# IMPACTS OF THE 2010 CHILE EARTHQUAKE ON EARTH ROTATION

T. NILSSON, J. BÖHM, H. SCHUH
Vienna University of Technology, Institute of Geodesy and Geophysics
Gußhausstraße 27-29, 1040 Vienna, Austria
e-mail: tobias.nilsson@tuwien.ac.at

ABSTRACT. We investigate the impact of the 2010 Chile Earthquake on the geometry and rotation of the Earth. We find that the Earthquake moved the city Concepción 310 cm towards West and 65 cm towards South. The Earthquake should also have increased the length of day by 0.3–0.5 $\mu$s and moved the figure axis of the Earth by 2.5–3 mas, however these changes are too small to be confirmed by measurements.

## 1. INTRODUCTION

The impact of Earthquakes on the rotation of the Earth has been a topic of research since the 1960's (Mansinha and Smylie, 1967, Dahlen, 1971, 1973, Chao and Gross, 1987, Gross and Chao, 2006). Theoretically, an Earthquake should change both the rotation speed of the Earth and the figure axis. However, the effect has still not been observed. The reason is that the change in Earth rotation caused by an Earthquake is usually very small. Only very strong Earthquakes (magnitude $\gtrsim$9) can cause changes in the Earth rotation large enough to get be observed with current space geodetic techniques.

On February 27, 2010, at 06:34 UTC a magnitude 8.8 Earthquake occurred in Chile about 155 km NNE of the city Concepción. This has been the strongest Earthquake in recent years. In this work we investigate the displacements and changes in Earth rotation due to this Earthquake.

## 2. DISPLACEMENT OF TIGO CONCEPCION

In Concepción there is a VLBI (Very Long Baseline Interferometry) radio telescope, TIGO, which regularly participates in IVS (International VLBI Service for Geodesy and Astrometry, Schlüter and Behrend (2007)) geodetic VLBI sessions. It survived the Earthquake relatively well and was able to start observing again about 2.5 weeks after the Earthquake. Sessions with TIGO before and after the Earthquake were analysed with the Vienna VLBI software (VieVS) (Böhm et al., 2010) in order to determine how much this station was moved by the Earthquake. The results can be seen in figure 1. As comparison, the results from GPS are shown, obtained from the IGS (International GNSS Service, Dow et al. (2009)) weekly solutions. We can see that TIGO was moved about 310 cm to the West, 65 cm to the South, and about 4–5 cm downwards. The results from VLBI and GPS are in good agreement.

## 3. EFFECT ON EARTH ROTATION

An Earthquake causes displacements of masses inside the Earth, i.e. the moment of inertia will change. Thus, due to the conservation of angular momentum, the rotation of the Earth will also change. The change in the pole coordinates ($p = p_x - i\, p_y$) can be calculated using the Euler-Liouville equation:

$$p(t) + \frac{i}{\sigma_{ch}}\frac{dp}{dt} = \chi(t) \tag{1}$$

where $\sigma_{ch}$ is the frequency of the Chandler Wobble and $\chi = \chi_x + i\,\chi_y$ is the polar motion excitation function. The change in $\chi$ due to an Earthquake, $\Delta\chi$, is related to the change in the moment of inertia, $\Delta I$, by (Gross and Chao, 2006):

