



Low-Degree Gravitational Change and Surface Mass Variations

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Main Objective:

To investigate degree-2 gravitational changes, ΔC_{21} , ΔS_{21} , & ΔC_{20} using multiple sources of data, including

- Earth rotation
- Climate models (atmosphere, ocean, and hydrosphere)
- Satellite laser ranging (SLR)
- GRACE

with a focus on long-term time scales, including interannual, decadal, and long-term trend.



Earth Rotation & Gravity

Geometric Approach: (only valid at long-term time scale)

- In Earth gravity model, C_{21} and S_{21} coefficients describe the position of the Earth's figure axis.
- When averaged over many years (decades), the figure axis should closely coincide with the observed position of the rotation pole averaged over the same time period.
- This leads to a linear relationship between the fully normalized C_{21} and S_{21} coefficients and the mean pole position (x and y).
- Long-term C_{21} and S_{21} rates are derived by long-term polar motion rates.

$$C_{21} = C_{21}(t_0) + \dot{C}_{21} [t - t_0]$$

$$S_{21} = S_{21}(t_0) + \dot{S}_{21} [t - t_0]$$



Earth Rotation & Gravity

Dynamic Approach: (only valid at long-term time scale)

- **ΔC_{21} , ΔS_{21} , and ΔC_{20} from Earth rotational excitations**

Mass-induced Earth rotational excitations (χ_i) are proportional to ΔC_{21} , ΔS_{21} , and ΔC_{20} via,

$$\Delta C_{21} = - (1 + k_2) \sqrt{\frac{3}{5}} \frac{(C - A)}{1.098 R^2 M} \epsilon_1$$

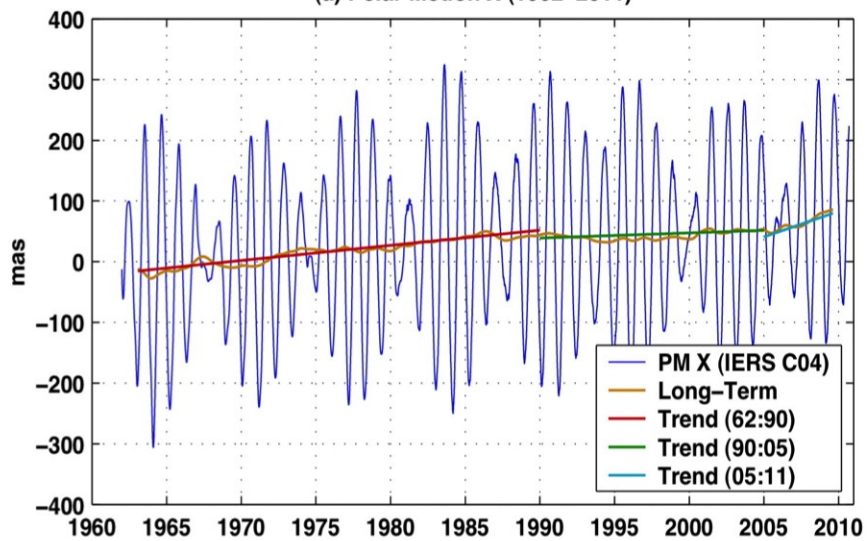
$$\Delta S_{21} = - (1 + k_2) \sqrt{\frac{3}{5}} \frac{(C - A)}{1.098 R^2 M} \epsilon_2$$

$$\Delta C_{20} = - (1 + k_2) \frac{3}{2\sqrt{5}} \frac{C_m}{0.753 R^2 M} \epsilon_3 + \frac{1}{2\sqrt{5}} \frac{DT}{MR^2}$$

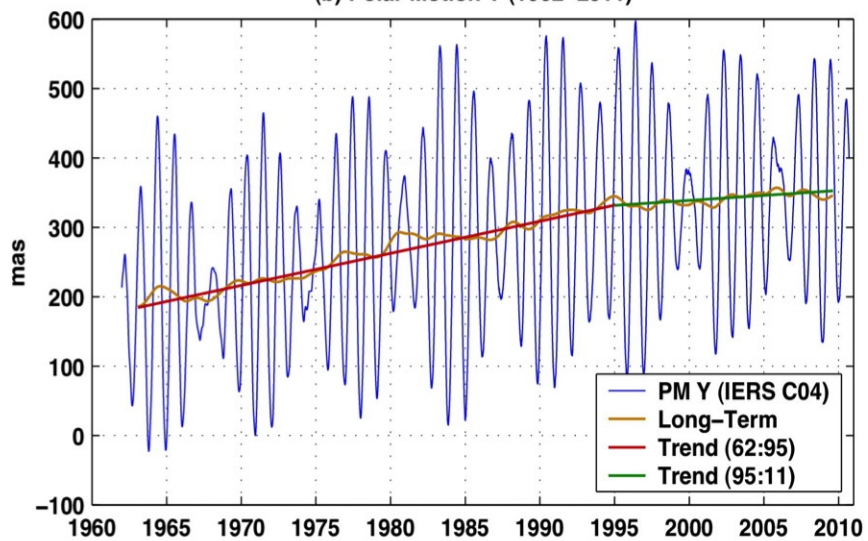
where $\Delta T=0$, when considering mass load change on a sphere surface for a mass conserving Earth system (atmosphere, ocean, land water), and

$$\chi_i = C_i^{observed} - C_i^{wind} - C_i^{current} \quad i = 1, 2, 3$$

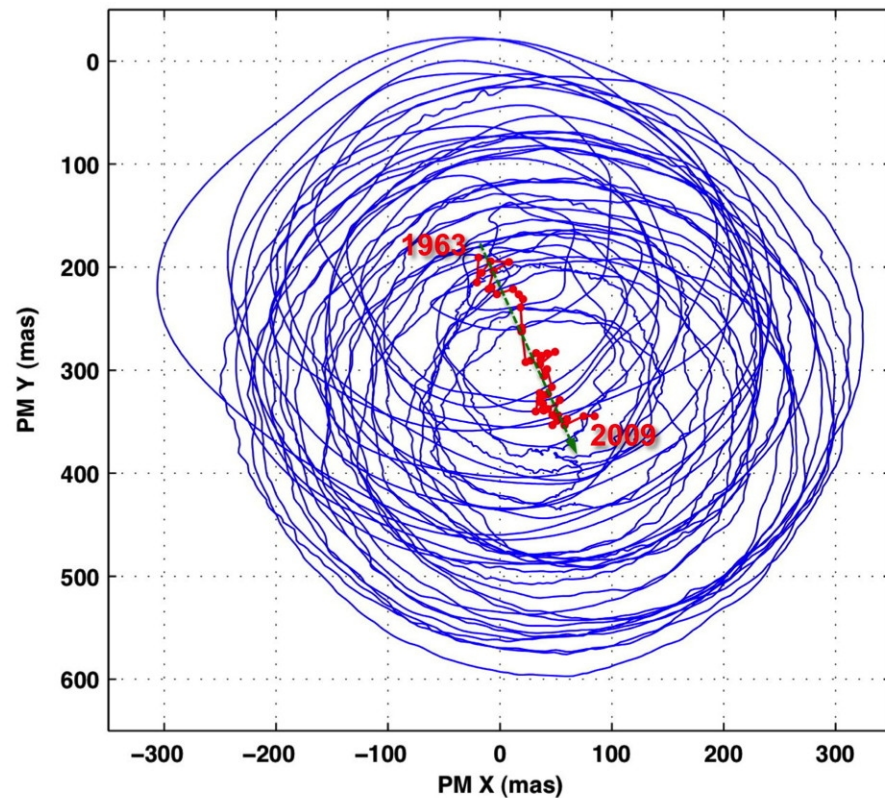
(a) Polar Motion X (1962–2011)



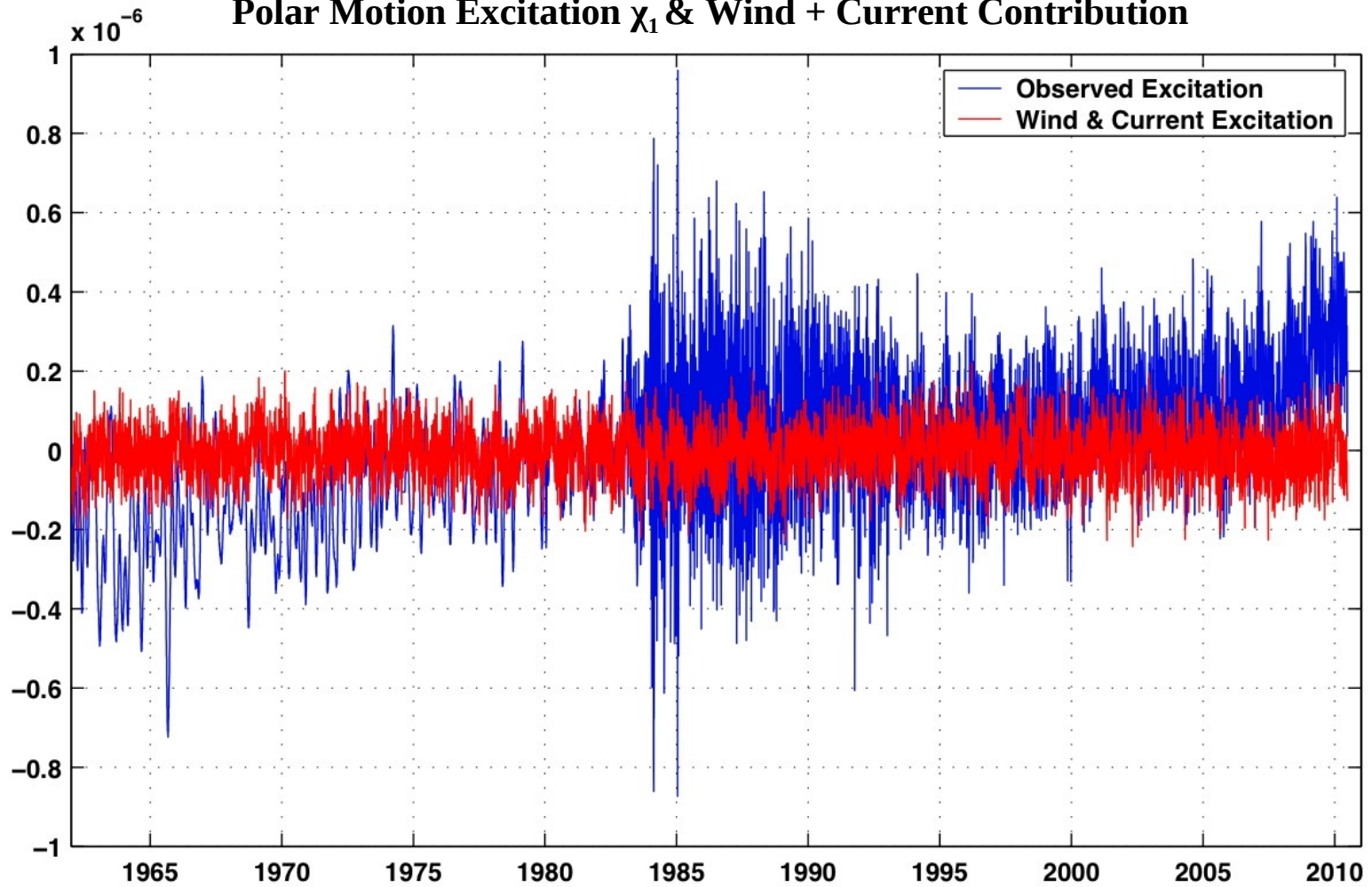
(b) Polar Motion Y (1962–2011)



