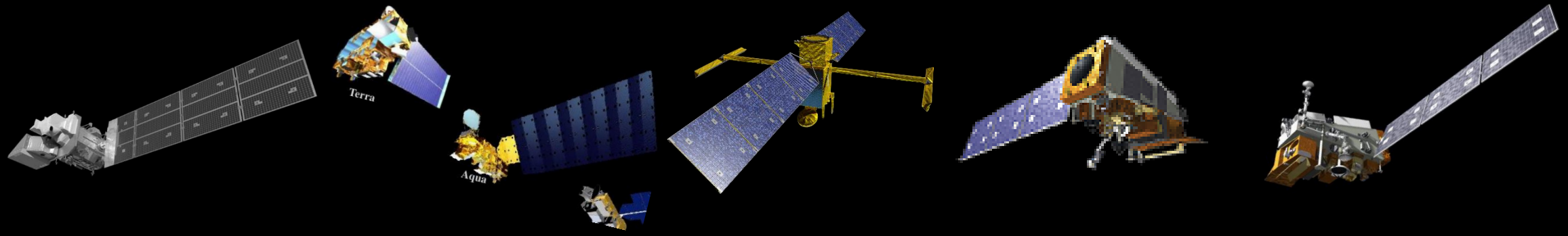


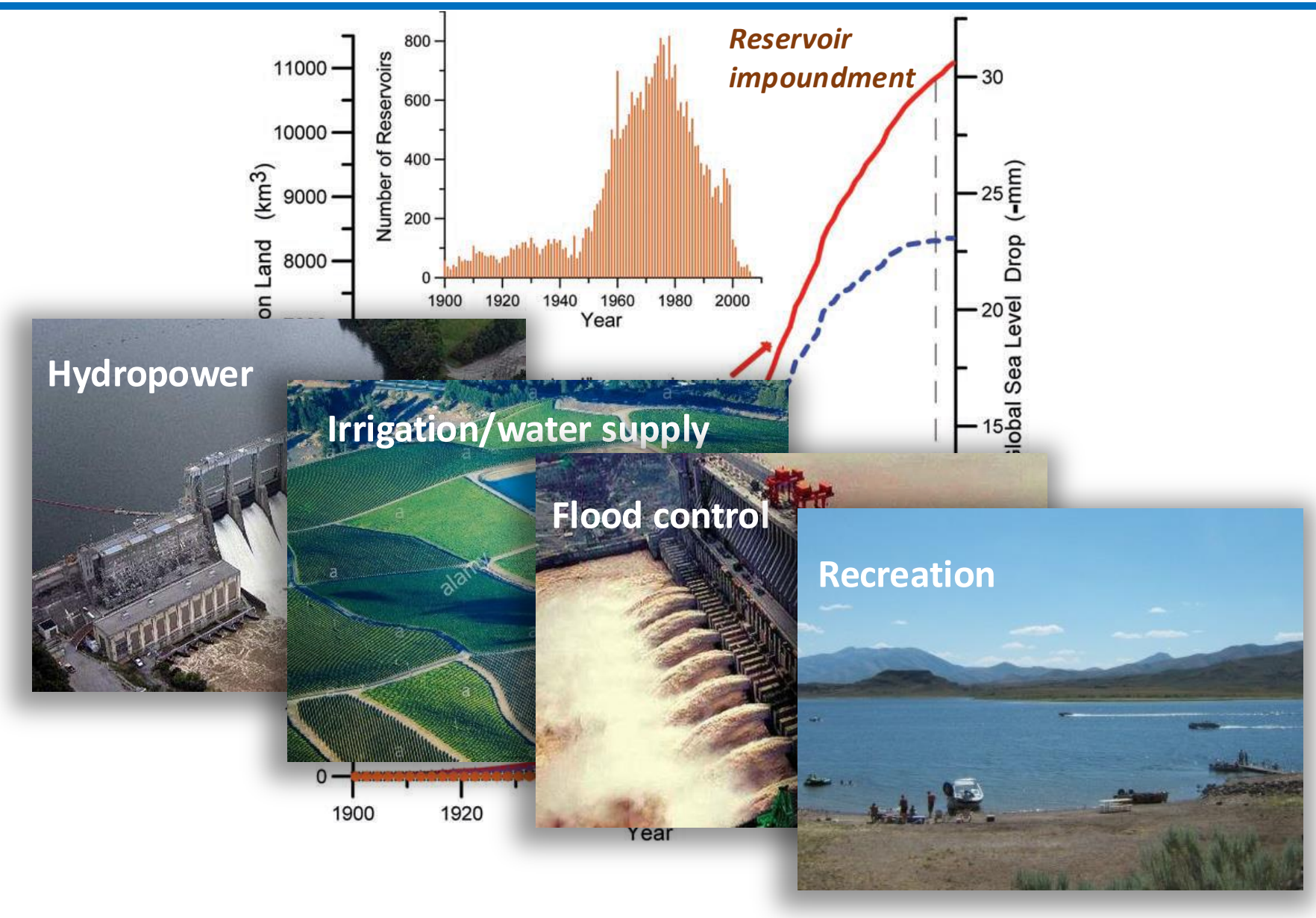
Monitoring reservoirs using multi-satellite observations

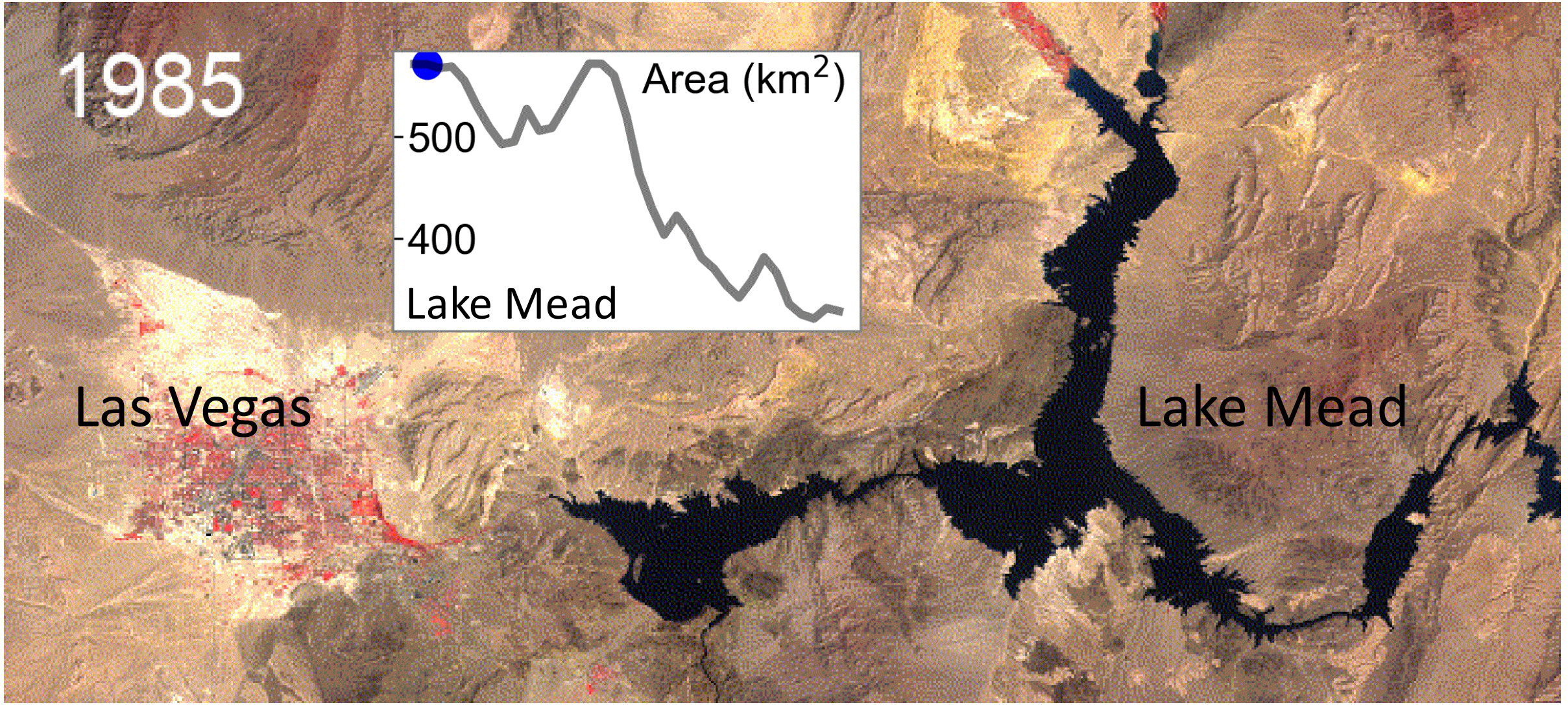
Huilin Gao
Dept. Civil & Environmental Engineering
Texas A&M University
5/18/2025

