Hydrology and Oceanography Drivers of the SWOT Mission

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(presented by Larry Smith)

funded by:

CNES, JPL, NASA

Acknowledgements

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Key Points

- CNES and NASA have a workshare agreement.
- Hydrologic and oceanographic science problems are equally addressed by the mission with its global measurements of water surface elevations.
- Technology is a Ka-band interferometric SAR system producing centimetric height accuracies and 10s meter postings across a 140-km wide swath.
- 2019 SWOT launch with AirSWOT activities prior to launch.

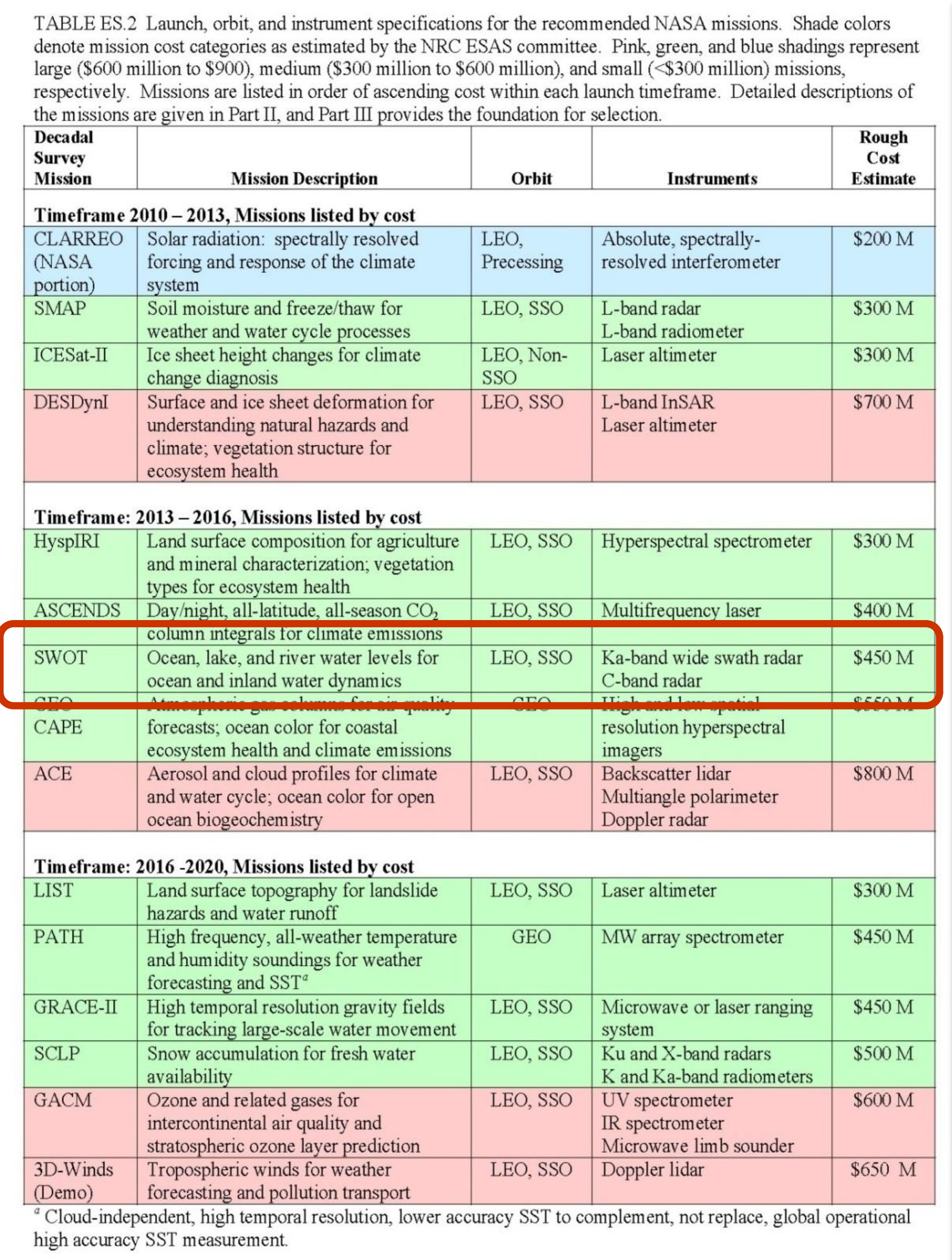
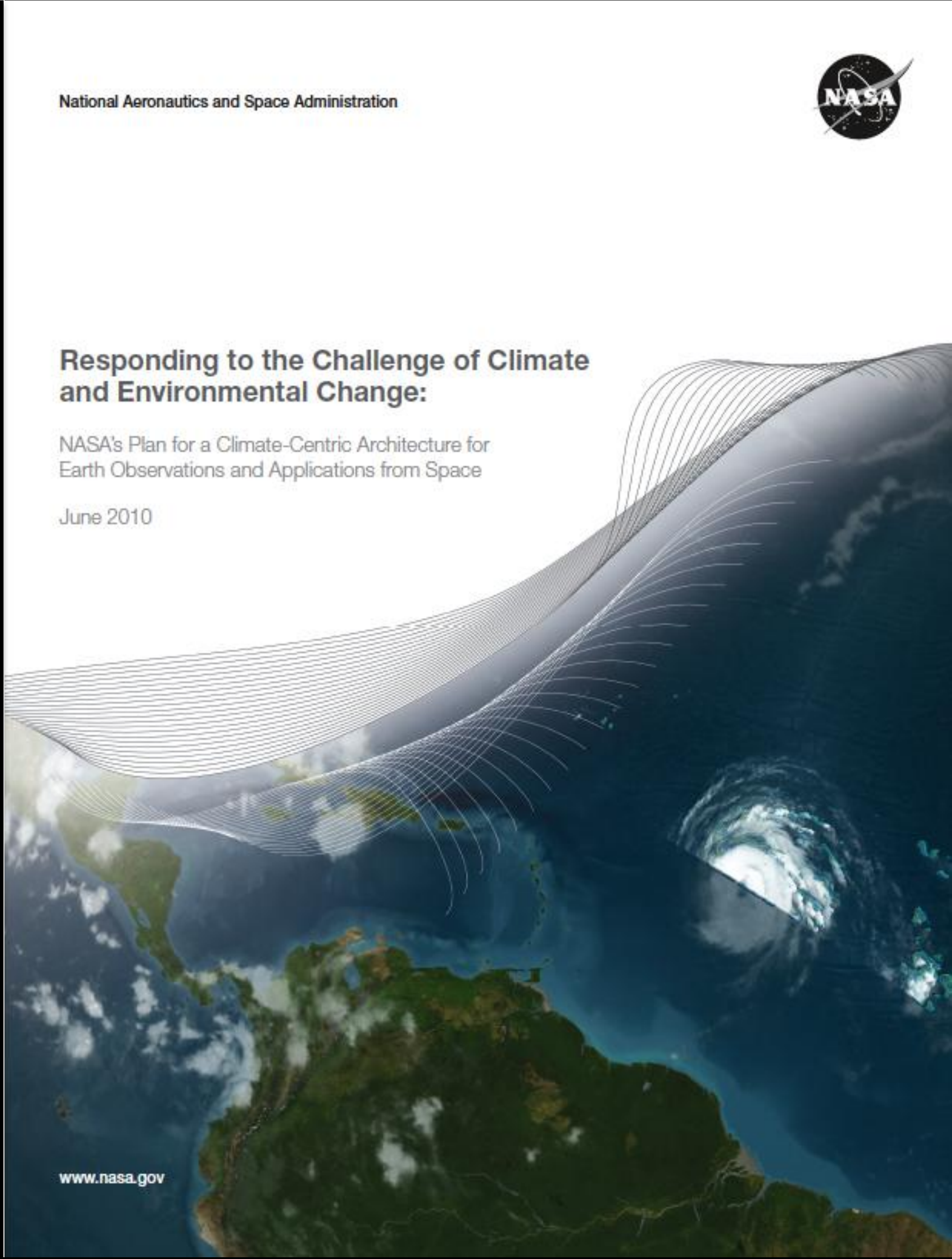


TABLE ES.2 Launch, orbit, and instrument specifications for the recommended NASA missions. Shade colors denote mission cost categories as estimated by the NRC ESAS committee. Pink, green, and blue shadings represent large ($600 million to $900), medium ($300 million to $600 million), and small (<$300 million) missions, respectively. Missions are listed in order of ascending cost within each launch timeframe. Detailed descriptions of the missions are given in Part II, and Part III provides the foundation for selection.

Decadal Survey Mission	**Mission Description**	**Orbit**	**Instruments**	**Rough Cost Estimate**
Timeframe 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer	$200 M
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	$300 M
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter	$300 M
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter	$700 M
Timeframe: 2013 – 2016, Missions listed by cost				
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer	$300 M
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser	$400 M
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar	$450 M
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers	$550 M
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar	$800 M
Timeframe: 2016 -2020, Missions listed by cost				
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter	$300 M
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST[a]	GEO	MW array spectrometer	$450 M
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system	$450 M
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers	$500 M
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	$600 M
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	$650 M

[a] Cloud-independent, high temporal resolution, lower accuracy SST to complement, not replace, global operational high accuracy SST measurement.