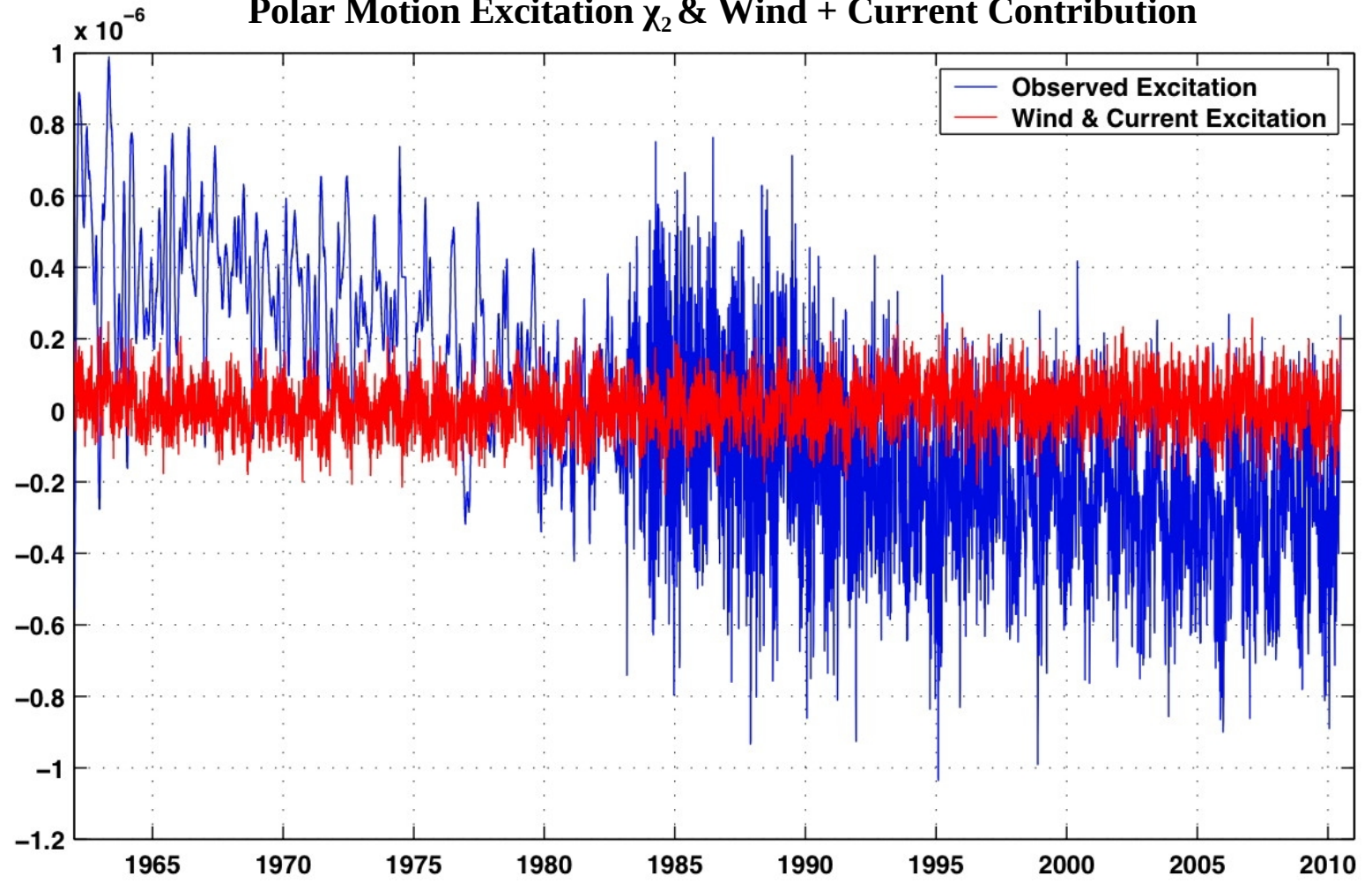
(c) Trace of pole position (1962–2011)



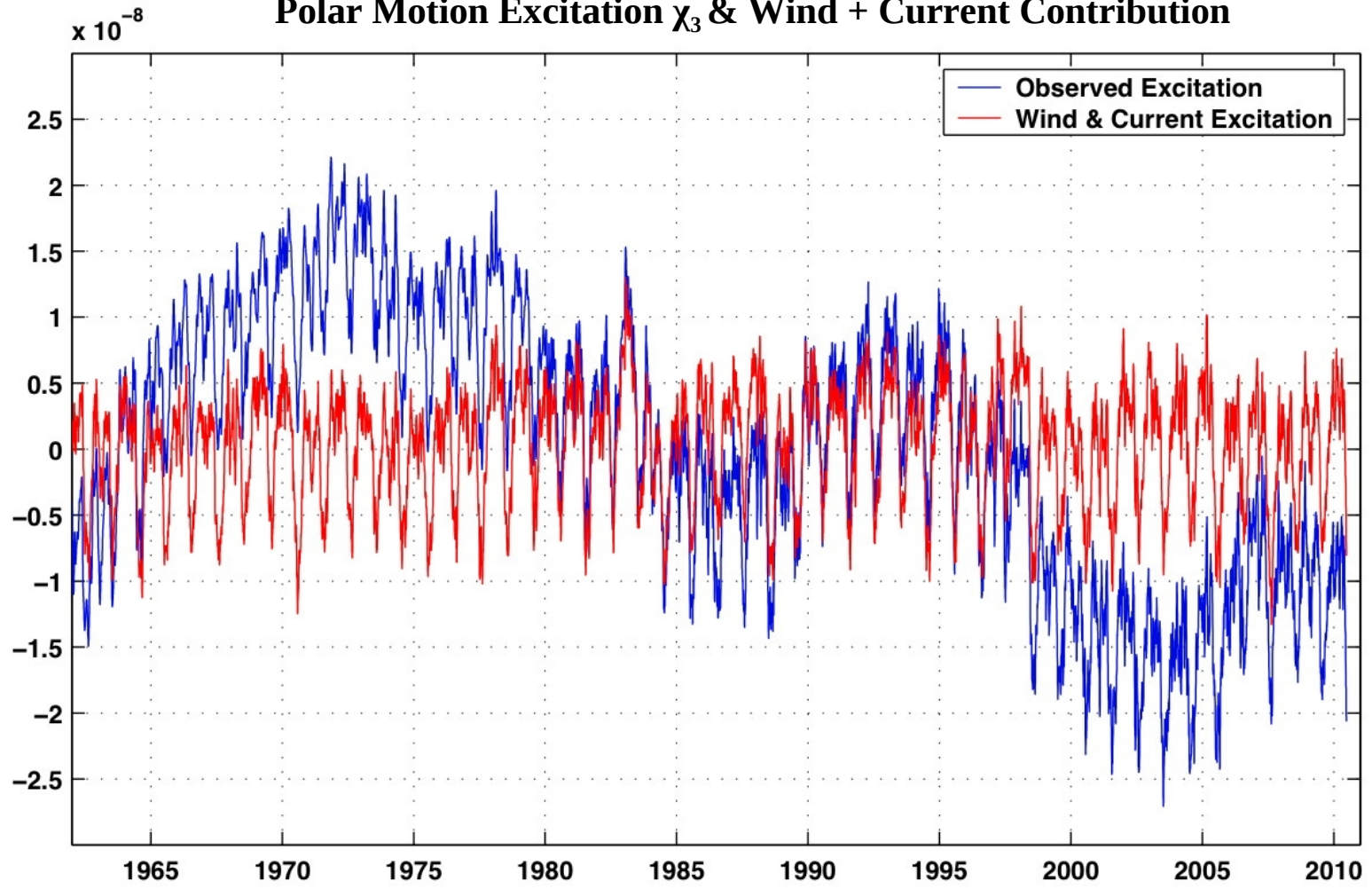
Polar Motion Excitation χ_1 & Wind + Current Contribution



