GRACE Equivalent Water Mass Balance of the Himalayas and Tibet Plateau

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Abstract

The Himalayas and the Tibet Plateau form a region of about 3.4 million square kilometers. Home to numerous large lakes and tarns (glacier lakes), and to more than 50,000 glaciers and high-elevation snowfields, this region is the source of the Indus, Ganga, Brahmaputra, and Yamuna Rivers, the Indo-Gangetic River system. The Himalayan Mountains and associated ranges form a boundary separating continental air masses associated with the westerlies, and marine air masses associated with the summer South Asian monsoon. Adverse changes in water storage / river discharge driven by effects of climate change will impact agriculture, hydroelectric power facilities, commerce, and the lives of more than 1.3 billion people. Monthly water equivalent thickness, i.e. hydrologic mass balance, from the Gravity Recovery and Climate Experiment (GRACE) Level-3 Release 4 de-striped global grids from the University of Texas Center for Space Research are being investigated to assist in assessment of hydrologic changes. Processing adjusts the GRACE monthly grids for modeled atmosphere water mass, solid Earth and ocean tides and pole tides, and geoid. The ΔC_{20} geopotential coefficient which is caused by water mass transport is not modeled at this time. In this study, the monthly grids were adjusted for glacial isostatic adjustment (Paulson et al., 2007; ICE-5G/VM2), and regional-averages were computed for the Himalaya Tibet Plateau and the Eastern India Bay of Bengal to derive time series. Over the period of the GRACE observations, August 2002 through December 2006, annular periodicity of the mass balance is evident with minima occurring in May and maxima occurring in September. Comparison of the regional time series shows near synchronized annular periodicities with high positive correlation. Least-squares regression after removal of an annual periodicity, suggests the Himalaya Tibet Plateau had an area-average water thickness reduction of 0.031 ± 0.019 cm/month, equivalent to a water volume loss of 17.9 ± 11.0 km^3/yr. On continental regions, GRACE hydrologic mass balance can be composed of signals from changes in groundwater storage, permafrost, soil moisture, glacier mass balance and seasonal snowfield loads, and river discharge. Comparisons with other related geophysical datasets will be needed for validation, assessment of uncertainty, and separation of source components of the GRACE monthly trends and variations of hydrologic Mass balance.

GRACE Surface Mass Change

The co-orbiting satellites of the Gravity Recovery and Climate Experiment (GRACE) do not measure variations in gravity or mass directly (Chambers, 2006a). Rather, measurements in the variations of the inter-satellite range (range rate and range acceleration) is measured, coupled with accurate GPS location relative to the International Terrestrial Reference Frame 2005, to estimate values of the time change in spherical harmonic geopotential coefficients, ΔC and ΔS, to degree and order 120 (Level-3 grids are complete to degree and order 40 however). These are then used in the expansion below to estimate movement of water mass:

$$\Delta h(\phi, \lambda, t) = \frac{a_e \rho_e}{3 \rho_w} \sum_{l=0}^{120} \sum_{m=0}^{l} \frac{(2l+1)}{(1+k_l)} W_l P_{lm} \sin\phi \left[\Delta C_{lm}(t) \cos m\lambda + \Delta S_{lm}(t) \sin m\lambda\right]$$

[Length unit: cm in water equivalent]

$$W_l = \exp\left[\frac{(lr/a_e)^2}{4\ln(2)}\right]$$

P_{lm} : Normalized Legendre polynomials
ΔC_{lm}, ΔS_{lm} : Normalized time-varying Stokes spherical harmonic Geopotential coeficients

a_e -- Earth mean radius
ρ_e -- Earth mean dinsity
ρ_w -- Density of water
r -- Earth radius
t -- Time
ϕ, λ -- latitude and longitude
k_l -- Love numbers

(From D. Chambers, 2006a)

Method

The GRACE datasets come from the Center for Space Research, University of Texas at Austin. These are the Release 4 Level 3 products, from August 2002 through December 2008, Land and Ocean monthly grids (Chambers, 2006b). The grids were combined to give global land and ocean coverage, then adjusted by a Glacial Isostation Adjustment grid provided by Paulson et al. (2007). Latitude-by-longitude regions were then extracted for each month, and the region sample mean and standard deviation were computed. Least-squares trends were then derived. The region-average time series and trends are shown at the center of the poster.

Prospective

In this poster I have illustrated GRACE water equivalent mass changes, secular trends and variations, on the region of the Himalaya Mountains and Tibet Plateau. Regionally averaged trends indicate both water equivalent volume losses, on the central Himalayas, and increase on the northern Tibet Plateau. The next part of the investigation will validate the secular trends and variations with available in-situ datasets. A recent paper by Ramillien et al. (2008) using GRACE datasets on a global basis suggest that terrestrial water losses, as contributions to global sea-level change, may become comparable in magnitude to those from the ice sheets.

