Continental freshwater dynamic from multi-satellite observations. Towards the storage and fluxes at high spatio-temporal resolution

Fabrice Papa, Frédéric Frappart, Daniel Moreira, Filipe Aires, Victor Pellet, Javier Tomasella, Rodrigo Paiva, Joecila Dos Santos, Ayan Fleischmann, Alex Ovando, M-P Bonnet, Augusto Getirana, Frédérique Seyler, Stephane Calmant, Catherine Prigent et al.

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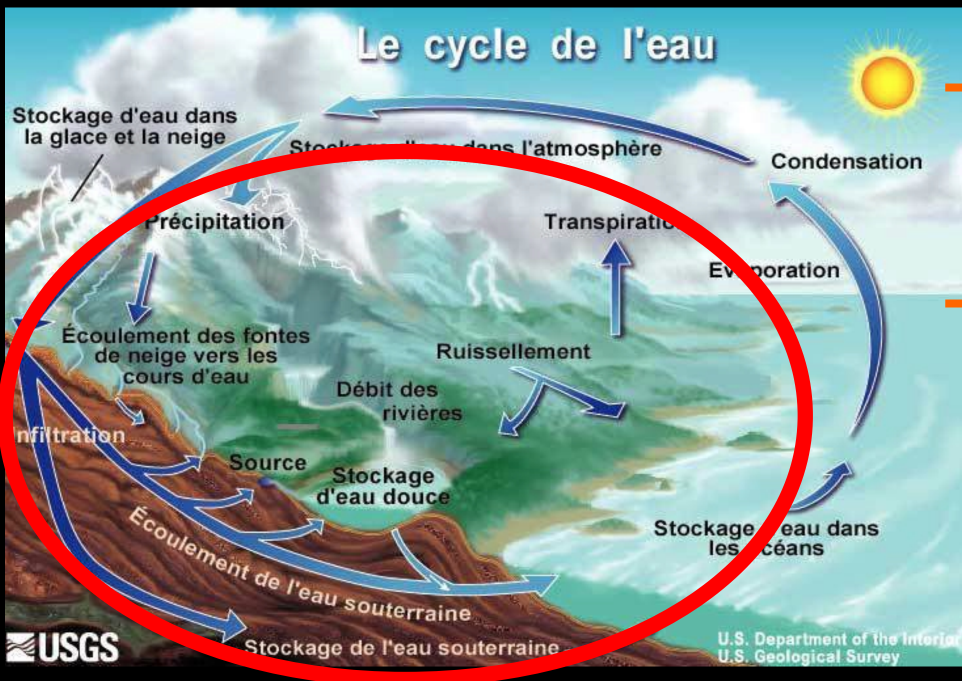
LEGOS

French National Research Institute for Sustainable Development
IRD
Institut de Recherche pour le Développement
FRANCE

Continental Waters in the climate system

Freshwater, an essential ressource 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 ressource policy / society

Continental Waters in the climate system

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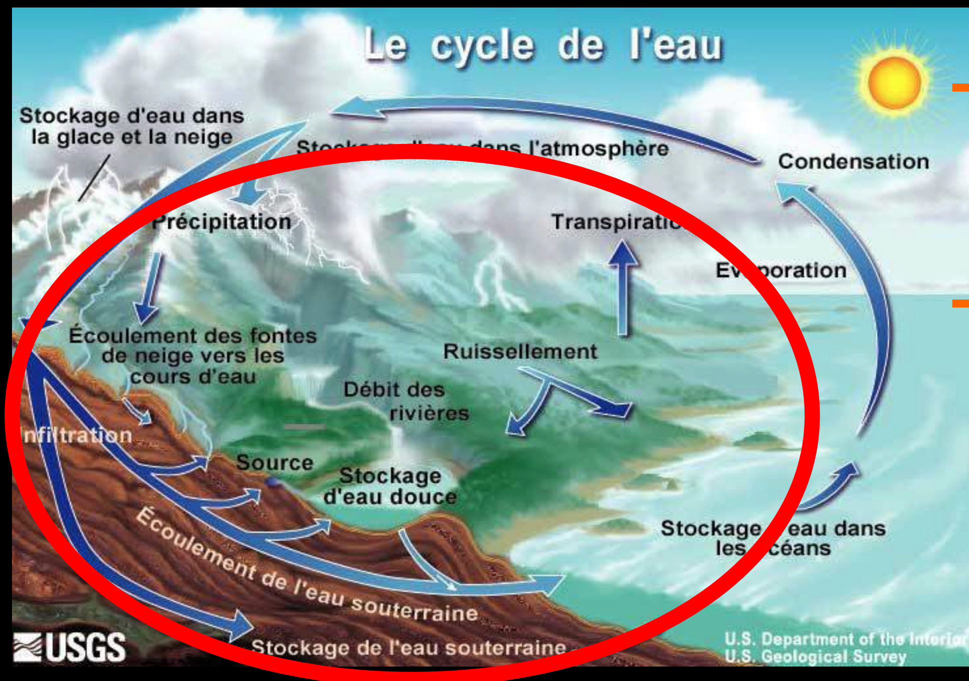

Critical to sustain life and for human Health, activities and the environment

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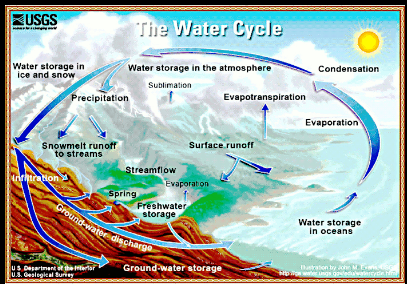
Water ressource policy / society

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

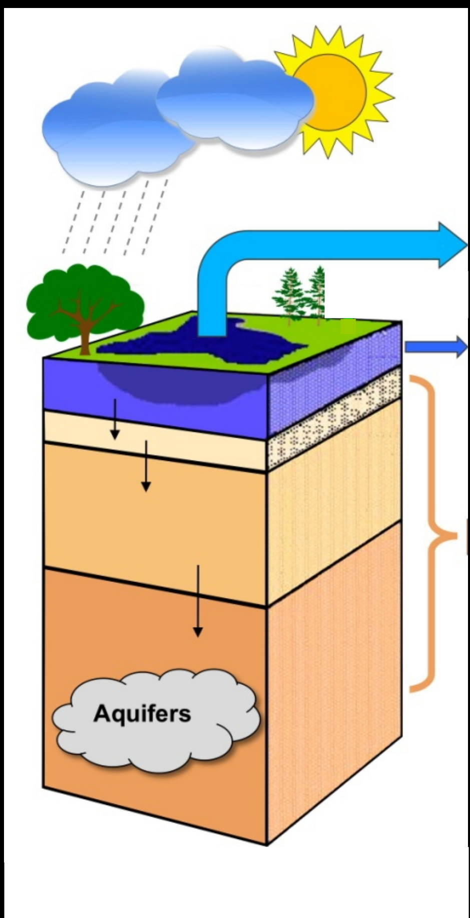
What are their interactions with the climate and the anthropogenic pressure?

The Continental Water Cycle and Water Storage and fluxes



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)

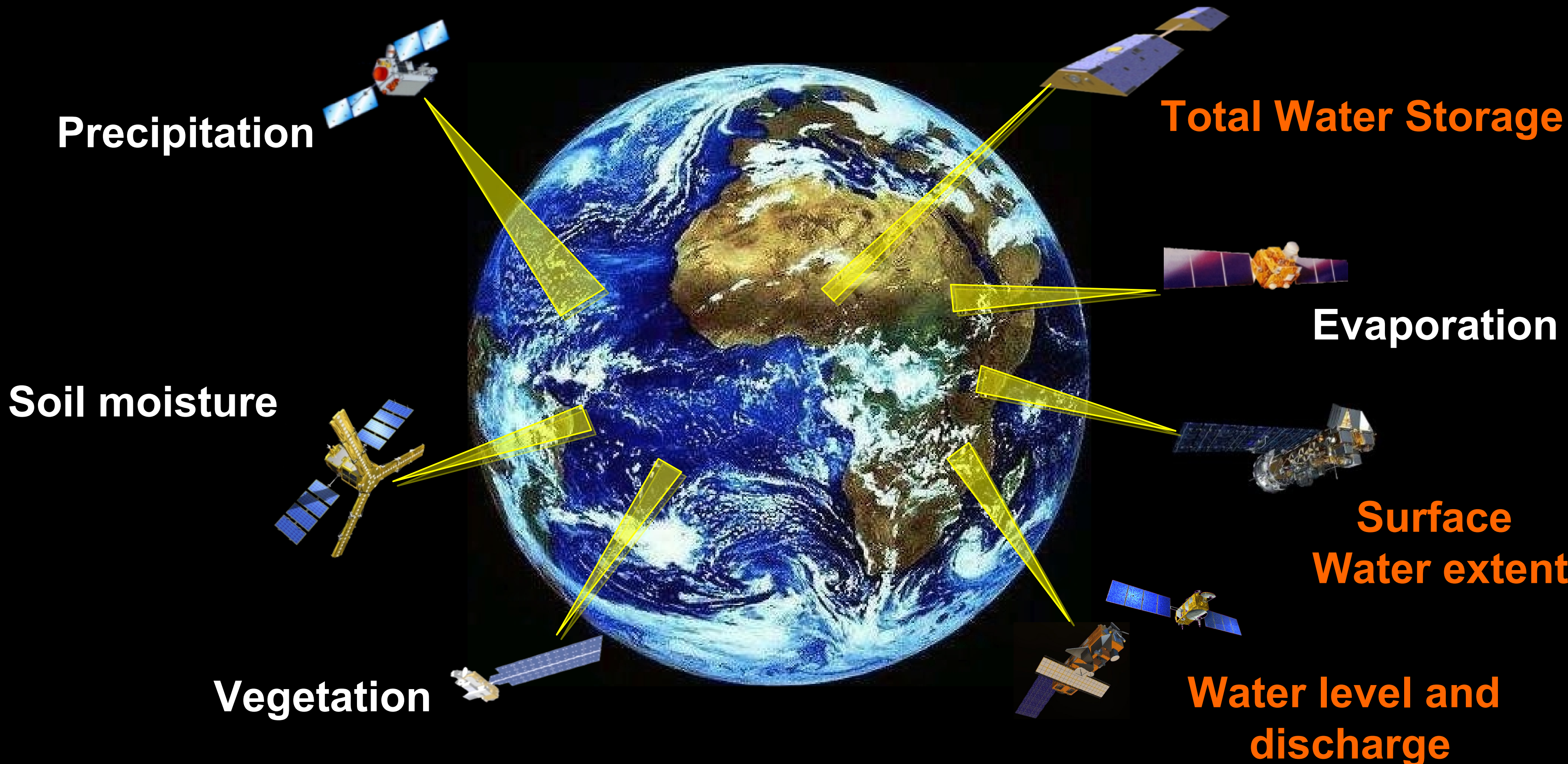
- Large uncertainties
- Lack of (available) *in situ* obs. network
- Individual contribution of each reservoir to total storage, their variability and interactions poorly known

➡ This limits our understanding on the continental/global water cycle and water resources availibility

