New determination of period and quality factor of Chandler wobble, considering geophysical excitations*

Jan Vondrák, Cyril Ron, AI CAS, Prague
Yavor Chapanov, NIGGG BAS, Sofia

Outline:

- ♦ Introduction;
- ♦ Description of the data;
- ♦ New method proposed;
- ♦ Results based on 40-year data series;
- ♦ Conclusions.

***Based on paper submitted to Advances in Space Research**

Introduction:

- Excitations by geophysical fluids play dominant role in polar motion. Rapid changes of amplitude & phase of the free term (Chandler wobble) occur near the epochs of geomagnetic jerks (GMJ), as recently demonstrated by:
  - Gibert & le Mouël (2008), or
  - Vondrák & Ron (2015), who demonstrated that better agreement with observations is obtained if additional impulse-like excitations due to GMJ are added to the effects of geophysical fluids.
- Here we propose a new method of determining period and Q-factor of Chandler wobble, using the numerical integration of broad-band Liouville equations with these geophysical excitations.

Data used (1974.0-2014.0), all of them smoothed and long-periodic part removed:

- Polar motion, as observed by different techniques (optical astrometry before 1988, space geodesy afterwards):
  - IERS C04 combined solution;
- Geophysical fluids:
  - Atmospheric excitations: ERA, with 6-hour steps;
  - Oceanic excitations: OMCT, with 6-hour steps;
- Geomagnetic jerks (rapid changes of geomagnetic field):
  - Epochs 1978.0, 1986.0, 1991.0, 1994.0, 1999.0, 2003.5, 2004.7, 2007.5, 2011.0.

Astronomical Institute of the Czech Academy of Sciences

Method of determining period *P* and *Q*-factor

- We use numerical integration of Brzezinski's broad-band Liouville equations with geophysical excitations, in two variants:
  - Atmospheric + oceanic excitations only;
  - Atmospheric, oceanic + GMJ excitations,
- for three different intervals:
  - 1974.0-1994.0,
  - 1994.0-2014.0,
  - 1974.0-2014.0.
- The integration is repeated for many different combinations of *P*, *Q*; for each combination the best fitting initial pole position (and amplitudes of GMJ excitations) is found.
- *P*, *Q* values yielding the best root-mean-square (rms) fit to observed pole path are then chosen.

Astronomical Institute of the Czech Academy of Sciences

Brzeziński's broad-band Liouville equations (in complex form):

$$\ddot{p} - \mathrm{i}(\sigma_C + \sigma_f)\dot{p} - \sigma_C \sigma_f p =$$
$$= -\sigma_C \left\{ \sigma_f (\chi_p + \chi_w) + \sigma_C (a_p \chi_p + a_w \chi_w) + \mathrm{i}\left[(1 + a_p)\dot{\chi}_p + (1 + a_w)\chi_w \right] \right\}$$

where

p is the polar motion;

σ_C, σ_f are Chandler and Free Core Nutation frequency;

χ_p, χ_w, are pressure and wind term of the excitation;

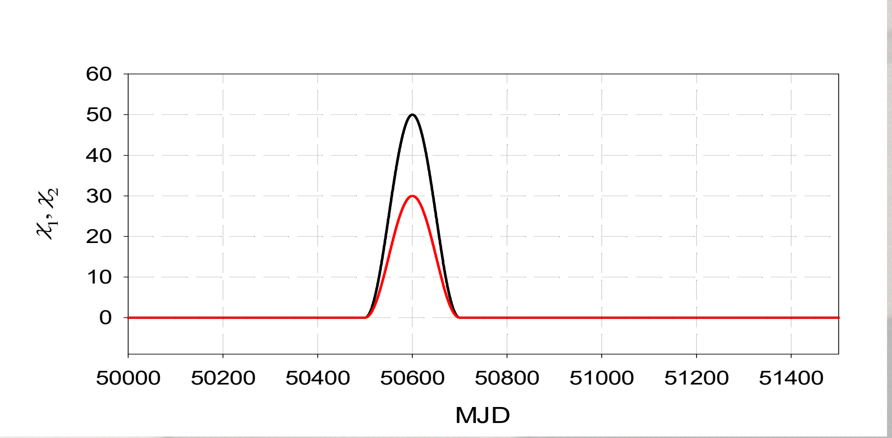
$a_p = 9.200 \times 10^{-2}$, $a_w = 2.628 \times 10^{-4}$ are numerical constants.

We fix the value of $\sigma_f = -6.31498 + 0.000153\mathrm{i}$ [rad/day], and calculate $\sigma_C = \Omega(1 + \mathrm{i}/2Q)/P$, where $\Omega = 6.30038$ rad/day is the mean speed of Earth's rotation.

Numerical integration of Brzeziński's eqs.:

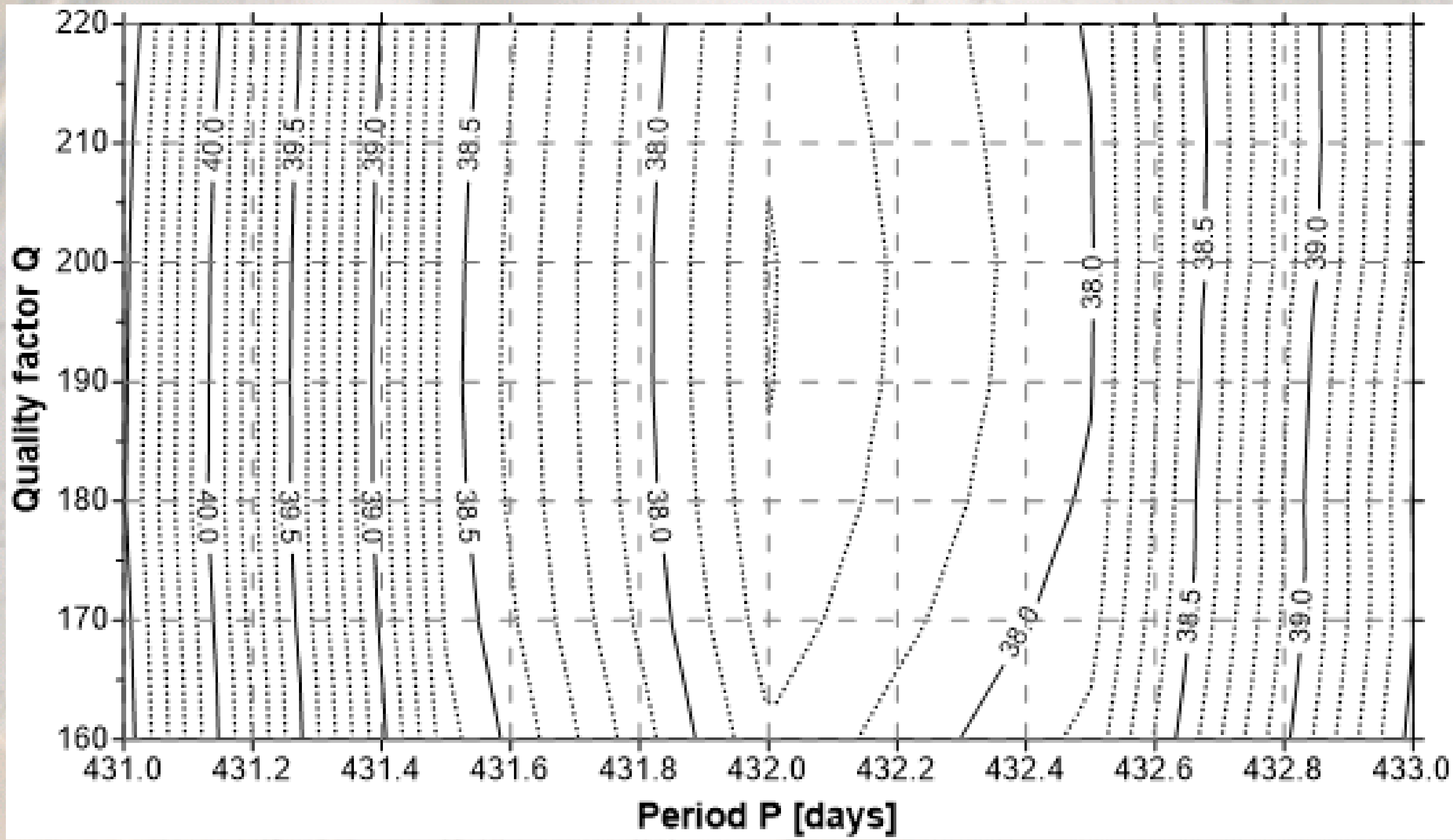
- We use 4-order Runge-Kutta procedure (in complex form), with 6-hour step:
  - The initial conditions are chosen to assure the best fit to observations, and also to get rid of 'forbidden' quasi diurnal free motions.
  - For GMJ (rapid changes of the secular variations of geomagnetic field) we model the excitations as bell-shaped functions centered at GMJ epochs, 200 days wide, complex amplitudes a are estimated to yield the best fit to observations:

$$\chi_{GMJ} = \frac{a}{2}\left[1 + \cos\frac{2\pi(t - t_0)}{200}\right]$$



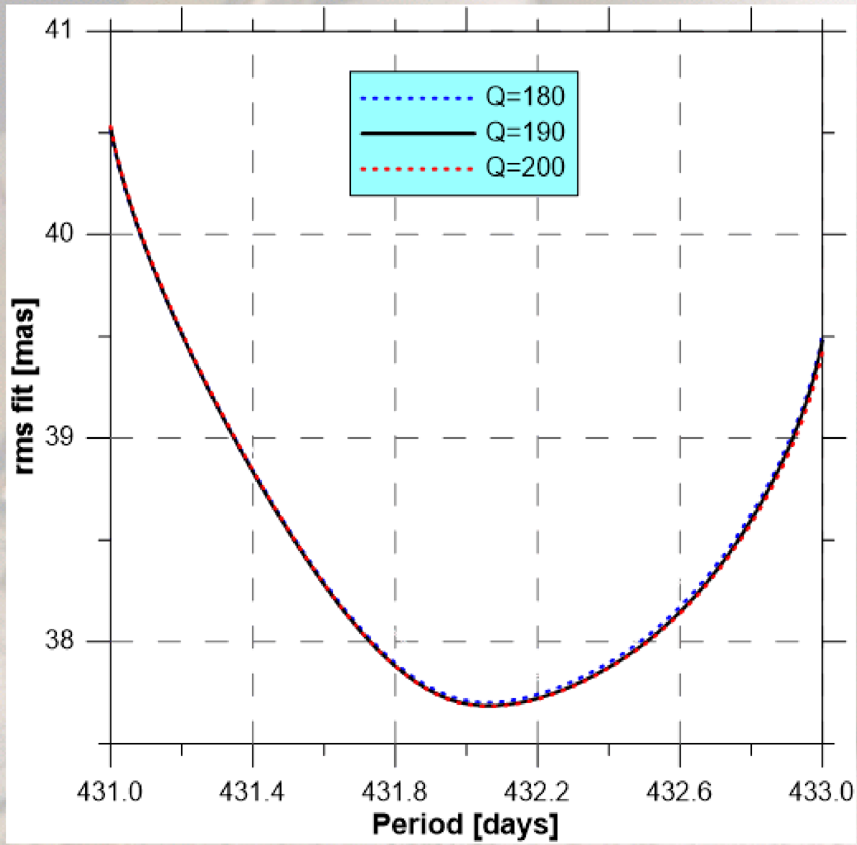
Results for 1974.0-1994.0

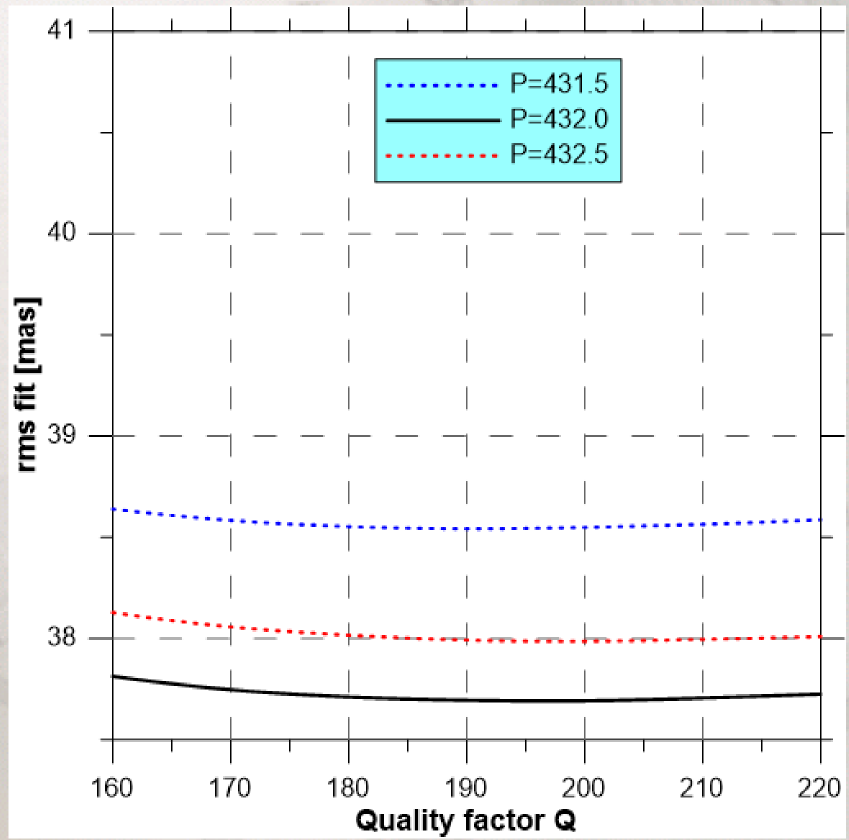
A) only atmosphere + oceans



Contour plot of rms fit [mas]

Profiles for 3 different values of P, Q (A+O, 1974.0-1994.0):



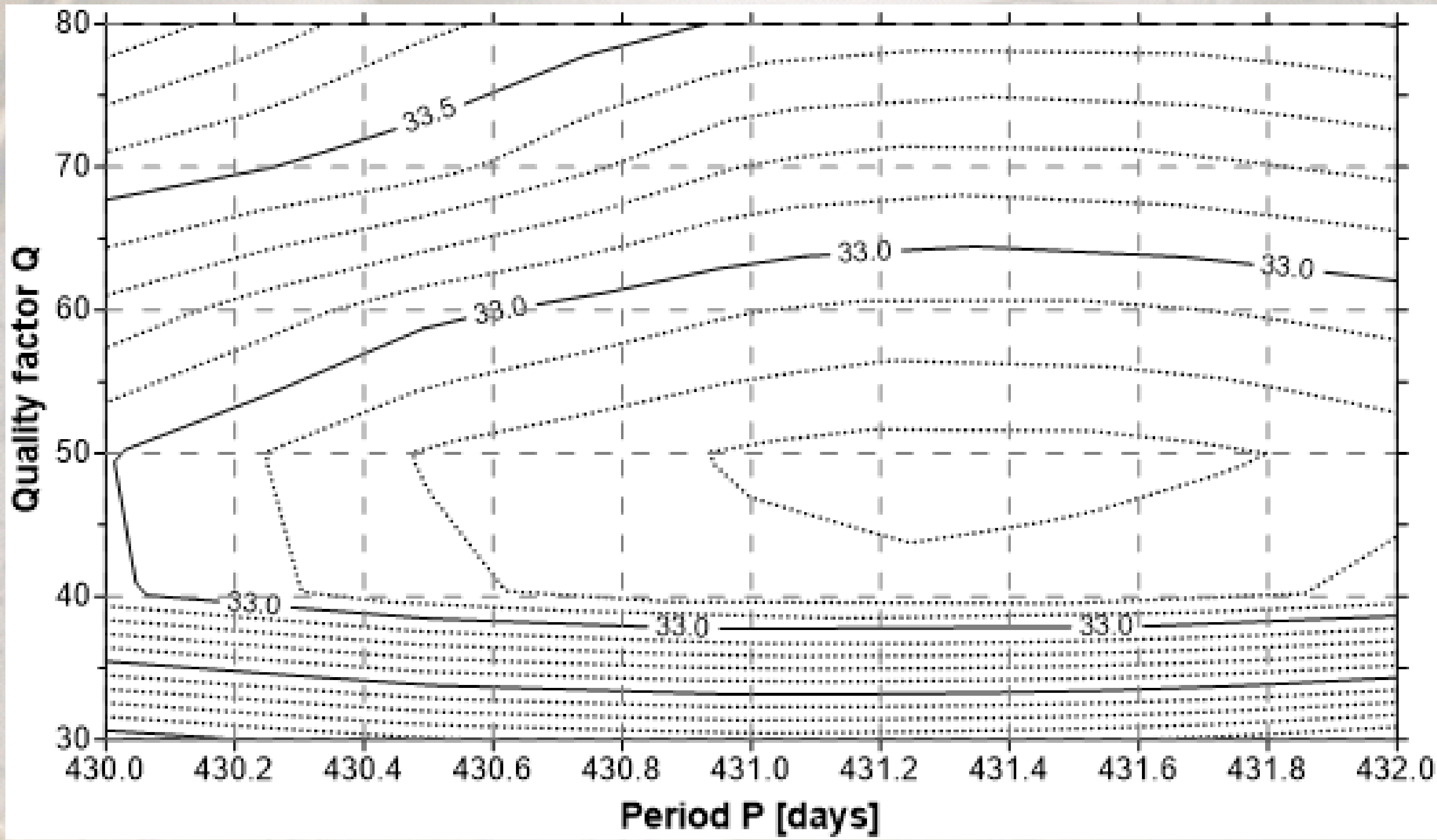


P=432.13±0.56 days

Q=197 (155, 269)

