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2005 drought event in the Amazon River basin as measured by GRACE and estimated by climate models

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[1] Satellite gravity measurements from the Gravity Recovery and Climate Experiment (GRACE) provide new quantitative measures of the 2005 extreme drought event in the Amazon river basin, regarded as the worst in over a century. GRACE measures a significant decrease in terrestrial water storage (TWS) in the central Amazon basin in the summer of 2005, relative to the average of the 5 other summer periods in the GRACE era. In contrast, data-assimilating climate and land surface models significantly underestimate the drought intensity. GRACE measurements are consistent with accumulated precipitation data from satellite remote sensing and are also supported by in situ water-level data from river gauge stations. This study demonstrates the unique potential of satellite gravity measurements in monitoring large-scale severe drought and flooding events and in evaluating advanced climate and land surface models.

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1. Introduction

[2] In the summer of 2005, the Amazon basin experienced an extreme drought. Many areas, especially in the west and south, suffered the worst drought in over a century, leading to official declarations of ‘‘public calamity’’, forest fires, crop losses, and economic havoc [*Rohter*, 2005]. The event appears connected both to the 2002–03 El Niño and to abnormal warming of the northern tropical Atlantic, which was up to two degrees warmer than average [*Zeng et al.*, 2008a]. This paper compares measures of this event taken from satellite gravity observations and from data-assimilating hydrologic models.

[3] Understanding and quantification of drought occurrence, extent, and intensity is limited by conventional data resources. Numerical climate models are valuable in analyzing and diagnosing climate variability, but quantifying and simulating abnormal events such as droughts remains a major modeling challenge. Prediction is an even greater challenge. Conventional observations, especially in situ meteorological and hydrological samples, are limited in both space and time. Furthermore, model representations of dynamical connections between boundary conditions and extreme climate events tend to be poor.

[4] Terrestrial water storage (TWS) change, a major component of the global water cycle, includes changes in water stored in soil, as snow over land, and in ground water reservoirs. TWS change reflects accumulated precipitation, evapotranspiration, and surface and subsurface runoff within a given area or basin. TWS change provides a good measure of abnormal climate conditions such as drought, and is valuable for agriculture and other water uses. However, TWS change is difficult to quantify because of limited fundamental observations (ground water, soil moisture, precipitation, evapotranspiration, snow water equivalent, and others) at basin or smaller scales. Numerical model estimates are useful but exhibit limited accuracy [e.g., *Matsuyama et al.*, 1995]. Remote sensing data (such as TRMM satellite precipitation data) and in situ measurements (such as river level and discharge from gauge stations) are valuable assets in estimating TWS changes [e.g., *Crowley et al.*, 2007]. Unfortunately, in situ measurements alone are not sufficient, both because they tend to be point measurements, and because other hydrological parameters (e.g., evapotranspiration) must be estimated separately to determine TWS change.

[5] The Gravity Recovery and Climate Experiment (GRACE) is the first dedicated satellite gravity mission, jointly sponsored by NASA and the German Aerospace Center (DLR). Launched in March 2002, GRACE has been measuring Earth gravity change with unprecedented accuracy [*Tapley et al.*, 2004] for over 6 years. Early GRACE time-variable gravity observations showed an accuracy of ~1.5 cm of equivalent water thickness change at about 1000-km spatial scale [*Wahr et al.*, 2004]. Various studies applied early GRACE results to a variety of problems including TWS change [e.g., *Wahr et al.*, 2004], polar ice sheets mass balance [e.g., *Velicogna and Wahr*, 2006; *Chen et al.*, 2006], and oceanic mass change [e.g., *Chambers et al.*, 2004; *Lombard et al.*, 2007].

[6] In early 2007, reprocessed GRACE release-04 (RL04) time-variable gravity fields with improved background geophysical models and data processing techniques were released [*Bettadpur*, 2007a]. RL04 shows significantly

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