National Aeronautics and Space Administration

NASA

Responding to the Challenge of Climate and Environmental Change:

NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space

June 2010

www.nasa.gov

SWOT is recommended in the 2007 NRC "Decadal Survey"

In 2010, NASA lists SWOT launch as 2020, recent CNES-NASA agreements endorse 2019.

www.nap.edu/catalog/11820.html

http://science.nasa.gov/media/medialibrary/2010/07/01/Climate_Architecture_Final.pdf

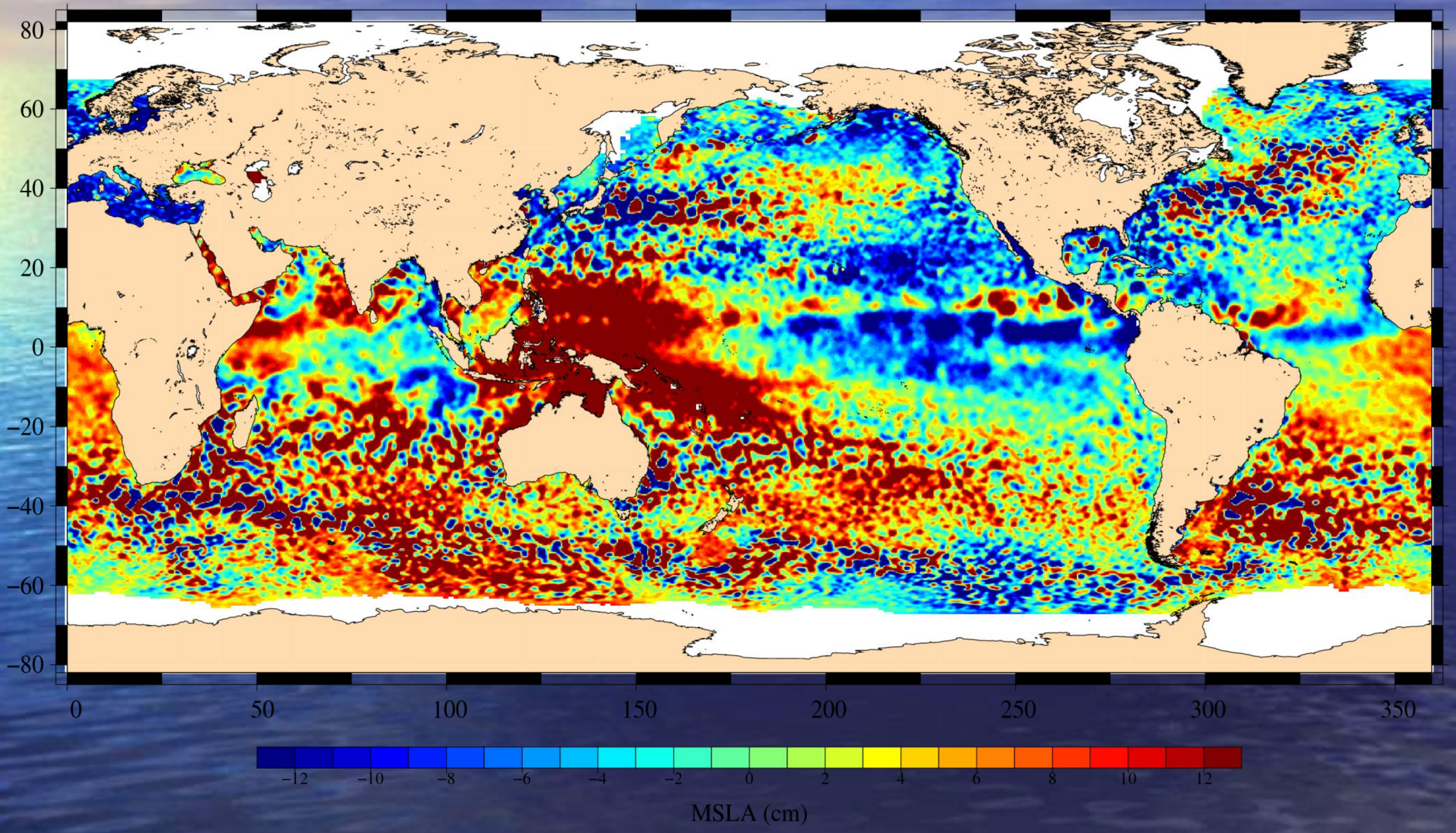
Goals

- Science Goals – (1) study the oceanic mesoscale and submesoscale processes that determine the kinetic energy of ocean circulation and its transport of water properties; and (2) measure the storage and discharge rate of water on land.
- Societal Benefits – Address two key issues facing a warming planet: (1) the capacity of ocean circulation in regulating the rate of warming; and (2) the variability of fresh water resources.
- Technology Goals – Set the standard for future operational altimetry missions.

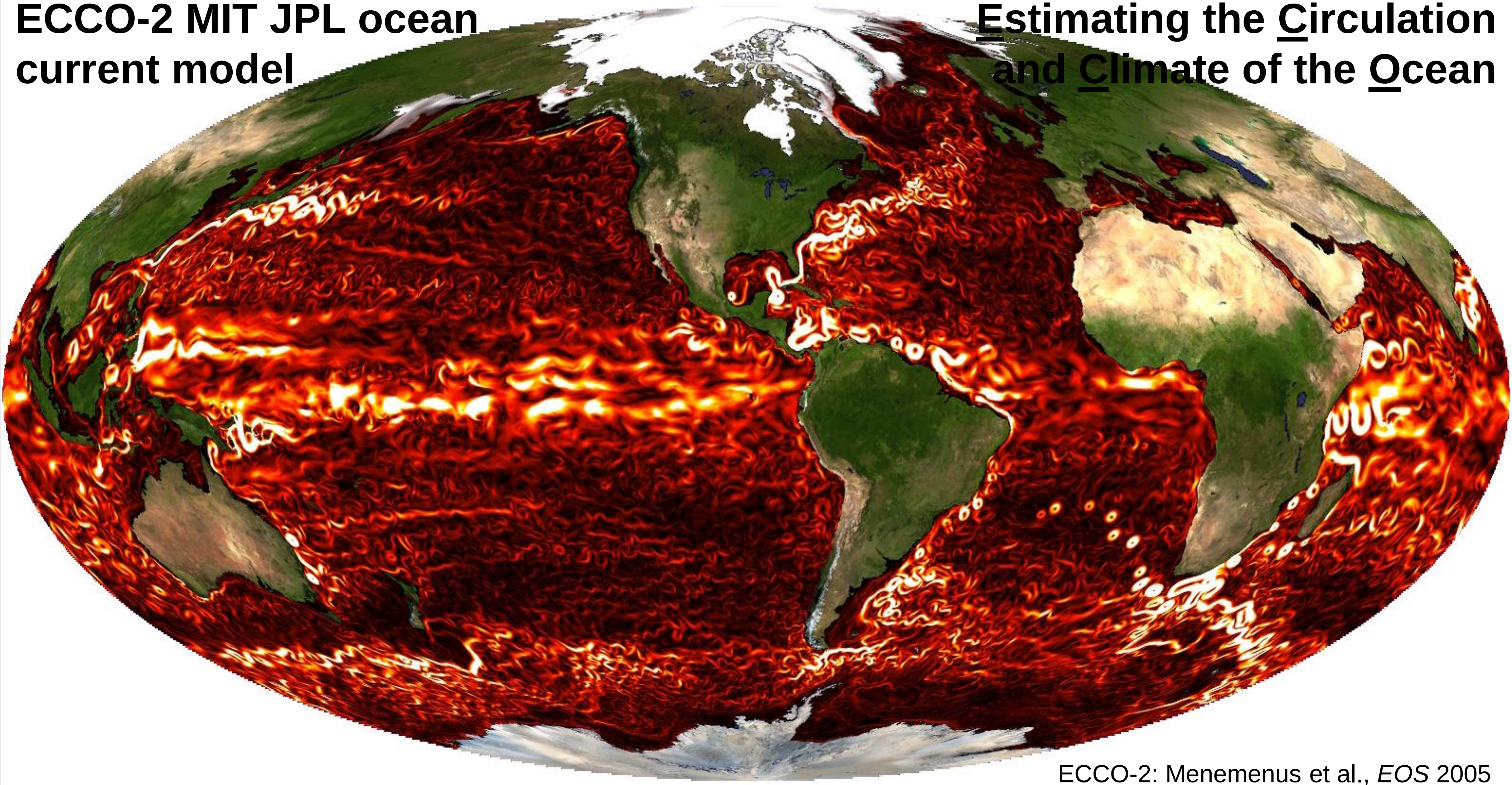
Sea Surface Height map from combined Jason-2 + Jason-1 observations

Revealing ocean eddies that contain 90% of the ocean’s kinetic energy

Despite the much improved resolution, the map still misses an important range of scales less than 100 km.