Acknowledgements

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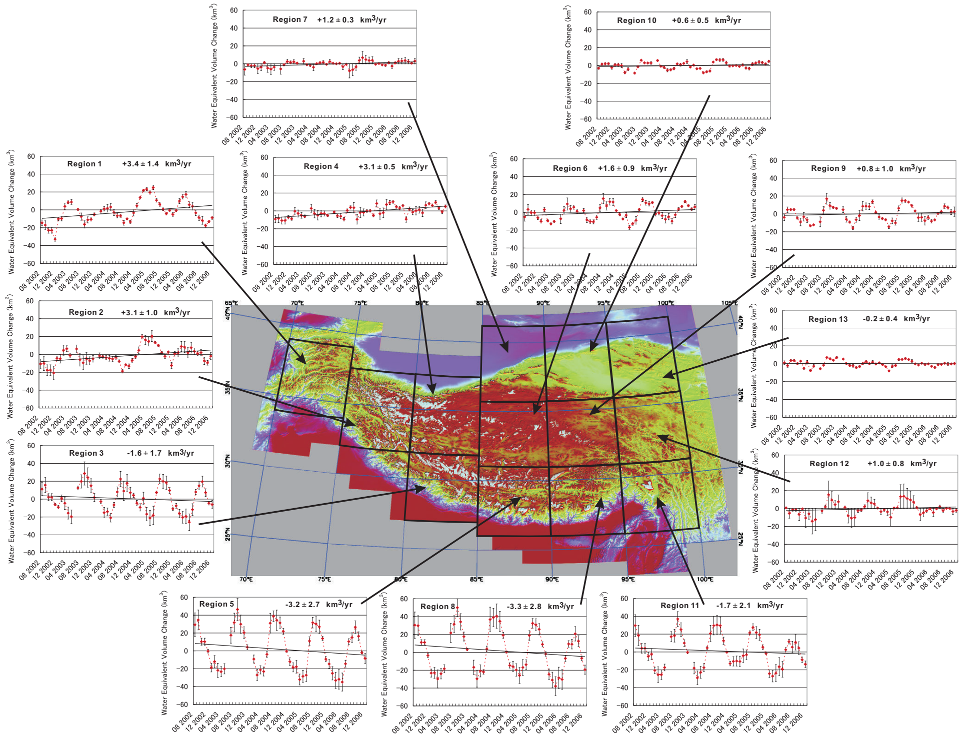
GRACE Sub-Region Secular Trends and Variations from 8-2002 through 12-2006

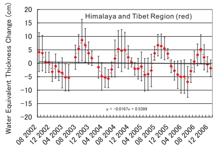


The plots above illustrate GRACE secular trends and variations in 5 by 5 degree regions from August 2002 through December 2006. Seasonal near-periodic variations are well resolved in regions of the central Himalaya Mountains (regions 3, 5, and 8). Resolution of the near-periodic variations decrease in region from south to north on the Tibet Plateau. Least-squares derived secular trends show water equivalent volume losses along the arc of the main Himalaya Mountains, with water equivalent volume increases on the Pamirs and Karakoram (regions 1 and 2) and on the Tibet Plateau (regions 4, 6, 9, 10, and 12). The GRACE volume loss trends in regions 3, 5, 8 and 11, may be following trends of negative glacier mass balance and reduction of snow cover. Are the GRACE volume gain trends in regions 4 and 5 following similar glacier mass balance trends (positive mass balance) and expansion of snow cover? What about changes in groundwater storage? Validation with in-situ data is needed.

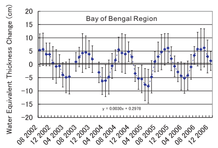
References:

Chambers, D.P. (2006a). Evaluation of new GRACE time-variable gravity data over the ocean. Geophys. Res., Lett., 33 (17), Li7603, doi: 10.1029/GL027296.
Chambers, D.P. (2006b). Observing seasonal steric sea level variations with GRACE and satellite altimetry. J. Geophys. Res., 111, C03010, doi: 10.1029/2005/JC002914.
Paulson, A., S. Zhong, and J. Wahr (2007). Inference of mantle viscosity from GRACE and relative sea level data, *Geophys. J. Int.*, 171: 497-508, doi: 10.1111/j.1365.246X.2007.03556.x.
Ramillien, G., S. Bouhours, A. Lombard, A. Cazenave, F. Flechtner, and R. Schmidt (2008). Land water storage contribution to sea level from GRACE geoid data over 2003 -- 2006. Global and Plan. Change, 60, 381-392, doi: 10.1016/j.gloplach.2007.04.002.

GRACE Region Secular Trends and Variations

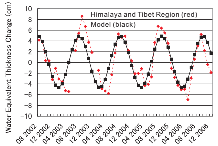


GRACE regionally-averaged water equivalent thickness time-series, and least-squares derived secular trend is shown in the left. The near-periodic Seasonal variation is evident. The trend of water equivalent thickness change is near-zero, suggesting near-balance in water exchanges. The region of GRACE data extraction is from 24.5° N to 35.5° N, and 65.5° E to 104.5° E.



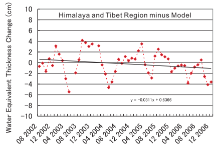
GRACE regionally-averaged water equivalent thickness time-series and least-squares trend are show at left. The similarity of the near-periodic Seasonal variation is significantly positively correlated with the Himalaya-Tibet time series. If spatial contamination is not an issue, then the correlation suggests a strong influence from the southern Asian monsoon pattern. The region of GRACE data extraction is from 0° to 22° N, and 75° E to 100° E.

Least-Squares Fitted Sinusoidal Model



A simple analytical sinusoidal model was least-squares fitted to the GRACE Himalaya-Tibet water equivalent thickness time series. The correlation of the fit was at an R^2 of 0.82.

Residual Trend (GRACE - Model)



The plot at left shows the result of removal of the model seasonal periodic variation series from the GRACE Himalaya-Tibet water equivalent thickness time series. The residual trend may be from combined sources of water mass variation (snow accumulation / precipitation, groundwater storage, soil water storage and glacier ice).

Sub-dividing the Himalaya-Tibet region, as shown in the center of the poster, indicates water equivalent volume loss occurring on the central Himalaya Mountains, which are home to glaciers with large negative mass balances, on average.

Further experiments with the GRACE secular trends and comparisons to in-situ data and models are being conducted.