Earth's Dynamic oblateness observed by GPS

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Estimation of J2 from GPS

- Dynamic oblateness of the Earth (J2) is consequence of Earth rotation, variations due to various physical processes
- Related to spherical harmonics of the Earth's potential by:

$$J_n = -\sqrt{(2n+1)}\, V_{n0}^{C}$$

- Earth's response under surface loads:

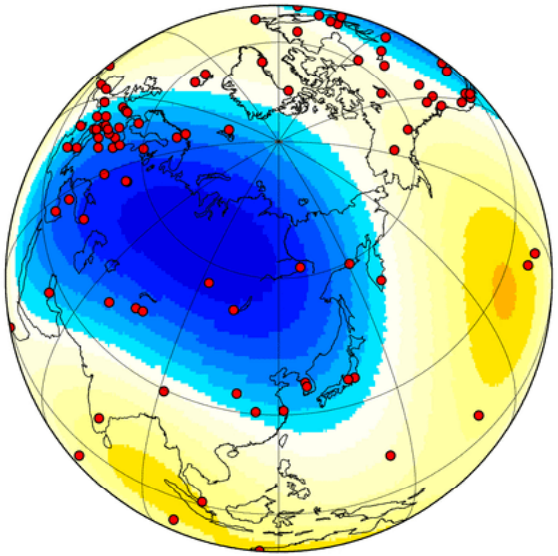
$$V(\Omega) = \frac{\rho_S}{a\rho_E} \sum_{n=1}^{\bar{n}} \sum_{m=0}^{n} \sum_{\Phi}^{\{C,S\}} \frac{3(1+k_1')}{(2n+1)} T_{nm}^{\Phi} Y_{nm}^{\Phi} \qquad H(\Omega) = \frac{\rho_S}{\rho_E} \sum_{n=1}^{\bar{n}} \sum_{m=0}^{n} \sum_{\Phi}^{\{C,S\}} \frac{3h_n'}{(2n+1)} T_{nm}^{\Phi} Y_{nm}^{\Phi}$$

$$L(\Omega) = \frac{\rho_S}{\rho_E} \sum_{n=1}^{\bar{n}} \sum_{m=0}^{n} \sum_{\Phi}^{\{C,S\}} \frac{3l_n'}{(2n+1)} T_{nm}^{\Phi} Y_{nm}^{\Phi}$$

- Thus GPS surface displacements (Caused by loading!) can be used to estimate J2

Estimation of J2 from GPS

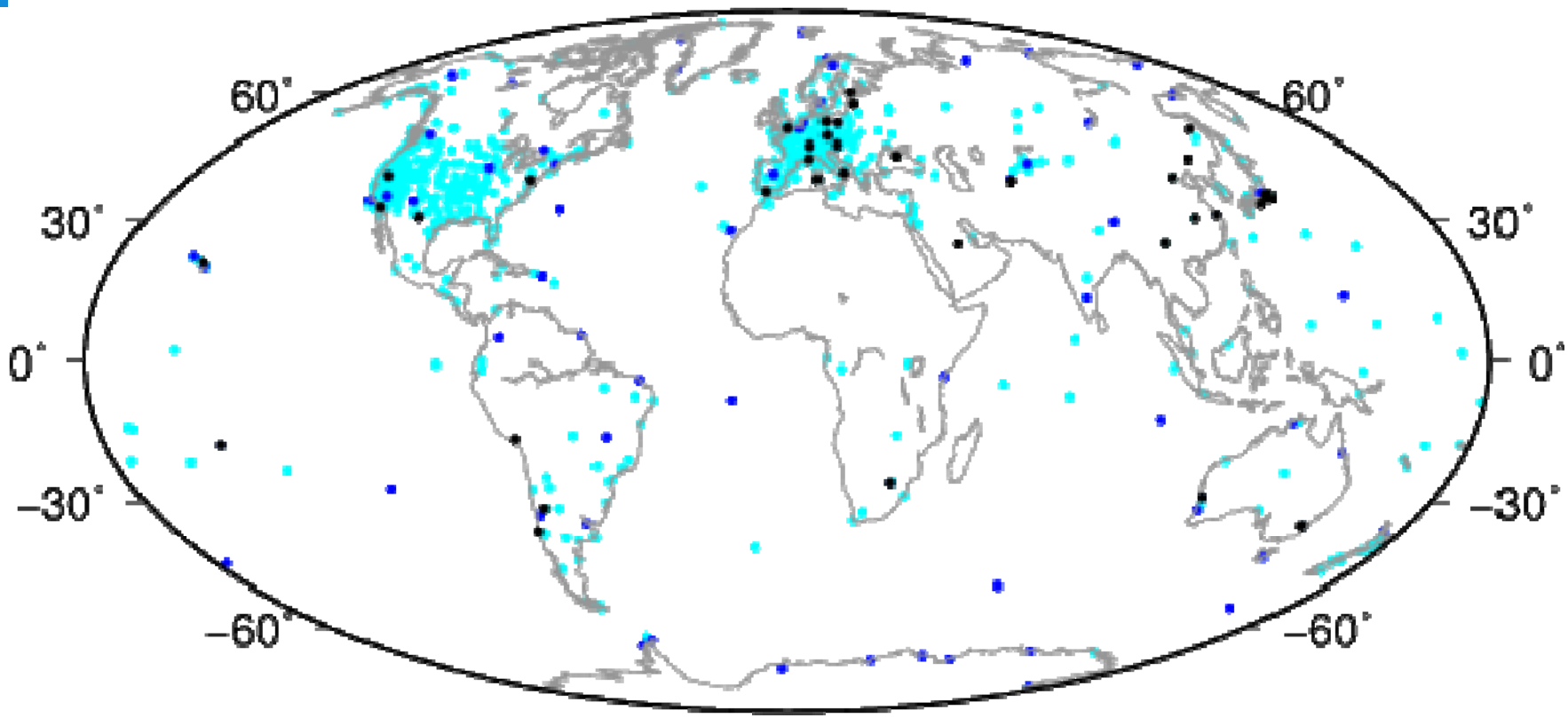
- Inversion for spherical harmonic coefficients is ill-posed
- Use horizontal and vertical displacements (triples number of equations) and constrain via load love numbers
- Sparse distribution of GPS in ocean areas cannot sufficiently constrain sufficiently high degree spherical harmonic expansion
- We use physical constraints on land/ocean load distribution enacted via alternative basis functions [Clarke et al., 2007]



