Hydrologic Science and Satellite Measurements of Surface Water

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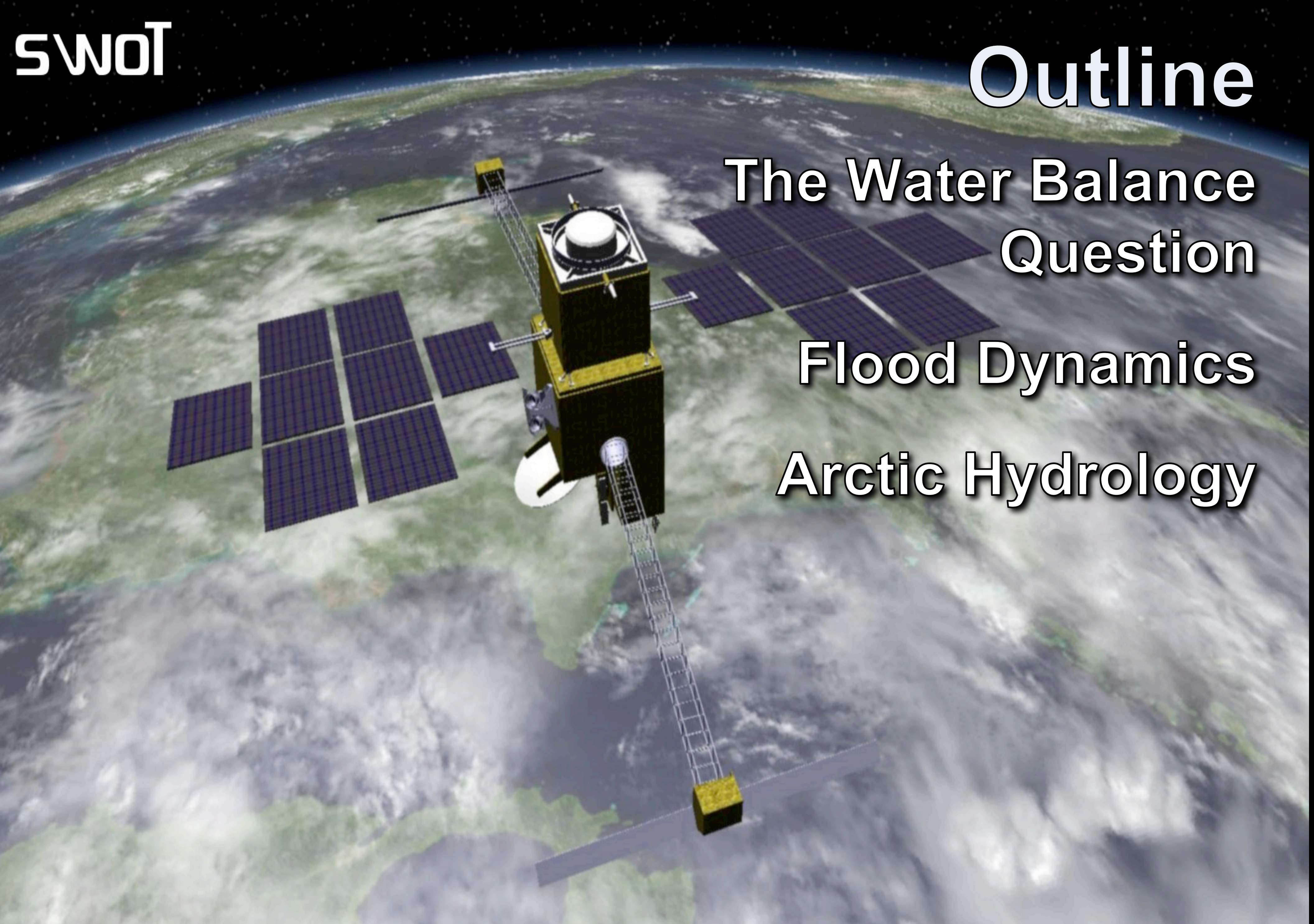
SWOT

Outline

The Water Balance Question

Flood Dynamics

Arctic Hydrology



Credit: CNES

Terrestrial Water Balance

$$\Delta S = P - E - Qs - Qg$$

Applied to an entire basin: Key = time

- ΔS: Storage change summed from soil moisture, snow water content, surface water storage, vegetation water content, ground water, and glaciers
- P, E: Precipitation and Evaporation
- Qs: River discharge
- Qg: Groundwater flux across basin boundary

Amazon Water Balance

ΔS = zero = P – E – Qs

	P	**E**	**Q**	**P-E-Q**
Averages	**2.13**	**1.32**	**1.02**	**-0.22**
	2.13 m/yr	3.62 mm/day	195000 m^3/s	**-41138** m^3/s
	P	**E**	**Q**	**P-E-Q**
Lows	**1.90**	**1.13**	**1.02**	**-0.26**
	1.90	3.10	195000	**-49737**
	P	**E**	**Q**	**P-E-Q**
Highs	**2.32**	**1.68**	**1.02**	**-0.38**
	2.32	4.60	195000	**-72664**
	P	**E**	**Q**	**P-E-Q**
Lows Highs	**2.32**	**1.13**	**1.02**	**0.17**
	2.32	3.10	195000	**31503**

E from Costa, M.H., and J.A. Foley, JGR, 1999; P from Costa, M.H., and J.A. Foley, GRL, 1998.

Congo Water Balance

ΔS = zero = P – E – Qs

	P		E		Q		P-E-Q	
As given	**1.30**	m/yr	**0.79**	m/yr	**0.36**	m/yr	**0.15**	
	3.56	mm/day	2.16	mm/day	41800	m^3/s	**18036**	m^3/s
Adjust E	**P**		**E**		**Q**		**P-E-Q**	
	1.30		**0.94**		**0.36**		**0.00**	
	3.56		2.59		41800		**0**	
Adjust P & E 7.40%	**P**		**E**		**Q**		**P-E-Q**	
	1.20		**0.85**		**0.36**		**0.00**	
	3.30		2.32		41800		**0**	
Adjust P & E above by 1.75%	**P**		**E**		**Q**		**P-E-Q**	
	1.23		**0.83**		**0.36**		**0.04**	
	3.36		2.28		41800		**4214**	

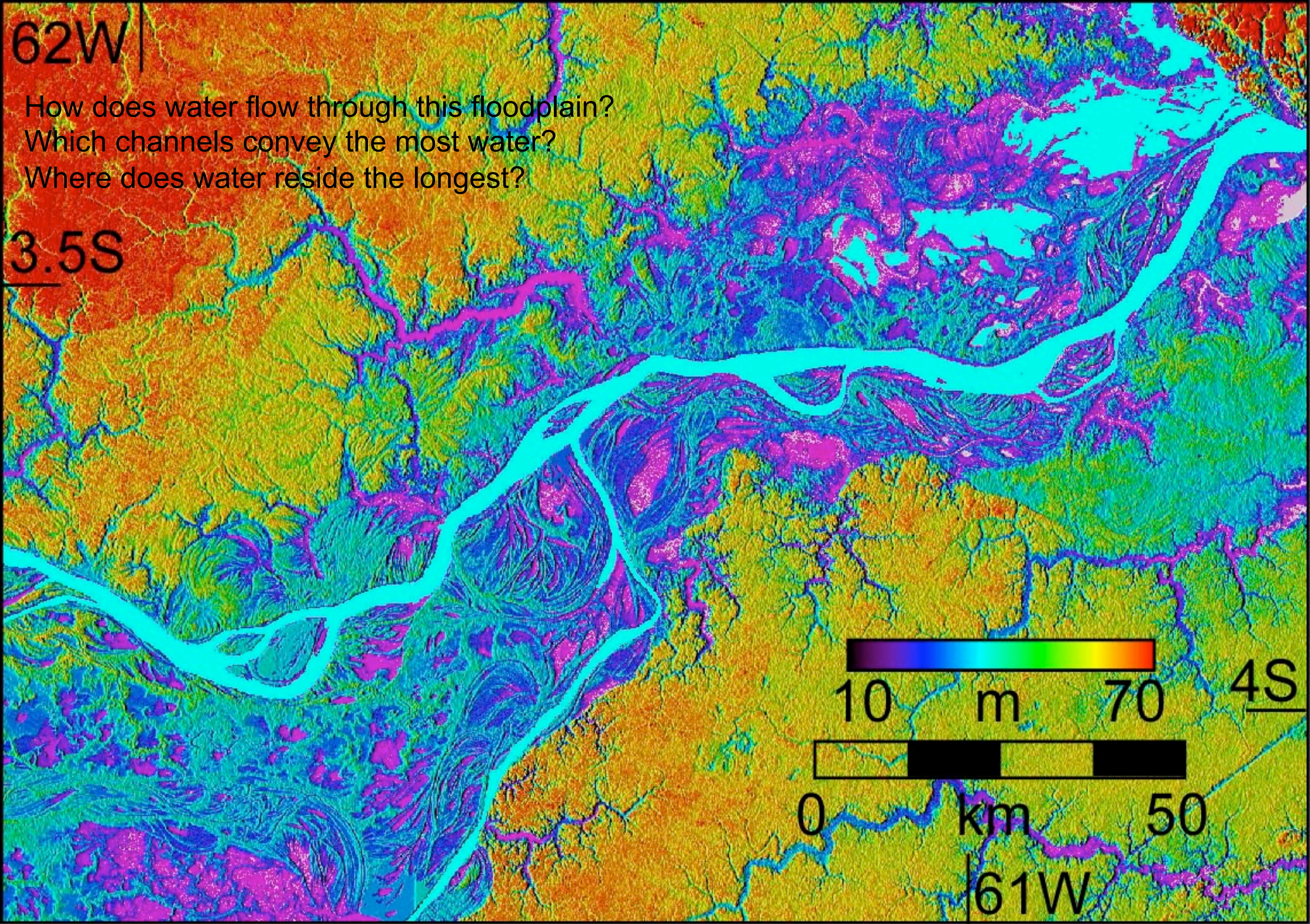
P and E from Beighley et al., 2010 in press with Hydrological Processes

