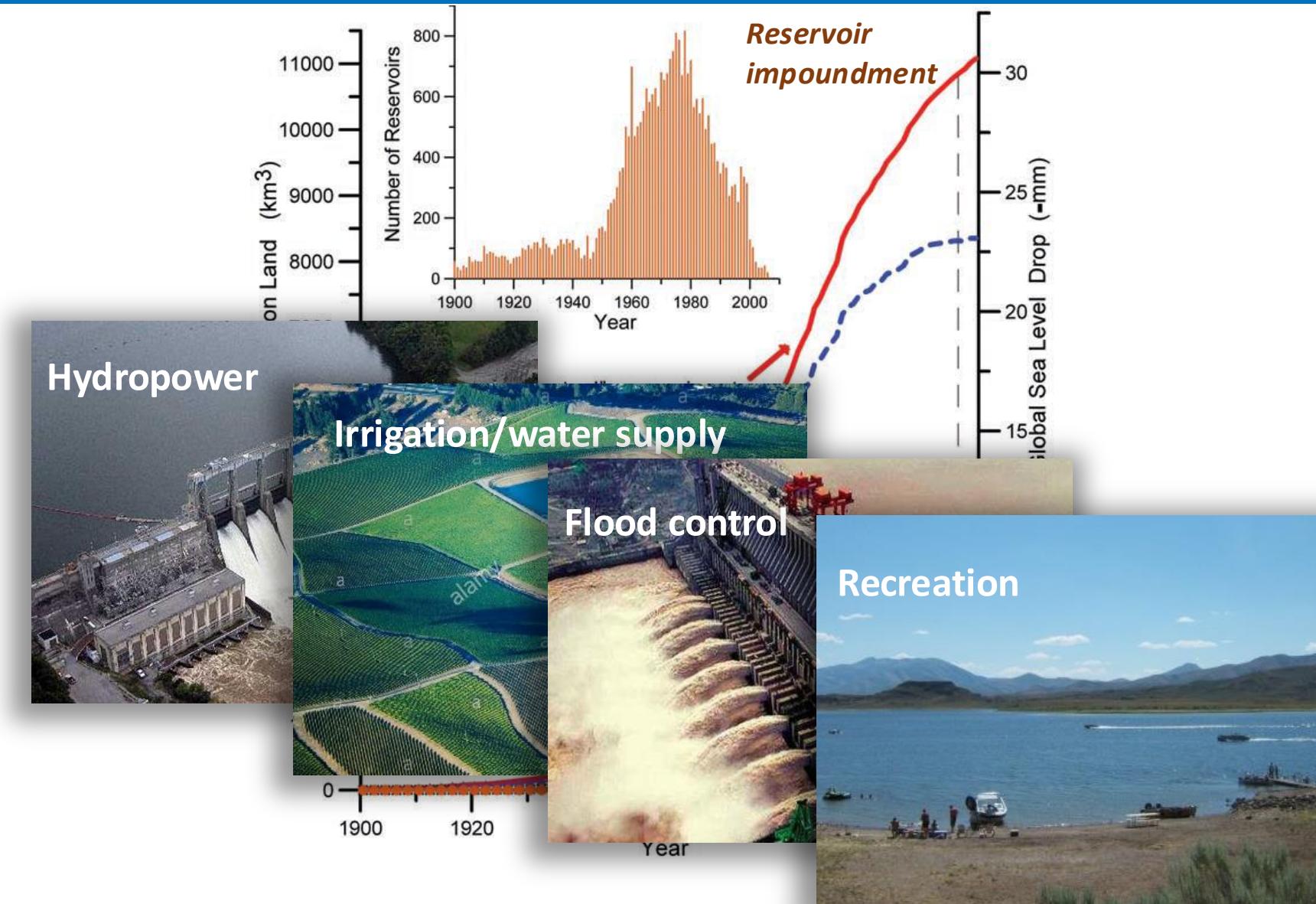


# Monitoring reservoirs using multi-satellite observations

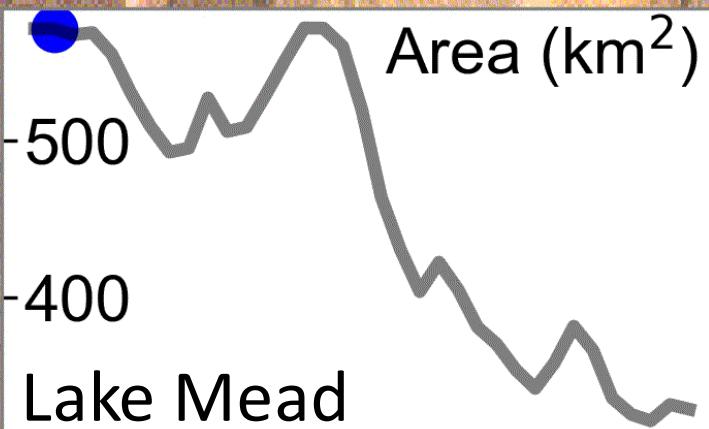
Huilin Gao  
Dept. Civil & Environmental Engineering  
Texas A&M University  
5/18/2025

# Reservoir Water Impoundment and Functions



1985

Las Vegas



Lake Mead

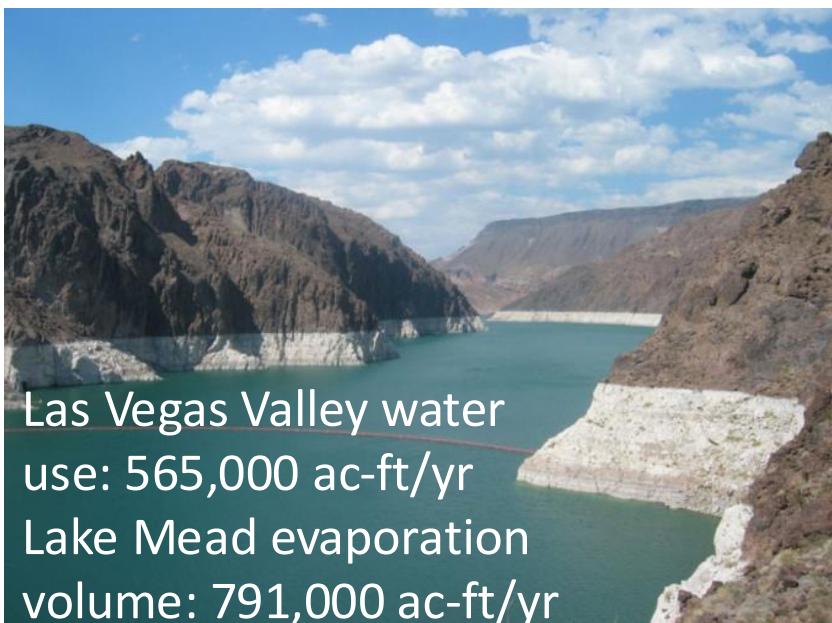
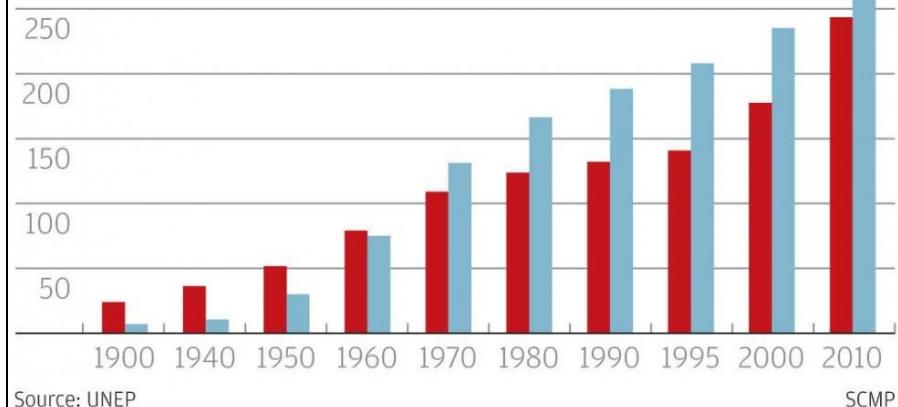
# Lake Evaporation

## A global phenomenon

Industrial and domestic consumption

Evaporation from reservoirs

300 (km<sup>3</sup> per year)



