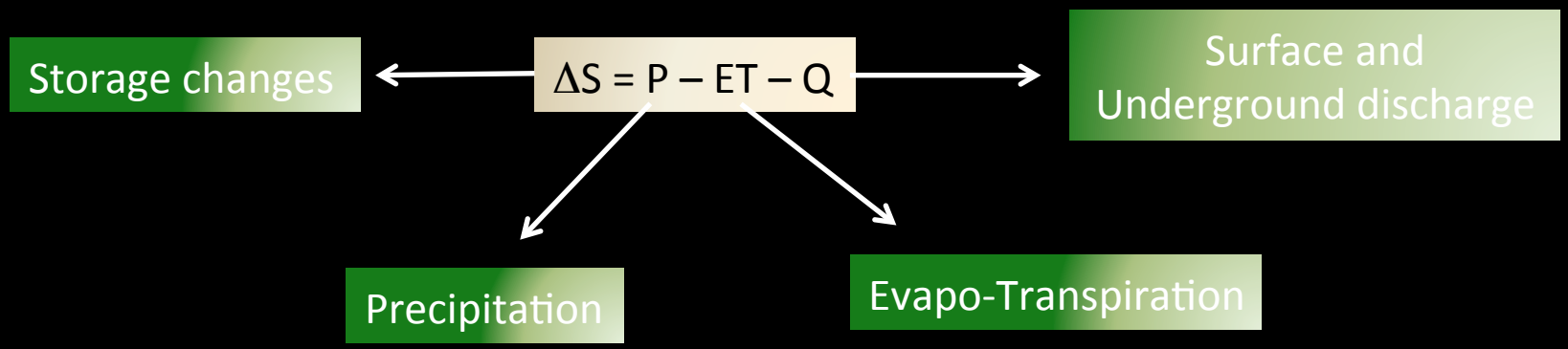
Summary of the key themes and challenges for SWOT Hydrology Science

- Provide a global inventory of all terrestrial surface water bodies whose surface area exceeds $(250m)^2$ (goal: $(100m)^2$) (lakes, reservoirs, wetlands) and rivers whose width exceeds 100m (goal: 50m).
- Measure the global storage change in terrestrial surface 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.



SWOT will directly provide estimation of: ΔS &Q; indirectly of ET

Objective of SWOT for hydrology

- *What are the temporal and spatial scales of the hydrologic processes controlling surface water storage and transport across the world's continents?*

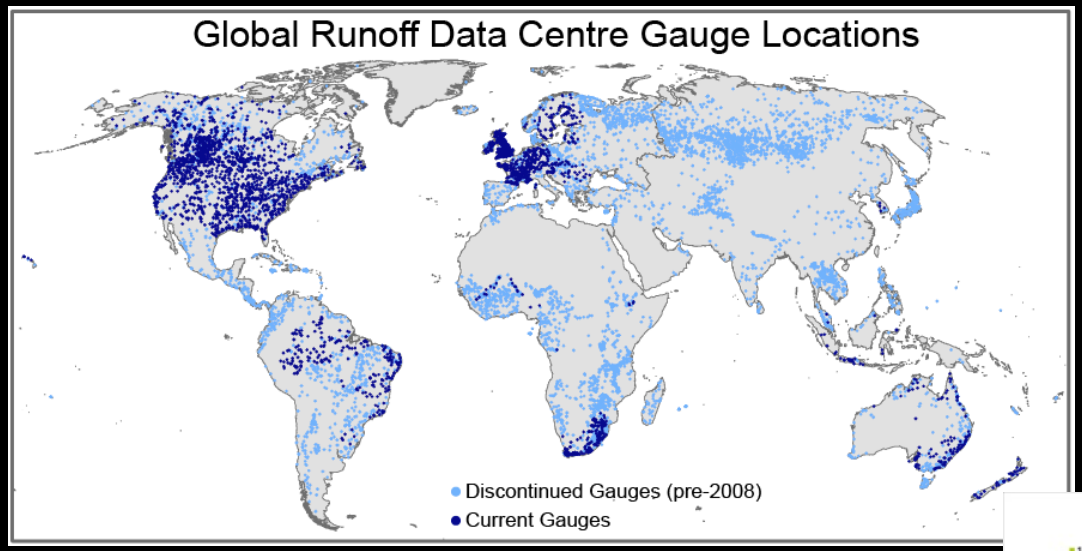
- *What are the spatially distributed impacts of humans on surface water, for example through water impoundment behind dams, withdrawals and releases to rivers and lakes, trans-boundary water sharing agreements, diversions, levees, and other structures?*

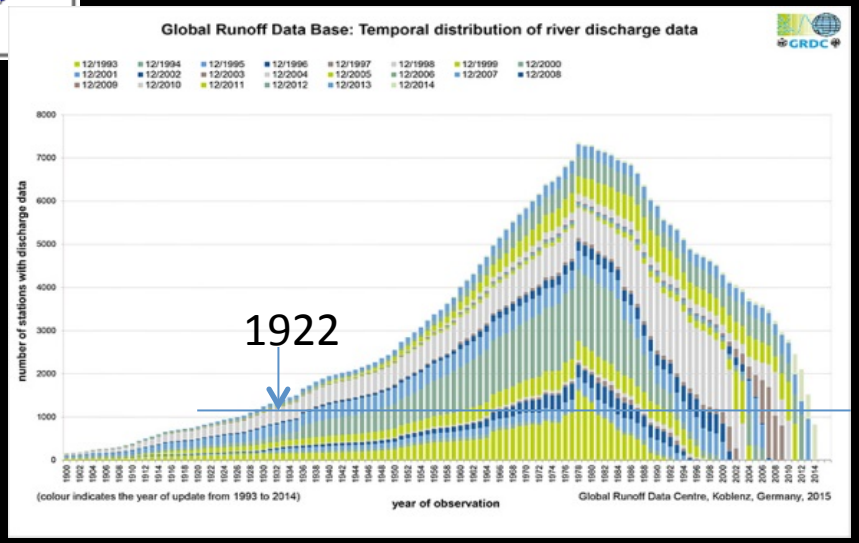
- *What are the regional- to global-scale sensitivities of surface water storages and transport to climate, antecedent floodplain conditions, land cover, extreme droughts, and the cryosphere?*

- *Can regional and global extents of floodable land be quantified through combining remotely sensed river surface heights, widths, slopes, and inundation edge with coordinated flood modeling?*

- *What are the hydraulic geometries and three-dimensional spatial structures of rivers globally, knowledge of which will improve our understanding of water flow?*

