Long-term Polar Motion and Its Impact On GRACE/-FO Pole Tide Correction

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Pole Tide

- Polar motion is the nutation of the Earth about its axis of rotation.
- The polar motion time series consists of two predominate modes, the Chandler wobble (14-month period) and the annual wobble (12-month period)
- Long term interdecadal variability is driven by mass redistribution in and on the surface of the Earth
- Long term **linear** trend is from GIA

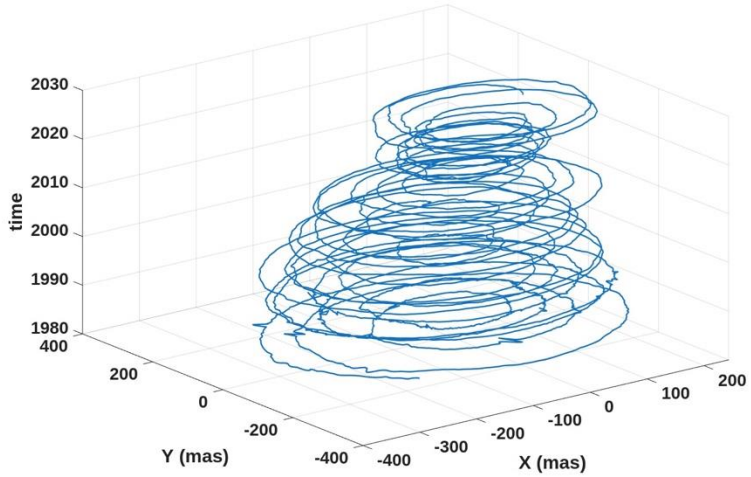

Fig. 1 *Polar motion plotted with time.*

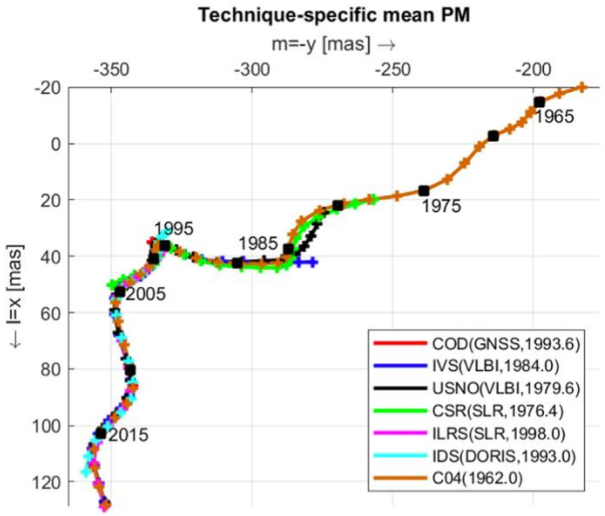

Fig. 2 Filtered polar motion where annual and Chandler wobble periods are removed (*Fig. 5 Beutler et al. 2020)*

Pole Tide

- Movement of the axis of rotation changes the centrifugal potential in an **Earth fixed** reference frame.
- The change of the moment of inertia causes a degree-2 order-1 signal
- The Earth is in hydrostatic equilibrium and thus a change in potential deforms the Earth, causing the pole tide.

