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Updating the Pole Tide Model for Satellite Altimetry

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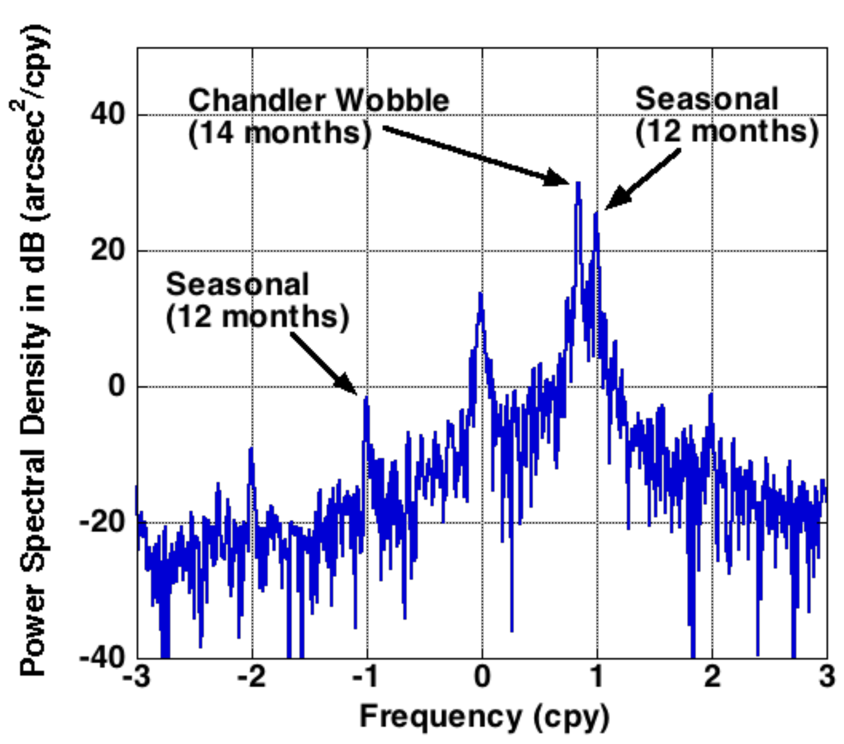
Abstract

We evaluate errors in the pole tide model that is currently adopted by most users of satellite altimeter sea surface height measurements and identify possible improvements to that model. Of the various geophysical models that are typically applied as corrections to these measurements, those for the pole tide and luni-solar body tide have not been revised since the launch of TOPEX/Poseidon more than two decades ago. We describe two improvements to the pole tide model for satellite altimeter measurements. Firstly, we recommend an approach that improves the model for the response of the oceans by including the effects of self-gravitation, loading, and mass conservation. Our recommended approach also specifically includes the previously ignored displacement of the solid Earth due to the load of the ocean response, and includes the effects of geocenter motion. Altogether, this improvement amplifies the modeled geocentric pole tide by 15%, or up to 2 mm of sea surface height displacement. We validate this improvement using two decades of satellite altimeter measurements. Secondly, we recommend that the altimetry pole tide model exclude geocentric sea surface displacements resulting from the long-term drift in polar motion. The response to this particular component of polar motion requires a more rigorous approach than is used by conventional models. We show that erroneously including the response to this component of polar motion in the pole tide model impacts interpretation of regional sea level rise by +/- 0.25 mm/year.

What is the Pole Tide?

- Displacement in geocentric sea surface caused by differential centrifugal force that results from polar motion:
  - Polar motion is variation in the location of the Earth's instantaneous rotation axis.
  - Geocentric sea surface displacements have amplitudes of up to 70 mm/arcsec.
    - Amplitudes as large as 20 mm.
  - Spatial dependence is primarily degree 2 order 1 spherical harmonic.
- Polar motion, and therefore pole tide, dominated by periodic variations at periods:
  - 14 months (prograde motion) with time varying amplitude of 0.05-0.25 arcsec.
    - Chandler wobble free-mode of the Earth.
  - 12 months with amplitude of 0.12 arcsec.
    - Seasonal mass redistribution.
- Polar motion also has long-term drift.
  - 0.0035 arcseconds/year



