Name: Jay Famiglietti
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Presentation Type: Oral Presentation

Title: Terrestrial and Global Hydrology from GRACE: Opportunities and Challenges

Abstract:
While the GRACE time-variable gravity mission has already made several important contributions to terrestrial and global hydrology, many key issues remain unresolved. In this presentation, several of these will be discussed, with implications for the research needs as well as the design of future gravity missions. Examples for discussion include acceleration of the hydrological cycle, water mass changes in Earth's land, ocean and ice reservoirs, land contributions to sea level rise, and future stresses on surface and groundwater availability. The need for higher space-time resolution information, and for user-friendly data products, will be highlighted, in order to increase the usage of satellite gravity information by the mainstream hydrologic community.

Name: Huilin Gao, Qiuhong Tang, Fengge Su, Dennis P. Lettenmaier
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Presentation Type: Oral Presentation

Title: Applications of GRACE data in understanding the water budget over U.S. river basins

Abstract:
The water budget terms from a suite of remote sensing products are compared with those estimates using a hydrological modeling framework over the 13 U.S. hydrological regions and aggregates thereof for the period 2003 to 2006. The remote sensing data include three precipitation products (TMPA-RT, CMORPH, and PERSIANN), three MODIS based evapotranspiration (ET) estimates (by Princeton University, University of Montana, and University of Washington), and three GRACE terrestrial water storage (TWS) products (by CSR, GFZ, and JPL). To assess the feasibility of monitoring the terrestrial water balance at large spatial scales from space, inferred runoff (as a residual of remote sensing estimates of precipitation, ET, and TWS) are evaluated in comparison with observations at major river outlets. Our results suggest that the largest source of error in closing the water budget, when all terms are based on remote sensing, is precipitation. Over most of the hydrologic regions, GRACE TWS are reasonably consistent with model simulations. However, the amplitudes of the seasonal cycle in GRACE TWS over two western U.S. hydrologic regions (the Pacific Northwest and California) are much less than those from model results for all GRACE TWS products. To further investigate this difference, a satellite/surface observation-based estimation of terrestrial water storage changes (TWSC) in the Klamath and Sacramento River basins is with GRACE and modeling results. The observation-based TWSC is calculated from ground-based precipitation, satellite-based ET estimates, and observed river runoff. Comparison of the observation-based and GRACE TWSC shows that the amplitudes of GRACE TWSC is substantially underestimated by GRACE in these cases as well. In these river basins, which are highly managed, our analysis nonetheless shows that seasonal storage changes in water-management reservoirs account for about 12% of the seasonal amplitude of TWSC on average, but can be up to 30% at the sub-basin scale.

Name: Jianliang Huang
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Presentation Type: Oral Presentation

Title: Detecting groundwater storage change within the Great Lakes Water Basin using GRACE

Abstract:
Detecting groundwater storage change within the Great Lakes Water Basin using GRACE

J. Huang (1), J. Halpenny (1), W. van der Wal(2), C. Klatt(1)

(1) Geodetic Survey Division, CCRS, Natural Resources Canada, Ottawa, Ontario, Canada
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The Great Lakes Water Basin (GLB) comprises one of the most important hydrologic systems in the world. While the change of lake levels is well-gauged, dynamic flows and states of the groundwater storage within the GLB and its interaction with the lakes are inadequately understood. In this study, the groundwater storage change within the GLB is estimated using the monthly GRACE gravity models, as well as soil moisture models from GLDAS and water level records of the lakes for the period of 2002-2008. Results show that the Total Water mass Storage (TWS) change estimated from GRACE is comparable with the soil moisture content change in terms of both phase and amplitude. The 7-year time series of water storage changes obtained for soil moisture (GLDAS) and lake levels (water gauges), along with the TWS change from GRACE have respective RMS of 44, 43 and 43 mm in Water Thickness Equivalent (WTE). From these independent measures, estimates of seasonal groundwater storage changes varying from -56 mm to 61 mm with a RMS of 23 mm in WTE were obtained. Over this period,, the storage of both ground and lake water declined at a rate of 7.1+/-2.7 mm/yr and 3.1+/-1.9 mm/yr. Ground and lake water storage change are shown to respond to TWS change with phase delays of about 6 and 3 months. This study also reveals that the mass increase from Glacial Isostatic Adjustment and TWS loss are of comparable magnitude within the GLB.