Ocean fronts and eddies simulated by a high-resolution model



ECCO-2 MIT JPL ocean current model

Estimating the Circulation and Climate of the Ocean

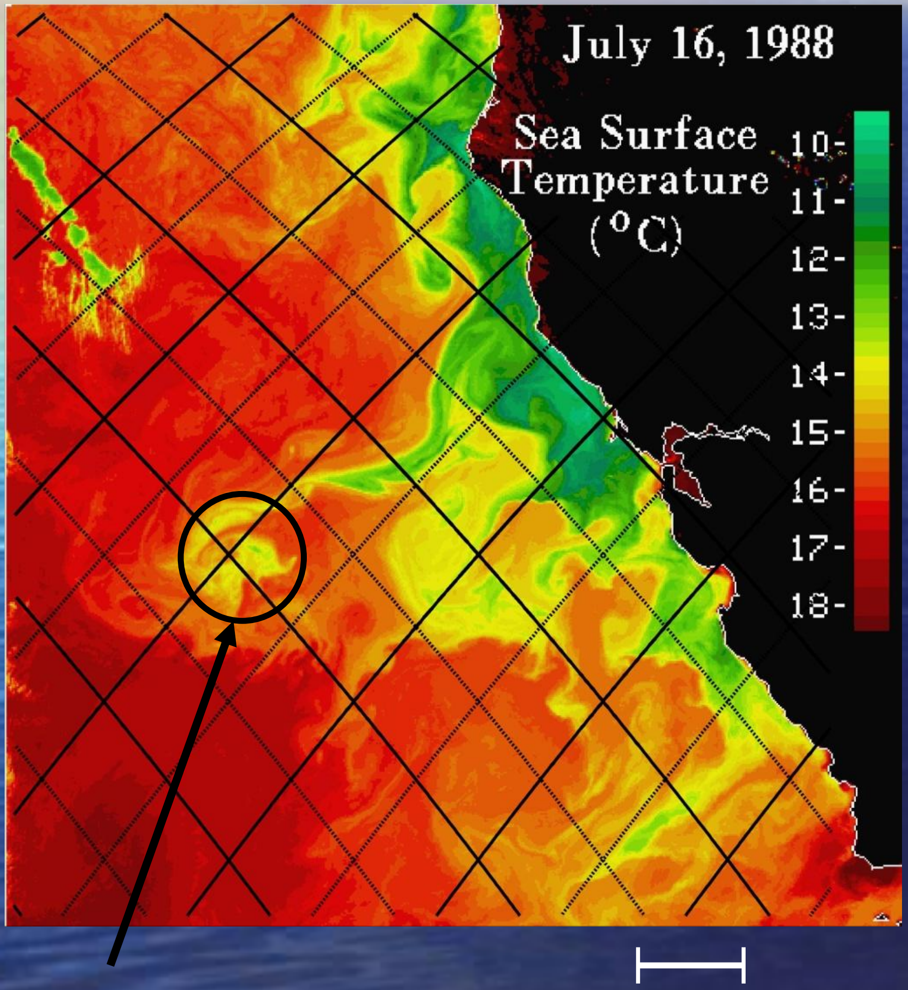
ECCO-2: Menemenus et al., *EOS* 2005

Although altimetry data have significantly advanced the study of the dynamics of oceanic variability, we have not resolved the critical scales that contain most of the kinetic energy of the ocean. For example, the cross-stream scale of the Gulf Stream is 100 km, which is not fully resolved in two dimensions by the best altimeter data set one can put together. A large fraction of the mesoscale eddy field kinetic energy appears to reside at scales close to the deformation radius which is shorter than 100 km in most of the ocean. In addition, recent work suggests that there is a rich spectrum of processes at scales shorter than 100 km that hold the key to understanding the evolution of oceanic kinetic energy and its implications for biogeochemistry.

L. Fu and R. Ferrari

The ocean's kinetic energy resides in scales not well resolved by a nadir-looking altimeter

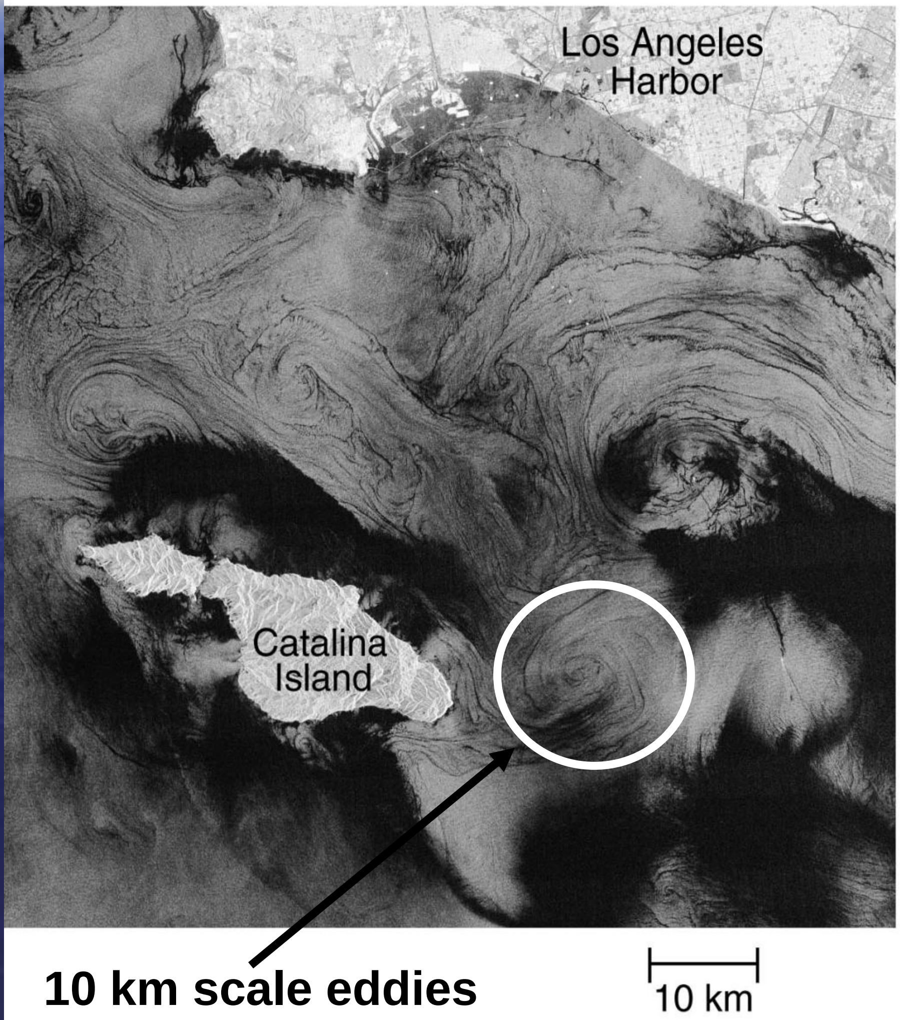
ground tracks of Jason (thick)
and T/P (thin) Tandem Mission



