Developing a Long-term Global Reservoir Product Series by Fusing Multi-Satellite Observations

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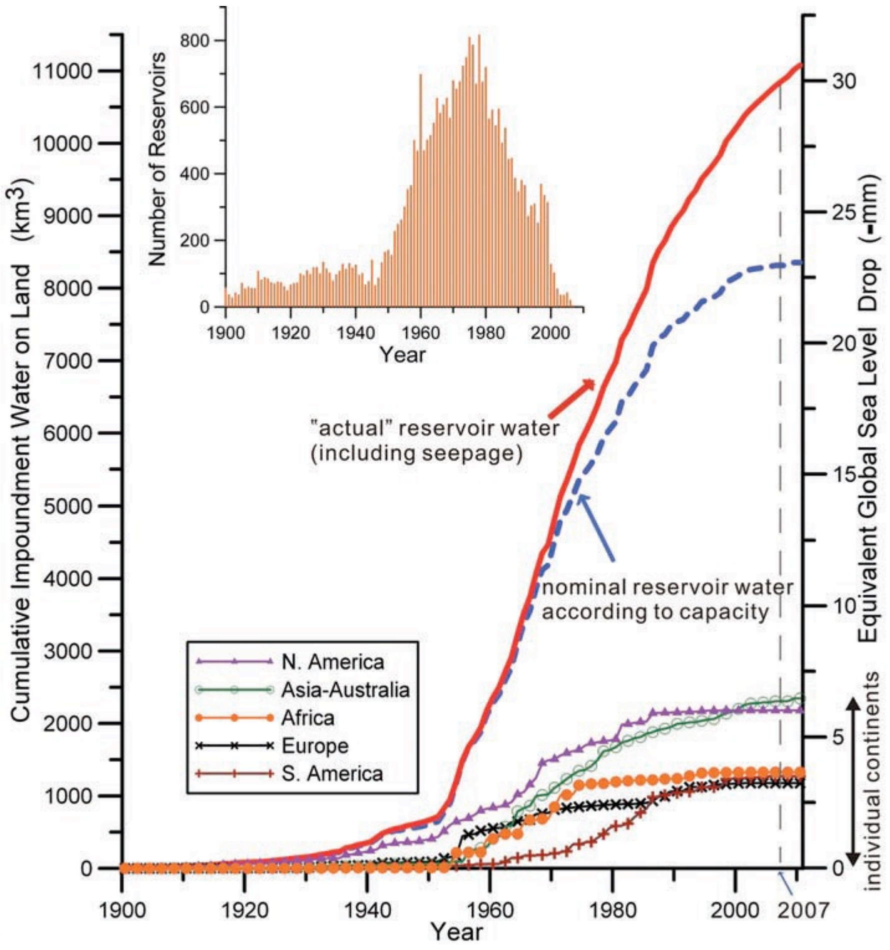
TEXAS A&M UNIVERSITY

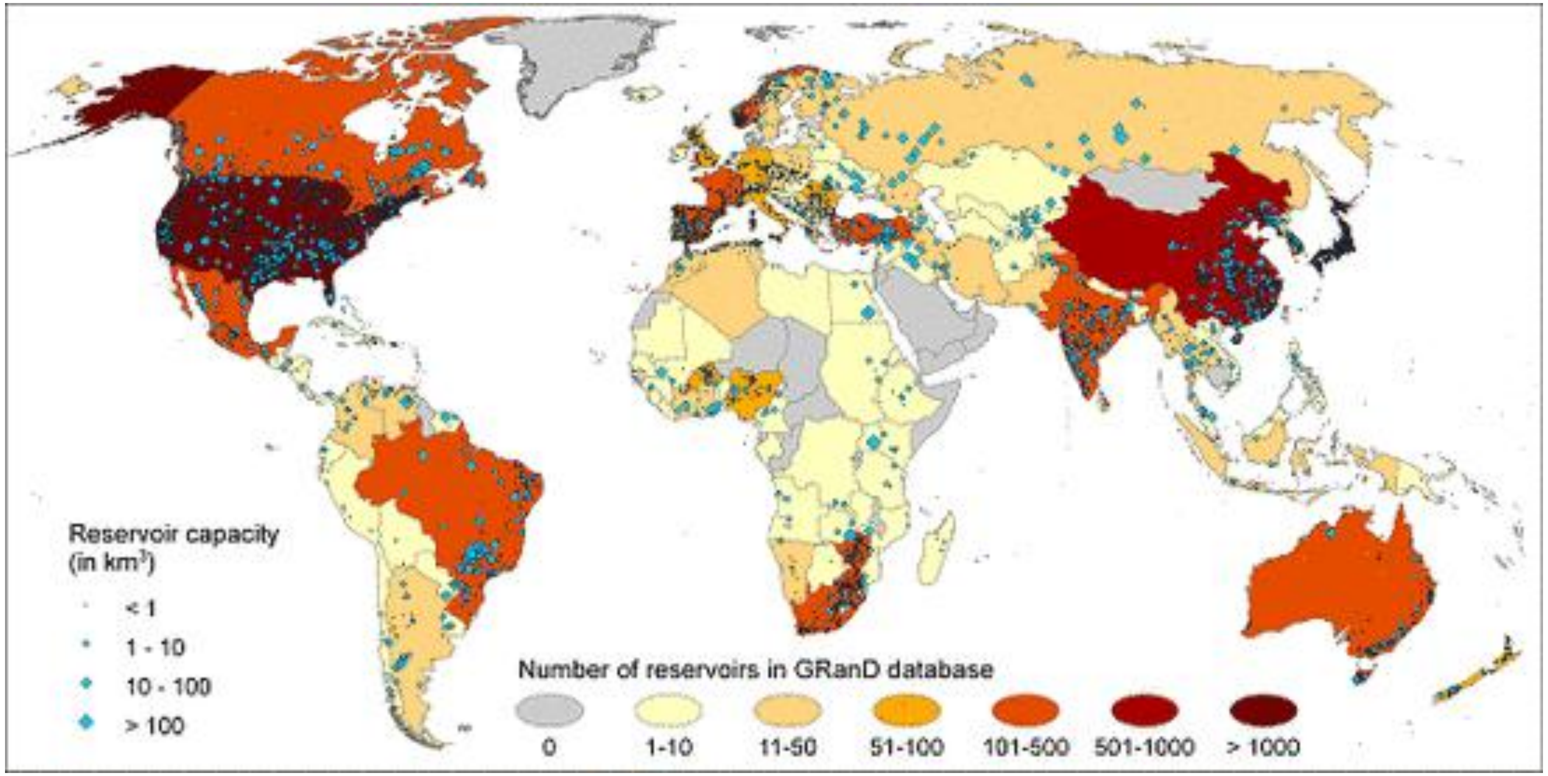
Global Reservoirs



Chao et al., 2008

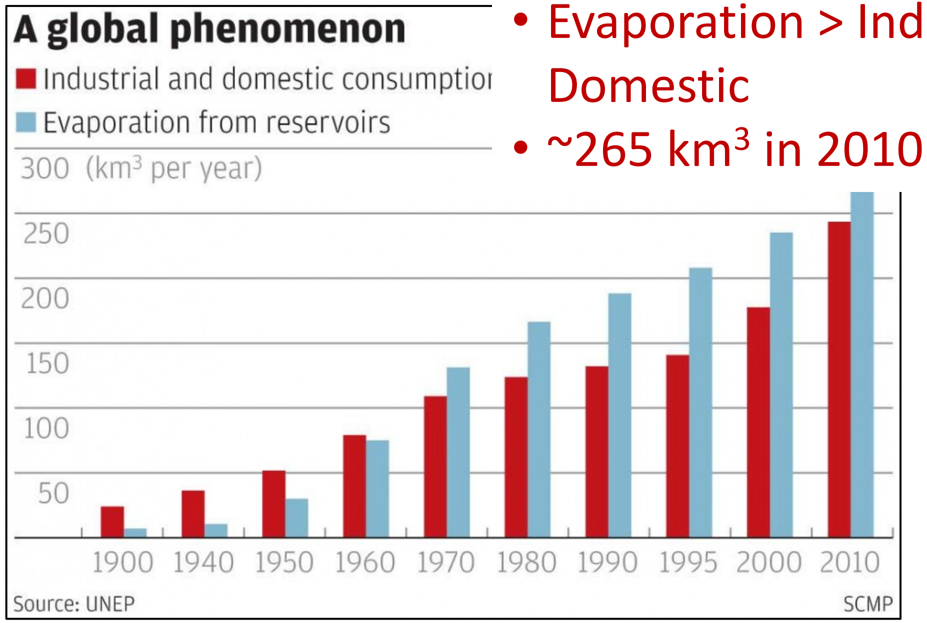
Global Reservoir and Dam (GRanD) Database

Global capacity > 6200 km^3



Lehner et al., 2011

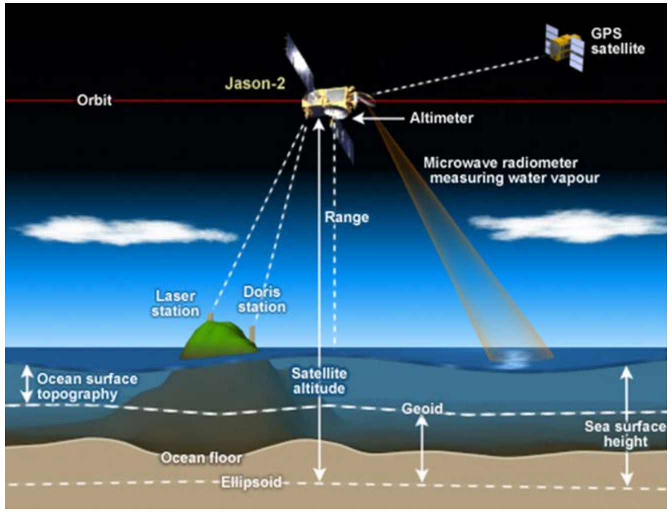
Reservoir Storage vs. Reservoir Evaporation