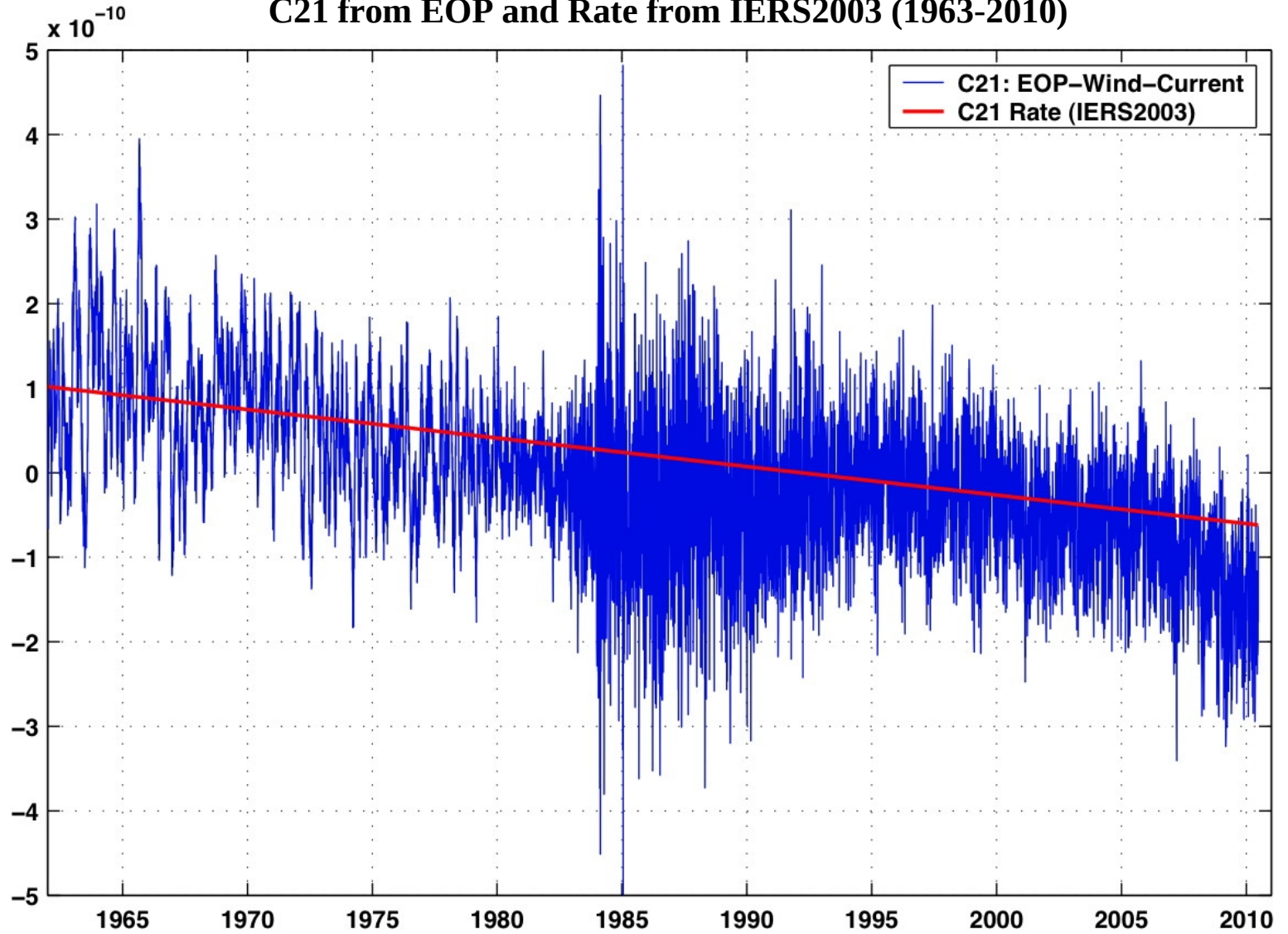
Polar Motion Excitation χ_2 & Wind + Current Contribution



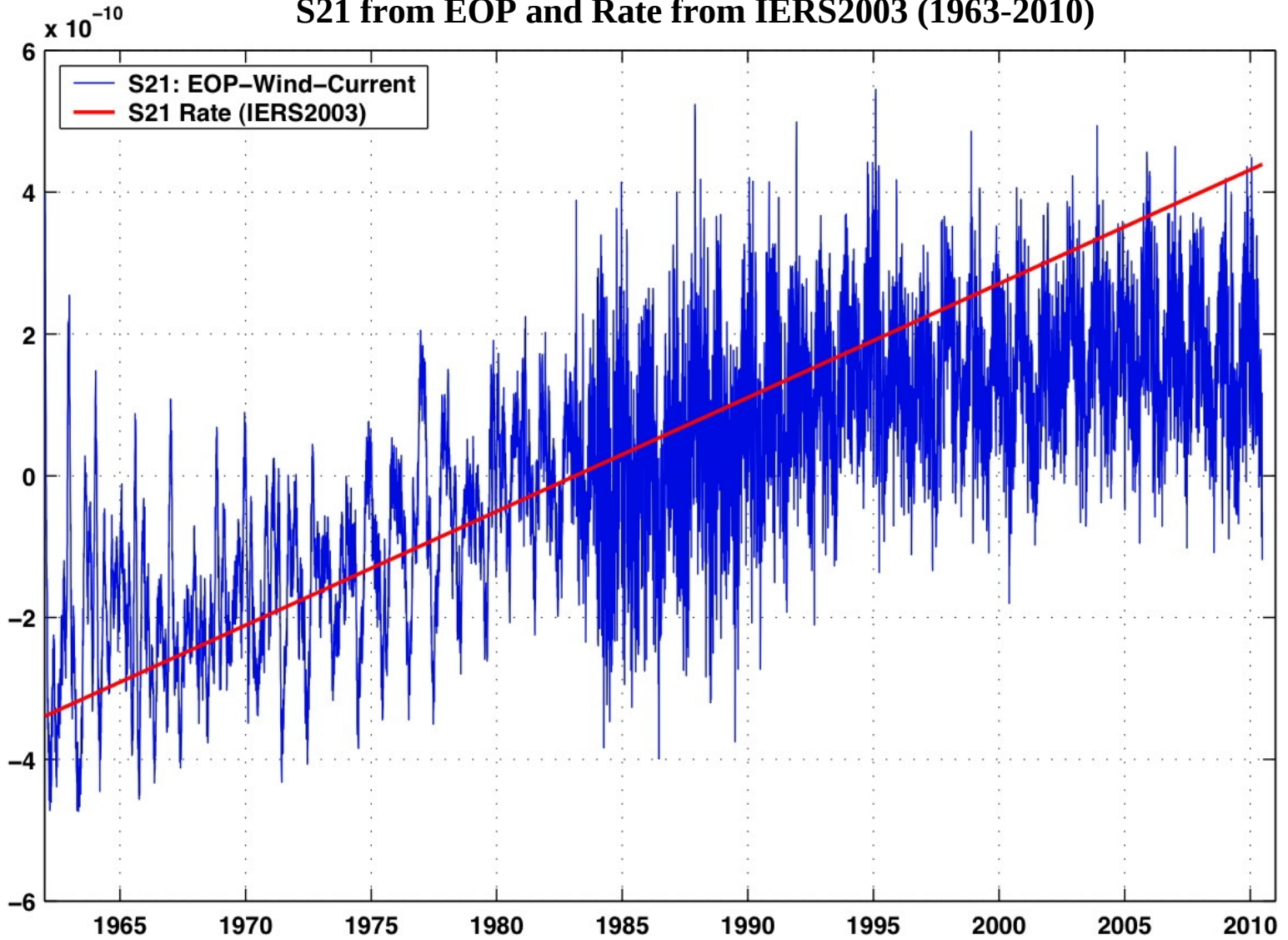
Polar Motion Excitation χ_3 & Wind + Current Contribution



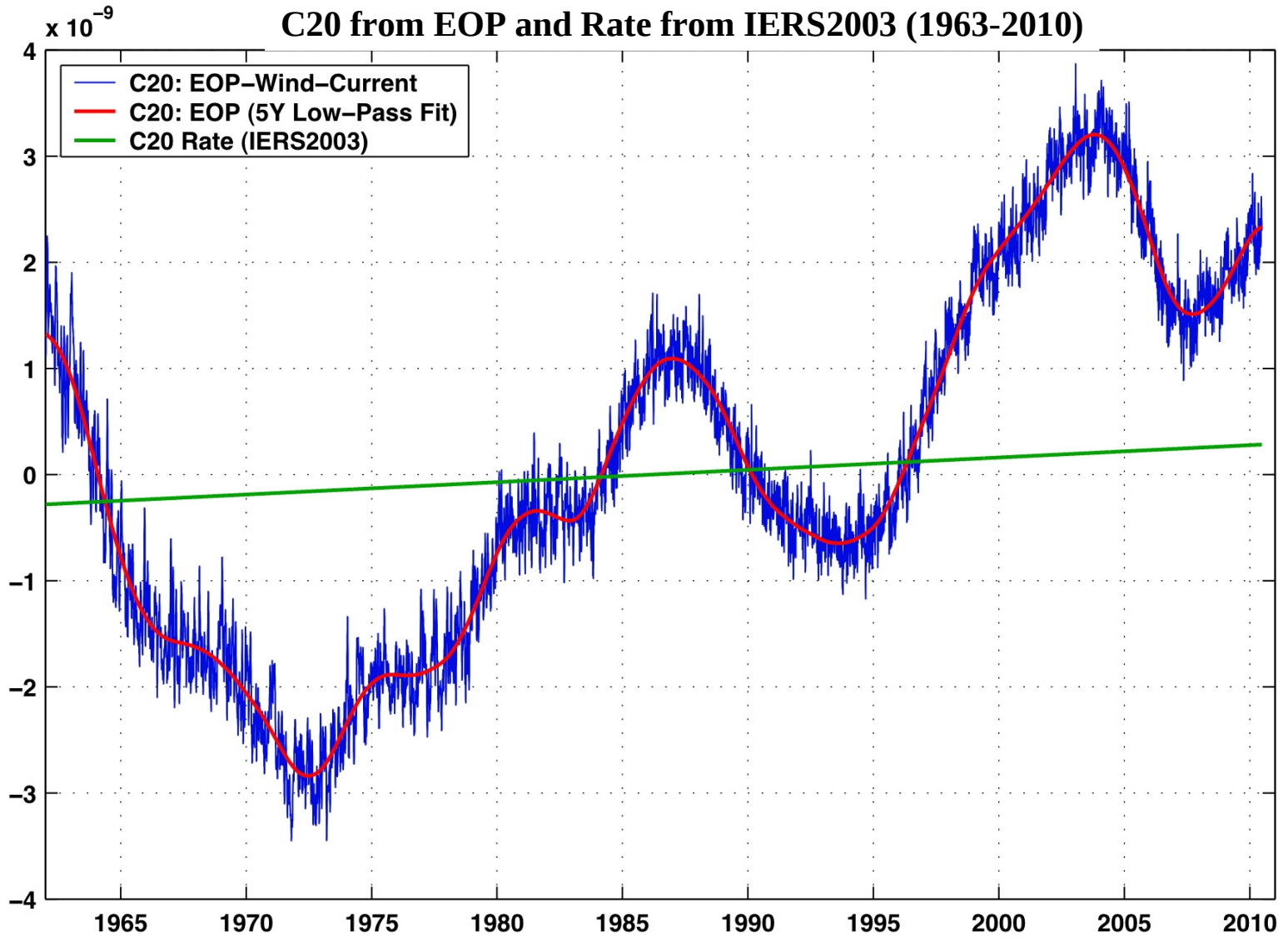
C21 from EOP and Rate from IERS2003 (1963-2010)



