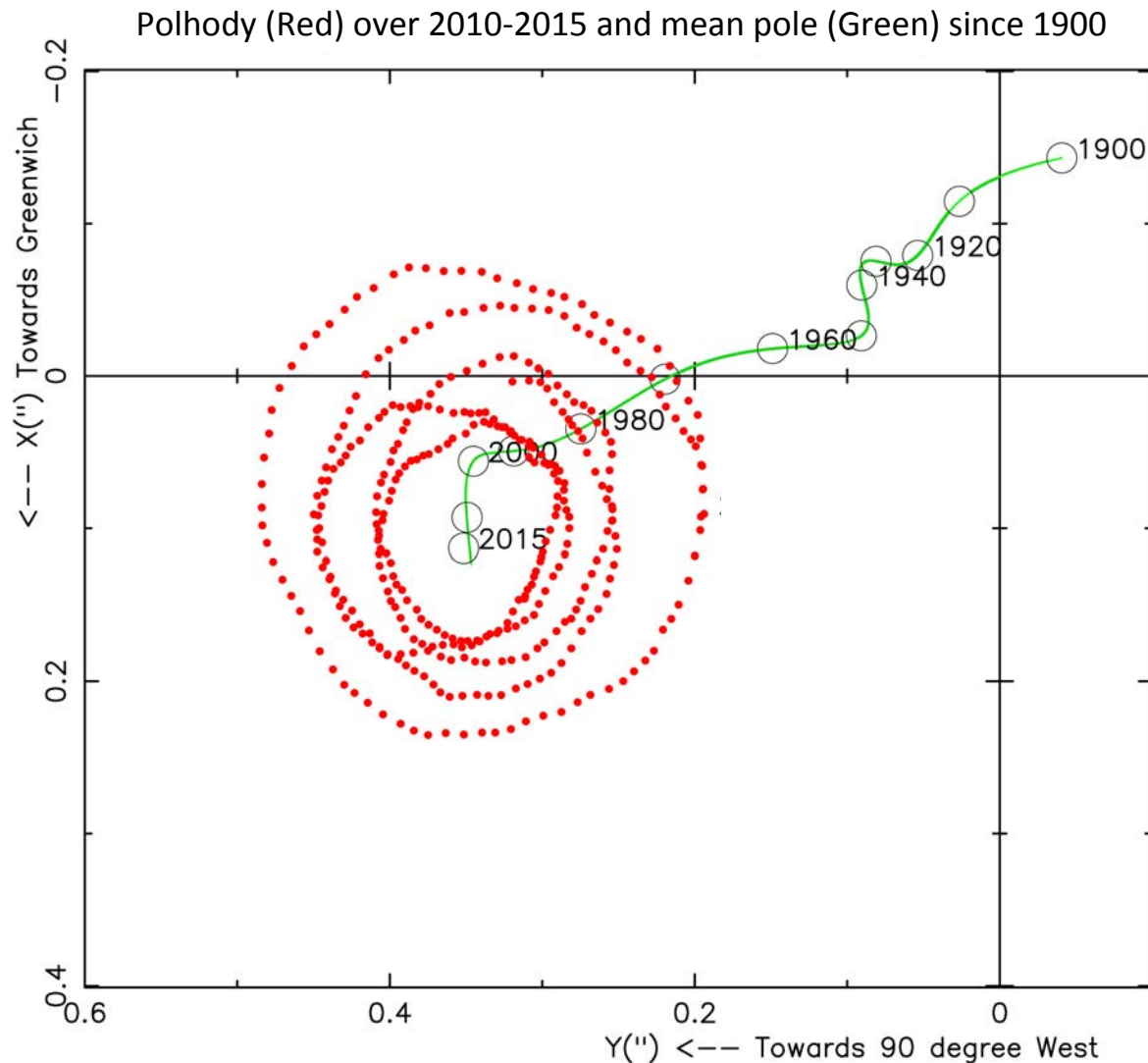


Conventional Model Update for Rotational Deformation



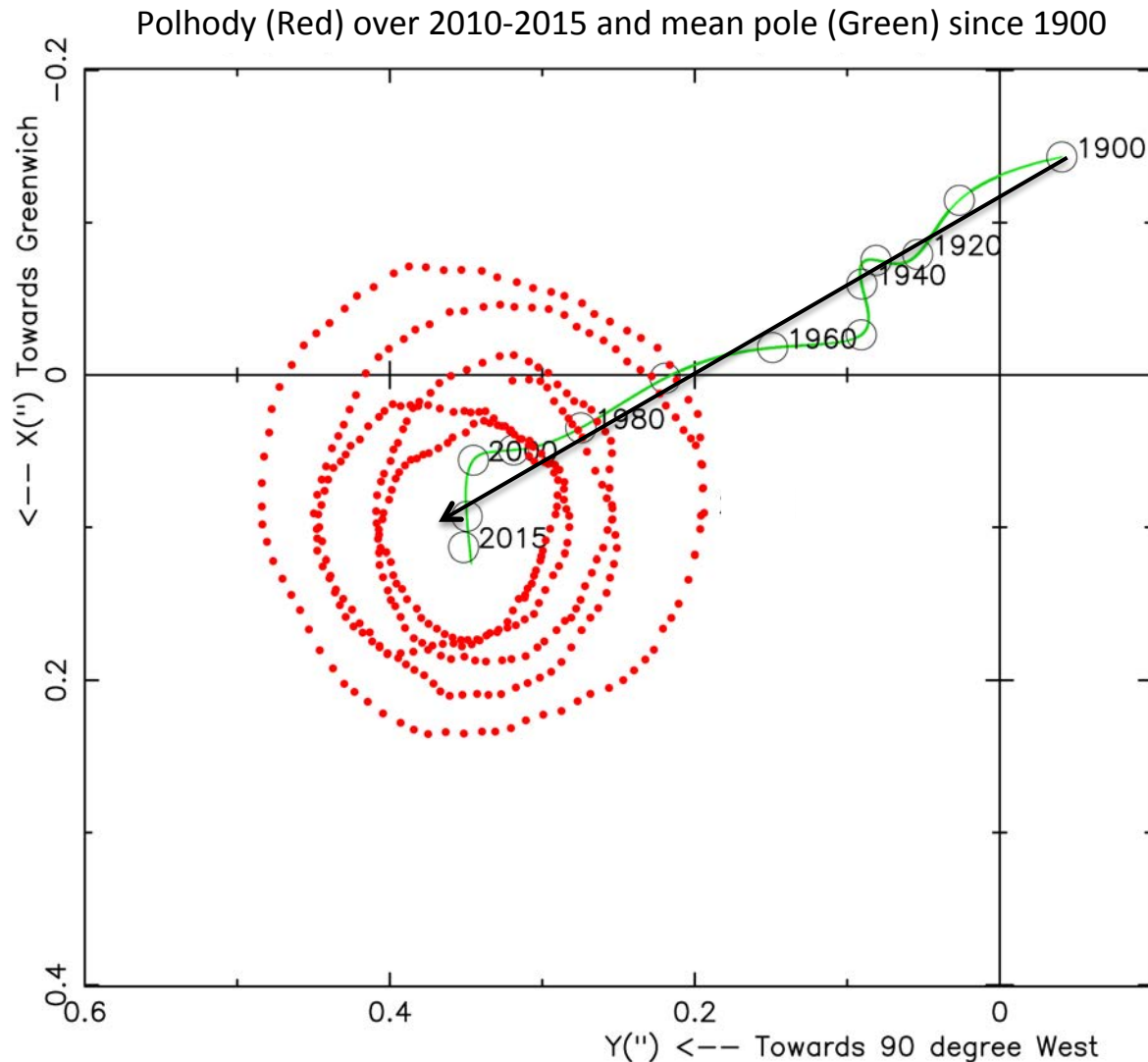
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with very helpful contributions
from S. Desai, M. Tamisiea,
S. Bettadpur, C. Bizouard,
E. Pavlis, M. King,
Z. Altamimi and others

