

# The variability of water storage and fluxes from multisatellite observations: current advances and future opportunities

**Fabrice Papa**

**[fabrice.papa@ird.fr](mailto:fabrice.papa@ird.fr)**

**LEGOS-IRD, Toulouse, France**

**Now at UNB, Inst. Geociencias, Brasilia, Brazil**



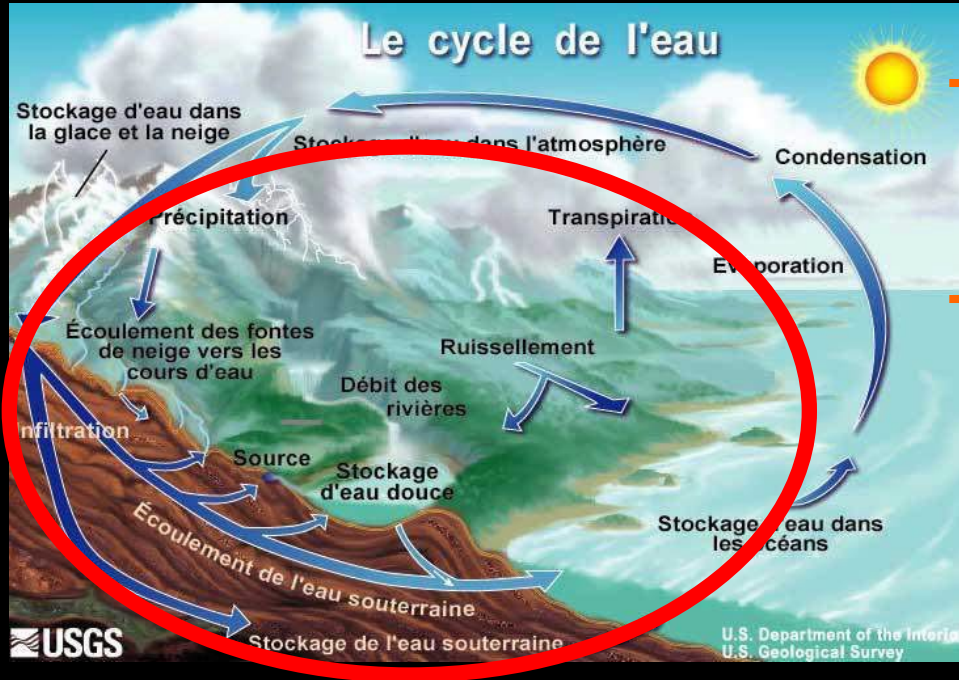
French National Research  
Institute for Sustainable  
Development



# Scientific question

## Freshwater, an essential resource but limited

Continental water = ~1% of the total amount of water on Earth



Critical to sustain life and for human Health, activities and the environment

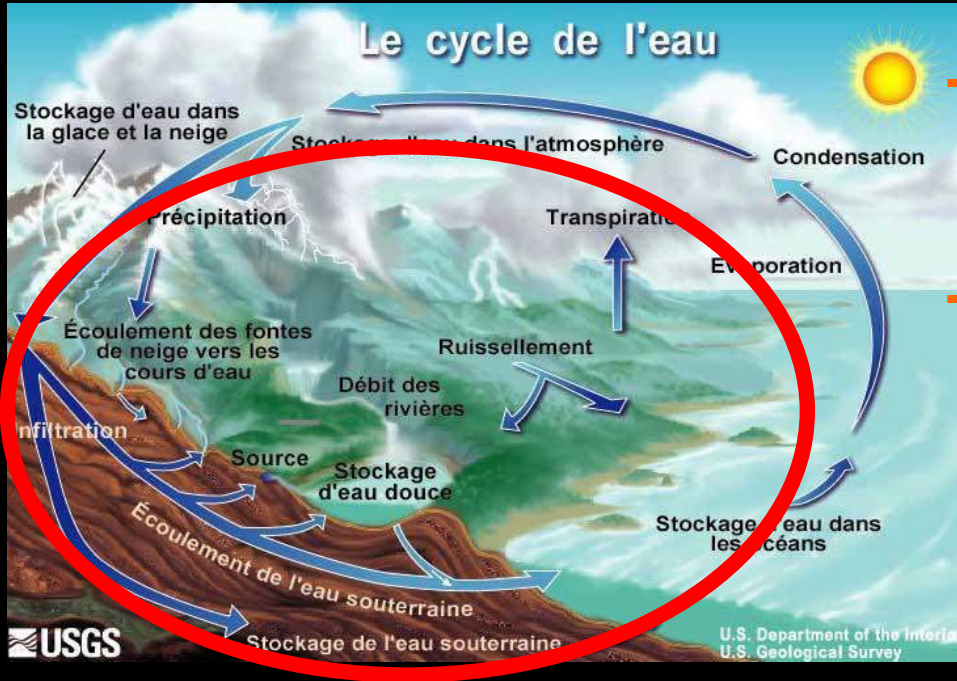
Play a key role in the global water and energy cycles, the climate system and its variability

**Water resource policy / society**

# Scientific question

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Play a key role in the global water and energy cycles, the climate system and its variability

Water resource policy / society

**What are the spatio-temporal variations of the fluxes and storage of continental freshwater?**

**What are their interactions with the climate and the anthropogenic pressure?**




# Continental waters in the global water cycle and climate

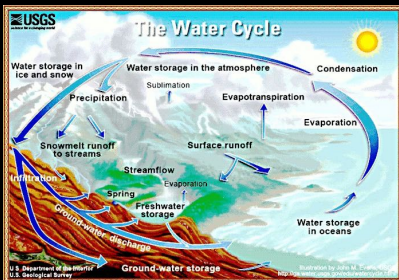
More specifically over the Tropics, and for the Amazon and Congo RB:

- The two largest river basin in the world.  
**Amazon 20% of total discharge to ocean**
- Subject to large climate variability  
**Prolonged extensive drought/floods**
- Major role in the tropical/equatorial forest and ecosystems sustainability  
**and Carbon cycle**
- Key for global and local water resources
- **Vulnerability** facing global change and anthropogenic pressure



 **Need of comprehensive and accurate estimates of continental freshwater extent/storage, fluxes (P, Q, E) and their variations at basin to global scale at adequate spatial and temporal resolution.**

# The Continental Water Cycle and Water Storage



Basin-scale water balance equation

$$dW/dt = P - E - Q$$

Total  
Water Storage

=

Surface  
water

?

Soil  
Moisture  
RZ

?

Ground  
Water

??

Precipitation

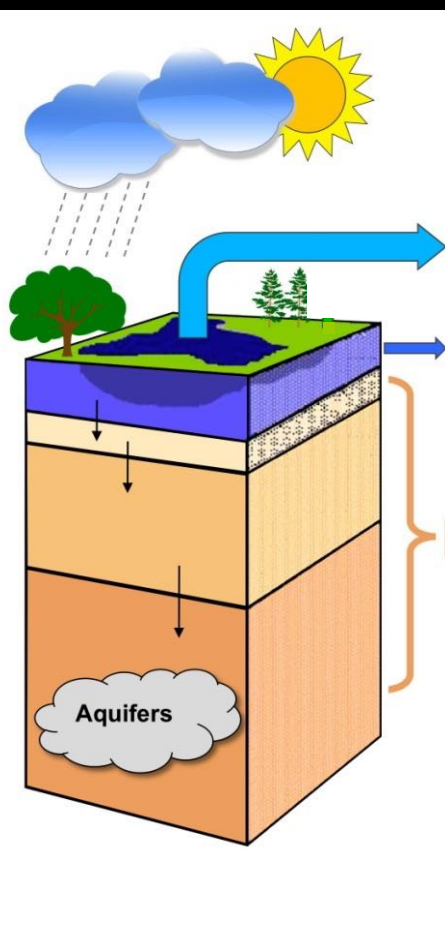
Evapotran.