100 km scale eddies

100 km

RADARSAT - December 26, 1998

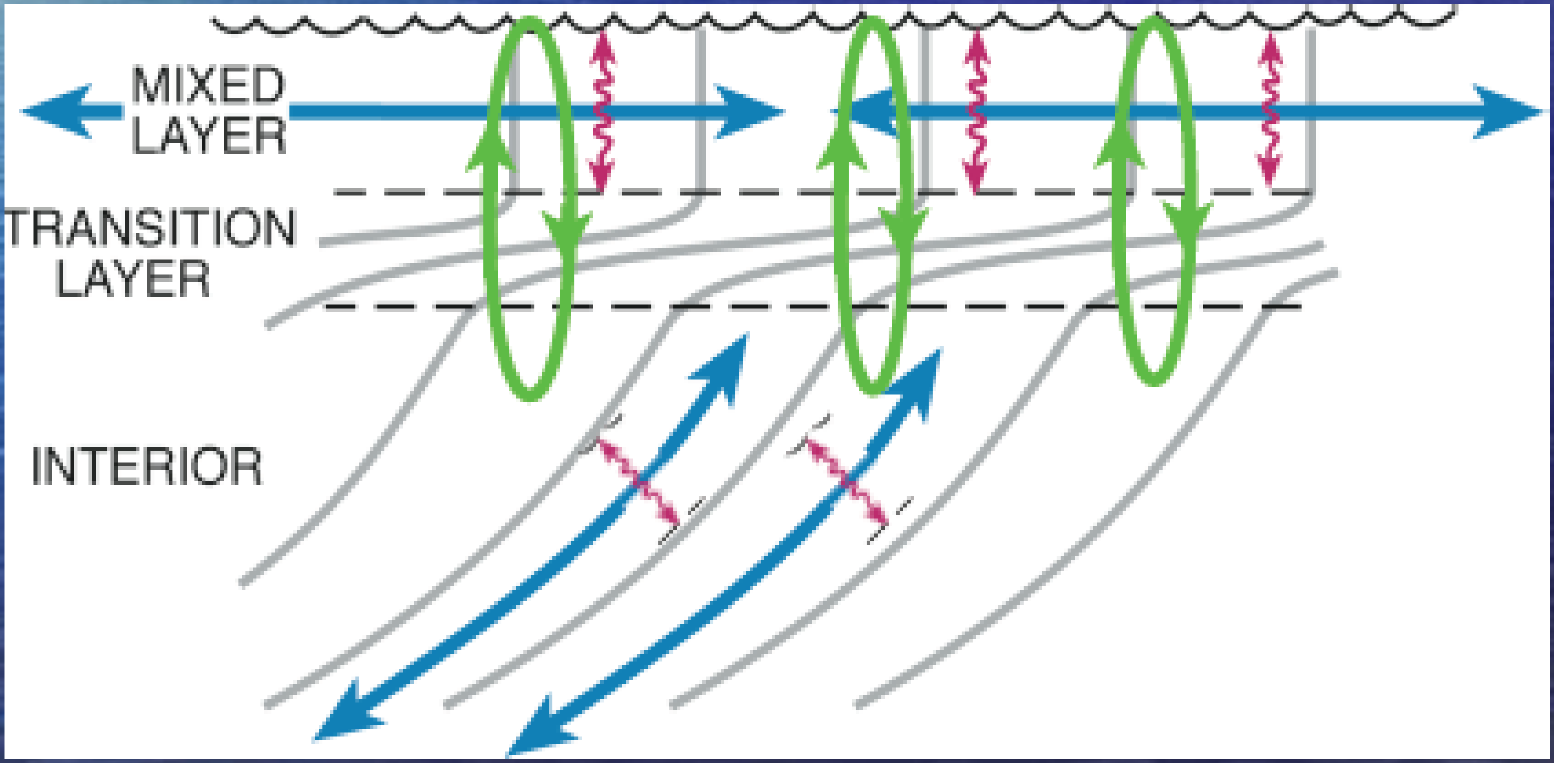


10 km scale eddies

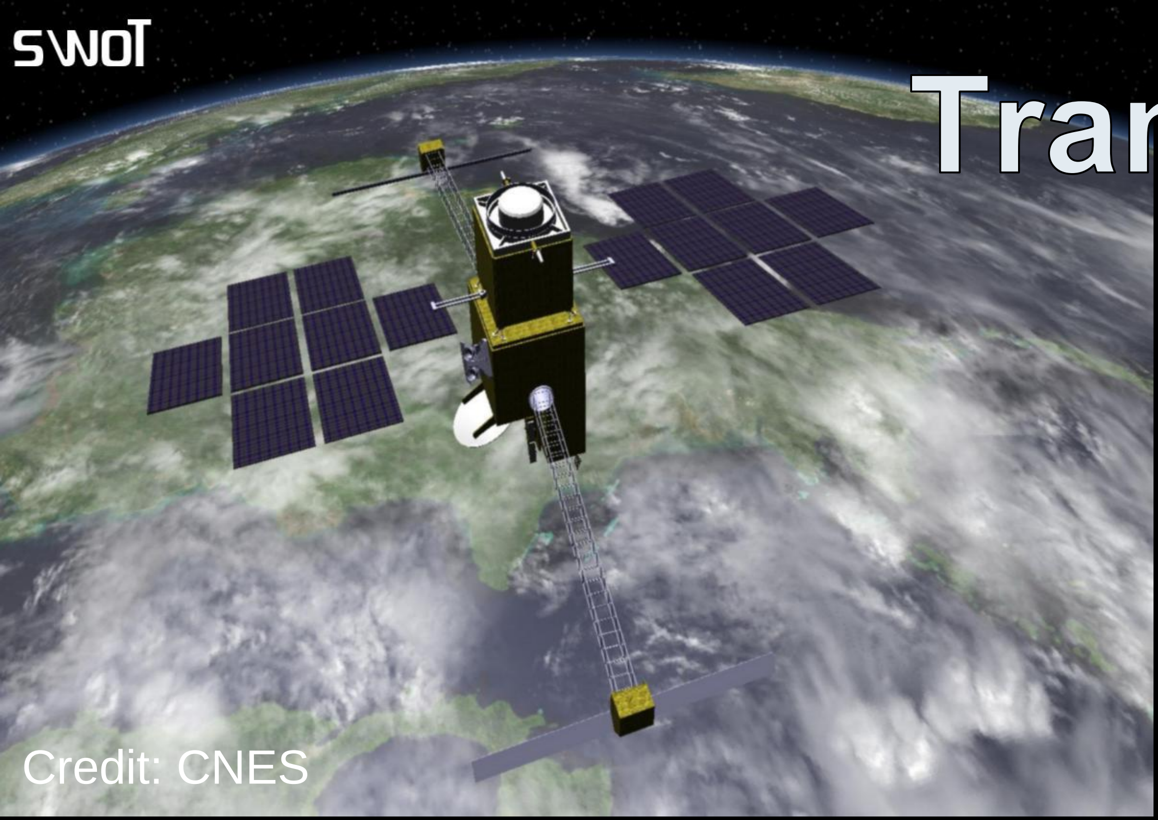
The importance of oceanic submesoscales:

About 50% of the vertical motion in the world’s oceans responsible for heat and CO_2 uptake takes place at the submesoscales

$$\bar{b}_t + \bar{\boldsymbol{u}}\cdot\nabla\bar{b} = -\underbrace{\nabla_H\cdot\overline{\boldsymbol{u}'_H b'}}_{\text{mesoscale}} - \underbrace{\partial_z\overline{w'b'}}_{\text{submesoscale}} + \underbrace{\partial_z\overline{\kappa\bar{b}_z}}_{\text{boundary layer}}$$



