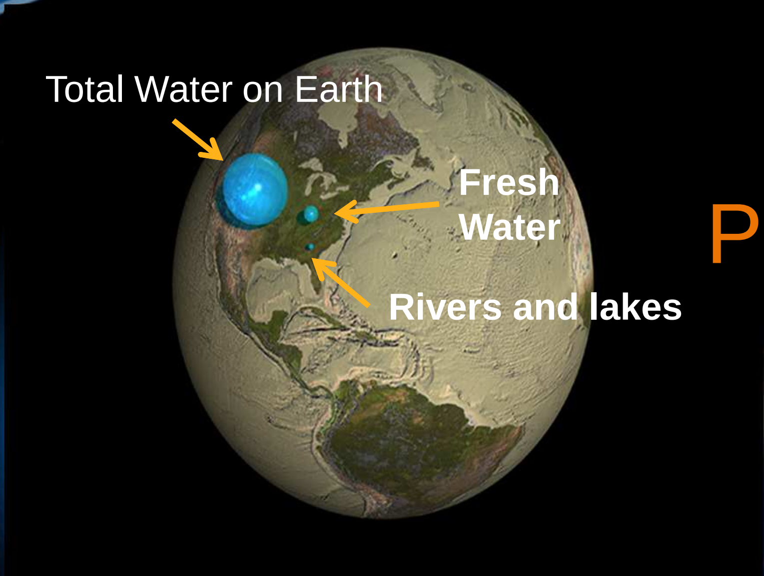


Programmatic Context

Selma CHERCHALI

Land and Hydrology Program Manager
CNES – Science, Applications and Innovation Directorate

Lakes and Climate: The Role of Remote Sensing

CESBIO, June 1st 2017

Introduction

The new challenges

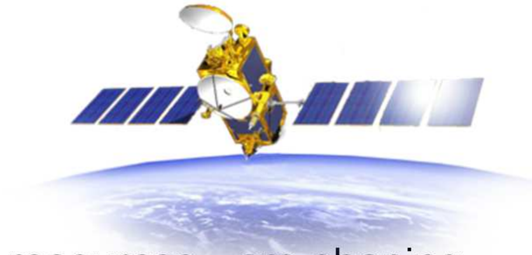
Climatic and environmental stakes

" We do not inherit the land from our ancestors, we borrow it from our children"

(Native American proverb)

- What climate shall we have tomorrow?
  - Increases in global sea and air temperatures
  - Widespread melting of snow and ice
  - Rising global sea level

- How to improve our models to quantify the changes?
  - What are the observations and accuracy needs for global water and energy cycle research, and for global climate change research? **regional to global scales to augment climate networks.**
- How to predict at a finer scale to mitigate the impacts (IPCC reports?
  - What are the accuracy needs for water management, flood prediction, reservoir operation, agriculture and drought assessment? **regional problems and real-time data needs to augment operational networks.**



→ To spatialize and to refine scale of perception

- Observations at high spatial and temporal scales

- Global changes - Climate change & increased demand on water resources - are shaping the challenges associated to hydrology that humanity needs to tackle in the next century:

food security / flood mitigation / water quality

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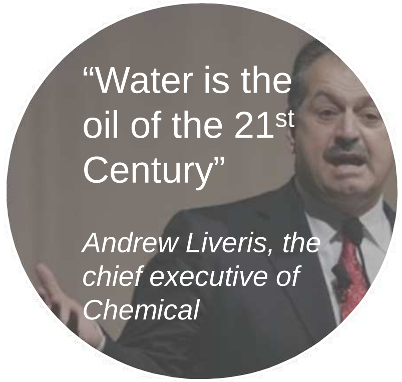
Introduction
The new challenges

Water is a major stake in the 21th century



There is still a need to understand the processes that govern the production and distribution of water in the compartments of the Earth surface and to evaluating the impact of human activities on them.

What are the data needs and with which distribution scheme ?