Name: Hua Su
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Presentation Type: Poster Presentation

Title: Multi-sensor Snow Data Assimilation at Continental Scale: the Value of GRACE TWS Information

Abstract:
This investigation establishes a multi-sensor snow data assimilation system over North America (from Jan 2002 to Jun 2007), toward the goal of better estimation of snowpack (in particular, snow water equivalent (SWE) and snow depth) via incorporating both GRACE terrestrial water storage (TWS) and MODIS SCF information into the Community Land Model (CLM). The different properties associated with the SCF and TWS observations have been accommodated through a unified approach using the ensemble Kalman filter (EnKF) and smoother (EnKS). Results show that this multi-sensor approach can provide significant improvements over MODIS only approach, for example, in Saint Lawrence, Fraser, Mackenzie, Churchill & Nelson, and Yukon river basins, and the south-west rim of Hudson Bay. In middle latitude, e.g., North Central and Missouri river basins, the inclusion of GRACE information preserves the advantages (compared with Open Loop) shown in the MODIS only run. However, in some high latitude areas and given months, the open loop run can have a comparable or even better performance, implying considerable room for refinements on the multi-sensor algorithm. In addition, ensemble based metrics are calculated and interpreted at domain wide. They indicate the potential importance of accurate representation of SWE auto-covariance in assimilating TWS observations, and the regional and/or seasonal dependence of the GRACE capability in reducing ensemble variance. These analyses contribute to clarifying the effects of GRACE's special features (e.g., a vertical integral of different land water changes, coarse spatial and temporal resolution) in the snow data assimilation system.

Name: Jean-Paul Boy
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Presentation Type: Oral Presentation

Title:
New results from the GHYRAF (Gravity and Hydrology in Africa) experiment in relation to the use of ground and space geodesy to constrain water storage changes

Abstract:

Hydrological time-varying processes (soil moisture, aquifers) redistribute underground water and hence lead to alter the gravity and shape of the Earth at various length scales (from very local catchment size to continental size) because of Newtonian attraction and elastic loading.

A new experiment called GHYRAF (Gravity and Hydrology in Africa) was set up in 2008 in West Africa. The first goal is to better characterize the annual cycle of water storage in West Africa and to assess the predictions of global hydrology models for this region. A by-product of this project is also to validate satellite gravity observations (GRACE) with ground gravity and GPS observations. This multidisciplinary project (space and ground gravimetry, geodesy, subsurface geophysics, hydrology) is conducted on three distinct regions: the Sahara (Tamanrasset, South of Algeria) with almost no rainfall (20 mm), the Sahelian zone (Niamey and Diffa in Niger) with moderate and highly variable rainfall (500 mm) and, finally, the equatorial monsoon region (Djougou, Benin Republic) with heavy rainfall (1200 mm). Since gravity is sensitive to various length scales involved in hydrology, we will use satellite gravimetric observations from GRACE for the large scales and rely on dense in-situ measurements (rain gauges, piezometers, soil moisture probes) and subsurface geophysics surveys (MRS) to model the local gravity effects we measure with absolute and relative spring meters at ground.

The first yearly cycle of the project is now completed and we will report on the first results. On the semi-arid site near Niamey in Southwest Niger, we found a nice agreement between the measured surface gravity changes and the modeled ones using local piezometry observations during the 2008 monsoon. Similarly, the water storage estimates from the hydrological devices or measured by absolute gravimetry on the Djougou site (culture-fallow hillslope) are compatible. The good agreement on these two sites shows that gravimetry appears to be a promising tool to monitor the water storage variations.