Global River Discharge Observations

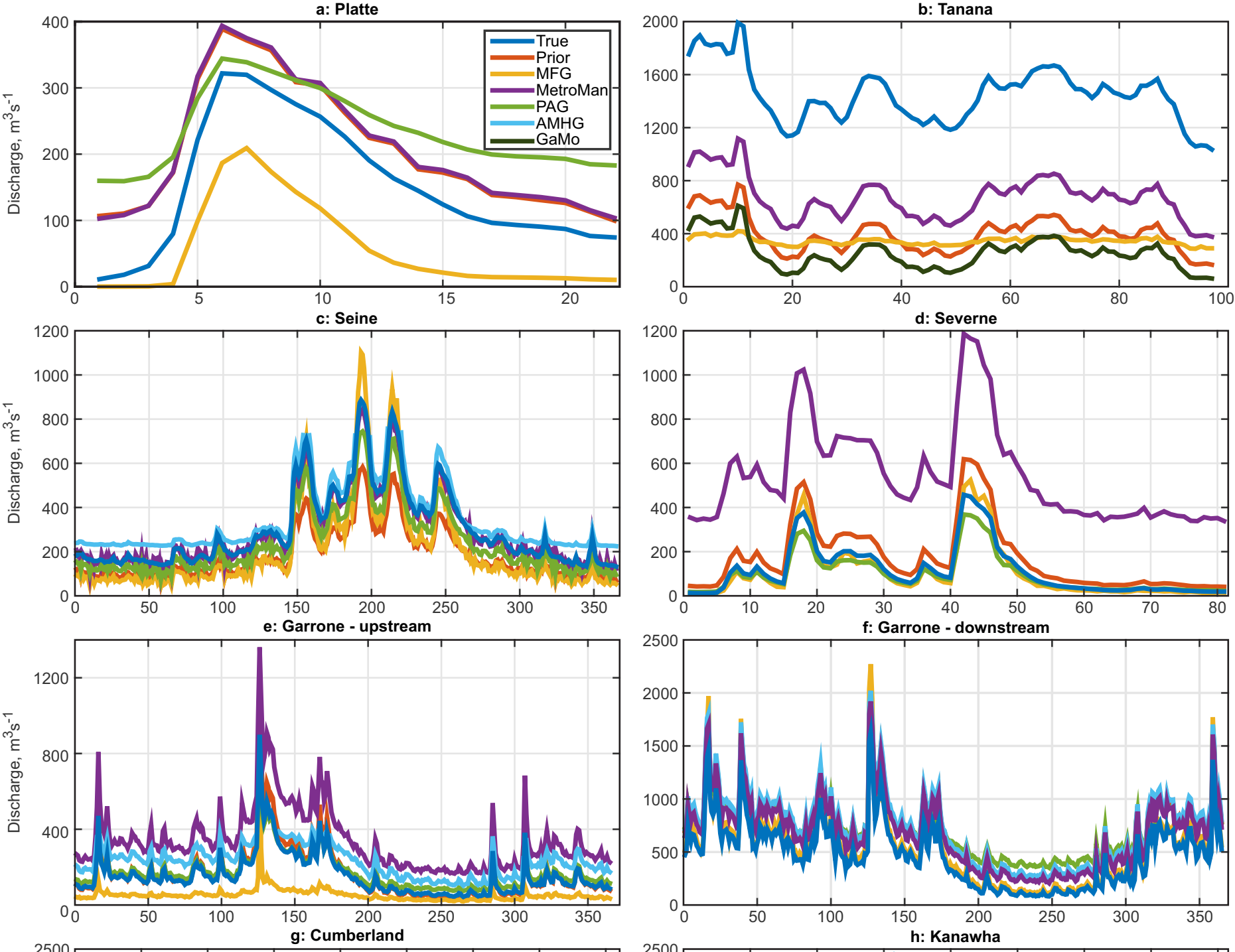




- Globally, our best publicly available discharge dataset is insufficient for many of our needs.
- Nadir altimeters are only providing water height and the only way to infer discharge is to use rating curves (from ADCP or from models).

Four primary methods for discharge inversion

Author(s)	Algo Basis	Identified variables	Data required	Comments
Bjerklie	Mannning	K, A, hence Q	In situ Q + W, S and H	Assumes mean annual flow is known
[Durand et al 2014] JoH	Temporal mass+manning $\begin{cases} \partial_x Q + \partial_t A = 0 \\ Q = K A R_h^{2/3} \sqrt{S} \end{cases}$ + Bayesian MCMC	K, A_0, hence Q	W, Z, S	Requires a first guess, mass conservation integrated in time
[Gleason and Smith 2014] PNAS, WRR	$w=aQ^b \rightarrow Q=(w/a)^{1/b}$ a,b Estimate from width obs at Nr*Nt sections qith dxQ=0 + Genetic Algorithm	a,b, hence Q	W	Statistical method requiring time varying w at several locations
[Garambois and monnier 2015] AdWR	$\begin{cases} \partial_x Q = 0 \\ Q = K A R_h^{2/3} \sqrt{S} \end{cases}$ + Levenberg-Marquardt algorithm	K, A_0, and Q	W, Z, S	Effective (topography,roughness) Requires a first guess

