ATMOSPHERIC, OCEANIC AND GEOMAGNETIC EXCITATION OF NUTATION

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Introduction

- Atmospheric and oceanic excitations play dominant role in polar motion and rotational velocity of the Earth.
- Thanks to the use of the new precession/nutation model IAU2000/2006 after 2003, the amplitudes of observed celestial pole offsets by VLBI are less than 1 mas.
- Small but non-negligible effects can be seen also in nutation.
- These effects are caused by quasi-diurnal changes of angular momentum functions of the atmosphere and oceans. High-resolution data are needed (at least 6-hour)

Motivation

- In our previous solutions we found that the atmospheric/oceanic effects cannot explain the observed celestial pole offsets (CPO) completely.
- The integrated excitations in CRF in comparison with the observed CPO became out-of-phase after some period
- We suppose that other excitations have effect. We tested:
    - geomagnetic jerks (Malkin 2013),
        - GMJ – rapid changes of the secular variations of geomagnetic field.
    - strong earthquakes (mag > 8.8),
        - Sumatra 2005.0, Chile 2010.2, Japan 2011.9
- Re-initialization of the integration in the dates of these events was used and
- the best agreement found when the GMJ epochs have been used.

Motivation

- But the re-initialization of the integration leads to stepwise changes in CPO that are physically not acceptable.
- Here we use a different approach – additional continuous excitation near GMJ epochs.

Method used

Broad-band Liouville equations

- The excitations of the Earth rotation in the celestial reference frame (nutation) by atmosphere and ocean were studied using
- Brzezinski's broad-band Liouville equations (1994)

$$\ddot{P} \quad -i(\sigma'_C + \sigma'_f)\dot{P} - \sigma'_C\sigma'_f P = -\sigma_C \left\{\sigma'_f(\chi'_p + \chi'_w) + \right. \\ \left. \sigma'_C(a_p\chi'_p + a_w\chi'_w) + i[(1+a_p)\dot{\chi}'_p + (1+a_w)\dot{\chi}'_w]\right\}$$

where

- $P = dX + idY$ is excited motion of Earth's spin axis in celestial frame (CRF),
- σ'_C, σ'_f are the complex Chandler and FCN frequencies in CRF, respectively, σ_C in TRF.
- $a_p = 9.509 \times 10^{-2}$, $a_w = 5.4809 \times 10^{-4}$ are dimensionless constants,
- χ'_p and χ'_w are the angular momentum excitation functions (presure and wind) in CRF

Method used

Solution of the differential equations

$$\begin{aligned}\ddot{P} \quad & -i(\sigma'_C + \sigma'_f)\dot{P} - \sigma'_C\sigma'_f P = -\sigma_C\left\{\sigma'_f(\chi'_p + \chi'_w) + \right. \\ & \left. \sigma'_C(a_p\chi'_p + a_w\chi'_w) + i[(1+a_p)\dot{\chi}'_p + (1+a_w)\dot{\chi}'_w]\right\}\end{aligned}$$

- We apply substitutions

$$\begin{aligned}y_1 &= P, \quad \text{and} \\ y_2 &= \dot{P} - i\sigma'_C P,\end{aligned}$$

- and get two first-order equations

$$\begin{aligned}\dot{y}_1 &= i\sigma'_C y_1 + y_2 \\ \dot{y}_2 &= i\sigma'_f y_2 - \sigma_C\left\{\sigma'_f(\chi'_p + \chi'_w) + \sigma'_C(a_p\chi'_p + a_w\chi'_w) + \right. \\ & \left. + i[(1+a_p)\dot{\chi}'_p + (1+a_w)\dot{\chi}'_w]\right\}\end{aligned}$$

