A 33 Year Time History of the J2 Changes from SLR

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- SLR data and models
- Observed variations in J2
- 18.6 tidal variation
- ENSO and PDO effects
- Comparison of J2 Variations from SLR and GRACE data
- Conclusion

Earth Oblateness and J2

$$V = \frac{GM}{r} \sum_{n=2} \sum_{m=0}^{l} \left(\frac{a}{r}\right)^n (C_{nm} \cos m\lambda + S_{nm} \sin m\lambda) P_{nm}(\sin \phi)$$

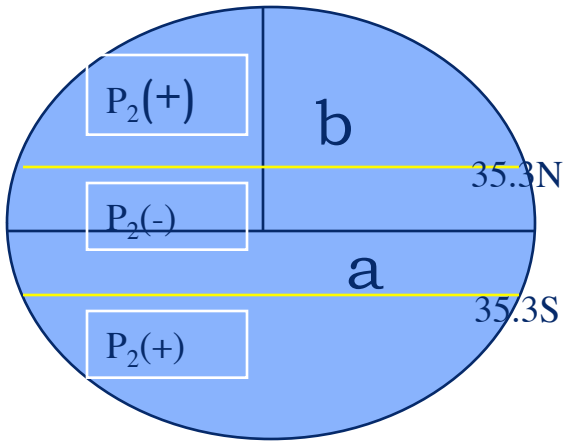
For a rotational symmetic Earth [Heiskanen & Moritz, 1967, p78]

$$J_2 = -C_{20} = \frac{2}{3} f - \frac{1}{3} m_s + O(f^2) \qquad J_2 \approx 1.08263 \times 10^{-3}$$

$$f = \frac{a-b}{a} = \frac{1}{298.257} \qquad m_s = \frac{\omega^2 a^3}{GM} \approx 0.00346 \approx 1.03 f$$

$$\Delta J_2 \approx 0.323 \Delta f \approx -0.323 \frac{f}{a} \Delta a = -1.7 \times 10^{-10} (1/m) \cdot \Delta a(\mathrm{m})$$

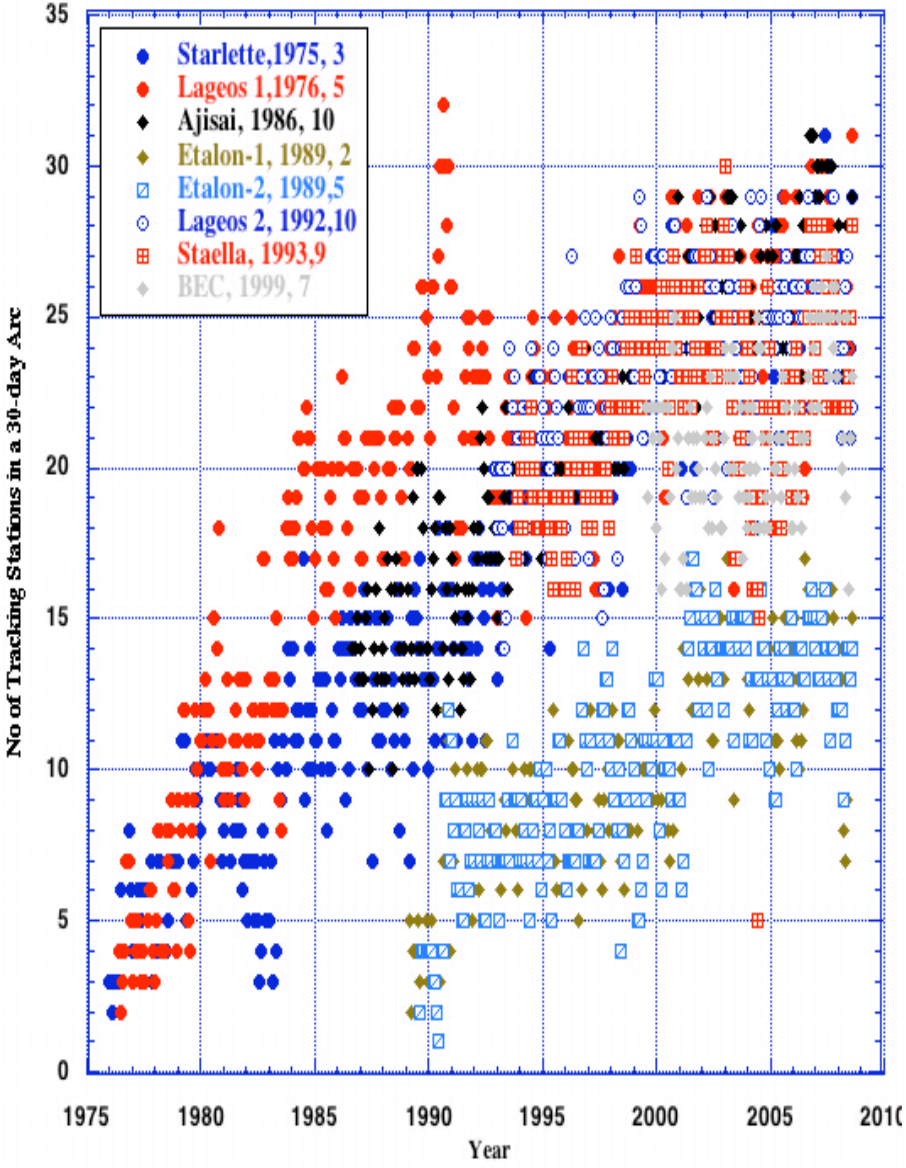
$$\Delta a(m) = -0.59 \times 10^{10} \cdot \Delta J_2 \qquad \delta\omega \approx -30.331 \Delta J_2 \ ("/\mathrm{sec})$$