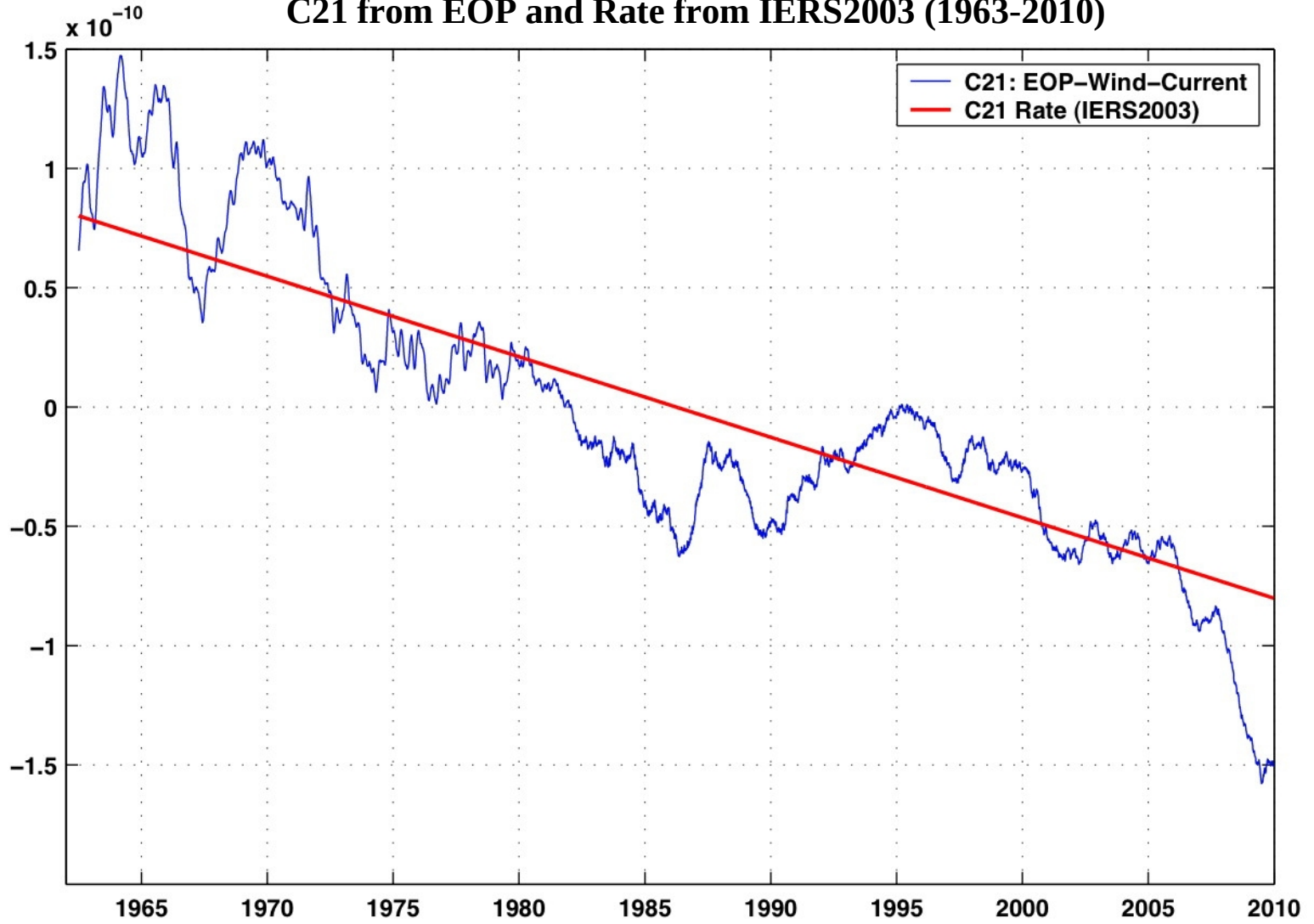
S21 from EOP and Rate from IERS2003 (1963-2010)



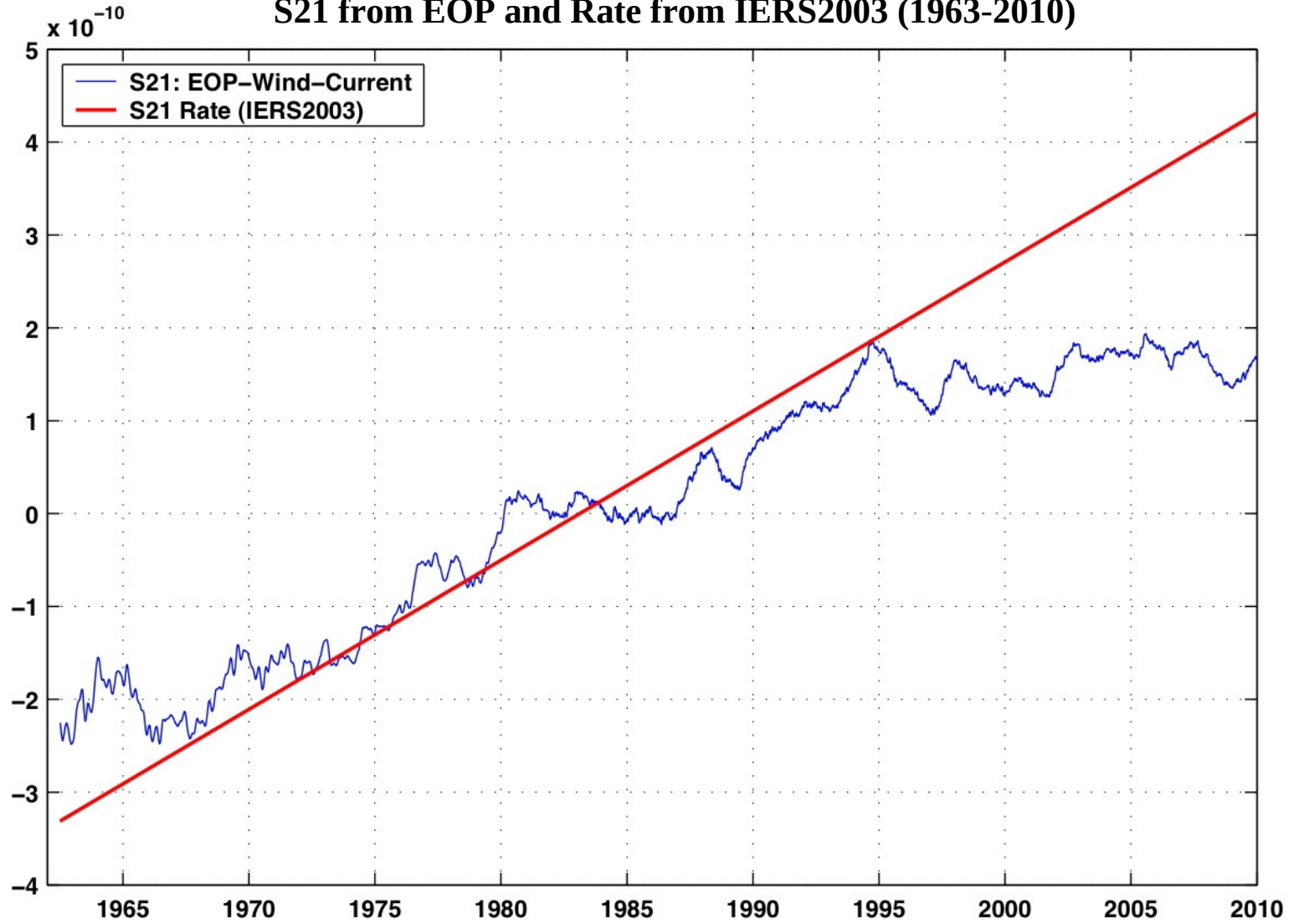
C20 from EOP and Rate from IERS2003 (1963-2010)