Key Point for Global Water Cycle

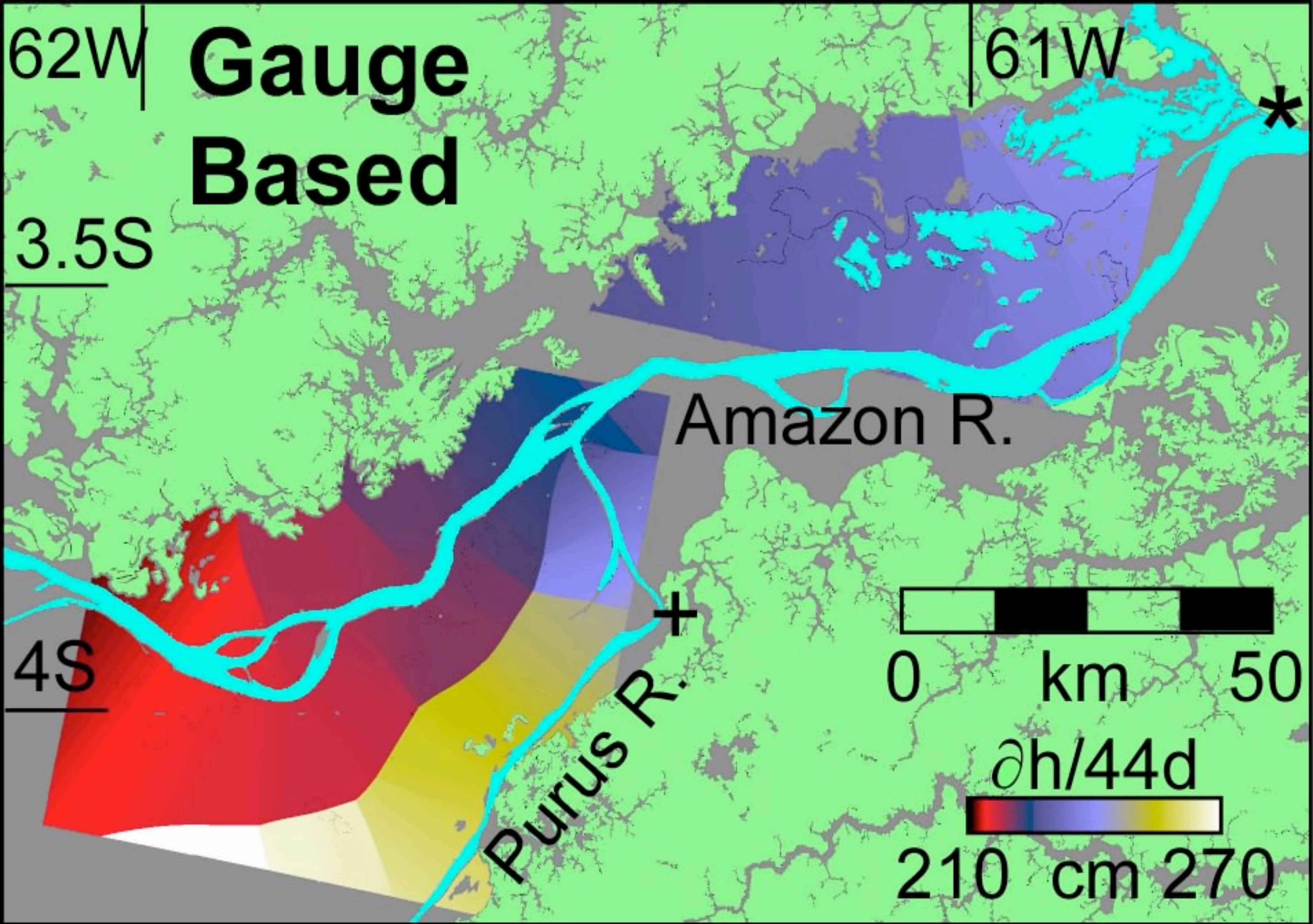
Science: In the Amazon and Congo, even a basic water balance has significant errors. Such errors impact our understanding of energy, carbon, nutrients, sea level, etc.

Measurements: Discharge from the SWOT mission would provide significant improvements in overall basin water balances.

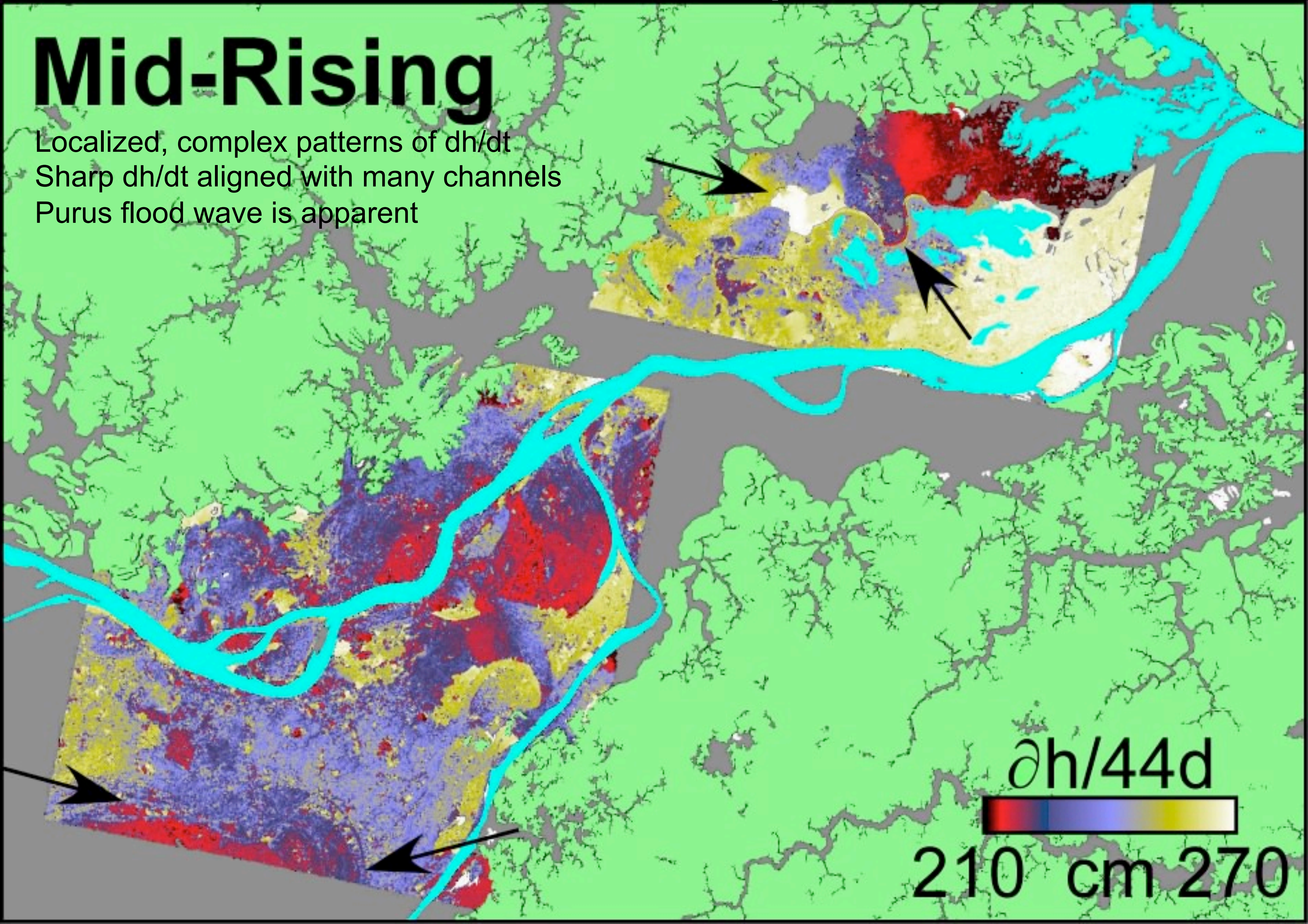
That was a very coarse resolution, what about high resolution?