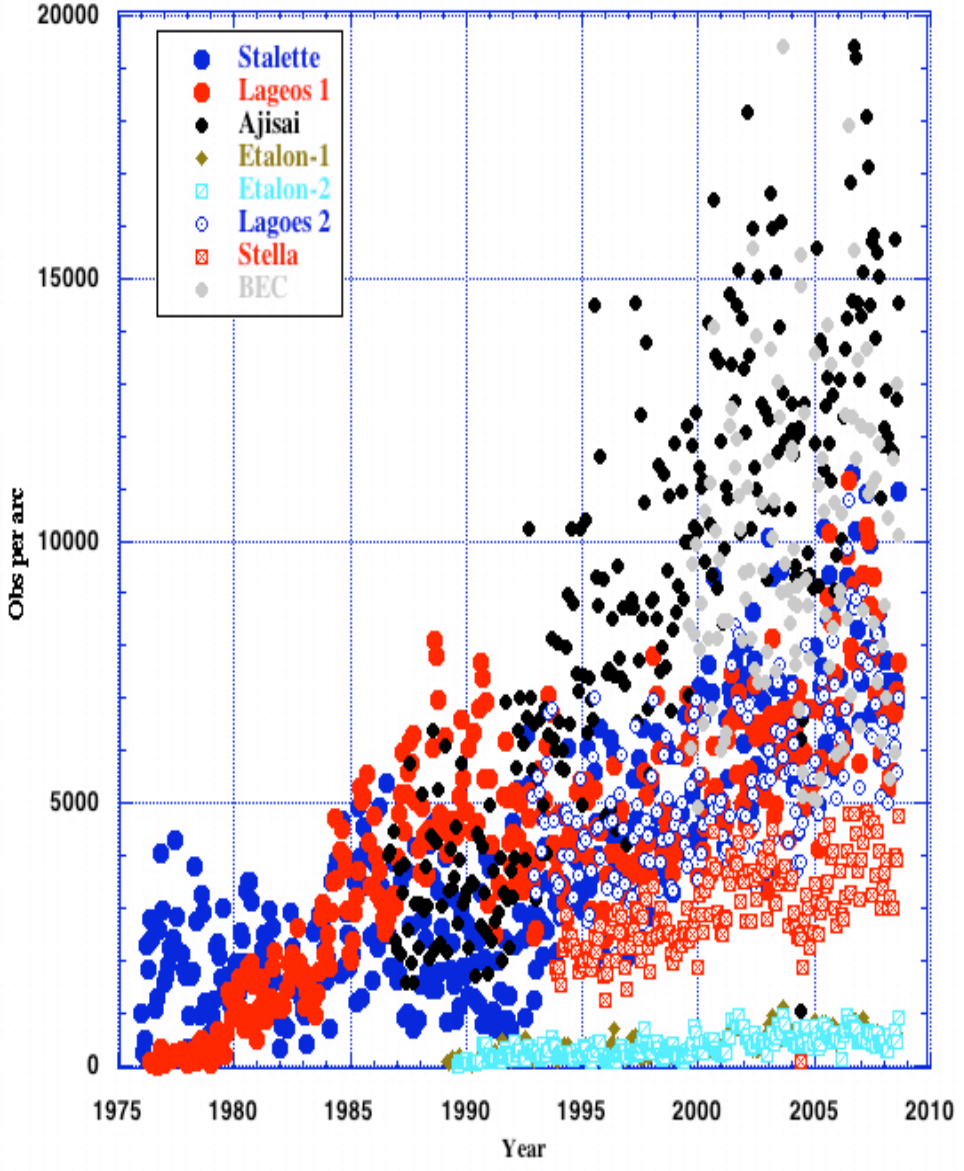


$$\Delta J_2 = -\frac{1+k_2'}{5} \frac{R^2}{M} \sum_i \Delta m(\phi_i) \bar{P}_2(\sin \phi_i) S_i$$

J2 variations are calculated as weighted sum of zonal net mass changes, and represent the imbalance of zonal mass variations between 'tropical' and extratropical area.