➡ Need of an integrated approach: satellites/*in situ*/modeling

Observing the water cycle from space

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



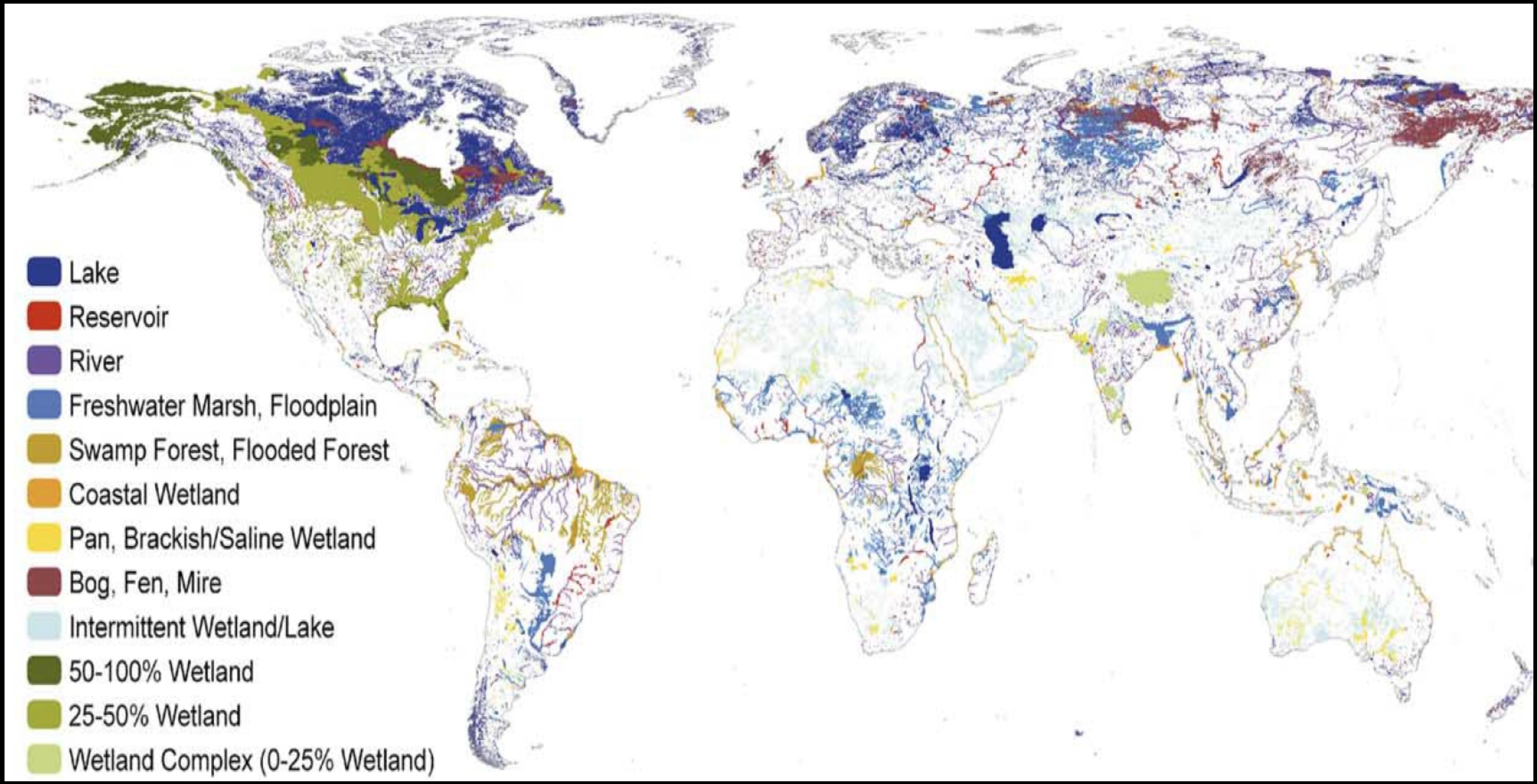
$$dW/dt = P - E - Q$$

Available surface water datasets today (not exhaustive)

High-resolution inundation extent datasets

- Global but static

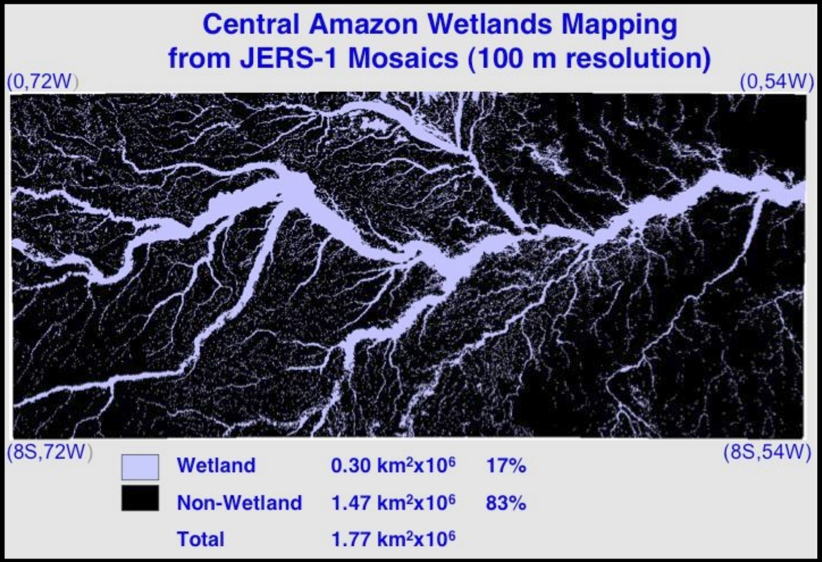
  → from inventory collections (GLWD Lehner and Doell, 2004 at 30s)



Available surface water datasets today (not exhaustive)

High-resolution inundation extent datasets

- Global but static
  - ➞ from inventory collection (GLWD Lehner and Doell, 2004 at 30s)
- Over limited regions and limited time period, from satellite
  - ➞ from satellite obs. in the visible/IR images, only under clear conditions and low vegetation density, but with good temporal sampling (MODIS, AVHRR, S2, e.g., Sakamoto et al., 2004, Berger et al., 2014, etc)
  - ➞ From SAR images, even under clouds and forests, but very limited time sampling (e.g., Hess et al., 2003, 2015 over the Amazon, 100m)



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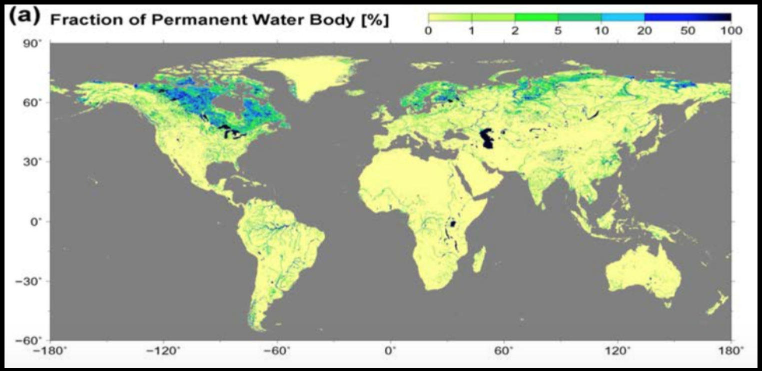
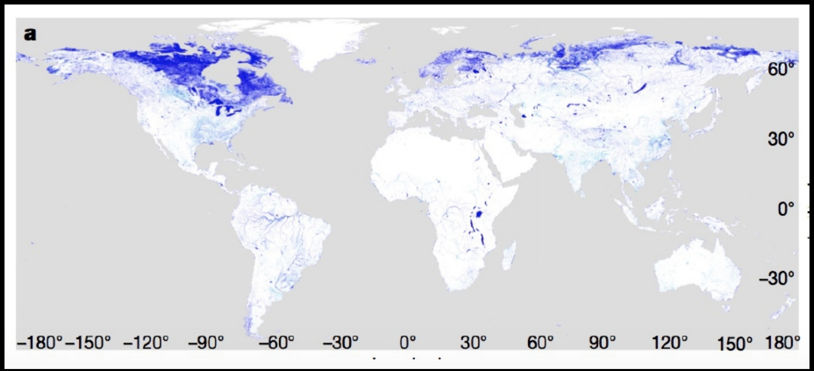
  - → From SAR images, even under clouds and forests, but very limited time sampling (e.g., Hess et al., 2003 over the Amazon, 100m)
- Global and dynamic
  - → from SAR, Sentinel 1 (Santoro et al., 2019, not yet available)
  - → from Landsat: G3WBM (Yamasaky et al. 2015, 3s) and GSWO (Peckel et al. 2016, at 30m)

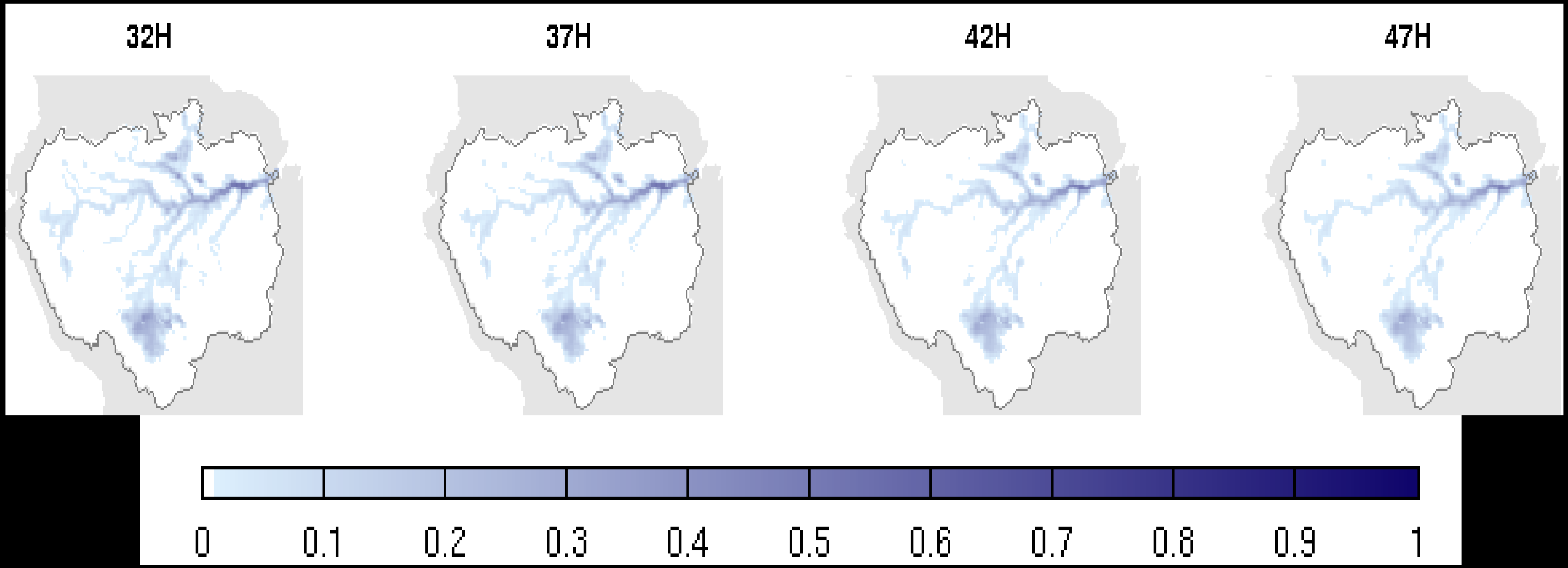




Available surface water datasets today (not exhaustive)

Low-resolution inundation extent datasets

- Regional and dynamic
  - → Using passive microwaves observations such as SMMR (Sippel et al., 1998) or SMOS (Parrens et al., 2017) over the Amazon bassin



Available surface water datasets today (not exhaustive)

Low-resolution inundation extent datasets

- Regional and dynamic
  - → Using passive microwaves observations such as SMMR (Sippel et al., 1998) or SMOS (Parrens et al., 2017) over the Amazon bassin
- **Global and dynamic using multi-satellite observations**
  - → **SWAMPS** (Schroeder et al. 2016), from NASA/JPL: recent years, coarse resolution, not fully evaluated as shown in Pham-Duc et al., 2017

Available surface water datasets today (not exhaustive)

Low-resolution inundation extent datasets

- Regional and dynamic
  - → Using passive microwaves observations such as SMMR (Sippel et al., 1998) or SMOS (Parrens et al., 2017) over the Amazon bassin
- Global and dynamic using multi-satellite observations
  - → SWAMPS
  - → Merging SMAP, AMSR2 and Landsat (Du et al., 2018)