TEXAS A&M UNIVERSITY

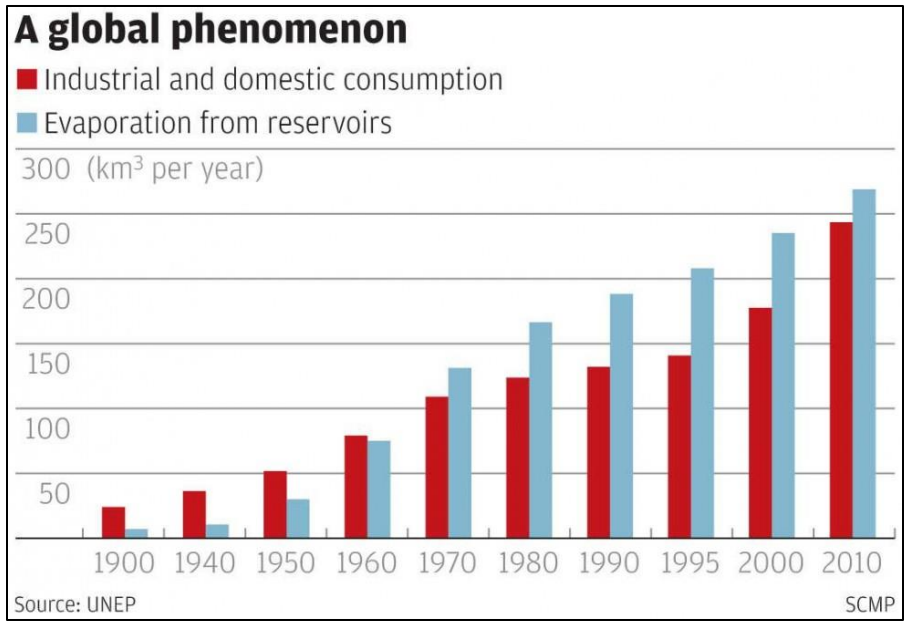
NASA

Reservoir Water Impoundment and Functions

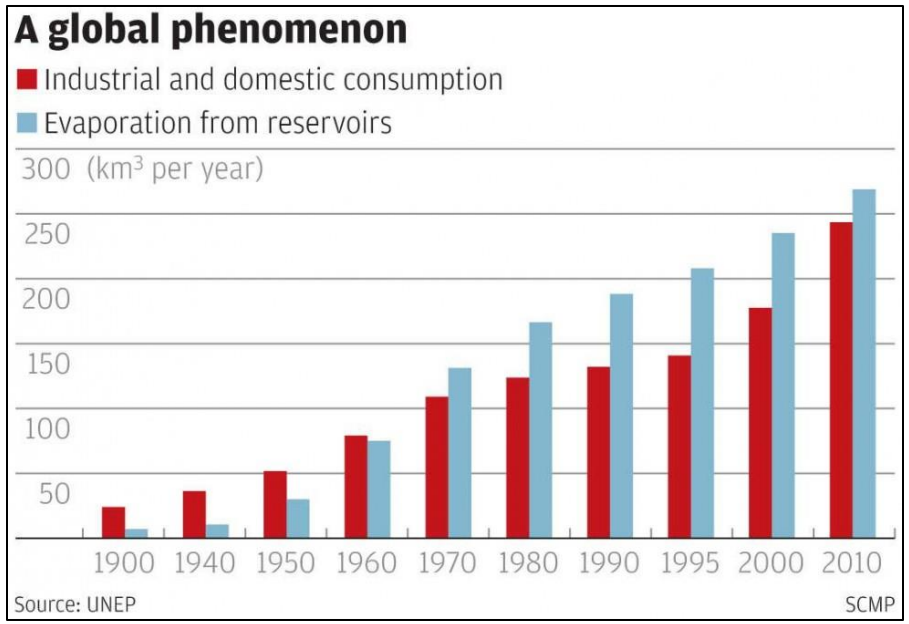



1985
Area (km^2)
500
400
Lake Mead
Las Vegas
Lake Mead

Lake Evaporation

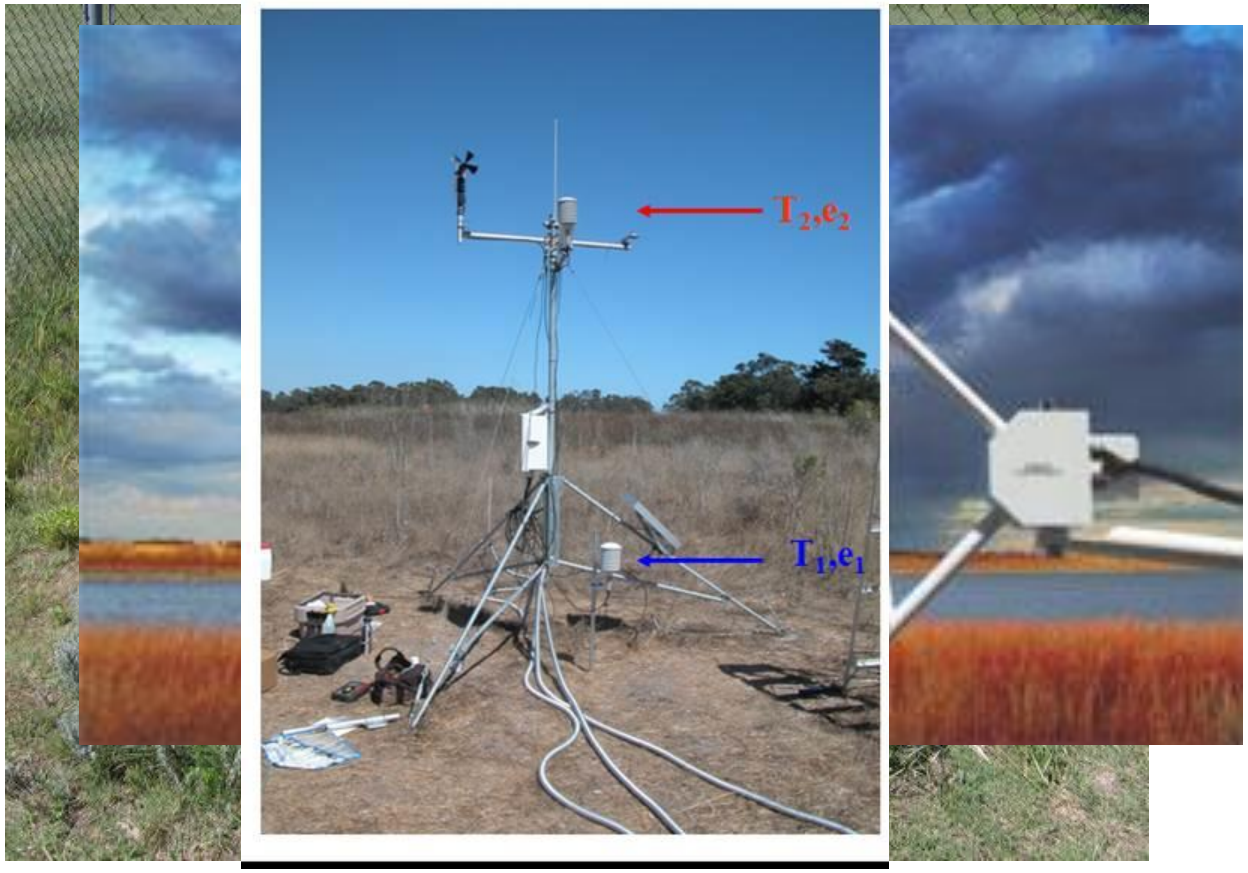


Lake Evaporation



Limited in-situ observations

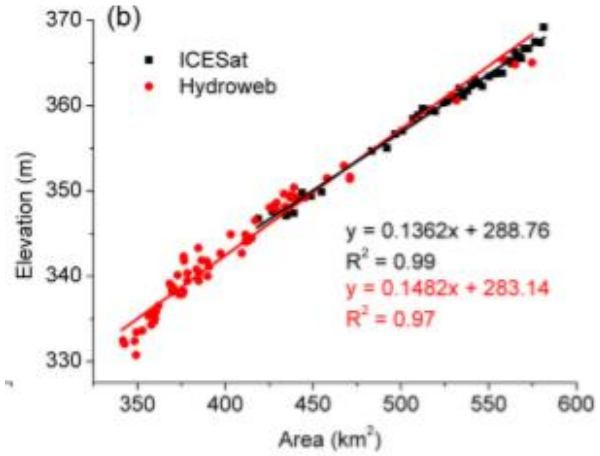
- Class-A pan evaporation
  - Large uncertainty
- Eddy covariance
  - Expensive and data is difficult to process
- Bowen ratio energy balance
  - $LE = R_n - H + \Delta U + F_{in} - F_{out} - G$



Remote Sensing of Reservoir Elevation, Area, and Storage

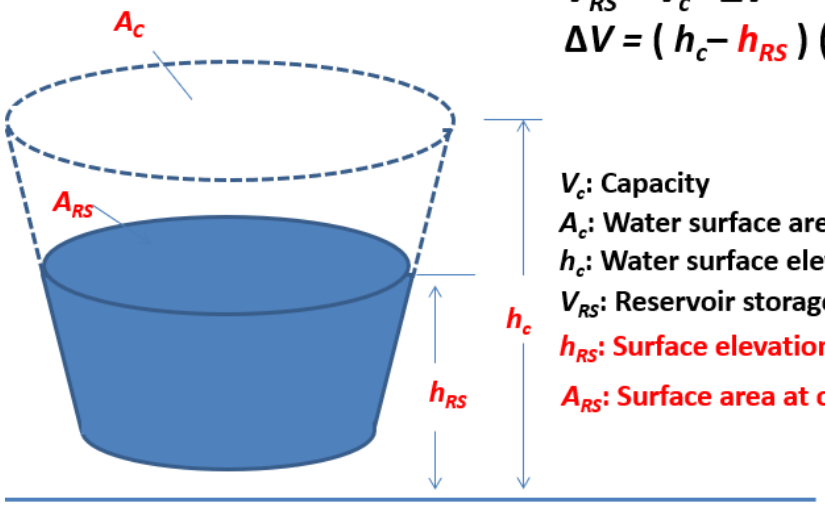
Sensors for elevations

- Radar altimeters (e.g.,T/P, Jason 3)
- Lidar altimeters (e.g., ICESat-2)
- ……



$$V_{RS} = V_c - \Delta V \quad (1)$$

$$\Delta V = (h_c - h_{RS})(A_c + A_{RS})/2 \quad (2)$$



V_c: Capacity
A_c: Water surface area at capacity
h_c: Water surface elevation at capacity
V_{RS}: Reservoir storage at certain time from satellite
h_{RS}: Surface elevation at certain time from satellite
A_{RS}: Surface area at certain time from satellite

Sensors for area estimations

- Landsat
- MODIS/VIIRS
- AVHHR
- Sentinel-2
- Sentinel-1 SAR
- ……

With the Area-Elevation (A-E) relationship and parameters at capacity, the storage can be estimated from either A or E values

Remote Sensing of Reservoir Evaporation and Evaporation Volume

Penman Equation

$$E = \frac{s(R_n - \Delta U) + \gamma f(u_2)(e_s - e_a)}{\lambda_v (s + \gamma)}$$

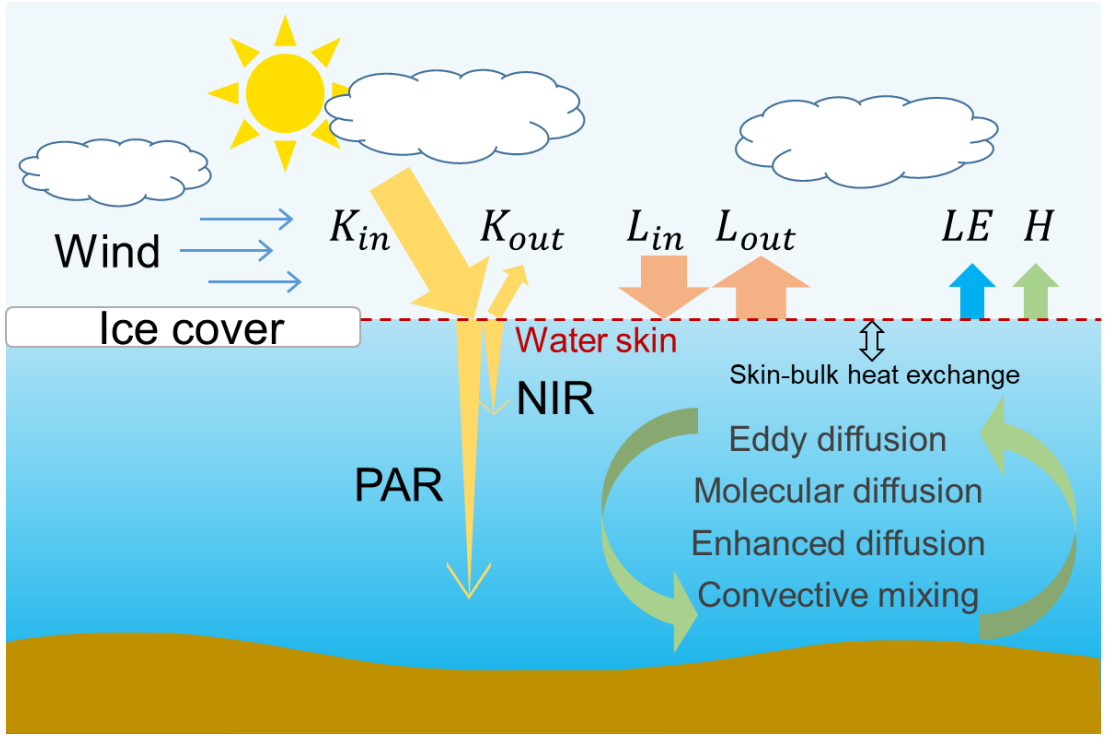
Heat storage effect

Wind function

Zhao and Gao, 2019

s: slope of the saturation vapor pressure curve (kPa·ºC^{-1})
R_n: net radiation (MJ·m^{-2}·d^{-1})
γ: psychrometric constant (kPa·ºC^{-1})
$f(u_2)$: wind function (s·m^{-1})
δ_e: vapor pressure deficit (kPa)
λ_v: latent heat of vaporization (MJ·kg^{-1})

