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Converting Waste Into Resources

LADWP Los Angeles Department of Water & Power

Geosyntec consultants

OC SAN ORANGE COUNTY SANITATION DISTRICT

DSWA DELAWARE SOLID WASTE AUTHORITY

dc water is life®

We will begin our presentation in a few minutes…






Leadership and Excellence in Environmental Engineering and Science

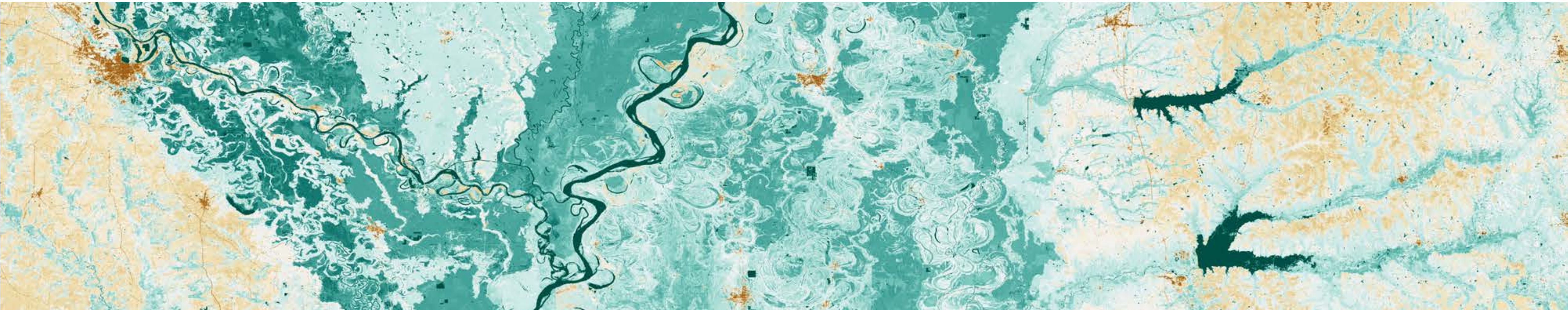
Towards locally relevant global soil moisture monitoring for water resources and climate applications

Noemi Vergopolan, PhD
Atmospheric and Ocean Sciences Program, Princeton University
NOAA Geophysical Fluid Dynamics Laboratory

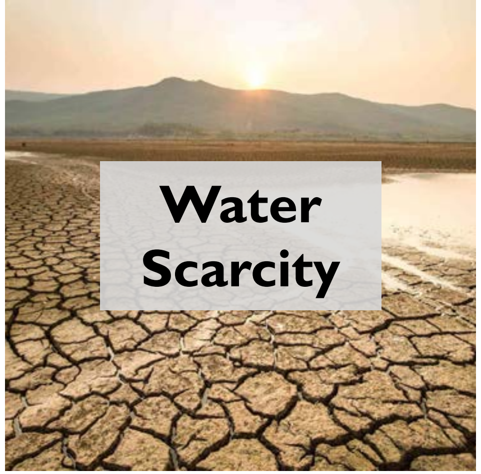
September 7th, 2022 – American Academy of Environmental Engineers and Scientists (AAEES)

Geophysical Fluid Dynamics Laboratory GFDL NOAA

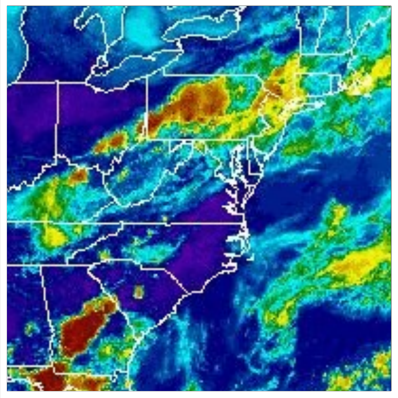
PRINCETON UNIVERSITY



The grand challenge of monitoring and predicting terrestrial water



How terrestrial water system will be impacted by climate change?






SOIL MOISTURE

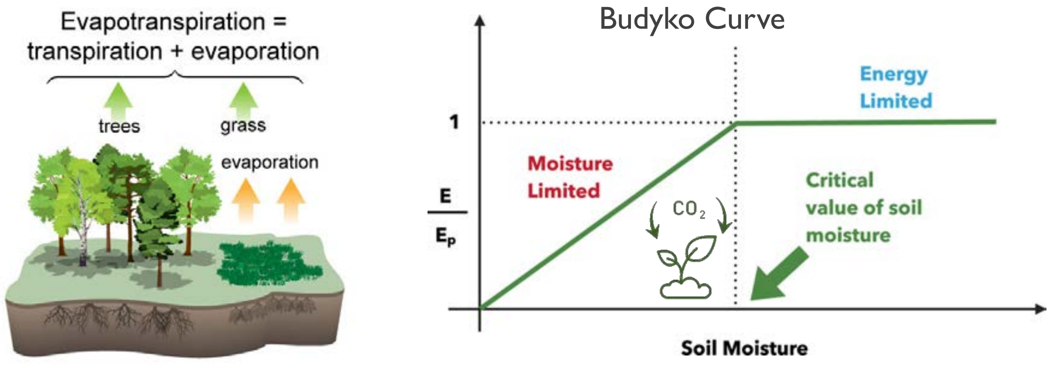
Controls the exchanges of water, energy, and carbon fluxes at the land surface



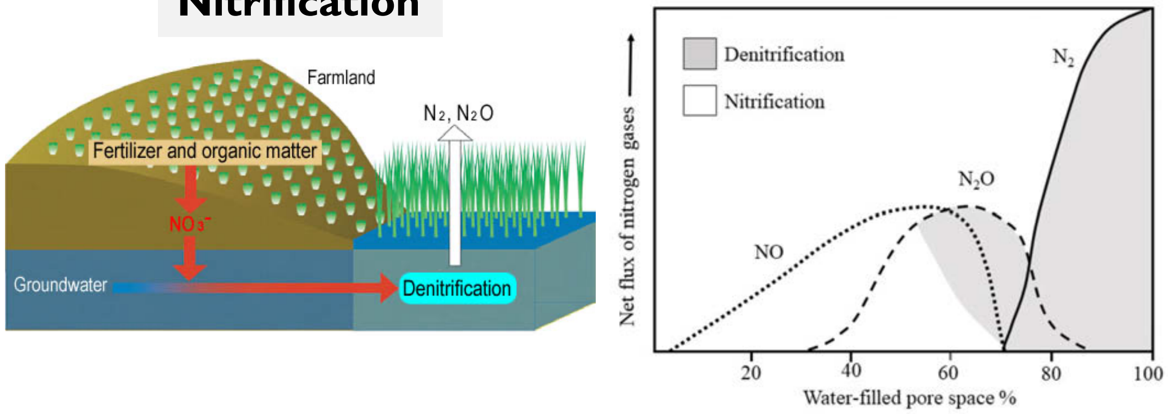



Many processes behave non-linearly with soil moisture at the local-scales

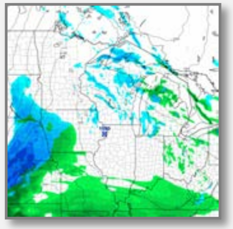
Evapotranspiration and crop productivity



Nitrification



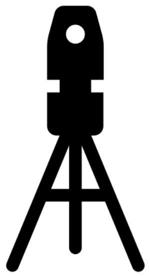
Hydroclimate & Carbon Cycles

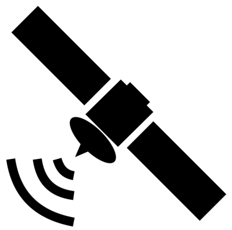


Natural Geohazards

Species Distributions

How can we measure and predict soil moisture?





In-situ Soil Moisture Observations

Characteristics:

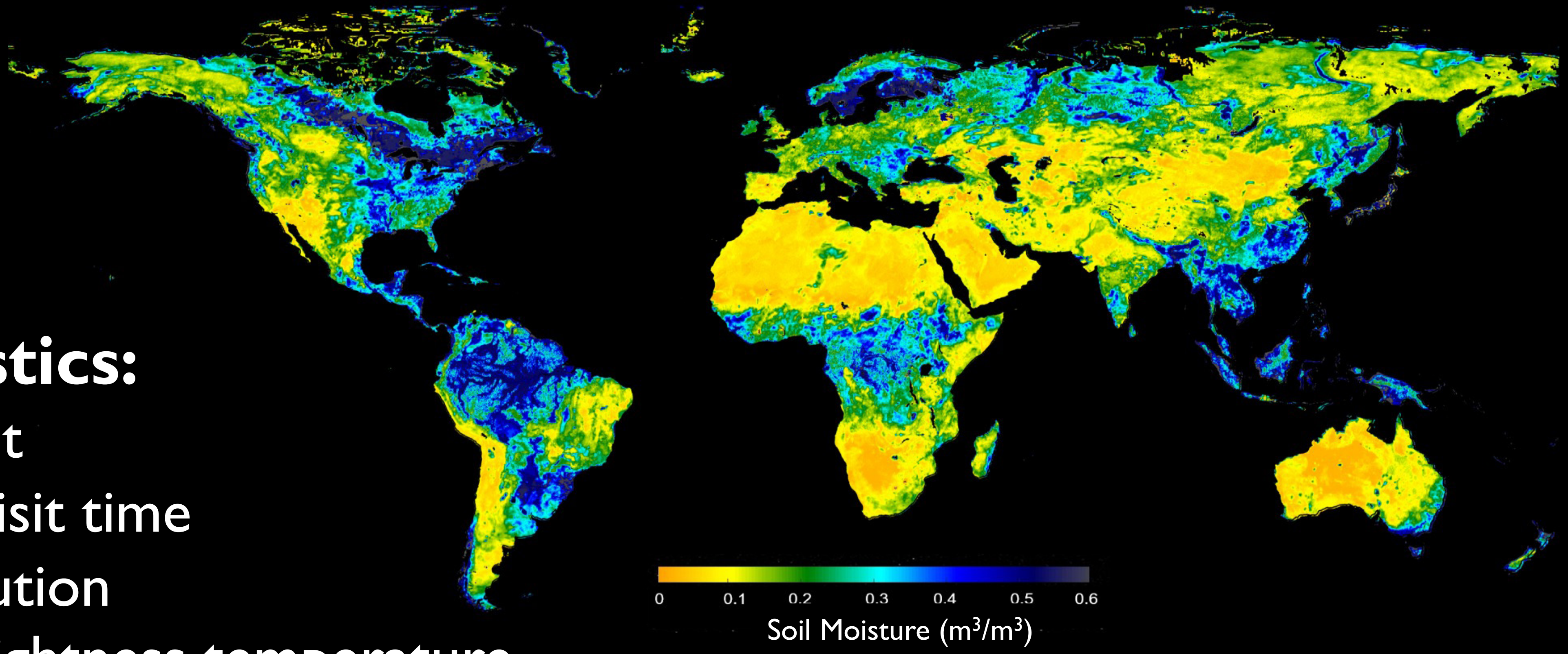
- Gravimetric measurements:
  - Laborious to collect, dry, and weight the sample
- Indirect sensor measurements:
  - Electrical resistance, dielectric constant, or interaction with neutrons
  - Require individual calibration

→ Local representativeness (0.1–500 meters)

→ Costly and not widely available

Satellite Observations:
NASA Soil Moisture Active-Passive Mission (SMAP)

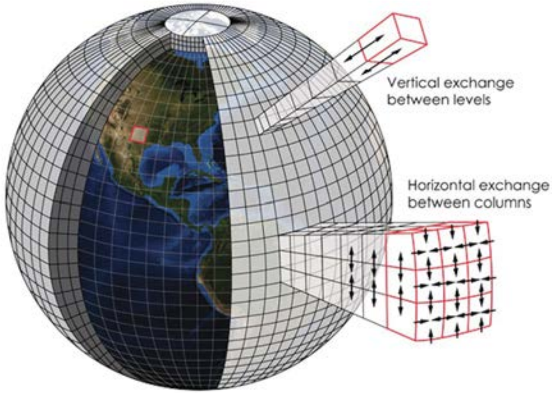
SMAP Soil Moisture 8-day Composite (May 28th – June 4th, 2019)



