Degree 2 and Geocenter Variations from Satellite Laser Ranging

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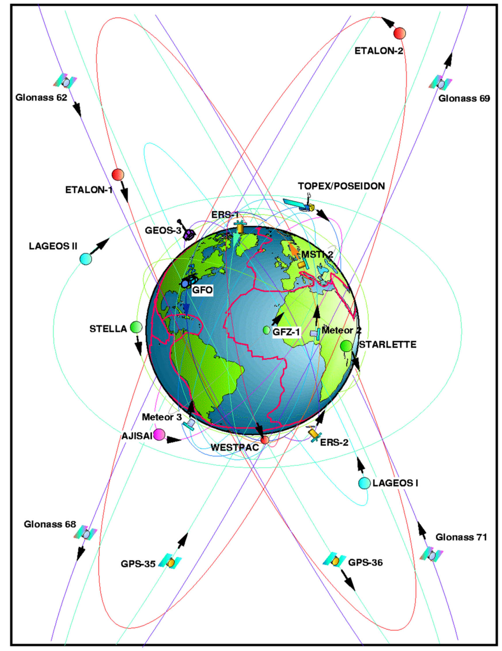
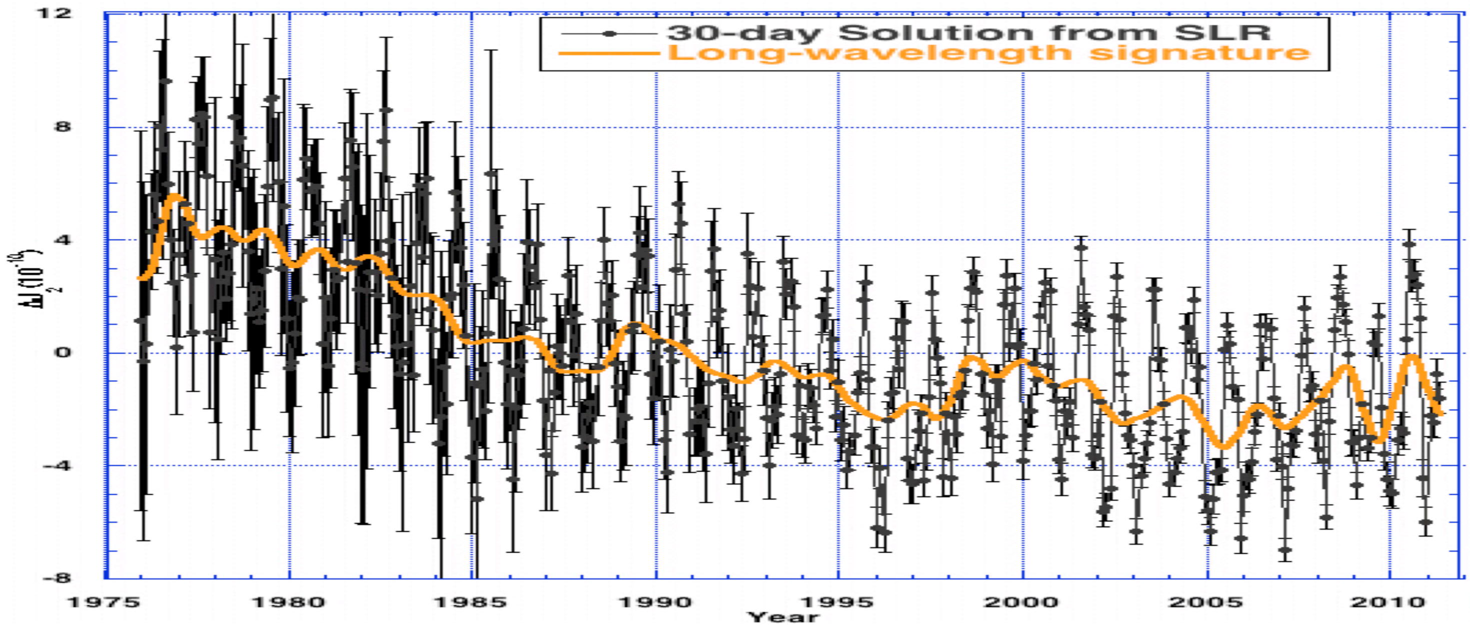


- SLR solution
- J2 variations from SLR and GRACE
- Variation in the Earth’s figure axis
- Geocenter variations
- Summary

