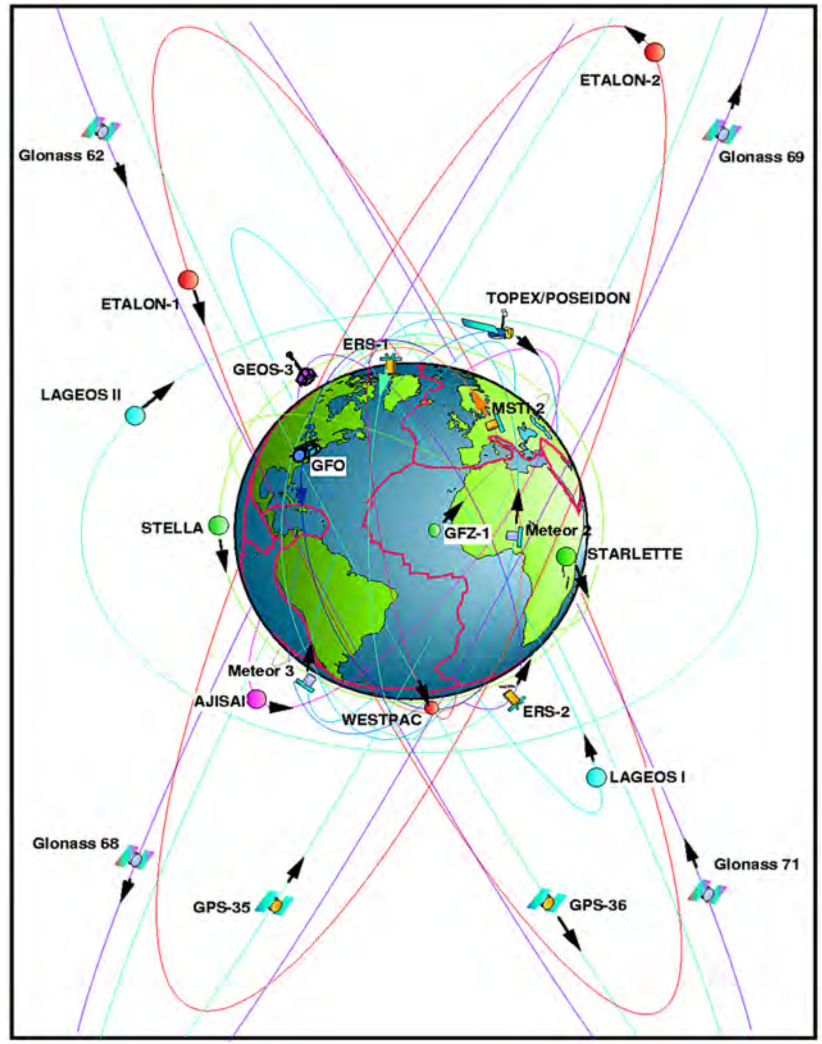
Application of Satellite Laser Ranging for Long-Wavelength Gravity Field Determination

J. C. Ries

Center for Space Research
The University of Texas at Austin



Low Degree Gravity Variations from SLR

- GRACE is largely insensitive to geocenter (i.e., degree-1) variations
  - Annual variation represents largest-scale mass redistribution
    - Need to be included to get complete picture of mass variations
  - Slow non-linear trends should be observable from SLR
    - These will represent long-term non-linear mass redistribution, such as present-day <u>accelerated</u> ice mass loss

- C20 is observable by GRACE but it is corrupted by tide-like aliases (S1, S2, …)
  - Source is uncertain but likely due to thermal variations on the s/c
  - SLR provides critical replacement estimate
  - Updated time series indicate dramatic changes in C20 relative to long-term trend

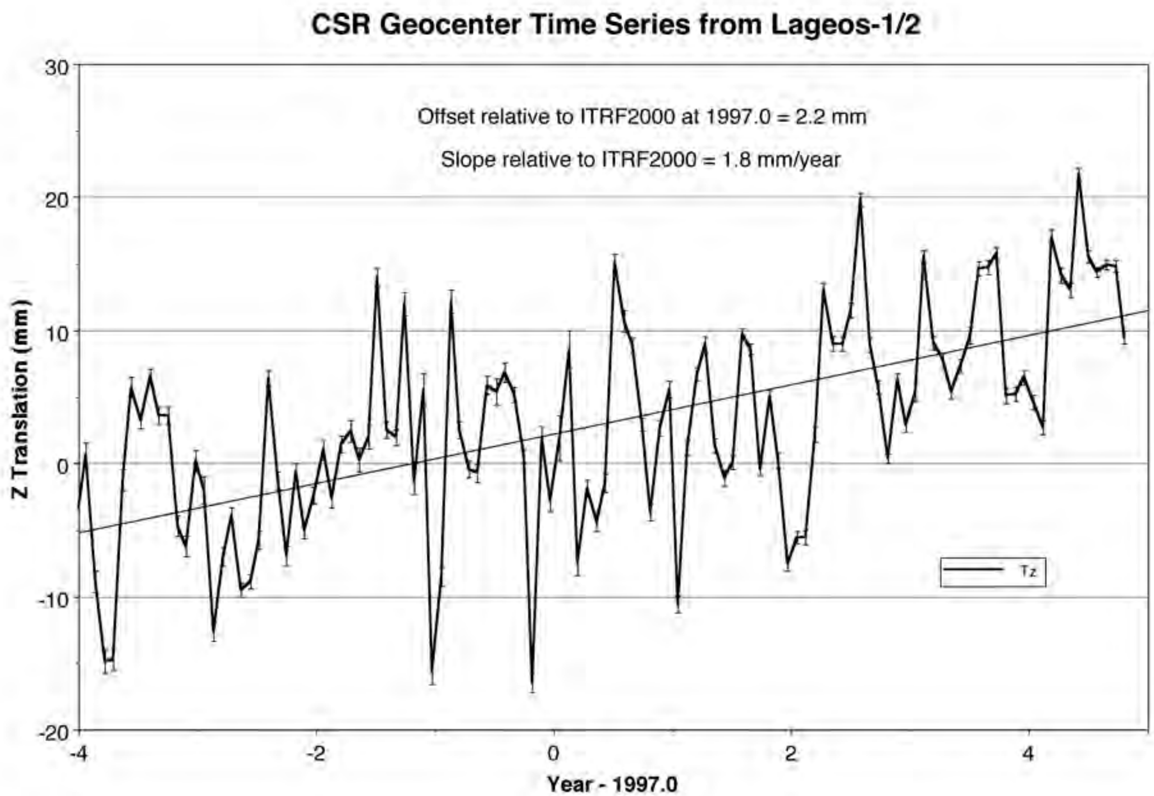
- C21/S21 estimates from SLR and GRACE reflect same seasonal variations but sometimes different trends are observed

Seasonal Geocenter Motion (Degree-1)

- We have a tidally-coherent (diurnal and semi-diurnal) geocenter motion model but not for non-tidal variations, which dominate the annual geocenter motion.
    - Geocenter motion, equivalent to a degree-1 mass load, is the largest scale mass transport signal
    - Need degree-1 for complete picture of seasonal mass redistribution
- No provision in the ITRF definition for non-linear trends, so such trends remain in the residuals and so should be observable.
- Note that 'secular' geocenter is unobservable, as it has been subsumed into the very definition of the ITRF. Any residual linear trends in SLR time series represent error in the ITRF, the SLR analysis, or some of both.