Statistics for SLR Tracking in 30-day Arc





Data and Models Used in this study

- SLR data for 30-day solution of J2:

  Entire data from 7 geodetic satellites:

  Starlette, Ajisai, Stella, Lageos 1 and 2, Etalon 1 and 2

  and BEC data from July 15, 1999

- Models

  IERS 2003 Standards

  TEG4 Gravity Model and CSR4.0 Ocean tide model

  Solid Earth tides: IERS 2003 Anelastic model

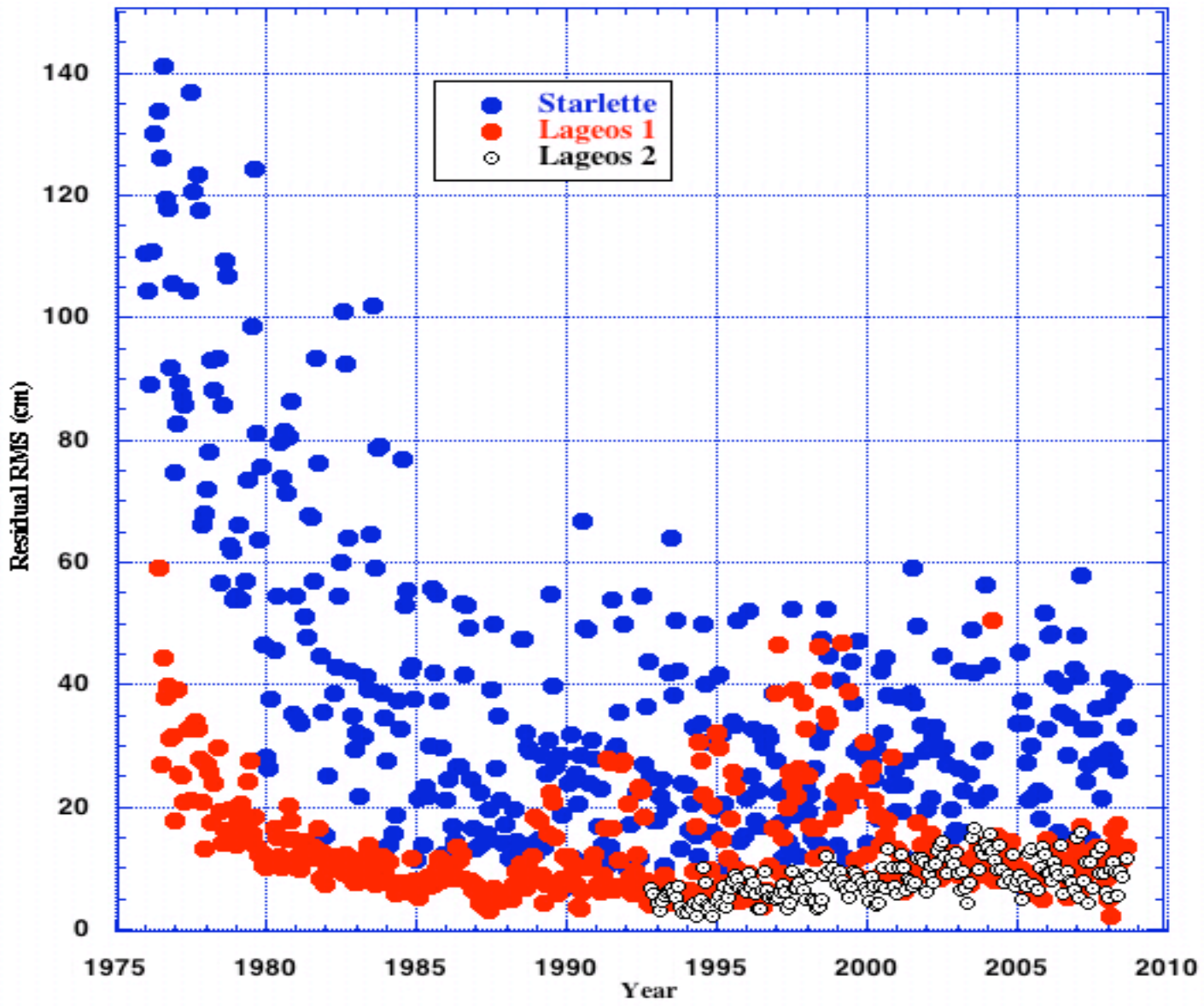
- Adjust Parameters

  Satellite State, 3x3 gravity field (+J4,J5) per 30-day arc

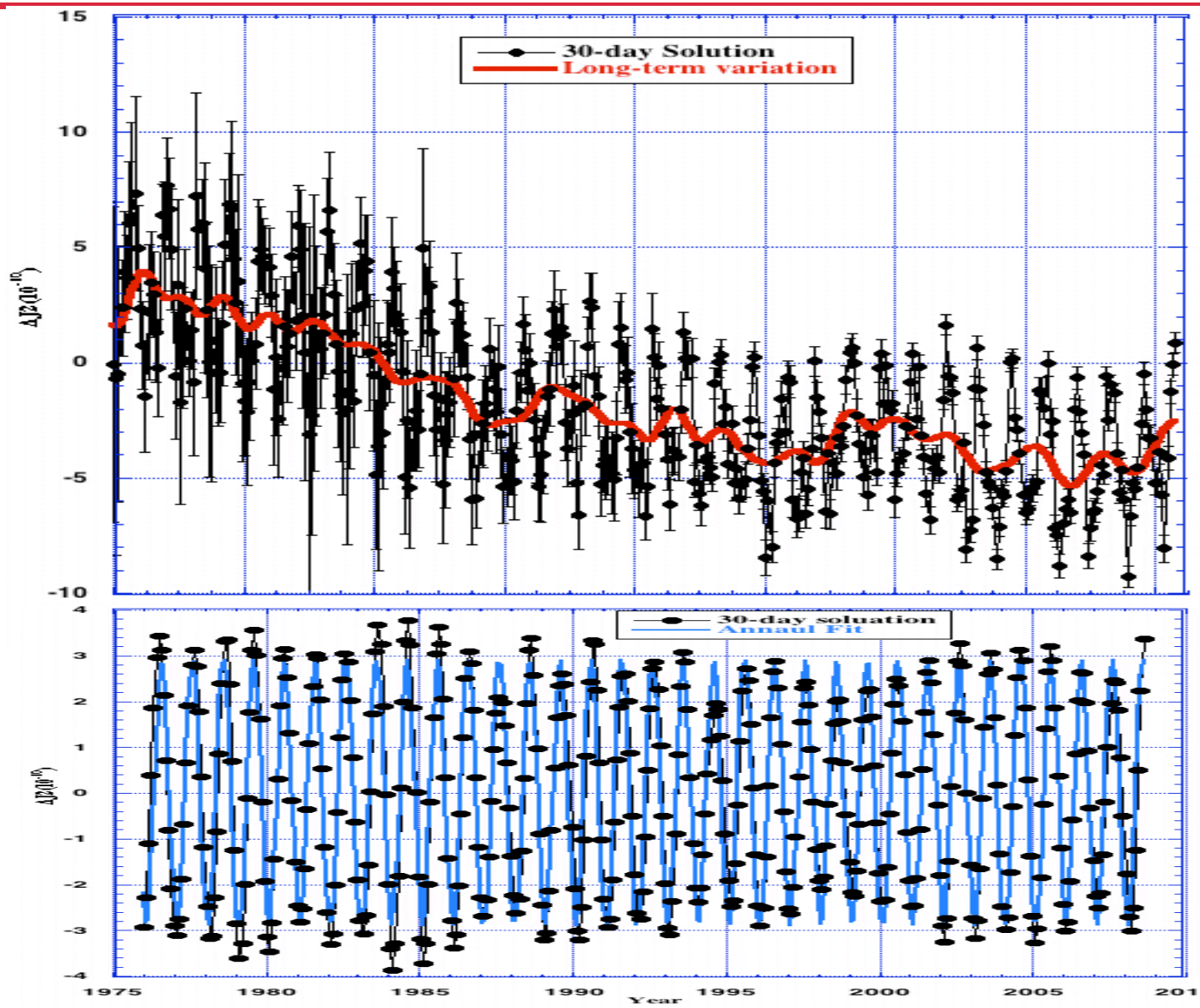
  Daily Cd for Starlette, Stella, Ajisai, 0.5 Day for BEC