GRACE Science Team Meeting
Austin, Texas
October 10- 12, 2017

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

A note on terminology



Secular:

Secular variation = long term non-periodic variation

Secular trend (drift) = linear part of the long term trend

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

Filtered mean pole = secular variation (linear mean pole plus long-term non-periodic variations)

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)

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

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

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

Surface displacement

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

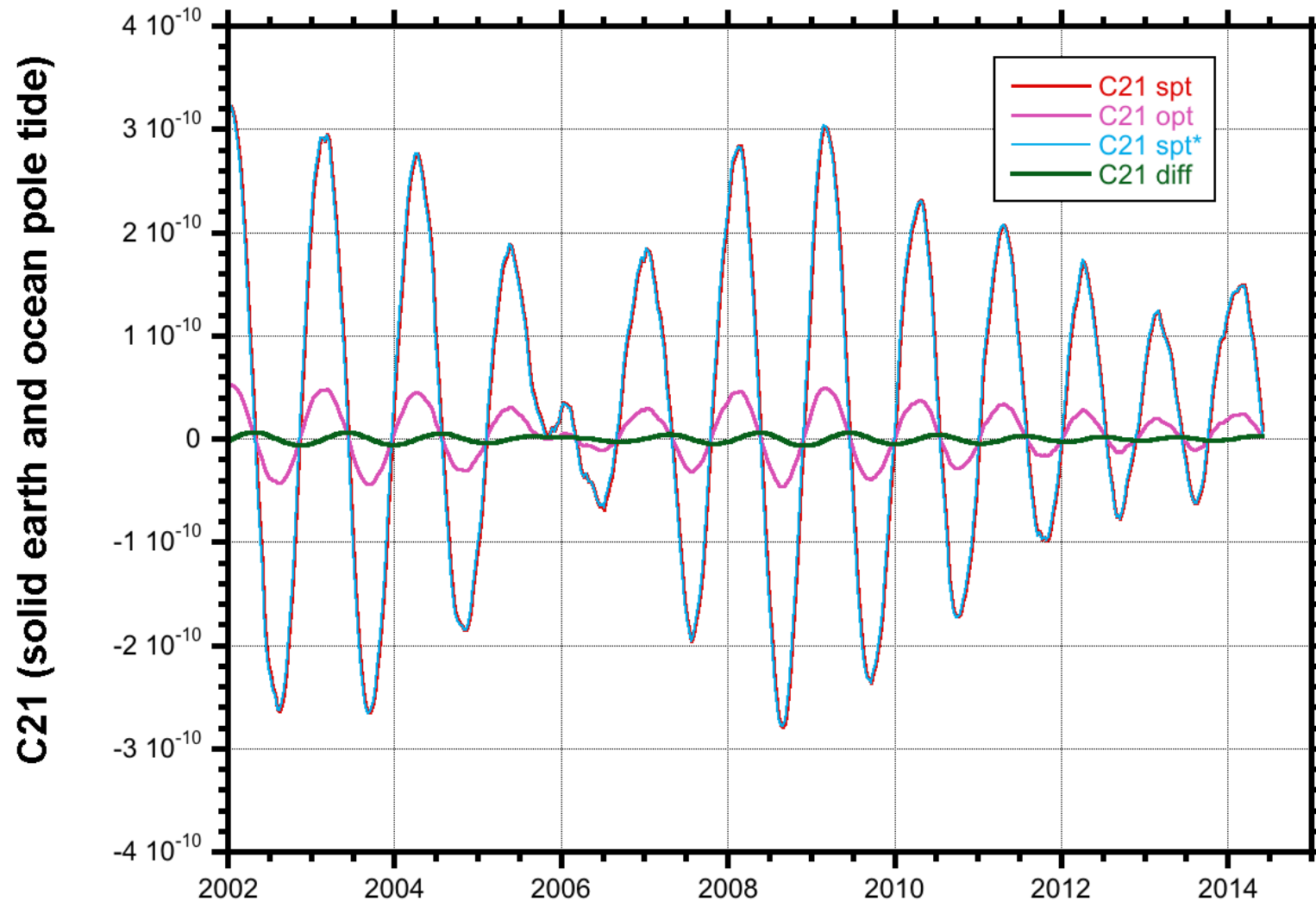
$$S_\theta = -9 \cos 2\theta (m_1 \cos \lambda + m_2 \sin \lambda) \text{ in mm,}$$