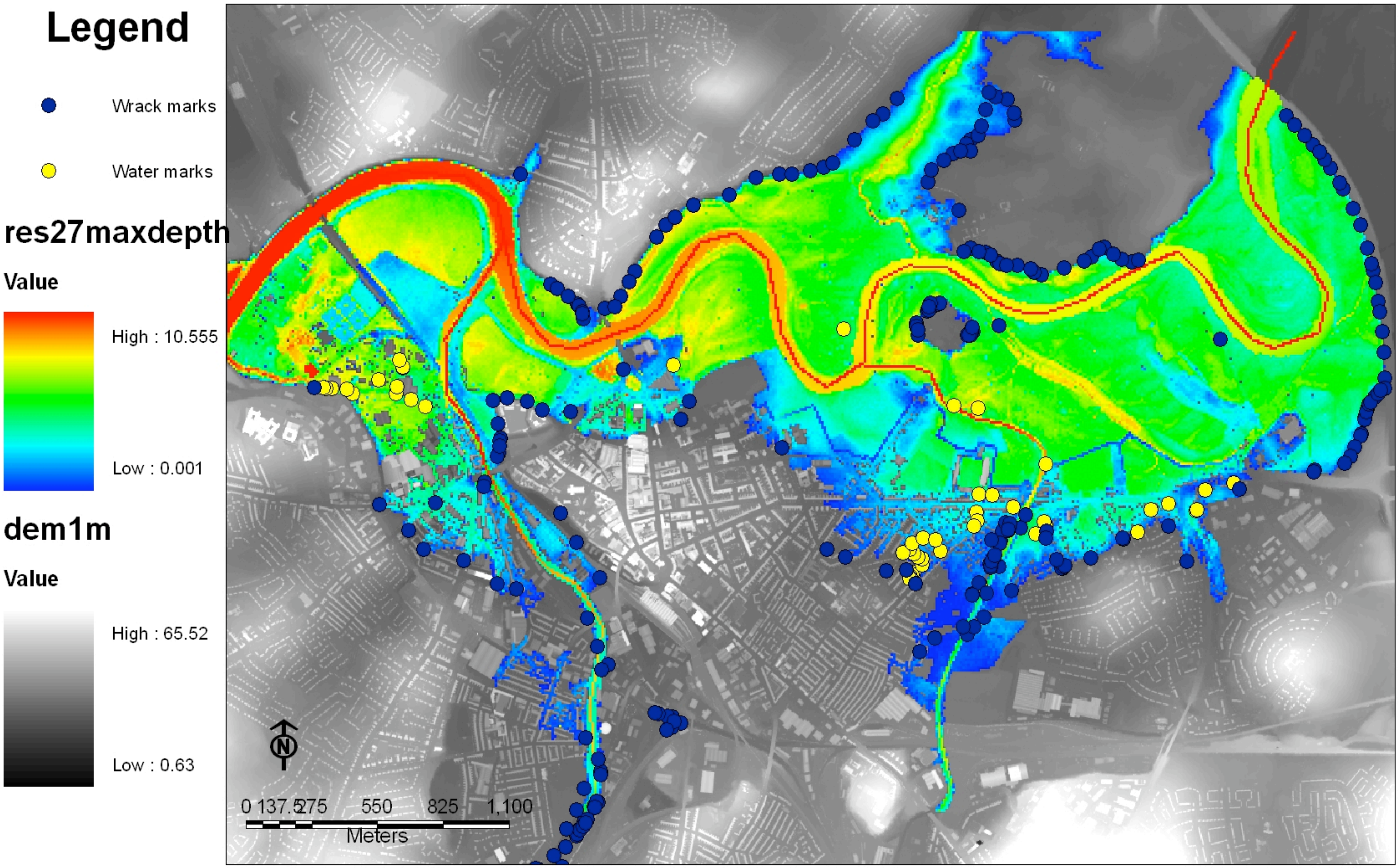
Conventional Idea of Floodplain Inundation



Measurements of Floodplain Inundation



Carlisle, UK – 10m model vs. ground survey



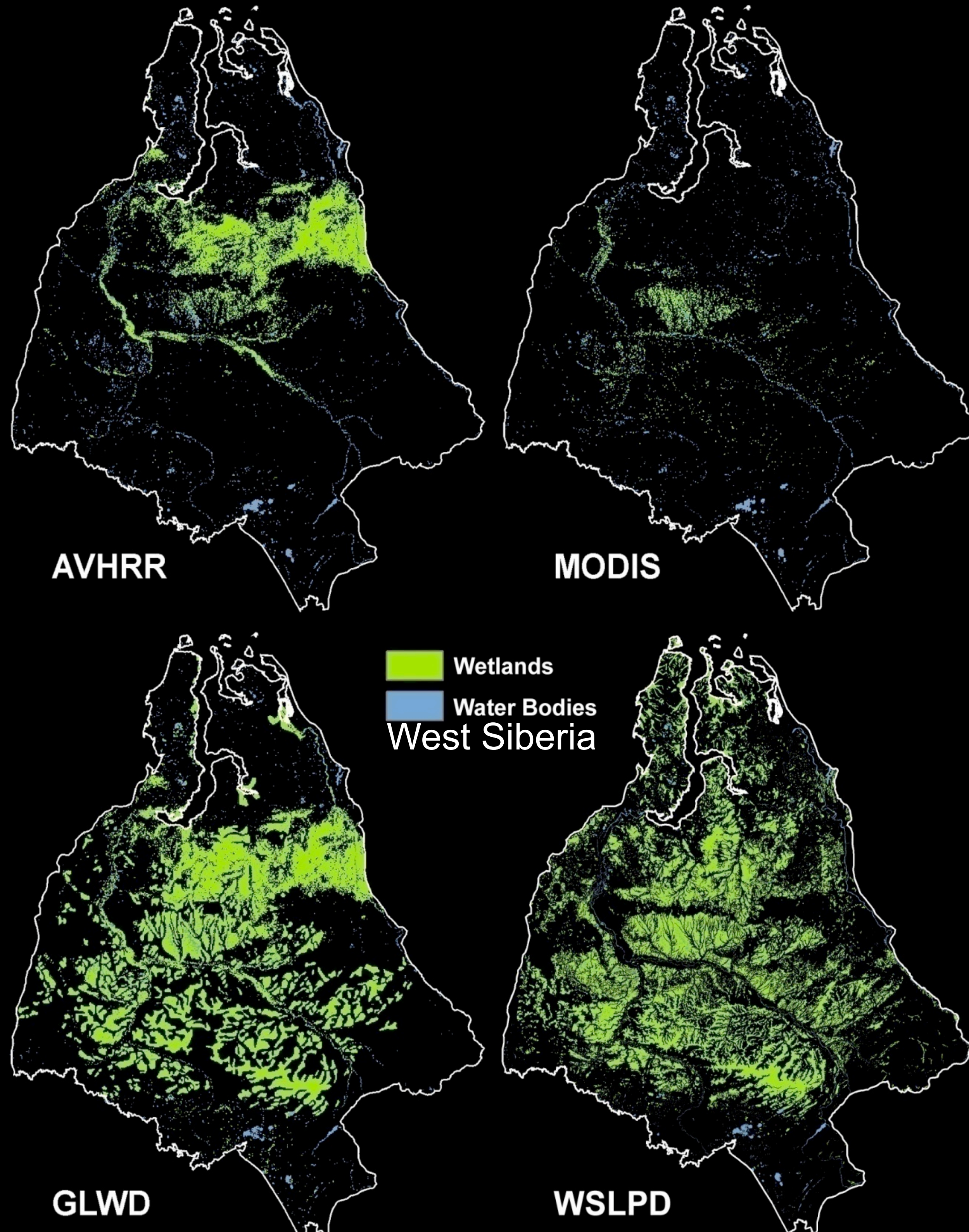
RMSE on water depth = 0.32 m

Key Point for Floodplain Processes and Flooding

Science: How do floodplain and wetland flows interact with complex topography, vegetation and buildings, and how do the storage effects and energy losses so generated control the development of hazardous flooding?

