Spaceborne Gravity Sensors for Continental Hydrology and Geodynamic Studies

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The complicated dynamic processes of the Earth system are linked with phenomena of global climate change and processes potentially associated with natural hazards. The NASA/GFZ Gravity Recovery and Climate Experiment (GRACE) mission is designed to measure small mass changes over a large spatial scale. The scientific objectives of GRACE include the mapping and understanding of climate-change signals associated with mass-variations within solid Earth-atmosphere-ocean-cryosphere-hydrosphere system with unprecedented accuracy and resolution in the form of time-varying gravity field [e.g., Wahr et al., 1998]. GRACE was launched in March 2002 for a mission span of 5 years or longer and have recently completed calibration and validation. The satellite mission is consisted of two identical co-orbiting spacecrafts with a separation of 220±50 km at a mean initial orbital altitude of 500 km with a circular orbit and an inclination of 89^0 for near-global coverage [Thomas, 1999; GRACE Science Mission Requirement Document, 2000; Bettadpur and Watkins, 2000]. The dual-one way K- (24.5 GHz) and Ka- (32.7 GHz) band microwave inter-satellite ranging system with a precision of 0.1 m/sec (in range-rate) [Kim et al., 2001], the Ultra-Stable Oscillator (USO) accurate to within 70 picosecs of time-tagging, the 3-axis super-STAR accelerometers with a precision of 4x10-12 m/s2 [Davis et al., 1999; Perret et al., 2001] and the dual-frequency 24-channel

Blackjack GPS receivers comprise the instrument suite for GRACE's mapping of the global gravity field with unprecedented accuracy and resolution.

European Space Agency's Gravity field and steady state Ocean Circulation Explorer (GOCE) space gravity gradiometer (SGG) mission, scheduled to launch in 2006, is anticipated to determine the mean gravity field of the Earth with an unprecedented geoid accuracy of several cm rms with wavelength of 130 km or longer. The mission duration is about 20 months. In a sun-synchronous near-polar orbit and at an altitude of 250 km, the GOCE onboard space gravity gradiometer (SGG) will measure primarily 4 components (3 diagonals and 1 off-diagonal) of the Earth gravity tensor (e.g., ESA, 1999; Schrama, 2003). The onboard GPS receiver will be used to determine the precise orbit, the long wavelength component of the gravity field, and to register the gravity tensor observables within a few cm of accuracy. Although SSG's noise characteristics prohibit the precise determination of lower degree coefficients, it is expected to have significant improvement in higher degree geopotential coefficients (i.e., N_{max}=300 or higher). GOCE senses not only static gravitational forces but also tides and other temporal signals resulting from mass variations of various Earth processes. These signals manifest as gravity field changes and include effects such as atmospheric loading on the Earth, ground water movement, oceanic mass variations, and ice mass fluxes.

The measurements of terrestrial water storage (soil moisture, snow, lake, ground water, river, and vegetation) variation with regional scale (several hundreds to thousands km) are difficult to acquire using the ground-based sensors (Alsdorf et al., 2003). Space-borne remote sensing technique (i.e., GRACE) offers the promise of allowing one to monitor hydrological change at regional scales with homogeneous accuracy as well as spatial and temporal resolutions. One of the important scientific objectives from the GRACE mission includes monitoring of the regional continental water mass variation (Wahr et al., 1998). Previous investigations (Wahr et al., 1998; Rodell and Famiglietti, 1999; Rodell and Famiglietti, 2001) developed methods to extract the hydrological signals and presented promising results using simulations via analysis of GRACE observed Earth's gravity changes. The methods primarily use the time-series of Stokes' coefficients, which are one of the so-called Level-2 science data products of the GRACE mission (Tapley, et al., 2004; Wahr et al., 2004). For the temporal variation of the Earth gravity fields, relatively well-known geophysical effects such as tides, atmospheric mass redistribution, and barotropic ocean response due to atmospheric forcing are forward modeled in the analysis of the GRACE observations to isolate the observed climate-sensitive signals such as hydrology, ice sheet mass balance, and ocean mass change.

Tectonically driven spatio-temporal signals manifest from complex geophysical processes. These processes include convergent plate boundaries, earthquake deformation cycle, mantle convection, intra-plate deformations and Glacial Isostatic Adjustment (GIA). At present, these processes generate small but measurable signals in the form of surface deformations, which at present can only be detected over land by either point measurements using GPS, or on small spatial scales (<100 km) using InSAR. These "slow deformation" signals have spatial scales longer than hundreds of km to continental and planetary scales, and temporal scales of a year to decades, and millennia. The Earth's gravity field and its spatio-temporal variations, providing insight on the integrated mass redistributions within the Earth's systems, represent a unique fundamental measurable quantity to directly study mechanisms which drive these complex processes with many degrees of freedom. Spaceborne gravity measurements, including GRACE and GOCE, have potential to detect some of these slow deformations including tectonically driven processes.

This paper presents primarily GRACE measurement concepts and simulation studies and first results using the GRACE data to study continental hydrology and alternate methodology to enhance localized regional hydrological signals. Simulated studies to use GRACE and GOCE for potential detection of GIA and plate convergence signals are also presented.