INTERNATIONAL GEOSCIENCE PROGRAMME (IGCP)

Annual Report of IGCP Project No. 565

IGCP project short title: Geodetic Monitoring of the Global Water Cycle

Prepared by

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Guidelines for Annual Report

1. Website address(es) related to the project

In order to increase visibility, the web page of the project has been moved from http://geodesy.unr.edu/igcp565/ to http://www.iag-ggos.org/igcp565. This web page is used for project documentation, outreach, workshop organization, and resource deposit in terms of electronic documents. Several web pages, including the main page of the Global Geodetic Observing System (GGOS) at http://www.iag-ggos.org link to the IGCP 565 Project web page.

2. Summary of major past achievements of the project

In the first project year (2008), the research projects contributing to the IGCP 565 Project underlined the versatility of the combined geodetic observations for the monitoring of global water cycle on a range of spatial and temporal scales. A review of the open water cycle issues relevant to regional water management concluded that deep groundwater (both total quantity and changes) is one of the largest uncertainties in the budget of the water cycle, which is a major obstacle for regional water management, particularly in regions where a main part of the water supply depends on groundwater mining. The geodetic techniques have the potential to measure changes in groundwater storage. In 2008, the research projects achieved progress towards a utilization of this potential through improved forward modeling of the signals of water mass redistribution in geodetic observations, improvements in data processing and geophysical modeling inherent in geodetic analysis with the goal to preserve an unbiased water mass signals in the space-geodetic in situ geodetic time series, and validation of surface mass variations derived from geodetic observations. Based on the research results, a concept for utilization of the geodetic observations for products relevant for regional water management was developed, which is based on a hybrid approach combining local implementation with space-borne global and in situ regional observations (both surface displacements and gravity). Assimilation of the geodetic observations in regional hydrological models with predictive capabilities was identified as the ultimate goal.
With a growing realization of the importance of GRACE for the monitoring of the water cycle, in 2008 concerns about the absence of an immediate follow-on mission mounted and we addressed the question to what extent space-geodetic observations of changes in Earth's shape and rotation could be used to bridge a potential gap between GRACE and a future gravity mission. We showed that, in particular, the global network of GPS stations could help to bridge the gap if these data are assimilated in well-calibrated hydrological models.

3. Achievements of the project this year only

3.1. List of countries involved in the project

The following countries contributed actively during 2009: Australia, Austria, Canada, China, France, Germany, Italy, Republic of Korea, South Africa, The Netherlands, United States of America.

3.2. General scientific achievements and social benefits

Several studies demonstrated the high potential of GRACE to detect changes in major components of the water cycle. Several of these examples are described in "one-page stories" available at http://www.iag-ggos.org/workshops/ and there under the link "Workshop Outputs." Here we mention only two example, i.e., the detection of rapid melting of the Antarctic and Greenland ice sheets, and, highly relevant for the IGCP project, the detection and quantification of dramatic groundwater depletion in northwest India (Rodell et al., 2009). Both examples illustrate the potential of the geodetic techniques to detect changes in the water cycle of direct societal relevance and importance for decision making: the rapid and accelerating ice loss of the two large ice sheets requires a correction of sea level rise projections for the next fifty to hundred years to much larger values, and the rapid depletion of groundwater in a densely populated area with intensive irrigation-based agriculture requires a change in land use, if a major disaster is to be avoided.

A major concern in the scientific community arises from the fact that the GRACE mission is likely to end operation in 2012 and no immediate follow-on mission is planned. The roadmap for future gravity satellite missions prepared by the 2nd IGCP 565 Workshop (2nd IGCP 565 Workshop Participants, 2009; see next section) formulates the Strategic Target: "*A multi-decade, continuous series of space-based observations of changes in the Earth's gravity field begun with the GRACE mission, and leading, before 2020, to satellite systems capable of global determination of changes in the Earth's gravity field from global down to regional spatial scales and on time scales of two weeks or shorter, as a contribution to an integrated, sustained operational observing system for mass redistribution, global change, and natural hazards, and in support of global water management, the understanding of climate variations, and the characterization and early detection of natural hazards*." Furthermore, this roadmap details activities in four main areas required for improved future satellite missions, data processing, and products. Although not a scientific achievement in the strict sense, this roadmap is considered a major achievement of the IGCP 565 Project realized in cooperation with the broader scientific community, GGOS, and GEO (see Section 3.7 for a description how the roadmap and other project documents have been used to argue for an immediate follow-on gravity mission).

