Free core nutation
possible causes of changes of its phase and amplitude

Cyril Ron, Jan Vondrák, Yavor Chapanov

AI AS CR, Prague, NIGGG BAS, Sofia

Free core nutation
possible causes of changes of its phase and amplitude

Cyril Ron, Jan Vondrák, Yavor Chapanov

AI AS CR, Prague, NIGGG BAS, Sofia

Introduction

- In our previous solutions of the integrated atmospheric and oceanic excitations in CRF and their comparison with the observed celestial pole offsets the series became out-of-phase after some time

Introduction

- In our previous solutions of the integrated atmospheric and oceanic excitations in CRF and their comparison with the observed celestial pole offsets the series became out-of-phase after some time
- we suppose that other excitations have effect:

Introduction

- In our previous solutions of the integrated atmospheric and oceanic excitations in CRF and their comparison with the observed celestial pole offsets the series became out-of-phase after some time
- we suppose that other excitations have effect:
  - geomagnetic jerks (Malkin 2013),

Introduction

- In our previous solutions of the integrated atmospheric and oceanic excitations in CRF and their comparison with the observed celestial pole offsets the series became out-of-phase after some time
- we suppose that other excitations have effect:
  - geomagnetic jerks (Malkin 2013),
  - strong earthquakes,

Introduction

- In our previous solutions of the integrated atmospheric and oceanic excitations in CRF and their comparison with the observed celestial pole offsets the series became out-of-phase after some time
- we suppose that other excitations have effect:
    - geomagnetic jerks (Malkin 2013),
    - strong earthquakes,
    - ...

Introduction

- In our previous solutions of the integrated atmospheric and oceanic excitations in CRF and their comparison with the observed celestial pole offsets the series became out-of-phase after some time
- we suppose that other excitations have effect:
  - geomagnetic jerks (Malkin 2013),
  - strong earthquakes,
  - ...
- we have done new integration divided into the intervals taking into account these events.

The method used

- The excitations of the Earth rotation in the celestial reference frame (nutation) by atmosphere and ocean were studied.

The method used

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

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

where

The method used

- The excitations of the Earth rotation in the celestial reference frame (nutation) by atmosphere and ocean were studied.
- The solution is based on the 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),

The method used

- The excitations of the Earth rotation in the celestial reference frame (nutation) by atmosphere and ocean were studied.
- The solution is based on the 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.

The method used

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

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

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.
- $a_{p,w}$ are dimensionless constants and

The method used

- The excitations of the Earth rotation in the celestial reference frame (nutation) by atmosphere and ocean were studied.
- The solution is based on the 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.
- $a_{p,w}$ are dimensionless constants and
- χ'_p and χ'_w are the angular momentum excitation functions (presure and wind) in CRF

The method used

Initial values

- 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 method used

Initial values

- 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 method used

Initial values

- 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,

The method used

Initial values

- 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.

Used data
Celestial pole offsets

- Celestial pole offsets (CPO)

Used data

Celestial pole offsets

- Celestial pole offsets (CPO)
  - IVS combined solution `ivs13q2X.eops` covering the interval 1984.1-2013.5. dX and dY are given in unequally spaced intervals, (sometimes with outliers).

Used data

Celestial pole offsets

- Celestial pole offsets (CPO)
  - IVS combined solution `ivs13q2X.eops` covering the interval 1984.1-2013.5. dX and dY are given in unequally spaced intervals, (sometimes with outliers).
  - We cleaned the data by removing CPO $>$ 1mas and cut the data before 1993.0

Used data

Celestial pole offsets

- Celestial pole offsets (CPO)
  - IVS combined solution `ivs13q2X.eops` covering the interval 1984.1-2013.5. dX and dY are given in unequally spaced intervals, (sometimes with outliers).
  - We cleaned the data by removing CPO $>$ 1mas and cut the data before 1993.0
  - we added the empirical Sun-synchronous correction in order the CPO to be comparable with the atmosheric contribution.

Used data

Celestial pole offsets

- Celestial pole offsets (CPO)
  - IVS combined solution `ivs13q2X.eops` covering the interval 1984.1-2013.5. dX and dY are given in unequally spaced intervals, (sometimes with outliers).
  - We cleaned the data by removing CPO $>$ 1mas and cut the data before 1993.0
  - we added the empirical Sun-synchronous correction in order the CPO to be comparable with the atmosheric contribution.
  - Interpolation at regular 10-day intervals, using a filtr to retain only periods between 180 and 6000 days.

Used data

Atmospheric angular momentum

- Atmospheric angular momentum excitation function (AAM) both pressure and wind terms

Used data

Atmospheric angular momentum

- Atmospheric angular momentum excitation function (AAM) both pressure and wind terms
  - European Centre for Medium-Range Weather Forecasts (ECMWF) ERA40, reanalysis model before 2001, operational model afterwards.

Used data

Atmospheric angular momentum

- Atmospheric angular momentum excitation function (AAM) both pressure and wind terms
  - European Centre for Medium-Range Weather Forecasts (ECMWF) ERA40, reanalysis model before 2001, operational model afterwards.
- Oceanic angular momentum excitation functions (OAMF) both matter and motion terms

Used data

Atmospheric angular momentum

- Atmospheric angular momentum excitation function (AAM) both pressure and wind terms
  - European Centre for Medium-Range Weather Forecasts (ECMWF) ERA40, reanalysis model before 2001, operational model afterwards.
- Oceanic angular momentum excitation functions (OAMF) both matter and motion terms
  - OMCT model, 1990.0-2013.5.0 (Dobslaw et al., 2010) driven by reanalysis atmospheric model ERA40 before 2001 and by operational model afterwards.

