Time-Variable Gravity from SLR and DORIS Tracking

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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
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 $N_{max} = 4$ forward modeled

- Time Variable Gravity Solution(s):
  - 30x30 Static, 6x6 Rate + Annual and 4x4 Semi-Annual
  - 4x4 monthly series
Satellite Tracking Temporal Coverage

The chart illustrates the temporal coverage of various satellites from 1976 to 2006. The satellites listed are:

- Lageos-1
- Starlette
- BE-C
- Ajisai
- Lageos-2
- T/P SLR/DORIS
- Stella
- GFZ-1
- Westpac

Each bar represents the duration of coverage for each satellite.
C$_{2,0}$ Time Series
C$_{2,0}$ Time Series: What happened to the 1998 anomaly?

1998 C$_{2,0}$ Anomaly is a jump, not a slope reversal

Shown with 1980-1997 slope removed (1.34 x 10$^{-11}$ per year)
Post 1997 slope nearly identical (1.36 x 10$^{-11}$ per year)
$C_{2,0}$ Time Series

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

\[ \overline{C}_{2,0} = -\frac{J_2}{\sqrt{5}} \]
$C_{2,0}$ 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
$N_{max}=6$ Annual, $N_{max}=4$ Semi

Resolution: ~3300 km

SLR/DORIS Derived using 1998-2005
Inverted Barometer used for Ocean
$N_{max}=6$ Annual, $N_{max}=4$ Semi
Annual and Semi-Annual Variation (mov)

SLR/DORIS Derived using 2001-2005
Inverted Barometer used for Ocean
$N_{max}=6$ Annual, $N_{max}=4$ 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, $N_{max}=6$
Annual Signal Strength and Uncertainty

SLR/DORIS Gravity Field Annual Signal
RMS Spectra

Value (normalized)
7.0E-11
6.0E-11
5.0E-11
4.0E-11
3.0E-11
2.0E-11
1.0E-11
0.0E+00

Harmonic Degree
1
2
3
4
5
6
7

Signal
Uncertainties
GRACE
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


Global Uncertainty: ~0.16 mm/yr

Period: 1996-2001

Period: 1999-2004

Nmax = 6

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, $N_{max} = 6$.

**With Level-2 C2,0 Rate**

**Using SLR/DORIS C2,0 Rate for 1999-2004**
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
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 $N_{max} = 6$ (~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