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

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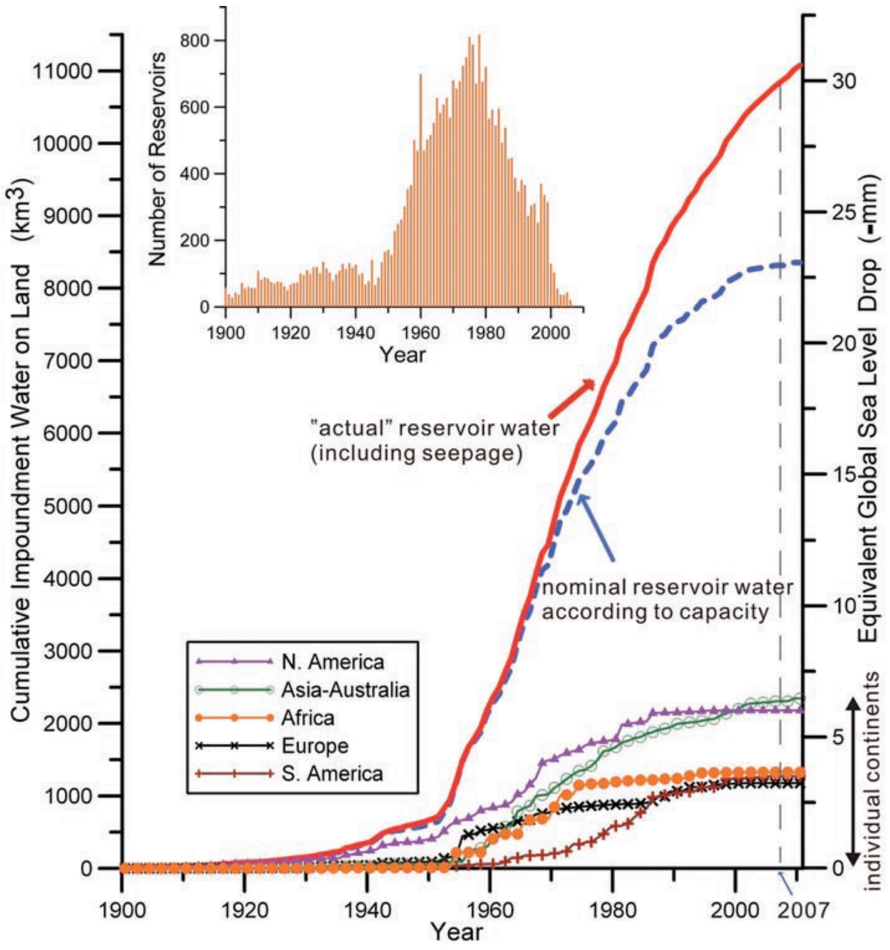
TEXAS A&M UNIVERSITY

