Conventional Model Update for Rotational Deformation

Polhody (Red) over 2010-2015 and mean pole (Green) since 1900

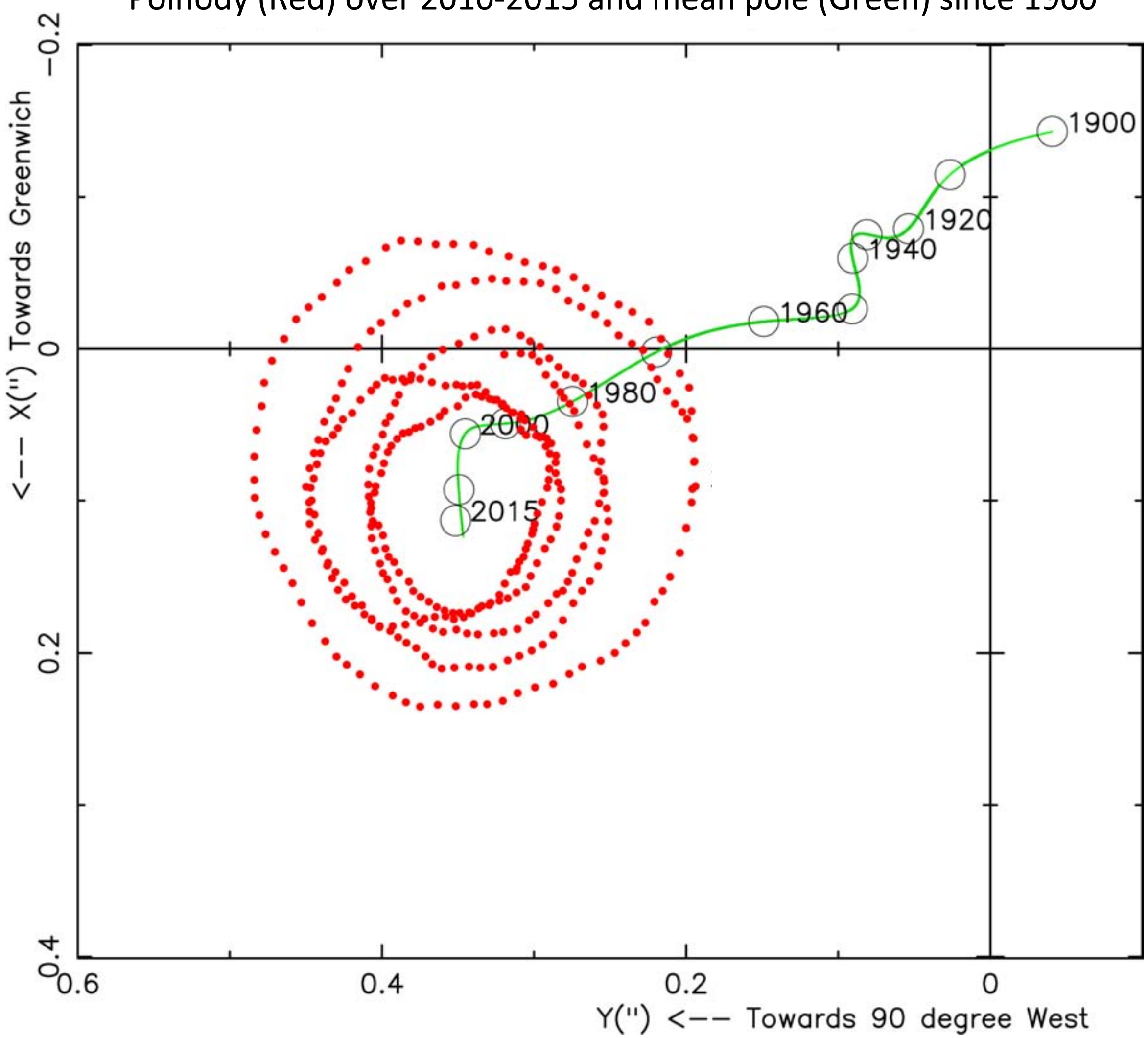

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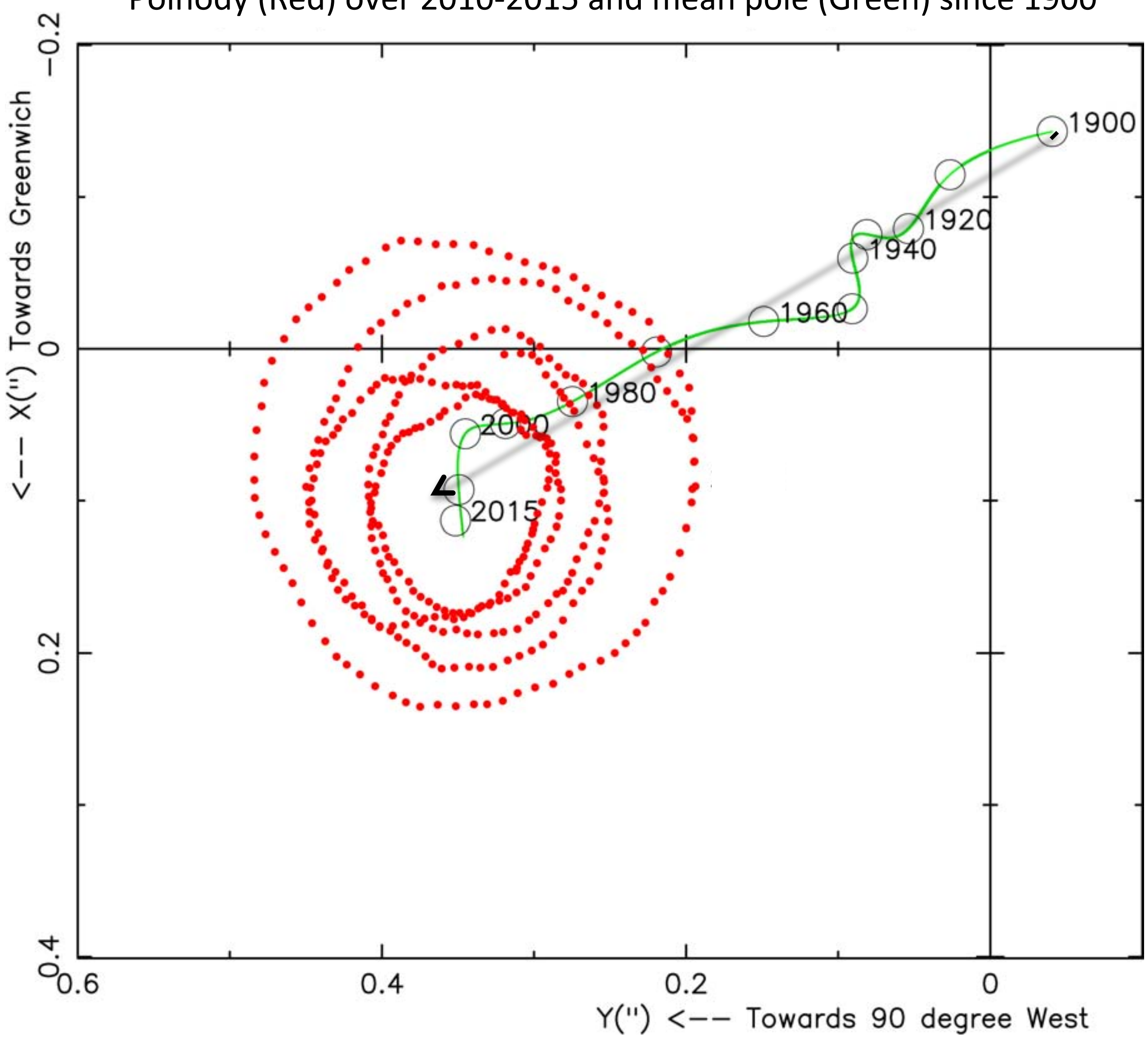
Figure from
ftp://iers.obspm.fr/iers/eop/eopc01/