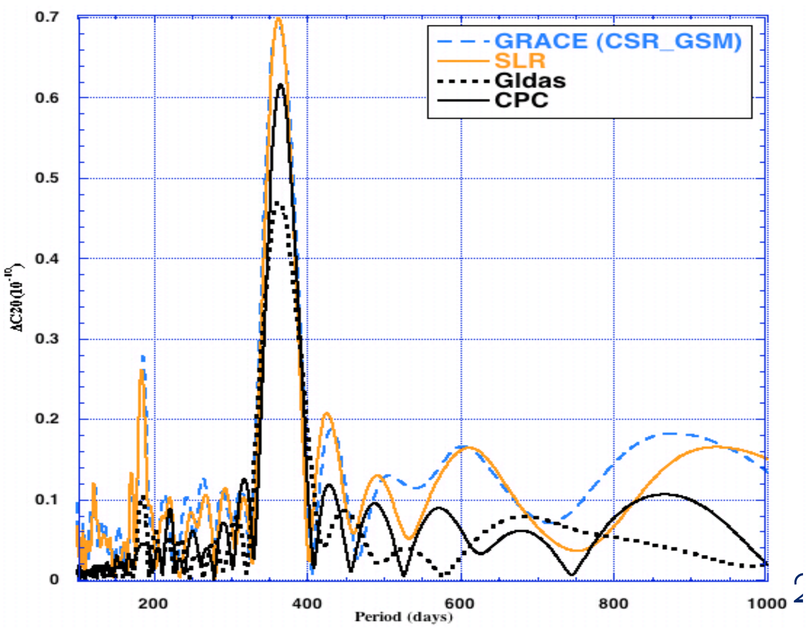
SLR solution

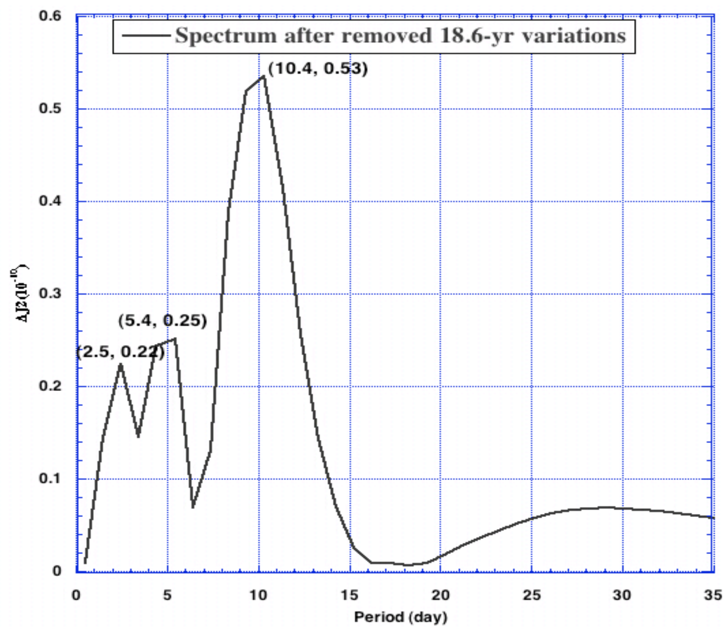
- Evaluation of the large-scale mass change represented by updated time-series for the low degree gravity harmonics from GRACE and SLR
- SLR data from 5 or 8 geodetic satellites (depending on case):
  - Starlette, Ajisai, Stella, LAGEOS 1 and 2, BEC, Etalon 1 and 2.
- New 30-day solutions of J2 from 8 satellites from 1976 to date based on updated models.
  - IERS 2010 standards, LPOD2005 (consistent with ITRF2005) for station coordinates, EGM08 gravity model, FES2004/GOT4.8 ocean tide, and solid earth/ocean pole tide.
- Weekly and 30-day solutions for Geocenter and 5x5 gravity field from 5 satellites from 1984 to date based on new models
- Monthly solutions of Geocenter and 5x5 gravity field from 5 satellites consistent with GRACE (RL04) model with time span from January 2002-February 2012.
- New time series of monthly solution consistent with GRACE (RL05) model

Variation in J2 from SLR data

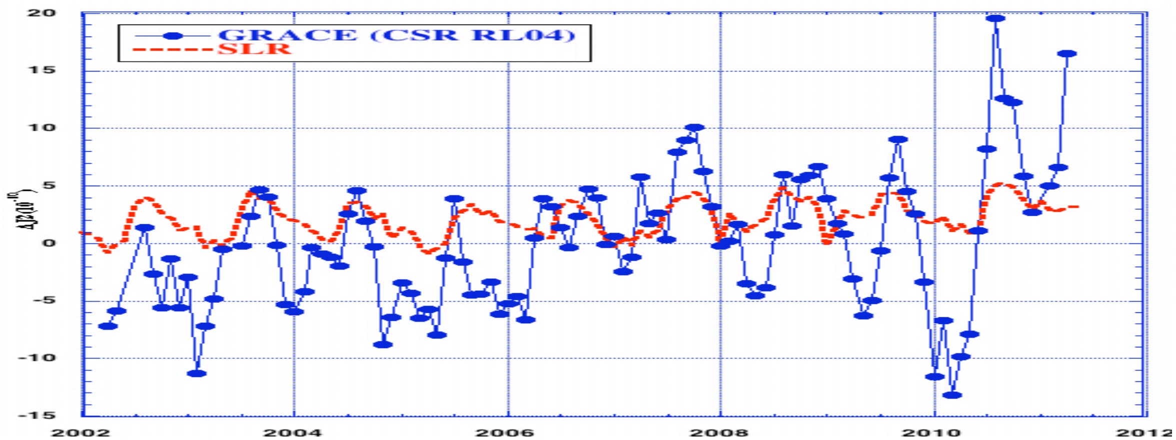


J2 has undergoes a significant ENOS related decadal variations, which affects the rate estimate.





