Quasi-diurnal atmospheric and oceanic excitation of nutation

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Outline:

- ♦ Introduction;
- ♦ Resonance around FCN, geophysical excitations;
- ♦ Broad-band Liouville equations, numerical integration;
- ♦ Comparison with VLBI observations.

Introduction:

- ♦ There are only weak geophysical excitations in short-periodic (near diurnal) range in terrestrial frame;
- ♦ Due to the existence of a flattened fluid and rigid inner core, there are however strong resonances in this part of the spectrum, leading to
  - ★ a non-negligible influence on the celestial motion of the Earth's spin axis in space - nutation.
- ♦ The strongest resonance in this region is the Free Core Nutation (FCN) with retrograde period:
  - ★ in terrestrial frame: around 23h 53min mean solar time,
  - ★ in celestial frame: around 430 days.

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- ♦ The period of retrograde FCN (in space) is inversely proportional to the dynamical ellipticity of the fluid core;
- ♦ If the core were in hydrostatic equilibrium, the period would be ≈460 days - model IAU1980 (Wahr 1980);
- ♦ VLBI observations before 2000 showed that the ellipticity is by about 4% larger ⇒ period ≈430 days - model IAU2000 (Mathews et al. 2002);
- ♦ Our own recent studies yield:
  - ★ From the combination of VLBI/GPS observations 1994.7-2004.6 (Vondrák et al. 2005) 430.55±0.11 days,
  - ★ From VLBI observations 1982.4-2005.6 (Vondrák & Ron 2006) 430.32±0.07 days.

Resonance (Mathews-Herring-Buffet transfer function):

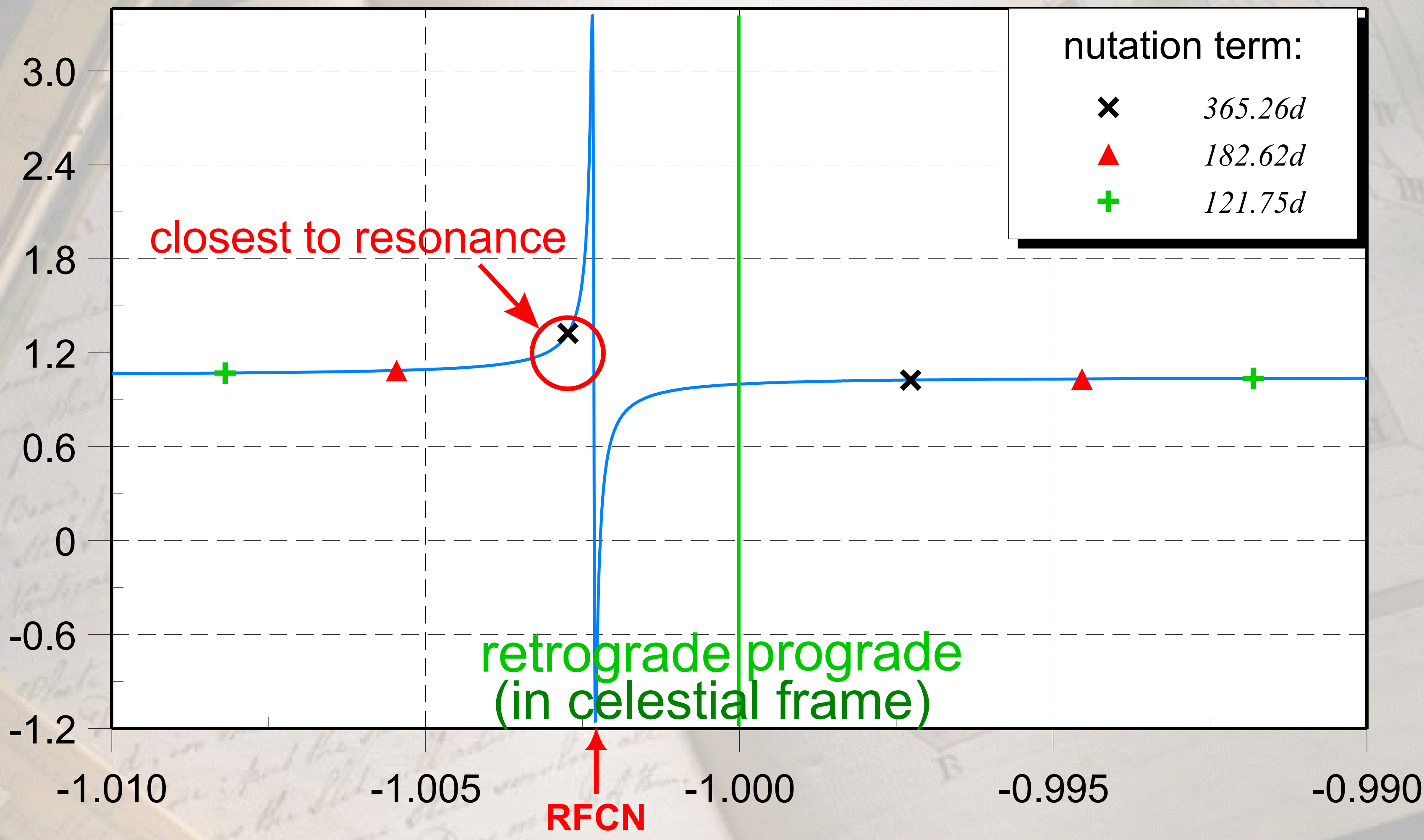
amplitude ratio of non-rigid/rigid Earth model:

$$T(\sigma) = \frac{e_R - \sigma}{e_R + 1} N_0 \left[1 + (1+\sigma)\left(Q_0 + \sum_{j=1}^{4} \frac{Q_j}{\sigma - s_j} \right) \right]$$

where e_R is dynamical ellipticity of rigid Earth, σ is the frequency of nutation (in ITRF), *N, Q* are constants, and s_j are resonance frequencies:

1. Chandler Wobble - CW ($P_{ter.}$ = 435 d);
2. Retrograde Free Core Nutation - RFCN ($P_{cel.}$ = 430 d);
3. Prograde Free Core Nutation - PFCN ($P_{cel.}$ = 1020 d);
4. Inner Core Wobble - ICW ($P_{ter.}$ = 2400 d).

Transfer function MHB2000 - real part



Data used:

- ♦ Nutation, irregular distribution 1-7 days:
  - ★ Combined IVS solution ivsM6q4X.eops (1979.6-2007.0) - celestial pole offsets δX, δY (from IAU2000A model);
- ♦ Geophysical excitations, 6-h intervals:
  - ★ Atmospheric Angular Momentum functions
    - ★ NCEP/NCAR re-analysis (1948.0-2006.7);
    - ★ ERA (1979.0-2001.00).
  - ★ Oceanic Angular Momentum functions
    - ★ ECCO model (1993.0-2006.2);
    - ★ OMCT model (1979.0-2001.0);
    - ★ Rui Ponte model (1993.0-2000.5).

Atmospheric and oceanic excitations:

- ♦ AAM, OAM are given in terrestrial frame, they must be transformed into celestial (non-rotating) frame;
- ♦ We are interested only in long-periodic motions, therefore we further re-calculated the transformed AAM/OAM:
  - ★ Short-periodic signal (P<60 days) was smoothed out.
- ♦ Following combinations of geophysical excitations are used:
  - ★ NCEP AAM with inverted barometer (IB) correction;
  - ★ NCEP AAM + ECCO OAM;
  - ★ ERA40 AAM + OMCT OAM;
  - ★ NCEP AAM + PONTE OAM.

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Numerical integration of broad-band Liouville equations:

(after Brzezinski, in celestial frame, complex form, only "matter terms" retained)

$$\ddot{P} - \mathrm{i}(\sigma'_C + \sigma'_f)\dot{P} - \sigma'_C\sigma'_f P = \sigma_C a_P(\sigma'_C\chi'_P - \mathrm{i}\dot{\chi}'_P)$$

where

P is the motion in celestial system;

σ'_C, σ'_f are Chandler and FCN frequency in celestial frame;

