IGS Observations during the February 27, 2010 M 8.8 Chilean Earthquake

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The main motivation for looking at this 2010 mega earthquake was to see how receivers survived this big earthquake, since we may see something similar at Canada's Pacific West Coast, according to some recent news and also, how our PPP handles such extreme shaking. Unfortunately, the 1-sec data has stopped at the earthquake beginning, at 06:34:46 at the closest IGS station *conz* (about 100 km away from the epicenter 35.909°S, 72.733°W, (see http://earthquake.usgs.gov/earthquakes/recenteqsww/Quakes/us2010tfan.php; the official earthquake epoch is 6:34:14 UTC). However, the *conz* 30-sec data (from the same receiver as the 1-sec data) had no data breaks during the earthquake, though at the 06:35:00 and 06:36:00 GPS time (i.e., UTC +15 sec) epochs, 4 and 8 out of the observed 8 GPS satellites, respectively, had phase breaks flagged by PPP. No doubt, some of the detected phase breaks during the earthquake may/(or may) not be correct/real, and are resulting from an extreme shakings, as the narrow lane (NL) 30-sec interval changes exceeded several times the cycle slip limit of 10.7 cm. The GPS-only kinematic (i.e. independent epoch) PPP solutions, using the IGR orbits/5-min clocks (Fig. 1) and the 30-sec sampling kin PPP's with EMR orbits/clocks (Fig. 2) clearly show the large, nearly step-like negative latitude (south) and longitude (west) shifts, with little or no change in the height. However, both the 5-min (Fig.1) and 30-sec (Fig. 2) PPP's detected large height decreases of about -5 m for one 5-min and the two 30-sec epochs, discussed above. Since most of the GPS satellite phases have been reset at the above two problem epochs in GPS-only PPP's, the solution were also rerun with ESA GPS/GLONASS orbits/clocks. Fortunately, the *conz* station observes both GPS and GLONASS satellites, the PPP results during the earthquake are shown in Fig. 2a. Here there are no -5 meter height drops for the two 30-sec epochs, and the height solutions are well determined and also well behaved. This is because most of the GLONASS satellites have maintained a continuous phase at 06:35:00, though at 06:36:00 only one GLONASS satellite had a continuous phase tracking (at least it was not flagged by the PPP as having a discontinuous phase). This should be expected, as GLONASS signal and phase tracking is stronger than the GPS ones.

At the station *sant* (about 360 km away) there is a data gap at both the 30-sec and 1-sec data files (namely, between 6:36:38 and 6:37:11). Furthermore, the first 2 1-sec epochs after the gap at 6:37:11 and 6:37:12 had cycle slips detected at all the 5 observed satellites (real ones, with NL changes > 1000m!). Similarly to Figs. 1&2, the *sant* kinematic PPP's were run with IGR orbits/5-min clocks (Fig. 3) and EMR orbits/30-sec clocks (Fig. 4). Since *sant* observes only GPS, no GPS/GLONASS solutions could be run here. However, the 1-sec data is available, and was used in Fig. 4, together with interpolated 30-sec EMR clocks.

It is interesting to see the strange *sant* behaviour before, during and after the quake. It is likely real, except for the first two (weakly determined) epochs after the gap. It represents seismic surface waves arriving at *sant* , with horizontal amplitudes initially up to 0.5 m. Unfortunately, the most interesting the middle part is missing due to the *sant* data gap. Note that such surface seismic waves have already been observed before, even for smaller earthquakes (see eg. Larson et al 2003, Kouba 2003 and 2005). No doubt, had *conz* 1-sec data been available, even more interesting seismic waves would have also been observed there. The 30-sec sampling is simply too coarse to show such oscillations (see e.g. Kouba 2003). Note that according the recent, heartbreaking (1^{st}) post-earthquake station report (see IGSMail-6095), all the *conz* GPS/GLONASS data have been observed, however, still there are no 1-sec data at the CDDIS or BKG Data Centers after 6:34:46 (GPS Time), February 27, 2010.