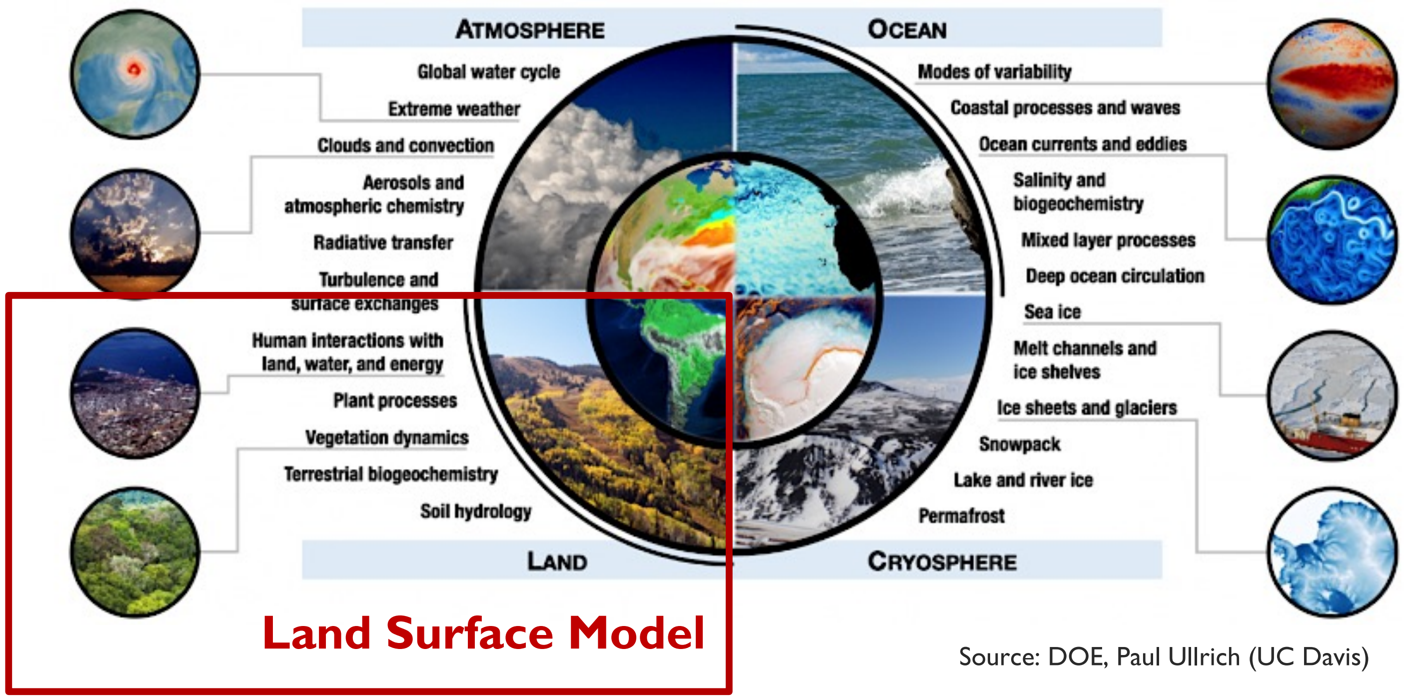
Characteristics:

- 2015–current
- 2–3 days revisit time
- 36-km resolution
- Measures brightness temperature
- Retrieves soil moisture via Radiative Transfer Model (RTM)

Earth System Models (ESMs)



Our best representation of the complex Earth system through physical equations



Source: DOE, Paul Ullrich (UC Davis)

Characteristics:

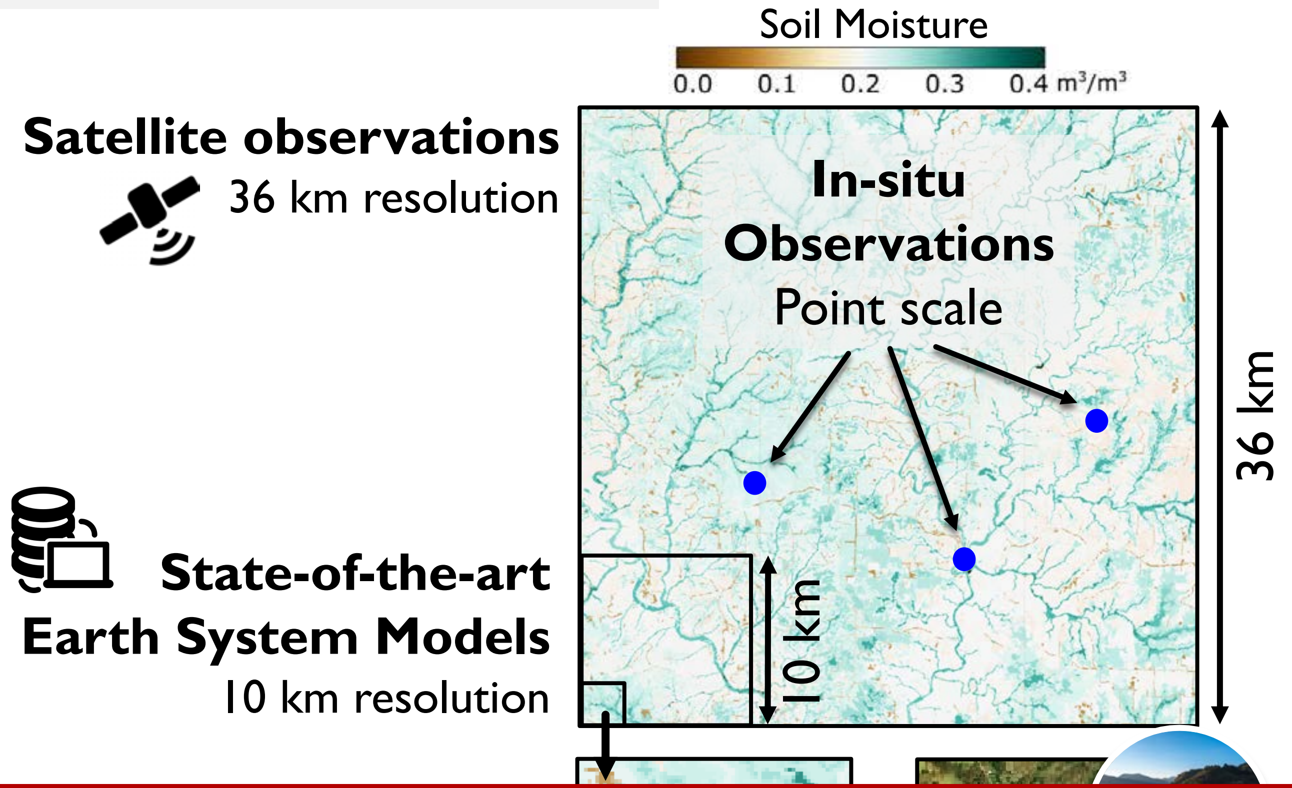
- Numerical model
- Integrated Earth system
- Provides process understanding
- Physically resolve soil-water
- State-of-the-art: 10-km res.
- Computationally expensive

The challenge:
Soil moisture is highly variable in space and time

In-situ observations
- ✓ Accurate, but costly and **not widely available**
- ✓ Not representative of large domains

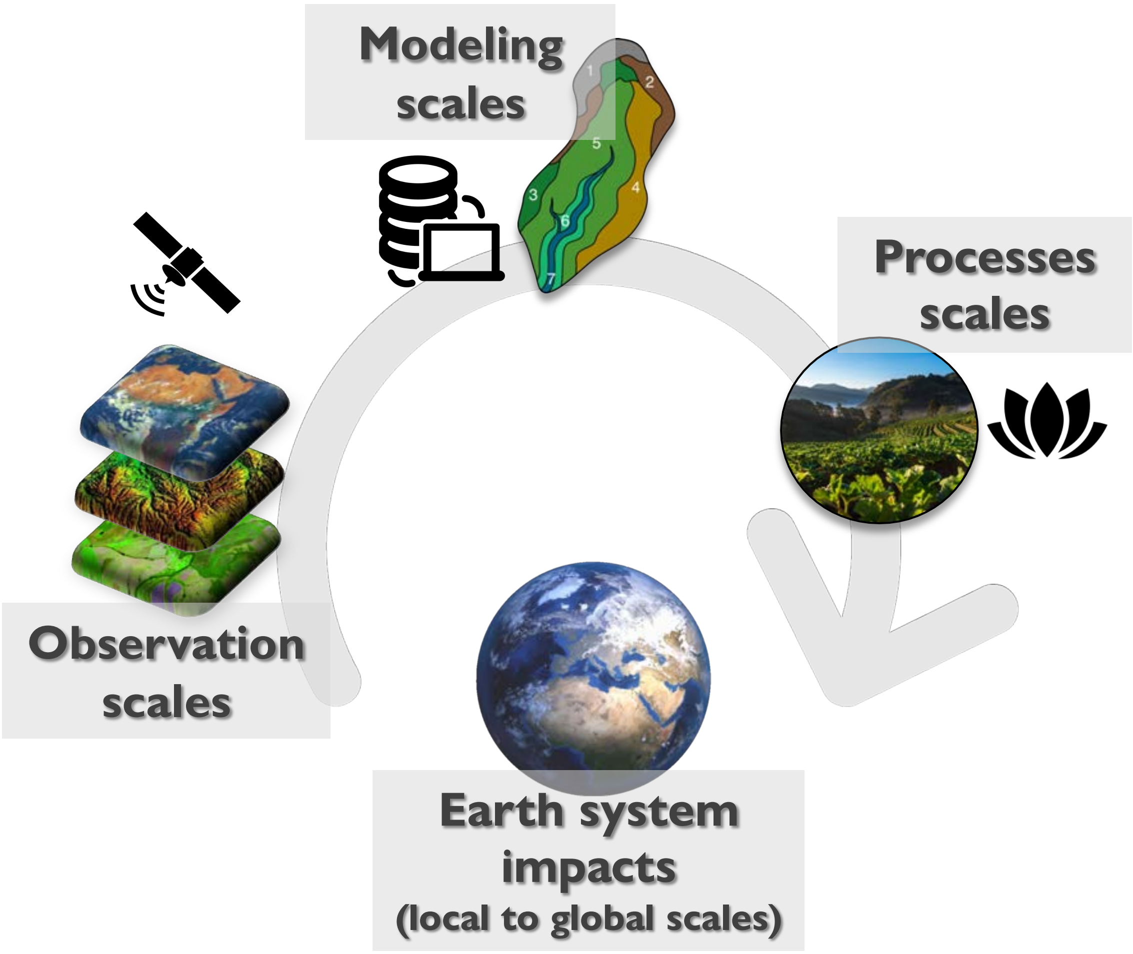
Satellite observations
- ✓ Good **accuracy** & **global** coverage
- ✓ **Coarse** resolution (e.g., 36 km)

Hydrological and Earth System Models
- ✓ Provide process **understanding**
- ✓ **Coarse** and **computationally expensive**



Unresolved spatial scale mismatch between observations, models, and processes

To address terrestrial water grand challenges…



There is a need for **integrated** approaches that **reconcile** the scale of observations, models, and processes to **stakeholder-relevant** spatial scales

Timely Opportunities:

- ✓ Big Data: Satellite Earth Observation
- ✓ Statistics and Machine Learning

Landsat & Sentinel
10-30m Derived databases

Soil Properties:
30m POLARIS
250m SoilGrids

Land Cover:
30m NLCD
30m GlobeLand

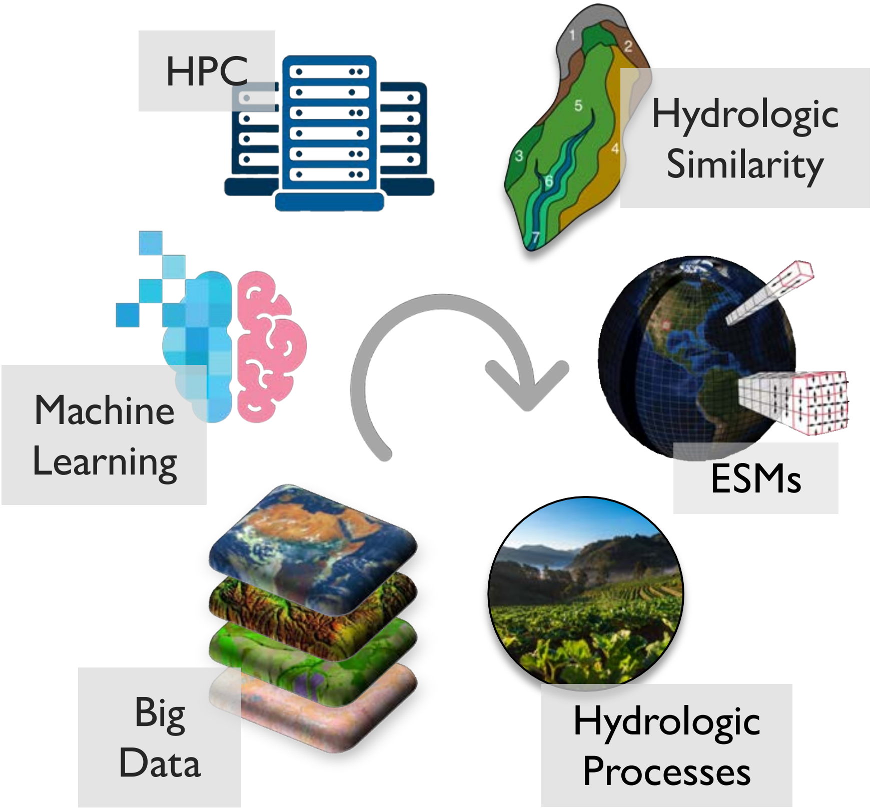
Topography:
10m USGS NED
30m SRTM

How can we leverage these unique opportunities to understand and predict soil moisture dynamics locally?