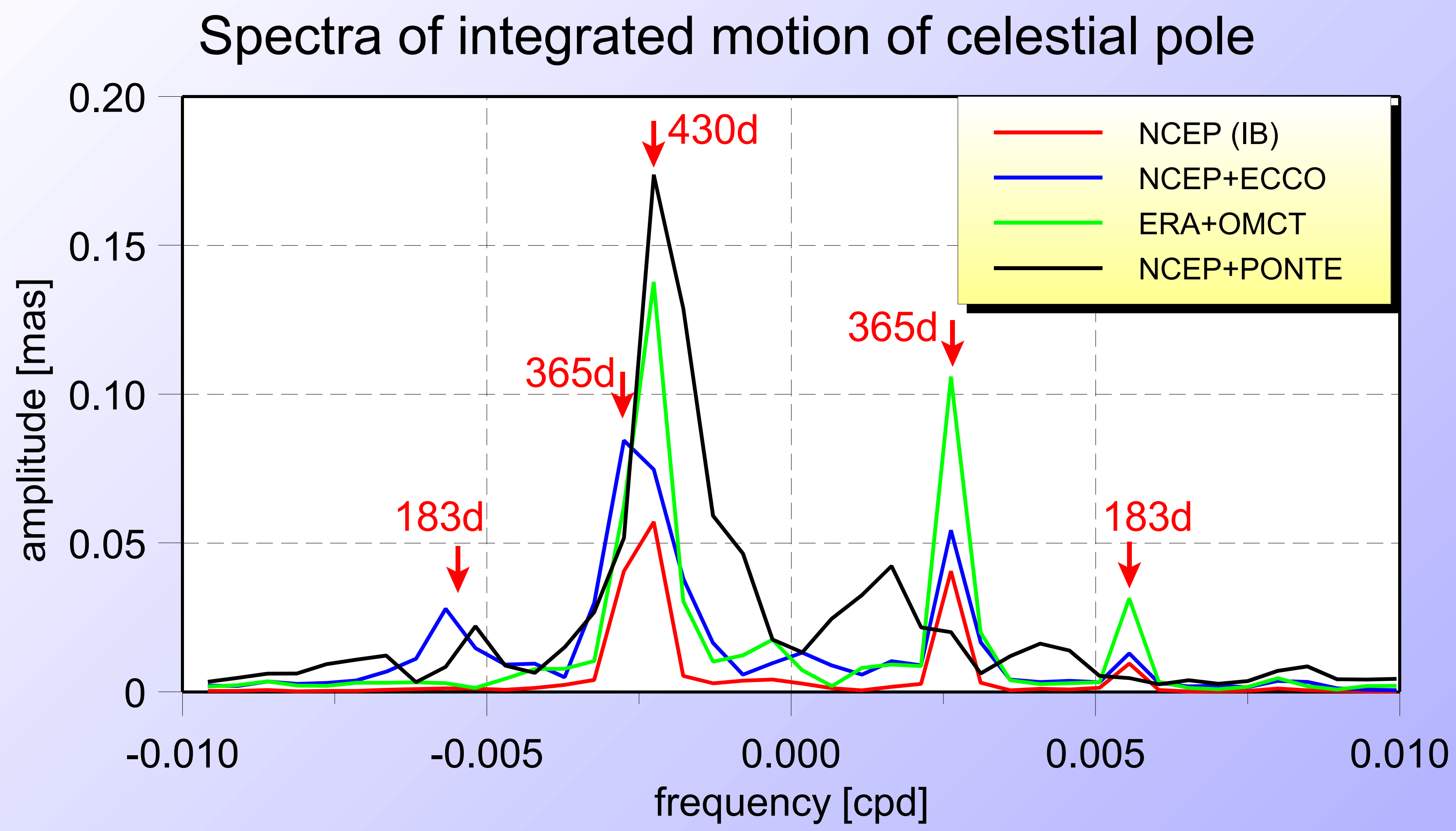
σ_C is Chandler frequency in terrestrial frame;

χ'_P is excitation (matter term) in celestial frame;

$a_p = 9.2\times10^{-2}$ is a numerical constant.