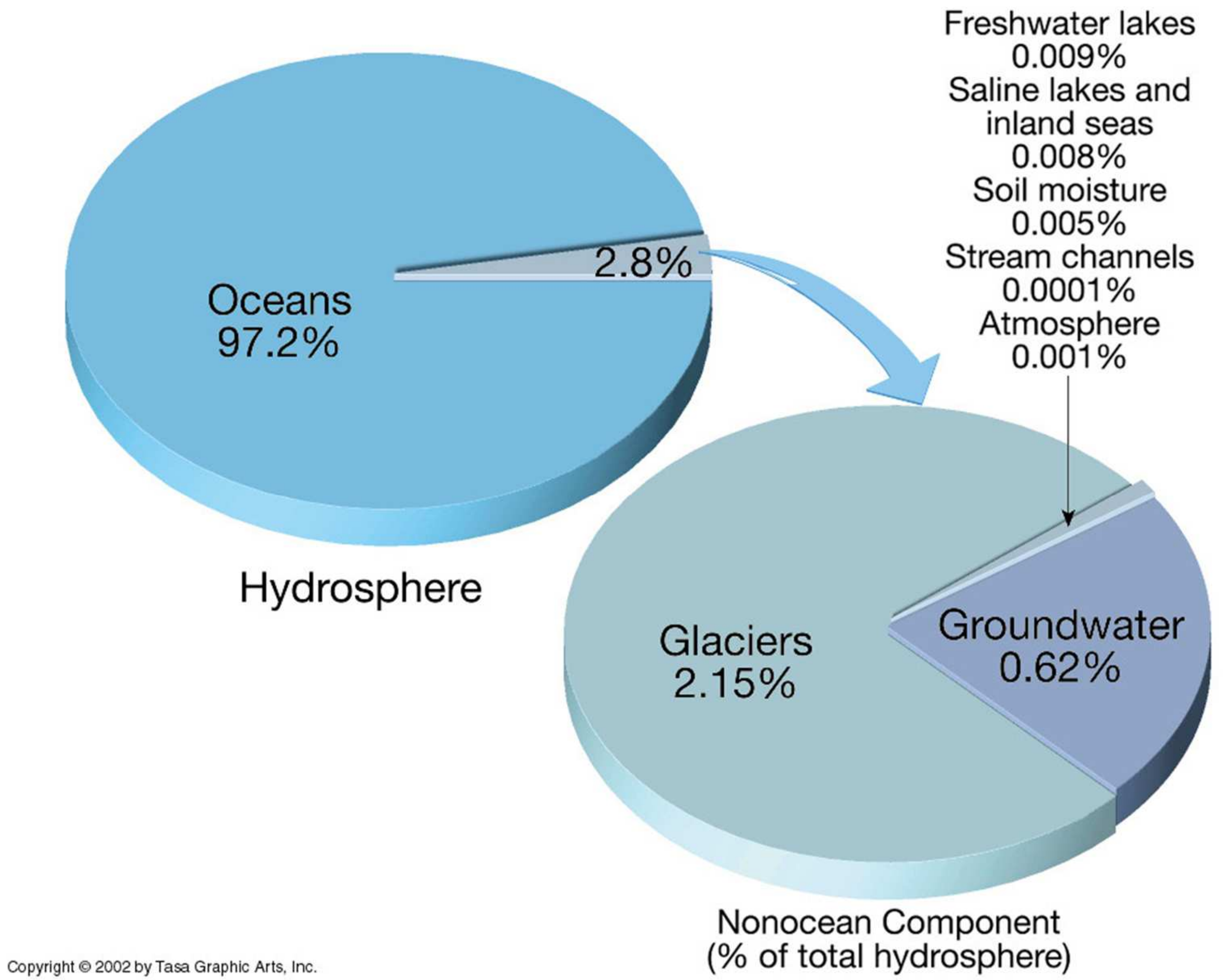
- World programs in hydrology and water are looking to space-based observations to provide needed observations **of sufficient accuracy for water resource applications.**

How to address the socio-economic benefits?

- Consider end-users requirements
- Benefits of Earth observations applications to decision making
- Develop services

Introduction

The new challenges



GCOS
GLOBAL CLIMATE OBSERVING SYSTEM

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	**Surface:** Air temperature, **Wind speed and direction**, Water vapour, Pressure, Precipitation, Surface radiation budget **Upper-air: Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar irradiance)** **Composition: Carbon dioxide, Methane, and other long-lived greenhouse gases, Ozone and Aerosol, supported by their precursors**
Oceanic	**Surface: Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice,** Surface current, Ocean colour, Carbon dioxide partial pressure, Ocean acidity, Phytoplankton **Sub-surface:** Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers
Terrestrial	River discharge, Water use, Groundwater, **Lakes, Snow cover, Glaciers and ice caps, Ice sheets**, Permafrost, **Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Above-ground biomass,** Soil carbon, **Fire disturbance, Soil moisture**

The ECVs – satellite observations make a major contribution to the ECVs shown in bold

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The « revolution » in space missions for hydrology

Increase in accuracy (more adapted spectral bands)

example of soil moisture:
from AMSR-E (C-Band) *to* SMOS, SMAP (L-Band)

Increase in spatial resolution

example of altimetry:
from Jason (kilometric), Altika, Sentinel3 *to* SWOT (100m)

Increase in temporal resolution

example of visible:
from SPOT5-6 (local) *to* Sentinel 2 (5 days)