For completeness the next nearest IGS stations *cfag*, nearly 1000 km from the epicenter, has also been reduced with kinematic PPP, using IGR orbits/(5-min) clocks (Fig. 5). Here, after the earthquake, one cannot observe any significant changes/oscillations, except, perhaps for a small west shift of a few cm.

Any possible PM shift (due to the earthquake) is also of a great interest, no doubt we all must have heard/read the news that the Earth's axis has moved by about 3 inches (2.7 mas), it was reported everywhere. So, Fig. 6 plots and compares the observed IGR PM (accuracy ~ 0.05 mas) with the extrapolated PM from the IGR PM's of Feb. 23 - Feb. 26. During this interpolation interval of 4 days, the PM was nearly perfectly linear (see Fig. 6), with a straight line fit RMS of only 0.09 mas. However, the extrapolated PM on Feb. 27 disagreed with the observed IGR PM by 0.46 ± 0.16 mas and on Feb. 28 by

0.70 ± 0.20 mas. While these PM changes are statistically quite significant (at 3 × sigmas), they are much less than the reported 2.7 mas. Note that IGR PM are 24-h averages (0 - 24h interval), so the Feb. 27 PM value is based on about 27% before and 73% after the earthquake, while the Feb. 28 PM is 100% after the earthquake. Consequently, the Feb. 27 PM change after the earthquake should be about 1.37 times of the observed Feb. 27 PM change, which gives 0.63 mas, which agrees quite well with the Feb. 28 change of 0.70 mas. Furthermore, even the following day (Feb. 29), the observed IGR PM continued to change linearly, giving the 3-day extrapolation – IGR PM difference of 0.64 ± 0.24 mas (see Fig. 6). So, based on the real observations (IGR- i.e. IGS Rapid combined PM solutions), it looks like 0.6 mas (or 2 cm) is the actual (or a more realistic) Earth's spin axis (and PM) change due to the Chilean Earthquake of Feb. 27, 2010.

References

Larson K.M., Bodin P. and Gomberg J., 2003. Using 1-Hz GPS Data to Measure Deformations Caused by the Denali Fault Earthquake. *Science*, **300(5624)**, 1421-1424

Kouba J., 2003. Measuring seismic waves induced by large earthquake with GPS. *Stud. Geophys. Geod.*, **47**, 741−755.

Kouba J., 2005. A possible detection of the 26 December 2004 Great Sumatra-Andaman Islands Earthquake with solution products of the International GNSS Service, *Stud. Geophys. Geod.*, ***49*** (2005), 463−483