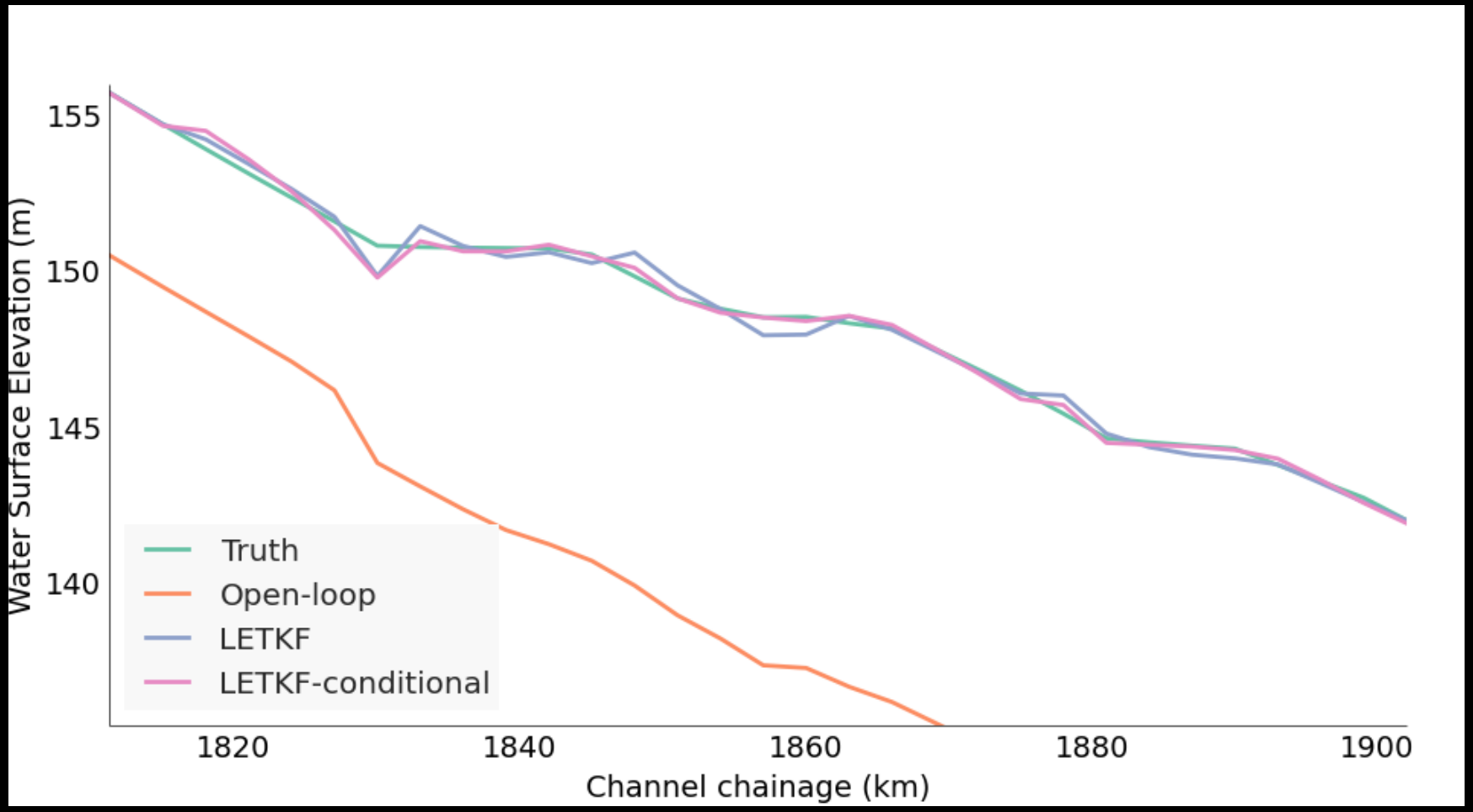

a: Platte
b: Tanana
c: Seine
d: Severne
e: Garrone - upstream
f: Garrone - downstream
g: Cumberland
h: Kanawha
Discharge, m3s-1
True
Prior
MFG
MetroMan
PAG
AMHG
GaMo

Key Challenges for SWOT Discharge

- Improved stand-alone SWOT discharge algorithms.
- Develop and test robust, global assimilation schemes in hydrologic and hydrodynamic models.
- Develop more datasets to test algorithms: models, simulator, AirSWOT
- Identify optimal ways to leverage existing *in situ* and satellite datasets to improve SWOT discharge estimates.
- Figure out how to robustly estimate and incorporate layover.

SWOT data assimilation: hydraulics

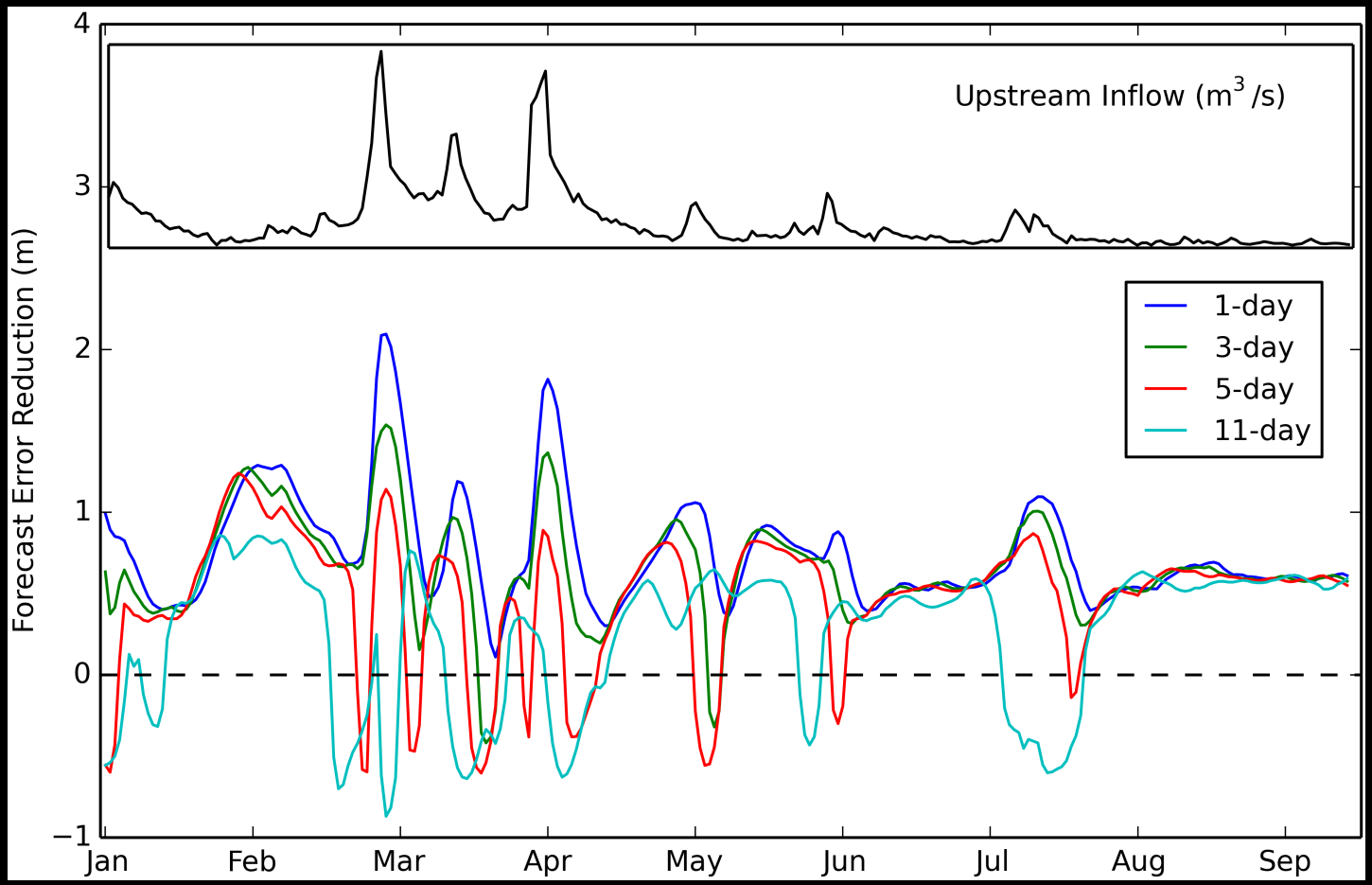
- Many studies demonstrating the feasibility of assimilating SWOT observations into hydrodynamic models
- Example of estimating water surface elevation profile from the Arkansas River:



Courtesy K. Andreadis

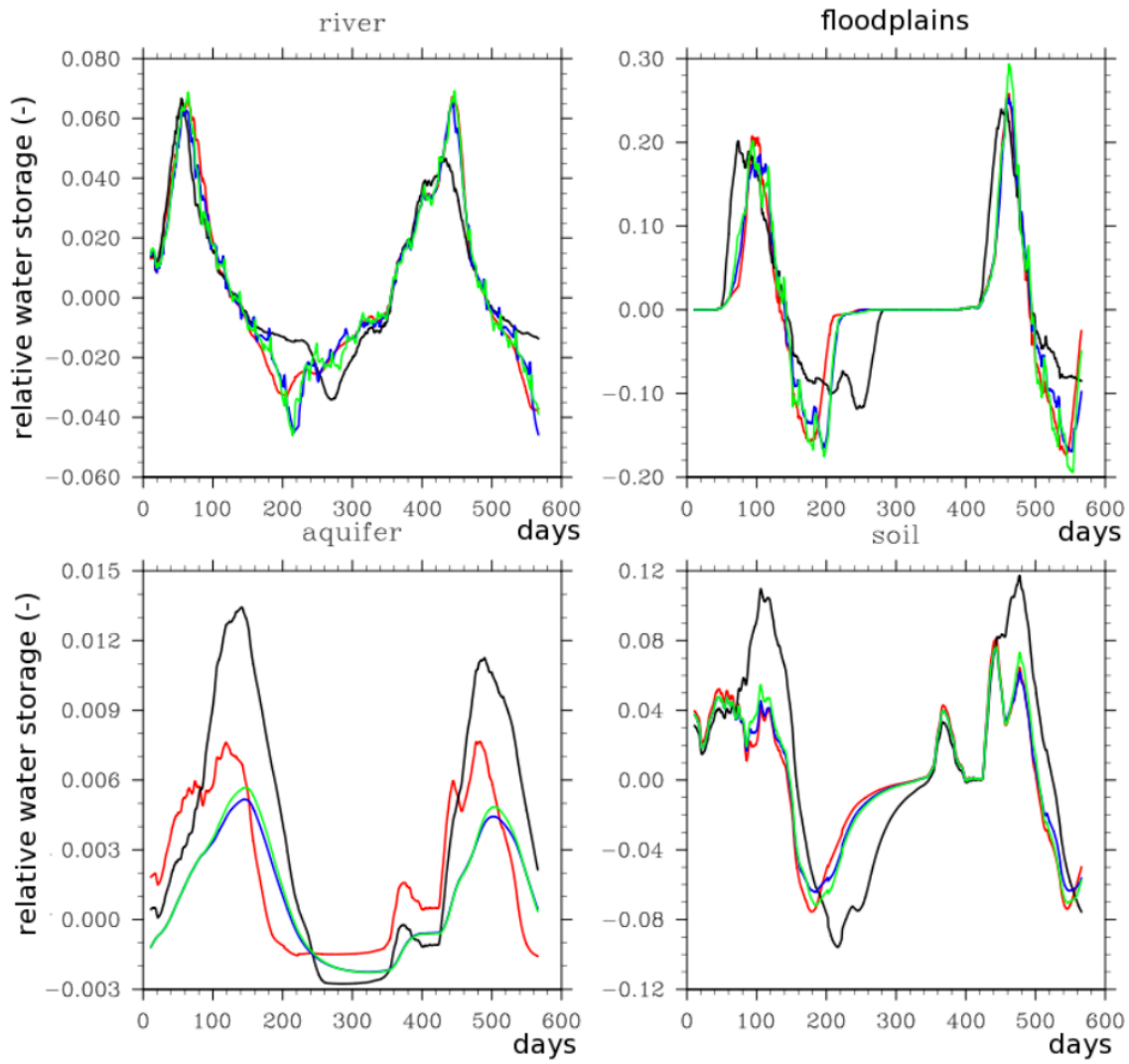
Improving model predictability with SWOT

- Assimilating SWOT observation at time of forecast initialization can improve skill up to 11 days later.
- Example from Ohio River

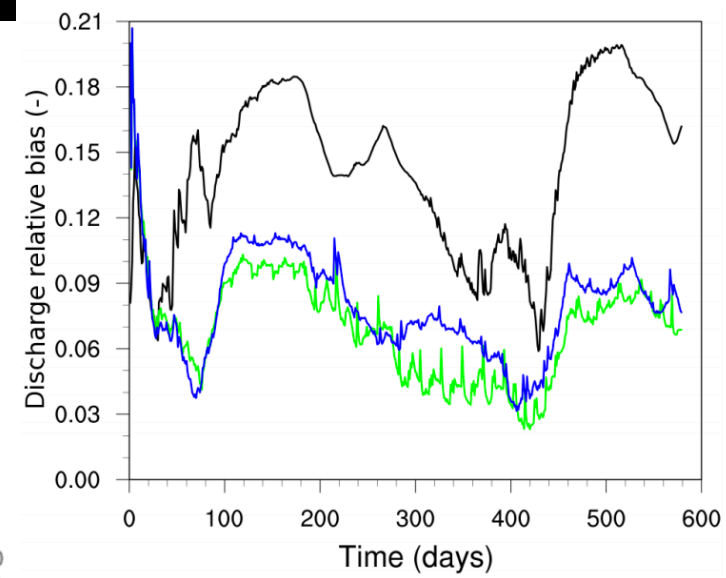


Andreadis and Schumann, AWR, 2014

SWOT data assimilation: hydrology



Improved representation of water storage results from SWOT data assimilation



Decreased bias in discharge from SWOT data assimilation

Assimilation of SWOT data into a hydrologic modeling system appears to substantially improve representation of the water cycle.

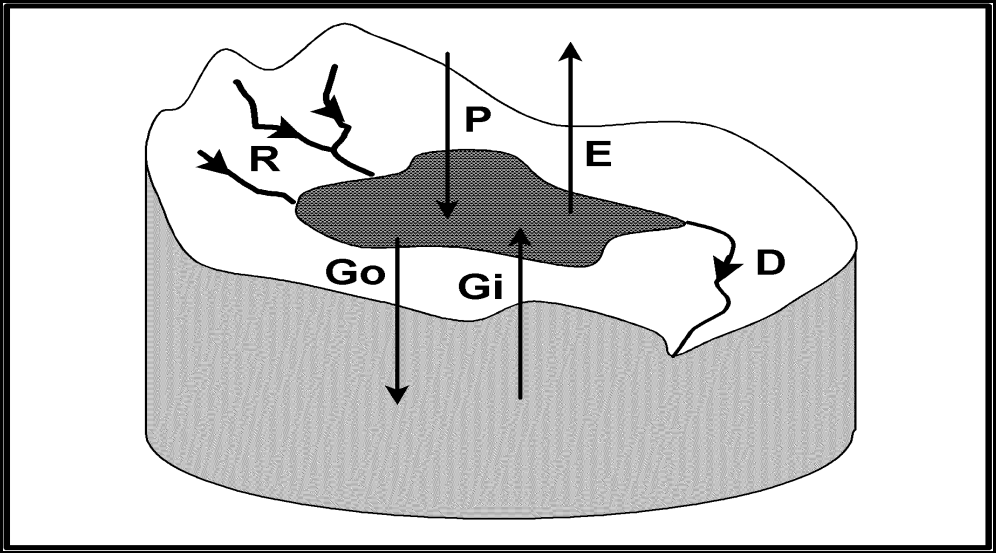
Pedinotti et al., 2014, HESS

Key Challenges for SWOT and Models

- Development of robust models and assimilation schemes that can be applied globally.
- Assessment of how assimilation of SWOT data will improve representation of the water cycle.
- Development of assimilation schemes to leverage SWOT data in 1-D and 2-D hydrodynamic models.
- Application of model results to improve SWOT algorithms.