Example: ITRF2000

Z-drift of 1.8 mm/y observed in CSR analysis using ITRF2000

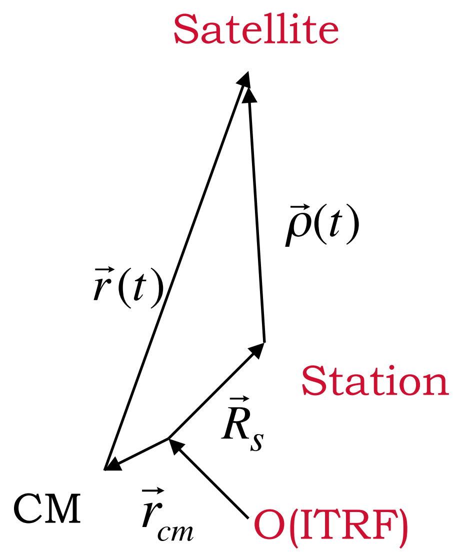


Observed trend had no geophysical significance; it was simply error in the background ITRF

ITRF2005 corrected trend by 1.8 mm/yr and no such trend is observed now

‘Dynamical’ Approach to Determine Geocenter Motion

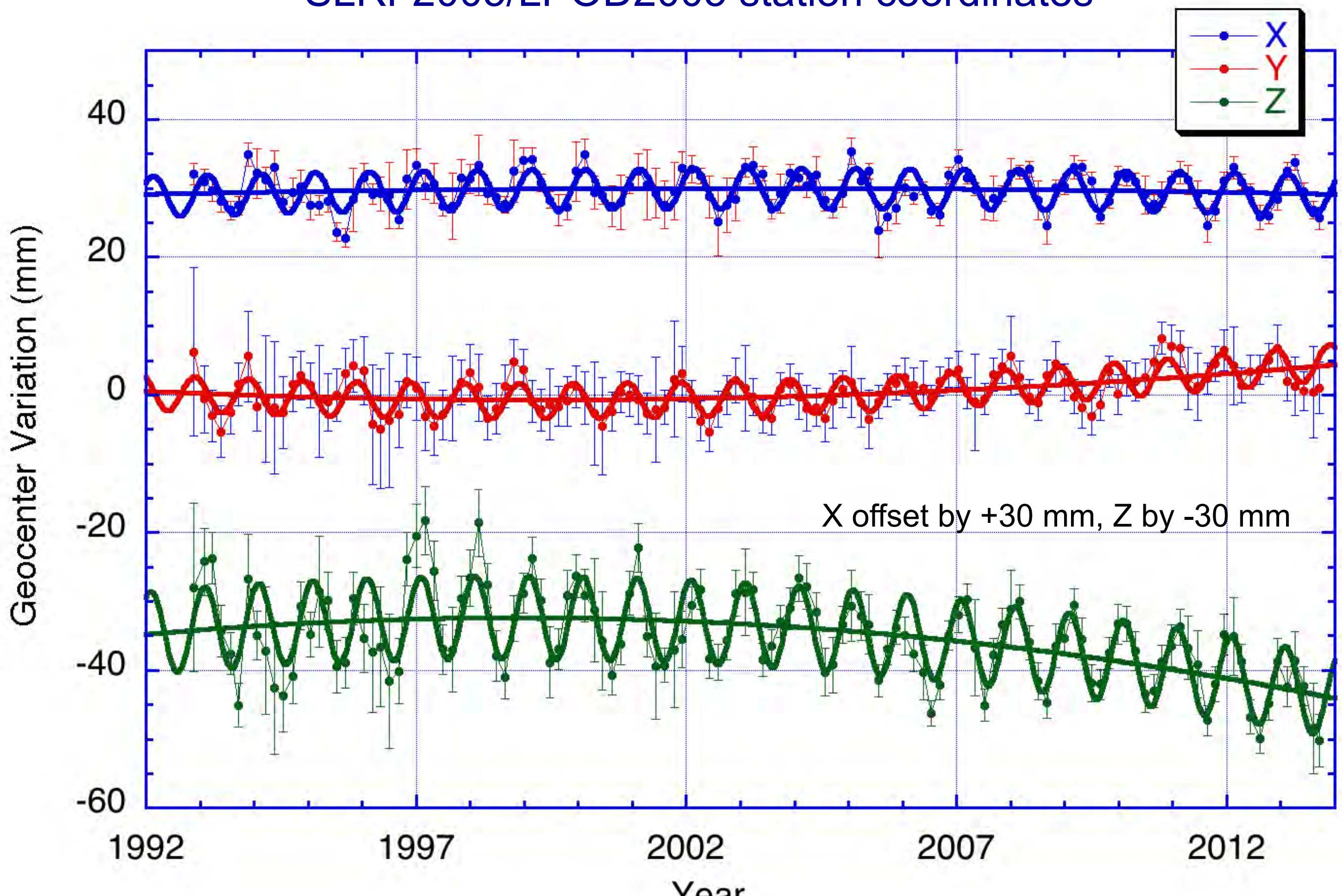
- Satellites orbit about the center of mass of the entire Earth system (solid Earth, oceans and atmosphere).
- Geocenter motion vector $\vec{r}_{cm}$ can be estimated simultaneously with the orbit (holding ITRF coordinates fixed).
- This is identical to estimating degree-1 gravity harmonics (as long as a Coriolis-type correction is included to account for the fact that the geocentric frame origin is no longer an inertial point [Kar, 1997]).
- Degree-1 mass redistribution (load) and geocenter motion tend to be used interchangeably.



$$\vec{r}_{cm} = a_e(C_{11}, S_{11}, C_{10})$$

Geocenter Motion from SLR

60-day estimates of geocenter from LAGEOS-1/2
SLRF2005/LPOD2005 station coordinates

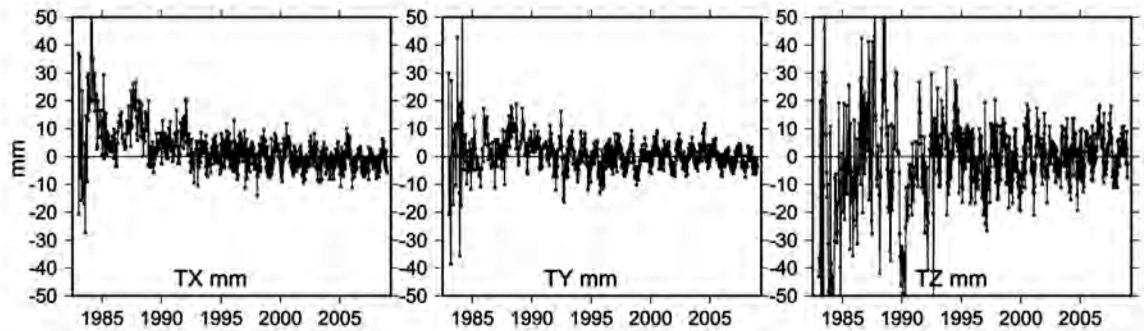


X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)	Reference (comments) (phase is in degrees)
2.9	48	2.6	325	6.0	31	Ries, 2013 (60-day estimates; 1993-2013)
2.9	44	2.5	324	6.4	35	Ries, 2013 (30-day estimates; 1993-2013; estimate 2x2 gravity)

‘Kinematic’ Approach

Stack time series of loosely-constrained frame estimates

Z. Altamimi et al.



Altamimi et al., 2010

Fig. 4 Weekly translation components of the SLR ILRS solution with respect to ITRF2008, in millimeter along the *X*, *Y* and *Z*-axes: *left*, *middle* and *right*, respectively