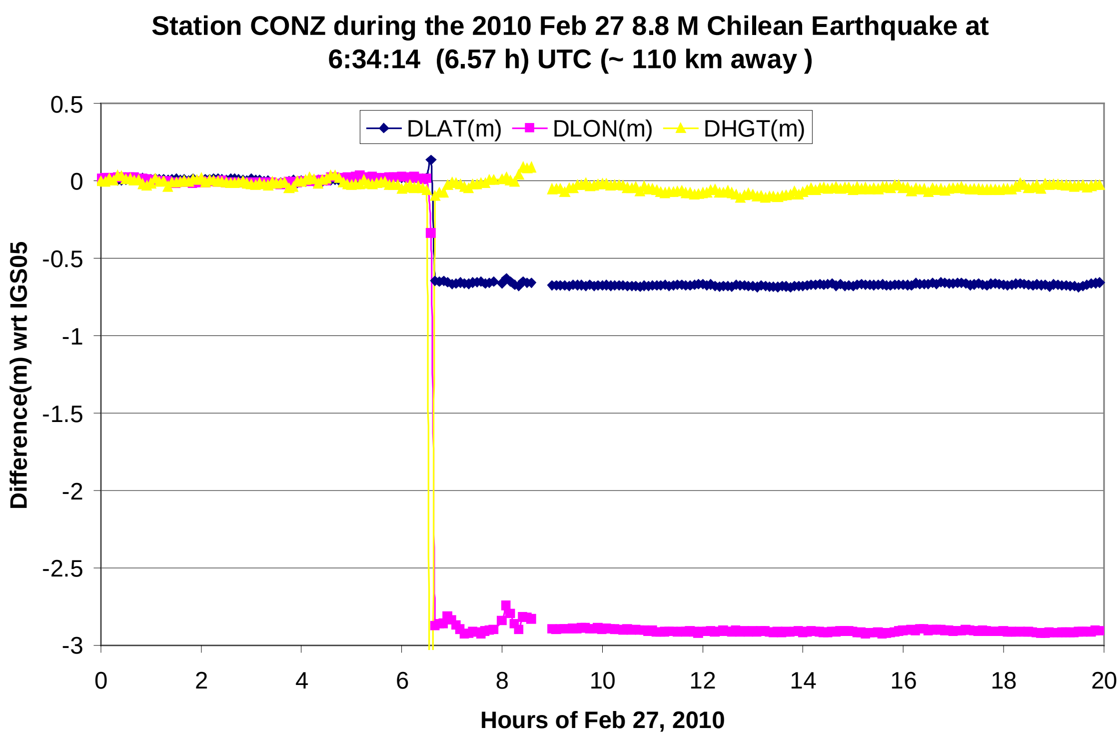

Figure 1. Kinematic PPP at the IGS station *conz* during the nearby Chilean 8.8 M Earthquake, using IGR orbits and clocks with 5-min sampling. At 06:35:00 and 6:36:00 4 and 8 out of 8 observed satellites had discontinuous phase, respectively (DGHT = -5.04±0.18 m at 6:35:00).

