Excitation of Earth rotation by strong Earthquakes

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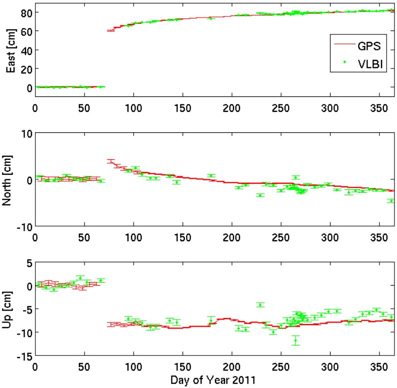
Introduction

- Earthquakes affect the Earth orientation parameters (EOP), like polar motion and length of day (LOD)
- In this work we investigate how much the EOP change by an Earthquake
- We also discuss the possibility to detect these changes using EOP measurements

Earthquake displacements

- Earthquakes cause mass displacements within the Earth that can be measured on the surface
- These displacements will affect the inertia tensor of the Earth
- Thus the EOP will change



Displacement of Tsukuba measured by GPS and VLBI after the Earthquake on March 11, 2011.

Theory (I)

The change in the inertia tensor $\Delta\mathbf{I}$ can be calculated from:

$$\Delta\mathbf{I} = \int_V \rho(\mathbf{r}) \left[2(\mathbf{r}^T\mathbf{u})E - (\mathbf{u}\mathbf{r}^T + \mathbf{r}\mathbf{u}^T) \right] dV$$

ρ: density
$\mathbf{u} = \mathbf{u}(\mathbf{r})$: Earthquake displacement field
E: unit tensor
If the displacement fieled $\mathbf{u}$ is known at every point inside the Earth, $\Delta\mathbf{I}$ can be calculated.

The changes in the polar motion excitation functions $\chi = \chi_x + i\chi_y$ and LOD can then be calculated from:

$$\begin{aligned} \delta\chi &= \frac{1.61}{C-A}\left[\Delta I_{xz} + i\Delta I_{yz}\right] \\ \delta LOD &= \frac{LOD_0}{C_m}\Delta I_{zz} \end{aligned}$$

$C - A$: difference between the principal moments of inertia
LOD_0: nominal length of day (86400 s)
C_m: polar moment of inertia of the mantle

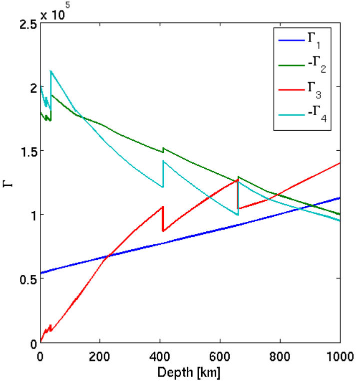
Theory (II)

With knowledge of the elastic properties of the Earth and information about the Earthquake – i.e. the moment tensor M, colatitude θ, longitude λ, and depth d – the displacement field $\mathbf{u}$ can be calculated.

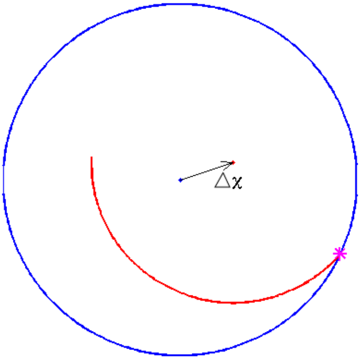
After some calculations one can arrive at the following expressions:

$$
\begin{aligned}
\Delta I_{xz} &= \Gamma_1(d)\left[\frac{M_{tt}-M_{pp}}{2}\sin(2\theta)\cos(\lambda)\right. \\
&\qquad \left. -2M_{tp}\sin(\theta)\sin(\lambda)\right] \\
&\quad -\Gamma_2(d)M_{rr}\sin(2\theta)\cos(\lambda) \\
&\quad -\Gamma_3(d)\left[M_{rt}\cos(2\theta)\cos(\lambda)\right. \\
&\qquad \left. -M_{rp}\cos(\theta)\sin(\lambda)\right] \\
\Delta I_{yz} &= \Gamma_1(d)\left[\frac{M_{tt}-M_{pp}}{2}\sin(2\theta)\sin(\lambda)\right. \\
&\qquad \left. +2M_{tp}\sin(\theta)\cos(\lambda)\right] \\
&\quad -\Gamma_2(d)M_{rr}\sin(2\theta)\sin(\lambda) \\
&\quad -\Gamma_3(d)\left[M_{rt}\cos(2\theta)\sin(\lambda)\right. \\
&\quad \left. +M_{rp}\cos(\theta)\cos(\lambda)\right] \\
\Delta I_{zz} &= -\Gamma_1(d)[M_{tt}-M_{pp}]\sin^2(\theta) \\
&\qquad -2\Gamma_2(d)M_{rr}\left[\cos^2(\theta)-\frac{1}{3}\right] \\
&\quad +\Gamma_3(d)M_{rt}\sin(2\theta)+\Gamma_4(d)\frac{M_{rr}}{3}
\end{aligned}
$$