Terminology is important

Polhody (Red) over 2010-2015 and mean pole (Green) since 1900



Filtered mean pole = includes long-term non-periodic variations but not annual and Chandler components

Linear mean pole = secular trend or drift of the mean pole (presumably dominated by GIA)

Conventional model for rotational deformation

Rotational deformation (also called the "pole tide") is the deformation resulting from the centrifugal effect of polar motion on the solid earth and ocean, which manifests itself as variations in ocean heights, in the gravity field and in surface displacements.

Gravitational effect (solid earth)

$$\Delta\bar{C}_{21} = -1.333 \times 10^{-9}(m_1 + 0.0115 m_2)$$

$$\Delta\bar{S}_{21} = -1.333 \times 10^{-9}(m_2 - 0.0115 m_1)$$

Maximum effect ~$3\text{x}10^{-10}$ (about 10 times smaller for ocean pole tide)

Surface displacement

$$S_r = -33 \sin 2\theta \, (m_1 \cos\lambda + m_2 \sin\lambda) \text{ in mm},$$

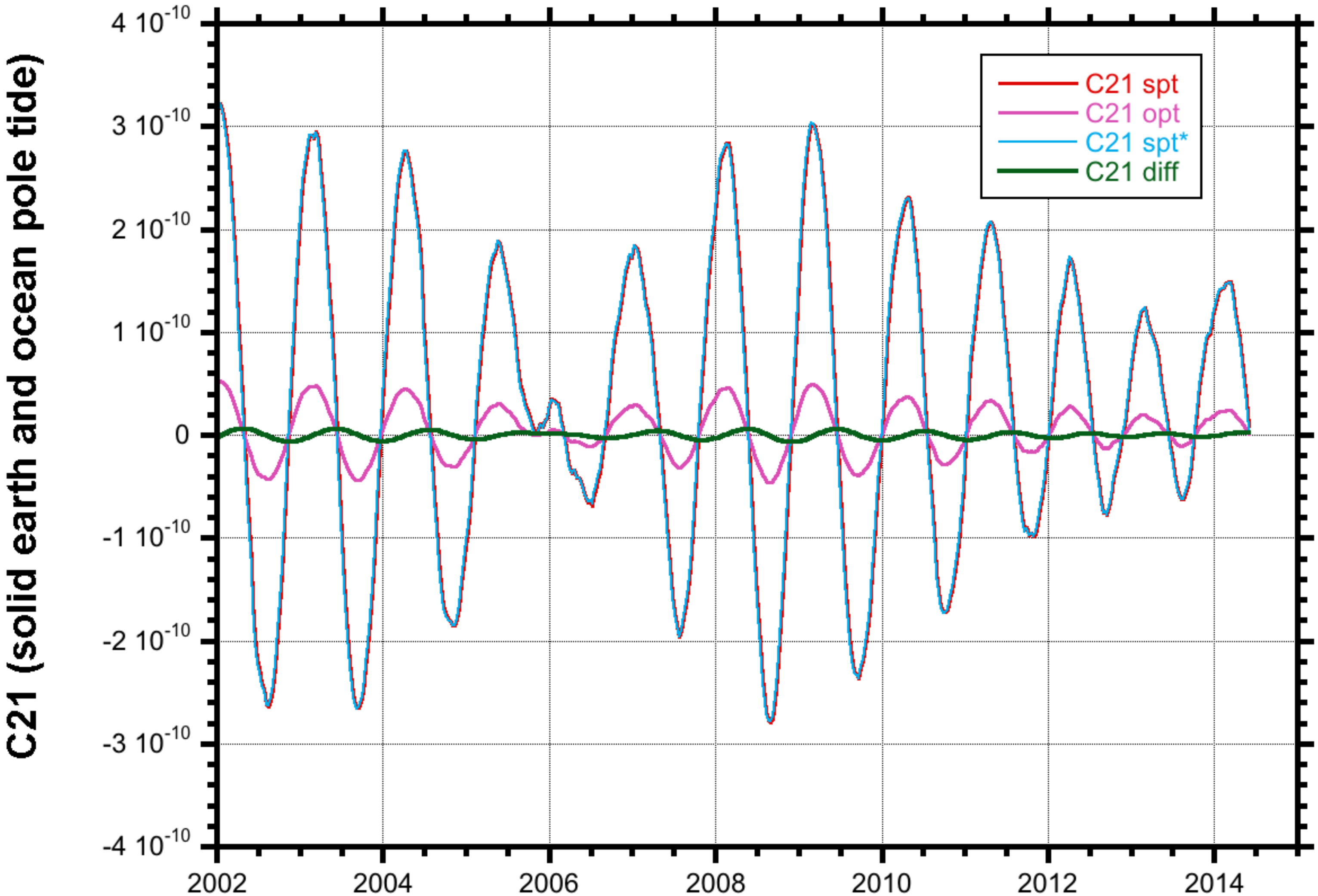
$$S_\theta = -9 \cos 2\theta \, (m_1 \cos\lambda + m_2 \sin\lambda) \text{ in mm},$$

$$S_\lambda = 9 \cos\theta \, (m_1 \sin\lambda - m_2 \cos\lambda) \text{ in mm},$$

Maximum vertical displacement is ~25 mm and the maximum horizontal displacement is ~7 mm

These models for rotational deformation assume a primarily elastic response of the Earth to the centrifugal potential and apply body tide Love numbers.

