Surv Geophys (2016) 37:191–194
DOI 10.1007/s10712-016-9356-4

Foreword: International Space Science Institute (ISSI) Workshop on Remote Sensing and Water Resources

A. Cazenave[1,2] · N. Champollion[2] · J. Benveniste[3] · J. Chen[4]

Received: 3 January 2016 / Accepted: 4 January 2016 / Published online: 22 January 2016

About 97 % of the total amount of water on Earth is found in the oceans and 2 % is stored in the Greenland and Antarctic ice sheets. It is only the remaining 1 % that is the amount of water available for the biospheric processes and for all human needs. This fresh water component is stored in both surface and subsurface reservoirs. On the surface, the storage volumes consist of rivers, lakes, man-made reservoirs, wetlands and inundated areas. Subsurface reservoirs include root zones (the uppermost few metres of the soil), as well as confined and unconfined aquifers and other geological formations. Except for the deep aquifers that evolve on thousand-year timescales, terrestrial waters are continuously exchanged with the atmosphere and oceans through vertical and horizontal mass fluxes (i.e. precipitation, evaporation, transpiration of the vegetation and surface and underground runoff). These exchanges as well as the associated storage of water in the different components of the climate system characterize the global water cycle.

On land, changes in the global water storage result from climate variations, from direct human interventions in the water cycle and from human modifications of the physical characteristics of the land surface. Climate variations (which are due to both natural and

✉ A. Cazenave
anny.cazenave@issibern.ch; anny.cazenave@legos.obs-mip.fr

N. Champollion
champollion@issibern.ch

J. Benveniste
Jerome.benveniste@esa.int

J. Chen
chen@csr.utexas.edu

1 LEGOS, CNES, 18 Avenue Edouard Belin, 31401 Toulouse Cedex 9, France

2 ISSI, Hallerstrasse 6, 3012 Bern, Switzerland

3 ESA-ESRIN, Via Galileo Galilei, 0044 Frascati, Italy

4 CSR, University of Texas at Austin, Austin, TX, USA

anthropogenic causes) produce changes in the land water balance, leading to either an increase or a decrease in water storage. For example, cold and wet climatic conditions have the tendency to increase water storage, while a warm and dry climate has the opposite effect. Many human activities directly affect land water storage; examples are groundwater pumping in aquifers, the construction of dams on rivers to form artificial man-made reservoirs and irrigation for improved agricultural production. Anthropogenic changes in land surfaces such as urbanization, agriculture and deforestation also lead to water storage changes.

Being an integral part of the climate system, terrestrial waters have important links to, and feedbacks with and from, the atmosphere and oceans via energy and moisture fluxes. Gaining a better understanding of the global hydrological cycle, in particular its terrestrial component, is thus a key issue in climate research today. It is also of significant importance for creating an inventory of water resources and for managing them.

In the last two to three decades, global estimates of the spatio-temporal changes in land water storage (surface, soil and underground waters, as well as snow packs) have relied on hydrological models, either coupled with atmosphere–ocean global circulation models or forced by meteorological observations. However, hydrological phenomena are so complex that it is very difficult to represent the hydrological system in such a simple way. What is needed is the acquisition of a huge amount of observations and their assimilation into complex models.

In situ gauging networks have been installed for several decades in many lakes and river basins. However, they are distributed non-uniformly throughout the world, and they often suffer from intermittent operation. In situ measurements provide time series of water levels and discharge rates, which are used for studies of regional climate variability, as well as for socio-economic applications (e.g., water resources inventory, navigation, land use, planning infrastructures, hydroelectric energy, flood hazards) and environmental studies (rivers, lakes, wetlands and floodplains hydroecology). However, for more than two decades, ground-based gauge networks have declined in many regions (Alsdorf and Lettenmaier 2003), because of economic pressures or for political reasons. For example, over 20 % of the freshwater discharge to the Arctic Ocean is ungauged; surface water across much of Africa and portions of the Arctic is either not measured at all or has experienced the loss of over two-thirds of the gauges (Shiklomanov et al. 2002). The physical removal of gauges from many lakes and river basins is, unfortunately, a common situation in many parts of the world. Besides, the distribution of collected data is often restricted, because water-related data are often considered to be sensitive national information. Therefore, to accurately measure, monitor and forecast global supplies of fresh water using in situ methods is almost impossible because of the lack of access to an adequate amount of in situ measurements worldwide.

For the past 10–15 years, remote sensing techniques have demonstrated their excellent capability to monitor several components of the water balance of large rivers, lakes and reservoirs, on timescales ranging from months to decades (e.g., Alsdorf and Lettenmaier 2003; Alsdorf et al. 2007; Famiglietti et al. 2015). For example, radar and laser satellite altimetry are routinely used for systematic monitoring of the water levels of large rivers, lakes, reservoirs and floodplains. If combined with satellite imagery, satellite altimeter observations also enable the variations of surface water volumes to be estimated. Passive and active microwave sensors offer important information on soil moisture (e.g., the SMOS mission) as well as on wetlands and snowpacks. Space gravity missions (in particular the GRACE mission) directly measure the spatio-temporal variations of vertically integrated terrestrial water storage. When combined with hydrological model estimates or other observations of surface waters and soil moisture made from space (e.g., from satellite altimetry and SMOS), satellite gravity data can be used to study groundwater storage variations. Synthetic Aperture Radar Interferometry (InSAR) can be also used to estimate river flow.