The GPS data available in West Africa mainly originating from the AMMA (African Monsoon Multidisciplinary Analyses) program have been analyzed and the vertical motion of the sites clearly exhibits the annual load signature due to continental hydrology.

We will finally present some comparisons between satellite-derived gravity data (GRACE), hydrology models and hydro-meteorological data for the Niger and Chad basins.

Name: Shin-Chan Han
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Presentation Type: Oral Presentation

Title: Analysis of large-scale water storage observations over the Amazon and its vicinity from GRACE

Abstract:
We present the ongoing analysis of GRACE observations and GLDAS land surface model (LSM) simulations over the Amazon and its surrounding areas. The apparent disagreement found between the observations and various GLDAS/LSM storage simulations are discussed. A simple yet effective runoff routing scheme based on a continuity equation is implemented in a spectral domain to obtain total land water storage from the LSM outputs such as soil storage and runoff. We present quite distinct spatial patterns in soil moisture and river storage distributions. The soil moisture storage tends to disperse with smaller magnitude while the river storage is more intense only along river and channel. Such characteristics are important to interpret large scale GRACE observations of total land water storage, particularly to assess the LSM runoff outputs. Various effective velocities for runoff routing are tested to delineate the best possible spatial and temporal patterns of the lateral flow based on the GRACE observations. We assess each of water cycle parameters from various LSMs including NOAH, CLM, VIC, and Mosaic based on GRACE total storage observations and give possible physical interpretation.

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Presentation Type: Oral Presentation

Title: Incorporating GRACE observations into hydrological modeling using Bayesian model averaging to investigate fluvial transport in Amazon

Abstract:
Fluvial transport through river networks based on topographic gradient is investigated in Amazon basin. Ensemble hydrological simulations are performed to estimate runoff and each water storage component, and model generated runoff is routed with 18 different effective velocities ranging from 0.01m/s to 10m/s. To estimate contributions of different transport velocity components, Monthly variations of total terrestrial water storage from 2002 to 2007 observed by GRACE are incorporated into the river routing model by Bayesian modeling averaging (BMA). It is found that 0.3m/s and 0.4m/s are dominant elements of horizontal transport in both observed discharge and GRACE incorporated simulations. Obtained BMA weights are used to calculate optimized ensemble mean of river discharge. It is compared to gauged discharge for the span from 1979 to 1995 and marks better statistics than any individual ensemble member. GRACE is able to provide useful information of local flow dynamics for discharge estimation in ungauged basins.

Name: W. Timothy Liu
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Presentation Type: Oral Presentation

Title: Applications of GRACE data with atmospheric moisture advection

Abstract:
We have derived and validated moisture advection integrated over the depth of the atmosphere, the divergence of which is the fresh water flux at the surface for time scales longer than a few days. We will demonstrate a few scientific applications in synergism with GRACE data. We have shown that the total mass change of the continent of South America measured by GRACE agrees, in magnitude and annual phase, with moisture transport into the continent less the river discharge integrated over the entire coastline. We have further demonstrated that the mass change of the ocean balances the surface water flux and the river discharge from land and ice. We will show that the annual global sea level change derived from GRACE data agree with the water input from continental discharge and from atmosphere, both in magnitude and in phase but with bigger discrepancy during an ENSO event. GRACE data also contribute to the time dependent component in estimating the Atlantic Ocean meridional water and heat transports from ocean surface fluxes.