Astronomical Institute of the Czech Academy of Sciences

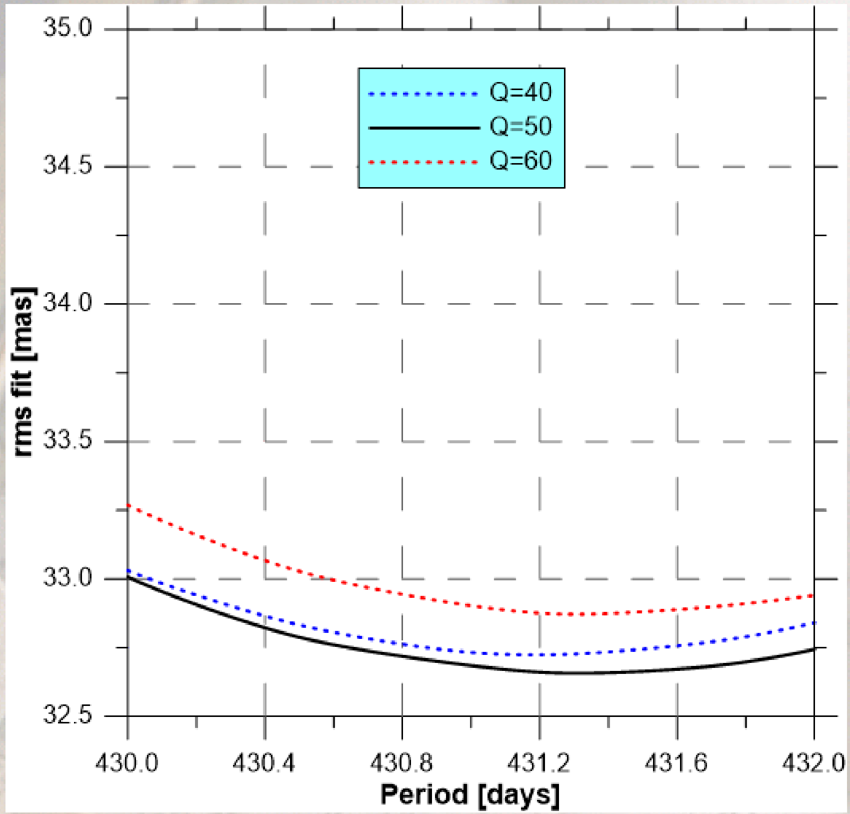
B) atmosphere + oceans + GMJ, 1974.0-1994.0

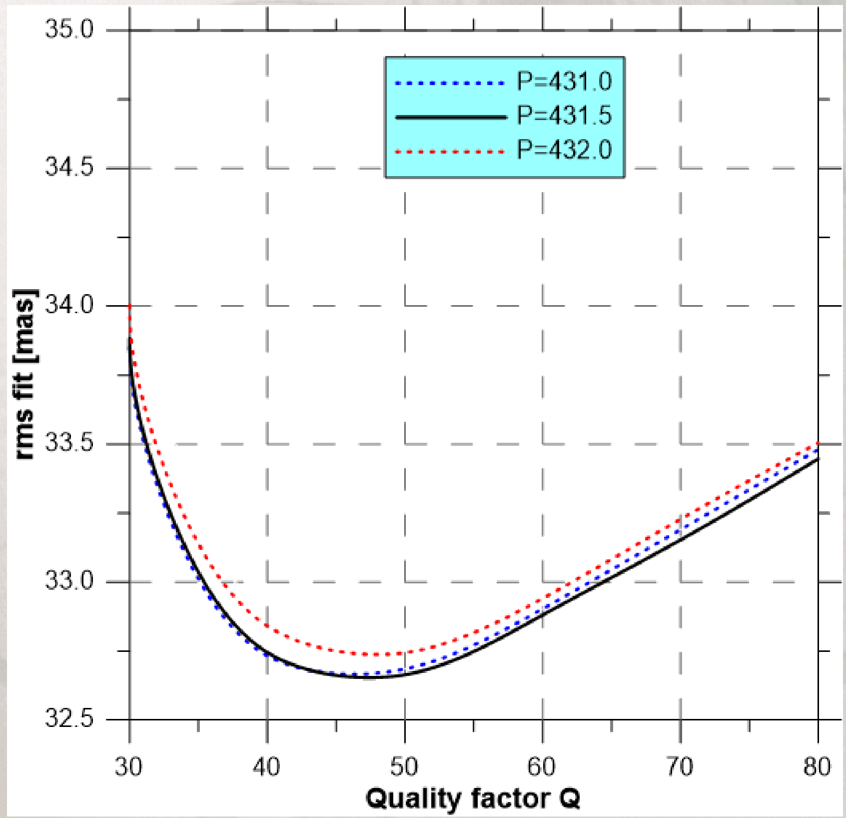


Contour plot of rms fit [mas]

Astronomical Institute of the Czech Academy of Sciences

Profiles for 3 different values of P, Q (A+O+G, 1974.0-1994.0):



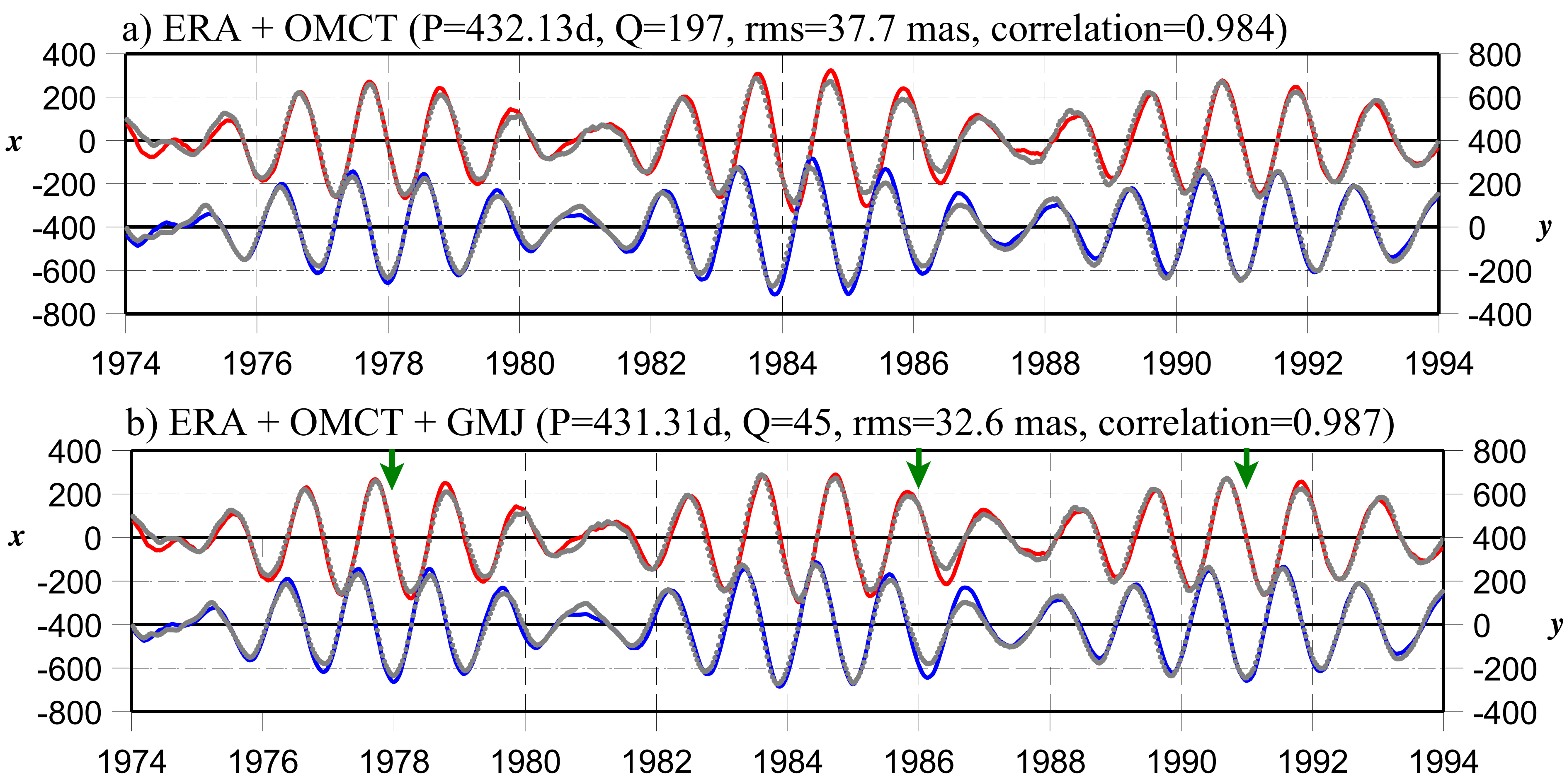


P=431.31±0.91 days

Q=45 (40, 55)