Increase in accessibility of data

Vast majority (S2,3, SMOS, SMAP, LandSat)
are freelly accessible

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Water balance components

Soil moisture

Surface water

Ground water

$$\frac{dS_{SM}}{dt} + \frac{dS_{SW}}{dt} + \frac{dS_{GW}}{dt} = P - E - Q$$

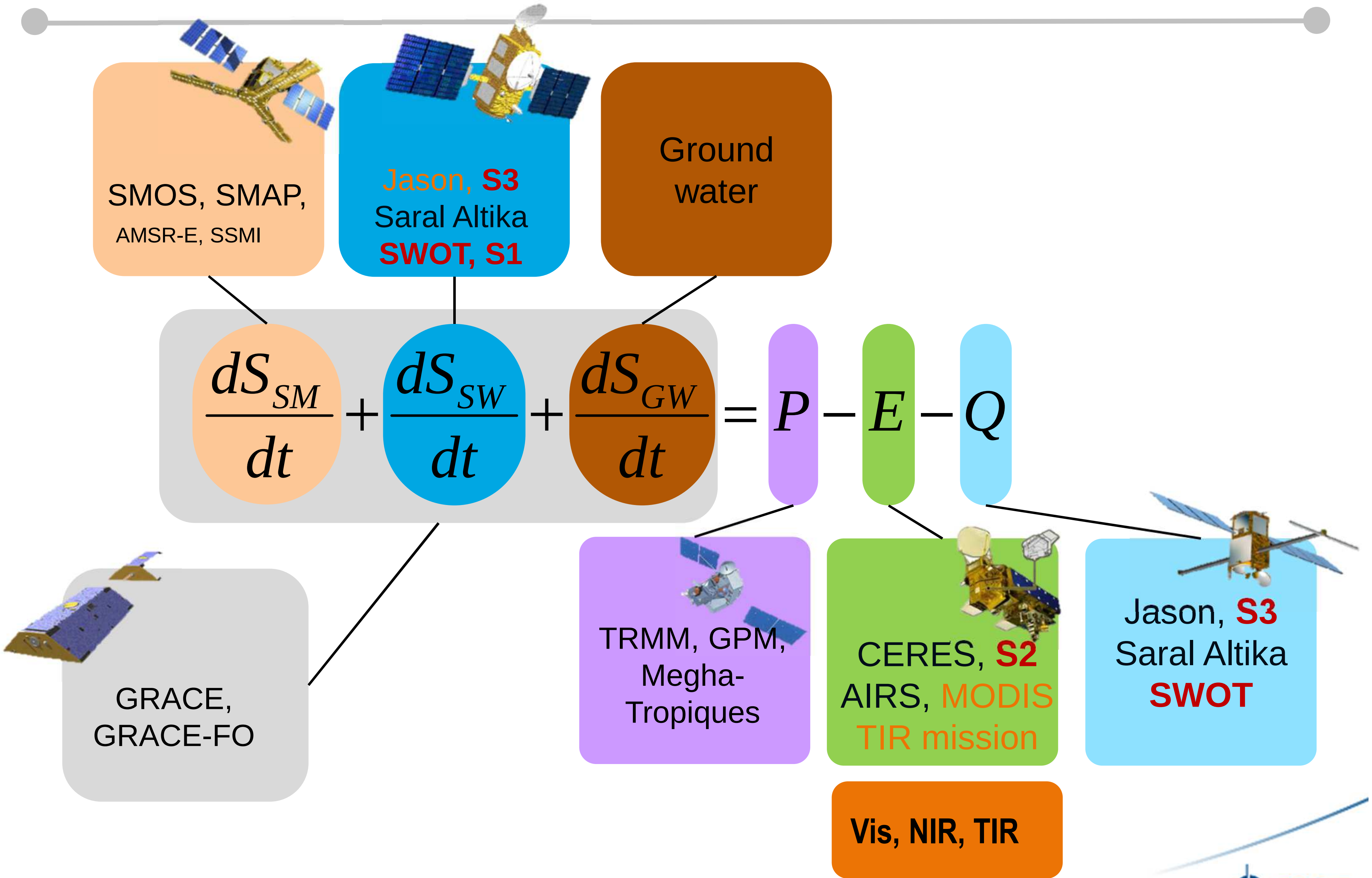
Precipitation

Evapo-transpiration

Discharge

Energy budget

Space measurements for water cycle



Not all components are observed at the desired resolution and accuracy

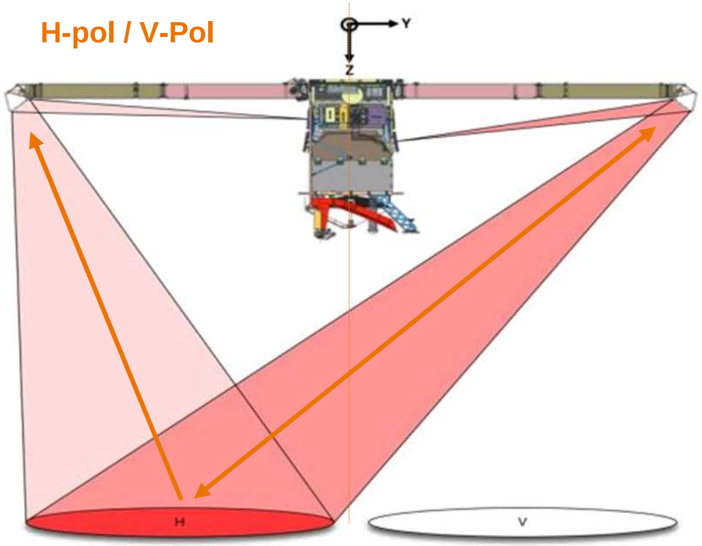
SWOT Mission FACT SHEET

Mission Science

Oceanography: Characterize the ocean mesoscale and sub-mesoscale circulation at spatial resolutions of 15 km and greater.

Hydrology: To provide a global inventory of all terrestrial water bodies whose surface area exceeds (250m)^2 (lakes, reservoirs, wetlands) and rivers whose width exceeds 100 m (rivers).

- **To measure the global storage change in fresh water bodies at sub-monthly, seasonal, and annual time scales.**
- To estimate the global change in river discharge at sub-monthly, seasonal, and annual time scales.



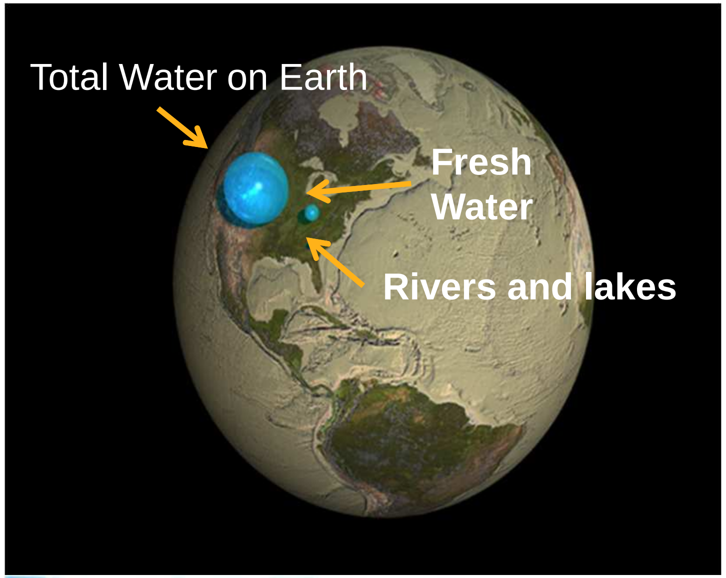
Mission Architecture

- Ka-band SAR interferometric (KaRIn) system with 2 swaths, 50 km each
- Produces heights and co-registered all-weather imagery
- Use conventional Jason-class altimeter for nadir coverage, radiometer for wet-tropospheric delay, and GPS/DORIS/LRA for POD.
- On-board data compression over the ocean (1 km^2 resolution).