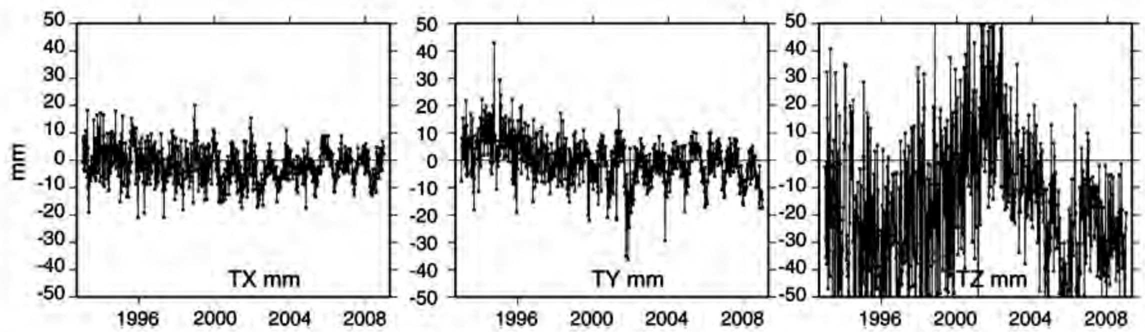
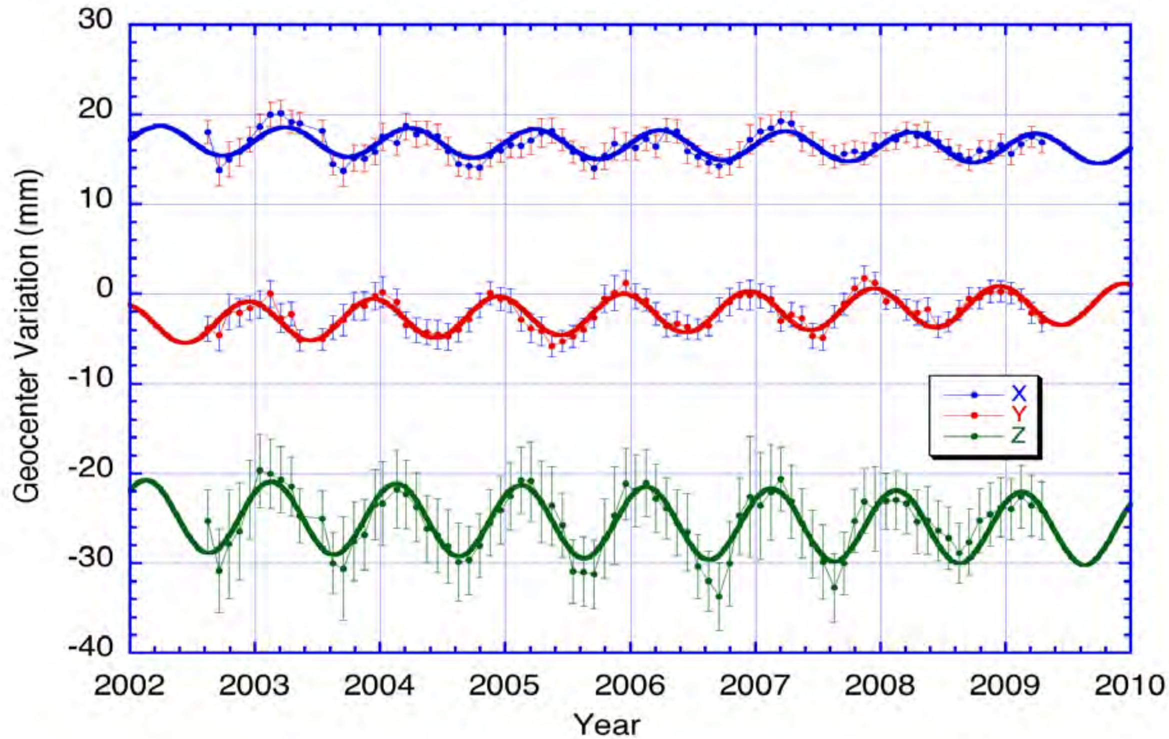


Fig. 5 Weekly translation components of the DORIS IDS-3 solution with respect to ITRF2008, in millimeter along the *X*, *Y* and *Z*-axes: *left*, *middle* and *right*, respectively

X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)	Reference (comments) (phase is in degrees)
2.6	42	3.1	315	5.5	22	Altamimi et al., 2010 (ILRS contribution to ITRF2008)

‘Global Inversion’ Approach

Estimate degree-1 deformation from GPS, using other information (GRACE, Ocean bottom pressure, etc.) to remove load signal above degree 1

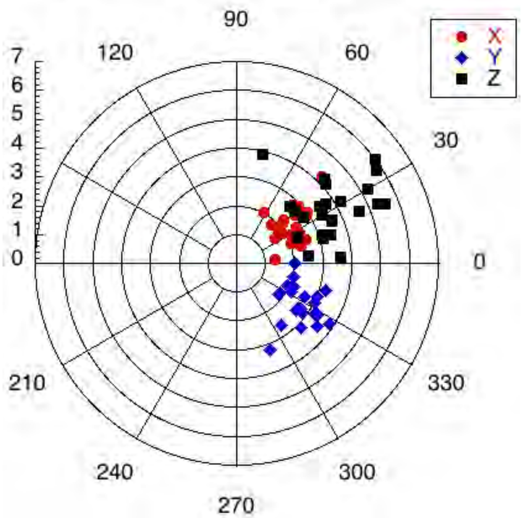


Wu et al., 2010

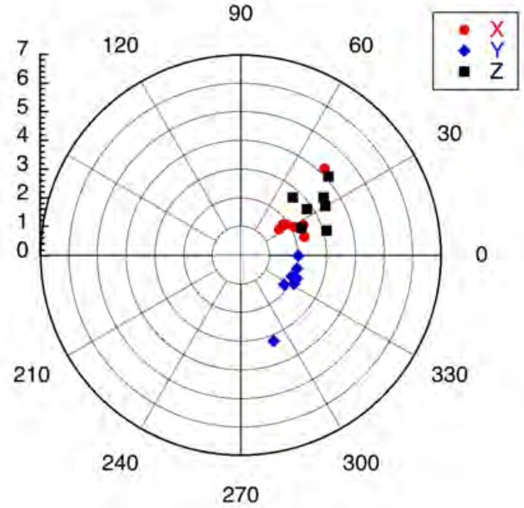
X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)	Reference (comments) (phase is in degrees)
1.9	42	3.2	328	3.6	25	Wu, 2006
2.0	21	2.6	334	3.6	24	Jansen et al., 2009
1.8	49	2.7	325	4.2	31	Wu et al., 2010
2.0	62	3.5	322	3.1	19	Rietbroeck et al., 2011 (updated June 2011)

