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MOVING WATER TO SOUTH AMERICA AS OBSERVED FROM SPACE

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ABSTRACT

The approximate balance of the mass change rate measured by the Gravity Recovery and Climate Experiment (GRACE) with the moisture influx across the entire coastline less climatological river discharge for South America (SA), in agreement with the conservation principle, bolsters not only the credibility of the spacebased measurements, but supports the characterization of ocean's influence on the annual variation of continental water balance. The moisture transport integrated over the depth of the atmosphere is estimated using measurements by QuikSCAT and Special Sensor Microwave/Imager. The large-scale geographic patterns of precipitation from the Tropical Rain Measuring Mission (TRMM) and the mass change rate were found to follow similar annual changes over South America.

1 INTRODUCTION

The controlling influence of the water cycle on climate changes and the need of interdisciplinary and multisensor approaches to study water cycle have been well expounded [e.g. Chahine, 1992]. Past studies of oceanic influence on the SA water balance were largely demonstrations of the relation between precipitation (P) over the landmass and the sea surface temperature (SST) of surrounding oceans [e.g., Nobre and Shukla, 1996; Fu et al., 2001]. The analyses were based on numerical model simulation, operational products of numerical weather prediction (NWP), in situ measurements of rainfall, and spacebased observations of outgoing longwave radiation. Three sets of spacebased observations have recently become available and may give new perspectives of continental water balance and the oceanic influence. These data are described in Section 2.

While sufficient coverage and resolution can be best achieved from the vantage point of space, the validation of spacebased measurements has always been difficult because there is a lack of appropriate standards. Useful scientific application may be the best validation of their usefulness. The possible closure of continental water balance, as revealed by the three sets of data, is discussed in Section 3.

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2 DATA

GRACE is a geodesy mission to measure Earth's gravity field, but the variations of the gravity field are largely the result of the movement of water [Tapley et al., 2004; Chambers et al., 2004]. The first public release of 21 months of GRACE data was used. The mass of the atmosphere is removed during data processing using atmospheric NWP pressure field from European Center for Medium Weather Forecast. The monthly mass change rates, dM/dt, for two annual cycles, from August 2002 to July 2004, were computed for this study. Three months of missing data, December 2002, January 2003, and June 2003, are obtained through linear interpolation.

While SST influences large scale atmospheric circulation and, consequently, continental convection and rainfall, the most direct link between ocean and continental water balance is through moisture transport integrated over the depth of the atmosphere (Θ). The method of deriving Θ from ocean surface wind vector (u_s) measured by QuikSCAT and precipitable water (W) measured by Special Sensor Microwave/Imager (SSM/I) is based on Liu and Tang [2005]. They viewed Θ as the column of W advected by an equivalent velocity (u_e), which is the depth-averaged wind velocity weighted by humidity, and it was related to u_s through a statistical relation. Θ normal to the coastline was computed and integrated around the SA continent as $\int\Theta$, for the same period as GRACE.

Spacebased infrared and microwave observations have been used to estimate P in the past decades, and TRMM has provided important calibration since 1998. TRMM data product 3B42 [Huffman et al., 1995], a merged infrared and microwave spacebased data set, covering from 50°N to 50°S, with 3-hourly, 0.25° x 0.25° resolutions was used.

There is no spacebased measurement of river discharge (R) from the continent to the ocean, and considerable uncertainties were found in climatology derived from in situ measurements. There is large flow variation among SA rivers [e.g. Garcia and Vargas, 1998]. River gauges are sparse and not situated at the mouth of the river. The climatological R compiled by Dai and Trenberth [2002], is shown in Figure 1, as a reference in this study.

3 CONTINENTAL BALANCE

Figure 1 shows that the mass change, M, for the whole continent, peaks in autumn (April-May). The mass change rate integrated over the SA continent should satisfy

$$\frac{dM}{dt} = \int \Theta - R \text{, and } \int \Theta = P - E \qquad (1),$$

where E is the evaporation/transpiration. M is in approximate quadrature with dM/dt, which peaks in summer (January-March). ∫Θ (positive going onshore) has high values during summer, similar to dM/dt. When R is subtracted out from ∫Θ, the result is approximately in phase with dM/dt, but with slightly higher value. With dM/dt subtracted out from ∫Θ, the value, which should represent R, is approximately in phase but slightly higher than one of the climatologies derived from in situ measurements.

Over large geographical regions, where the variations of E and surface/ground water outflow are small, P should dominate the annual variation of dM/dt (see Eq. 1). The large-scale geographic patterns of P and dM/dt were found to follow similar annual changes over the northern half of SA (animation of the variations can be viewed at http://airsea.jpl.nasa.gov/movie/SA-TRMM-GRACE.qt). In austral spring (October/November), positive values of dM/dt and high values of P occur over the western end of Amazon Basin, followed by the intensification of positive/high pattern in the south Amazon Basin and eastern Brazilian Highland south of the equator. This positive/high pattern has a maximum in austral summer (January and February), when it reaches the equator at the mouth of the Amazon. The positive/high center moves westward and northward to the Caribbean coast, where it peaks in June (boreal summer). Both parameters show this apparent counterclockwise annual march. The landmass is narrower in the south and there is less agreement between the geographic patterns of dM/dt and P.