Key Challenges for SWOT and Lakes

- What can we learn:
  From lakes?
  On lakes?



$$\frac{dV}{dt} = [R + P + Gi] - [D + E + Go]$$

Lake in equilibrium:

$$A_{LE} = \frac{R}{(E - P)}$$

Equilibrium response time: to reach a fraction (1-1/e), ⇔ 63% of the total change:

$$\tau_E = \frac{1}{dA / dV (E - P)}$$

If one component of the water balance equation is modified

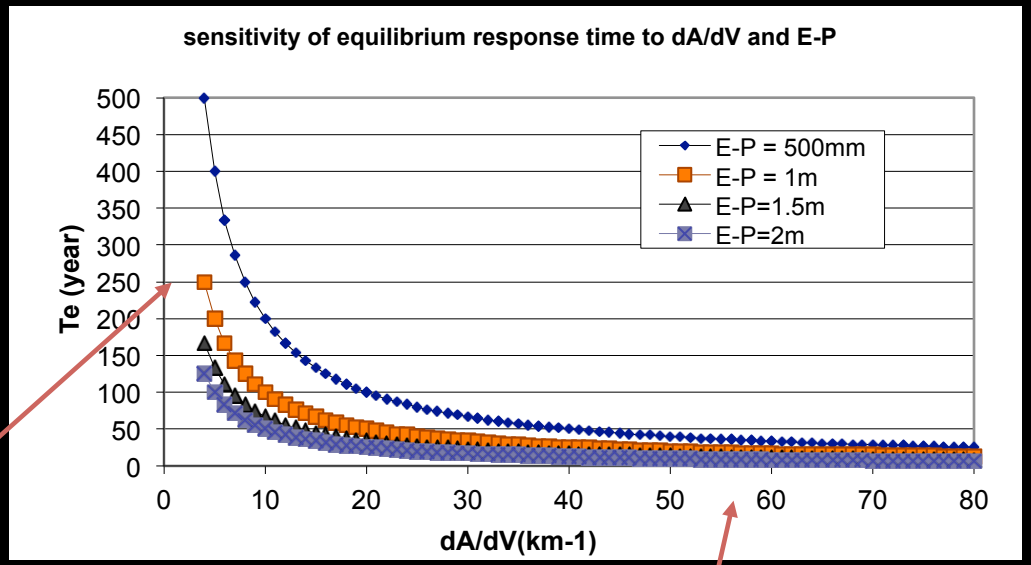
$$L(t) = L_0 + [L_{LE} - L_0](1 - e^{\frac{-t}{\tau_e}})$$

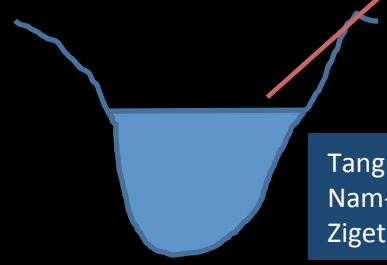
How can we interpret the water balance of a Lake?

A lake acts as a low pass filter with potentially long response time (> 100 years) depending on E-P and the morphology (dA/dV)

Two neighboring lakes affected by the same environmental changes will react differently

Interpretation / reconstruction of CC from lakes is possible depending on time series length of dV/dt and the choice of adequate lakes





Tangra-Yumco , 522 years
Nam-co, 160 years
Zigetang-co, 134 years

Ayakkum, 24 years
Grande/ petiteAral, 23 / 17 years
Urmia, 10 years
Small / Large lake Tchad, 1/4 years

SWOT has the potential to allow determining morphology of lakes (& floodplains) worldwide in order to define group of large number of lakes for detecting CC impacts on water ressources, which has never been done before on large scale

Observability of Lake Storage from SWOT

- W.r.t climate change, the lakers are both

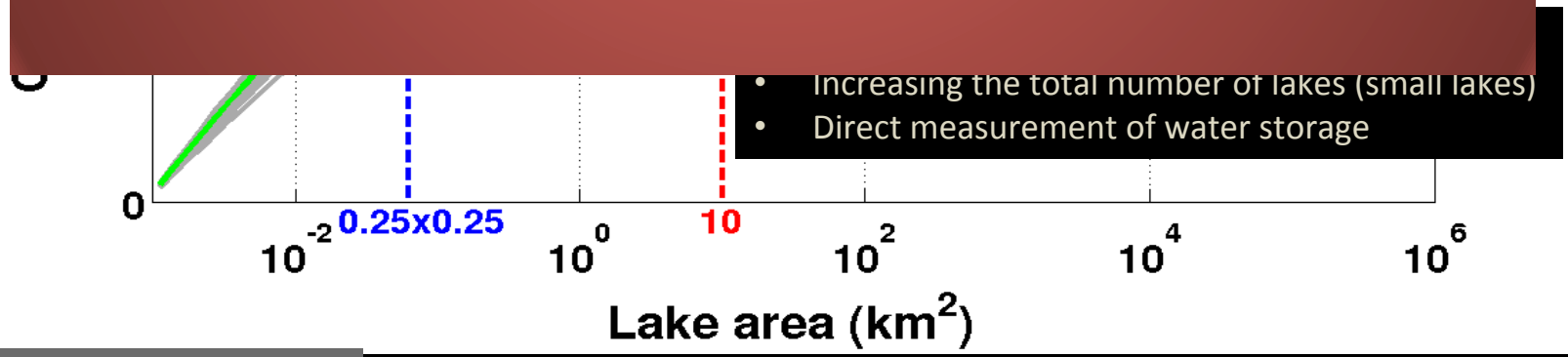
A proxy
An actor

- Storage changes therefore needed to be assimilated into models:

LSM
GCM

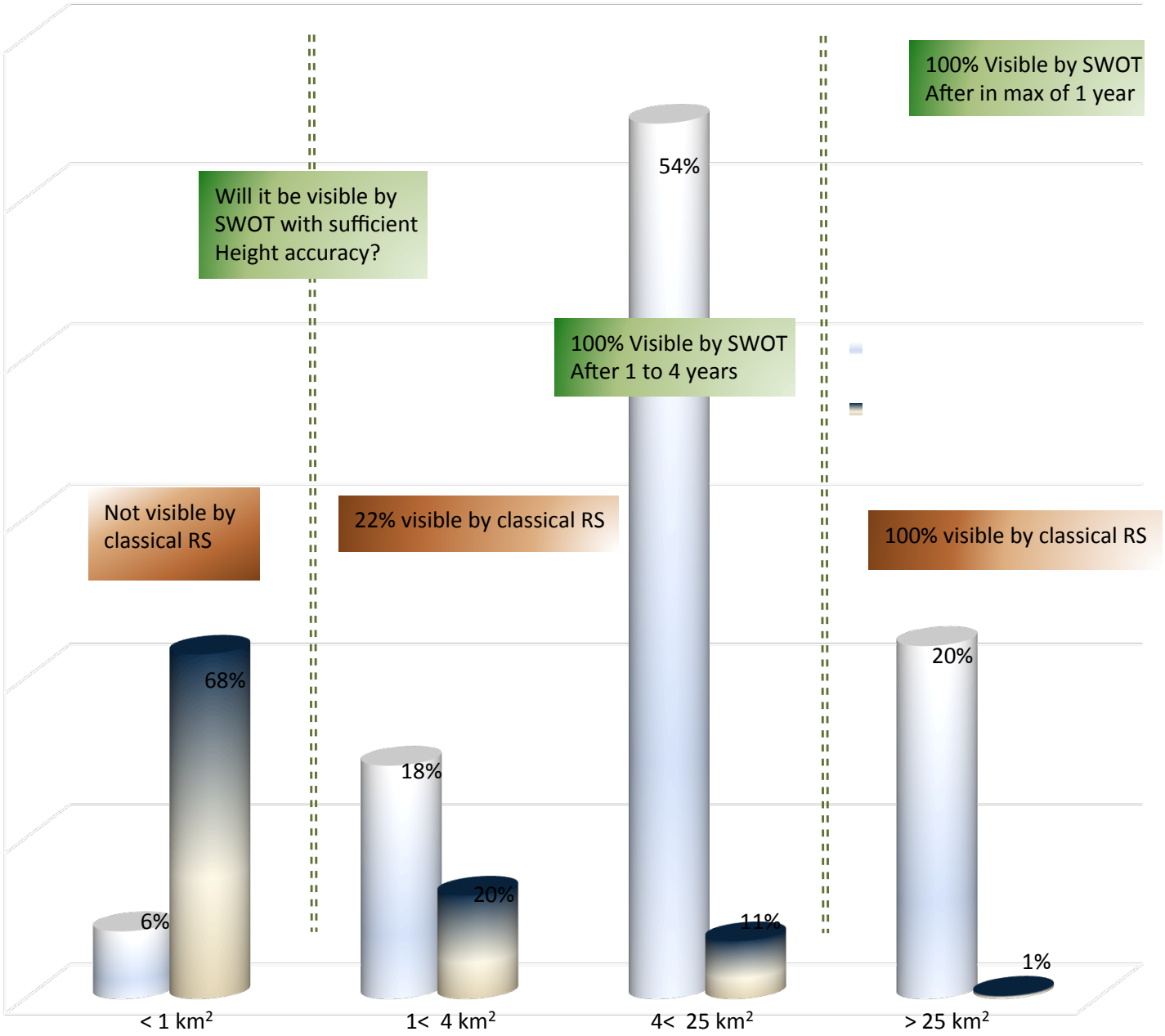
- Rôle of reservoirs in the GSLR

- What about connectivity with floodplains and rivers?

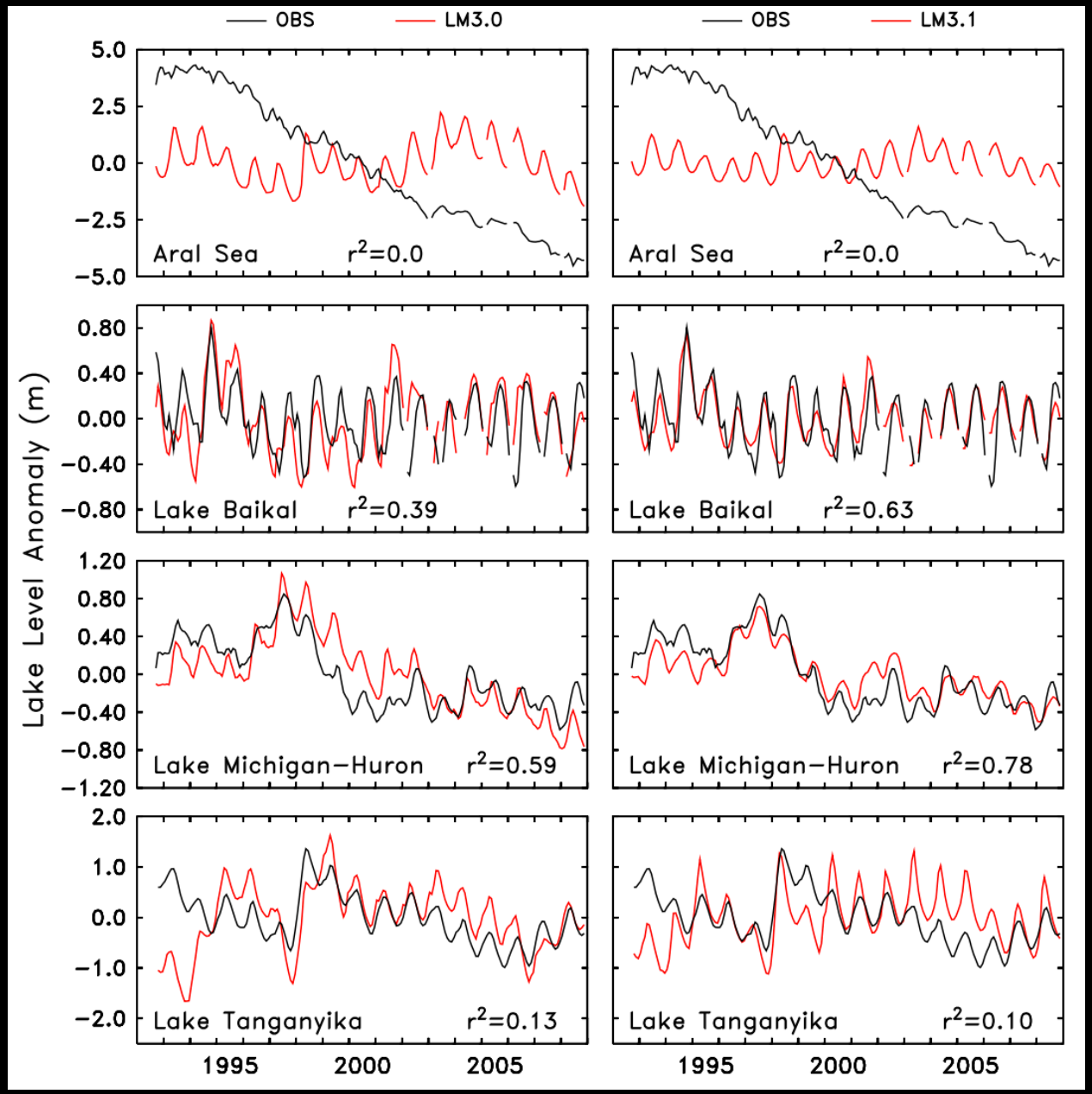


- Increasing the total number of lakes (small lakes)
- Direct measurement of water storage

Courtesy S. Biancamaria, H Yesou


100% Visible by SWOT
After in max of 1 year
Will it be visible by
SWOT with sufficient
Height accuracy?
54%
100% Visible by SWOT
After 1 to 4 years
Not visible by
classical RS
22% visible by classical RS
100% visible by classical RS
68%
6%
18%
20%
11%
20%
1%
< 1 km²
1< 4 km²
4< 25 km²
> 25 km²

