



## Annual Report of IGCP Project No. 565

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

**Duration:** 2008-2012

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## Annual Report

### 1. Website address(es) related to the project

The web page of the project is at <http://www.igcp565.org>. This web page is used for project documentation, outreach, workshop organization, and library in terms of electronic documents. Several web pages link to the IGCP 565 Project web page.

### 2. Summary of major past achievements of the project

In the first three years (2008 - 2010), the research projects coordinated in the IGCP 565 Project focused on the advancement of hydrogeodesy. The projects identified the key contributions and assessed the spatial and temporal resolution achievable for hydrological quantities with geodetic observations. Deep groundwater (both total quantity and changes) was identified as one of the largest uncertainties in the budget of the water cycle. In many regions where water supply depends to a large extent on groundwater mining, the lack of sustained monitoring of subsurface water storage is a major obstacle for water management. Improved observations of changes in subsurface water storage on land are needed in order to support regional and local water management. While geodetic observations of changes in the Earth's gravity field and rotation are central to the monitoring of the global water cycle, the combination of in situ and spaceborne geodetic observations of gravity and surface displacements is required to achieve high spatial resolution down to local scales. Geodetic observation capture the integrated signal of all physical Earth system processes and in order to utilize hydrogeodesy for groundwater monitoring, signals caused by, e.g., tectonic processes, atmosphere and ocean loading need to be modeled. The projects contributed to improved forward modeling of the geodetic signals of these processes. These improved models are used to further improve the geophysical modeling inherent in geodetic analysis, which helps to preserve unbiased water mass signals in space-geodetic and in situ time series.

Since 2008, concerns about the absence of an immediate follow-on mission for the GRACE mission mounted. Therefore, we focused attention on two questions:

(1) To what extent could space-geodetic observations of changes in Earth's shape and rotation be used to bridge a potential gap between GRACE and a future gravity mission? The global network of GPS stations, which today has more than 10,000 publicly available stations, could help to bridge the gap if these data are assimilated in a well-calibrated model of the global hydrological cycle. However, there are severe gaps in the global station distribution, and we engaged in addressing these gaps particularly in Africa.

(2) How can we accelerate the development and deployment of a follow-on mission for GRACE? We reviewed the scientific rationale for an immediate follow-on GRACE mission and in 2009 developed a Road Map for future gravity satellite missions. A number of studies carried out by project participants demonstrated the high potential of GRACE to detect changes in major components of the water cycle, and several examples were described in "one-page stories." The Road Map and the one-page stories were distributed to the participants of the VI Plenary of the intergovernmental Group on Earth Observations (GEO) in November 2009 in Washington, D.C. In 2010, NASA included a GRACE follow-on mission in its plans with the launch scheduled for 2016. In 2011, the financing of this mission was settled and we are now optimistic that the follow-on mission will be in place in 2016. Considering the degrading state of current GRACE mission, which is already leading to data loss, this is a very positive development.

A challenge to the application of hydrogeodesy for water management is the limited number of examples that show its practical applicability to local and regional water management. Water managers often have little knowledge of hydrogeodesy, and hydrogeodetic products of direct use for water management are not readily available. Therefore, in 2010 and 2011, we have focused on the development of pilot projects that demonstrate the relevance of hydrogeodesy applications for water

management. A key pilot is built around the Central Valley in California, where initial GRACE studies have demonstrated the value of the space-geodetic constraints for the modeling of water resources. Initial steps for a pilot project in Africa have been taken.

### 3. Achievements of the project this year only

#### 3.1. *List of countries involved in the project (\* indicates the countries active this year)*

The following countries contribute to the project (\* indicates active contributions in 2011): Angola(\*), Australia(\*), Austria, Botswana(\*), Cameroon(\*), Canada(\*), China, Democratic Republic of Congo(\*), Ethiopia(\*), France(\*), Germany(\*), Ghana(\*), Italy(\*), Japan(\*), Malawi(\*), Morocco(\*), Mozambique(\*), Nigeria(\*), Poland, Republic of Korea, Rwanda(\*), South Africa(\*), Tanzania(\*), The Netherlands, Uganda(\*), United States of America (\*), Zambia(\*), Zimbabwe(\*).

