Satellite Laser Ranging Applications for Gravity Field Determination

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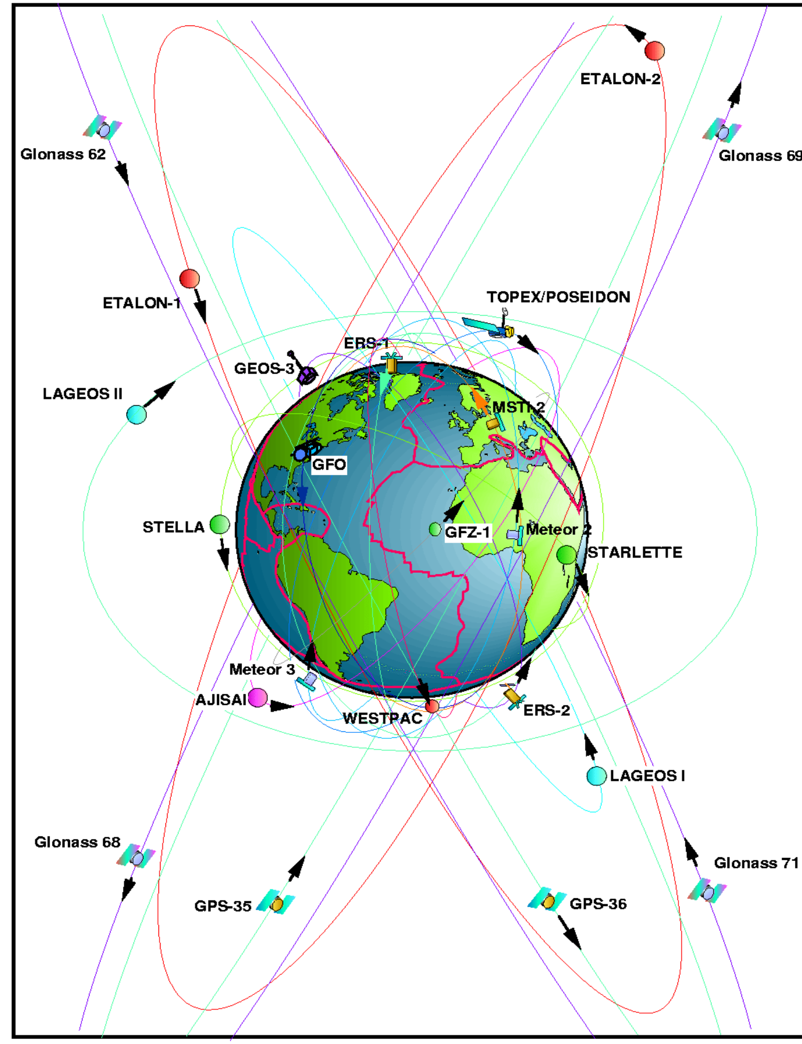
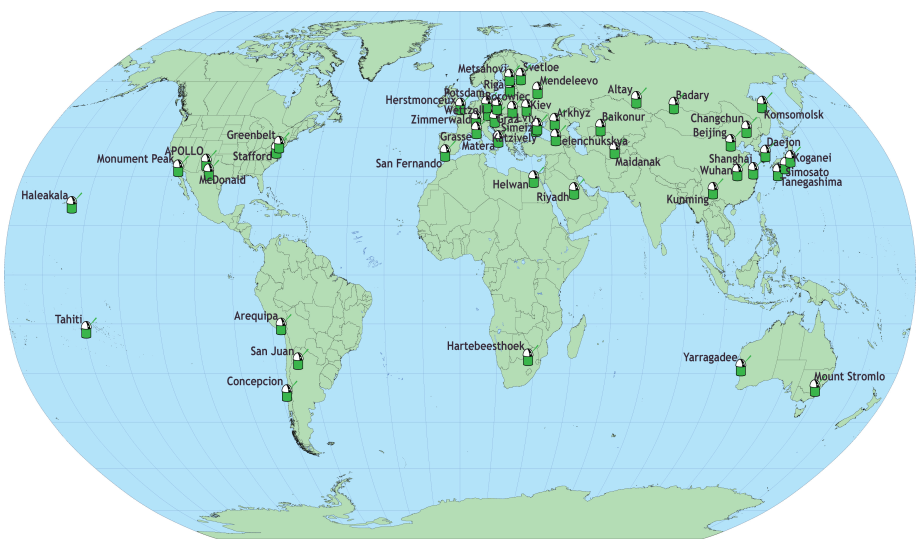
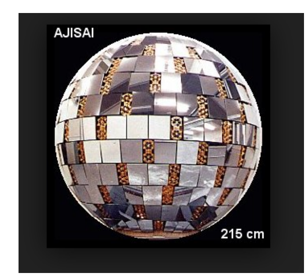






SLR and Gravity

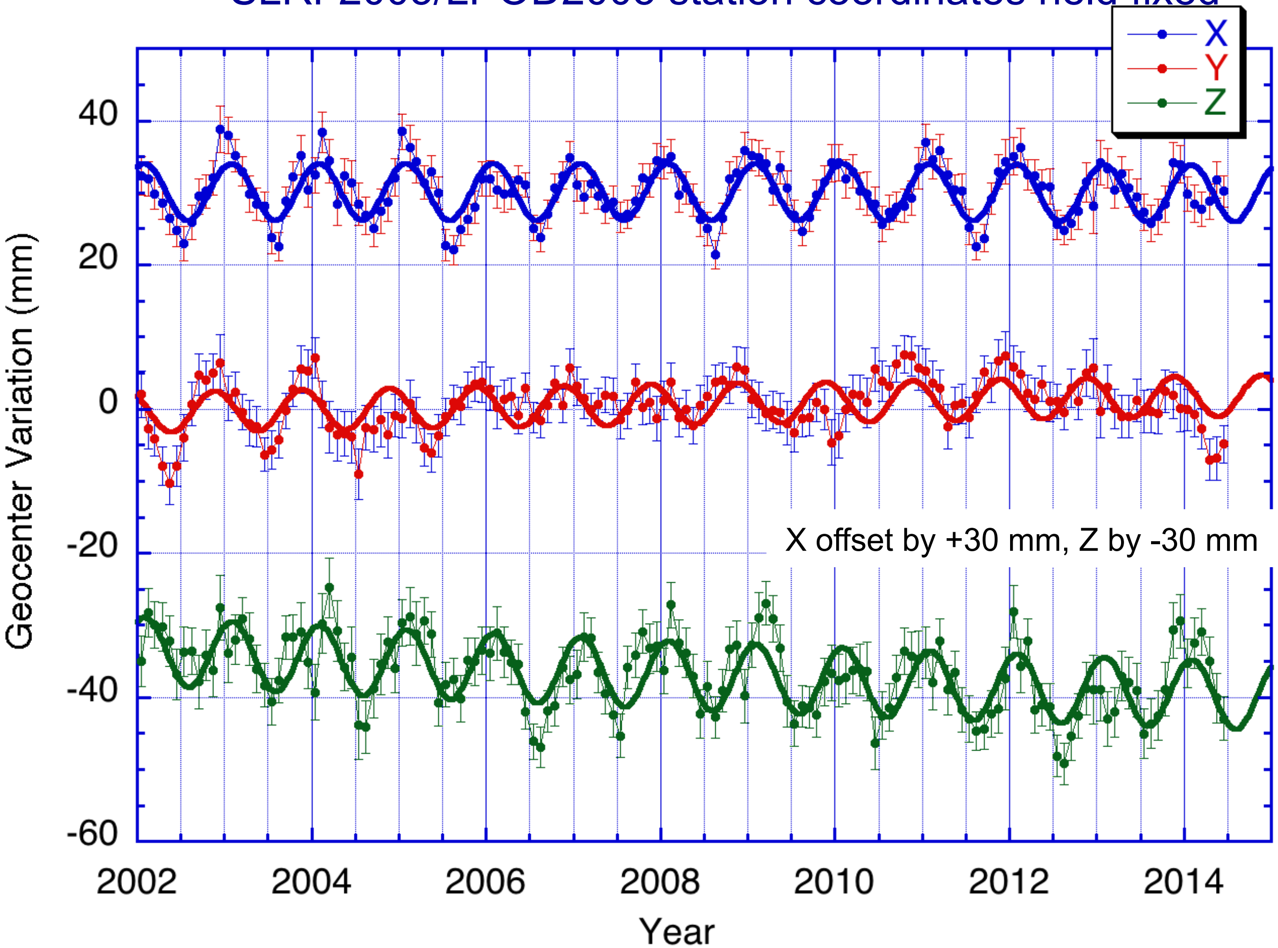
- SLR has been an essential part for determing the longest wavelength components of the gravity field over the years
  - GM (G * mass of the Earth)
    - Strongly influences scale of SLR and other satellite-based refrerence frames)
  - Geocenter (equivalent to degree-1)
    - Need degree-1 mass variations, which are not observed by GRACE, to determine total mass redistribution
  - Degree-2
    - C_{20} (J_2) needed to augment GRACE (affected by tide-like aliases)
    - Observations of C_{20} as far back as 1976 help put current estimates into context of long-term change
  - Relativistic gravity
    - General Relativity prediction of Lense-Thirring orbital precession confirmed to ~10%.