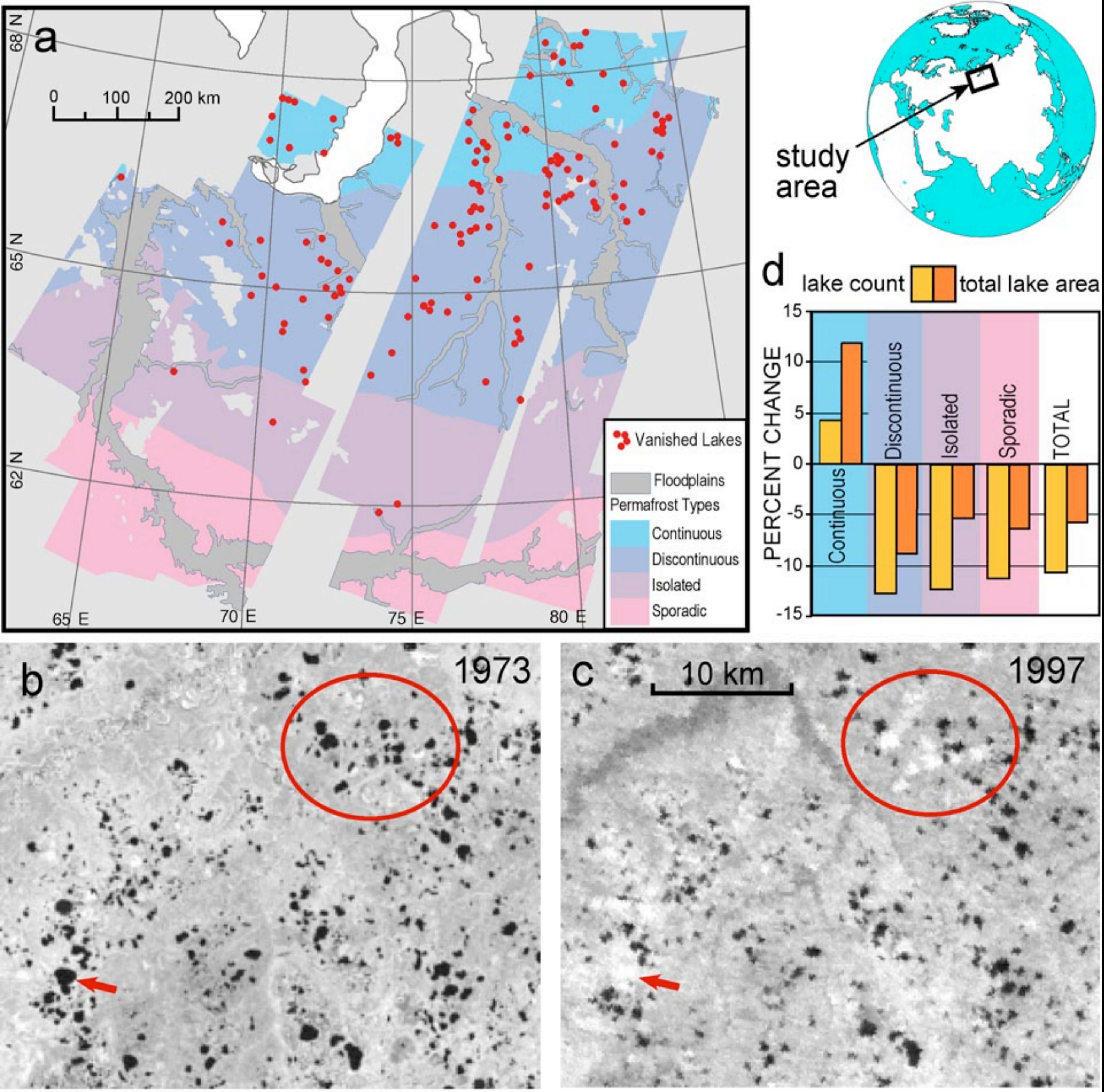
Measurement: SWOT will address the above question either directly, through measurements of inundation extent, water surface elevation, h, its temporal and spatial derivatives dh/dt and dh/dx, ΔS, and Q, or indirectly, by better constraining models of the above processes. Furthermore, a SWOT mission byproduct will also be the first global DEM of floodplain and wetland area with decimetric accuracy that can at last be used to parameterize hydraulic and hydrologic models of these systems adequately.

The current lake & wetland extent is poorly known, let alone storage.



Frey and Smith, GBC, 2008

Photo: Larry Smith



Arctic lakes are losing storage, despite a slight increase in precipitation. The spatial pattern of lake loss strongly suggests that the melting of permafrost is driving the process (rather than evaporation). At first, permafrost melting increases lake storage, but continued melting breaches the underlying frozen ground allowing the lake to drain into the subsurface.

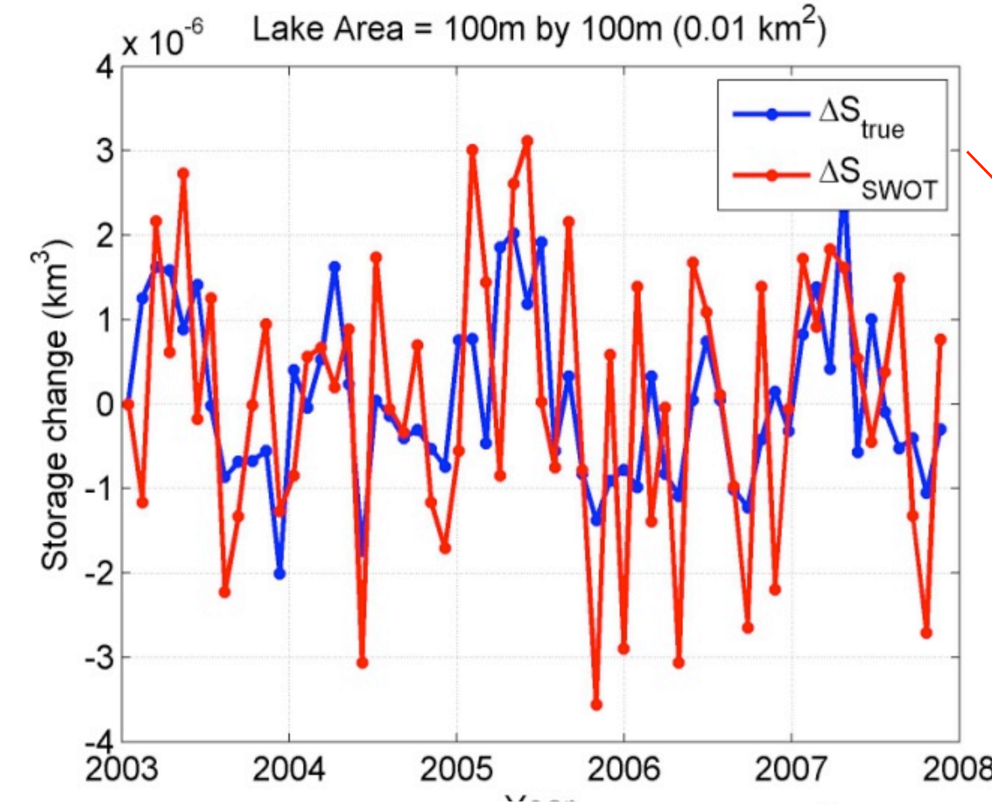
Smith et al., "Disappearing Arctic Lakes," Science, 2005

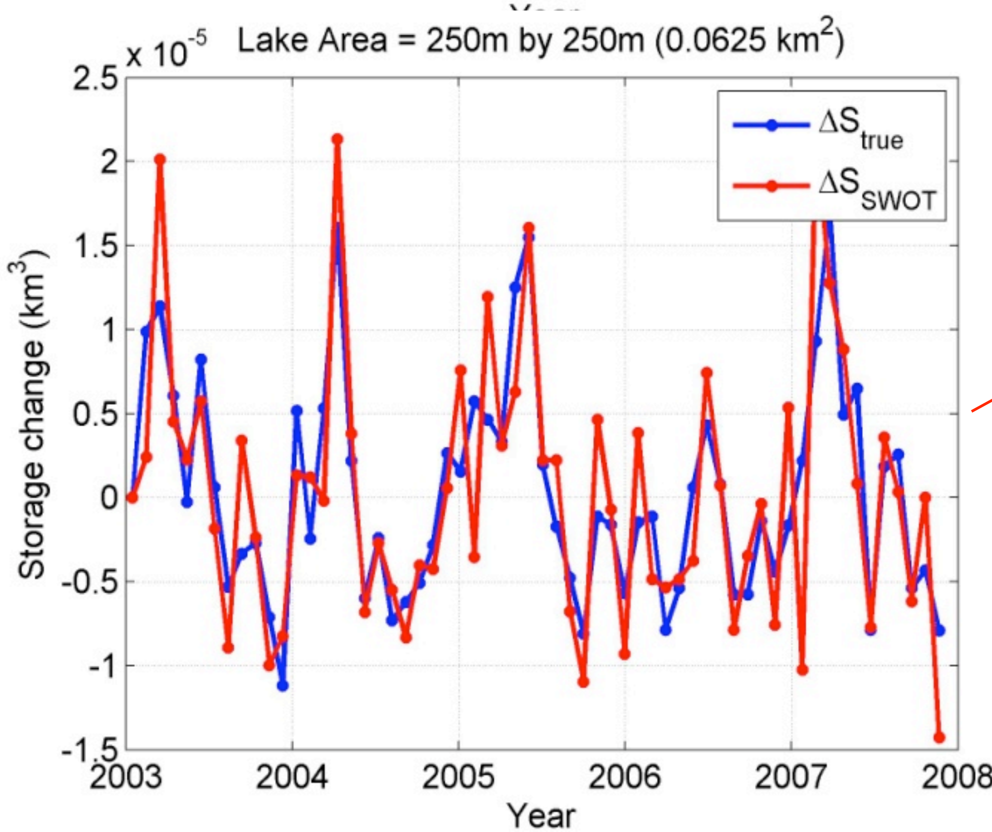
Key Point for Arctic Hydrology and Global Lakes