*Evaporation volume = evaporation rate * A*



Zhao et al., RSE, 2020

MODIS/VIIRS Global Water Reservoir (GWR) Product

- Everything Everywhere All at Once

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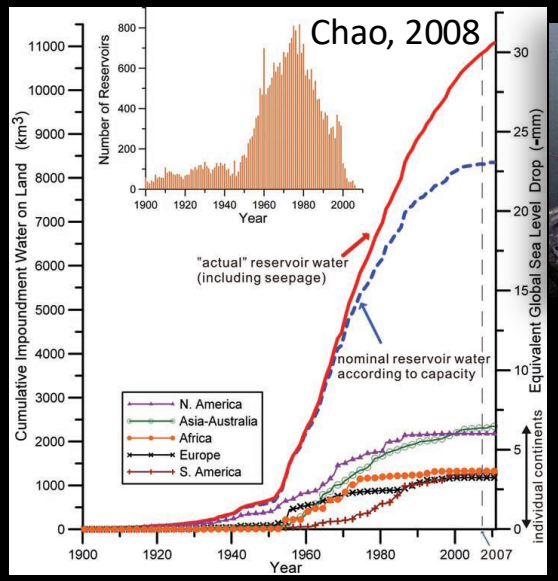
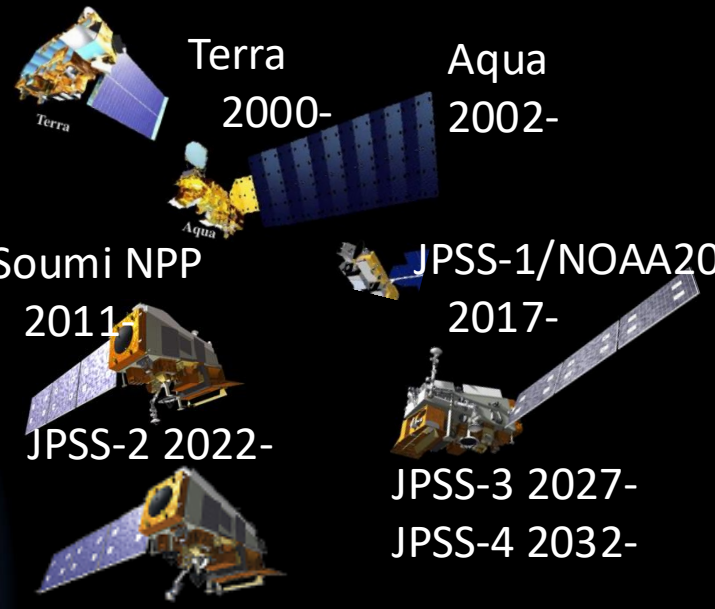


Hydropower
Flood control
Irrigation
Water supply



MODIS images of Urmia Lake

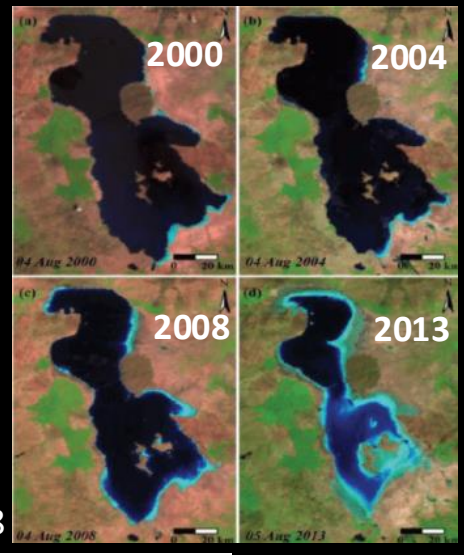
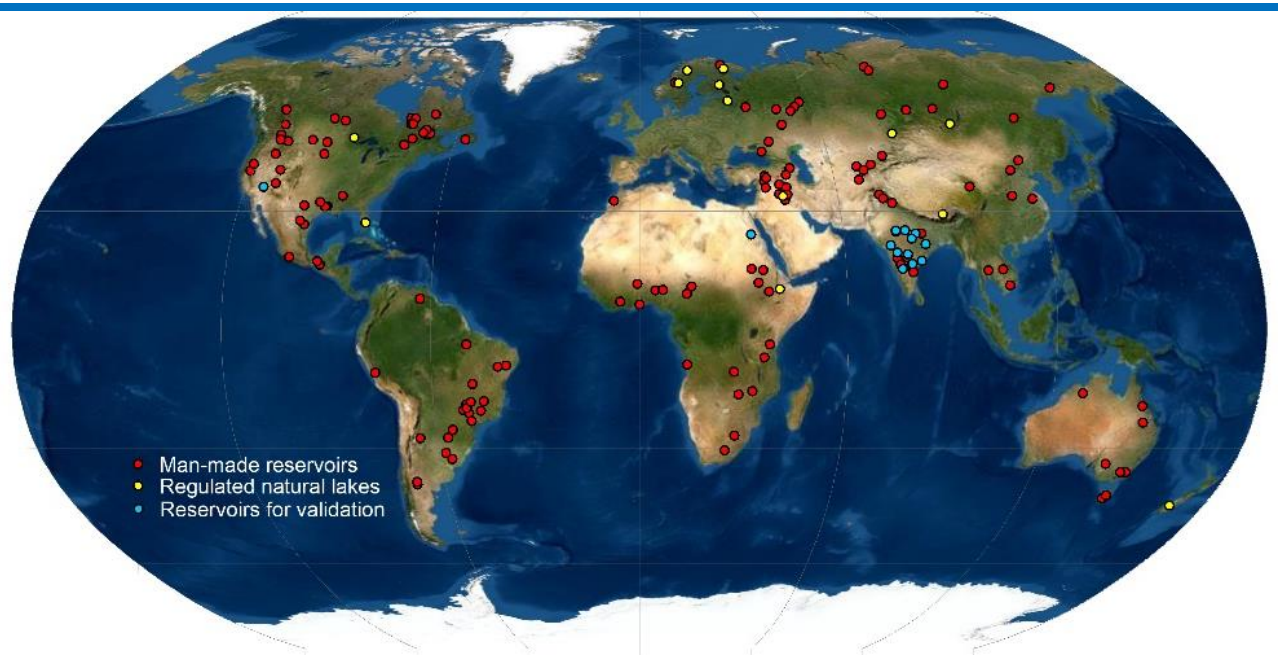


Figure from Mohebzadeh, 2018

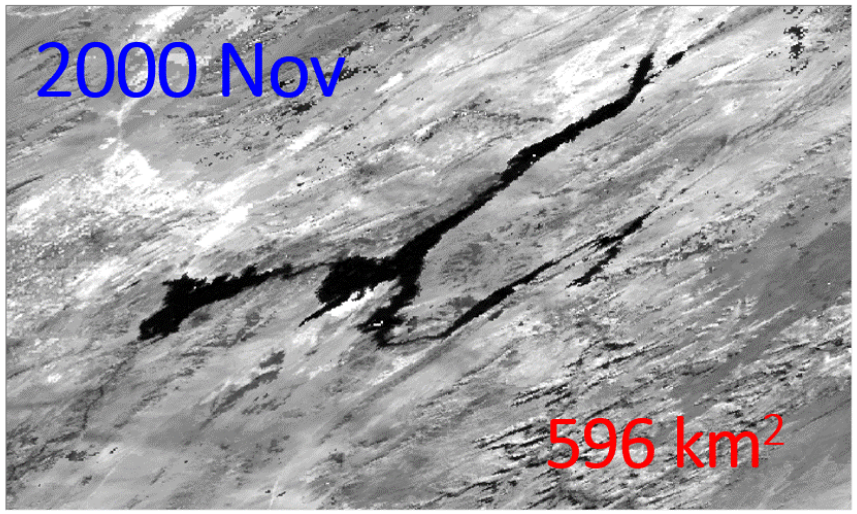
- **Reservoir storage can be inferred using surface reflectance classifications** (Gao et al., 2012)
- **Reservoir evaporation can be better estimated using LST** (Zhao et al., 2020)
- **Simultaneous storage & evaporation observations can provide comprehensive monitoring capability**

MODIS/VIIRS Global Reservoir Products



Locations of the 164 reservoirs (46% global capacity)

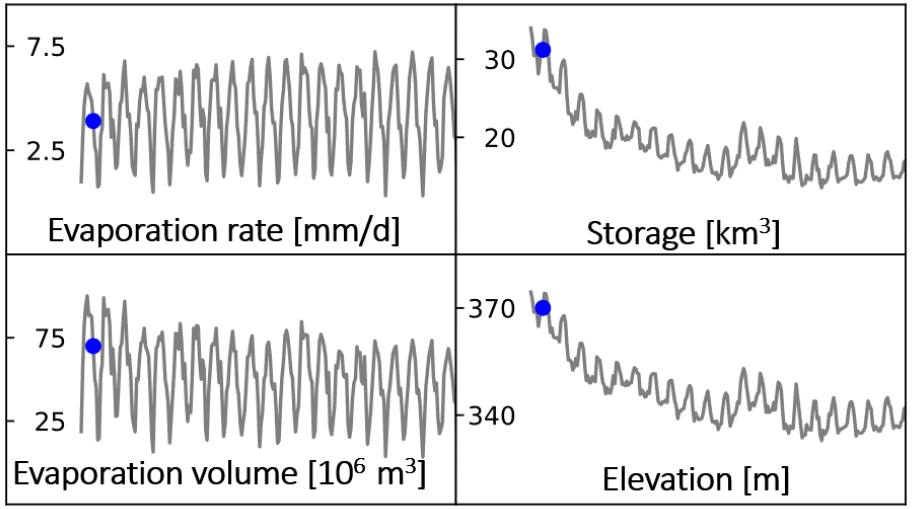
Lake Mead (ID: 61)



Key inputs:
8-day reflectance, Monthly LST

Temporal Resolution	Variables
8-day	Area, elevation, storage
Monthly	Area, elevation, storage, evaporation rate and volume

Product name	Period
MxD28 (C6.1)	2000-present
VNP28 (C2)	2012-present
VJ128[2] (C2)	2018-present

