Time-Variable Gravity from SLR and DORIS Tracking

Goddard Space Flight Center

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Introduction

- GRACE is providing a valuable new source of high resolution gravity data for assessment of surface mass transport
- Intercomparison of this new technology with SLR/DORIS based results can accomplish several objectives:
  - Validation of GRACE, where the performance of the SLR/DORIS tracking allows
  - Improvement of the SLR/DORIS processing via new models, processing algorithms, and independent quality assurance
  - Thereby leveraging GRACE into the pre-GRACE era
- The final objective being to provide valid and useful geoid change and surface mass transport over the past ~25 years for geophysical analysis

- This is only possible because of the tracking services and missions

International Laser Ranging Service

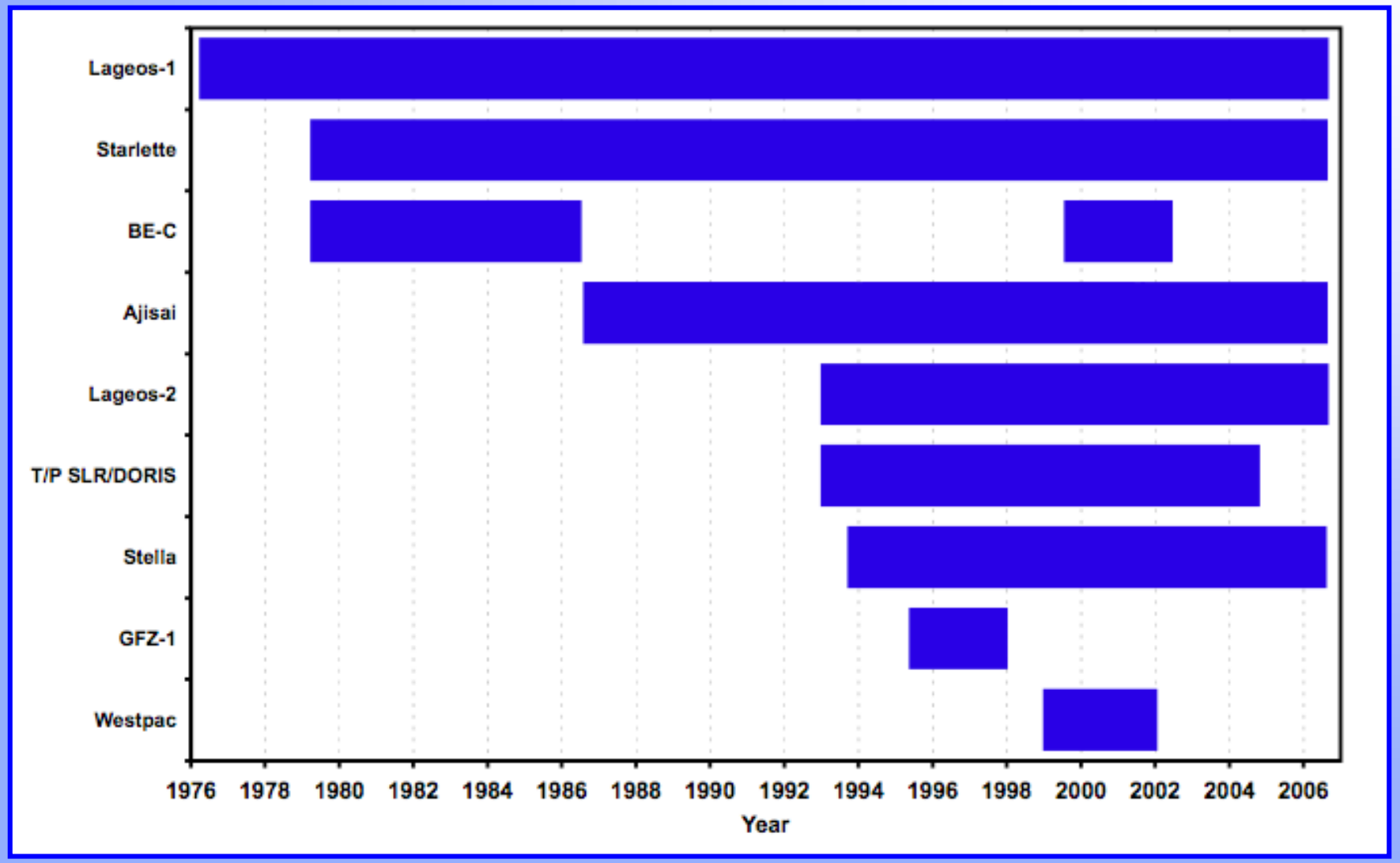
IDS INTERNATIONAL DORIS SERVICE

GRACE NASA CSR GFZ DLR

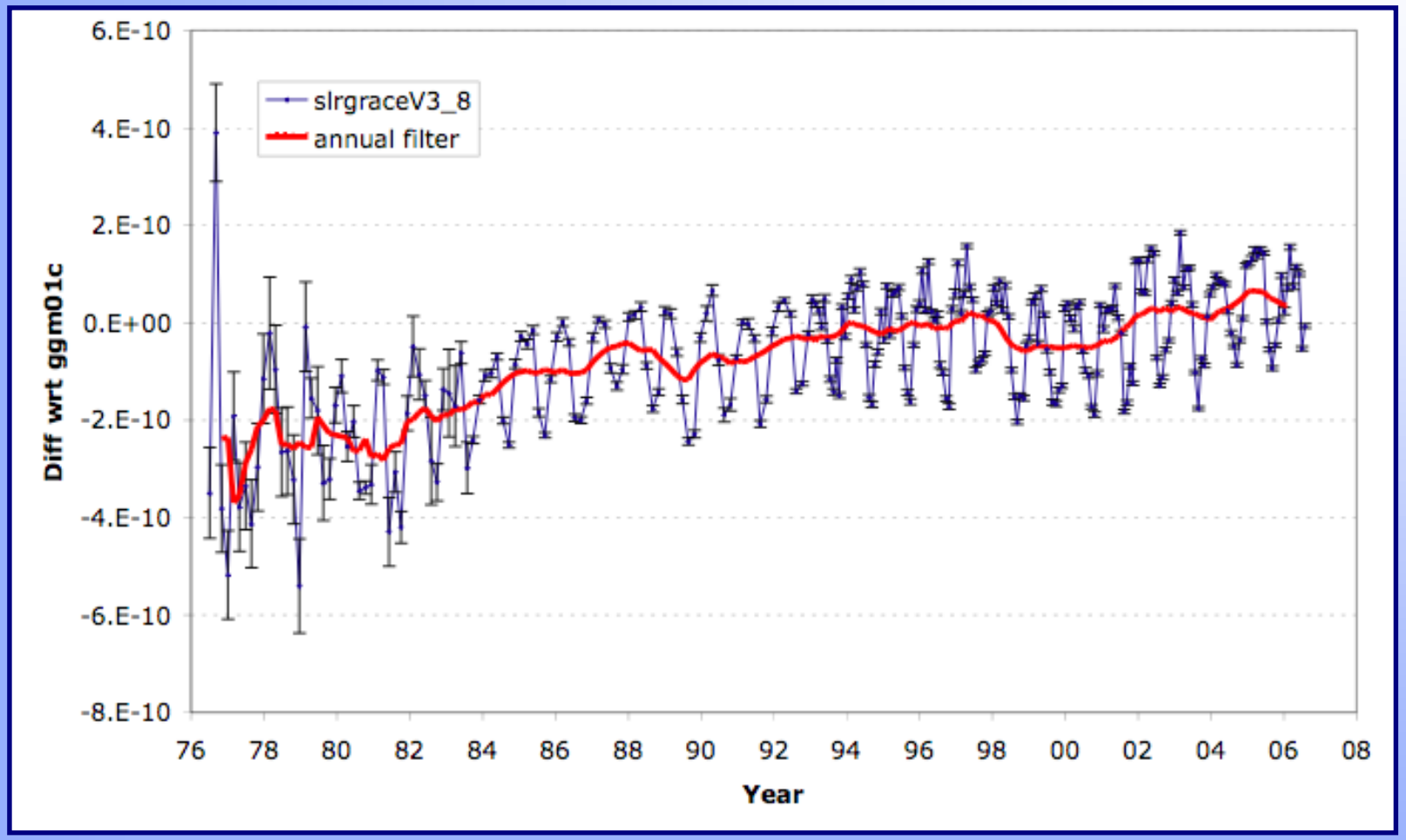
New SLR Processing

- Data from Lageos-1/2, Starlette, Stella, Westpac, Ajisai, GFZ-1, TOPEX/Poseidon, and BE-C
- All SLR/DORIS data reprocessed using:
  - ITRF2000 Reference frame + corrections
  - GGM01C GRACE gravity model
  - IERS2003 Solid Earth Tides, including anelasticity
  - GOT00.2 Ocean Tides
    - Self-Consistent equilibrium long period tides, including 18.6-yr ocean tide
  - NCEP-derived atmospheric gravity *variations wrt 2000-2001 mean* modeled
    - Monthly, 20x20 correction
    - IB assumed for Ocean
  - Observed annual gravity terms to *Nmax* = 4 forward modeled
- Time Variable Gravity Solution(s):
  - 30x30 Static, 6x6 Rate + Annual and 4x4 Semi-Annual
  - 4x4 monthly series