Discharge (G+S)

- Large uncertainties

- Lack of *in situ* obs. network

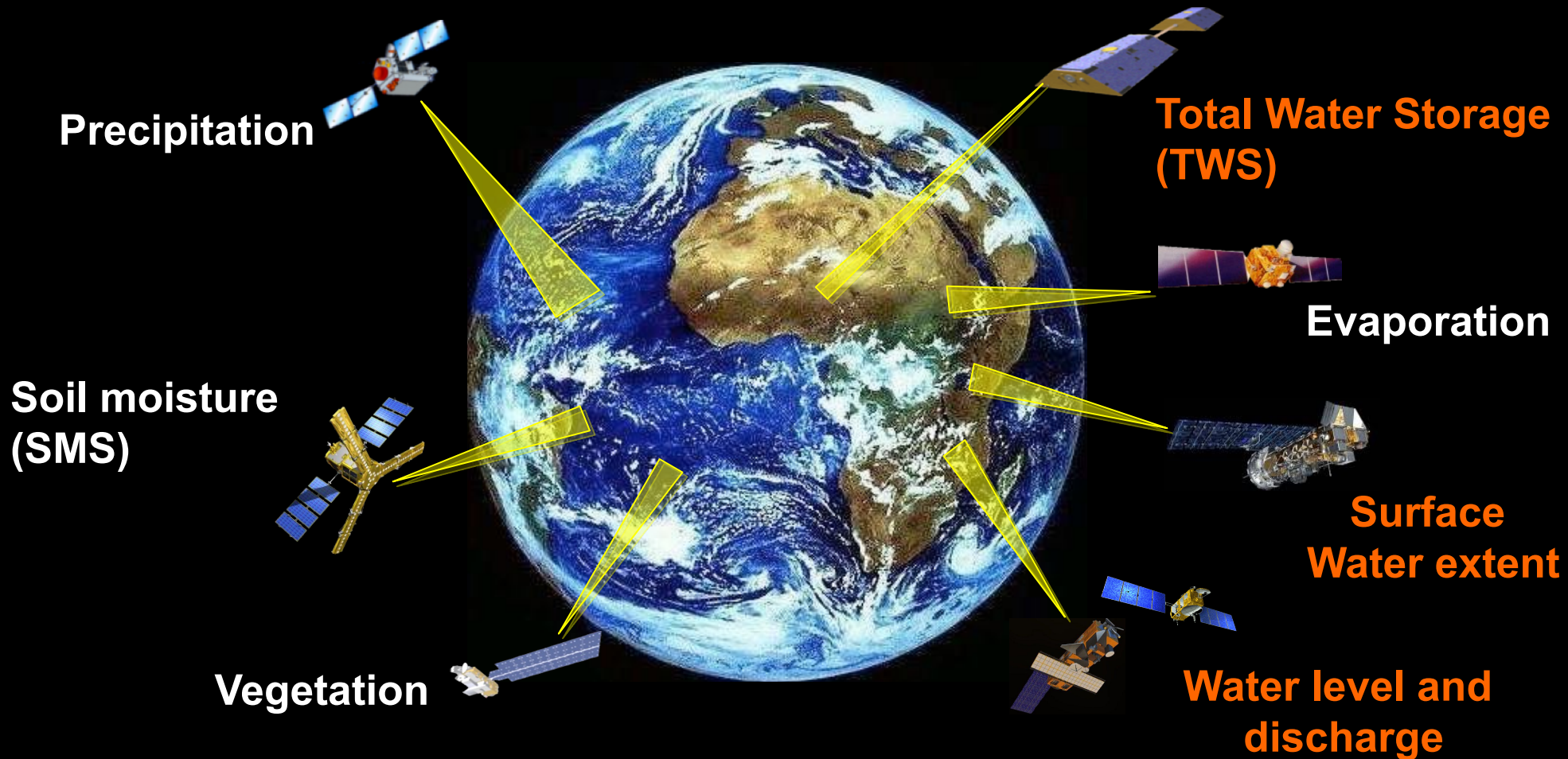
- Individual contribution of each reservoir to total storage is poorly known



→ This limits our understanding on the continental water cycle and water resources availability, especially in basin with extensive floodplains

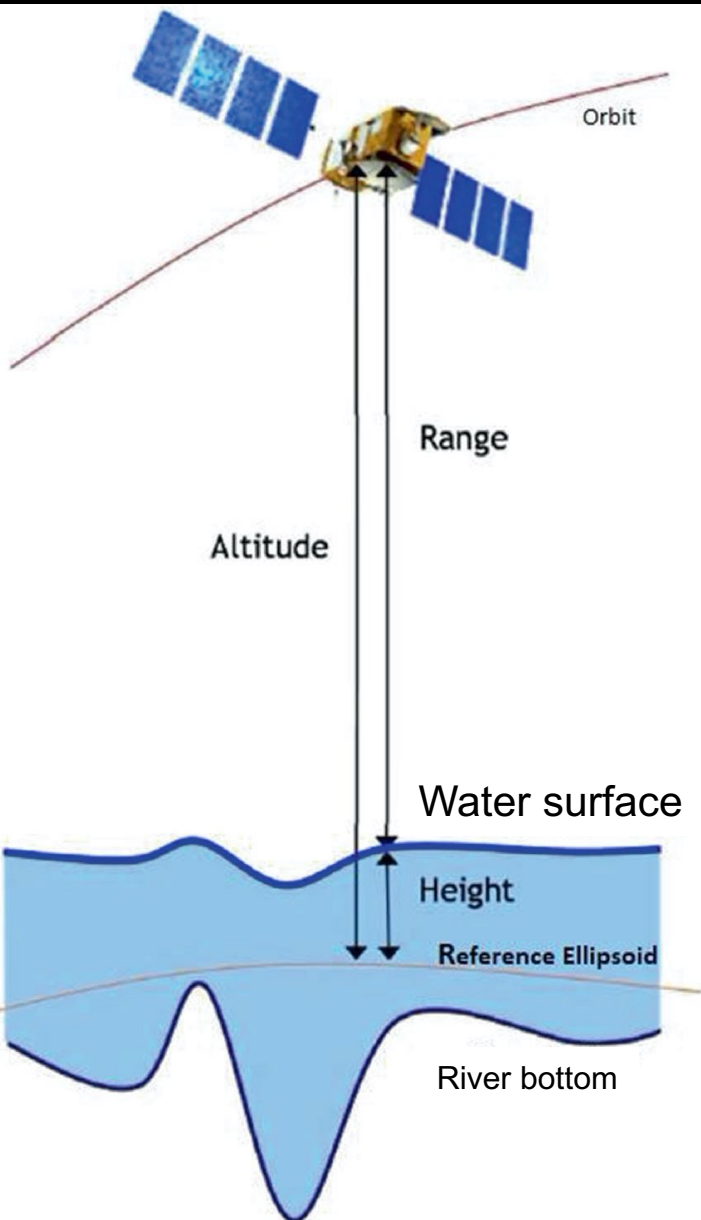
# Observing the water cycle variables from space

We have now a suite of complementary satellite missions that help us to characterize the variations of continental water storage



$$\Delta TWS = \Delta SWS + \Delta SMS + \Delta GW$$

# Radar altimetry over continental surface and water bodies



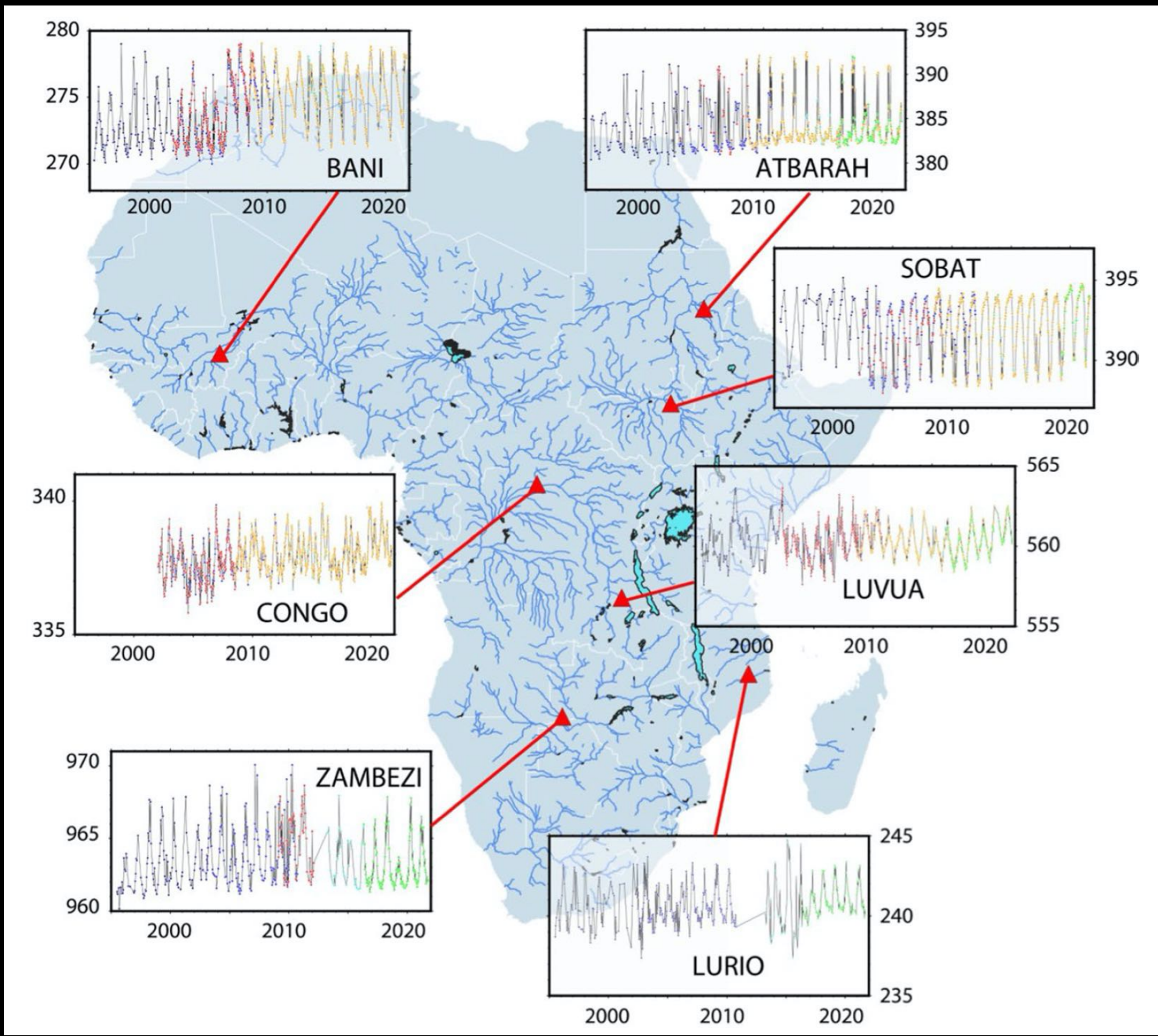
Primarily designed to measure sea surface height variations