Variation in J2 from SLR and GRACE data

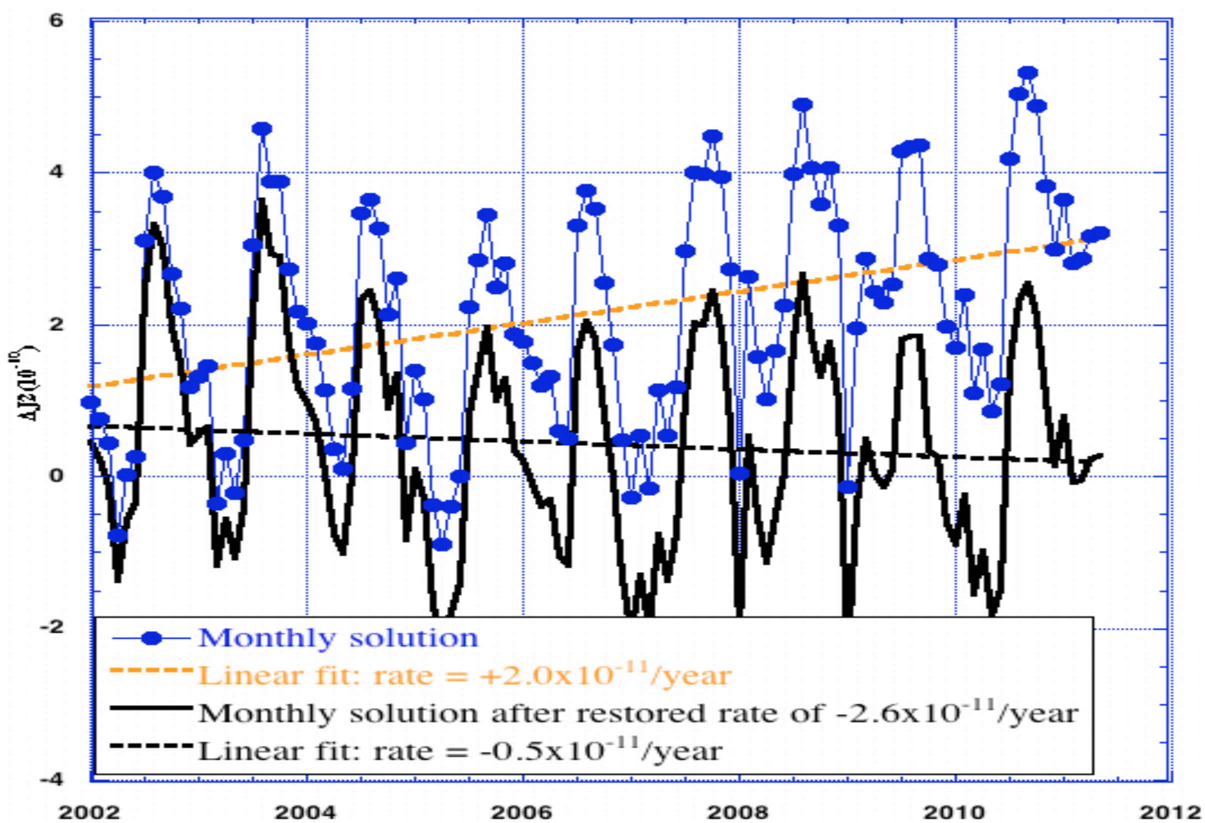


Uniform sea-level rise and J2

$$\Delta J_2 = +1.57 \times 10^{-11} \Delta h (mm/y)$$

$$\Delta \dot{J}_2 = +2.09 \times 10^{-11} / y$$

$$\Delta \dot{h} = \sim 1.33\ mm/y$$



It is in good agreement with estimate by Wills et al. [2010]:1.3±0.6 mm/y for the period from 2002 to 2010