- Partnered mission : CNES/ NASA /CSA/ UKSA
- Science mission duration of 3 years
- Calibration orbit: 857 km, 77.6º Incl., 1 day repeat
- Science orbit: 891 km, 77.6º Incl., 21 day repeat
- Flight System: ~2000kg, ~1900W
- Launch Vehicle: NASA Medium class
- Target Launch Readiness: Apr. 2021

SWOT - MISSION GOALS

- **Science Goals**
  - study hydrological processes by determining the storage and discharge rate of water on land.
  - study the oceanic mesoscale and submesoscale processes that determine the kinetic energy of ocean circulation and its transport of water properties.



- **Societal Benefits**

Address two key issues facing a warming planet:
  - the variability of fresh water resources.
  - the capacity of ocean circulation in regulating the rate of warming.

- **Technology Goal**

 Set the standard for future operational altimetry missions.

- It will fulfill important observations of the amount and variability of water stored in global lakes, reservoirs, wetlands, and river channels and will support derived estimates of river discharge.

SWOT – An ambitious and challenging mission

• Scientific Stakes : Leading scientific innovation

- New technologies on board SWOT allow the collection of unprecedented oceanographic and hydrographic data on a global scale
  - Essential contribution of SWOT: spectacular gain in spatial resolution from ~ 100 km to100 m or more

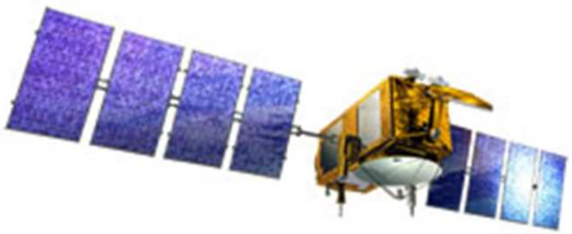
• Applications Stakes: Providing information on freshwater

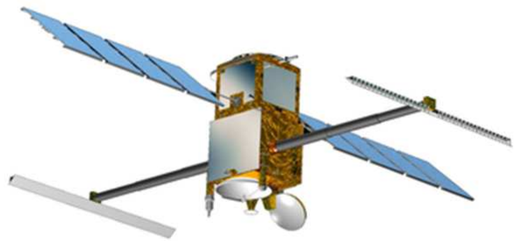
  - Beyond the scientific contribution to a better understanding of the water cycle, SWOT could have an economic and social impact through the development of new applications

• Technological Stakes: New path for satellite altimetry

- The SWOT mission is a breakthrough in the field of space altimetry
  - The instrument KaRIN is the main innovation of the SWOT mission and presents a significant technical challenge
- KaRIN is essentially a smaller version of SRTM with two Ka-band SAR antennae at opposite ends of a 10 m boom and both antennae transmitting and receiving the emitted radar pulses along both sides of the orbital track.

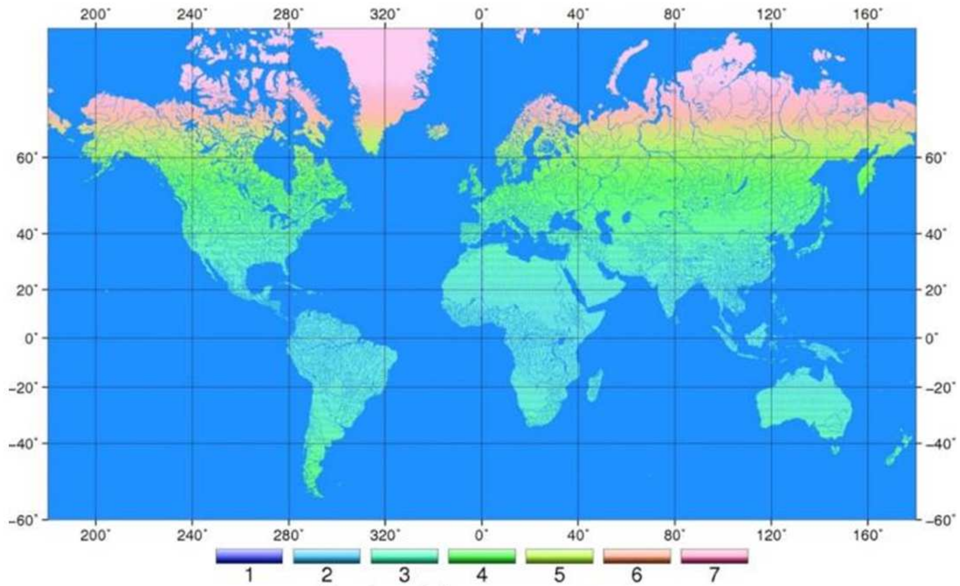
SWOT Coverage Leap - *from local altimetry to topography*





Conventional Nadir Altimeter

SWATH Altimeter : SWOT



SWOT mission will address challenges and shortcomings of conventional altimetry (e.g., spatial coverage and resolution) in both oceanographic and hydrologic applications and will enable a wide range of research opportunities in oceanography and land hydrology.

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SWOT application program support

- **Outreach :** Inform the stakeholders about the SWOT capabilities (website, workshop), develop communication strategies to target and support requirements of the user community etc…

- **The improvement of the existing applications**
  - Sea transport shipping, fisheries, prediction of ENSO, forecast of extreme events (cyclones, storms) and the monitoring of climatic parameters

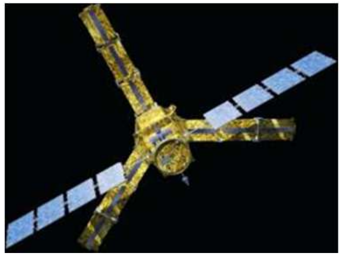
- **Innovative applications for coastal areas**
  - In particular for coastal management and off shore resource exploitation mining, oil continental shelves

- **The creation of new environmental services**
  - For inland waters (lakes, reservoirs, major rivers) at global scale to leverage opportunities for water resources management, estuaries, the risk prevention of flood, the prevention of the propagation of epidemics

- **An open data policy**
  - This will strengthen the existing services for oceanography and create new services in for water resources