#### 3.2. *General scientific achievements and social benefits*

In addition to continuing the research in basic areas of hydrogeodesy via research projects coordinated in the IGCP project, specific research in 2011 focussed on the development of pilot projects that could demonstrate the applied value of hydrogeodesy for regional water management, as well as the development of a framework for the joint interpretation of geodetic observations.

Scientific progress has been made towards validation of the hydrological signals extracted from geodetic techniques through inter-comparison with independent data (e.g., Becker et al., 2010) and integrated processing of geodetic data (e.g., Wu et al., 2010; Hammond et al., 2010). With respect to hydrogeodetic applications of GRACE, the GRACE Science Team has continued to make progress in the determination of hydrological signals and the interpretation of these signals, with the IGCP 565 project team contributing to this progress.

The uniquely large database of GPS-derived time series of surface displacements has been used to improve the characterization of surface displacements and the models predicting these displacements. Together with results produced by other IGCP 565 research teams, these results provide a basis to improve the separation of the hydrological signal from other signals, which is a prerequisite for the next step: assimilation of geodetic observations in terrestrial water storage models.

Considerable progress has also been made in terms of demonstrating the value of hydrogeodesy for regional water management. A particular example is the Central Valley in California, where the combination of GRACE, GPS and InSAR provides constraints for trends in groundwater storage that can be related to climatic and anthropogenic changes. The project is now in the position to carry out a demonstration project as an outreach to regional water managers.

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

In 2011, one major project meeting was organized as the fourth annual Workshop held on November 22-23, 2011 in conjunction with the AfricaArray Workshop at the University of Witwatersrand, Johannesburg, South Africa. This workshop was attended by 38 participants from 18 countries, including 15 African countries.

#### 3.4. *Educational, training or capacity building activities*

During the Fourth Workshop, a tutorial session on the use of GRACE data was organized. This session included two lectures and was attended by 25 participants mainly from the 15 African countries.

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

The Fourth IGCP 565 Workshop had 31 participants from 15 developing countries in Africa. Most of these participants were funded with project funds. Participation in research projects includes scientists from South Africa, Ethiopia, Nigeria, and Zimbabwe. Andiswa Mlisa, Umvoto Africa Ltd, Muizenberg, South Africa, work on the research project, “GPS Application for Groundwater Resource Assessment, Hermanus, South Africa”. She also is the P.I. of a project proposal that was submitted to GEO. Jean-Marie Kileshye Onema as a young scientist now at WaterNet, Zimbabwe, and is involved in the development of a project in Namibia. Elias Lewis Teklemariam, Ethiopia, provides a link to hydrogeodetic research and water management authorities in Ethiopia. Through the Lake Victoria and East Africa projects, Miller and Calais, respectively, and several African scientists are linked to project activities and contribute to the project goals. Christian Ezigbo, Nigeria, is a P.I. in a relevant proposal submitted to GEO. As a result of the 2011 Workshop a new initiative is being developed for groundwater projects in Botswana.

### 3.6. List of most important publications in 2011

(\*: peer review literature)

(\*) Famiglietti, J.S., M. Lo, S.L. Ho, J. Bethune, K.J. Anderson, T.H. Syed, S.C. Swenson, C.R. de Linage, and M. Rodell, Satellites measure recent rates of groundwater depletion in California's Central Valley. *Geophys. Res. Letters*, 38, L03403.

(\*) Gross, R., Schuh, H., Huang, C.-L., 2011. Spin, Wobble, and Nutation - Observing and Understanding Earth Rotation: A Joint GGOS/IAU Science Workshop; Shanghai, China, 25–28 October 2010. *Eos Trans. AGU*, **92**, , doi:10.1029/2011EO040004.