A better C20 coefficient from SLR has been an essential component for GRACE application, and can provide constraint on Sea-level rise

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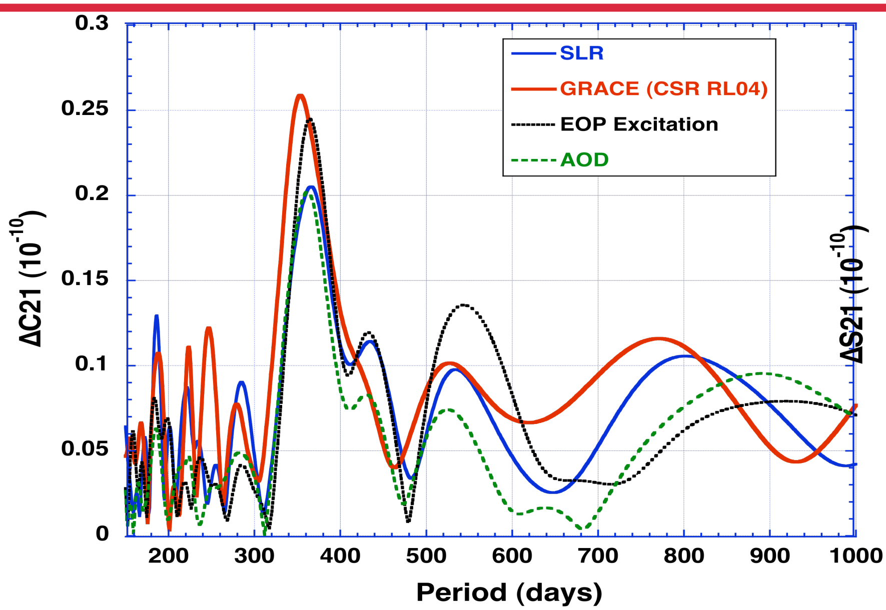
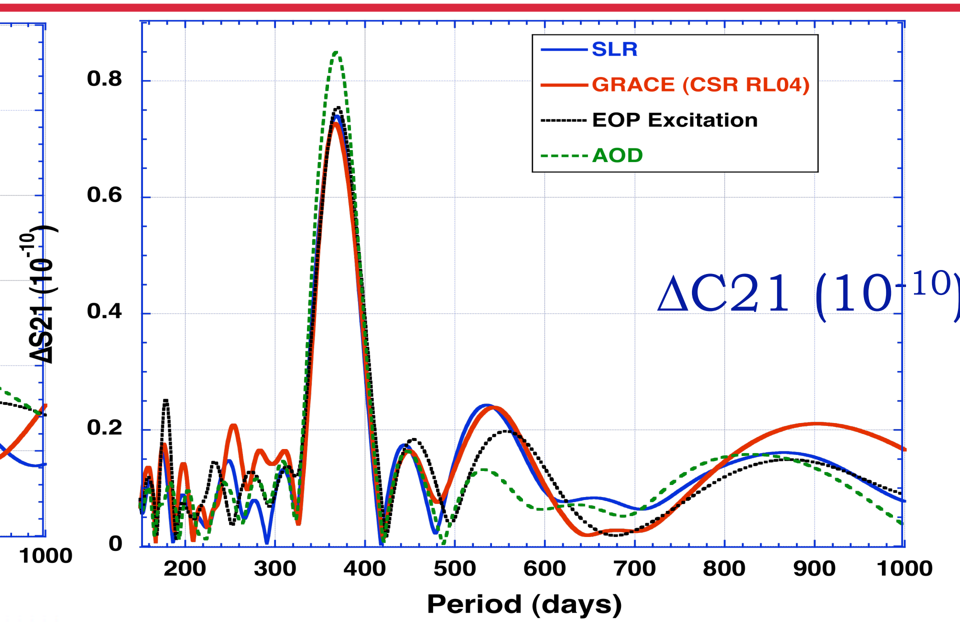
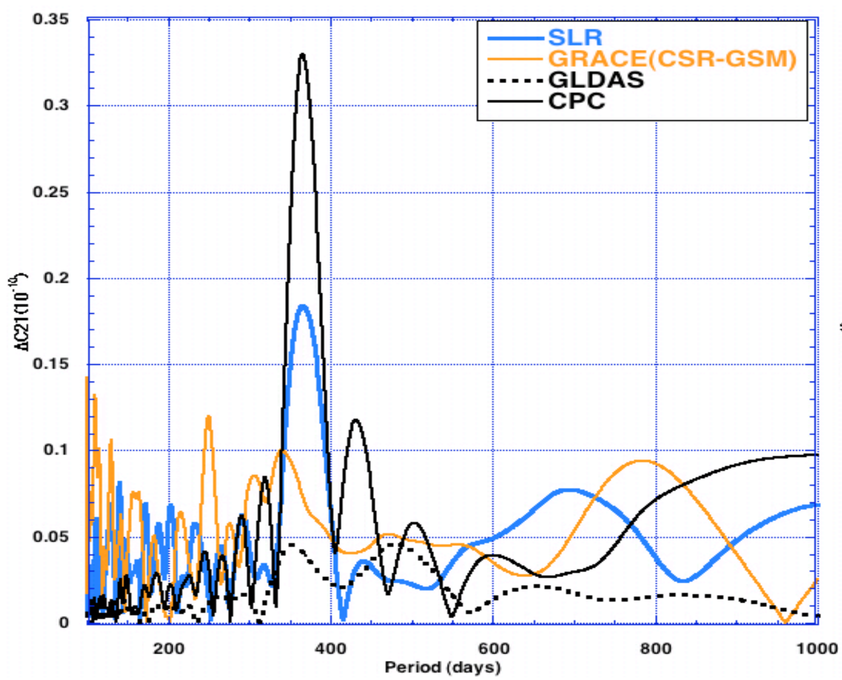
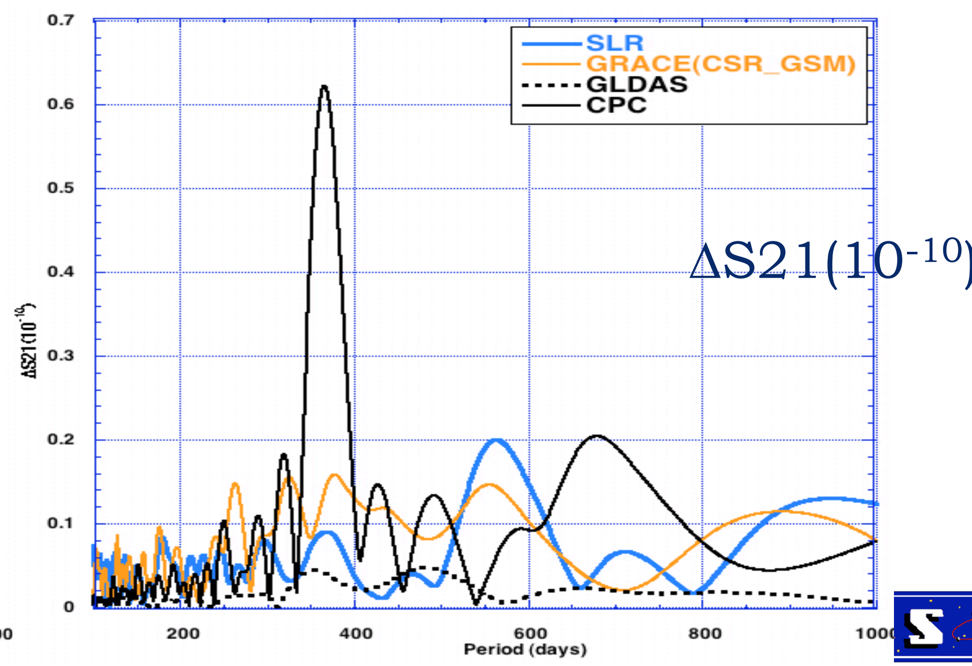
Spectrum of the Variations in C21/S21