Objective: Demonstrate how big environmental data, machine learning, and HPC enables locally-relevant hydrologic information

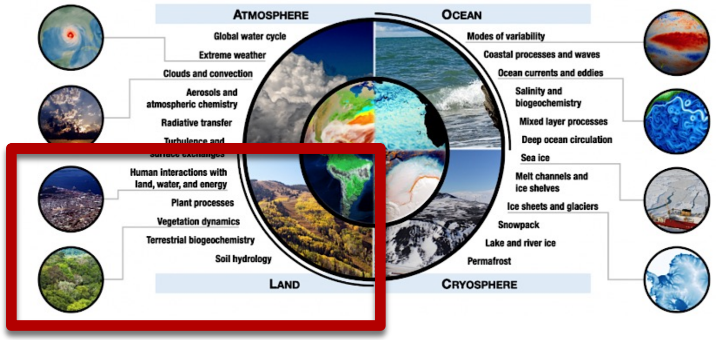
Outline:

1. **HydroBlocks** – Advancing realism in Earth system models through Big environmental data
2. **SMAP-HydroBlocks** – Unlocking the potential of satellite Earth observation via land data assimilation
3. **Spatial scaling of soil moisture** – Investigate the impact of local-scale hydrology for Earth system predictability

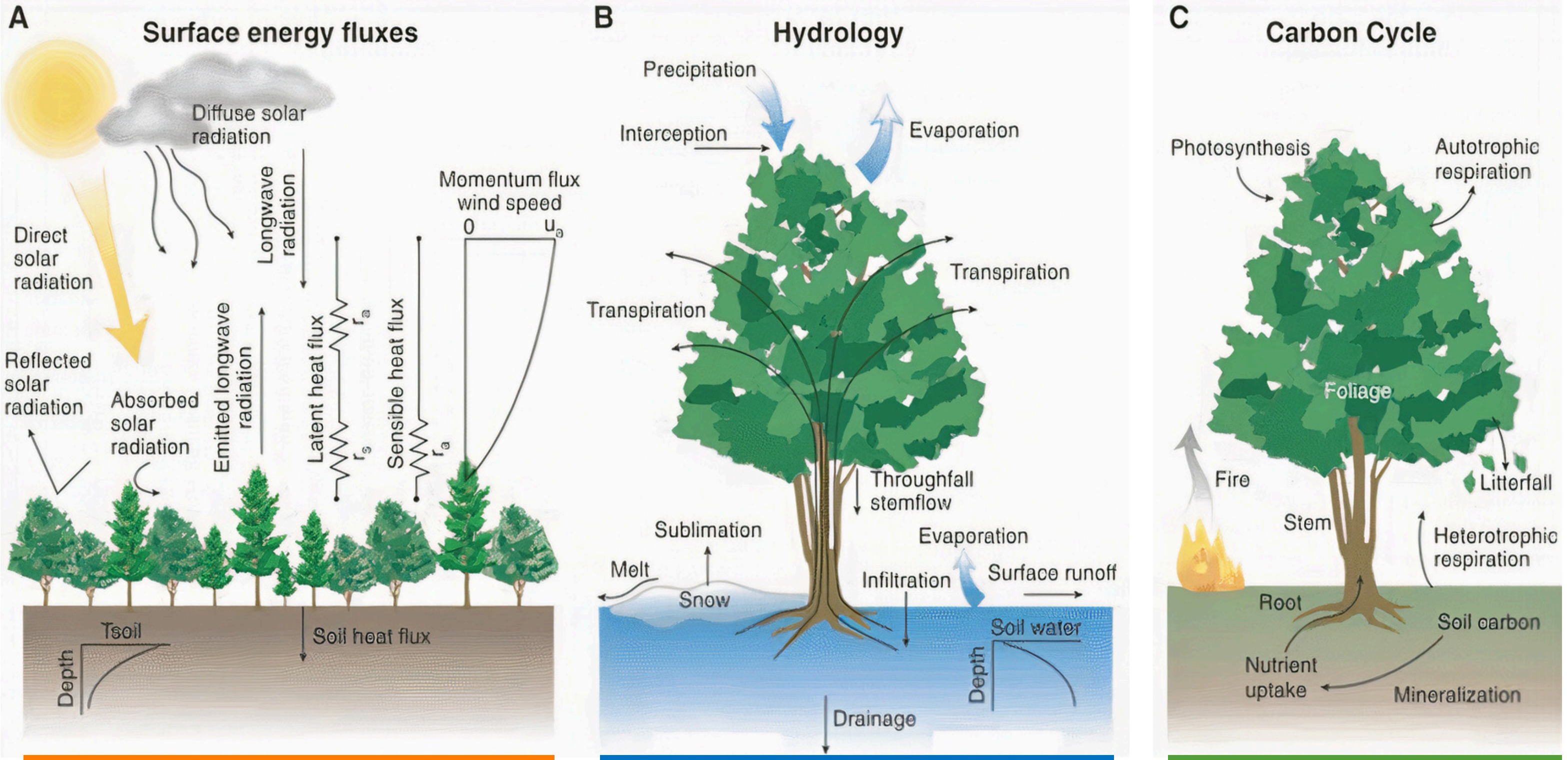


Land Surface Models

Earth System Models



Our best representation of the complex **land surface system** through physical and statistical equations



Energy | **Water** | **Carbon**

Source: Adapted from Bonan (2008)

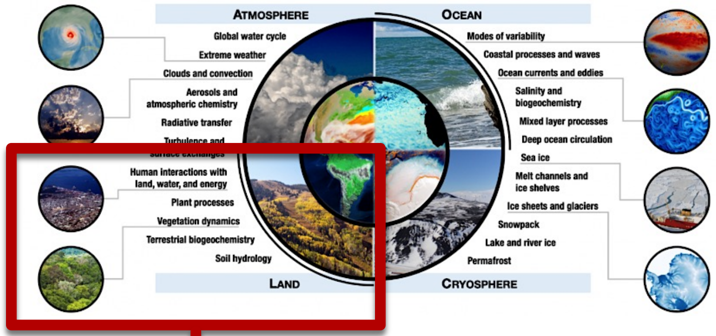
Soil Moisture Dynamics

Physically modeling soil water dynamics in different soil layers via Richards Equation

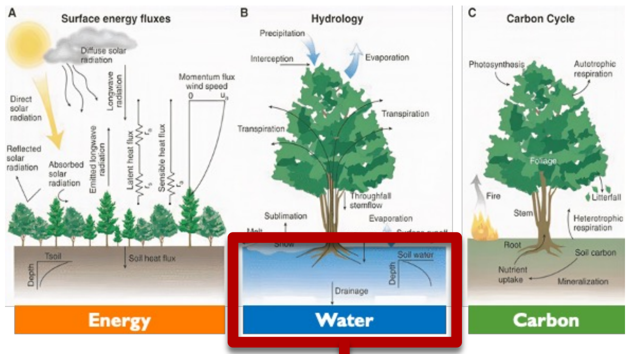
$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K_z(\theta)\frac{\partial (z+\psi)}{\partial z}\right) + S$$

θ soil moisture
t time
z elevation
K_z hydraulic conductivity
ψ soil water potential
S sources/sink

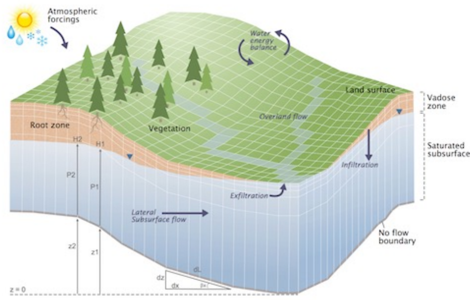
Earth System Models



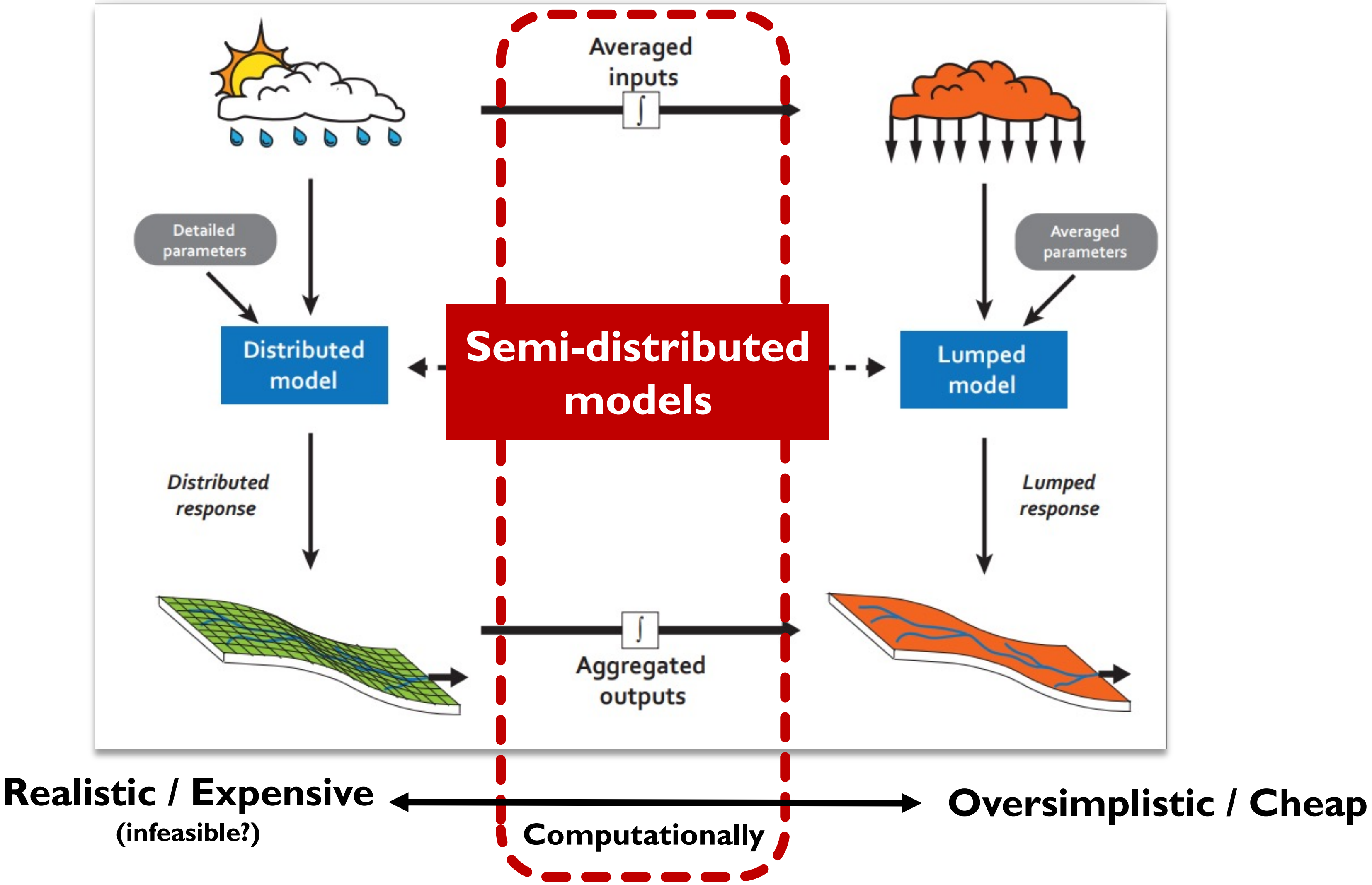
Land Surface Models



Soil Moisture Dynamics



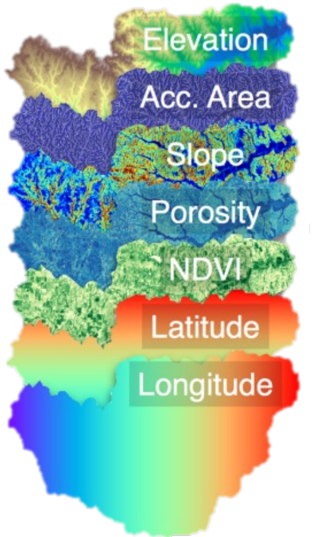
Fully Distributed vs. Lumped Models



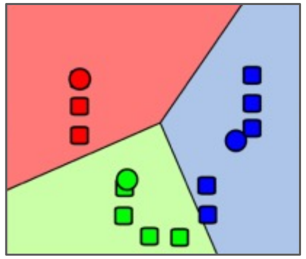
Source: Adapted from Peters-Lidard et al. (2017)

Hydrologic Similarity

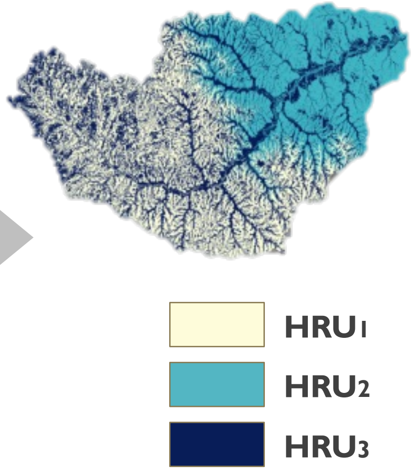
Locations with similar landscape and climate characteristics yield similar hydrologic response