Annual Geocenter Motion Estimates

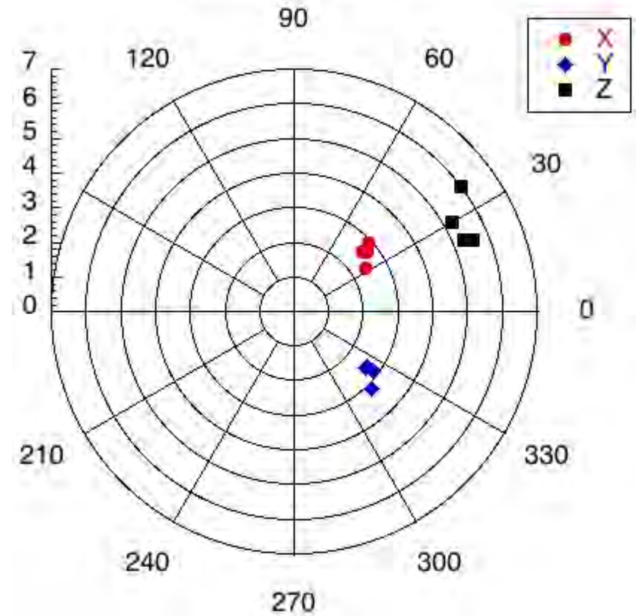
All Geodetic Estimates and Models



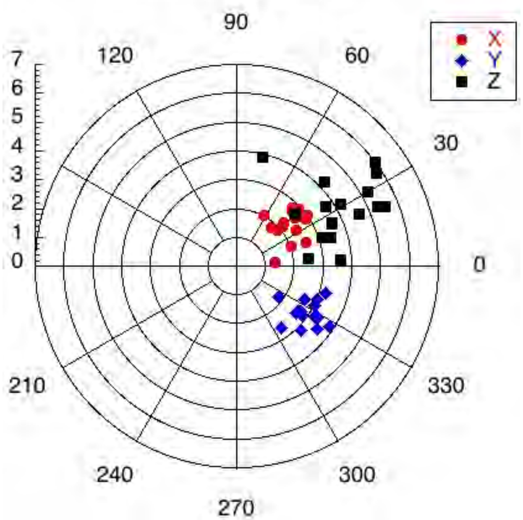
Geophysical models



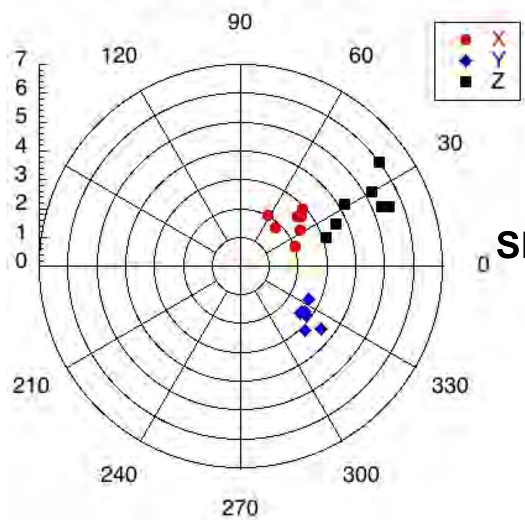
SLR-only Estimates



Geodetic Estimates



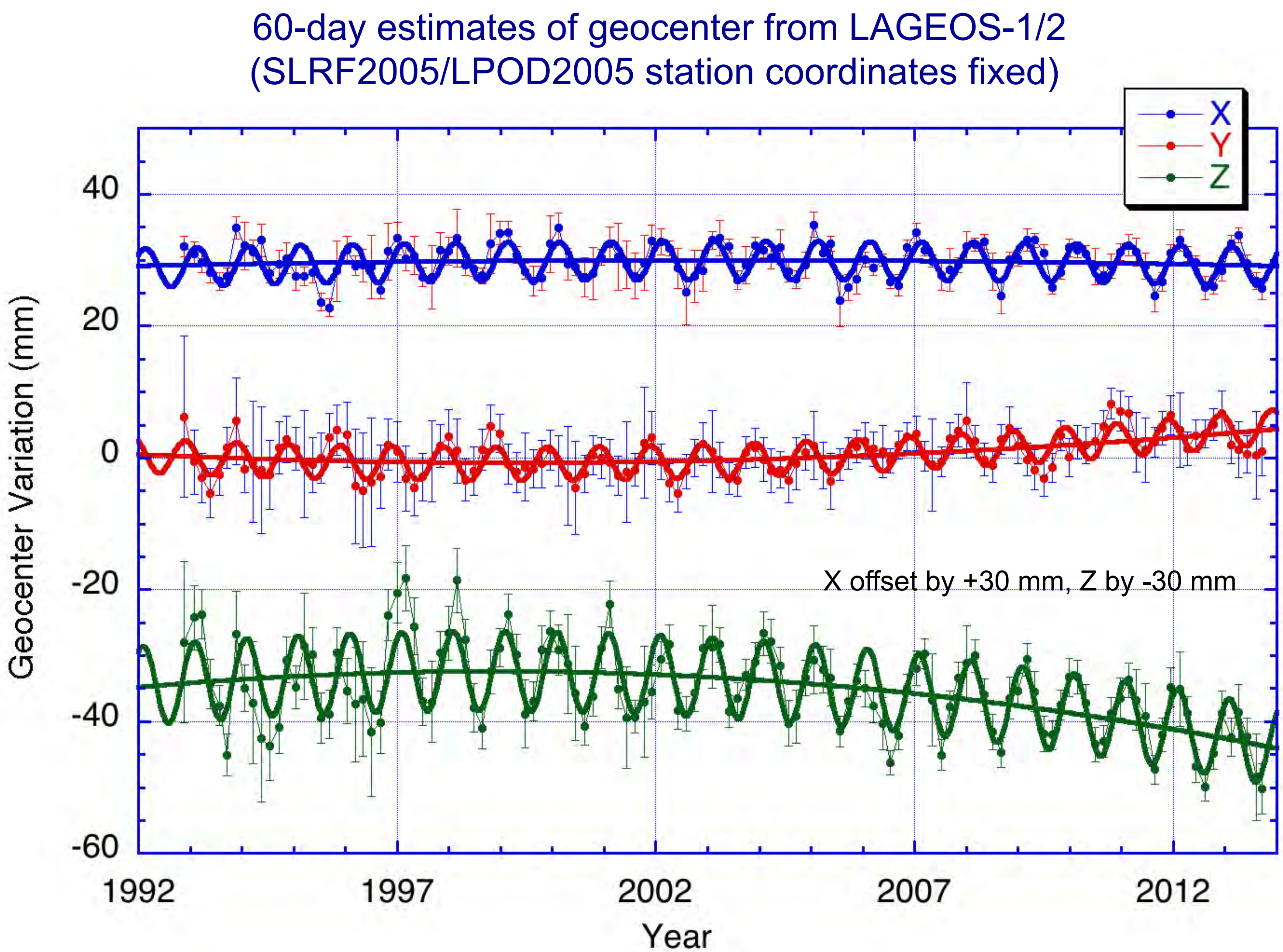
Selected Geodetic Estimates



"Climatological model"
SLR-only; all four span 15 or more years

X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)
2.7	39	2.8	321	5.5	28
0.2	5	0.2	4	0.4	7

Geocenter Motion from SLR



If analyses are consistent, there should be no slope over the interval 1993-2005 that defines ITRF2005

Over this period, no slope exceeds 0.1 mm/y

Clear long-term trend in Y and Z, while X appears to be completely flat

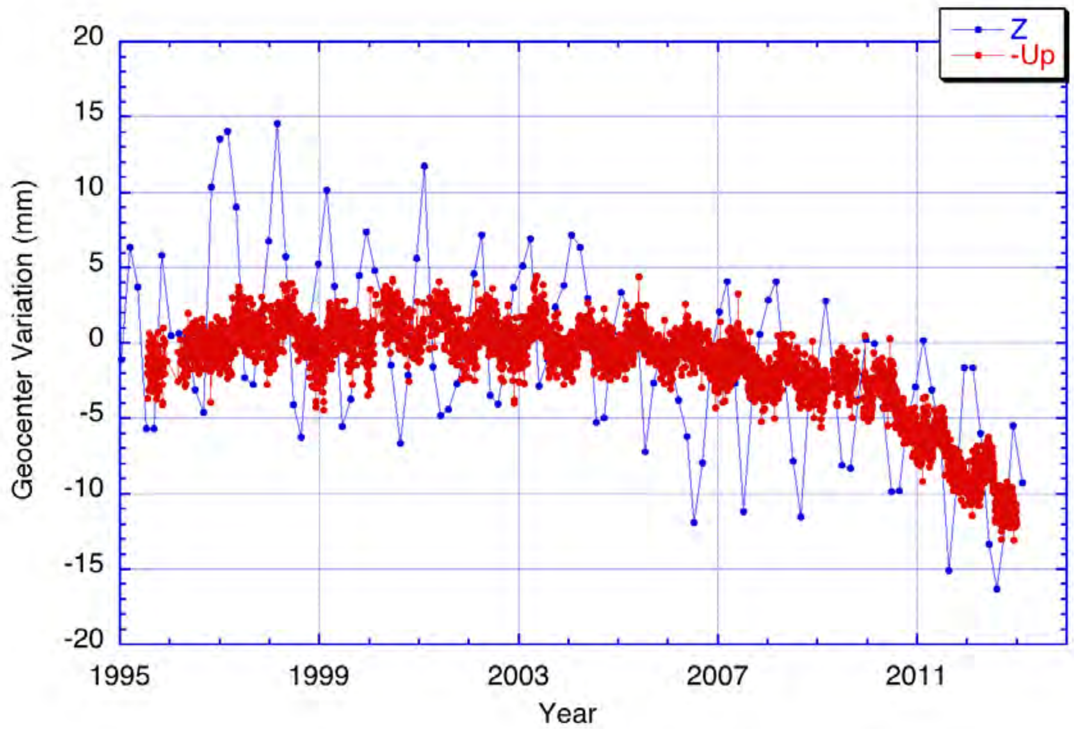
Is Long-term Trend a Real Signal?