It is also used to estimate water level variability over rivers/ lakes/ floodplains/ wetlands

Virtual stations

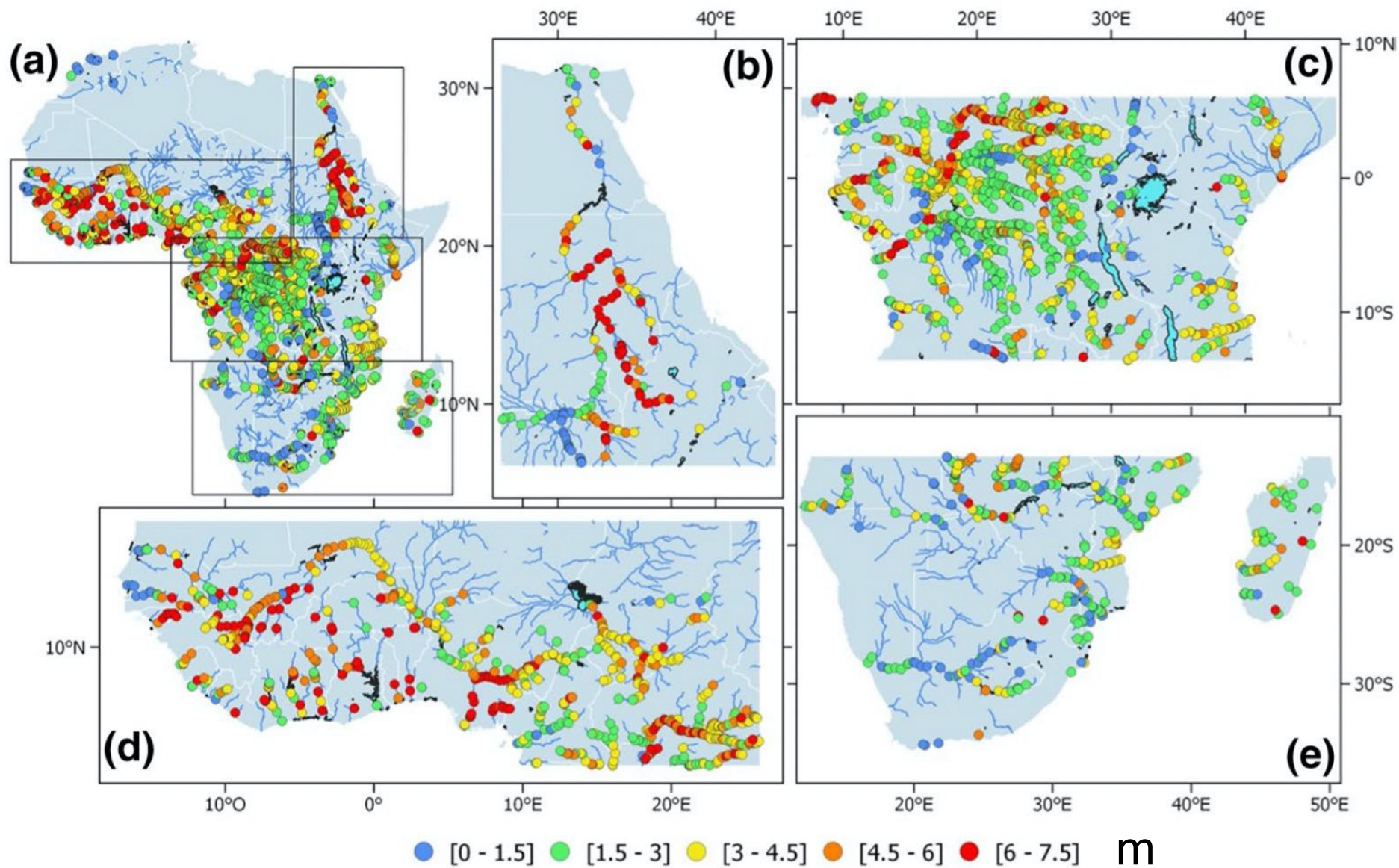


# L'altimétrie sur les rivières africaines





# L'altimétrie sur les rivières africaines



# Satellite Radar Altimetry over Continental Water Bodies



[hydroweb.theia-land.fr](http://hydroweb.theia-land.fr) free access of data with registration



# Variations of continental freshwater storage

## From surface to groundwater

Integrated Approach: multi-satellites *in situ* / modeling

$$dW/dt = P - E - Q$$

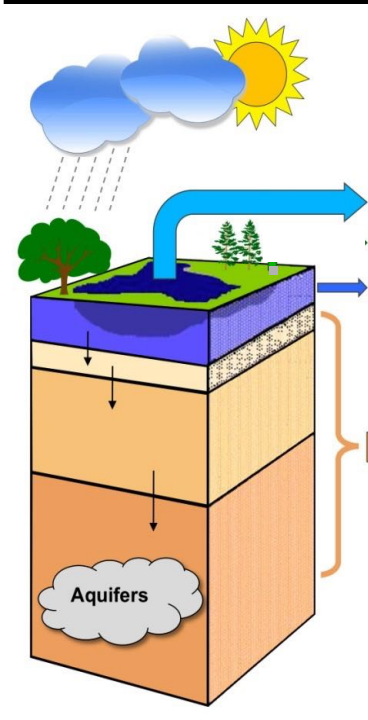
Total Water Stock

=

Surface  
water SWS

Soil moist.  
SMS

Ground-  
water  
GWS





# Variations of continental freshwater storage

## From surface to groundwater

Integrated Approach: multi-satellites / *in situ* / modeling

$$dW/dt = P - E - Q$$

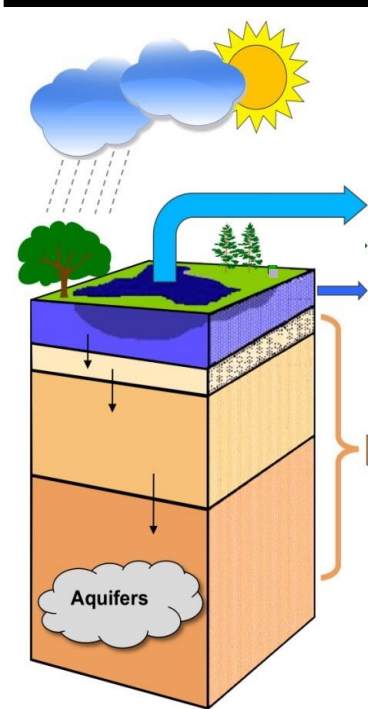
Total Water Stock

=

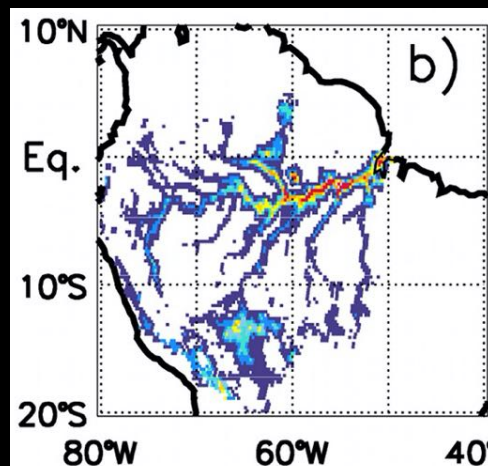
Surface  
water SWS

Soil moist.  
SMS

Ground-  
water  
GWS



## Dynamic of surface water storage: Amazone



More than 900 ENVISAT-derived Virtual Stations  
of water level heights combined with  
monthly GIEMS estimates 2003-2011