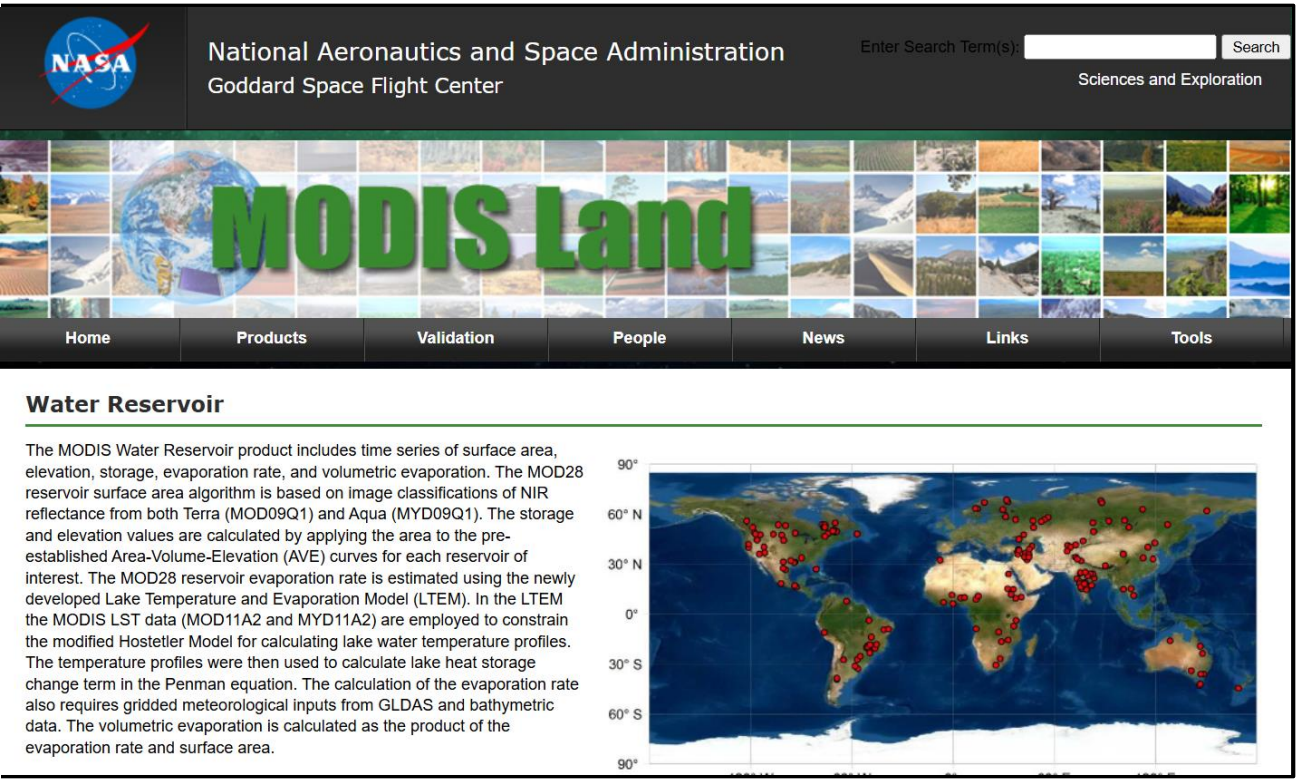


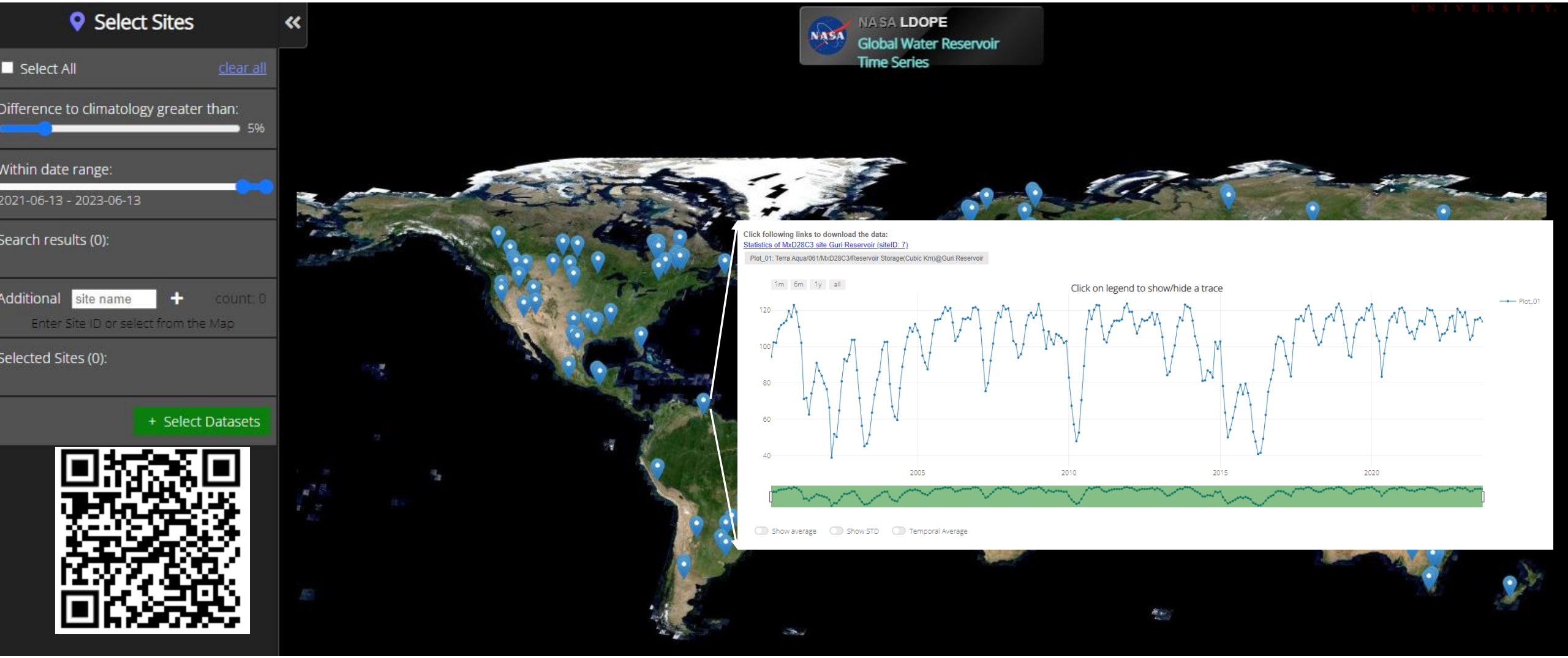
Zhao et al., 2020; Shah et al., 2024

MODIS/VIIRS Global Reservoir Products

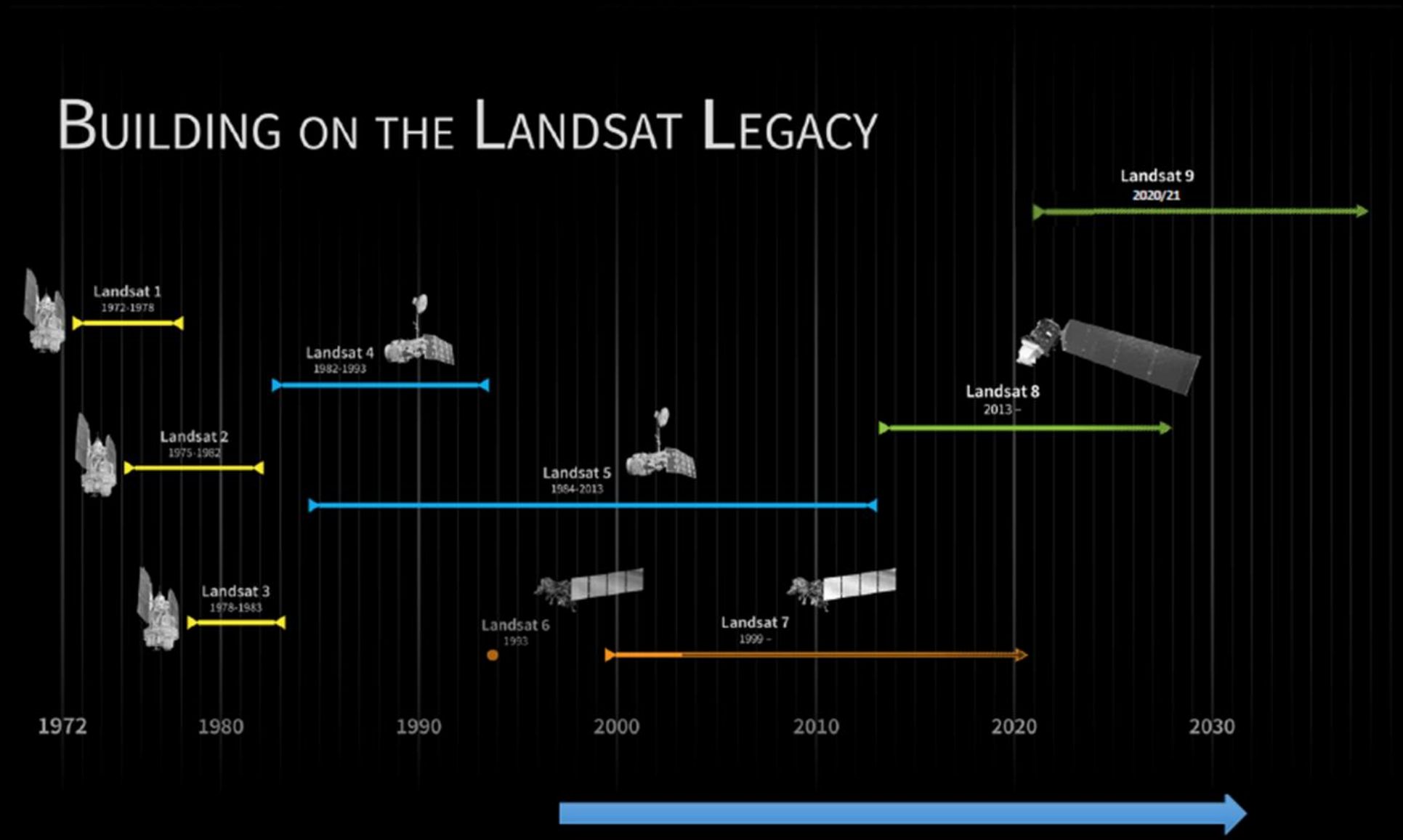
https://modis-land.gsfc.nasa.gov/modgwr.html