Scientific progress has been made towards validation of the hydrological signals extracted from geodetic techniques through cross-validation (Gross et al., 2009) and inter-comparison with independent data (e.g., LeBlanc et al., 2009, Tregoning et al., 2009, Syed et al., 2009). With respect to GRACE, the GRACE Science Team has made considerable progress in the determination of hydrological signals and the interpretation of these signals. The research projects integrated in the IGCP 565 Project significantly contributed to this progress.

Processing of the large GPS database collected by the Nevada Geodetic Laboratory has been improved and a database of more than 4000 homogeneous and high-quality time series of surface displacements in an improved geodetic reference frame is now available. This database for the first time provides a basis for a detailed study of the consistency of surface displacements and gravity changes (as observed by GRACE). This study is underway and will

provide valuable input for the joint integration of surface displacements and gravity changes in global hydrological models.

3.3. List of meetings with approximate attendance and number of countries

- 2nd IGCP 565 Workshop "Towards a roadmap for future satellite gravity missions, Graz, Austria, September 30 to October 2, 2009. 55 participants from 12 countries and 3 continents. See http://www.iag-ggos.org/workshops/Graz.
- Project Meeting, San Francisco, December 12-13, 2009. 11 participants, 5 countries, and 3 continents. See http://www.iag-ggos.org/igcp565/workshops/SF_2009.

3.4. Educational, training or capacity building activities

In 2009, no specific training courses were organized in the frame of the IGCP 565 Project. The most appropriate time for specific training courses and capacity building activities will be the last two years of the project, when focus will be on regional applications in Africa.

3.5. Participation of scientists from developing countries, and in particular young and women scientists

Besides other scientists from South Africa, Andiswa Mlisa, Umvoto Africa Ltd, Muizenberg, South Africa, works in the research project "GPS Application for Groundwater Resource Assessment, Hermanus, South Africa" (see the presentations available at http://www.iag-ggos.org/igcp565/workshops/SF_2009). She also took the lead in submitting a Project-related proposal to a CfP published by GEO. Through the Lake Victoria and East Africa projects of Miller and Calais, respectively, a number of African scientists are linked to project activities and contribute to the project goals.

3.6. List of most important publications (including maps)
Distinguish between peer review literature and other (no abstracts)

Peer-reviewed publications:

Gross, R. S., D. A. Lavallée, G. Blewitt, and P. J. Clarke, Consistency of Earth rotation, gravity, and shape measurements, in Observing Our Changing Earth, edited by M. G. Sideris, pp. 463–472, IAG Symposia vol. **133**, Springer-Verlag, New York, 2009.

Harmsen, E.W., N.L. Miller, N.J. Schlegel, J.E. Gonzalez, Downscaled climate change on agricultural water resources in Puerto Rico, *Agricultural and Water Management*, **9**, 1061-1180, 2009, ISSN 0378-3774

Leblanc, M. J., Tregoning, P., Ramillien, G., Tweed, S. O., Fakes, A., 2009. Basin-scale, integrated observations of the early 21st century multiyear drought in southeast Australia. *Water Resources Research*, **45**, W04408, doi: 10.1029/2008WR007333.

Miller, N.L., L.L. Dale, C.F. Brush, S.D. Vicuna, T.N. Kadir, E.C. Dogrul, and F.I. Chung: Drought resilience of the California Central Valley surface-groundwater-conveyance system. *J. Amer. Water Resources Association*, **45**, 4, 857-866, doi: 1111/j.1752-1688.2009.00329.x, August 2009.