Scale & Terrestrial Reference Frame (SLR)

- The SLR scale is determined from the speed of light, orbital dynamics (including relativistic considerations) and the LAGEOS center of mass model (➔GM)
- In 1992, GM estimated using 5 years of LAGEOS-1 data to determine value currently in use (based on a nominal CoM = 251 mm)
  - Must simultaneously estimate orbit, GM and all station heights to avoid locking in apriori scale
  - GM = 398600.4415 ± 0.0008 km^3/s^2 (~2 ppb)   (TDT or TT value)
  - Considered biases plus a ‘quesstimate’ for troposphere error (~4-5 mm in zenith delay)
- Updated troposphere model (Mendes&Pavlis) suggests that troposphere is not a limiting factor; changed GM by less that ½ ppb
- Limiting factor appears to be LAGEOS CoM model uncertainty
  - 3 mm of error in the CoM corresponds to 1 ppb error in GM (and ~0.8 ppb error in SLR reference frame scale)
  - New best estimate of GM = 398600.4416 ± 0.0002 km^3/s^2
  - New estimate not significantly different from current standard; no change warranted
  - Difference in GM from L1 and L2 is equivalent to 1.2 mm difference in mean CoM

Geocenter / Degree-1

Estimate orbit, 5x5 gravity field and geocenter using 5 SLR satellites
SLRF2005/LPOD2005 station coordinates held fixed



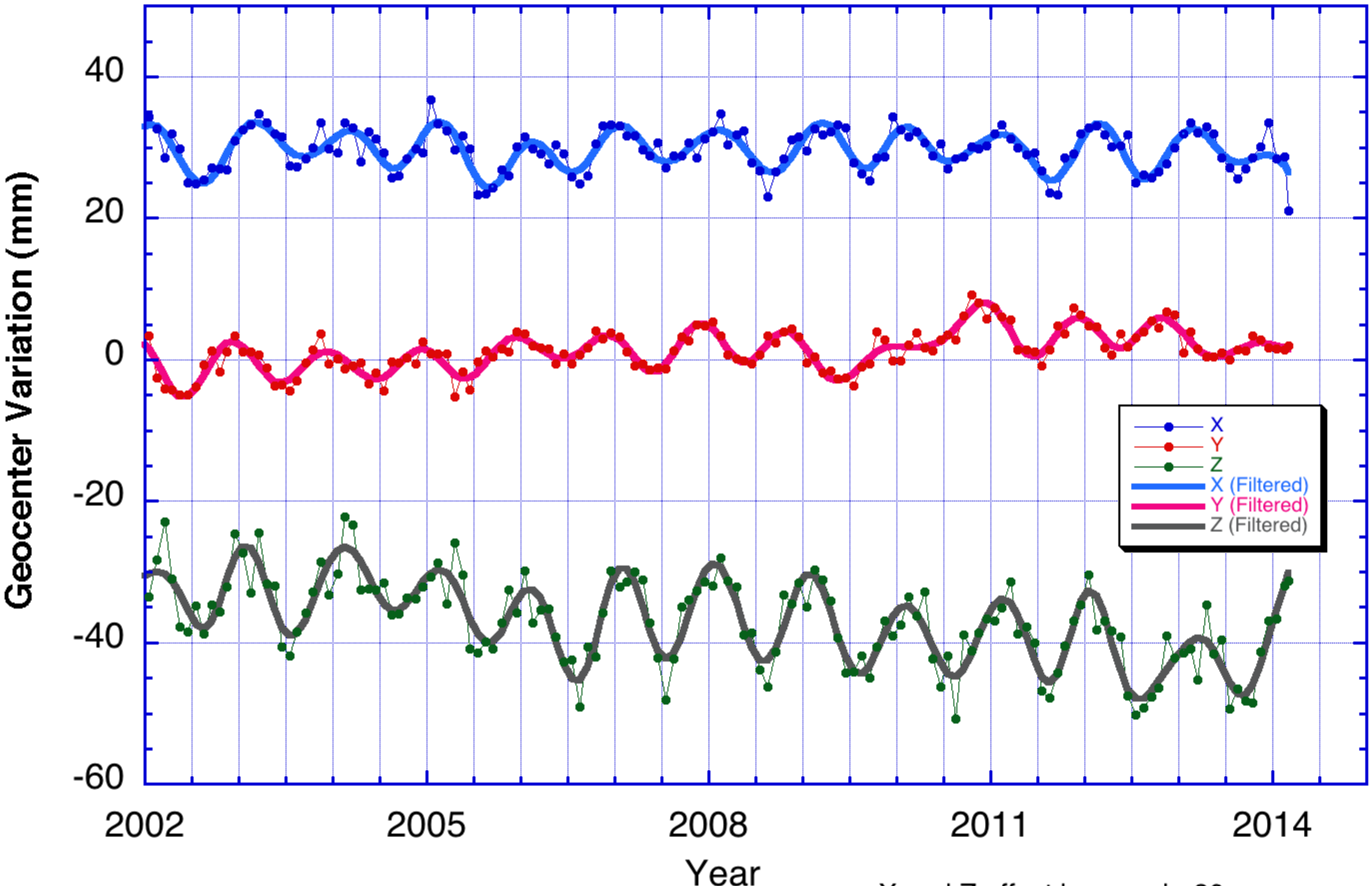
X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)	Reference (comments) (phase is in degrees)
2.7	35	2.8	309	5.2	25	Cheng et al., 2011 (weekly solutions, estimating 5x5 gravity, 1993-2010)
2.6	42	3.1	315	5.5	22	Altamimi et al., 2010 (ILRS contribution to ITRF2008)

Operational Series

- Currently, there are only two sources of regular monthly estimates of geocenter/degree-1 (needed to account for the longest-wavelength seasonal mass variations
  - Swenson, Chambers and Wahr (2008) use GRACE plus ocean model (http://podaac.jpl.nasa.gov/dataset/TELLUS_1_DEG_COEF)
    - Requires monthly GRACE solutions
    - Amplitude in X and Y reasonably consistent with SLR but amplitude of Z is only about half
    - This will affect high latitude studies (ice/snow variations)
  - CSR provides monthly geocenter values consistent with GRACE RL05 processing (updated with C_{20} given in GRACE TN07)
    - Time series is rather noisy at monthly time scale
    - Wavelet filtering appears to be effective, reducing noise with no noticeable impact on annual signal