Rotational deformation (pole tide) for C21



Seasonal variation for S21 is ~$1x10^{-10}$; seasonal variation in C21 is small

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Role of the mean pole

The position of the Earth's mean rotation pole has a secular variation, and its coordinates in the Terrestrial Reference Frame discussed in Chapter 4 are given, in terms of the polar motion variables (x_p, y_p) defined in Chapter 5, by appropriate running averages $\bar{x}_p$ and $-\bar{y}_p$. Then

$$m_1 = x_p - \bar{x}_p, \qquad m_2 = -(y_p - \bar{y}_p). \tag{7.24}$$

The assumed tidal (mostly elastic) response is not applicable to secular motion of mean pole, so a secular mean pole must be removed.

The current filtering approach removes only the annual and Chandler variations from the polar motion time series.

The resulting filtered mean pole model retains longer period variations (not just linear) that are consequently *not included* in the rotational deformation model.

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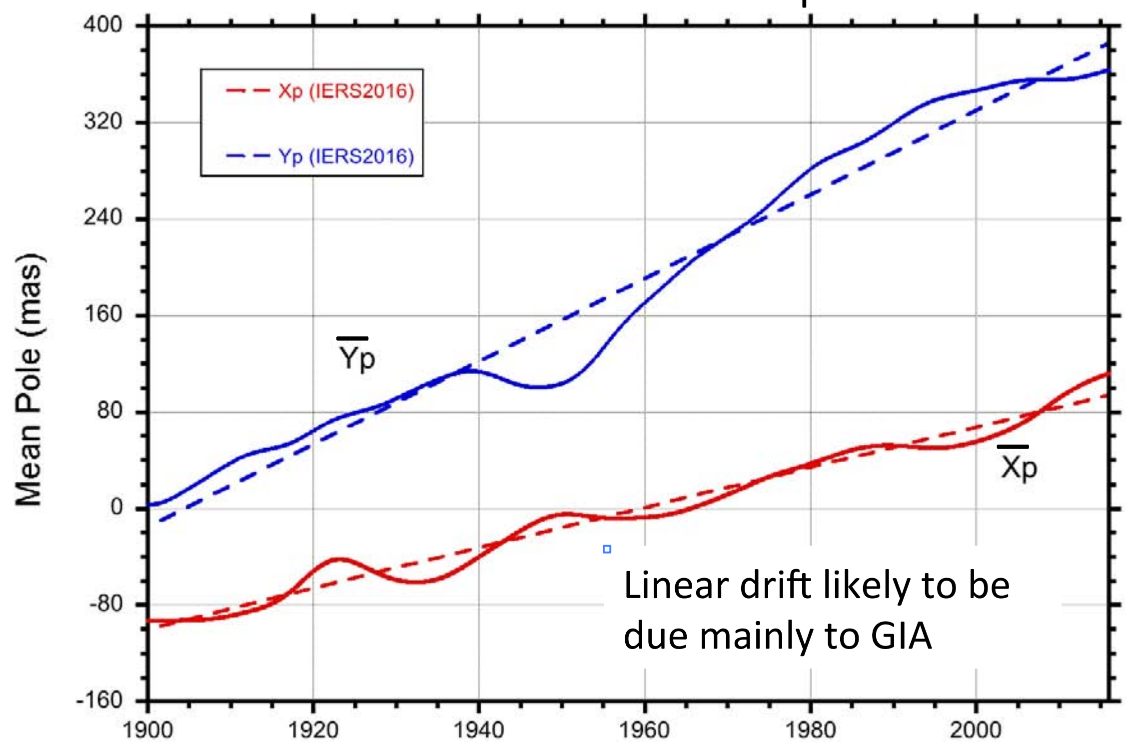
So, ‘appropriate running averages’ are *not* appropriate

- The annual and Chandler wobble period elastic Love number should be applicable to longer period variations

- For example, Eanes (1995) showed that the Love number, k2, for the 18.6 year tide was nearly the same as the Love number used for the pole tide
- Consequently, only the secular (i.e., linear) trend of the mean pole, due presumably to GIA, should be modeled
- In this way, the pole tide model correctly includes rotational deformation from longer period variations in polar motion and excludes only the response due to the secular trend in polar motion

IERS Filtered C01 mean pole



References: King & Watson, GJI, 2014; Desai, Wahr & Beckley, JGeod, 2015; Wahr, Nerem & Bettadpur, JGR, 2015

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Some questions

- What is the impact if a linear mean pole is adopted?
- Can we determine a reliable linear pole path that we can interpret as representative of the true secular trend of the mean pole (driven by GIA)? Does it even have to be intepreted as dominated by GIA?
- Is the use of the mean pole to align the geopotential (IERS2010, Chapter 6) affected?

Oceanographic effects

Current altimeter products use just a constant mean pole (Topex/Poseidon model).

This allows a secular trend to be introduced via the pole tide model, and introduces an anomalous trend in the sea level time series.