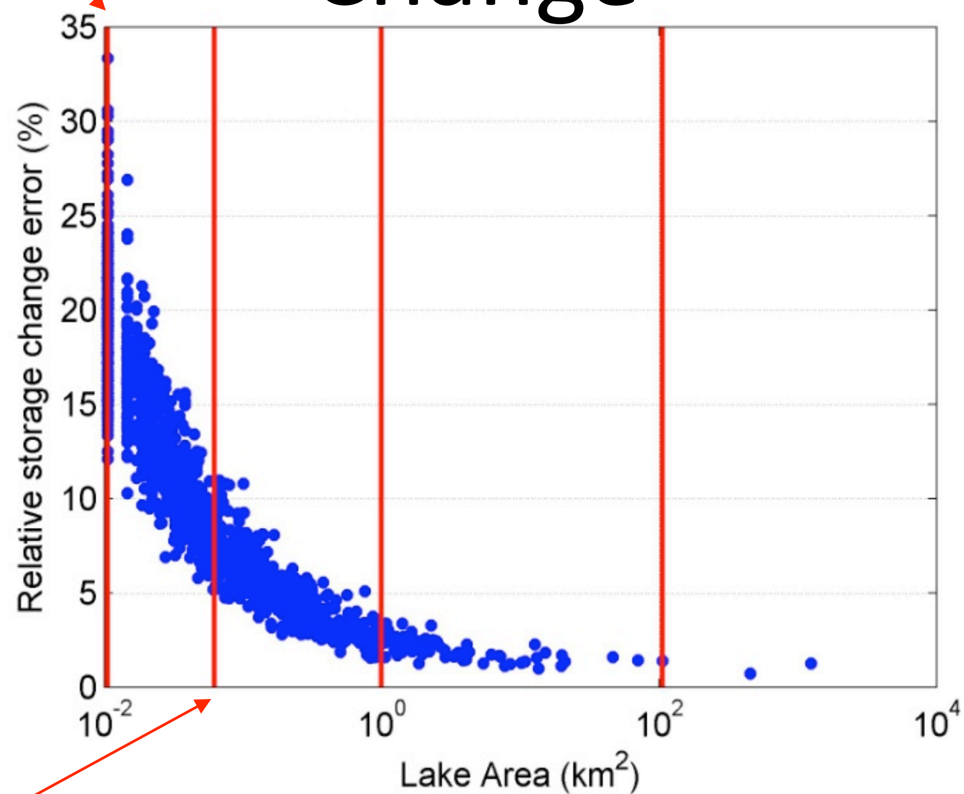
Science: Arctic surface water hydrology is linked to cryospheric processes associated with ice sheets, glaciers, river and lake ice, and permafrost. Climate change and water cycle acceleration expressed in these linkages as changes in Q and ΔS. Impacts on carbon balance from these changes is not known, e.g., inundation of floodplains and the related exchange of carbon and nutrients is not well known.

Measurement: The abundance of Arctic lakes suggests that ΔS is a key hydrologic driver, yet is unknown. By allowing substitution of contemporary, permafrost-driven *spatial* variations in hydrologic regime (i.e., ΔS and Q) for future *temporal* changes in permafrost extent, SWOT observations will improve projections of climate change impacts on Arctic lake hydrology.

SWOT Ability to Observe Storage Change



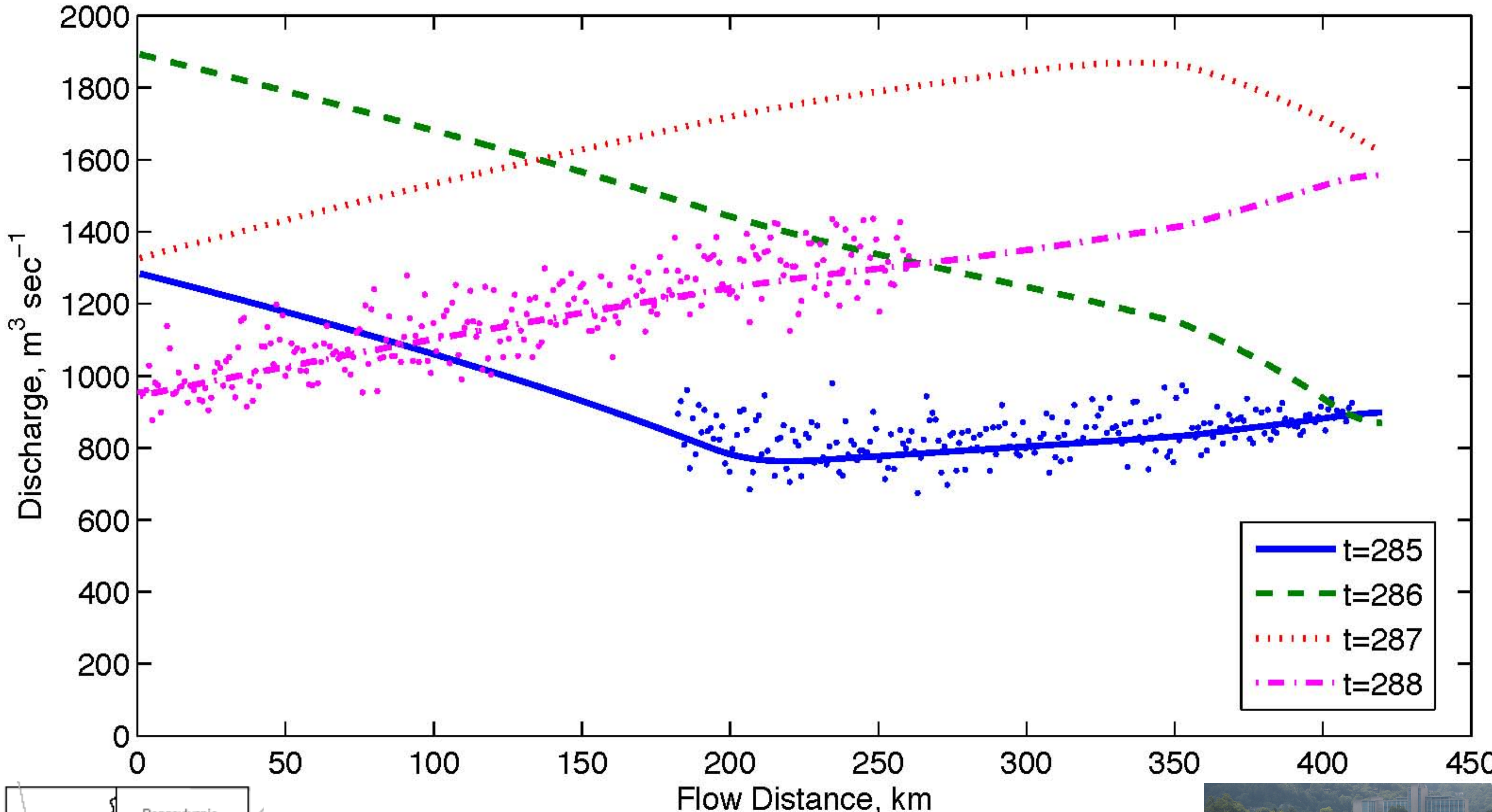




Lakes in Peace-Athabasca, Alaska, and Siberia. Approach uses altimetry, remote sensing, in-situ, and statistics to create “truth”. SWOT orbits and height errors to create storage change estimates.