Can long-term geocenter motion provide constraints on ice-mass loss?

Linear term is absorbed into definition of TRF, but accelerations would remain

Comparison of Z geocenter with time series of vertical motion at KELY, Greenland (multiplied by -0.2)

(mass loss in Greenland would move geocenter towards –Z and result in uplift at KELY)



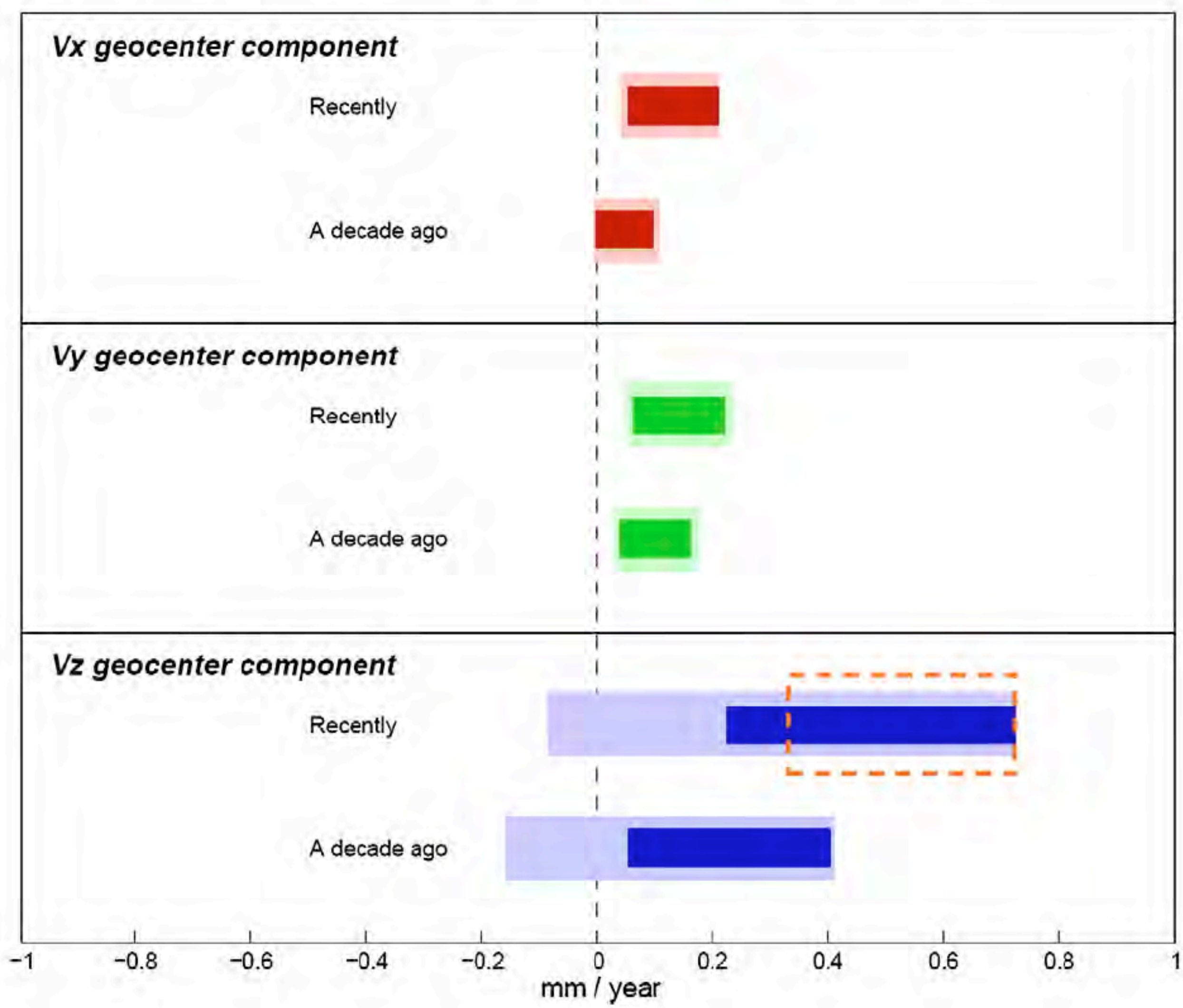
Trends are Consistent with Observed Ice Mass Loss

Métivier et al. (2010) computed expected geocenter velocity due to possible range of ice melt estimates

Linear velocity is unobservable but changes from the 1993-2005 baseline would be

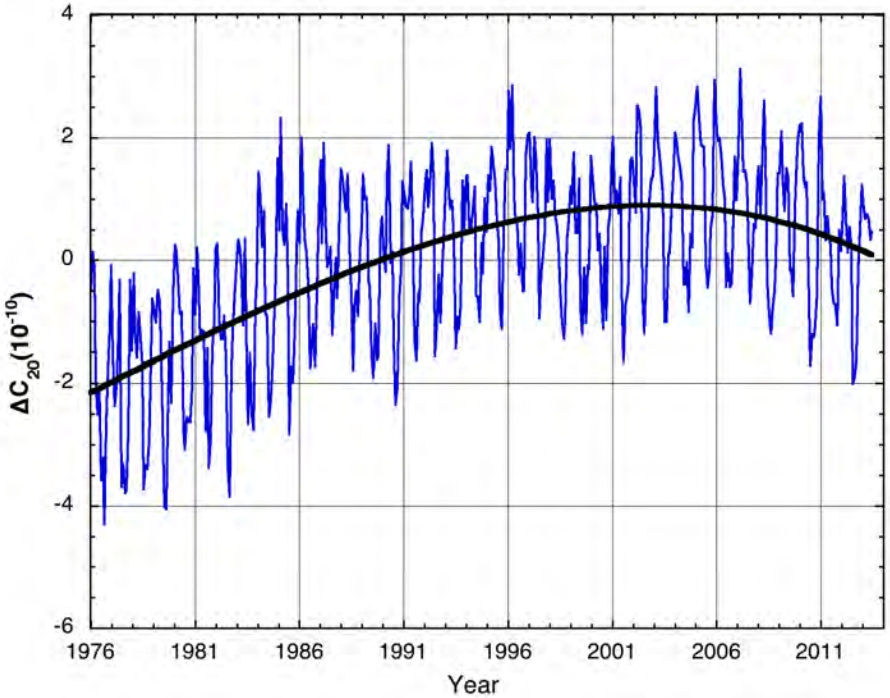
A few tenths of a mm/y change is consistent with observed trends in geocenter series