(\*) Plag, H.-P. & Miller, N. M., 2011. Applying Geodesy to Hydrologic Cycle Monitoring. *EOS, Trans. Am. Geophys. Union*, **92**, 136.

Plag, H.-P., Gross, R. S., Miller, N. L., Rothacher, M., Zerbini, S., & Rizos, C., 2011. IGCP 565 Project: Developing the Global Geodetic Observing System into a monitoring system for the global water cycle. In Fried, J. and Scherfig, J., *International Conference on Water Scarcity, Global Changes, and Groundwater Management Responses, December 2008, University of California, Irvine, United States, Proceedings*, 953-972. The Urban Water Research Center, University of Irvine, Irvine, CA, United States.

(\*) Jacob, T., Wahr, J., Gross, R., Swenson, S., Geruo, A., 2011. Estimating geoid height change in North America: past, present and future. *J. Geodesy*, DOI 10.1007/s00190-011-0522-7

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

In 2011, the work carried out in the IGCP 565 Project provided the basis for an invited presentation on new observations of the water cycle given at the Joint IPCC-GEOSS Workshop “GEOSS support for IPCC assessments” held on February 1-4, 2011 in Geneva, Switzerland.

The IGCP 565 project is coordinated with the Water Cycle Community of Practice and the Africa Water Cycle Symposium of the Group on Earth Observations (GEO).

Coordination with the AfricaArray has been increased in 2011. A joint session was organized during the co-located AfricaArray and IGCP 565 Workshops in November in Johannesburg. Currently, a joint proposal for a Research Network bringing together AfricaArray and IGCP 565 participants to address

hydrological problems in Africa is under preparation for submission by 3<sup>rd</sup> February 2012. The interaction with the WaterNet program has been strengthened.

We are currently preparing an NSF Research Coordination Network proposal for organizing a network of hydrologic data resources and sharing within Africa. This project includes collaborators and partners from more than 20 African and 10 U.S. Universities, and will provide a means to train local researchers on data collection and archiving.

#### **4. Activities planned**

##### *4.1. General goals*

A key recommendation of the 2010 Workshop was the implementation of two demonstration projects for the practical application of hydrogeodesy to regional water management. In 2011, major progress has been made in developing these pilot projects, and a main focus in 2012 will be on fully implementing the first stage of these pilots. The pilot project in the Central Valley, California, which is conducted together with the California Department of Water Resources, will be further developed and a pending NASA proposal further advances this coordinated activity, as well as planning toward implementation in the Nile Basin. During the 2011 IGCP 565 Workshop, continued progress and local coordination was advanced for a similar pilot project in Africa. A smaller demonstration project located in Windhoek, Namibia, has been discussed with African partners and it appears realistic to start implementation, and is already under preparation for a 2012 start. Additionally, a research project on surface-groundwater monitoring in Botswana is also in preparation in coordination with local researchers.

Another recommendation of the 2010 Workshop was the development of a web-based modeling framework for hydrogeodesy, which would include tutorials and support for non-expert decision makers. A proposal for such a framework as part of a larger community-based geodesy modelling framework part of the above mentioned NASA proposal and another is under preparation.

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

The Fifth and final IGCP 565 Annual Workshop will be held in Cape Town, South Africa, most likely October 28-31, 2011. This workshop will be jointly organized with a number of organizations and projects focusing on water issues in Africa, including but not limited to the GEO Africa Water Cycle Initiative, WaterNet, UNESCO's IHP, AfricaArray, TIGER, AMMA (Africa Monsoon Multidisciplinary Analysis program), FEWS-NET (Famine Early Monitoring Systems Network), GIMS (Geographical Information Systems, Africa). Several of these organizations have already confirmed their participation in the organization of this event as a major Africa water meeting. The goal of this workshop is to bridge the current gap between the many scientific programs and projects and those responsible for regional and local water management. The workshop will be open for participation of all interested scientific and societal stakeholders in water-related problems in Africa as well as experts from outside of Africa.