Lee et al., 2009

SWOT Simulated Discharge Along the Kanawha River



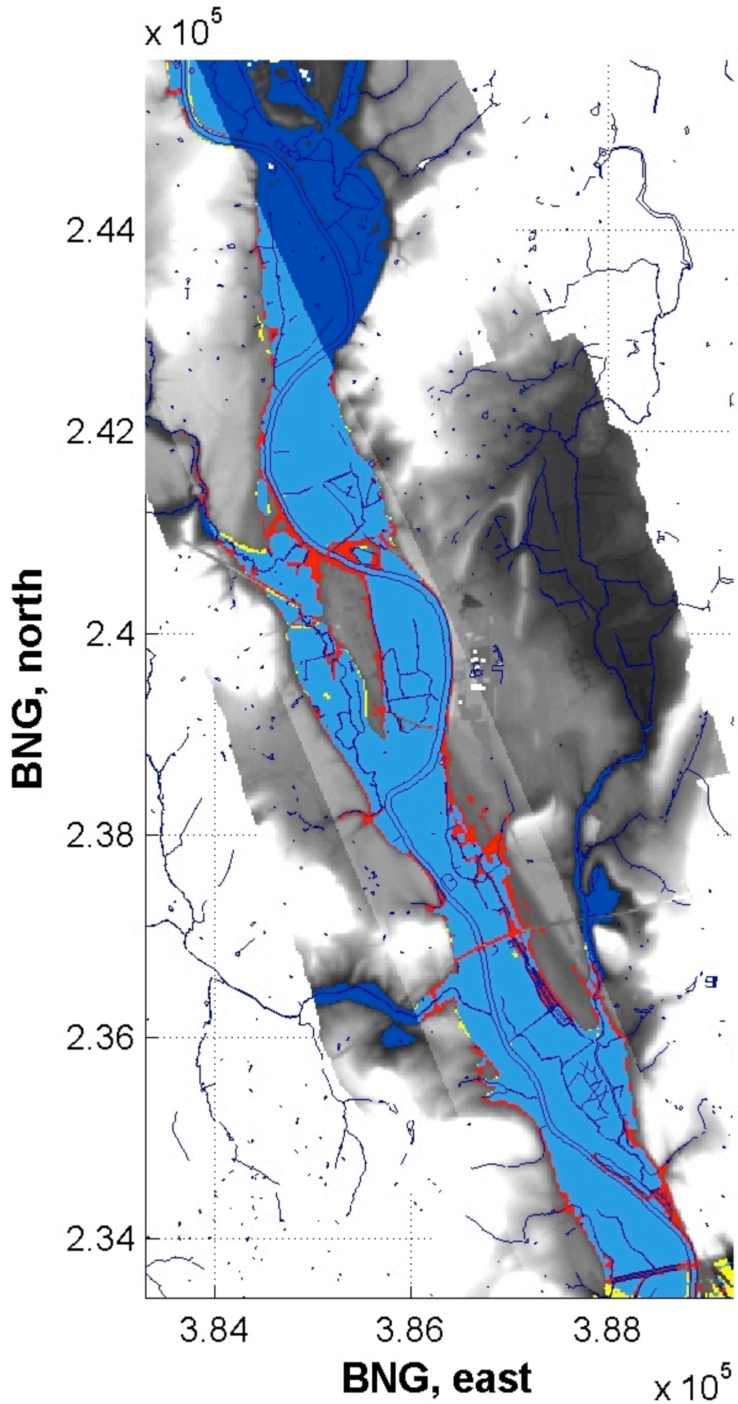
Durand et al., 2009

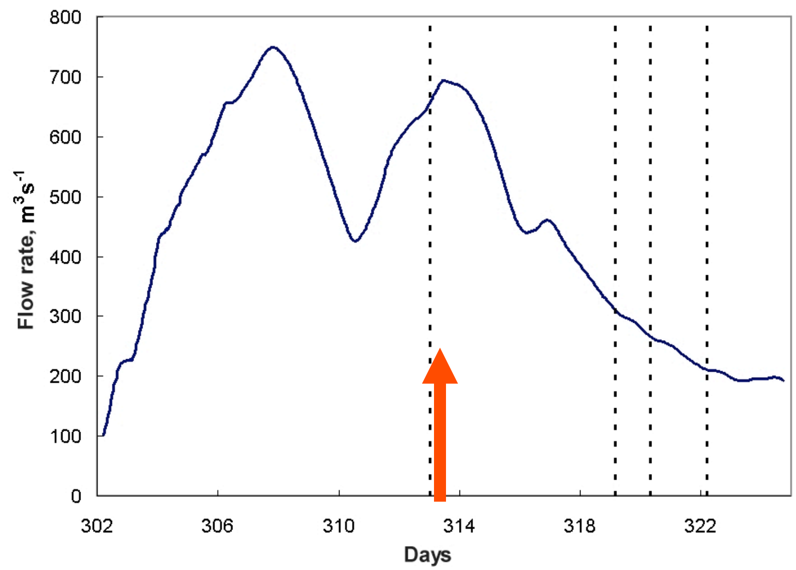
SWOT Concluding Thoughts

- There are a host of scientific and societal questions that will be directly addressed by SWOT's hydrodynamic measurements and Q and ΔS products.
- Questions range from impacts on the water cycle from climate change to flooding hazards in developed floodplains.
- Surface water flow is 2-dimensional, spatially. SWOT will match this with 2D measurements. This is a "revolutionary" change from our current 1D stream-gauging approach.
- This mission is for everybody, please join us via: **http://swot.jpl.nasa.gov/**

Extra Slides

Upton on Severn, UK – 18m model vs Airborne SAR

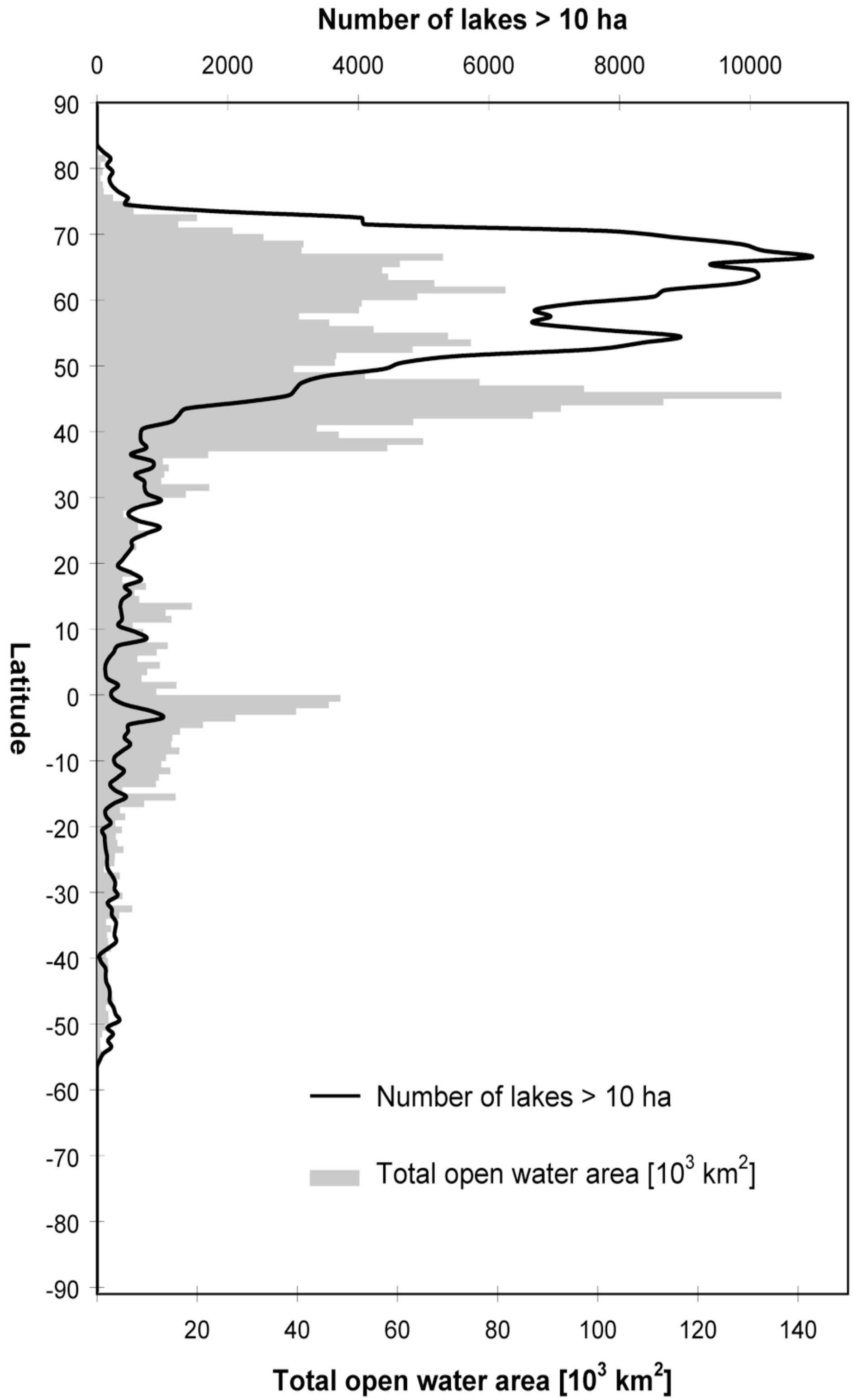




Model fit = 89%

Hydraulic models for flood prediction need extent images and water elevations to calibrate friction parameters and provide independent validation

- = correct
- = over-prediction
- = under-prediction
- = predicted as flooded, no ASAR coverage



Where are the World's Lakes?