# Variations of continental freshwater storage

## From surface to groundwater

Integrated Approach: multi-satellites / *in situ* / modeling

$$dW/dt = P - E - Q$$

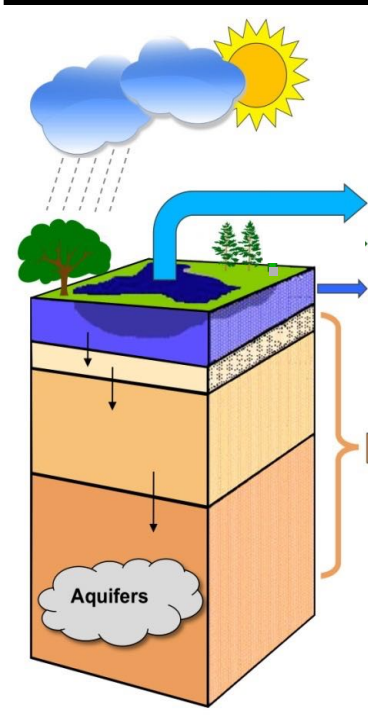
Total Water Stock

=

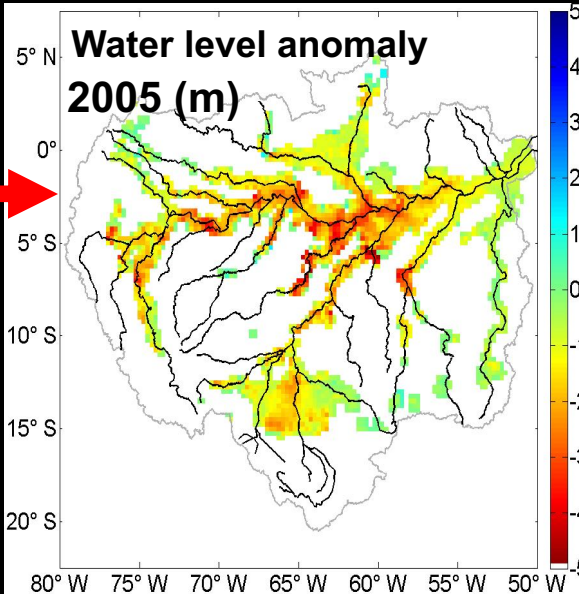
Surface  
water SWS

Soil moist.  
SMS

Ground-  
water  
GWS

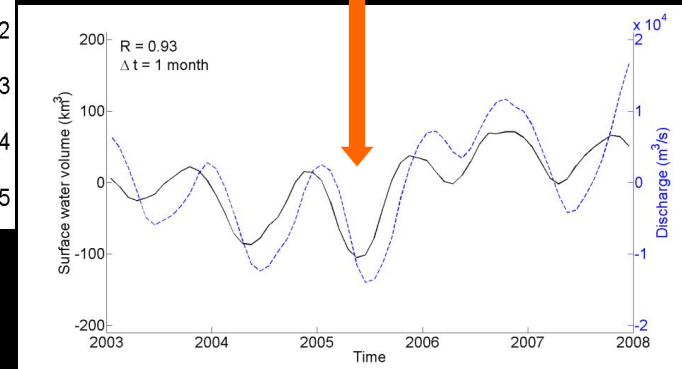


## Dynamic of surface water storage: Amazone



Papa et al., 2011, 2013  
Frappart et al., 2008, 2011, 2012  
Getirana et al., 2012 ;  
Pfeffer et al., 2014, Aires et al., 2014

**2005 Drought:  
SWS deficit in the  
Amazone basin = 70%**



**Mean annual amplitude of SWS variations of  
~1000 km<sup>3</sup> +/- 10%**

# Variations of continental freshwater storage

## From surface to groundwater

Integrated Approach: multi-satellites / *in situ* / modeling

$$dW/dt = P - E - Q$$

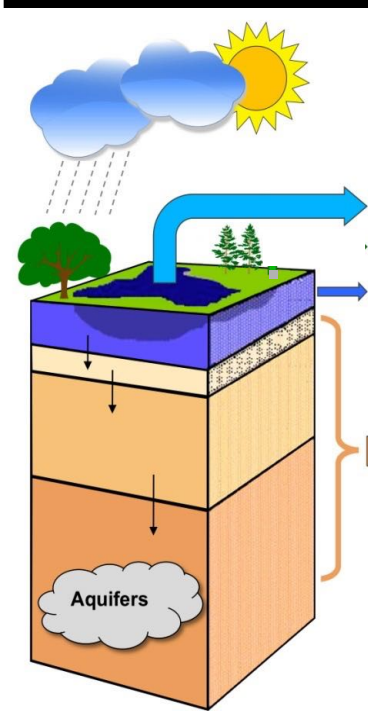
Total Water Stock

=

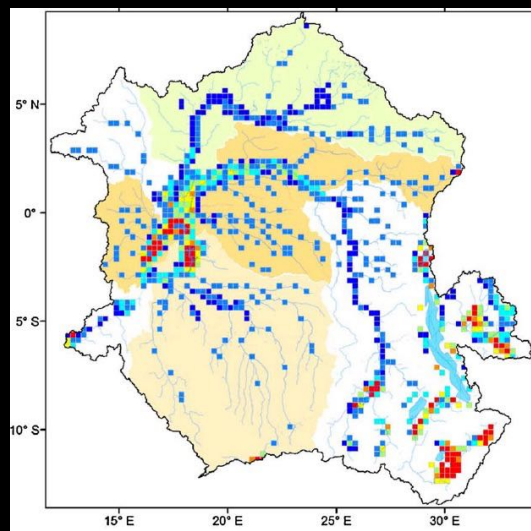
Surface  
water SWS

Soil moist.  
SMS

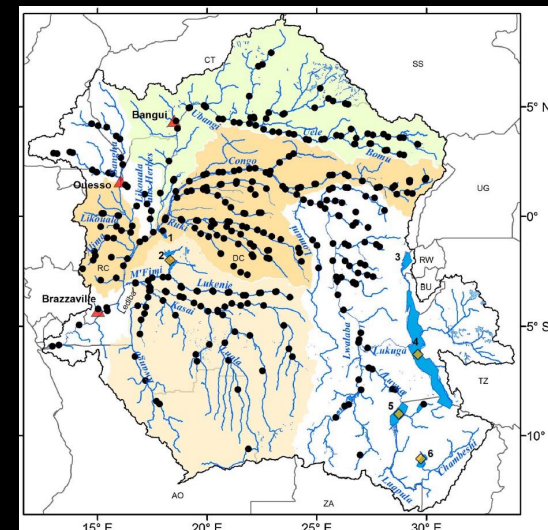
Ground-  
water  
GWS



## Dynamic of surface water storage : Congo



+



More than 300 ENVISAT-derived Virtual Stations of water level heights combined with monthly GIEMS estimates 2003-2007