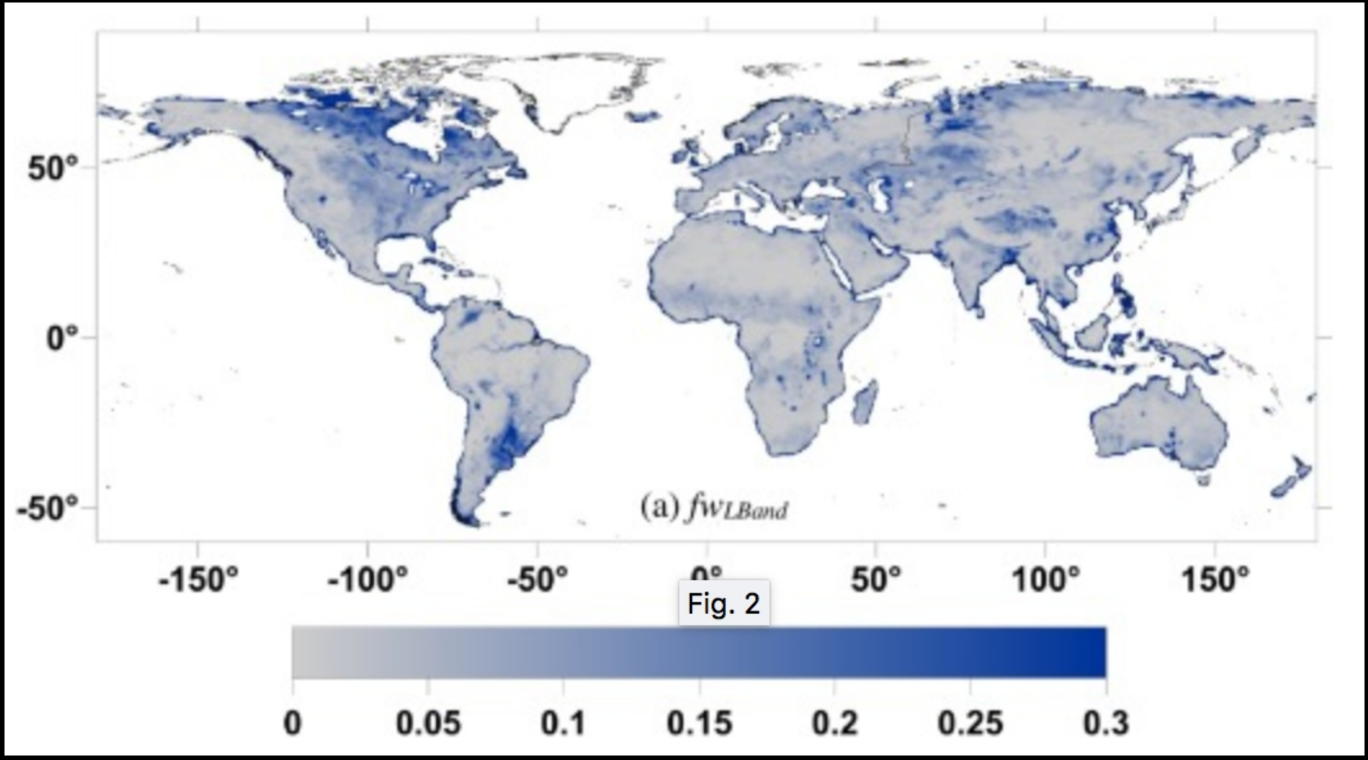
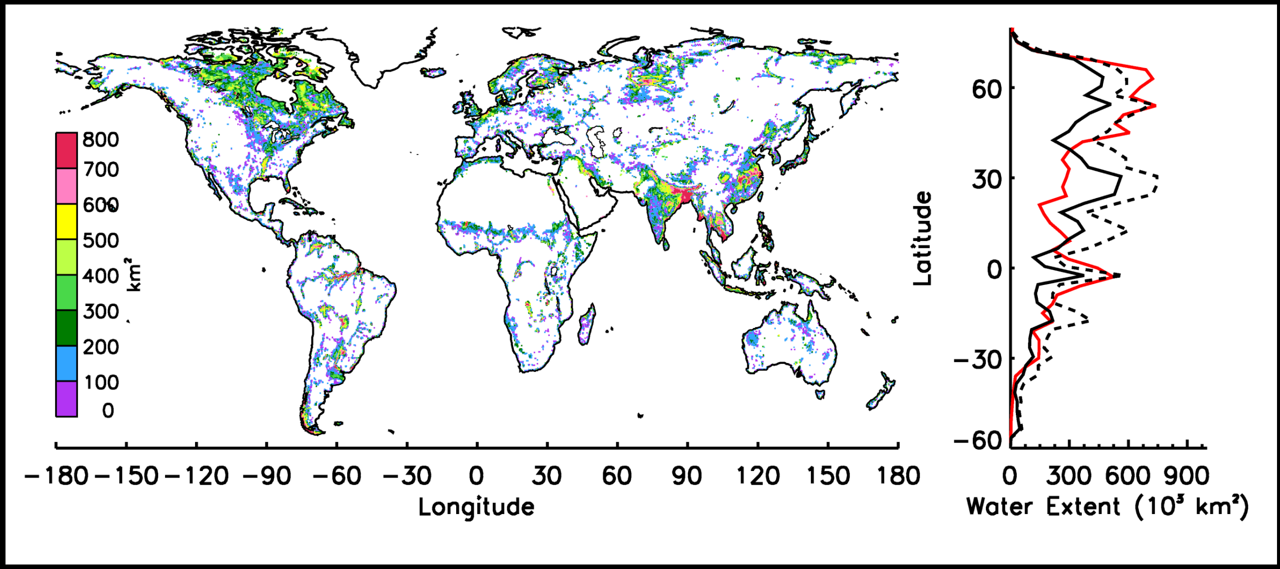


Fig. 2

Available surface water datasets today (not exhaustive)

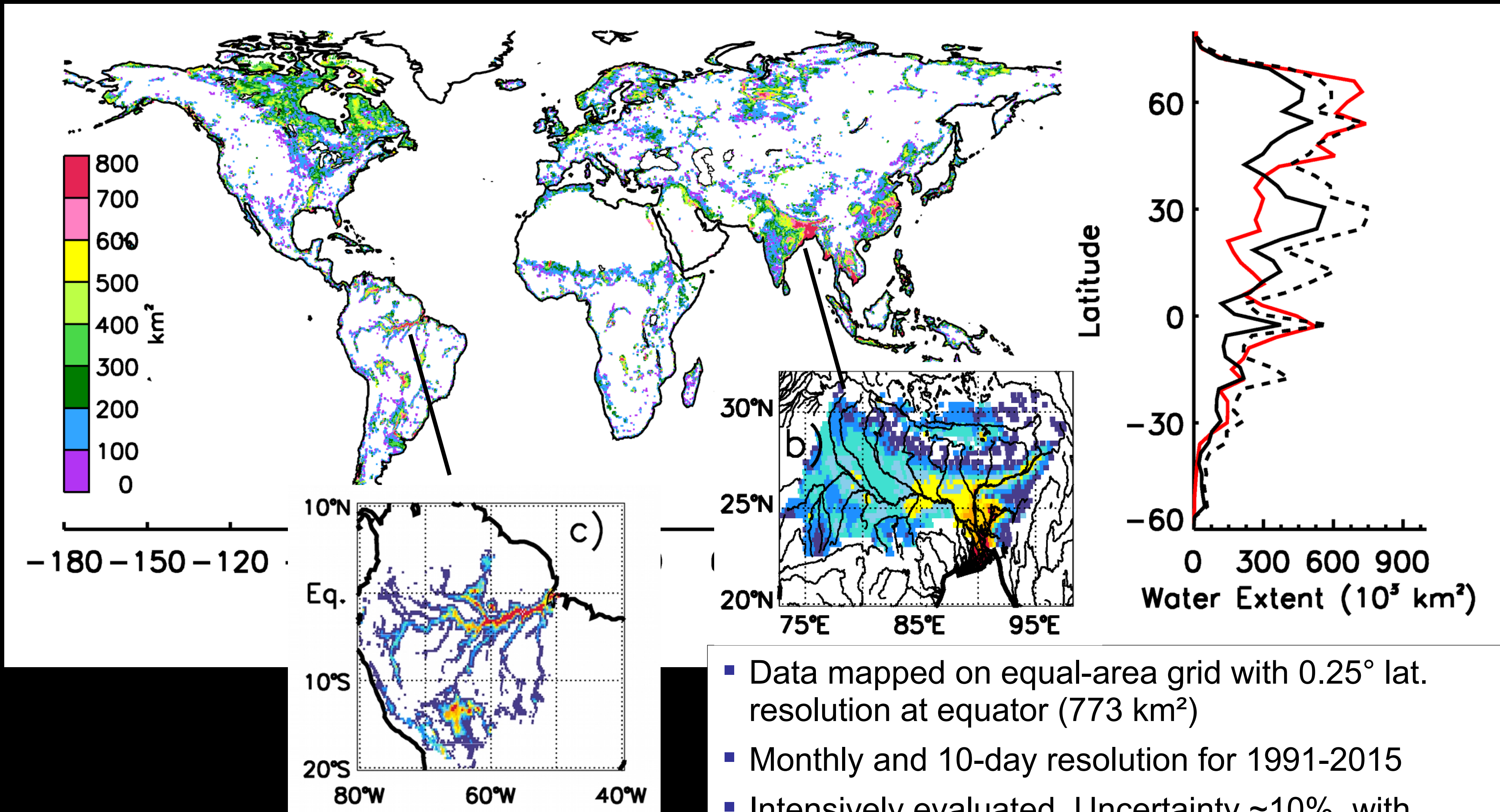
Low-resolution inundation extent datasets

- Regional and dynamic
  - → Using passive microwaves observations such as SMMR (Sippel et al., 1998) or SMOS (Parrens et al., 2017) over the Amazon bassin
- Global and dynamic using multi-satellite observations
  - → SWAMPS
  - → Newly products merging SMAP, AMSR2 and Landsat (Du et al., 2018)
  - → GIEMS Global Inundation Extent from Multi-Satellite (Papa et al., 2010; Prigent et al., 2007, 2012, 25km, monthly, 1993-2007) and Downscaling: GIEMS-D15 and GIEMS-D3 (Aires et al. 2017, 90m, monthly, 1993-2007)



Dynamic of surface water extent at global scale from multi-satellite

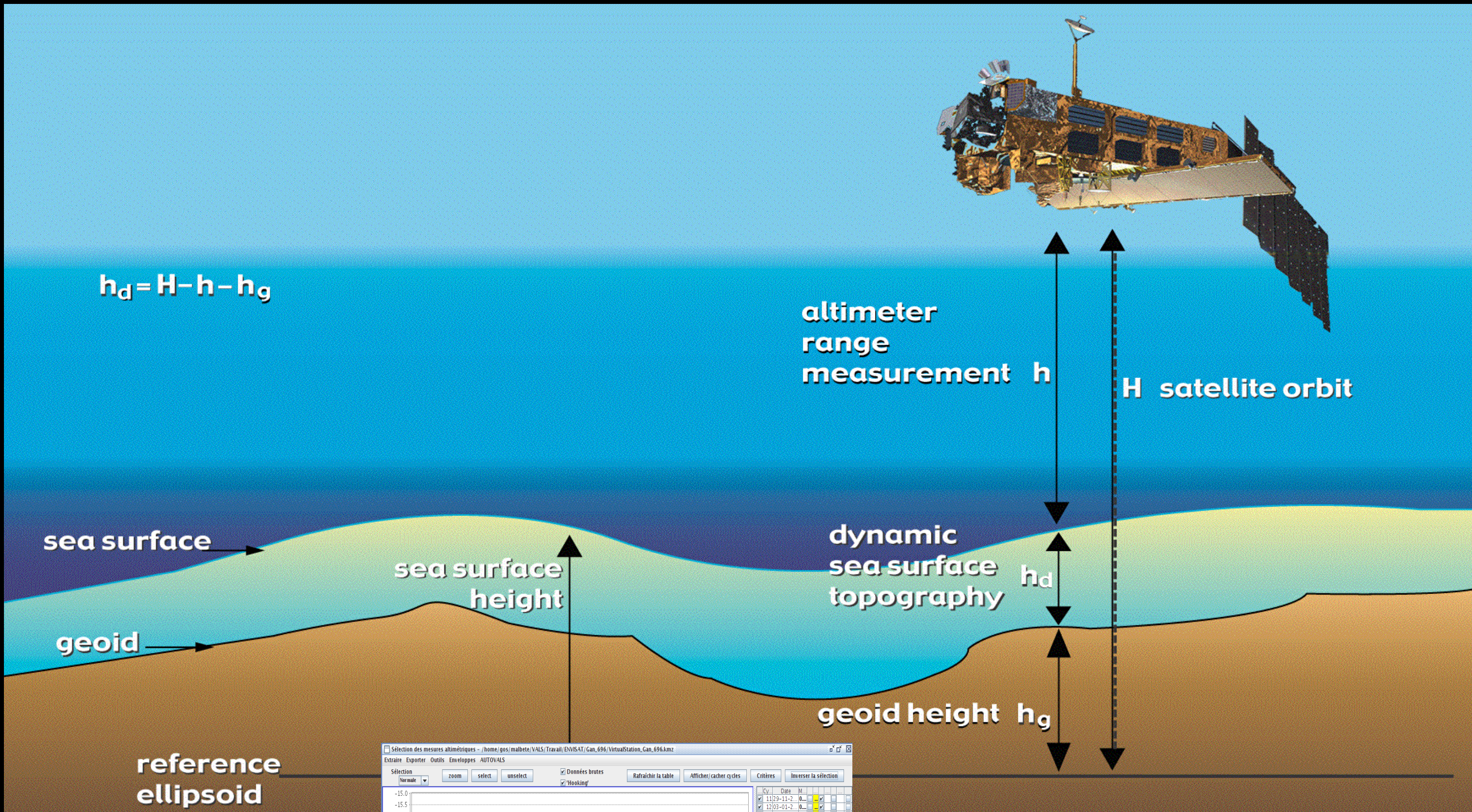
Mean fractional surface water extent at annual maximum