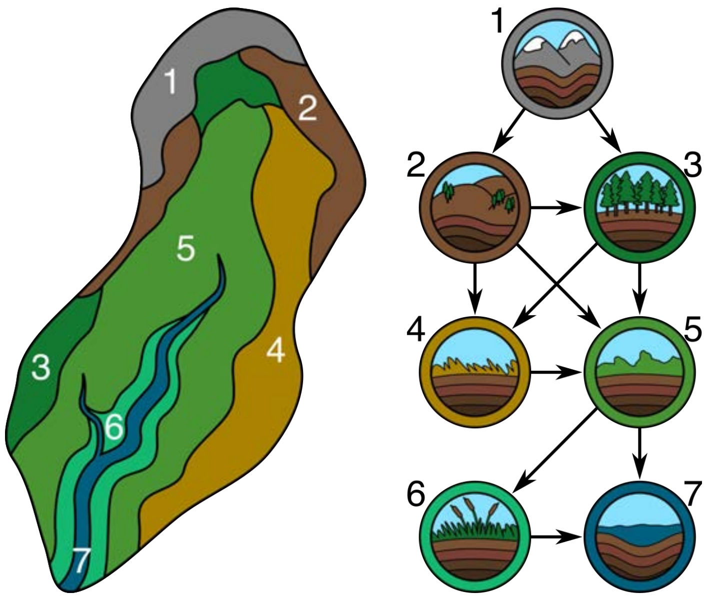


30-m Big Geospatial Environmental Data



Machine Learning Clustering Scheme





Partition the domain into 100-500 HRUs instead of 1 million grid cells

Cluster → Hydrologic Response Unit (HRU)

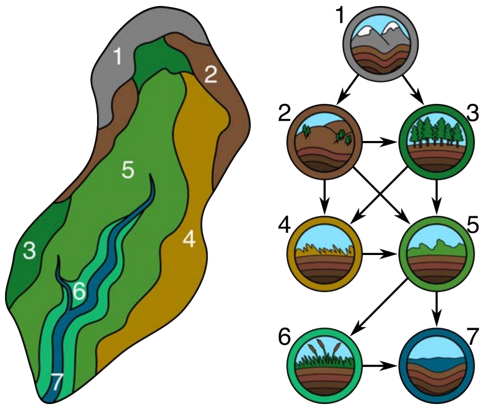
Vergopolan et al. (2021). SMAP-HydroBlocks, a 30-m satellite-based soil moisture dataset for the conterminous US. Nature Scientific Data.
Chaney, et al. (2021). HydroBlocks v0.2: enabling a field-scale two-way coupling between the land surface and river networks in Earth system models. Geoscientific Model Development.

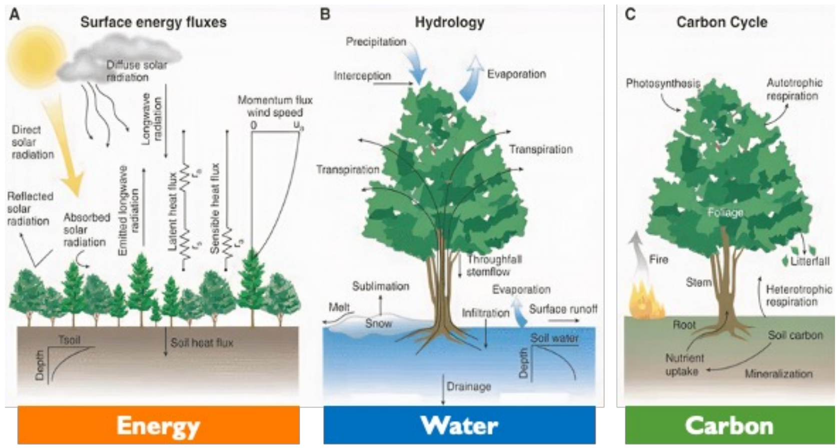
HydroBlocks Land Surface Model

HydroBlocks

Physically resolve land surface processes in the HRU-space instead of grid-space

- HRUs define the computational mesh
- Core physics of Noah-MP land model
- Effective 30-m spatial resolution
- Computationally efficient
- Storage efficient
- Scalable from local to global scales

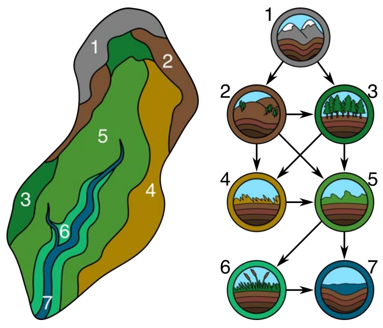




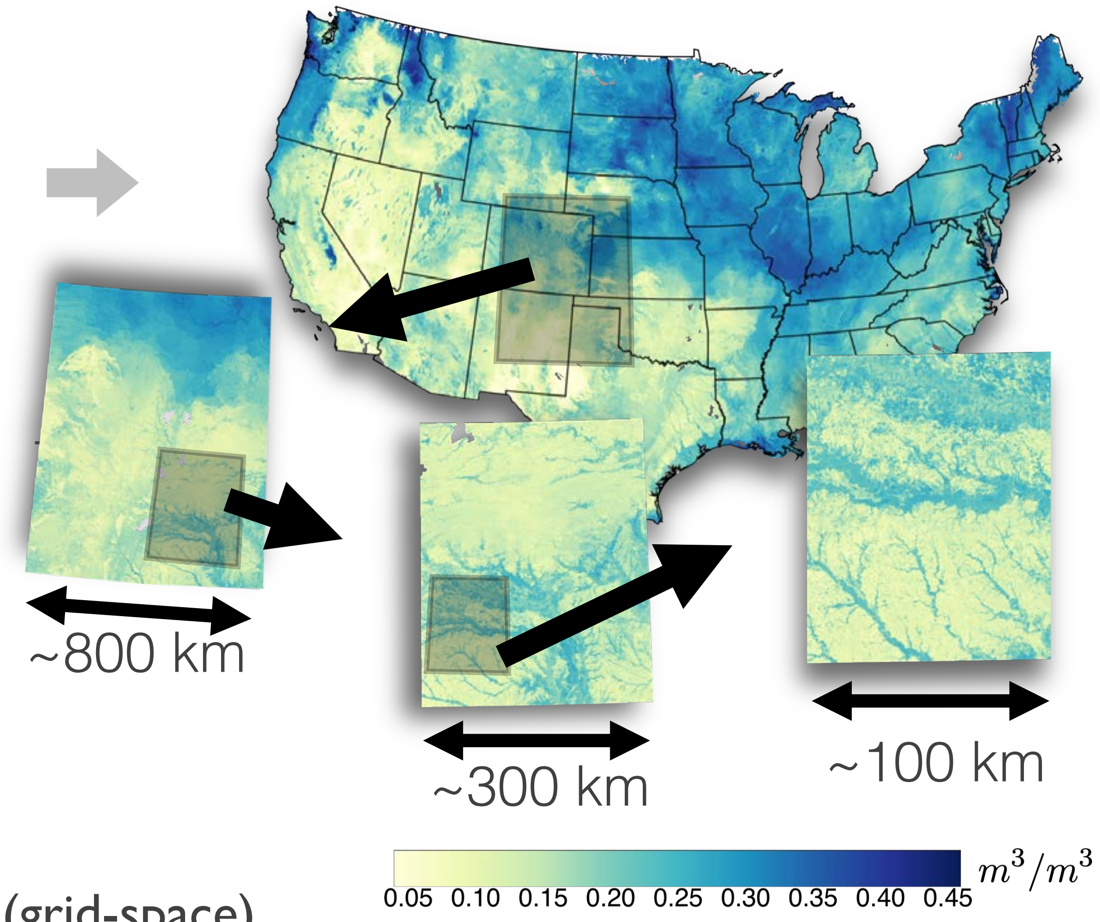
HydroBlocks CONUS Simulation

Environmental Data

HydroBlocks



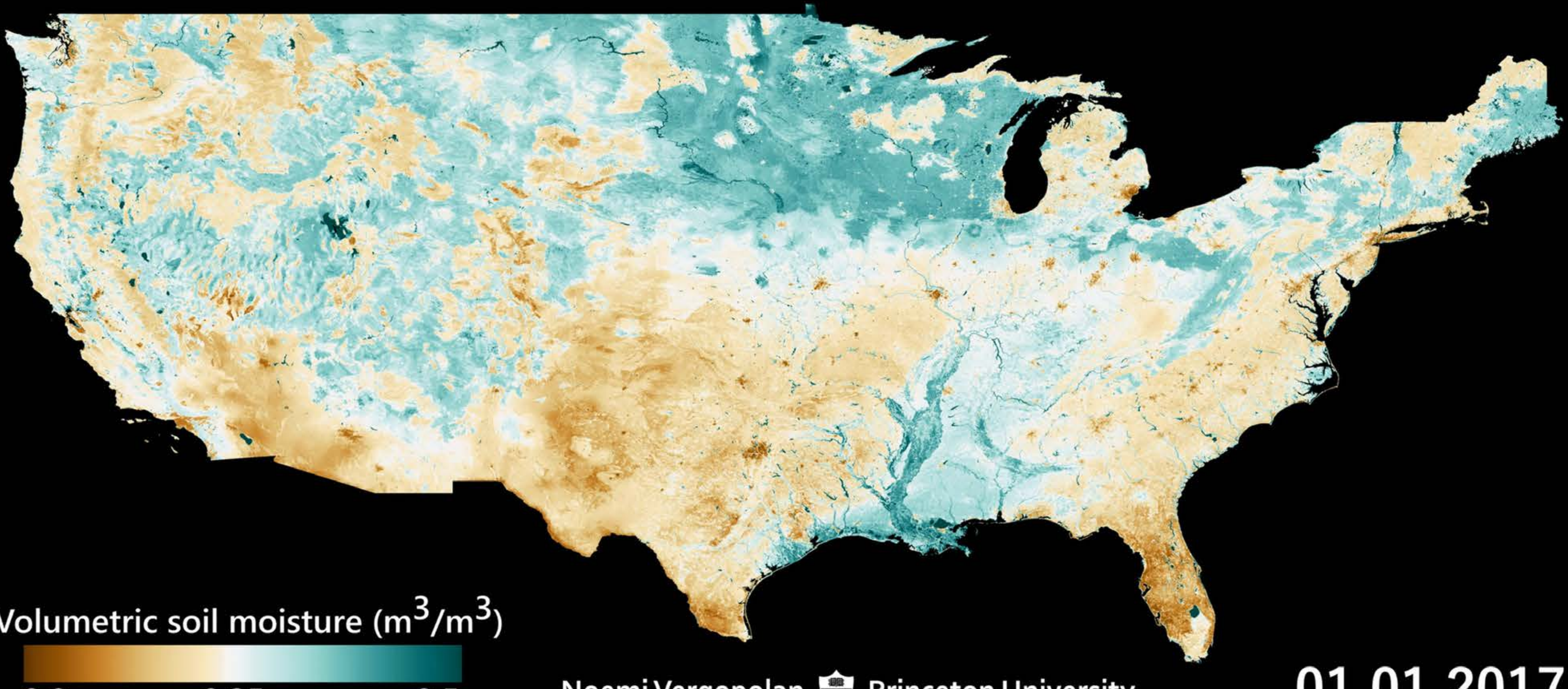
Soil Moisture Simulations



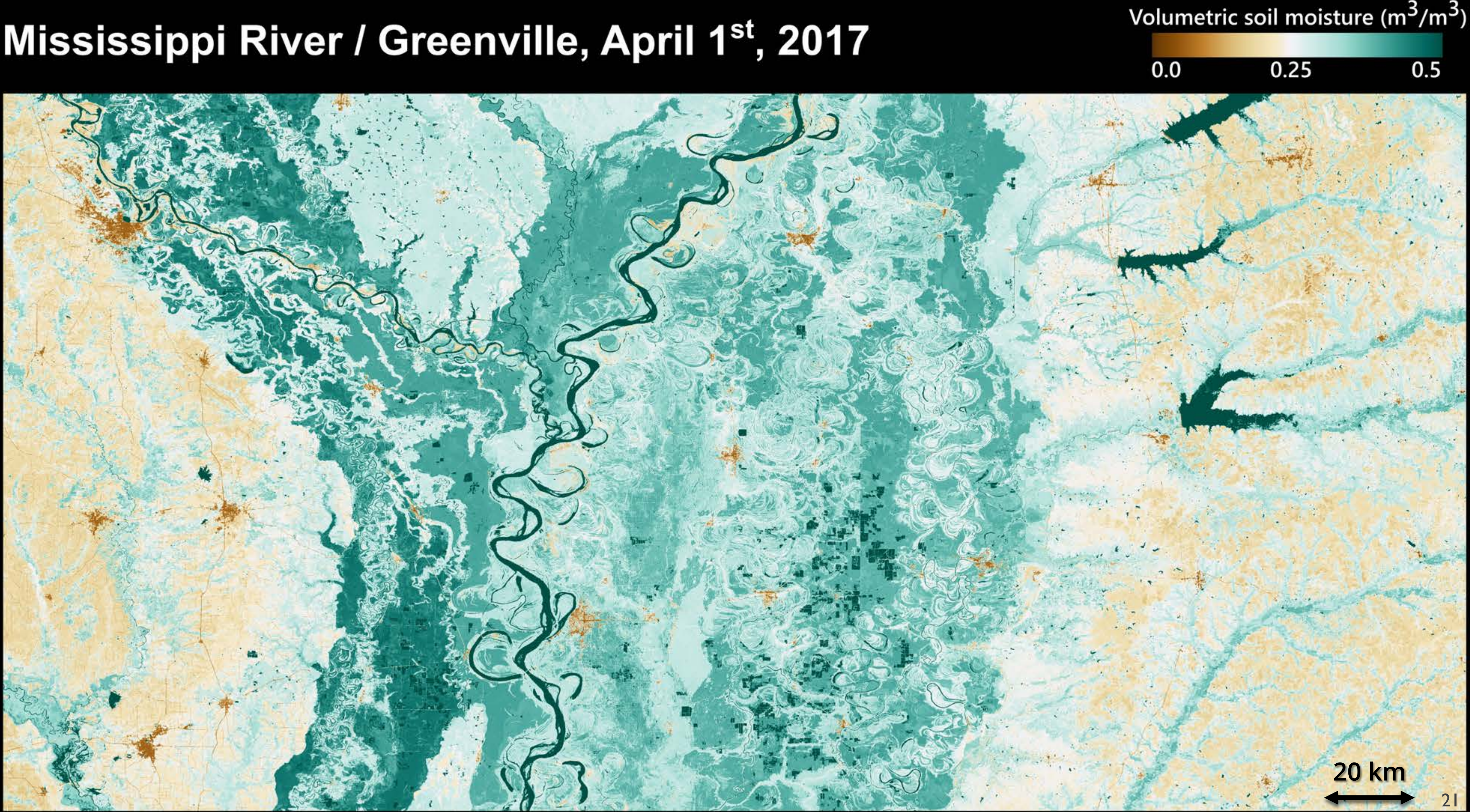
- Continental United States ~7.7 million km^2
- ~5 million HRUs (instead of ~8 billion 30-m grid cells)
- 3-h temporal res., 30-m (effective) spatial res.
- 2010 to 2019 (2010 to 2014 spin up)
- Run on HPC system using 300 cores (~1 week)
- Output variable/year: 200 GB (HRU-space) or ~312 TB (grid-space)