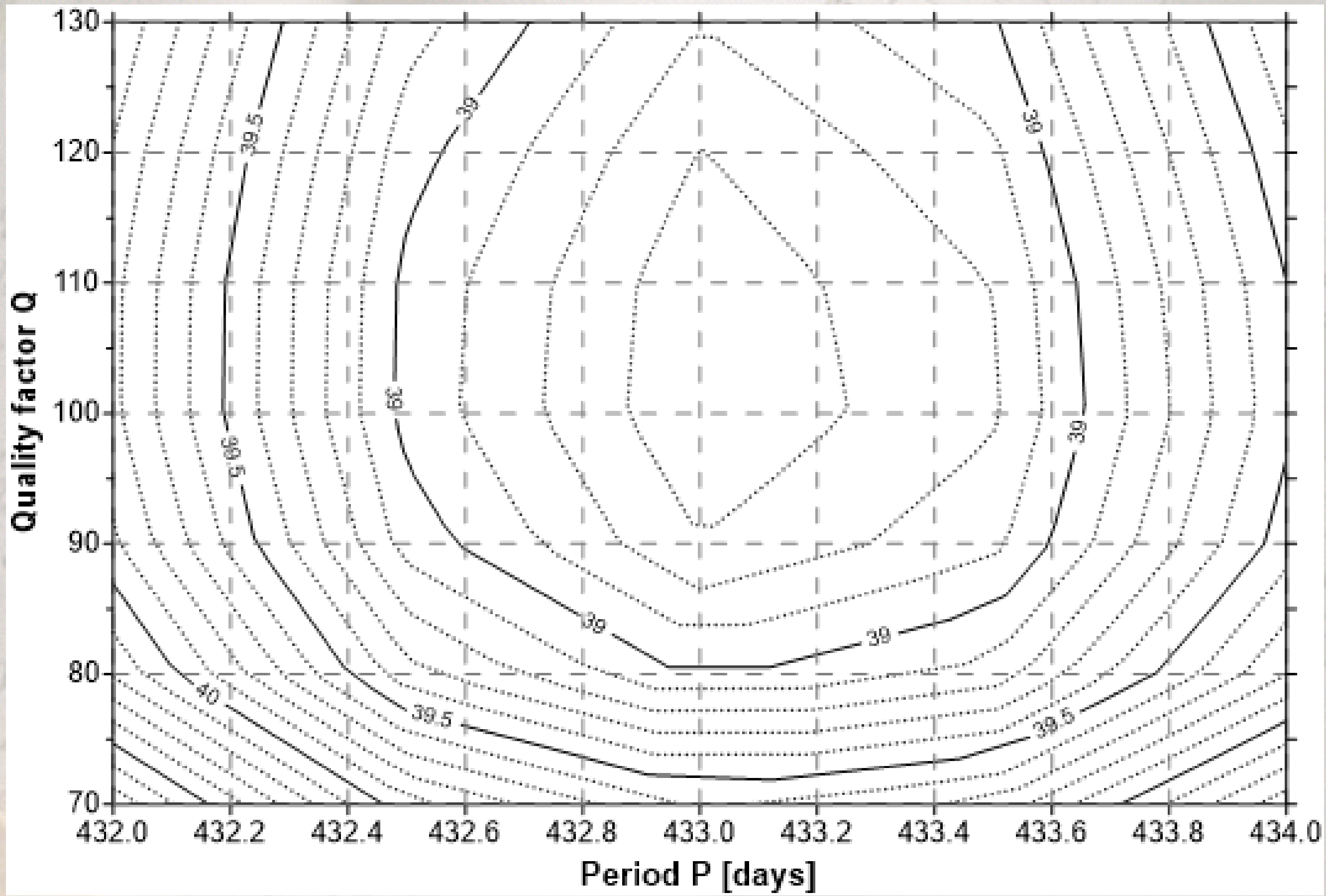
Astronomical Institute of the Czech Academy of Sciences

Integrated and observed polar motion, 1974.0-1994.0



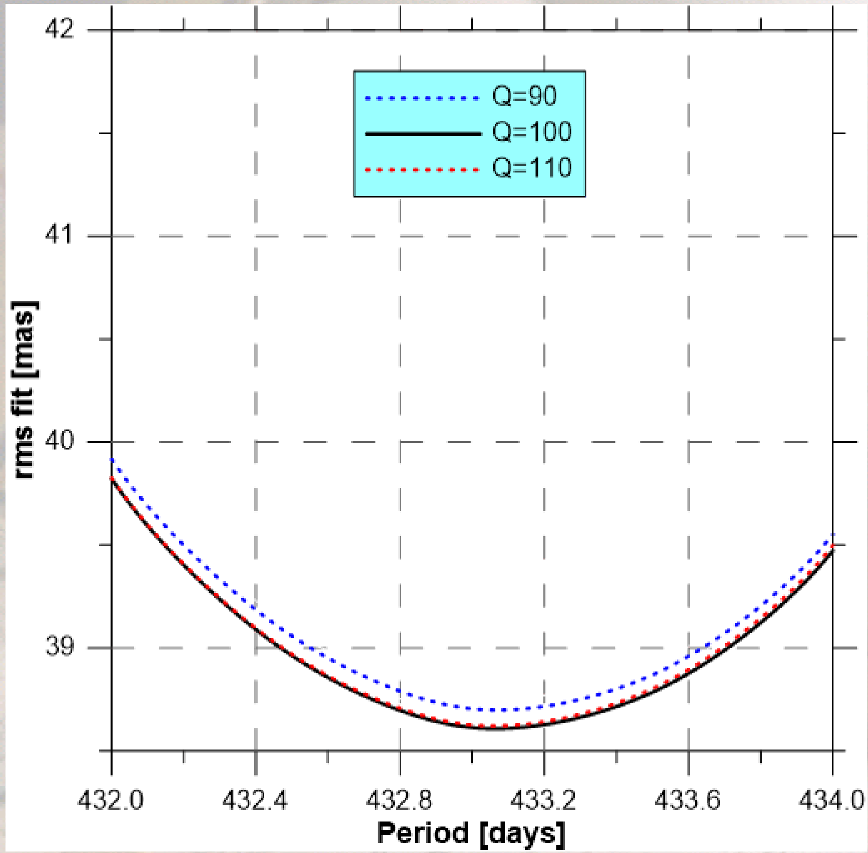
Results for 1994.0-2014.0

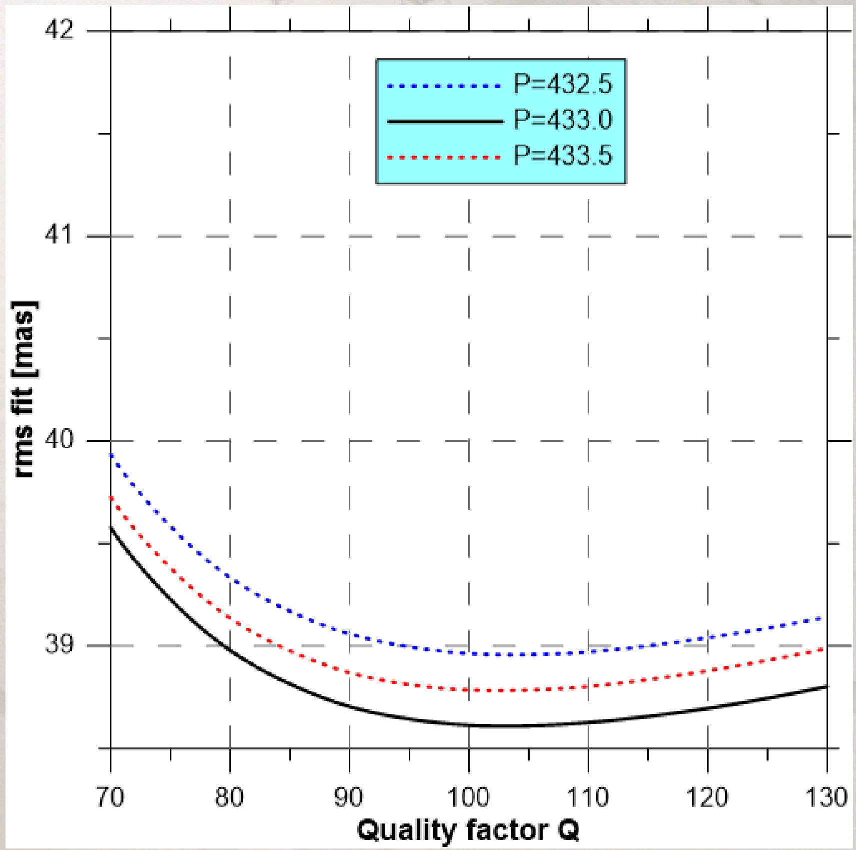
A) only atmosphere + oceans



Contour plot of rms fit [mas]

Profiles for 3 different values of P, Q (A+O, 1994.0-2014.0):



