

Monitoring and Forecasting Daily Reservoir Evaporation in Texas



Morris Shepard Dam, Possum Kingdom Lake, Texas

Huilin Gao

Texas A&M University

Coauthors: Bingjie Zhao¹, Christopher Pearson², Thomas Ott², Justin Huntington², John Zhu³, Andrew Weinberg³, Kathleen D. Holman⁴, Ron Anderson⁵, Max Strickler⁶, Jerry Cotter⁶, and Nelun Fernando³



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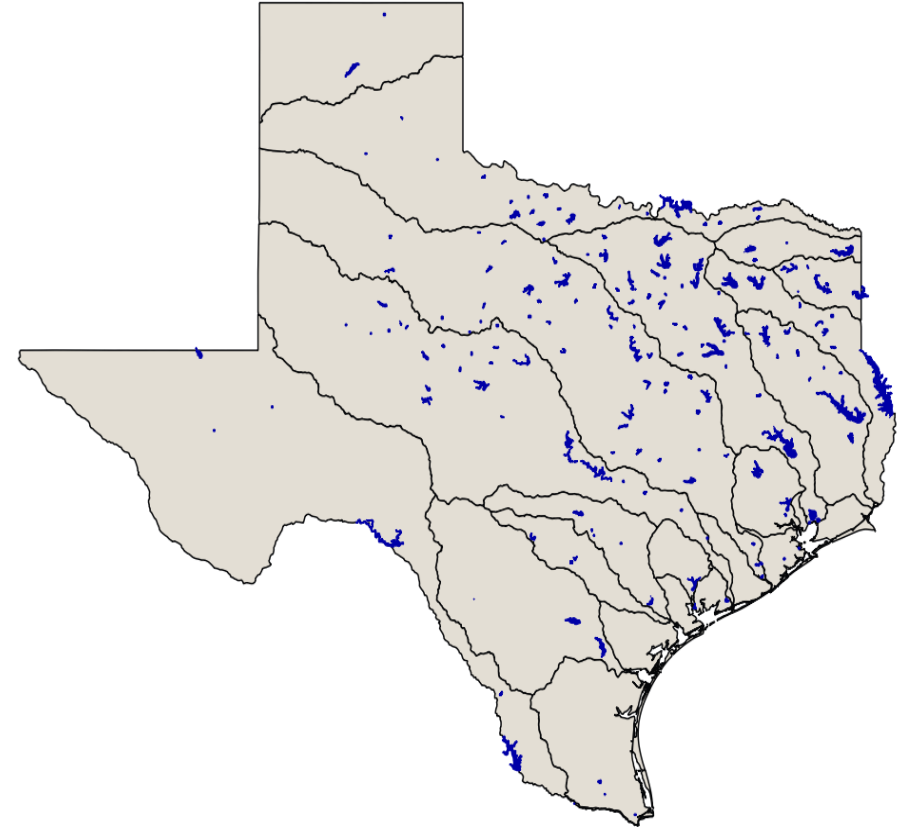


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Overview of Reservoir Evaporation in Texas

- For the 188 major reservoirs, the annual average gross evaporation loss and net evaporation loss values are 7.38 million acre-feet and 2.04 million acre-feet, respectively.
- An annual net evaporative loss of 5.42 million ac-ft was estimated over the 188 major reservoirs in 2011, which exceeded the total municipal water use.
- The net evaporation for 2011 is 3.51 million acre-feet greater than the average net evaporation of 1.91 million acre-feet.

The Distribution of 188 Major Reservoirs



(Zhu et al., Texas Water Development Board technical report, 2021)

Representative Evaporation Measurement Methods

Pan Evaporation:

- ✓ Low cost; Easy to install.
- ✓ Commonly used.
- Doesn't account for heat storage effect.
- Large errors and uncertainties.



Coast Guard Station (facing south to southern end of Lake Tahoe)



Eddy Covariance:

- ✓ A “direct technique” based on physical processes.
- ✓ Most accurate.
- Cost expensive.
- Difficult to collect data over water with floats/buoys.



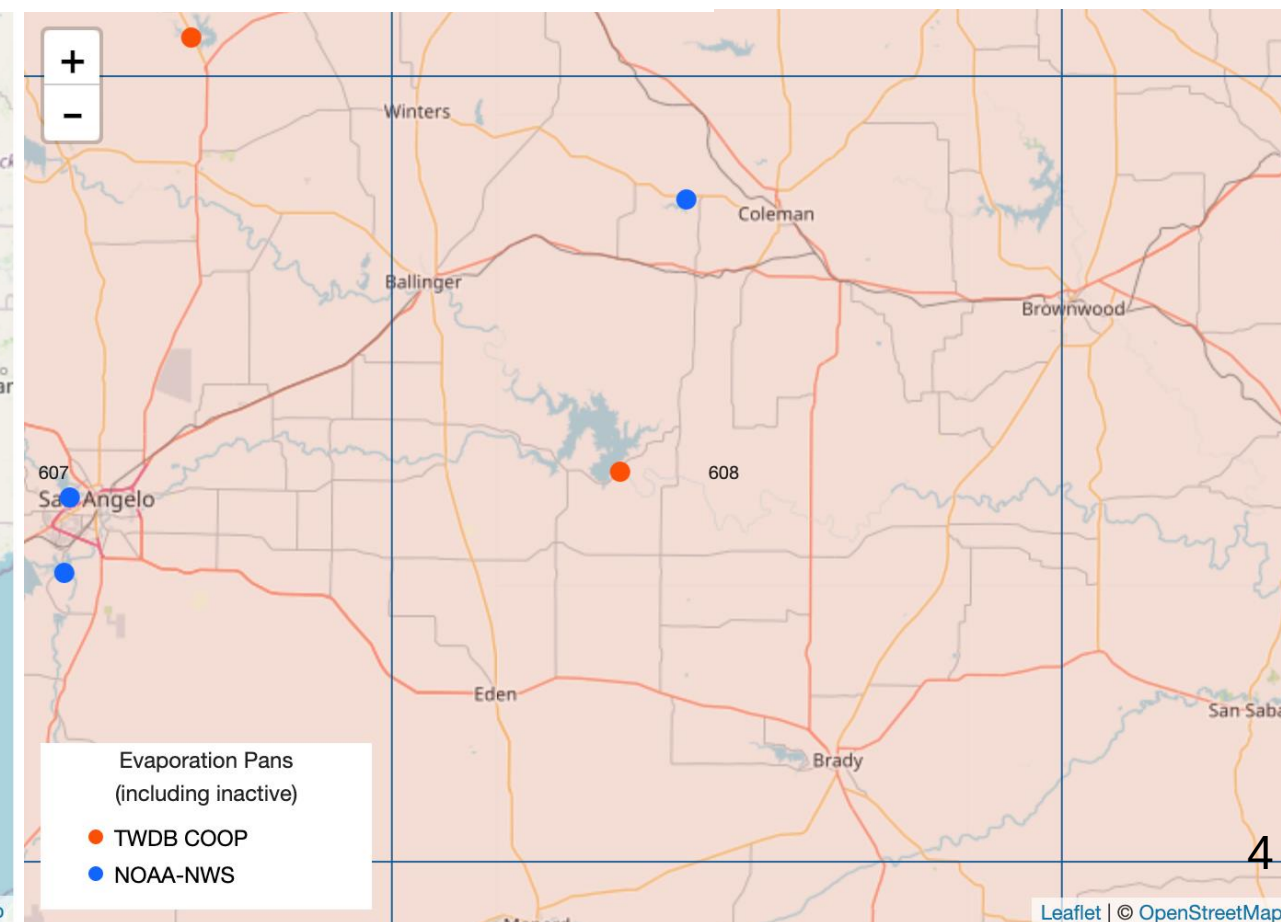
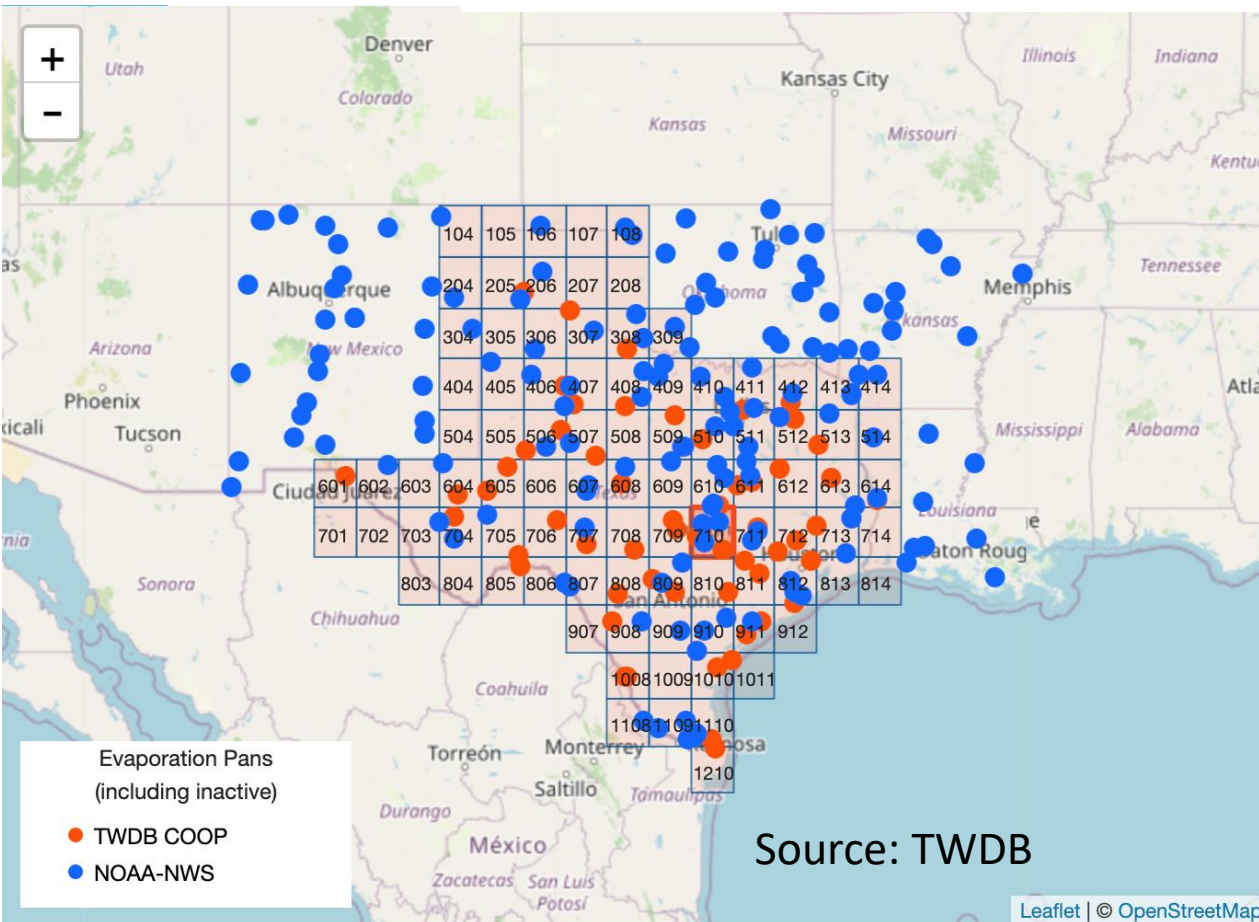
In situ measurements at Lake Mead, Lake Powell. Credit by USBR