$$\Delta\chi = \frac{1.61}{C - A}\Delta I \tag{2}$$

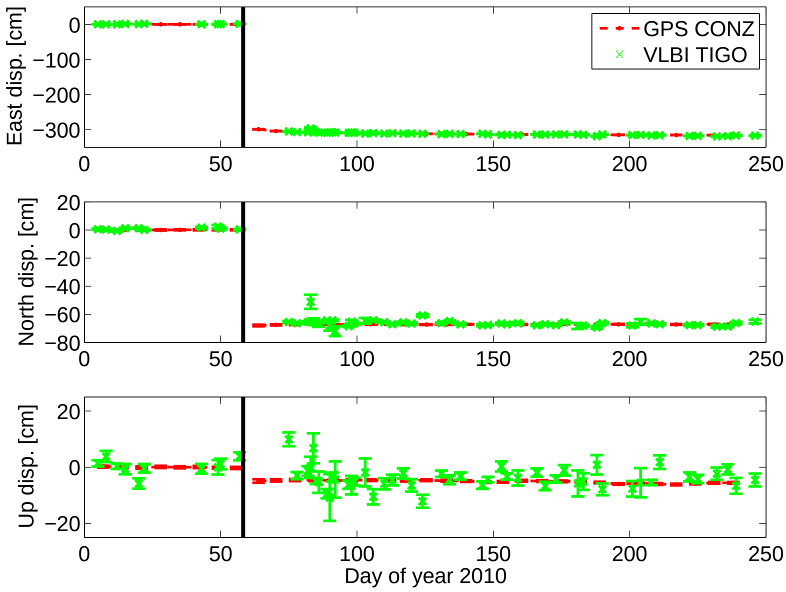


Figure 1: Displacement of Concepción measured by GPS (red) and VLBI (green).

| | LOD [$\mu$s] | $\chi_x$ [mas] | $\chi_y$ [mas] |
|---|---|---|---|
| Global CMT | 0.3 | -0.1 | 2.5 |
| USGS | 0.5 | -0.4 | 2.8 |

Table 1: Predicted changes in the Length of Day (LOD) and polar motion excitations ($\chi$) due to the 2010 Chile Earthquake

where $C$ and $A$ are the axial and equatorial moment of inertia, and $\Delta I = \Delta I_{xz} + i\,\Delta I_{yz}$. Assuming that the change in the moment of inertia can be described by a step function, it can be shown that the change in $p$ is:

$$\Delta p(t) = \frac{1.61 \Delta I}{C - A}\left[1 - e^{i\sigma_{ch}(t-t_0)}\right] \tag{3}$$

where $t_0$ is the time epoch of the Earthquake. We can easily see from this equation that the effect of the Earthquake is a change in the mean position of the pole (the figure axis) and in the amplitude of the Chandler Wobble. The instantaneous change in the pole coordinates ($\Delta p(t_0)$) will however be almost zero. Thus, when trying to detect the impact of the Earthquake on the Earth rotation, we should investigate the polar motion excitation function rather than the polar motion directly.

Similarly the change in Length of Day (LOD), $\Delta\Lambda$, can be related to the change in the axial moment of inertia, $\Delta I_{zz}$, through (Gross and Chao, 2006):

$$\Delta\Lambda = \frac{\Lambda_0}{C_m}\Delta I_{zz} \tag{4}$$

where $\Lambda_0$ is the nominal LOD (86400 s) and $C_m$ is the axial moment of inertia of the crust and the mantle.

In order to calculate $\Delta\chi$ and $\Delta\Lambda_0$ we need to know the change in the moment of inertia of the Earth. Using elastic dislocation theory, Dahlen (1971, 1973) presented a model for this change expressing it as a function of the Earthquake location (latitude $\theta$, longitude $\ell$, and depth $h$), and seismic parameters for the Earthquake (seismic moment $M_0$, strike angle $\alpha$, dip angle $\delta$, and rake angle $\lambda$):

$$\Delta I_{jz} = M_0 \sum_{k=1}^{3} \Gamma_k(h) g_{jk}(\theta, \ell, \alpha, \delta, \lambda) \tag{5}$$