SWOT and Models: Lakes



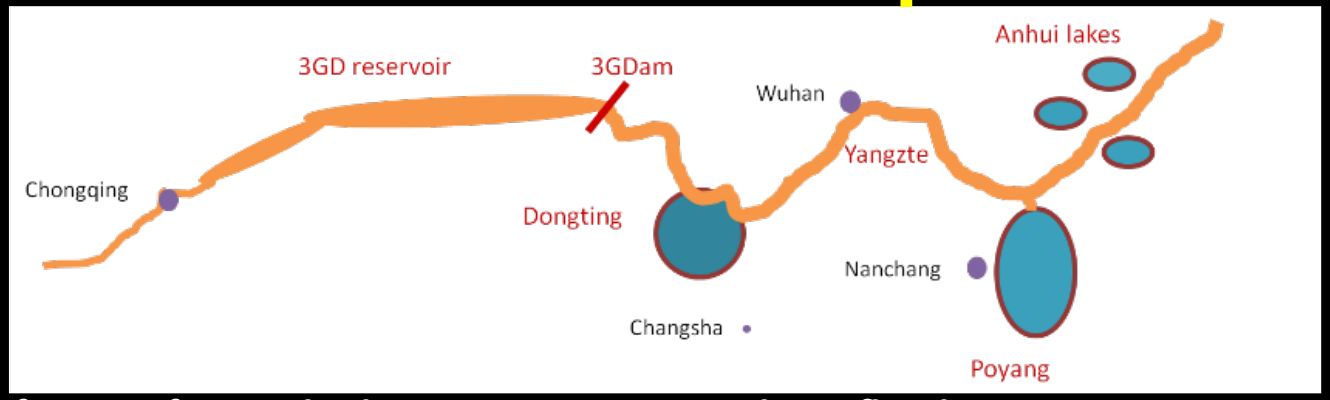
Milly et al., *J. Hydromet.*, 2015

Lake processes are increasingly being included in land surface hydrology models.

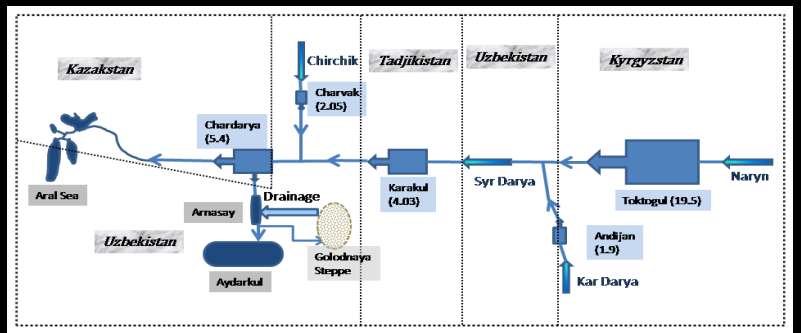
SWOT will provide regular measurements of inundation extent and water surface elevation in nearly all lakes larger than $(250\ \mathrm{m})^2$ worldwide.

Lakes can serve as integrators of the water cycle, and assimilating SWOT lake data into models may improve overall simulations of the water cycle.

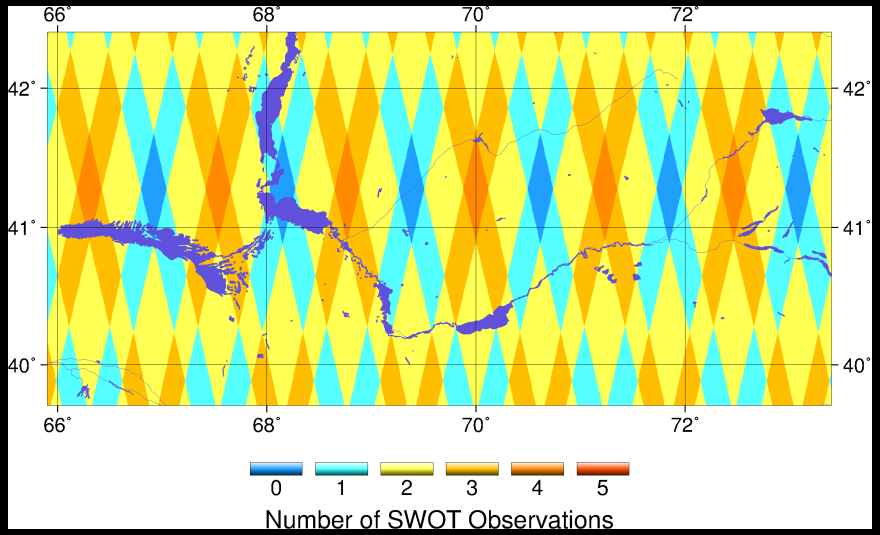
Connectivity of lakes and reservoirs with rivers and floodplains



- Diversity of types of water bodies, narrow reservoir, large flat depression, etc ..
- water surface extent behaviors, depending of the season, size factor 5
- huge water height variations from 40 to 1 m depending of the water body
  - Challenge for generation of data products & for data assimilation into models



Transboundary river management: case of Syr Darya with cascade of reservoirs sharing between several countries for both agriculture and hydroelectricity generation=> SWOT as an independant operationnal monitoring system for river, reservoirs & floodplains in



What are the key questions and tasks for the ST on lakes

Creating a priori Lake data base and developing apropriate algorithms to respect the SRD => Pavelsky & Cretaux sessions on Wednesday

How are we going to correctly assimilate the SWOT products in models?

Will need to discuss more closely with the GCM and LSM community
Will need to correctly assess the error budget

Creating a space for discussing issues on water management sector in particular w.r.t reservoirs monitoring

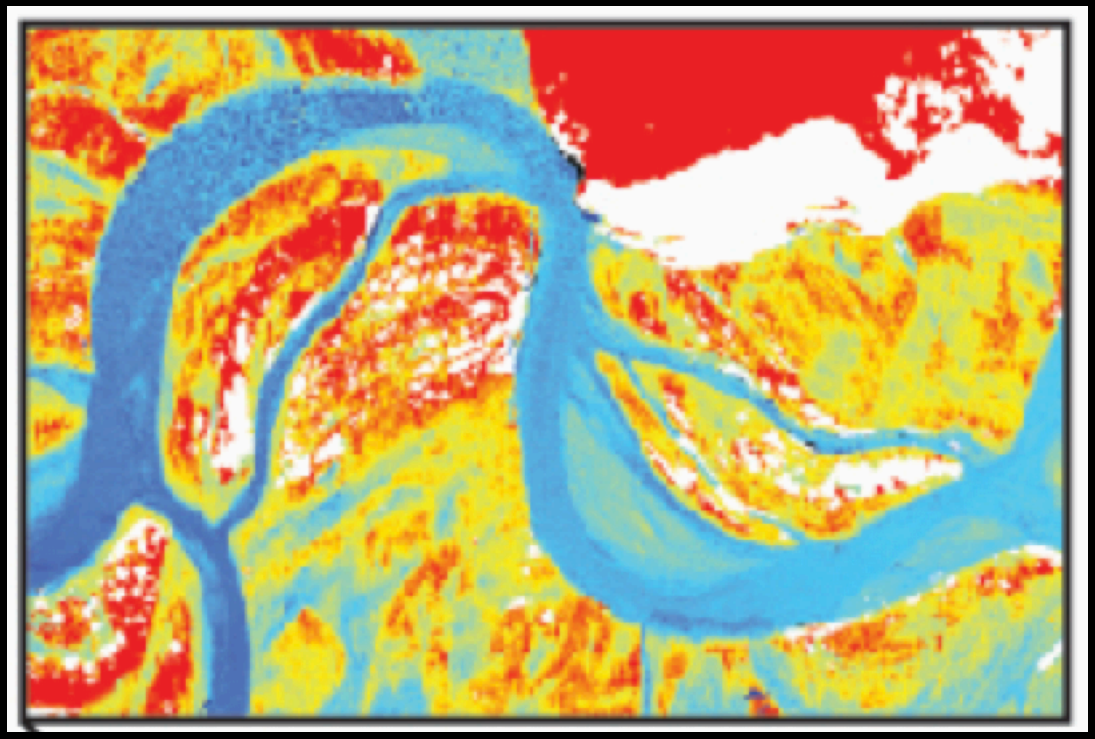
How are we doing the cal/val? => Calmant & Rodriguez sessions on Wednesday