Quadrangle Lake Evaporation

Lake Evaporation and Precipitation

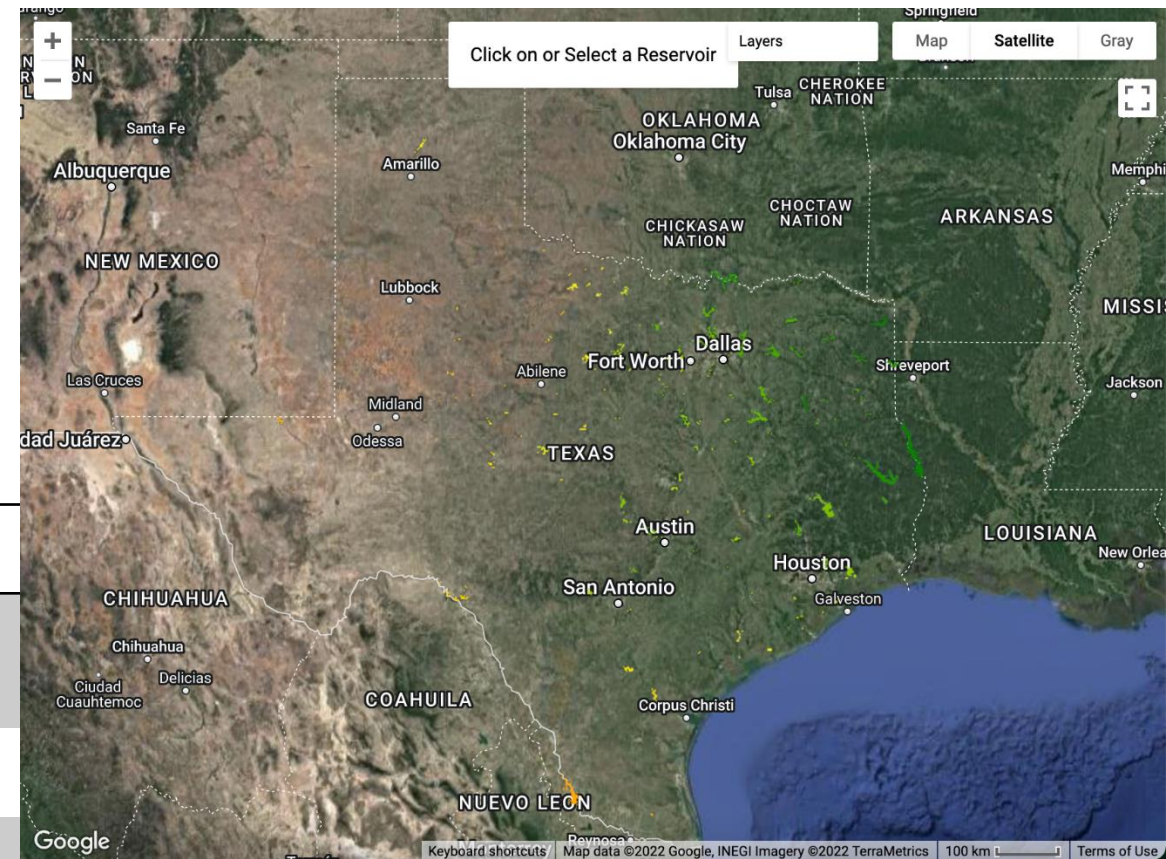
Parameter: Quad ID: Start Date: End Date:

Download Data



Objectives

- Develop a daily lake evaporation model and validate the results using in-situ measurements.
- **Monitor and forecast daily reservoir evaporation by driving the model using easily accessible gridded weather datasets.**
- Develop a user-friendly web interface for researchers and stockholders to visualize and download the data.



	Current	New
Algorithm-based	Pan evaporation	Penman Equation w/ heat storage & fetch
Temporal Resolution	Monthly	Daily
Spatial Resolution	1 degree (~111km)	Individual Reservoirs

Daily Lake Evaporation Model (DLEM)

Heat storage effect: $\Delta U = \bar{h}\rho c [T_w(t) - T_w(t - \Delta t)]$

Spring and summer – absorb heat

Fall and winter – release heat

Wind function for fetch effect:
 $f(u_2) = \lambda_v (2.33 + 1.65u_2) L^{-0.1}$

Penman Equation

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

s : slope of the saturation vapor pressure curve ($\text{kPa} \cdot ^\circ\text{C}^{-1}$)

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

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

$f(u_2)$: wind function ($\text{s} \cdot \text{m}^{-1}$); u_2 : wind speed at 2m

δ_e : vapor pressure deficit (kPa)

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

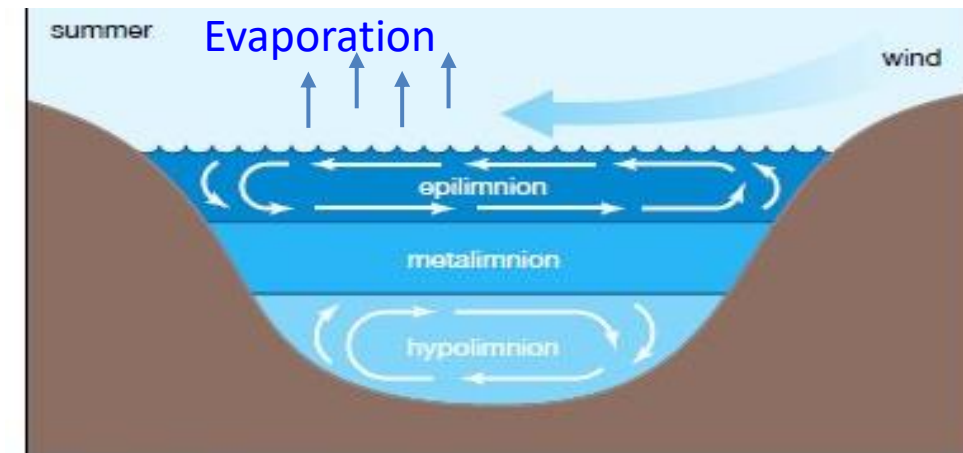
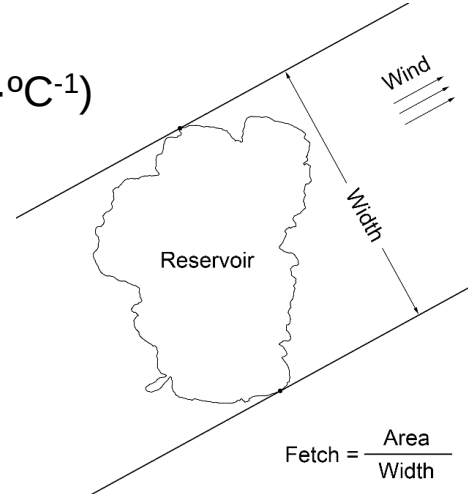
$\bar{h}$: average depth

ρ : water density

c : specific heat of water

L : fetch length

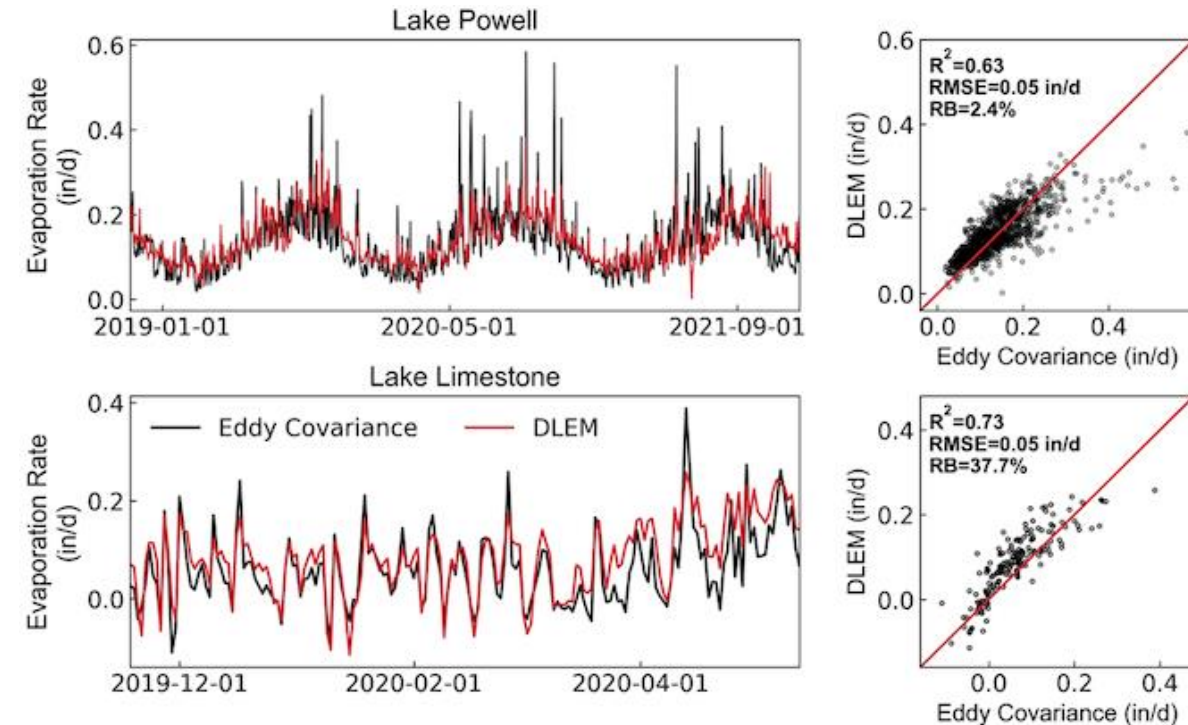
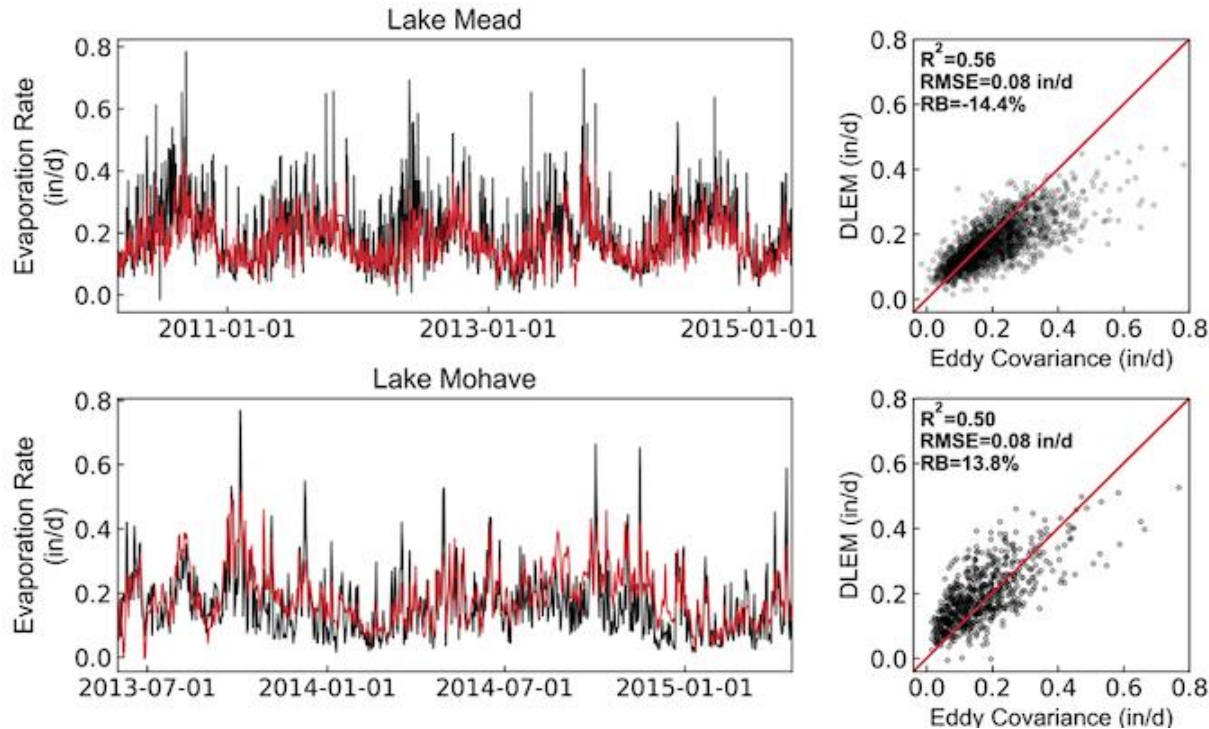
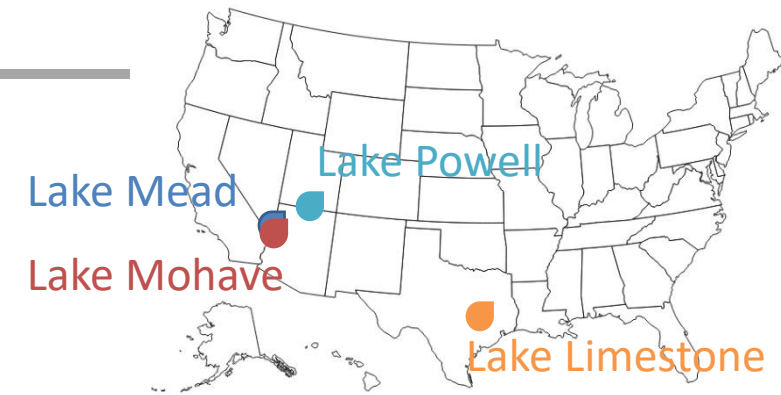
$T_w(t)$: water temperature at time step $t=1\text{day}$