See Becker et al., 2018; Kitmbo et al., 2022



# Variations of continental freshwater storage

## From surface to groundwater

Integrated Approach: multi-satellites / *in situ* / modeling

$$dW/dt = P - E - Q$$

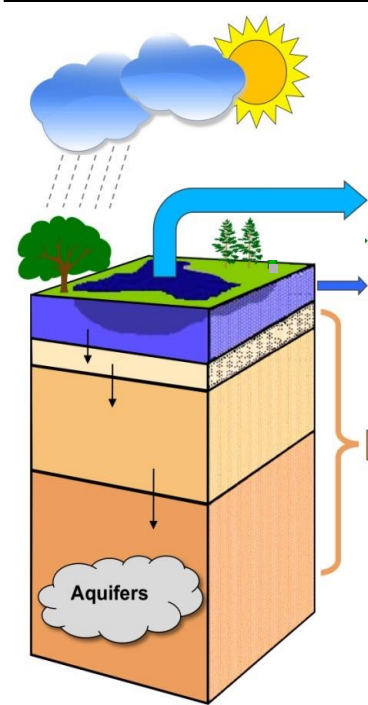
Total Water Stock

=

Surface  
water SWS

Soil moist.  
SMS

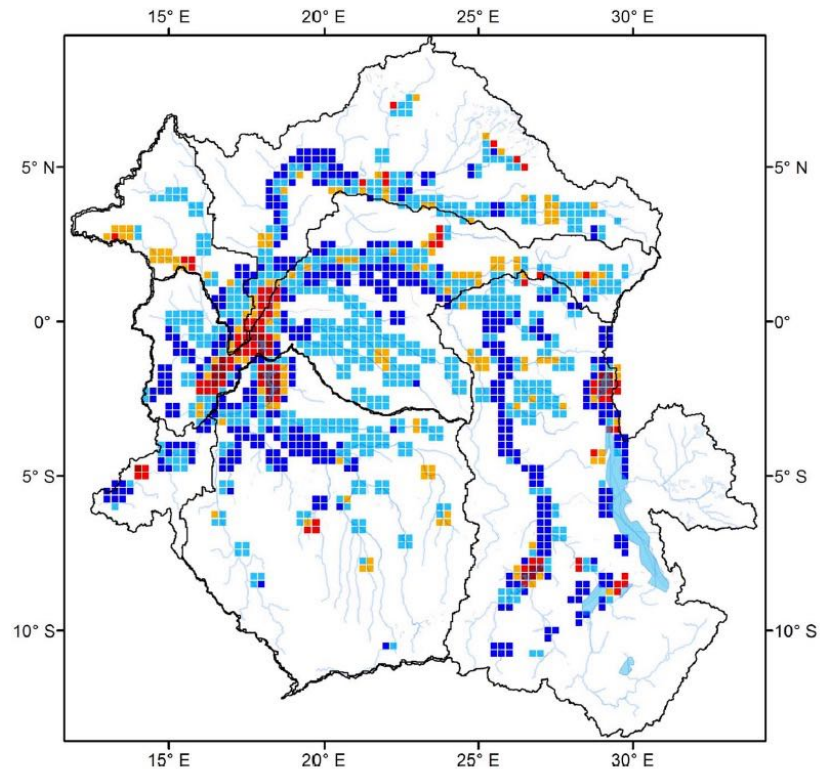
Ground-  
water  
GWS



## Dynamic of surface water storage: Congo

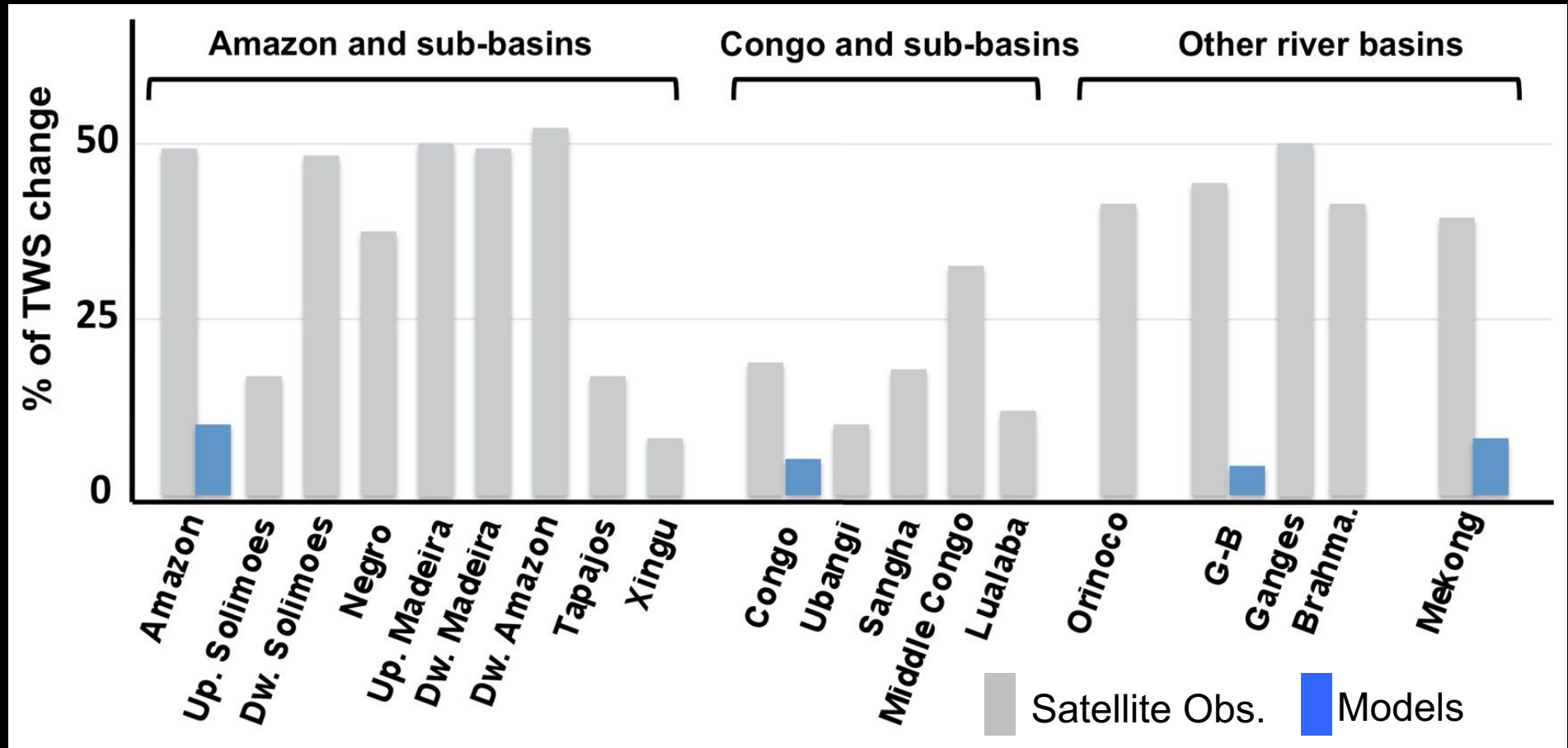
Maximum annual amplitude of SWS over 2003-2007 (km<sup>3</sup>)

■ [0,0 - 0,1] ■ [0,1 - 0,2] ■ [0,2 - 0,3] ■ [0,3 - 0,6] ■ [0,6 - 1,3]



# Variations of continental freshwater storage

The relative contribution of SWS to TWS over the Amazon, Congo, sub-basins and other large tropical rivers



The contribution of SWS, to TWS is found highly variable among the various basins and sub basins, in link with climatic and geological features

# Variations of continental freshwater storage

## From surface to groundwater

Integrated Approach: multi-satellites / *in situ* / modeling

$$dW/dt = P - E - Q$$

Total Water Stock

=

Surface  
water SWS

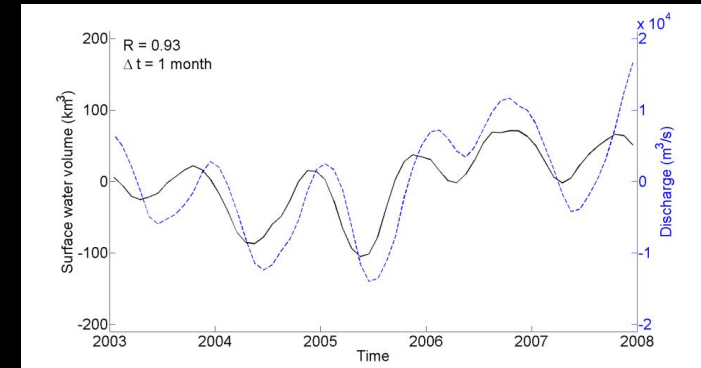
Soil moist.  
SMS

Ground-  
water  
GWS

Storage SWS=

Storage SMS= satellites obs. or modeling results ens.  
(WGHM, ISBA, GLDAS)