https://viirsland.gsfc.nasa.gov/Products/NASA/GWR.html



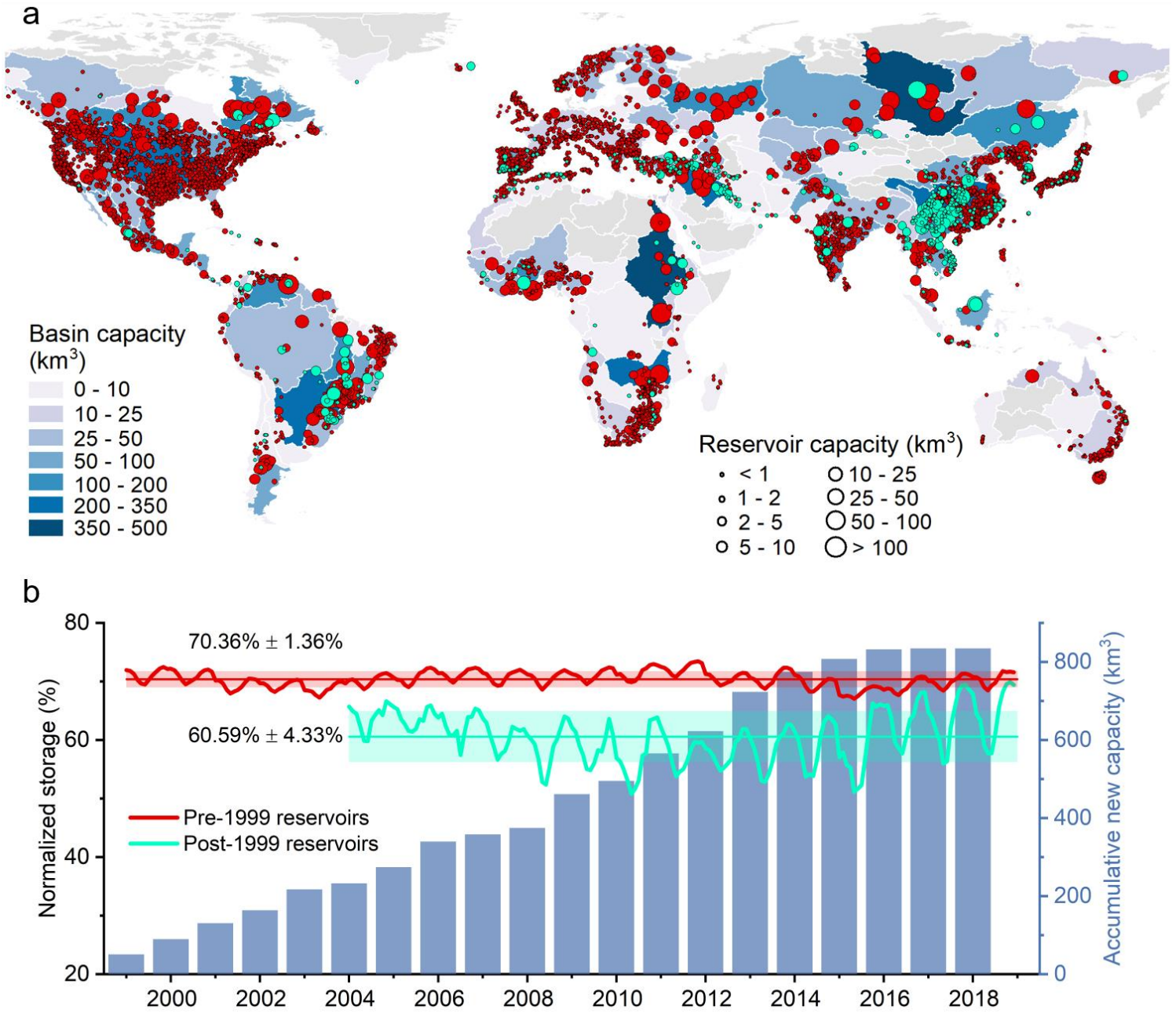


https://landweb.modaps.eosdis.nasa.gov/lake



NASA-USGS Interagency Partnership

- NASA: Space Segment and Launch
- USGS: Operations & Data Processing/Distribution



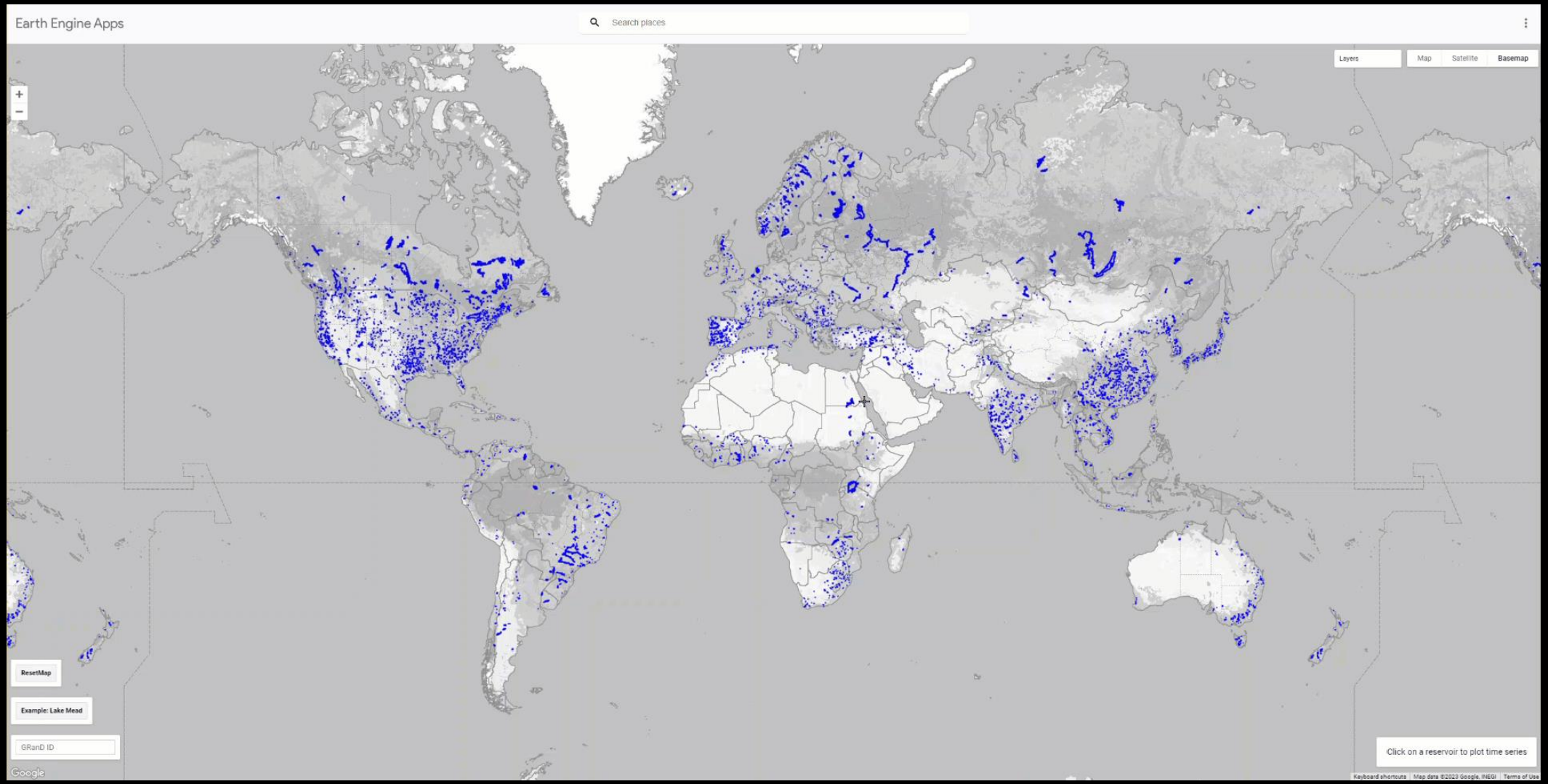
Li et al, Nature Communications, 2023

Diminishing storage returns of reservoir construction

Global Reservoir Storage (GRS)

Sobradinho Reservoir, Brazil

https://yao.users.earthengine.app/view/grs



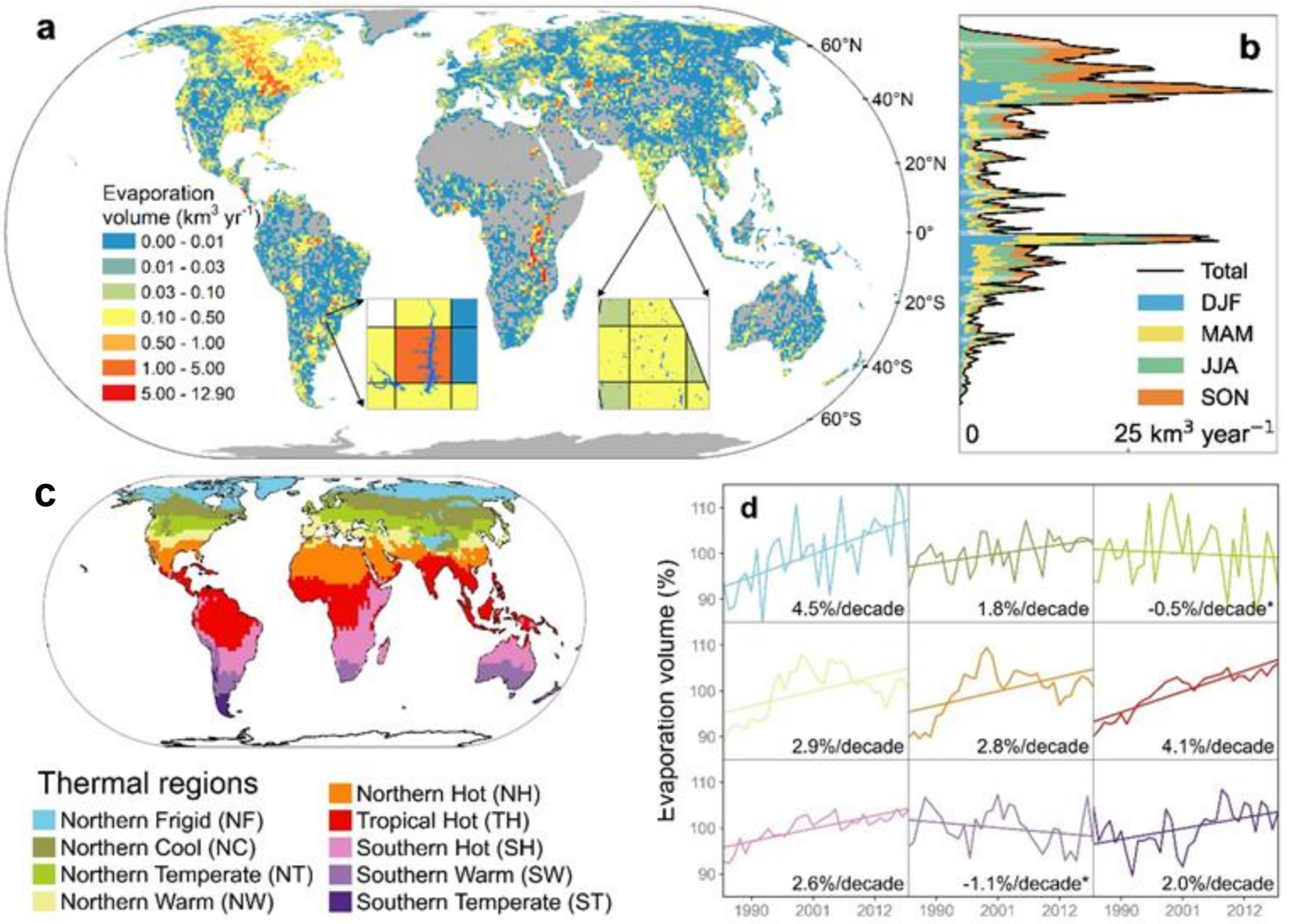
Global Lake Evaporation Volume (GLEV) Dataset

Evaporative water loss of 1.42 million global lakes (monthly, 1985-2018)