(Zhao and Gao, Remote Sensing of Environment, 2019
 Zhao et al., Water Resources Research, in review)

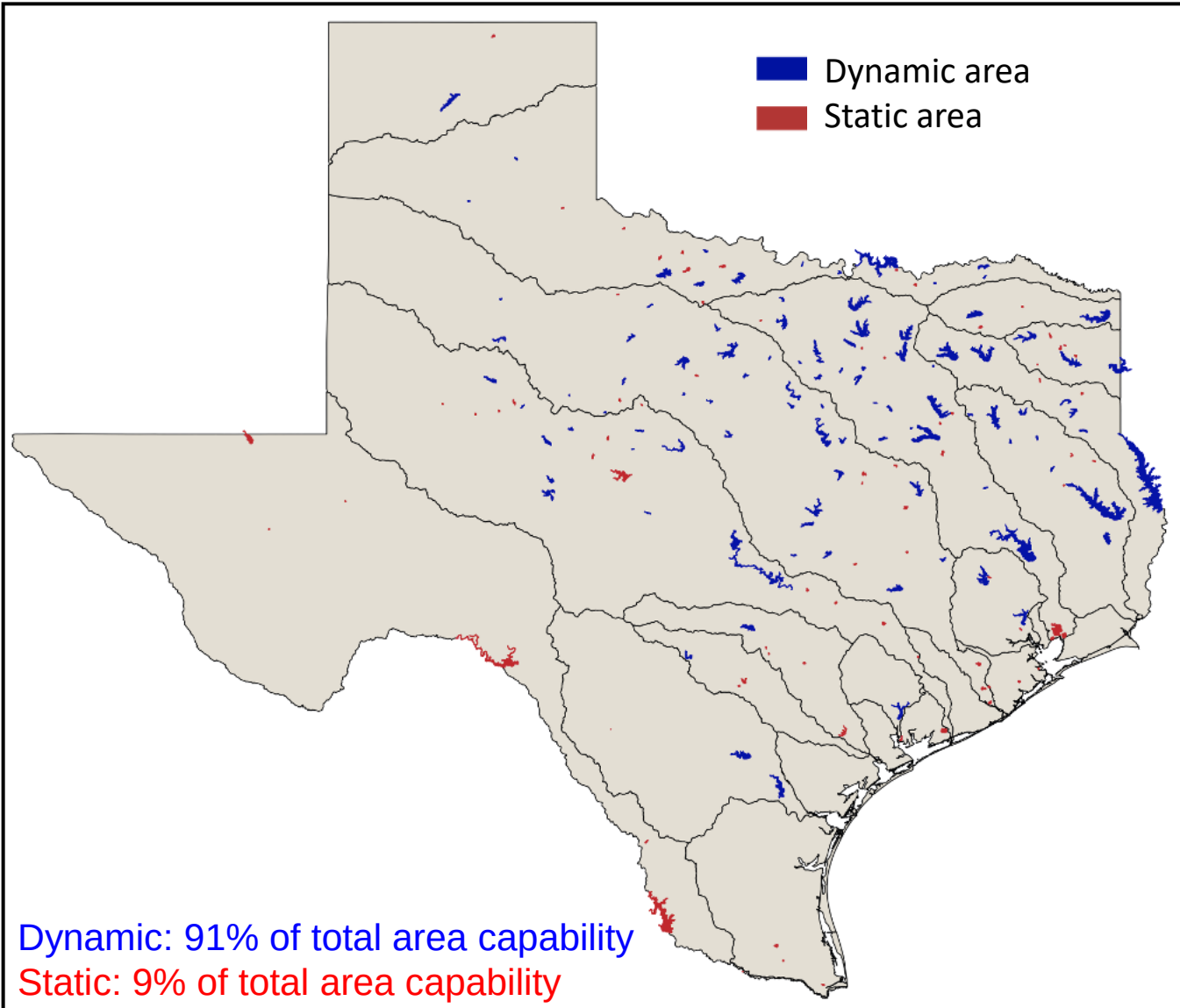
Validation

- There are only limited daily EC measurements available.
- DLEM results show good agreement with EC.
- DLEM results show smaller dynamic ranges over large reservoirs.



(Zhao et al., Water Resources Research, in review)

Main Inputs into DLEM in Texas



Reservoir Datasets:

- Daily average depth
- Daily reservoir Area

Meteorological Data Sources:

- gridMET (Daily; 1980-2015; ~4km)
- RTMA (Daily; 2016-now; ~2.5km)

Meteorological Variables:

- Shortwave radiation
- Air temperature
- Vapor pressure deficit
- Wind speed / direction

TWDB Reservoir Evaporation

Time Step

monthly

Select Reservoir

Select a Reservoir

Start Year

2010

End Year

2023

Historical Evaporation Rate (in/year)☒ Show Gross Evap ☒ Show Net Evap ☒ Show Evap Vol ☒ Show Area ☒ Show Precip

Download Data

Time Step

monthly

[Download Data](#)

Update Link

Start Year

2010

End Year

2023



Click on or Select a Reservoir

Layers

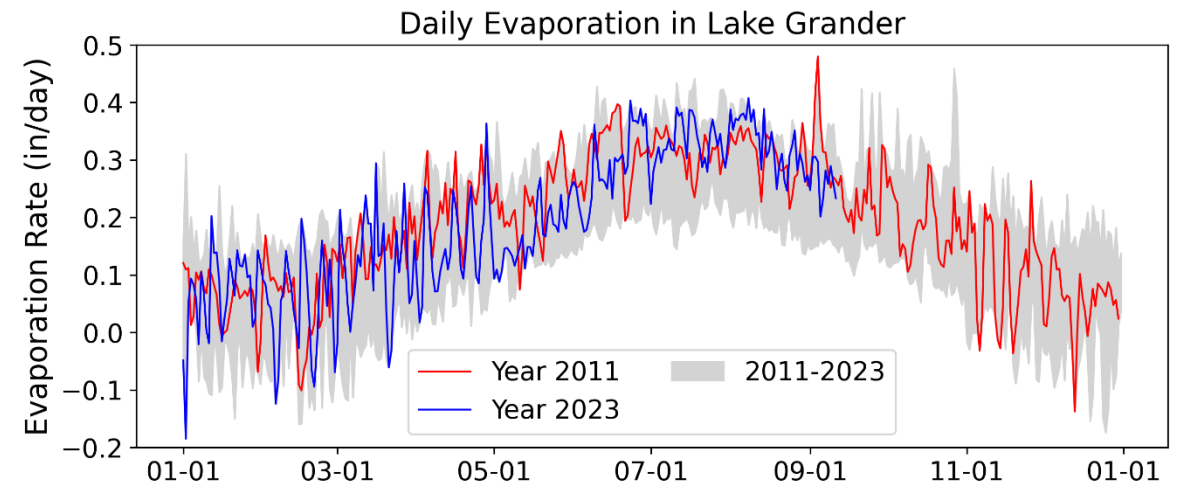
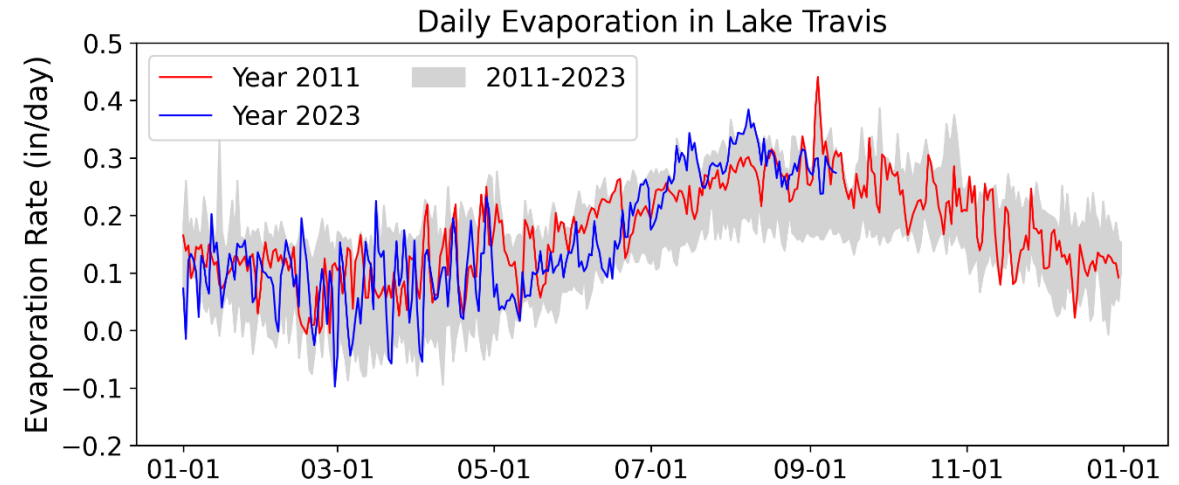
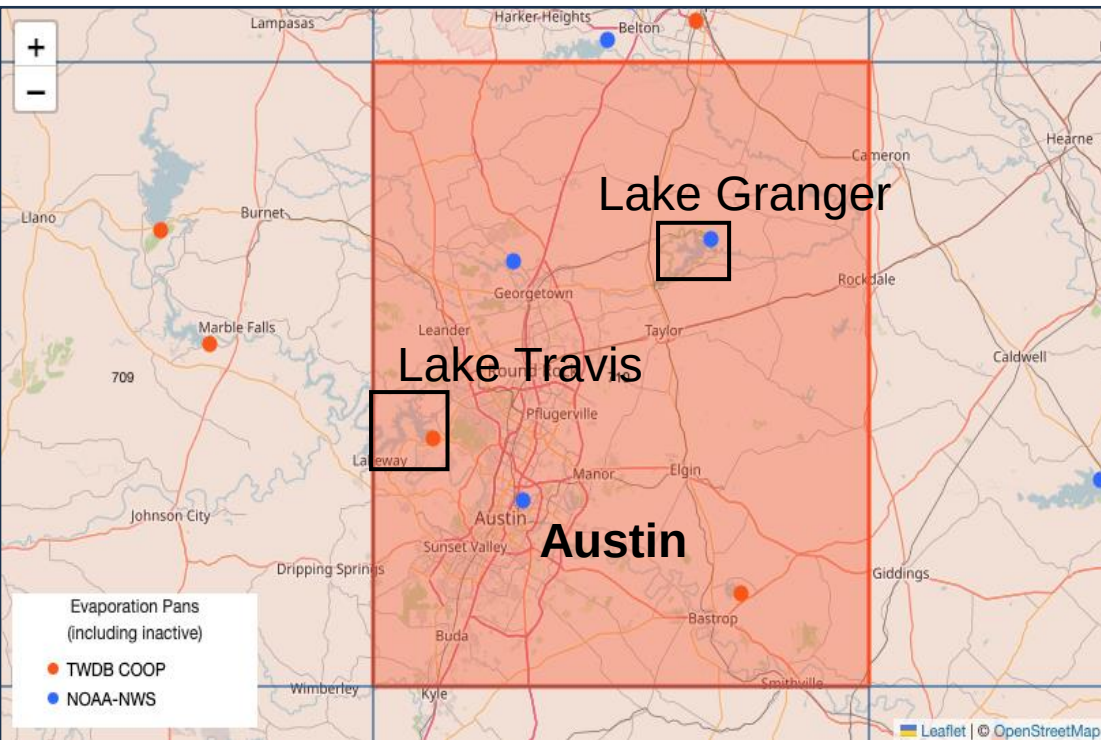
Map