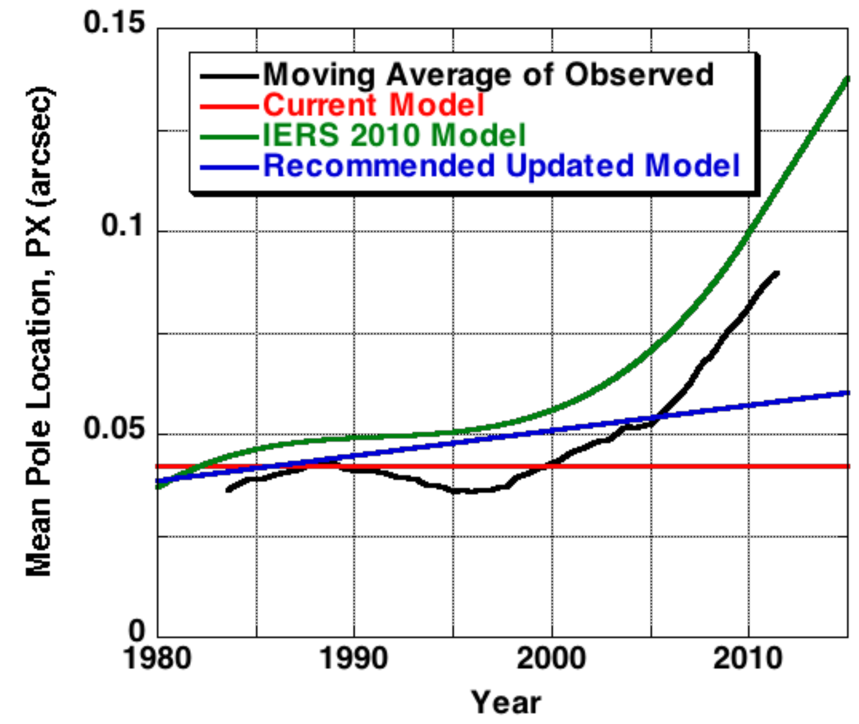
Current Pole Tide Model for Altimetry

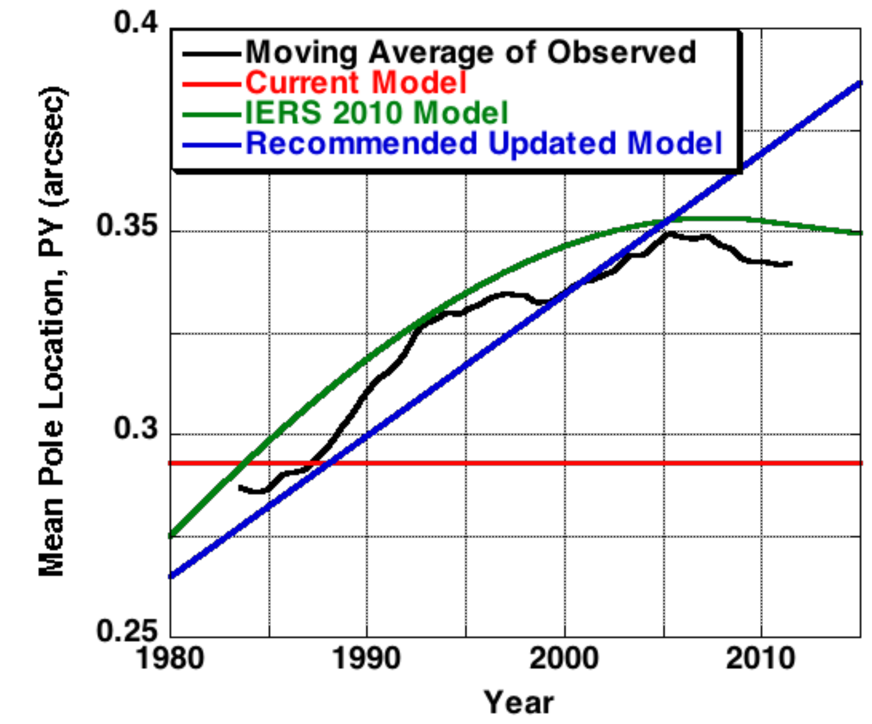
- Current model not revised since before launch of Topex/Poseidon mission (1992).
  - **Has two deficiencies:**
    1. **Not valid for long-term drift in polar motion.**
       - Models response of solid Earth and oceans using elastic Love number k_2 that is ONLY valid for periodic variations.
    2. **Ignores effects of self-gravitation, loading, conservation of mass, and geocenter motion arising from redistribution of mass of oceans.**
       - Only models very long-wavelength sea surface displacement using degree 2 order 1 spherical harmonic distribution function.