The functions Γ_1, Γ_2, Γ_3, and Γ_4 depend on the Earth model assumed for the calculations. Below are these functions calculated from the ak135-f model (Kennett, Engdahl, and Buland,1995).



Effects on polar motion



- Before the Earthquake the pole has moved in aprroximately a circular motion of the pole around some central point (Chandler Wobble)
- When the Earthquake occurs the position of the pole will not change
- Afterwards the pole will move around another point, with a different amplitude

EOP excitations by a few strong Earthquakes

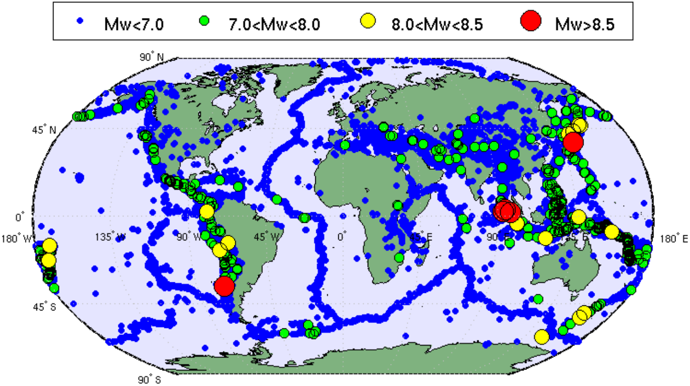
Effects of a few strong Earthquakes

Earthquake	Mw	$\Delta\chi_x$ [mas]	$\Delta\chi_y$ [mas]	ΔLOD [μs]
Chile 1960	9.6	-10.37	21.06	-7.64
Alaska 1964	9.2	-7.99	-3.27	6.85
Sumatra 2004	9.0	-0.67	0.62	-2.32
Sumatra 2005	8.6	-0.23	0.11	-0.60
Chile 2010	8.8	-0.96	2.35	-1.20
Japan 2011	9.1	-2.67	3.38	-1.26
Sumatra 2012	8.6	1.01	0.02	0.45
Meas. accuracy		5	5	5

Earthquake information taken from the Global CMT catalogue, except for Chile 1960 (Kanamori and Cipar, 1974) and Alaska 1964 (Kanamori 1970)

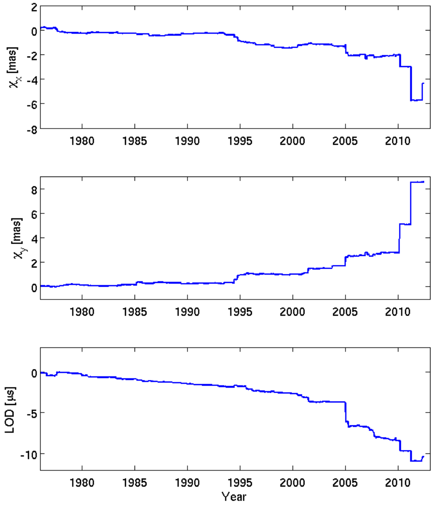
Earthquakes January 1976 – May 2012

Earthquakes in the global CMT catalogue, Mw$\gtrsim$5.5



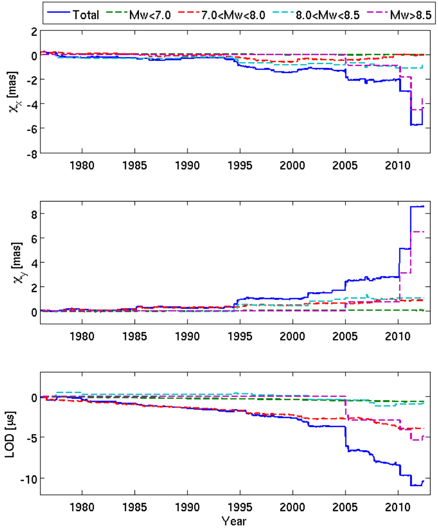
Magnitude	7.0$<$	7.0–8.0	8.0–8.5	$>$8.5	Total
# events	36635	405	17	5	37062