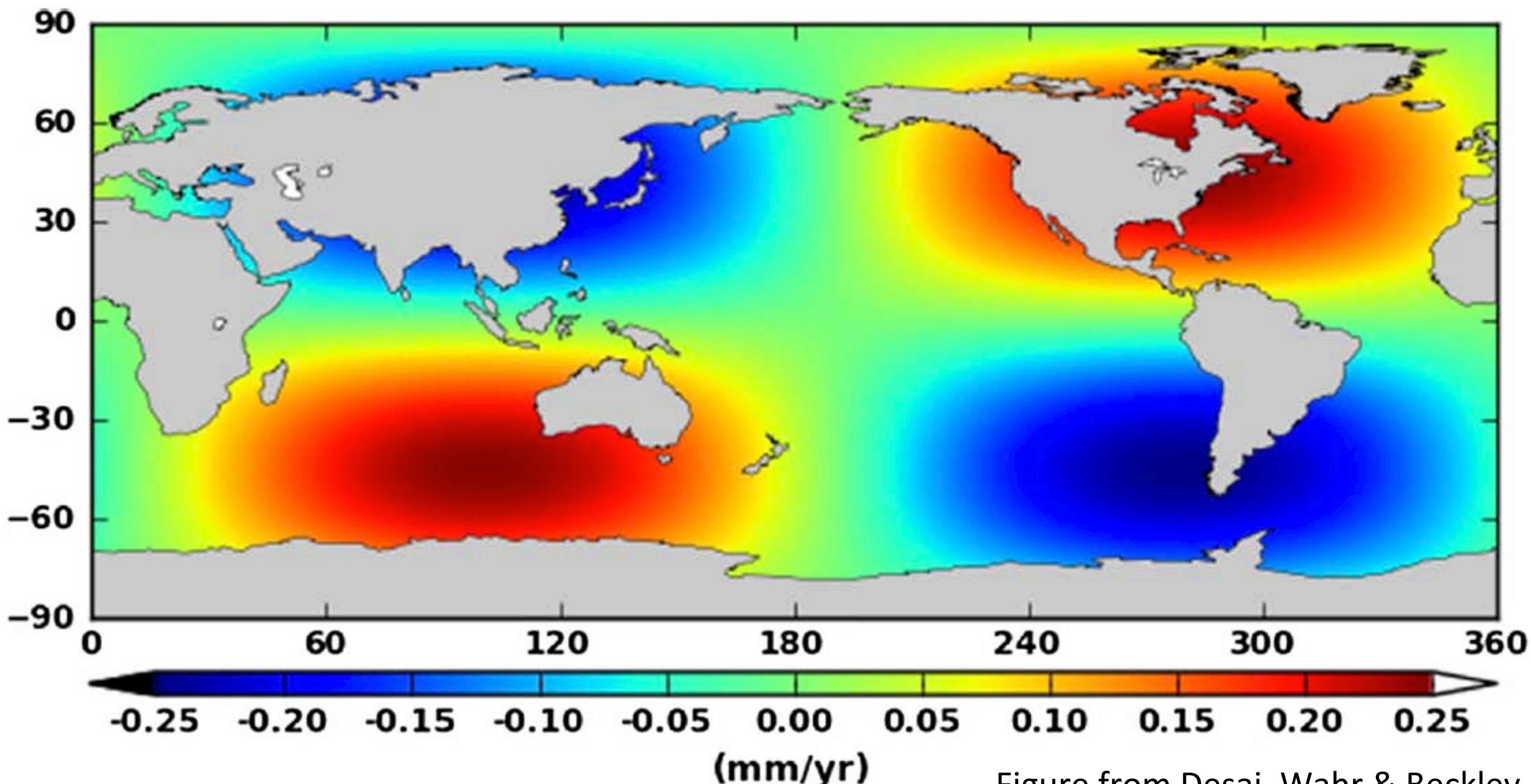

Figure from Desai, Wahr & Beckley, JGeod, 2015

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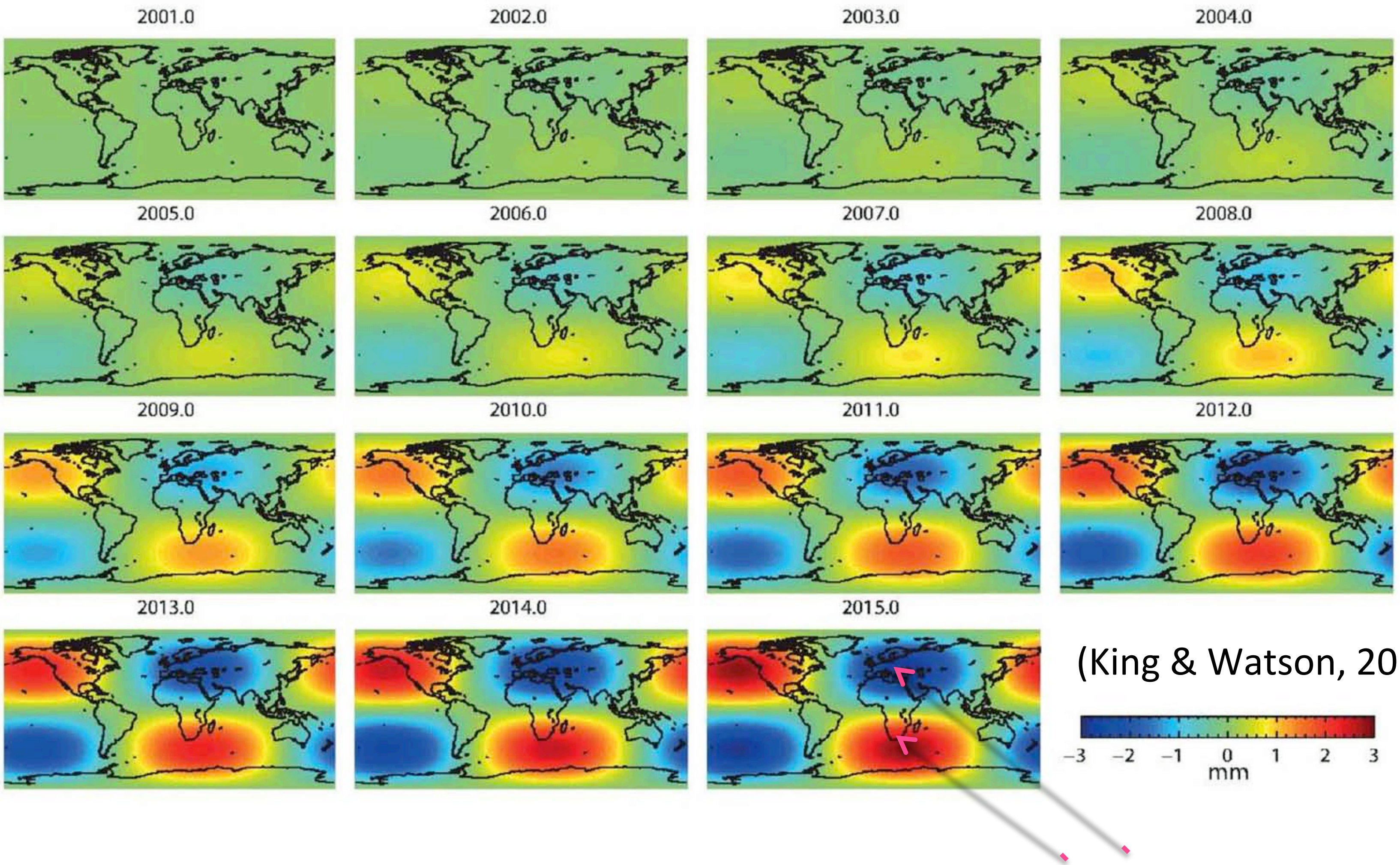
Reference frame effects

Using a non-linear mean pole, the ITRF will contain an anomalous deformation dominated by a degree-2/order-1 pattern