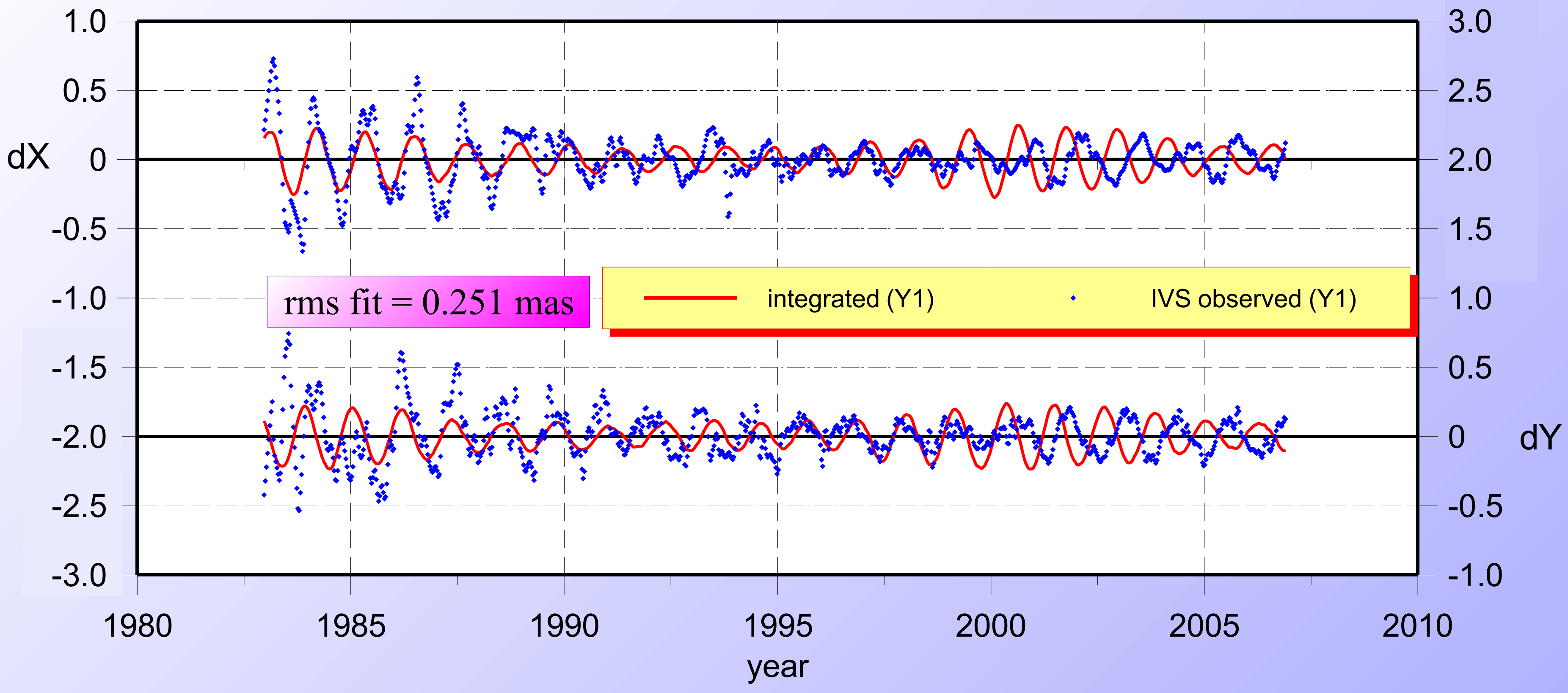
- Solution of broad-band Liouville equations generally yields two free motions:
  - ★ Prograde Chandler Wobble with frequency in celestial system: $\sigma'_C = 6.32000 \mathrm{rad/day}$,
  - ★ Retrograde Free Core Nutation with frequency in celestial system: $\sigma'_f = -0.0146011 \mathrm{rad/day}$
- plus forced nutations, depending on excitation function.

Numerical integration by Runge-Kutta method of fourth order is used, with 6-hour step.