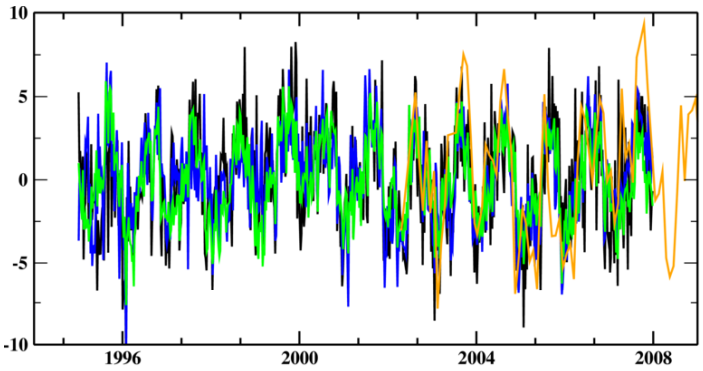
Data processing 1995-2008

- SLR to Lageos 1 and 2
  - 47 sites
  - FES2004
  - 3x3 degree gravity field
  - Site positions, polar motion, LOD
  - 7 day arcs centered on GPS week
- GPS reprocessed series (GAMIT)
  - 80 sites
  - 2nd and 3rd order ionosphere [Petrie et al., 2009]
  - Absolute antenna phase centers
  - FES2004, VMF1
  - Daily solutions combined into weekly

Sites



J2 series



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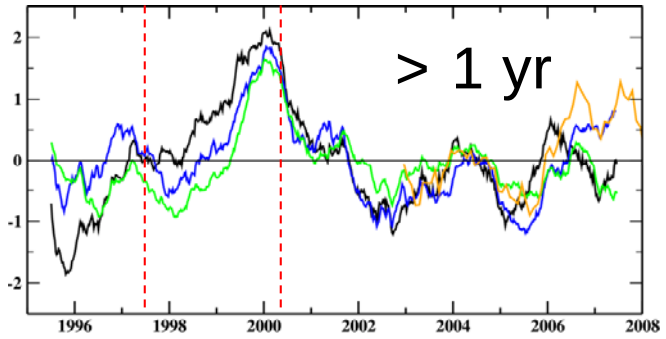
"1998 anomoly"