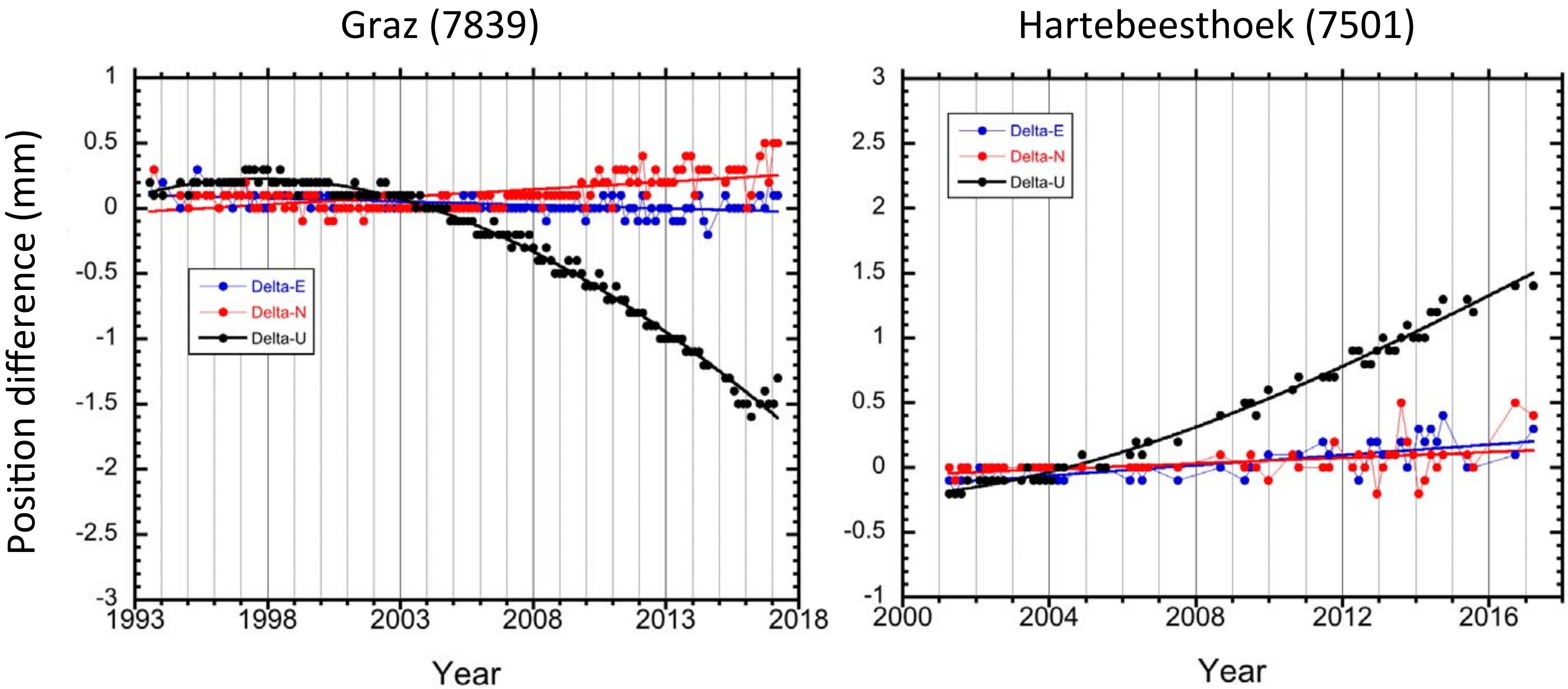
We can look at Graz and Hartebeesthoek as these appear to be close to maximas



(King & Watson, 2014)

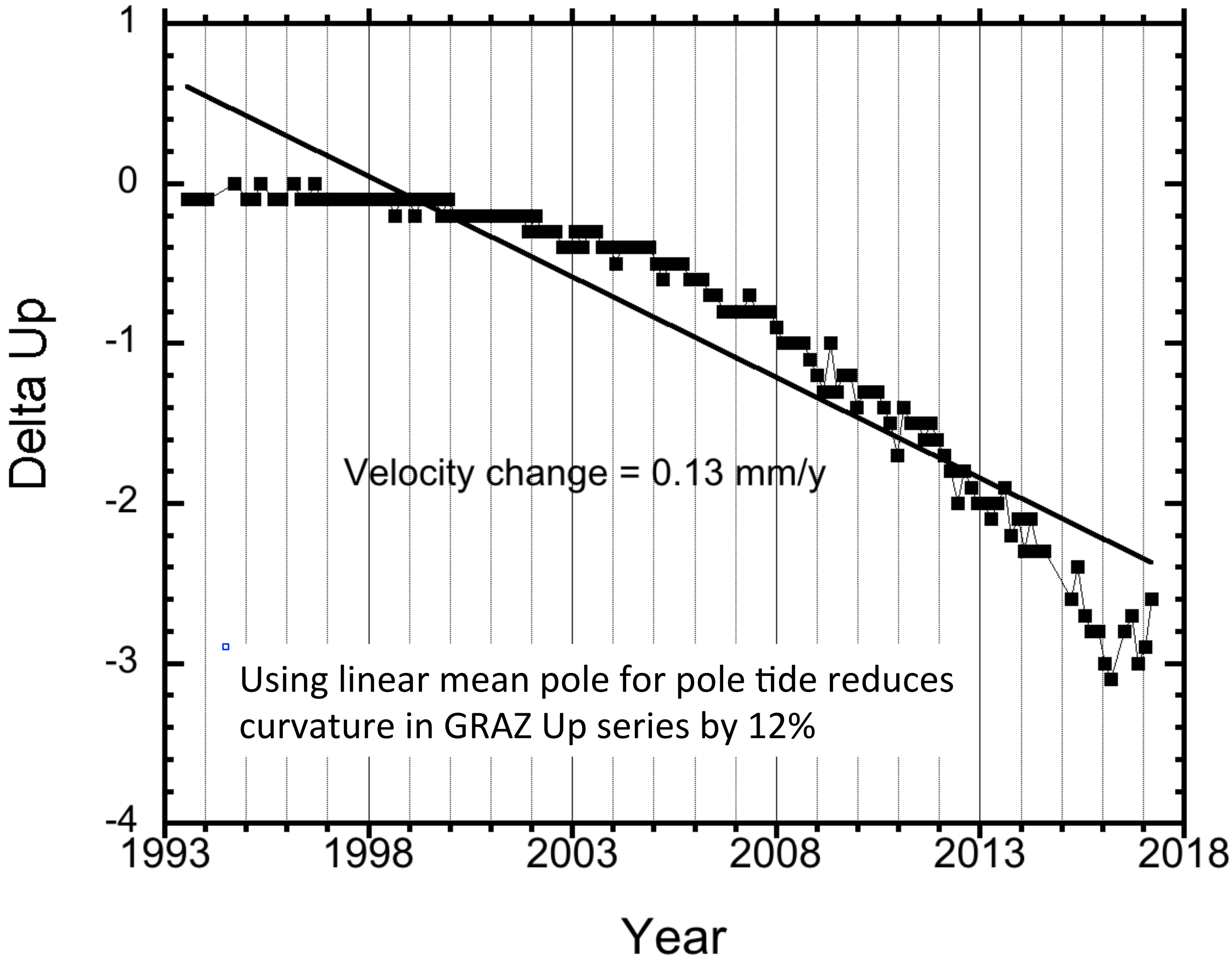
Effect on station position due to adopting a linear mean pole model

Because of the curvature,
velocities will be different over different time periods



(relative to IERS2015)

Same but relative to IERS2010 mean pole



Using linear mean pole for pole tide reduces curvature in GRAZ Up series by 12%

Geopotential effects (1)