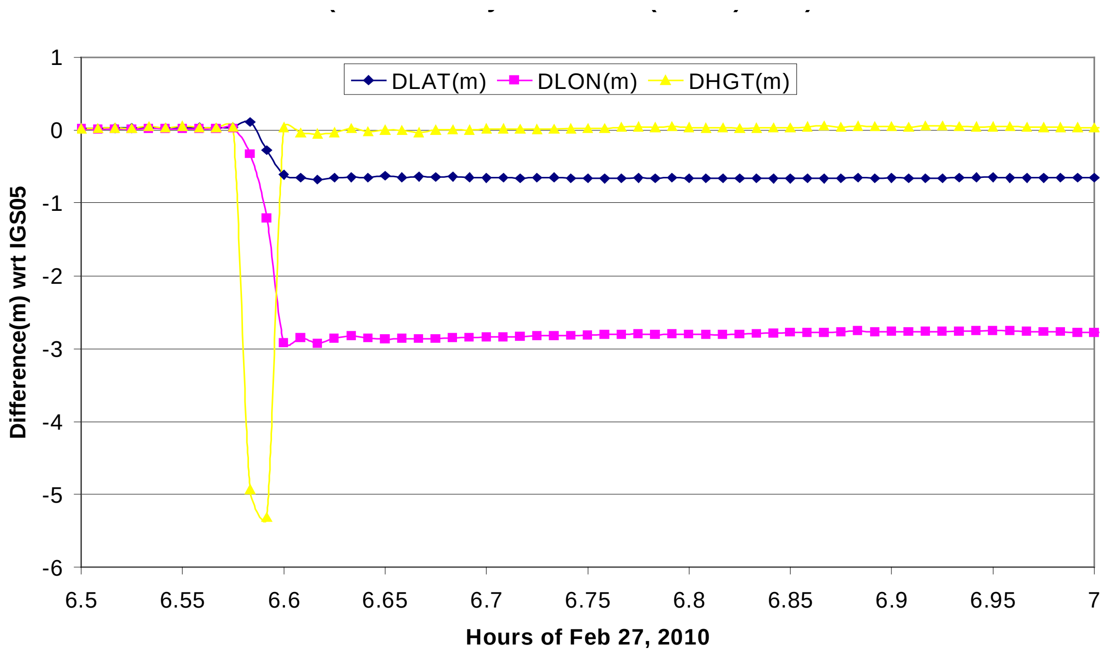

Figure 2. 30-sec kinematic PPP at the IGS station *conz* during the nearby Chilean 8.8 M Earthquake, using EMR orbits / 30s EMR clocks. No data gaps during the Earth quake, though 4 and 8 out of the 8 observed satellites had experienced phase breaks at 6:35:00 & 6:36:00, respectively (the two extreme DHGT < -5m are at 6:35:00 &6:35:30), with PPP sigmas of about 0.4m. Note that the 1-s *conz* data ends at 06:34:46 and also that IGS (Final) combined 30-sec clocks will be available within about 10 days only.

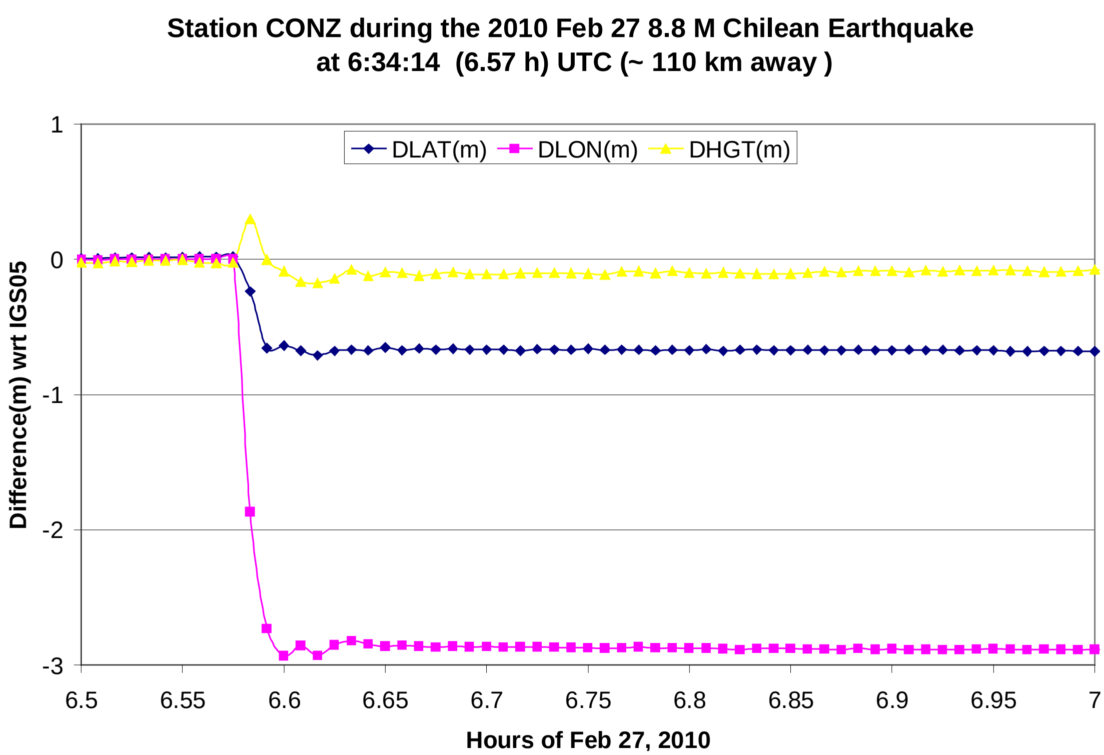

Figure 2a. The same as Fig.2, but with **GPS/GLONAS (using ESA orbits/30s clocks)**, several GLONASS satellites maintained the phase lock during the earthquake shaking at 06:35:00 and 06:35:30. The two –5 m DHGT's are no longer present, all the formal sigmas are < 0.1 m. Note the vertical scale change and also that only ESA AC currently generates GLONASS clock solutions.