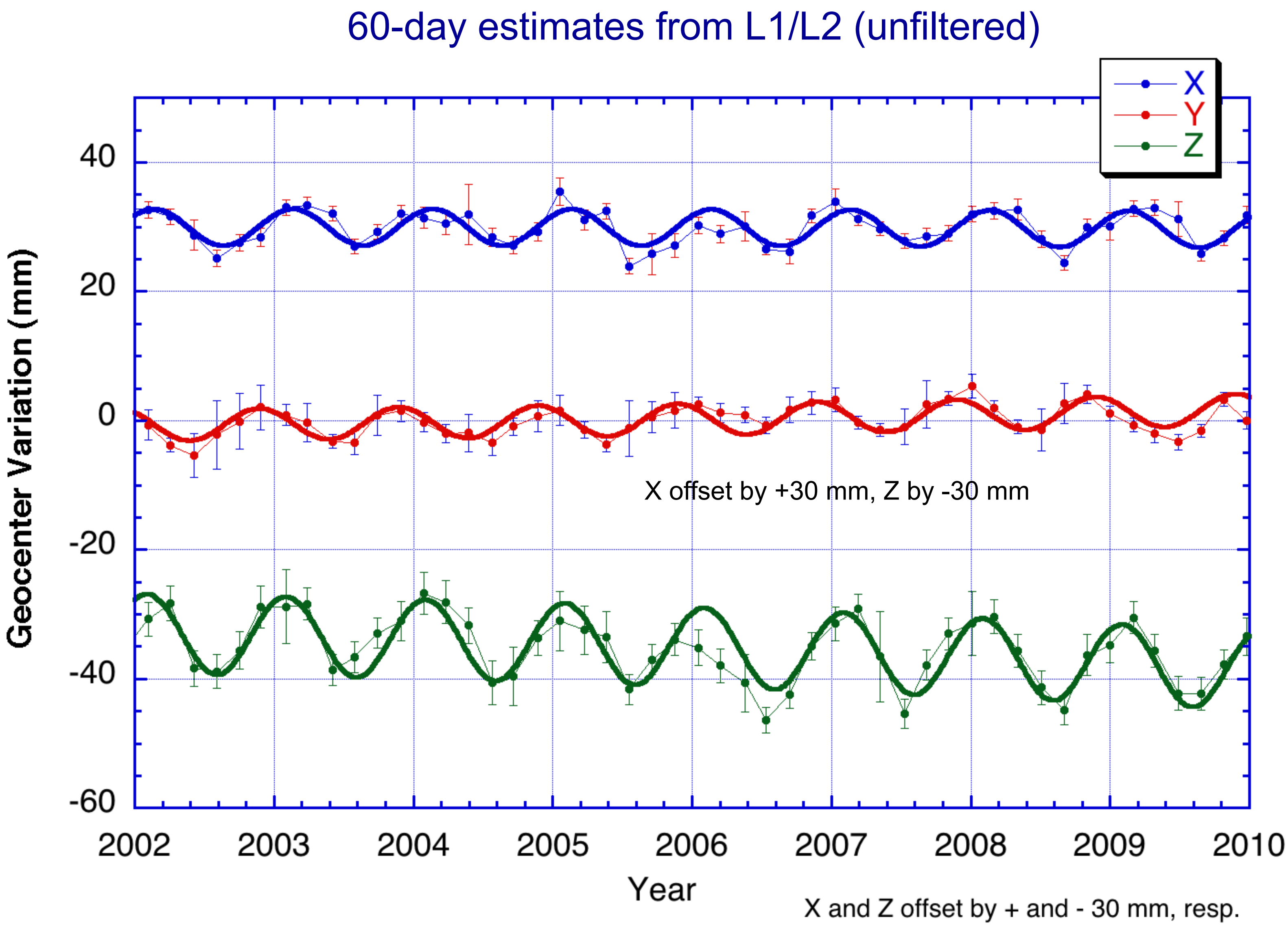
Wavelet-filtered Geocenter

30-day estimates filtered to remove shorter than seasonal variations



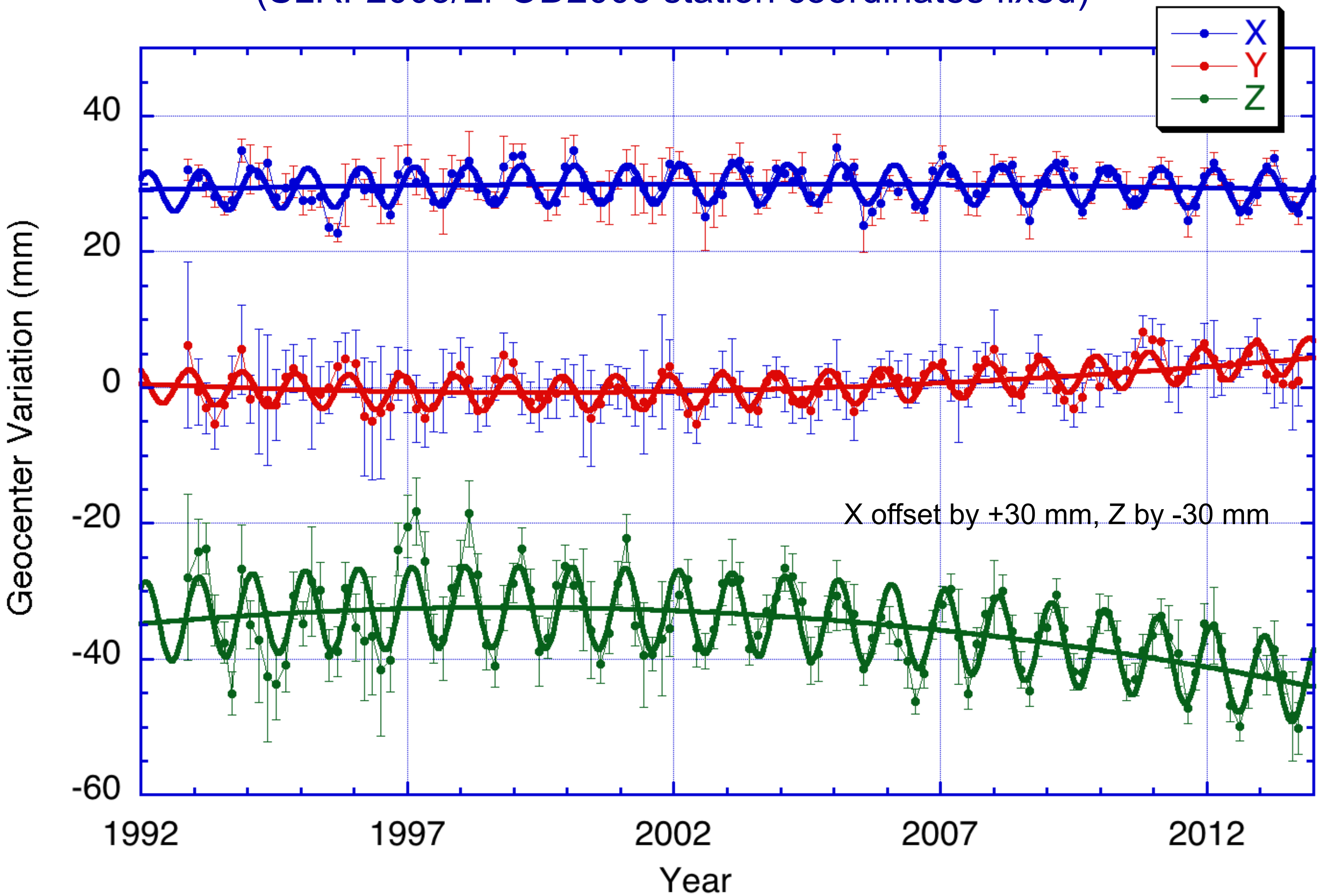
X and Z offset by + and - 30 mm, resp.

60-day Geocenter



Long-term Geocenter Motion

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



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

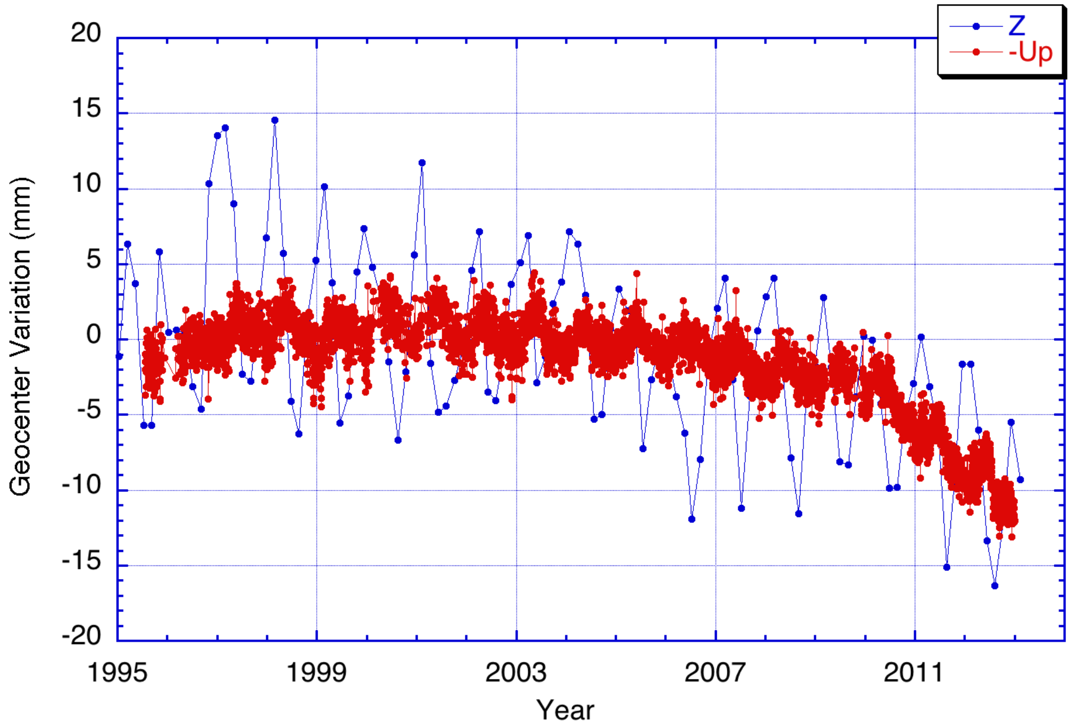
Is Long-term Trend a Real Signal?