- Estimates of C21/S21 should align, on average, with predictions from the full (filtered) mean pole, since the mean principal figure axis tends to stay aligned with the mean rotational axis (Wahr, 1987)

$$\begin{aligned} \bar{C}_{21}(t) &= \sqrt{3}\bar{x}_p(t)\bar{C}_{20} - \bar{x}_p(t)\bar{C}_{22} + \bar{y}_p(t)\bar{S}_{22}, \\ \bar{S}_{21}(t) &= -\sqrt{3}\bar{y}_p(t)\bar{C}_{20} - \bar{y}_p(t)\bar{C}_{22} - \bar{x}_p(t)\bar{S}_{22}, \end{aligned} \quad (6.5)$$

- We can expect that the agreement should be best if the most correct mean pole is used in pole tide model

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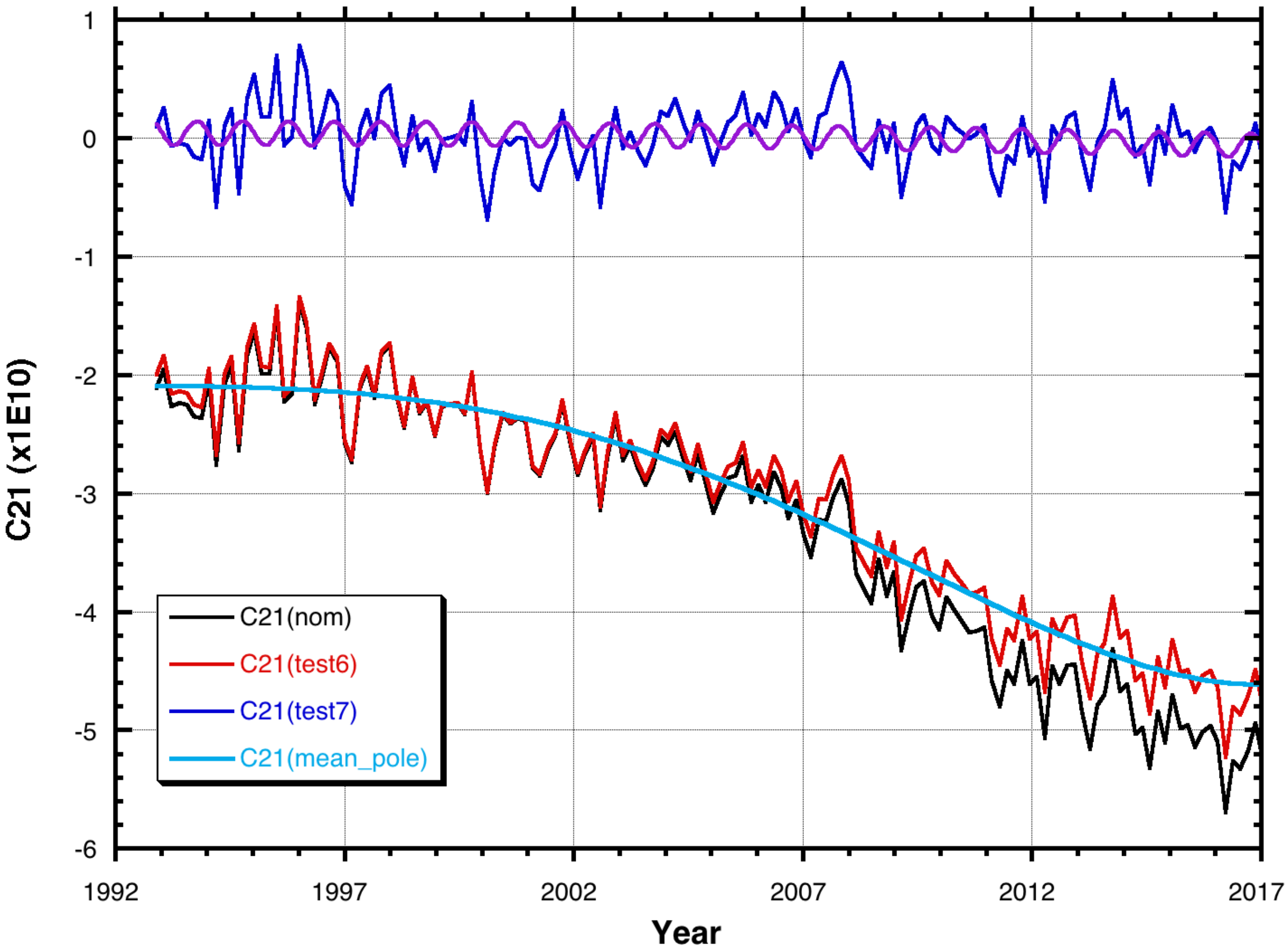
Geopotential effects (2)



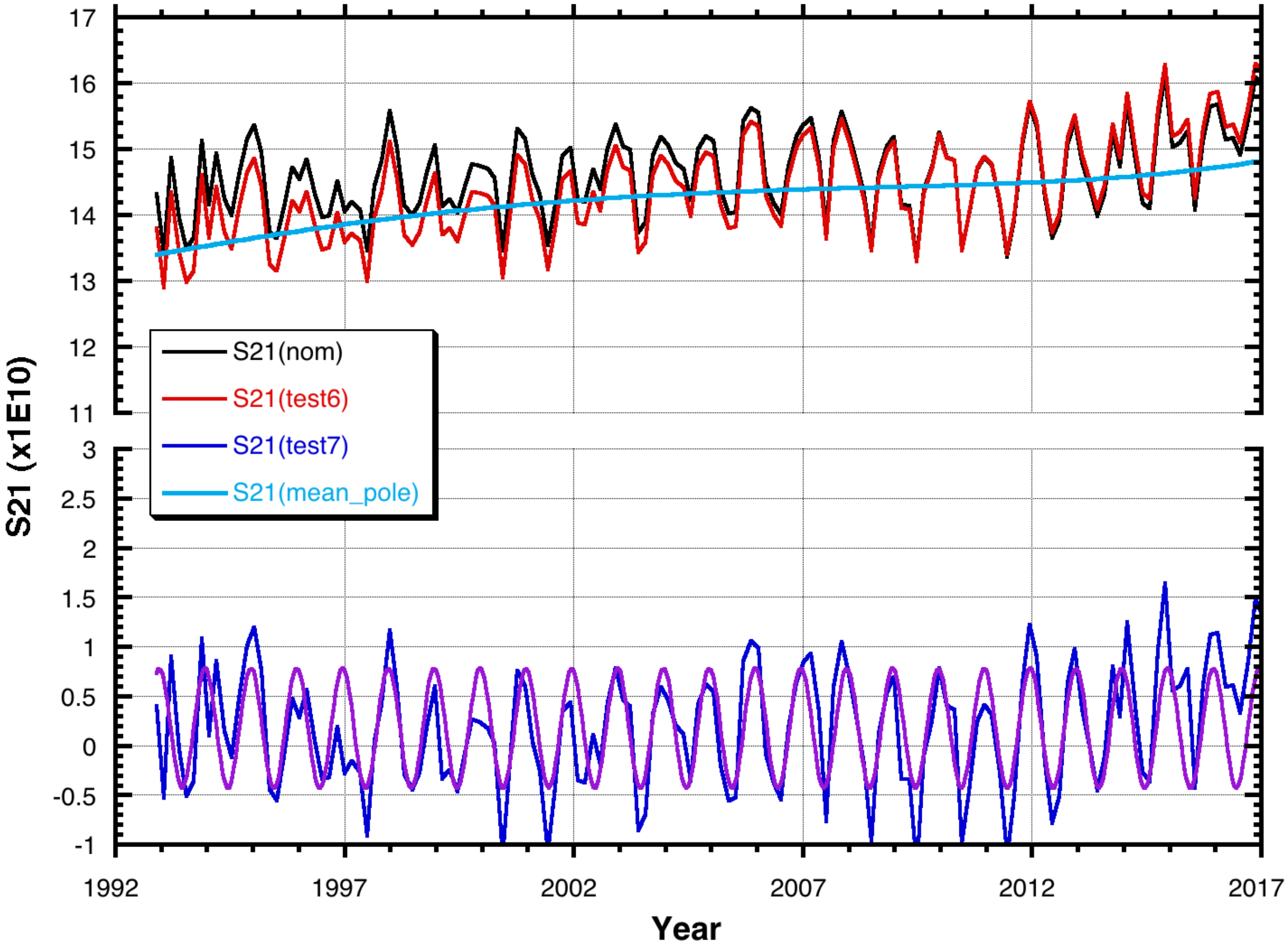
C21 estimated from SLR tracking to LAGEOS-1/2.