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Annual + Semi annual terms

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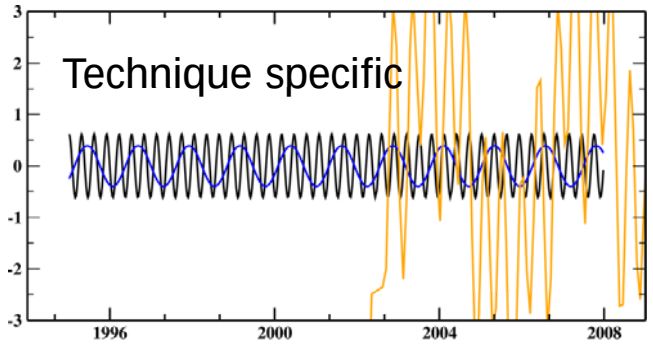
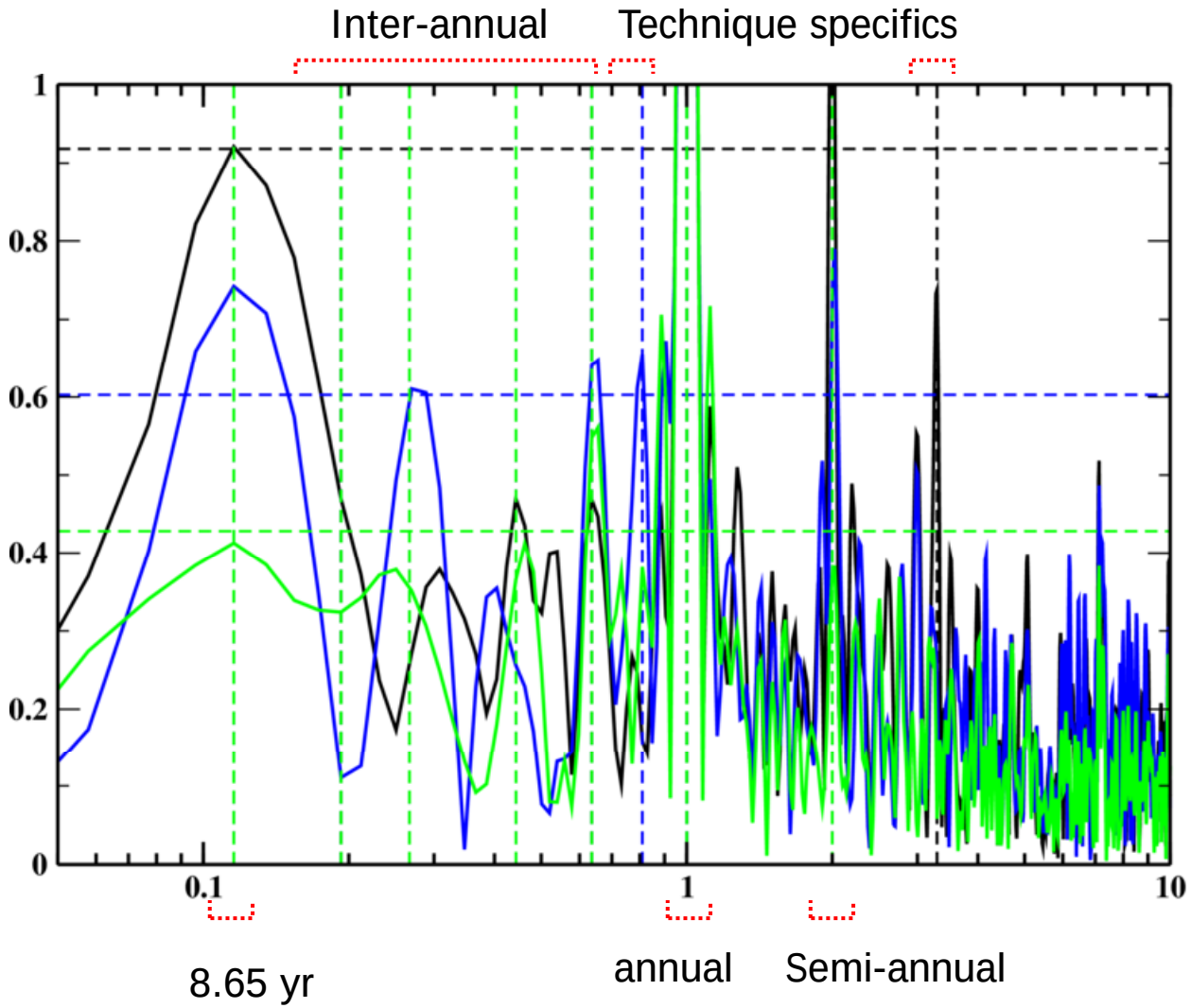