$$\Delta GW = \Delta TWS - \Delta SWS - \Delta SMS$$

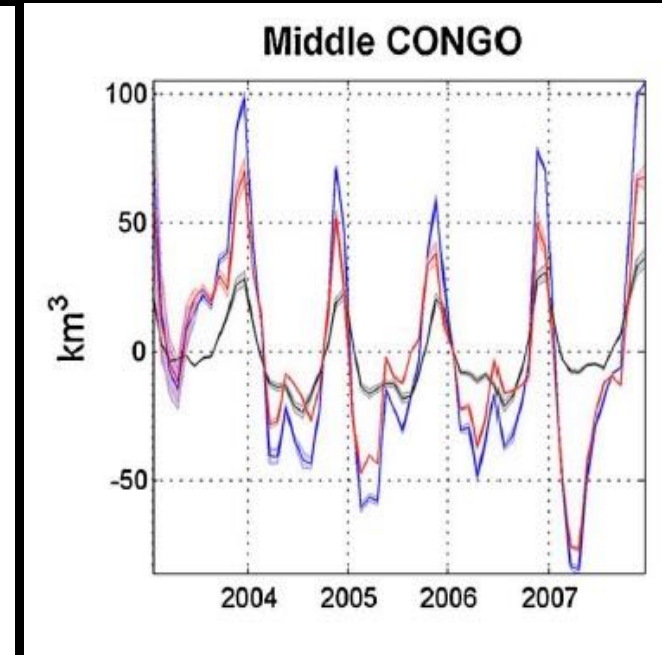
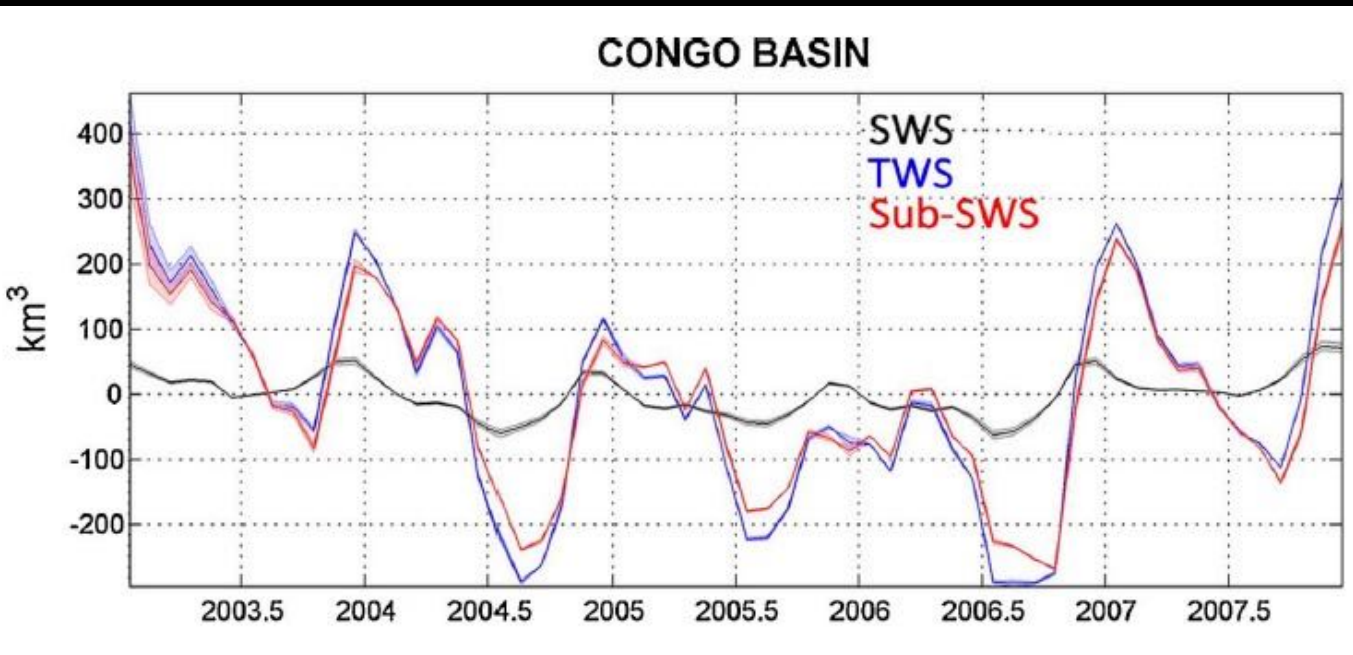


Towards the decomposition of  
GRACE TWS over the Amazon and Congo



# Variations of continental freshwater storage

## Variations of Congo sub-surface storage (SMS+GWS)

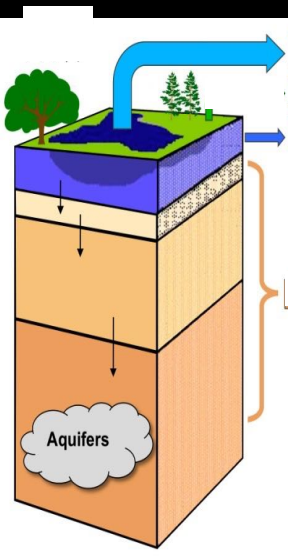
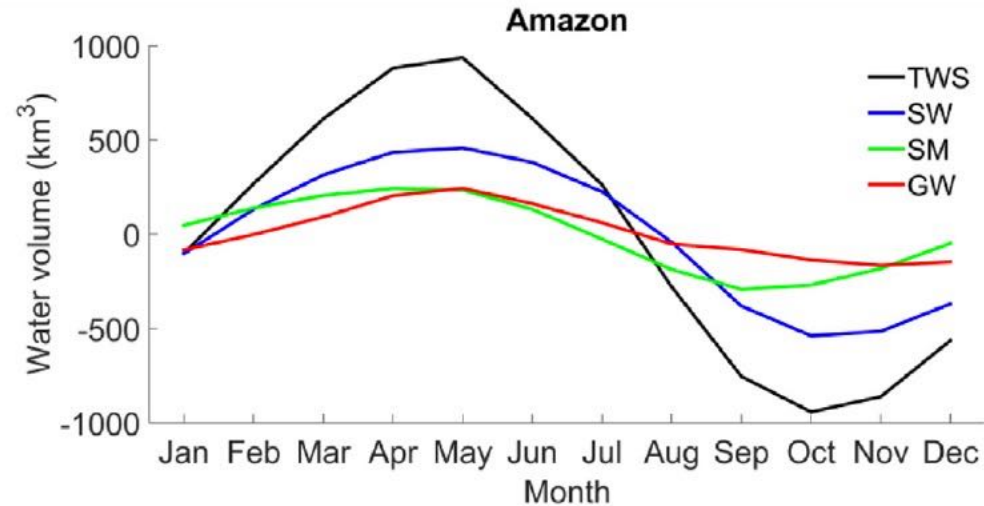
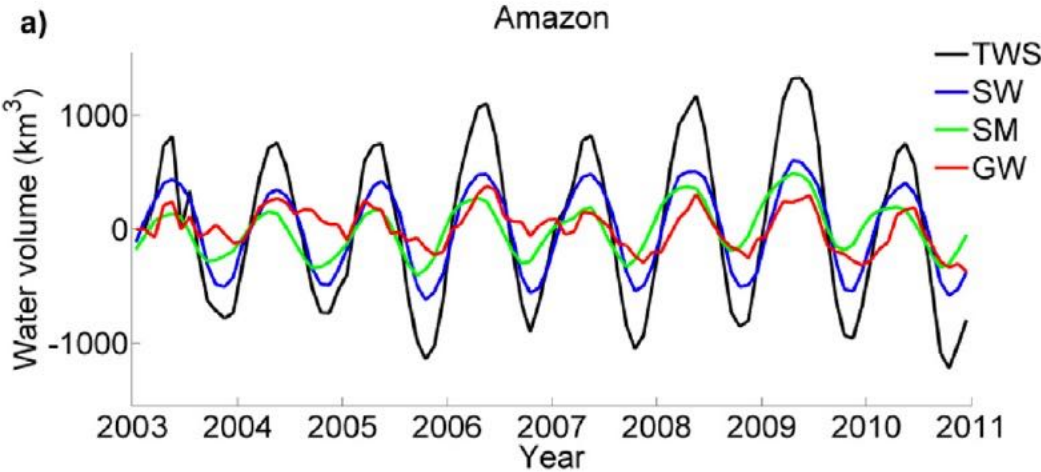


The basin-scale variability of water storage is driven by sub-surface freshwater changes (soil moisture + groundwater) but with spatial heterogeneity.

In the Cuvette Centrale SWS plays a key role.

# Variations of continental freshwater storage

## The first full decomposition of continental water storage : the Amazon



Surface water  
~45% of TWS variations

Soil moisture RZ  
~25% of TWS variations

Ground-water  
~30% of TWS variations

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journal homepage: [www.elsevier.com/locate/advwatres](http://www.elsevier.com/locate/advwatres)

The spatio-temporal variability of groundwater storage in the Amazon River Basin

F. Frappart<sup>b,\*</sup>, F. Papa<sup>b,c</sup>, A. Güntner<sup>d</sup>, J. Tomasella<sup>e</sup>, J. Pfeffer<sup>f</sup>, G. Ramillien<sup>g</sup>, T. Emilio<sup>h,i</sup>, J. Schiatti<sup>b</sup>, L. Seoane<sup>g</sup>, J. da Silva Carvalho<sup>j</sup>, D. Medeiros Moreira<sup>j</sup>, M.-P. Bonnet<sup>k</sup>, F. Seyler<sup>k</sup>