Method used

Initial values

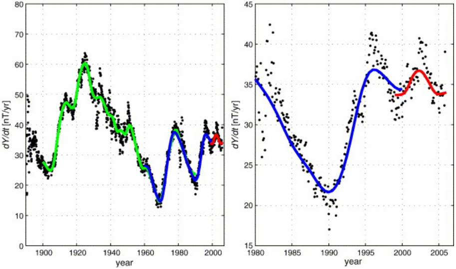
$$\begin{aligned}
\dot{y}_1 &= i\sigma'_C y_1 + y_2 \\
\dot{y}_2 &= i\sigma'_f y_2 - \sigma_C \left\{\sigma'_f(\chi'_p + \chi'_w) + \sigma'_C(a_p\chi'_p + a_w\chi'_w) + \right. \\
&\quad \left. + i[(1 + a_p)\dot{\chi}'_p + (1 + a_w)\dot{\chi}'_w]\right\}
\end{aligned}$$

- To integrate the system we need the initial values P_0, $\dot{P}_0$ constrained so that the free Chandlerian term (with quasi-diurnal period in celestial frame) vanishes.
- The initial values are closely connected to the phase and amplitude of the integrated series.
- The final choice of P_0 was made by repeating integration with different values P_0 to fit the integrated motion to VLBI observations so that reaches a minimum rms differences,
- numerical integration with Runge-Kutta 4th order in 6h steps.

Method used

Procedure of searching the additional excitations

- We are looking for an additional excitation
- Geomagnetic jerks (or secular geomagnetic variation impulse) is a relatively sudden change in the second derivative of the Earth's magnetic field with respect to time.

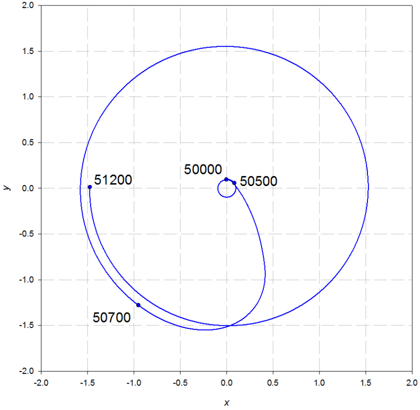


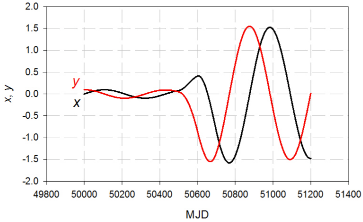
Olsen & Mandea, 2007, EPSL 255, 94

- We found the double ramp function as the closest one.

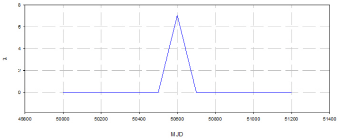
Method used

Integration with simulated schematic excitation





schematic excitation ("double ramp" function) χ_1, χ_2



Method used

Procedure of searching the additional excitations

- We fix the the central epochs of additional excitations around GMJ epochs:
  - 1991.0, 1994.0, 1999.0, 2003.5, 2004.7, and 2007.5.
- GMJ last typically several months.
- We fix the length of excitation to 200 days.
- The complex amplitudes of the excitations were estimated to lead to the best rms fit to observed celestial pole offsets.
- In our previous studies we also tested if the excitations is preceeding, delaying or corresponding to the GMJ epochs[1]:
  - $\mathrm{GMJ} - 100\mathrm{d} \Rightarrow \mathrm{rms} = 0.211$ mas, corr. $= 0.578$
  - $\mathrm{GMJ} \Rightarrow \mathrm{rms} = 0.196$ mas, corr. $= 0.632$
  - $\mathrm{GMJ} + 100\mathrm{d} \Rightarrow \mathrm{rms} = 0.213$ mas, corr. $= 0.570$
- The best agreement was found for the epochs of GMJ.

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[1] These values were obtained from shorter interval and do not correspond to the presented solution.