R. Ferrari (MIT)


Credit: CNES

Transformational Opportunties

2.2.1 Global Water Cycle
Aaron Boone

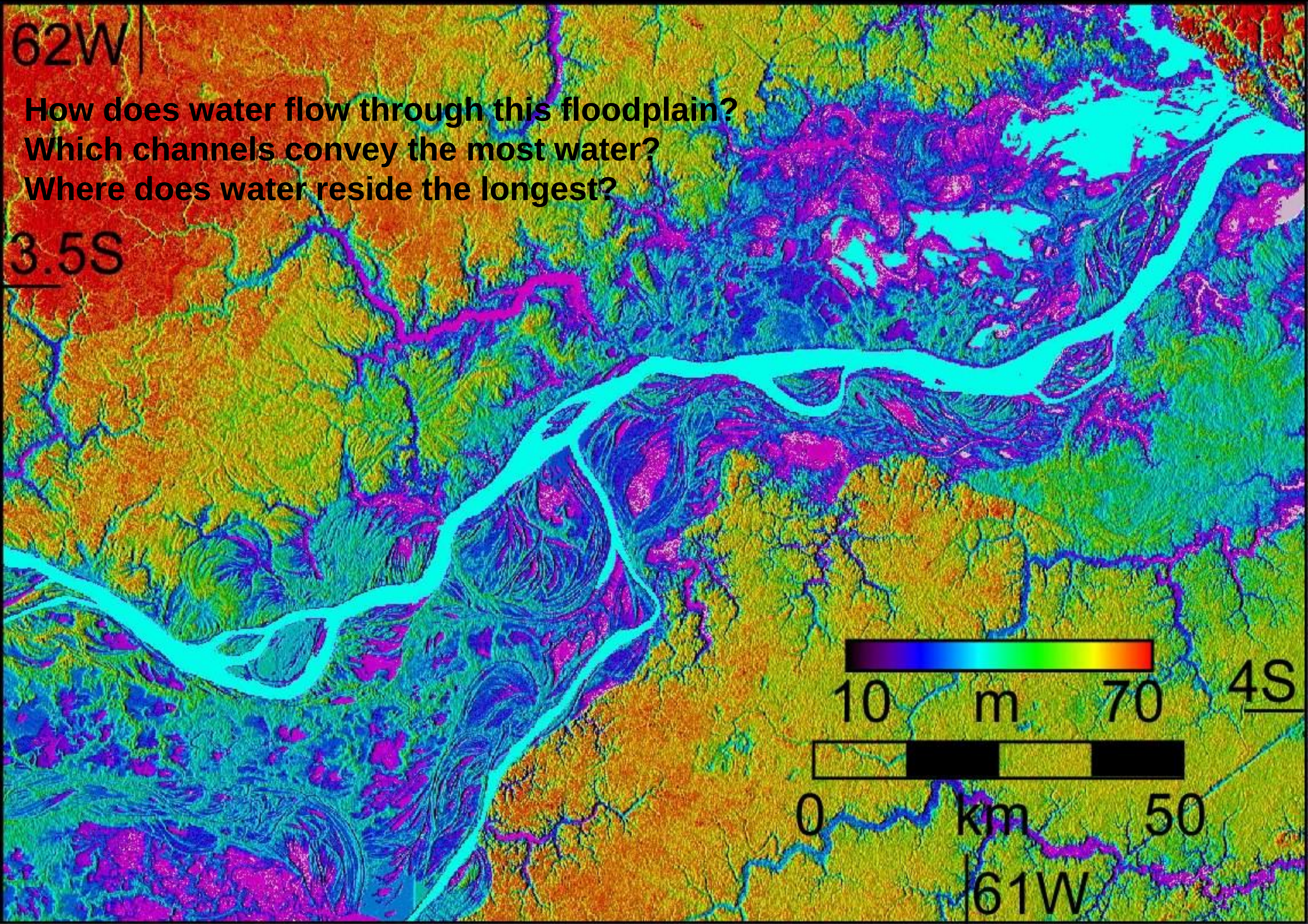
2.2.5 Arctic Hydrology
Tamlin Pavelsky

2.2.3 Reservoirs and Human Impacts
Faisal Hossain

2.2.4 Floodplain Processes
Paul Bates

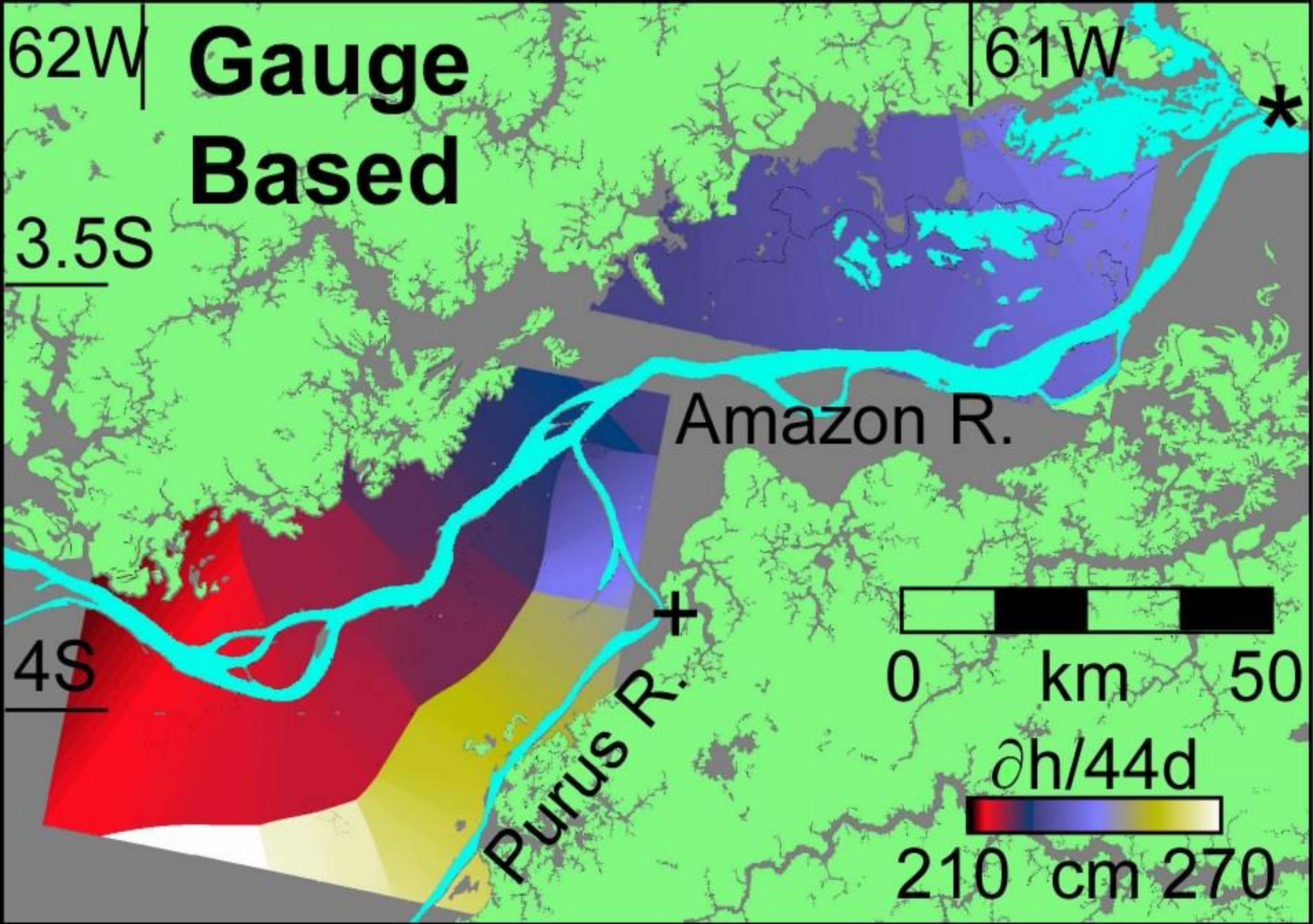
2.2.6 Flooding
Paul Bates

SRTM 90m Resolution DEM of Purus-Solimoes Confluence

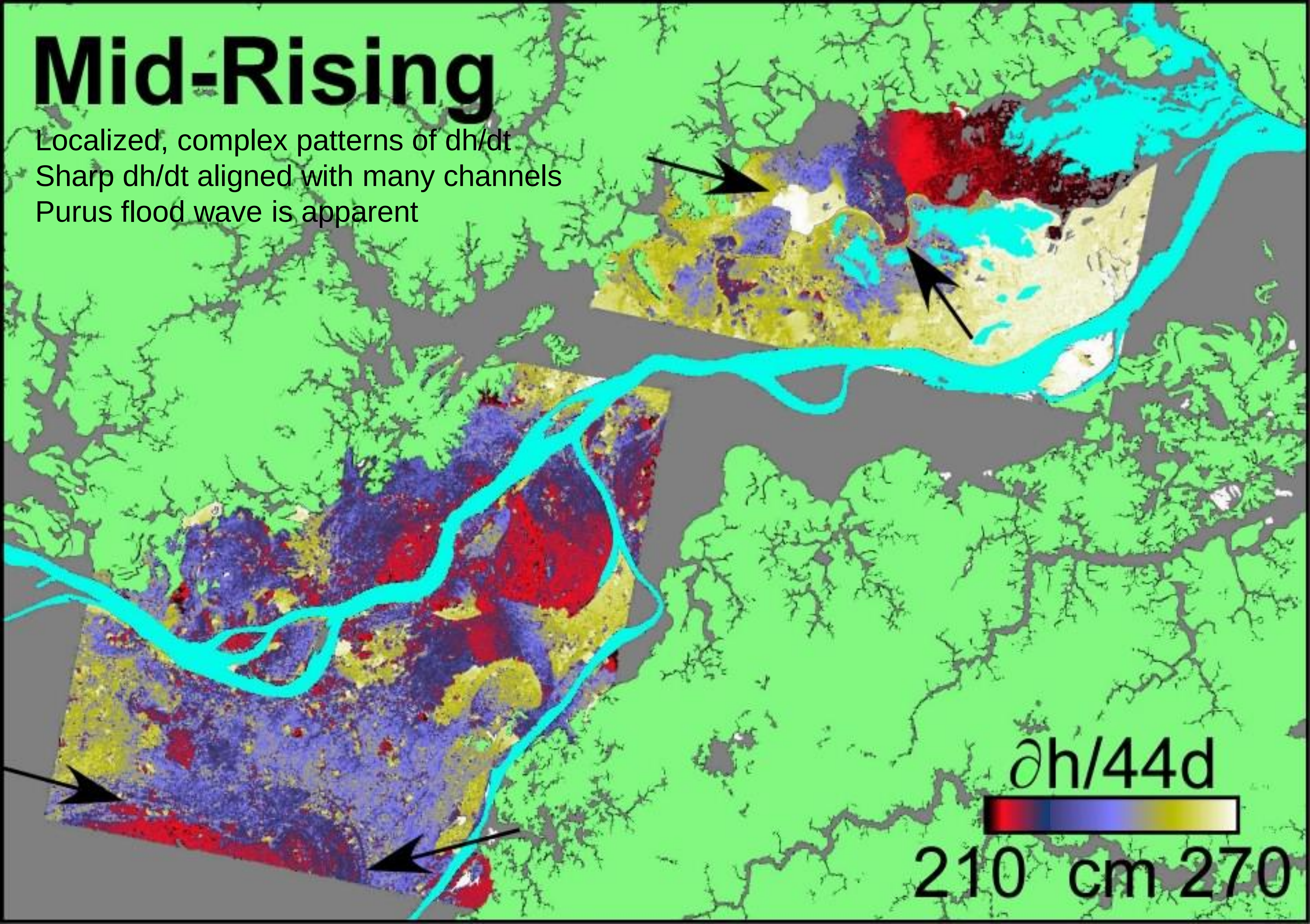


How does water flow through this floodplain?
Which channels convey the most water?
Where does water reside the longest?

Conventional Idea of Floodplain Inundation



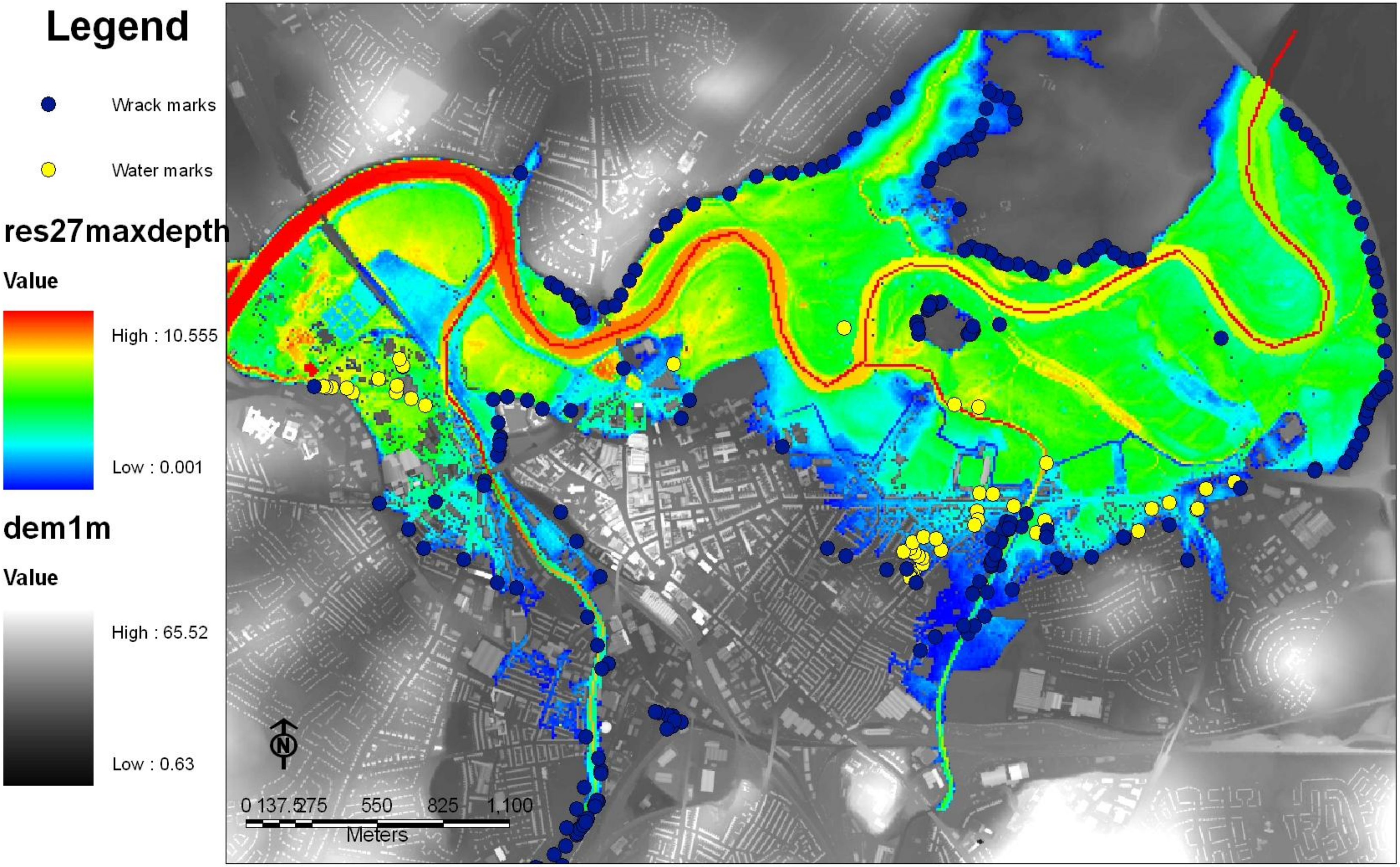
Measurements of Floodplain Inundation



Mid-Rising

Localized, complex patterns of dh/dt
Sharp dh/dt aligned with many channels
Purus flood wave is apparent

Carlisle, UK – 10m model vs. ground survey



RMSE on water depth = 0.32 m

Key Point for Floodplain Processes and Flooding

Science:

1. How does inundated area vary annually across the globe and how do these spatial and temporal variations impact processes such as methane emission?

2. What are the residence times and flow paths of floodplain flow and what are the implications for spatial patterns of biogeochemical cycling, ecology, and sediment transport?