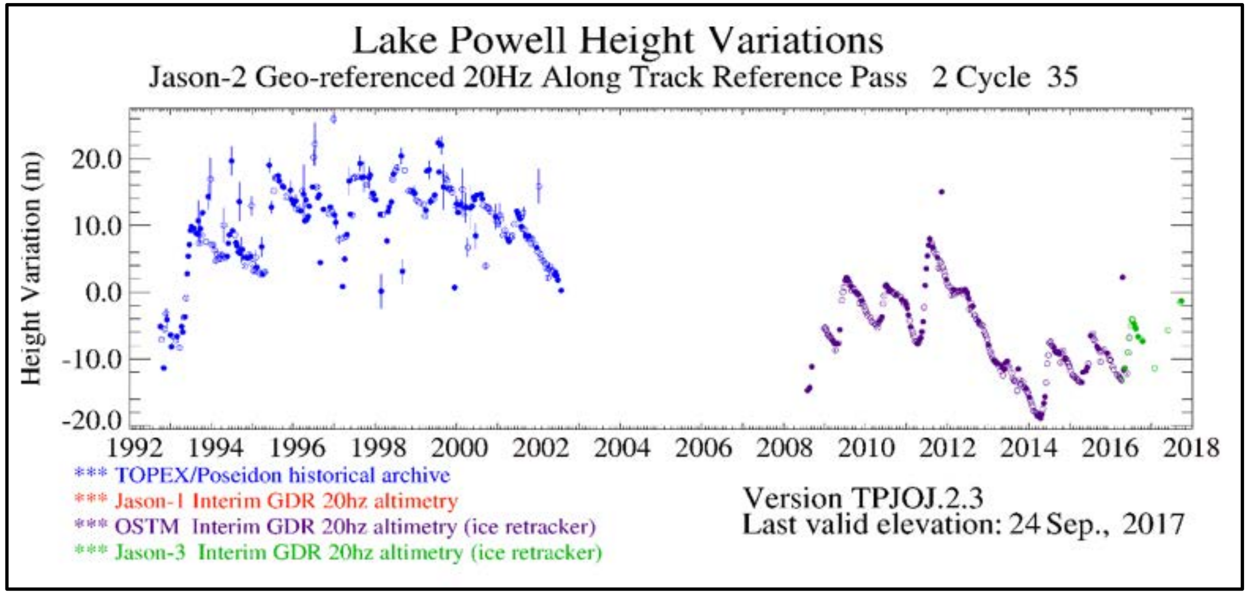


- Evaporation > Industrial + Domestic
- ~265 km^3 in 2010

- Lake Mead annual evaporation =791,000 acre-feet

Motivation





RESERVOIR EVAPORATION IN THE WESTERN UNITED STATES

Current Science, Challenges, and Future Needs

Friedrich et al., 2017 **BAMS**

FUTURE NEEDS.
Uniform, coherent, and long-term measurements.

Reservoir evaporation represents a substantial loss of available water. Improved understanding, estimation, and forecasting of evaporation rates will help to manage this water loss more efficiently, particularly when water is scarce.

Objectives

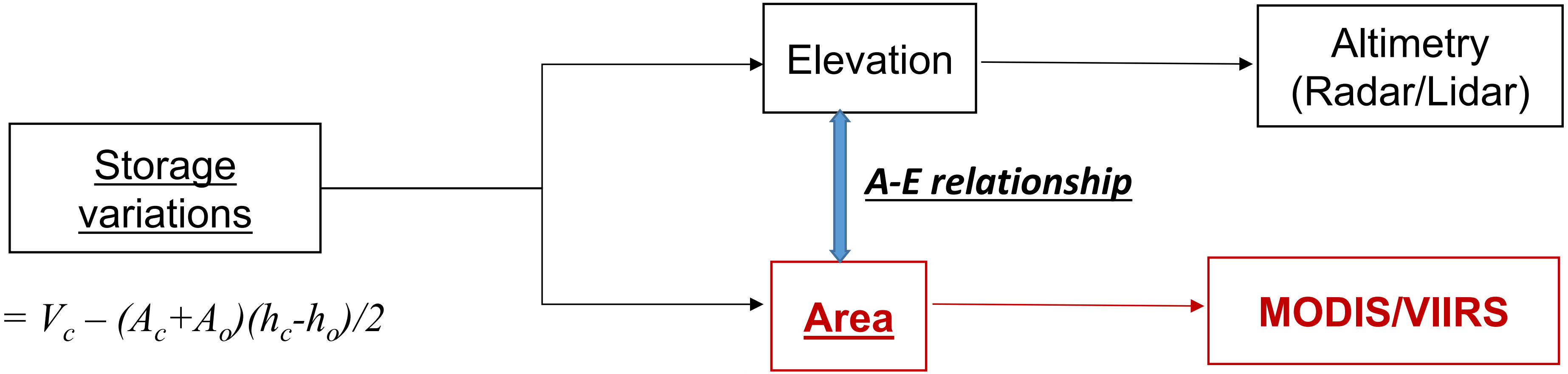
To generate ***a comprehensive, coherent, and long term global reservoir product series*** at improved spatial coverage (and at improved temporal resolution) by combining **MODIS/VIIRS** observations with data from other satellite sensors.

- Develop a long term reservoir storage variation dataset under all-weather conditions.

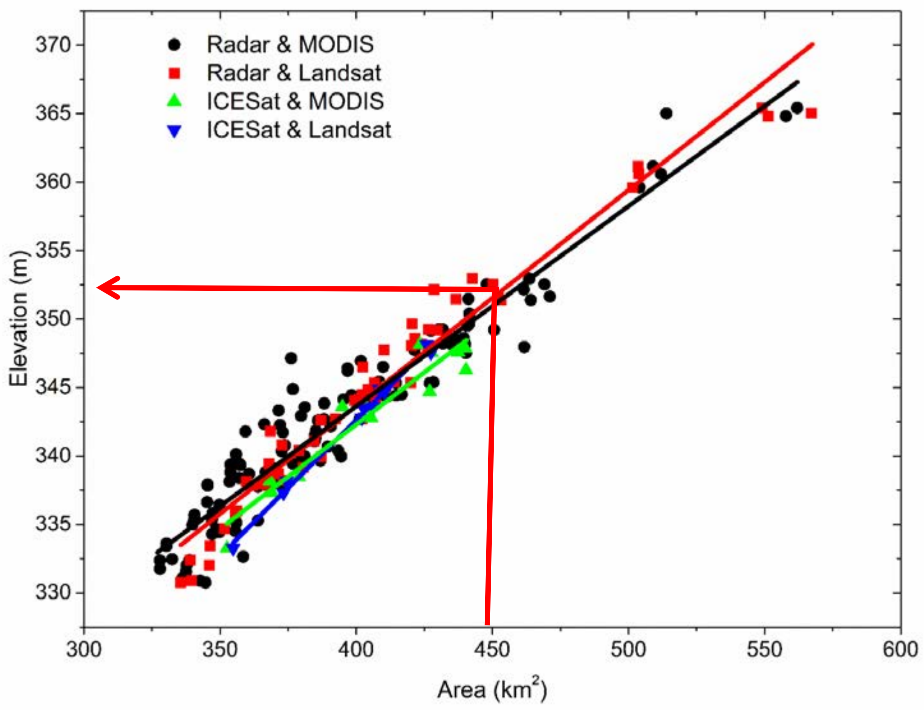
- Generate a **first** long term record of the reservoir evaporation rate and the evaporation loss.

- Validate the reservoir product series and quantify the uncertainties associated with the datasets.

Reservoir Storage Variations



$$V_o = V_c - (A_c + A_o)(h_c - h_o)/2$$

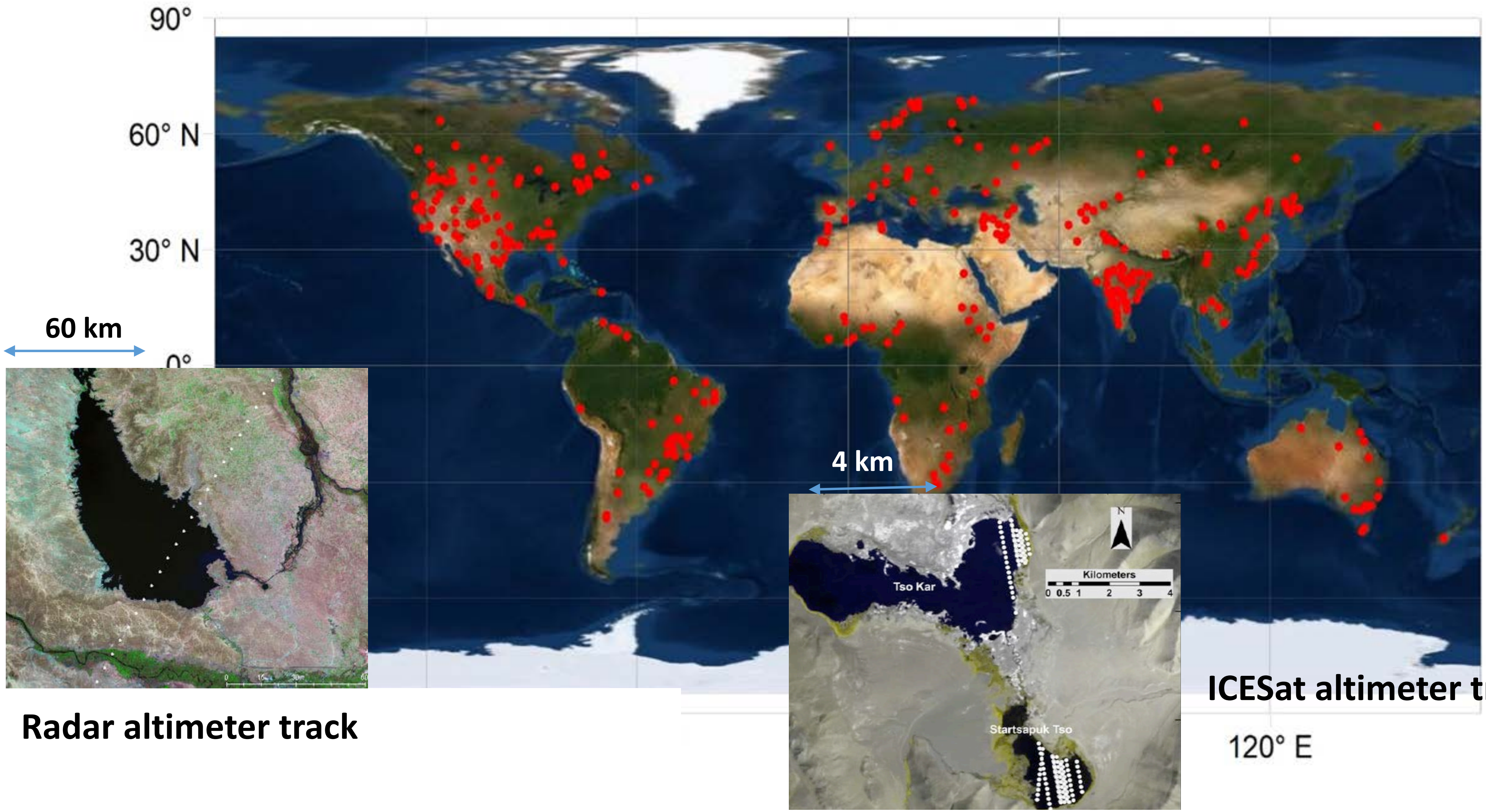


A-E relationship at Lake Mead

Satellite combination	A-E relationship	Sample number	R^2
Radar-MODIS (RM)	y = 0.146x + 285.18	118	0.92
Radar-Landsat (RL)	y = 0.158x + 280.57	58	0.96
ICESat-MODIS (IM)	y = 0.152x + 281.33	14	0.91
ICESat-Landsat (IL)	y = 0.199x + 263.15	10	0.99

Spatial Coverage of the Dataset

347 reservoirs (3123 km^3, 50% of global capacity)



60 km

Radar altimeter track

4 km

ICESat altimeter track

Algorithm for Bathymetry (A-E relationship)