Las Vegas Valley water

use: 565,000 ac-ft/yr

Lake Mead evaporation

volume: 791,000 ac-ft/yr

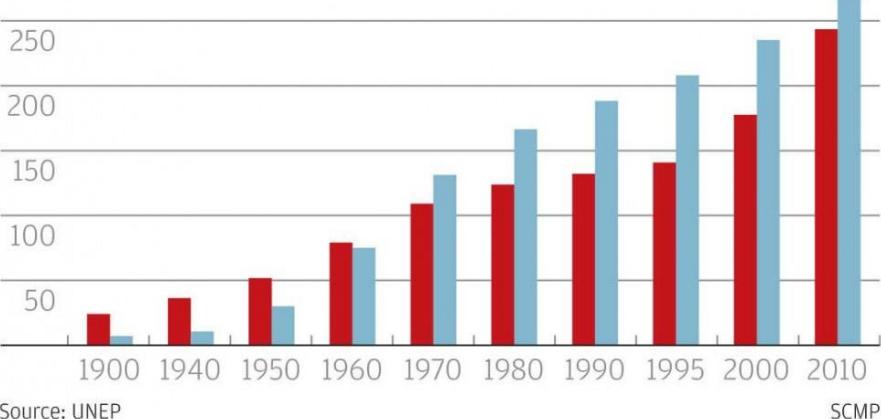
# Lake Evaporation

## A global phenomenon

Industrial and domestic consumption

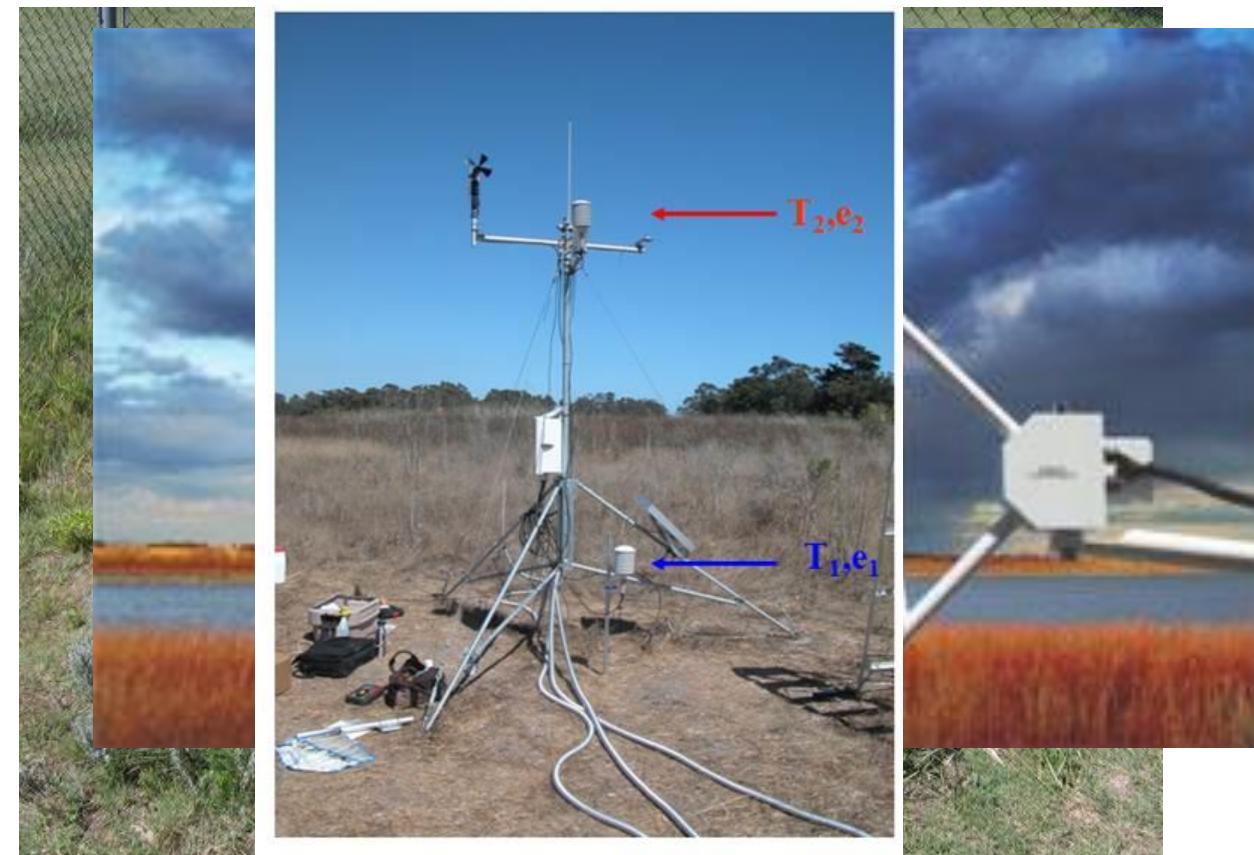
Evaporation from reservoirs

300 (km<sup>3</sup> per year)



## Limited in-situ observations

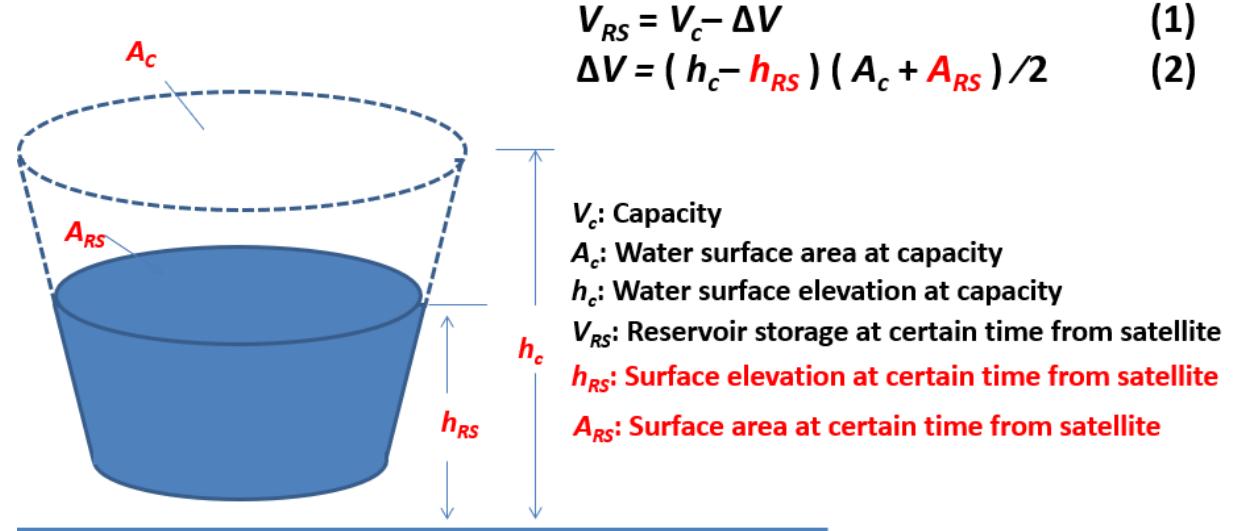
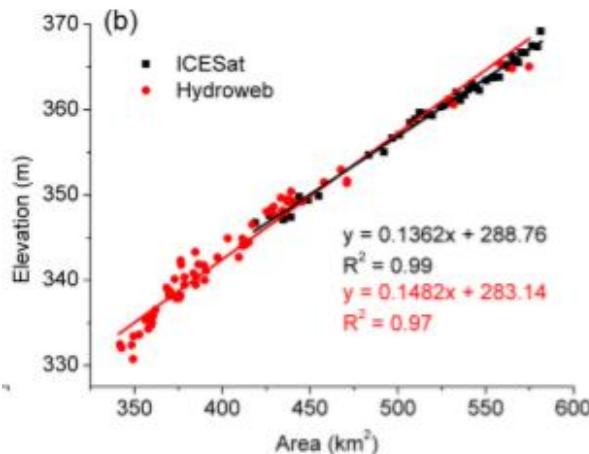
- Class-A pan evaporation
  - Large uncertainty
- Eddy covariance
  - Expensive and data is difficult to process
- Bowen ratio energy balance
  - $LE = R_n - H + \Delta U + F_{in} - F_{out} - G$



# 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)
- .....



## Sensors for area estimations

- Landsat
- MODIS/VIIRS
- AVHRR
- 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 ( $\text{kPa} \cdot ^\circ\text{C}^{-1}$ )

$R_n$ : net radiation ( $\text{MJ} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ )

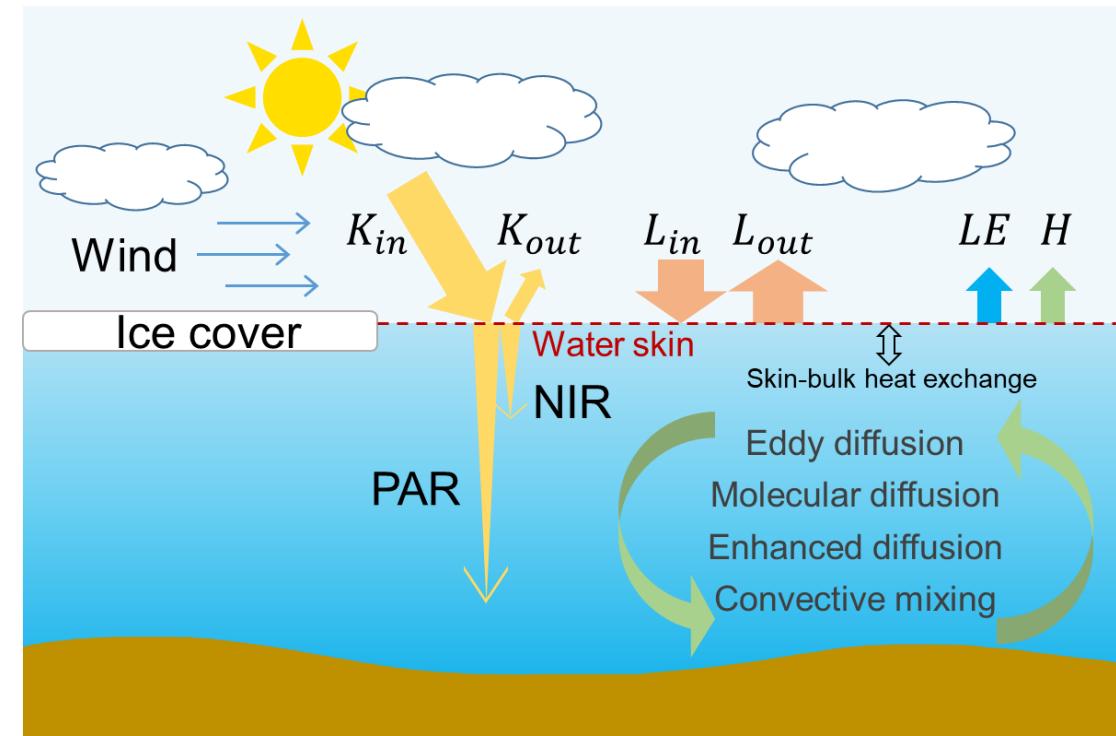
$\gamma$ : psychrometric constant ( $\text{kPa} \cdot ^\circ\text{C}^{-1}$ )

$f(u_2)$ : wind function ( $\text{s} \cdot \text{m}^{-1}$ )

$\delta_e$ : vapor pressure deficit ( $\text{kPa}$ )

$\lambda_v$ : latent heat of vaporization ( $\text{MJ} \cdot \text{kg}^{-1}$ )