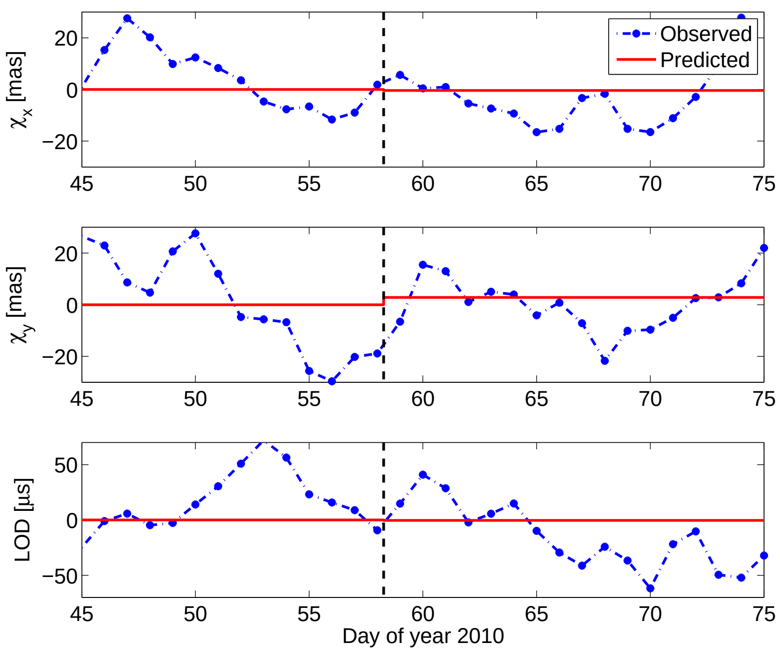


Figure 2: Polar motion excitation functions and Length of Day (LOD) observed around the time of the 2010 Chile Earthquake. From the time series the excitations due to the atmosphere, oceans and hydrology have been removed (see text). The red lines show the predicted changes due to the Earthquake (from table 1).

For explicit expressions of the functions $\Gamma$ and $g$, see Dahlen (1973) or Lambeck (1980).

Table 1 gives the predicted changes in the polar motion excitation functions and in the LOD caused by the 2010 Chile Earthquake. The seismic parameters for the Earthquake were obtained from two sources: the Global CMT (Centroid Moment Tensor) Catalogue (`http://www.globalcmt.org/`) and from the USGS (US Geological Survey) CMT solution (`http://earthquake.usgs.gov/`). As seen the predictions obtained using the two CMT solutions agree relatively well.

## 4. CAN THE EFFECT BE OBSERVED?

There are mainly two problems with observing the change in Earth rotation caused by the Earthquake. The first problem is that the accuracy of the Earth rotation measurements is limited. Currently, space geodetic techniques like VLBI and GPS can measure LOD with and accuracy of 5–10 $\mu$s and polar motion excitation functions with an accuracy of about 5 mas (Gross and Chao, 2006), i.e. the predicted changes (table 1) are smaller than the measurement accuracies. The other problem is that there are processes in e.g. the atmosphere and the oceans causing variations in Earth rotation which are much larger than the predicted change due to the Earthquake. For example, variations caused by the atmosphere over one day can be 100 $\mu$s in LOD and several tens of mas in the polar motion excitation functions. Clearly, these variations need to be modelled very precisely in order to have any chance to detect the change caused by the Earthquake.

We calculated the LOD and the polar motion excitation functions from the IERS 05 C04 series (Bizouard and Gambis, 2009) for the time period around the 2010 Chile Earthquake. From the time series, we removed the excitations due to the atmosphere, oceans, and hydrology (obtained from `ftp://ftp.gfz-potsdam.de/home/ig/ops/`, Dobslaw et al. (2010)). From the LOD time series we also removed the variations caused by zonal Earth tides (Defraigne and Smits, 1999). The resulting time series are shown in figure 2. We see that the variations from day to day are still much larger than the predicted changes due to the Earthquake. Thus, we are not able to confirm the predicted changes in Earth rotation.

## 5. CONCLUSIONS

The 2010 Chile Earthquake caused the city of Concepción to move about 310 cm to the West and 65 cm to the South. The Earthquake should also have had an effect on the rotation of the Earth, the LOD should have increased by 0.3-0.5 $\mu$s and the polar motion should have changed by 2.5–3 mas (mostly in the y-component). This change currently cannot be confirmed by measurements, the measurement accuracies are too low and all other excitations (due to atmosphere, oceans, hydrology, and other sources) are currently not known with high enough accuracy. For the effect of an Earthquake on Earth rotation to be observable by current techniques, the Earthquake would need to be much stronger than the 2010 Chile Earthquake. For example, the 1960 Chile Earthquake (magnitude 9.5) is predicted to have changed polar motion excitation functions by over 20 mas (Chao and Gross, 1987), and this would most likely be possible to observe if such an Earthquake would happen today.

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