<td>Tohoku</td>
<td>11 Mar. 2011</td>
<td>05:46 UT</td>
<td>38.322°N 142.369°E</td>
<td>9.0</td>
</tr>
</tbody>
</table>

Ionospheric TEC Dataset -- GIM

• The Global Ionospheric Maps (GIM) products generated from global positioning system (GPS) data, which is routinely published in a 2-hr interval. The spatial resolutions of the GIM on the ±87.5°N latitude and ±180°E longitude are 2.5° and 5°, respectively.

(ftp://cddisa.gsfc.nasa.gov/pub/gps/products/ionex)

• 14 months TEC are analyzed
  – 12-month before the EQ
  – 2-month after the EQ
Outline

- Introduction
- **Characteristics of 5 new parameters**
  - dTEC
  - $\Delta$dTEC
  - TECR
  - Percentage of the variation
  - Power of the TECR
- Detection for disturbances
- Discussion and Summary
Definition of the parameters

We define 5 new parameters dTEC, ΔdTEC, TECR, Percentage (written as Per for abbreviation), and Power, which could represent the TEC disturbances,

• \( d_{\text{TEC}}_{\text{DOY}} = T_{\text{DOY}} - T_{\text{DOY}} - 3 \)
  DOY means Day of Year.

• \( \Delta d_{\text{TEC}}_{\text{DOY}} = d_{\text{TEC}}_{\text{DOY}} - d_{\text{TEC}}_{\text{DOY}} - 3 \)
  the dTEC and ΔdTEC of earthquake day (EQ) contain the information of 3-day and 6-day prior to the earthquake.
Definition of the parameters

- \( TEC_{DOY} = |TEC_{DOY} - TEC_{DOY - 1}| \)

\( TEC_{DOY} \) represents the variations of TEC in 24 hours.

- \( \text{Per} = \frac{TEC}{TEC} \)

\( \text{Per} \) represents the relative variation of the TEC

- \( \text{Power} = \frac{\sum_{1}^{n}(TECR)^2}{n} \)

we take \( n=6 \)
Characteristics of dTEC (I)

\[ \text{dTEC}_{\text{EQ-6}} = \text{TEC}_{\text{EQ-6}} - \text{TEC}_{\text{EQ-9}} \]

\[ \text{dTEC}_{\text{EQ}} = \text{TEC}_{\text{EQ}} - \text{TEC}_{\text{EQ-3}} \]

2008 Wenchuan EQ

EQ Time: 0628 UT

2011 Tohoku EQ

EQ Time: 0546 UT
Characteristics of dTEC (II)

2008 Wenchuan EQ

6 and 3 days prior to the EQ, there are obvious fluctuations

2011 Tohoku EQ

3 days prior to the EQ, there are obvious fluctuations
Characteristics of $\Delta d\text{TEC}$

**2008 Wenchuan EQ**

3 days prior to the EQ, there are obvious fluctuations.

**2011 Tohoku EQ**

3 days prior to the EQ, there are obvious fluctuations.
In 7 days before the EQ, there are disturbances in all four EQs.
Characteristics of Per

In 1-15 days before the EQ, there are disturbances in all four EQs.

2004 Sumatra EQ
2008 Wenchuan EQ
2010 Chile EQ
2011 Tohoku EQ
Characteristics of Power

The characteristics of the Power near the EQ are different from other days.

2004 Sumatra EQ

2011 Tohoku EQ
Outline

- Introduction
- Characteristics of 5 new parameters
- Detection for disturbances
  - Existing method
  - New method
  - Reference values
  - Results
- Discussion and Summary
Existing Method

Quartile-based process

• Compute the median $M$ of every successive 15 days of the TEC and find the deviation between the observed TEC on the 16\textsuperscript{th} day and $M$.

• Assume the distribution of TEC is a normal distribution $(m, \sigma)$, the expected value of $M$ and LQ (the first quartiles) or UQ (the third quartiles) are $m$ and $1.34\sigma$, respectively.

• The lower bound: $LB=M-1.5(M-LQ)$

• The upper bound: $UB=M+1.5(UQ-M)$

• Thus when an observed TEC on the 16\textsuperscript{th} day is greater or smaller than UB or LB, one can declare an upper or lower abnormal TEC signal.
New Method

• Using 5 new parameters dTEC, ΔdTEC, TECR, Per, and Power to detect ionospheric disturbances.

• Take the values of the window [EQ, EQ-6] as the references. Select a window [DOY, DOY+6] at two adjacent UT before and after the time earthquake occurred, and slide the window to compare with the reference.