Rodell, M., I. Velicogna, J.S. Famiglietti: Satellite-based estimates of groundwater depletion in India. *Nature*, 2009, **460** (7258) pp. 999-U80, doi: 10.1038/nature08238

Syed, T.H., J.S. Famiglietti, M. Rodell, J. Chen, C. R. Wilson: Analysis of terrestrial water storage changes from GRACE and GLDAS. *Water Resources Research*, **44**, W02433, doi:10.1029/2006WR005779. Feb. 2008

Tregoning, P., Watson, C., Ramillien, G., McQueen, H., Zhang, J., 2009. Detecting hydrological deformation using GRACE and GPS. *Geophys. Res. Lett.*, **36**, L15401, doi:10.1029/2009GL038718.

Zaitchik, B.F. and M. Rodell: Forward-Looking Assimilation of MODIS-Derived Snow-Covered Area into a Land Surface Model. *J. Hydrometeorology*, DOI: 10.1175/2008JHM1042. Feb. 2009.

Other publication:

2nd IGCP 565 Workshop Participants, 2009. Roadmap Towards Future Satellite Gravity Missions in Support of Monitoring of Mass Redistribution, Global Change, and Natural Hazards. Available at http://www.iag-ggos.org/workshops/ Graz.

3.7. Activities involving other IGCP projects, UNESCO, IUGS or others

The IGCP 565 Project is linked to the GEO Water Cycle Community of Practice, which originated from the IGOS Theme on Integrated Global Water Cycle Observations, and it contributes to the GEO Work Plan Tasks in the Water Societal Benefit Area. The 2nd IGCP 565 Workshop was organized as a Joint IGCP 565, GGOS, IAG, and GEO Workshop. The IGCP 565 participated in the GRACE Science Team meeting and presented the results of the 2nd IGCP 565 Workshop there. Together with a Workshop Declaration, the roadmap produced by the 2nd IGCP 565 Workshop was distributed to the participants of the Sixth GEO Plenary held on November 17-18, 2009 in Washington. D.C. It is mentioned here that the IGCP 565 Project developed into a forum for the interdisciplinary discussion between hydrologists and geodesists.

4. Activities planned

4.1. General goals

The overall goal in 2010 is the extraction of the signal of land water storage changes from the geodetic observations. A particular focus will be on the separation of tectonic and hydrological signals in the geodetic observations. This will feed directly into the goals for 2011, i.e., the assimilation of geodetic observations into hydrological models. The research projects contributing to IGCP 565 are likely to produce significant results concerning validation of the hydrological signals extracted from geodetic observations.

4.2. Tentative list of specific meetings and field trips (please list the participating countries)

3rd IGCP 565 Workshop: *Determination of mass transports in the hydrological cycle from geodetic observations.* Reno, Nevada, September/October 2010. This workshop will focus on the separation of tectonic and hydrological signals, using the South-West U.S., Northern India, and East Africa as example regions. The workshop will be open and international participation from many countries is expected. Additional funding will be sought from NSF. The number of expected participants is on the order of 150.

A project meeting is planned for December 2010, most likely in conjunction with the AGU Fall meeting in San Francisco.

4.3 Linking to other activities

The IGCP 565 project is planned to be presented at the Joint workshop of the GEO Coastal Zone Community of Practice and UNESCO's International Hydrological Program, Cotonou, Benin, February 15-18, 2010 (http://www.czcp.org/workshops/Cotonou). This workshop is international with participation from many African countries and some European and North American countries.

The project will be represented (by Miller) at the International African Water and Sanitation Congress and Exhibition, March 15-18, Kampala, Uganda. The Project status will also be presented (by Plag and Miller) at the Workshop on Water Resource Assessment and Applications on February 23-24, 2010 in New York, and the subsequent meeting of the Integrated Global Water Cycle Observations (IGWCO) Community of Practice at the same venue will be used for coordination.

The project will participate in the AfricaArray Workshop tentatively planned for March 31 – April 2, New York. This workshop will discuss the extension of AfricaArray for (among others) hydrological applications.