  2-day CT for Lageos 1&2, 15-day CT for Etalon 1 &2

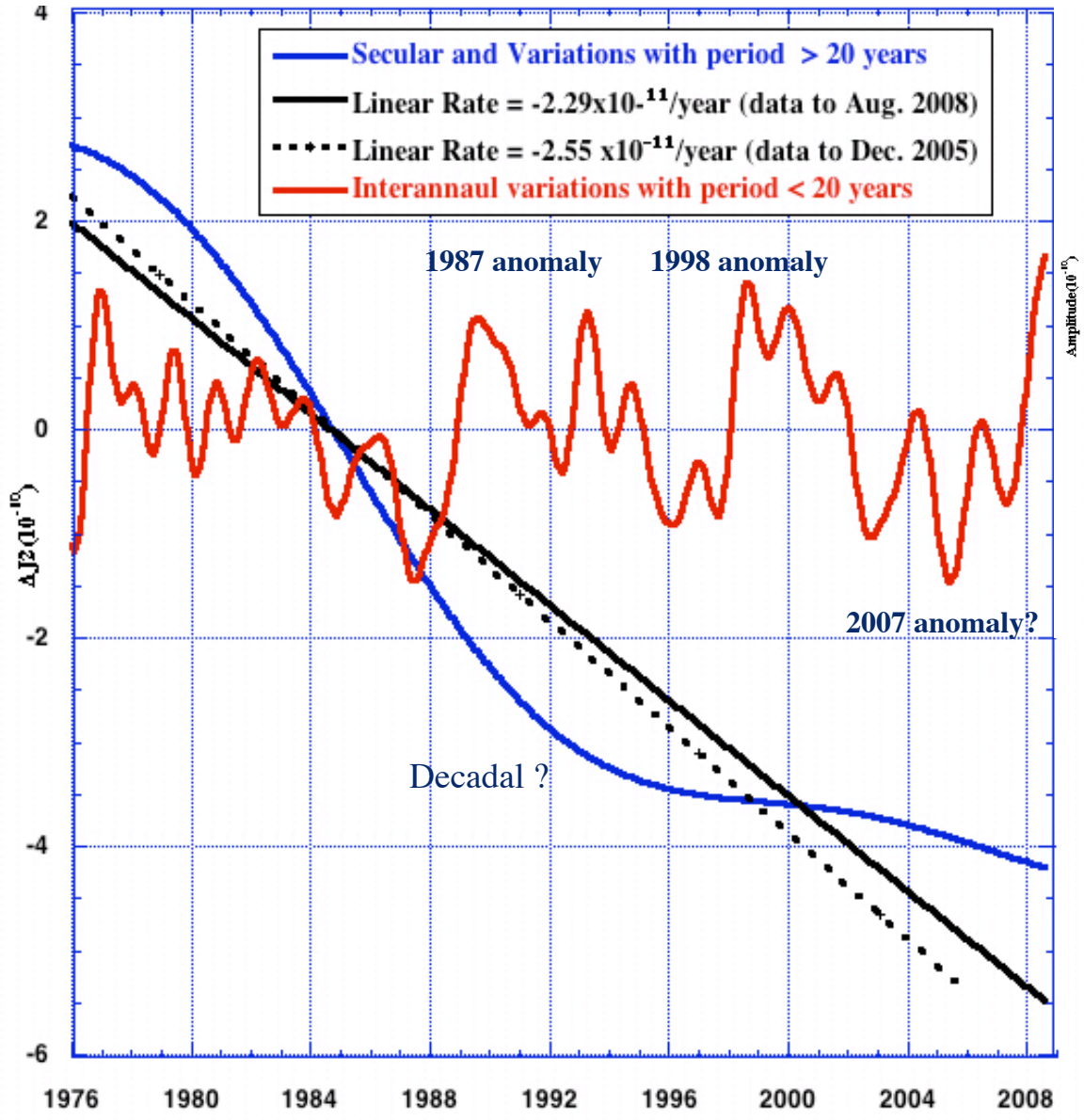
SLR Residual RMS from 30-day Orbit Fit

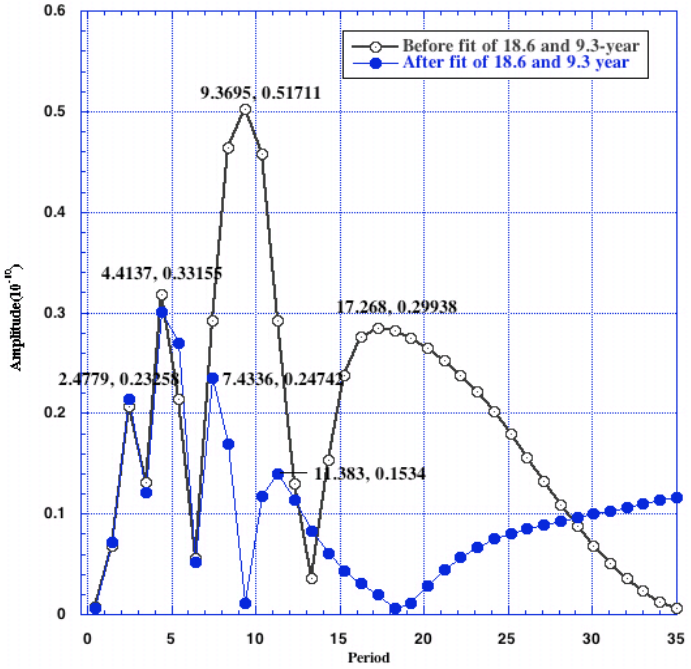


Monthly Solution for J2 from SLR data



Long-term Variations in J2 from SLR data





- Signals are visible for variations with period from 4 to 6 years
- Signal of 18.6 year tide can be separated from other terms
- Significant aliasing effect on 9.3 tide
- Linear trend is affected by the interannual and decadal variation