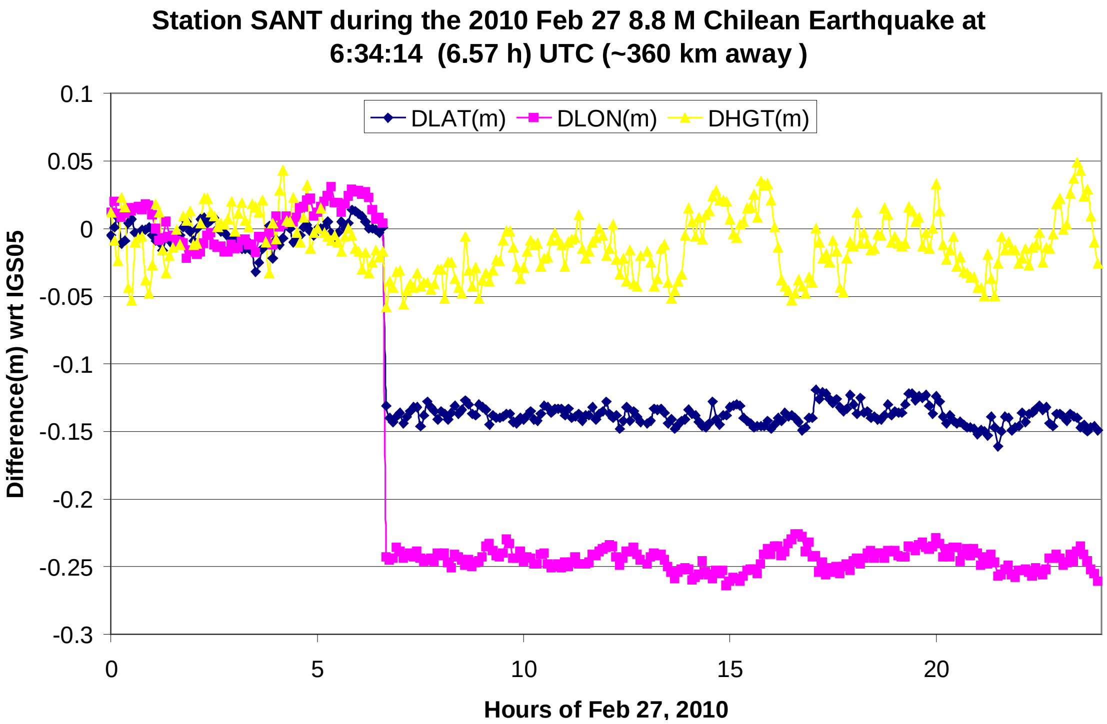

Figure 3. Kinematic PPP at the IGS station *sant* during the Chilean 8.8 M Earthquake, using IGR orbits and clocks with 5-min sampling.