Satellite

Gray

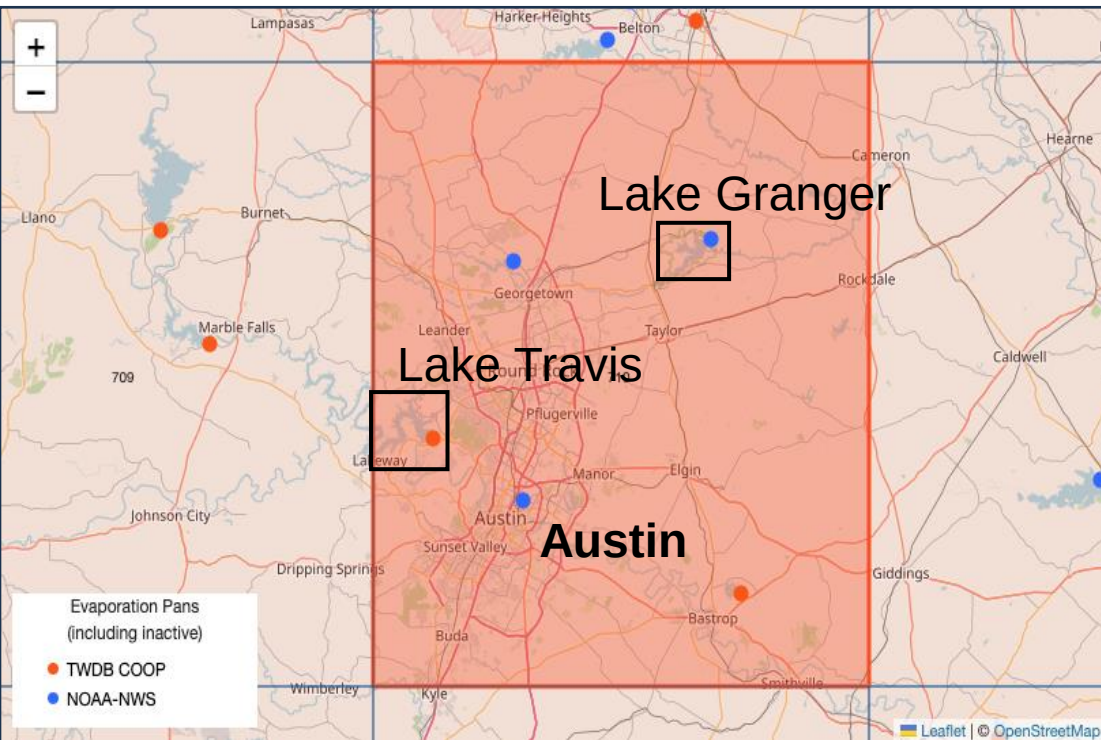
2020

Benefits of Reservoir Specific Daily Evaporation

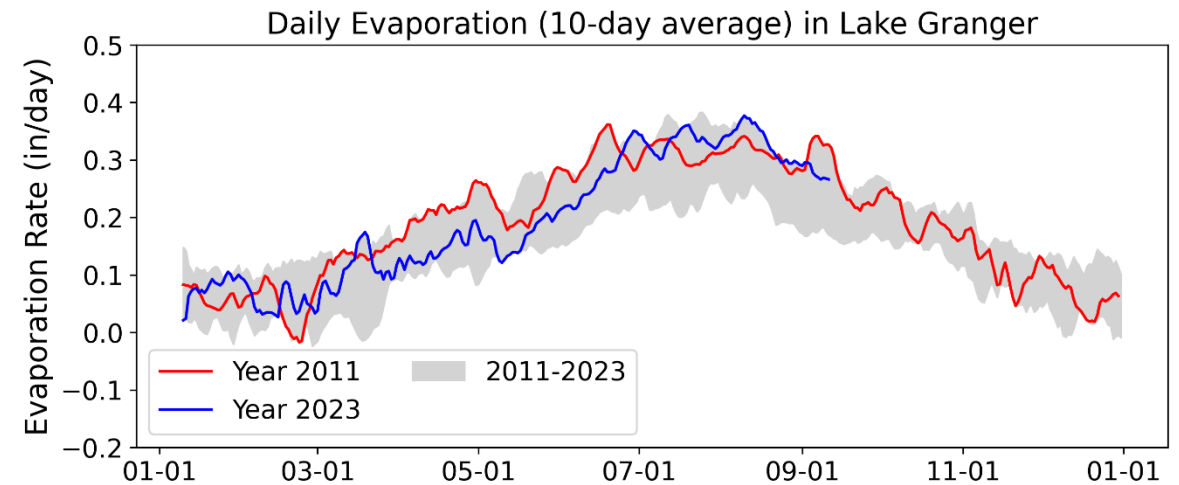
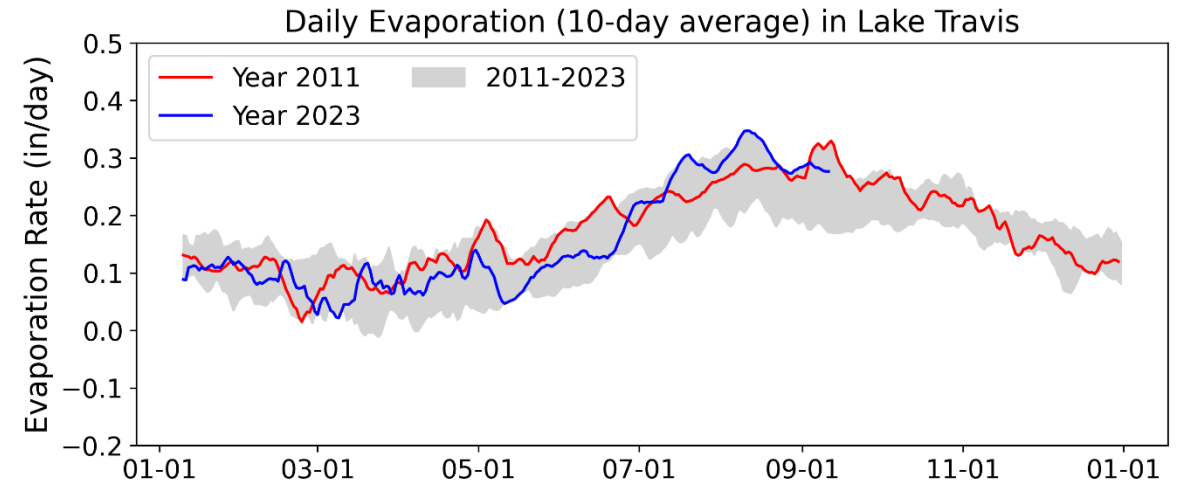


Lake Travis: 19.3 meters (depth), 73 km³ (area).
Lake Granger: 3.8 meters (depth), 17 km³(area).

Benefits of Reservoir Specific Daily Evaporation

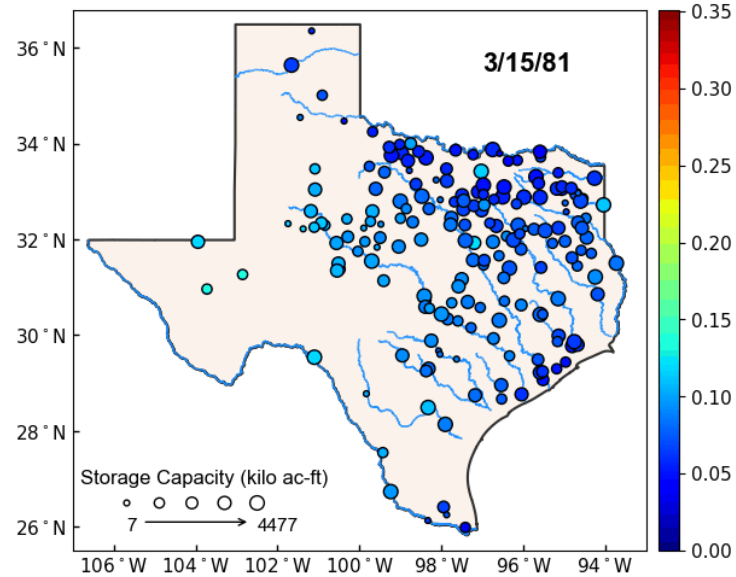


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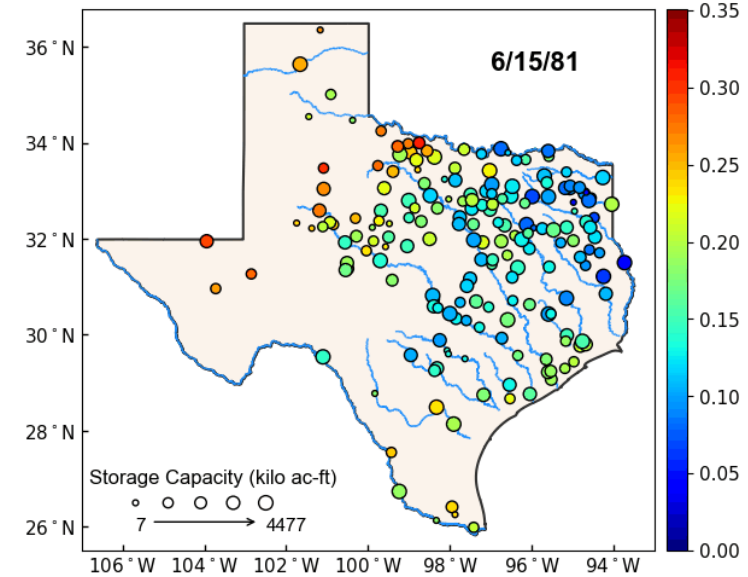


