Coseismic displacements and ionospheric changes of the 2013 Ms7.0 Lushan earthquake from GPS measurements

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Abstract: By inverting GPS data recorded at stations of the Crustal Movement Observation Network of China (CMONOC) near the 2013 Lushan Ms7.0 earthquake, we found a horizontal displacement of 22 mm at a site about 32 km SW of the epicenter and vertical displacements of as much as 12.4 mm at several sites. The vertical displacements were generally uplift on the west side of the nearby Longmenshan fault zone and subsidence on the east side. We also found coseismic ionospheric disturbances about 0.5 to 0.9 TECU in amplitude that lasted for about one hour.

Key words: GPS; Ms7.0 Lushan earthquake; CMONOC; coseismic displacement; coseismic ionospheric disturbances

1 Introduction

A Ms7.0 earthquake occurred in Lushan County, Yaan City, Sichuan Province (30.3°N, 103.0°E) at 8:02 on 20 April 2013[1]. In this study, we investigated coseismic near-field displacements and time series of ionospheric (TEC) changes by inverting GPS data recorded at nearby stations of the Crustal Movement Observation Network of China (CMONOC).

2 Data

We collected 1-Hz high frequency GPS data from 06:00 to 10:00 on 20 April 2013, and data with 30-second sampling interval from 17 April to 22 April. Figure 1 shows the locations of the epicenter and GPS stations. Table 1 shows the longitude, latitude and epicentral distances of the GPS stations.

3 The 1-Hz GPS measurements

We processed the set of high frequency data with the PANDA software (developed by Wuhan University) in a procedure shown in Table 2[2,3]. We also processed the GPS data of 23 COMNOC stations with 30-second sampling interval from 17 April to 19 April 2013 by using the PANDA software, and obtained the coordinates in the framework of ITRF2008 before this earthquake. We obtained the coordinates after this earthquake in the same way by processing the GPS data from...
Table 1 Longitude, latitude and epicentral distance of GPS stations

<table>
<thead>
<tr>
<th>GPS site</th>
<th>Latitude (°)</th>
<th>Longitude (°)</th>
<th>Distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCTQ</td>
<td>30.1</td>
<td>102.8</td>
<td>32</td>
</tr>
<tr>
<td>SCKJ</td>
<td>31.0</td>
<td>102.4</td>
<td>98</td>
</tr>
<tr>
<td>SCSM</td>
<td>29.2</td>
<td>102.4</td>
<td>131</td>
</tr>
<tr>
<td>SCMB</td>
<td>28.8</td>
<td>103.5</td>
<td>170</td>
</tr>
<tr>
<td>SCMX</td>
<td>31.7</td>
<td>103.8</td>
<td>176</td>
</tr>
<tr>
<td>SCYX</td>
<td>28.7</td>
<td>102.5</td>
<td>186</td>
</tr>
<tr>
<td>SCDF</td>
<td>31.0</td>
<td>101.1</td>
<td>192</td>
</tr>
<tr>
<td>SCLJ</td>
<td>29.0</td>
<td>101.5</td>
<td>200</td>
</tr>
<tr>
<td>SCXD</td>
<td>28.3</td>
<td>102.4</td>
<td>226</td>
</tr>
<tr>
<td>SCMN</td>
<td>28.3</td>
<td>102.2</td>
<td>229</td>
</tr>
<tr>
<td>SCYX</td>
<td>31.4</td>
<td>100.7</td>
<td>251</td>
</tr>
<tr>
<td>SCLH</td>
<td>30.5</td>
<td>105.6</td>
<td>252</td>
</tr>
</tbody>
</table>