• When the value exceeds the reference values, we define it is a disturbance.
The reference values of Sumatra and Wenchuan EQs

For 2004 Sumatra earthquake, take the value of 4 UT and 6 UT as the reference.

Table 1  The reference values for 2004 Sumatra earthquake, the units of TEC and Power are TECU and TECU^2

<table>
<thead>
<tr>
<th></th>
<th>dTEC</th>
<th>dTEC</th>
<th>ΔdTEC</th>
<th>ΔdTEC</th>
<th>TECR</th>
<th>PerEQ-3</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 UT</td>
<td>-9.5</td>
<td>7.6</td>
<td>-7</td>
<td>17.1</td>
<td>9.9</td>
<td>0.184</td>
<td>31.195</td>
</tr>
<tr>
<td>6 UT</td>
<td>-8.8</td>
<td>8.8</td>
<td>-4.8</td>
<td>14.5</td>
<td>12.6</td>
<td>0.491</td>
<td>37.178</td>
</tr>
</tbody>
</table>

For 2008 Wenchuan earthquake, take the value of 6 UT and 8 UT as the reference.

Table 2  The reference values for 2008 Wenchuan earthquake, the units of TEC and Power are TECU and TECU^2

<table>
<thead>
<tr>
<th></th>
<th>dTEC</th>
<th>dTEC</th>
<th>ΔdTEC</th>
<th>ΔdTEC</th>
<th>TECR</th>
<th>PerEQ-3</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 UT</td>
<td>-9.2</td>
<td>1</td>
<td>-15.4</td>
<td>9.8</td>
<td>2.6</td>
<td>0.176</td>
<td>19.36</td>
</tr>
<tr>
<td>8 UT</td>
<td>-5.3</td>
<td>7.6</td>
<td>-11.1</td>
<td>12.9</td>
<td>5.5</td>
<td>0.272</td>
<td>13.707</td>
</tr>
</tbody>
</table>
The reference values of Chile and Tohoku EQs

For 2010 Chile earthquake, take the value of 6 UT and 8 UT as the reference.

Table 3  The reference values for 2010 Chile earthquake, the units of TEC and Power are TECU and TECU²

<table>
<thead>
<tr>
<th></th>
<th>dTEC</th>
<th>dTEC</th>
<th>ΔdTEC</th>
<th>ΔdTEC</th>
<th>TECR</th>
<th>PerEQ-3</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 UT</td>
<td>-5.2</td>
<td>1.2</td>
<td>-5.7</td>
<td>2.7</td>
<td>2.6</td>
<td>0.303</td>
<td>3.067</td>
</tr>
<tr>
<td>8 UT</td>
<td>-5.3</td>
<td>2.4</td>
<td>-6</td>
<td>4.3</td>
<td>2</td>
<td>0.254</td>
<td>5.21</td>
</tr>
</tbody>
</table>

For 2011 Tohoku earthquake, take the value of 4 UT and 6 UT as the reference.

Table 4  The reference values for 2011 Tohoku earthquake, the units of TEC and Power are TECU and TECU²

<table>
<thead>
<tr>
<th></th>
<th>dTEC</th>
<th>dTEC</th>
<th>ΔdTEC</th>
<th>ΔdTEC</th>
<th>TECR</th>
<th>PerEQ-3</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 UT</td>
<td>-2.3</td>
<td>5.4</td>
<td>-7.7</td>
<td>0.6</td>
<td>5.3</td>
<td>0.184</td>
<td>12.885</td>
</tr>
<tr>
<td>6 UT</td>
<td>0.1</td>
<td>7.4</td>
<td>-7.3</td>
<td>3.4</td>
<td>8.1</td>
<td>0.255</td>
<td>27.878</td>
</tr>
</tbody>
</table>
2004 Sumatra EQ

The counts of the ionospheric disturbances in different UT regions on the basis of 5 parameters in 12 months before the EQ and 2 months after the EQ. (Do not including the disturbance associated with EQ)

Table 5  The results of the detection for the 2004 Sumatra earthquake

<table>
<thead>
<tr>
<th>dTEC &amp; ΔdTEC &amp; TECR &amp; Per &amp; Power</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
<th>18</th>
<th>20</th>
<th>22</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

EQ Time: 00:58 UT

The numbers mean the count of detected disturbances.
### Wenchuan, Chile and Tohoku EQs