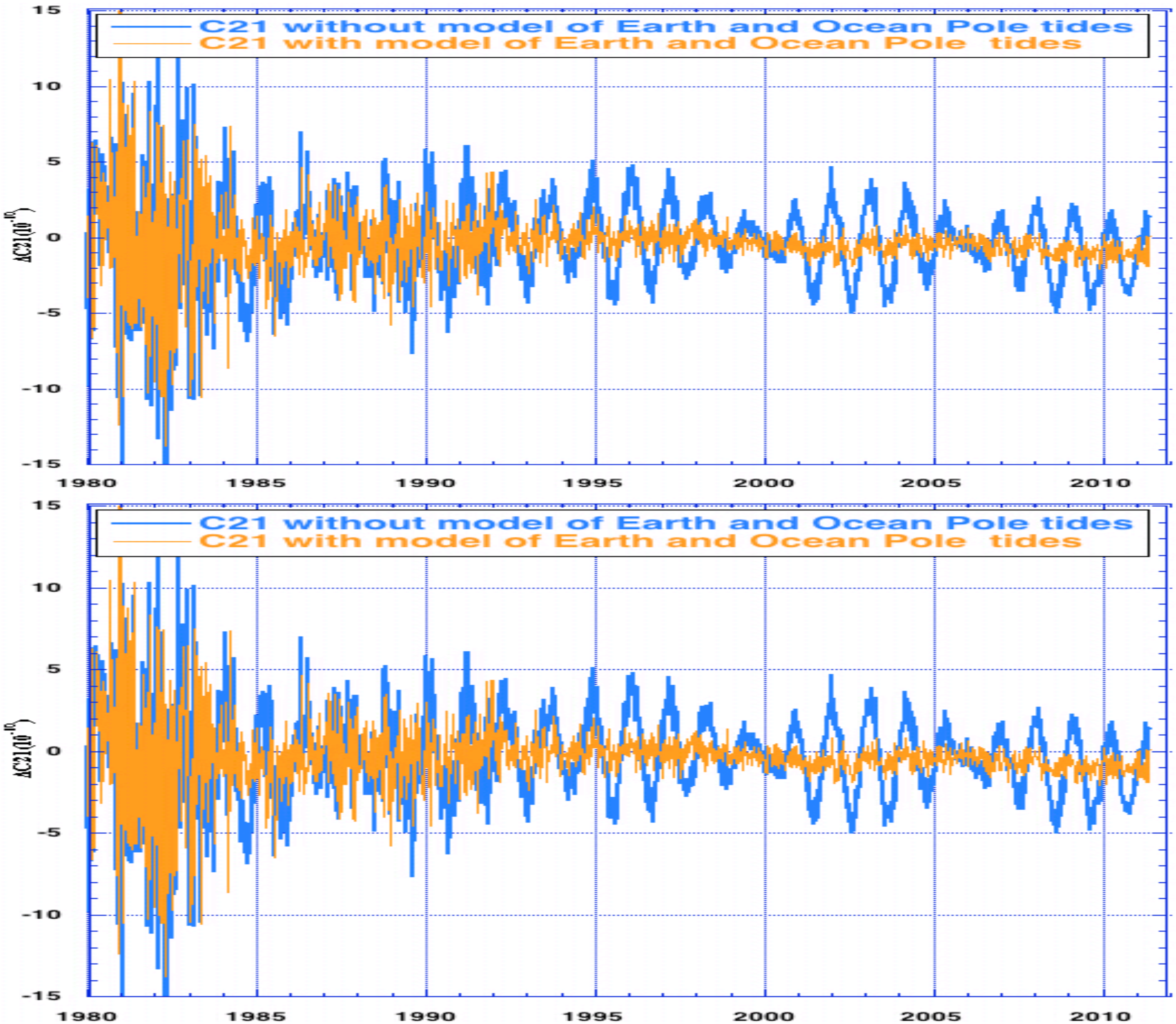








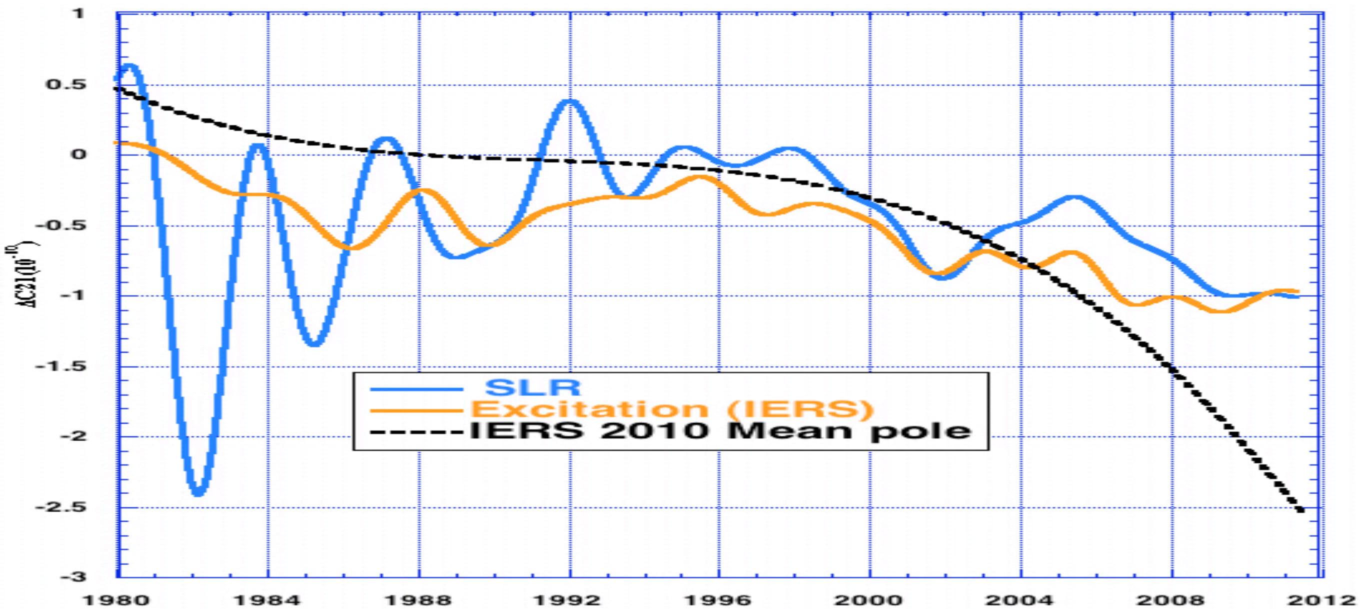
Variations in C21/S21 from SLR Data (weekly)