Estimated C21 should align with prediction from full (filtered) mean pole (Wahr, 1987)

- nom = use conventional IERS mean pole model for computing rotational deformation
- test6 = use linear mean pole model
- test7 = use linear mean pole but remove full mean pole from C21 (i.e., forward model long-term trend)

Note: C21 is well-characterized by the filtered mean pole (seasonal signal is quite small)

Geopotential effects (3)



S21 estimated from SLR tracking to LAGEOS-1/2.

Estimated S21 should align with prediction from full (filtered) mean pole (Wahr, 1987)

- nom = use conventional IERS mean pole model for computing rotational deformation
- test6 = use linear mean pole model
- test7 = use linear mean pole but remove full mean pole from S21 (i.e., forward model long-term trend)

Note: S21 is well-characterized by the filtered mean pole and a seasonal term

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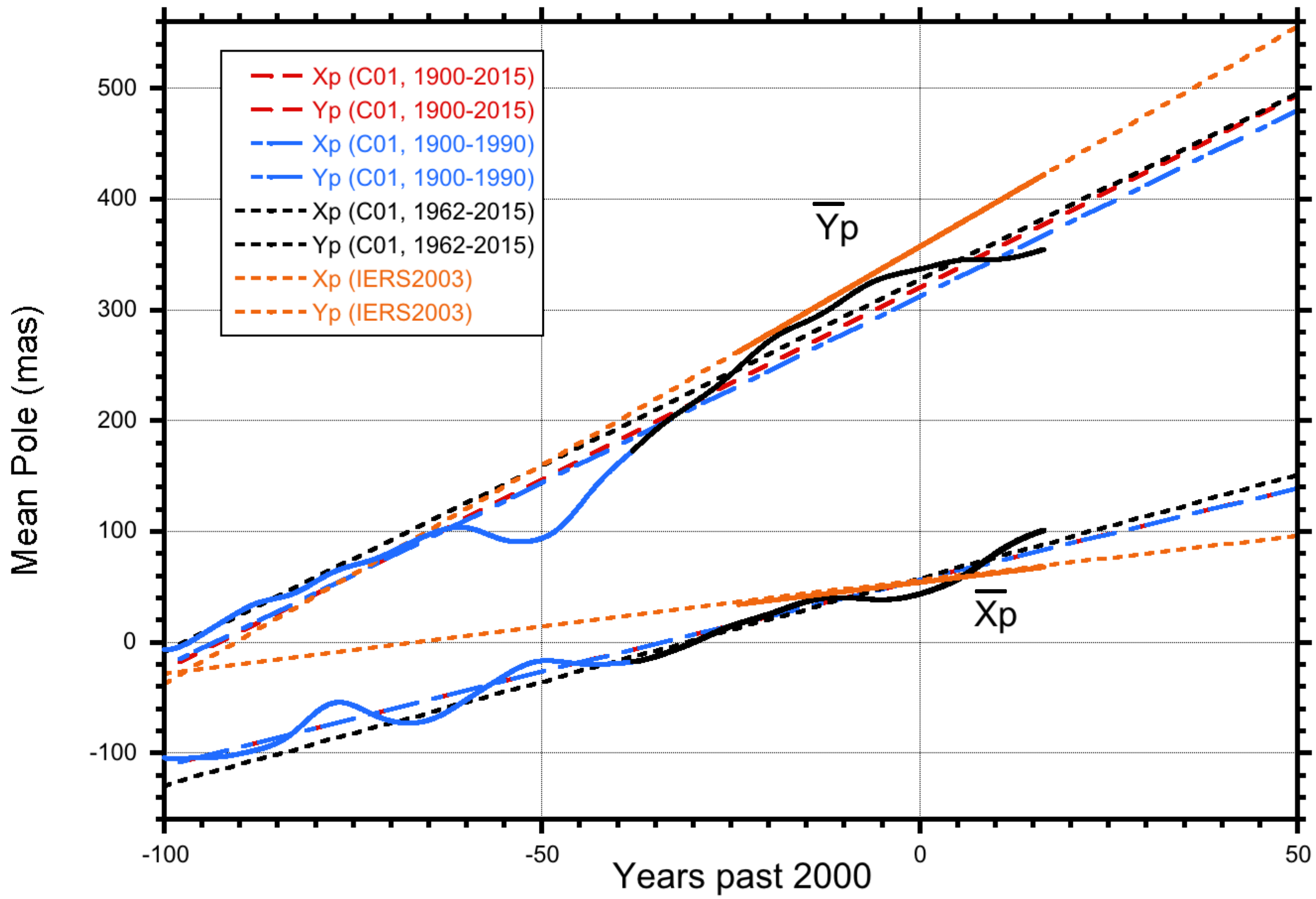
Determining an appropriate linear mean pole (1)



IERS2003 is the linear mean pole from the IERS2003 Conventions

(based on a linear fit to the IERS mean pole over 1976-2000)