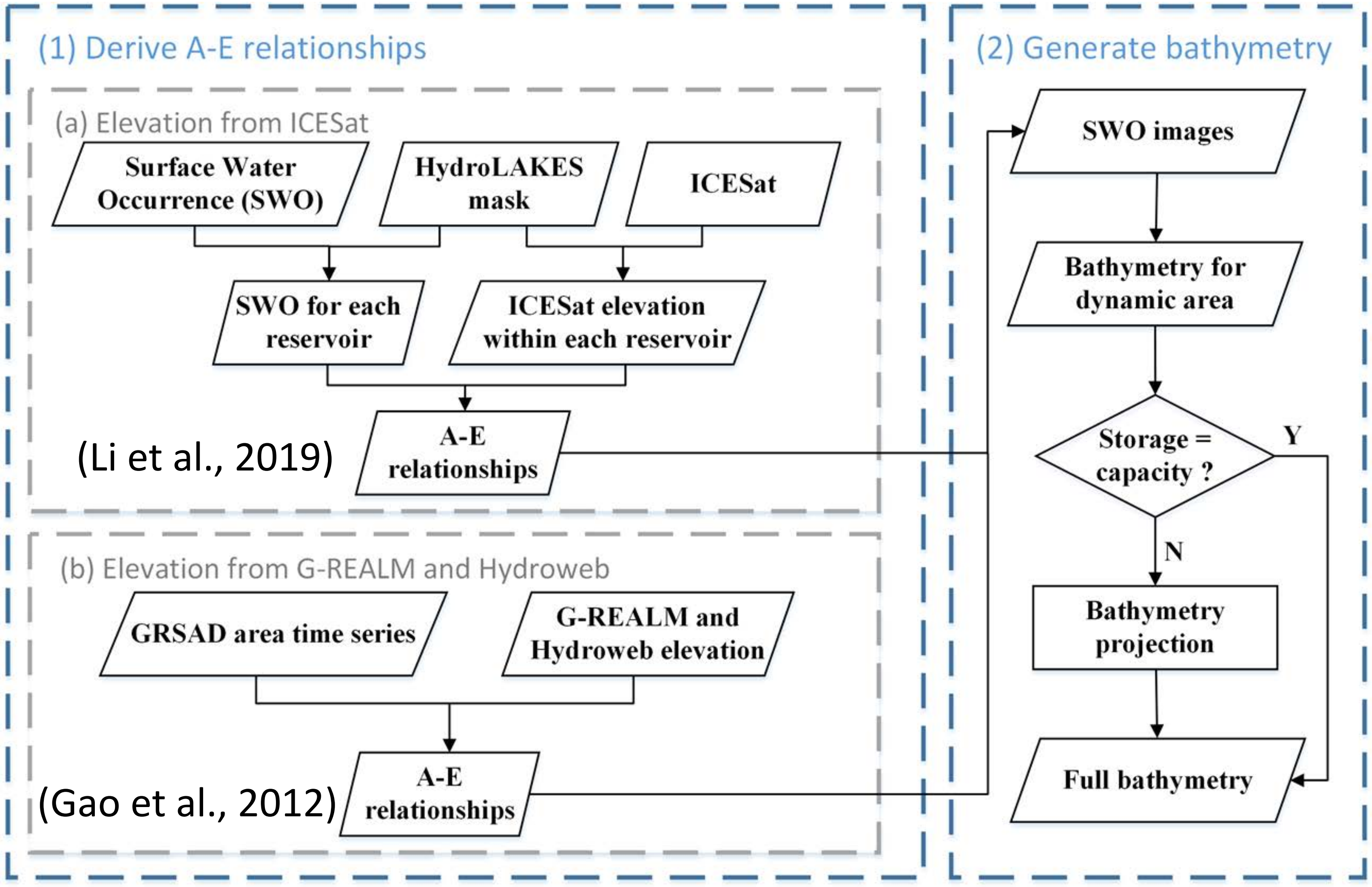
Data

Landsat-based water classfications

- Surface Water Occurrence (SWO) from Global Surface Water (GSW) dataset (Pekel et al., 2016)
- Global Reservoir Surface Area Dataset (GRSAD) (Zhao and Gao, 2018)

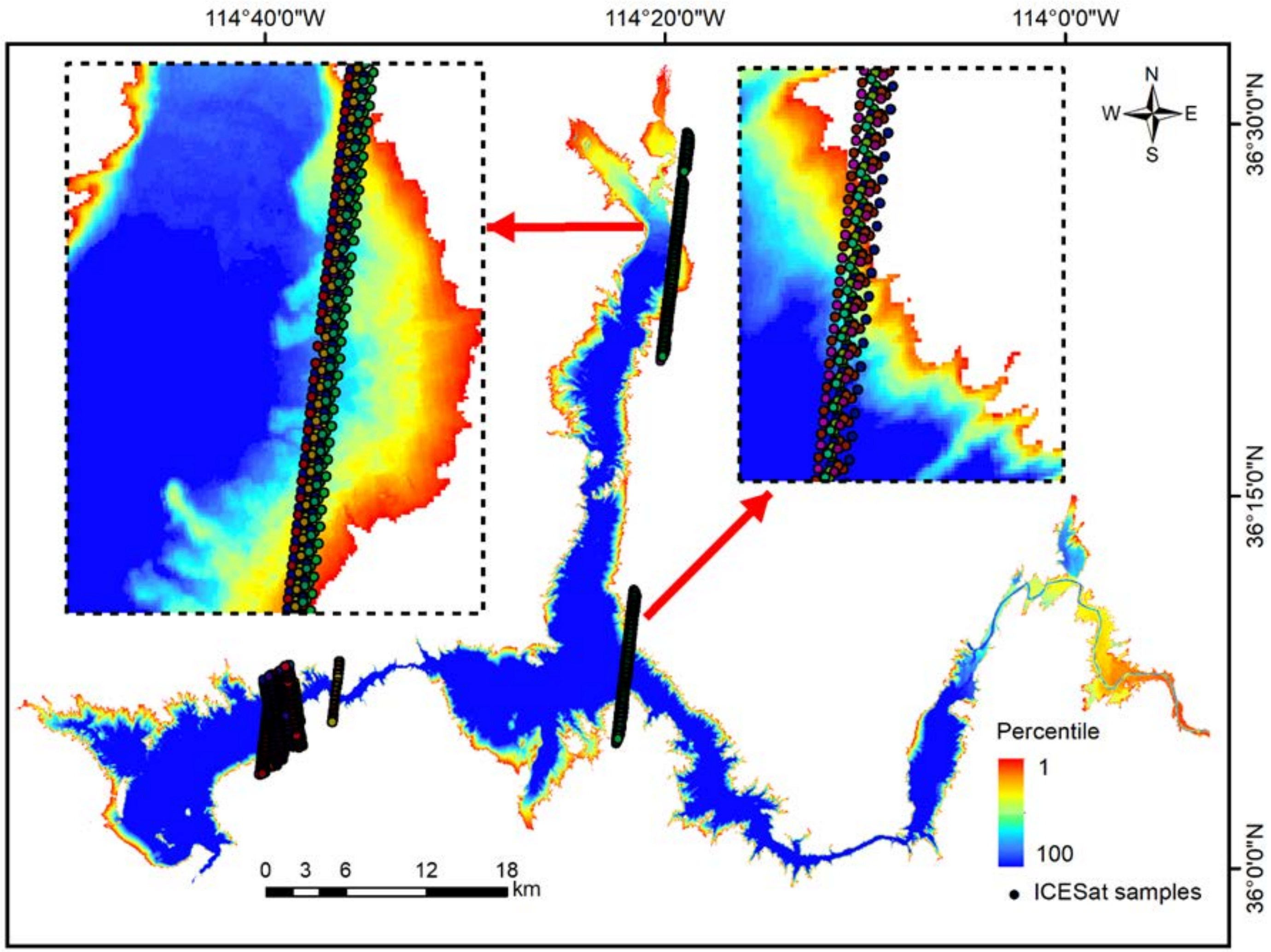
Stallite altimetry dataset

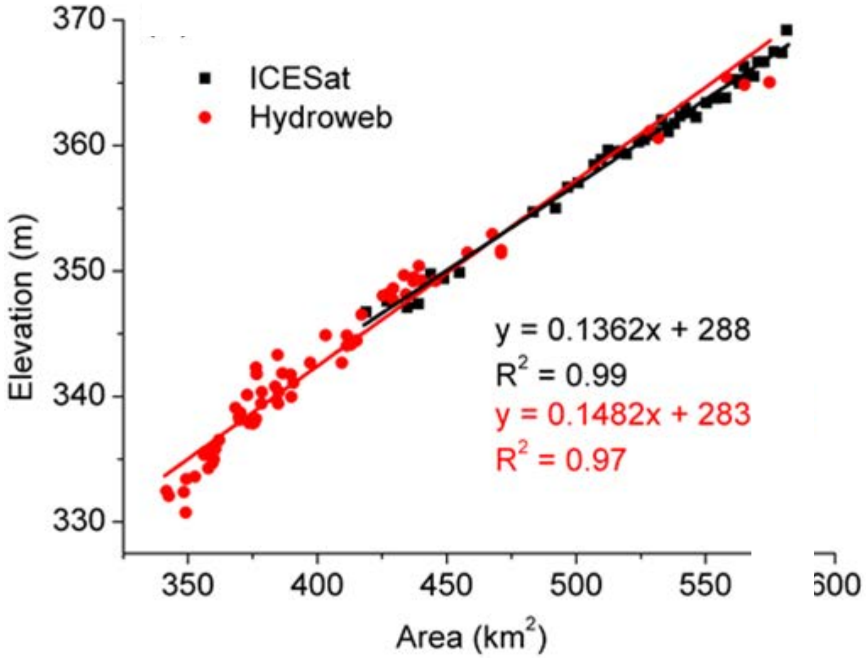
- ICESat/GLAS lidar altimetry dataset
- Global Reservoir and Lake Monitor (G-REALM)
- Hydroweb