EOP excitation by Earthquakes, 1976-2012



- Cumulative effect of all Earthquakes in the global CMT catalogue

EOP excitation by Earthquakes, 1976-2012



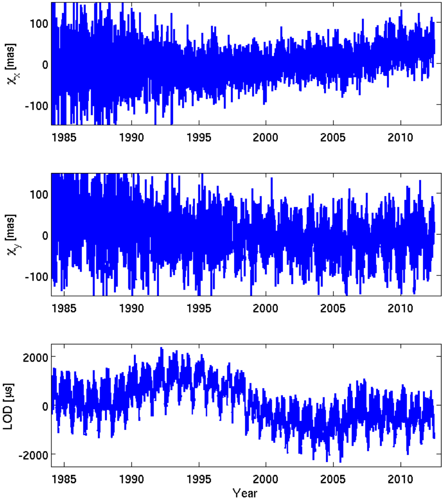
- Cumulative effect of all Earthquakes in the global CMT catalogue
- Effects of Earthquakes of different strengths
- Largest effect caused by the strongest ($Mw > 8.5$) Earthquakes, but the cumulative effect of Earthquakes $7 < Mw < 8$ is causing a significant part of the total change

Can the Earthquake excitations be observed?

Problems in observing the effects of Earthquakes on EOP:

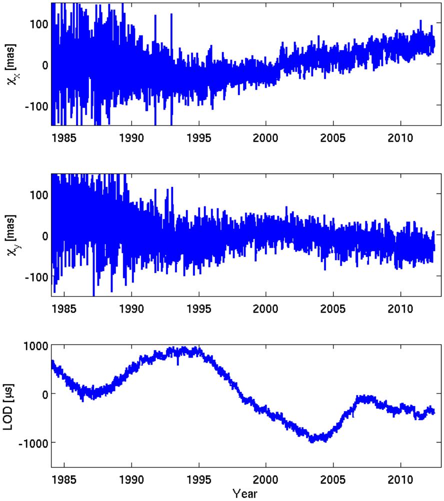
- Predicted changes (a few mas in χ, a few μs in LOD) smaller than the EOP measurement accuracies:
  - 5 mas for χ (50 μas uncertainty in polar motion)
  - 5 μs for LOD
- All other EOP excitations need to be modelled and removed from the observations, since these are much larger than the effects of the Earthquakes
  - Atmosphere
  - Oceans
  - Tides
  - Core-mantle coupling
  - ...
- Possible strategies for avoiding these problems:
  - Average over a longer time period (should reduce white noise)
  - Investigate high frequency EOP (unmodeled slowly varying excitations unimportant)

Observed EOP excitations 1984-2012



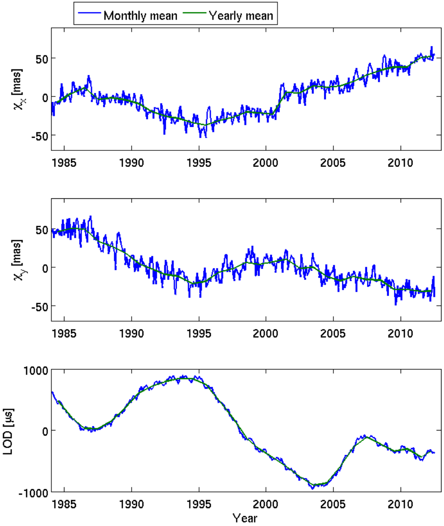
- EOP excitation functions calculated from the IERS 08 C04 series

Observed EOP excitations 1984-2012



- EOP excitation functions calculated from the IERS 08 C04 series
- Excitations due to zonal tides (LOD only), atmosphere, oceans, and hydrology removed using data from `ftp://ftp.gfz-potsdam.de/home/ig/ops/`