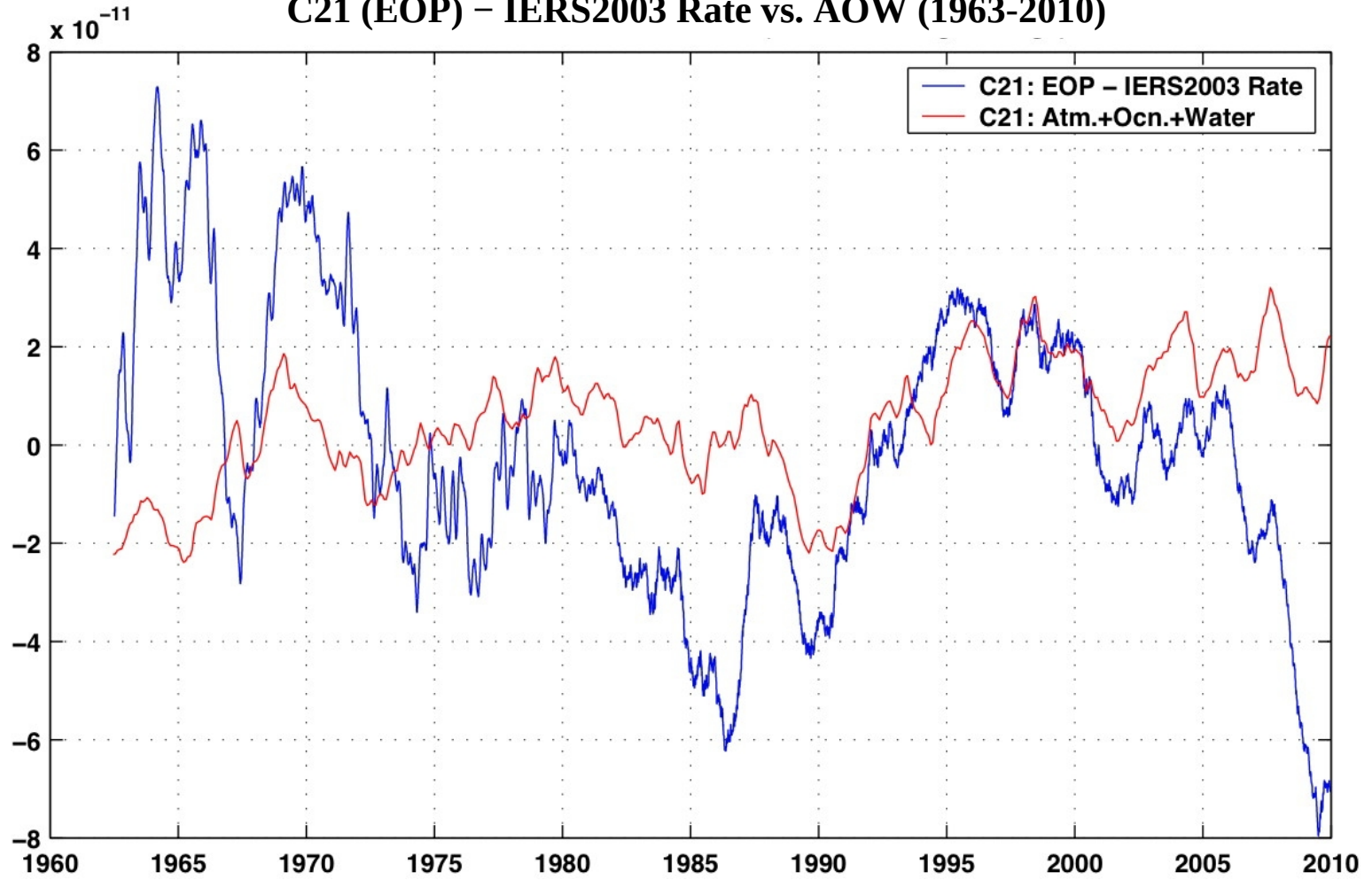
C21 from EOP and Rate from IERS2003 (1963-2010)



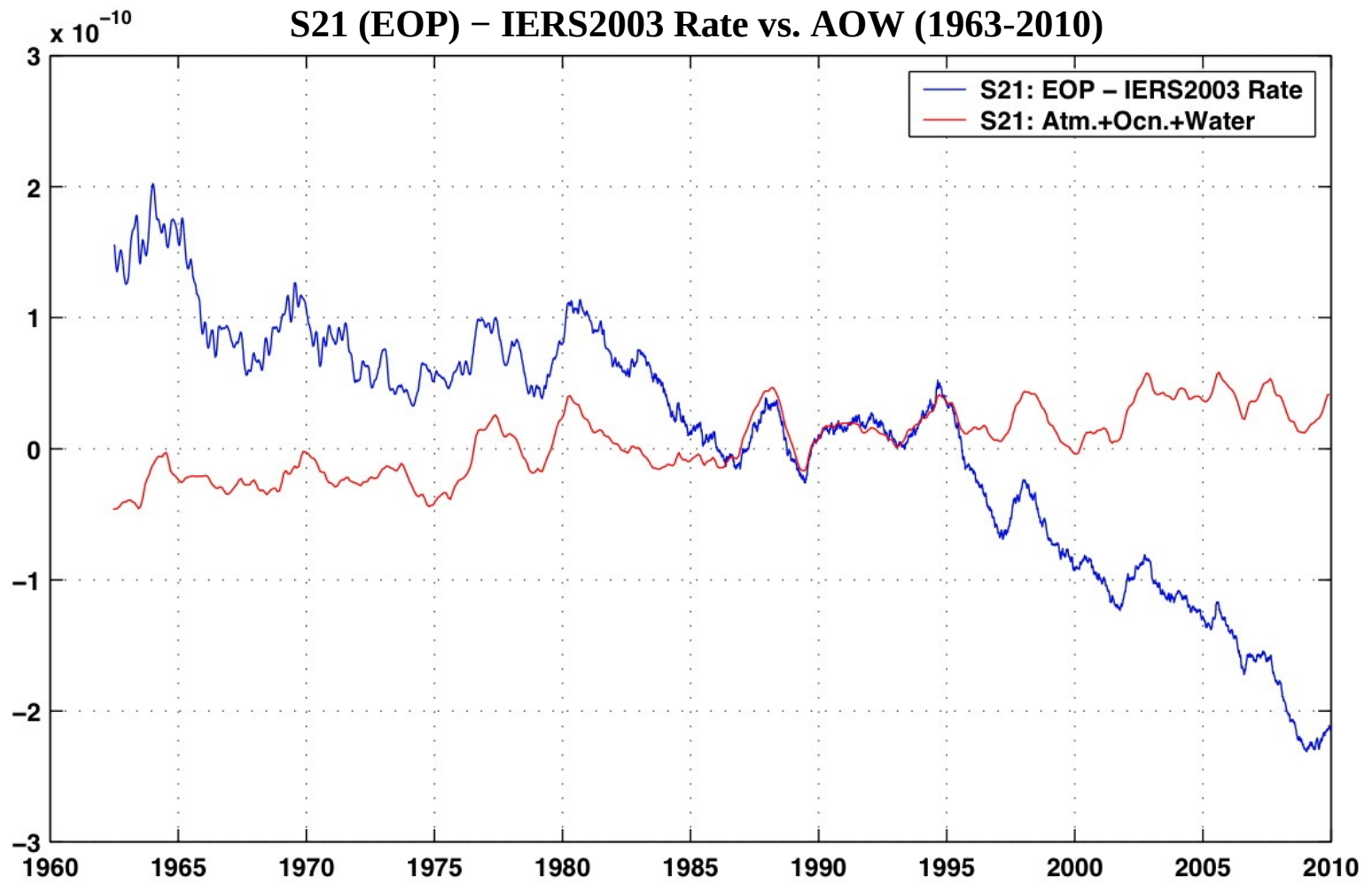
S21 from EOP and Rate from IERS2003 (1963-2010)



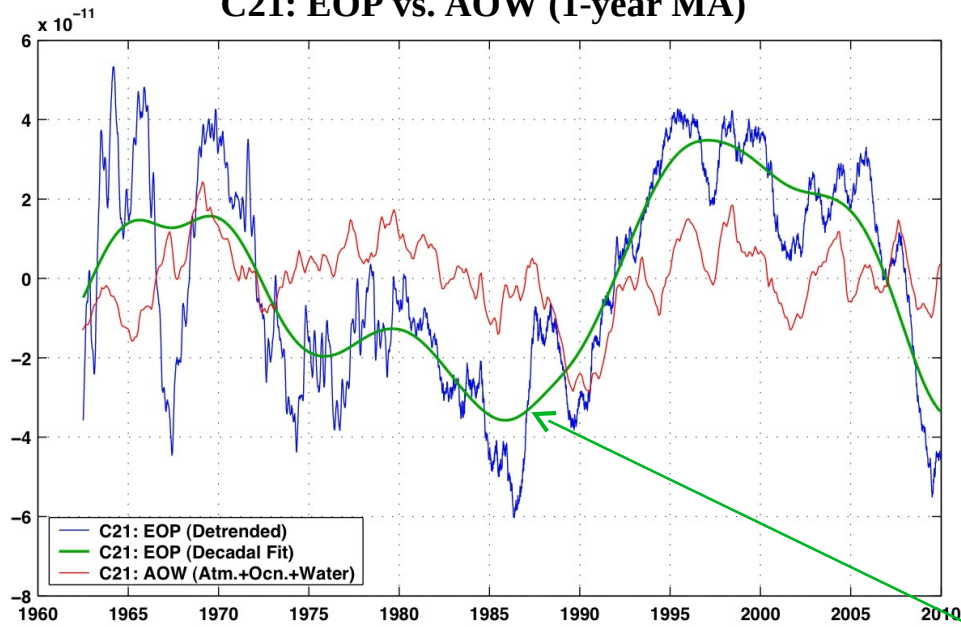
C21 (EOP) – IERS2003 Rate vs. AOW (1963-2010)



S21 (EOP) – IERS2003 Rate vs. AOW (1963-2010)

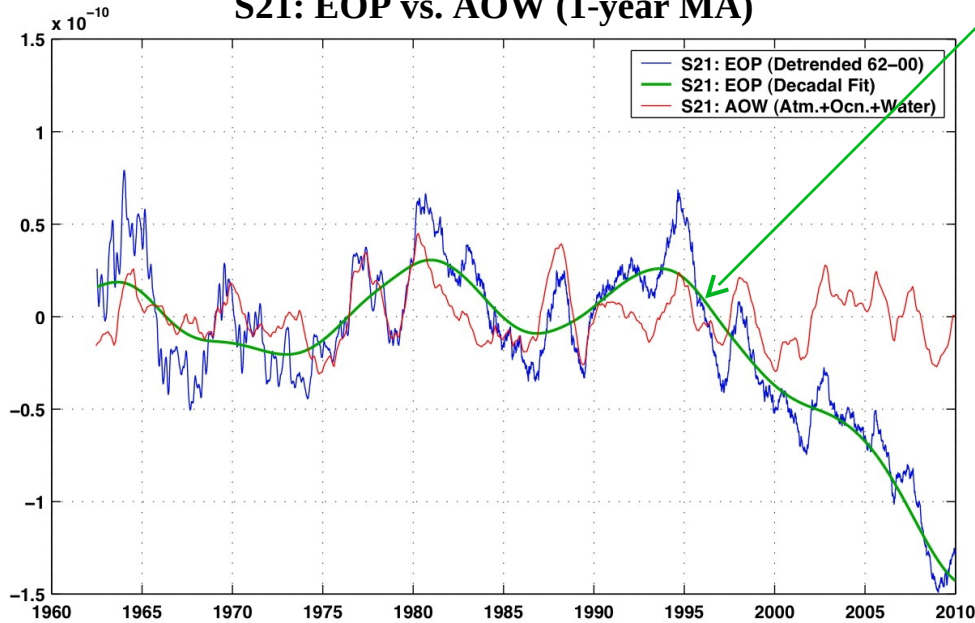


C21: EOP vs. AOW (1-year MA)