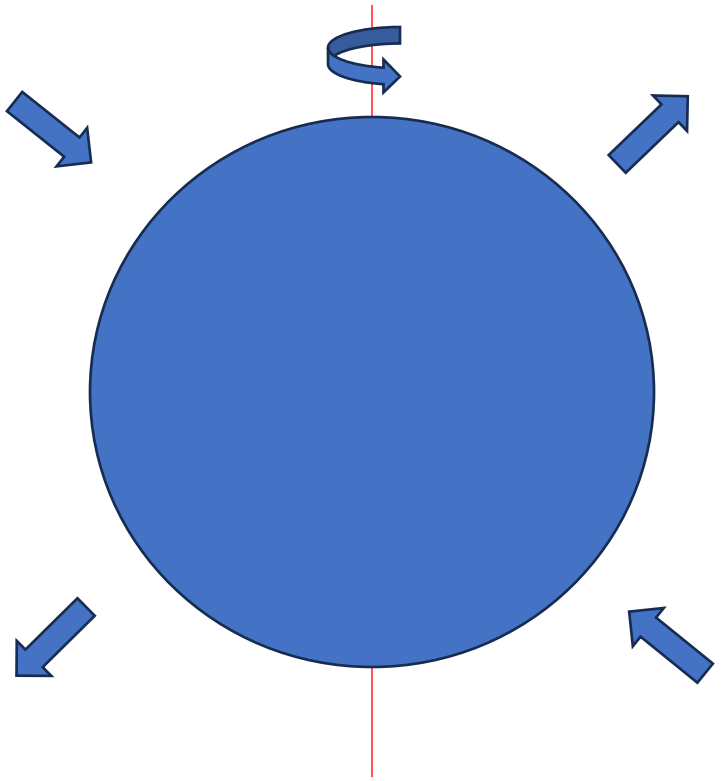

Fig. 3 Conceptual diagram of the deformation caused by polar motion.

Love Numbers

- Body Love numbers relate a change in potential to vertical, horizontal, and the potential change from deformation.
- They are numerically calculated using the mechanical and structural properties of the Earth model using models.
- For a fully elastic Earth the deformation is constant across frequencies, but for long time scales the inelasticity is accounted for with frequency dependent Love numbers
- Frequency-dependent Love numbers have a real and imaginary component:

$$k_2 = k_2^r + ik_2^i$$

To find the deformation for long period changes (such as GIA) a convolution with the frequency dependent love number and the deformation must be performed (Wahr et al. 2015).

Wahr et al. 2015 Pole Tide Correction

K_2 is evaluated at 14-month Chandler Wobble **not valid for GIA**

Wahr et al. 2015 pole tide correction:

$$\begin{pmatrix} C_{21}^{\mathrm{PT+GIA}} \\ S_{21}^{\mathrm{PT+GIA}} \end{pmatrix} = \begin{pmatrix} C_{21}^{\mathrm{GIA}} \\ S_{21}^{\mathrm{GIA}} \end{pmatrix} - 1.333 \times 10^{-9} \begin{pmatrix} \left[x_p - x_p^{\mathrm{GIA}}\right] + 0.0115 \left[y_p - y_p^{\mathrm{GIA}}\right] \\ \left[y_p - y_p^{\mathrm{GIA}}\right] - 0.0115 \left[x_p - x_p^{\mathrm{GIA}}\right] \end{pmatrix}$$
$$+ \begin{pmatrix} -2.1778 \times 10^{-10} \left(\left[x_p - x_p^{\mathrm{GIA}}\right] - 0.01724 \left[y_p - y_p^{\mathrm{GIA}}\right]\right) \\ -1.7232 \times 10^{-10} \left(\left[y_p - y_p^{\mathrm{GIA}}\right] + 0.03365 \left[x_p - x_p^{\mathrm{GIA}}\right]\right) \end{pmatrix}$$

GIA models include a pole tide so no need to calculate it separately

In order for the K_2 Love number to be valid the GIA trend must be subtracted

Wahr et al. 2015 Pole Tide Correction

- Wahr et al. 2015 introduced a pole tide correction that splits short period (Chandler and annual) variation, interdecadal variation, and GIA driven polar motion.
- By using GIA models, which contain a pole tide correction, and are already usually subtracted from GRACE/-FO data the GIA-driven pole tide is properly corrected for.
- In this correction the GIA model is assumed to perfectly model polar motion due to GIA and the trend subtracted from the polar motion time series accurately represents the polar motion due to GIA.