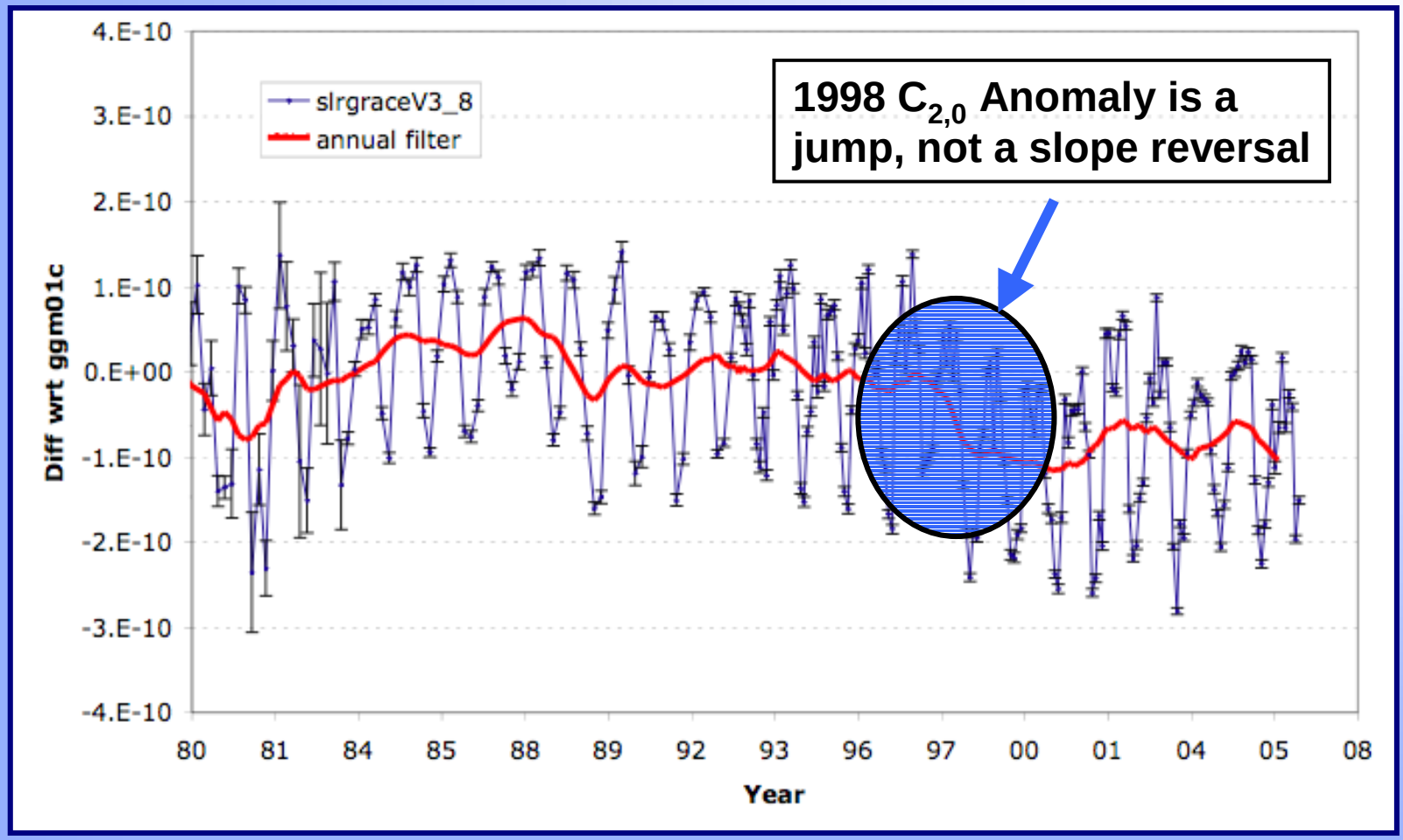
Satellite Tracking Temporal Coverage



$C_{2,0}$ Time Series



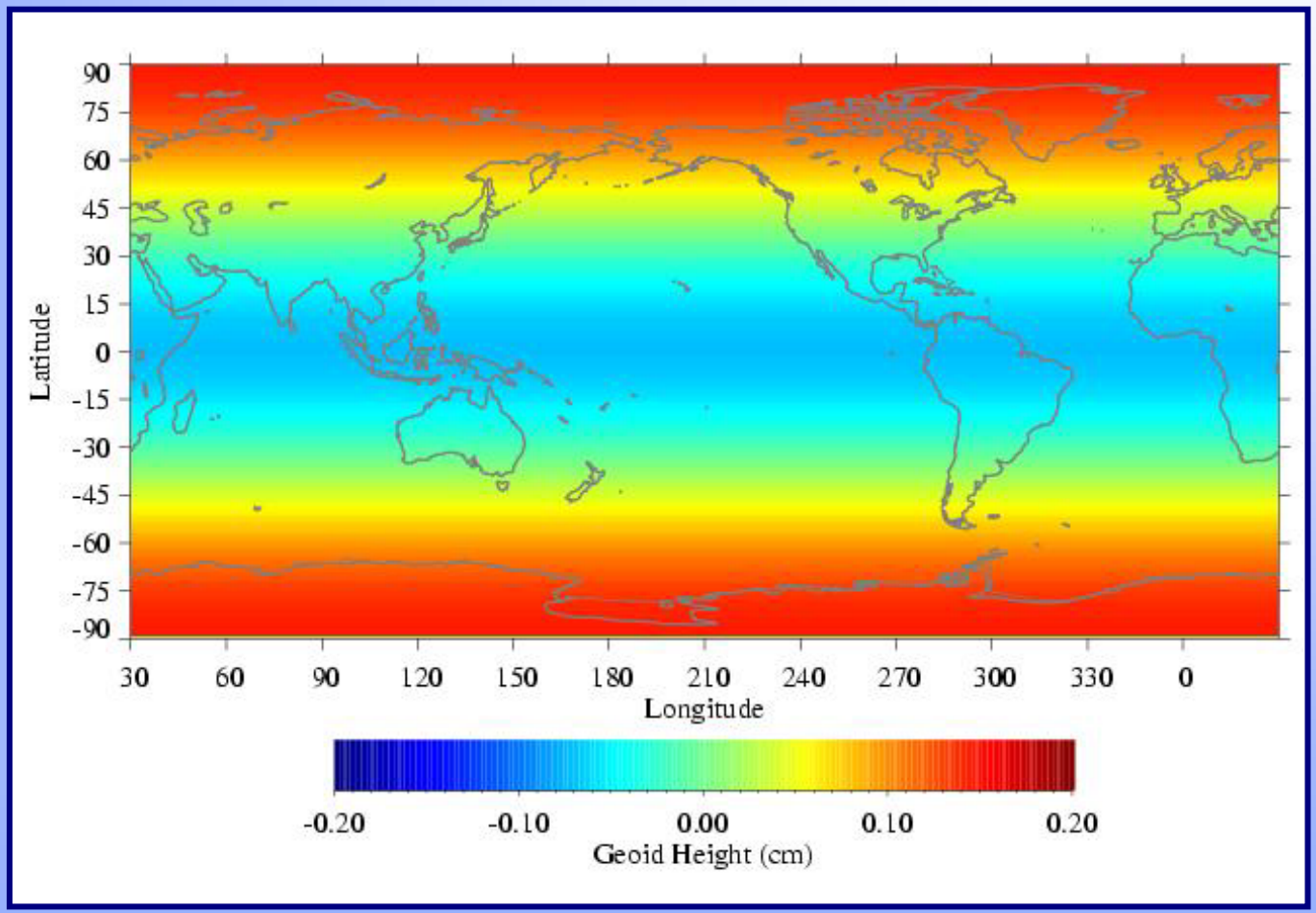
$C_{2,0}$ Time Series: What happened to the 1998 anomaly?



Shown with 1980-1997 slope removed (1.34×10^{-11} per year)
Post 1997 slope nearly identical (1.36×10^{-11} per year)