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

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 $\sim 1 \times 10^{-10}$; seasonal variation in C21 is small

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

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

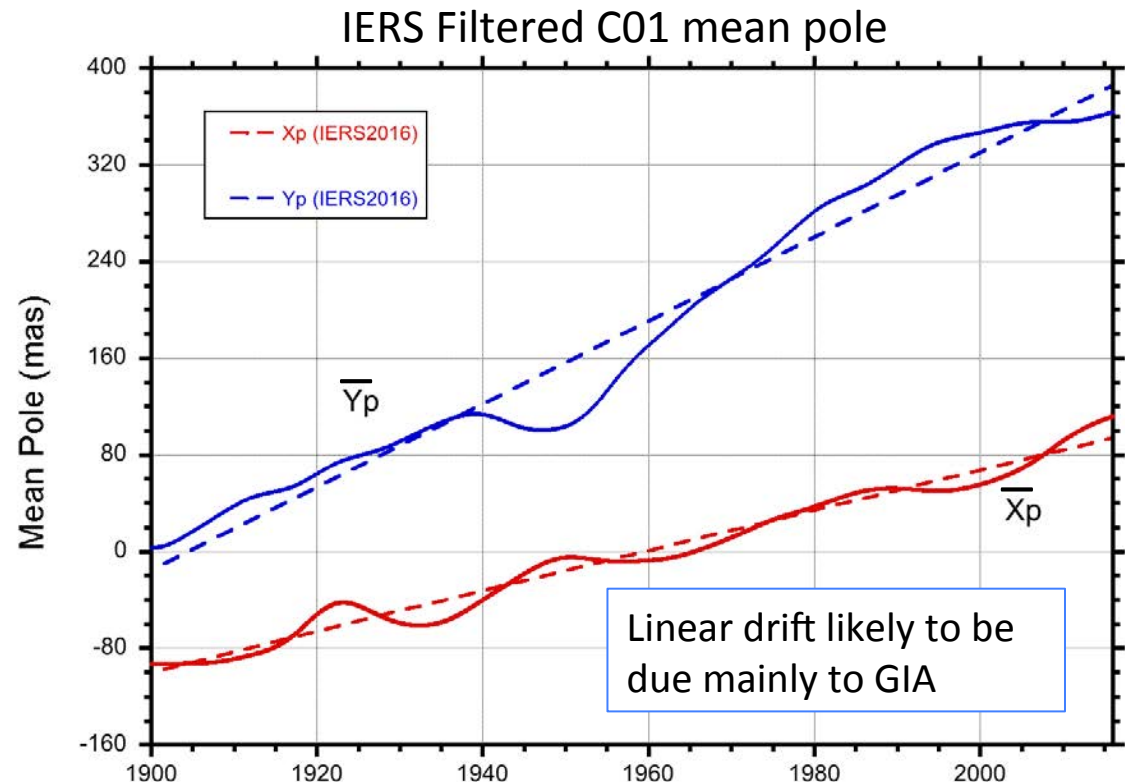
The assumed tidal (mostly elastic) response is not applicable to secular motion of mean pole, so a secular mean pole must be removed.

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.

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, k_2 , 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



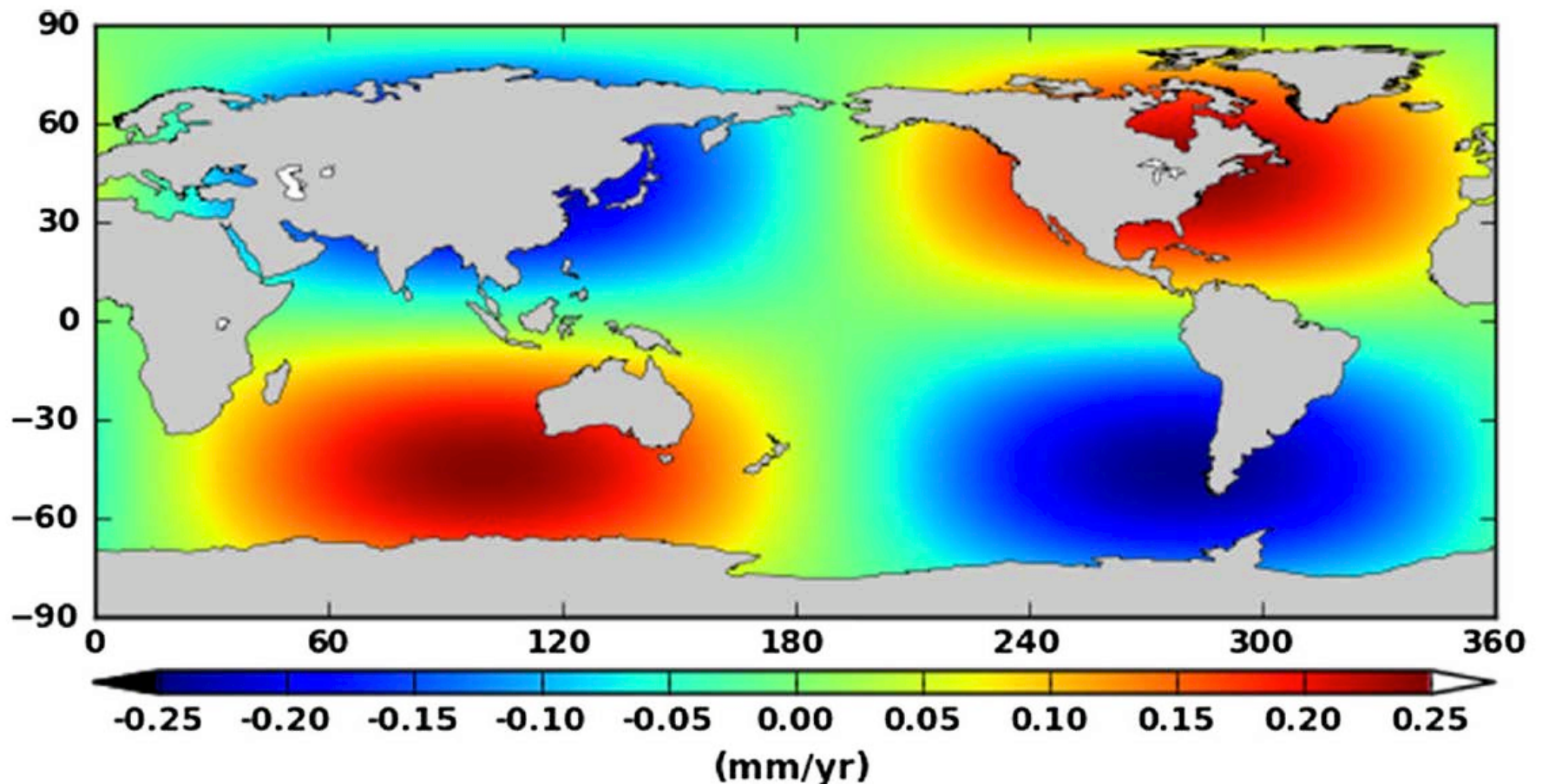
References: King & Watson, GJI, 2014; Desai, Wahr & Beckley, JGeod, 2015; Wahr, Nerem & Bettadpur, JGR, 2015