Impact On GRACE/-FO Pole Tide Correction

- If the pole tide is not properly removed then there will be a residual degree 2 order 1 signal.
  - This could come from improper modeling of GIA driven polar motion in GIA models or an incorrect trend chosen from observation data for the trend
  - Ideally we would select a GIA model and polar motion trend that perfectly agree

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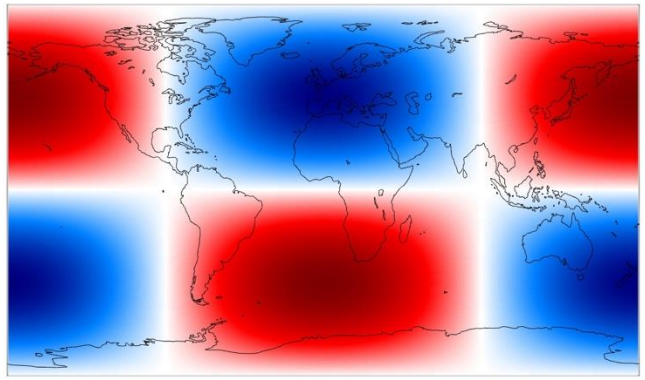

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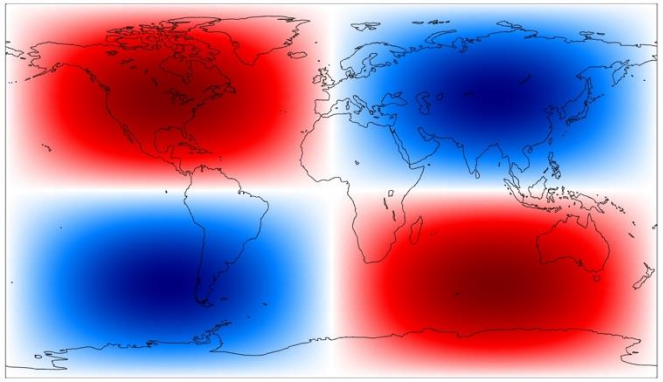


The pole tide has a maximum impact at +/- 45 degrees latitude.

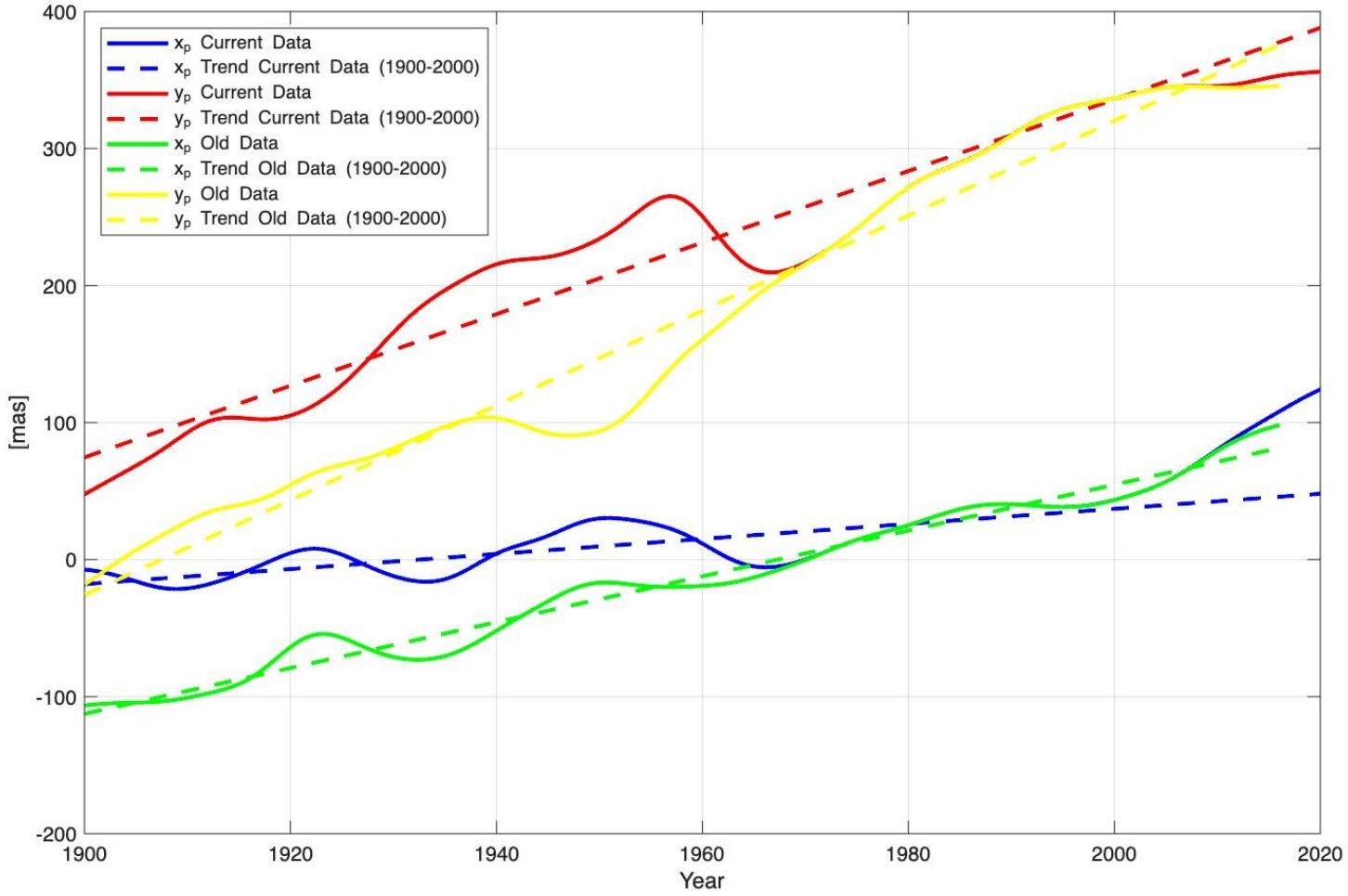
Wahr et al. 2015 estimate the ratio of pole tide to degree 2 order 1 mass variations about 50%

