GRACE Monthly Estimates Compared with Surface Gravity Variations at mid-North American Sites

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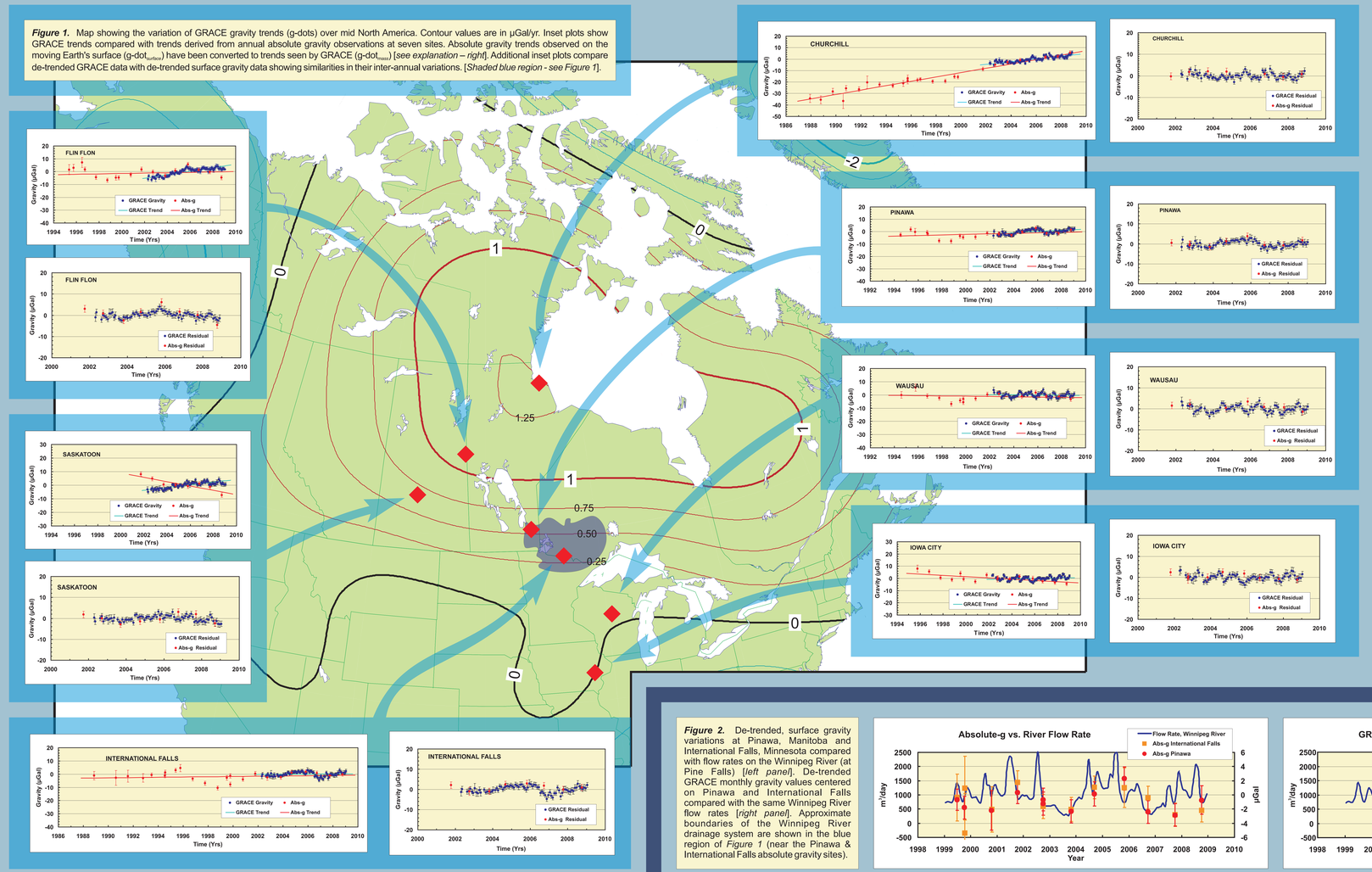
OVERVIEW

GRACE monthly gravity estimates have been compared with annual surface gravity measurements at mid-continent North American sites to examine similarities and differences in observed trends and inter-annual variations. At some sites the GRACE trends are significantly different from the surface absolute gravity trends corrected for vertical movement, probably as a result of different spatial averaging of the dominant postglacial rebound signal. However, at sites where inter-annual variations are significant, there are strong similarities between GRACE and surface gravity data, indicating the presence of large-scale changes in groundwater storage.

• Monthly GRACE gravity values were derived from the CSR-RL04 spherical harmonic monthly models for the period of April 2002 to January 2009.

• Surface gravity observations have been carried out annually at mid-continent sites for well over a decade. The surface gravity values reported here are based on at least 24 hours of gravity observations using free-fall absolute gravimeters.

Figure 1. Map showing the variation of GRACE gravity trends (g-dots) over mid North America. Contour values are in μGal/yr. Inset plots show GRACE trends compared with trends derived from annual absolute gravity observations at seven sites. Absolute gravity trends observed on the moving Earth's surface ($g\text{-}dot_{surface}$) have been converted to trends seen by GRACE ($g\text{-}dot_{mass}$) [*see explanation – right*]. Additional inset plots compare de-trended GRACE data with de-trended surface gravity data showing similarities in their inter-annual variations. [*Shaded blue region - see Figure 1*].