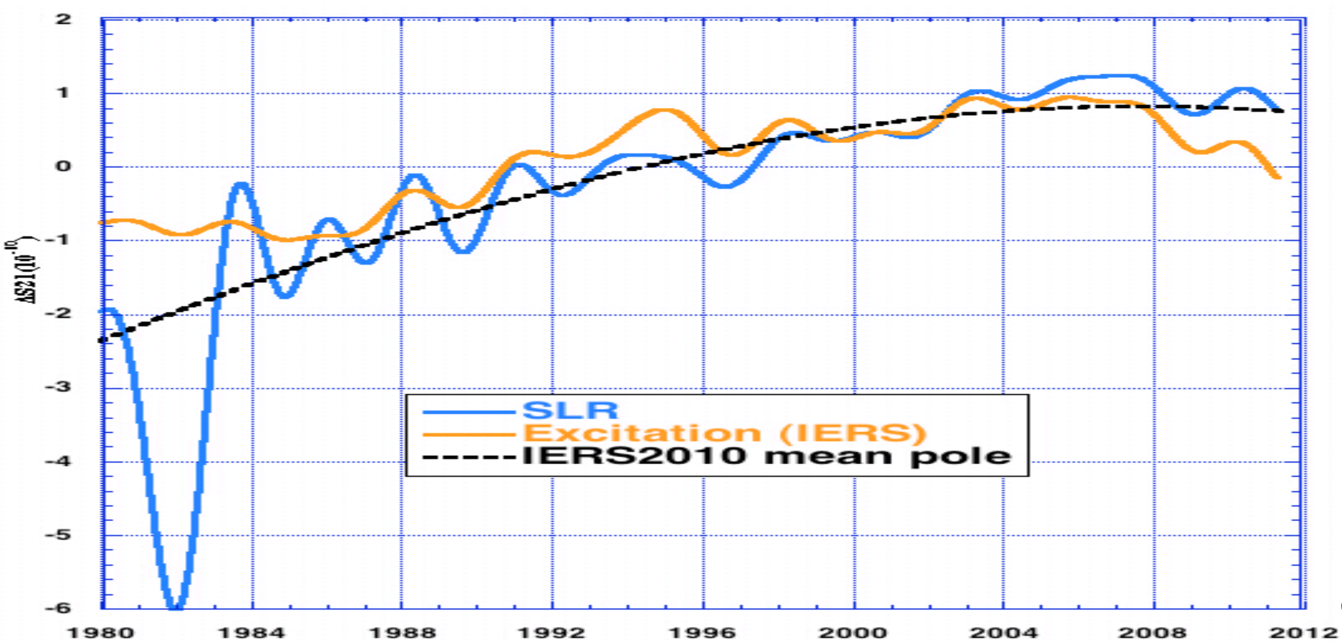


Remark: Significant Chandler variation in C21/S21 is due to pole tides in Solid Earth and ocean.

The SLR solutions of C21/S21 are reliable after ~1984

Long-wavelength Variations





There is significant decadal variation in order of 4x10^{-11} with period > 20 years in the SLR and Polar motion excitation. This decadal variation could be produced by an inner core tilt of 0.04 degreee based on the Eqs. of Dumbery [2008].

The variations with ~4 to 9-yr could related to ENSO events, see Poster:G53A-0876 by Ming Fang et al.

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Definition of Geocenter

Geocenter: the Center of Mass(CM) of entire Earth system, including solid Earth and its fluid thin layer, defined by the degree one geopotential coefficients:

$$\vec{r}_{cm} = \frac{1}{M}\iiint_E (x\vec{e}_x + y\vec{e}_y + z\vec{e}_z)dm = a_e\sqrt{3}(\bar{C}_{11}, \bar{S}_{11}, \bar{C}_{10})$$

The Geocenter vector from ITRF to CM can be represented by the sum of integrals for the solid Earth and fluid part:

$$\vec{r}_{cm} = \vec{r}^{\,s}_{cm} + \vec{r}^{\,f}_{cm}$$

- The Geocenter vector can be directly determined from SLR [Cheng et al, 2011, 2012]

$$\vec{r}(t) = \vec{\rho}(t) + \vec{R}_s(t) - \vec{r}_{cm}; \qquad \vec{R}_s(t) = \vec{R}_s(t_0) + (t - t_0)\vec{V}_s(t_0) + \Delta\vec{R}_s(t)$$

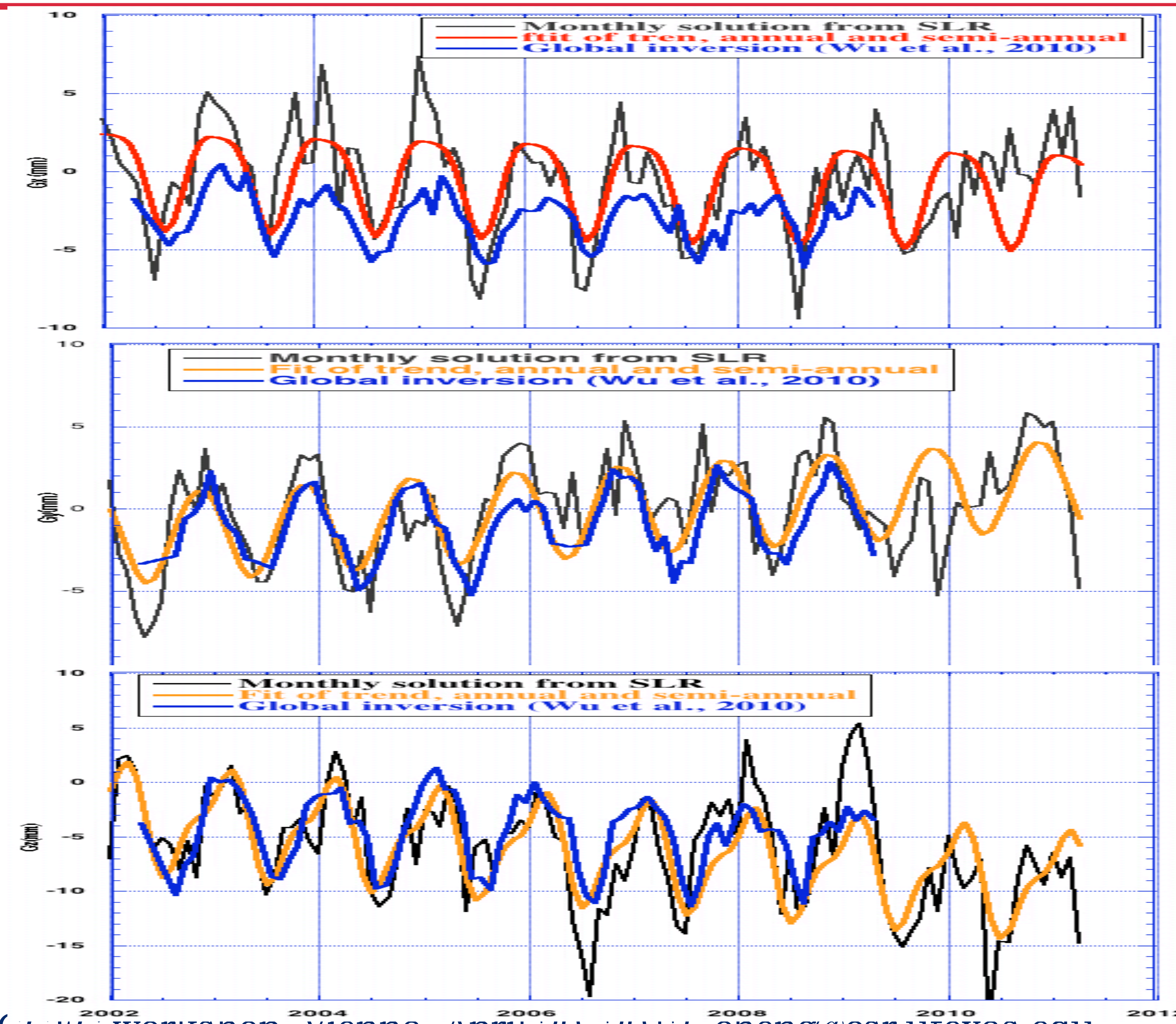
- The center of mass of the fluid thin layer due to changes in mass loading and surface displacements [Trupin et al., 1992, Wahr et al., 1998]

$$\vec{r}^{\,f}_{cm} = \frac{a_e\rho_w}{\rho_e}\sqrt{3}\left(1 - \frac{h_1^{'} + 2l_1^{'}}{3}\right)(\sigma^c_{11}\vec{e}_x + \sigma^s_{11}\vec{e}_y + \sigma^c_{10}\vec{e}_z)$$