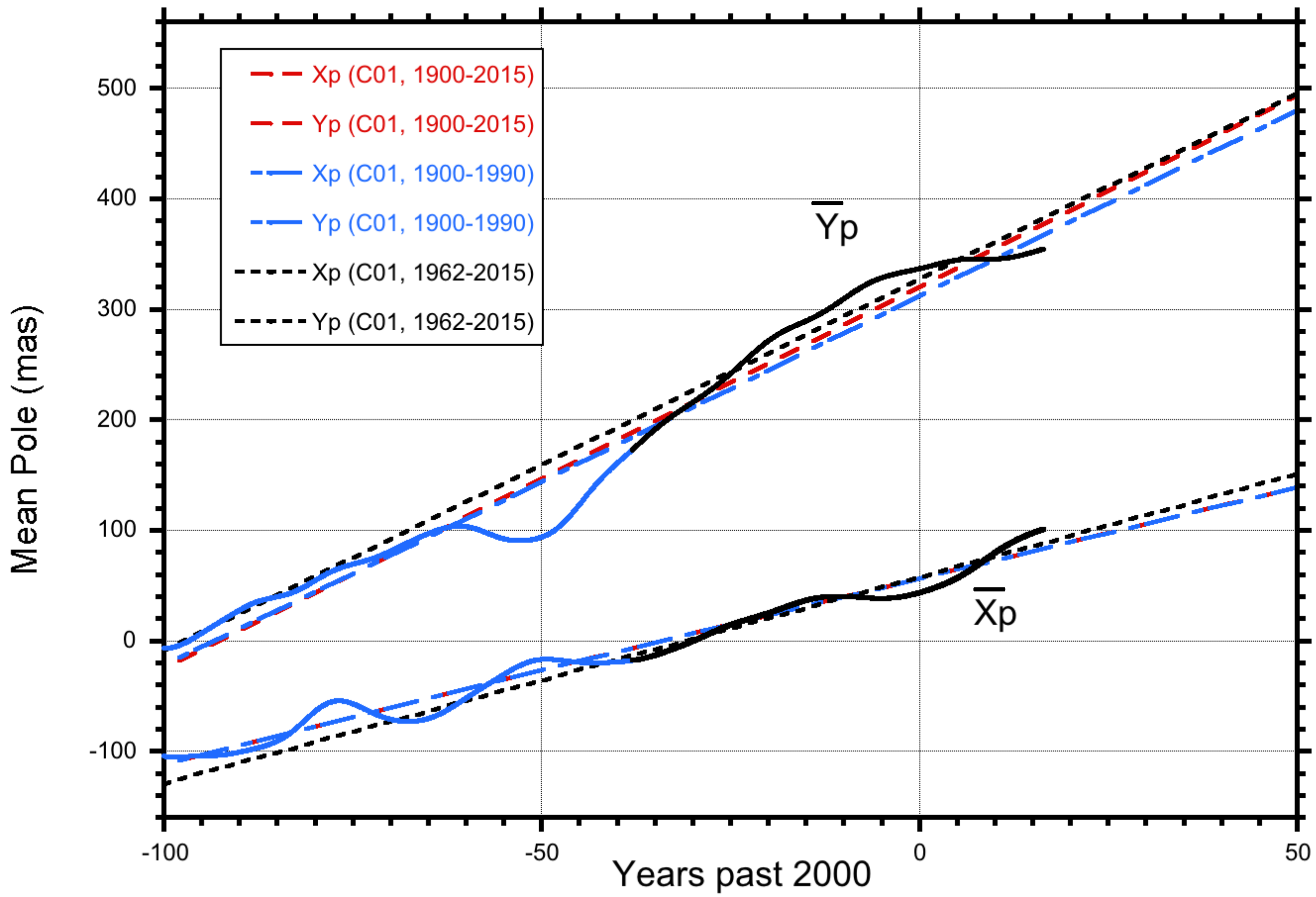
C01 is the IERS filtered mean pole at ftp://iers.obspm.fr/iers/eop/eopc01/mean-pole.tab

Three intervals fitted: 1900-2015 (longest baseline)

1900-1990 (avoids effects of recent ice mass loss)

and 1962-2015 (avoids more uncertain C01 data before 1962)

Determining an appropriate linear mean pole (2)



Recommended model:

In milliarcsec:

$\overline{Xp}$ = 55.0 + t*1.677

$\overline{Yp}$ = 320.5 + t*3.460

t is years past 2000

Any of these fits to C01 seem reasonable and consistent with the overall trend, though the span of 1900-2015 provides the longest baseline for a linear (presumably GIA-dominated) mean pole

Even if we cannot be sure this represents the true effect on the mean pole due to GIA, it is likely to <u>best represent the future secular trend of the IERS polar motion</u>

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Conclusions

- What is the impact if a linear mean pole is adopted?
  - The effects are small but not insignificant
  - These could be modified in post-processing for gravity
  - The effects on the TRF would be more difficult to accommodate in post-processing; station velocities will be different over different time periods if the mean pole model is incorrect

- Can we determine a reliable linear pole path that we can interpret as representative of the true secular motion of the pole (driven by GIA)? Does it even have to be intepreted as dominated by GIA?
  - Fitting the intervals 1900-2015, 1900-1990, or 1962-2015 all lead to similar linear models,
  - The long-term trend in C01 is likely to be dominated by GIA
  - However, even if we cannot be certain this is a “GIA-dominated” mean pole, it is likely to best represent the secular trend of the IERS polar motion, and that the variations about this are the variations we wish to preserve in the pole tide model

- Is the use of the mean pole to align the geopotential (IERS2010, Chapter 6) affected?
  - In fact, the agreement between C21/S21 and the prediction from the full mean pole is improved when a linear mean pole is used for computing rotational deformation

Two Recommendations and a Comment

- IERS conventions should be updated to replace the filtered mean pole with a linear mean pole model
  - Basic pole tide model is unchanged; only the mean pole subtracted from the IERS polar motion changes
  - Simple code change and avoids issues with updates of the mean pole
  - All of the fits to the C01 series shown here do not differ by much more than the nominal 10 mas goal, even when extended up to 2050, but the fit to 1900-2015 is recommended as it spans the longest interval
- IERS continues to provide a filtered mean pole table for purposes of modeling/comparing the long-term trend in C21/S21
  - Useful in forward modeling C21/S21 for precision orbit determination
- C21/S21 are well characterized by the full (filtered) mean pole and a seasonal variation, but is the part that simply reflects the mean pole a real mass redistribution signal?

Sources:

Matt King and Christopher Watson, Geodetic vertical velocities affected by recent rapid changes in polar motion, Geophys. J. Int. (2014) 199, 1161–1165.

Shailen Desai, John Wahr, Brian Beckley, Revisiting the pole tide for and from satellite altimetry, J Geod (2015) 89:1233–1243.

John Wahr, Steven Nerem, and Srinivas Bettadpur, The pole tide and its effect on GRACE time-variable gravity measurements: Implications for estimates of surface mass variations, J. Geophys. Res., (2015), 120, 4597–4615.