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

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

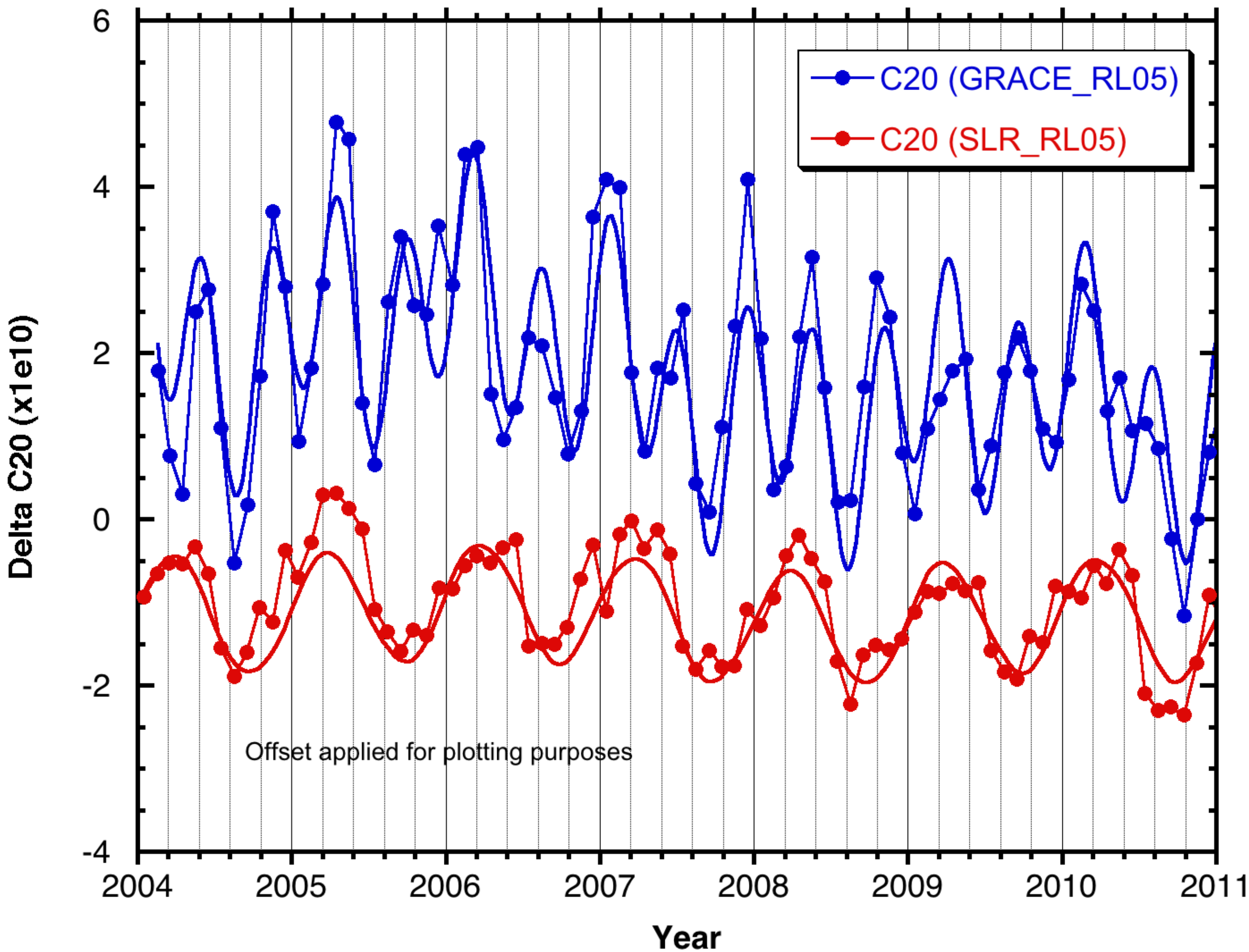
Comparison of Z geocenter with time series of vertical motion at KELY, Greenland(multiplied by -0.2)