Changes In Polar Motion Data

- Changes in the IERS C01 polar motion time series around 2018 make trend derived from prior data inconsistent with current IERS polar motion data
  - Change in the underlying astrometric solution used for data pre-1972
- Trend should be determined using data from before ~2000 where polar motion diverges due to mass loss in the arctic.
  - With the previous IERS time series, inclusion of post 2000 data did not impact the trend (Ries 2017), with current IERS data this is not the case

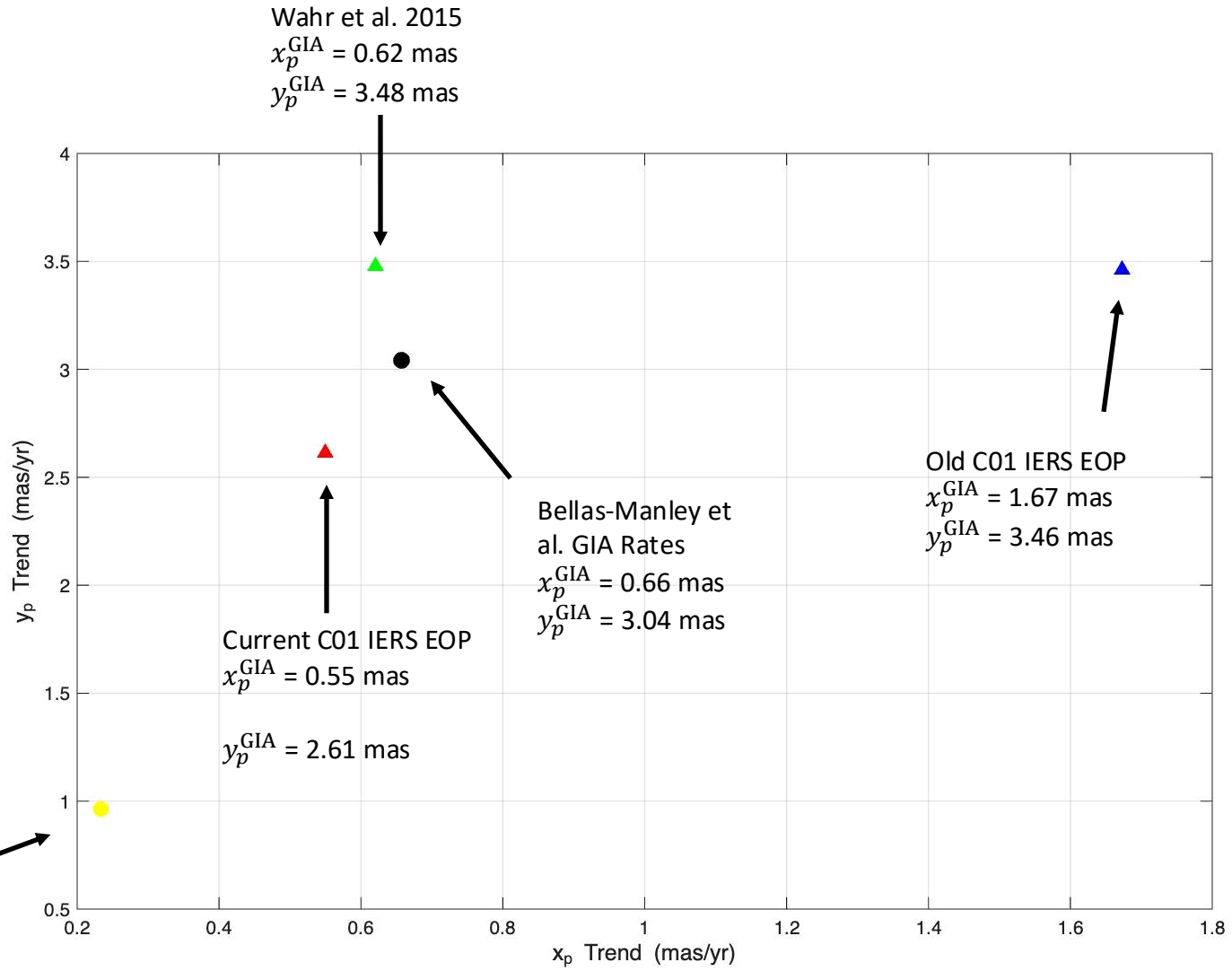
Changes In Polar Motion Data

- Data shown here is with a Gaussian filter with a width of 3.40 years (consistent with IERS mean pole)
- Trend is calculated from 1900-2000 which does not capture the impact of present-day ice mass loss
- Change in pre-1972 C01 data causes significant change in calculated long-term trends



Comparison of Trends

- Using the trend computed from the previous IERS EOP time series and the ICE6GD which is commonly removed from GRACE data there will be a residual degree 2 order 1 signal that is from an improper pole tide correction.
- Current IERS data agrees better with GIA models and should remove the pole tide more effectively.
- More work needs to be done to understand the reliability of polar motion time series and polar motion predicted by GIA models