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 interpreted as dominated by GIA?
- Is the use of the mean pole to align the geopotential (IERS2010, Chapter 6) affected?

Oceanography

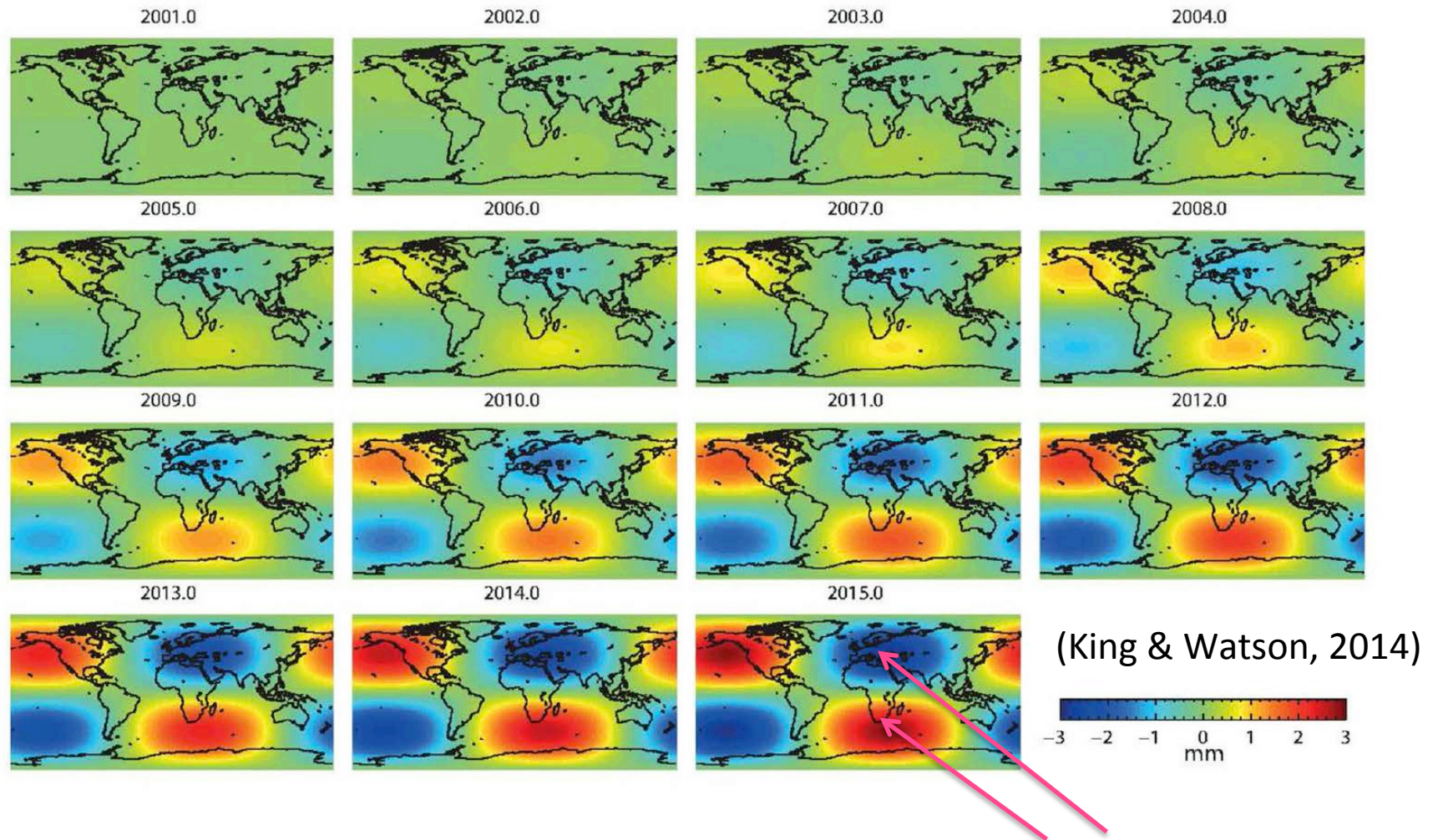
Current altimeter products use just a constant mean pole (Topex/Poseidon model). The altimeter community needs to adopt a better mean pole model for the ocean pole tide; otherwise they are introducing errors in the sea level time series with a degree-2/order-1 shape (figure from Desai et al., 2015)