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



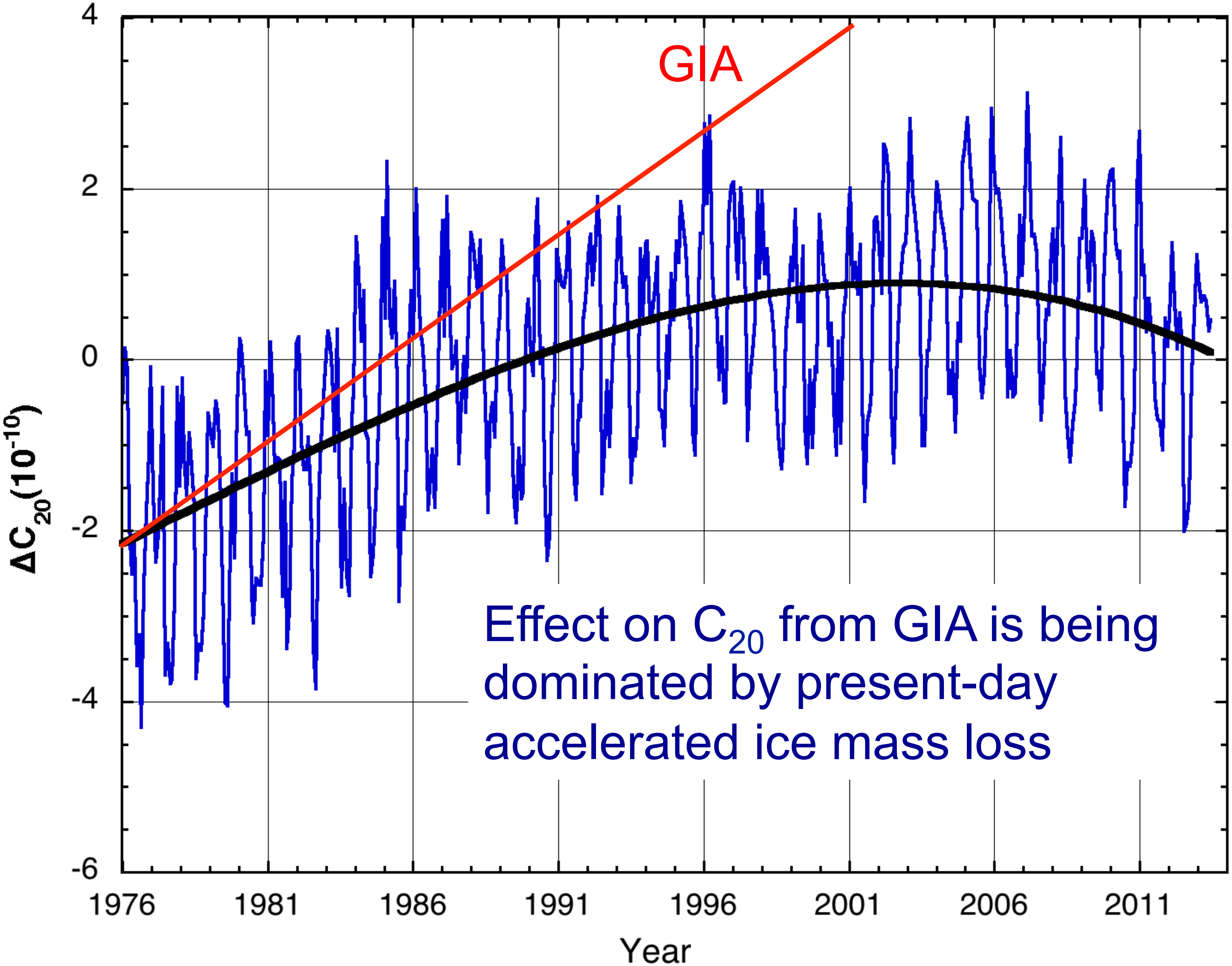
C_{20} from GRACE and SLR

GRACE estimates dominated by S2/S1 “tide-like” aliases



Nearly 40 years of C_{20} Estimates from SLR

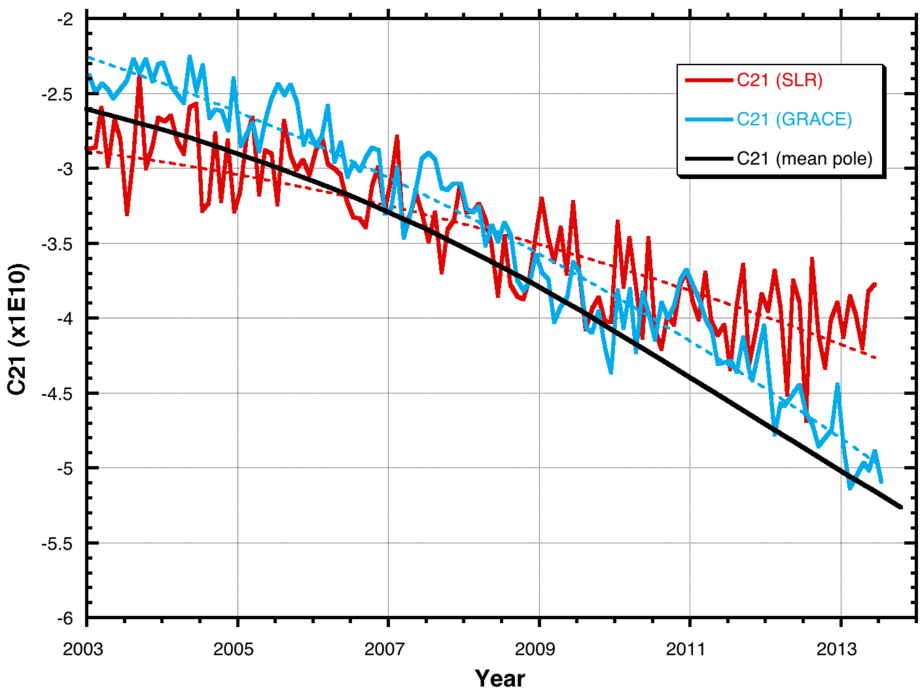
International Laser Ranging Service



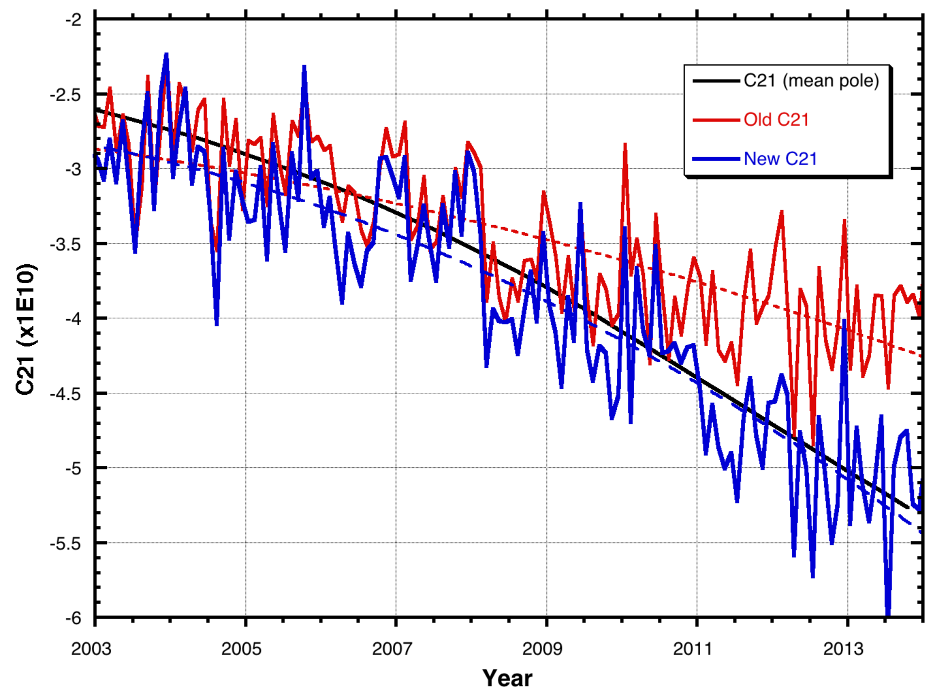
Effect on C_{20} from GIA is being dominated by present-day accelerated ice mass loss

C21 from SLR and GRACE

CSR 5 SLR satellites and 5x5 gravity field
C21 from SLR exhibits inconsistent trend



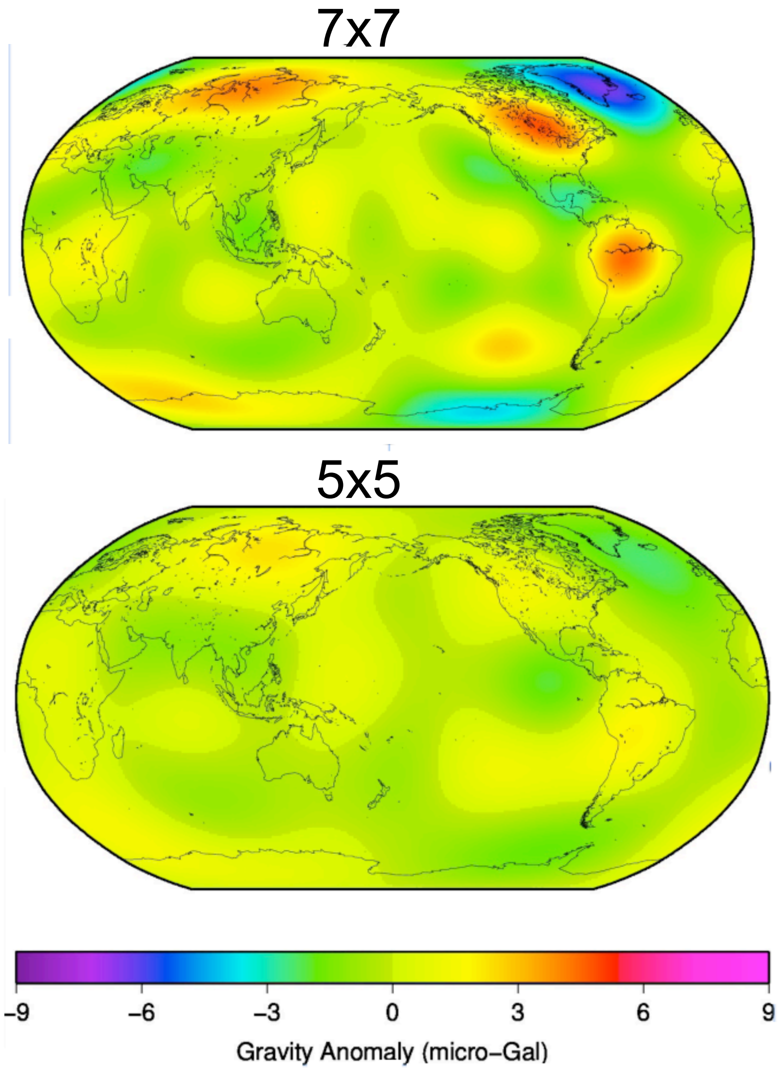
Same but add C61/S61
Trend is now consistent



Over the long-term, C21/S21 will tend to follow the mean pole.

Adding 6,1 harmonic increases scatter somewhat but trend is corrected.

How to fill the GRACE gap?

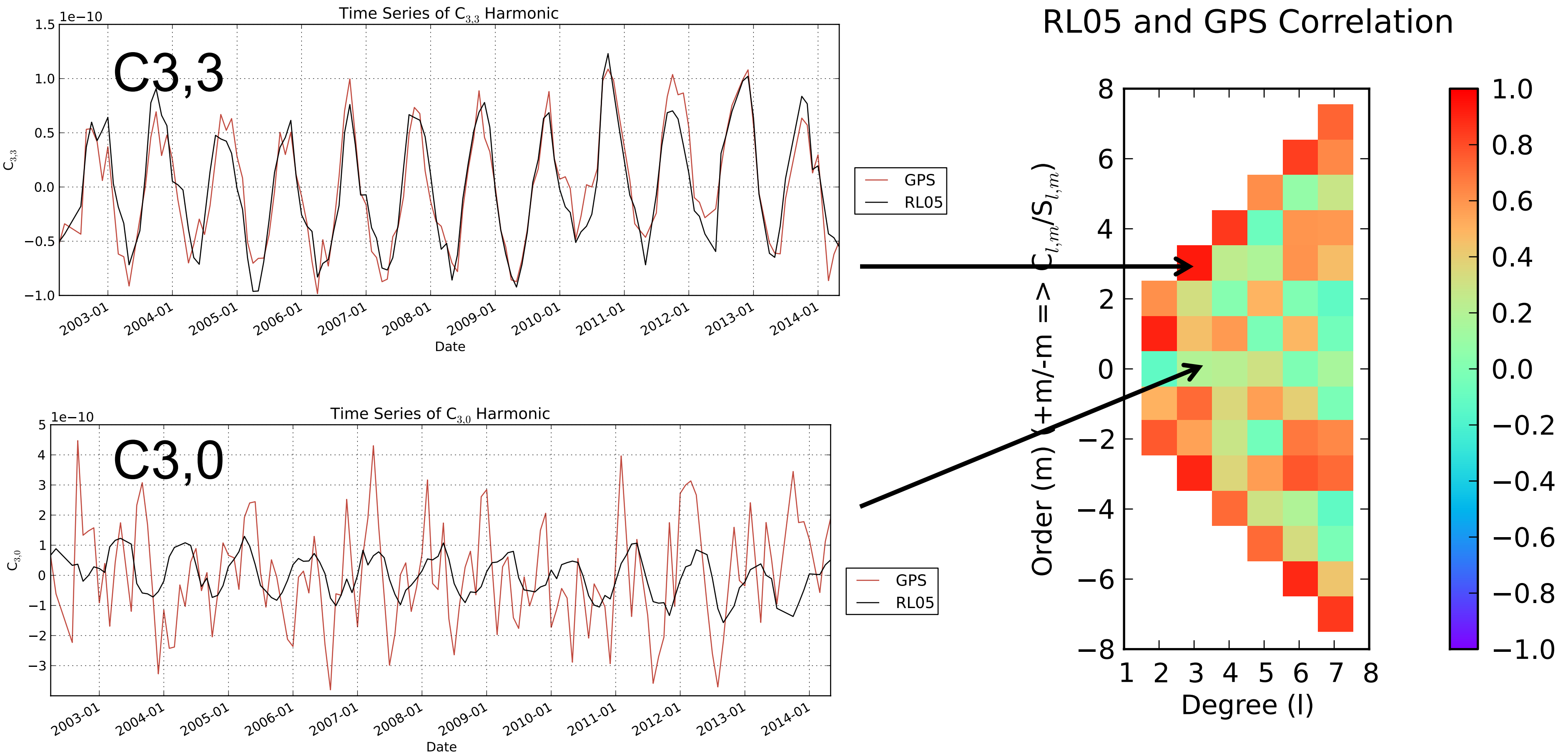


A gap between GRACE and GRACE Follow-on is likely, due to loss of K-band ranging system. However, we may still have one working satellite with GPS and accelerometer.