References

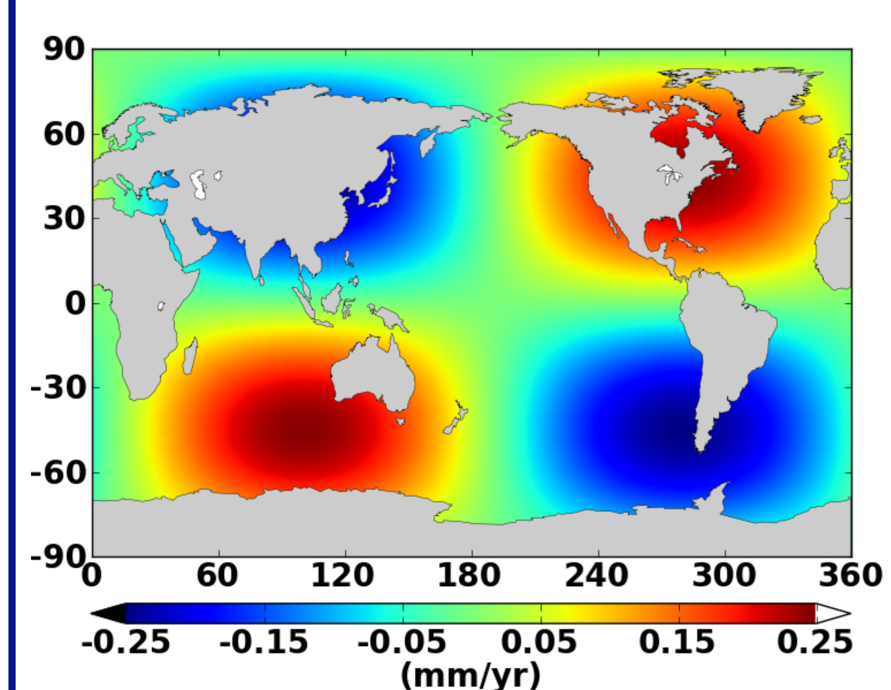
- Desai, S. D., Wahr. J., and B. Beckley (2015), Revisiting the pole tide for and from satellite altimetry, J. Geodesy, doi: 10.1007/s00190-015-0848-7.
- Wahr, J., R. S. Nerem, and S. Bettadpur (2015), The pole tide and its effect on GRACE time-variable gravity measurements: Implications for estimates of surface mass variations, J. Geophys. Res. Solid Earth, 120, 4597-4615, doi: 10.1002/2015JB011986.