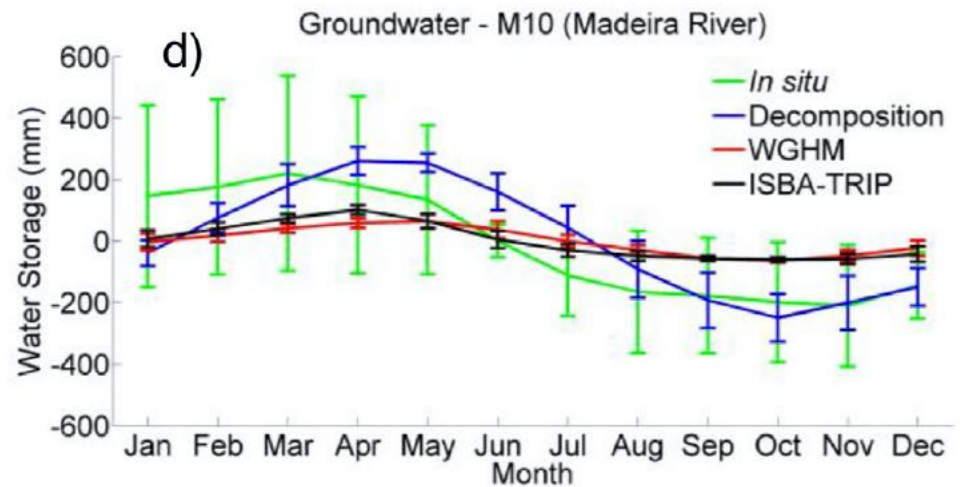
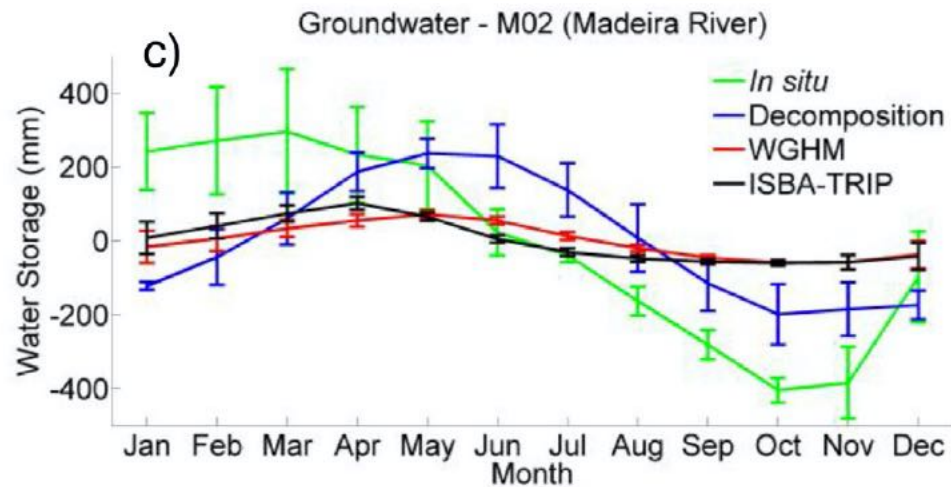
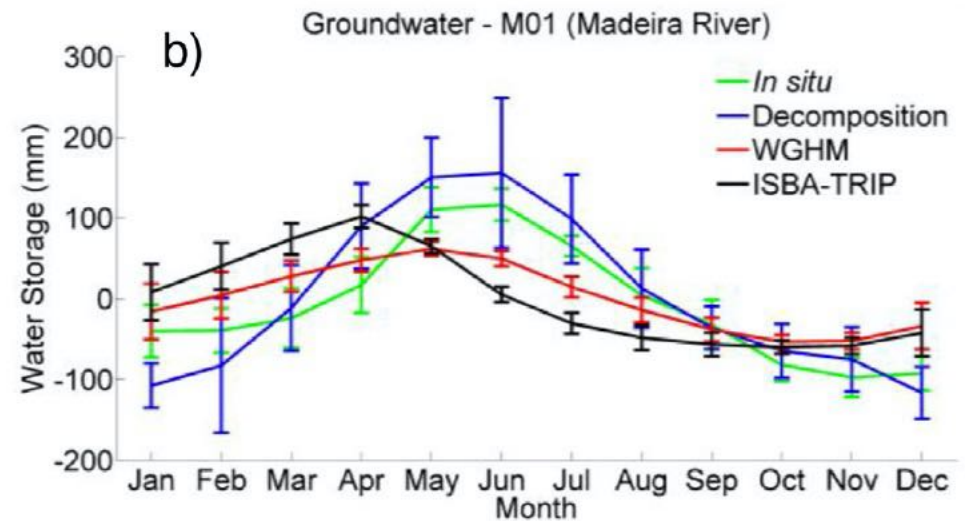
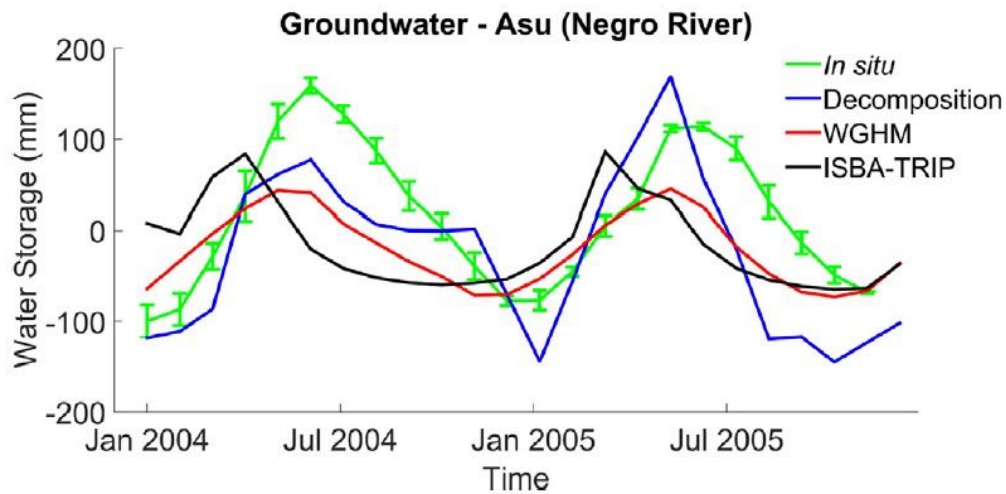
<sup>a</sup> Géosciences Environnement Toulouse (GET), UMR 5563, CNRS/IRD/UPS, Observatoire Midi-Pyrénées (OMP), 14 Avenue Edouard Belin, 31400 Toulouse, France  
<sup>b</sup> Laboratoire d'Études en Géophysique et Océanographie Spatiales (LEGOS), UMR 5566, CNRS/IRD/UPS, Observatoire Midi-Pyrénées (OMP), 14 Avenue Edouard Belin, 31400 Toulouse, France  
<sup>c</sup> IFCWS, IRD-IISc, Joint International Laboratory, Indian Institute of Science, 560012 Bangalore, India  
<sup>d</sup> Deutsches GeoForschungsZentrum (GFZ), Telegrafenberg, Potsdam, Germany  
<sup>e</sup> Centro Nacional de Monitoramento e Alerta de Desastres Naturais - CEMADEN, Rodovia Presidente Dutra km 39, 12630-000 Cachoeira Paulista, SP, Brazil  
<sup>f</sup> Research School of Earth Sciences, Australian National University, Canberra, Australian Capital Territory, Australia  
<sup>g</sup> Comparative Plant & Fungal Biology, Royal Botanic Gardens, Kew, Richmond, Surrey, UK  
<sup>h</sup> Instituto Nacional de Pesquisas da Amazônia (INPA), Manaus, AM, Brazil  
<sup>i</sup> Universidade Federal do Amazonas (UFAM), Manaus, AM, Brazil  
<sup>j</sup> CPRM/Geological Survey of Brazil, Rio de Janeiro, Brazil  
<sup>k</sup> IRD, UMR Espace-Dev, Maison de la télédétection, 500 rue JF Breton, 34093 Montpellier Cedex 5, France

\* Department of Plant Biology, Institute of Biology, University of Campinas, CEP 13083-970, Campinas, SP, Brazil

# Variations of continental freshwater storage

Can we validate our results of Groundwater Storage estimates?