**Table 6** The results of the detection for the 2008 Wenchuan earthquake

<table>
<thead>
<tr>
<th></th>
<th>0 UT</th>
<th>2 UT</th>
<th>4 UT</th>
<th>6 UT</th>
<th>8 UT</th>
<th>10 UT</th>
<th>12 UT</th>
<th>14 UT</th>
<th>16 UT</th>
<th>18 UT</th>
<th>20 UT</th>
<th>22 UT</th>
</tr>
</thead>
<tbody>
<tr>
<td>dTEC &amp; ΔdTEC &amp; TECR &amp; Per &amp; Power</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**EQ Time: 06:28 UT**

**Table 7** The results of the detection for the 2010 Chile earthquake

<table>
<thead>
<tr>
<th></th>
<th>0 UT</th>
<th>2 UT</th>
<th>4 UT</th>
<th>6 UT</th>
<th>8 UT</th>
<th>10 UT</th>
<th>12 UT</th>
<th>14 UT</th>
<th>16 UT</th>
<th>18 UT</th>
<th>20 UT</th>
<th>22 UT</th>
</tr>
</thead>
<tbody>
<tr>
<td>dTEC &amp; ΔdTEC &amp; TECR &amp; Per &amp; Power</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

**EQ Time: 06:34 UT**

**Table 8** The results of the detection for the 2011 Tohoku earthquake

<table>
<thead>
<tr>
<th></th>
<th>0 UT</th>
<th>2 UT</th>
<th>4 UT</th>
<th>6 UT</th>
<th>8 UT</th>
<th>10 UT</th>
<th>12 UT</th>
<th>14 UT</th>
<th>16 UT</th>
<th>18 UT</th>
<th>20 UT</th>
<th>22 UT</th>
</tr>
</thead>
<tbody>
<tr>
<td>dTEC &amp; ΔdTEC &amp; TECR &amp; Per &amp; Power</td>
<td>0</td>
<td>9</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**EQ Time: 05:46 UT**
The distribution of the disturbance day at different UT times.

2008 Wenchuan EQ

There is no disturbance in 1-month before the EQ at all UTs. But disturbance occurred on EQ day.

There is no disturbance in 12-month before the EQ at 00-06 UT and 12-24 UT.

The disturbance occurred 7-month before the EQ at 06 UT.
The distribution of the disturbance day at different UT times.

2010 Chile EQ

There is no disturbance in 12-month before the EQ during 00-16 UT

There is disturbance in 2-10 days before the EQ during 18-24 UT

The disturbance occurred 2-day before the EQ at 20 UT and 22 UT

The distribution of the counts of the disturbance in a day.
The distribution of the disturbance day at different UT times.

There is no disturbance in 1-month before the EQ at all UTs.

There is no disturbance in 12-month before the EQ at 08-10 UT and 14-24 UT.

The disturbance occurred 1-month before the EQ at 02 UT and 12 UT.

The distribution of the counts of the disturbance in a day.
Outline

- Introduction
- Characteristics of 5 new parameters
- Detection for disturbances
- Discussion and Summary
Possible reason for TEC disturbances

- **Geomagnetic condition**

- **From upper atmosphere**
  - Electric field. Electric field would impact the distribution of the electron density and cause the TEC disturbances.
  - Interplanetary Magnetic Field (IMF). Fluctuations of IMF Bz may cause the ionospheric disturbances and contribute to the TEC fluctuations.

- **From lower atmosphere**
  - Gravity Wave. Travelling Ionospheric Disturbance (TID)
Summary

◆ There are ionospheric disturbances in some days prior to large magnitude earthquakes. The peak-to-peak amplitude of the differential TEC between the earthquake day and 3-day (or 5-day) before the EQ day could be above 10 TECU.

◆ The absolute differential TEC between the two adjacent days could reach 12 TECU prior to the earthquake.

◆ The percentage of the variation of TEC in 6-days before the EQ could be about 30~40%.
Summary

◆ There is no disturbance in some months prior to EQ detected by 5 parameters.

<table>
<thead>
<tr>
<th></th>
<th>2004 Sumatara</th>
<th>2008 Wenchuan</th>
<th>2010 Chile</th>
<th>2011 Tohoku</th>
</tr>
</thead>
<tbody>
<tr>
<td>No ionospheric disturbances’ months prior to EQ</td>
<td>12 (06-12 UT) 7(06 UT)</td>
<td>12(00-16 UT) 2-10 days (18-24 UT)</td>
<td>12 (14-24 UT) 1 (02 and 12 UT)</td>
<td></td>
</tr>
</tbody>
</table>

◆ The new parameters may be used to detect the ionospheric disturbances associated with earthquakes.
The end

Thanks for your attention!