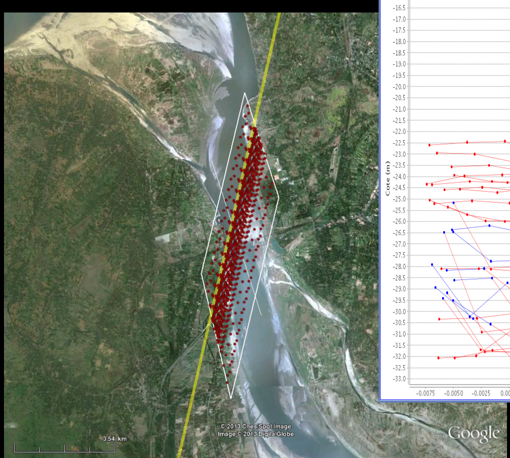
- Data mapped on equal-area grid with 0.25° lat. resolution at equator (773 km²)
- Monthly and 10-day resolution for 1991-2015
- Intensively evaluated. Uncertainty ~10%, with mainly underestimation in area with low water extent

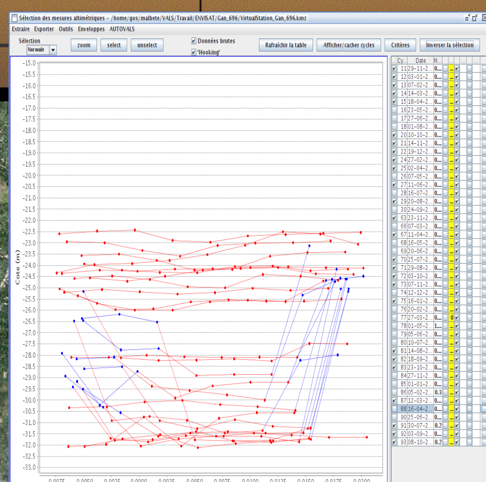
Papa et al., 2006, 2007,2008a,b, 2010, 2013
Prigent et al, 2001; 2007; 2012, 2016, 2019

Water Level : Radar Altimetry over Continental Water Bodies



Topex-Poseidon
ERS1/2
ENVISAT
Jason-1/2/3
AltiKa
S-3
.....





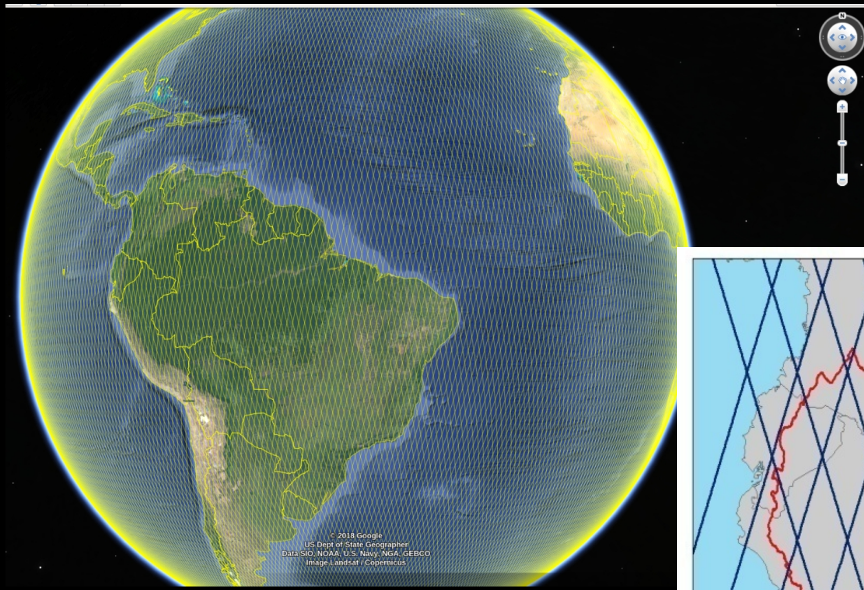
MAPS

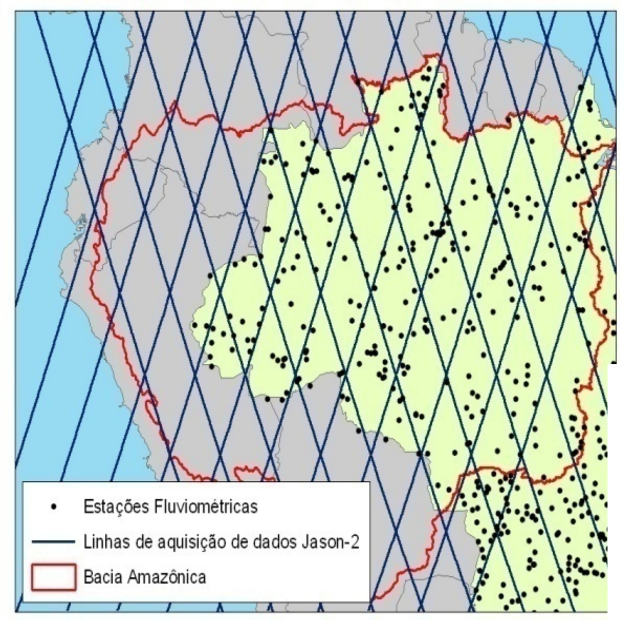
Radar altimetry was originally designed to study the variations of sea level

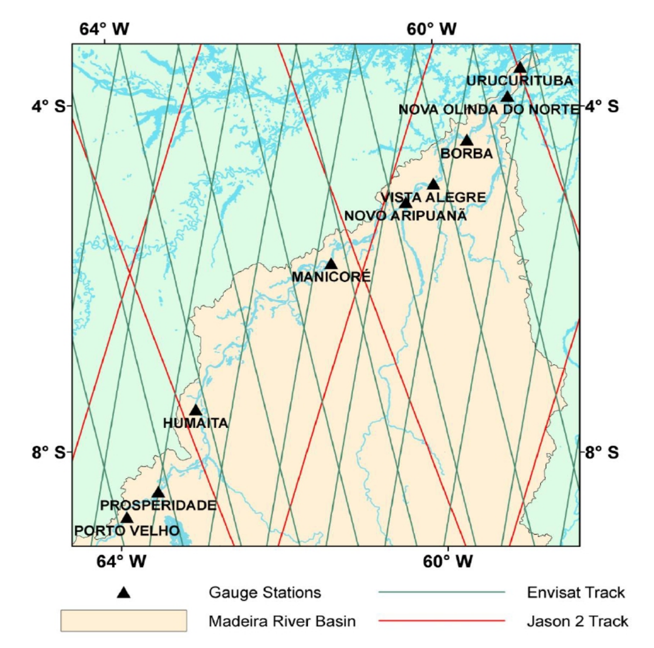
But it can also be used to estimate variations of water level over rivers and floodplains

Satellite Radar Altimetry over Continental Water Bodies

Virtual station (VS) and water level estimation



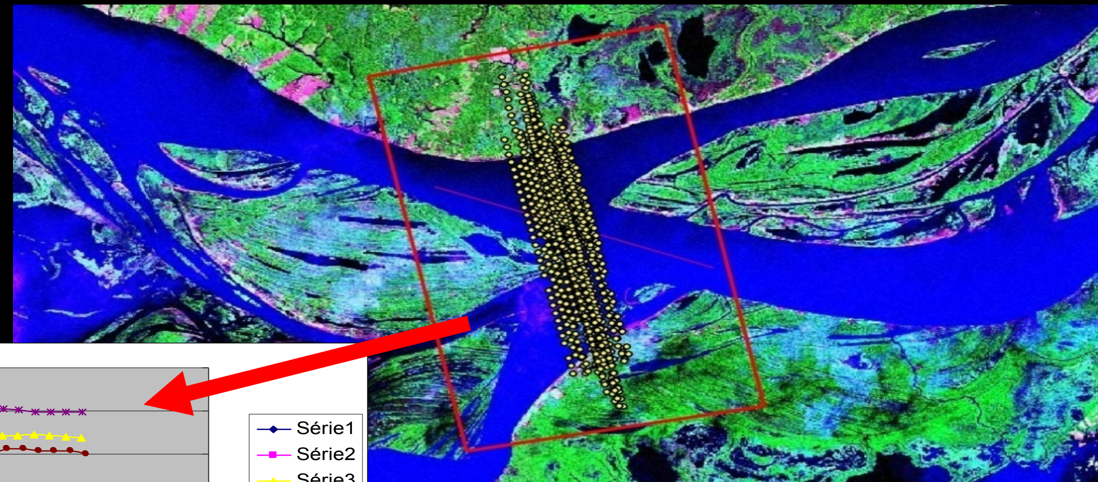


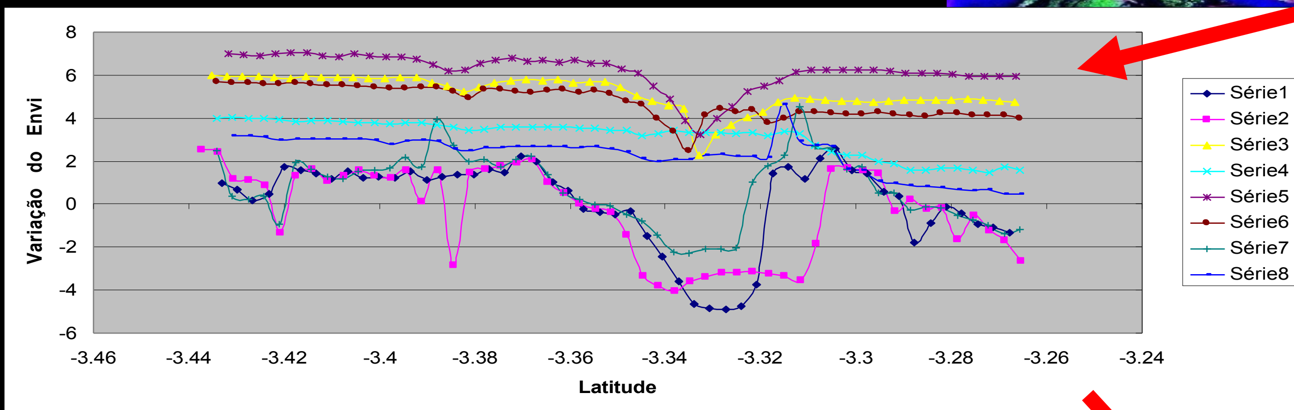


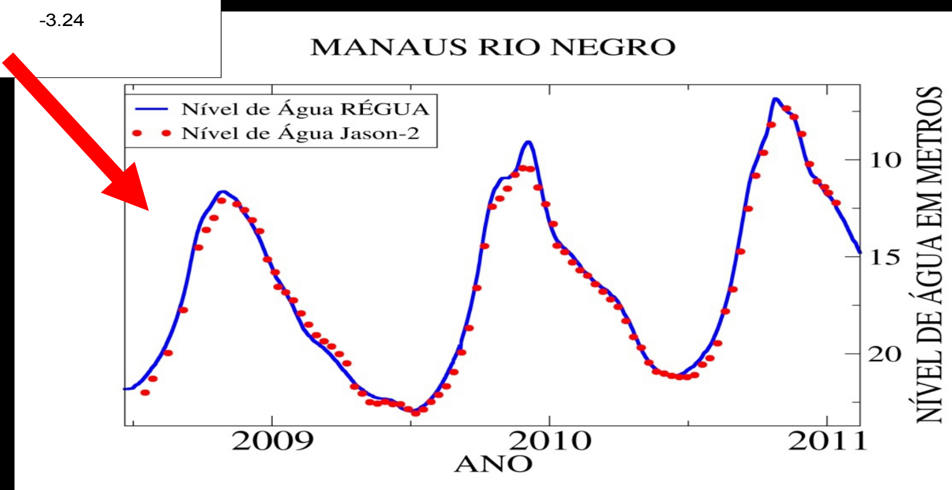
Slide couresy of Daniel Moreira and Stephane Calmant