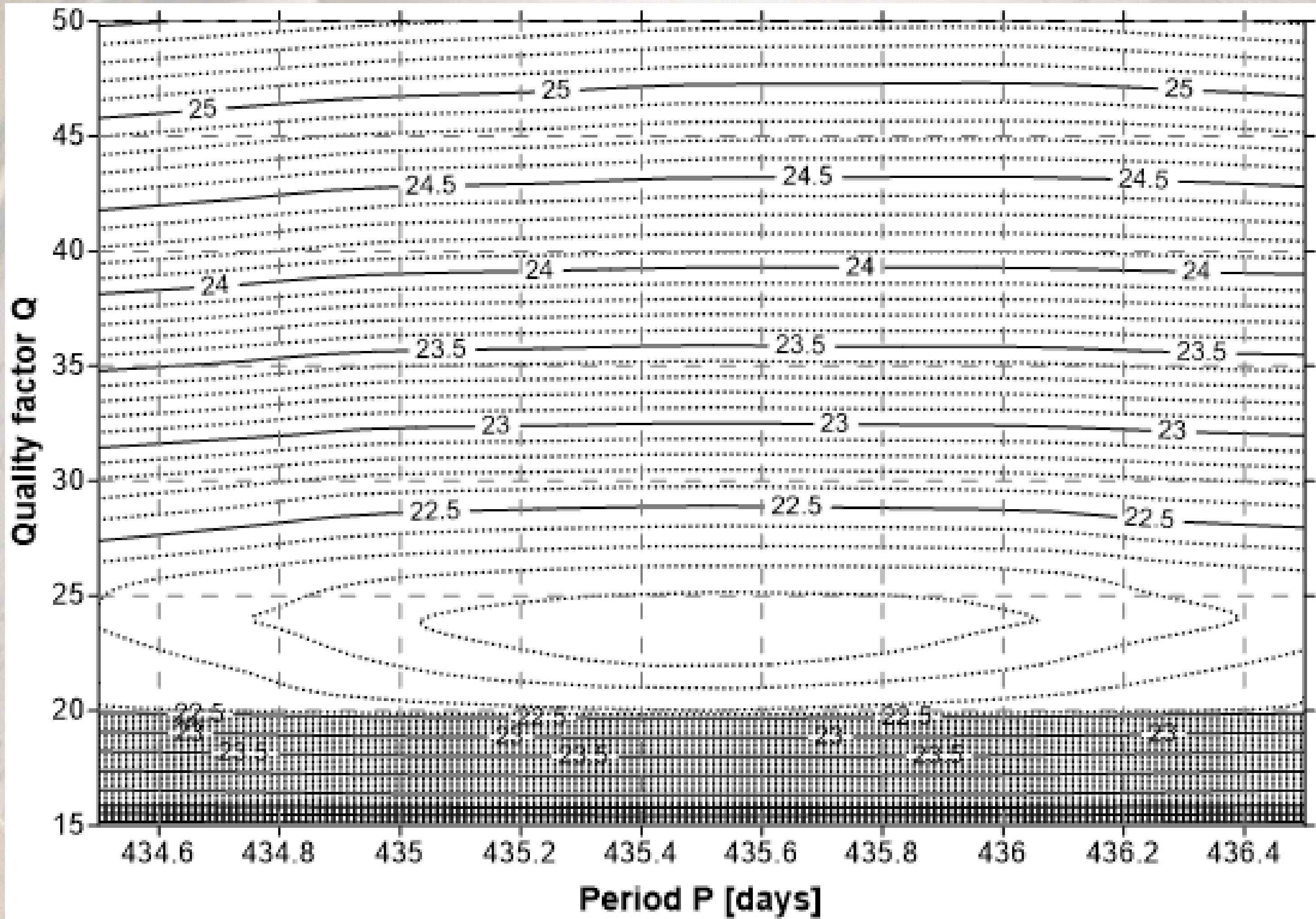


P=431.09±0.43 days

Q=103 (85, 130)

Astronomical Institute of the Czech Academy of Sciences

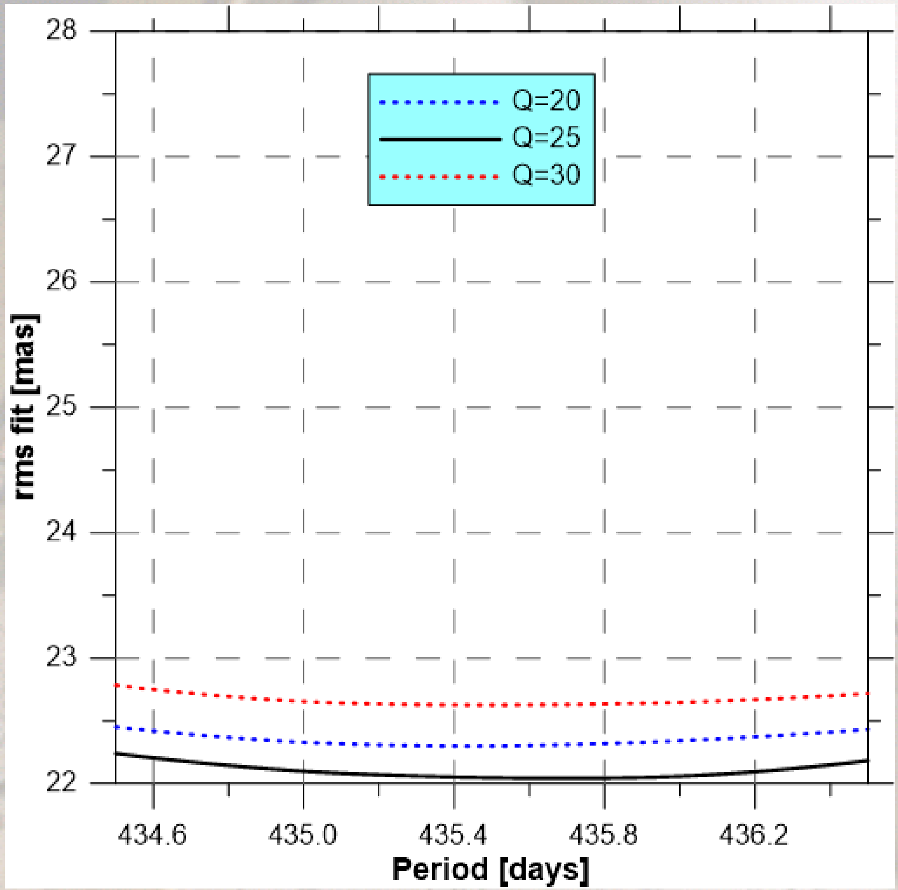
B) atmosphere + oceans + GMJ, 1994.0-2014.0

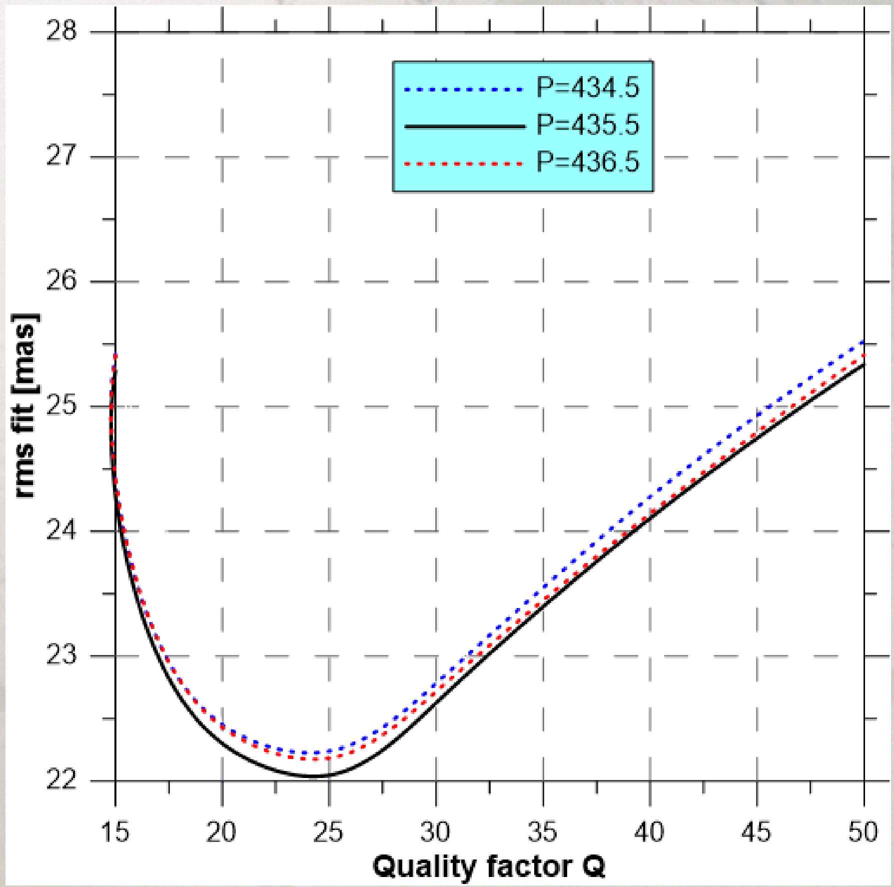


Contour plot of rms fit [mas]

Astronomical Institute of the Czech Academy of Sciences

Profiles for 3 different values of P, Q (A+O+G, 1994.0-2014.0):