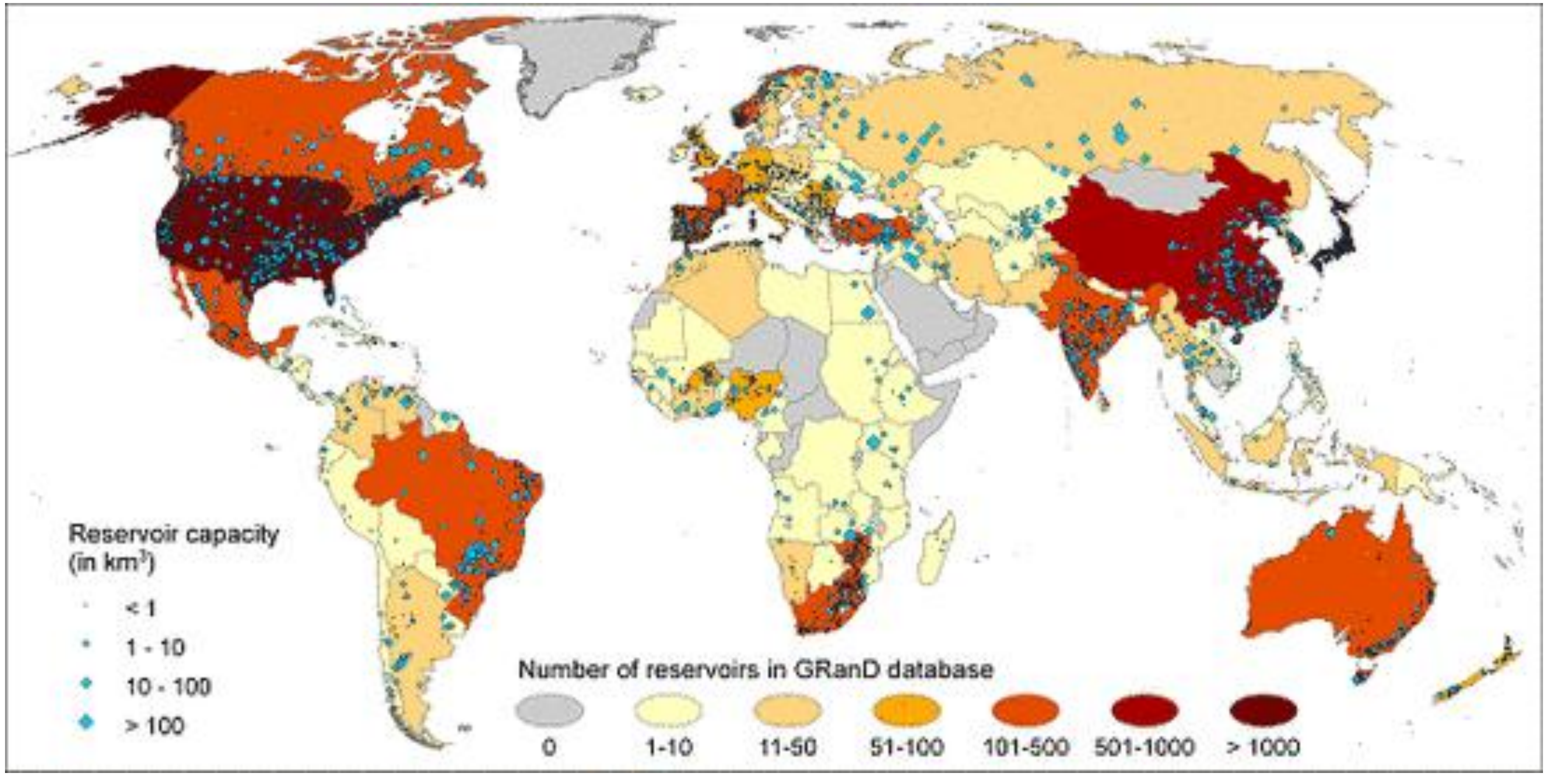
Global Reservoirs



Chao et al., 2008

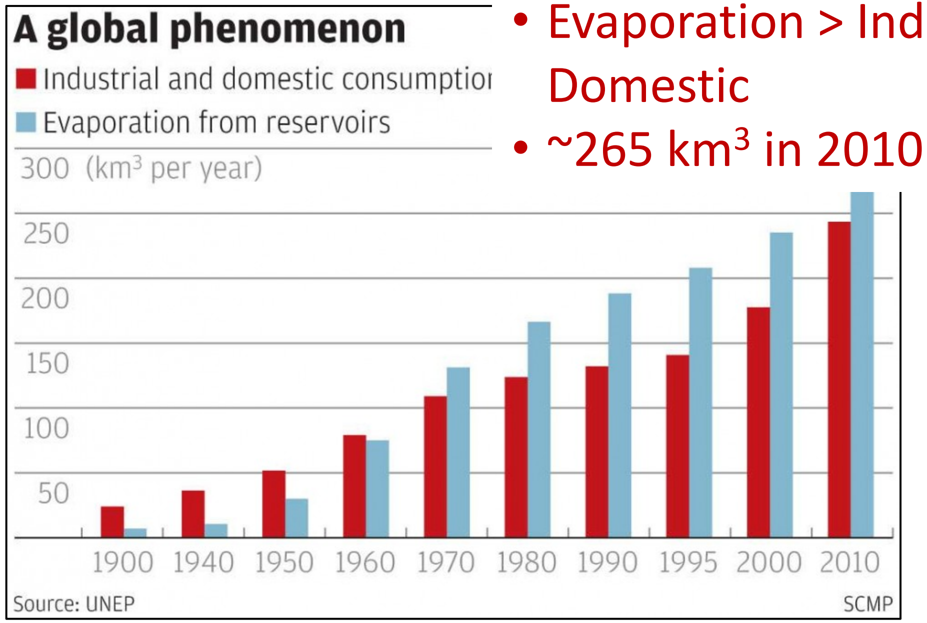
Global Reservoir and Dam (GRanD) Database