- The degree one coefficients of the surface density changes of the fluid thin layer, can be determined from the 3-D displacements of the GPS network as known as the Global inversion [Blewitt, 2001; Wu et al., 2010]

- Theoretically, the center of the solid earth can be determined by difference between SLR and Global inversion [Cheng et al., 2012]

Geocenter Variations from SLR (monthly Solution)



Remark:

X: SLR estimate is large than from Global inversion

Y and Z: Good agreement from SLR and Global inversion

Comparison of Annual Geocenter Variation

Solution	X		Y		Z	
	A (mm)	Phase(d)	A (mm)	Phase(d)	A (mm)	Phase(d)
ITRF2008	2.6±0.1	42±3	3.1±0.1	325±2	5.5±0.3	22±10
SLR-w	2.7±0.2	40±2	2.8±0.2	323±2	5.2±0.2	30±5
SLR-m	2.9±0.4	35±3	2.6±0.2	306±2	4.3±0.3	33±2
Global In.	1.8±0.2	49±3	2.7±0.2	325±3	4.2±02	31±3

ITRF2008: Altamimin et al.[2011]. J. Geod, doi 10.2007/s00190-011-0444-4
SLR-w: Weekly solution from five satellites estimating 5x5 gravity field over interval from November 1992 to Dec. 2010
SLR-m: Monthly solution from five satellites estimating 5x5 gravity field covering the GRACE mission from January 2002 to Dec 2010.
Global In.: Global inversion from GPS/OBP/GRACE [Wu et al. 2010]

Comparison of Geocenter Solution

Solution	X		Y		Z	
	ΔX (mm)	$\dot{X}(mm/y)$	ΔY (mm)	$\dot{Y}(mm/y)$	ΔZ (mm)	$\dot{Z}(mm/y)$
ITRF2008	-0.5	0.3	-0.9	±0.2	-4.7	±0.2
SLR-w	-0.2	-0.23	-0.3	0.1	-4.8	-0.62
SLR-m	-0.2	-0.21	-0.7	0.3	-4.8	-0.45
Global in.	-2.9	-0.18	-1.2	0.4	-4.4	-0.88
PGR/ICE		~0.2		~0.2		0.3-0.8

ITRF2008: Altamimi et al., 2010

SLR-w: Weekly solution from five satellites with estimating 5x5 gravity field over interval from November 1992 to Dec. 2010

SLR-m: Monthly solution from five satellites with estimating 5x5 gravity field covering the GRACE period from January 2002 to Dec. 2010.

Global in.: Global inversion from GPS/GRACE/OBP by Wu et al(2010)

PGR/ICE: Metivier et al., 2010

Offset: ΔX,ΔY,ΔZ and rates are WRT the origin of ITRF2005 at epoch of 2005.0

The cause of rats estimated from SLR-w(m) are complicated, but mostly due to the error in ITRF

Summary

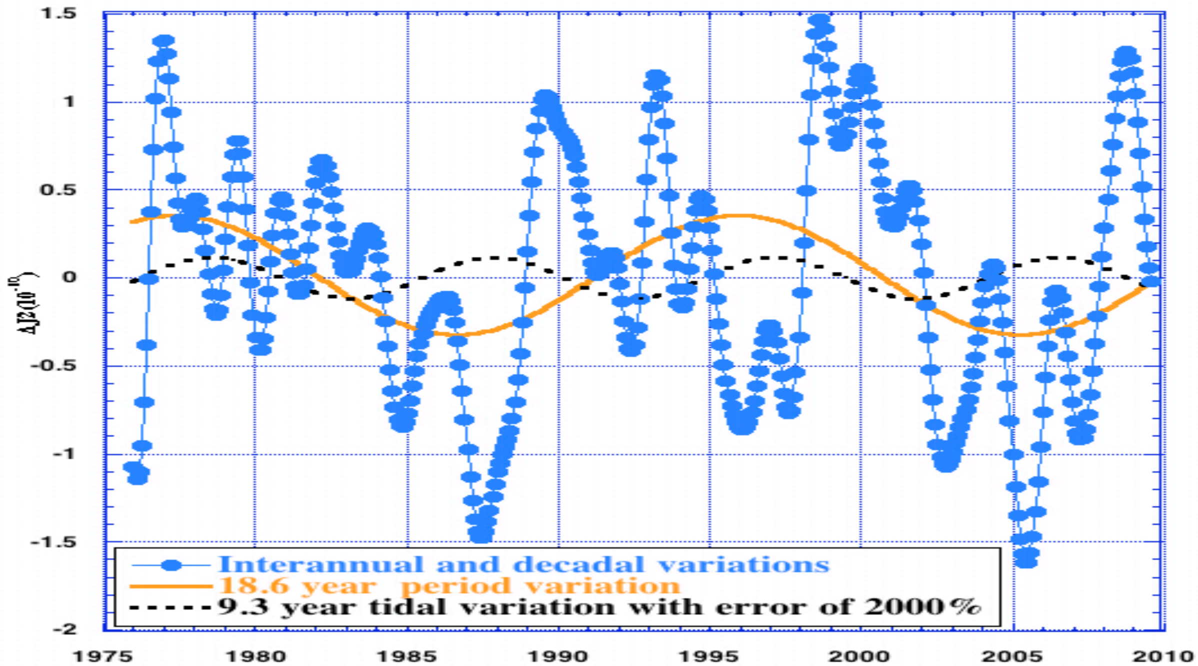
- SLR estimates of J2 and geocenter motion are essential for the GRACE science for extracting the entire mass redistribution signal. J2 has undergone significant interannal and decadal variations during the past 35 years. The trend of J2 is significantly affected by the recent mass changes resulting in sea level rise over 2002 to 2010.