Spatial Pattern of Daily Evaporation

Mid March

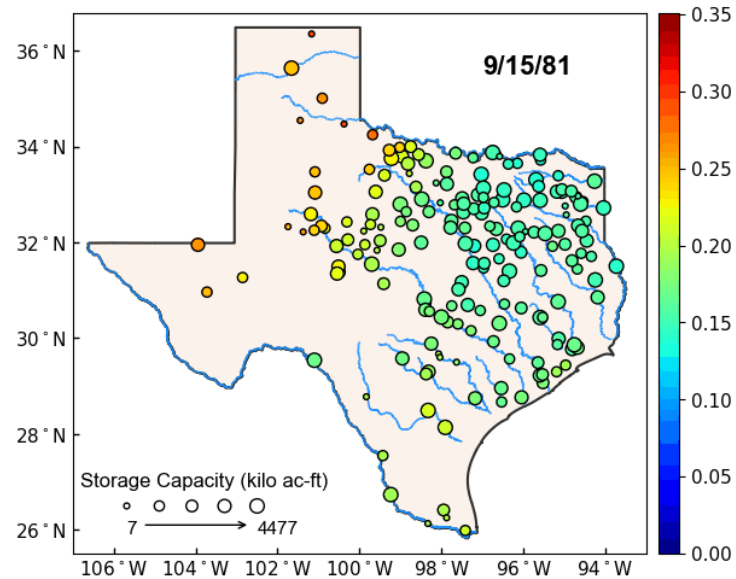


Mid June

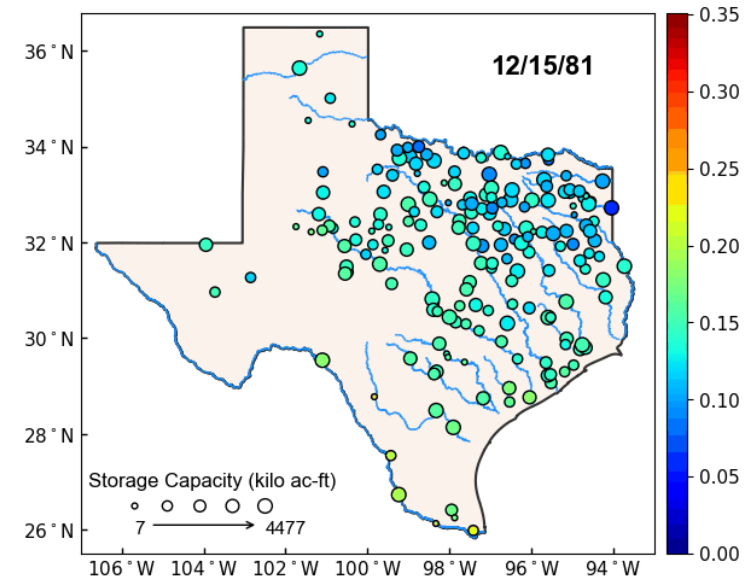


Evaporation Rate (in/d)

Mid September



Mid December

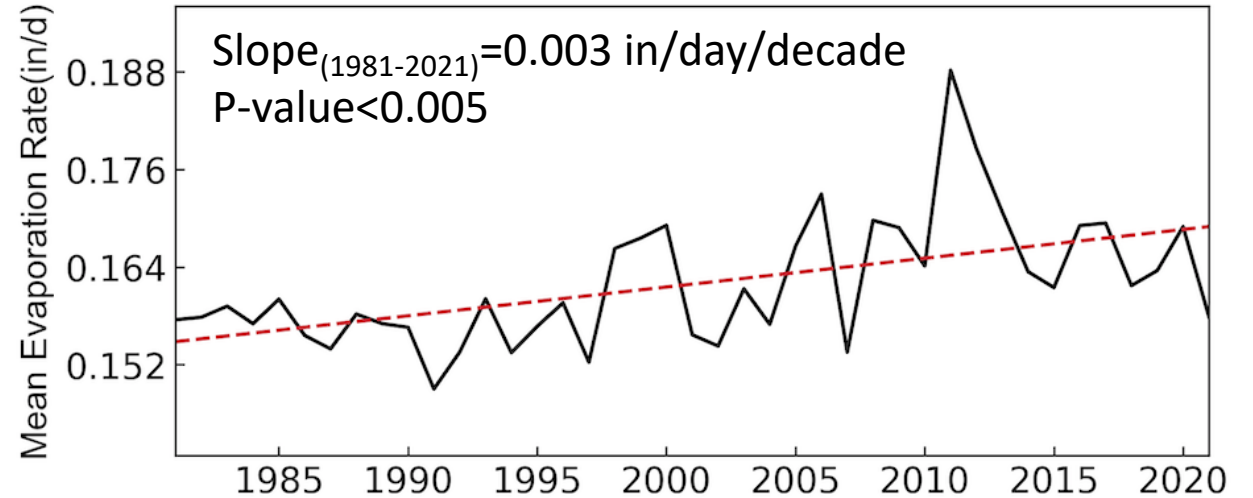


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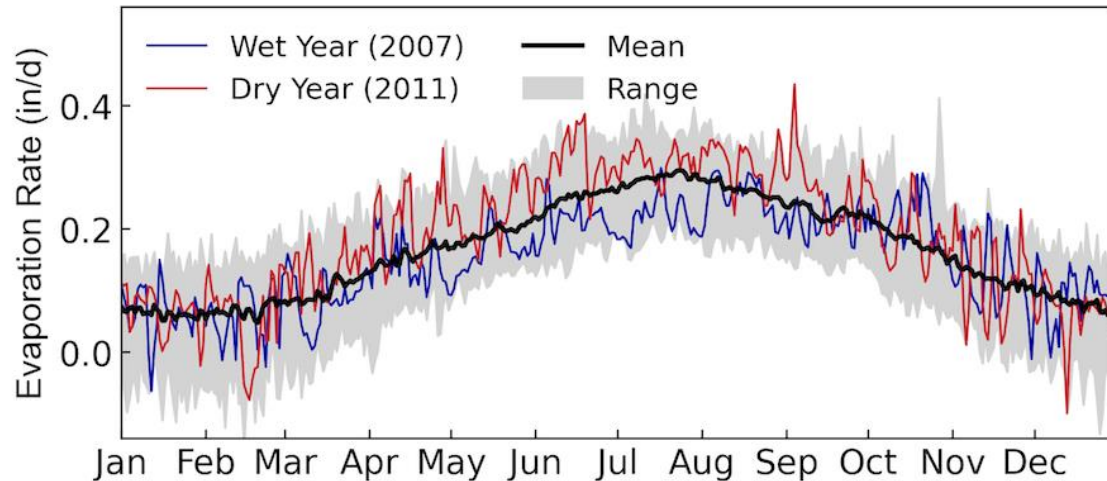
Long-term Trends and Seasonality

- The average annual evaporation rate shows a significant increase from 1980 to 2021, at 0.003 inch/d per decade.
- The daily evaporation variability has also shown an increasing trend.
- July and August have the largest evaporation rates (0.25 inch/day).