L. Métivier et al. / Earth and Planetary Science Letters 296 (2010) 360–366

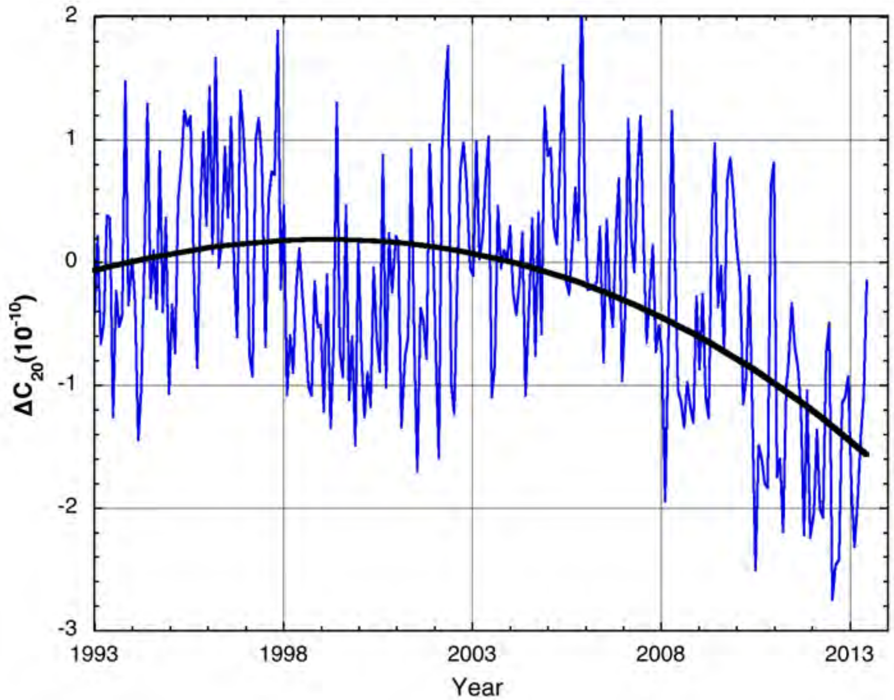


C20

C20 time series described in Cheng et al., 2013, JGR, extended to 2013

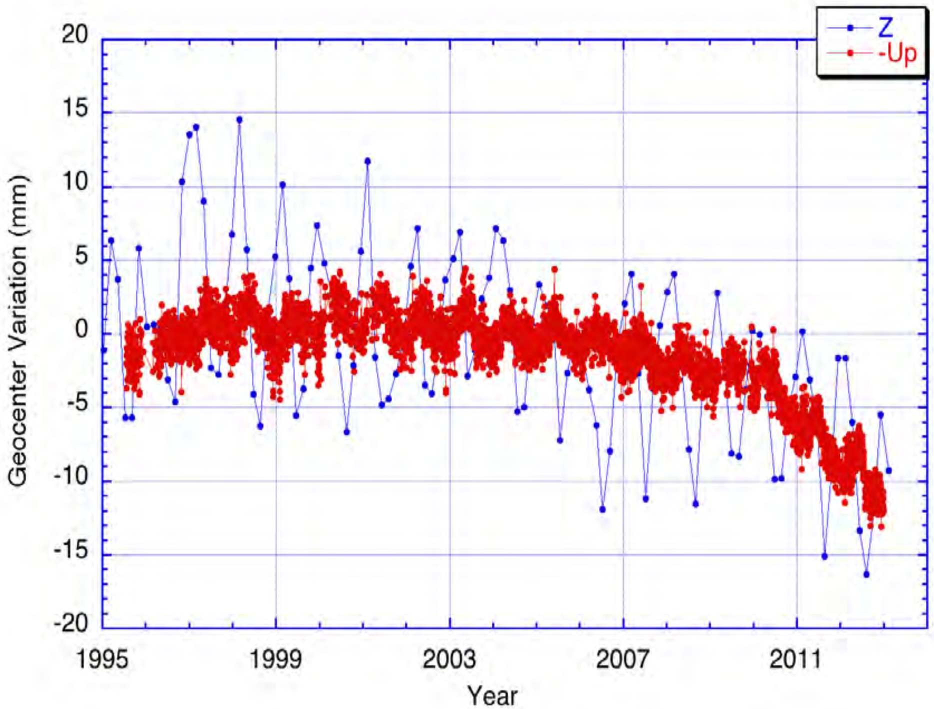


Remove prior to 1993, detrend over 1993-2005, remove annual

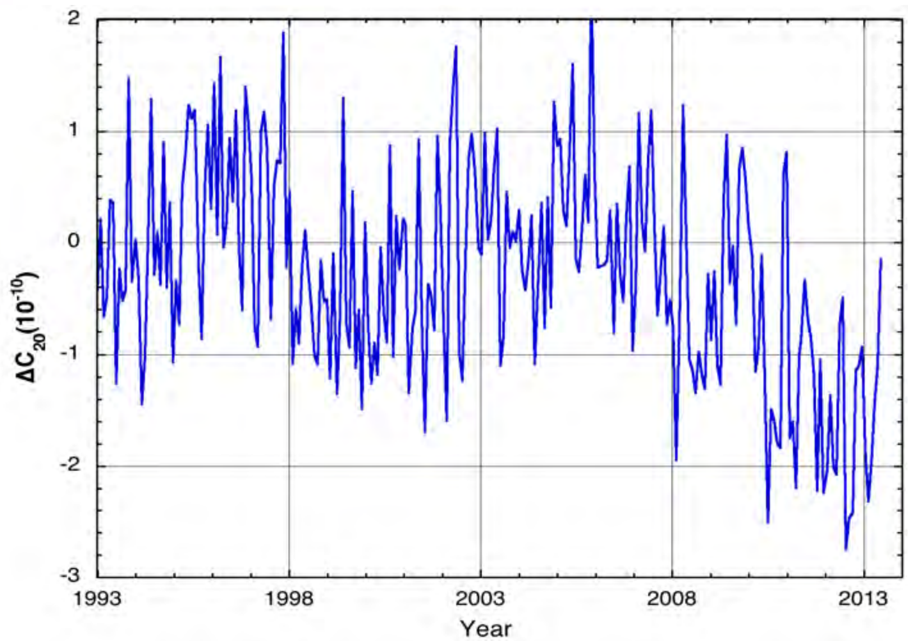


C10 and C20

Z geocenter and KELY uplift



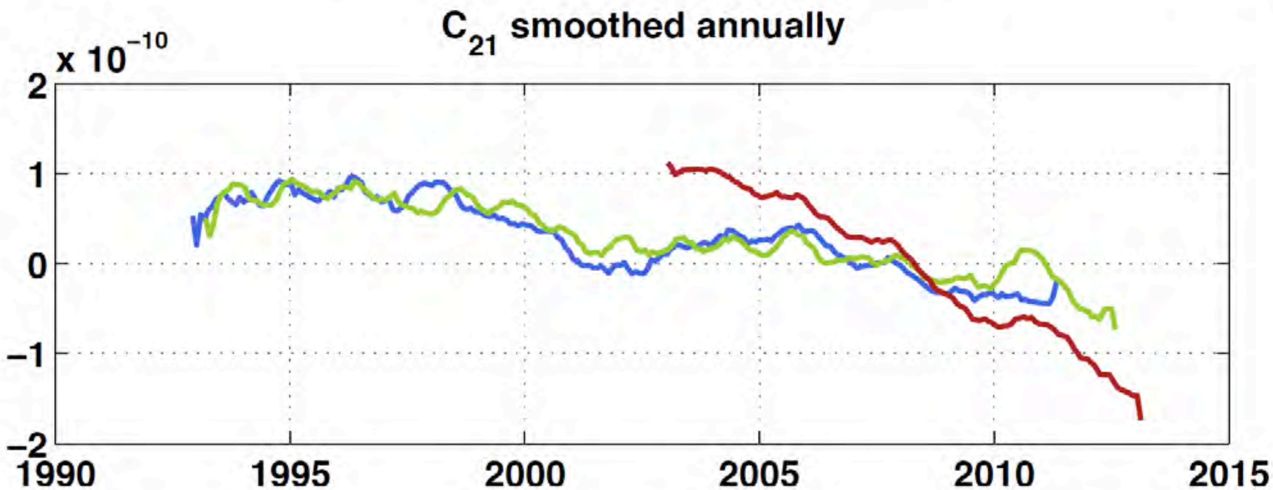
Remove prior to 1993, detrend over 1993-2005, remove annual