Name: Jianli Chen
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Presentation Type: Oral Presentation

Title: Long-Term Water Storage Variability and Climate Change from GRACE

Abstract:
Satellite gravity measurements from the Gravity Recovery and Climate Experiment (GRACE) provide accurate quantitative measures of terrestrial water storage (TWS) change associated with extreme climate events, such as major droughts and floods. In this presentation, we will examine global long-term TWS variability (with periods of a few years and longer) using over 7 years of GRACE time-variable gravity measurements. GRACE data has clearly captured some large-scale major climate change signatures, e.g., the prolonged drought in the La Plata basin (in South America) in recent years, the severe drought in the Amazon basin in 2005, and the significantly wetter seasons in Orinoco and eastern part of Amazon in recent years. Through comparisons of GRACE measurements with climate and land surface models estimates and available in situ observations, we can better understand these climate change events and evaluate the limitations of advanced climate and land surface models in resembling large-scale severe climate events.

Name: Matt Rodell
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Presentation Type: Oral Presentation

Title: The Potential Value of GRACE for Water Resources Applications

Abstract:
Water resources assessments, operational weather and climate predictions, and river flow forecasts, among other applications of societal importance, would benefit from the addition of new or improved hydrological observations. GRACE has proven that terrestrial water storage variations can be derived from a satellite gravimetry mission with enough precision to contribute to water cycle science, and because these observations are independent of the measurements and analyses that normally feed into decision support tools and models, they have the potential to improve water resources management and predictions. This presentation will describe ongoing projects which are attempting to apply GRACE observations for water resources assessments, the challenges faced, and implications for improving GRACE data products and planning future satellite gravity missions.

Name: Rasmus Houborg
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Presentation Type: Oral Presentation

Title:
Towards integrating GRACE terrestrial water storage data into the U.S. and North American Drought Monitors

Abstract:
NASA's Gravity Recovery and Climate Experiment (GRACE) satellites measure time variations of the Earth's gravity field enabling reliable detection of spatio-temporal variations in total terrestrial water storage (TWS), including groundwater. The U.S. and North American Drought Monitors (USDM and NADM) are two of the premier drought monitoring products available to decision-makers for assessing and minimizing drought impacts, but they rely heavily on precipitation indices and do not currently incorporate systematic observations of deep soil moisture and groundwater storage conditions. Thus GRACE has great potential to improve the Drought Monitors by filling this observational gap. This presentation will provide an update on our progress towards integrating GRACE TWS data into the USDM and NADM. Horizontal, vertical and temporal disaggregation of the coarse-resolution GRACE TWS data has been accomplished by assimilating GRACE TWS anomalies into the Catchment Land Surface Mode! l using an ensemble Kalman smoother. The Drought Monitors combine several short-term and long-term drought indices and indicators expressed in percentiles as a reference to their historical frequency of occurrence for the location and time of year in question. To be consistent, we are in the process of generating a climatology of estimated soil moisture and ground water based on a 60-year Catchment model simulation, which will be used to convert seven years of GRACE assimilated fields into soil moisture and groundwater percentiles. The potential benefit of incorporating the GRACE-based drought indicators into the objective blends that constitute Drought Monitor baselines was analyzed by comparing the soil moisture and ground water percentile maps against the current suite of short-term and long-term objective indicators and by correlating detectable differences at the regional and local scale to the final U.S. Drought Monitor product, which incorporates subjective input from a network of local climate and water experts. Furthermore, we evaluated Catchment model output against independent datasets including soil moisture observations from Aqua/AMSR-E and groundwater level observations from the U.S. Geological Survey's Groundwater Climate Response Network, in order to further assess the value of incorporating GRACE assimilated fields into the Drought Monitor process.

Name: Peter L. Bender
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Presentation Type: Oral Presentation

Title: Speculations on the Atmosphere-Hydrology Separation Problem at Short Wavelengths

Abstract:

For a possible future GRACE-type mission after GRACE-2 is launched, but with a considerable overlap in time, a moderate inclination orbit would have substantial benefits for determining mass changes over much of the globe. Reducing the uncertainties in the short wavelength geopotential results would be of most importance in improving the spatial resolution. It appears that, for quite short wavelengths and over continents, the main limitation for hydrology will be in separating the desired effects from uncertainties in changes in the atmospheric mass distribution at the same wavelengths.