10 July, 2016

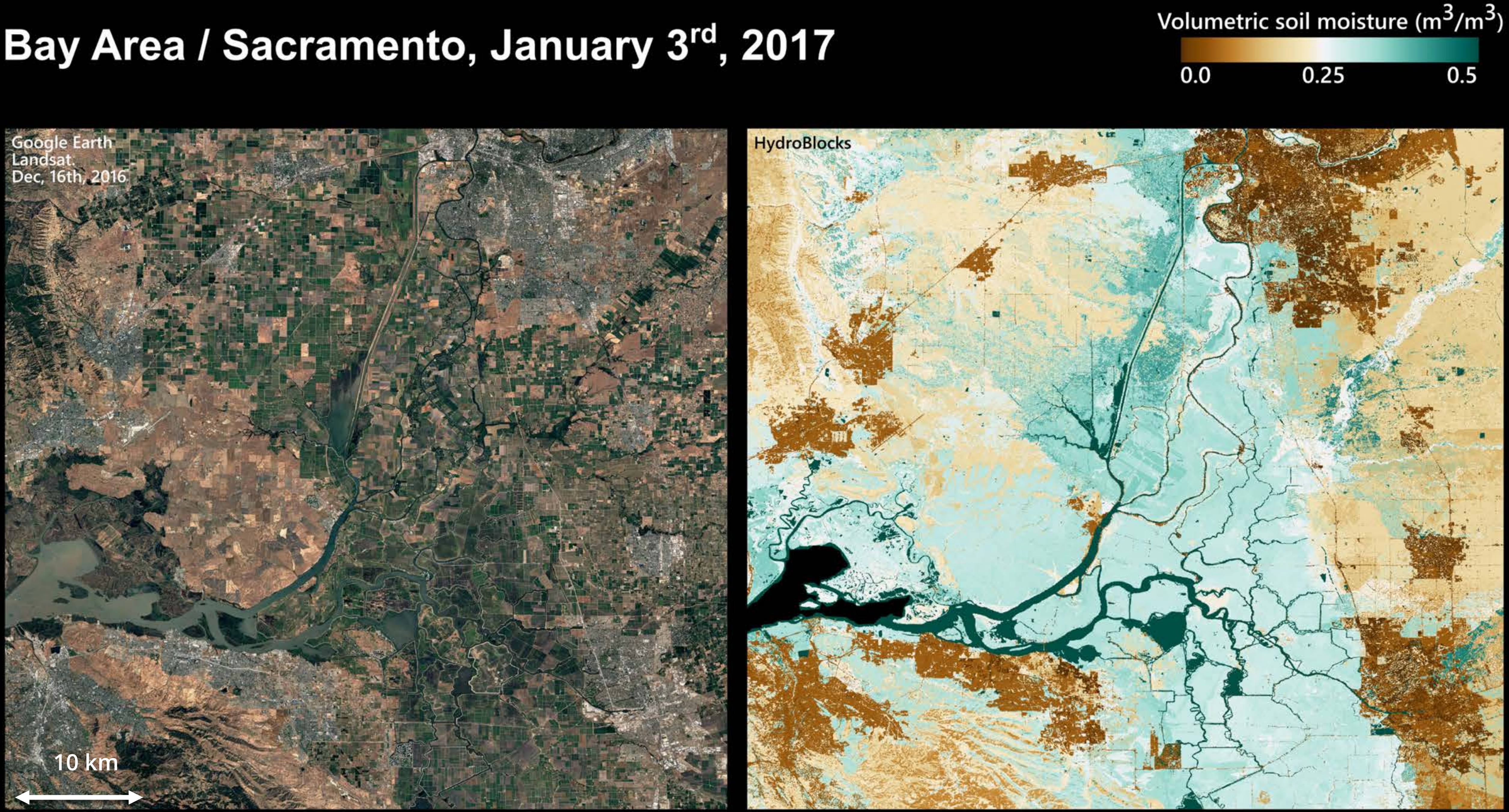
Hyper-resolution land surface modeling of
surface soil moisture



Mississippi River / Greenville, April 1st, 2017



Bay Area / Sacramento, January 3rd, 2017



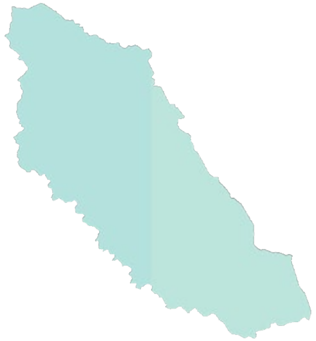
We have the model capabilities…

How can we take advantage of satellite and in-situ observations?

Data Assimilation

HydroBlocks Land Model 30 m

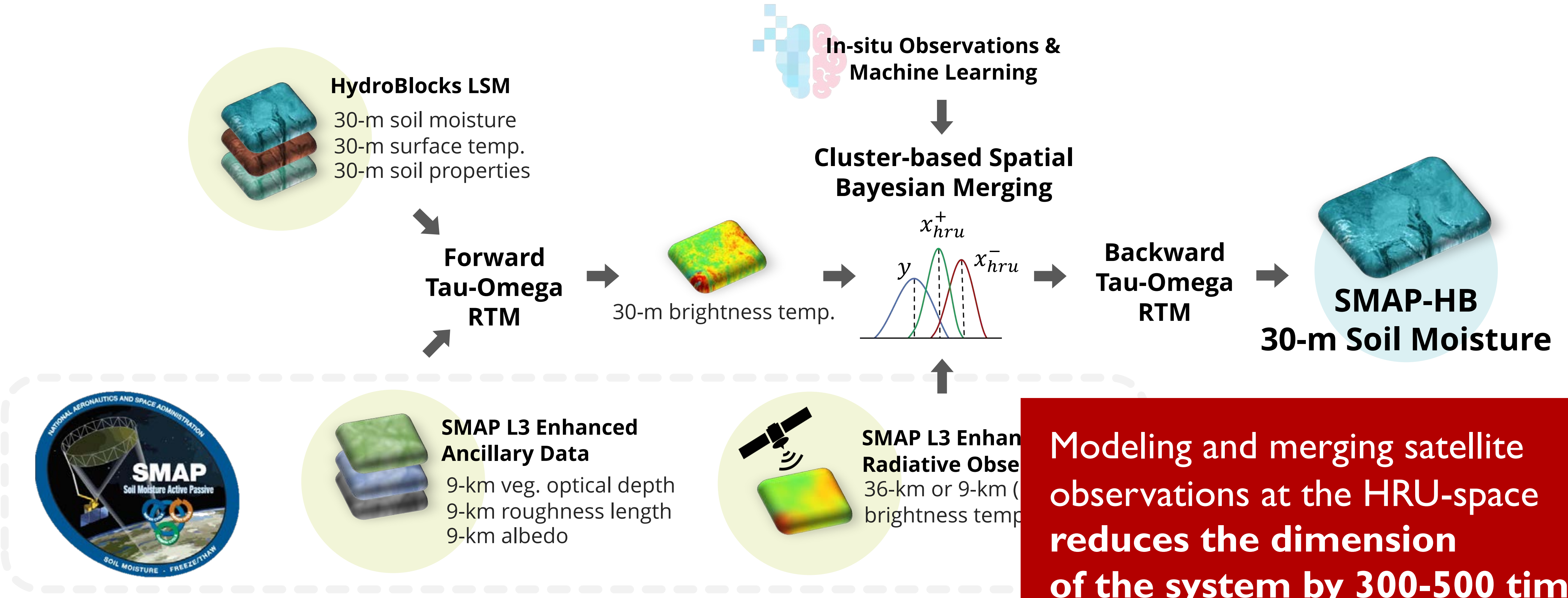
Satellite Observations 36 km



In-situ Observations point scale

SMAP-HydroBlocks:

Combining land surface modeling, satellite remote sensing, and in-situ observations

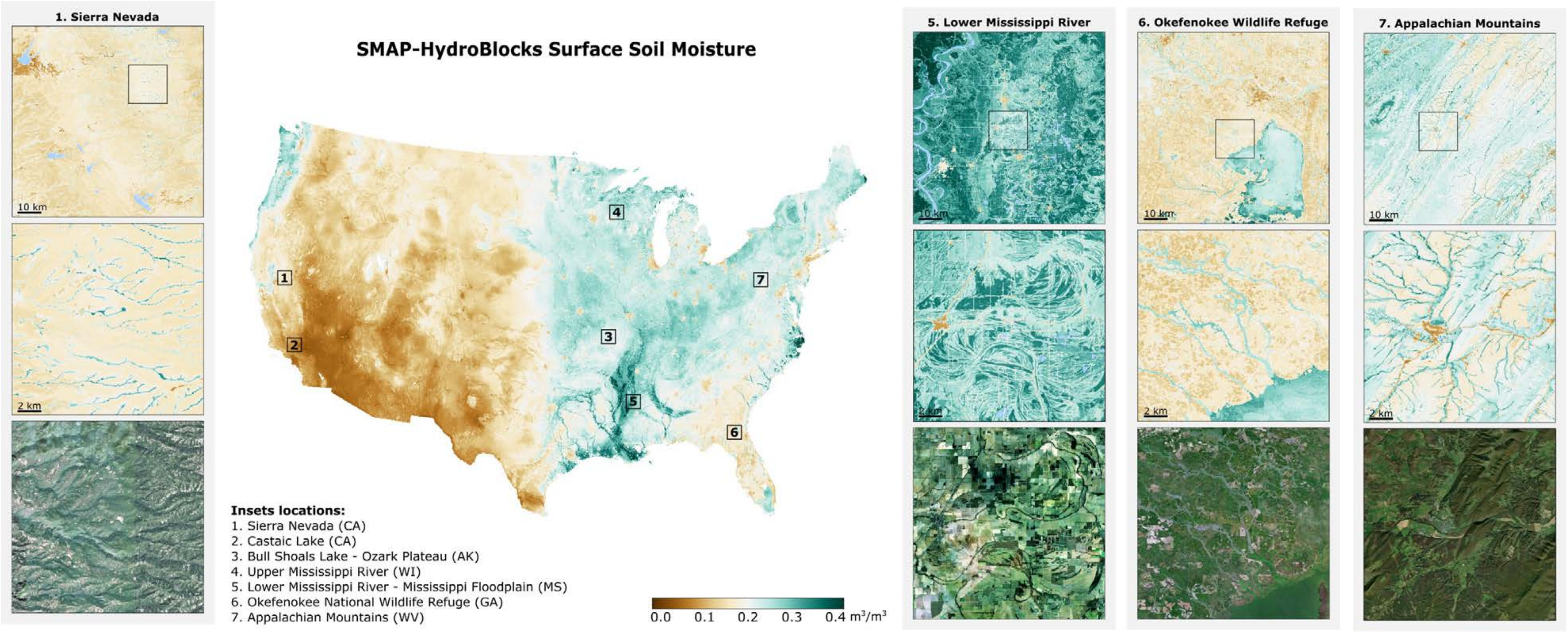


Modeling and merging satellite observations at the HRU-space reduces the dimension of the system by 300-500 times

Vergopolan et al. (2020). Combining hyper-resolution land surface modeling with SMAP brightness temperatures to obtain 30-m soil moisture estimates. Remote Sensing of Environment.

SMAP-HydroBlocks:

The first 30-m resolution satellite-based surface soil moisture dataset for the US



Vergopolan et al. (2021). SMAP-HydroBlocks, a 30-m satellite-based soil moisture dataset for the conterminous US. Nature Scientific Data.