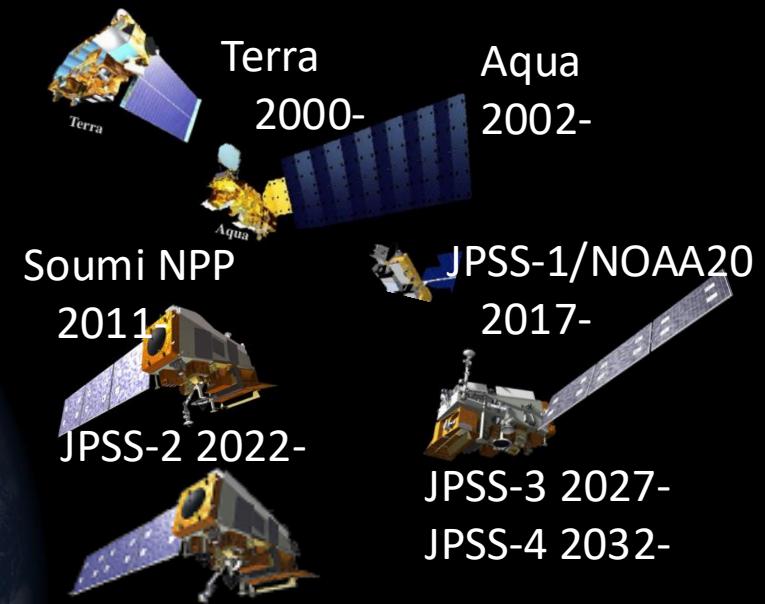
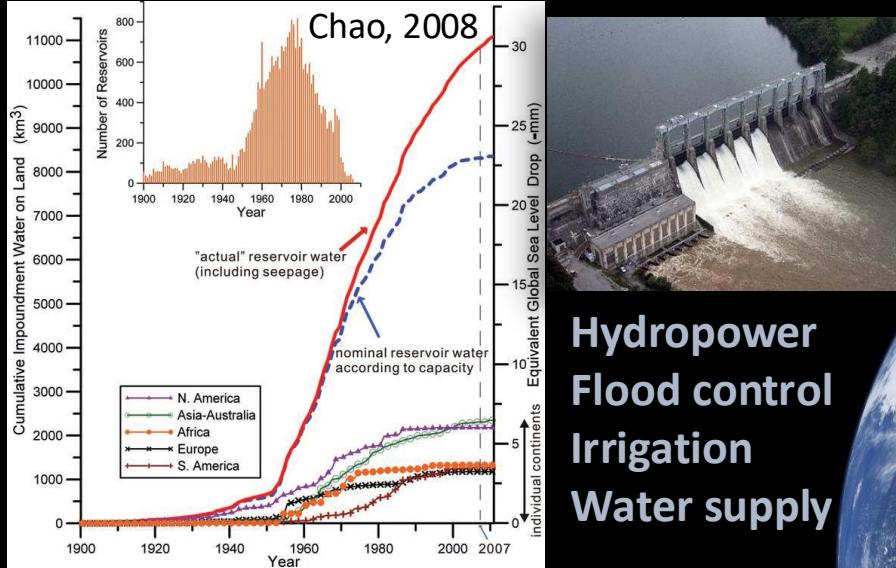
*Evaporation volume = evaporation rate \* A*



Zhao et al., RSE, 2020

# MODIS/VIIRS Global Water Reservoir (GWR) Product

*- Everything Everywhere All at Once*



MODIS images of Urmia Lake

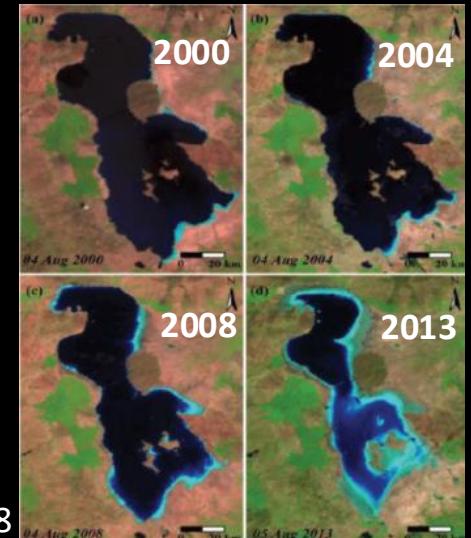
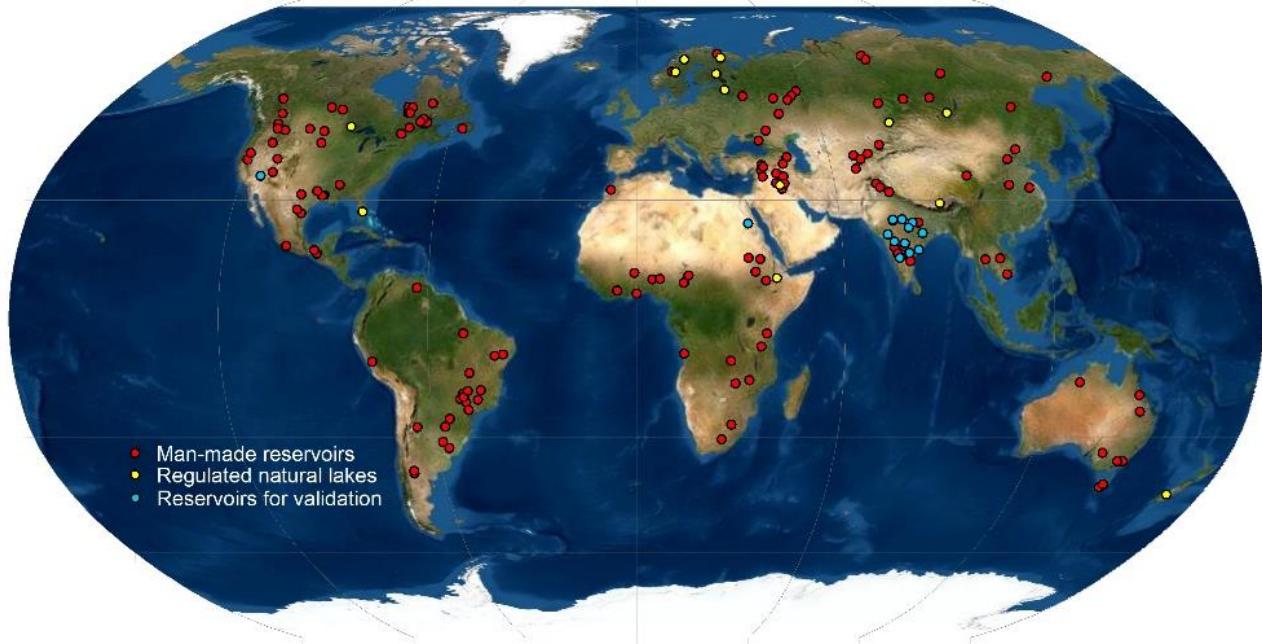


Figure from  
Mohebzadeh, 2018

# MODIS/VIIRS Global Reservoir Products



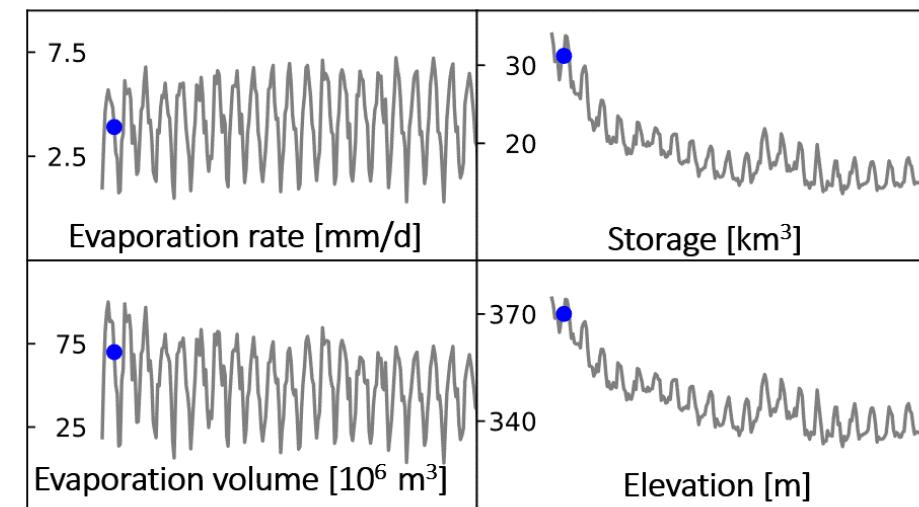
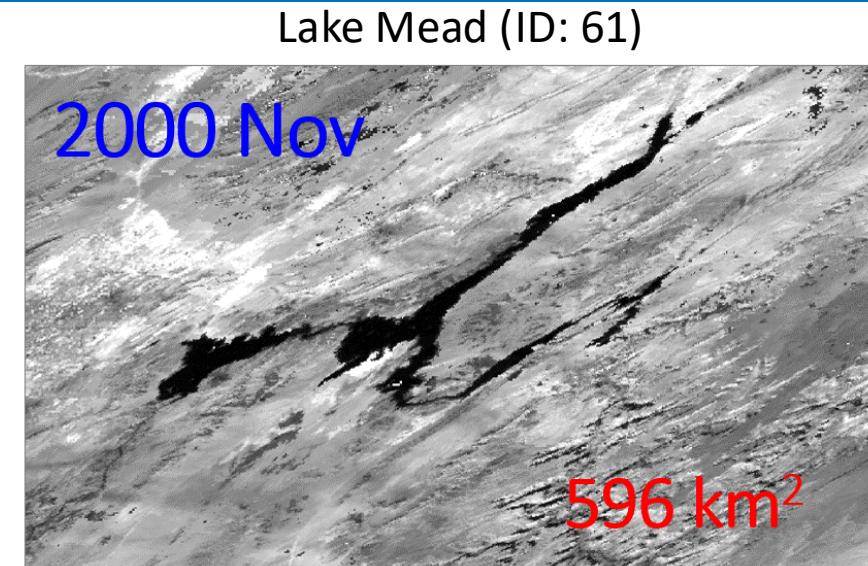
Locations of the 164 reservoirs (46% global capacity)

## 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 <sup>2</sup> (C2)	2018-present



# MODIS/VIIRS Global Reservoir Products

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

National Aeronautics and Space Administration  
Goddard Space Flight Center

Enter Search Term(s)  Search

Sciences and Exploration

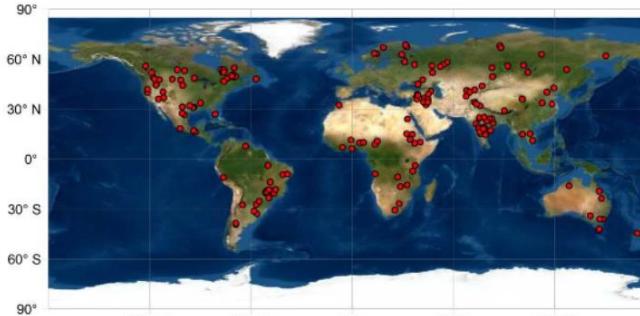


# MODIS Land

Home Products Validation People News Links Tools

## Water Reservoir

The MODIS Water Reservoir product includes time series of surface area, elevation, storage, evaporation rate, and volumetric evaporation. The MOD28 reservoir surface area algorithm is based on image classifications of NIR reflectance from both Terra (MOD09Q1) and Aqua (MYD09Q1). The storage and elevation values are calculated by applying the area to the pre-established Area-Volume-Elevation (AVE) curves for each reservoir of interest. The MOD28 reservoir evaporation rate is estimated using the newly developed Lake Temperature and Evaporation Model (LTEM). In the LTEM the MODIS LST data (MOD11A2 and MYD11A2) are employed to constrain the modified Hostetter Model for calculating lake water temperature profiles. The temperature profiles were then used to calculate lake heat storage change term in the Penman equation. The calculation of the evaporation rate also requires gridded meteorological inputs from GLDAS and bathymetric data. The volumetric evaporation is calculated as the product of the evaporation rate and surface area.