Spectra of integrated motion of celestial pole
0.20
0.15
0.10
0.05
0
amplitude [mas]
430d
365d
365d
183d
183d
NCEP (IB)
NCEP+ECCO
ERA+OMCT
NCEP+PONTE
-0.010
-0.005
0.000
0.005
0.010
frequency [cpd]

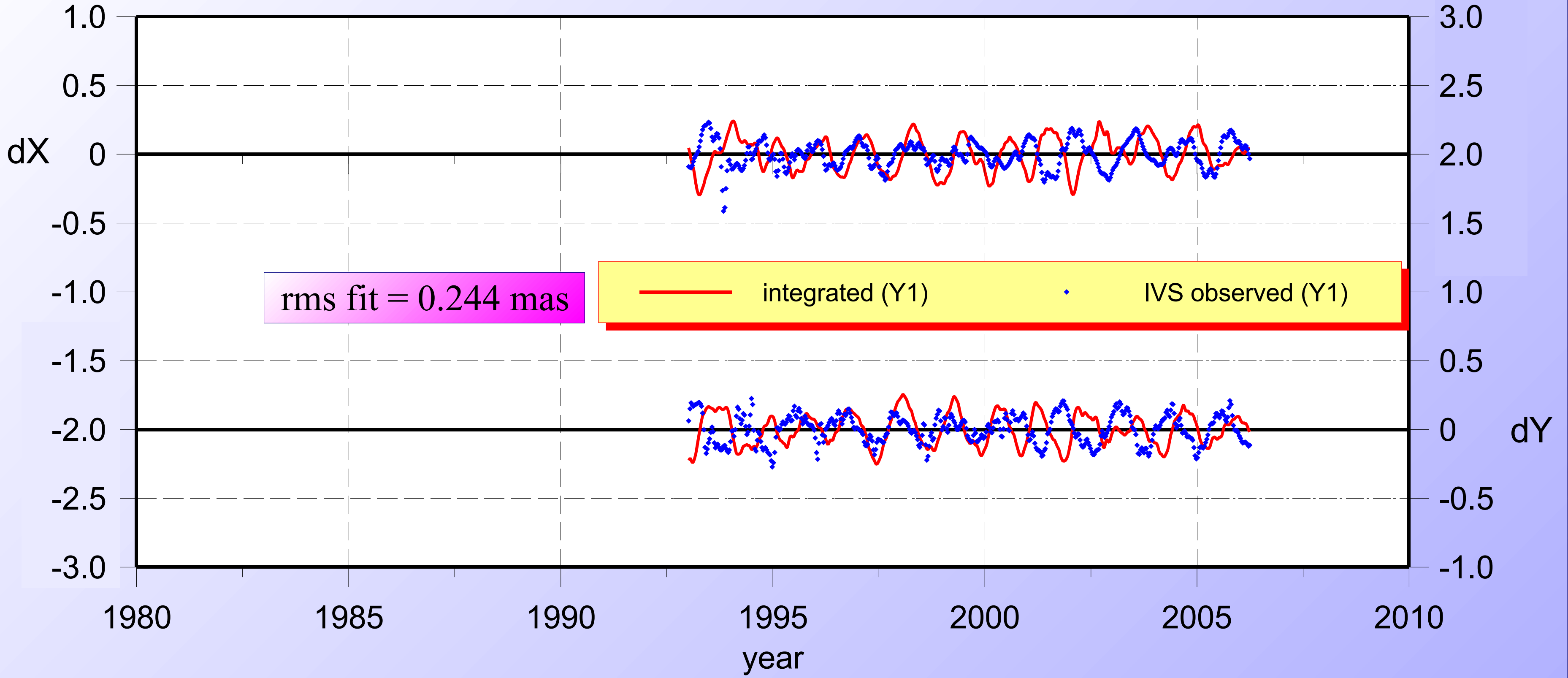
Observed and integrated celestial pole offsets