Satellite Radar Altimetry over Continental Water Bodies

Virtual station (VS) and water level estimation







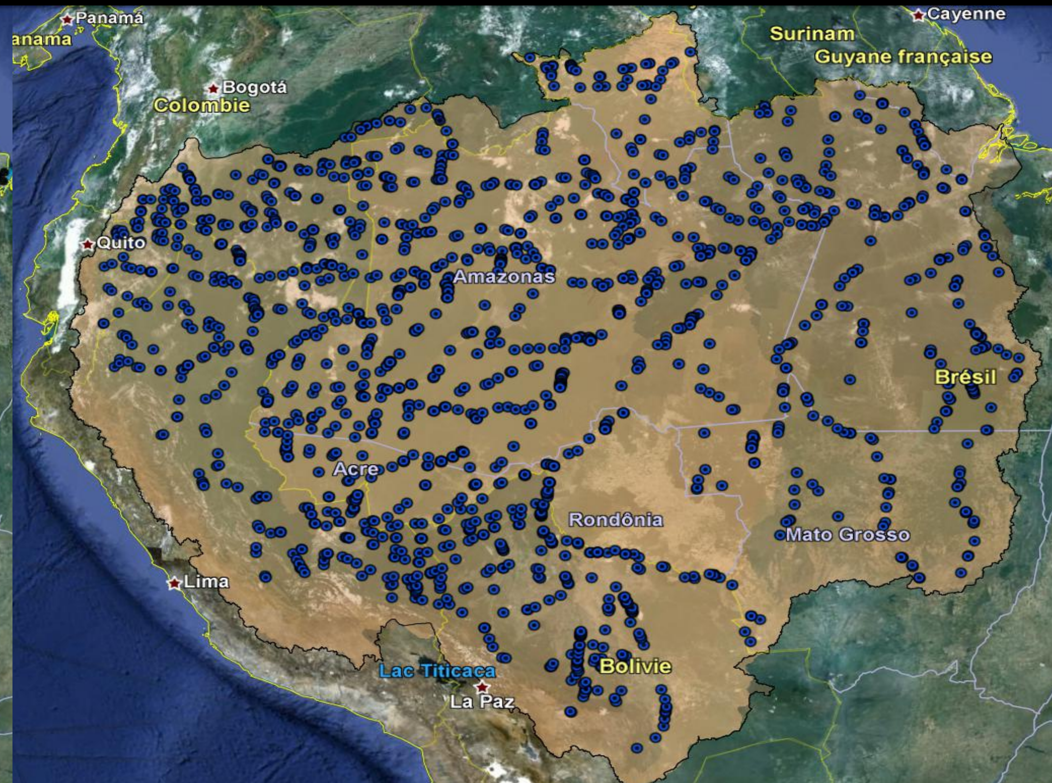
Virtual station (VS) and evaluation/validation against in situ observations

Slide couresy of Daniel Moreira and Stephane Calmant

Satellite Radar Altimetry over Continental Water Bodies

A complementary tool

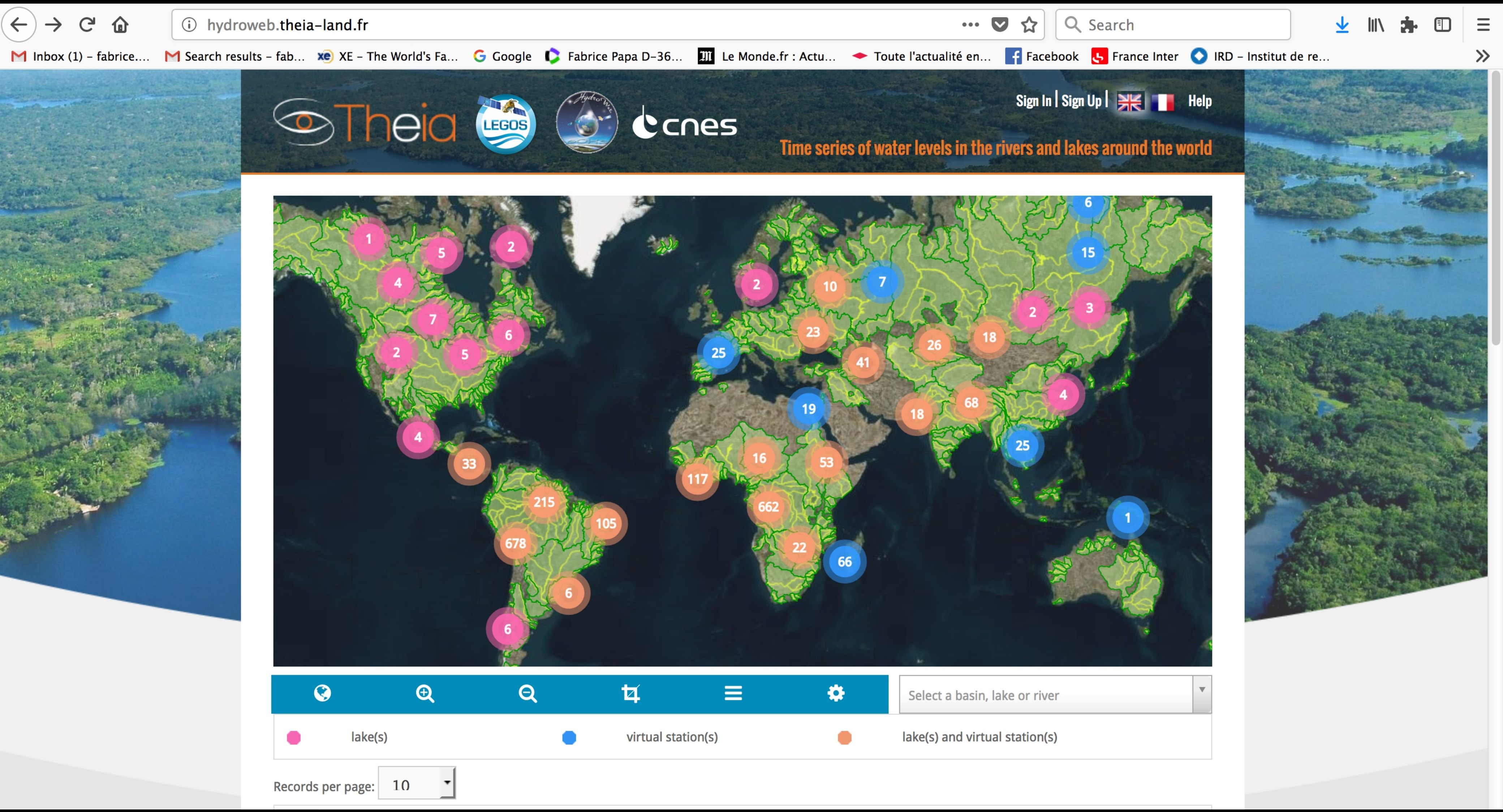
In situ network



Virtual station altimetry-derived network

Slide couresy of Daniel Moreira and Stephane Calmant

Satellite Radar Altimetry over Continental Water Bodies



hydroweb.theia-land.fr free access of data with registration

Variations of continental freshwater storage

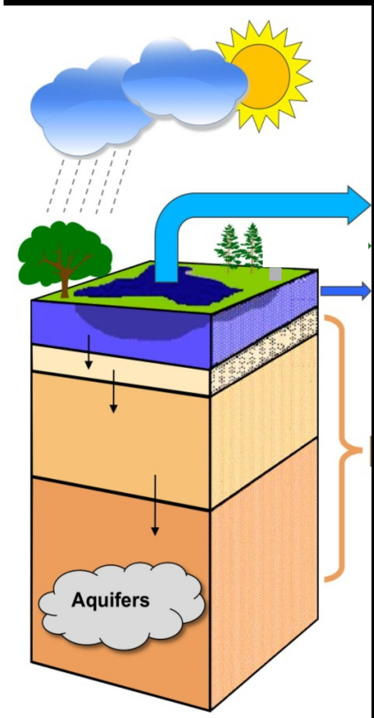
From surface to groundwater

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

$$\color{red}{dW/dt} = P - E - Q$$

Total Water Stock

=



Eaux de surface

Humidité des sols

Eaux souterr-aines

Variations of continental freshwater storage

From surface to groundwater

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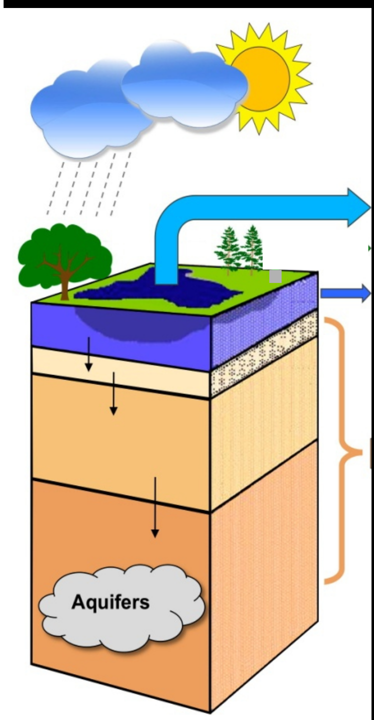
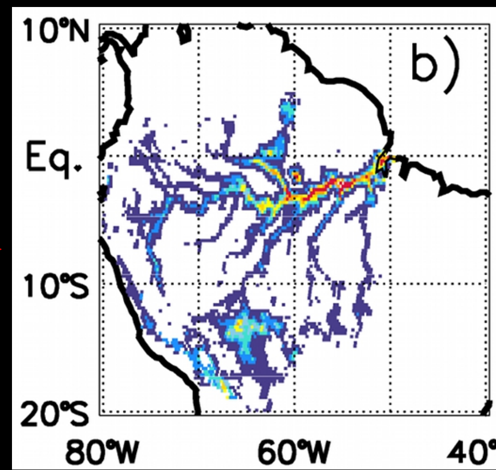


Eaux de surface

Humidité des sols

Eaux souterr-aines

Dynamic of surface water



+

More than 600 ENVISAT-derived Virtual Stations of water level heights combined with monthly GIEMS estimates for 2003-2007 and climatology 2003-2011

Variations of continental freshwater storage

From surface to groundwater

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

dW/dt = P - E – Q

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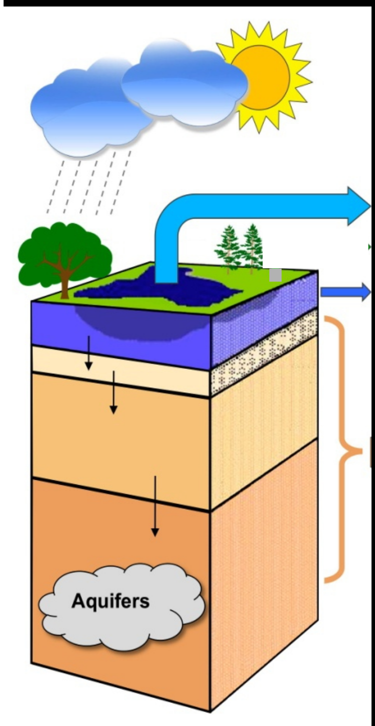
=



Eaux de surface

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Eaux souterr-aines

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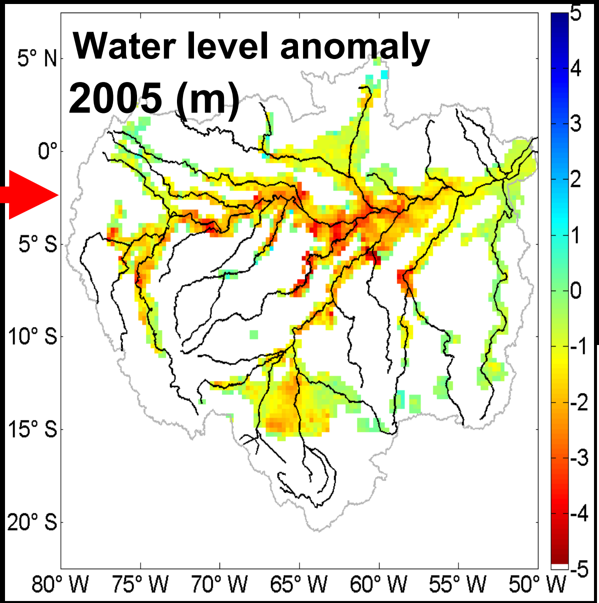
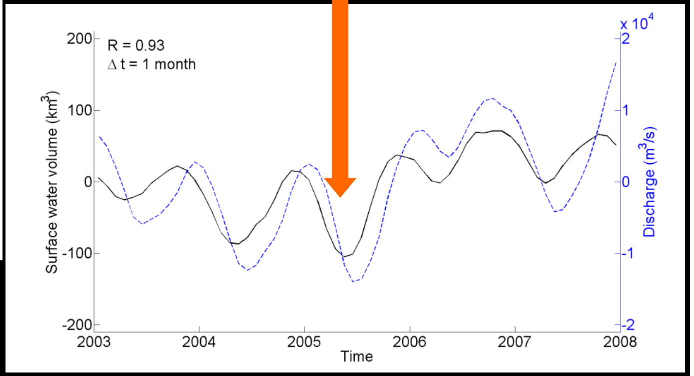