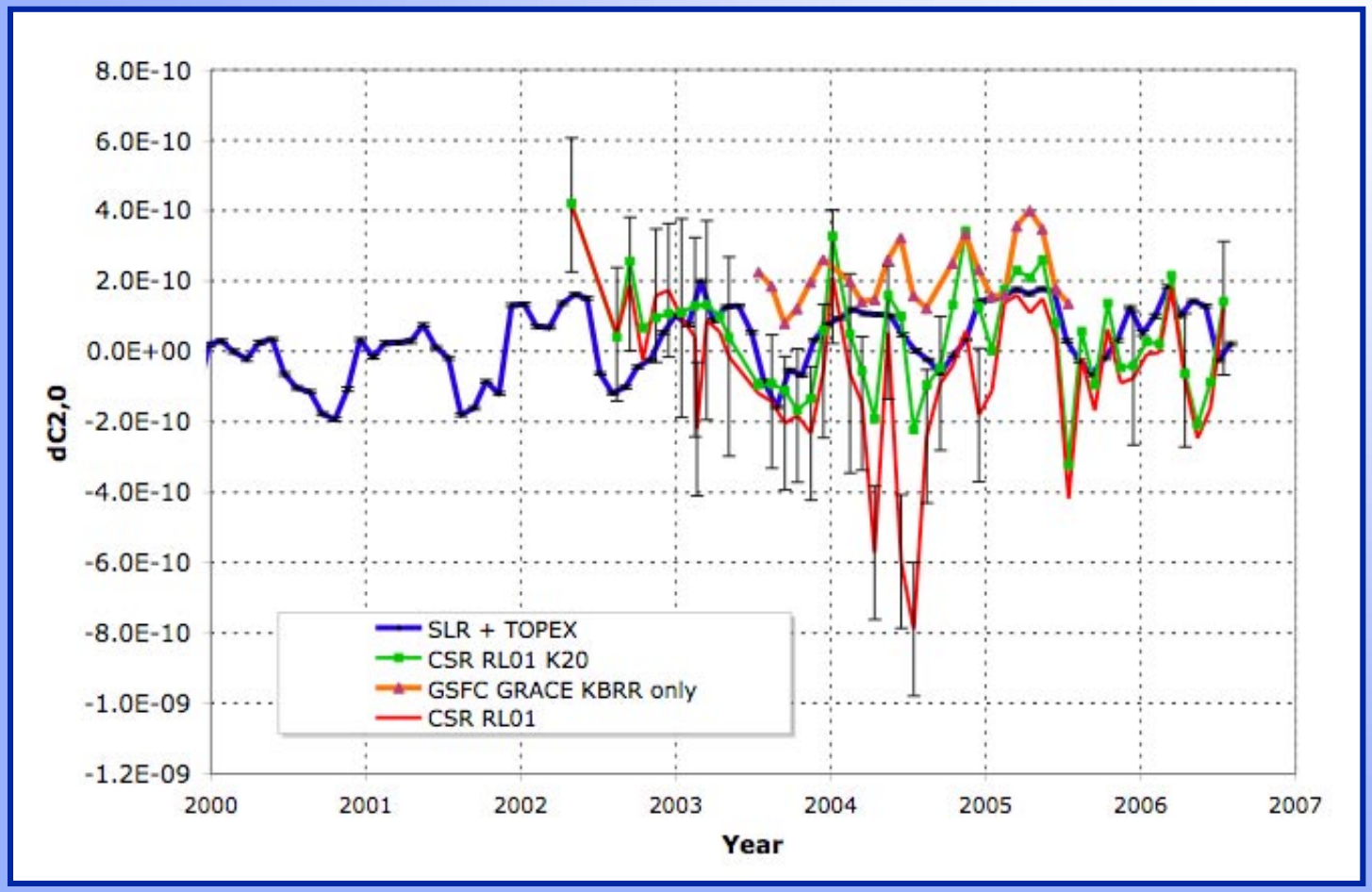
$C_{2,0}$ Time Series

Color range: +/- 2 mm Geoid change for 1x10^{-10} change in value



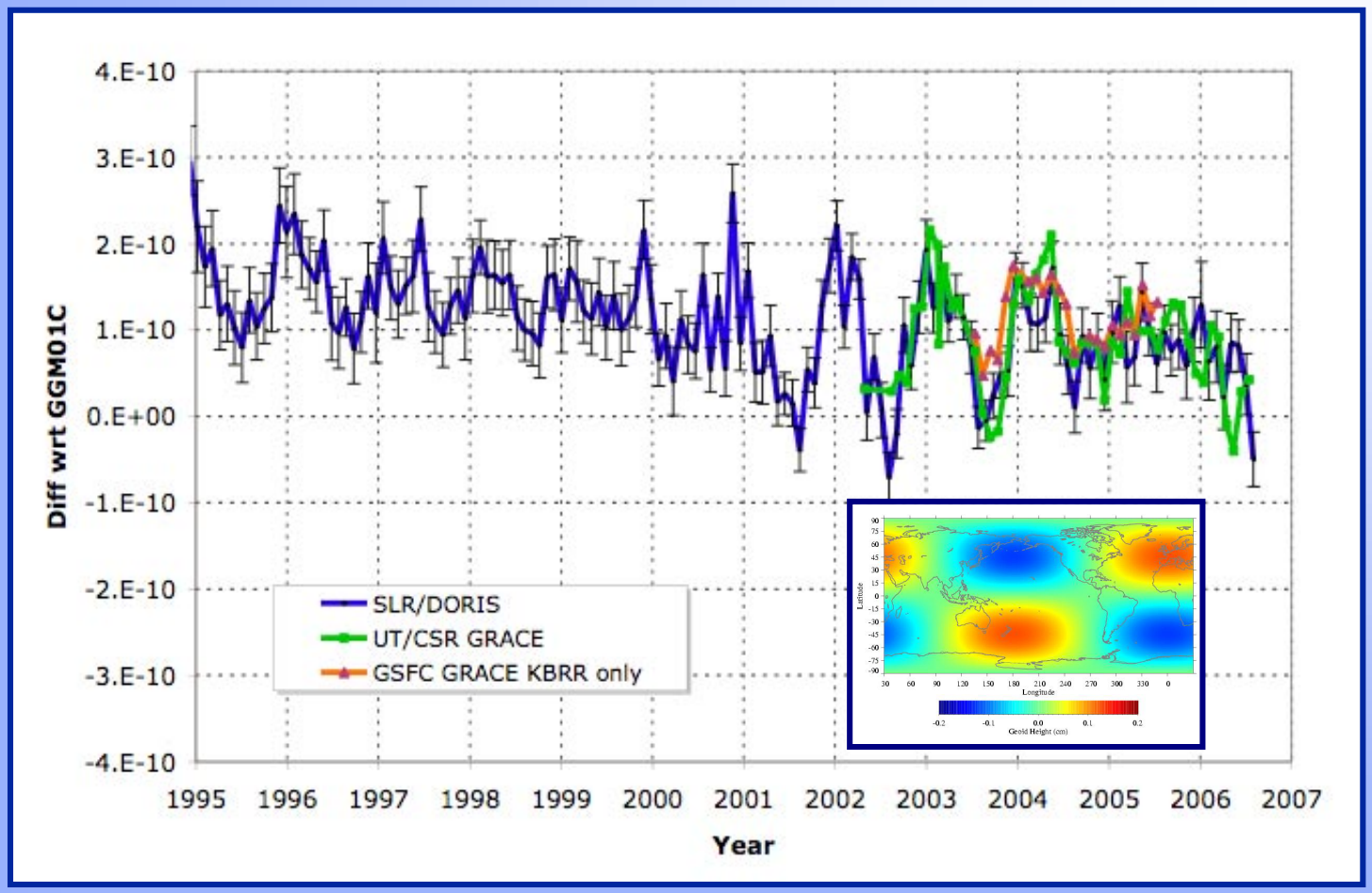
$$\overline{C}_{2,0} = -J_2 / \sqrt{5}$$