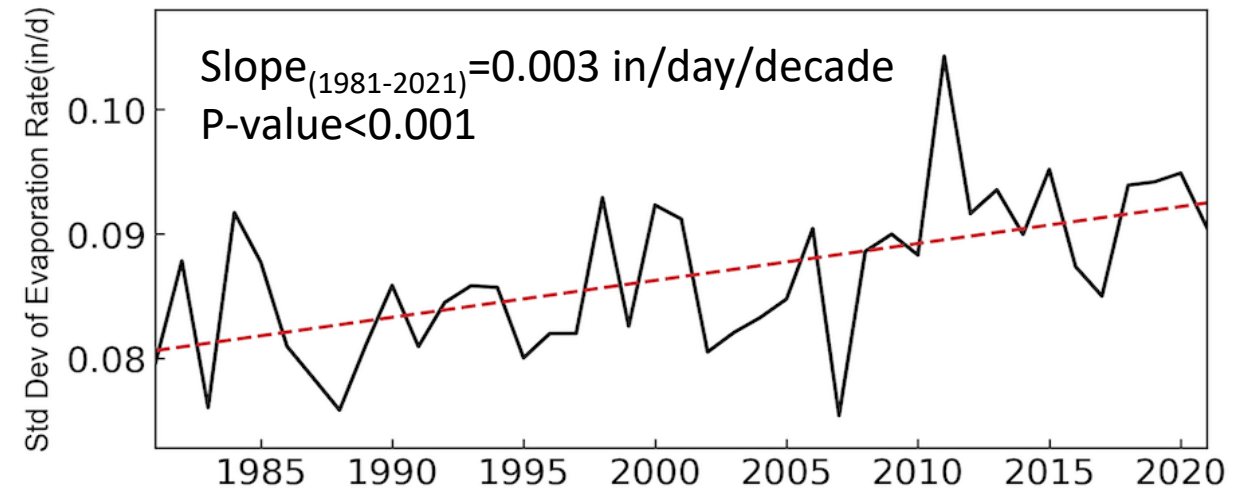
Annual Mean Evaporation



Seasonality



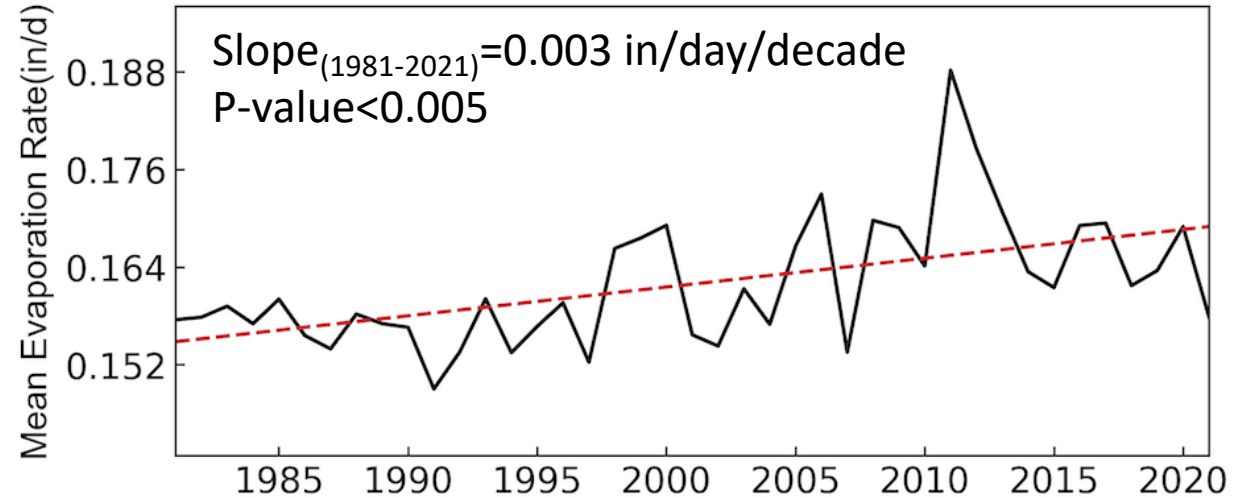
Standard Deviation by Year



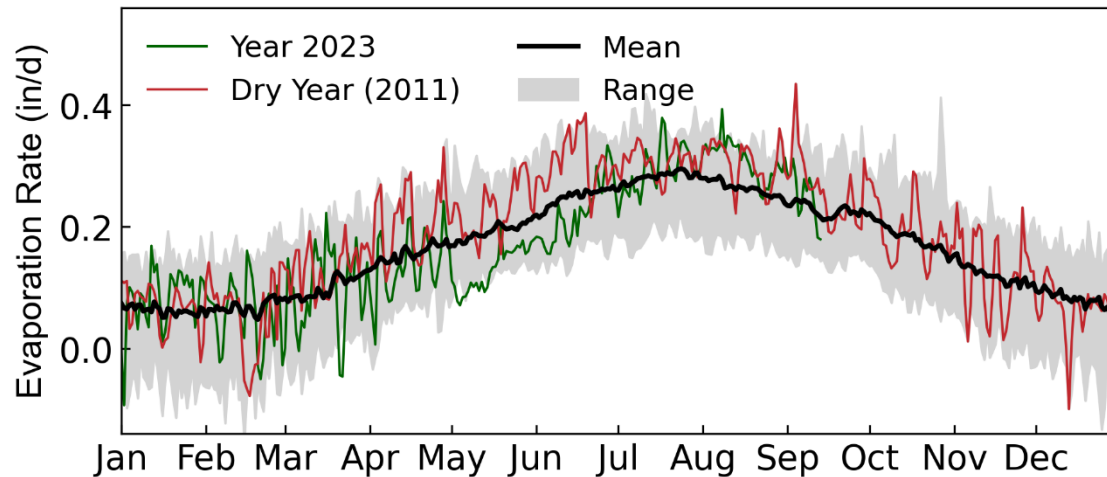
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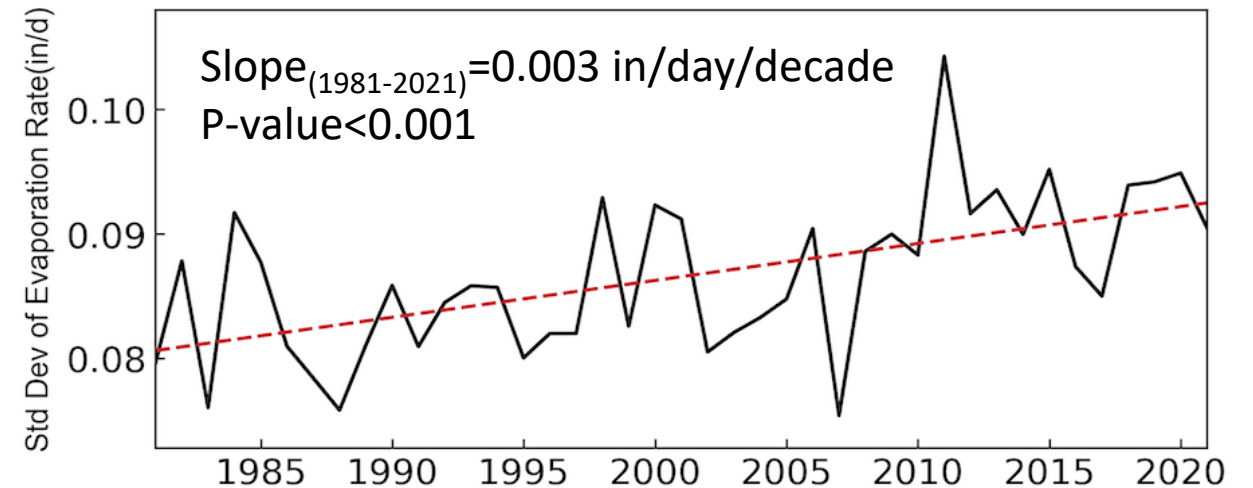
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Seasonality



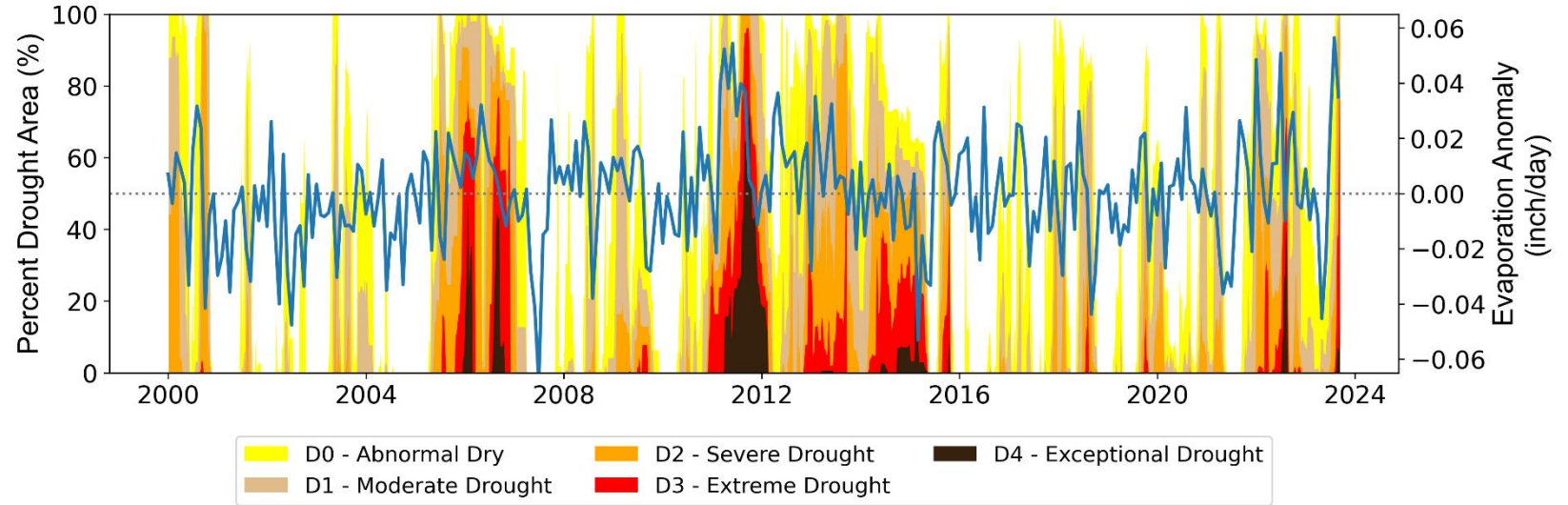
Standard Deviation by Year



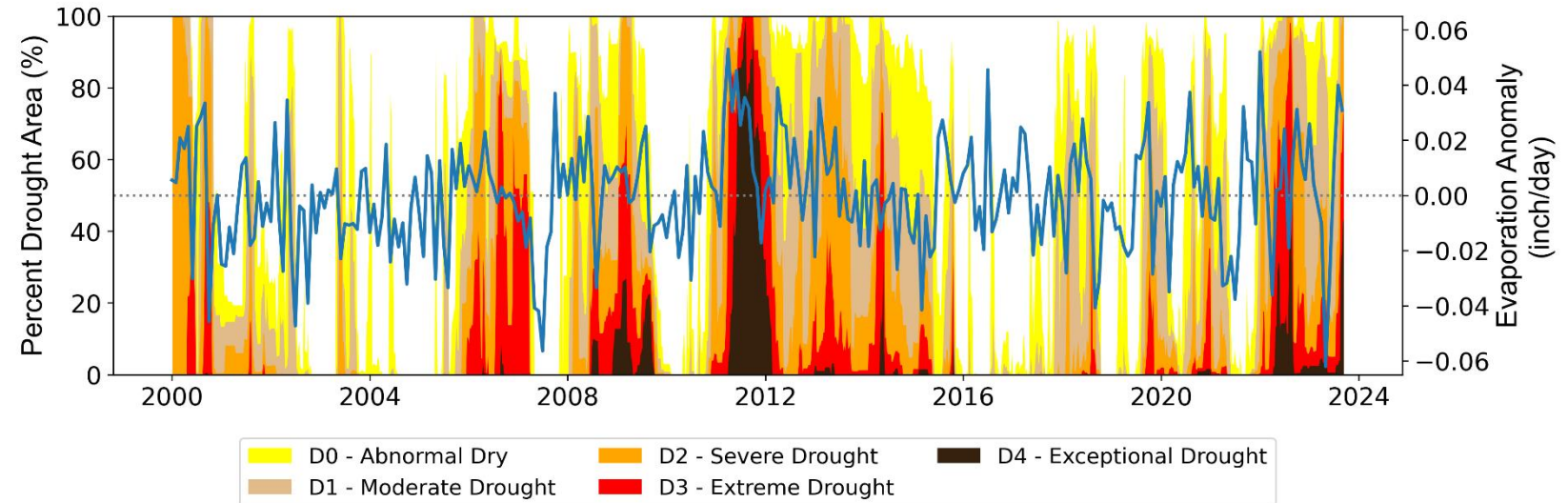
Drought and Reservoir Evaporation



Trinity River Basin



Colorado River Basin

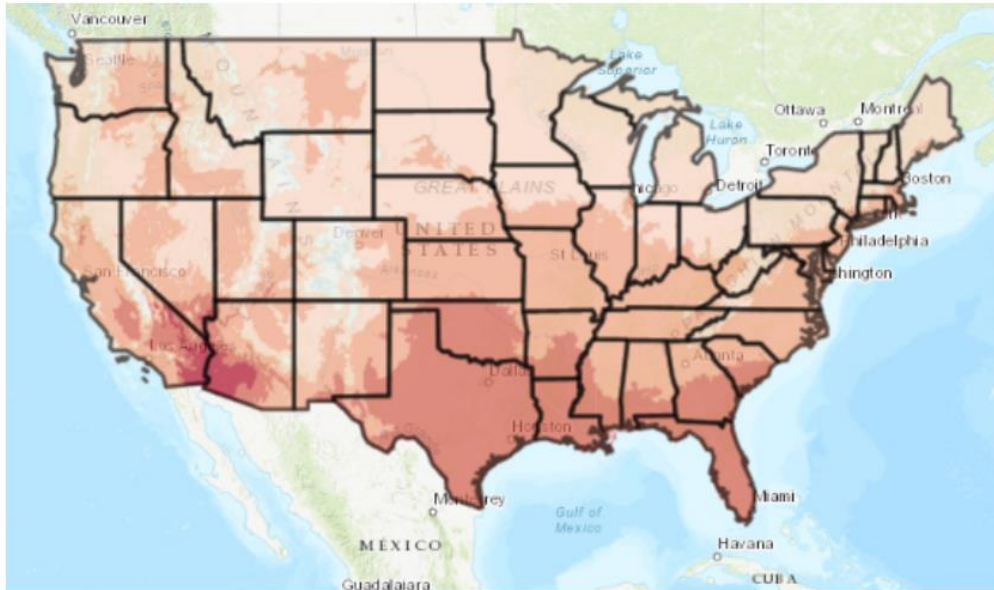


Source: U.S Drought Monitor. (<https://droughtmonitor.unl.edu>)

Sub-seasonal Forecast (30-day)

Subseasonal Weather Forecast Data

The subseasonal weather forecast dataset represents a downscaling of CFSv2 model forecasts for the next 30-days from the most recent 48 runs of the CFSv2 model utilizing statistics from the gridMET climate dataset. The downscaling is done by calculating anomalies from the 1981–2010 base period from CFS, interpolating these anomalies to the gridMET mesh, and applying them to the climatological values in gridMET for the corresponding period.



- gridMET-CFS
 - 30-day forecast
 - Daily timestep
 - Downscaled CFSv2 based on gridMET statistics
 - 4-km resolution, CONUS wide coverage
- Air temperature, radiation, specific humidity, wind, and precipitation.

McEvoy et al. (2016) demonstrated that CFSv2 has skill for evaporative demand forecasting and for use in water management activities.