2005 Drought: Water deficit in the Amazone basin = 70%



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

Variations of continental freshwater storage

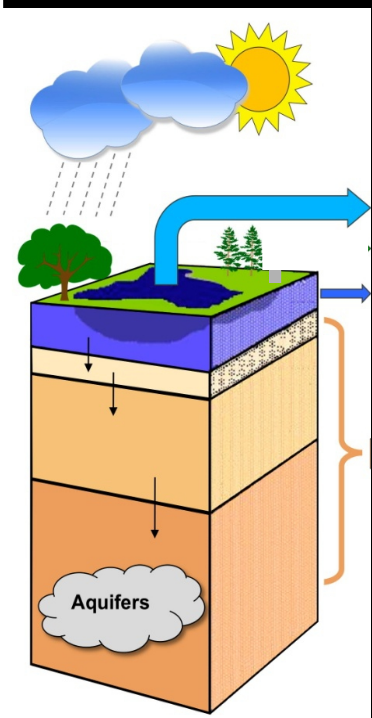
From surface to groundwater

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

dW/dt = P - E – Q

Total Water Stock

=

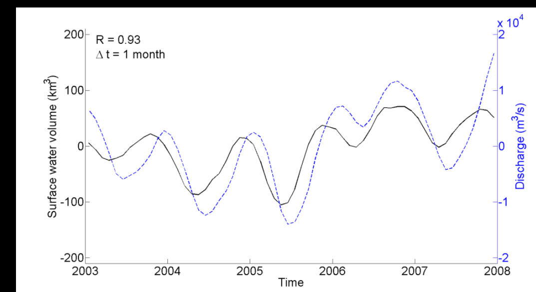


Eaux de surface

Humidité des sols

Eaux souterr-aines

Storage SWS=



2003-2011

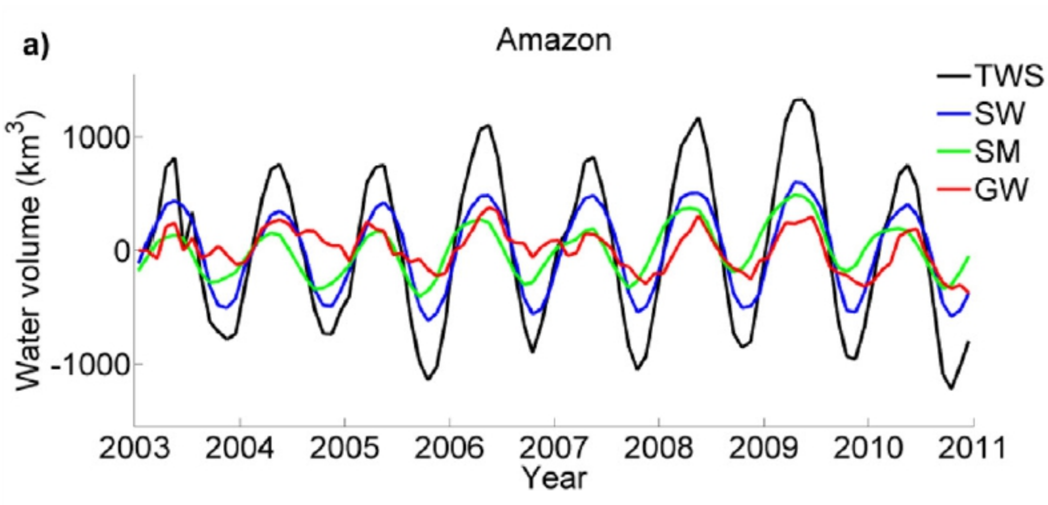
Storage SMS= modeling results ensemble (WGHM, ISBA, GLDAS)

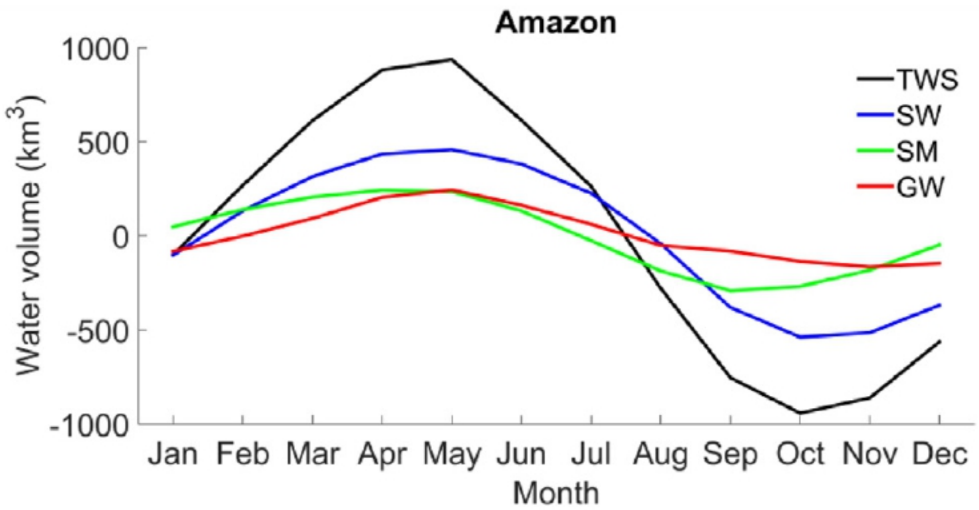
Storage GWS = GRACE TWS – (SWS + SMS)

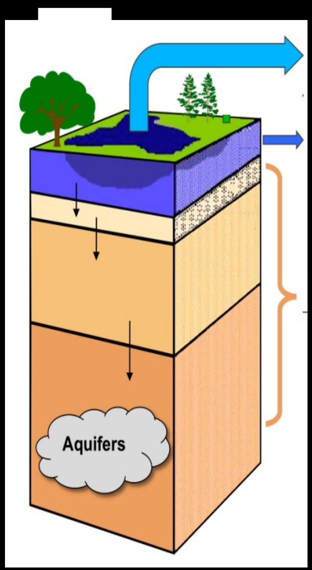
Towards the full decomposition of GRACE TWS over the Amazon

Variations of continental freshwater storage

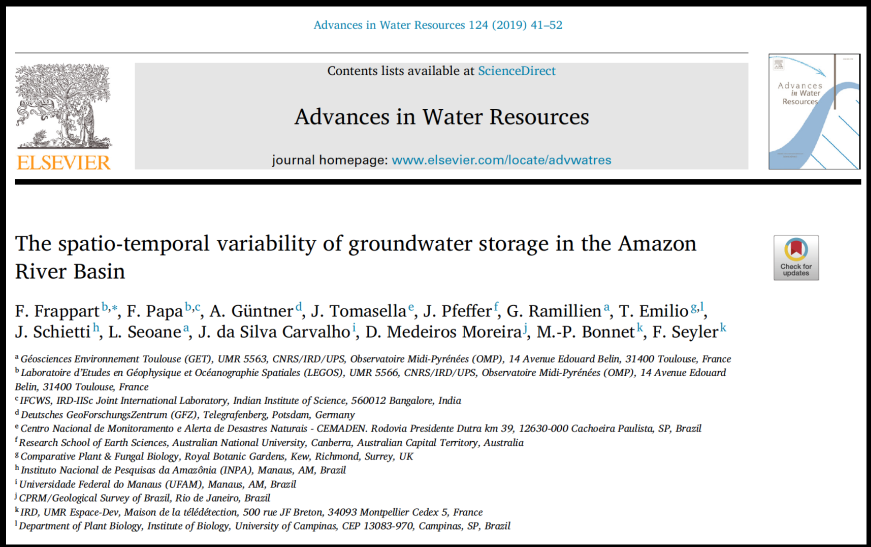
The first decomposition of continental water storage from RS







Surface water	~45% of TWS variations
Soil moisture RZ	~25% of TWS variations
Ground-water	~30% of TWS variations



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

F. Frappart[b,*], F. Papa[b,c], A. Güntner[d], J. Tomasella[e], J. Pfeffer[f], G. Ramillien[a], T. Emilio[g,l], J. Schietti[h], L. Seoane[a], J. da Silva Carvalho[i], D. Medeiros Moreira[j], M.-P. Bonnet[k], F. Seyler[k]

[a] Géosciences Environnement Toulouse (GET), UMR 5563, CNRS/IRD/UPS, Observatoire Midi-Pyrénées (OMP), 14 Avenue Edouard Belin, 31400 Toulouse, France
[b] Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), UMR 5566, CNRS/IRD/UPS, Observatoire Midi-Pyrénées (OMP), 14 Avenue Edouard Belin, 31400 Toulouse, France
[c] IFCWS, IRD-IISc Joint International Laboratory, Indian Institute of Science, 560012 Bangalore, India
[d] Deutsches GeoForschungsZentrum (GFZ), Telegrafenberg, Potsdam, Germany
[e] Centro Nacional de Monitoramento e Alerta de Desastres Naturais - CEMADEN. Rodovia Presidente Dutra km 39, 12630-000 Cachoeira Paulista, SP, Brazil
[f] Research School of Earth Sciences, Australian National University, Canberra, Australian Capital Territory, Australia
[g] Comparative Plant & Fungal Biology, Royal Botanic Gardens, Kew, Richmond, Surrey, UK
[h] Instituto Nacional de Pesquisas da Amazônia (INPA), Manaus, AM, Brazil
[i] Universidade Federal do Manaus (UFAM), Manaus, AM, Brazil
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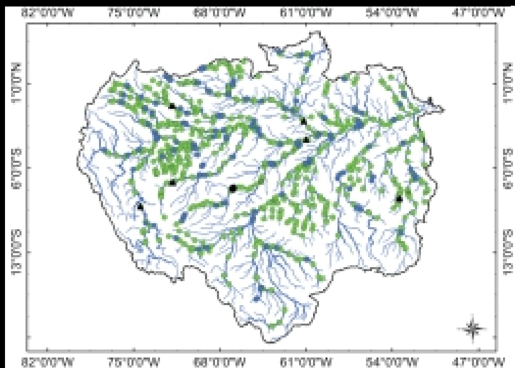
[k] IRD, UMR Espace-Dev, Maison de la télédétection, 500 rue JF Breton, 34093 Montpellier Cedex 5, France
[l] Department of Plant Biology, Institute of Biology, University of Campinas, CEP 13083-970, Campinas, SP, Brazil