An important issue is how much the atmospheric mass distribution uncertainties can be reduced in the future for favorable regions such as North America and Europe and for wavelengths less than about 1000 km. These uncertainties seem likely to represent the main noise source. Another question is the extent to which expected differences in the spatial and time correlations in the hydrological mass changes are different enough from those for the atmospheric mass variations so that some additional separation of effects can be achieved in the data assimilation process.

Name: L. Longuevergne, B.R. Scanlon, C.R. Wilson
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Presentation Type: Oral Presentation

Title: Bias and Leakage corrections for GRACE Level-3 data users

Abstract:
The Gravity Recovery and Climate Experiment (GRACE) satellites provide an opportunity to monitor regional water storage variations for hydrological studies. GRACE information may be provided as gridded data (level-3 data, based on spherical harmonics processing), similar to most remote sensing information. However, when focusing on a basin, limited GRACE resolution and applied spherical harmonic processing induce bias and leakage effects, leading to underestimation of stored water variations in most cases. While bias may be calculated based on knowledge of basin shape and applied processing only, leakage correction requires a-priori water storage information outside the basin area (for example from land surface schemes included in GLDAS). In this study, a total of 180 hydrological basins were delineated to cover all continents. The basins are based on the TRIP (Total Runoff Integrating Pathways) dataset and have been aggregated where necessary to fit GRACE spatial resolution requirements, following FAO basins groups when possible. Then, bias and leakage were calculated for each basin based on regular GRACE processing (as applied to Level-3 data) for both CSR RL4 monthly solutions and GRGS RL2 10-day solutions. The bias and leakage correction factors will be provided to hydrologists interested in estimating water storage variations in these basins. GRACE stored water variations were also calculated using an optimal concentration method based on Slepian functions to minimize leakage effects, and consequently, use of a-priori information.

Name: Sean Swenson
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Presentation Type: Oral Presentation

Title: A Note on Filtering & the University of Colorado GRACE Data Analysis Website

Abstract:
In this talk we discuss some of the effects of filtering GRACE data before giving a brief overview of the University of Colorado's GRACE data analysis website.

Name: Steve Klosko & David Rowlands
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Presentation Type: Oral Presentation

Title: GRACE Hydrology Products from GSFC

Abstract:
The GSFC GRACE Science Team Investigation has resulted in various gravity and mass flux solutions derived from Level 1 tracking data of the GRACE mission. Like other groups, we make monthly estimates of the gravity field from GRACE in terms of Stokes coefficients. This Level 2 product can be used with standard techniques to make a Level 3 estimate of mass flux. Our group also makes estimates of mass flux in 10 day intervals directly as a Level 2 product in the form of mass concentration (mascon) parameters on a grid. The mascon parameters are given in terms of equivalent water height and do not require smoothing. All of these GSFC solutions have been available for some time on a website (http://grace.sgt-inc.com) enabled by the NASA ACCESS program. The grid currently available is comprised of 4 degree equal angle blocks and is stitched together from regional solutions. We are now evaluating improved solutions based on a single global solution using an equal area 2 degree grid.

Name: H. Save, Z. Kang, S. Bettadpur, P. Nagel, R. Pastor, T. Pekker, S. Poole, B. Tapley, G. Kruizinga
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Presentation Type: Oral Presentation

Title: Quick-Look Gravity Solutions from GRACE

Abstract:
This presentation will describe a new GRACE product from the University of Texas Center for Space Research which is released with minimized latency (time after observation) for applications that require very recent data.

Name: Don Chambers
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Presentation Type: Oral Presentation

Title: Overview of GRACE Products for Hydrology at the GRACE Tellus Web-site

Abstract:
The various gridded products of land water storage from GRACE that are available at http://grace.jpl.nasa.gov will be reviewed. We will discuss how the files are created, what they represent, and note some cautions for their use.