with NCEP AAM (IB), in mas



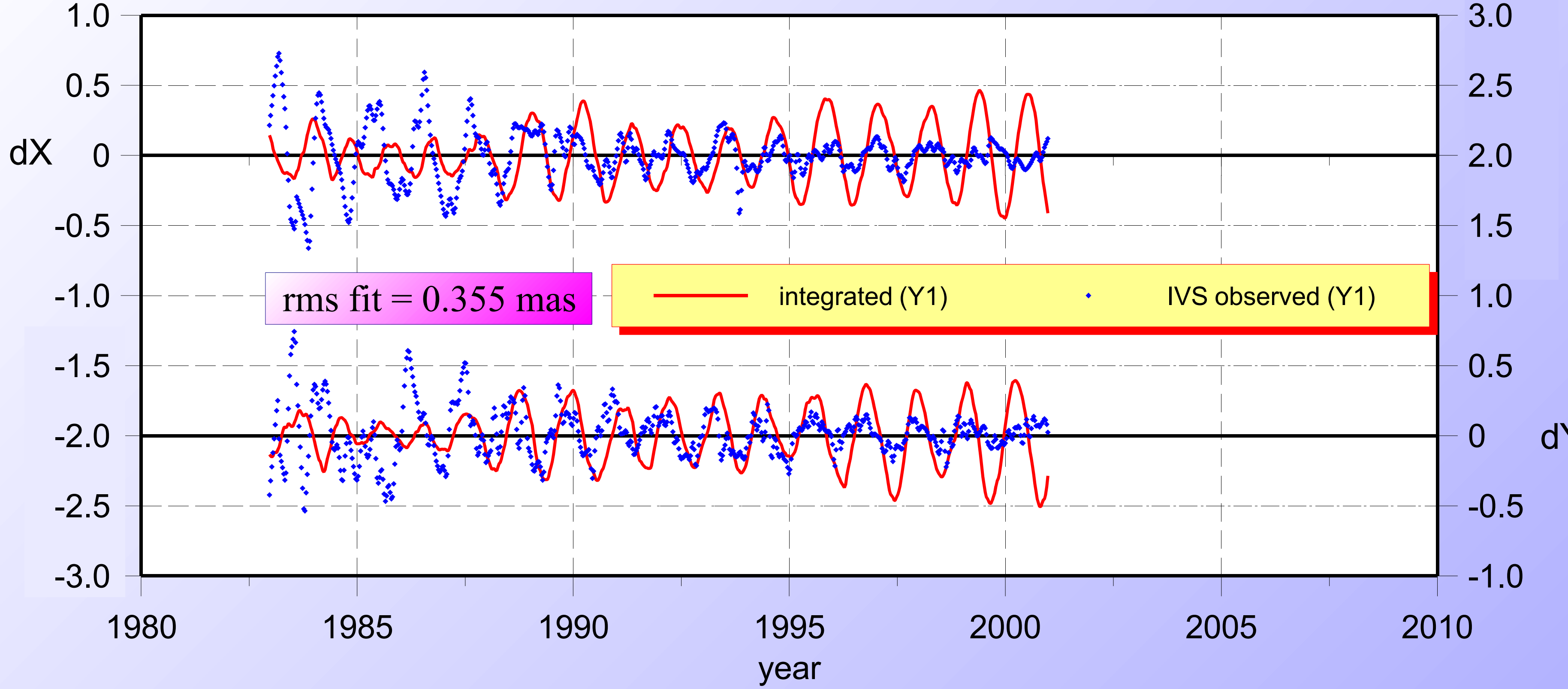
Observed and integrated celestial pole offsets