$$\dot{J}_2 = -2.6 \times 10^{-11} / year \quad ?$$

18.6 Year tidal Variation in J2

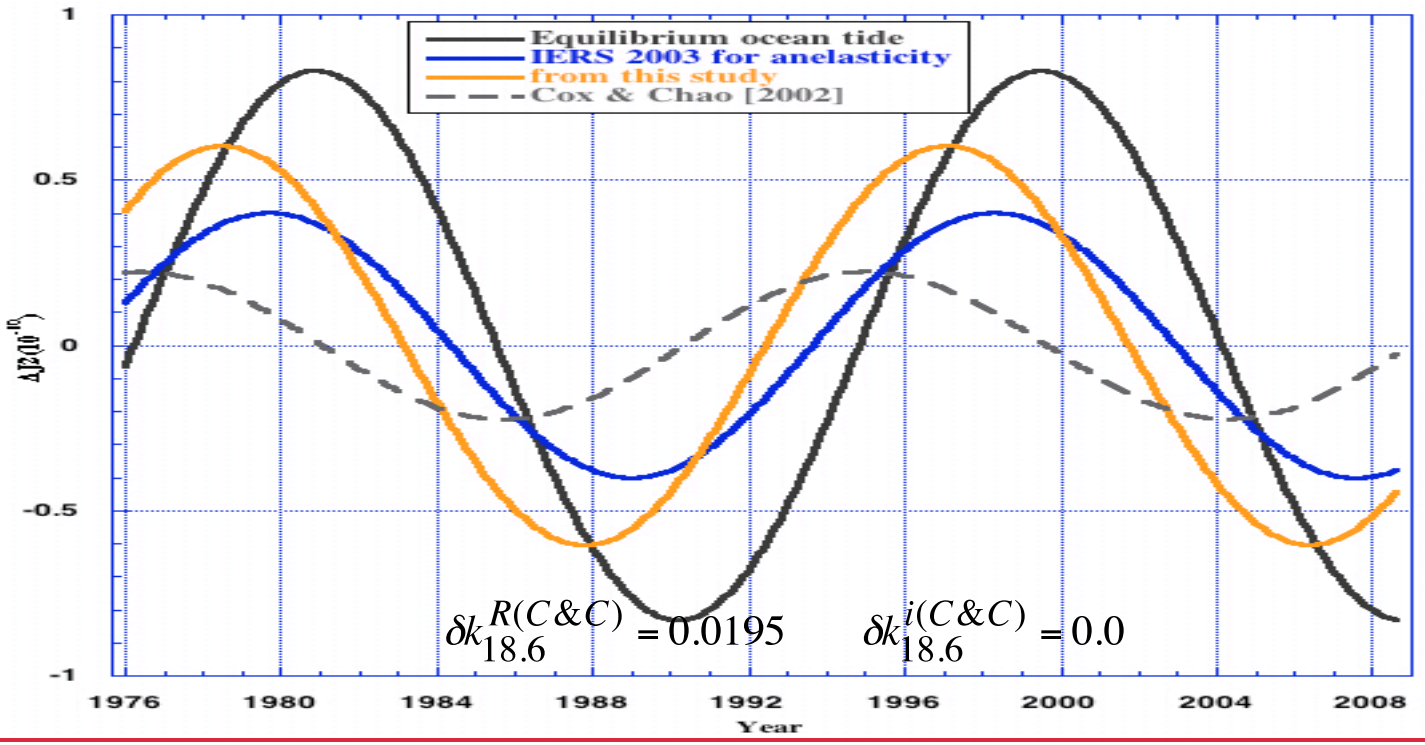
$$IERS: \quad \Delta C_{20}^{AE} = \sum_f A_0 H_f [\delta k_f^R \cos\theta_f - \delta k_f^I \sin\theta_f] \qquad \theta_f = 2\pi \dot{\theta}_f^Y (t - t_{1900})$$

$$\Delta J_2^o = A_f \cos[2\pi \dot{\theta}_f^Y (t - t_E) - \psi_f^c] \qquad \psi_f^c = 130^\circ.76 + \psi_f$$

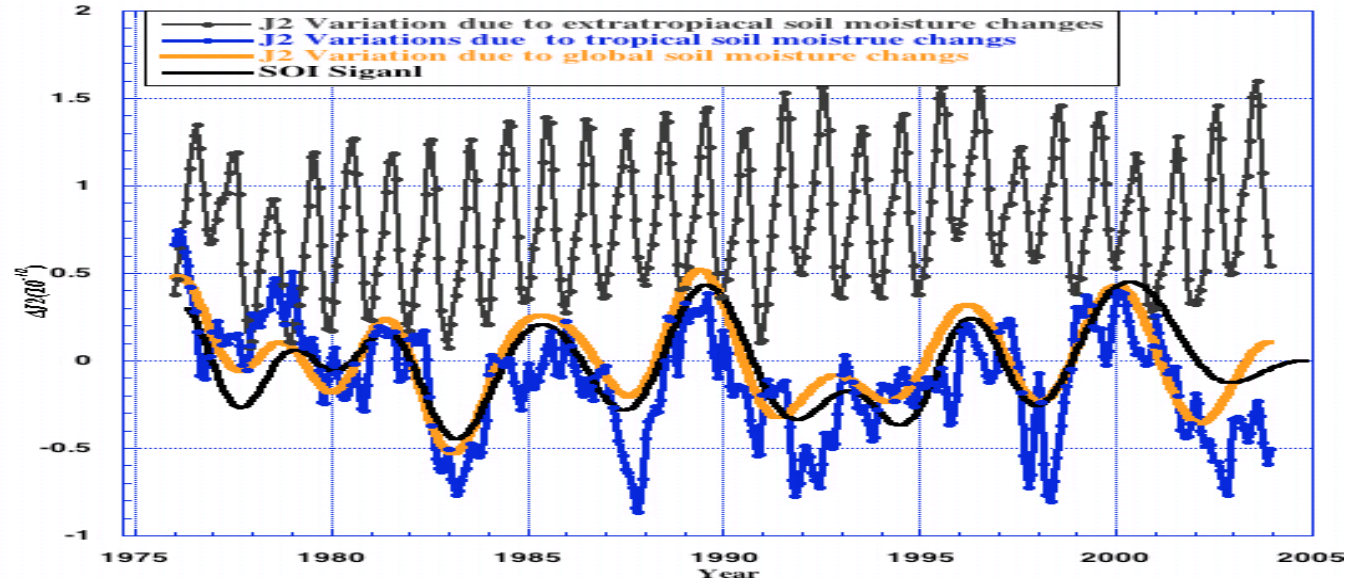
$$\delta k_{18.6}^{R(IERS)} = 0.01347 \qquad \delta k_{18.6}^{i(IERS)} = -0.00541$$