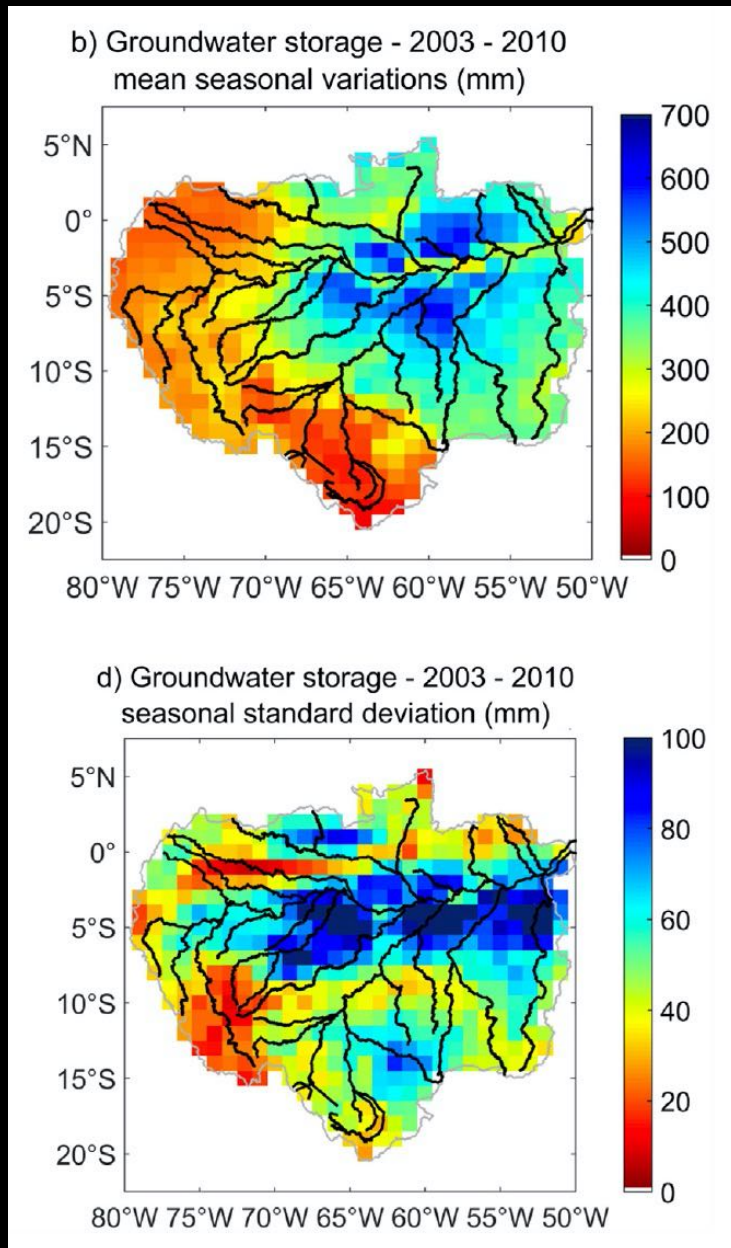
Very few in situ measurements available with the same time-span





# Variations of continental freshwater storage

## Groundwater storage variations

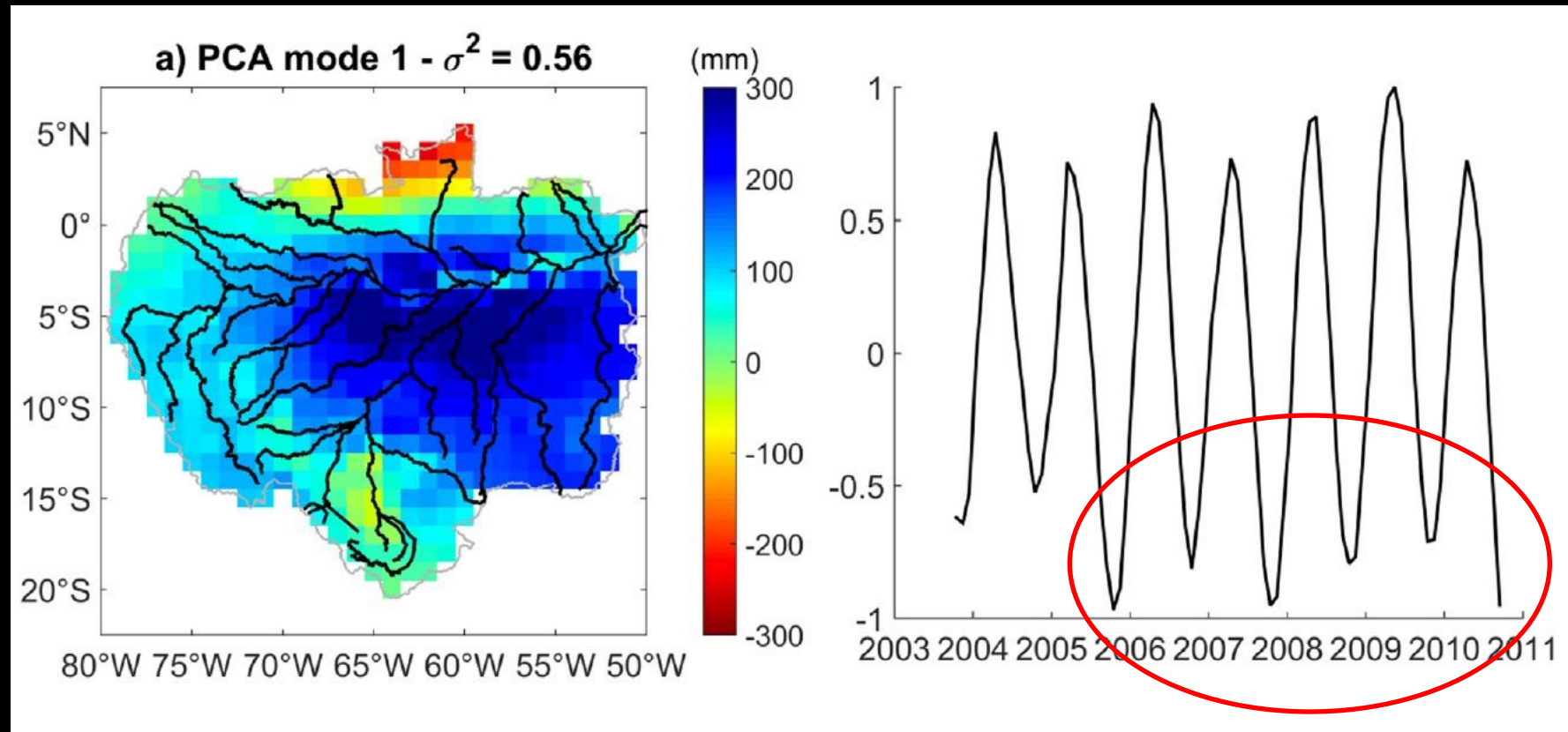


**Mean seasonal variations of  
Groundwater 2003-2010**

**and variability 2003-2010**

# Variations of continental freshwater storage

## Groundwater storage variations

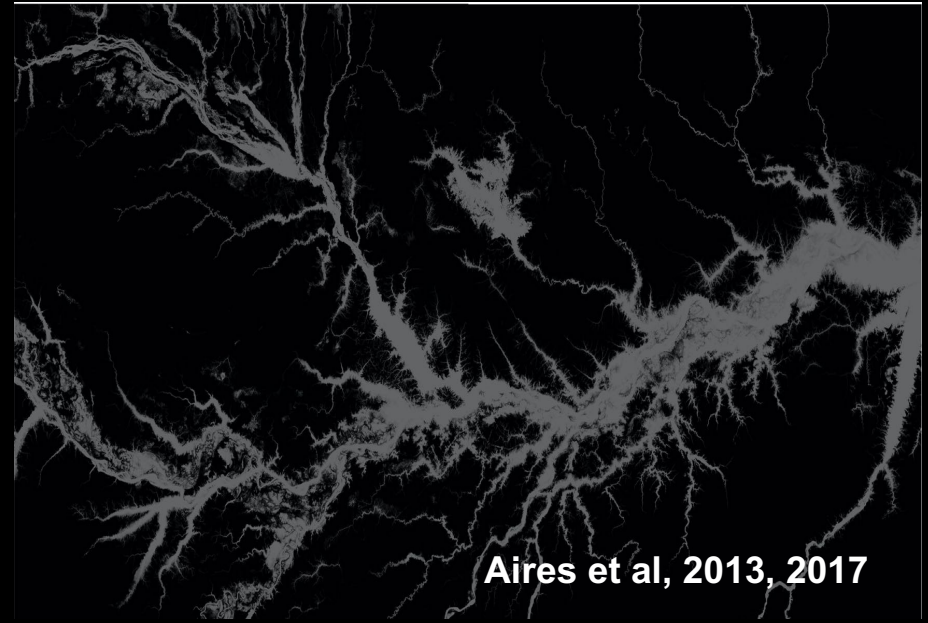


**Suggest a memory effect of the 2005 drought on the GW variations**

**(Datasets fully available upon request to authors)**

# Perspectives:

- **Derive Surface Water Storage at high resolution (90m)**
- **Merge the dataset to better understand flood dynamics and hydrological processes of SW and GW exchanges and the drivers during extreme events**
- **Support model development**
- **Extent the time series using the long-term (>20y) GIEMS-2 + Altimetry (from ERS-2 to S3-A/B) in combination with GRACE and GRACE-FO**
- **Methodology has been applied to other Basins (Ganges-Brahmaputra, Mekong, Chad) and is under development at the global scale**



Article | [Open Access](#) | Published: 26 March 2020

## The Lake Chad hydrology under current climate change

Binh Pham-Duc [✉](#), Florence Sylvestre [✉](#), Fabrice Papa, Frédéric Frappart, Camille Bouchez & Jean-Francois Crétaux

*See Pham-Duc et al., 2021*



# The future of Hydrology from Space

## Surface Water and Ocean Topography, 2022

- Provide with a global inventory of surface water (lakes, reservoirs, wetlands > 250x250 m) and rivers (>100 m)
- From intra- to pluri-annual scale, direct estimates of global surface water storage (and river discharge) variability