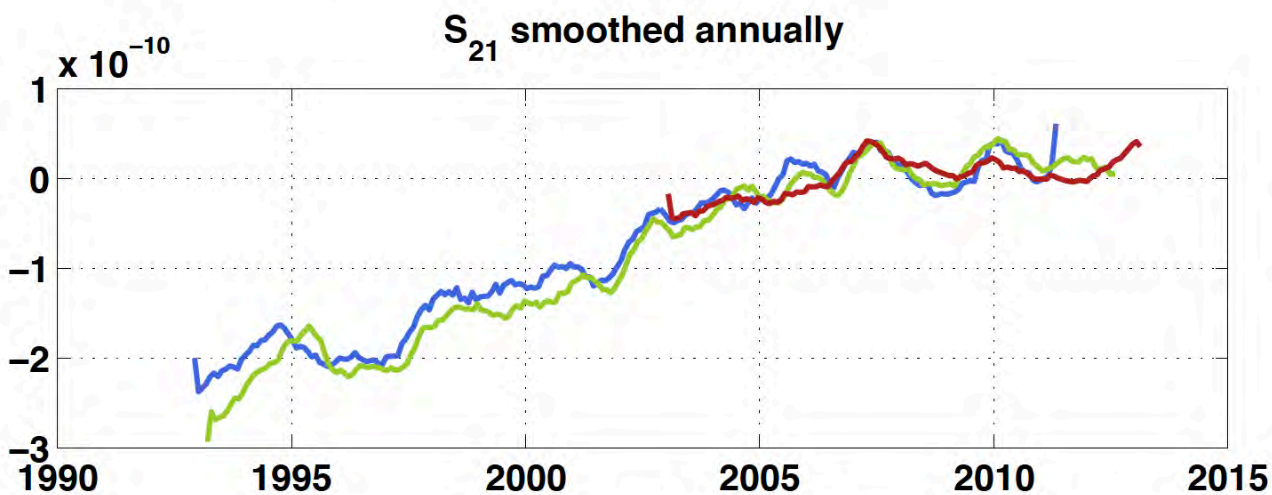


SLR time series of low degree harmonics provides context for recent accelerated mass changes

C21 Trend Discrepancy (1)

C21/S21 from (GSFC 4x4 and CSR weekly 5x5) and GRACE





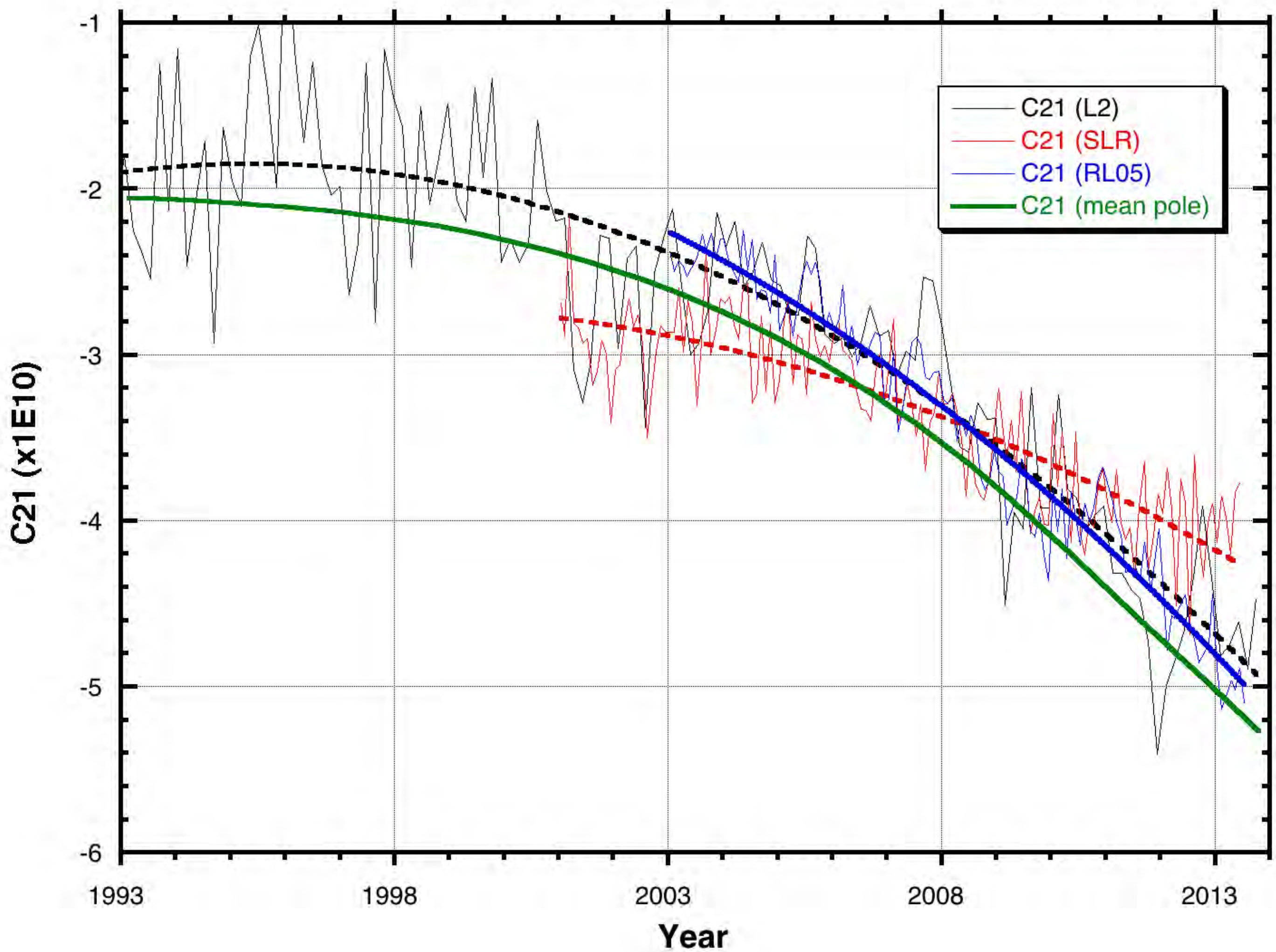
SLR-based estimates seem to disagree with GRACE in the long-term trend for C21, but these series are not directly comparable

Older series used previous mean pole model for pole tide correction.

Pole tide dominantly affects C21/S21

C21 Trend Discrepancy (2)