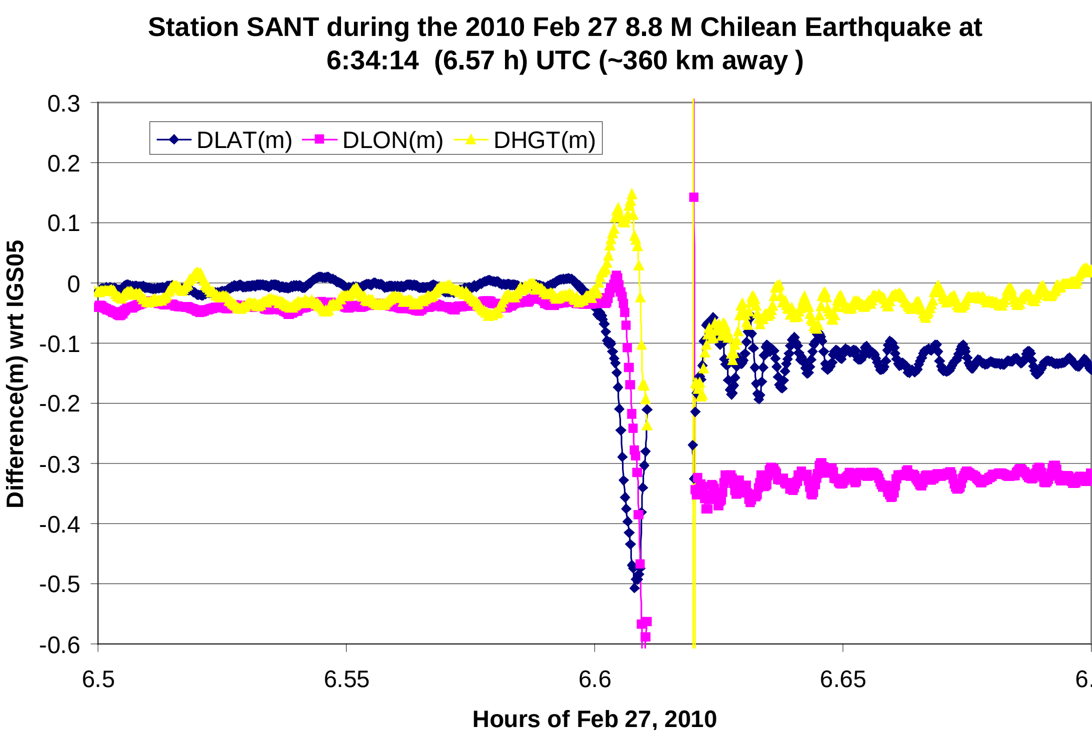

Figure 4. 1-sec kinematic PPP at the IGS station *sant* during the Chilean 8.8 M Earthquake, using EMR orbits & interpolated 30s EMR clocks. The large displacements at the earthquake beginning are well determined with a continuous phase on most satellites and small formal PPP sigmas (of several cm). However, the first two epochs after the break (at 6:37:11 & 12) experienced phase lock discontinuities on all of the 5 observed satellites and PPP's have sigmas of several m, all the subsequent epochs are well determined with sigmas of a few cm only.