Reference frame

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

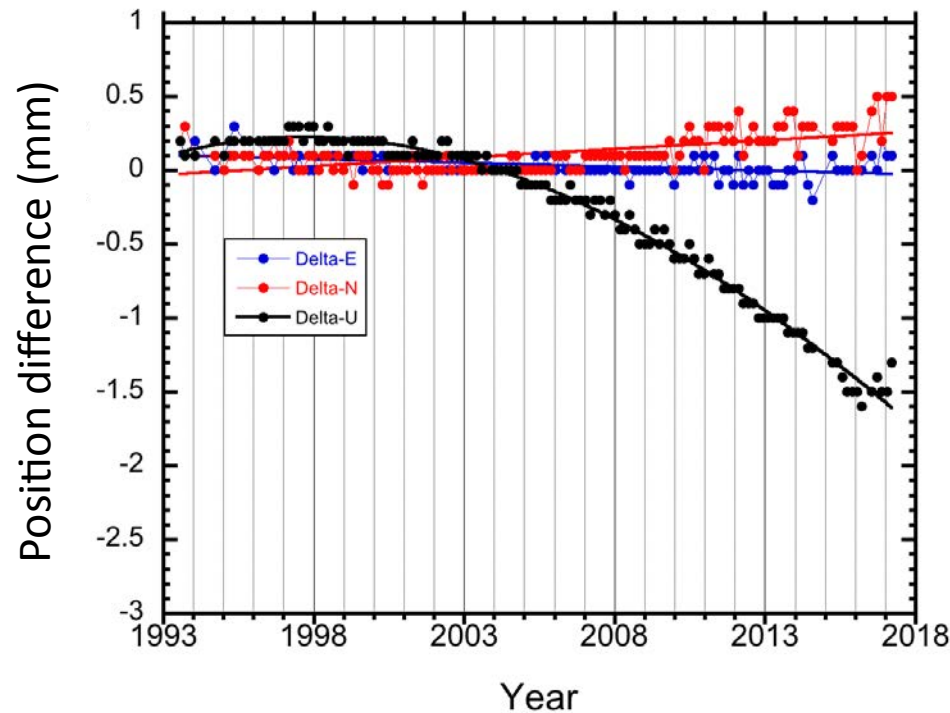
We can look at Graz and Hartebeesthoek as these appear to be close to maximas



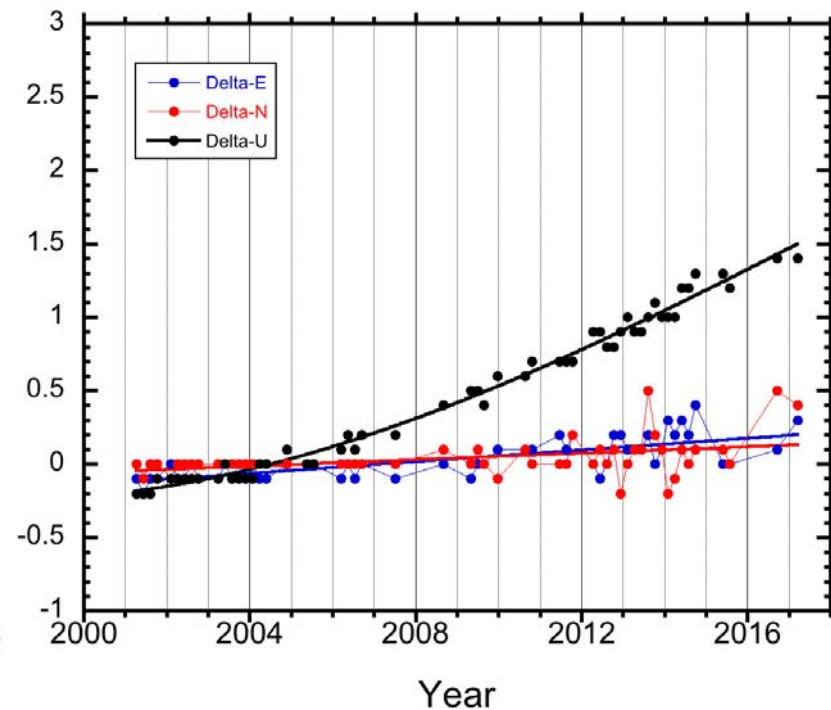
Effect on station position due to adopting a linear mean pole model

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

Graz (7839)