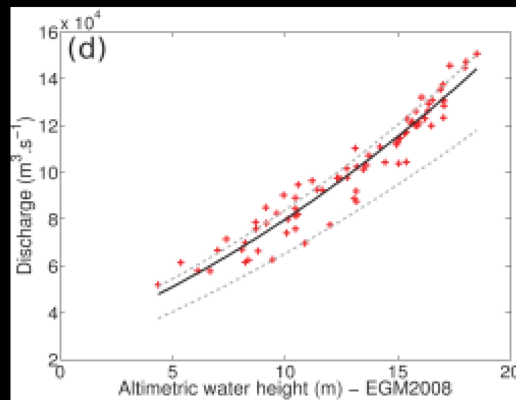
Frappart et al., 2019

Discharge estimation combining satellites and models

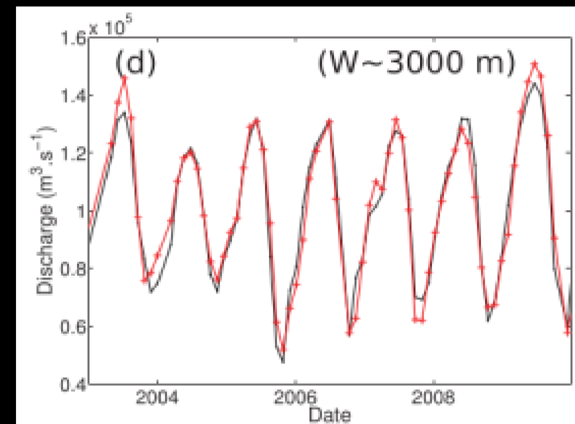


Water level over 920 altimetric virtual station
+
Discharge calibrated of MGB

Rating curve altimetry/model

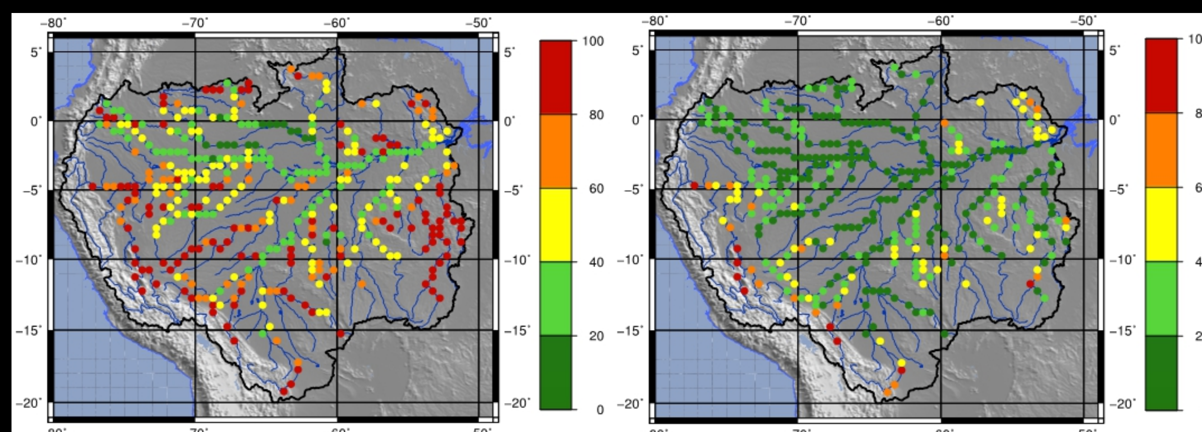


Altimetry-derived discharge (35j/10j)



Paris et al. (2016)

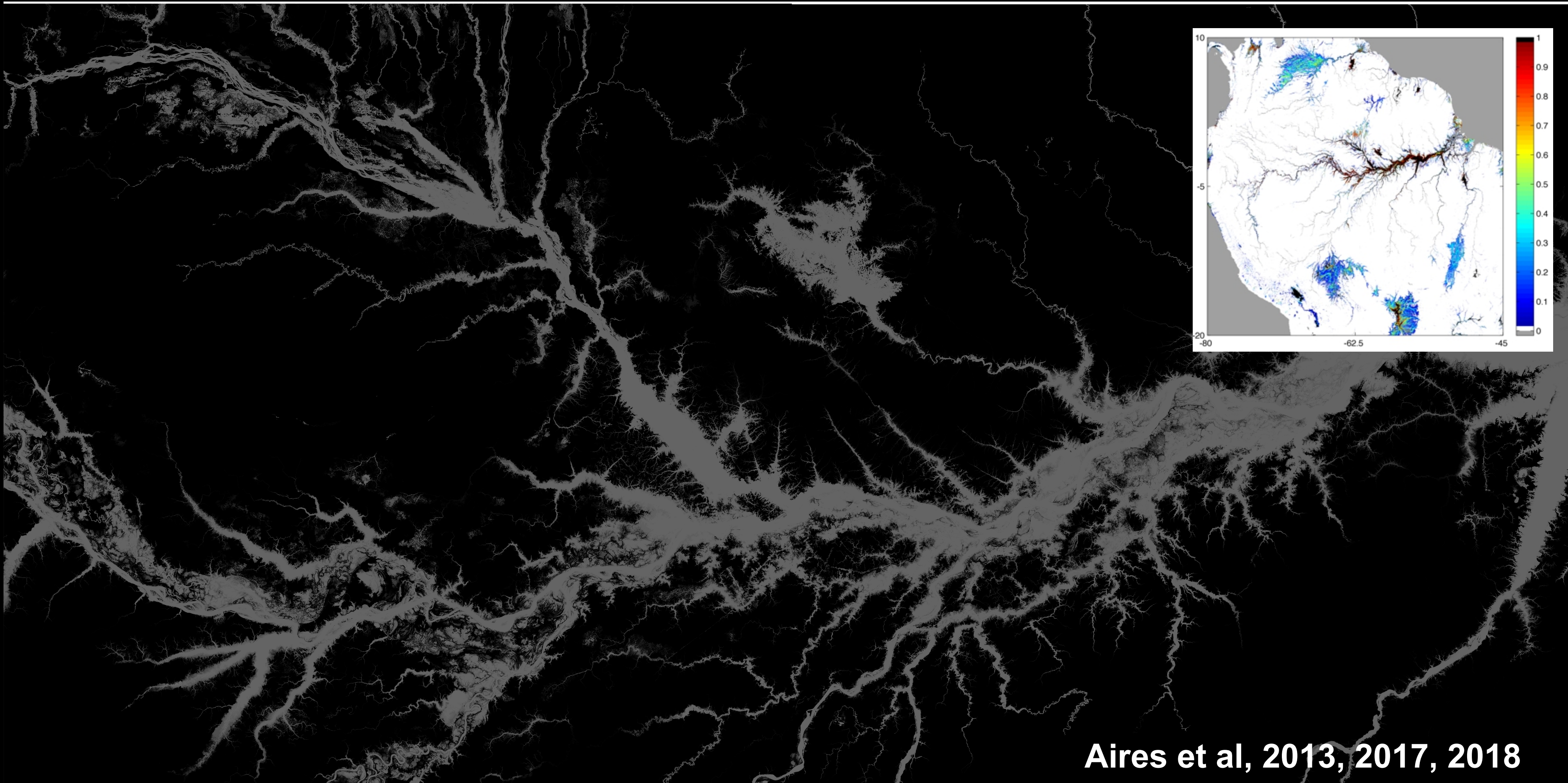
Assim. in ISBA-CTRIP (CNRM)



Emery et al. (2018)

Perspective: surface freshwater storage variations at HR

Surface water extent at high resolution (90m, GIEMS-D3) + hypso curve



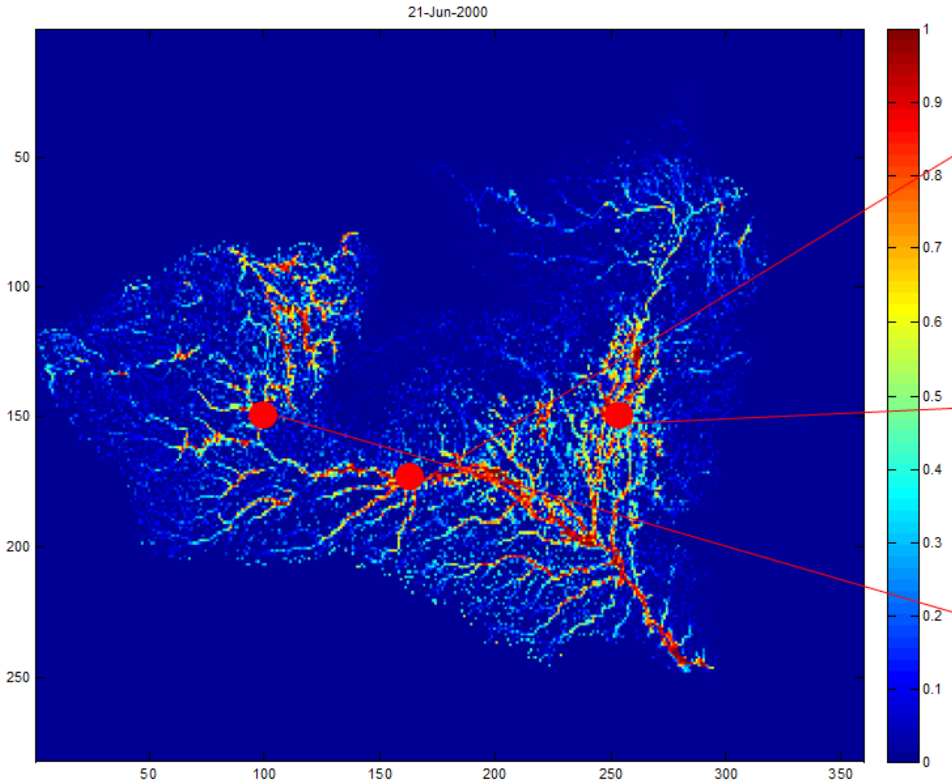
Very fine details of flood dynamics to study hydrological processes

Available 1993-2015 (monthly and 10-day sampling)

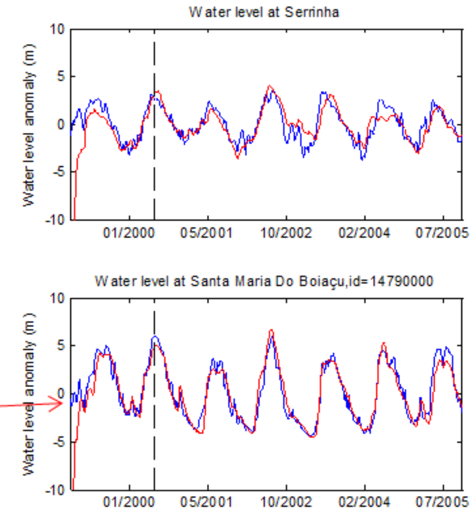
Supports high resolution hydrological modeling (MGB-IPH)

Fraction of flooded area per cell (total of 39882 simulation cells)

