A study on the water storage changes using GRACE and TRMM data in the Amazon Basin

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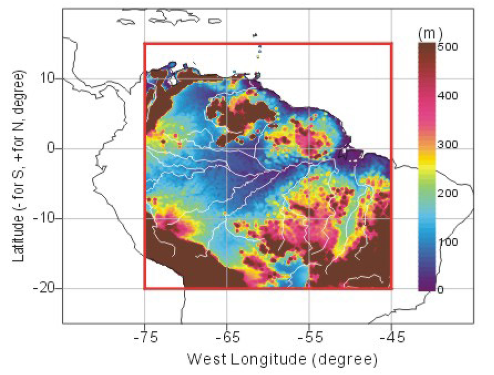
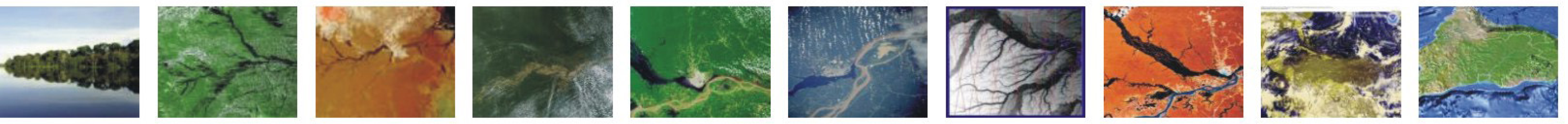
Abstract



The monthly gravity anomalies calculated by the GRACE Mission (NASA/GFZ Gravity Recovery And Climate Experiment) and precipitation data achieved by TRMM (Tropical Rainfall Measuring Mission) are compared and analyzed. The study area is the Amazon Basin which is located within 20S-15N and 285W-315W. The gravity anomalies are calculated at 500km altitude by the monthly spherical harmonic coefficients provided by UTCSR (the University of Texas, Center for Space Research) GRACE L-2 product. The GGM02S (Grace Gravity Model), which is achieved using 363-day data by UTCSR between April 2004 and December 2005, is then subtracted. To remove the tidal effects, low-order zonal coefficients are not included in the calculation whereas harmonic coefficients are used up to the degree 13 at 500km altitude. The study periods are between October 2002 and December 2003, without December 2002 and January 2003 due to the lack of GRACE data. The TRMM satellite was launched by NASA and NASDA (National Space Development Agency, Japan) in November 1997 for the purpose of researching and monitoring tropical precipitation as well as force and energy of atmospheric circulation which determines climate and weather patterns. The average TRMM measured precipitation for the period corresponding to GGM02S (between April 2004 and December 2005) is subtracted. Then, the differentials between the monthly TRMM precipitation and the average precipitation are used to calculate the gravity anomalies by Gauss-Legendre quadrature integration in spherical Earth coordinates at 500km altitude. In calculating the gravity anomalies, the total precipitation is divided by two because half of the precipitation is assumed to be evaporated. In making comparisons between GRACE and TRMM gravity anomalies in the Amazon Basin, good correspondence is shown for February and March which enjoys the most precipitation in a year, but other months display some differences. This is attributed to the influx of precipitation into the river. For calculating the amount of water flowing into the river, inversion by using the differences of GRACE and TRMM anomalies are implemented. From the result of this study, the periodic observation and calculation of global scale water storage mass balances are achieved by using GRACE and TRMM satellites which through forward modeling provide a better understanding of the hydroclimatology of the Amazon River and Basin.

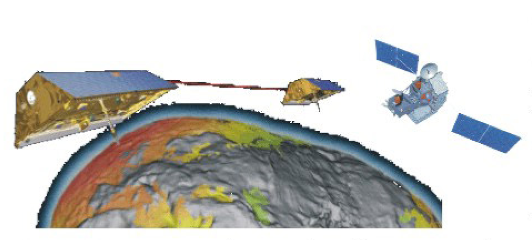


Introduction

The hydrologic fluxes and masses in the global water cycle are not well known but are critical for our understanding of water resources and climate change. Space based technologies are now key for measuring most components in the global water cycle including precipitation, terrestrial surface water, soil moisture, glaciers, and snow. The month to month changes in the sum of these components is measured by the Gravity Recovery And Climate Experiment (GRACE), a space based method of measuring monthly variations in the earth's gravitational field, which are directly related to changes in mass. However, the spatial resolutions of these various technologies are not easily compatible, thus making difficult an analysis of the global water cycle.