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

National Aeronautics and Space Administration  
Goddard Space Flight Center

Search NASA.gov  GO

Sciences and Exploration



# VIIRS Land

Visible Infrared Imaging Radiometer Suite

Home NASA ESDRs Validation People Tools Publications Links

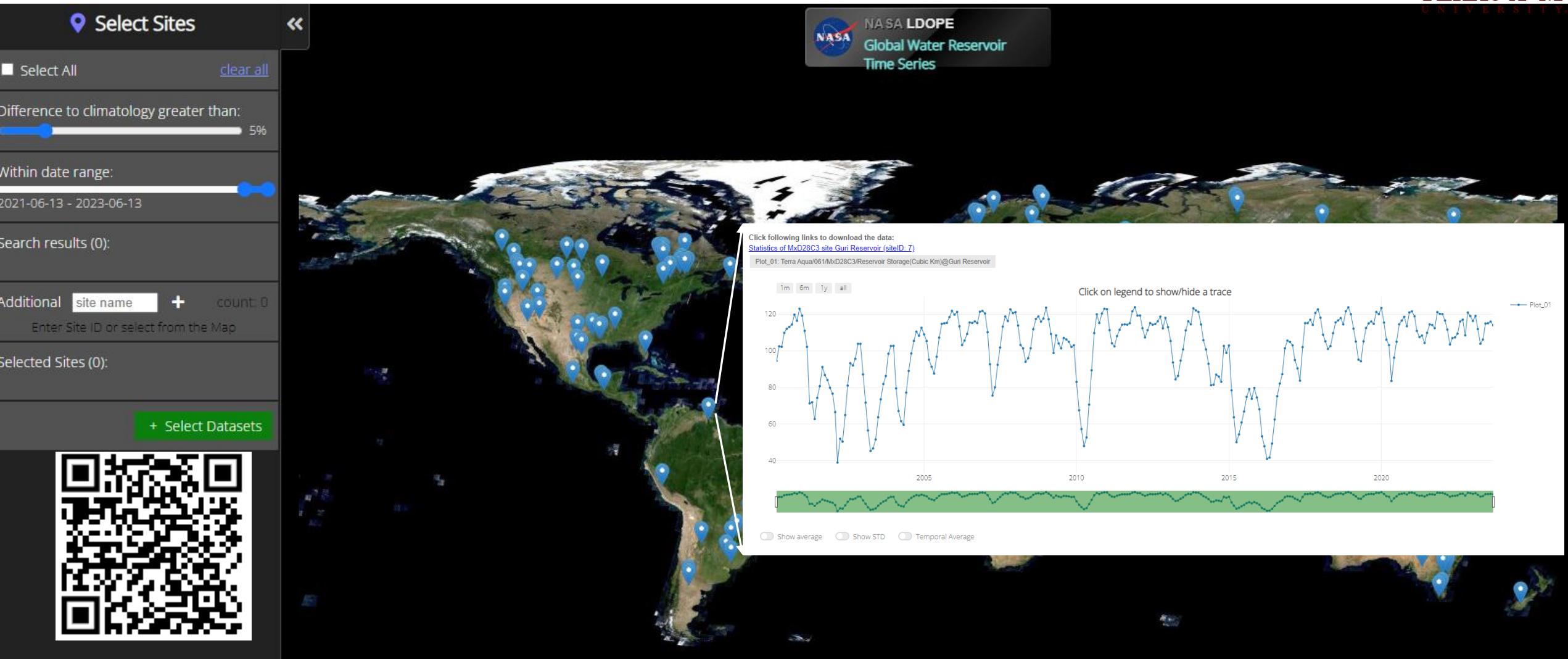
## NASA Water Reservoir Products

PI - Huijin Gao (Texas A&M University)

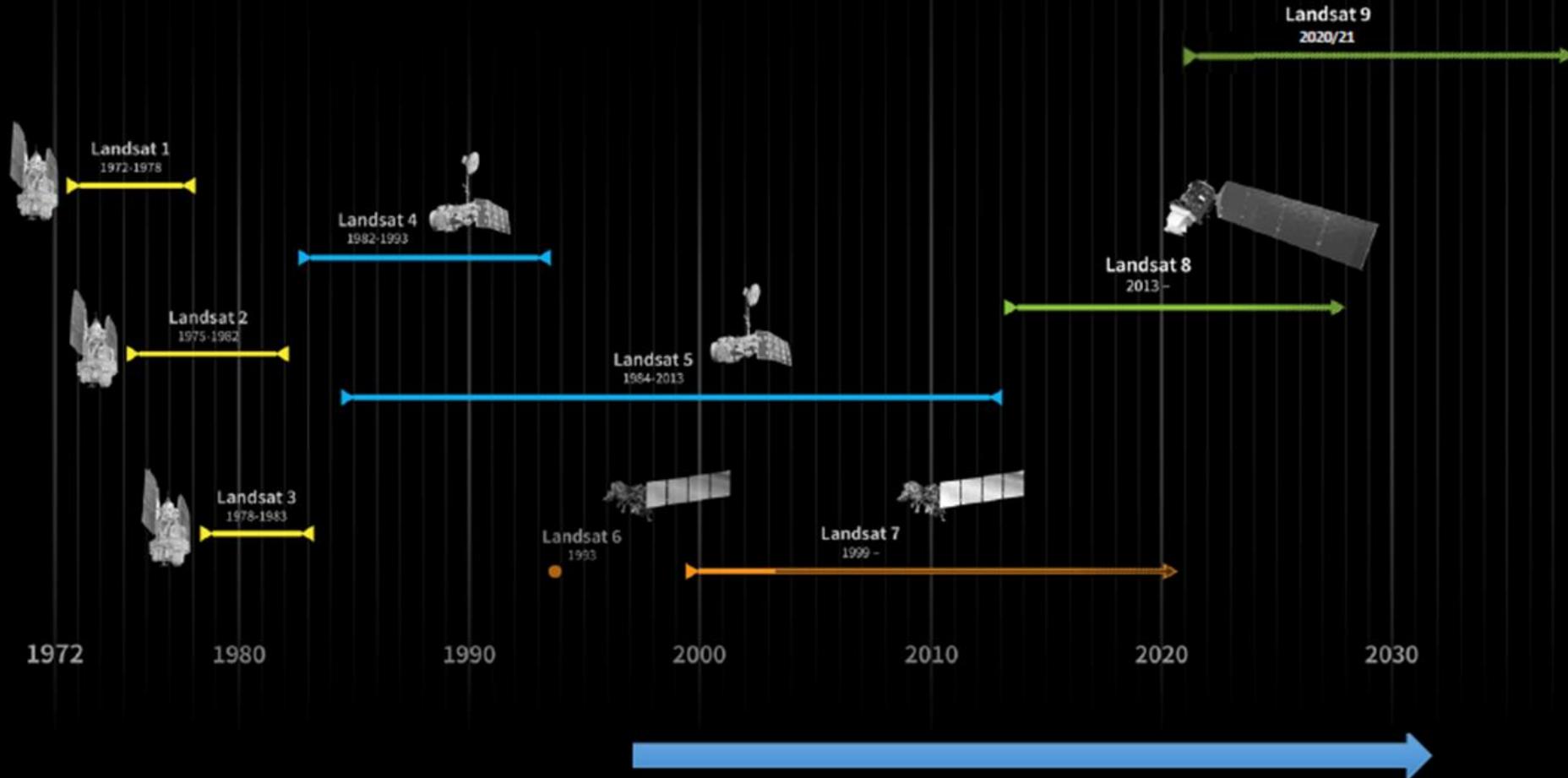
Product User Guide Product ATBD

Surface Reflectance  
Surface Albedo  
Active Fires  
Snow Cover  
Sea Ice Cover  
Ice Surface Temperature  
Land Surface Temperature  
Vegetation Index

The Collection 2.0 VIIRS Global Water Reservoir (GWR) product (VNP28) covers 164 reservoirs, including 151 man-made reservoirs (2,672 km<sup>3</sup>) and 13 regulated natural lakes (23,811 km<sup>3</sup>). The total storage capacity of man-made reservoirs represents 45.82% of the global capacity in this category, as per the Global Reservoir and Dam Database (GranaD). The user guide and ATBD include geographical locations and attribute information for these 164 global reservoirs, which were selected from the GRBD for having areas larger than 25 km<sup>2</sup>. The product is limited to these large reservoirs due to the availability of reliable area-elevation curves. The VIIRS GWR product includes time series of surface area, elevation, storage, evaporation rate, and volumetric evaporation at two temporal resolutions. Both 8-day and monthly products include reservoir area, elevation, and storage records, with the monthly product additionally featuring reservoir evaporation rate and volume records.