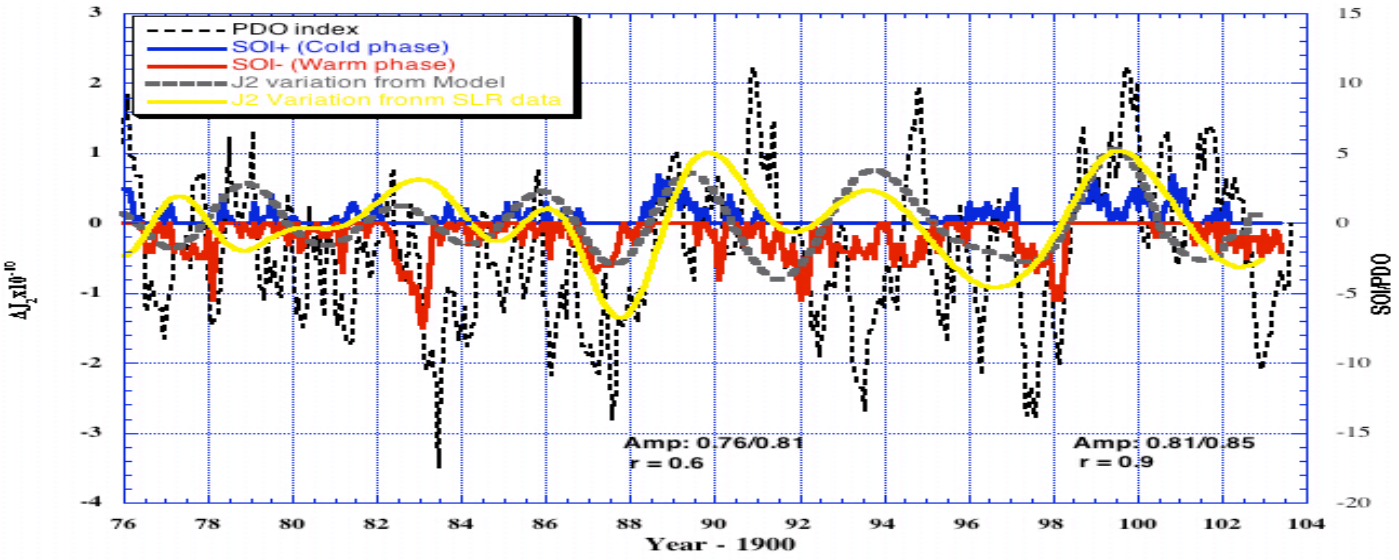
$$\delta k_{18.6}^{R(SLR)} = 0.02186 \qquad \delta k_{18.6}^{i(SLR)} = +0.00537$$

$$\delta k_{18.6}^{R(Wahr)} = 0.027 \pm 0.009 \qquad \delta k_{18.6}^{i(Wahr)} = -0.002 \pm 0.024$$