Geophysical Research Letters

RESEARCH LETTER

10.1002/2015GL067009

Key Points:

- Seasonal forecasts of E_0 often have

Improved seasonal drought forecasts using reference evapotranspiration anomalies

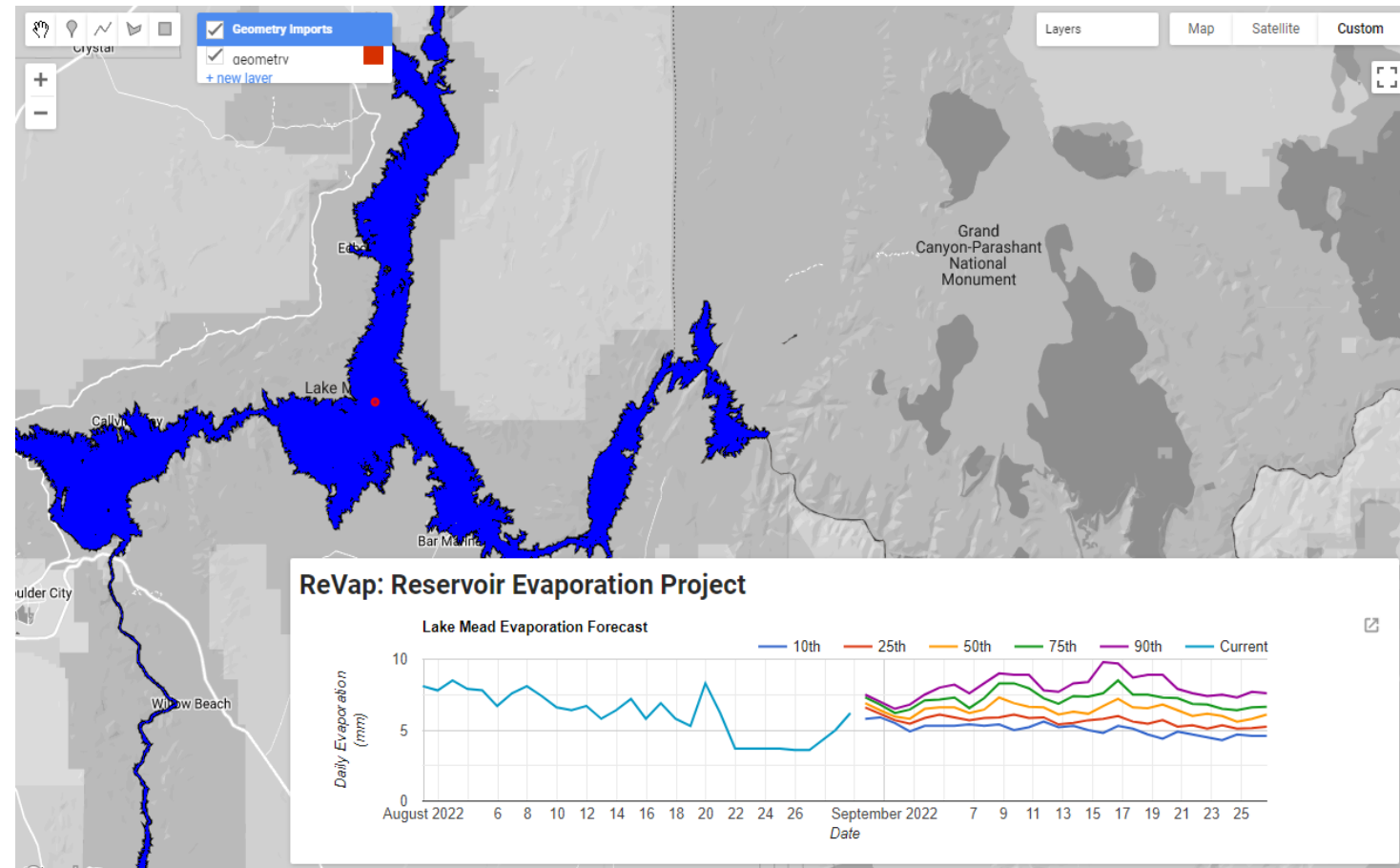
Daniel J. McEvoy^{1,2}, Justin L. Huntington^{1,2}, John F. Mejia¹, and Michael T. Hobbs^{3,4}

Sub-seasonal Forecast (30-day)

Each reservoir will be simulated with climate forecast datasets to produce an ensemble of evaporation estimates

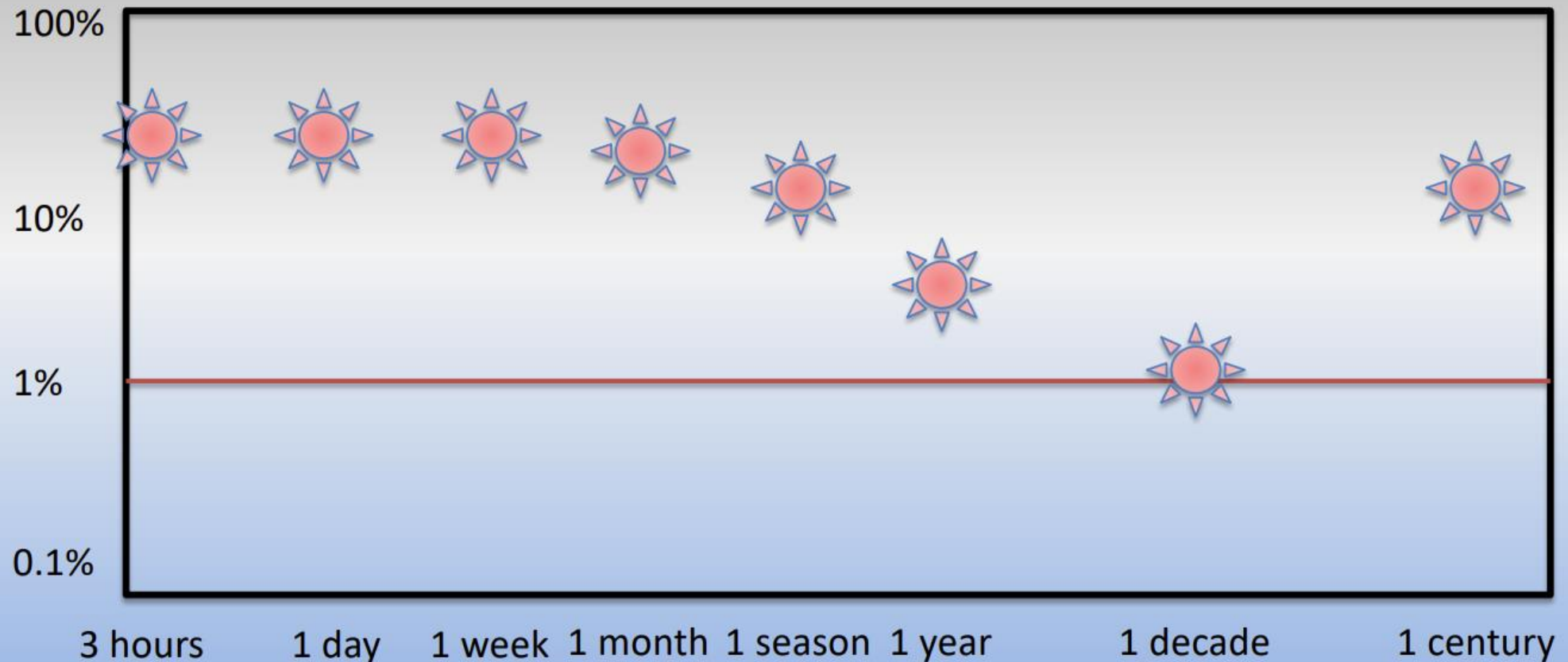
- CFS-gridMET: 48 scenarios
- Range of possible conditions
- Ensembles can be aggregated

E.g. 10th, 25th, median, 75th, 90th



Seasonal Forecast Skills

Maximum Predictable Probability?
(100-y drought in a given year)



Summary

- The Daily Lake Evaporation Model (DLEM) has been developed for monitoring daily evaporation over both large reservoirs and small ponds in Texas from 1980 to present (3-day lag).
- With heat storage represented, the reservoir specific daily evaporation can provide new information which evaporation pan based estimations are unable to offer.
- The corresponding evaporation web application offers easy access for water resource managers and stakeholders.
- Subseasonal forecasting of daily reservoir evaporation (30-day lead time) is under development.
- Seasonal reservoir evaporation forecasts (e.g., 6-12mo) are likely to benefit FIRO, especially under drought conditions.

Contact: Huilin Gao (hgao@tamu.edu)

Reference:

Zhao, G., & Gao, H. (2019). Estimating reservoir evaporation losses for the United States: Fusing remote sensing and modeling approaches. *Remote sensing of Environment*, 226, 109-124.

Zhu, J., PG, N. F., & Guthrie, C. G. (2021). Evaporative Losses from Major Reservoirs in Texas.

McEvoy, D. J., Huntington, J. L., Mejia, J. F., & Hobbins, M. T. (2016). Improved seasonal drought forecasts using reference evapotranspiration anomalies. *Geophysical Research Letters*, 43(1), 377-385.