Improvements to Model of Temporal Dependence



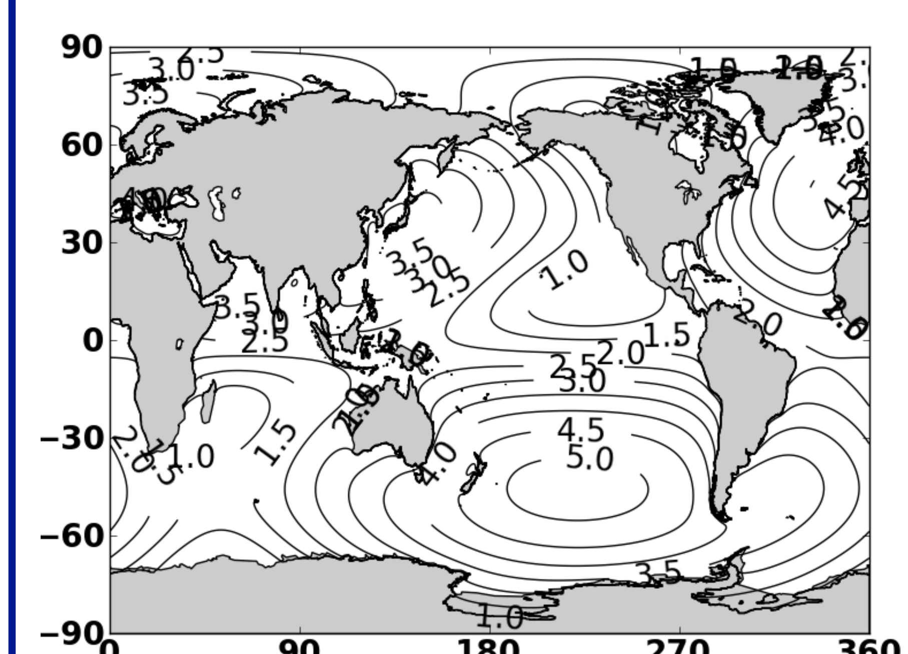


- "Mean Pole" must be removed from observed polar motion before applying conventional tidal Love number theory to compute displacements.
- Current model for mean pole location is outdated by 20 years.
  - Only uses bias and does not account for long-term drift in observed polar motion.
  - Tidal Love number theory cannot be applied to long-term drift.
- Recommended updated model of "Mean Pole" includes bias and long-term drift.
  - Drift determined from 80 years of observations.

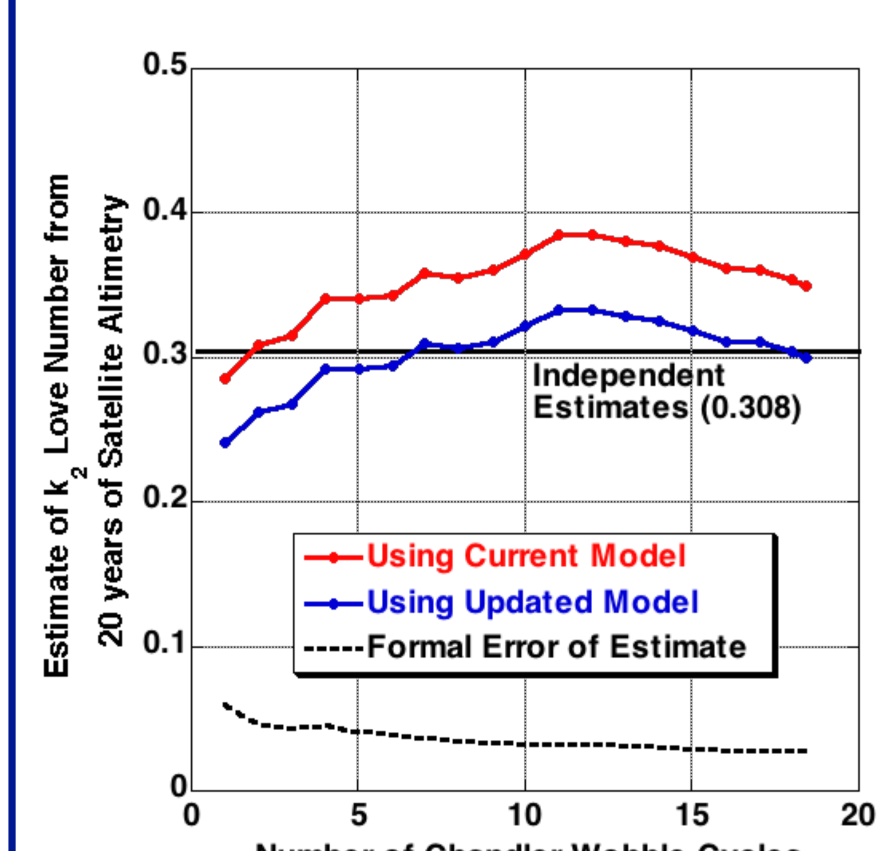


- Sea surface displacement caused by long-term drift in polar motion is incorrectly represented by current pole tide model.
  - Better to use GIA-models for these effects.
    - Following Wahr et al., (2015).
- **Regional mean sea level rise misrepresented when using the current pole tide model.**
  - **Error of +/- 0.25 mm/year.**
  - **Global average of 0.01 mm/year.**

Improvements to Model of Spatial Dependence



- Recommended updated model of expected geocentric response to polar motion accounts for self-gravitation, loading, mass conservation, and geocenter motion.
- Spatially dependent deviations from current model have maximum of 5.2 mm/arcsec and global RMS of 3 mm/arcsec.
  - Maximum of 1.3 mm and RMS of 0.8 mm with polar motion amplitude of 0.25 arcsec.



- 20 years of satellite altimetry sea surface height observations used to estimate pole tide Love number, k_2.
- **Estimate agrees very well with independent estimate (0.308) when using the updated model of expected geocentric response.**
  - $\mathbf{k_2 = 0.298 \pm 0.027}$.
- Estimate is 16% larger when using current model of expected geocentric response.
  - $k_2 = 0.347 \pm 0.029$
- **Updated model better represents geocentric response to polar motion.**