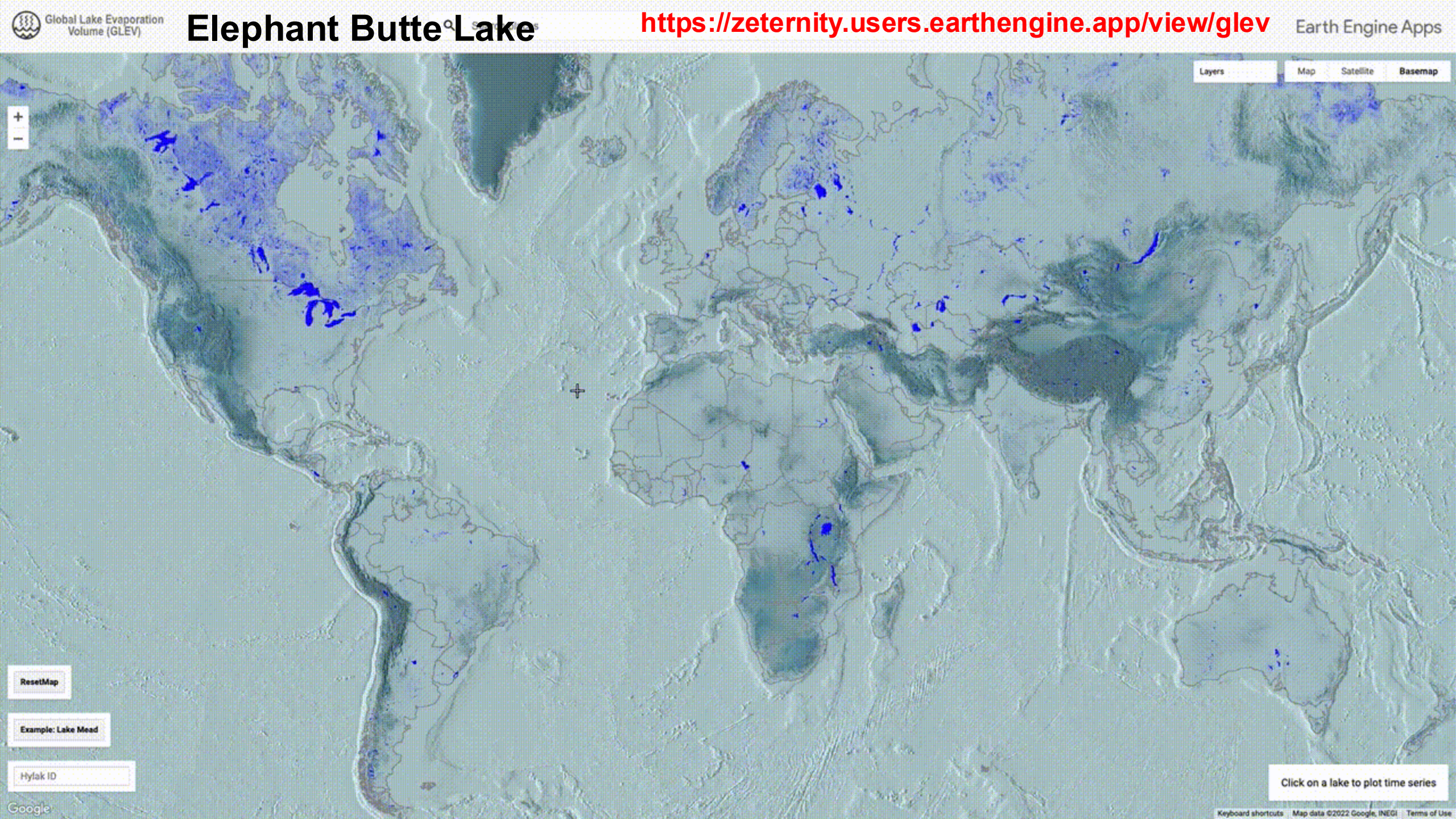
Dataset includes:

- **evaporation rate**
- **surface area**
- **evaporation volume**

Reservoir evaporative losses increase faster than natural lakes!



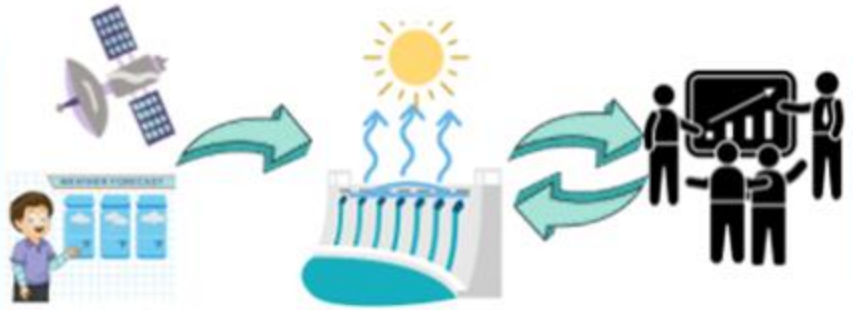
Zhao et al, Nature Communications, 2022


Global Lake Evaporation Volume (GLEV)
Elephant Butte Lake
https://zeternity.users.earthengine.app/view/glev
Earth Engine Apps
Layers
Map
Satellite
Basemap
ResetMap
Example: Lake Mead
Hylak ID
Click on a lake to plot time series
Google
Keyboard shortcuts
Map data ©2022 Google, INEGI
Terms of Use

ReVap: Reservoir Evaporation Monitoring and Forecasting System

Model:
A validated Daily Lake Evaporation Model (DLEM) for simulating daily reservoir evaporation

Inputs:
- Weather products
- Subseasonal forecasts
- Reservoir area&depth (from in situ and/or satellite)

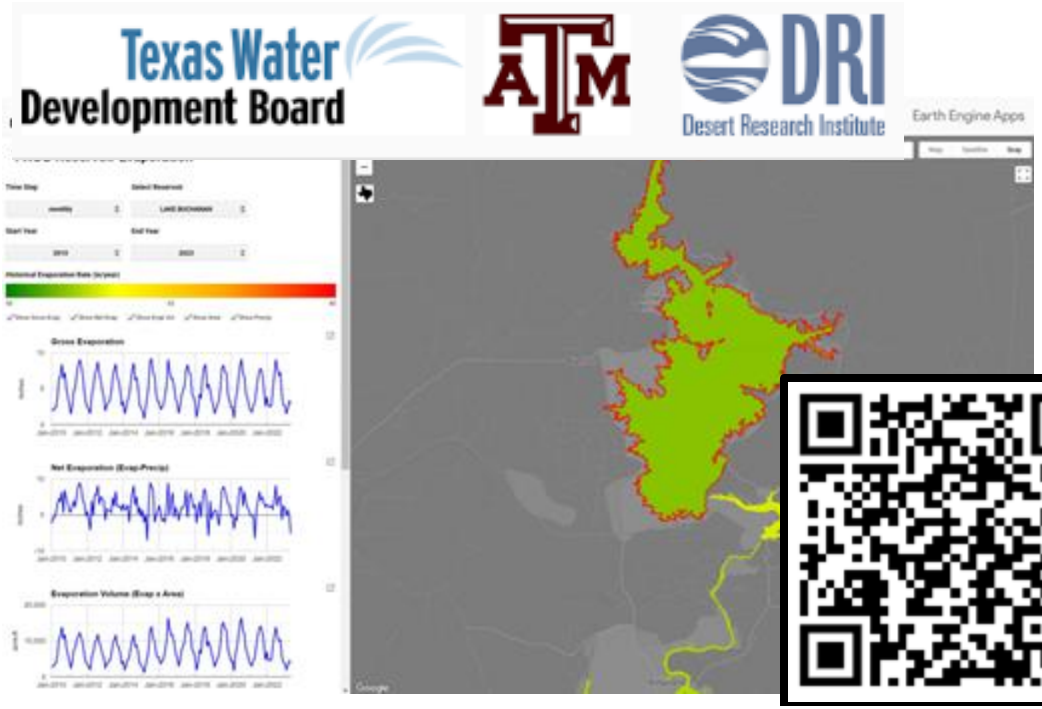


Outputs:
- Daily evaporation estimates (rate&volume)
- 1980 - near real-time
- 28 day evaporation rate forecasts

Data Portal:
An application programming interface (API) and a web map user interface (UI)

NASA | TEXAS A&M UNIVERSITY | DRI Desert Research Institute | VIRGINIA TECH | BUREAU OF RECLAMATION

Texas Reservoir Evaporation Dataset



https://dri-apps.earthengine.app/view/twdb-reservoir-evaporation

The dataset also provides small pond evaporation estimates based on gridded meteorological data over the entire state of Texas

In operation since May 2023!