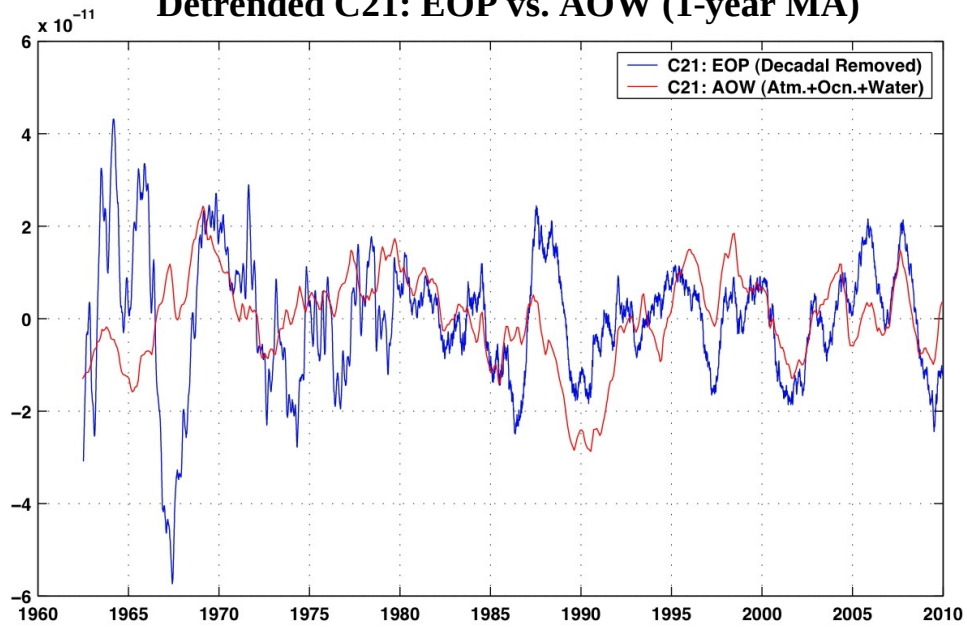


Decadal Signal

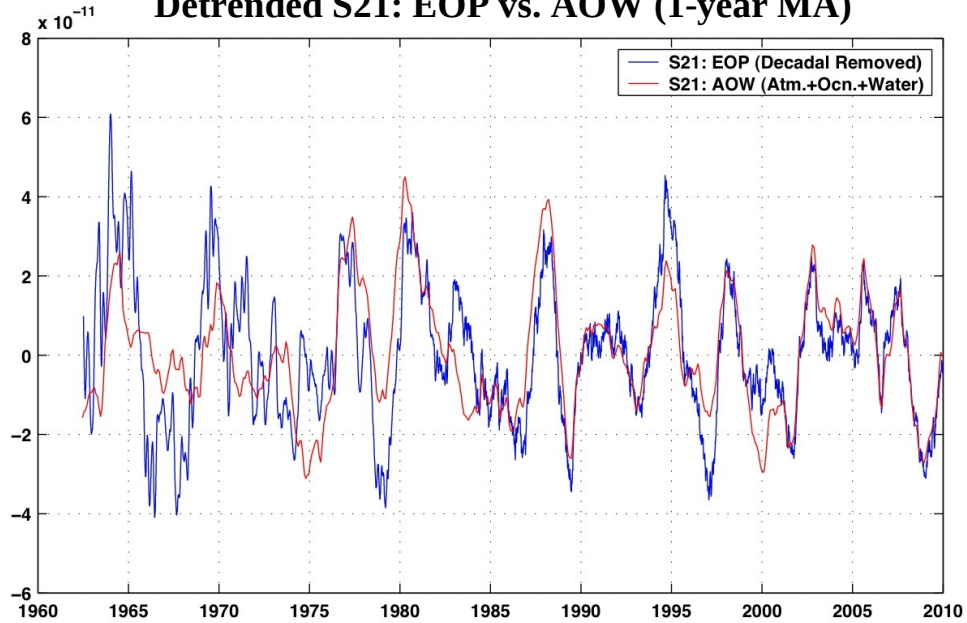
S21: EOP vs. AOW (1-year MA)

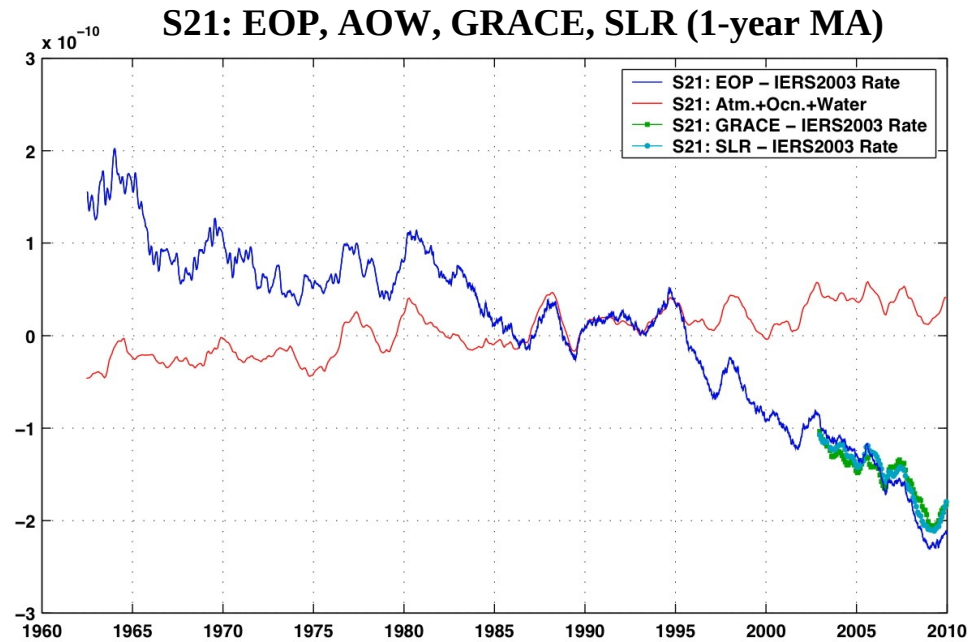
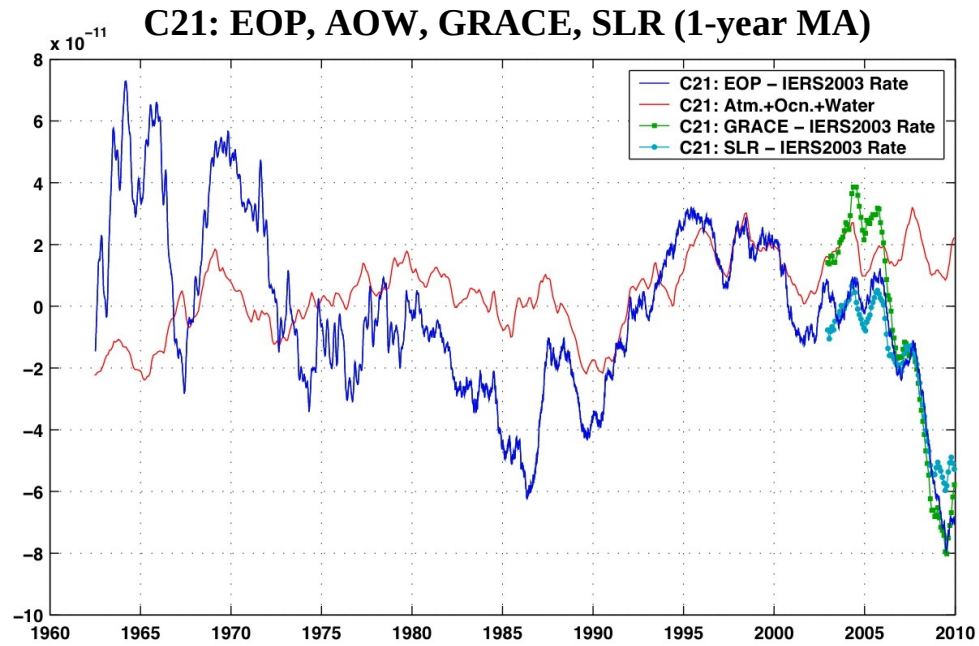


Detrended C21: EOP vs. AOW (1-year MA)

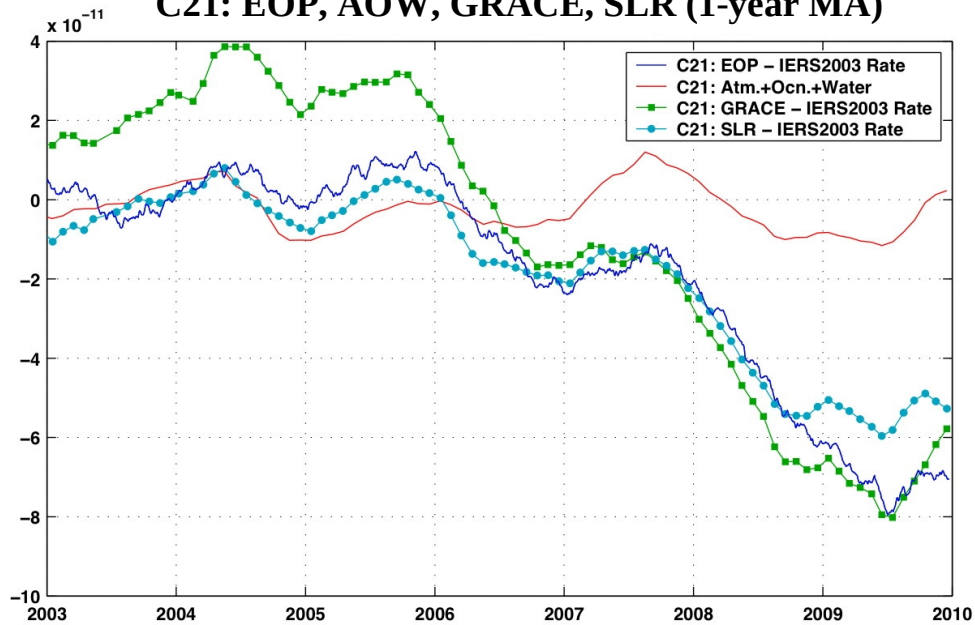


Detrended S21: EOP vs. AOW (1-year MA)