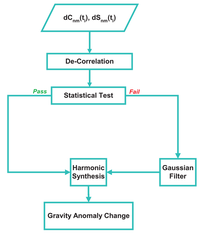
GRACE DATA PROCESSING

Fitting Model (7 unknowns):

$$\overline{C}_{nm}(t_i) \quad \overline{C}_{nm}(t_0) \quad \dot{v}^{C}_{nm}(t_0)(t_i - t_0) \quad \frac{1}{2}\ddot{a}^{C}_{nm}(t_i - t_0)^2$$

$$A^{C}_{nm}\cos 2 \quad t_i \quad t_0 \quad {}^{C}_{A} \quad B^{C}_{nm}\cos 4 \quad t_i \quad t_0 \quad {}^{C}_{S} \quad r^{C}_{nm} \qquad i \quad 1,2,..n$$

The flowchart on the right side describes the procedure used to determine gravity change estimates from the monthly GRACE gravity models [*Tapley et al.*, 2004]. First, a de-correlation process is used to remove the stripe noise [see *Swenson and Wahr*, 2006]. Second, a least-squares model is used to solve for linear and quadratic terms, and to solve for annual and semi-annual seasonal variation amplitudes and their respective phases. The standard deviations of the spherical harmonic coefficients are used to form initial diagonal covariance matrices for each coefficient time series. If the estimated trend (linear & quadratic) and seasonal terms have posteriori signal-to-noise ratios greater than 4 for the coefficient time series, it is directly used to compute gravity anomaly change without further filtering. Otherwise the coefficients times series goes through a 450 km Gaussian filter [*Wahr et al.*, 1998] before it is used to compute the gravity anomaly change. The unfiltered part constitutes 75% of the total gravity anomaly change.



SURFACE GRAVITY INSTRUMENTATION & DATA PROCESSING

Mid-continent Gravity Measurements

Absolute gravimeters:
- JILA2, JILA4 (1987-1992)
- FG5-102, FG5-111 (1993-2002)
- FG5-106 (1995-present) (*Faller et al.*, 1983, *Niebauer et al.*, 1995)

Absolute Gravity Data Processing

Data corrections:
- Solid earth tides
- Ocean loading
- Polar motion
- Local atmospheric attraction & loading

CORRECTION OF SURFACE GRAVITY FOR VERTICAL MOVEMENT

Absolute gravity trends are converted to trends seen by GRACE using the relation:

$$g\text{-}dot_{mass} = -1.053 * g\text{-}dot_{surface}$$

This relation arises when we correct the surface gravity rate for the effect of surface vertical velocity to arrive at the pure subsurface mass-redistribution effect:

$$g\text{-}dot_{mass} = g\text{-}dot_{surface} - (-0.3086\ \mu Gal/mm) * z\text{-}dot_{surface}$$

where -0.3086 μGal/mm is the free-air gradient. $z\text{-}dot_{surface}$ can be eliminated from this equation using the relation:

$$g\text{-}dot_{surface} / z\text{-}dot_{surface} = -0.15\ \mu Gal/mm$$

from theoretical and postglacial modeling results [*James and Ivins*, 1998].

SUMMARY OF RESULTS

• GRACE and surface gravity trends at mid-continent North American sites are in agreement at some sites but not in others. At Churchill the trend from surface measurements is expected to be higher than the GRACE trend as a result of Hudson Bay outflow, which should reduce the GRACE trend and increase the surface gravity trend. At other sites, such as Flin Flon and Saskatoon, the differences in trends are probably the result of the spatial averaging by GRACE. This possibility will be investigated in more detail at a later date.

• Where significant inter-annual, gravity variations are observed, *e.g.*, Pinawa and International Falls, there is good agreement between GRACE and surface, absolute-g measurements. Comparison with flow rate data for the Winnipeg River suggests that the inter-annual variations are related to large-scale variations in groundwater storage.

Poster Presentation

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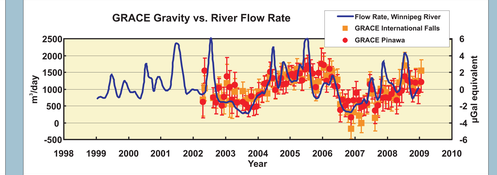
Figure 2. De-trended, surface gravity variations at Pinawa, Manitoba and International Falls, Minnesota compared with flow rates on the Winnipeg River (at Pine Falls) [*left panel*]. De-trended GRACE monthly gravity values centered on Pinawa and International Falls compared with the same Winnipeg River flow rates [*right panel*]. Approximate boundaries of the Winnipeg River drainage system are shown in the blue region of *Figure 1* (near the Pinawa & International Falls absolute gravity sites).



INTER-ANNUAL VARIATIONS: GRAVITY & RIVER FLOW RATES

Pinawa, Manitoba and International Falls, Minnesota are situated in the Winnipeg River drainage basin [*Figure 1*, boundary approximated by shaded blue region]. Gravity variations at these two sites and variations from GRACE centered at the same sites correlate well with variations in the base flow rate of the Winnipeg River (Pine Falls) [*Figure 2*].

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