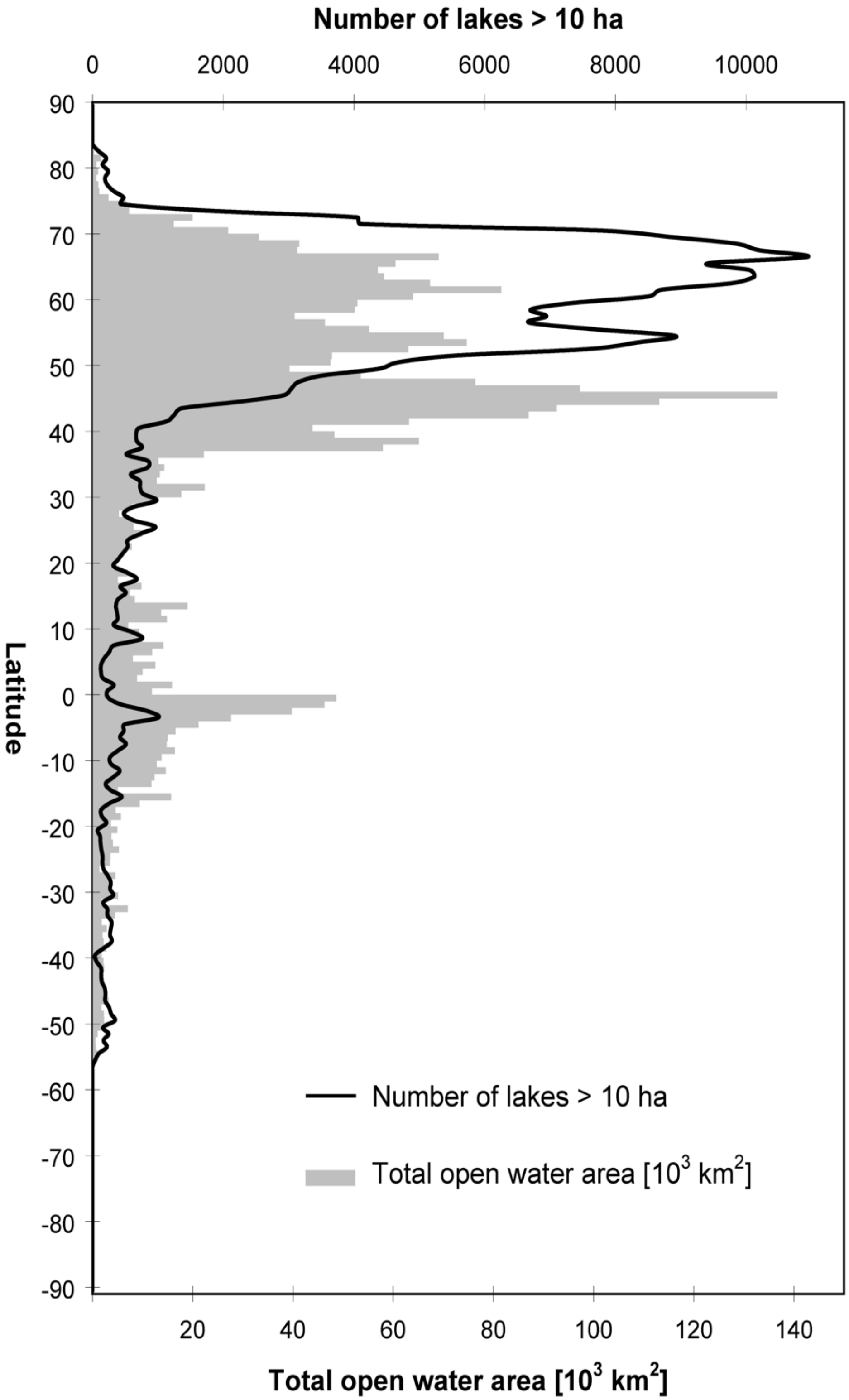
3. Where in the floodplain does terre-firme runoff mix with river water and how does this mixing of waters with different chemical and ecological signatures change dynamically?

4. What volume of water is exchanged between rivers and their floodplains, and how does this storage and release of water affect the downstream propagation of the flood pulse? Does this floodplain storage (which is entirely ungauged) lead to an underestimation of global terrestrial runoff?

5. 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 questions 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.

Where are the World’s Lakes?



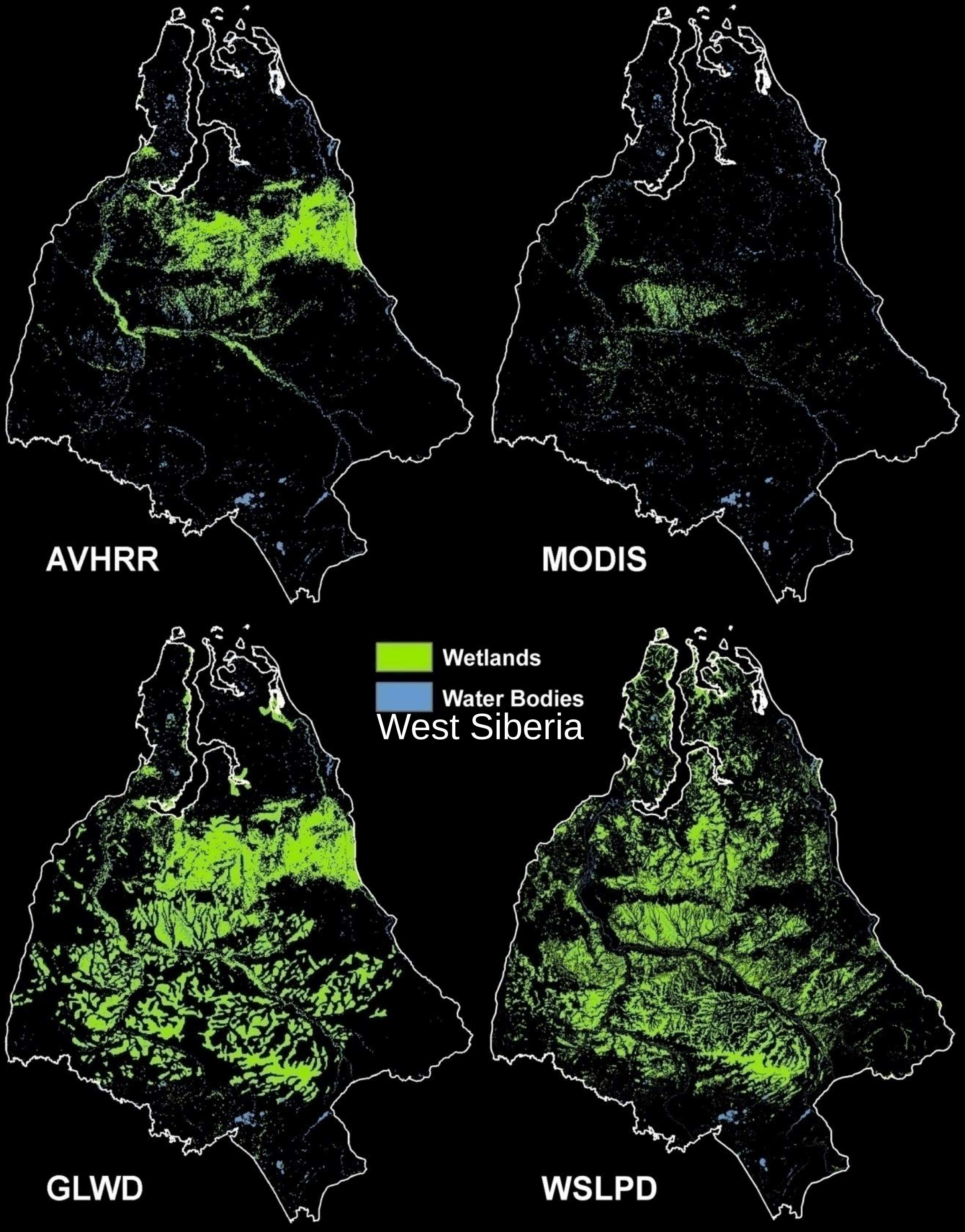
Published databases suggest that rivers and lakes north of 55 N represent:

>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)

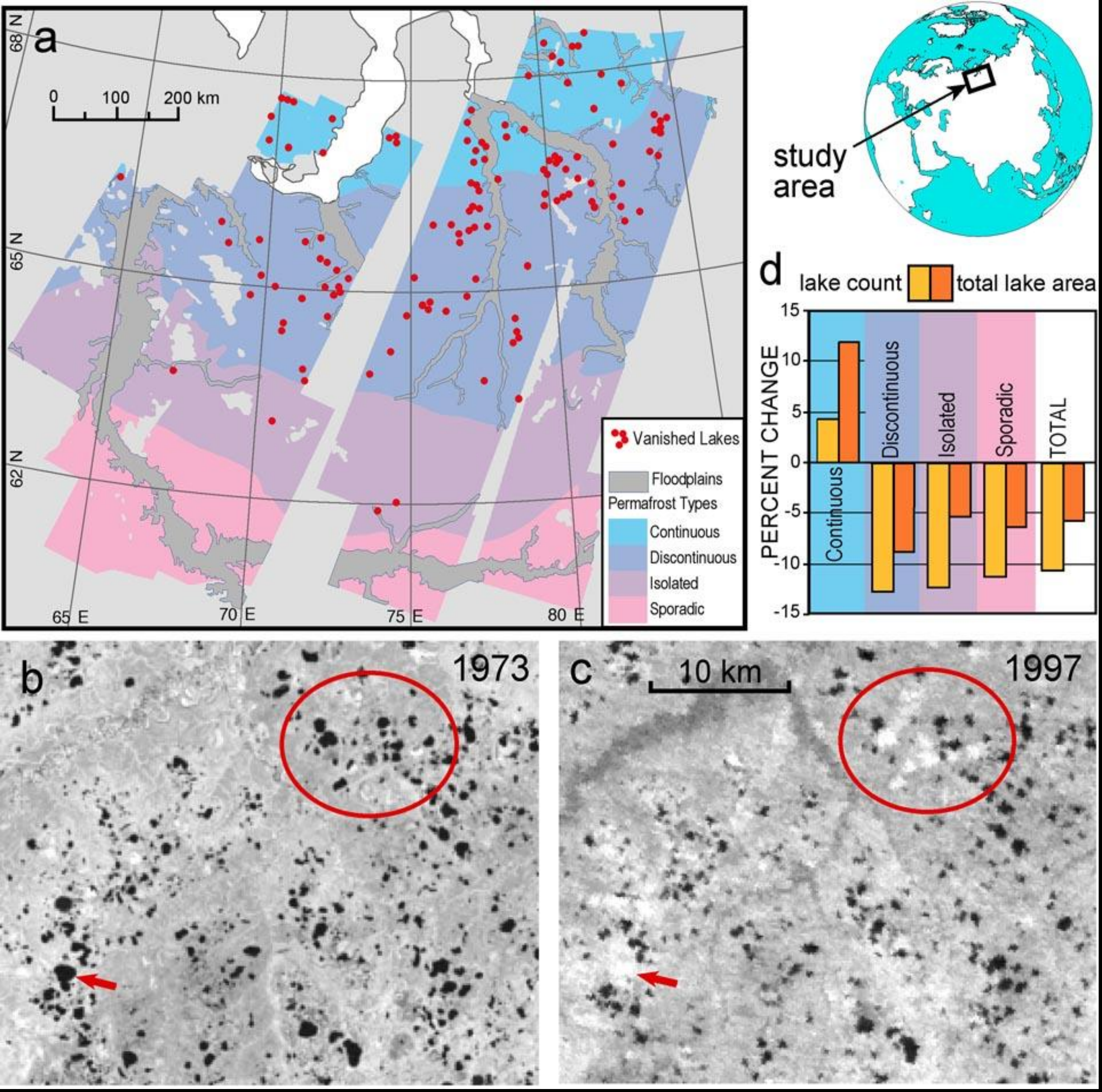
The current lake & wetland extent is poorly known, let alone storage.