SWOT-Aval – *pushing forward the SWOT applications*

A multi-sensor approach to support high-end applications from SWOT

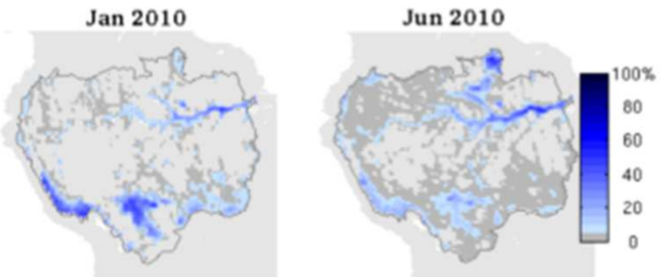


SMOS/SMAP

GPM/ MGT

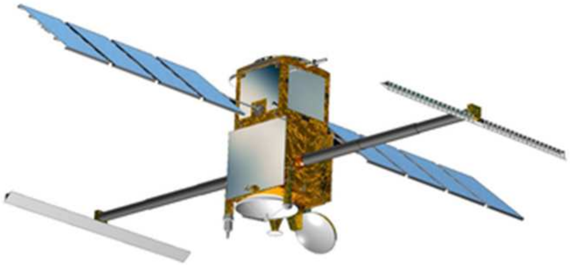
JS3/S3/S6

S2/LDCM/S1…

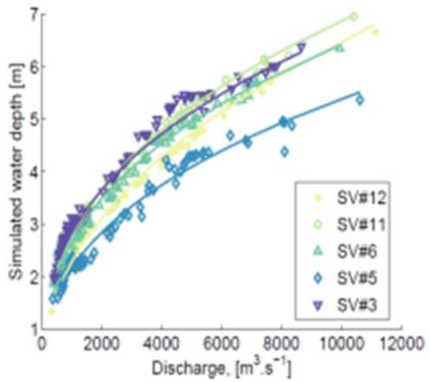


Dynamic wetlands surfaces and volumes (credits **Cesbio / Legos)**

A multi-sensor flood prediction system for the Niger Basin
(credits: **GET**)



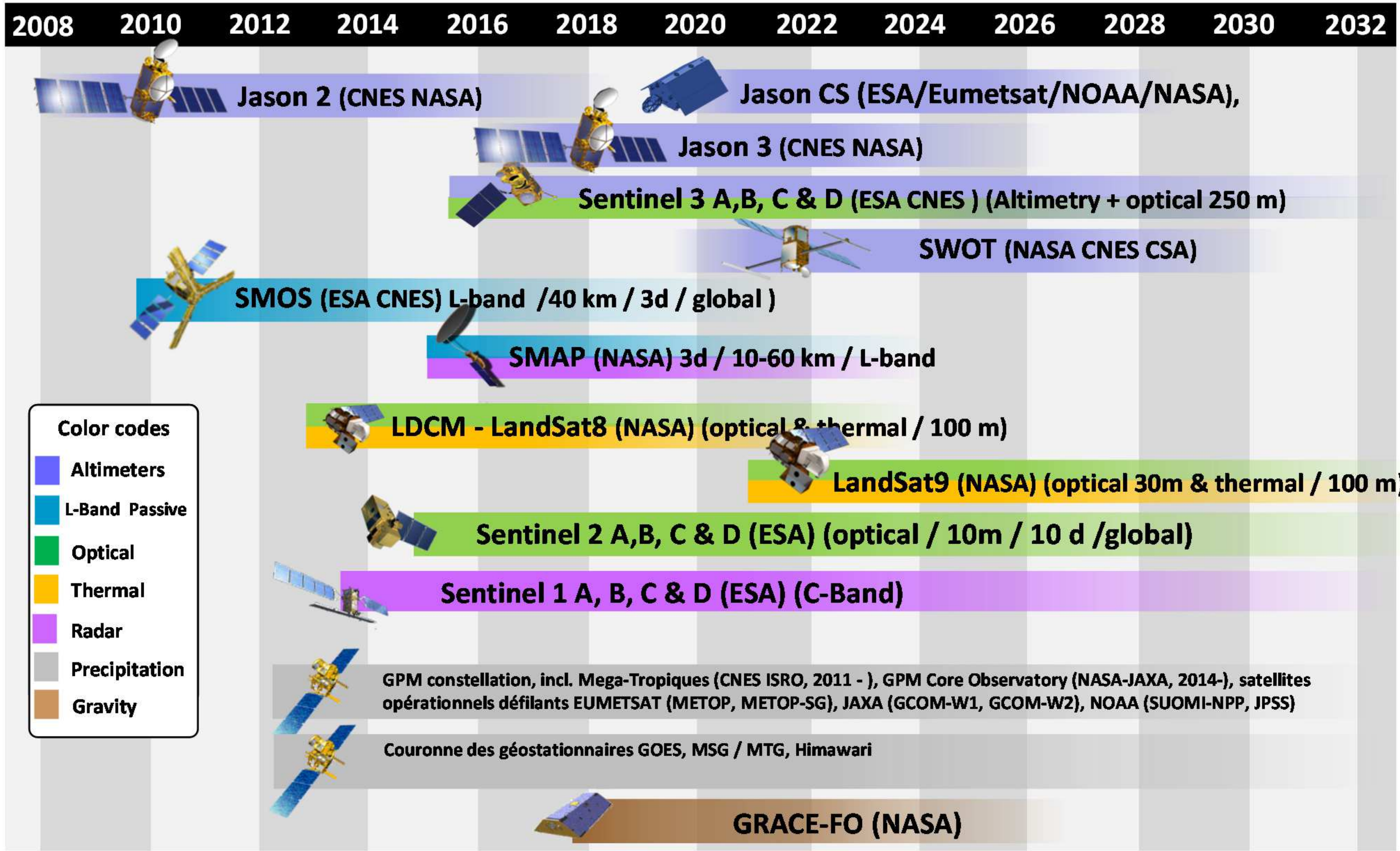
SWOT



A priori-discharge db based on SWOT simulator
(credits: **Legos/UFRGS**)

Lac Poyang water balance
(credits: **Sertit**)

The Roadmap for hydrology missions



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The future of Hydrology*…a strategy for integrated observations*

The hydrological sciences community is making it's mutation, as the atmospheric and ocean silences did before, by moving to **global multi-model and multi-sensors integrated modeling and assimilation systems.**

But this comes with **specific challenges** that need to be adressed like the complexity of the observed systems (spatial heterogeneity and temporal dynamics), and the impact of anthropogenic activities.