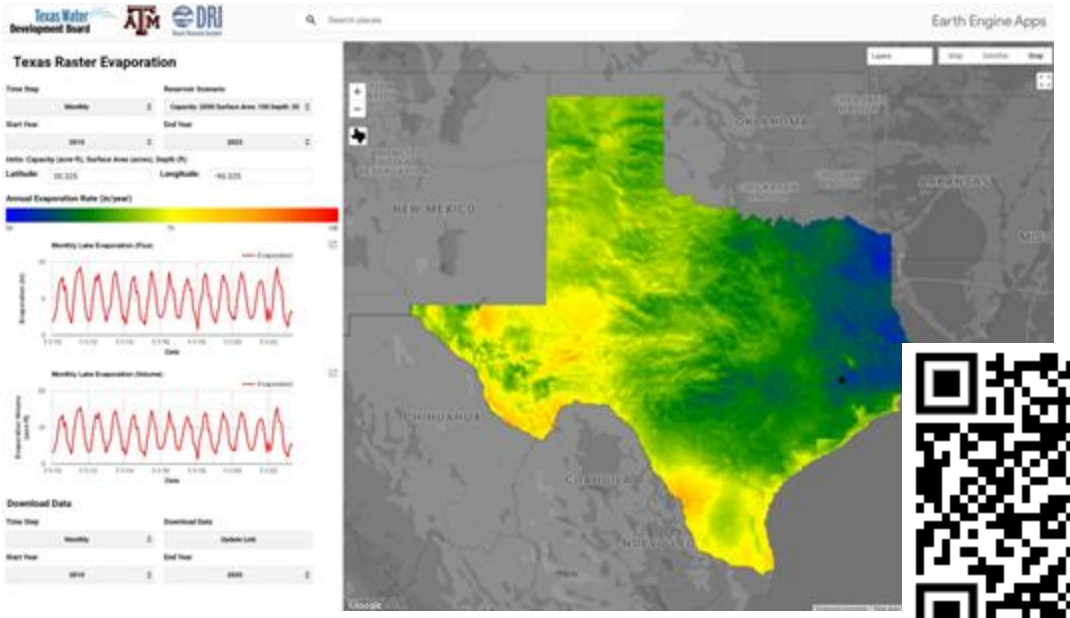
Water Resources Research

Research Article | Open Access

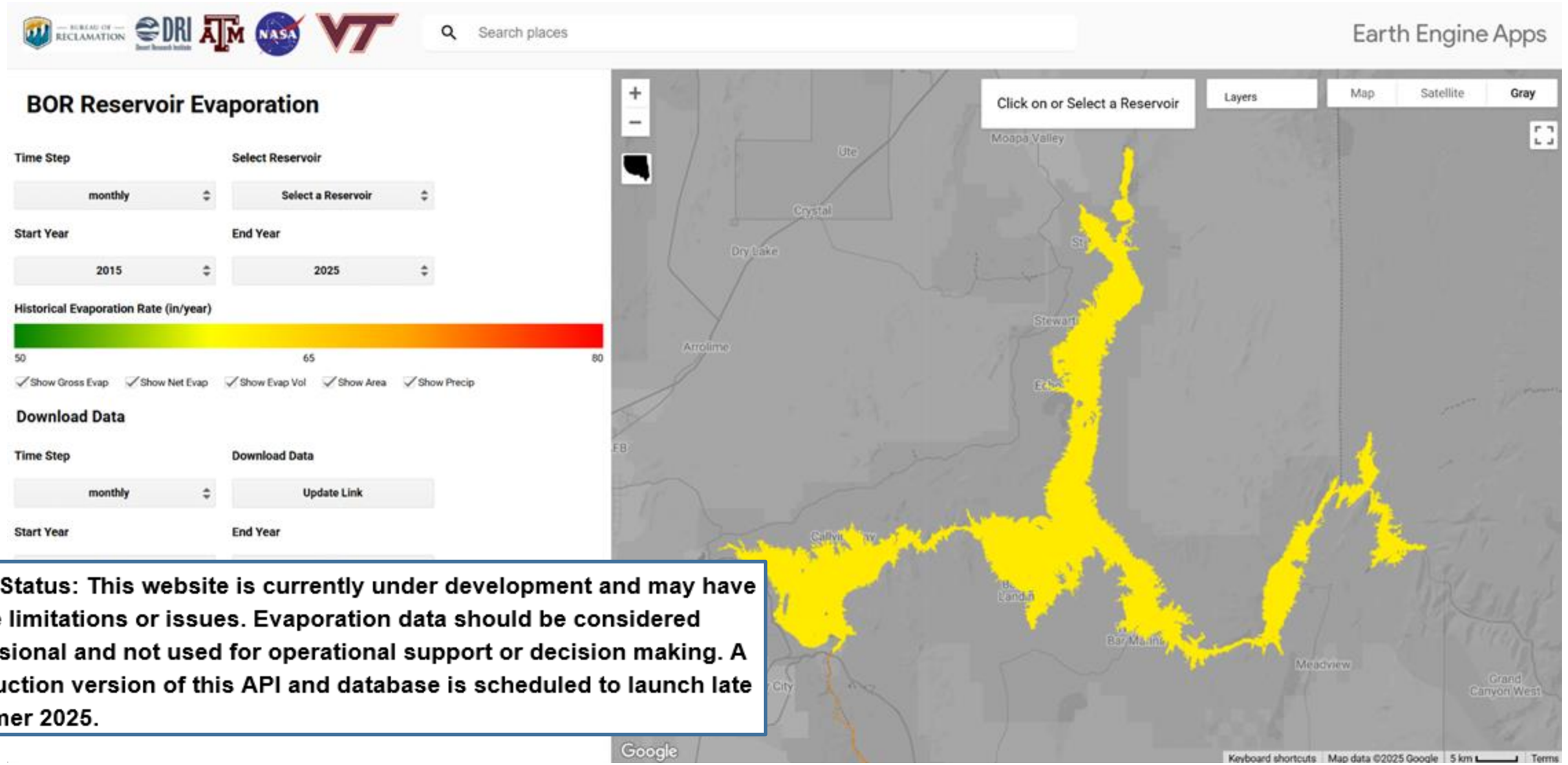
Developing a General Daily Lake Evaporation Model and Demonstrating Its Application in the State of Texas

Bingjie Zhao, Justin Huntington, Christopher Pearson, Gang Zhao, Thomas Ott, John Zhu, Andrew Weinberg, Kathleen D. Holman, Shuai Zhang, Ron Anderson, Maxwell Strickler, Jerry Cotter, Nelun Fernando, Kenneth Nowak, Huilin Gao ... See fewer authors

First published: 11 March 2024 | https://doi.org/10.1029/2023WR036181

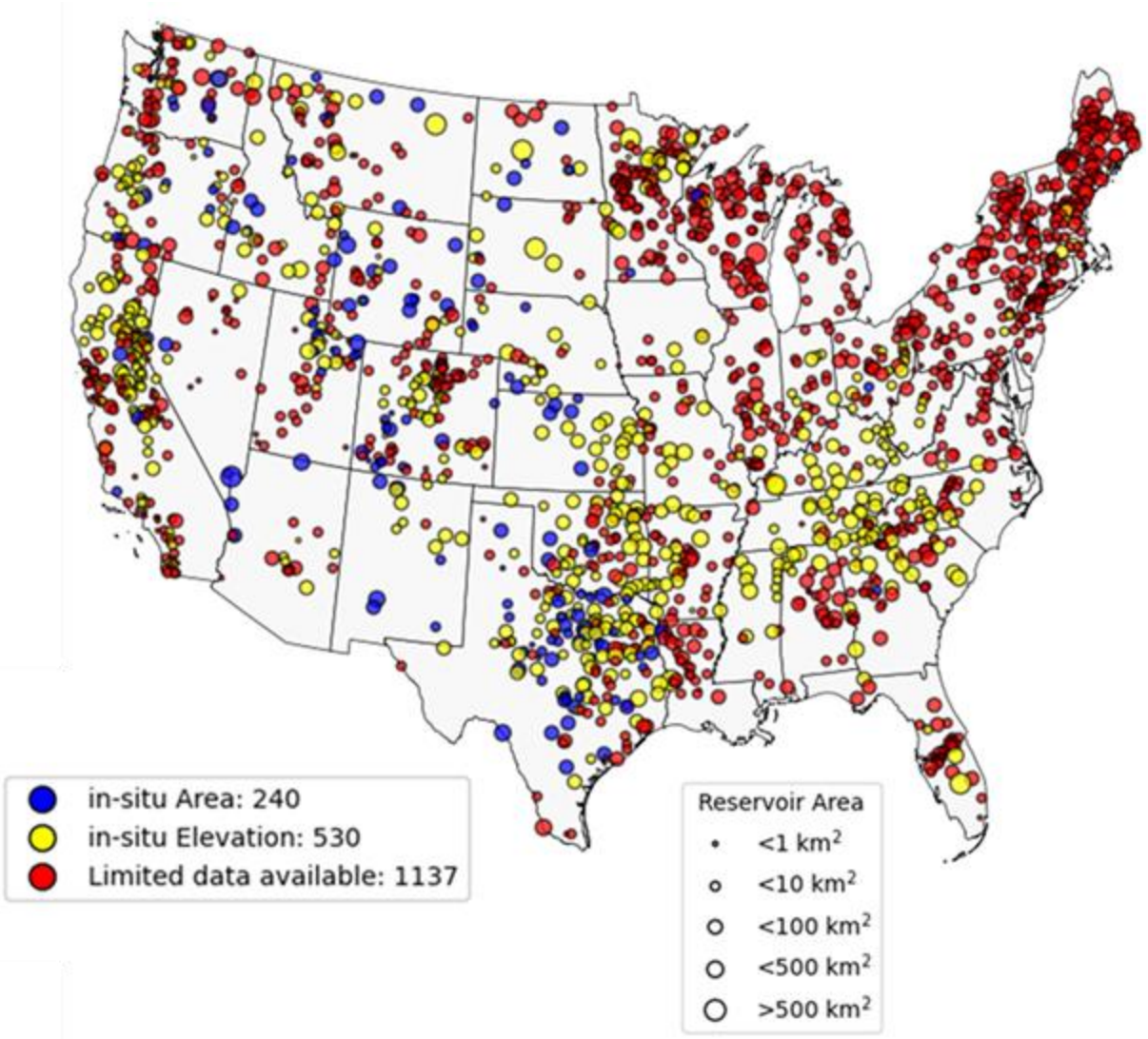


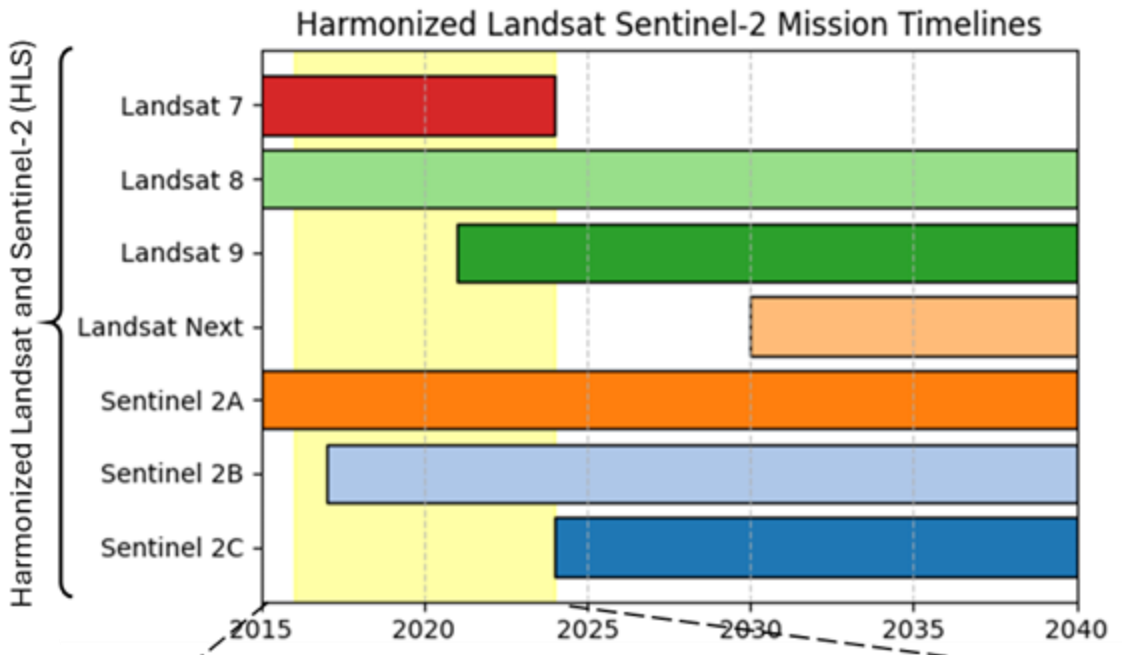
Daily Reservoir Evaporation Web App

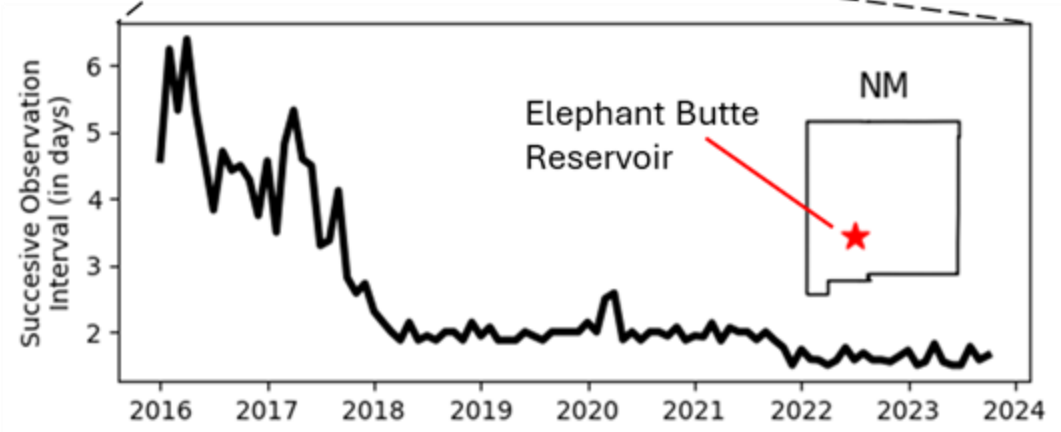


Beta Status: This website is currently under development and may have some limitations or issues. Evaporation data should be considered provisional and not used for operational support or decision making. A production version of this API and database is scheduled to launch late summer 2025.