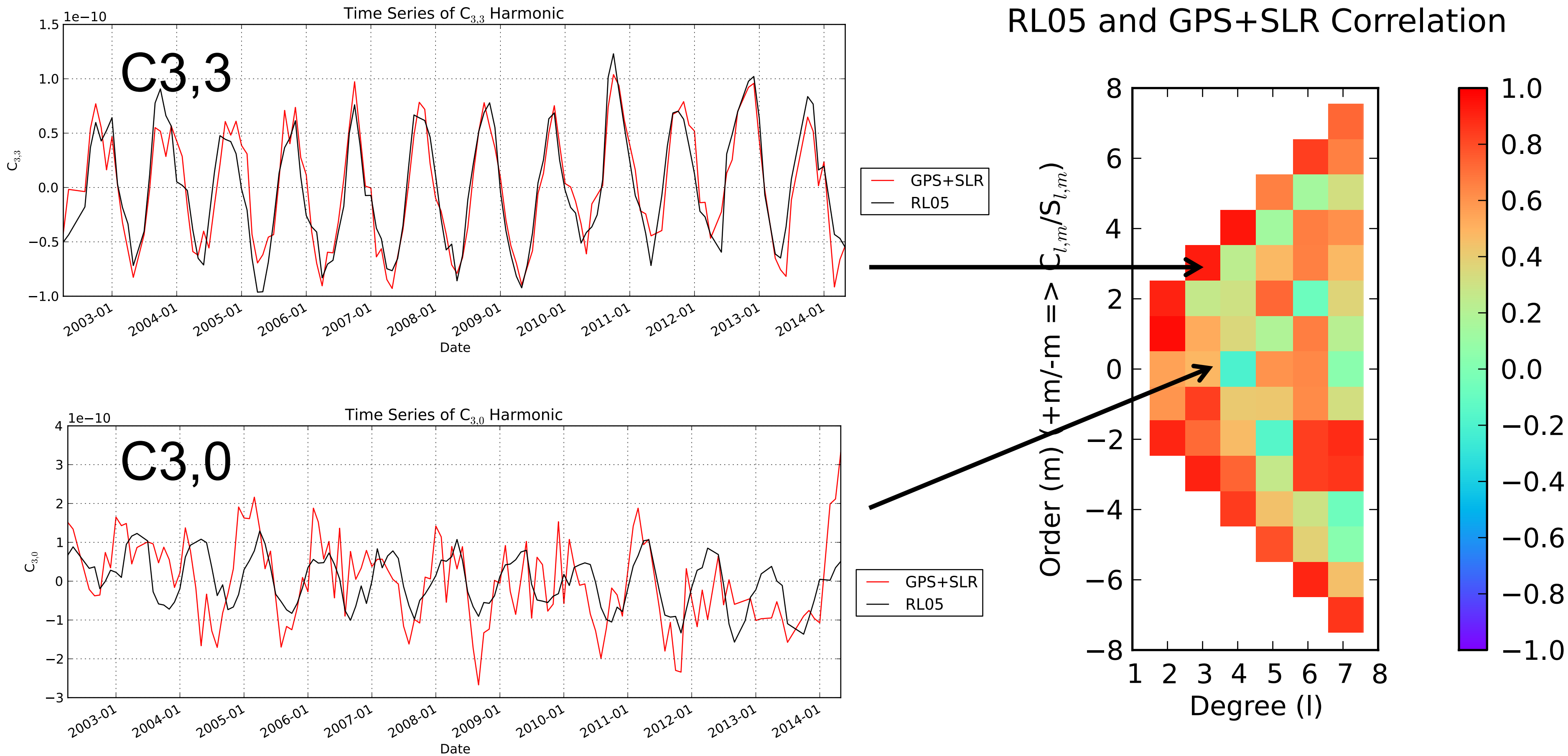
We need to estimate at least a 7x7 gravity field using GPS from GRACE and SLR tracking to capture continental scale signals.

Discrimination of finer scale features with full amplitude requires higher harmonic degrees.

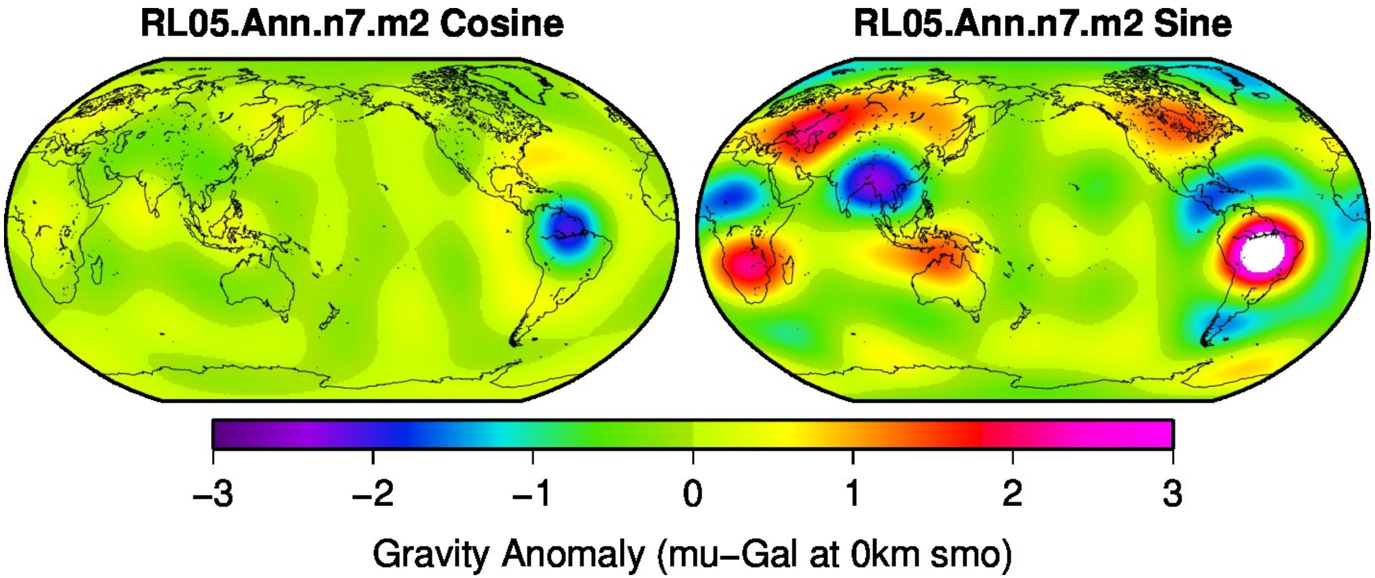
GPS-tracking gives good Sectorials but Poor Zonals