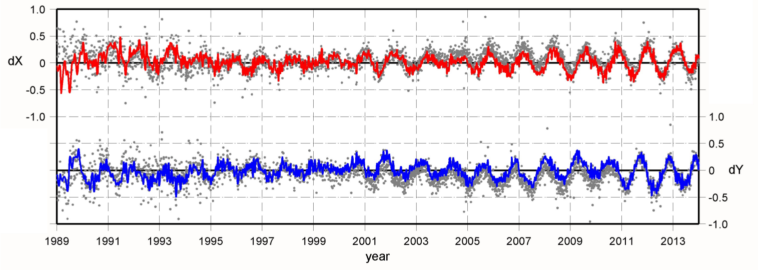
Data used

Celestial pole offsets

- Celestial pole offsets
  - IVS combined solution `ivs13q4X.eops` covering the interval 1989.0-2014.0. dX and dY are given in unequally spaced intervals, (sometimes with outliers).
  - We cleaned the data by removing CPO $>$ 1mas.
  - then has been added the empirical Sun-synchronous correction in order the CPO to be comparable with the atmosheric contribution.
  - filtered to retain only periods between 60 and 6000 days and interpolated at regular 10-day intervals and.

IVS Celestial pole offsets

Observed and filtered (60<P<6000d)

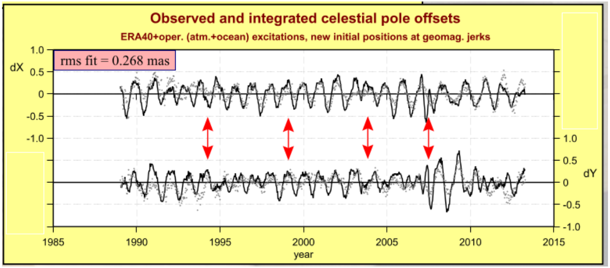


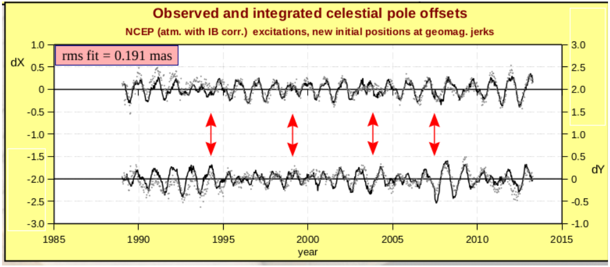
Data used

Atmospheric angular momentum

- There are two sources of Atmospheric angular momentum data
  - European Centre for Medium-Range Weather Forecasts (ECMWF), ERA40
    - Oceanic angular momentum based on the model OMCT (Dobslaw et al., 2010) is available.
  - Atmospheric and Environmental Research, USA, NCEP/NCAR reanalysis
    - No model of oceanic angular momentum available for the whole period
    - The pressure term with IB correction - a simple model of oceanic response on the pressure changes.
- Our previous studies based on atmospheric/oceanic angular momemtum function of European meteorological Center ECMWF ERA40 and on the ocean model OMCT showed relatively worse agreement in comparison with the NCEP/NCAR data.
- That is why we only used the NCEP/NCAR data here.

Previous NCEP × ERA40 solution





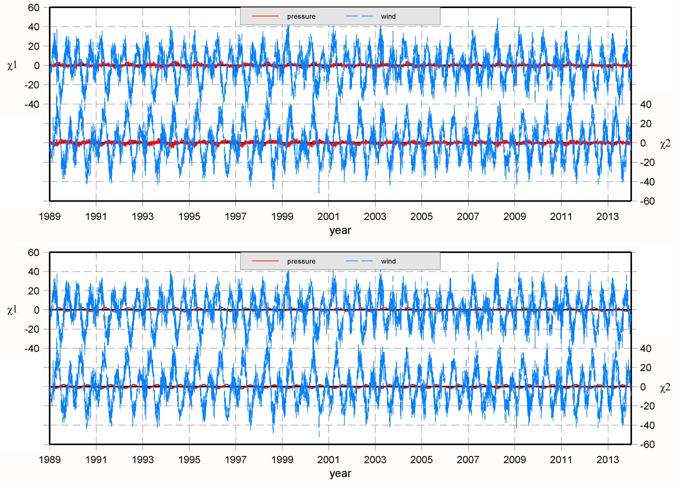
Data used

Atmospheric angular momentum

- The time series of AAM χ (complex values) were transformed from the terrestrial frame to the celestial frame by using the complex decomposition at retrograde diurnal frequency $\chi' = -\chi e^{i\Phi}$, Φ is the Greenwich sidereal time.
- Because we are interested in the long-periodic motion (comparable with nutation), we applied the smoothing to remove periods shorter than 10 days and calculated their time derivatives needed for integration.