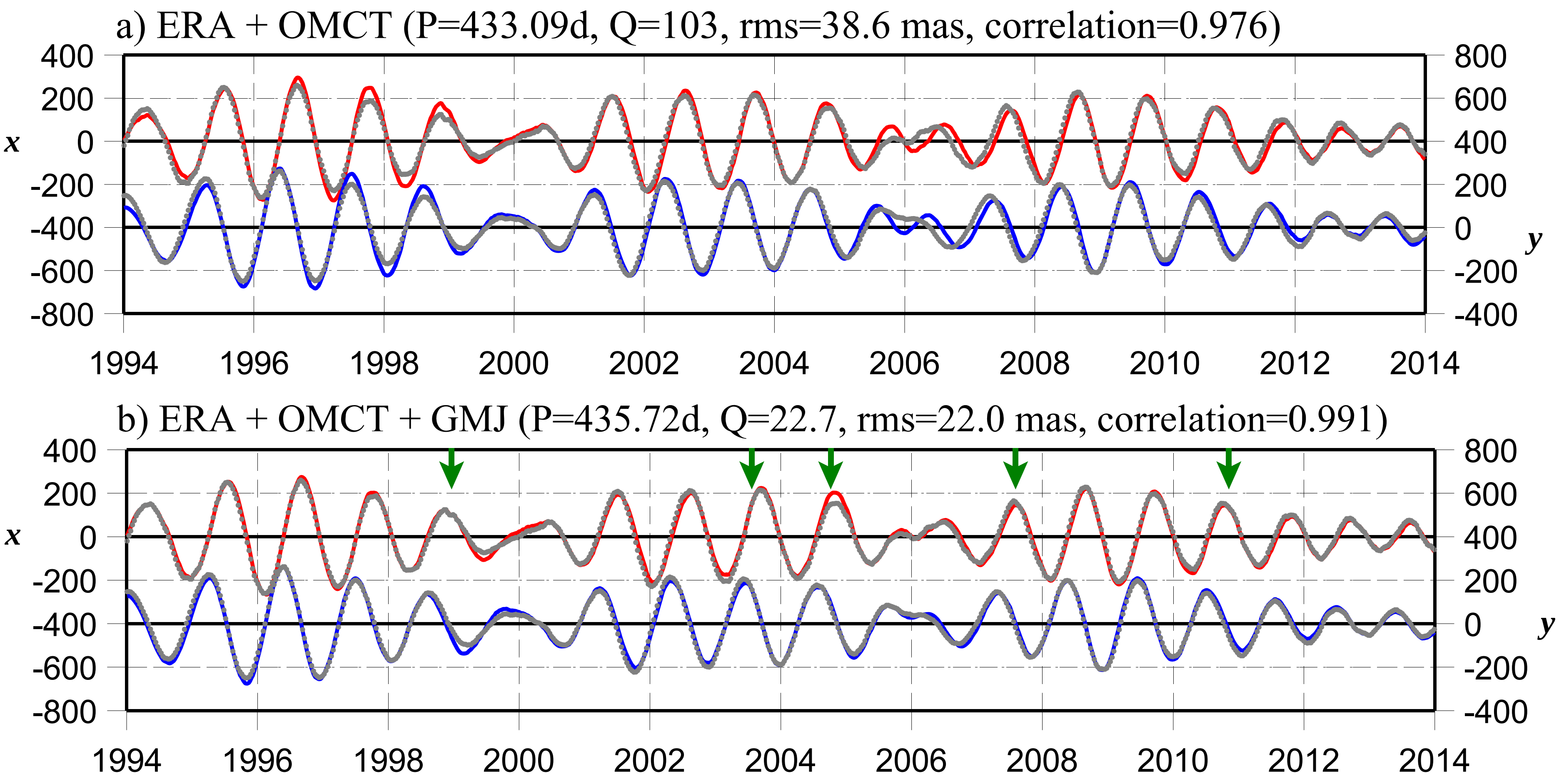




P=435.72±0.80 days

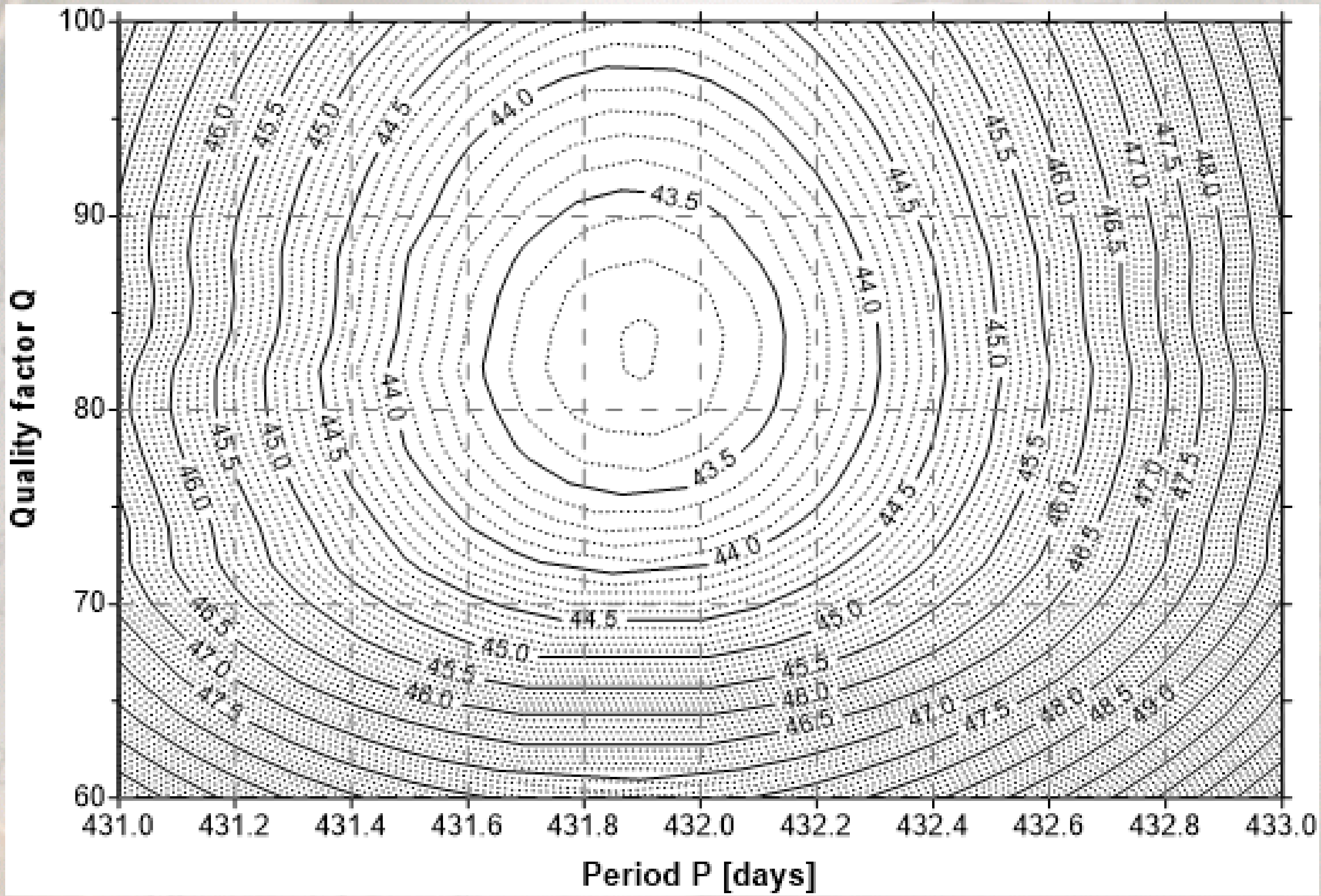
Q=22.7 (22.1, 24.6)