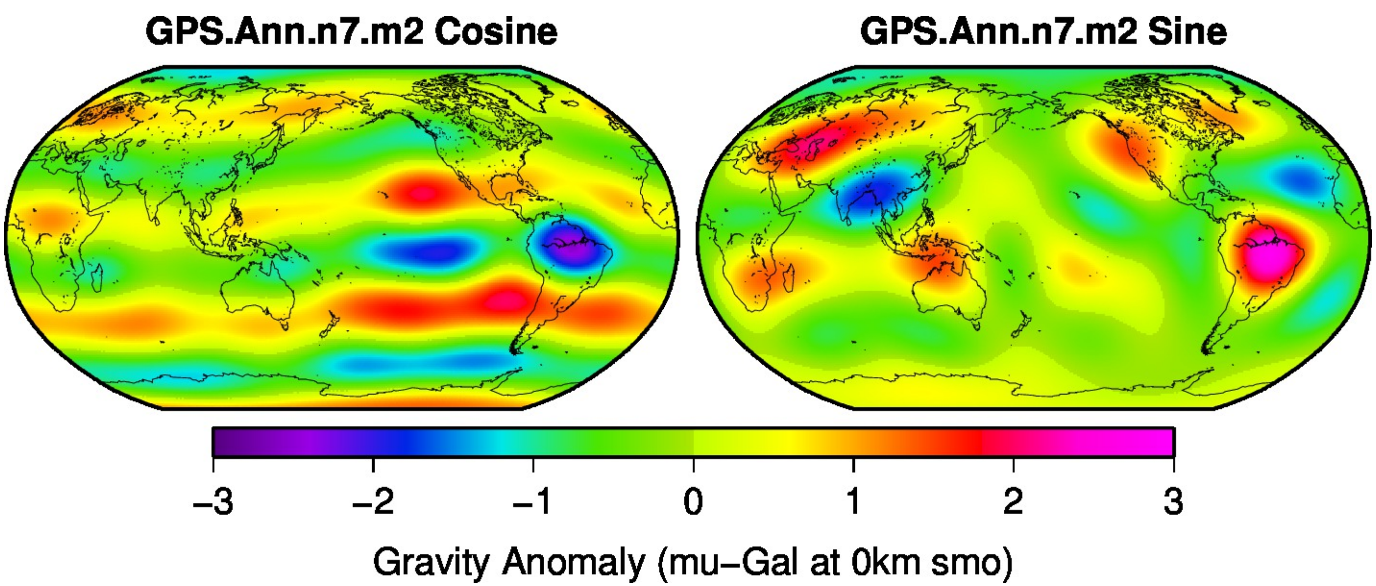
SLR can help improve the zonals

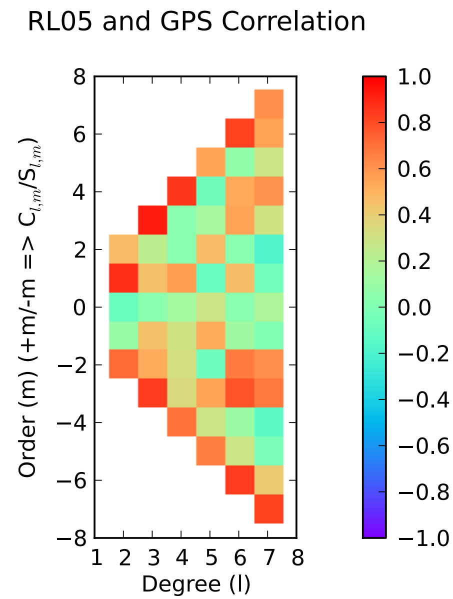


Seasonal Signal (1)

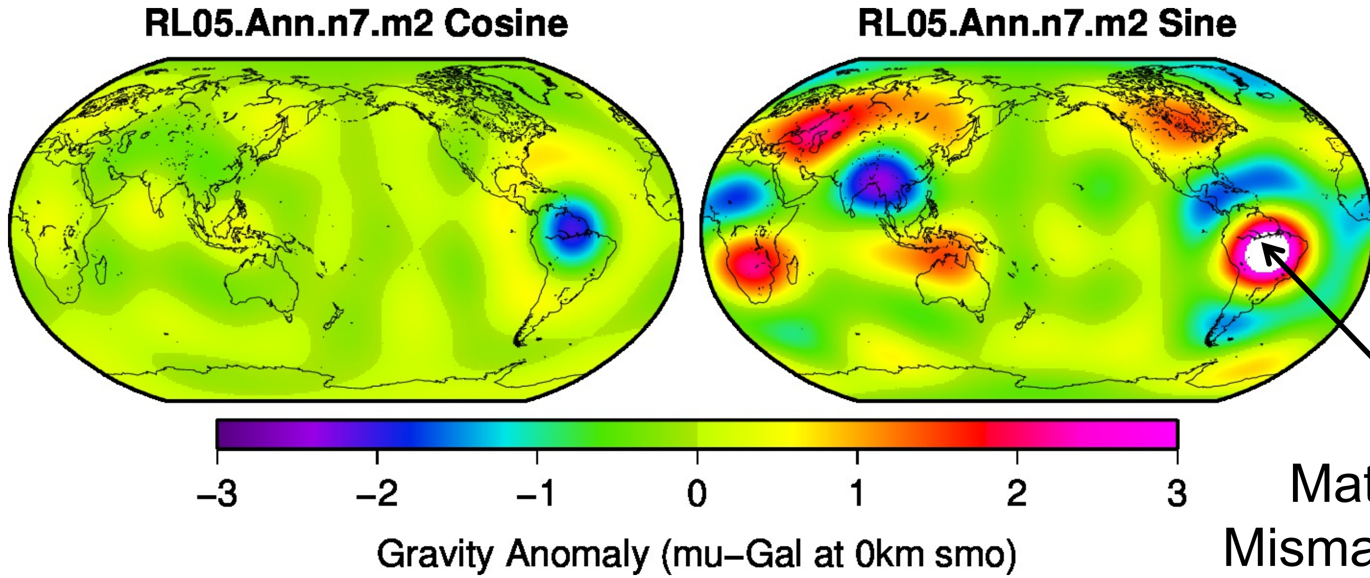


Promising mean annual signal recovery as well as limitations of single satellite GRACE mission are evident.



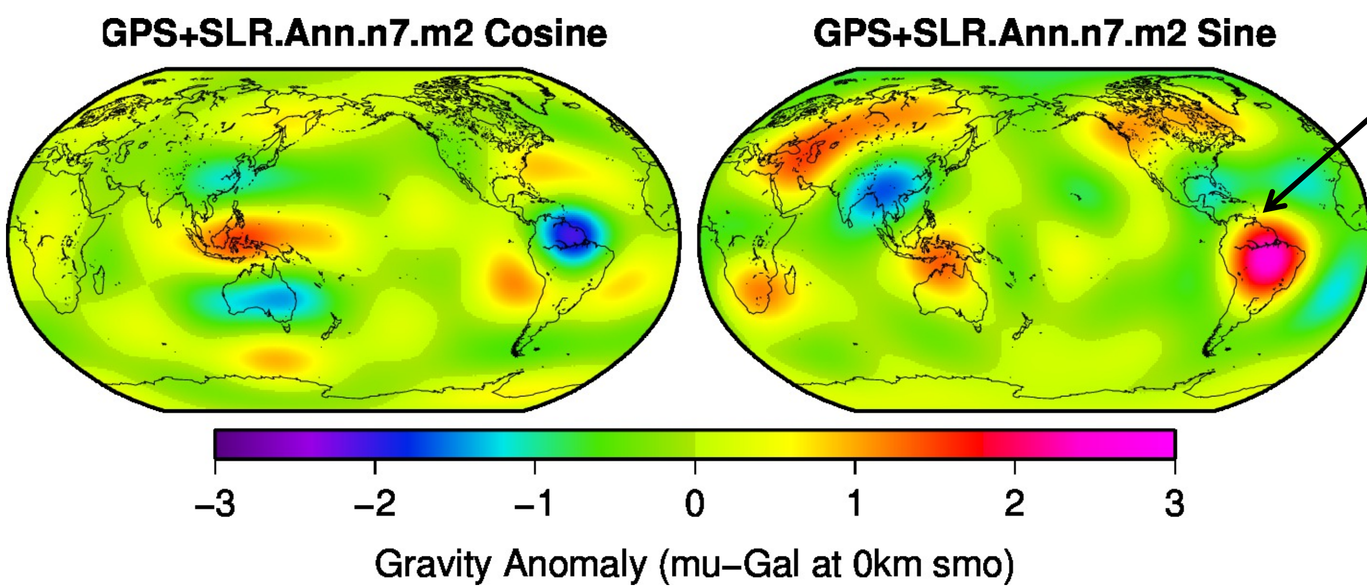


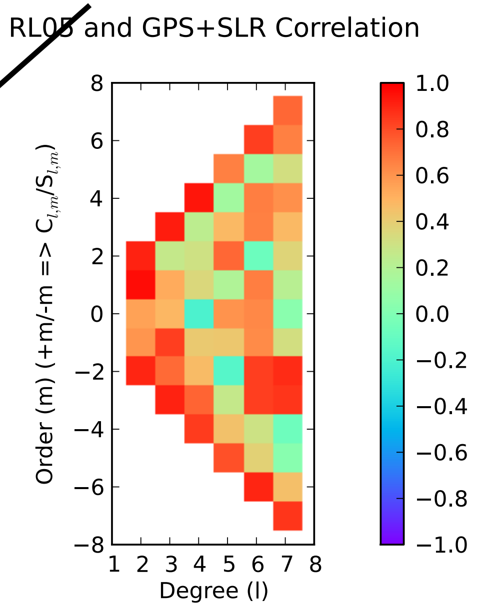
Seasonal Signal (2)



Addition of SLR improves the spatial patterns by reducing zonal errors.