- SLR=Black
- GPS=Blue
- GRACE=Orange
- Load model=Green

Amplitude spectra



Annual and Semi-annual

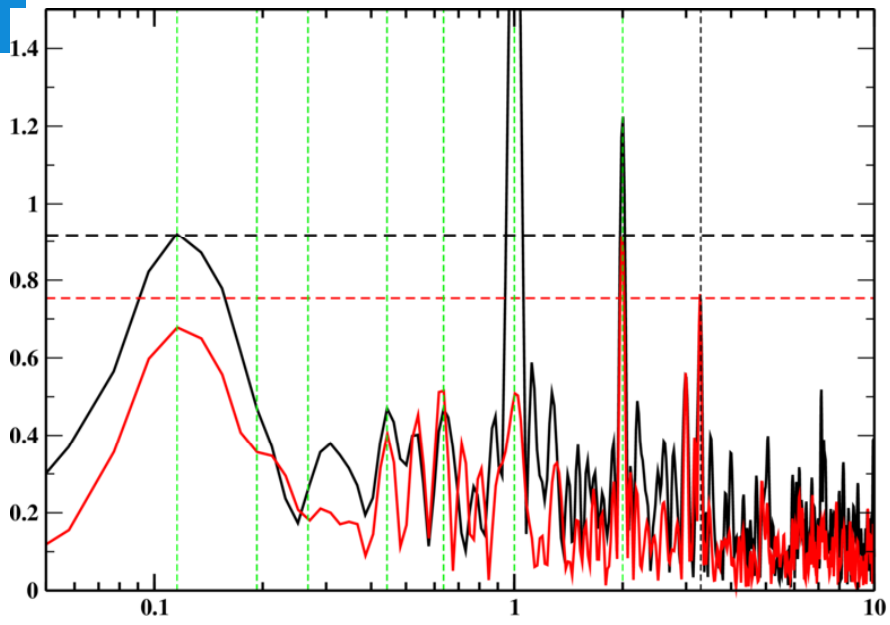
- Annual
- SLR: 2.26×10^{-10}, 232º
- GPS: 2.28×10^{-10}, 224º (SLR+3%)
- Model: 2.62×10^{-10}, 232º (SLR+16%)
- GRACE: 3.12×10^{-10}, 223º (SLR+38%)

- Semi-annual
- SLR: 1.28×10^{-10}, 161º (Model+237%, GPS+111%)
- GPS: 0.86×10^{-10}, 127º
- Model: 0.38×10^{-10}, 138º
- GRACE: 0.45×10^{-10}, 97º

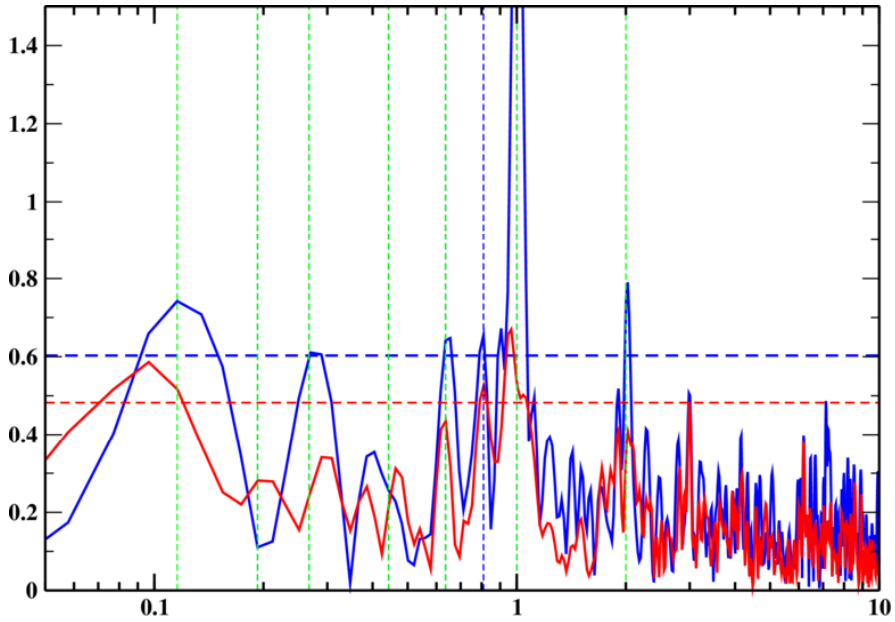
- Annual: Load mode is significantly bigger than GPS & SLR which agree
- Semi-annual: All three differ, SLR is particularly big.