Data characteristics:

- 2015-2019
- 30-m effective spatial resolution
- 2-3 days revisit time (SMAP)
- 122 TB of data

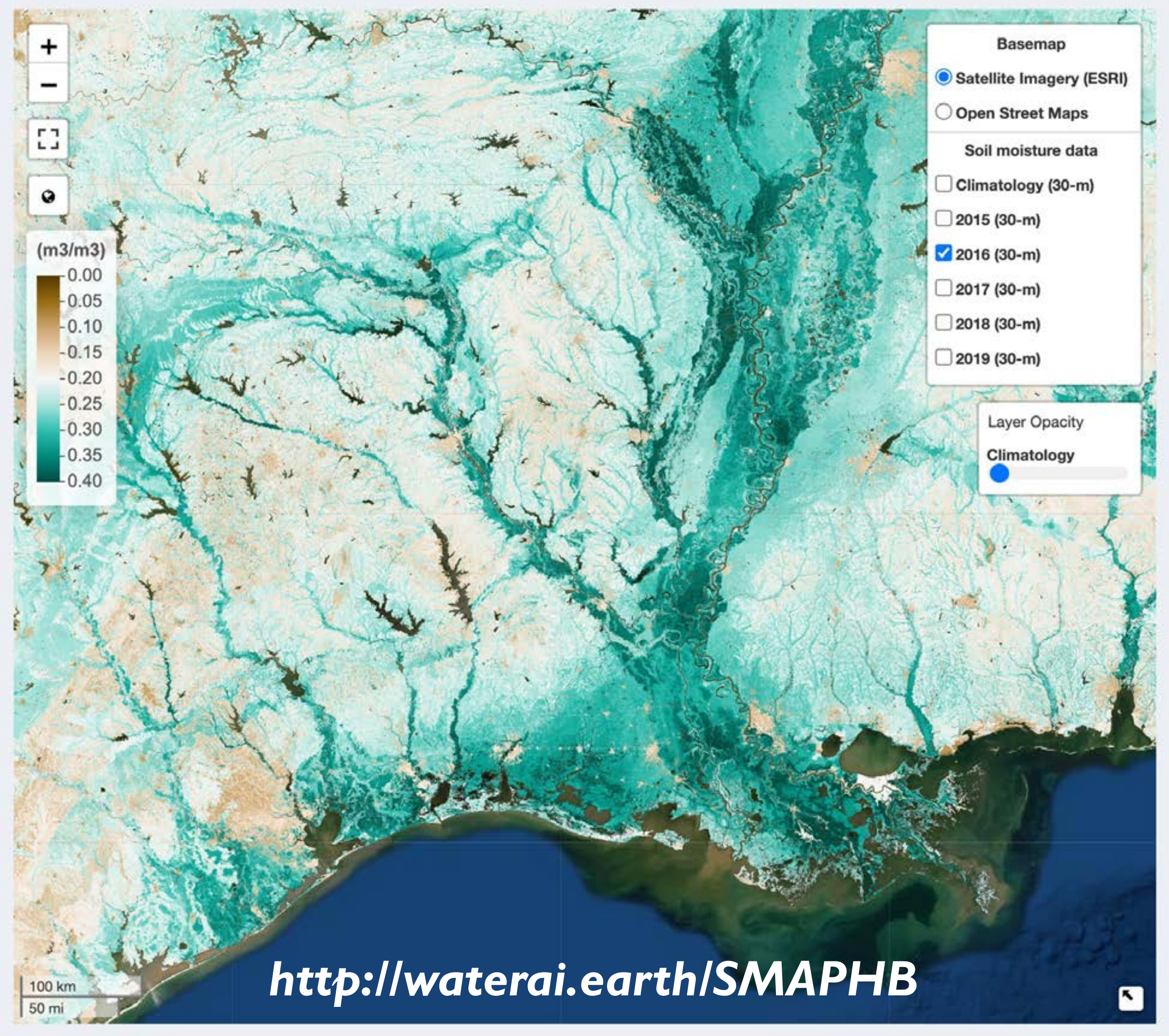
Ongoing applications:

- Drought conditions and impacts
- Crop water demands
- Antecedent conditions for: flooding, wildfires, landslides
- Distribution of species & ecosystems

Future research:

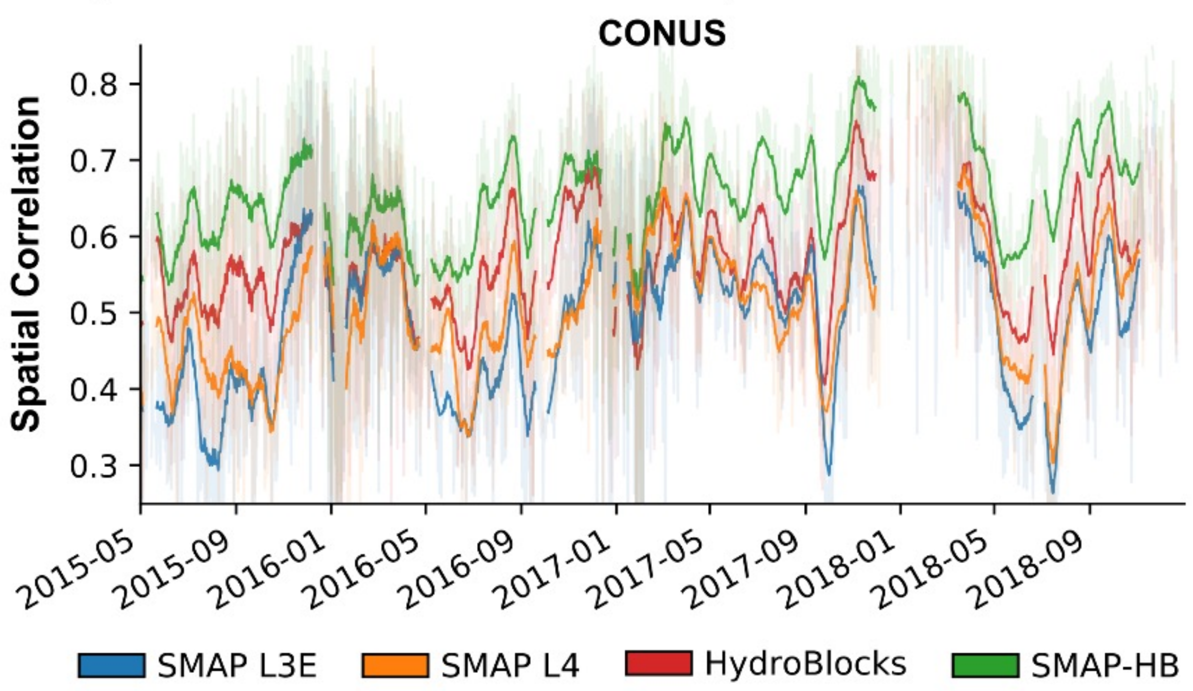
- Global coverage & current date
- Deep learning for assimilation
- Local-scale irrigation and wildfires (thermal/infrared + SAR sensors)

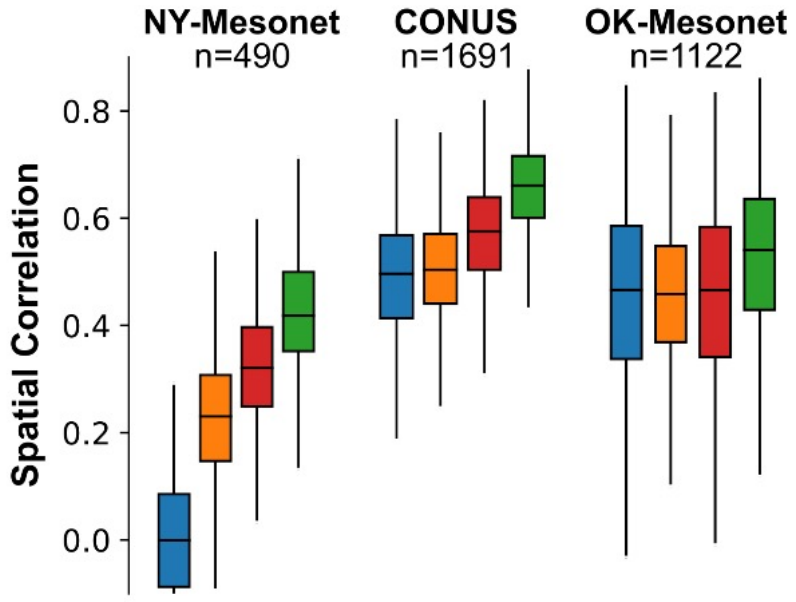
SMAP-HydroBlocks



Vergopolan et al. (2021). SMAP-HydroBlocks, a 30-m satellite-based soil moisture dataset for the conterminous US. Nature Scientific Data

SMAP-HydroBlocks:
Largely improves soil moisture spatial representativeness





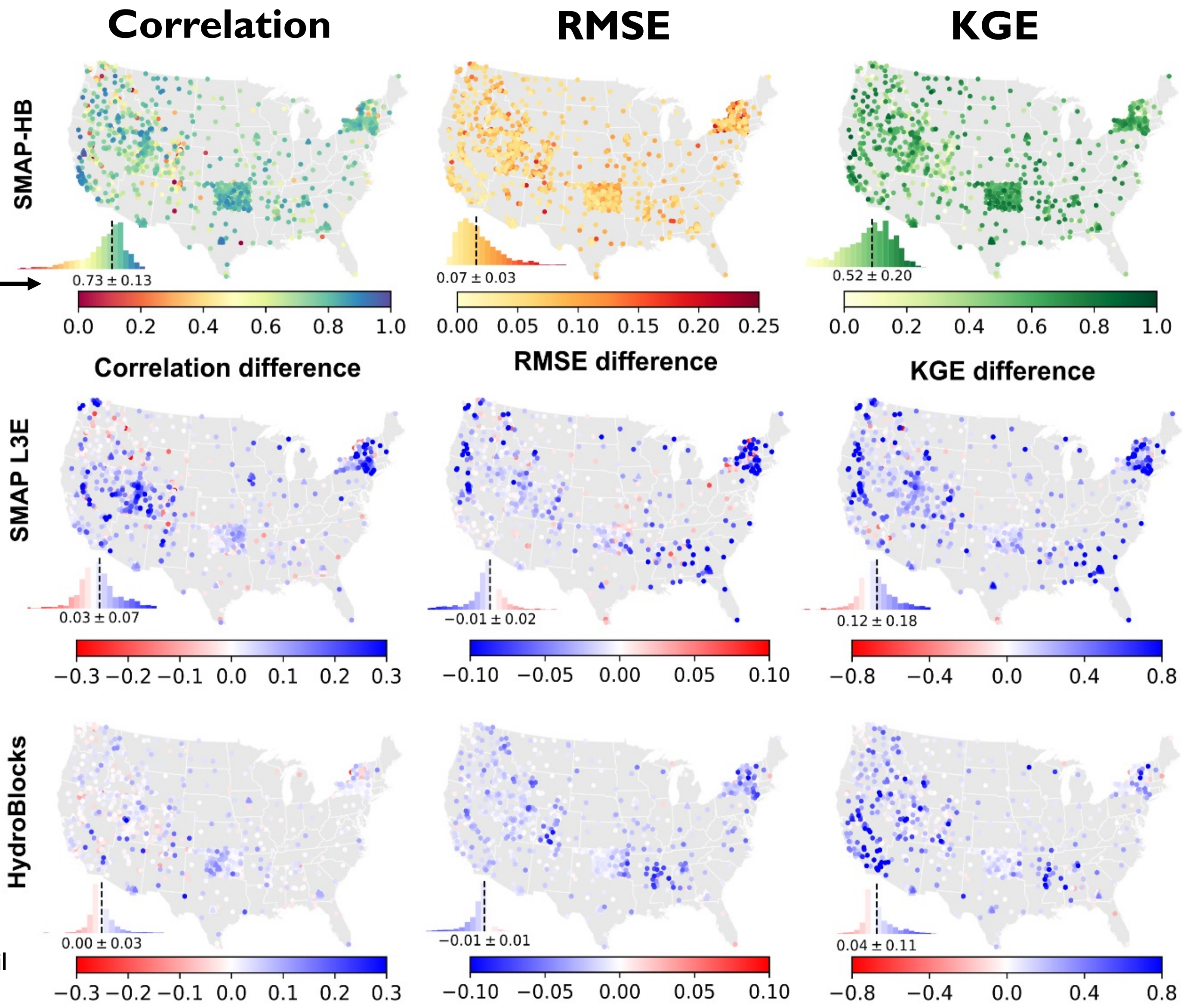
Spatial correlation:
Correlation calculated between in-situ observation and soil moisture products at each time step when at least 60 in-situ observations are simultaneously available

- SMAP L3: 9-km resolution (observation input)
- SMAP L4: 9-km resolution (NASA's state-of-the-art)
- HydroBlocks: 30-m resolution (model input)
- SMAP-HydroBlocks: 30-m resolution (best performance)

Vergopolan et al. (2021): SMAP-HydroBlocks, a 30-m satellite-based soil moisture dataset for the conterminous US. Scientific Data