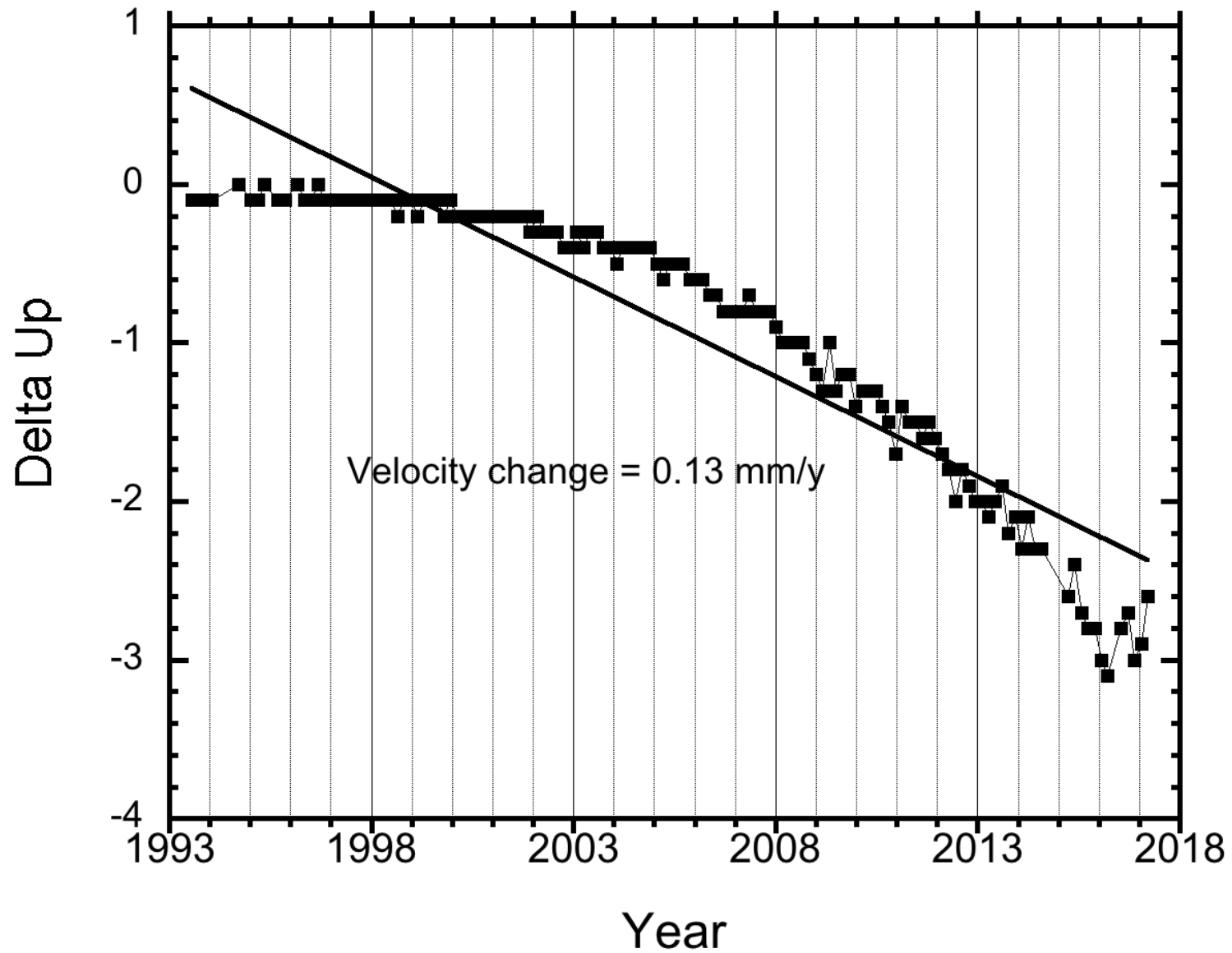


Hartebeesthoek (7501)



(relative to IERS2015)

Same but relative to IERS2010 mean pole



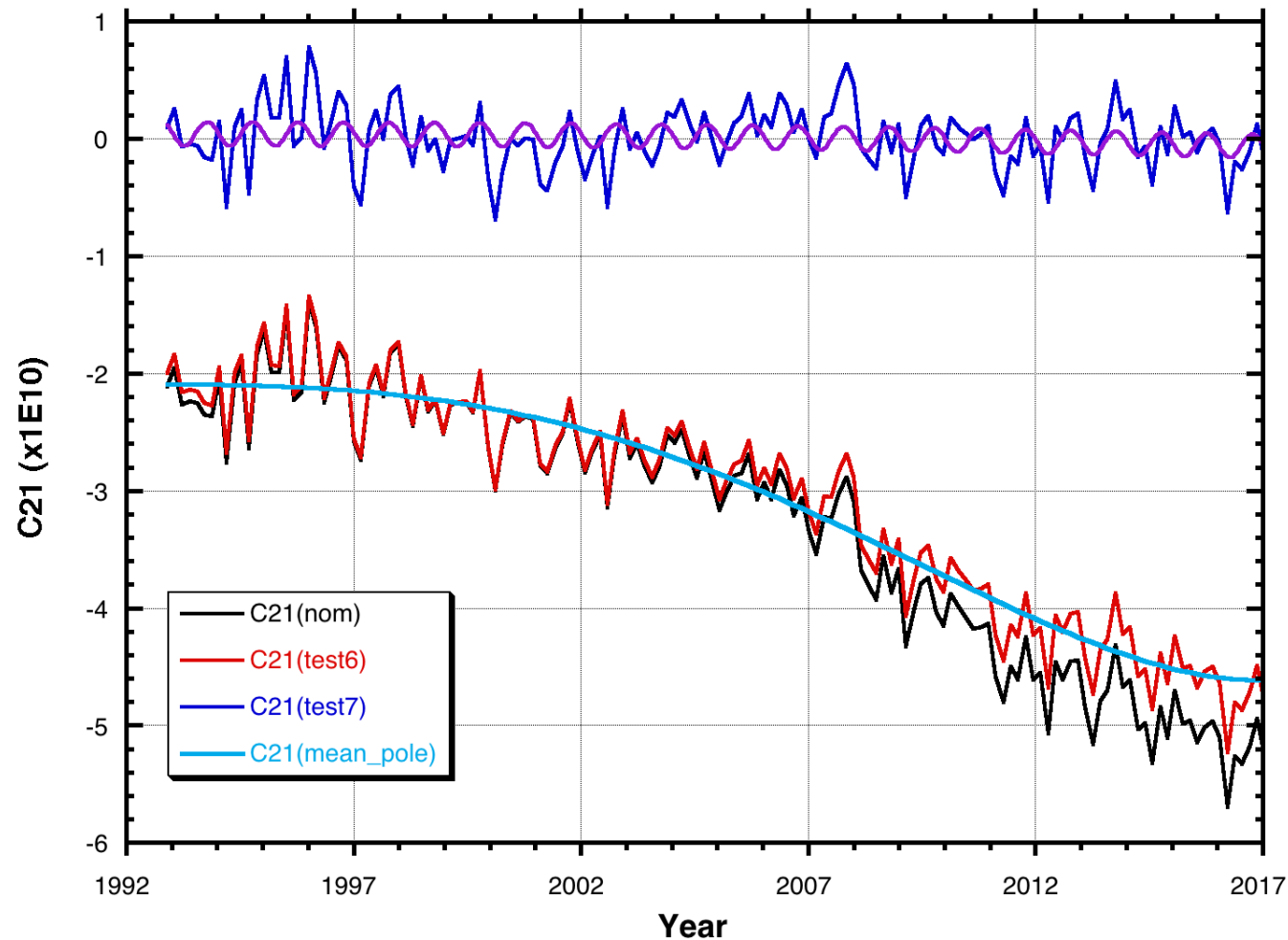
Geopotential (1)

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

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

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

Geopotential (2)