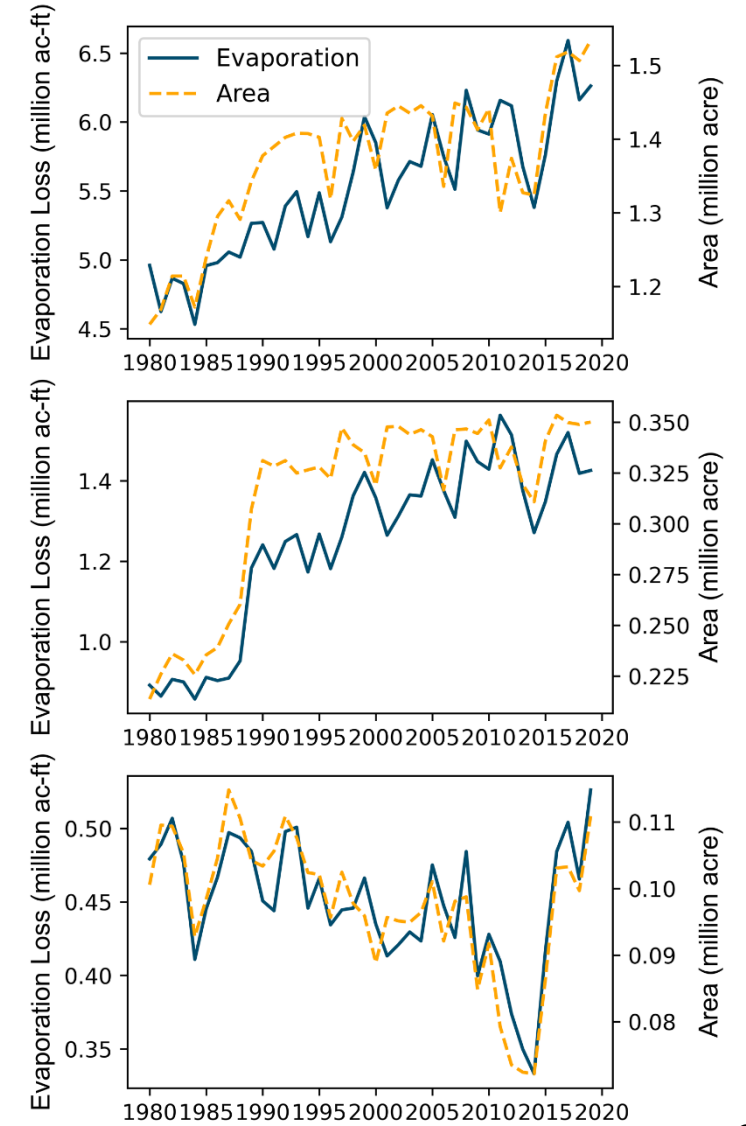
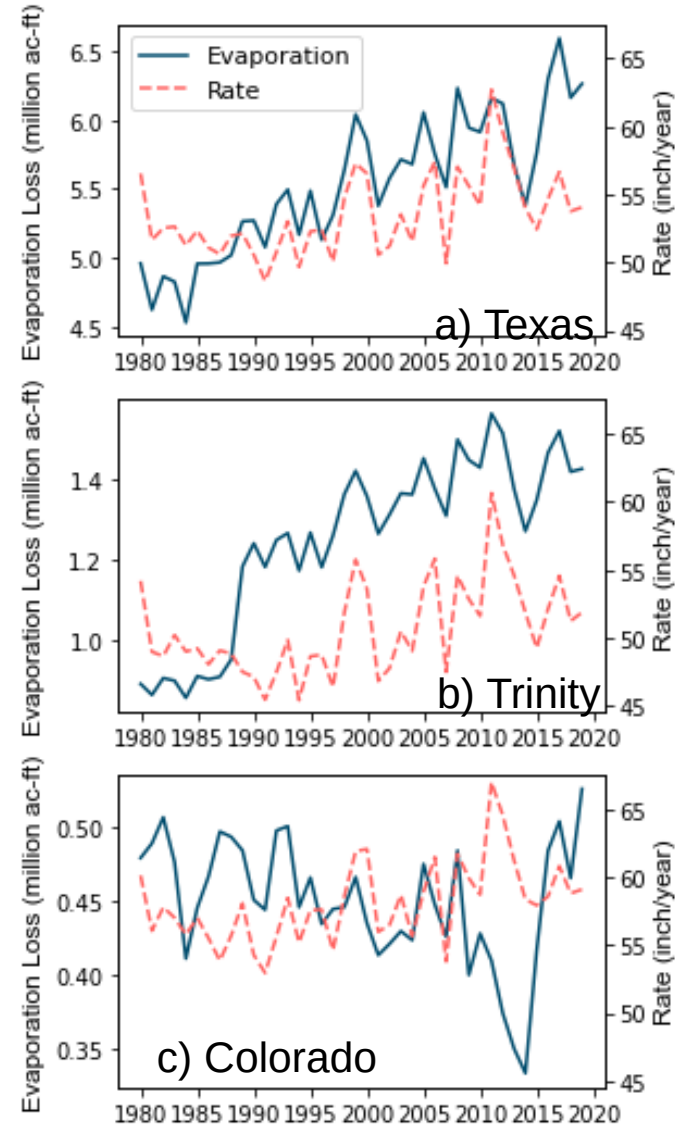
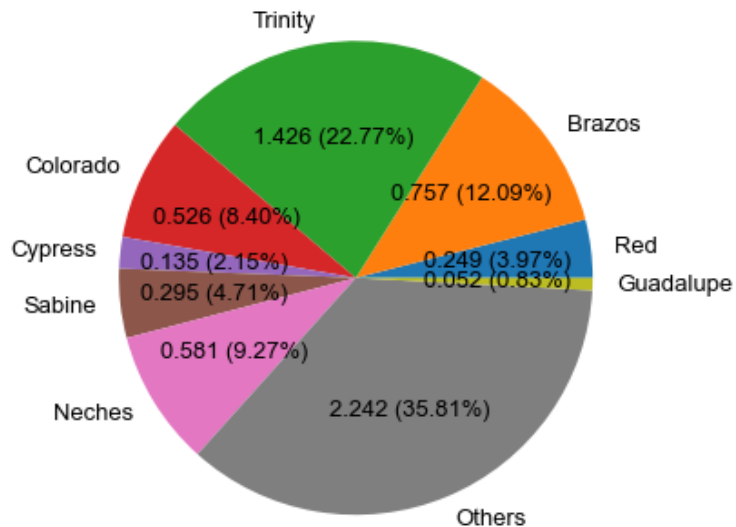
Zhao et al., Developing a Daily Lake Evaporation Model and Generating a Long-term Daily Reservoir Evaporation Dataset in Texas. *Water Resource Research*. (under review).

Texas Evaporation Analysis

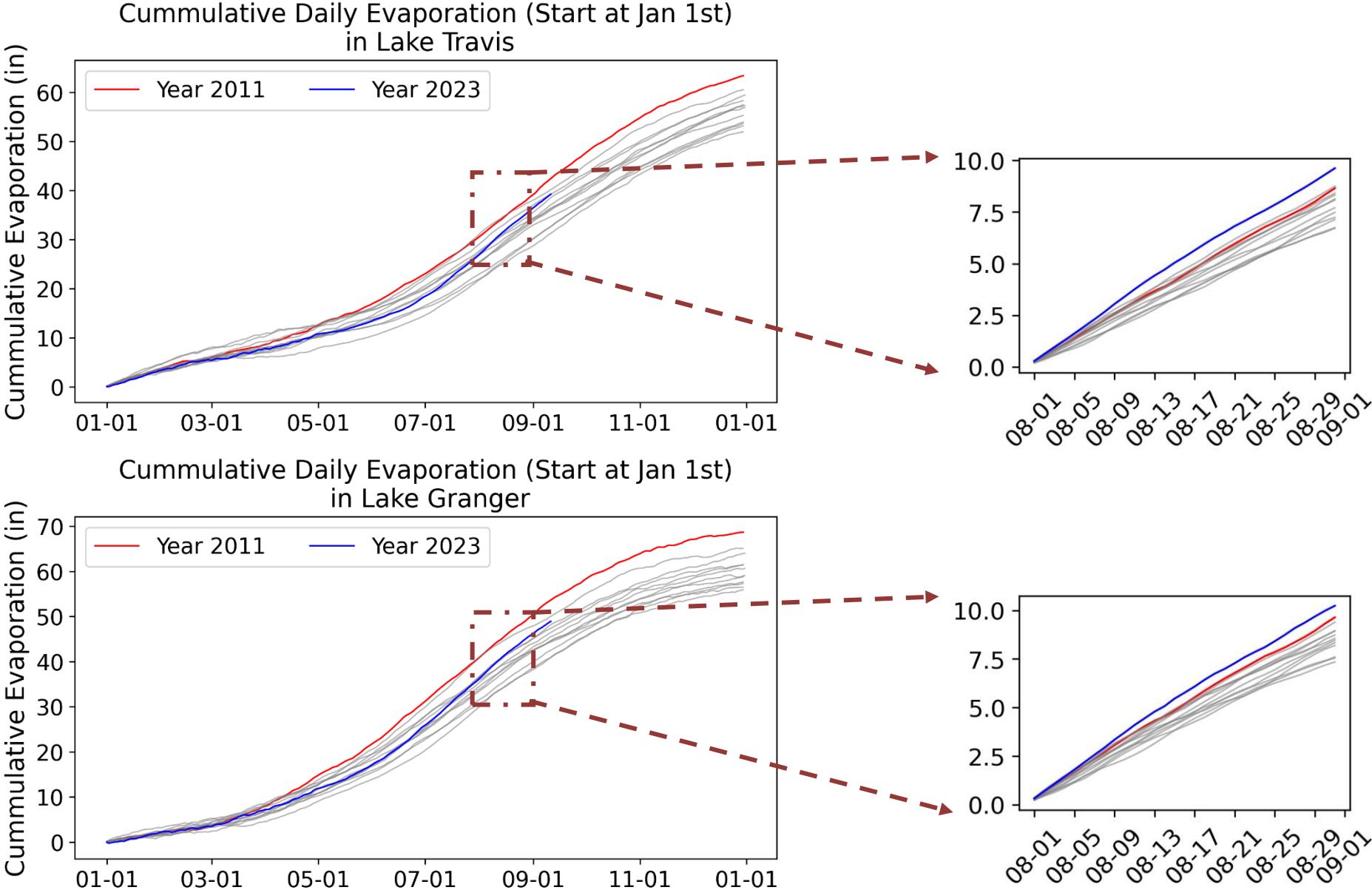
Texas regional evaporation trend analysis

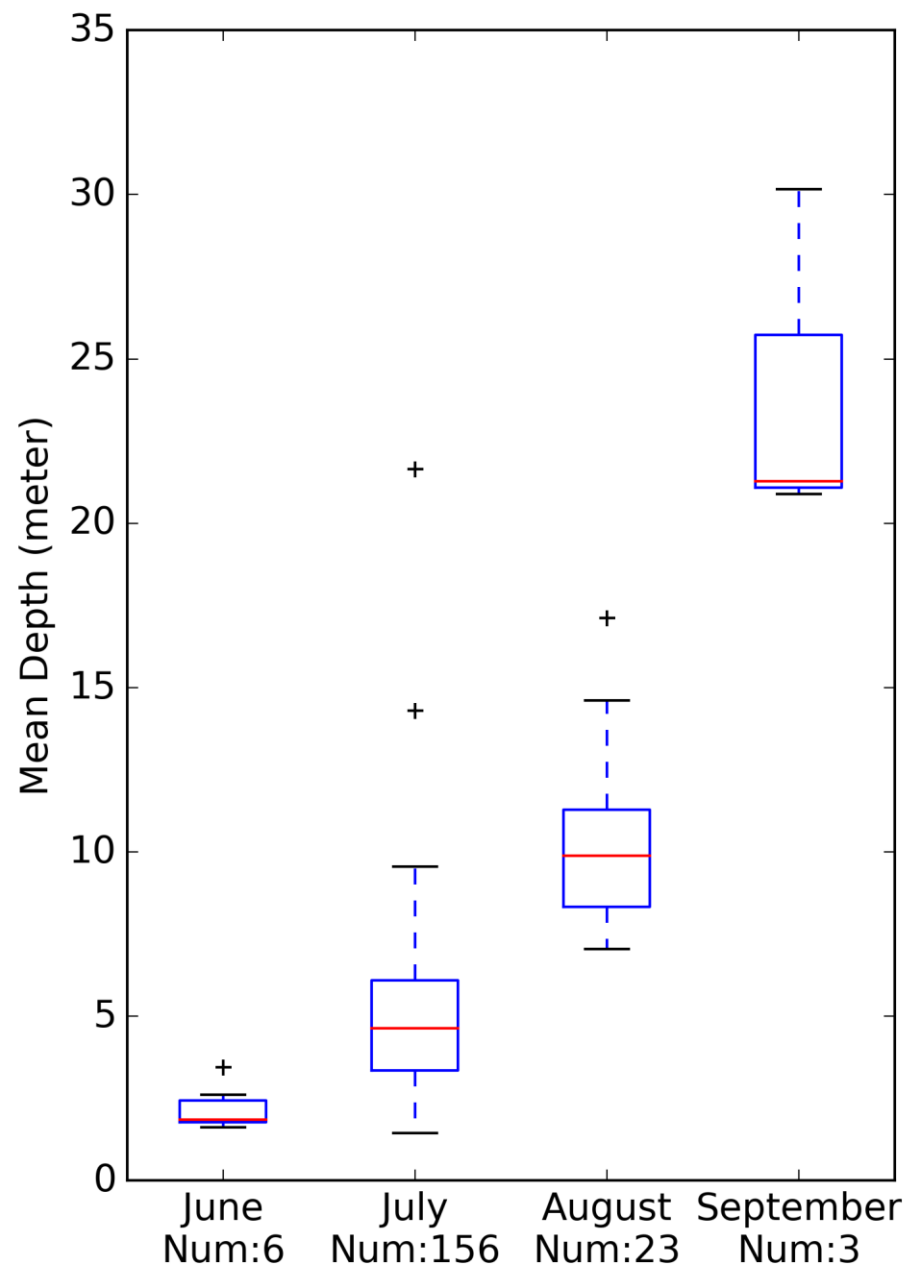


Evaporation Volume (million ac-ft)



Cumulative Daily Evaporation





Average Depth(m)