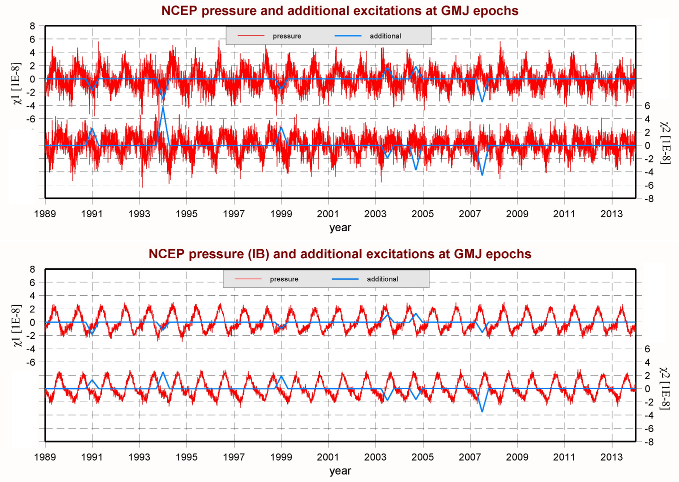
NCEP excitations pressure and wind

Pressure without (upper) and with (lower) IB correction



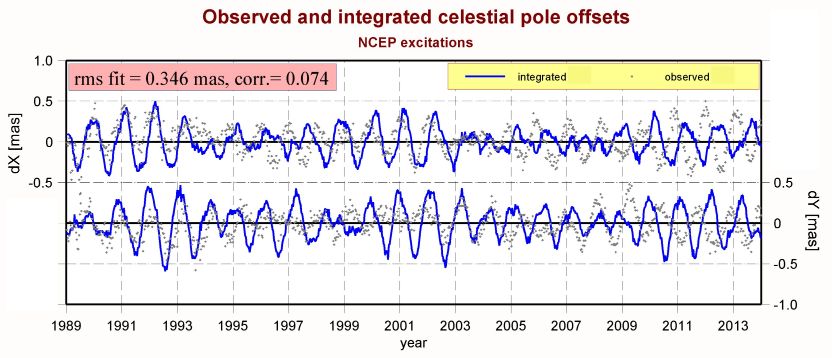
NCEP excitations pressure and wind

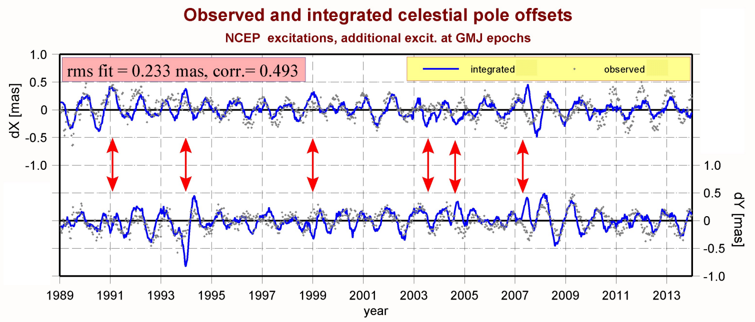
Pressure without (upper) and with (lower) IB correction