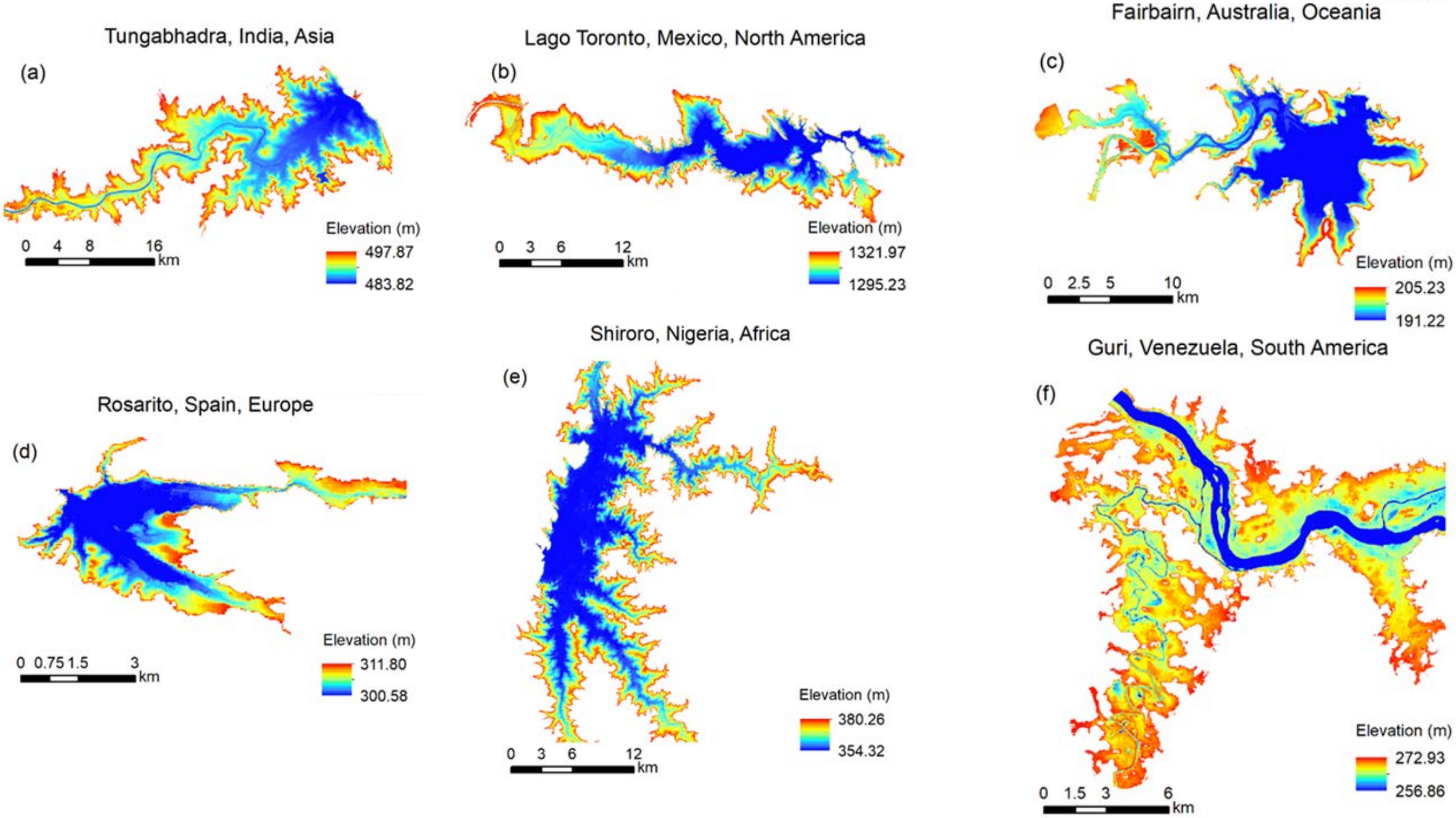
Bathymetry Results

Derive A-E relationships



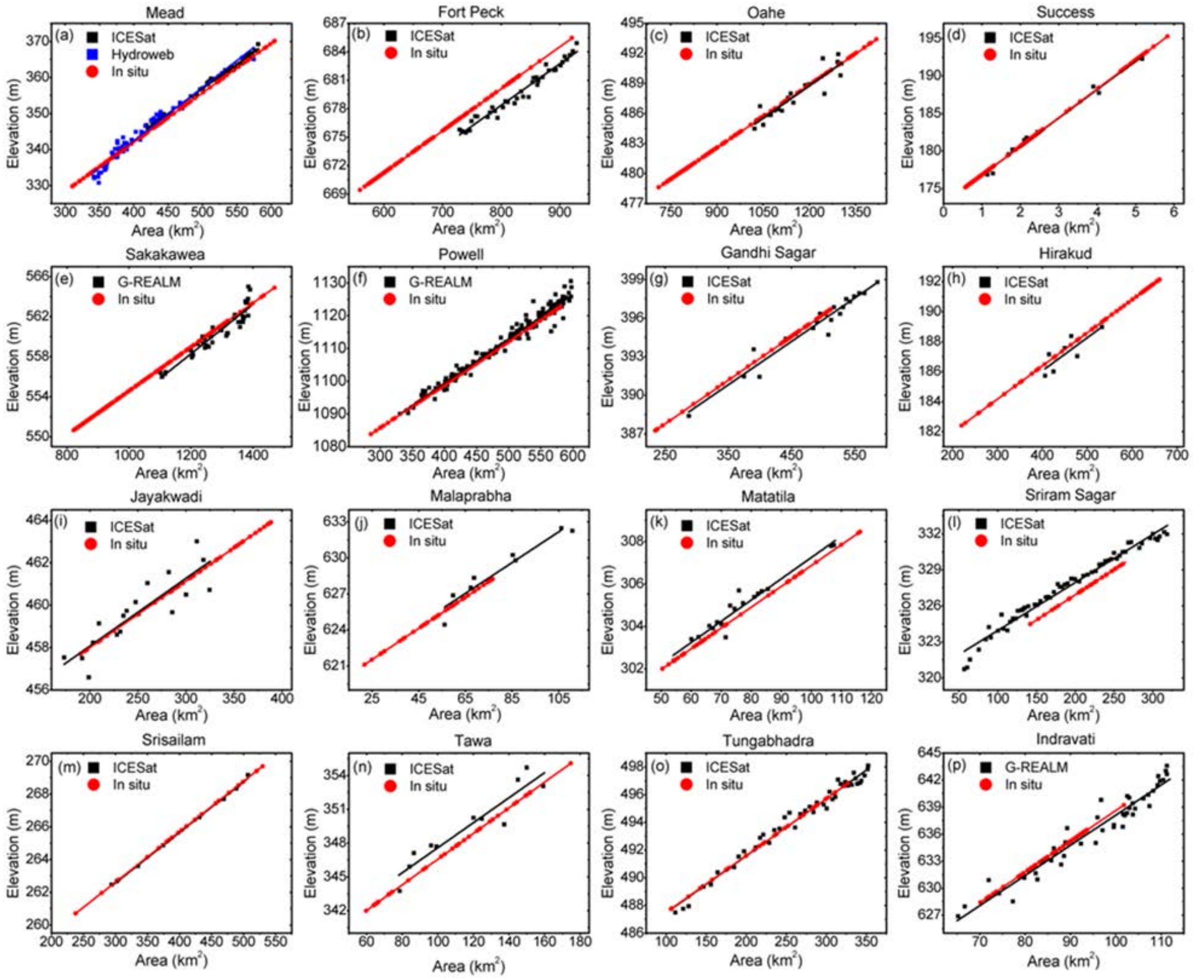


Bathymetry Results

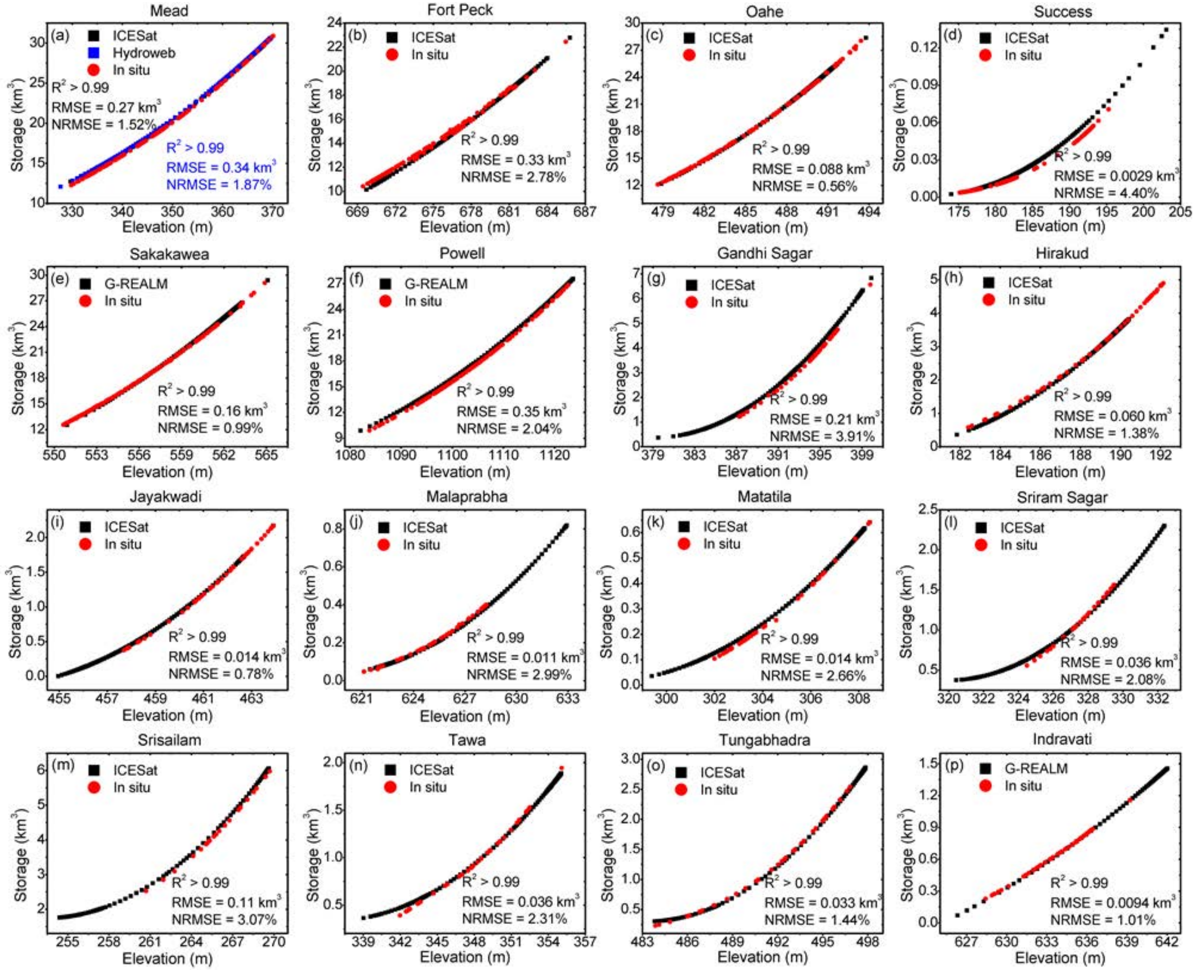