$C_{2,0}$: Comparison: SLR vs GRACE monthly



Formal Errors shown for SLR **Calibrated Errors shown for GRACE**

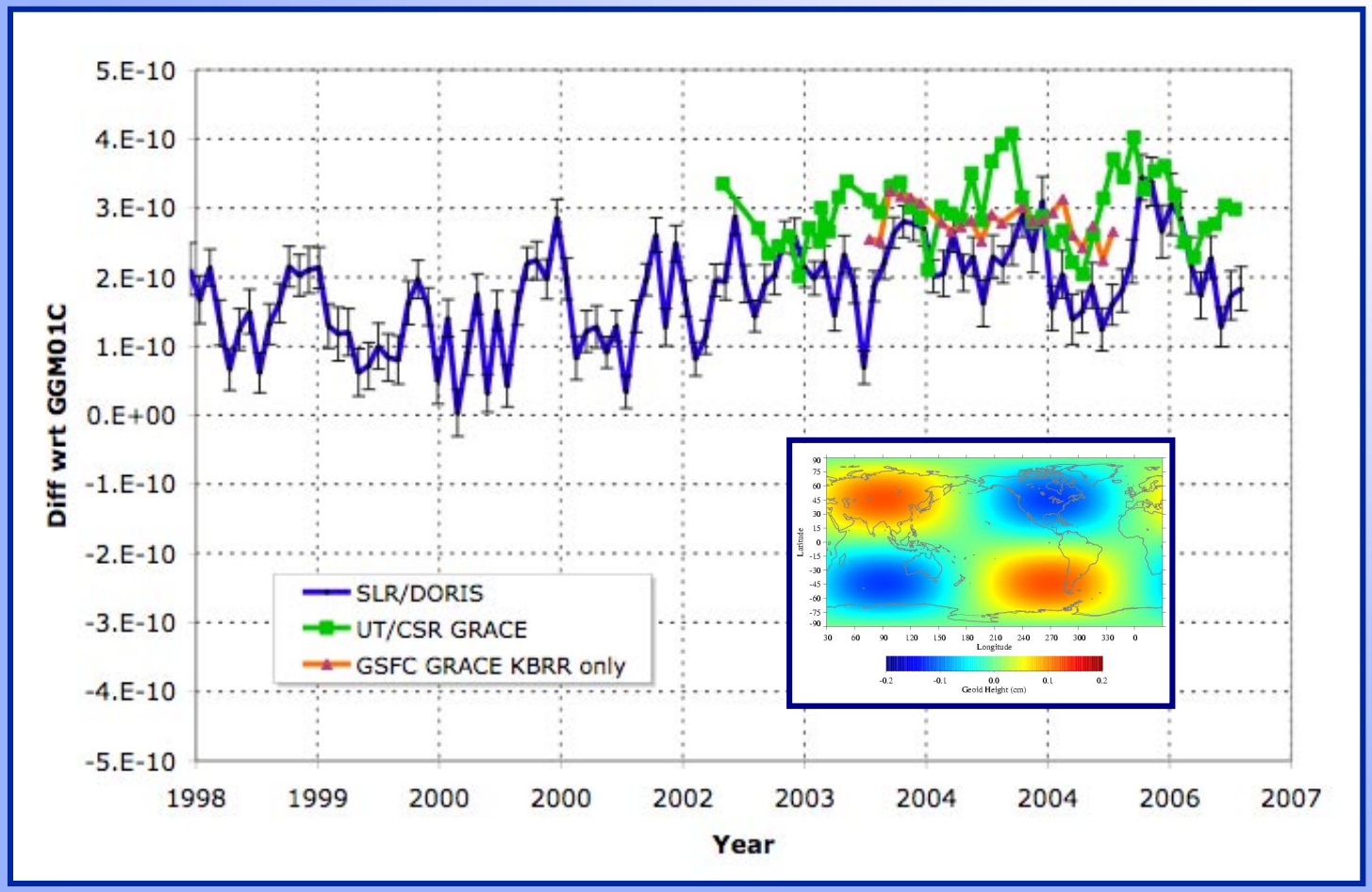
$C_{2,1}$: SLR vs GRACE monthly



Formal Errors shown for SLR

Calibrated Errors shown for GRACE

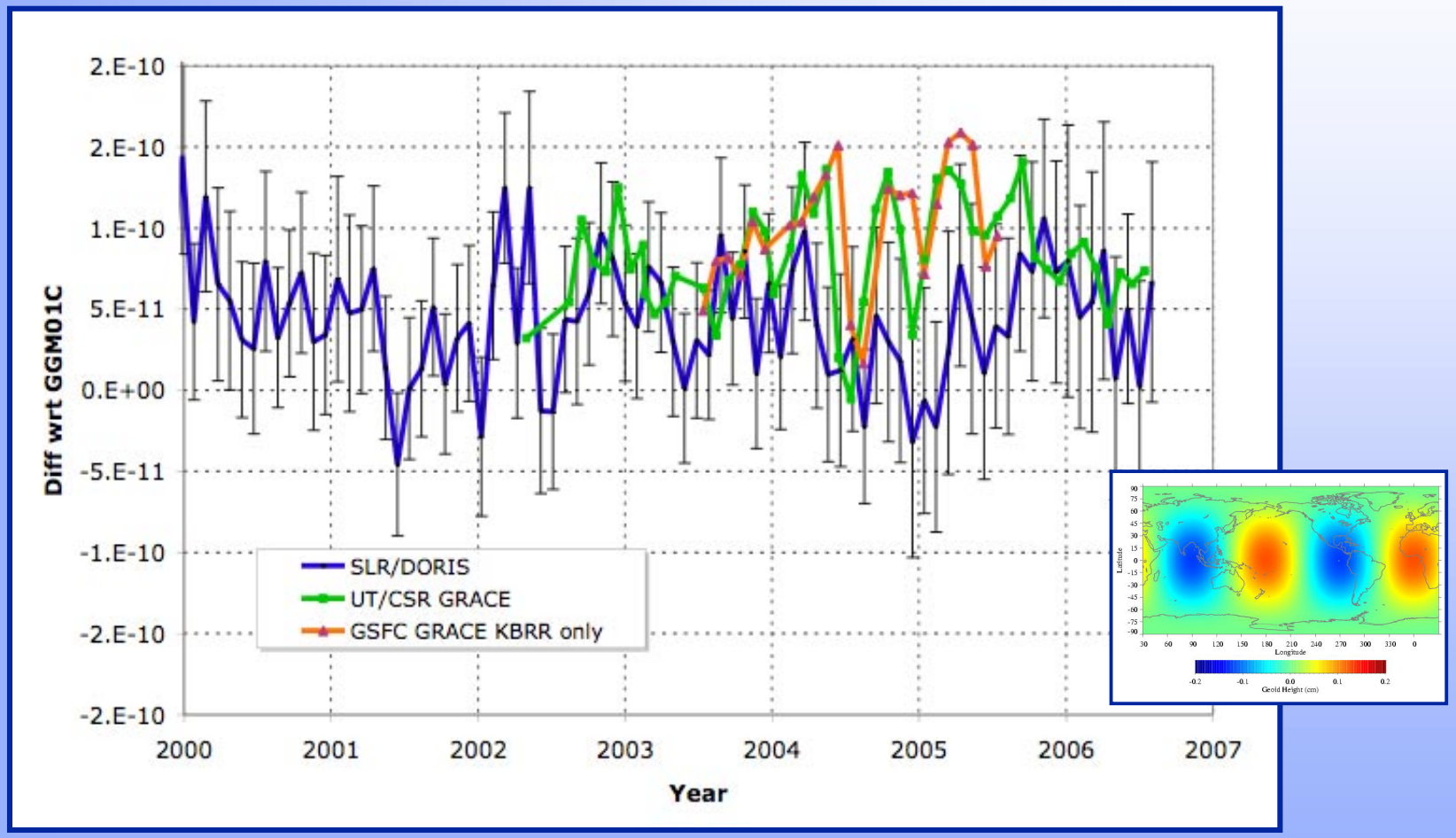
$S_{2,1}$: SLR vs GRACE monthly



Formal Errors shown for SLR

Calibrated Errors shown for GRACE

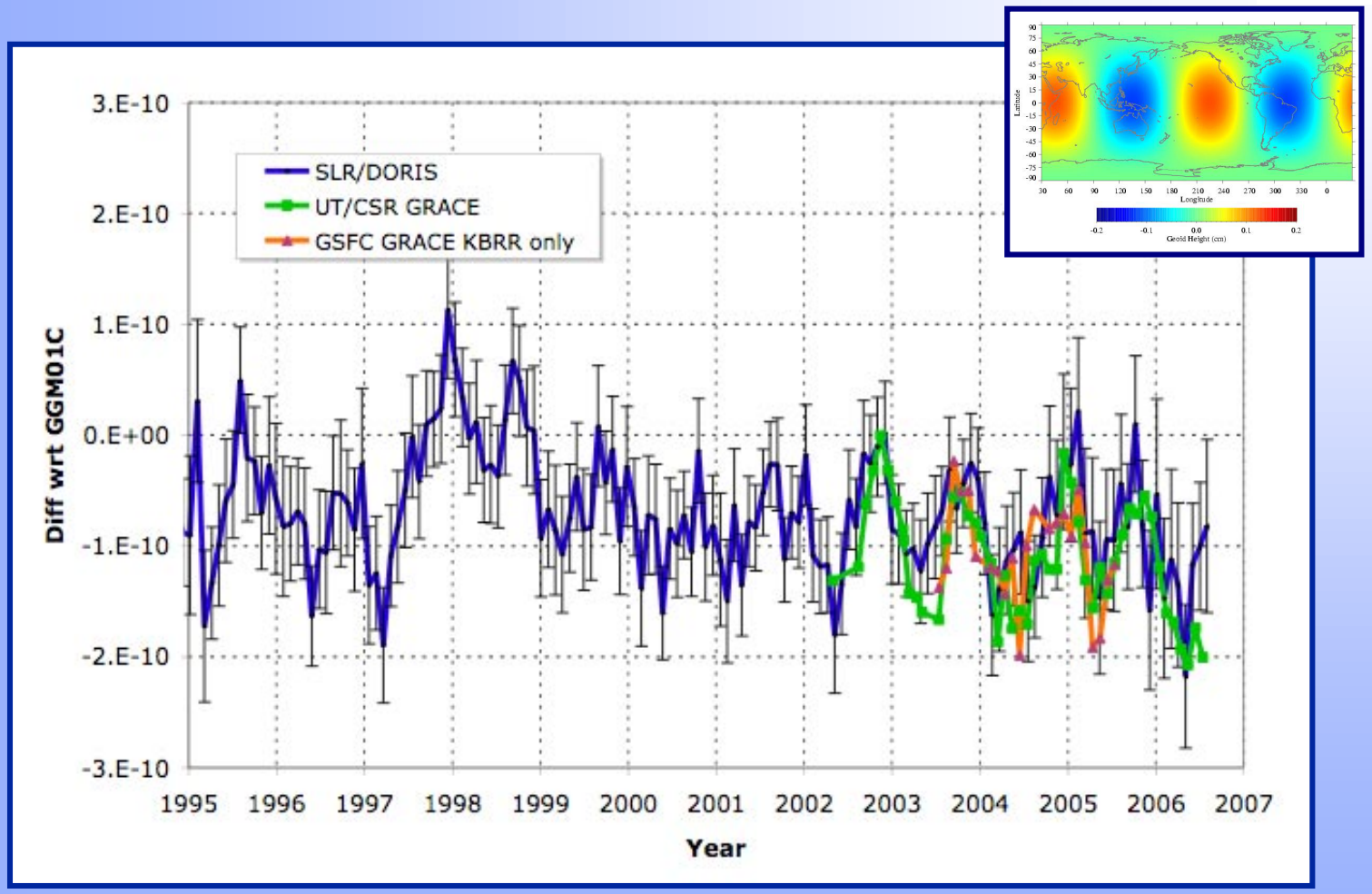
$C_{2,2}$: SLR vs GRACE monthly



Formal Errors shown for SLR