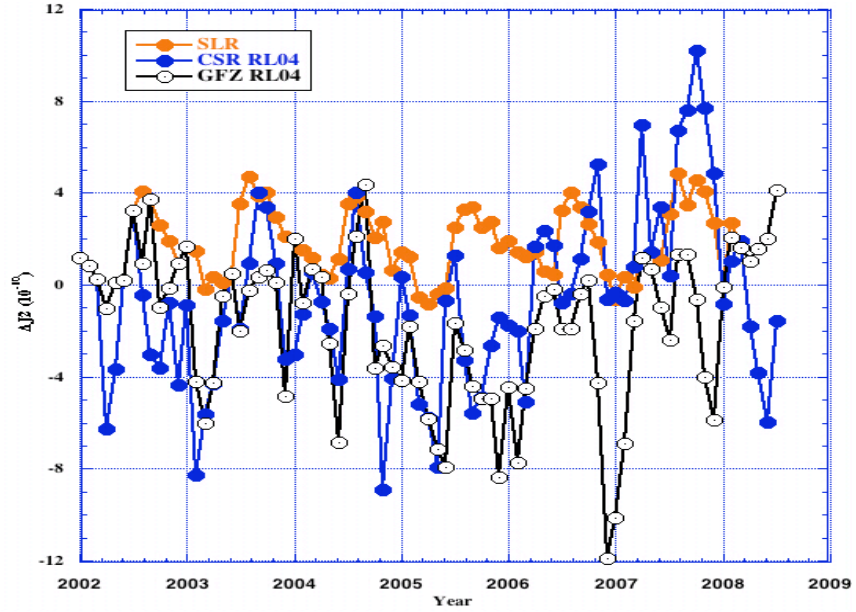


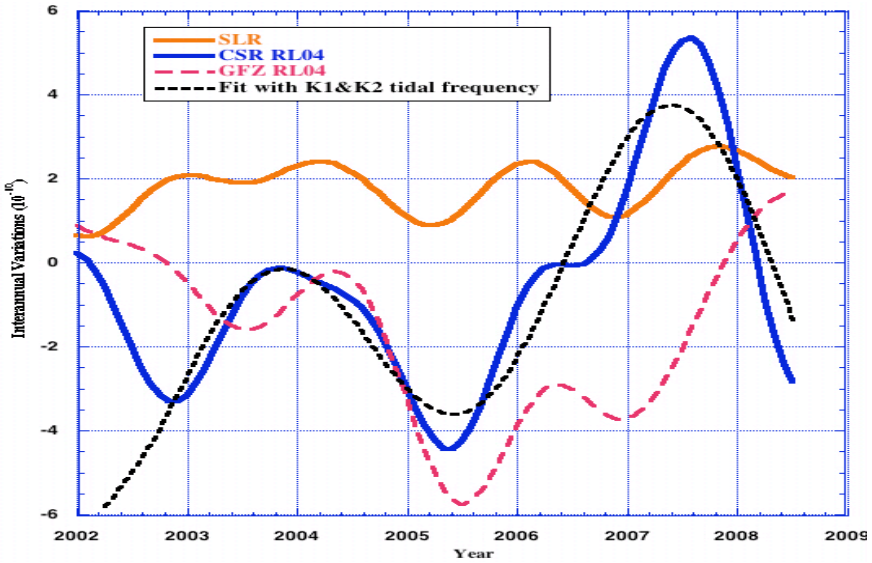
ENSO/PDO Effects on J2 Variations

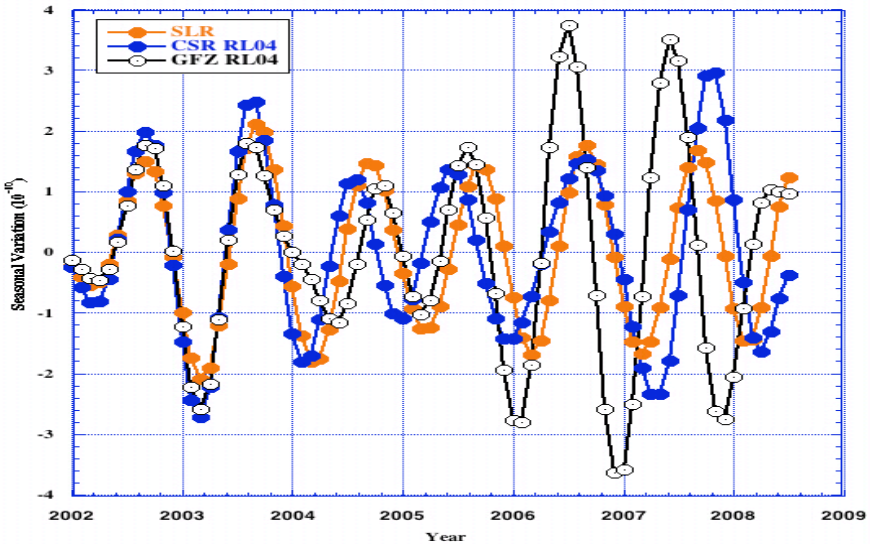




J2 Variations from SLR and GRACE







Remark:
Wavelet analysis is applied to separate the signals.

The Atmosphere-Ocean De-aliasing product was used in both GRACE and SLR data analysis. The primary signature is assumed to be due to the expected hydrological excitation. However, the tidal perturbations in GRACE orbit have been aliased into long-period signals in GRACE derived J2.

Conclusion

- J2 has undergone significant variations during the past 33 years:
  The estimate of the secular decreasing rate is affected by the significant interannual variations with amplitude as large as 0.5e-10 and time scales of ~10 years

- Two large interannual variations in J2 are correlated with the strongest ENSO events during the periods of 1986-1991 and 1996-2002. It appears a new cycle has started from 2007.

- It is evident that a siginificant deviation from the IERS model for the anelasticity of the Earth at 18.6 year period.

- The long-term SLR data is an especially valuable geophysical resource for monitoring the long-term changes in the Earth's gravitational field driven by climate changes.

- The J2 variation from SLR are the most reliable for the application of GRACE products to extract the signals of oceanic and hydrological mass variations.

Acknowledgments

We thank all the International Laser Ranging Service (ILRS) Stations and Data centers for proving high quality SLR data