Validations of A-E & E-V Relationships

A-E relationships

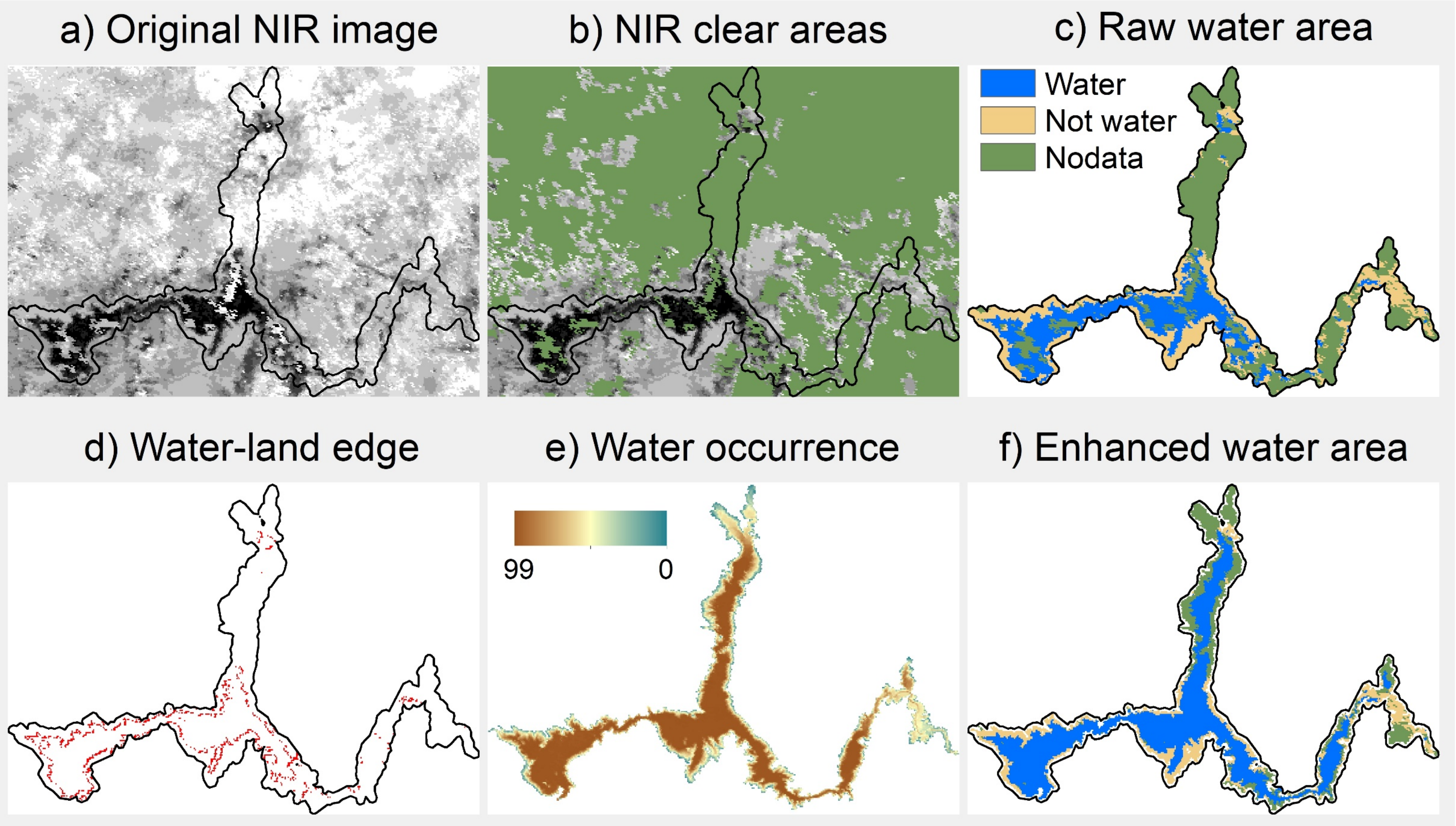


E-V relationships

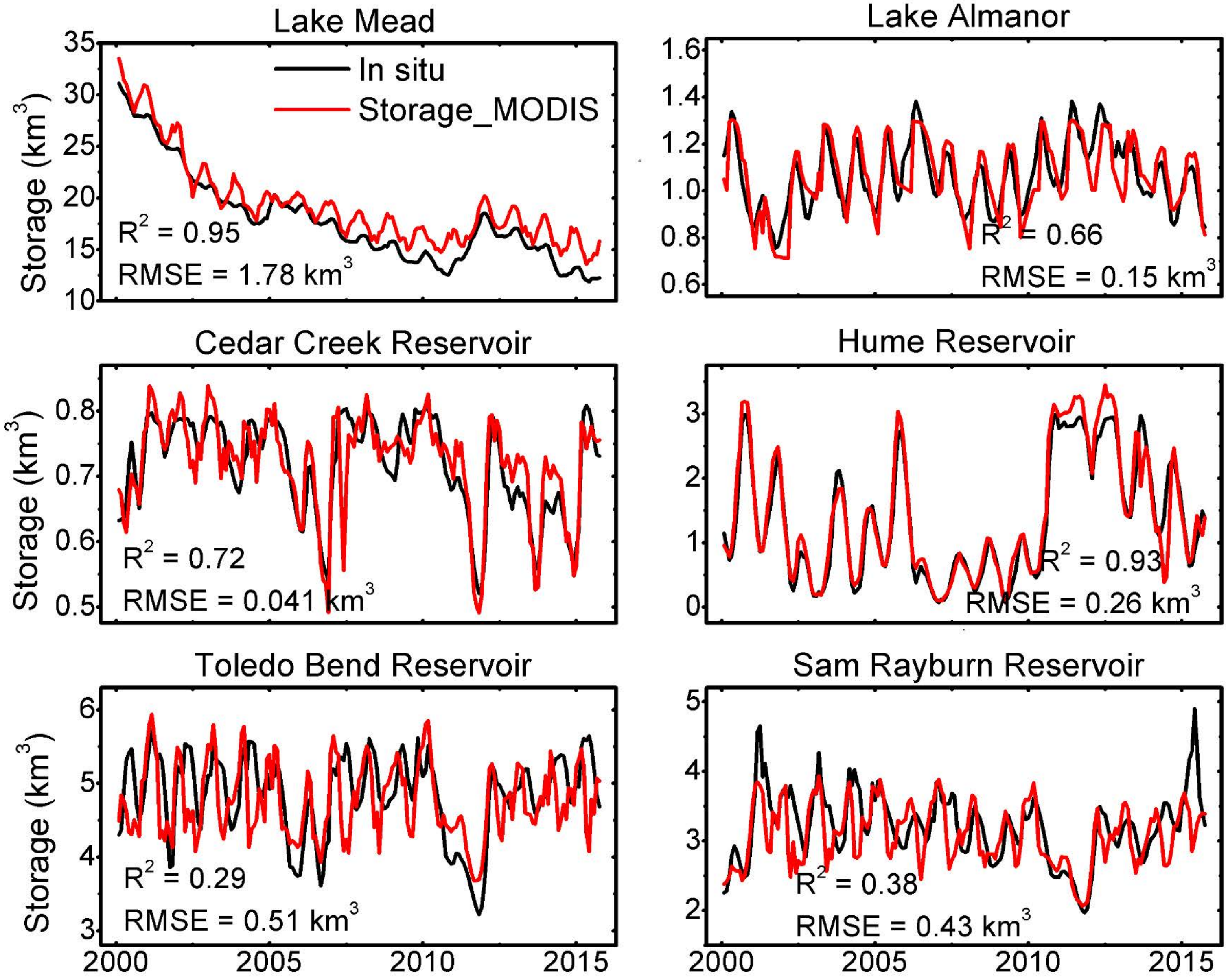


Li et al, RSE, in review.