Calibrated Errors shown for GRACE

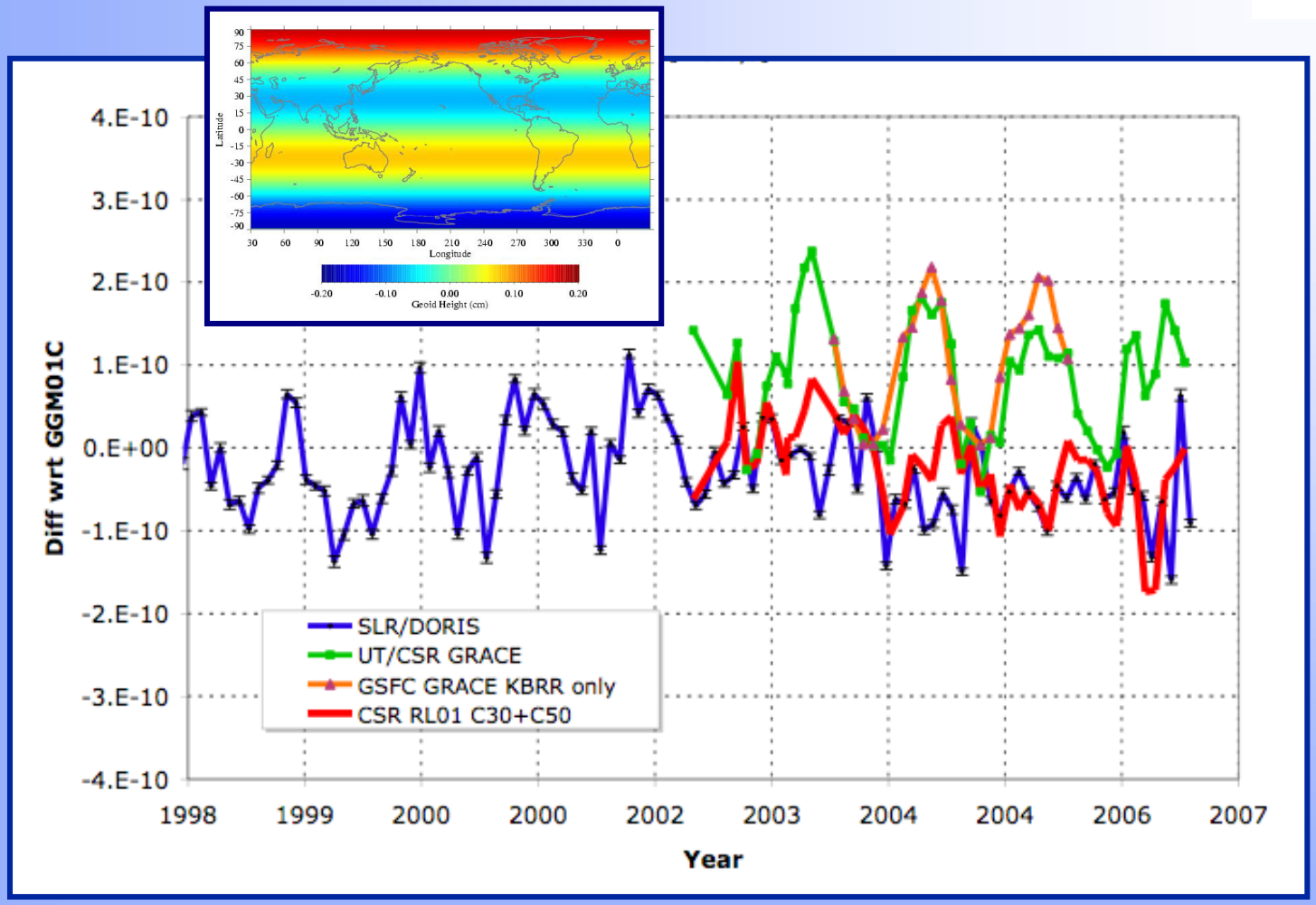
$S_{2,2}$: SLR vs GRACE monthly



Formal Errors shown for SLR

Calibrated Errors shown for GRACE

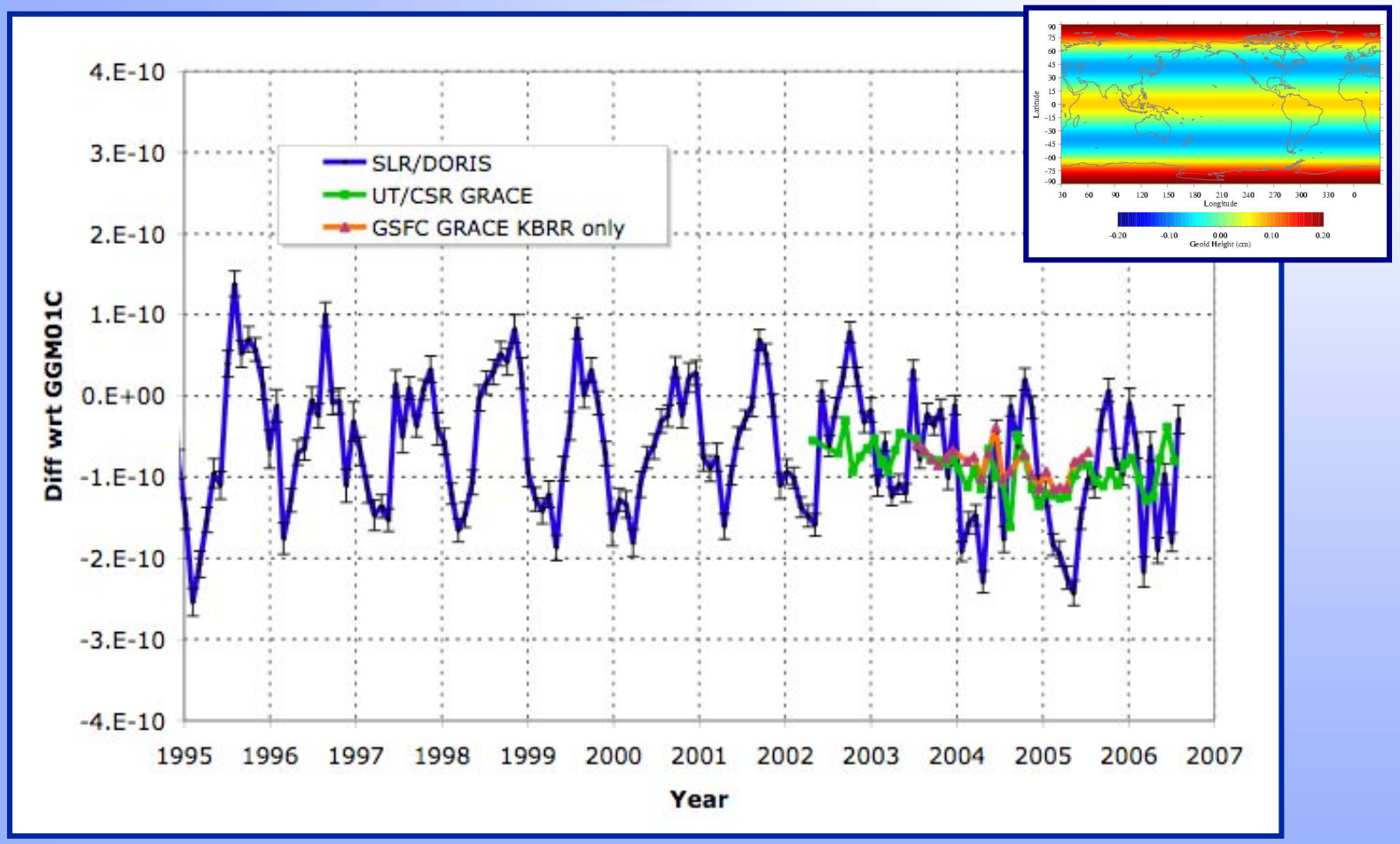
$C_{3,0}$: SLR vs GRACE monthly



Formal Errors shown for SLR

Calibrated Errors shown for GRACE

$C_{4,0}$: SLR vs GRACE monthly



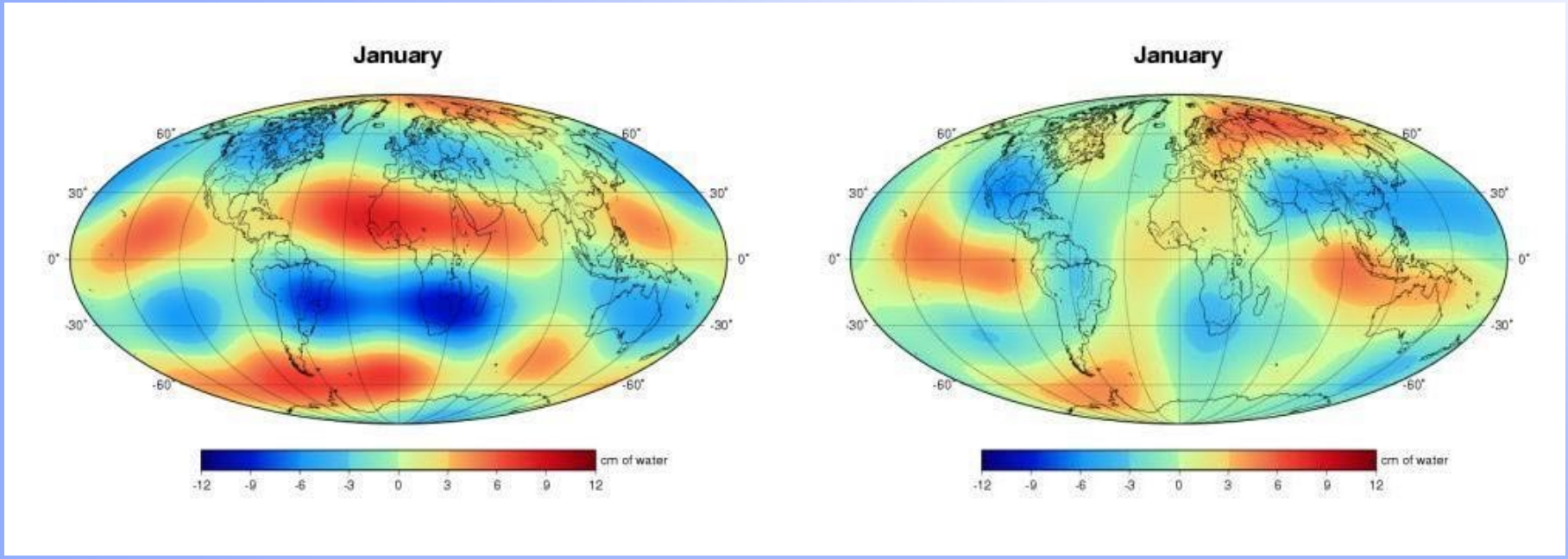
Formal Errors shown for SLR

Calibrated Errors shown for GRACE

Annual and Semi-Annual Variation (mov)