with NCEP AAM + ECCO OAM, in mas



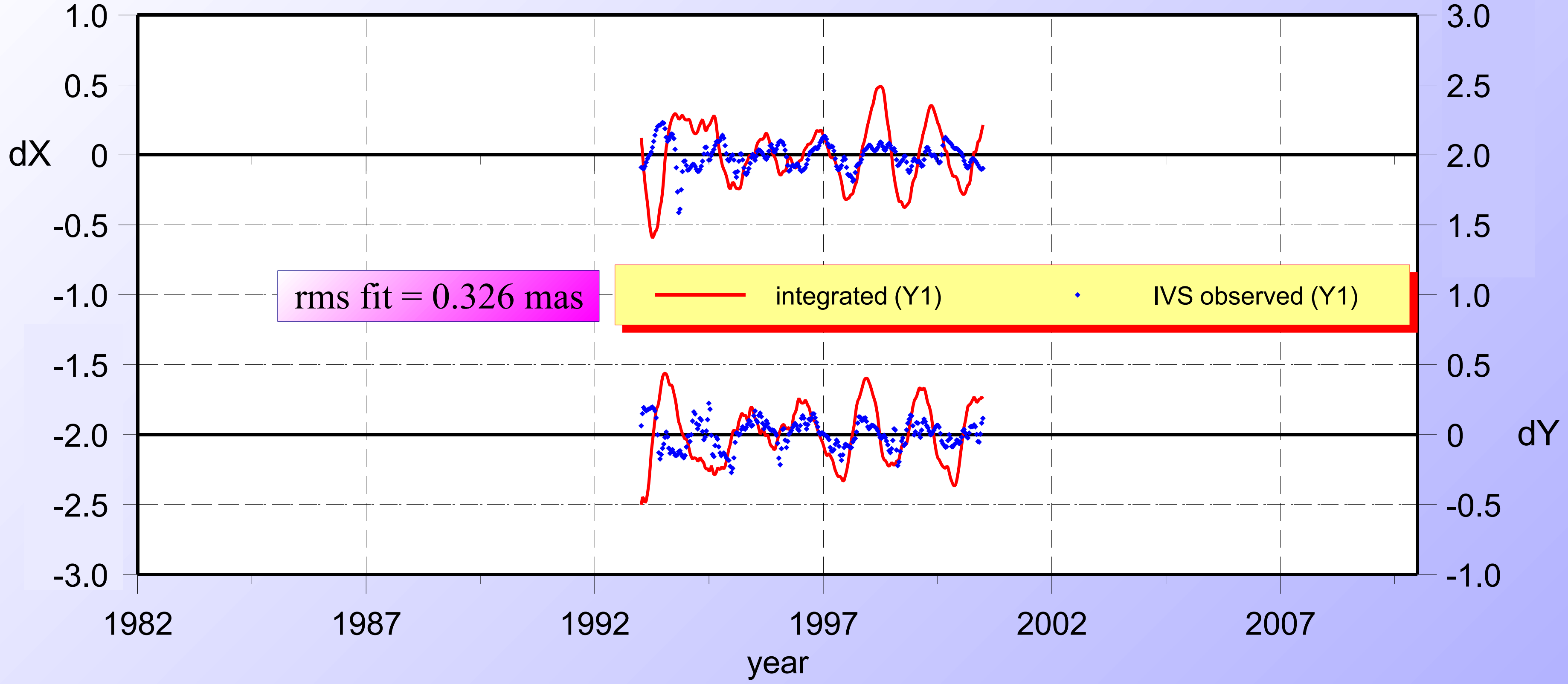
Observed and integrated celestial pole offsets

with ERA AAM + OMCT OAM, in mas



Observed and integrated celestial pole offsets

with NCEP AAM + PONTE OAM, in mas



Geophysical contributions to nutation

Excitation	dX annual		dX semi-annual		dY annual		dY semi-annual	
AAM+OAM	sin	cos	sin	cos	sin	cos	sin	cos
NCEP (IB)	−42.3 ±1.7	−80.1 ±1.7	+8.8 ±1.7	+20.5 ±1.7	−90.4 ±1.7	−85.5 ±1.7	+21.2 ±1.7	−5.7 ±1.7
NCEP+ECCO	−31.6 ±4.8	+41.3 ±4.9	−14.5 ±4.9	+38.5 ±4.9	−199.7 ±4.6	−43.1 ±4.7	−8.4 ±4.6	+8.5 ±4.6
ERA+OMCT	+45.4 ±5.4	−182.2 ±5.4	−21.4 ±5.3	+45.1 ±5.3	−159.9 ±5.3	−146.5 ±5.3	+50.2 ±5.3	+29.4 ±5.3
NCEP+PONTE	+14.1 ±11.0	+118.4 ±11.0	−20.2 ±10.9	+32.3 ±10.9	−255.0 ±11.0	+173.4 ±11.0	+9.5 ±11.0	+46.0 ±11.0

VCDZ
CEDR

Conclusions:

- ♦ Observed celestial pole offsets around FCN contain not only free, but also forced motions due to excitations by outer parts (atmosphere, oceans) of the Earth; significant are annual and semi-annual terms;
- ♦ Atmospheric pressure term with IB correction (simple oceanic model) is sufficiently large to excite the observed motion - numerical integration yields correct amplitudes, but the phase starts to be inconsistent with observations after 15 years of integration;
- ♦ The best fit to observations yields the combination of NCEP AAM with ECCO OAM, other two oceanic models (OMCT, Ponte) give significantly worse results;
- ♦ Geophysical contributions to nutation (annual & semi-annual terms) differ significantly, depending on oceanic model used.