In the very near future, the Surface Water Ocean Topography (SWOT) mission will provide frequently updated two-dimensional maps of surface water levels and river discharges, with global coverage and with unprecedented resolution ($\sim$100 m globally on land). All these observations, as well as those planned in the near future (e.g., the European Sentinel missions), will become increasingly important in improving our understanding of hydrological processes at work in large river basins and their links with climate variability and socio-economic activities. Significant new information can be expected by combining models and surface observations with space observations, which offer global geographical coverage, good spatio-temporal sampling, continuously repeated monitoring and the capability of measuring water mass changes occurring at or below the Earth's surface.

The scientific papers presented in this volume represent the outcome of a workshop on 'Remote Sensing and Water Resources' held in October 2014, in Bern, Switzerland, as part of the International Space Science Institute (ISSI) Earth Observation Programme. The objective of the workshop was to bring together leading scientists involved in the global water cycle, land hydrology and water resources research, either processing observations or running hydrological models or combining both. Two main issues were addressed during the workshop: (1) promoting the synergistic use of space observations for monitoring water storage changes in river basins worldwide, and (2) using the space data in hydrological models either by data assimilation or as external constraints. Participants in the workshop were experts in different disciplines, including remote sensing, hydrological modelling, meteorology, geophysics and climate science.

The first two articles address hydrological modelling, at the global scale ('Modelling fresh water resources at the global scale; challenges and prospects' by Döll et al.) and at the regional scale in a river basin that has been highly modified by human activities ('Hydrological modelling in highly anthropized river basins; example from the Garonne Basin' by Martin et al.). The paper by Zhang et al. 'On creating global gridded terrestrial water budget estimates from satellite remote sensing' investigates the reliability of global remote sensing products in closing estimates of the global water budget.

Three papers deal with the use of satellite altimetry and other remote sensing techniques to study surface waters. The paper by Crétaux et al. is an overview of lake monitoring from space. Biancamaria et al. demonstrate the high potential of the future SWOT mission to study surface waters with a precision, spatial resolution and temporal sampling that was previously unavailable. The issue of monitoring wetlands is addressed by Prigent et al. in an overview article entitled 'Towards high resolution monitoring of continental surface water extent and dynamics at global scale; from GIEMS (Global Inundation Extent from Multi-Satellites) to SWOT'.

The next three papers deal with the GRACE-based space gravimetry technique and its capability to measure total terrestrial water storage, accessing groundwater storage by removing model-predicted surface water storage change. The paper by Humphrey et al. 'Assessing global water storage variability from GRACE: trends, seasonal cycle, intra-annual anomalies and extremes' focuses on short-term water storage anomalies, as well as on extreme events such as droughts. The recovery of estimates of groundwater depletion in aquifers from GRACE measurements is discussed by Chen et al. in a paper entitled 'Groundwater storage changes: present status from GRACE observations'. The paper by Wada et al. 'Modelling global groundwater depletion: present state and future prospects' evaluates the recent advances which modelling approaches bring to enable groundwater depletion to be estimated at a global scale.

The capability of future space gravity missions with new on-board interferometric laser systems to improve both the precision and resolution of water storage measurements is evaluated in Flechtner et al. 'What can we expect from the GRACE-FO Laser ranging interferometer for Earth sciences applications?'. The next paper by Lopez et al. 'Subsurface hydrology in the Lake Chad Basin from space-based and hydrogeological data' investigates how space radiometry combined with hydrogeological data and modelling can provide constraints on groundwater circulation in semi-arid regions. Finally, an overview of the significant issue of the provision for human beings of 'Water and Food in the 21st century' is given by de Marsily and Abarca Del Rio.

This Special Issue includes the majority of the lectures presented at the workshop, in some instances grouped into a single article in order to reflect a broader view of the subject. This volume focuses on terrestrial waters and, as such, complements the book published as the outcome of a previous ISSI workshop which was mostly devoted to the atmospheric water cycle (Bengtsson et al. 2014).

Clearly, studying the global water cycle is a very complex problem as many Earth processes are at play, and we recognize that several other volumes would be necessary to fully cover the ongoing research in this domain. However, we hope that the present issue will contribute to

1. fostering the interests of the science community around future spaceborne missions,
2. supporting the exploitation of past, present and future invaluable spaceborne measurements, and
3. gathering multidisciplinary teams working together on satellite observations, in situ data, modelling and data assimilation techniques.

We thank ISSI and the European Space Agency for providing an inspiring framework which made such a fruitful workshop possible.

References

Alsdorf DE, Lettenmaier DP (2003) Tracking fresh water from space. Science 301:1492–1494

Alsdorf D, Fu LL, Mognard N, Cazenave A, Rodriguez E, Chelton D, Lettemaier D (2007) Measuring global oceans and terrestrial fresh water from space. EOS Trans AGU 88(24):253

Bengtsson L, Bonnet R-M, Calisto M, Destouni G, Gurney R, Johannessen J, Kerr Y, Lahoz WA, Rast M (eds) (2014) The Earth's hydrological cycle. Space sciences series of ISSI vol 46. ISBN 978-94-017-8788-8

Famiglietti J, Cazenave A, Eicker A, Reager JT, Rodell M, Velicogna I (2015) Satellites provide the 'big picture' for global hydrology. Science 349(6249):684–685

Shiklomanov AI et al (2002) Widespread decline in hydrological monitoring threatens Pan-Arctic research. EOS Trans AGU 83:13–16