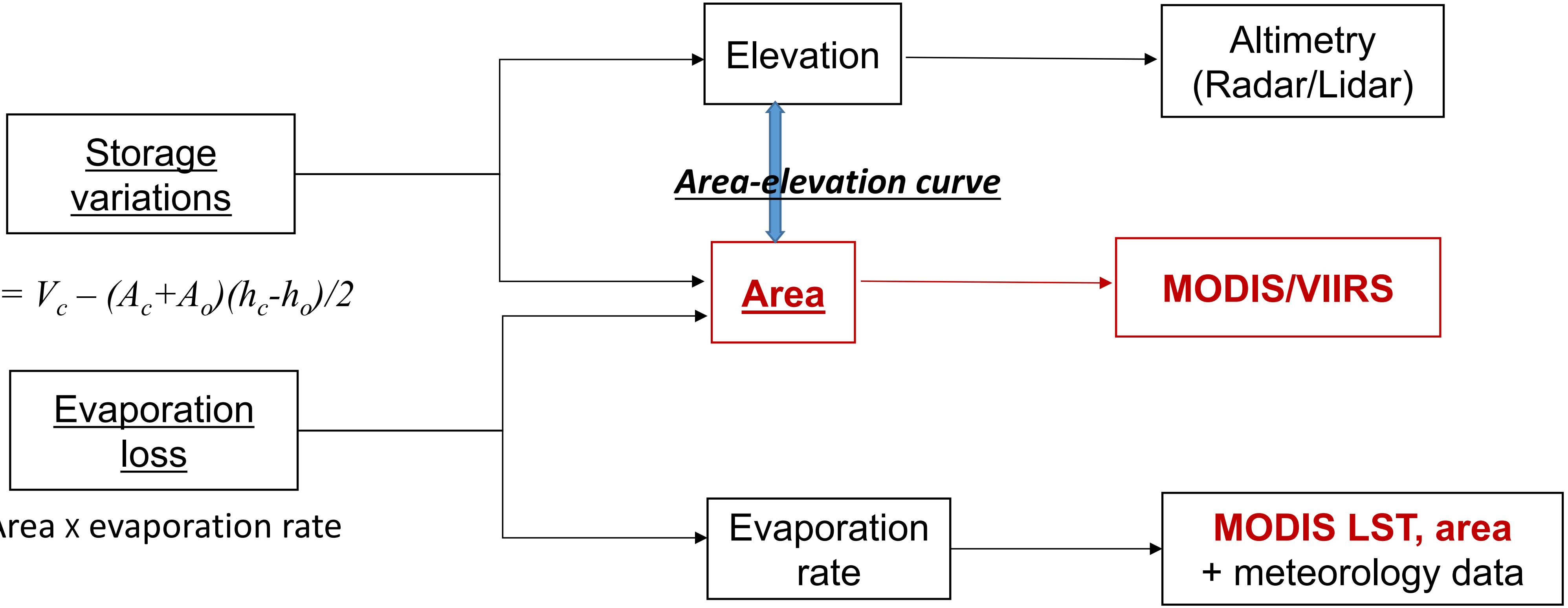
Lake area based on MODIS classification



Validation of the MODIS-based Storage



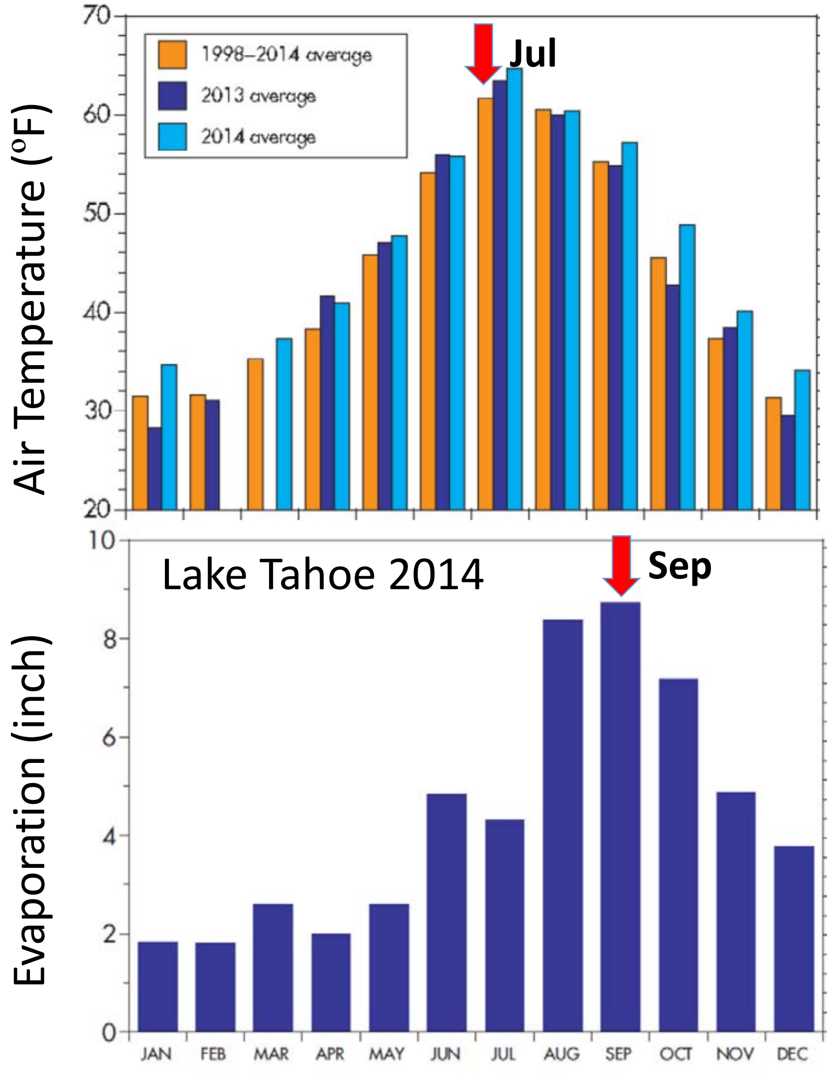
Reservoir Evaporation Estimation



$V_o = V_c - (A_c + A_o)(h_c - h_o)/2$

Area x evaporation rate

Heat Storage Effect on the Evaporation Rate



Heat storage effect:

Spring and Summer – absorb heat

Fall and Winter – release heat

Penman Equation

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

Wind function

$\boldsymbol{s}$: slope of the saturation vapor pressure curve (kPa·ºC^{-1})

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

$\boldsymbol{\gamma}$: psychrometric constant (kPa·ºC^{-1})

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

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

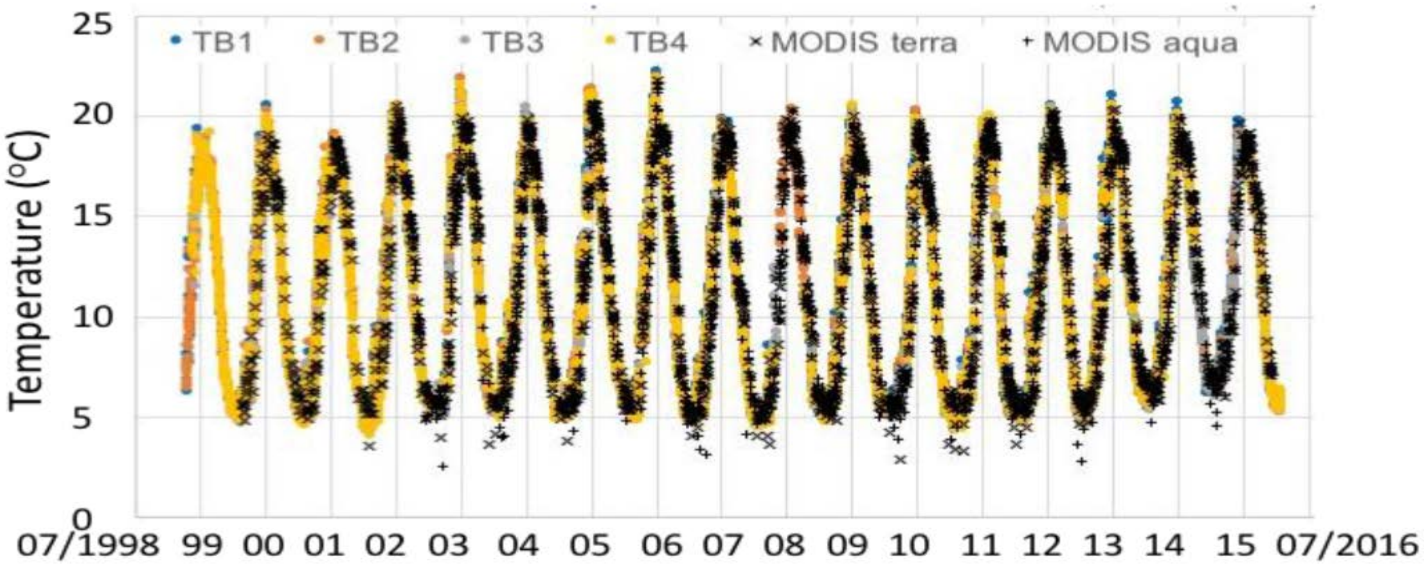
$\boldsymbol{\lambda_v}$: latent heat of vaporization (MJ·kg^{-1})

Improving the Estimation of Reservoir Evaporation Rate

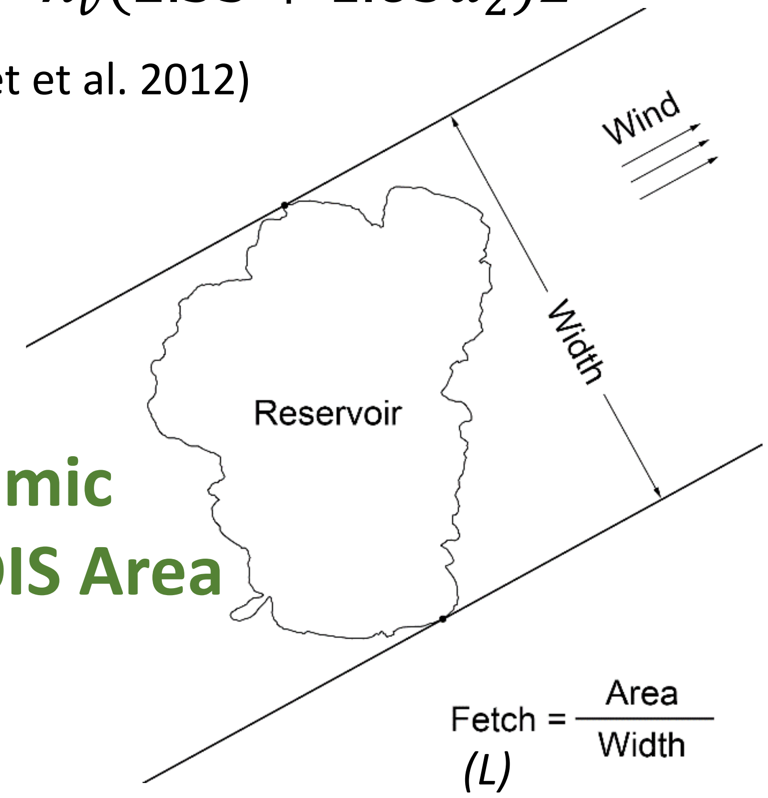
$$f(u_2) = \lambda_v(2.33 + 1.65u_2)L^{-0.1}$$

(McJannet et al. 2012)

Lake Tahoe



(Friedrich et al., 2017)