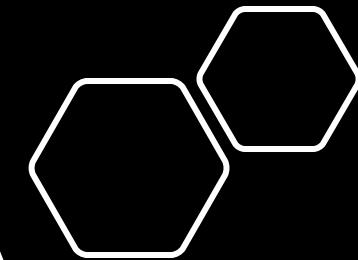
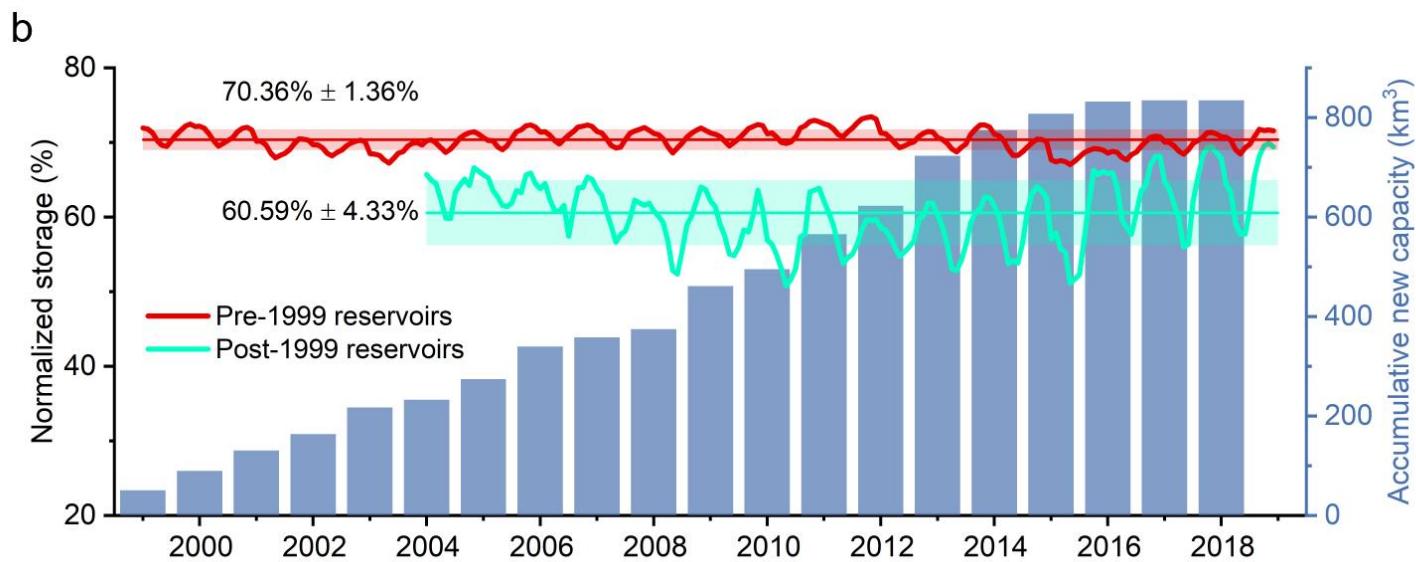
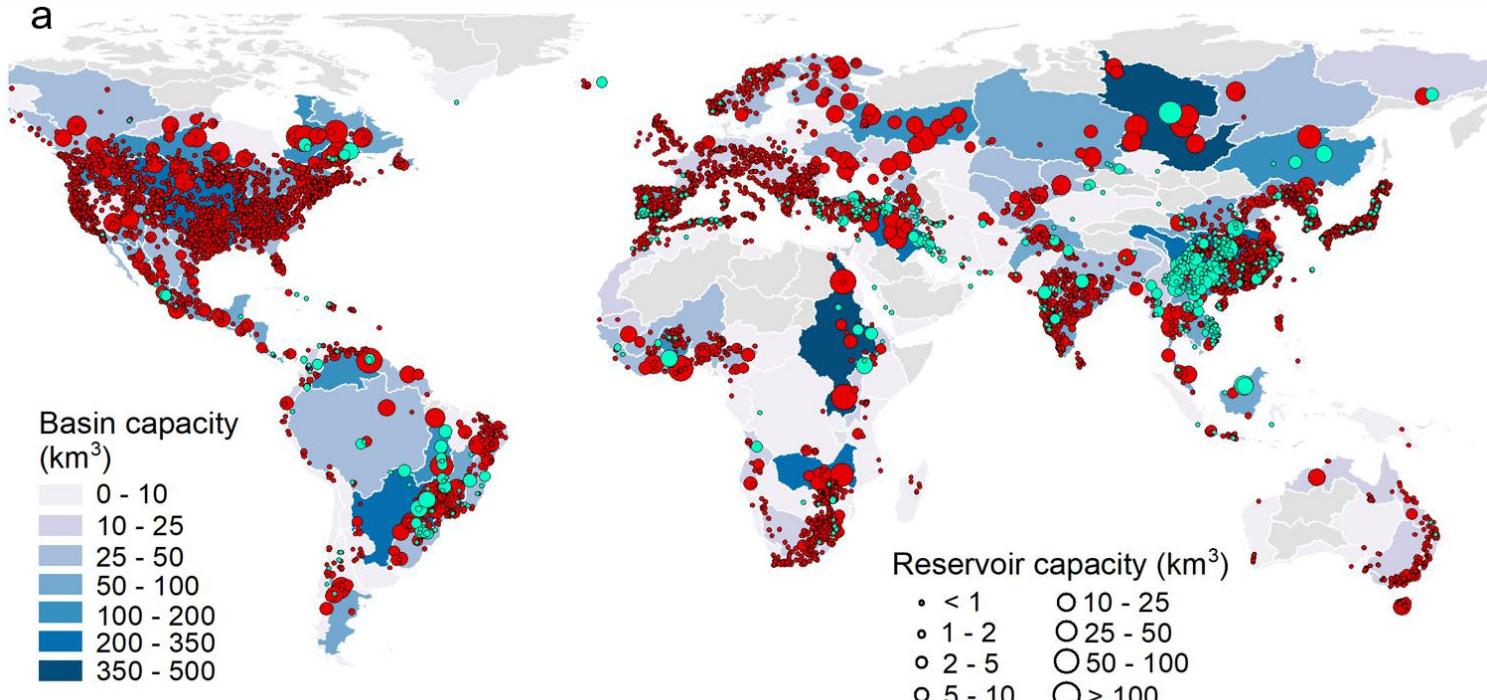