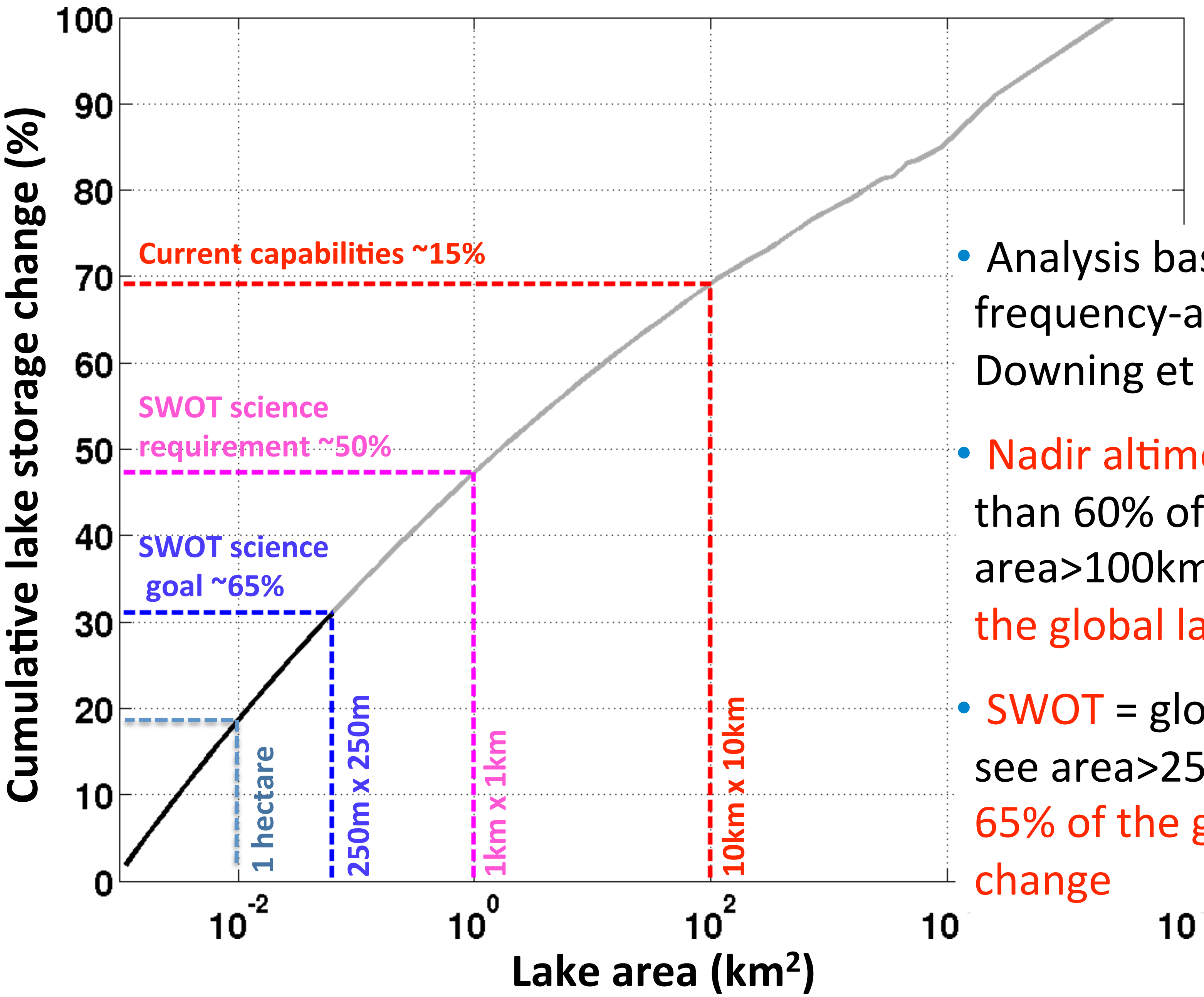
Published databases suggest that rivers and lakes north of 55 N represent:

>30% of global open water areas
>50% of all lakes larger than 0.1 km^2

Gauging even 1% of these lakes *in situ* is unfeasible—but SWOT can track all of them.

Lehner and Doll, 2004 (Global Lakes and Wetlands Database)

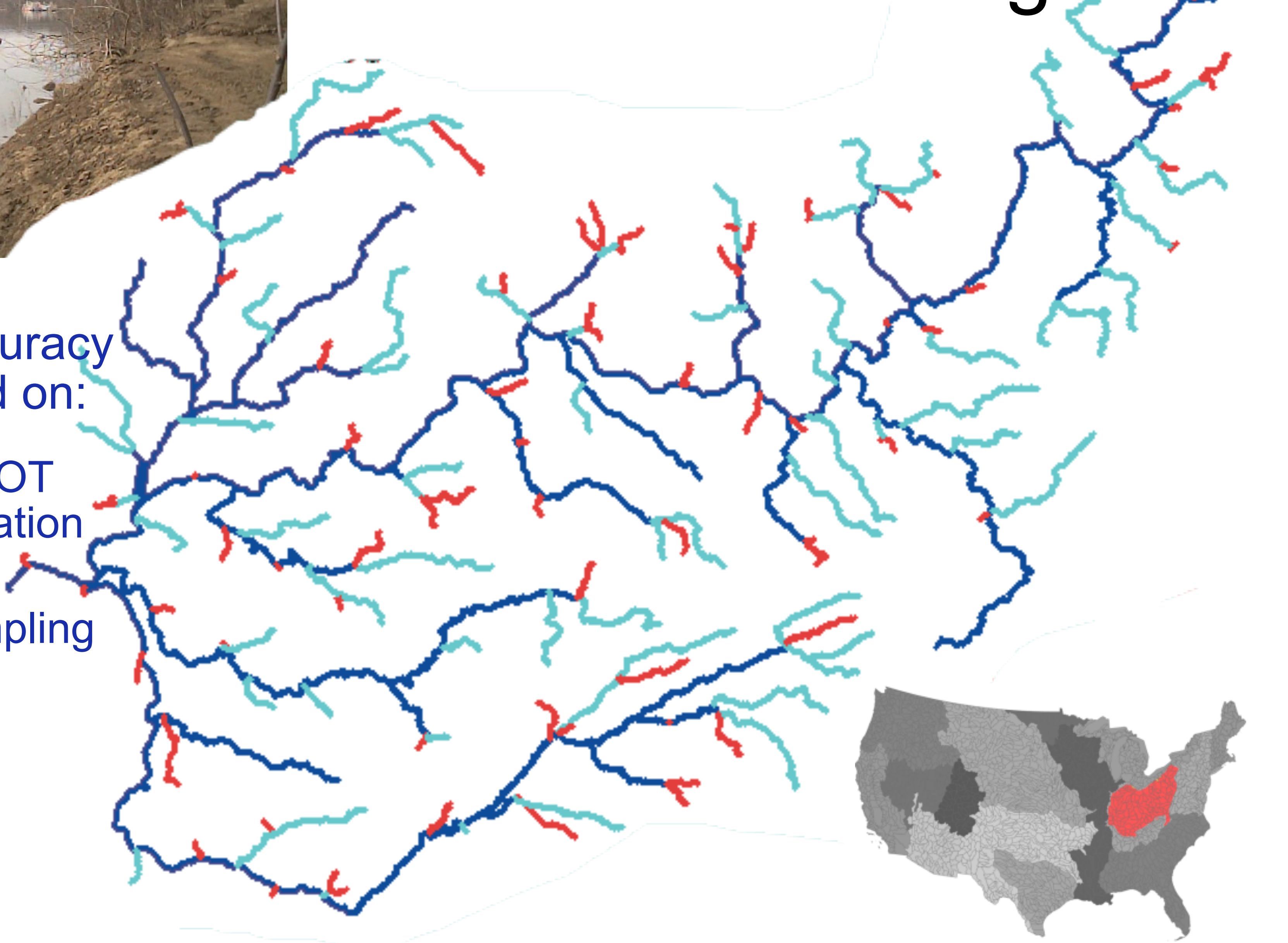
Lake storage change



- Analysis based on global lake frequency-area distribution by Downing et al., 2006.
- Nadir altimeters miss more than 60% of lakes and can see area>100km^2 -> see only 15% of the global lake storage change
- SWOT = global coverage and see area>250mx250m -> see 65% of the global lake storage change