Conclusions

- New GIA linear trend derived from current IERS C01 is significantly different from the previous trend
  - To be consistent with current IERS data, pole tide correction should be updated in GRACE/-FO processing
- Current IERS EOP derived trend agrees better with GIA models
  - Will better remove GIA pole tide
- More work needs to be done investigating IERS data and polar motion reported by GIA models

Thank You!

If you have any questions please email:

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References

[1] Beutler, Gerhard et al. (Dec. 2020). Long polar motion series: Facts and insights. doi:10.1016/j.asr.2020.08.033.

[2] Peltier, W.R., Argus, D.F. and Drummond, R. (2018) Comment on "An Assessment of the ICE-6G_C (VM5a) Glacial Isostatic Adjustment Model" by Purcell et al. J. Geophys. Res. Solid Earth, 123, 2019-2018, doi:10.1002/2016JB013844.

[3] Wahr, R. Steven Nerem, and Srinivas V. Bettadpur (2015). “The pole tide and its effect on GRACE time-variable gravity measurements: Implications for estimates of surface mass variations”. In: Journal of Geo-physical Research: Solid Earth 120 (6), pp. 4597–4615.issn: 21699356. doi: 10.1002/2015JB011986.

IERS C01 Data: https://hpiers.obspm.fr/iers/eop/eopc01/