Matched patterns,
Mismatched amplitudes

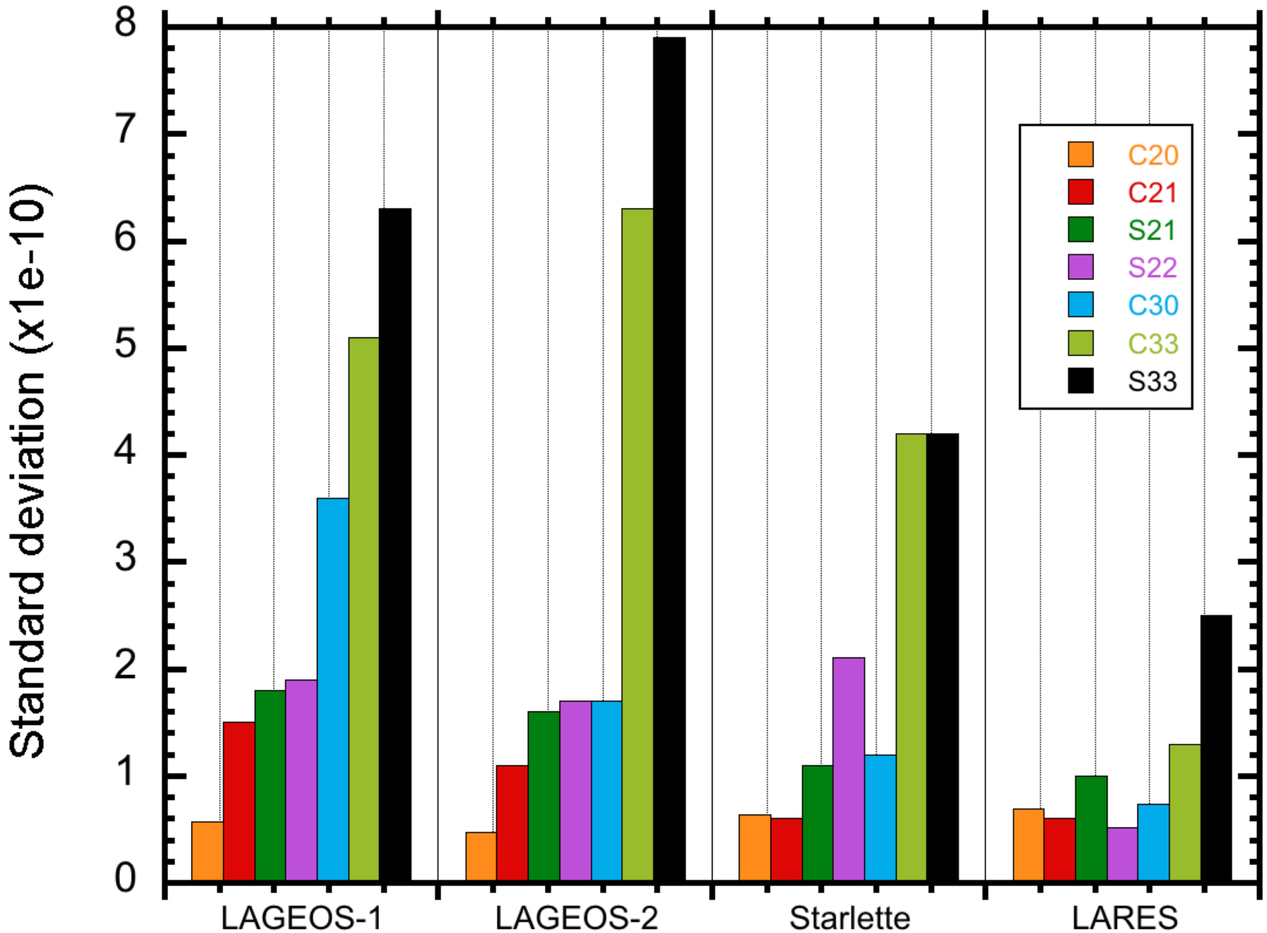




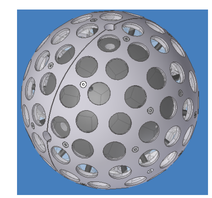
LARES not yet included

New Satellite: LARES launched Feb 2012

15-day estimates of 3x3 gravity



30 cm radius
407 kg
~6000 km altitude

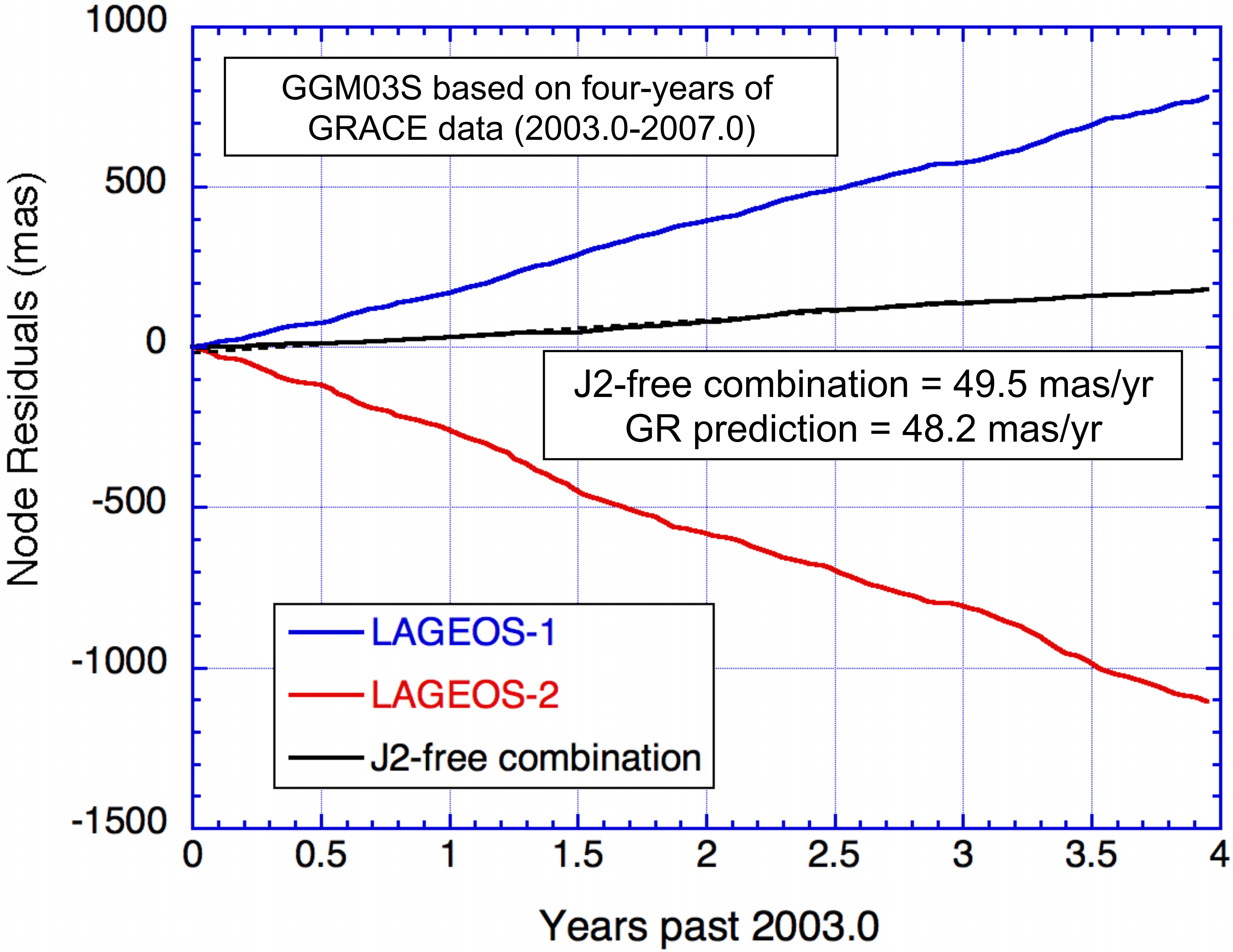


LARES
18 cm radius
387 kg
~1450 km altitude

Combination of lower altitude and very high density results in good gravity signal

Testing General Relativity

Lense-Thirring precession confirmed with LAGEOS-1 and 2



Conclusions

- In spite of more and better data, as well as new models, best estimate of GM has not significantly changed (scale uncertainty due to GM can be probably be reduced to ~0.4 ppb)
- Geocenter/degree-1 variations are an essential complement to GRACE and GRACE FO, required to get the total mass transport
- SLR-based replacement value for C_{20} is also essential and very likely to be required for GRACE FO
  - Source of tide-like aliases likely a thermal effect in the K-band ranging system, and both missions use same satellite design
- Long time series of low-degree terms from SLR help put observations from GRACE into context of long-term changes
- SLR combined with GRACEGPS (or other satellites with good accelerometers) will be essential to fill the gap between GRACE missions
- Test of General Relativity will continue to improve, particularly with the addition of LARES