SLR/DORIS Derived using 1979-1997
Inverted Barometer used for Ocean
***Nmax*=6 Annual, *Nmax*=4 Semi**

Resolution: ~3300 km

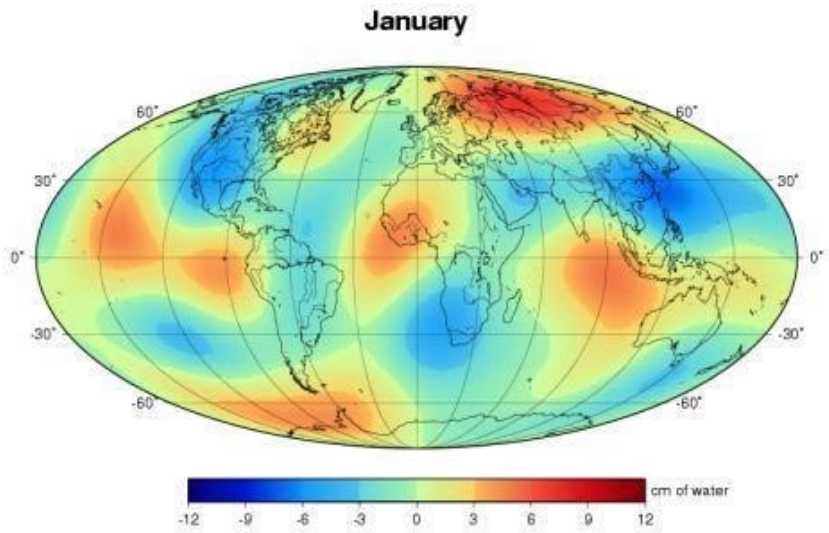


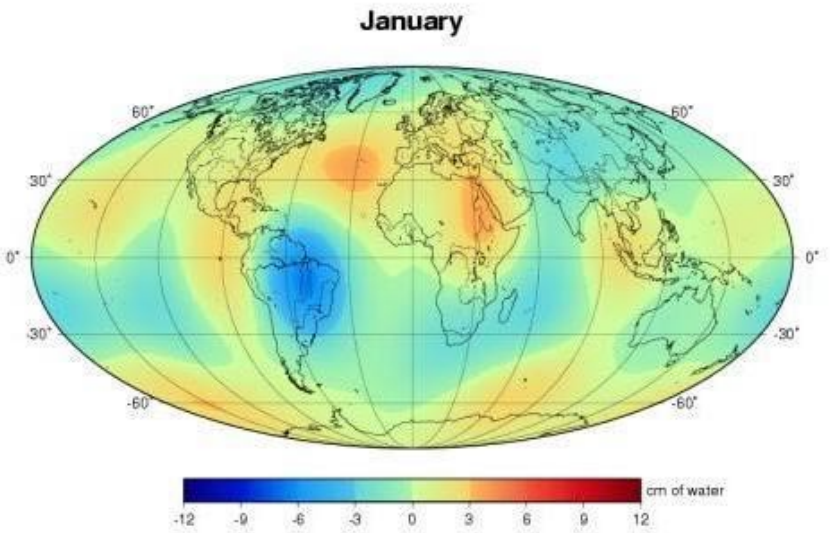
SLR/DORIS Derived using 1998-2005
Inverted Barometer used for Ocean
***Nmax*=6 Annual, *Nmax*=4 Semi**

Annual and Semi-Annual Variation (mov)

SLR/DORIS Derived using 2001-2005
Inverted Barometer used for Ocean
Nmax=6 Annual, *Nmax*=4 Semi