A key problem in understanding GRACE anomalies is relating its ~400 km scale sampling to hydrologic processes at ~1 to ~10 km scales. For example, the Amazon River and floodplain range from about 10 to 100 km wide whereas the Amazon Basin GRACE anomalies are at least an order of magnitude larger. Previous approaches for relating these differing scales have typically used water storage changes predicted by global hydrologic models and compared smoothed versions with water equivalents measured by GRACE. Although these approaches permit global scale comparisons, they limit direct comparisons with spaceborne hydrologic measurements of individual basins. We propose a forward modeling approach, based on established geophysical principles, (1) to calculate at any scale the gravity anomalies of hydrologic masses, (2) to upward continue these values to GRACE altitudes, and (3) to subtract the anomalies and invert the results for water volumes. Although it is anticipated that all components of the global water cycle will be remotely measured, only precipitation is now routinely sampled by a dedicated mission, the Tropical Rainfall Measuring Mission (TRMM). In our study, we use TRMM data over the Amazon Basin to demonstrate our method of comparing to differing hydrologic measuring schemes.

GRACE and TRMM Data



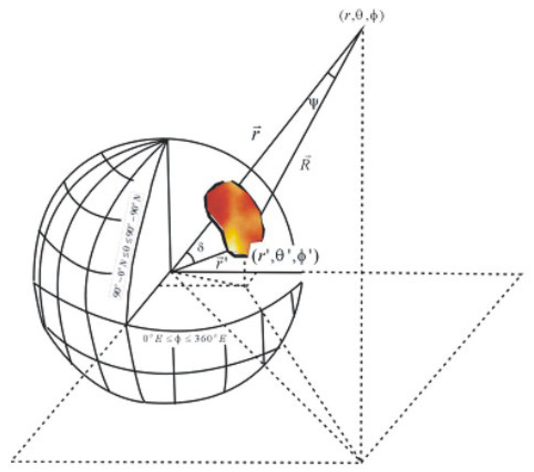
GRACE: The gravity effect were calculated at 500 km altitude using the GRACE L-2 monthly spherical harmonic coefficients provided by UTCSR. Low-order zonal coefficients of the expansion were set to zero to remove tidal effects whereas harmonic coefficients were used up to degree and order 13 to avoid possible errors in high-order coefficients. Average gravity anomalies were removed by subtracting the GGM02S from the GRACE L-2 measurements.

TRMM: was launched to monitor tropical precipitation as well as the force and energy of atmospheric circulation which determines climate and weather patterns. It carries various sensors including microwave imager, infrared scanner, and a precipitation radar, the first instrument that can accurately measure rain over land. The precipitation radar has a horizontal resolution at the ground of about 4 km and a swath width of 220 km. We analyzed TRMM and other satellites precipitation product, TRMM 3B43. We assumed that mass that is equivalent to the amount of the precipitation that was added to the surface under the other assumption that no surface subsidence occurred due to the surface water loading. We obtained the surface topographic undulation from the SRTM. We adapted only 50% of the total accumulated surface rainfall in the gravity effect estimation in order to consider the large amount of evaporation in the Amazon Basin. We first derived the average precipitation for the period corresponding to the GGM02S , which was subtracted from the monthly TRMM 3B43 data for estimating monthly gravity effects.

The Forward and Inverse Methods

FORWARD: To calculate the gravity effect from the water volume estimate by TRMM data, Gaussian Legendre quadrature (GLQ) integration (*von Frese et al.*, 1981a) was applied to water prism in the spherical Earth coordinate. Eight nodes were assigned to each prism based on the GLQ decomposition of *Stroud and Secrest* (1966). These nodes approximate the interval of integration for the entire prism by a summation of densities at the nodes weighted by orthogonal polynomials. In determining the gravitational effects of the water prism, these nodes emulate the mass of the entire prism. They are assigned a geographic location and density contrast within each cell, and the cumulative gravitational effect of all of these nodes in all prisms is determined at spherical observation grid. Hence, the gravity effect is expressed as

$$\Delta g(\phi,\theta,r) \approx \Delta\phi'_l \sum_{l=1}^{nl} \{\Delta\theta'_j \sum_{j=1}^{nj} (\Delta r'_i \sum_{i=1}^{ni} [-G\frac{\partial}{\partial R}(\frac{1}{R})\frac{\partial R}{\partial r}\Delta m]A_i)A_j\}A_l$$