West Siberia

Frey and Smith, GBC, 2008

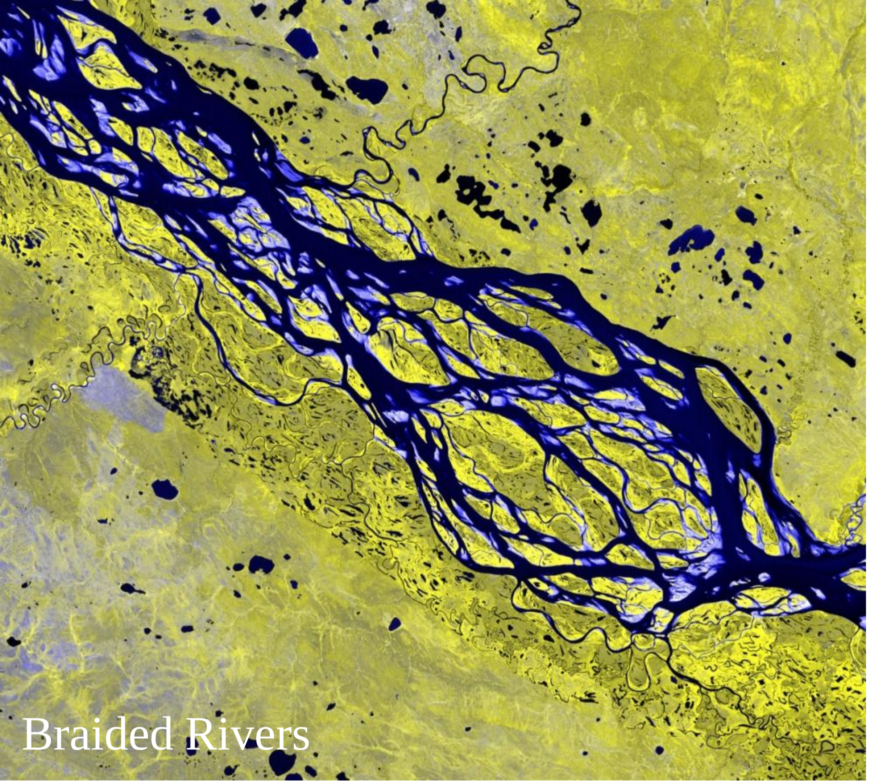
Photo: Larry Smith



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

Arctic Rivers



Braided Rivers

Permafrost

Courtesy International Permafrost Assn.

Among the most intractable problems in Arctic hydrology over the last decade is determining the source of recently observed increases in river discharge into the Arctic Ocean.

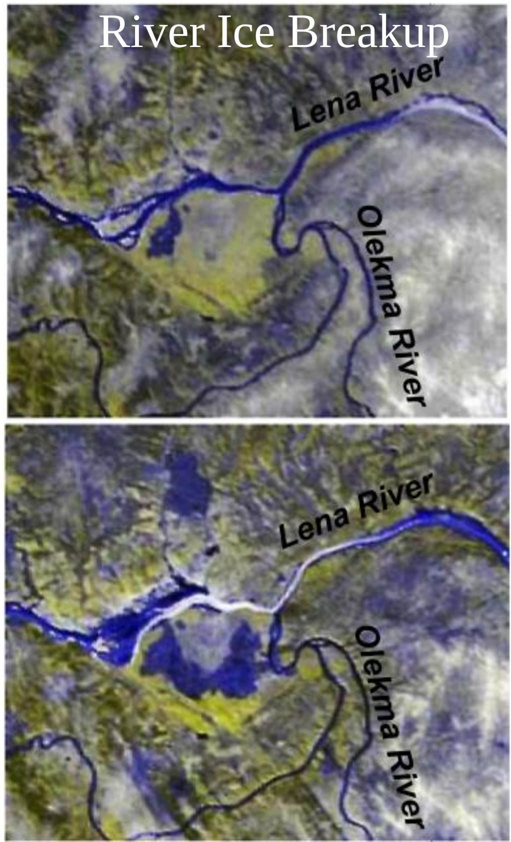
SWOT will:

- ▪ Track discharge in braided rivers that cannot be easily gauged *in situ*.
- ▪ Allow direct assessment of the effect of permafrost extent on downstream discharge variation.
- ▪ Monitor flow out of glacial rivers, tracking seasonal melt patterns and observing large glacial outburst events.
- ▪ Observe river-floodplain interactions during the critical spring ice-breakup season, when most water and nutrient exchange occurs.

Courtesy Stephen Codrington

Glacial Rivers

River Ice Breakup

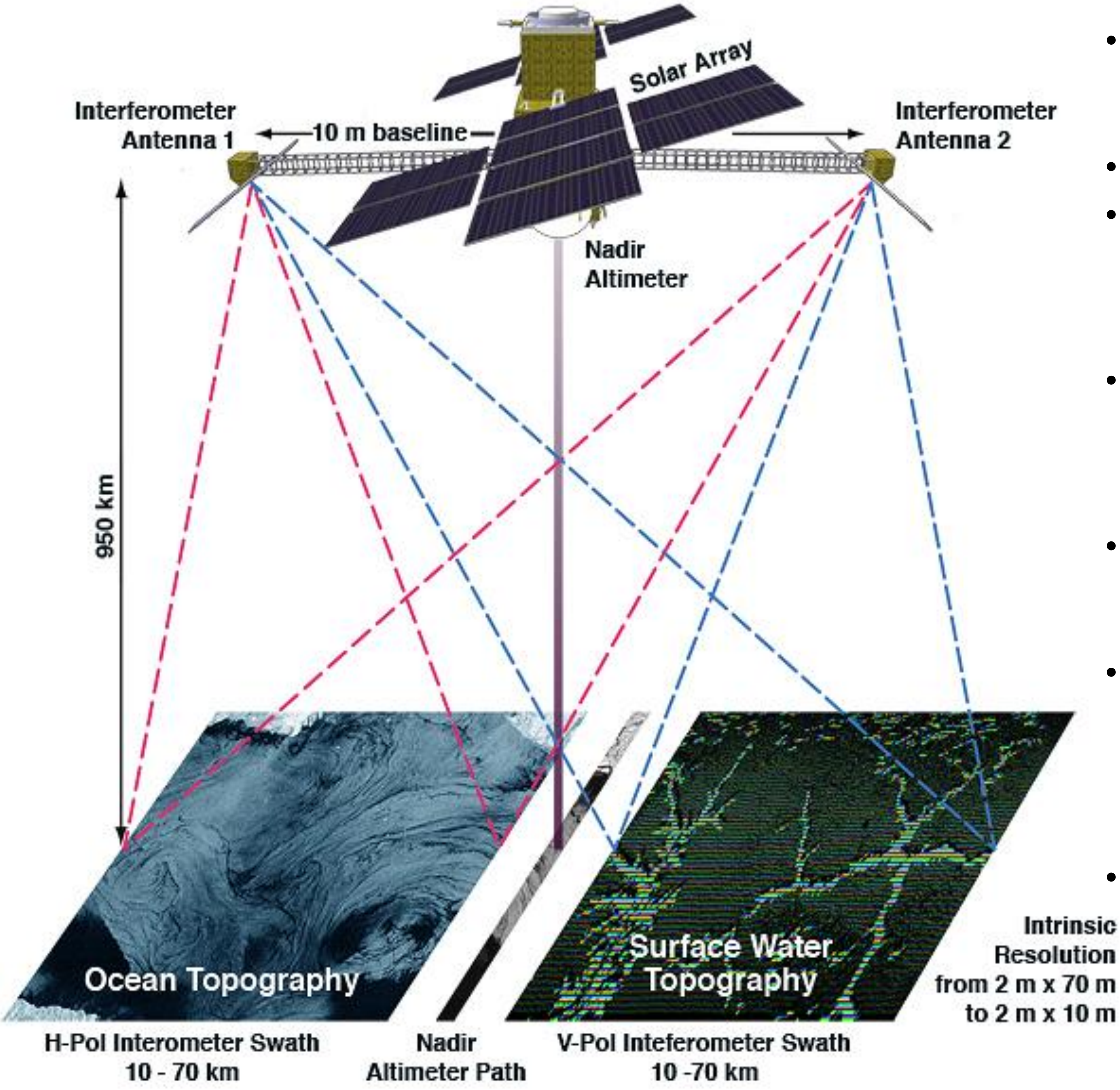


Key Point for Arctic Hydrology and Global Lakes

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.