CNES is supporting this dynamic by contributing to innovative missions including the **SWOT** and the **SMOS** missions , hydrology dedicated missions
And also is supporting science activities **in Jason Series, GPM MeghaTropiques, Sentinel 2 and 3**, **Venus, Biomass** ….

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The future of Hydrology…*a strategy for integrated observations*

A need for international coordination:

- Integrating observations (global lakes platforms..)
  - to establish a more complete system description
- Integrating model components
  - to build an earth modeling system
- Integrating research results
  - to establish end-user solutions
- Data Integration
  - to allow for spatial and temporal rectification and to allow for the intercomparison and quality evaluation of different models and observation data
- Data-Model Integration
  - to constrain data and its errors by physical processes using four dimensional data assimilation techniques
- Solution Integration
  - to develop water cycle solutions by integrating observations into applications

A fruitful meeting….from CNES perspective

- Bring together international experts in order to tackle future challenges in lakes domain
- Strengthen the collaboration between the 3 communities: modelers, in situ and satellite observations providers

- Synthesis of the needs and requirements in term of modelling and assimilation and dedicated products
  - TOSCA , ROSES, NSERC, NRC programs future activities : new projects ?
  - Inputs for Lacs ECV (ESA CCI + program)
- Prepare the exploitation of the next generation of space missions
  - Major trends for developments with the new generation of space observations
- New ideas for a new generation of sensors concepts (example of SMOS next)

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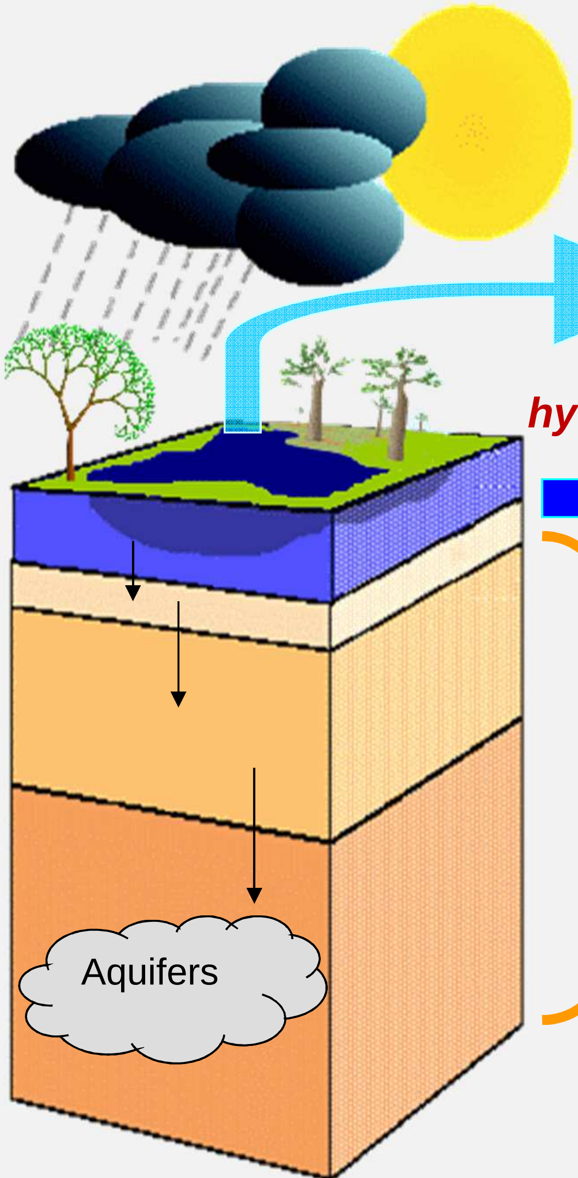
Extra slides