Resolution: ~3300 km

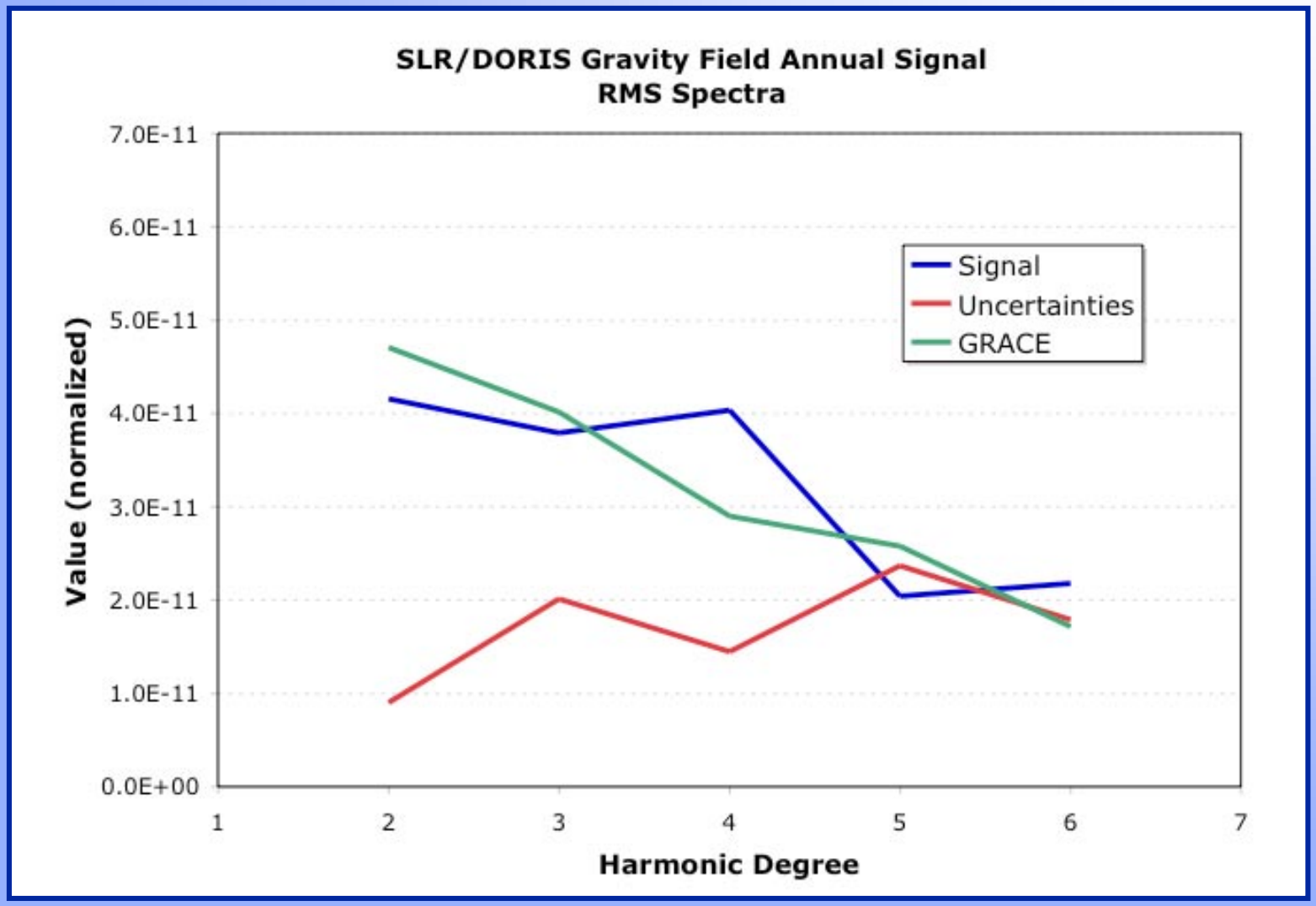




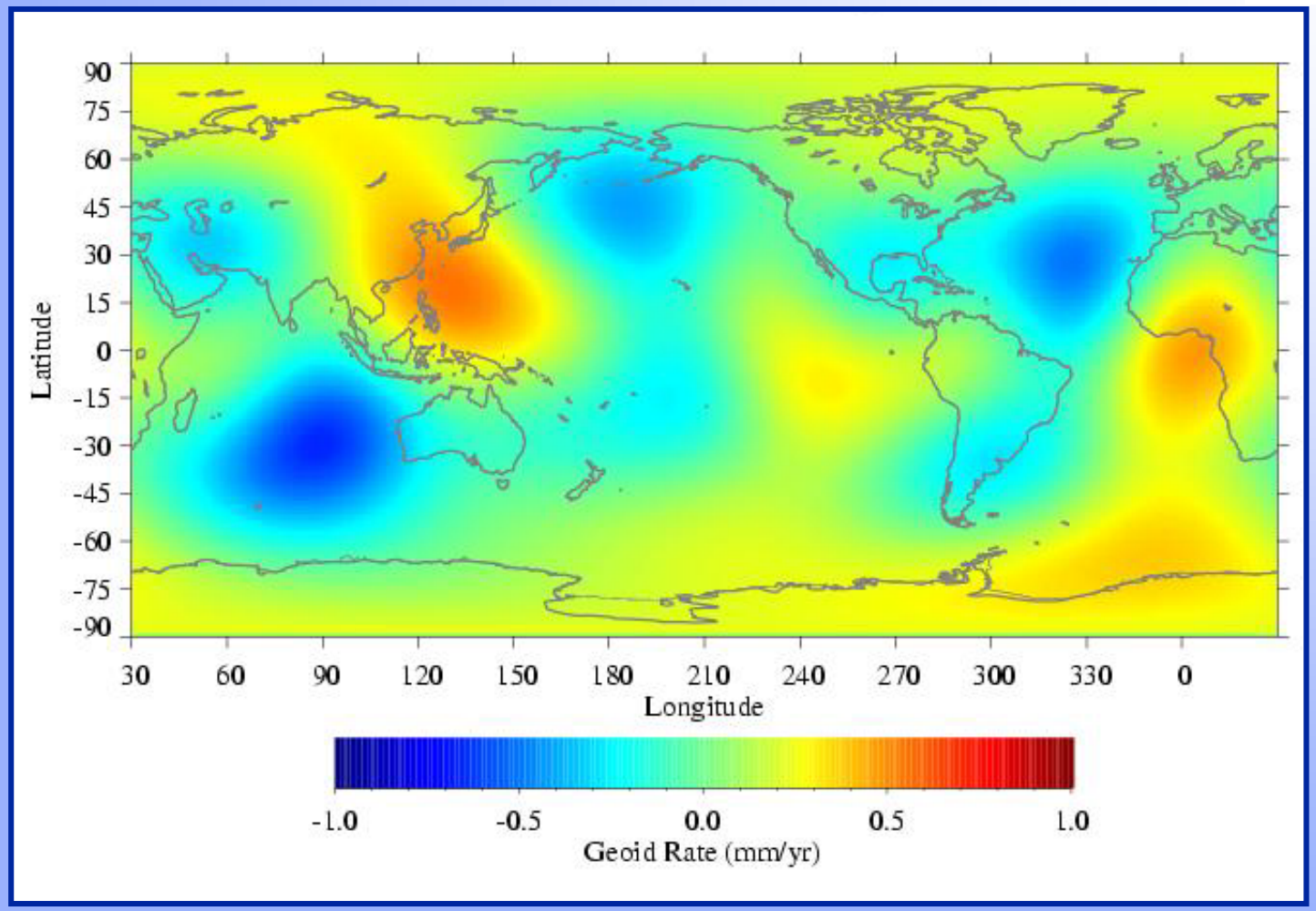
Power in GRACE comparable to pre 1998 SLR

GRACE (UT/CSR) Derived using 2002-2004
Includes wind and pressure driven ocean
SLR/DORIS $C_{2,0}$ terms used, *Nmax=6*

Annual Signal Strength and Uncertainty



SLR Observed Geoid Rates Through Degree 6

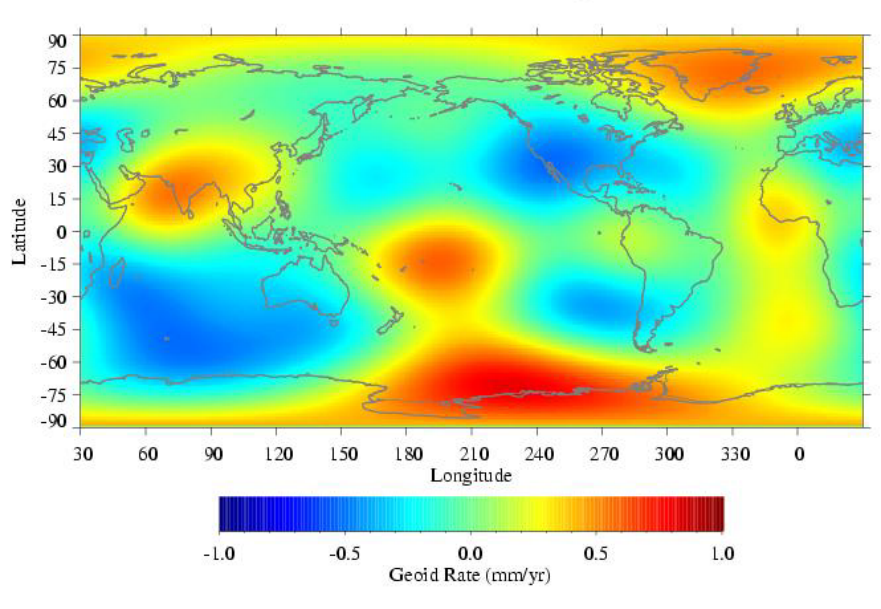


Period: 1979-2004

SLR Observed Geoid Rates: 1979-1997

SLR/DORIS observed rates

Error = 0.14 mm/yr

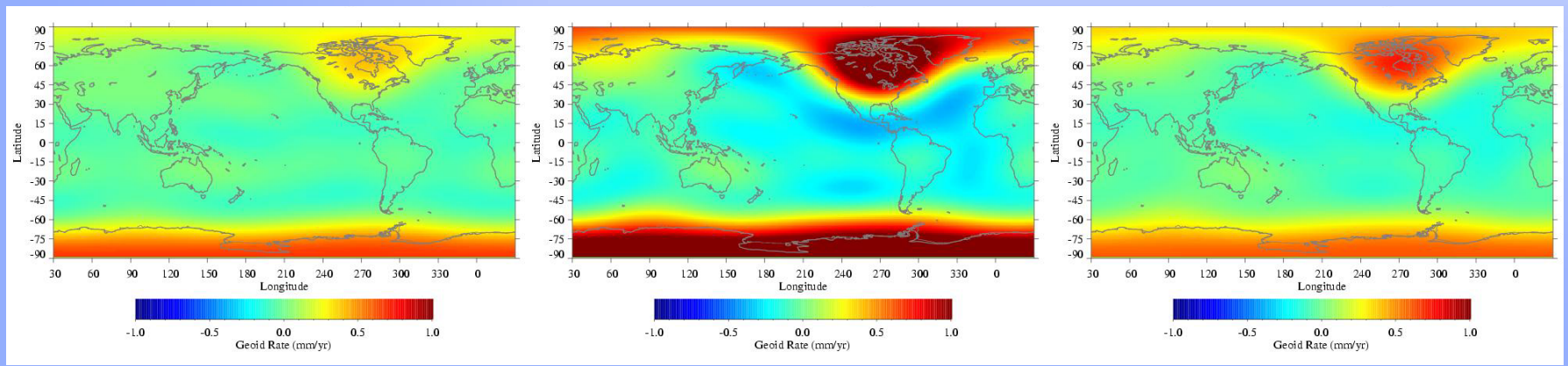


Post-Glacial Rebound model coefficients courtesy Erik Ivins of JPL

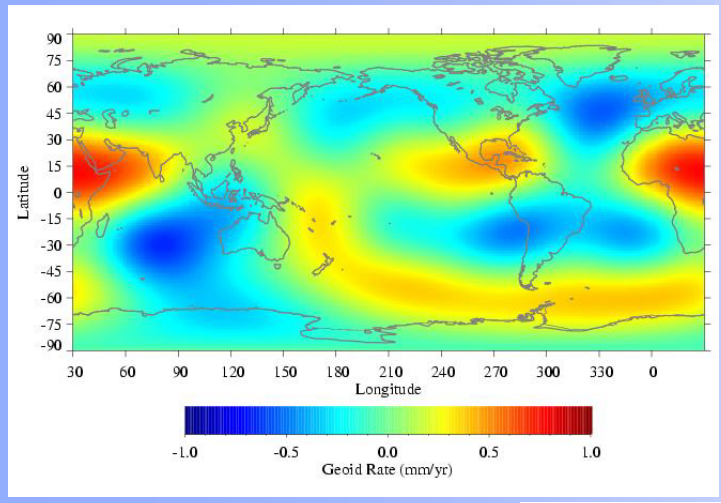
Lower Mantle Viscosity: 1.5x10^{-21} PaS