4 DISCUSSION

The new data from GRACE provide the constraint and reduce the uncertainties in the estimation of other hydrologic parameters. The small bias between dM/dt and ∫Θ-R may be attributed to errors in dM/dt or ∫Θ, but may also be caused by errors in R or its interannual variability which is not represented. The agreement in the phase of the annual cycle, and the small bias,

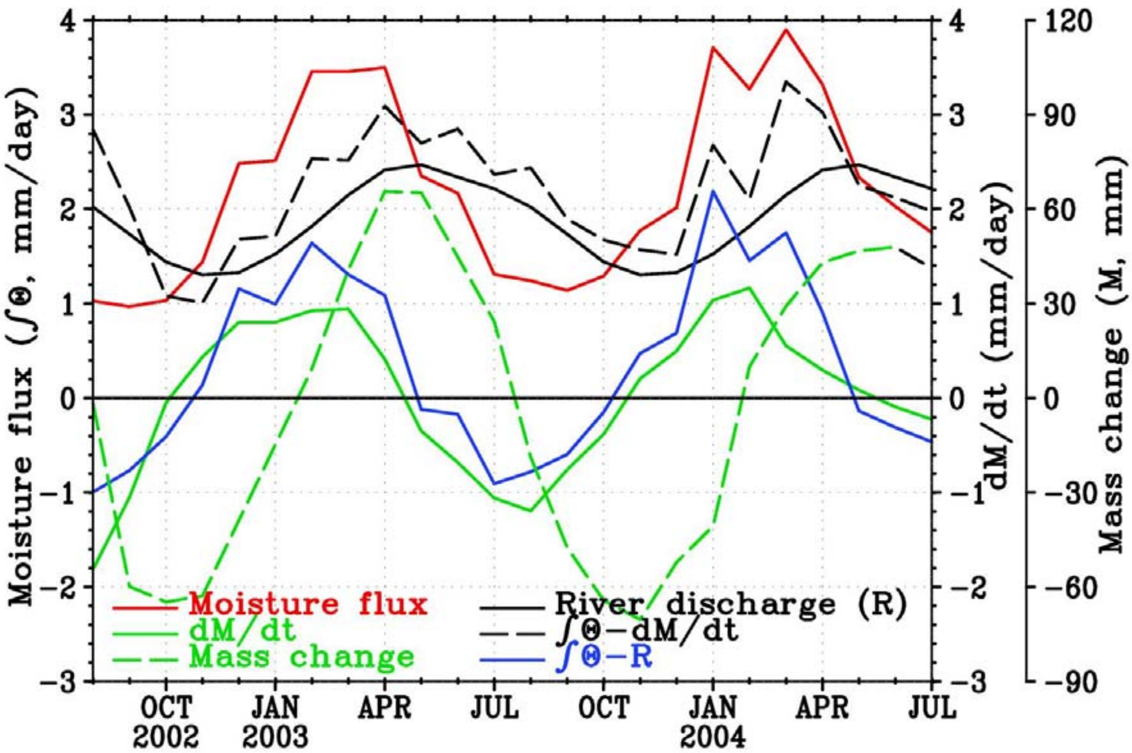

Fig. 1 Annual variation of hydrologic parameters over South America: mass change measured by GRACE M (dashed green line), mass change rate dM/dt (solid green line), climatological river discharge R (solid black line), total moisture transport across coastline into the continent ∫Θ (red line), ∫Θ-R (blue line), and ∫Θ-dM/dt (dashed black line).

between dM/dt and ∫Θ-R, can be viewed as support on the credibility of the spacebased observation of ∫Θ and dM/dt.

The in-phase relation between the annual variation of P and dM/dt, for the whole continent and for each river basin, suggests the dominance of P among the hydrologic parameters in their annual variations. Zeng [1999] derived P-E, over the Amazon basin, by equating it to the divergence of Θ computed from atmospheric model outputs, and showed that E has small annual variation. Using climatological river discharge, they attempted to characterize the change of water storage, which is equivalent to dM/dt in Equation (1). Recently, Syed [2005] used the same method to compute P-E over the same river basin, and by introducing GRACE data, attempted to estimate water discharge as residue. Our results are consistent with their analyses.

The prevalent postulate on rainfall variation is that the Bolivian High causes the onset of South American monsoon and the consequent transport of moisture from the Amazon to the La Plata Basin by the South American Low Level Jet (SALLJ) through Gran Chaco [e.g., Horel et al., 1989; Zhou and Lau, 1997]. The year-round positive ∫Θ for the whole continent indicates clearly that water needs to be transported from the ocean to make up the excess of P over E in SA. Ocean's moisture influx is part of the monsoon system, and strong relations are observed with local rainfall in the Andes, the Amazon Basin and La Plata Basin. Moisture influx may destabilize the atmospheric boundary layer and cause local convective rainfall [Fu at al., 1999] or large-scale convection may draw moisture influx from the ocean.

Although clear demarcation between the Orinoco and Amazon watersheds across the equator was shown in the GRACE data, in agreement with TRMM data, the spatial resolution of GRACE data is too coarse to resolve the water balance of the Andes Cordillera. Reprocessing of GRACE data and a follow-on mission are needed to offer higher resolution and better accuracy. TRMM was designed mainly to measure over tropical and subtropical oceans, and the planned Global Precipitation Mission will improve measurements of light rain and snow over land and high latitudes. Retrieval of high-resolution coastal wind from QuikSCAT [Tang et al., 2004] is being implemented. The European Space Agency's Soil Moisture and Salinity Sensor and National Aeronautics and Space Administration's (NASA) Aquarius promise unprecedented measurements of soil moisture and salinity. Spacebased studies of hydrologic balance lie very much in the near future; this is but an early demonstration.

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