Space measurements for the water cycle



Precipitation, Energy

Land Surface

Water Surface

→ **Vis, NIR, TIR, Radar**

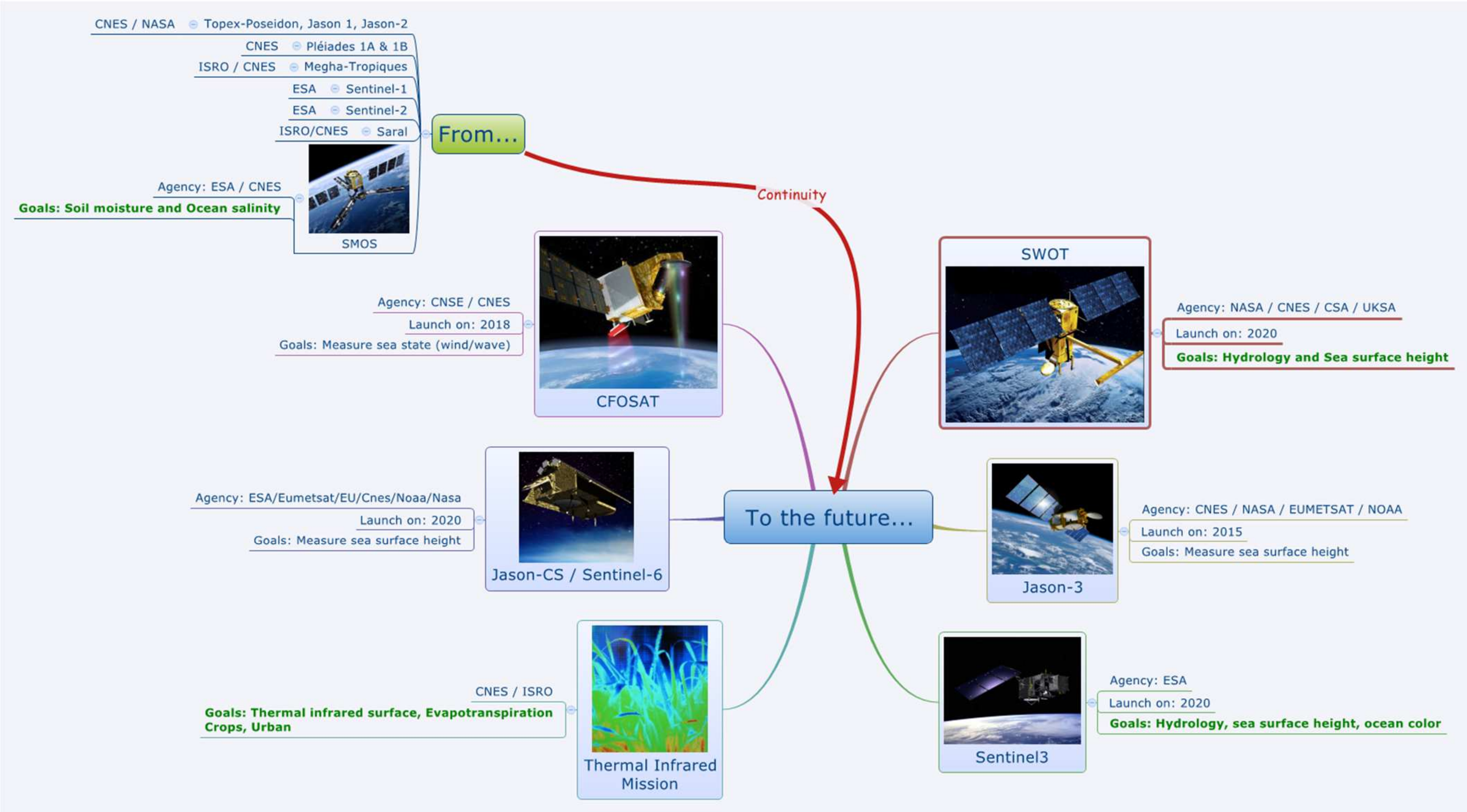
hydro network, water storage, Discharge, *Evapotranspiration*

Soil moisture → **Radar and passive microwaves**

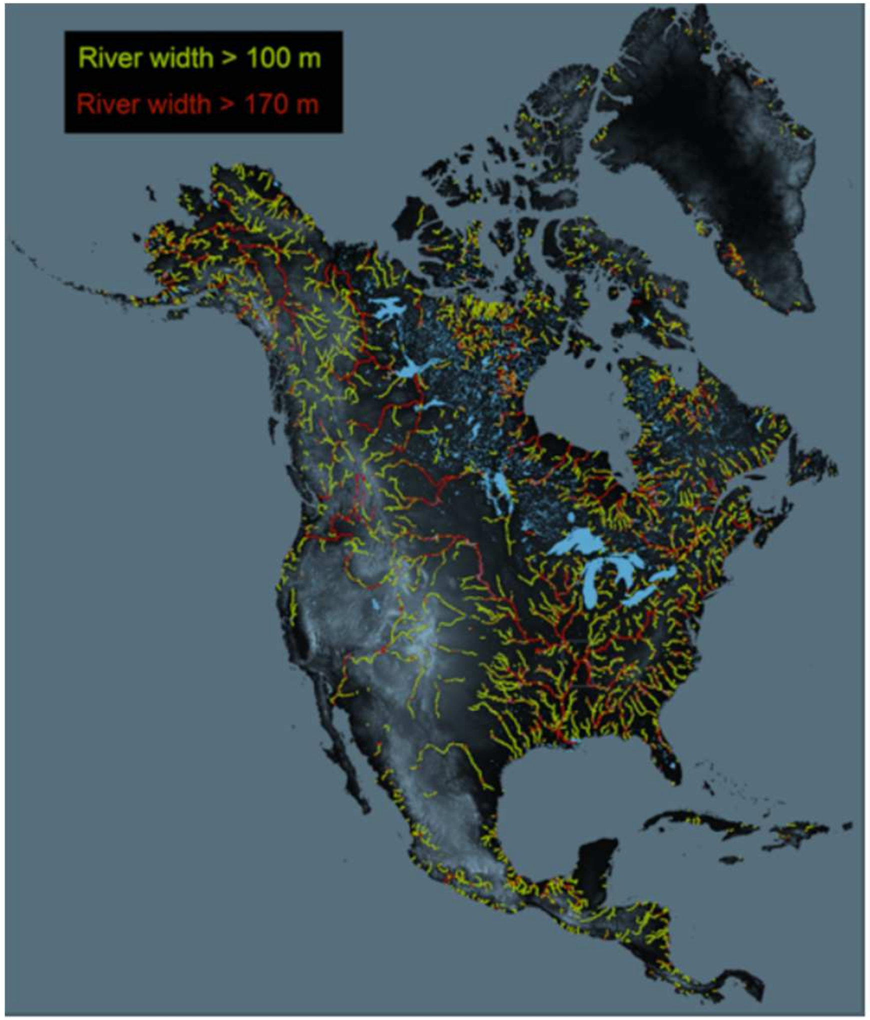
Ground water → **Gravimetry**

Direct or indirect measurements

CNES involvement in the missions dedicated to Water Cycle



SWOT – Requirements rivers



From Allen et al., in press, GRL

- Inundated Area/River Width:
  - 15% error for 100 m wide rivers over 10 km reach (baseline)
  - 15% error for 170 m wide rivers over 10 km reach (threshold)
- Water surface elevation/height:
  - 10 cm error for 1 km^2 area and 25 cm error for between $(250\ m)^2$ and 1 km^2 (baseline)
  - 11 cm error for 1 km^2 area (threshold)
- Water surface slope:
  - 10 μrad error for 100 m wide river over 10 km (baseline)*
  - 20 μrad error for 100 m wide river over 10 km (threshold)*