Integrated and observed polar motion, 1994.0-2014.0



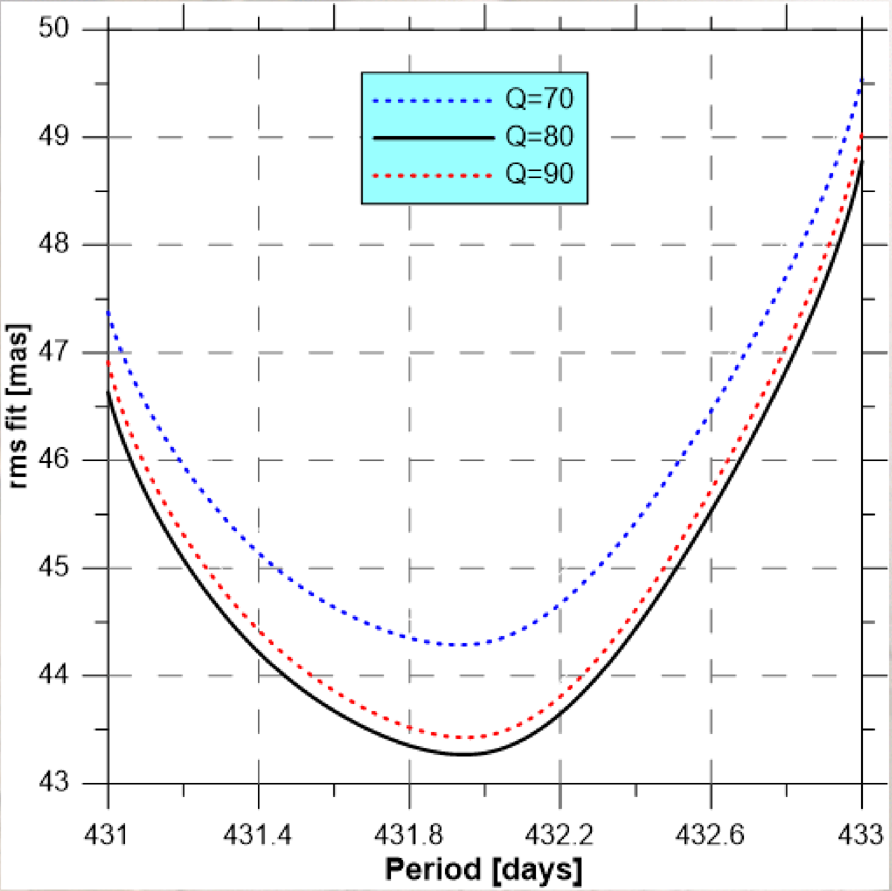
Results for 1974.0-2014.0

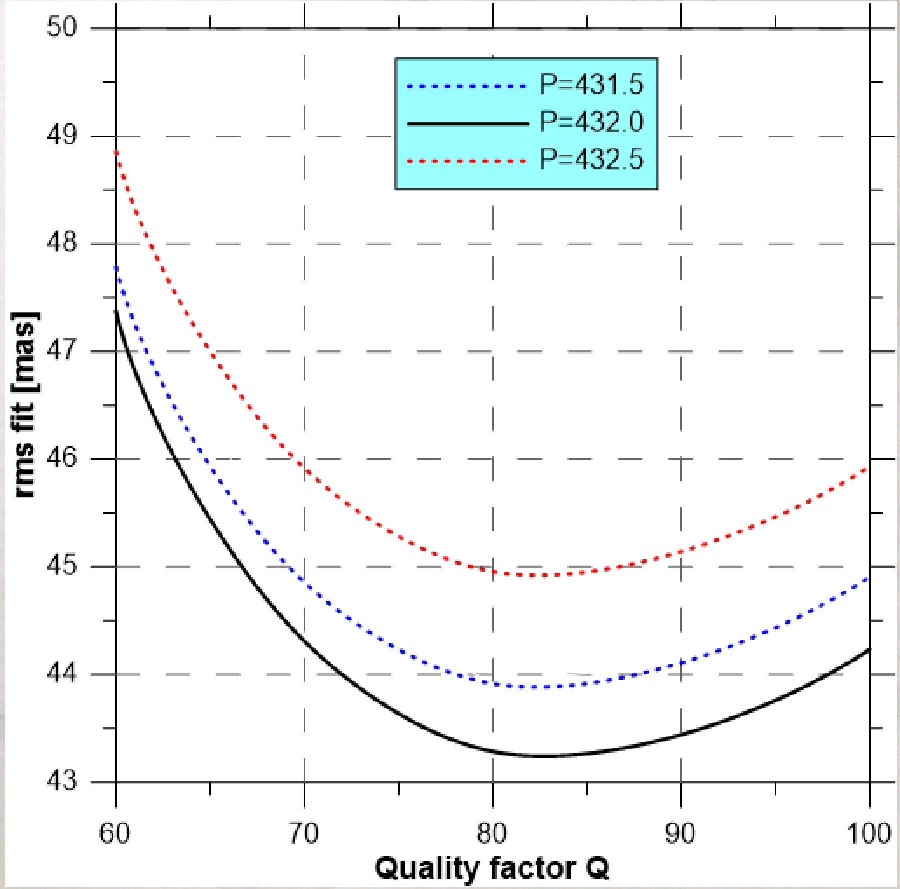
A) only atmosphere + oceans



Contour plot of rms fit [mas]

Profiles for 3 different values of P, Q (A+O, 1974.0-2014.0):

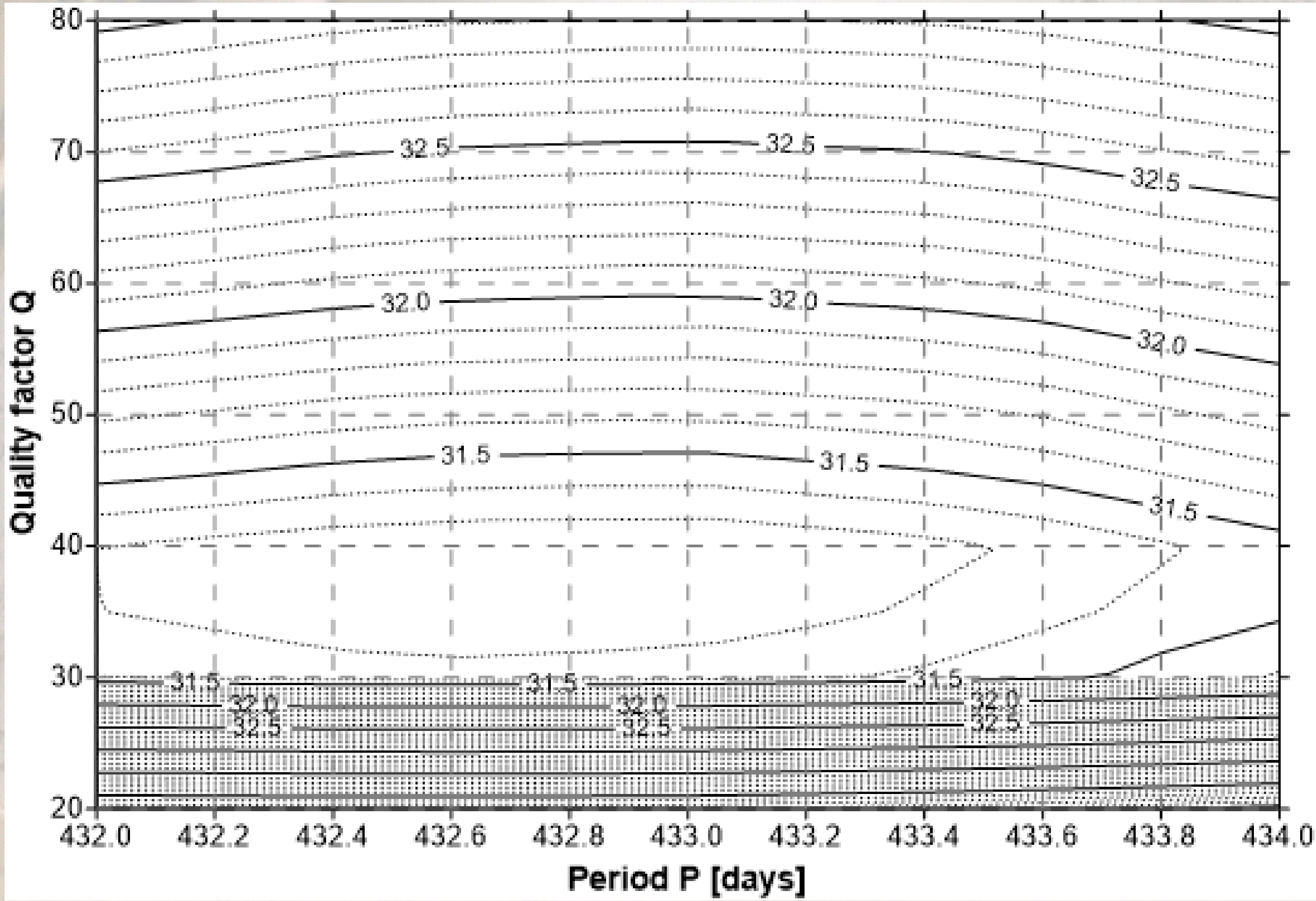




P=431.88±0.43 days

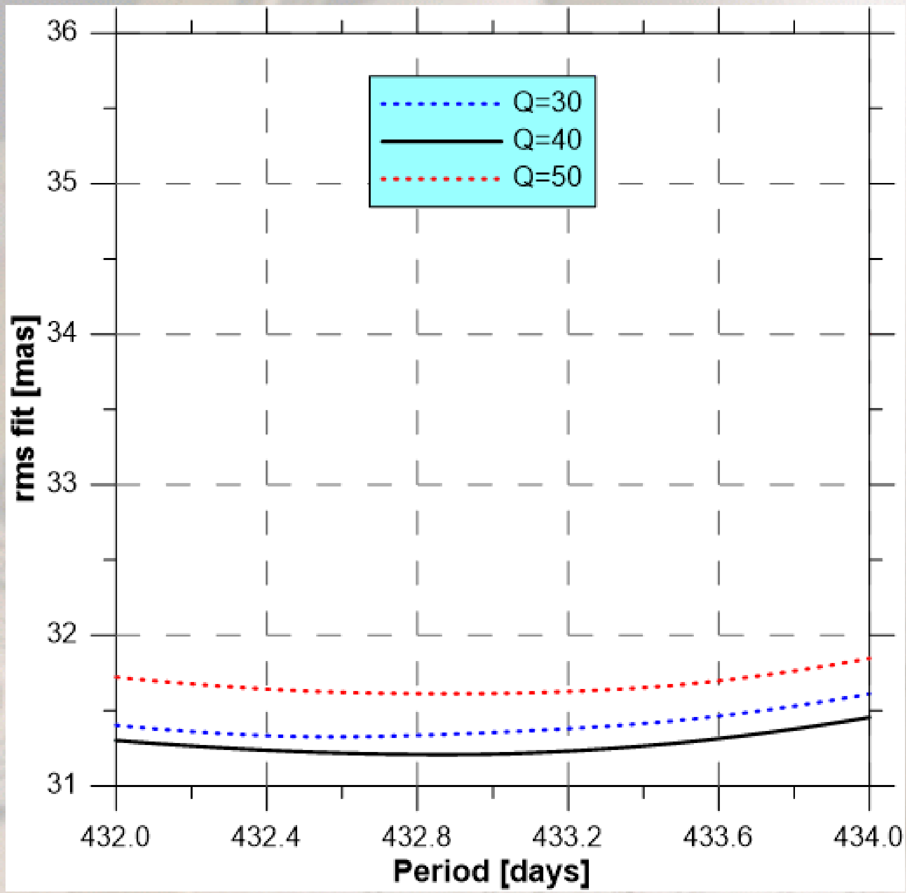
Q=83 (76, 90)