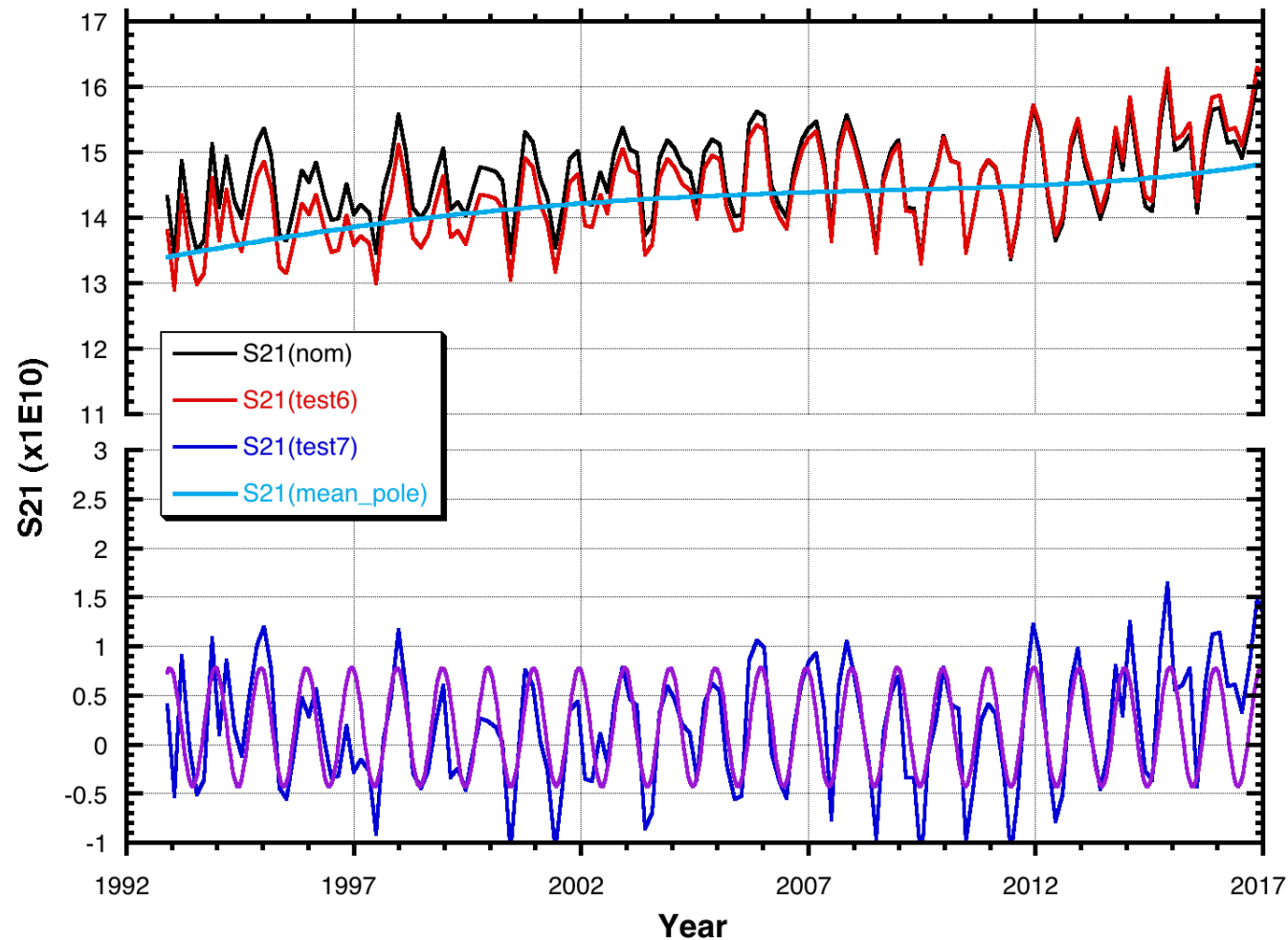


C21 estimated from SLR tracking to LAGEOS-1/2.

Estimated C21 should align with prediction from full 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)

Geopotential (3)