15x10^{-21} PaS

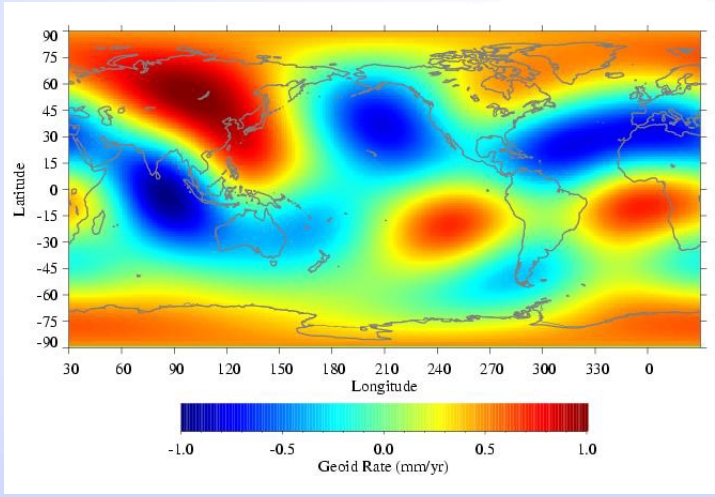
100x10^{-21} PaS



Variability in the Observed Geoid Rates



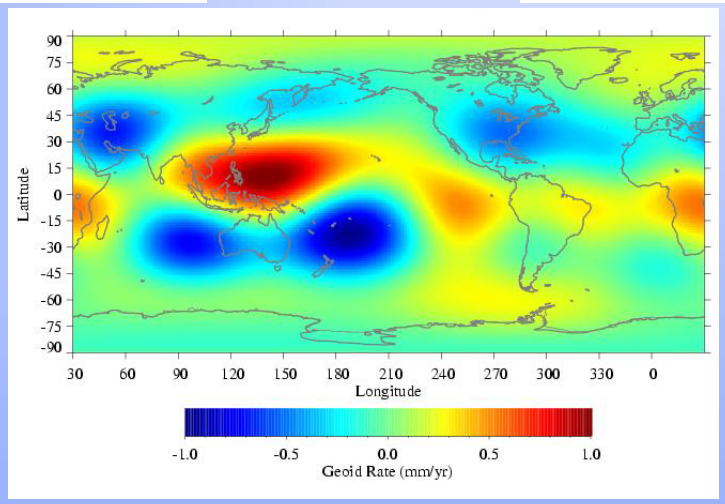
Nmax = 6



Period: 1993-1998

Period: 1999-2004

Global Uncertainty: ~0.16 mm/yr

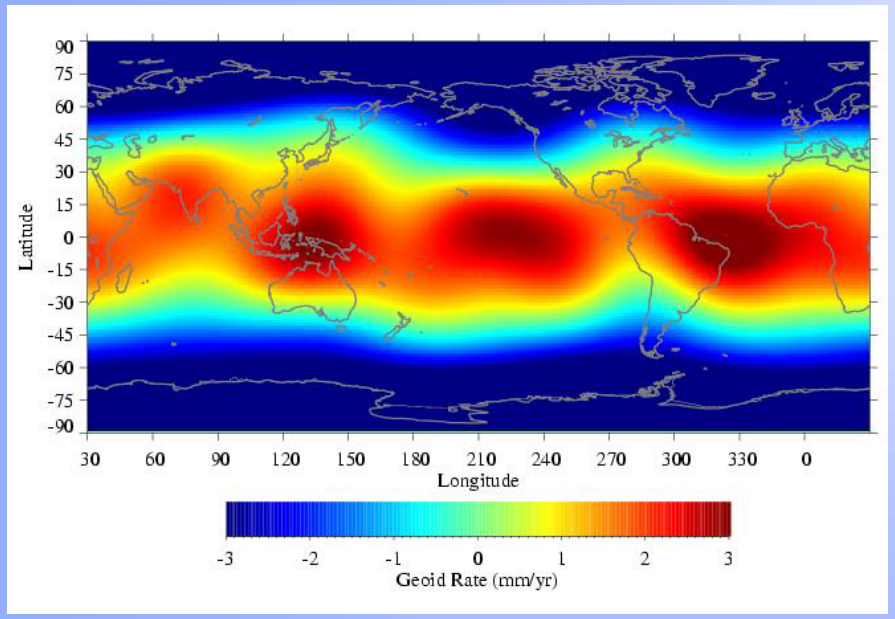


Period: 1996-2001

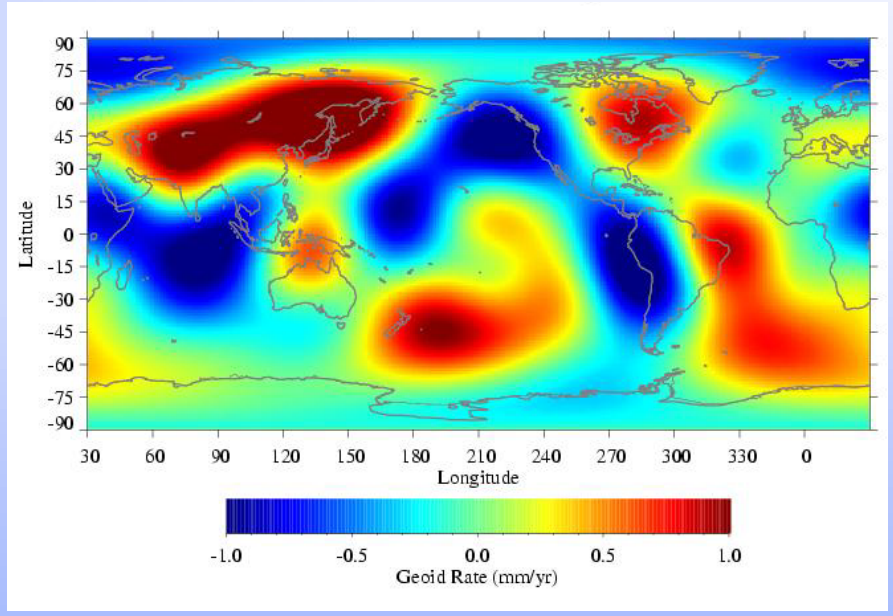
Note increase in amplitude and Asian High

GRACE Geoid Rates, 2002-2004

Based on fits of mean, rate, annual, and semi-annual terms to coefficients of UT/CSR Level-2 gravity field products, *Nmax* = 6.



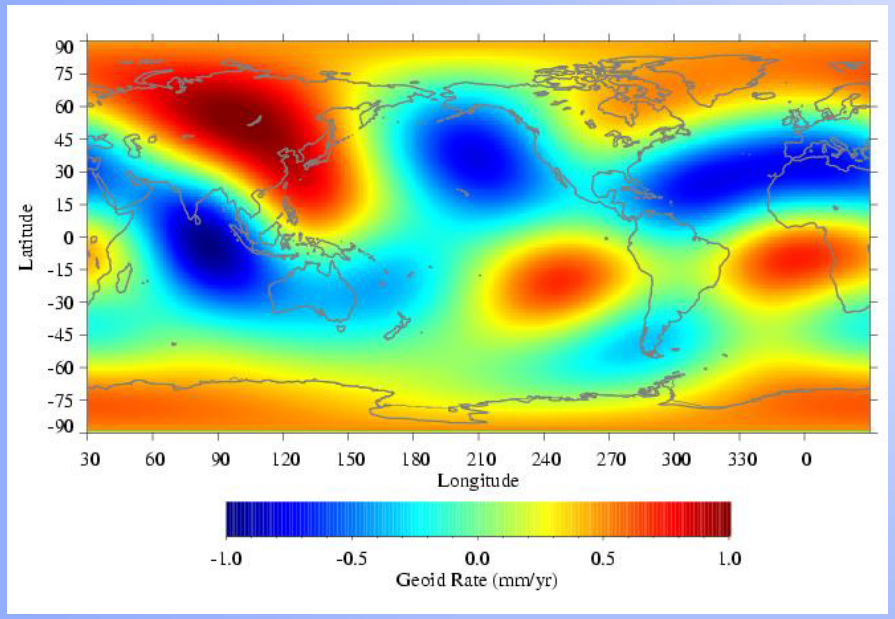
With Level-2 C2,0 Rate



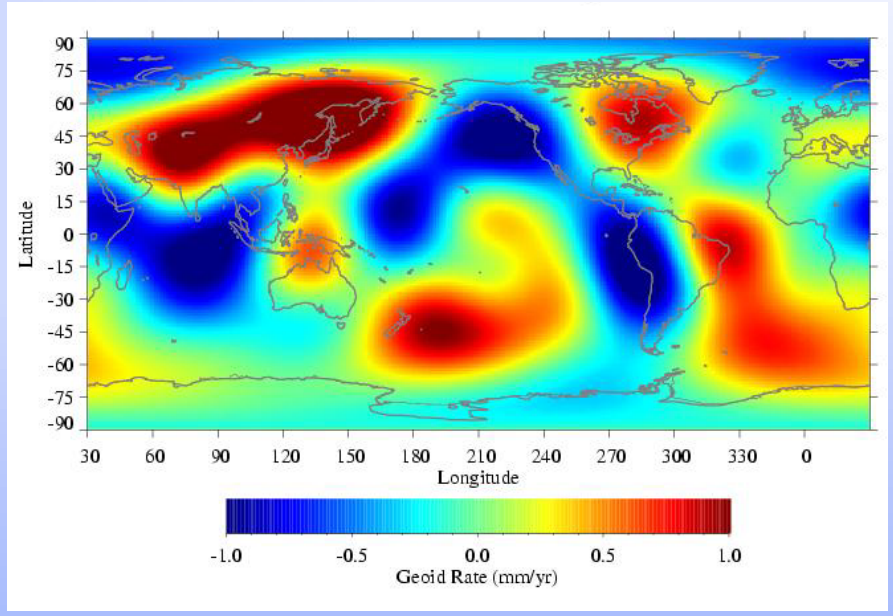
Using SLR/DORIS C2,0 Rate for 1999-2004

SLR/DORIS and GRACE

Despite the difference between the five and two year periods for the solutions SLR/DORIS and GRACE are seeing essentially the low/mid latitude signal



SLR/DORIS over 1999-2004



GRACE over 2002-2004

Conclusions

- 1998 $C_{2,0}$ anomaly appears to be a jump, or other interannual variation, not a long term state change
- Current GRACE $C_{2,0}$ *does not agree* with the SLR estimates
  - Otherwise GRACE and SLR/DORIS in reasonable agreement at degree 2
  - Significant disagreement in other zonal terms
- Overall SLR/DORIS and GRACE annual structure agrees
- Calibrated GRACE error bars seem reasonable
- Long wavelength rate terms
  - SLR/DORIS has the precision and long history necessary to address the long term geoid rate problem
    - Yields statistically significant geoid rates rates up to *Nmax* = 6 (~3300 km)
  - For the pre 1998 period the observed geoid rates are similar to Post Glacial Rebound predictions for the polar regions
  - Significant interannual variation is evident at time scales of 5-6 years
  - GRACE rate information shows larger geoid rates over a span of two years
    - Some similarities with SLR solution spanning the period

Future work

- Recompute time series using updated forward models.
- Add new satellites to time series:
  - Jason-2 (SLR/DORIS corrected for SAA);
  - Geosat (Doppler/Xover);
  - GFO (Doppler/Xover)
  - Etalons
  - DORIS Data