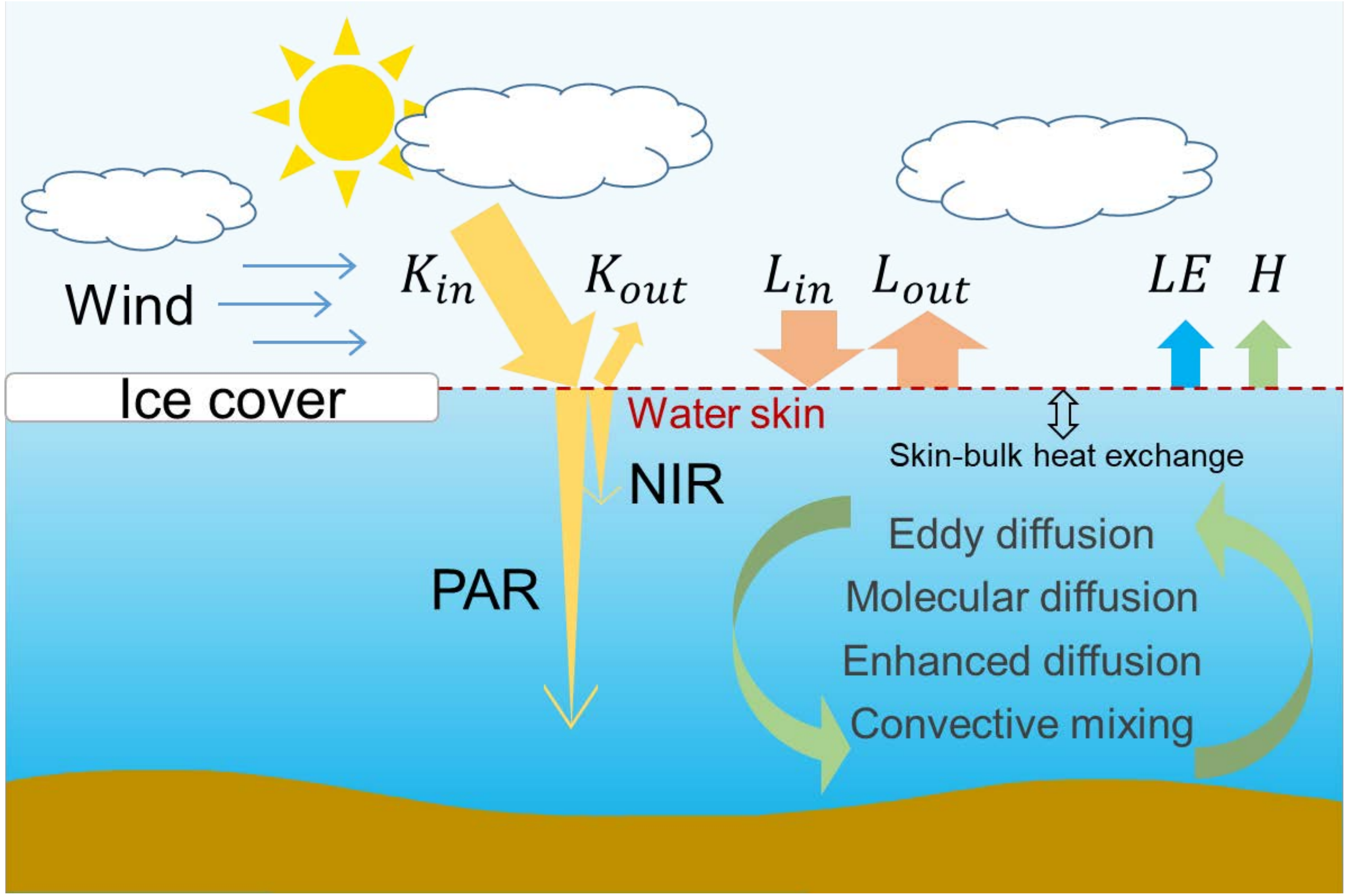


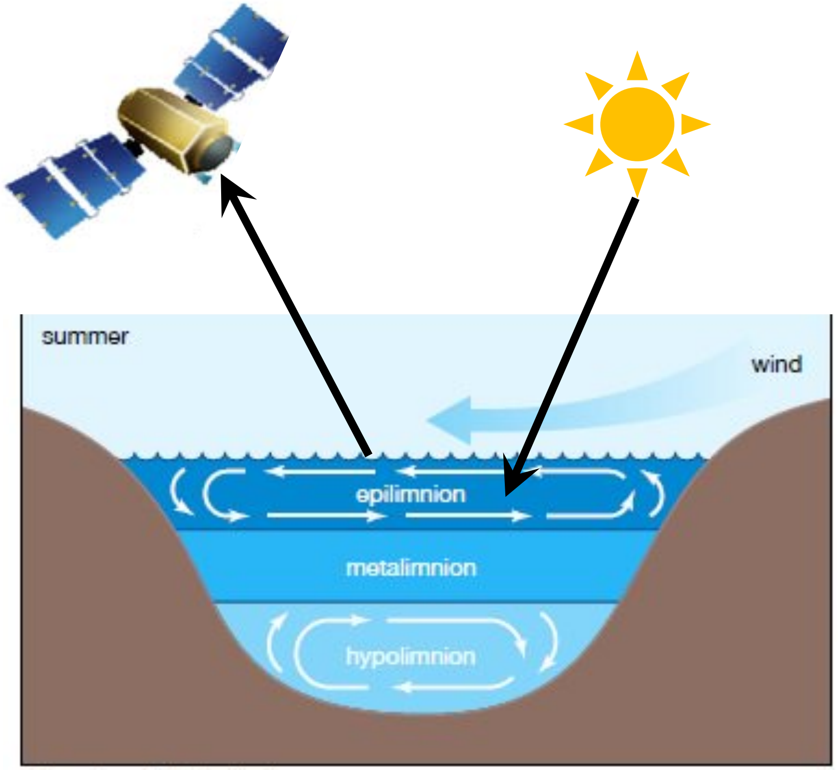
Dynamic MODIS Area

Zhao and Gao, RSE, 2019.

Improving the Estimation of Reservoir Evaporation Rate

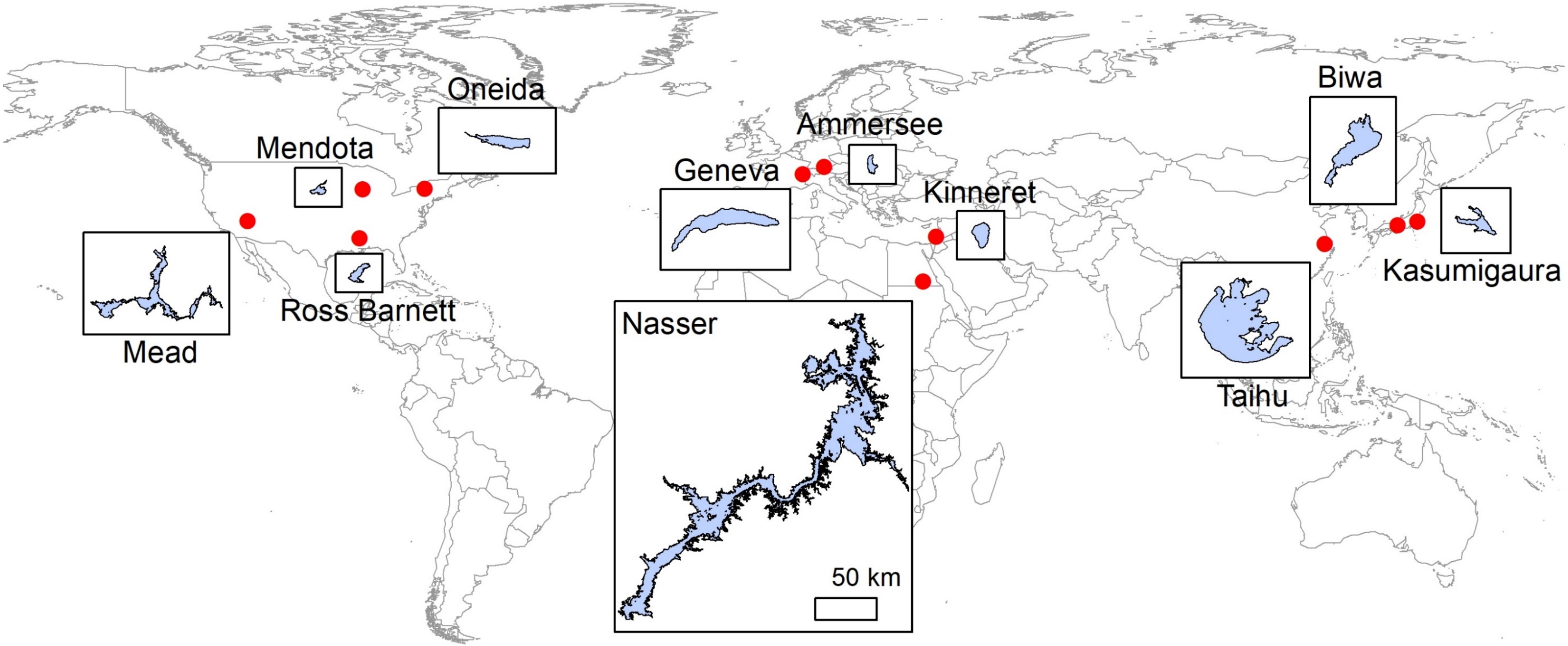
Lake Temperature Evaporation Model (LTEM)