Results

pressure term without IB correction

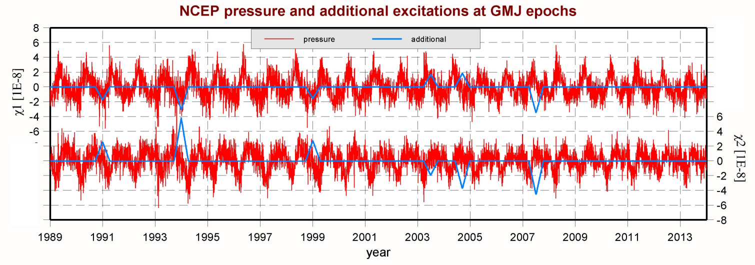




Observed and integrated celestial pole offsets

NCEP excitations, additional excit. at GMJ epochs

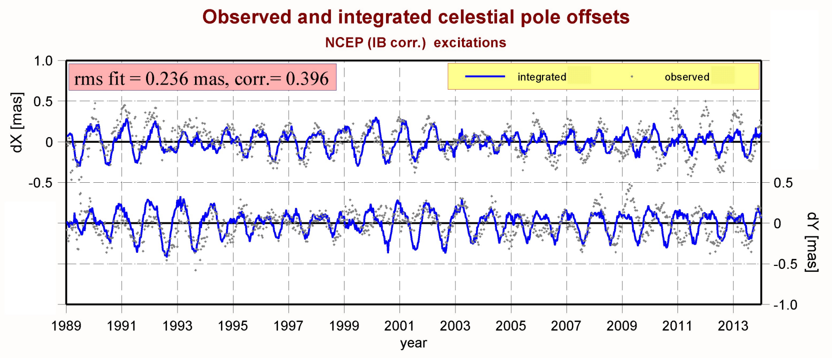
rms fit = 0.233 mas, corr.= 0.493

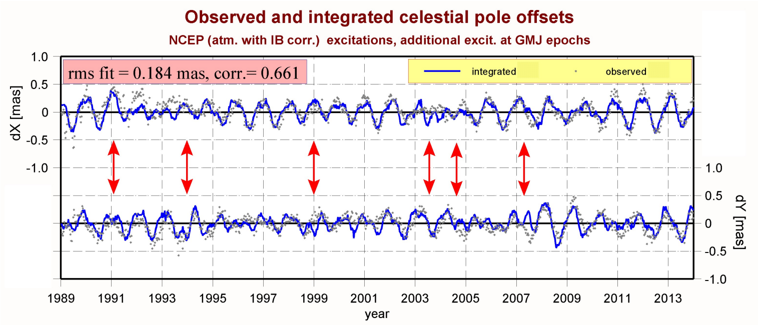


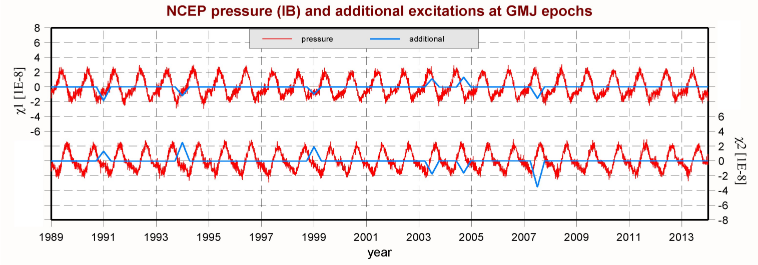
NCEP pressure and additional excitations at GMJ epochs

Results

pressure term with IB correction




Observed and integrated celestial pole offsets
NCEP (atm. with IB corr.) excitations, additional excit. at GMJ epochs
rms fit = 0.184 mas, corr.= 0.661
integrated
observed
dX [mas]
1.0
0.5
0
-0.5
-1.0
dY [mas]
1.0
0.5
0
-0.5
-1.0
1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013
year


NCEP pressure (IB) and additional excitations at GMJ epochs
pressure
additional
χ1 [1E-8]
8
6
4
2
0
-2
-4
-6
χ2 [1E-8]
6
4
2
0
-2
-4
-6
-8
1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013
year

Conclusions

- We detected considerable differences between ERA40 and ERAinterim the wind term in AAM data (30% relative difference in amplitude of the semi-annual wind term)
- NCEP solution with the inverted barometer correction leads to better agreement
- Geophysical excitations yield significant contribution to nutation, of the order of 0.1mas;
- The influence of motion (wind) terms is one order of magnitude smaller than that of matter (pressure) terms;
- The application of schematic additional excitations at GMJ epochs substantially improves the agreement of integrated pole position with VLBI observations.

Thank you for your attention.