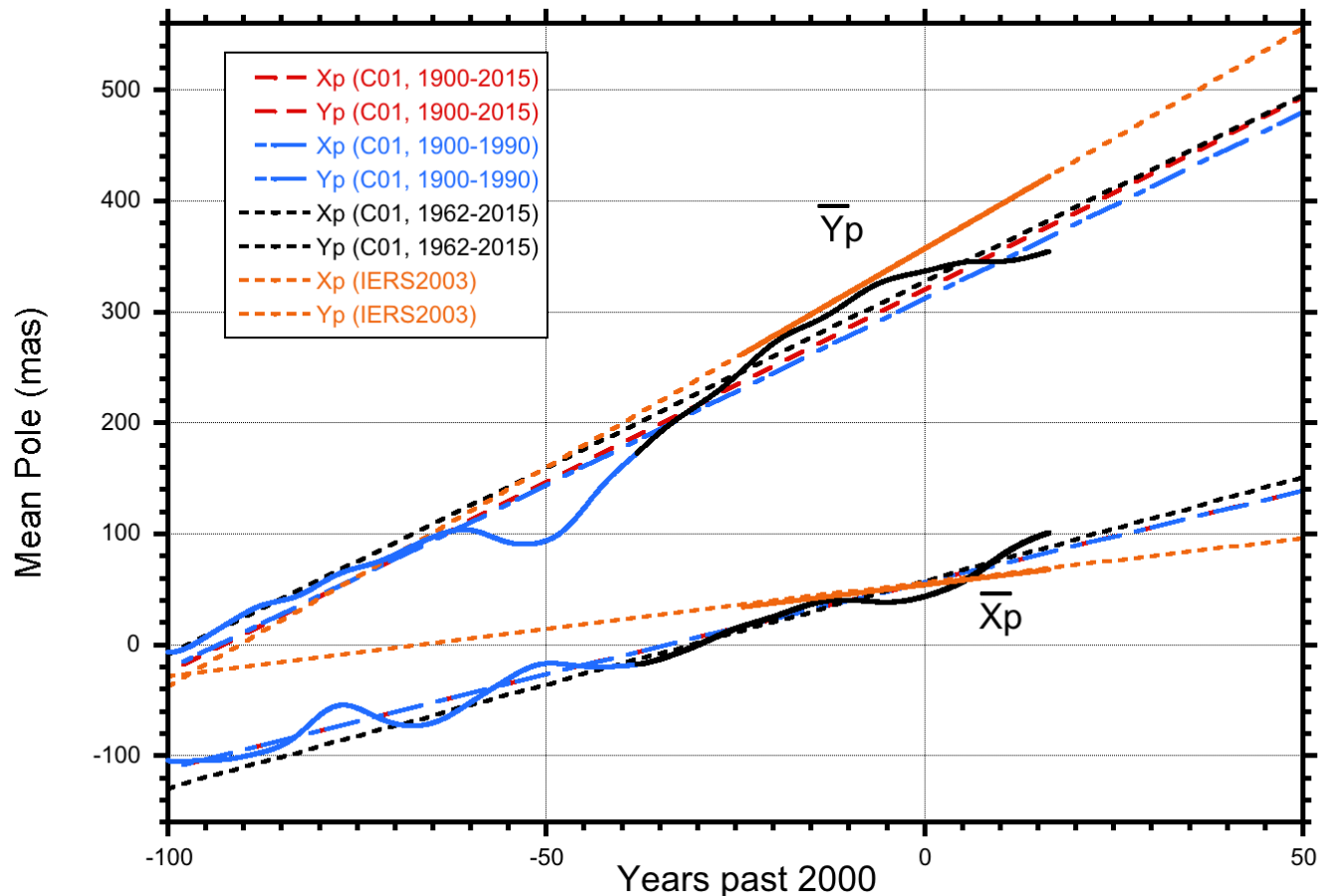


S21 estimated from SLR tracking to LAGEOS-1/2.

Estimated S21 should align with prediction from full 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)

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)

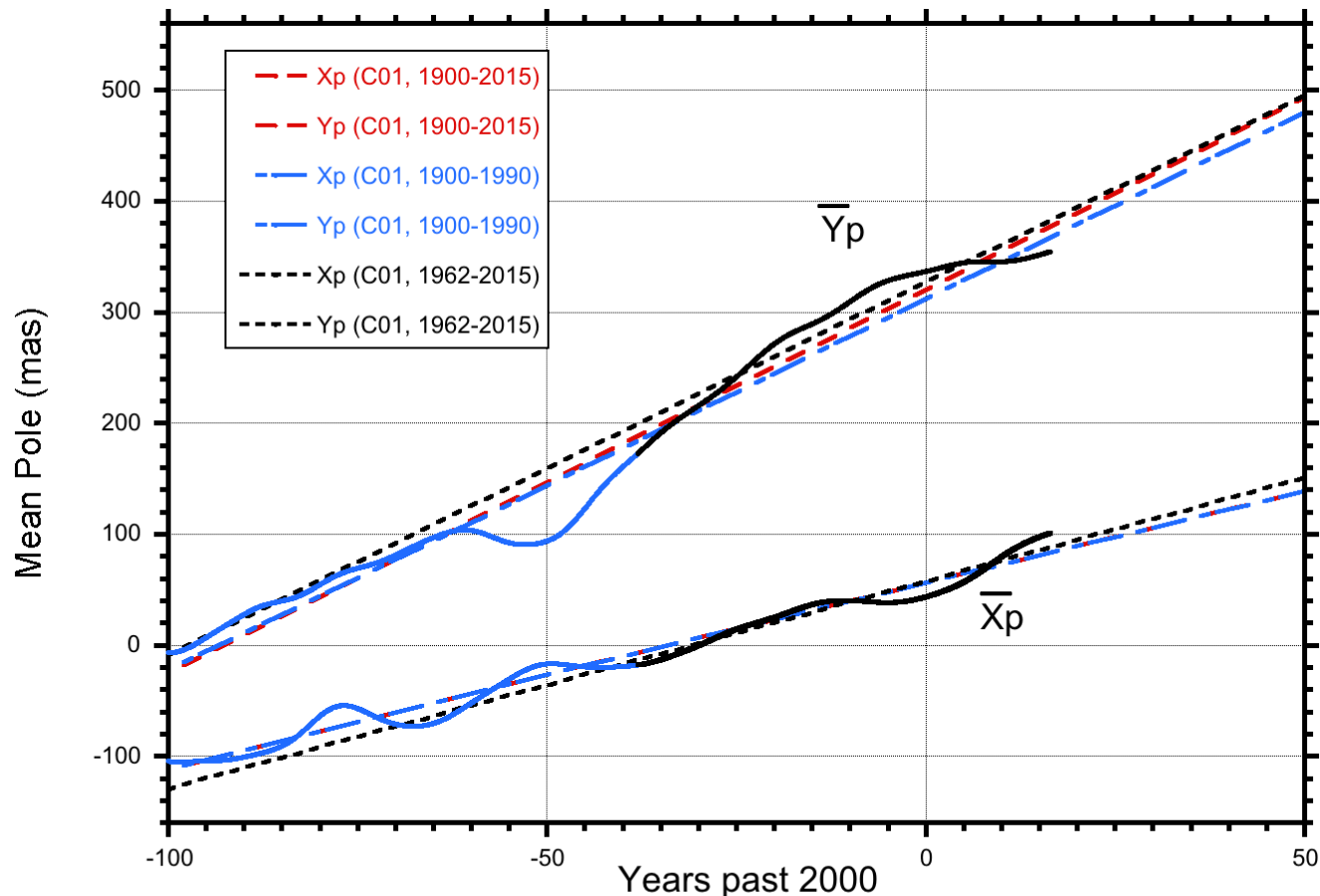
C01 is the IERS filtered mean pole at <ftp://iers.obspm.fr/iers/eop/eopc01/mean-pole.tab>

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:

$$\bar{X}_p = 55.0 + t * 1.677$$

$$\bar{Y}_p = 320.5 + t * 3.460$$

t is years past 2000

Any of these fits to C01 seem reasonable and internally consistent, 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 best represent the future secular trend of the IERS polar motion

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 interpreted as dominated by GIA?
 - Fitting the intervals 1900-2015, 1990-1990, 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

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?**