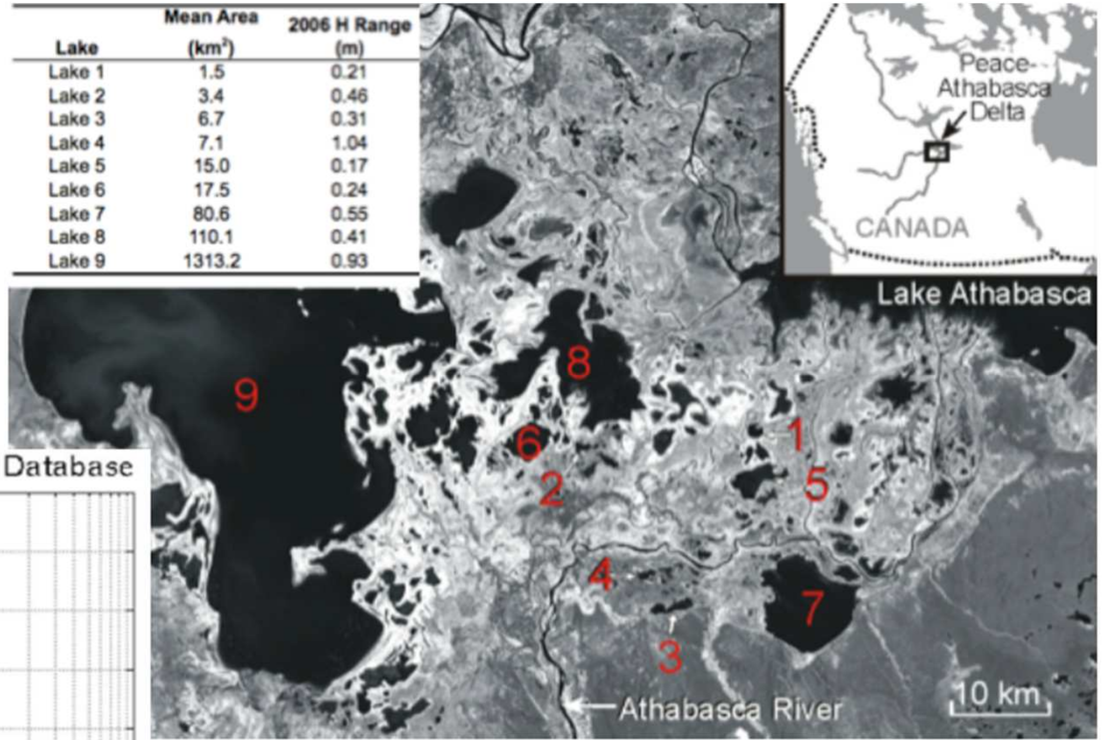
*Nominal

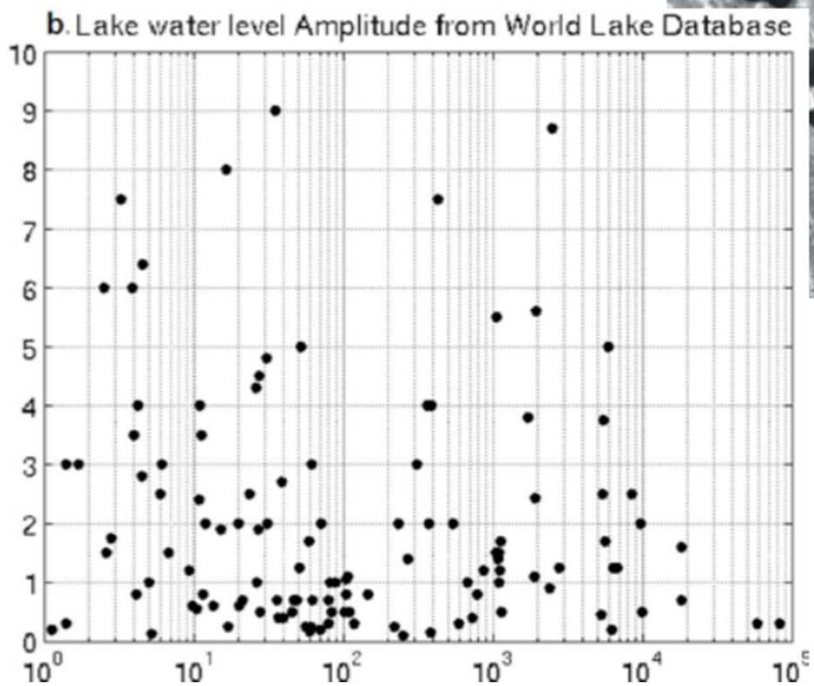
SWOT Mission Requirements lakes

Inundated Area:

- 15% accuracy for lakes larger than (250 m)^2 (baseline)
- 15% accuracy for lakes larger than 1 km^2 (threshold)

Lake	Mean Area (km^2)	2006 H Range (m)
Lake 1	1.5	0.21
Lake 2	3.4	0.46
Lake 3	6.7	0.31
Lake 4	7.1	1.04
Lake 5	15.0	0.17
Lake 6	17.5	0.24
Lake 7	80.6	0.55
Lake 8	110.1	0.41
Lake 9	1313.2	0.93





- Lake Water Surface Height:
  - 10 cm accuracy for lakes larger than 1 km^2 and 25 cm accuracy for lakes between 1 km^2 and (250m)^2 (baseline)
  - 11 cm accuracy for lakes larger than 1 km^2 (threshold)

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