High stage



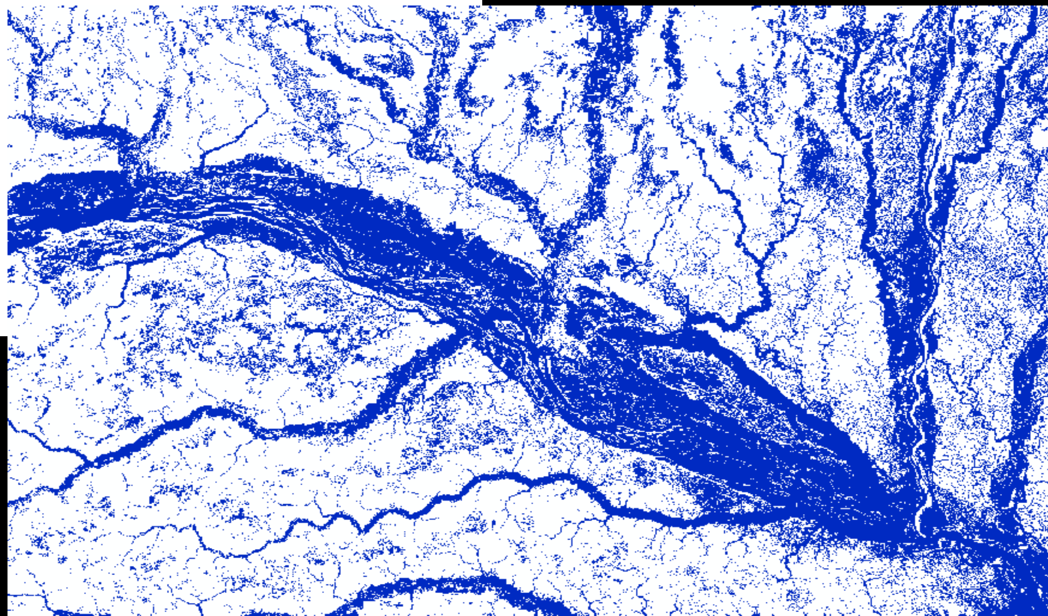
In situ x simulated level



1D/2D MGB-IPH model: to characterize wetland hydrology

Fleischmann et al., 2019

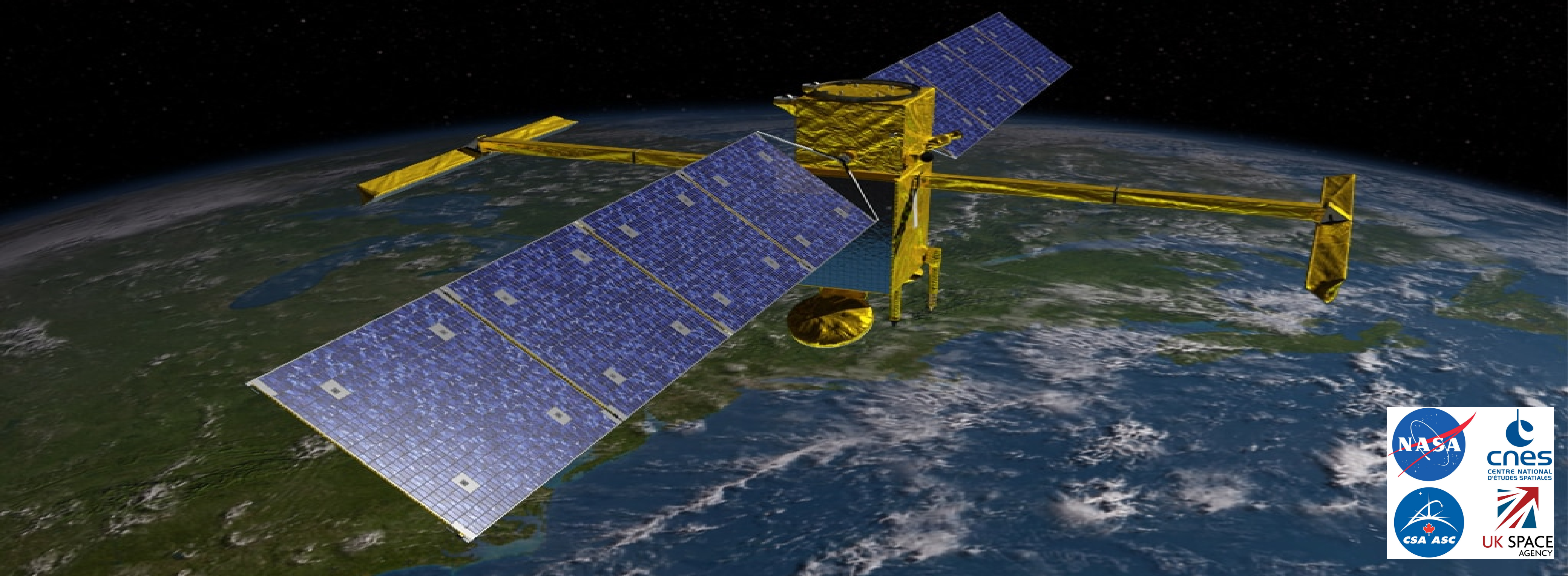
Flooded areas in the Negro-Branco confluence



The future of Hydrology from Space

Surface Water and Ocean Topography, 2021

- Provide with a global inventory of surface water (lakes, reservoirs, wetalnds > 250x250 m) and rivers (>100 m)
- From intra- to pluri-annual scale, estimate the variations of global surface water storage and river discharge

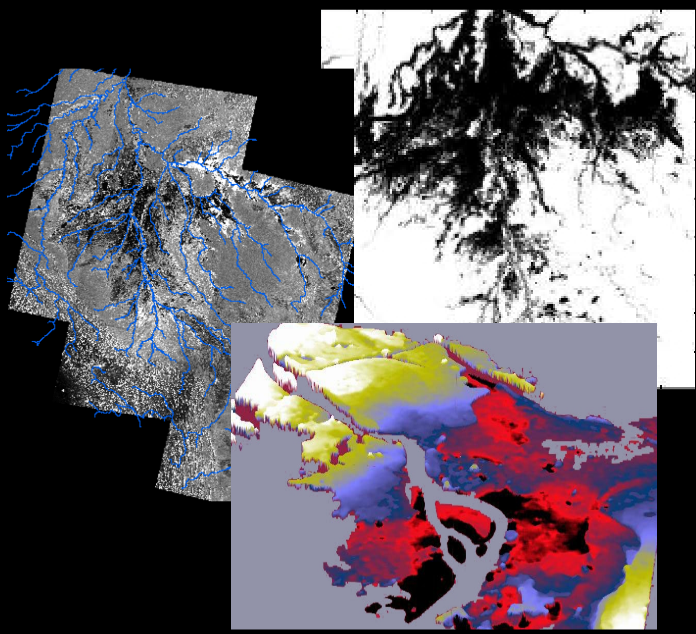


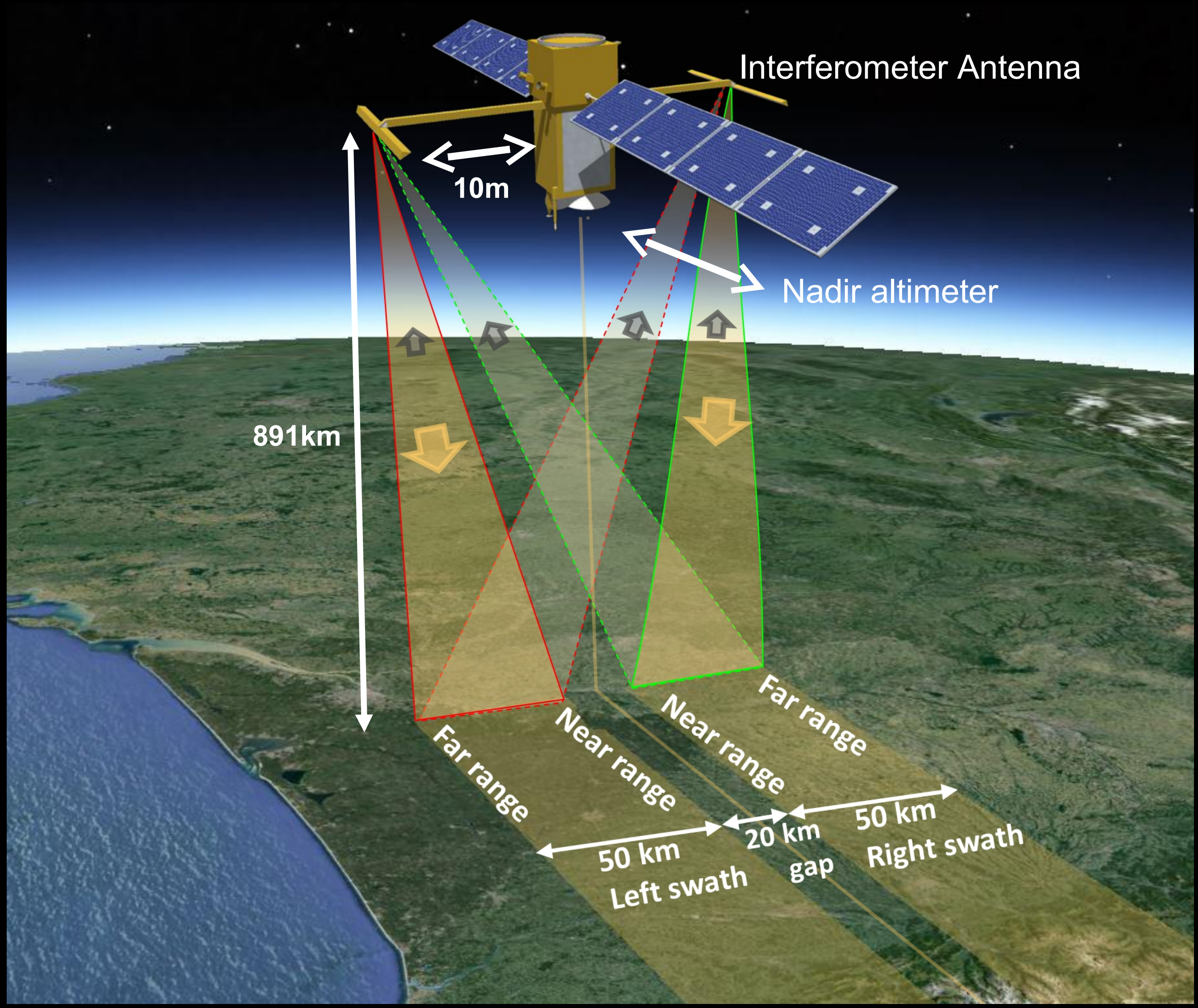
The future of Hydrology from Space

Surface Water and Ocean Topography, 2021

- KaRIN: Ka-band Radar Interferometer
- ~100 m spatial resolution
- 21 day

Map of S, h, dh/dt and dh/dx



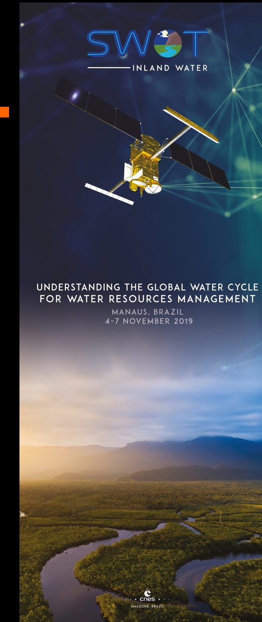


South America Water from Space 2019

A group of South American (Brazil, Chili, Colombia, Peru, Venezuela, Bolivia, Uruguay) and French and American scientists being part of the SWOT ST

Series of Conference South America Water from Space
2015 and 2017, CPRM, Rio de Janeiro , Brazil
2018, INACAP, Santiago, Chile

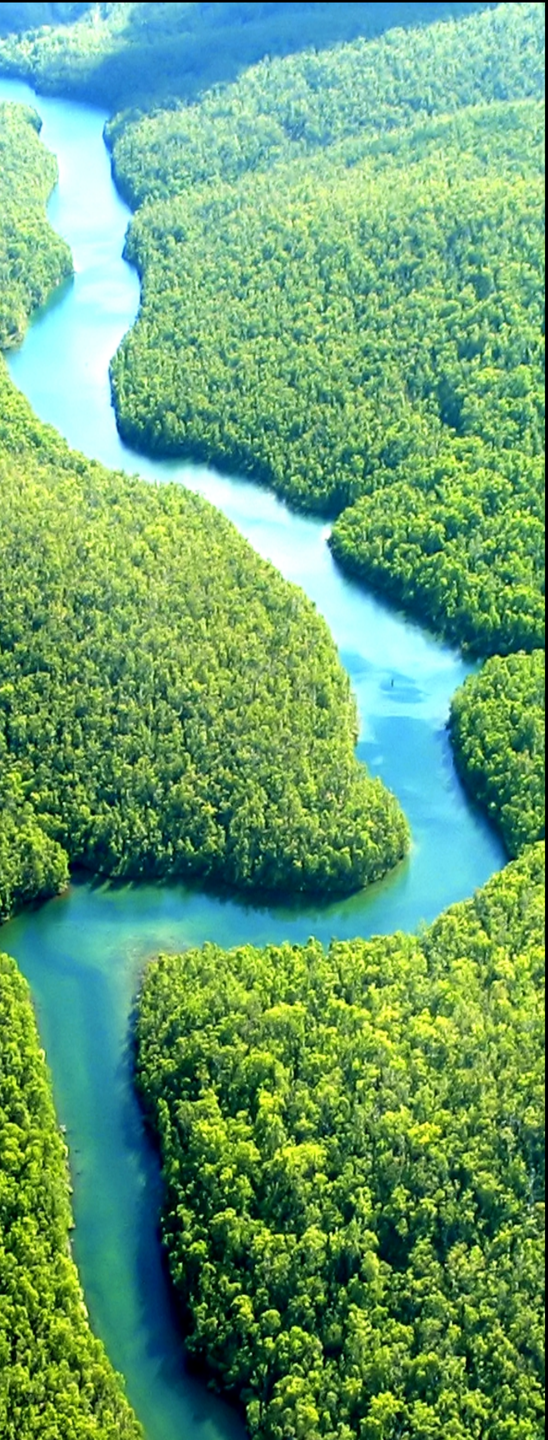
2019, 4-7 Nov, Manaus, Brazil , hydrologyfromspace.org



SOUTH AMERICA WATER from SPACE II
Conference

UEA Universidade do Estado do Amazonas · Géosciences Environnement Toulouse · LEGOS · cnes Centre National d'Études Spatiales · IRD Institut de Recherche pour le Développement France · Serviço Geológico do Brasil – CPRM

- **80 participants from 9 countries**
- **35 talks and 30 posters discussing the use of satellite for a better understanding of the water cycle and water resources management in the context of SWOT**
- **Opening speeches by the Ambassador of France to Brazil and CPRM Director**
- **Signature of inter-Institutional agreement between IRD and CPRM**



Continental freshwater dynamic from multi-satellite observations. Towards the storage and fluxes at high spatio-temporal resolution

Fabrice Papa, Frédéric Frappart, Daniel Moreira, Filipe Aires, Victor Pellet, Javier Tomasella, Rodrigo Paiva, Joecila Dos Santos, Ayan Fleischmann, Alex Ovando, M-P Bonnet, Augusto Getirana, Frédérique Seyler, Stephane Calmant, Catherine Prigent et al.

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