Observed EOP excitations 1984-2012



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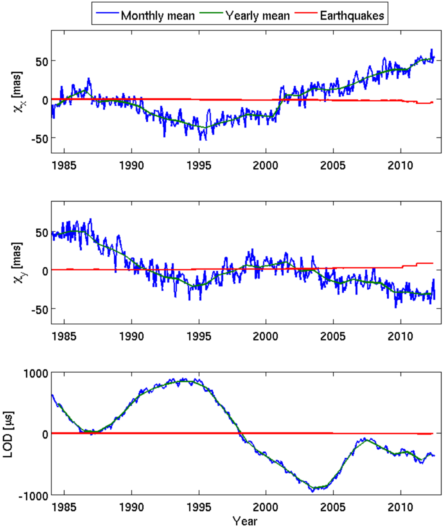
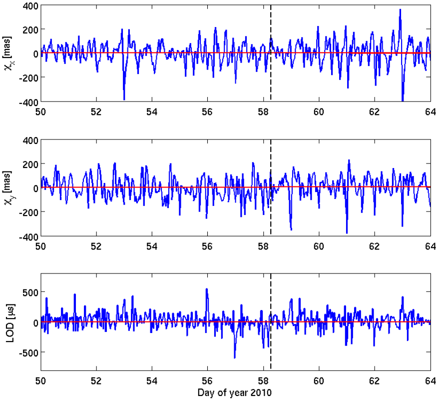
- Monthly and yearly mean values have been calculated

Observed EOP excitations 1984-2012



- EOP excitation functions calculated from the IERS 08 C04 series
- Excitations due to zonal tides (LOD only), atmosphere, oceans, and hydrology removed using data from `ftp://ftp.gfz-potsdam.de/home/ig/ops/`
- Monthly and yearly mean values have been calculated
- Unmodeled variations much larger than what is expected to be caused by Earthquakes remain (e.g. core-mantle coupling)

High frequency EOP excitation around the 2010 Chile Earthquake



- Excitations calculated from hourly EOP observed by GPS
- Too much noise in the excitation time series to see the Earthquake

Conclusions

- Large Earthquakes affect the rotation of the Earth
- The effect is however so far too small to be observed
- In order to see the effect we need:
    - Improved modelling of all other EOP excitations
    - More accurate EOP observations
    - A strong Earthquake (Mw>9.5)

Danke für Ihre Aufmerksamkeit!

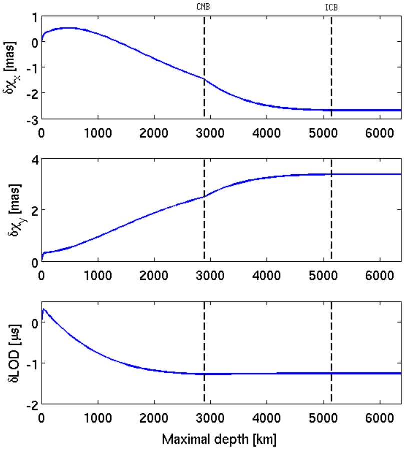
Results from different moment tensor catalogues

Using information from different Earthquake catalogues

Earthquake	Cat.	$\Delta\chi_x$ [mas]	$\Delta\chi_y$ [mas]	ΔLOD [μs]
Chile 2010	CMT	-0.96	2.35	-1.20
	USGS	-1.07	2.51	-1.27
Japan 2011	CMT	-2.67	3.38	-1.26
	USGS	-3.54	3.71	-1.68
	GFZ	-1.57	1.46	-0.71
Sumatra 2012	CMT	1.01	0.02	0.45
	USGS	0.91	0.05	0.62
	GFZ	0.75	0.01	0.61

CMT: Global CMT catalogue, `http://www.globalcmt.org`
USGS: U.S. Geological Survey, `http://earthquake.usgs.gov`
GFZ: GEOFON, GFZ Potsdam, `http://geofon.gfz-potsdam.de`

Sensitivity to the displacements at different depths



- EOP excitations when only considering the displacements down to a certain depth
- Earthquake in Japan, March 2011
- The displacements deep inside the Earth are important