AirSWOT

- AirSWOT is an airborne SWOT analogue and a primary SWOT calibration and validation tool.
- Primary payload is the Ka-band SWOT Phenomenology Airborne Radar (KaSPAR)
- Secondary payload is a NASA Color/IR Digital Cirrus Camera
- Integrated on a NASA King Air B200 out of NASA Dryden

AirSWOT Hydrology Campaigns

November 2014: Mono Lake & Lake Tahoe
March 2015: Sacramento and Willamette Rivers
May 2015: Wax Lake Delta & Atchafalaya Wetlands
June 2015: Tanana River and Yukon Flats, AK
Winter 2016: Tuolumne Meadows (for snow cover)



Preliminary results will be presented on Wednesday (Pavelsky)

Next Steps: Calibration and Validation

- Finalize Calibration & Validation Plan
  - Airborne and *in situ* measurements
  - 8-10 rivers, 6 lakes/lake complexes, 4 large wetlands
  - Cement International and Interagency Partnerships
  - Extensive prelaunch activities

- Conduct additional AirSWOT campaigns to improve understanding of SWOT phenomenology and develop robust validation techniques.
  - Atchafalaya Wetlands (Oct 2016)
  - Connecticut River
  - Prairie Potholes (Nebraska/Kansas)

- Develop global-scale scientific and observational networks to extend validation beyond project capabilities.

Data products and algorithms

Key works to be done (Hydro splinter on Wednesday & High level SWOT data product workshop on Thursday)

Data product definition and a priori databases (Pavelsky, Cretaux, Durand, Fraisson)

- how to generated pass-based and cycle-based products?
  - What is a point cloud product? Generation of rasters? Generation of reaches?

Water detection algorithm (Williams, Fjortoft)

- Development of LakeObs to extract lake vector products from pixel cloud

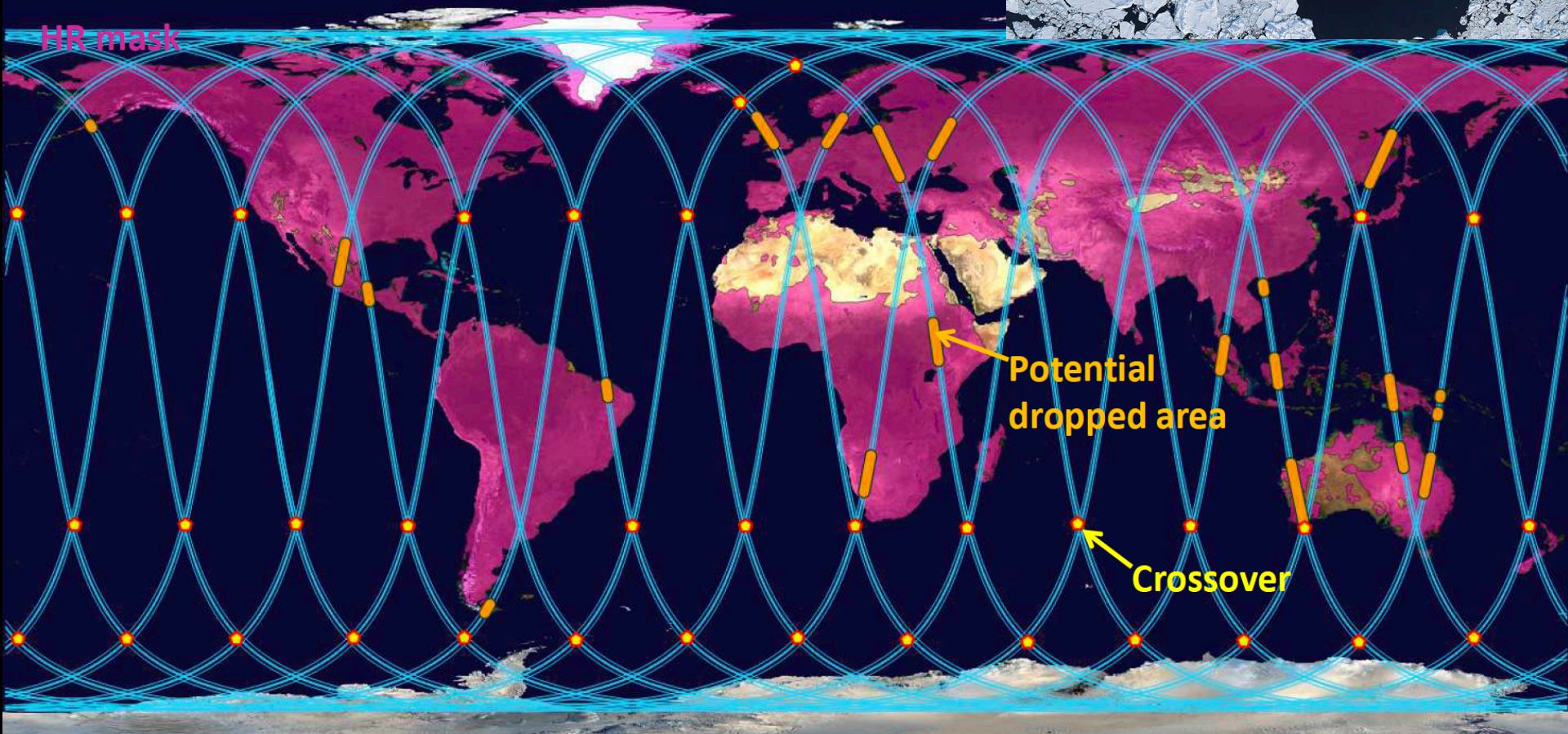
Crossover cal/val and impact over the continent (Ubelman)

Near real time product issue (Pavelsky, Rodriguez & Cherchali)

Wetlands data products (Simard & Calmant)

- what is a wetland?
- Do we need an a priori database on wetlands?
- which algorithm to be used? Which type of products?

Synergistic Science: Land/Ice/Ocean Margins

The high rate mask at the moment is focused primarily on hydrology, with additional data collection in selected ocean locations. Any additional collection off of continents would require very solid justification.

Question: for sea ice, what science can be accomplished with low-res data? Is there science that requires high-res data?