Table 2 The procedure of Epoch-by-Epoch PPP

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation</td>
<td>PC and LC combination observation</td>
</tr>
<tr>
<td>Apriori constraint</td>
<td>P1 3.0 m, L1 0.006 cycle</td>
</tr>
<tr>
<td>Elevation mask</td>
<td>10°</td>
</tr>
<tr>
<td>Observation weight</td>
<td>$w = 1$, $elev &gt; 30°$, $w = \sin(2 \cdot elev)$, $e \leq 30°$</td>
</tr>
<tr>
<td>Phase winding correction</td>
<td>Phase center variation correction</td>
</tr>
<tr>
<td></td>
<td>IGS_08 model</td>
</tr>
<tr>
<td>Error correction</td>
<td>Without considering</td>
</tr>
<tr>
<td>Tidal correction</td>
<td>Earth tide, polar shift tide, ocean loading tide</td>
</tr>
<tr>
<td>Satellite absolute phase center correction</td>
<td>IGS_08 model</td>
</tr>
<tr>
<td>Relativistic correction</td>
<td>Correction</td>
</tr>
<tr>
<td>Satellite orbit</td>
<td>IGS ultra-rapid orbit</td>
</tr>
<tr>
<td>Satellite clock</td>
<td>CMONOC precise clock (5 - sec sampling interval)</td>
</tr>
<tr>
<td>Coordinates of sites</td>
<td>Epoch-by-epoch kinematic positioning</td>
</tr>
<tr>
<td>ERP</td>
<td>IERS products</td>
</tr>
<tr>
<td>Troposphere</td>
<td>Saastamonine model + CMF mapping function + Multi-parameter estimation (2-hour)</td>
</tr>
<tr>
<td>Receiver clock error</td>
<td>Estimation by pseudorange + white noise, apriori constraint 9000 m</td>
</tr>
<tr>
<td>Ambiguity</td>
<td>Float solution</td>
</tr>
</tbody>
</table>

21 April to 22 April 2013. By comparing the results before and after the earthquake, we obtained the coseismic displacements in the near field.

4 Near-field coseismic displacements by GPS

Figure 2 shows the resultant displacement time series for the closest sites SCTQ and SCXJ. It may be seen that a permanent displacement occurred shortly after the arrival of the seismic oscillations. The permanent displacement was about 22 mm, with east-west and north-south components being about 10 and 20 mm, respectively. Figure 3 and table 3 show coseismic displacements of all the COMNOC stations with horizontal and vertical precisions better than 3 mm and 5 mm, respectively.

The horizontal coseismic displacements at other stations are less than 3 mm, however, and show no coherence. So we considered them to be measurement errors. Vertically, the stations on west side of the Longmenshan fault zone rose significantly while those on the east side dropped.
5 Coseismic ionospheric disturbances

Many previous investigators found transient coseismic ionospheric disturbances (CID) associated with large earthquakes\cite{4,5}, starting 30–40 minutes before the earthquake and reaching maximum values 10–20 minutes after the earthquake. The duration and amplitude of CID depend on the earthquake magnitude, longer and larger for the larger magnitude.

To see the background variation, we show in figure 4 the solar and geomagnetic activity during 1 April to 23
April 2013. These space-weather indices were fairly steady, indicating a small background variation at the time of the earthquake.

To search for the earthquake-related TEC changes, we first obtained the slant-TEC-change time series by processing GPS data at these COMNOC stations\(^6\). To isolate the anomalous changes, we fitted the normal variation of TEC by using the observation for the period 07:00 to 09:30 (for specific methods, see reference \(^5\)). Figures 5 and 6 show the measured and fitted slant-TEC-change time series for the satellites G18 and G21 at stations SCTQ and SCXJ, respectively.

As shown in figures 6, a positive TEC anomaly started at SCTQ about 30 minutes before the earthquake; it became more prominent and then gradually disappeared about 35 minutes after the earthquake.

Figure 7 shows the slant-TEC-change time series from all visible satellites at SCTQ and SCXJ. The observed anomalous changes are about 0.5 to 0.9 TECU quite consistently. In comparison with other earthquakes, the 11 March 2011 Tohoku-Oki earthquake (\(M_w9.0\)) caused lager anomalies of 7.5 and 6.3 TECU at epicentral distances of 319 and 431 km, respectively. The largest observed anomaly caused by the 2008 Wenchuan earthquake (\(M_w7.9\)) is less than 2 TECU at an epicentral distance of 298 km\(^5\). Thus, it appears that in general both amplitude and duration (not shown here) of CID increase with the earthquake magnitude.

![Figure 4 Indices of space weather from April 1 to 23, 2013](image-url)

![Figure 5 Time series of the measured and fitted slant TEC changes of satellites G18 and G21 at station SCTQ (The red line indicates earthquake time)](image-url)
Figure 6  Time series of the measured and fitted slant TEC changes of satellites G18 and G21 at station SCXJ (The red line indicates earthquake time)

Figure 7  Time series of slant TEC changes for all line-of-sight satellites at stations SCTQ and SCXJ (The red line indicates earthquake time)

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References