# BUILDING ON THE LANDSAT LEGACY



NASA-USGS Interagency Partnership

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

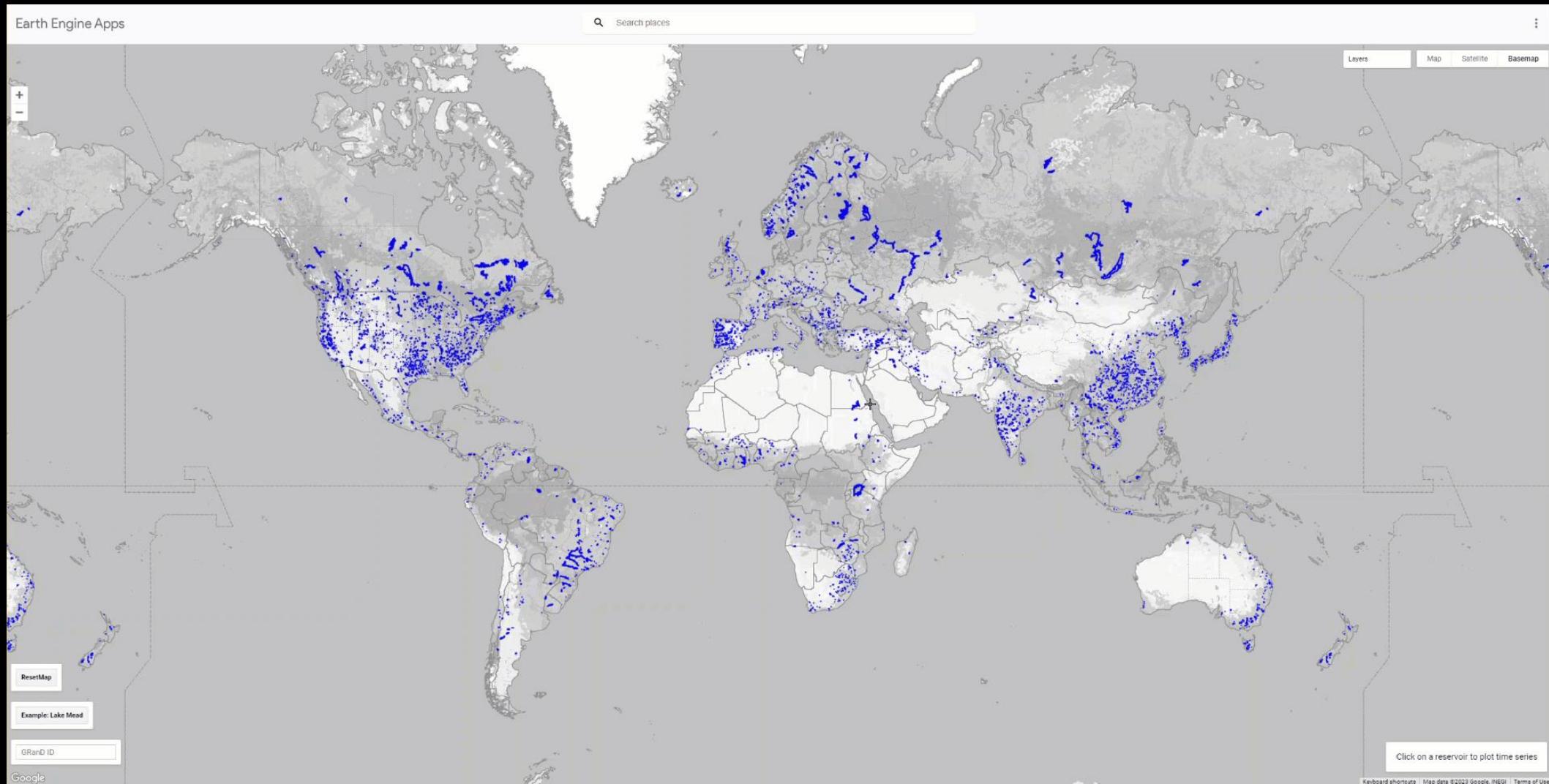


**Diminishing  
storage returns of  
reservoir  
construction**

**Global Reservoir  
Storage (GRS)**

## Sobradinho Reservoir, Brazil

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



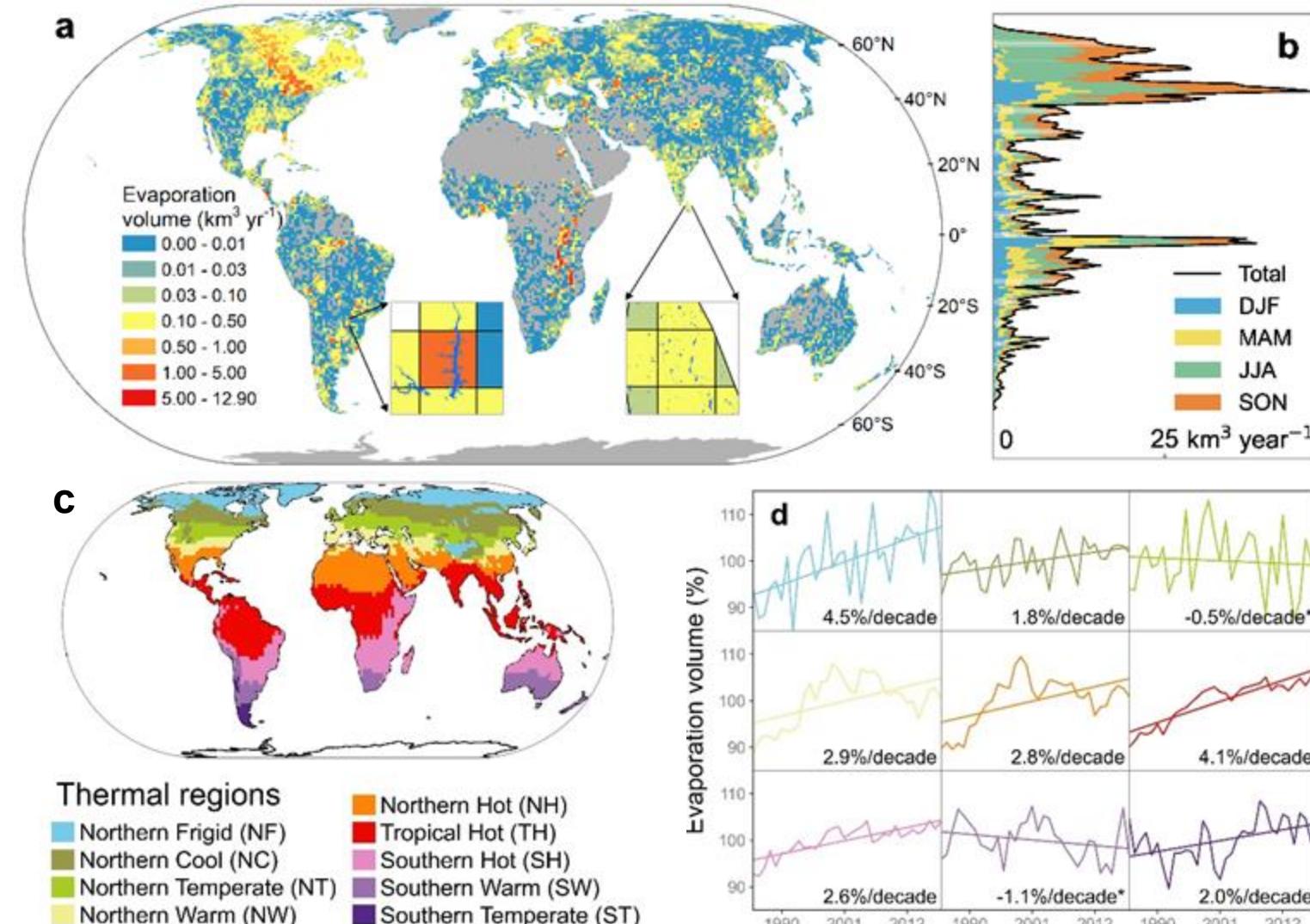
# Global Lake Evaporation Volume (GLEV) Dataset

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

Dataset includes:

- evaporation rate
- surface area
- evaporation volume

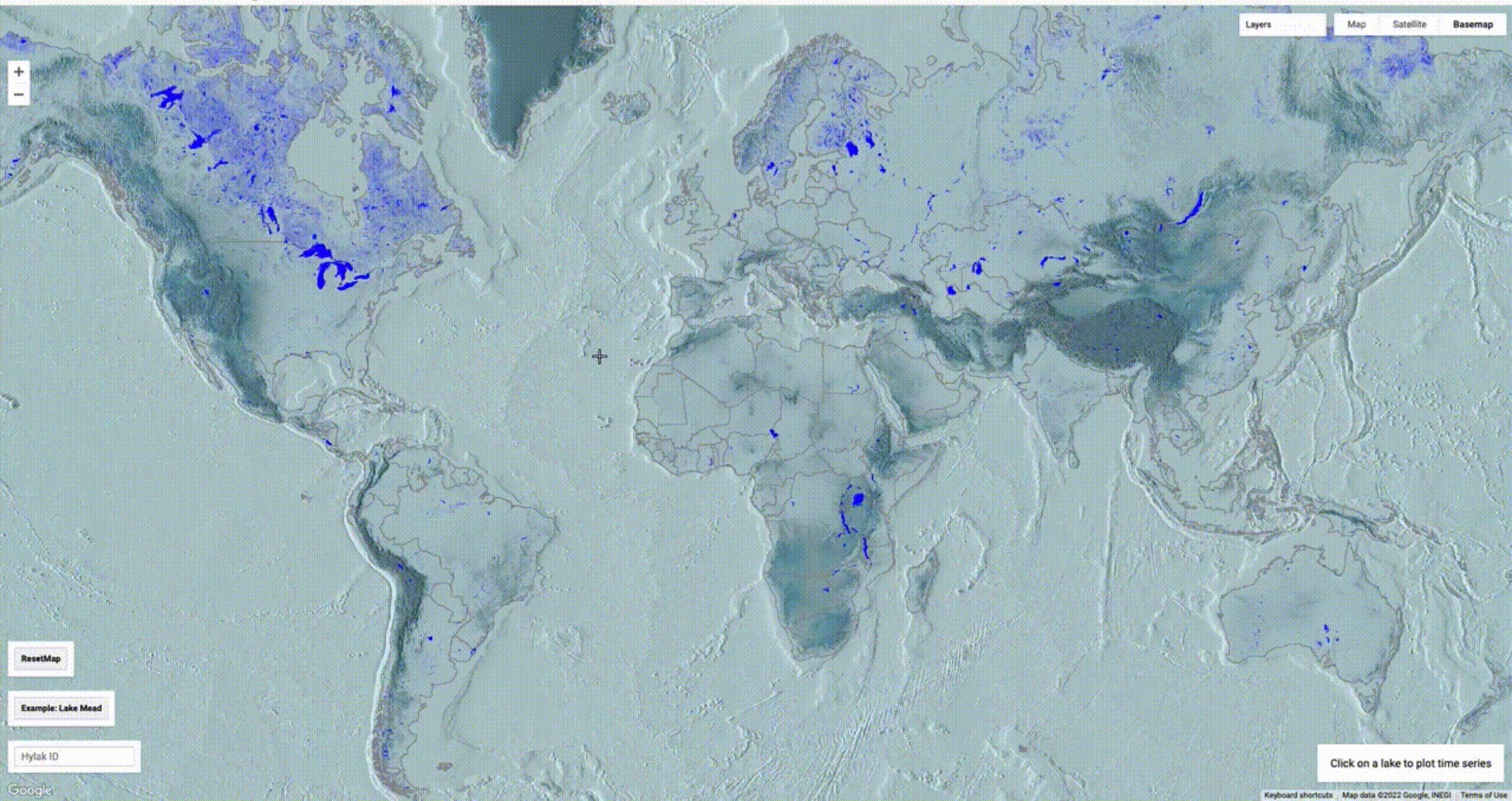
*Reservoir  
evaporative losses  
increase faster than  
natural lakes!*



# Elephant Butte Lake

<https://zertainty.users.earthengine.app/view/glev>

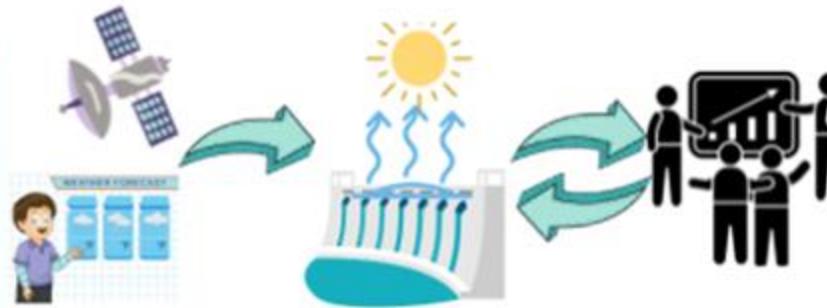
Earth Engine Apps



# ReVap: Reservoir Evaporation Monitoring and Forecasting System

## Inputs:

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



## Model:

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

## Outputs:

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

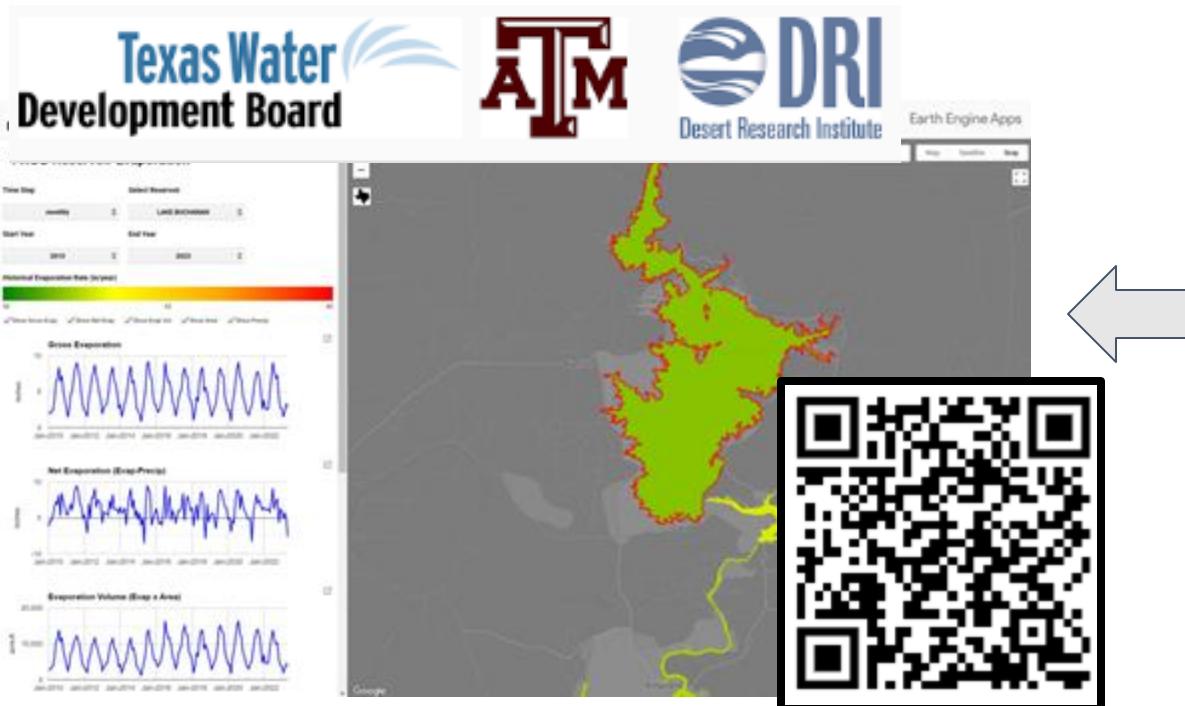
## Data Portal:

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



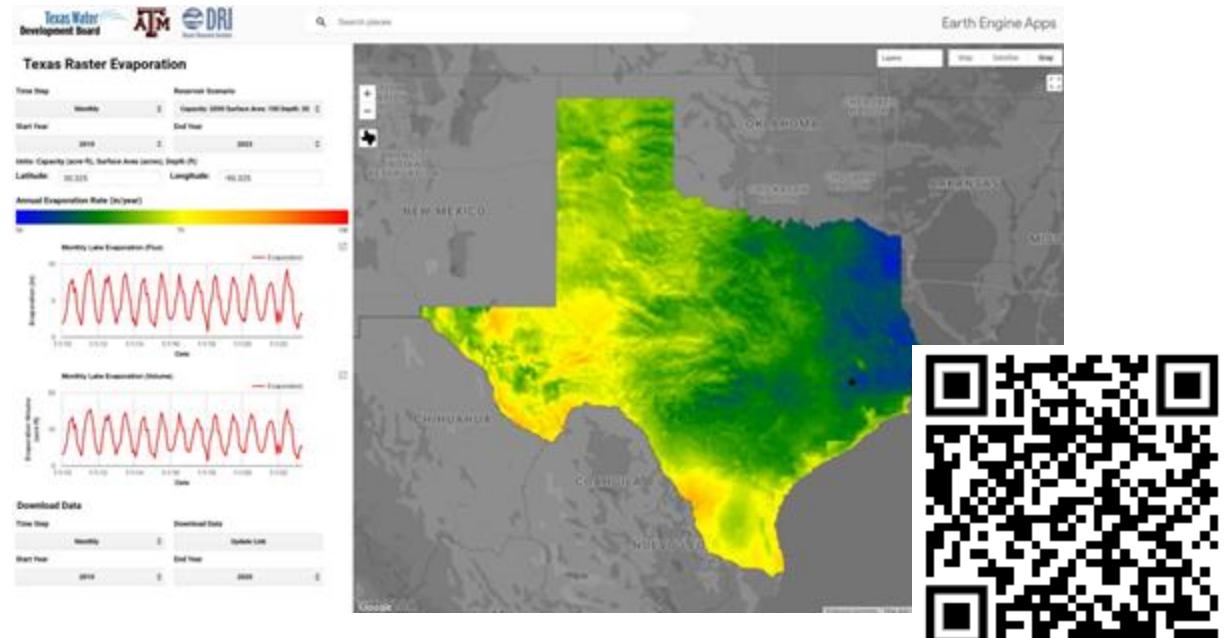
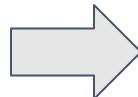
BUREAU OF  
RECLAMATION

# 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!



# Daily Reservoir Evaporation Web App

BUREAU OF RECLAMATION DRI **ATM** NASA VT

Search places

Earth Engine Apps

## BOR Reservoir Evaporation

Time Step Select Reservoir

monthly Select a Reservoir

Start Year End Year

2015 2025

Historical Evaporation Rate (in/year)

50 65 80

Show Gross Evap  Show Net Evap  Show Evap Vol  Show Area  Show Precip

Download Data

Time Step Download Data

monthly Update Link

Start Year End Year

**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.

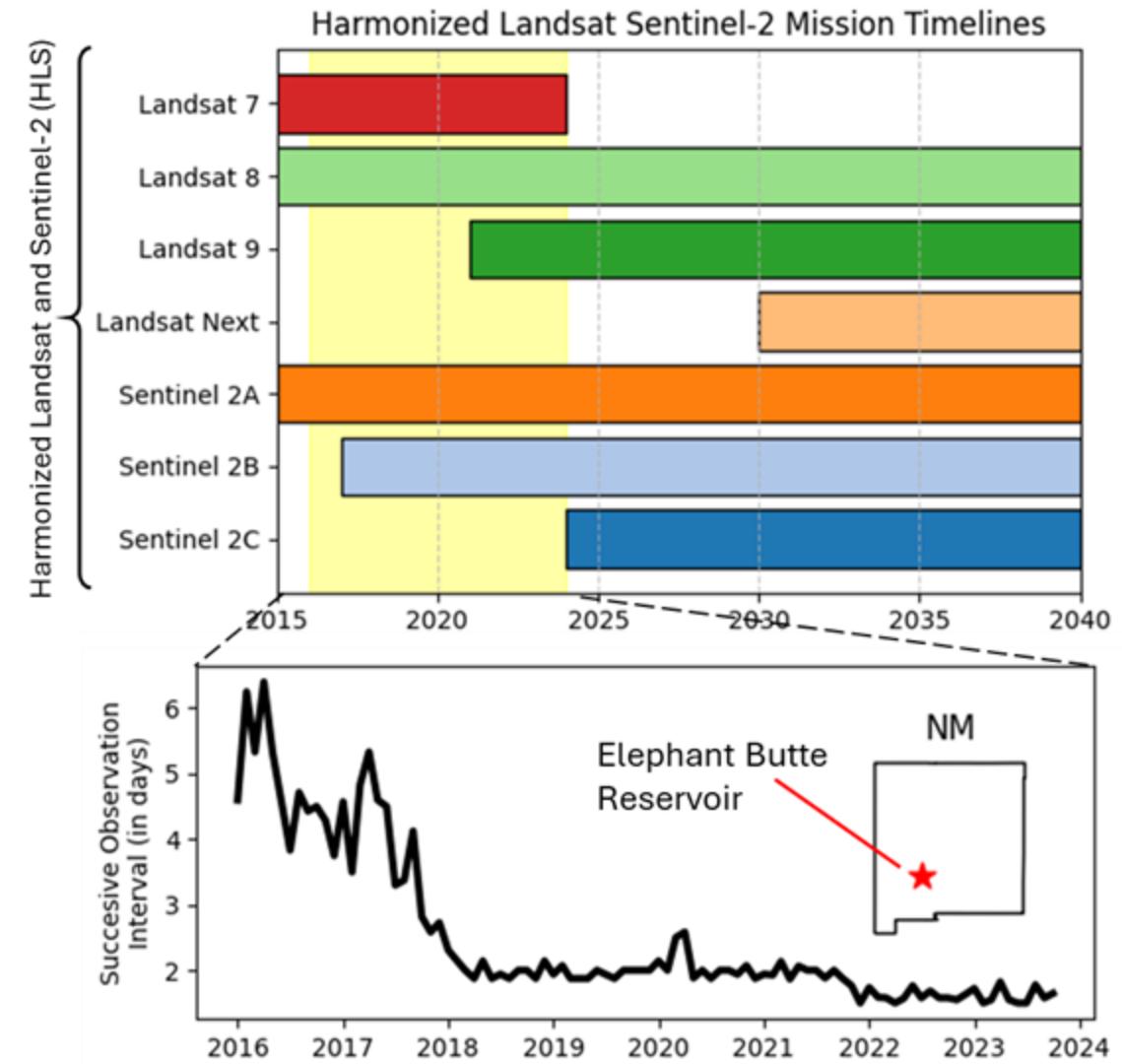
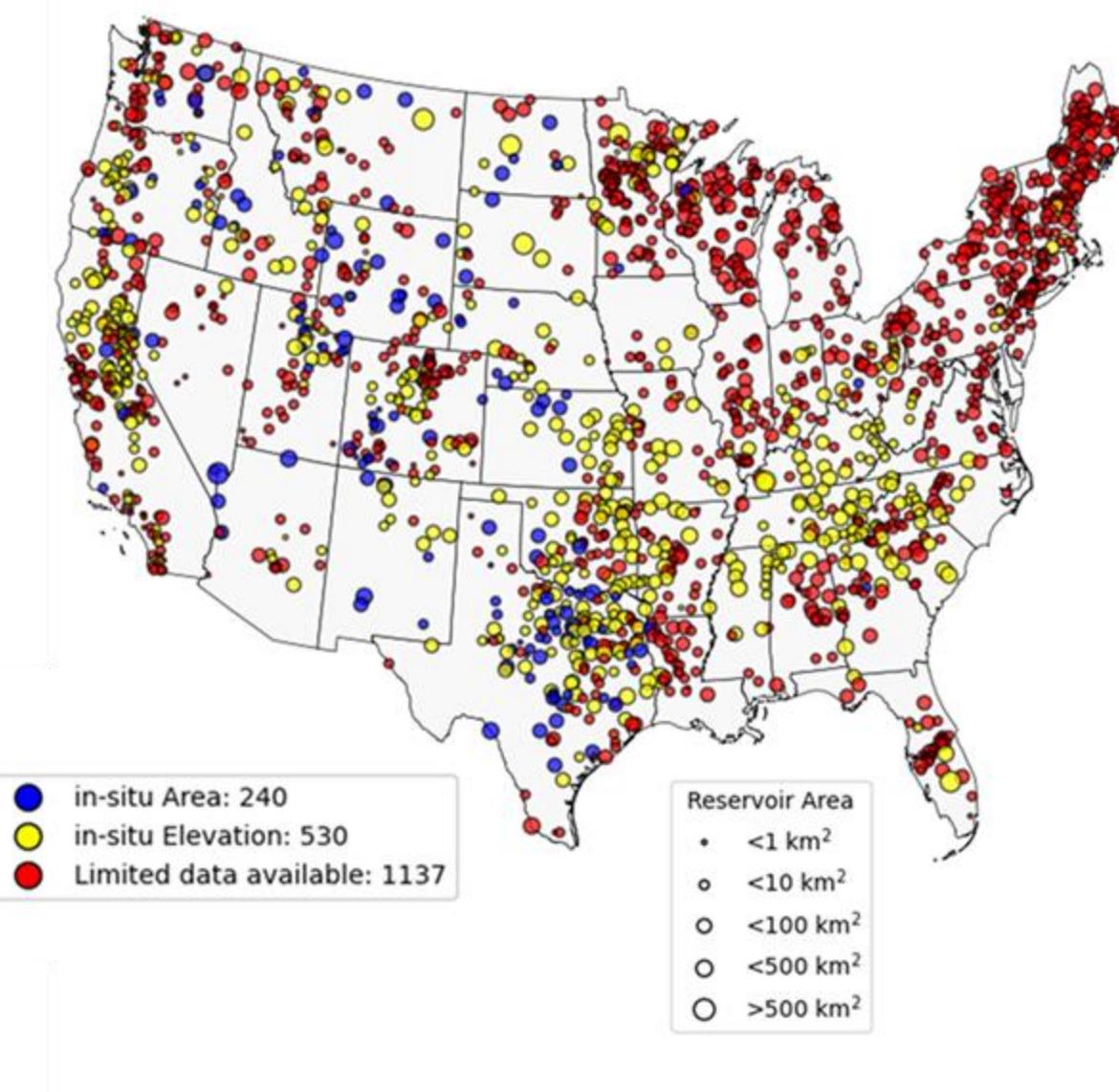
Click on or Select a Reservoir