C21 from SLR CSR monthly 5x5 (TN07) and GRACE

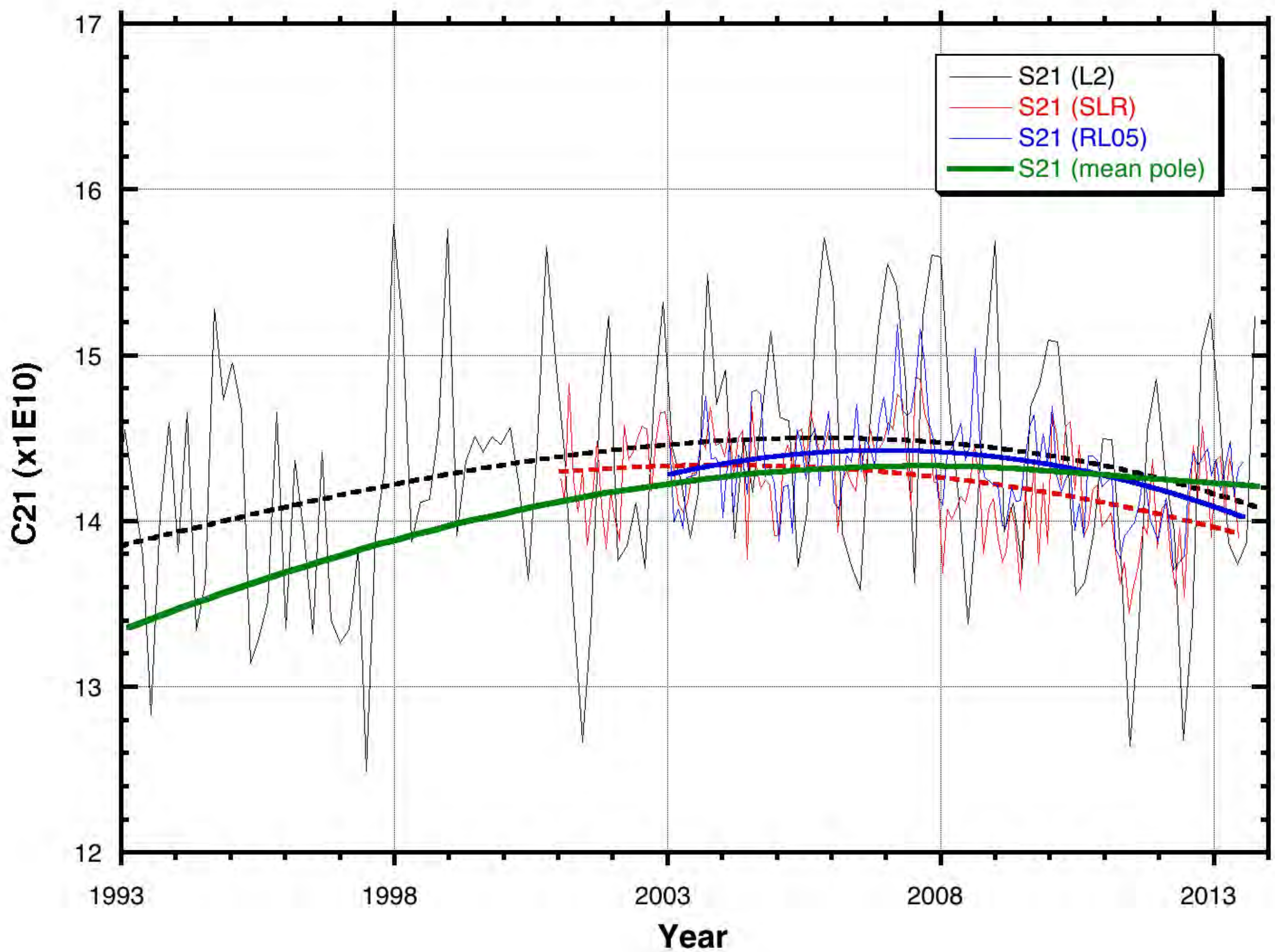


However, the new CSR SLR estimates do disagree with GRACE trend even though background models should be the same

Independent estimates using L1 and L2 alone, as well as computing C21 from mean pole, all appear to agree with GRACE

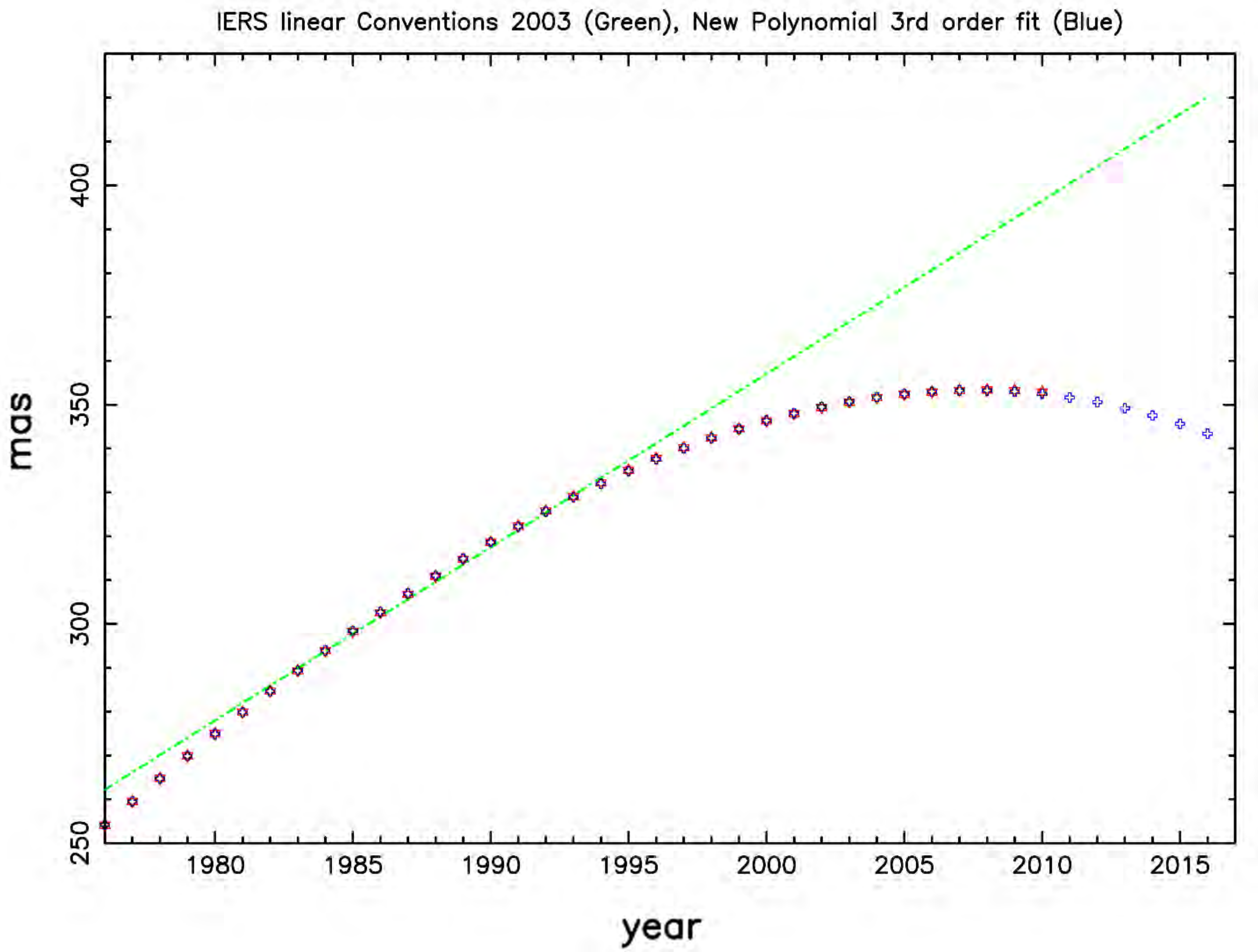
No Apparent Discrepancy for S21

S21 from SLR (CSR 5x5) and GRACE



Mean Pole Model (Yp)

Original linear model consistent with mean pole only during original fit interval of 1976-1999



Summary

- Seasonal geocenter motion seems well characterized by a simple sinusoid
  - Amplitude appears to be ~3 mm amplitude for X and Y, and 5-6 mm for Z
  - Estimate of annual geocenter motion from SLR is affected by local site loading, but the effect is relatively small for SLR stations (~10%)
  - Monthly estimates are likely too noisy to be used directly, but with some level of smoothing, it may be possible provide an alternative degree-1 series to be combined with GRACE results, particularly for high-latitude studies
- Long-term non-linear trends in geocenter are probably real, not an artifact of the analysis
  - Good consistency with present-day ice mass loss acceleration in Greenland, which would affect mainly Y and Z components
- Multi-decade time series for low degree terms provide context for recent dramatic gravity changes observed by GRACE, particularly ice sheet mass losses
- SLR and GRACE estimates of S21 generally consistent, but different trends observed for C21; reason remains to be determined
  - GRACE estimates follow mean pole as expected, so likely reliable