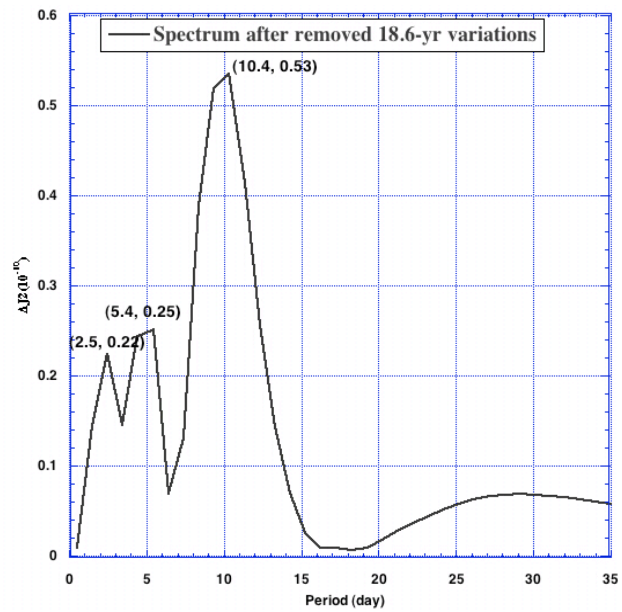
- Solution of C21/S21 from long-term SLR data provide an improved measurement of the Earth mean figure axis, which provide important global constraints on the core-mantle dynamic process: tilt of the core figure axis [Cheng et al. 2011].

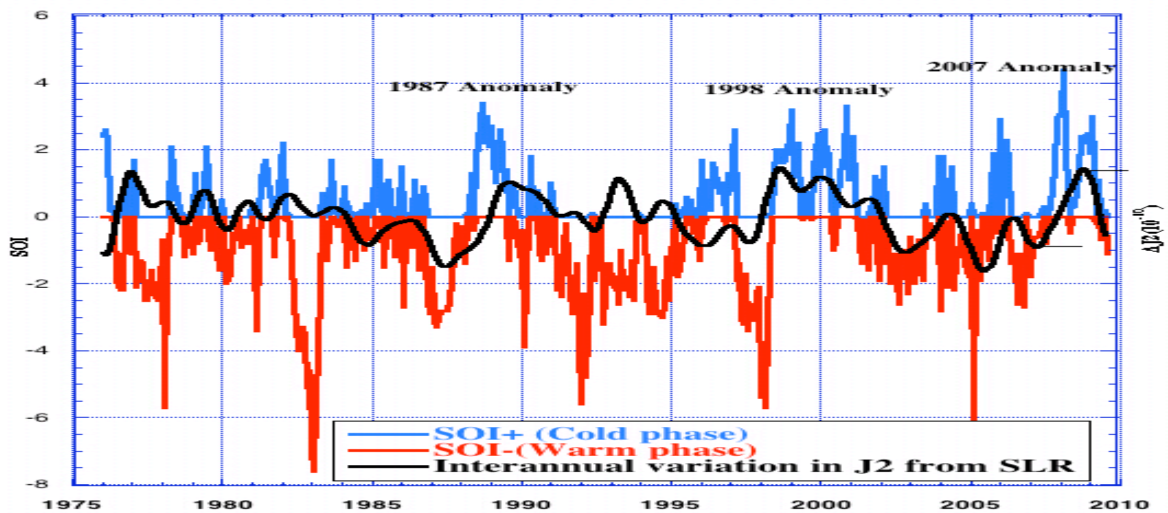
- The CSR SLR solutions (Annual and offset) are in good agreement with the ITRF2008 solution of the translation component. The monthly solutions (Annual) are in good agreement (except for X component) with the solution of the global inversion from GPS/OBP/GRACE. The difference between the results from SLR and Global inversion could provide information of the center of the solid Earth.

- The agreement of the rate estimate from CSR SLR solution and Global inversion is interesting if the signals are meaningful for the tectonic plate motion and large scale mass drift of the Earth?

Decadal Variations in J2 from SLR data







Comparison of Annual Variations in C21/S21

Solution	$\overline{C}_{21}(10^{-11})$		$\overline{S}_{21}(10^{-11})$	
	Sa(A/P)	CW(A/P)	Sa(A/P)	CW(A/P)
Weekly solution from SLR for the period from 1993-2009				
No pole tides	1.36/ 53	2.39/208	0.62/130	2.11/299
+SEPT	0.19/ 33	0.38/203	0.49/343	0.24/323
SEPT&OPT	0.08/306	0.08/217	0.64/340	0.10/ 36
EOP	0.21/285		0.65/330	
AOD	0.17/318		0.84/343	
Monthly Solution for GRACE period from 2002 to June 2009				
SLR	0.194/321		0.694/320	
GRACE	0.249/273		0.667/325	
EOP	0.231/268		0.684/316	
AOD	0.195/301		0.839/330	

Rate of C21/S21

Data	$\dot{\bar{C}}_{21}(10^{-12}/y)$	$\dot{\bar{S}}_{21}(10^{-12}/y)$	Time Span
IERS	-3.4	16.1	1976-2000
Mean Pole	-4.4	11.8	1976-2009
Weekly solution			
Mean Pole	-8.1	5.8	1993-2009
SLR	-5.2	8.4	1993-2009
Monthly solution			
Mean Pole	-16.3	2.7	2008-2008
SLR	-9.3	5.8	2002-2009
GRACE(CSR)	-17.2	4.0	2002-2009
GRACE(GFZ)	-14.9	-2.3	2002-2009
GIA(1)	1.3	-8.0	N/A
GIA(2)	13.1	-74	N/A

C22/S22 from GRACE and SLR