Name: Fengge Su
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Presentation Type: Poster Presentation

Title: Arctic terrestrial water storage changes from GRACE estimates and a land surface hydrology model

Abstract:
Continental water storage plays a key role in the global hydrological cycle. GRACE estimates of terrestrial water storage from 2002 on show strong interseasonal and interannual variations in terrestrial water storage (TWS) at high latitudes, which are attributable at least in part to the important role of snow water storage on the seasonal water cycle. Evaluation of the accuracy of the GRACE terrestrial water storage is complicated by the absence of direct observations of terrestrial water storage. Land surface hydrology models, forced with observations, provide an opportunity for evaluating GRACE estimates regionally and globally. In this study, the Variable Infiltration Capacity (VIC) land surface hydrology model, which calculates the land surface water and energy balance, is used to evaluate the GRACE estimates over the pan-Arctic region. Precipitation input for the VIC model is from the GPCP One-Degree Daily Precipitation Data Set, Version 1.1. The other input fields are from NCEP/NCAR reanalysis. The VIC runs cover the GRACE period 2002-2009. Storage components simulated by VIC including snow, soil moisture, and river/lake storage are segregated from the VIC simulations, and the contributions of each of these components to seasonal and interannual variations in GRACE terrestrial water storage are analyzed. In general, the interseasonal variability of GRACE estimates of TWC for the major Arctic river basins, as well as the pan-Arctic drainage area, are substantially lower than those estimated by the VIC model. We discuss possible reasons for these differences.

Name: J.Y. Guo, X.J. Duan, C.K. Shum, L. Wang
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Presentation Type: Poster Presentation

Title: Reduction of land-ocean mass change signal leakage caused by Gaussian smoothing

Abstract:
Our leakage reduction algorithm uses as input the mass change data computed from GRACE data after appropriately smoothing using a Gaussian filter. Based on the assumption that mass change signal over land is far larger than that over ocean along coasts, our method approximately recovers the smoothed mass change signal over both land and ocean as if a regional Gaussian filter with the same smoothing radius were applied over land and ocean separately, in which no signal leakages appear. The side lobe problem does not appear in our approach. As the assumption that mass change signal over land is far larger than that over ocean is not necessarily true along every fraction of coasts, the leakage reduction method should be used on a regional basis, i.e., along the coasts where the assumption holds. The leakage reduction method could also be applied to any selected region of interest if mass change signal outside the region could be assumed as being removed base on hydrological models. We present the results of mass changes computed from GRACE L2 data in several regions which show the efficiency of our method at reducing leakage over both land and ocean.

Name: Mark Fountain, Ph.D.
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Presentation Type: Poster Presentation

Title: GRACE & Satellite Based Water Monitoring: Potentially Supporting Sustainable Microalgae Cultivation for Green Energy & Greenhouse Gas CO2 Sequestration.

Abstract:
Satellite GRACE remote sensing data and in situ water monitoring measurements agree in estimating of the groundwater content in the United States High Plains aquifer, an amount declining as a result of feeding the irrigation needs of several states. Located at the southern tip of this aquifer and irrigating crops with this water, Texas possesses brackish water unsuitable for crop use, yet useable for microalgae cultivation, a green technology. Microalgae cultivation has potential utility on a large scale, consuming the greenhouse gas CO2 while growing in brackish water or wastewater and producing algal biomass, a potential biofuel. The groundwater impact of such microalgal cultivation could be negligible or positive, even on a large scale. In this study, microalgae was cultivated in brackish water outdoor ponds and indoor bioreactors with in situ monitoring and sampling to measure CO2, temperature, salinity, chlorophyll, biomass, and density. Such measurements are used to illustrate the potential of satellite monitoring in managing large scale microalgal cultivation by performing such measurements, and concurrently monitoring the impact on groundwater resources.