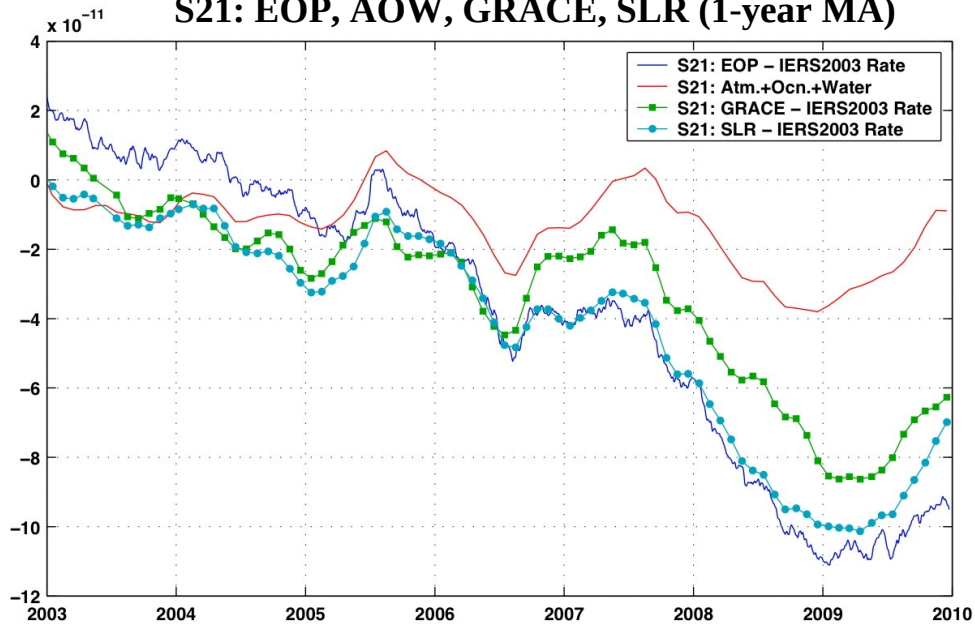


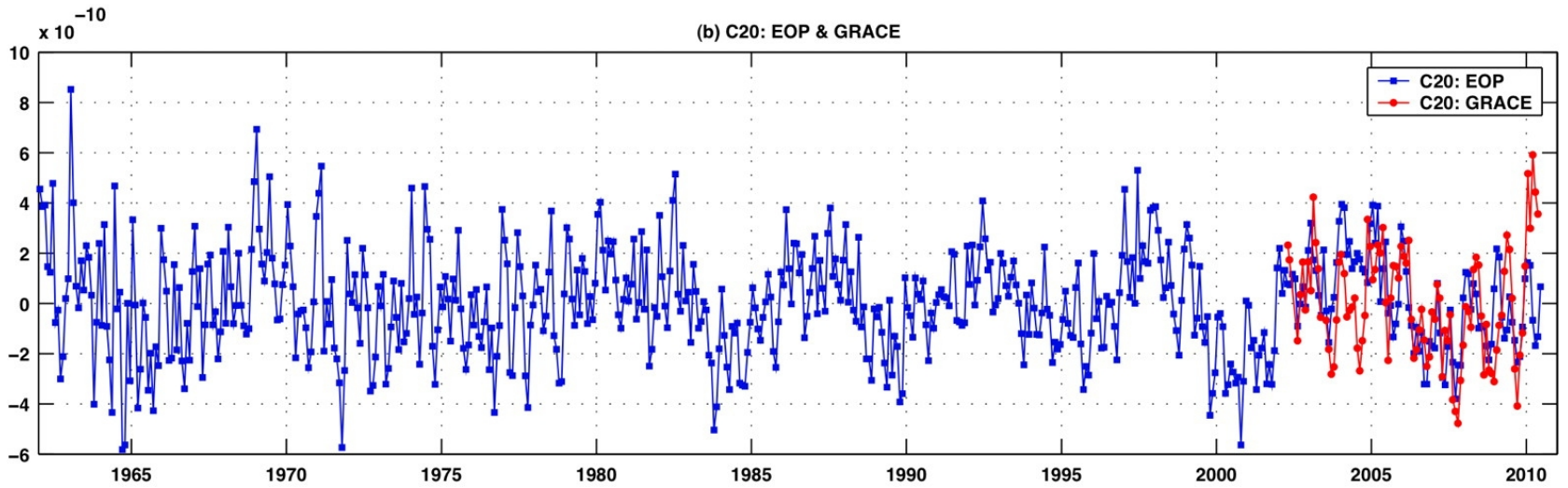
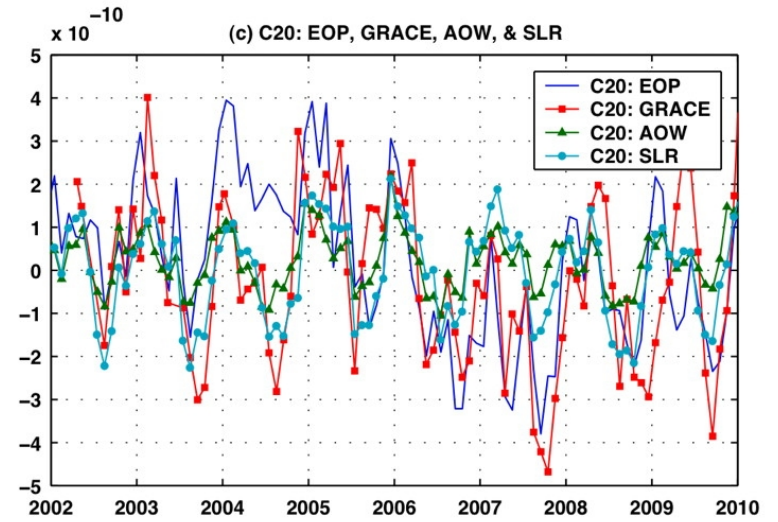
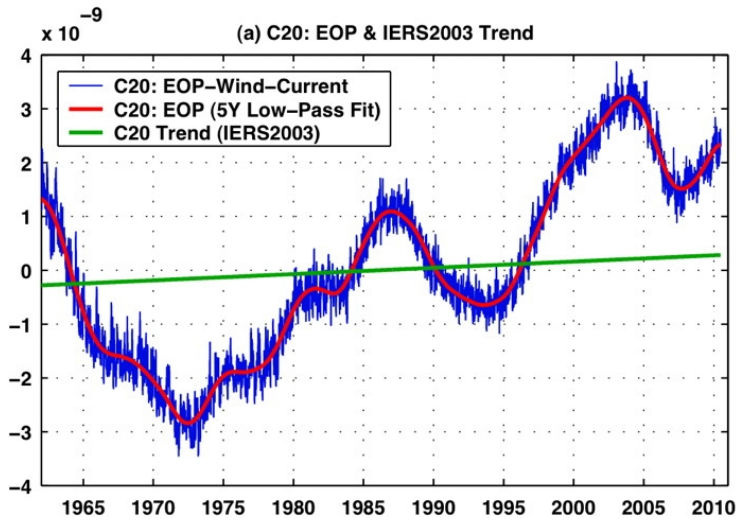


C21: EOP, AOW, GRACE, SLR (1-year MA)



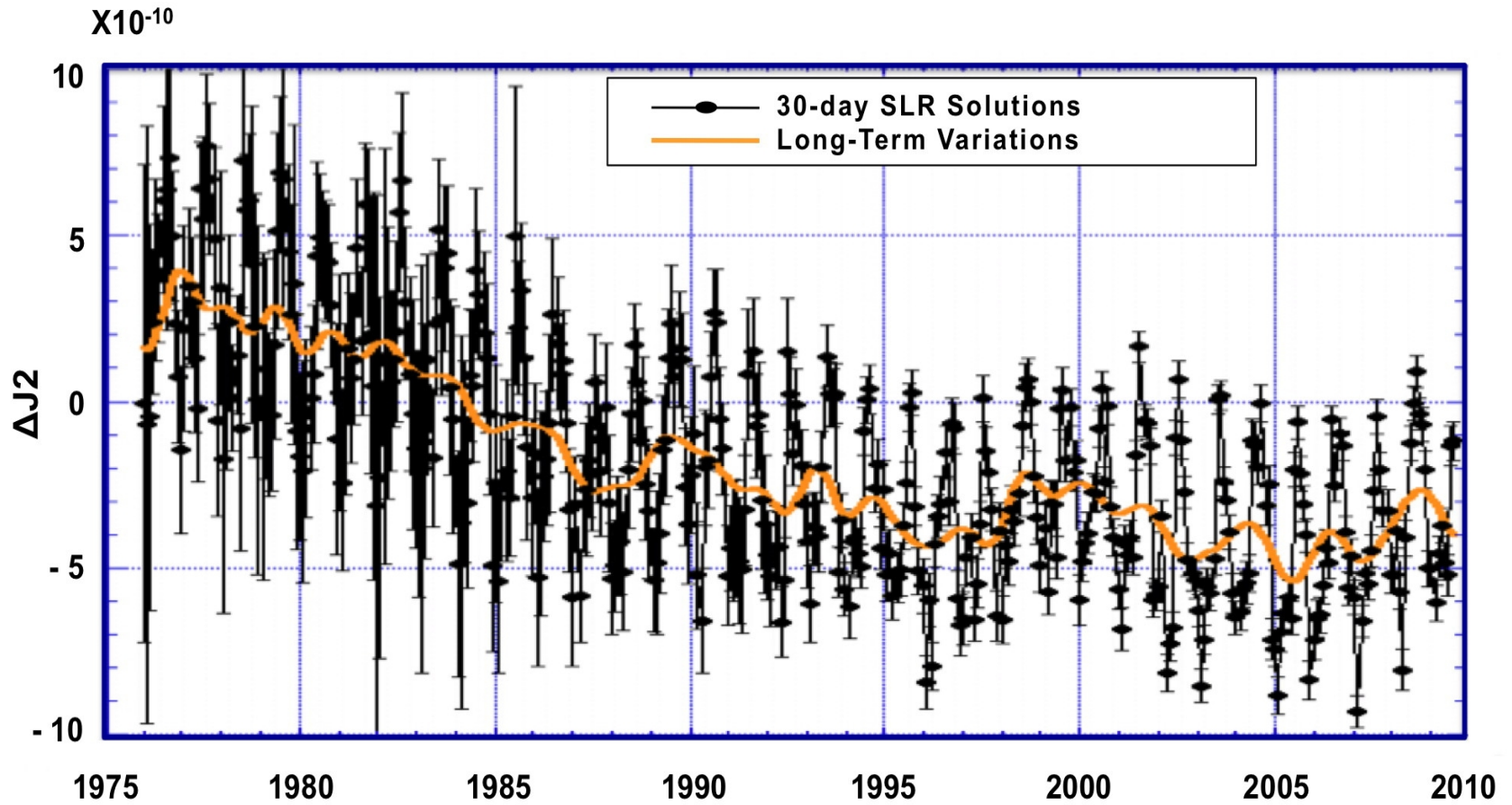
S21: EOP, AOW, GRACE, SLR (1-year MA)