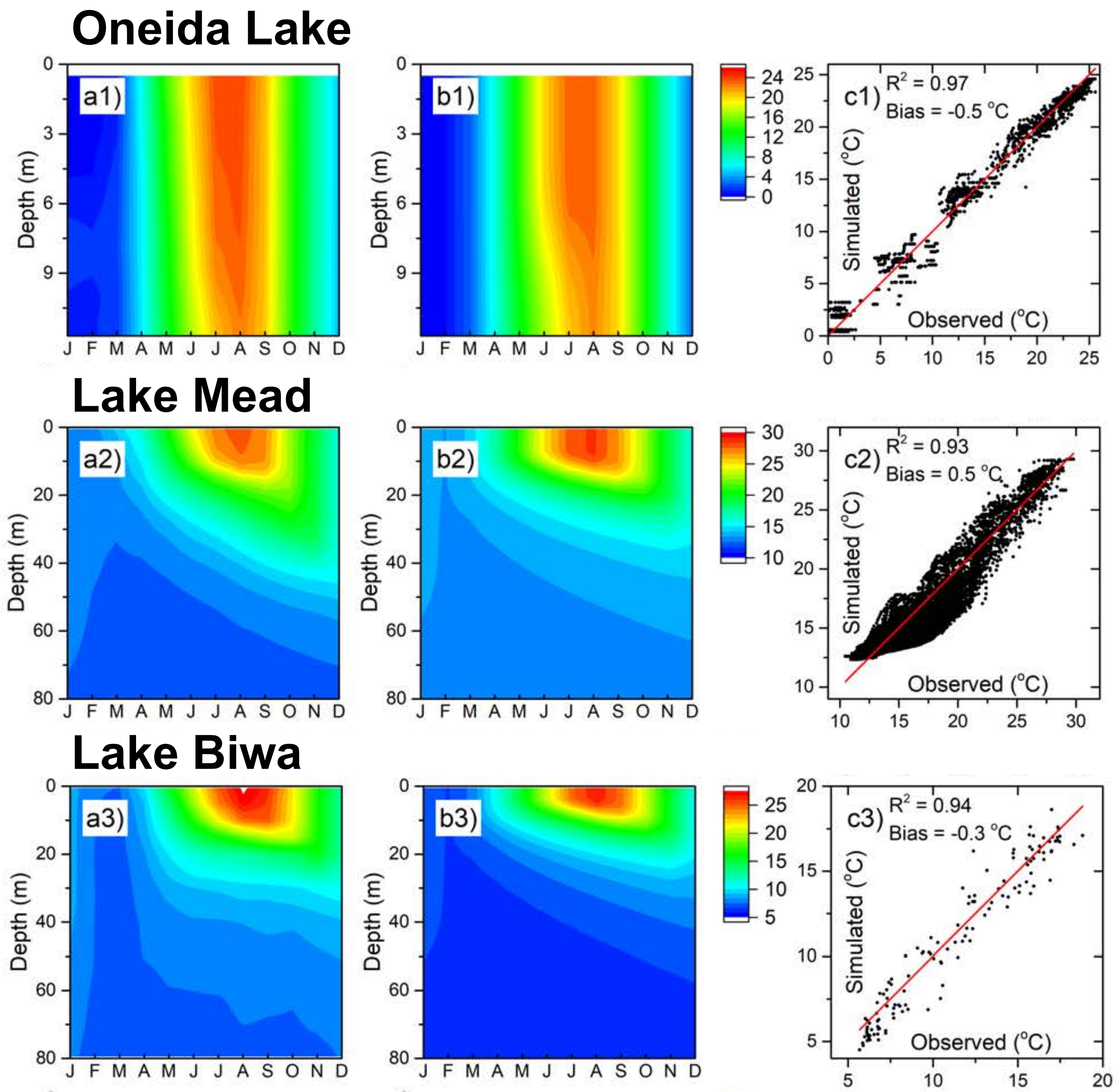


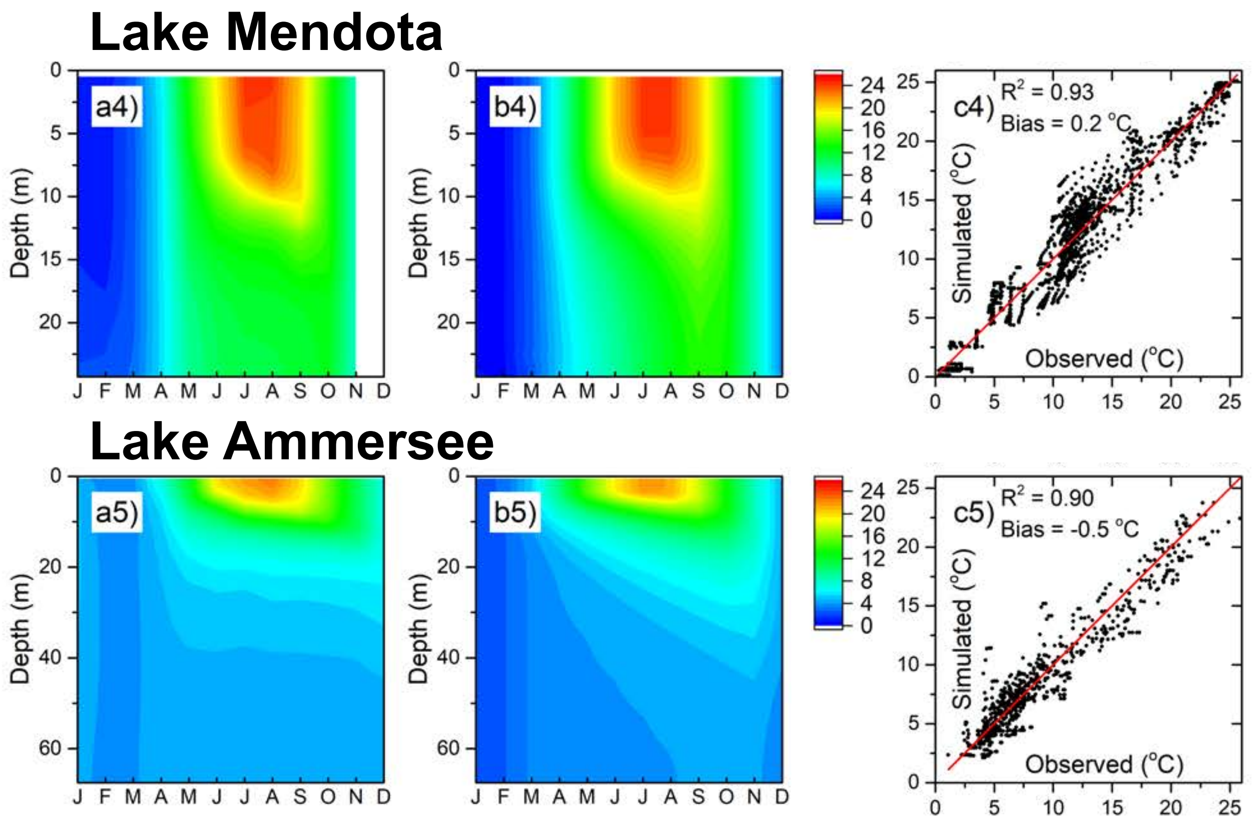
Translate MODIS LST to temperature profile & Calculate evaporation rate

Evaporation Validation Locations



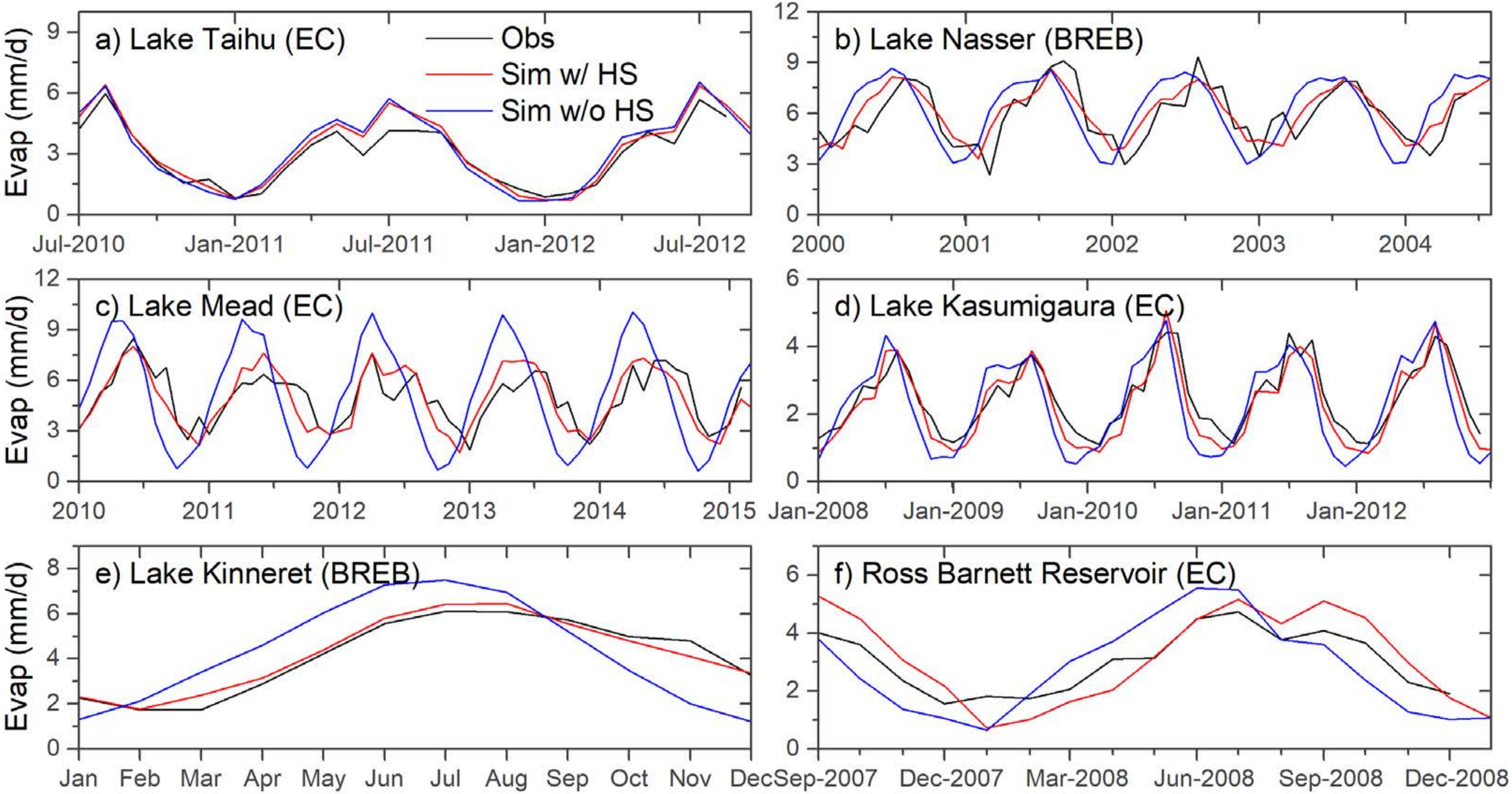
Temperature Profile Validation Results





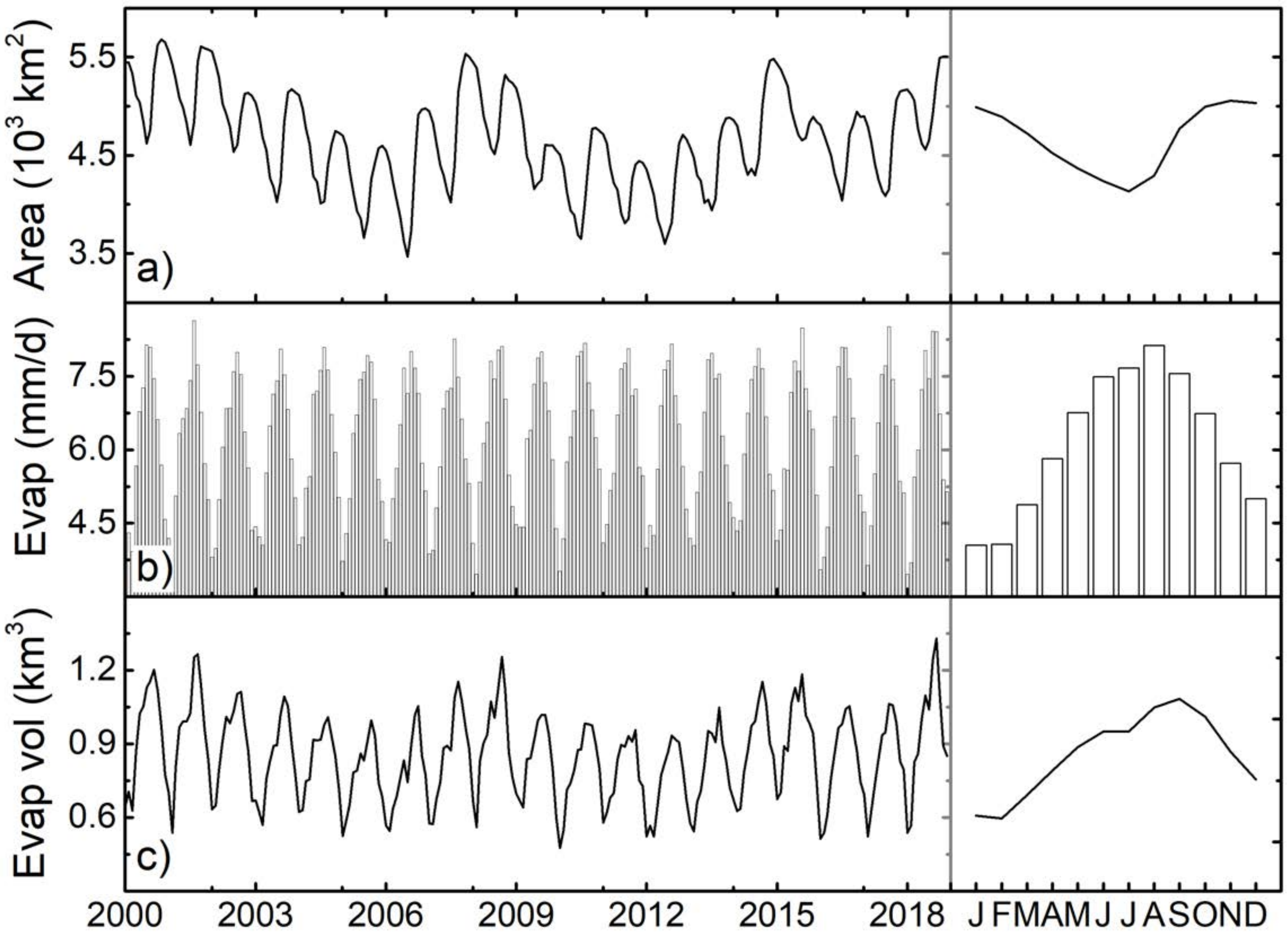
- Good agreement for mixing depth and temperature seasonality
- Overall, long-term biases range from -0.5 °C to 0.5 °C
- Monthly value biases range from -5.4 °C to 6.0 °C

Evaporation Rate Validation Results



- Average R^2 increase: 0.28
- More improvement for deep lakes (e.g. Mead: 0.44)

Evaporation Results for Lake Nasser



Zhao and Gao, Estimating lake temperature profile and evaporation losses by leveraging MODIS LST data (in prep)

Summary

✓ By leveraging MODIS observations along with satellite altimetry data, the spatial and temporal coverage of remotely sensed global reservoirs can be significantly improved.

✓ High quality A-E relationship can be achieved using Landsat and altimetry data.

✓By using MODIS LST to calculate the heat storage and considering fetch as a function of the dynamic lake area, reservoir evaporation rate can be better .

✓ Both the storage and evaporation algorithms have been validated using in situ data.

✓ Future work will focus on applying the algorithms to generate reservoir storage and evaporation product using both MODIS and VIIRS.

- Li et al., A high-resolution bathymetry dataset for global reservoirs using multi-source satellite imagery and altimetry, *Remote Sensing of Environment*, in review.
- Zhao and Gao, Estimating reservoir evaporation losses for the United States: Fusing remote sensing and modeling approaches, *Remote Sensing of Environment*, 226, 109-124, 2019.