Load model subtracted

SLR – load model



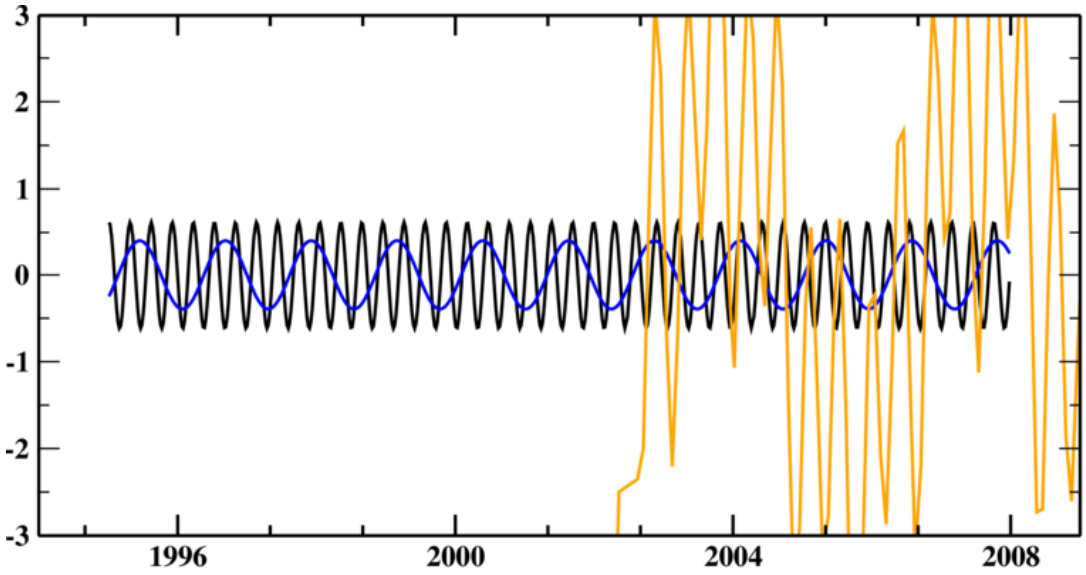
GPS – load model



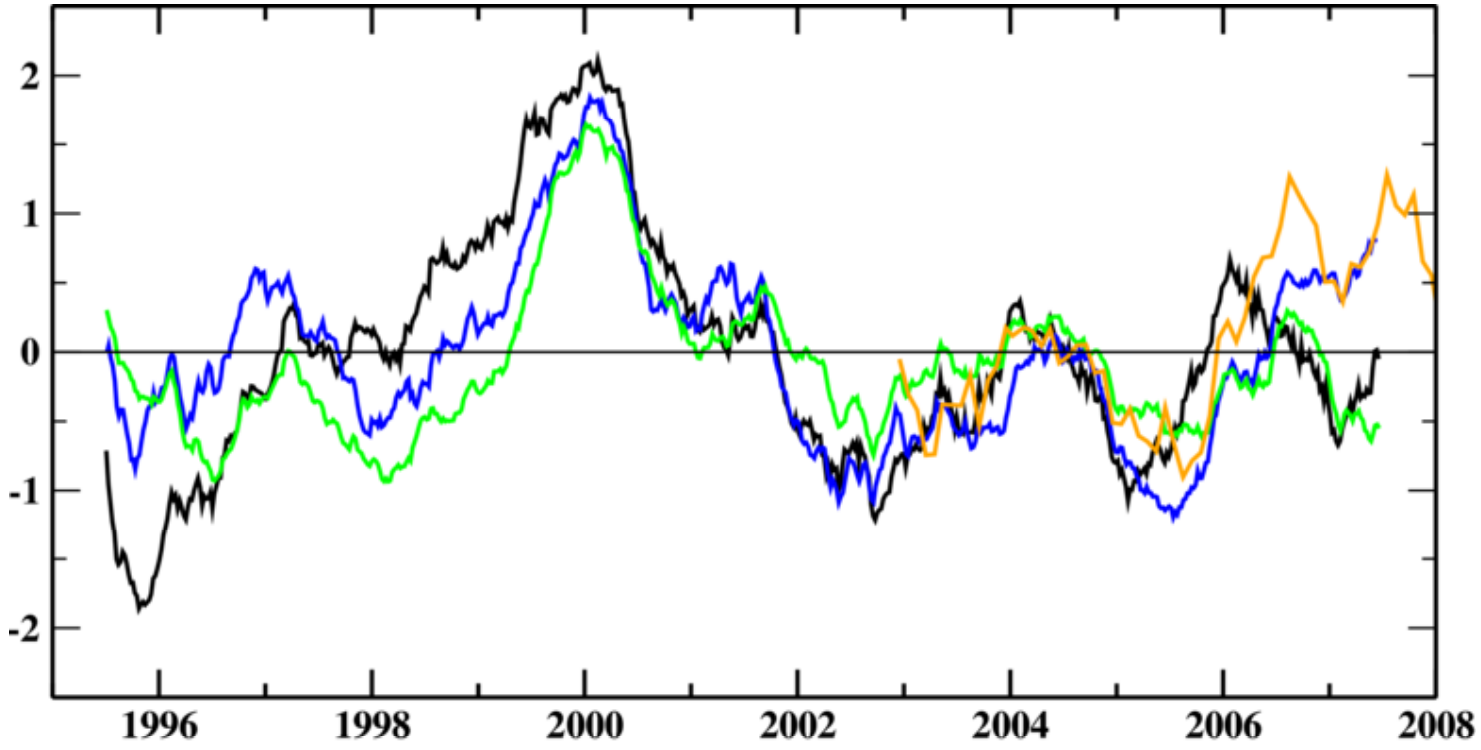
- Significant amplitude annual/near-annual remains in GPS
- Significant semi-annual remains in SLR
- Significant long period signal remains