6-Years Oscillations in LOD: 6-years torsional wave in the core [Gillet et al., 2010, Nature]

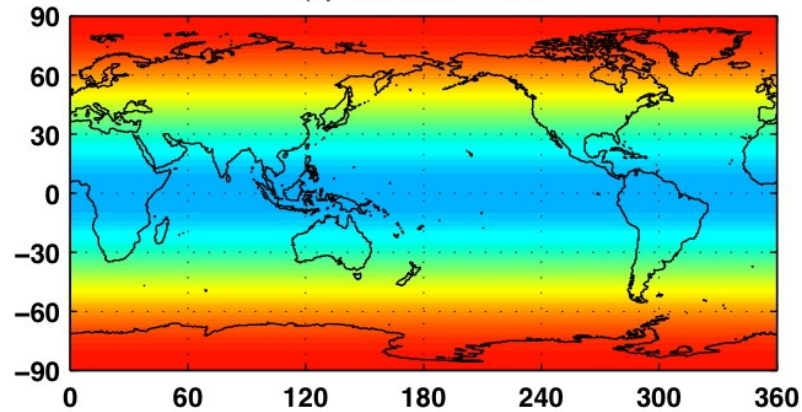
Satellite Laser Ranging (SLR) Estimates of C20 Variations



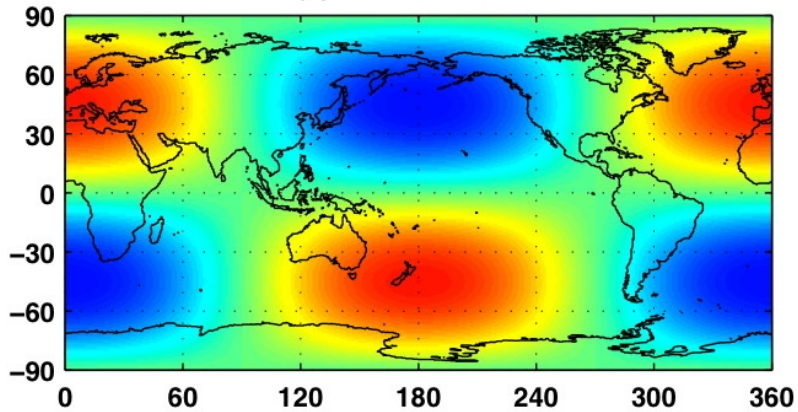
Courtesy of Minkang Cheng

Sensitivity of ΔC_{20} , ΔC_{21} , and ΔS_{21} to Mass Redistributions

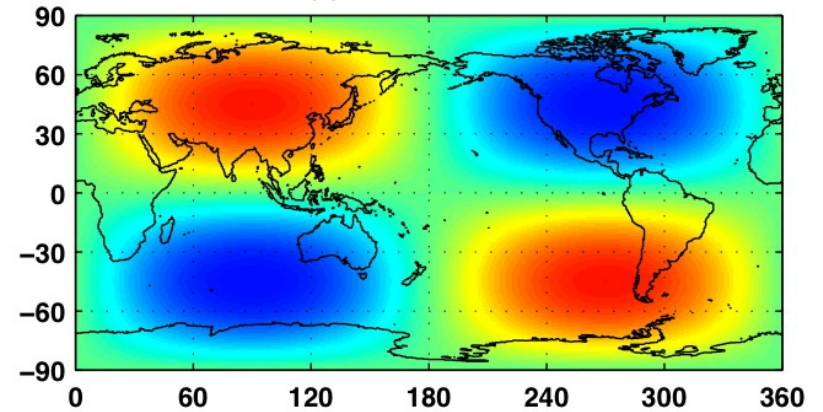
(a) C20 Mass Mode



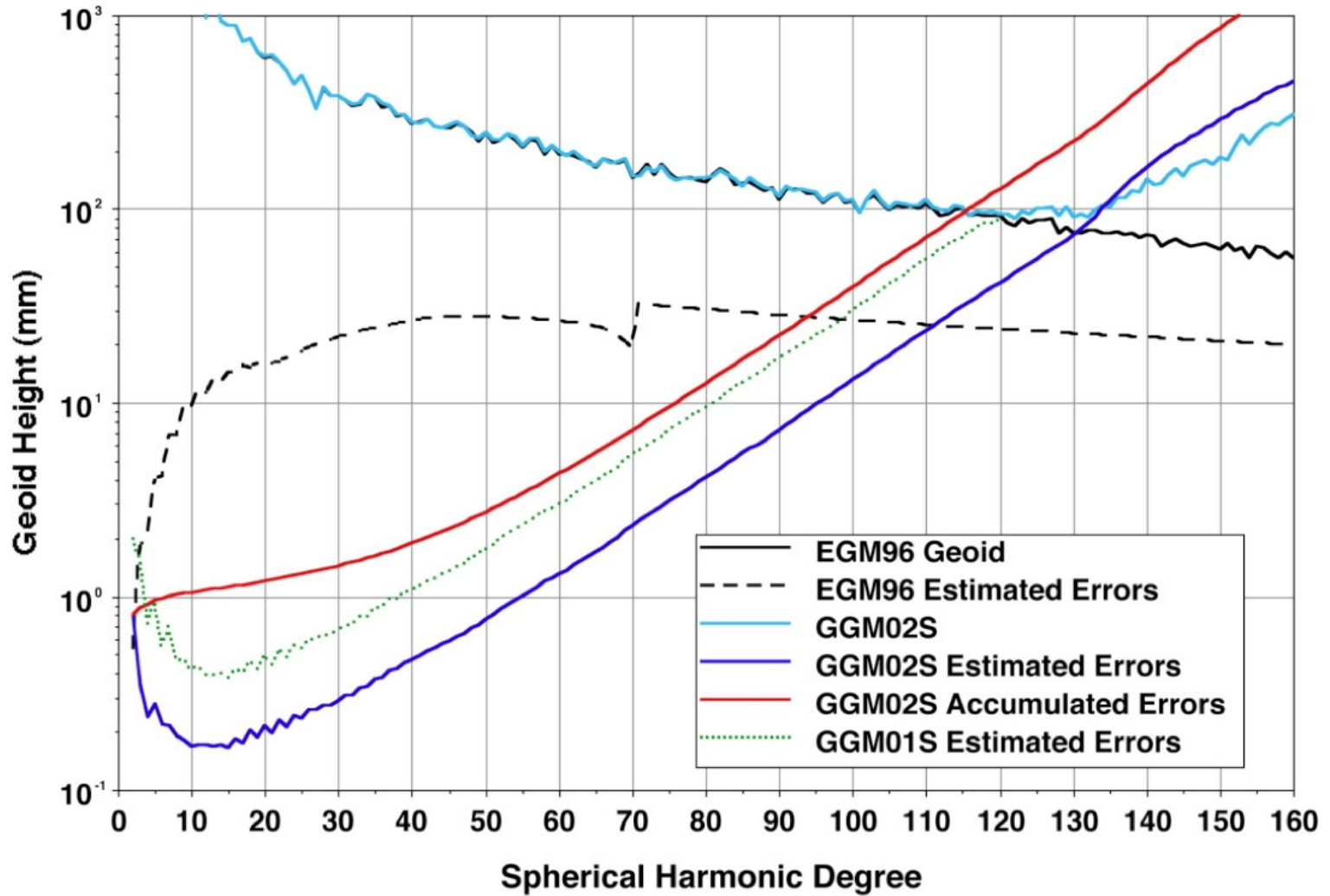
(b) C21 Mass Mode



(c) S21 Mass Mode



Strengthen GRACE Low-Degree Time-Variable Gravity Fields





Major Conclusions:

- ❑ Earth rotational observations offer an independent measure of degree-2 gravitational changes (ΔC_{21} , ΔS_{21} , and ΔC_{20}).
- ❑ At interannual time scales, EOP-derived ΔC_{21} and ΔS_{21} (especially ΔS_{21}) agree remarkably well with climate model predictions.
- ❑ Significant decadal variability exists in ΔC_{21} and ΔS_{21} , and the IERS ΔC_{21} and ΔS_{21} rates (dC_{21}/dt and dS_{21}/dt) does not represent their long-term trends well, especially in the recent decade.
- ❑ At 'decadal' scales, GRACE, EOP, & SLR estimates of ΔC_{21} and ΔS_{21} variations agree very well with each other.
- ❑ Model estimates of ΔC_{21} , ΔS_{21} , and ΔC_{20} fail to show the large long-term variability observed by GRACE, EOP, and SLR.



Much of the long-term variability of EOP-derived ΔC_{21} and ΔS_{21} may represent real signals from climate change (and/or