Temporal Evaluation:
SMAP-HydroBlocks show improvements over baseline products

Histograms shows the median ± MAD



Blue shows SMAP-HB improvements over base products

$$KGE = 1 - \sqrt{(r-1)^2 + (\beta-1)^2 + (\gamma-1)^2}$$

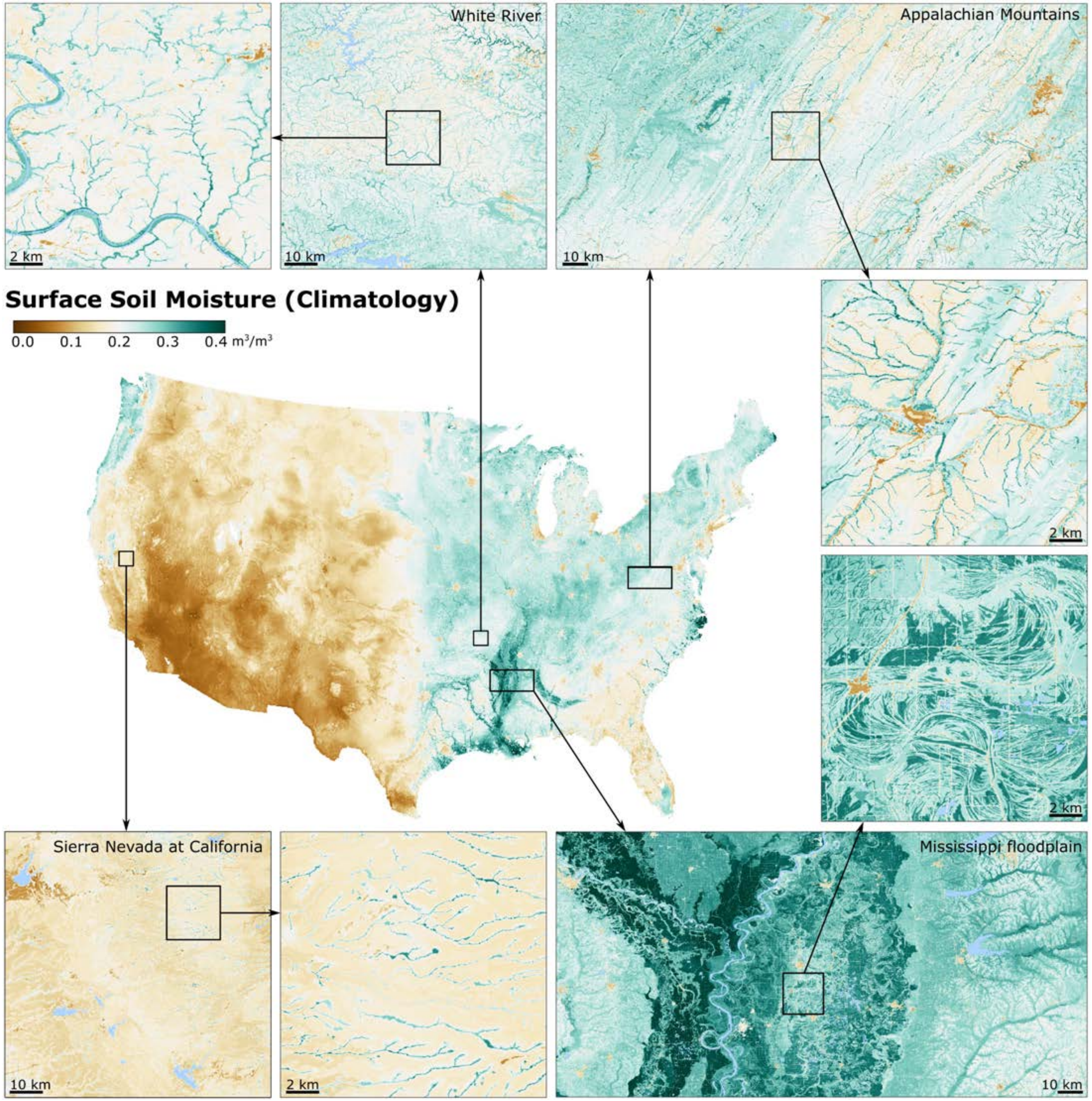
$$\beta = \frac{\mu_s}{\mu_o} \qquad \gamma = \frac{\sigma_s/\mu_s}{\sigma_o/\mu_o}$$

Vergopolan et al. (2021): SMAP-HydroBlocks, a 30-m satellite-based soil moisture dataset for the conterminous US. Scientific Data

SMAP-HydroBlocks enable us to understand for the first time…

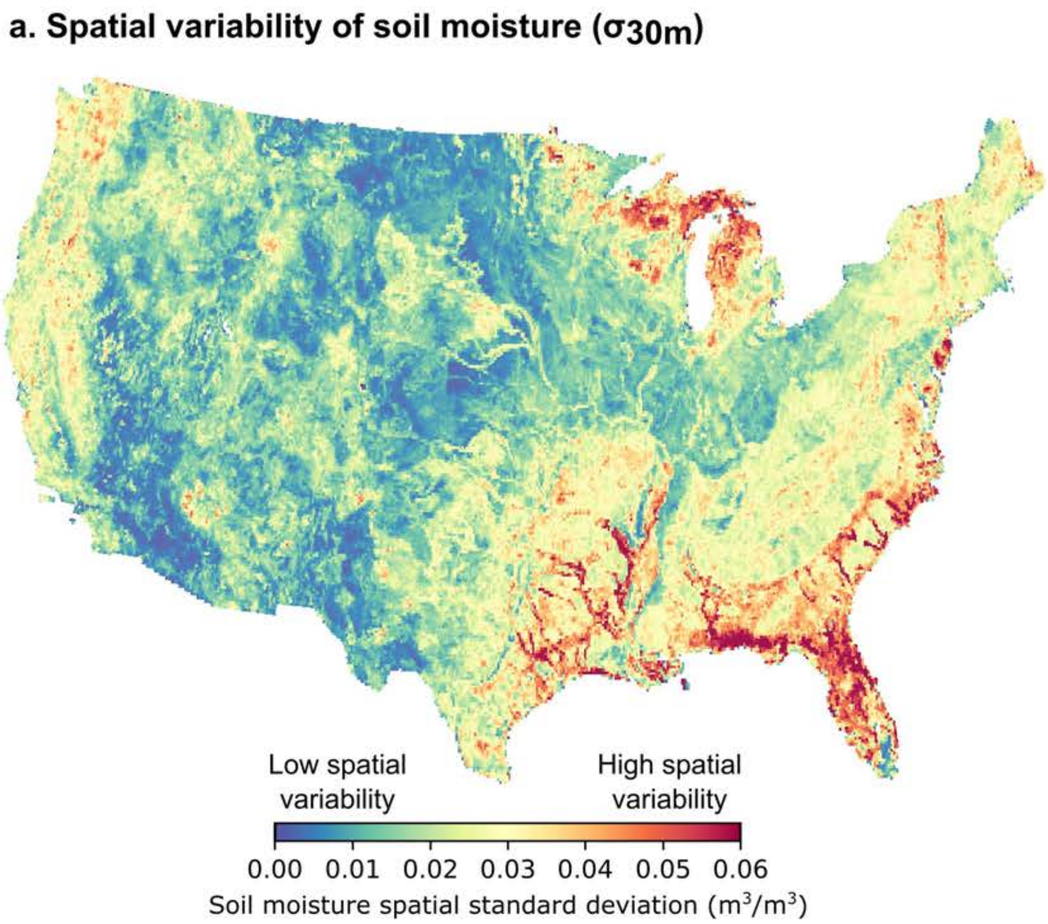
What is the soil moisture variability at local-scale?

How this spatial variability persists across scales?

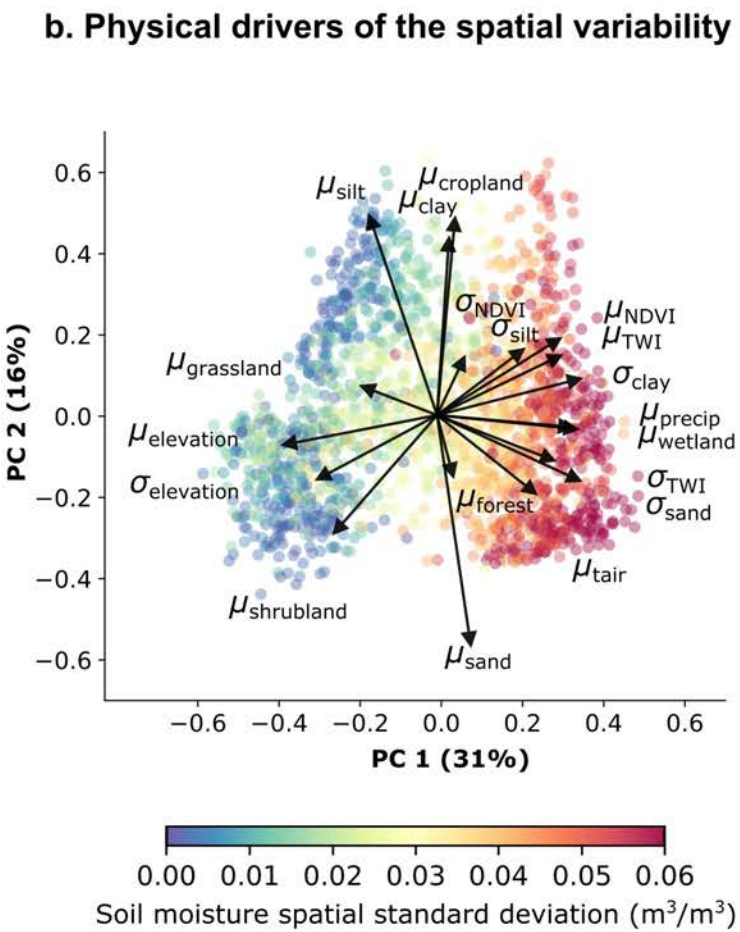


Vergopolan et al. (2022). High-resolution soil moisture data reveal complex multi-scale spatial variability across the United States. Geophysical Research Letters

What is and what drives the soil moisture spatial variability?



Spatial standard deviation (std) calculated at each 10-km grid cell using the 30-m SMAP-HB climatological soil moisture



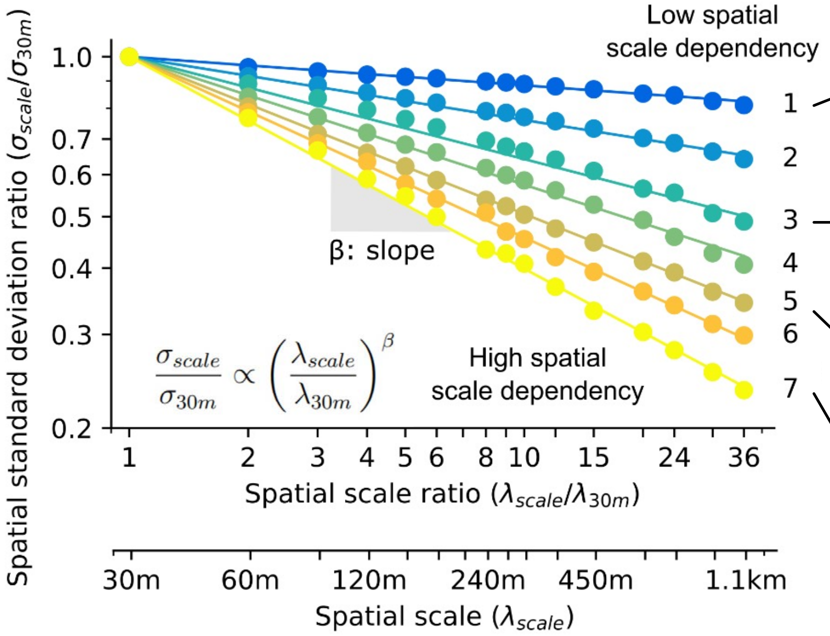
PCA comparing the soil moisture spatial std with the spatial mean and spatial std of the respective physical characteristics

Vergopolan et al. (2022). High-resolution soil moisture data reveal complex multi-scale spatial variability across the United States. Geophysical Research Letters

How this variability persists across scales?