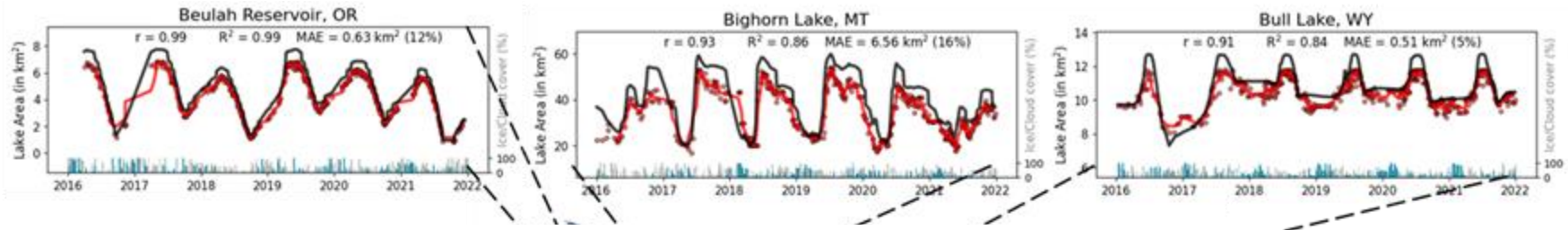
Surface Area from HLS (Landsat+Sentinel-2)

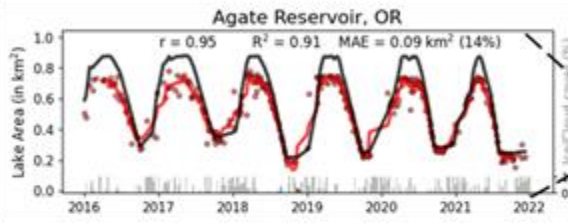


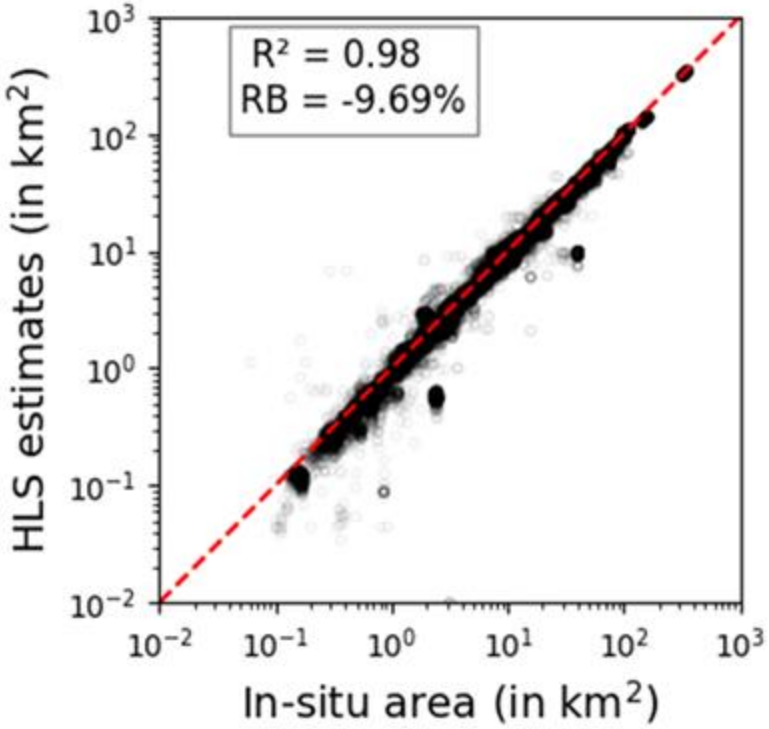


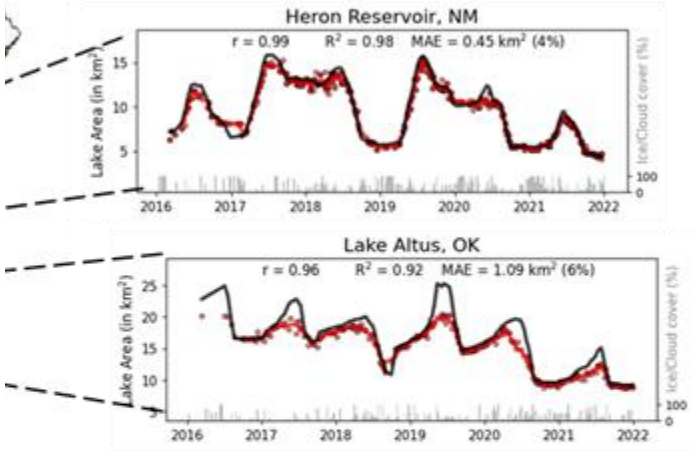


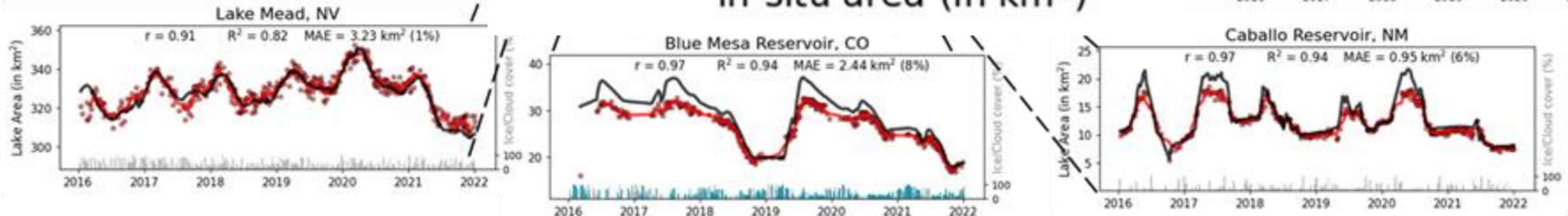
Surface Area Validation





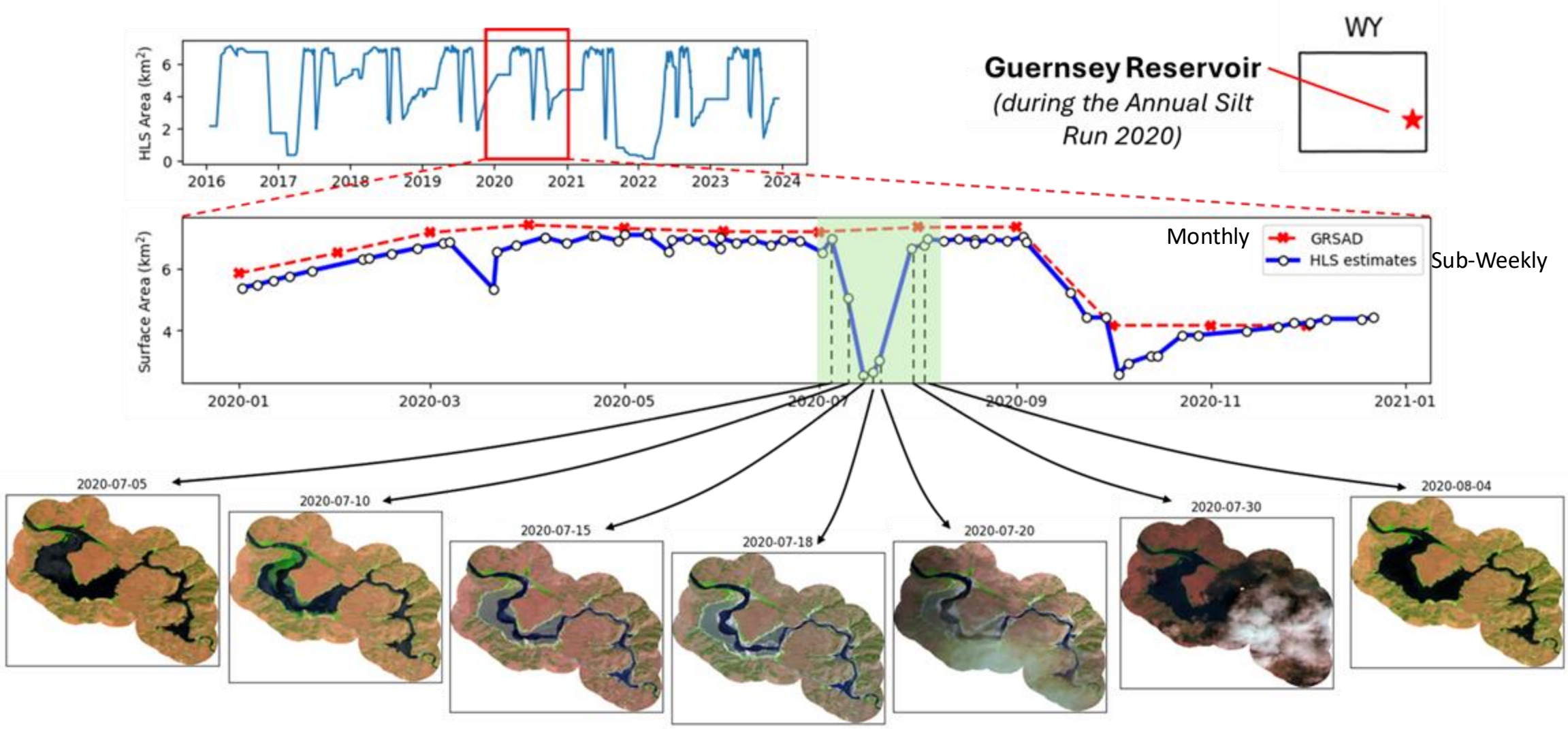






Yadav et al. 2025, (Geophysical Research Letters)

Application: Monitoring sub-monthly transient events



Thanks!
Questions?

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hgao@civil.tamu.edu

https://hgao.engr.tamu.edu/research/

Hands-on exercises

MODIS/VIIRS Global Water Reservoir (GWR)

Western US reservoir evaporation (Provisional)

Texas reservoir evaporation

Global Reservoir Storage (GRS)

Global Lake Evaporation Volume (GLEV)

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- Zhao, B., Huntington, J., Pearson, C., Zhao, G., Ott, T., Zhu, J., ... & Gao, H., Developing a general Daily Lake Evaporation Model and demonstrating its application in the state of Texas. Water Resources Research, https://doi.org/10.1029/ 2023WR036181, **2024**.
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