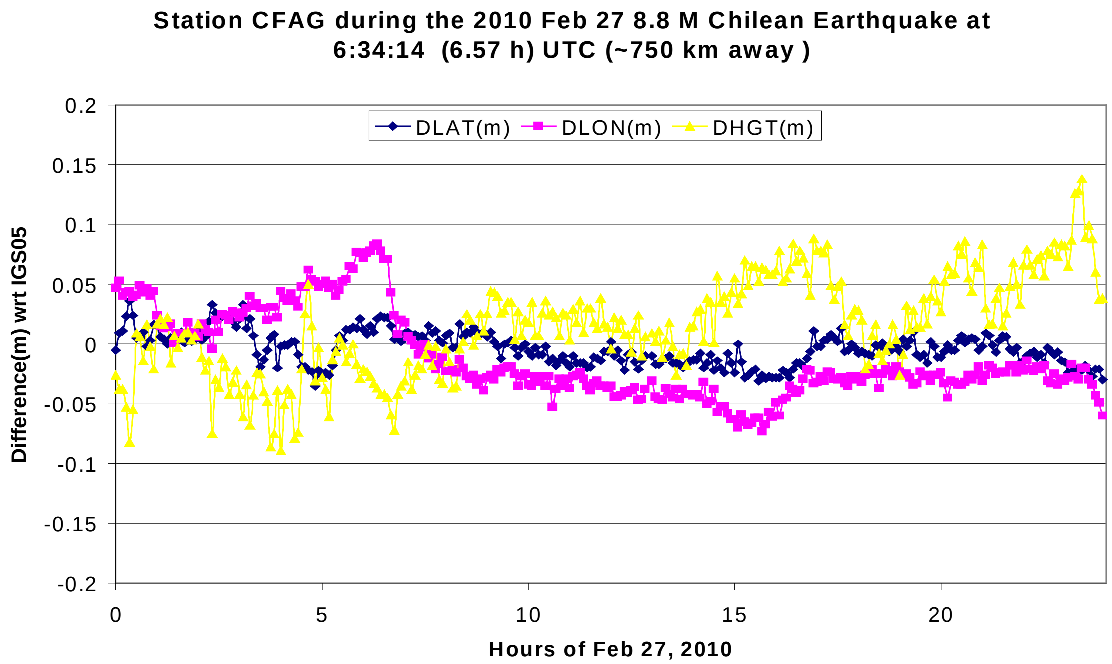

Figure 5. Kinematic PPP at the IGS station *cfag* during the Chilean 8.8 M Earthquake, using IGR orbits and clocks with 5-min sampling. Only a small western shift of a few cm is likely here after the earthquake.

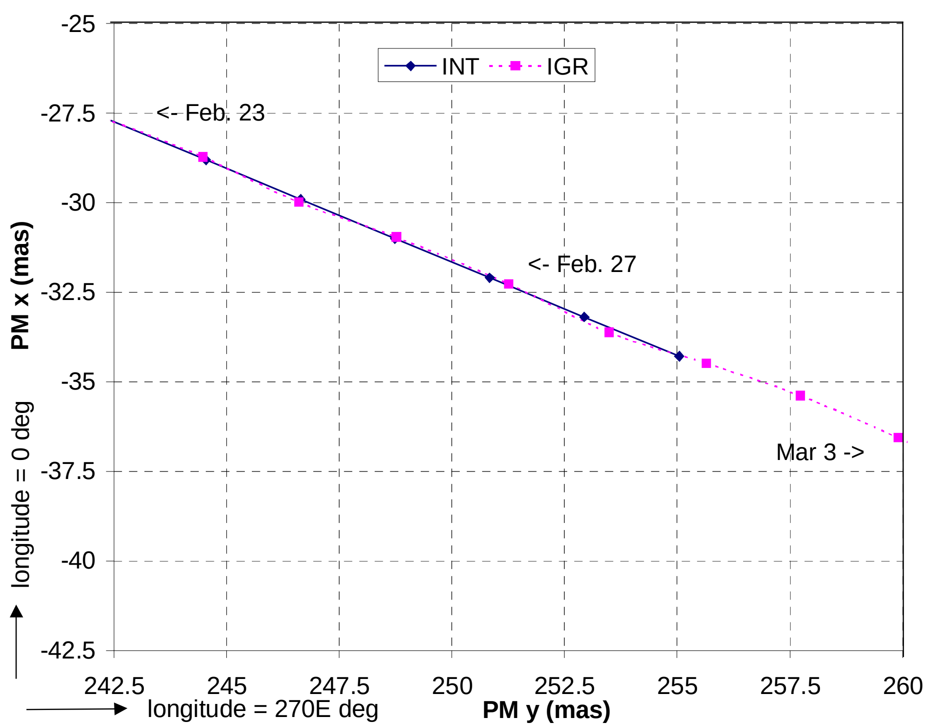

Figure 6. IGR PM's (0-24h UT averages) during the 2010 Feb 27 M 8.8 Chilean Earthquake (at 6:34:14 UT). Also shown is the extrapolated PM (INT) from Feb 23-26. While the interpolation INT agrees with the IGR PM (accuracy < 0.1mas) within 0.1mas during Feb 23-26, the extrapolated and observed PM of Feb 27 (about 27% before and 73 % after) and Feb 28 (100% after the earthquake) disagree by 0.46 $\pm$ 0.16 and 0.70 $\pm$ 0.20 mas, respectively. So the PM (and the Earth's spin axis) has changed, but much less than the 2.7 mas, widely reported in the press (see e.g. http://www.businessweek.com/news/2010-03-01/chilean-quake-likely-shifted-earth-s-axis-nasa-scientist-says.html). (The more precise, IGS Final combined PM for the week following Feb. 27 will be available within about 10 days)