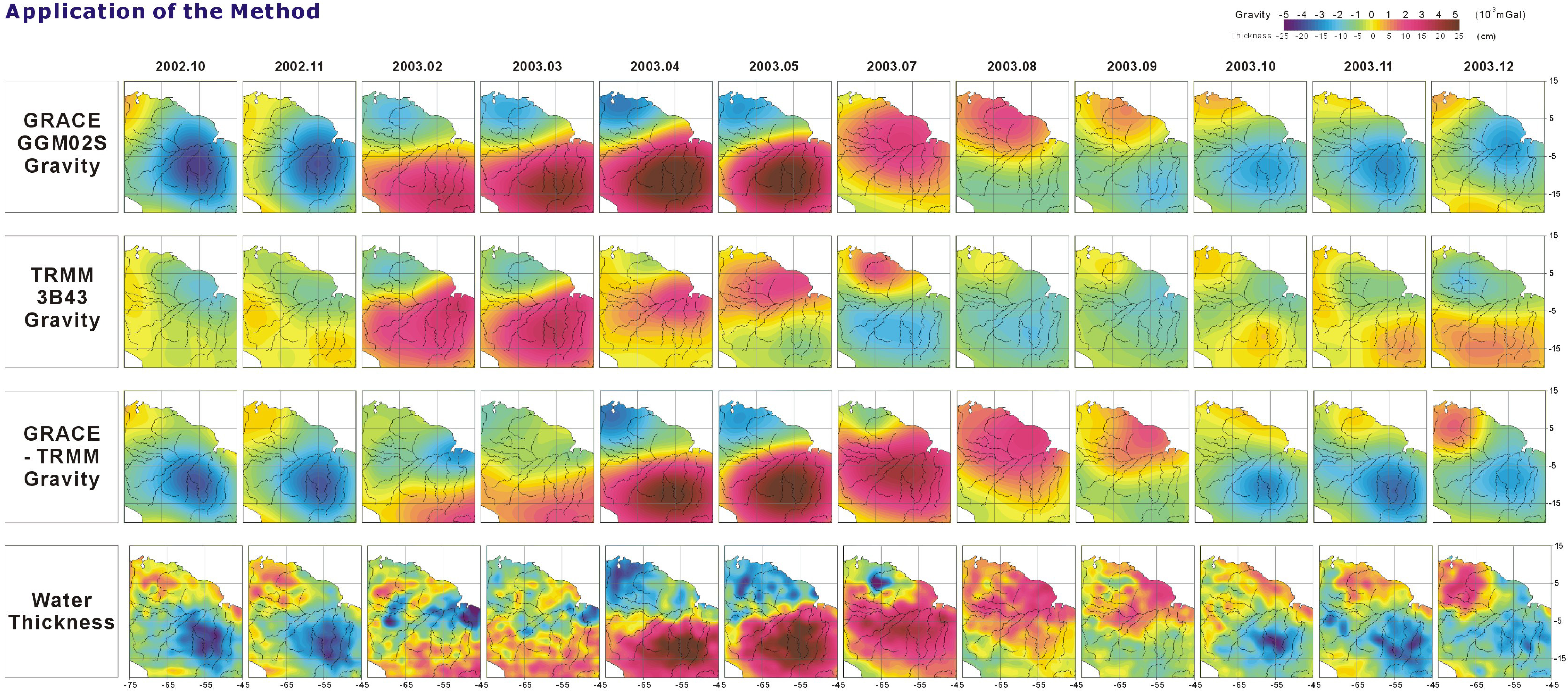


INVERSE: For calculating the amount (i.e. thickness) of water flowing into the river from the differenced gravity, the equivalent point source inversion (*von Frese et al.*, 1981b) and Generalized Minimum Residual Method (*Saad and Schultz*, 1986) were implemented to calculate the point mass. The radial gravity effect is expressed as

$$\Delta g(r) \propto [-G\frac{\partial}{\partial R}(\frac{1}{R})\frac{\partial R}{\partial r}]\cdot\Delta m$$

Once we calculated the density contrast from the inversion, we divided it by surface area and the density, since and , where and are water thickness and density of water (1.0 cgs), respectively, for each 3-D spherical prism. In this study, we set up the 4,200 source grid (30' x 30') and calculated the point masses for each grid.

Application of the Method



Conclusions

We estimated the gravity effects from GRACE and TRMM data at 500 km altitude to estimate the monthly water storage changes over Amazon Basin within the area -20S ~ 15N and -45W ~ -75W. From the GRACE L-2 monthly spherical harmonic coefficients, gravity anomalies between Oct. 2002 and Dec. 2003 were calculated and the Grace Gravity Model (GGM02S) was subtracted to residualize the temporal variations. To estimate the gravity effects from the precipitation, we implemented the Gauss-Legendre quadrature integration with the TRMM 3B43 data. We adapted only 50% of the total precipitation to consider the large amount of evaporation in the Amazon Basin. For calculating the amount of water flowing into the rivers, an inversion was implemented.

Based on our estimation, gravity effects from precipitation reach maximum in February and March. During this period, the temporal gravity variations at satellite altitude are primarily due to the precipitation because GRACE - TRMM gravity effects are relatively small. This concentrated precipitation and its related gravity effect seem to remain until July.

Furthermore, the high precipitation in February and March was immediately reflected to TRMM gravity, while its effect resulted in GRACE gravity peak in April and May. This phase shift can be attributed to the influx of precipitation into the rivers. The major gravity effects by February and March precipitation disappears from August.

References

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