Used data

Atmospheric angular momentum

- Atmospheric angular momentum excitation function (AAM) both pressure and wind terms
  - European Centre for Medium-Range Weather Forecasts (ECMWF) ERA40, reanalysis model before 2001, operational model afterwards.
- Oceanic angular momentum excitation functions (OAMF) both matter and motion terms
  - OMCT model, 1990.0-2013.5.0 (Dobslaw et al., 2010) driven by reanalysis atmospheric model ERA40 before 2001 and by operational model afterwards.
- Both series were taken from Data Center of IERS and the data were cut before 1993.0

Used Data

- The time series of AAM and OAM 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.

Used Data

- The time series of AAM and OAM 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.

3 different solutions

- The integration was divided into intervals defined by:

3 different solutions

- The integration was divided into intervals defined by:
    1. geomagnetic jerks (Malkin, 2013) in the epochs 1999.0, 2003.5, 2007.5

3 different solutions

- The integration was divided into intervals defined by:
  1. geomagnetic jerks (Malkin, 2013) in the epochs 1999.0, 2003.5, 2007.5
  2. Y. Chapanov (here) detected the jumps in CPO series, in the epochs 2004.3, 2009.3

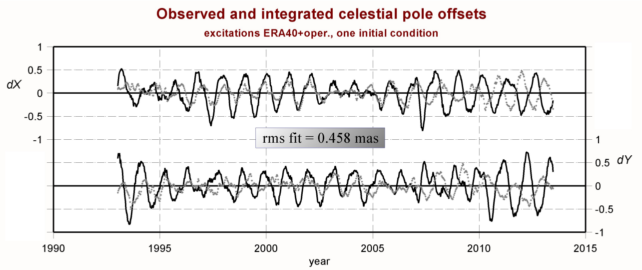
3 different solutions

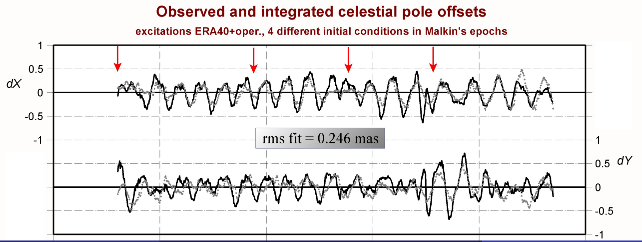
- The integration was divided into intervals defined by:
  1. geomagnetic jerks (Malkin, 2013) in the epochs 1999.0, 2003.5, 2007.5
  2. Y. Chapanov (here) detected the jumps in CPO series, in the epochs 2004.3, 2009.3
  3. the major earthquakes $M_s > 8.8$, Sumatra 2005.0, Chile 2010.2, Japan 2011.9

Results

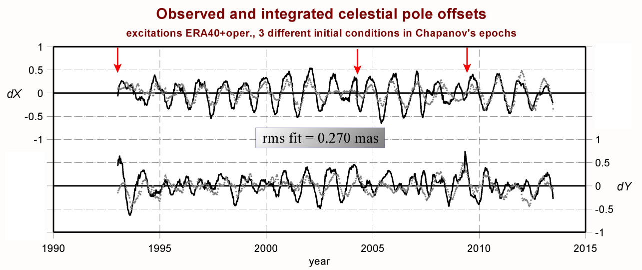
	interval	initial values	σ	$\overline{\sigma}$	shift
gm jerks	1993.0-1999.0	(-0.12; 0.41)	0.245	0.246	–
	1999.0-2003.5	(0.25; 0.26)	0.246		(0.09; 0.21)
	2003.5-2007.5	(0.02; 0.04)	0.248		(0.22; 0.29)
	2007.5-2013.5	(0.05;-0.32)	0.248		(0.19;-0.48)
jumps	1993.0-2004.3	(-0.12; 0.52)	0.279	0.270	–
	2004.3-2009.3	(-0.24; 0.19)	0.284		(-0.46;-0.19)
	2009.3-2013.5	(-0.18; 0.74)	0.228		(-0.03; 0.48)
earthquakes	1993.0-2005.0	(-0.10; 0.52)	0.286	0.262	–
	2005.0-2010.2	(0.33;-0.14)	0.276		(0.50;-0.20)
	2010.2-2011.9	(-0.28; 0.02)	0.158		(-0.35;-0.16)
	2011.9-2013.5	(0.35; 0.16)	0.189		(0.20; 0.07)

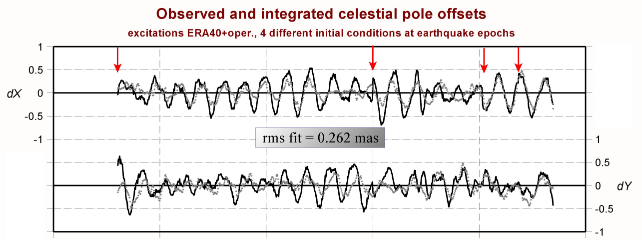
Results
(cont.)





Results
(cont.)





Conclusions

- 3 different solution - geomagnetic jerks, detected jumps in CPOs, large earthquakes were performed.
- The solution taking into account the geomagnetic jerks leads to the best agreement with observed CPO.
- A combination of the events will be done.

Thank you for your attention.