Layers Map Satellite Gray

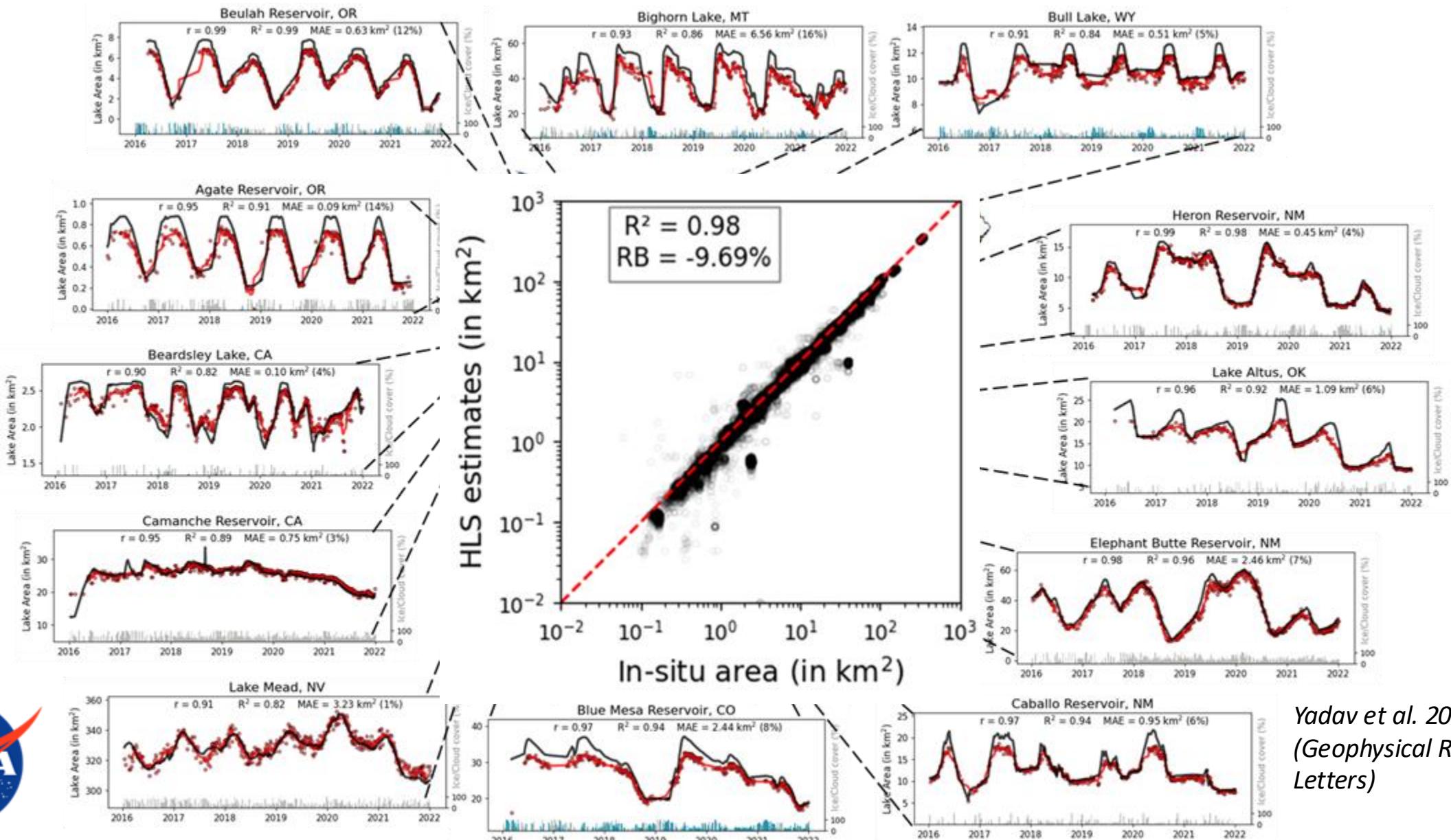
Google

Keyboard shortcuts Map data ©2025 Google 5 km Terms

# Surface Area from HLS (Landsat+Sentinel-2)



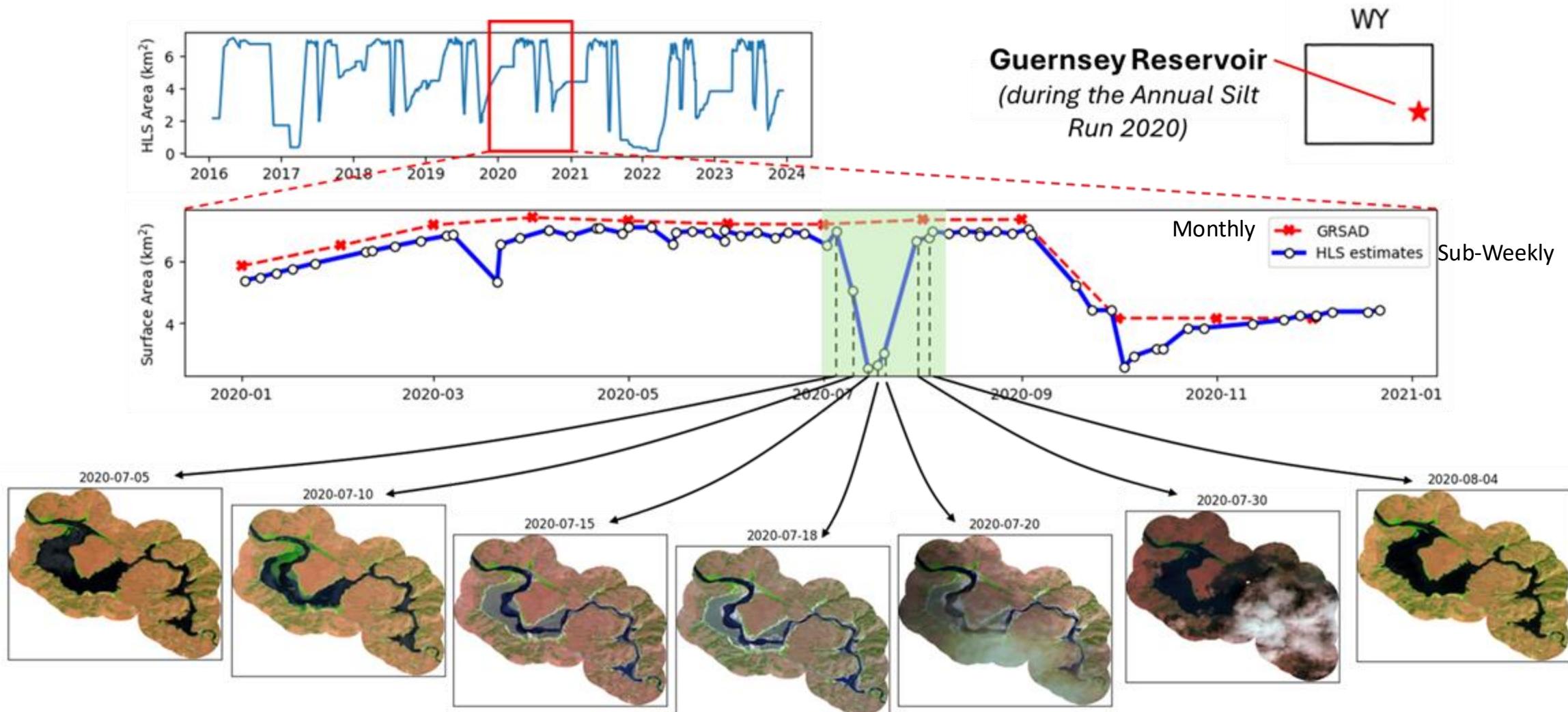
# Surface Area Validation



*Yadav et al. 2025,  
(Geophysical Research Letters)*



# Application: Monitoring sub-monthly transient events



# Thanks! Questions?

Contact: Huilin Gao  
[hgao@civil.tamu.edu](mailto: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, G., Li, Y., Zhou, L. and Gao, H., Evaporative water loss of 1.42 million global lakes. *Nature Communications*, 13(1), p.3686; <https://doi.org/10.1038/s41467-022-31125-6> , 2022.