Technique specifics

- SLR 0.3 years
  - 0.62×10^{-10}, 162º
- GPS 1.24 years
  - 0.39×10^{-10}, 115º
- GRACE
  - 3.74 years (K2)
  - 0.44 years (S2)
  - 0.86 years

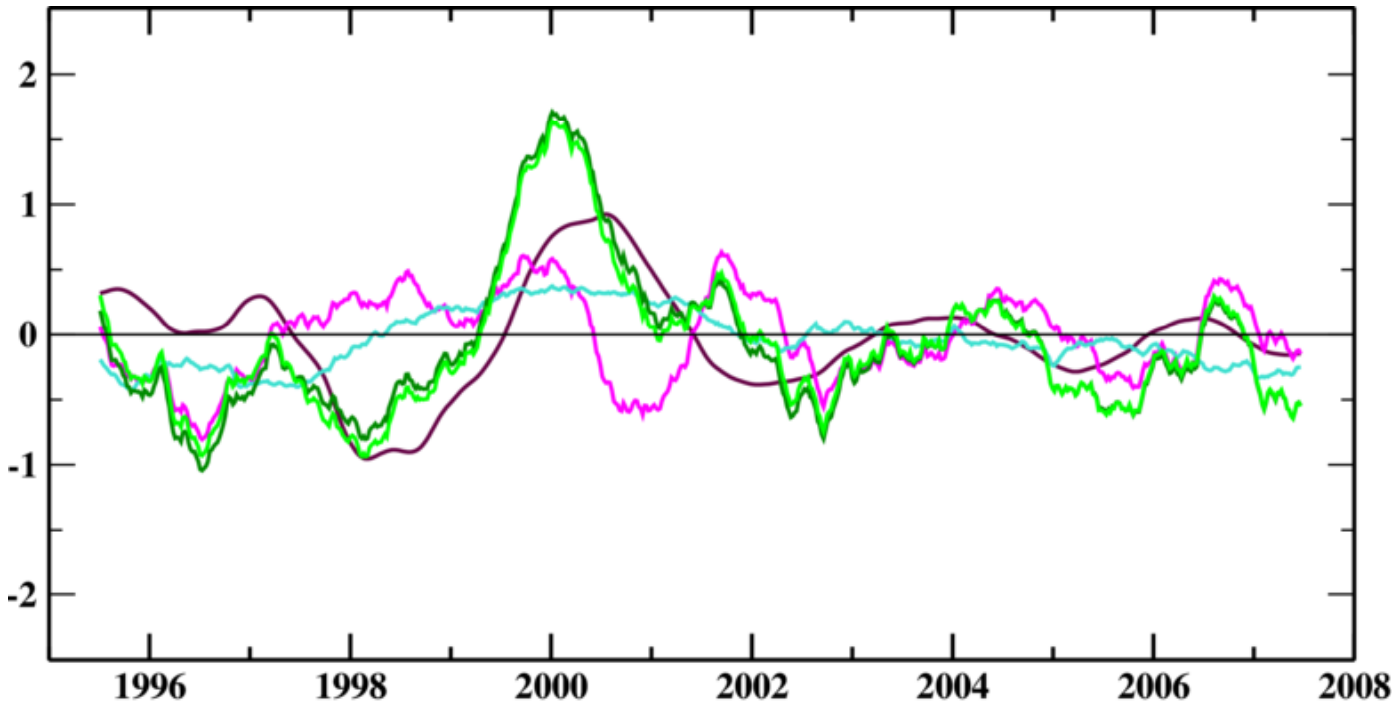


> 1 yr signal



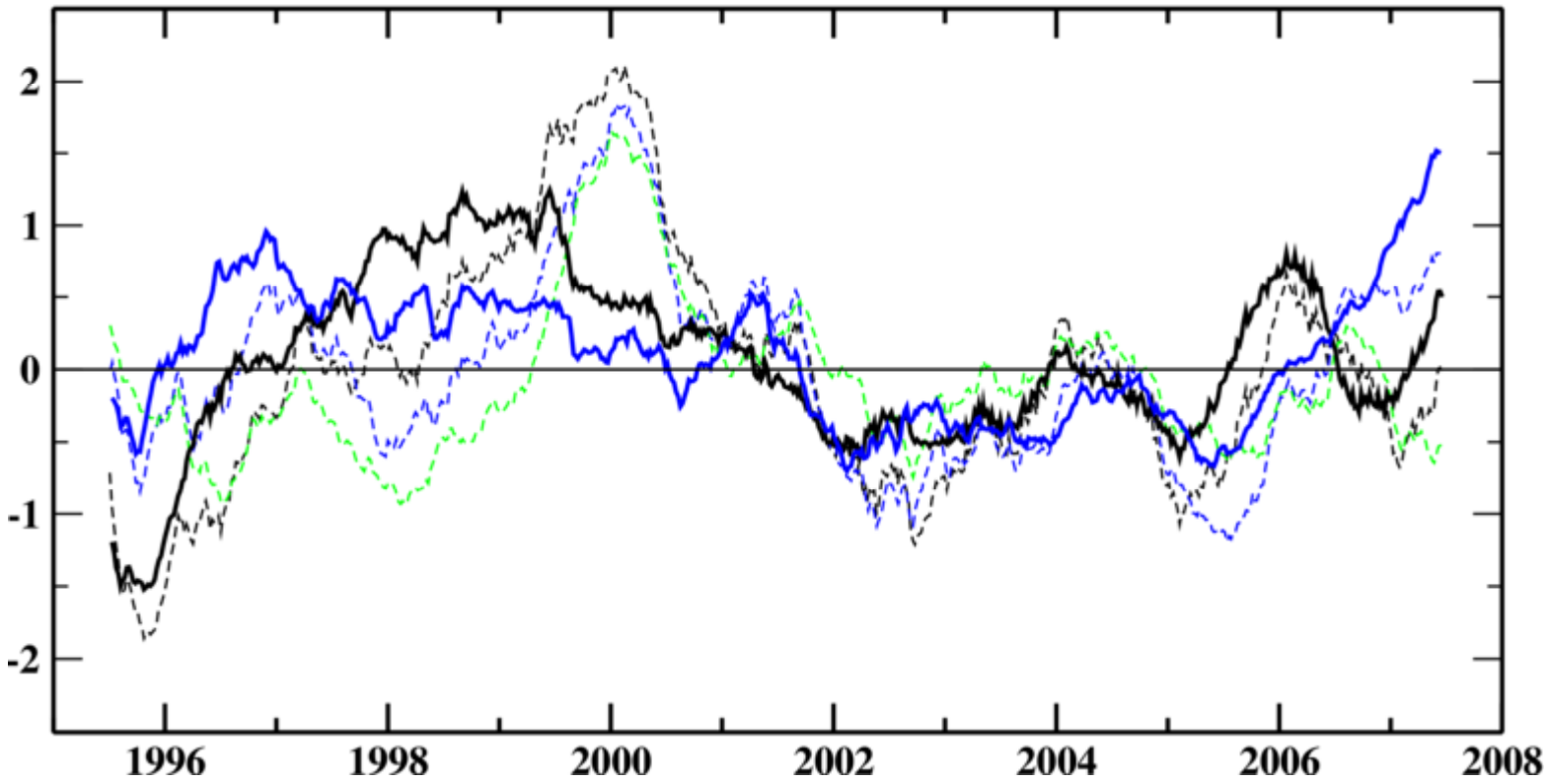
- GPS and SLR deviate from model during anomaly upward leg
- GPS approx 2x closer than SLR during upward leg
- GPS, SLR, model much closer during the return leg
- Best agreement for GPS and SLR during the period 2002-2005

> 1 yr loading signal components



- Land hydrology=Maroon
- Atmosphere=Magenta
- Ocean=turquoise
- Dark green=sum
- Light green=Mass conserving, equipotential total