Biancamaria et al., 2009

SWOT capability to estimate discharge



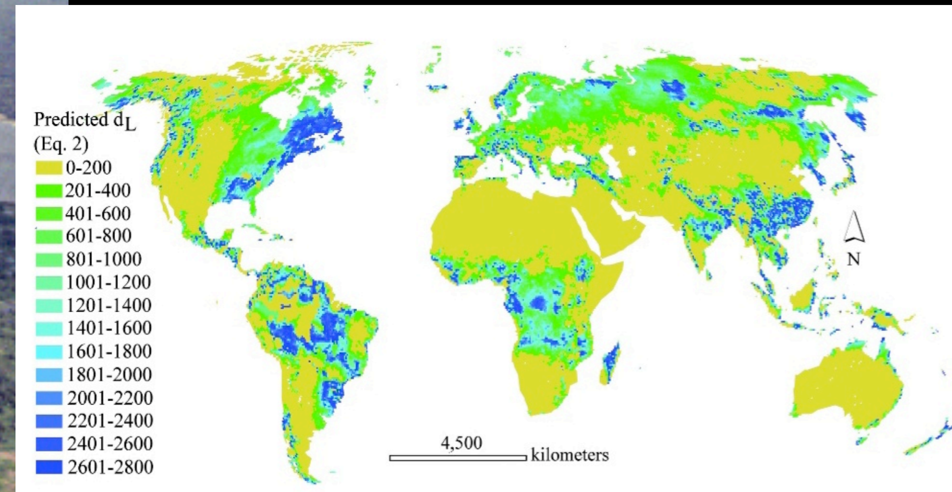
Ohio River accuracy estimate based on:

1) Expected SWOT height observation accuracy
2) Temporal sampling errors
3) River width

Legend

- Width < 50 m
- Width < 100 m
- Discharge at least 20% accurate
- Discharge less than 20% accurate

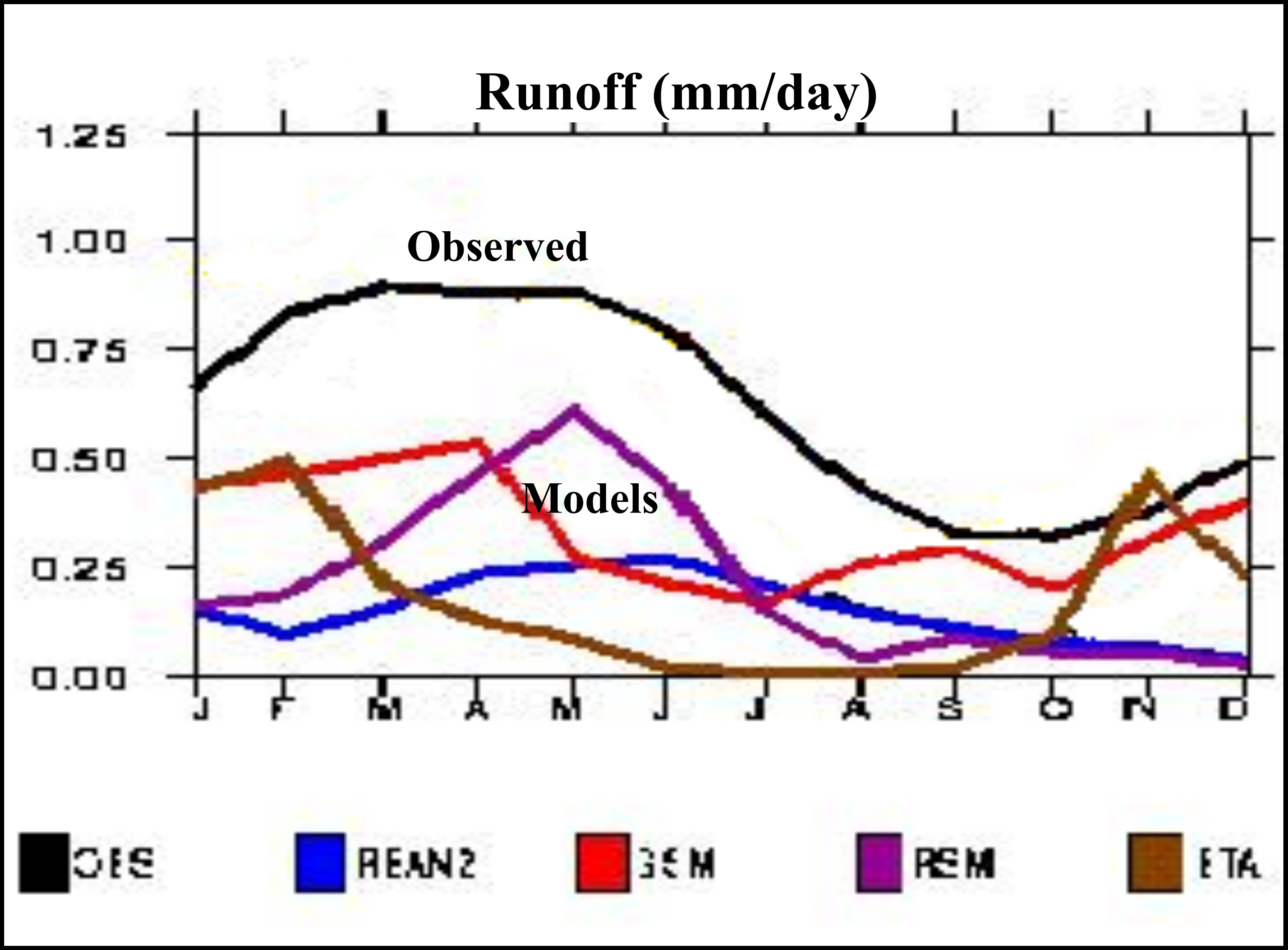
Courtesy: Elizabeth Clark, UW



Downing et al., 2006

Photos: K. Frey, B. Kiel, L. Mertes

Global Water Cycle & Climate Modeling

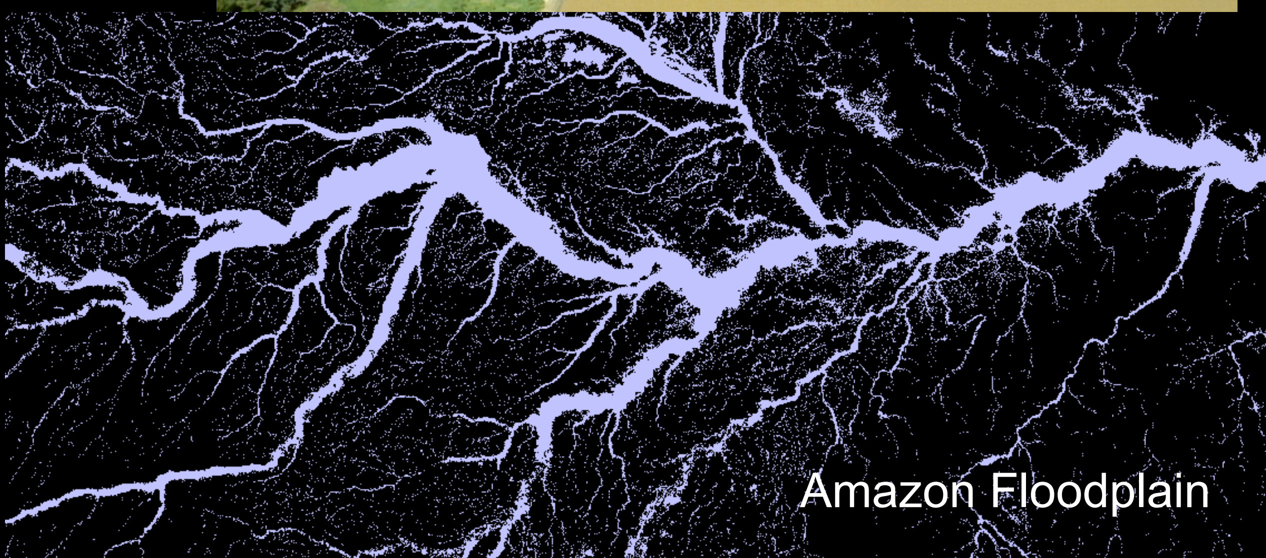


- How does the lack of measurements limit our ability to predict the land surface branch of the global hydrologic cycle?
- In locations where gauge data is available, GCM precipitation and subsequent runoff miss streamflow by 100%
- The question is unanswered for ungauged wetlands, lakes, and reservoirs throughout the world.

Roads et al., GCIP Water and Energy Budget Synthesis (WEBS), *J. Geophysical Research*, 2003

CO_2 Evasion from Water to Atmosphere

What is the role of wetland, lake, and river water storage as a regulator of biogeochemical cycles, such as carbon and nutrients? e.g., Rivers outgas as well as transport Carbon. Ignoring water borne C fluxes, favoring land-atmosphere only, yields overestimates of terrestrial C accumulation



<u>Results:</u> 470 Tg C/yr all Basin; 13 x more C by outgassing than by discharge. But what are seasonal and global variations? If extrapolate Amazon case to global wetlands, = 0.9 Gt C/yr, 3x larger than previous global estimates; Tropics are in balance, not a C Sink?

Richey, J.E., J.M. Melack, A.K. Aufdenkampe, V.M. Ballester, and L.L. Hess, Outgassing from Amazonian rivers and wetlands as a large tropical source of atmospheric CO2, ***Nature***, *416*, 617-620, 2002.