KaRIN: Ka-Band Radar Interferometer



- Ka-band SAR interferometric system with 2 swaths, each 60 km wide
- WSOA and SRTM heritage
- Produces heights and co-registered all-weather imagery ***required by both communities***
- **No land data compression onboard (+/-50 cm height accuracy per pixel)**
- Onboard data compression over the ocean (1km resolution)
- Because looking near nadir, height accuracy improved by more than an order of magnitude over SRTM.
- Noise is uncorrelated, thus averaging further improves height accuracy by sqrt(n).

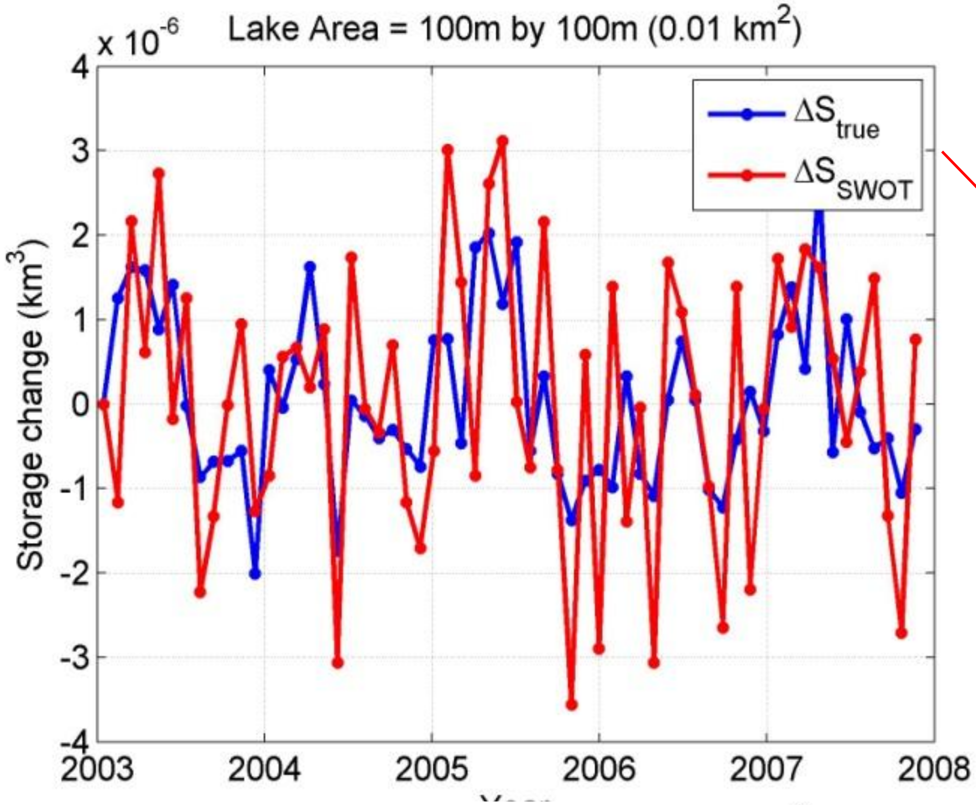
Graphics: Karen Wiedman

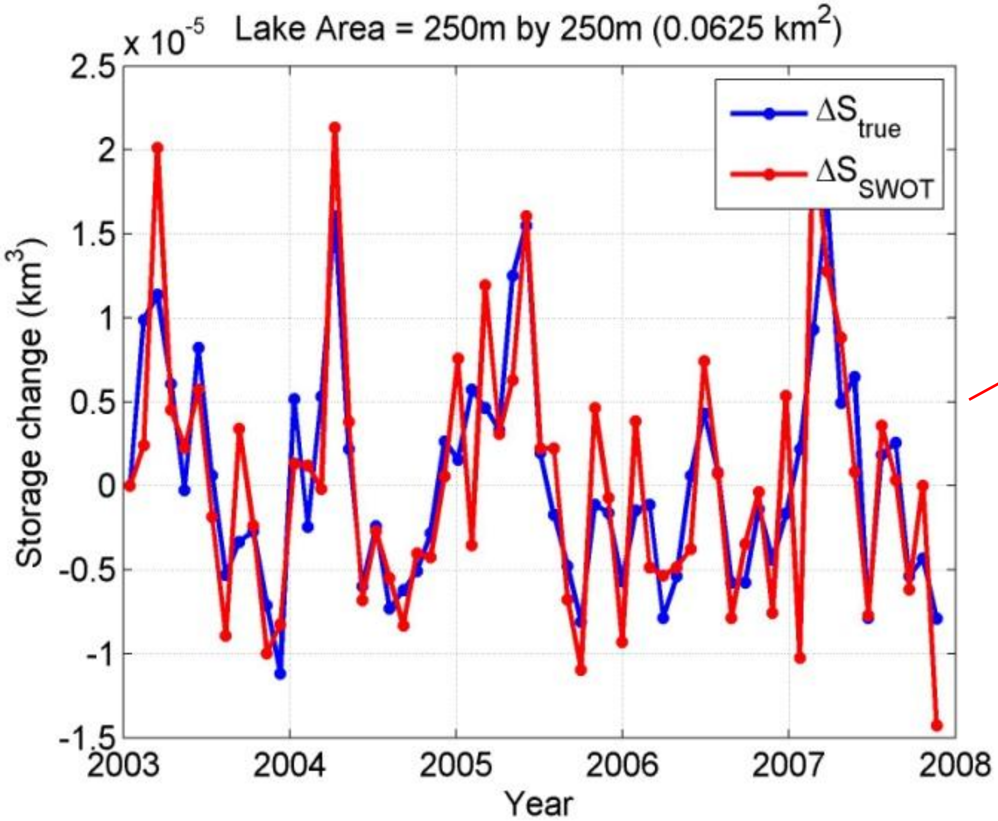
Summary

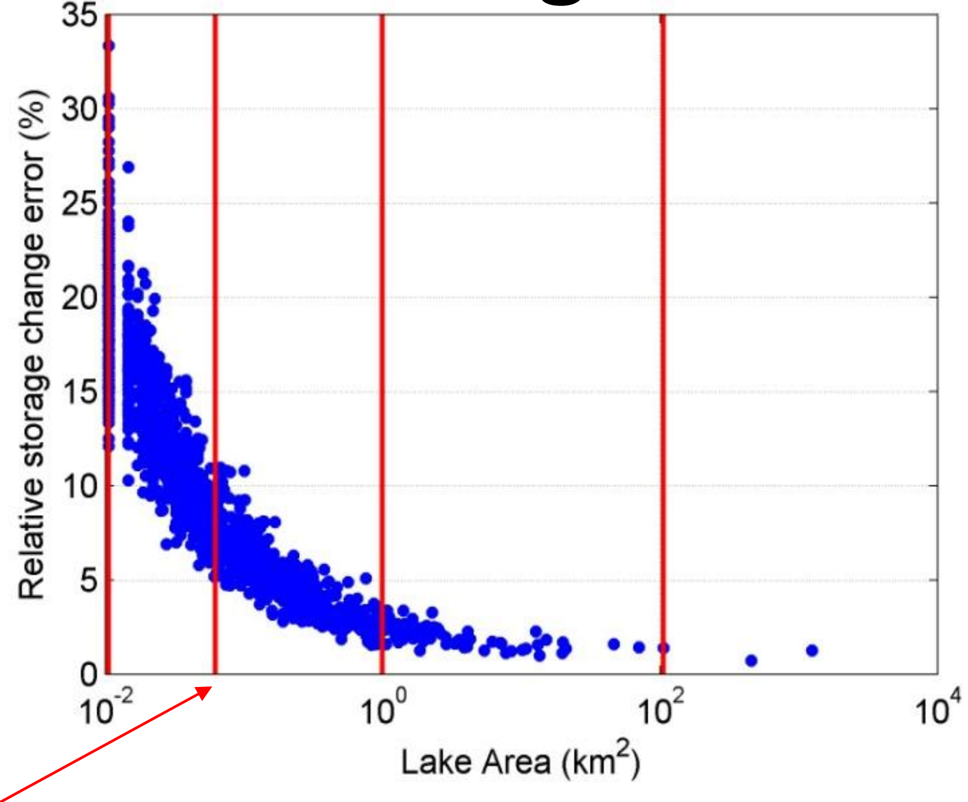
- SWOT will help determine:
  - How much surface water we have at any place on Earth and at any time during the mission, thus a significantly improved understanding of the global water cycle.
  - How floods work, i.e., the hydrodynamics of floods
  - River flow across international boundaries
  - Energy dissipation, ocean circulation, and climate change implications from ocean currents (e.g., Gulf Stream)
  - Coastal upwelling and cross-shelf transport, and thus implications on marine life, ecosystems, waste disposal, transportation, and spill mapping
  - Ocean bathymetry, sea ice thickness, floodplain topography
- SWOT will provide a revolutionary set of hydrodynamic and sea surface height measurements, globally (e.g., h, dh/dt, dh/dx, and area).
- This mission is for everybody, please join us via the mission web page: **http://swot.jpl.nasa.gov/**

Additional Slides

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

North America Rivers Measured by SWOT

Width estimated from discharge.

KaSPAR: Ka-band SWOT Phenomenology Airborne Radar

Two sets of transmit antennas:

- Illuminate inner (SWOT geometry) & outer swath to provide wide-swath coverage
- Use inner “SWOT” swath for classification and phenomenology pre-mission algorithm development
- Larger swath for SWOT cal/val, science and discharge retrieval development
- Overlapping beams for inter-calibration

Initial aircraft NASA King Air but design aircraft independent

- Swath performance generally better as altitude increases