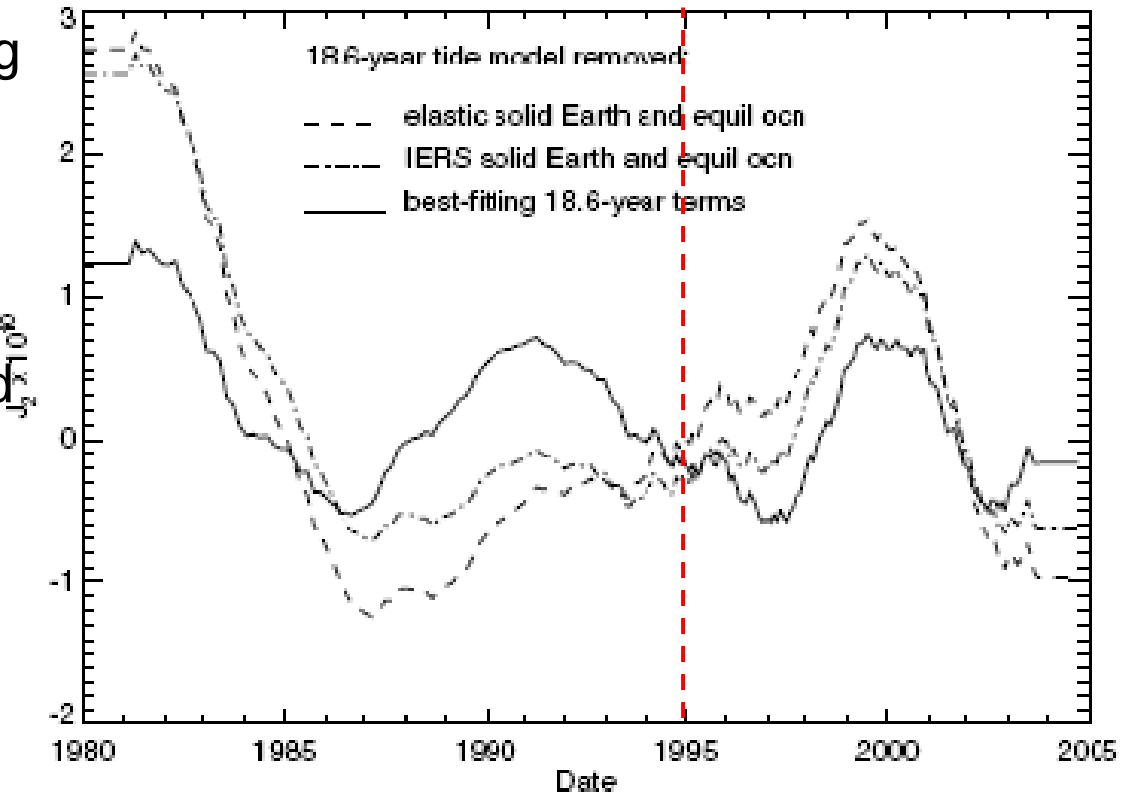
Load model subtracted



- 1998 anomaly disappears from GPS
- Residual anomaly in SLR
- Long period variation 8-10 years remains in both

Effects of 18.6 year tide model

- Benjamin et al 2006 fig 4. Note: atmos removed
- Note behaviour during upward and downward anomaly legs and “trough”
- Our SLR uses IERS model
- But why would GPS be affected differently?



Conclusions

- GPS provides an independent geodetic measurement of J2
- Our GPS J2 series agrees (perhaps surprisingly) with SLR
- GPS J2 series provide new, different insight into the 1998 J2 anomaly
- Effects of 18.6 year tide model need investigating
- Unexplained quasi-decadal variation in GPS and SLR J2
- Some more GPS specific frequencies to speculate on.

Detailed Summary

- GPS and SLR deviate from model during anomaly upward leg
- GPS 2x closer than SLR
- GPS, SLR, model closer during the return leg
- Best agreement during the period 2002-2005
- The 1998 anomaly is evident in the loading model series but between mid
- Presence of “trough” in GPS & load model 1997 - 2000
- Subtraction of load model completely removes anomaly from GPS.
- Residual anomaly remains in SLR.

- Significant amplitude annual/near-annual remains in GPS
- Significant semi-annual remains in SLR
- Significant long period signal (8-10 years) remains in both
- Annual: Load model is significantly bigger than GPS & SLR which agree
- Semi-annual: All three differ, SLR is particularly big.