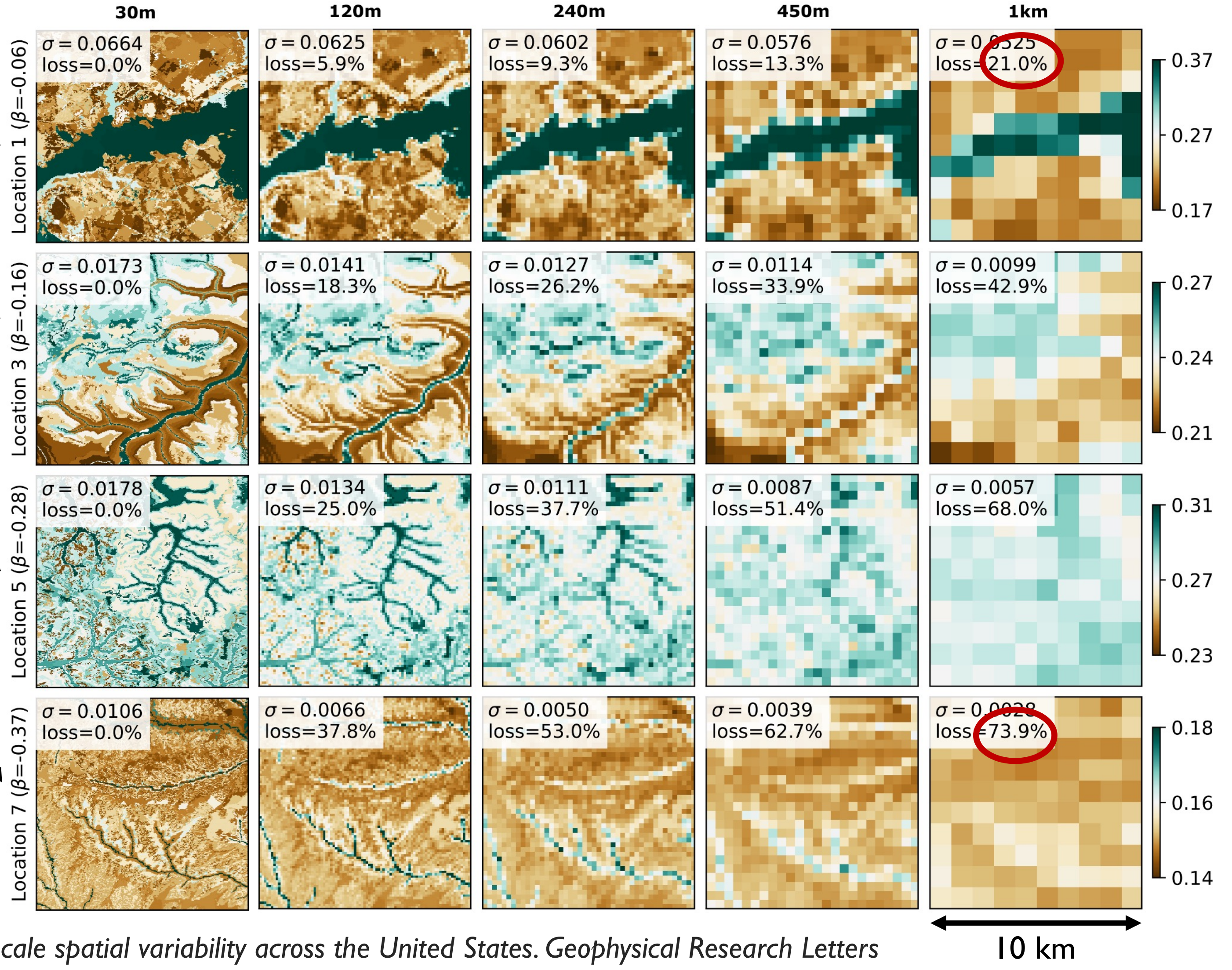
Spatial Scaling Analysis

Spatial standard deviation of soil moisture (σ)



Information Loss: $\frac{\sigma_{scale} - \sigma_{30m}}{\sigma_{30m}}$

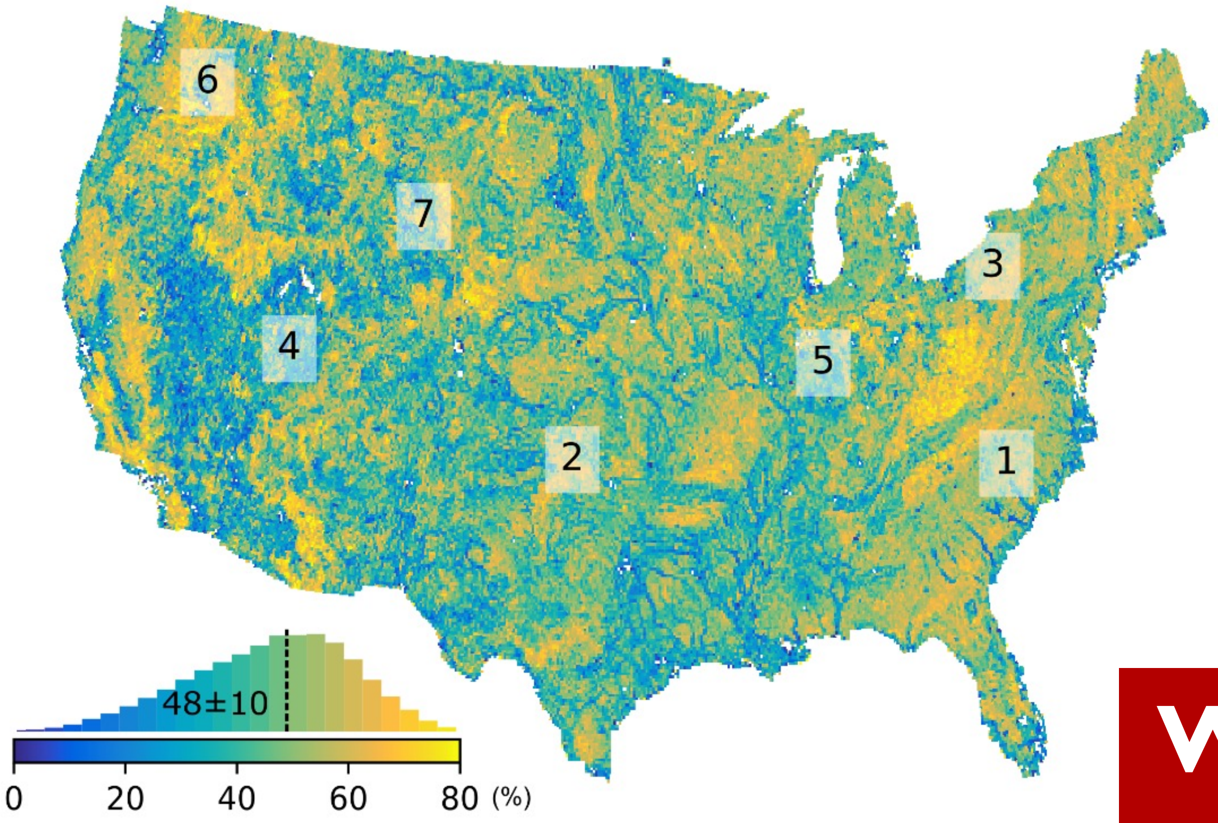
Synthetic Scaling (Spatial Aggregation)



Vergopolan et al. (2022). High-resolution soil moisture data reveal complex multi-scale spatial variability across the United States. Geophysical Research Letters

What is the soil moisture information loss across the US?

Information Loss of 1-km Resolution Data (%)



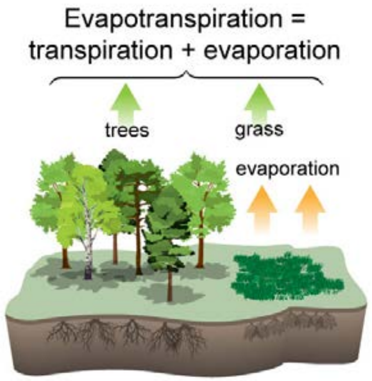
- Up to 80% of spatial variability loss
  (i.e., variability does not persist across scales)
- Larger losses at topographic gradients
- Tremendous loss at the scale of current modeling and observation capabilities (e.g., 1 to 25-km resolution)

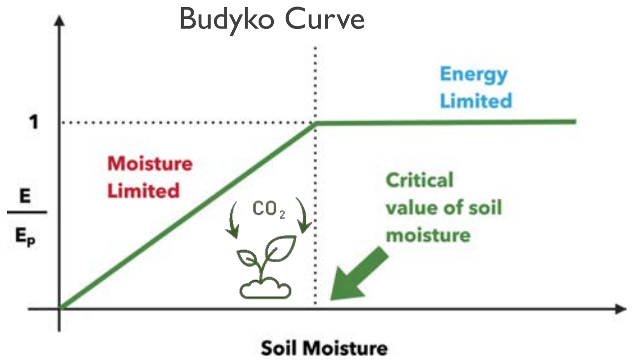
What are the implications of this information loss?

Vergopolan et al. (2022). High-resolution soil moisture data reveal complex multi-scale spatial variability across the United States. Geophysical Research Letters

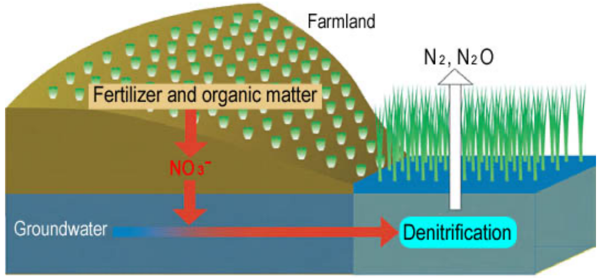
Many processes behave non-linearly with soil moisture at the local-scales

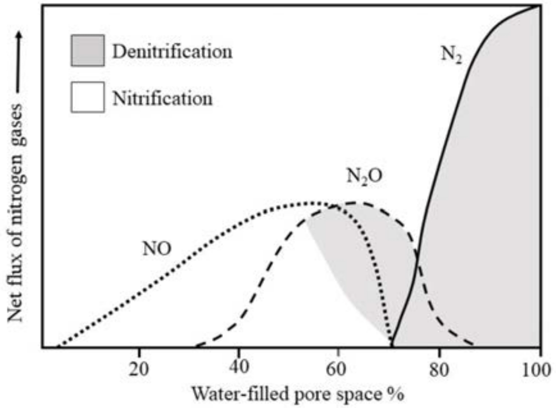
Evapotranspiration and crop productivity



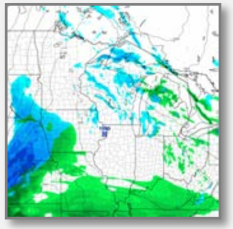


Nitrification





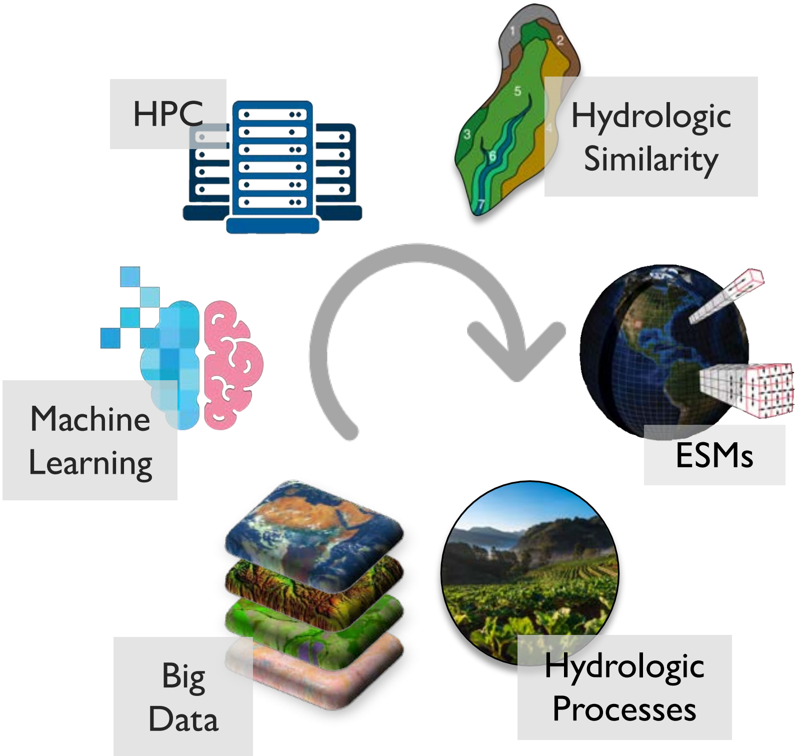
Hydroclimate & Carbon Cycles



Natural Hazards

Species Distributions

Towards locally-relevant global hydrologic monitoring for water resources and climate applications



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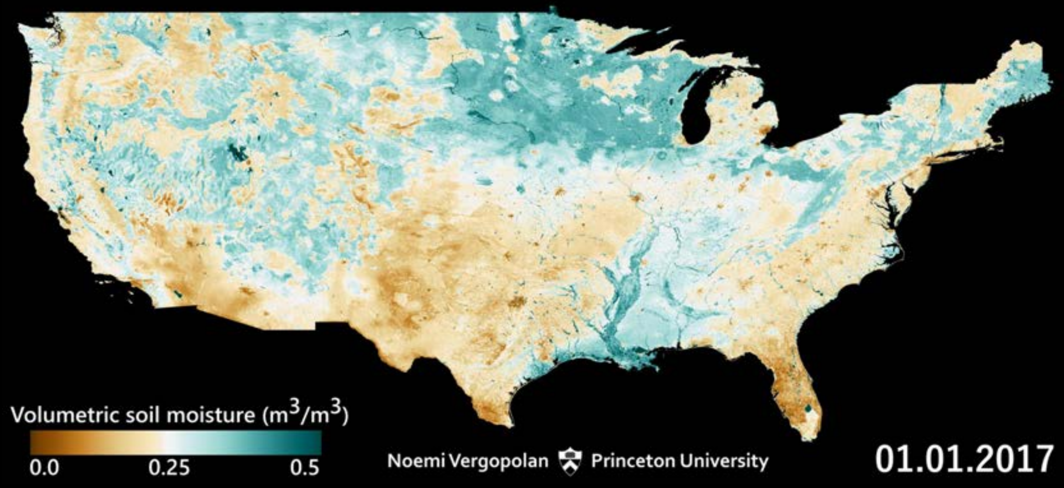
noemi@princeton.edu
@NVergopolan (Twitter)



Thank you for attending our webinar today.

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