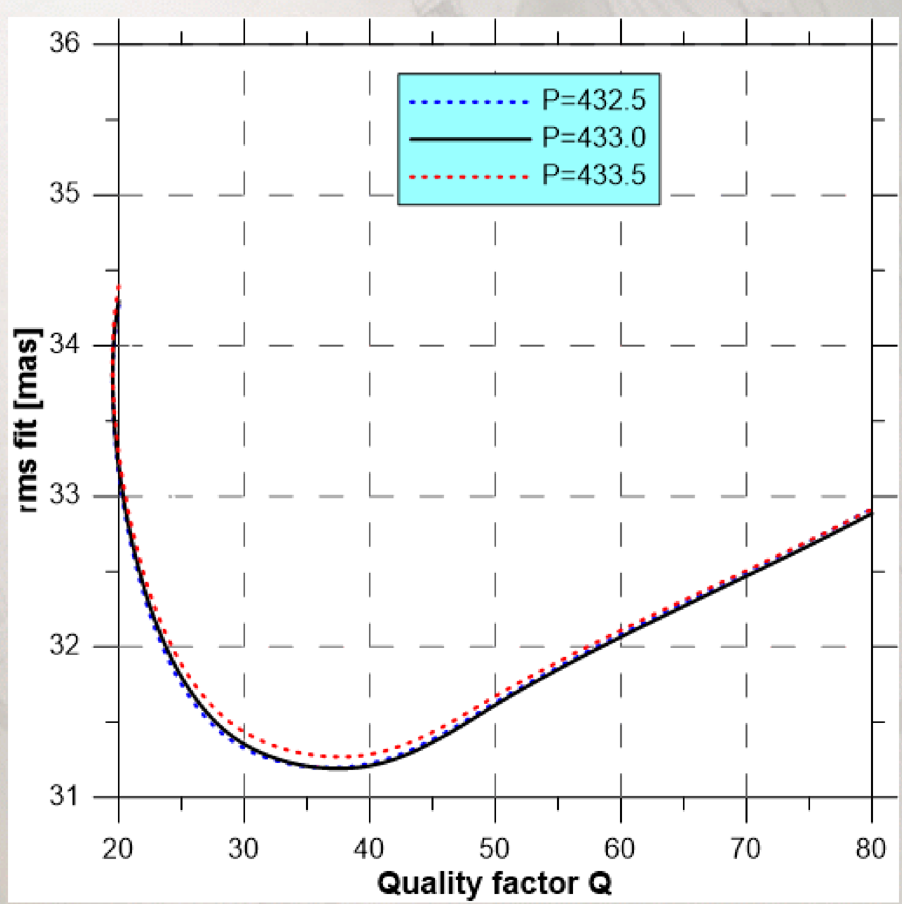
B) atmosphere + oceans + GMJ, 1974.0-2014.0



Contour plot of rms fit [mas]

Profiles for 3 different values of P, Q (A+O+G, 1974.0-2014.0):

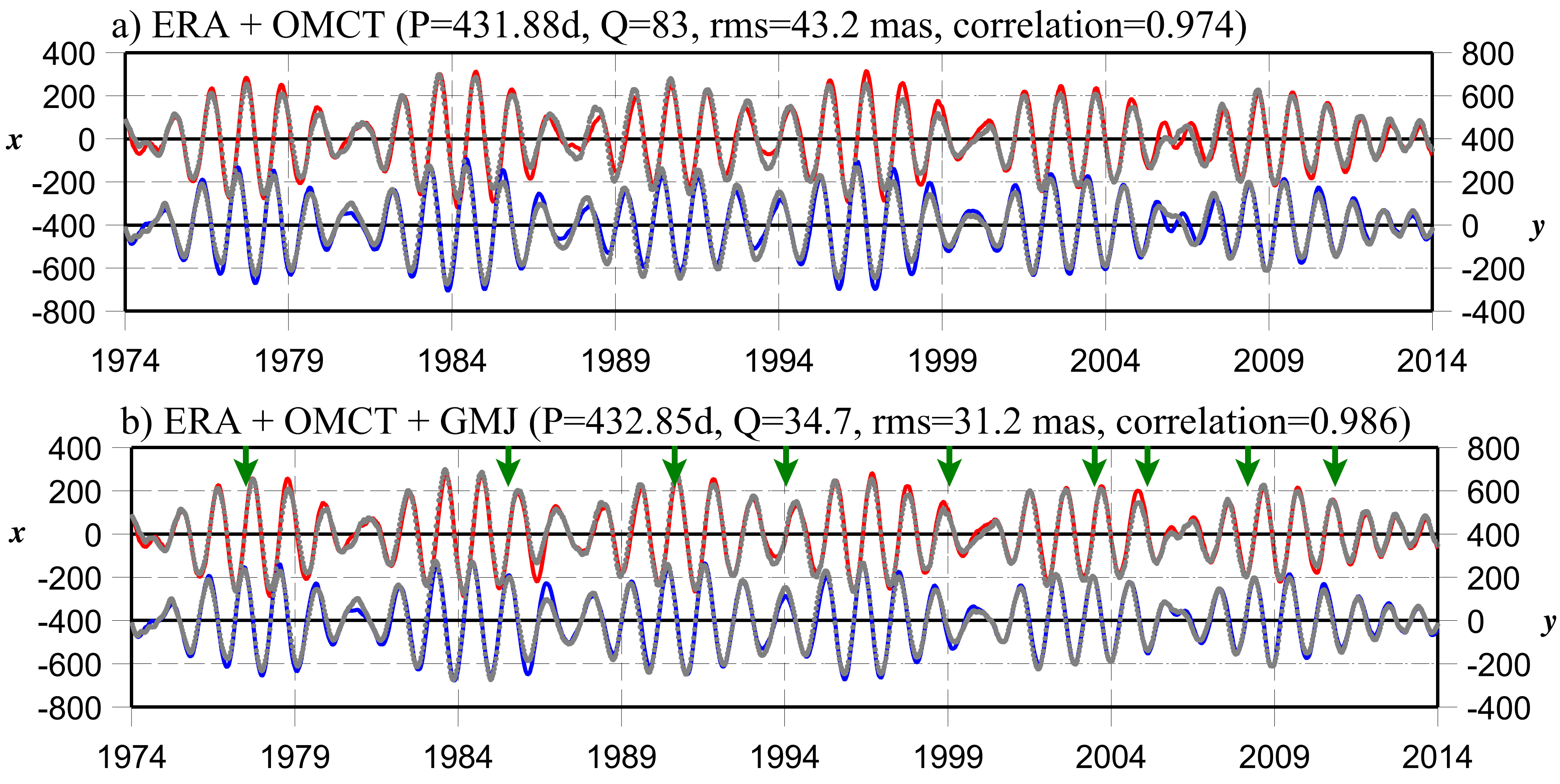




P=432.85±0.99 days

Q=34.7 (31.2, 39.5)

Integrated and observed polar motion, 1974.0-2014.0



Astronomical Institute of the Czech Academy of Sciences

Summary of the results:

Results of Chandler wobble period *P* (in days) and quality factor *Q*, obtained with only atmospheric and oceanic excitations (A+O), and with GMJ added (A+O+G). Root-mean-square fit rms between integrated and observed values (in mas) are also shown.

	A+O			A+O+G		
interval	*P*	*Q*	rms	*P*	*Q*	rms
1974.0-1994.0	432.13±0.56	197 (155, 269)	37.7	431.31±0.91	45 (40, 55)	32.6
1994.0-2014.0	431.09±0.43	103 (85, 130)	38.6	435.72±0.80	22.7 (22.1, 24.6)	22.7
1974.0-2014.0	431.88±0.43	83 (76, 90)	43.2	432.85±0.99	34.7 (31.2, 39.5)	31.2

Preferred values

Astronomical Institute of the Czech Academy of Sciences

Conclusions:

- ♦ **Geophysical excitations yield significant contribution to polar motion;**
- ♦ **Additional excitation by GMJ substantially improves the agreement with observations in all intervals studied;**
  - ♦ **determination of *Q*-factor is improved, and yields lower values (stronger damping):**
    - ♦ **dampings between GMJ events are stronger than average value over the whole interval,**
  - ♦ **determination of the period *P* is less accurate, but consistent with its values without GMJ:**
    - ♦ **it is based on short time intervals between individual GMJ events.**
- ♦ **Our preferred values are *P*=431.88±0.43, *Q*=34.7 (31.2,39.5)**

THANK YOU FOR YOUR ATTENTION!

Acknowlegments: This study was made possible thanks to the grant No. 13-15943S provided by the Grant Agency of the Czech Republic, and also to Joint Research Project between BAS and CAS.

Astronomical Institute of the Czech Academy of Sciences