Surface Freshwater Extent and Storage Variability at Basin-to-Global Scale from Multi-Satellite Observations

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The continental water cycle

Basin-scale water balance equation
\[ \frac{dW}{dt} = P - E - Q \]

Total Water Storage
- Precipitation
- Evapotransp.
- Discharge

- Large uncertainties
- Limited in situ observations
- Individual contribution to the total storage, their variability, and their interactions poorly known
Today, no satellite mission specifically dedicated to the evaluation of the surface waters, but complementary satellite missions can help better characterize and understand surface water dynamics at global scale:

**Surface water extent and its dynamics:**
Global Inundation Extent from Multi-Satellites (GIEMS)

**The variations of the surface water storage:**
Example of the Amazon basin
Surface water extent and its dynamics

Visible and infrared (e.g. AVHRR, MODIS)
- high spatial resolutions
- unable to penetrate vegetation and clouds
- very useful in semi-arid environments
  Ex: the Niger inner delta, Crétaux et al., 2014

Active microwave (SAR)
- very high spatial resolution
- large data volume: difficult to handle for global analysis
- few time samples so far: difficult to assess the dynamic
  Ex: the Mekong delta, Kuenzer et al., 2013

Passive microwave (e.g., SSM/I, AMSR)
- water reduces emissivities in both linear polarizations
- difficult to account for vegetation contribution when used alone
- low spatial resolution (~ 20 km)
  Ex: the Amazon, Sippel et al., 1998
Development of a multi-satellite technique that quantifies the monthly extent of surface water at the global scale

Merging of satellite data at different wavelengths to benefit from their synergy

Passive microwave (SSM/I, SSM/IS) emissivities at 19, 37 GHz, H and V polarizations

Active microwave (ERS, ASCAT) scatterometer backscattering coefficient at 5.25 GHz

Visible, near infrared (AVHRR, MODIS) visible and near-infrared reflectances and NDVI

Papa et al., 2006b, 2007, 2008a,b, 2010
Data mapped on an equal-area grid of 0.25° x 0.25° at the equator (773 km²)

Monthly and 10-day average for 1993-2007 and currently being extended to present

Intensively evaluated. Uncertainty ~10% with underestimation in area with low water extent

Prigent et al, 2001; 2007; 2012
Strong seasonal cycle and inter-annual variability. Overall decrease of surface water extent, especially over the Tropics at a rate of ~6% in 15 years. Decrease especially in the 1990’s and located essentially in region of large population increase.
Once we have the **surface water extent**, how to derive the **surface water volume** change?

*Two methods:*

To combine global surface water extent with water height from **altimeter data**

To combine global surface water extent with topography information from a **Digital Elevation Model (DEM)**
(Papa et al., 2013)
Variations of surface water storage

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Combination of the ASTER-GDEM at 30 m resolution with estimates of the global surface water extent (GIEMS) using an **hypsographic curve approach** to relate the flooded area to the elevation.

- Areas of lower elevations inundated first
- Applicable globally

**Papa et al., JGR, 2013**
Variations of surface water storage

Distribution of DEM elevation in ascending order for all ASTER data within a GIEMS pixel.

Hypsochoric curve from ASTER (red), ENVISAT (green) and ASTER-corrected (black)

Example for the Amazon River basin
Variations of surface water storage over the Amazon

Surface water

Mean Annual maximum amplitude
(Zoom on the main corridor)
Variations of surface water storage over the Amazon


Water level anomaly during the 2005 drought

Anomaly of minimum water level (m) - 2005

Water levels sometimes 8m below the 2002-2007 average.

Papa et al., 2013
Extensively evaluated against In situ data
Variations of continental water storage over the Amazon

The groundwater as the residual of the water budget

Total water storage (GRACE)

- **Surface water**
  - $\text{Storage} = \text{GIEMS} + \text{radar altimetry (Frappart et al. 2008-10-11-12)}$
  - GIEMS + DEM: hypsometric approach (Papa et al, 2013)

- **Soil moisture**
  - $\text{Storage} = \text{AMSR-E, WACMOS, SMOS, modeling results (GLDAS)}$

- **Groundwater**
  - $\text{Storage} = \text{GRACE TWS} - (\text{Surface water} + \text{Soil moisture})$

To isolate the “groundwater” components:

Understanding processes / Variability / Trend.
Better closure of the terrestrial water budget.
Variations of continental water storage over the Amazon

The decomposition of continental water storage components

- Surface water: ~50% of TWS variations
- Soil moisture: ~25% of TWS variations
- Ground-water: ~25% of TWS variations

Graph showing water volume (km³) from 2003 to 2008 for the Amazon region.
Conclusions and perspectives

A global data base of surface water extent and dynamics developed from multi-satellite observations, at 25 km spatial resolution, on a monthly basis from 1993 to 2007 (GIEMS)

- 10-day estimates under evaluation.
- Extension to present under way

This dataset widely used for modeling activities (Decharme et al., 2008, 2012, Ringeval et al. 2010, 2012, Melton et al., 2014…)

Combined with altimetric or topographic (DEM) information, it can provide the surface water volume change. Tested on the Amazon Basin.

The hypsometric methodology under development at global scale.

The groundwater volume change can be deduced as the residual from the total water change (Grace) minus the soil moisture variation and the surface water volume change data.