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

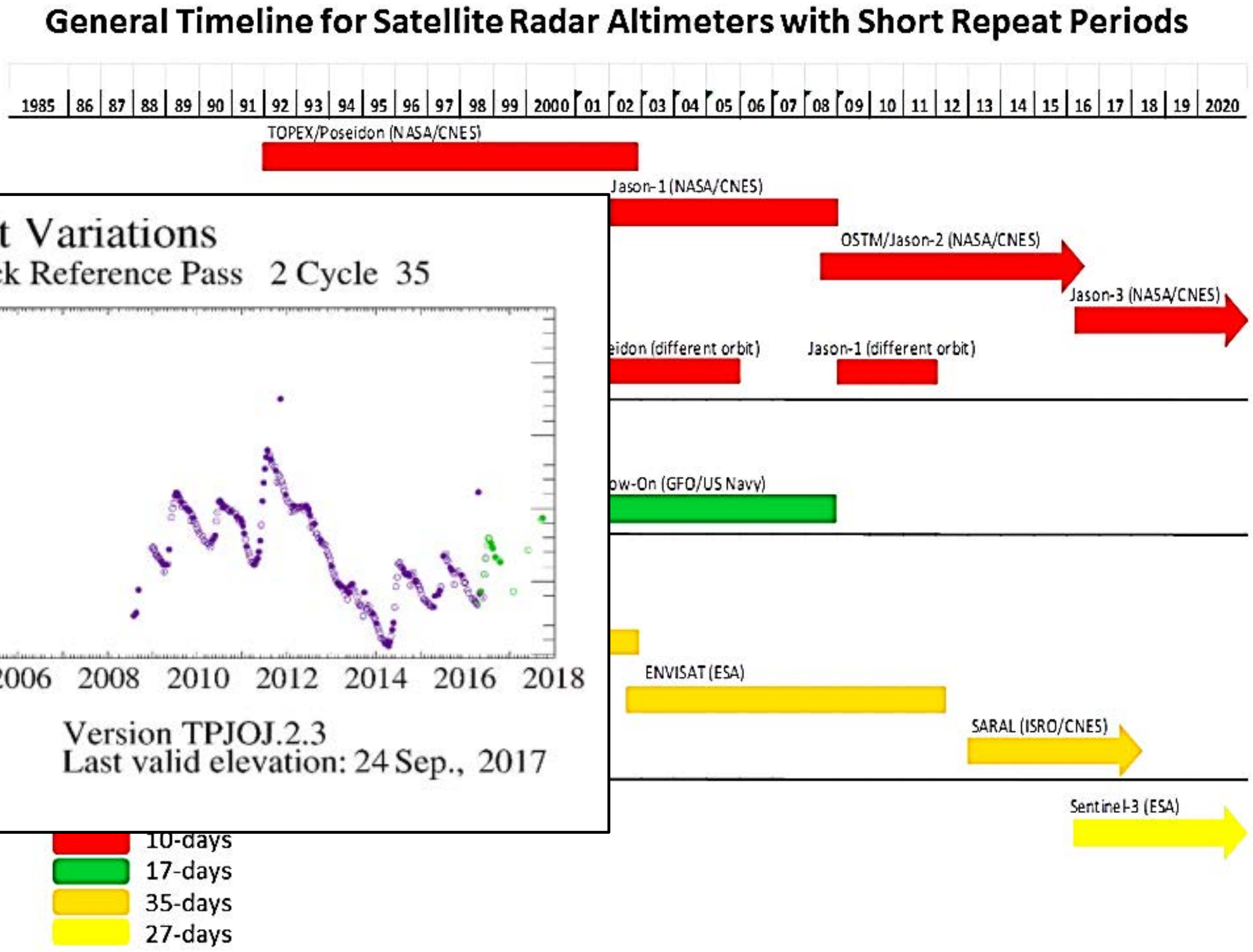
Limited data availability

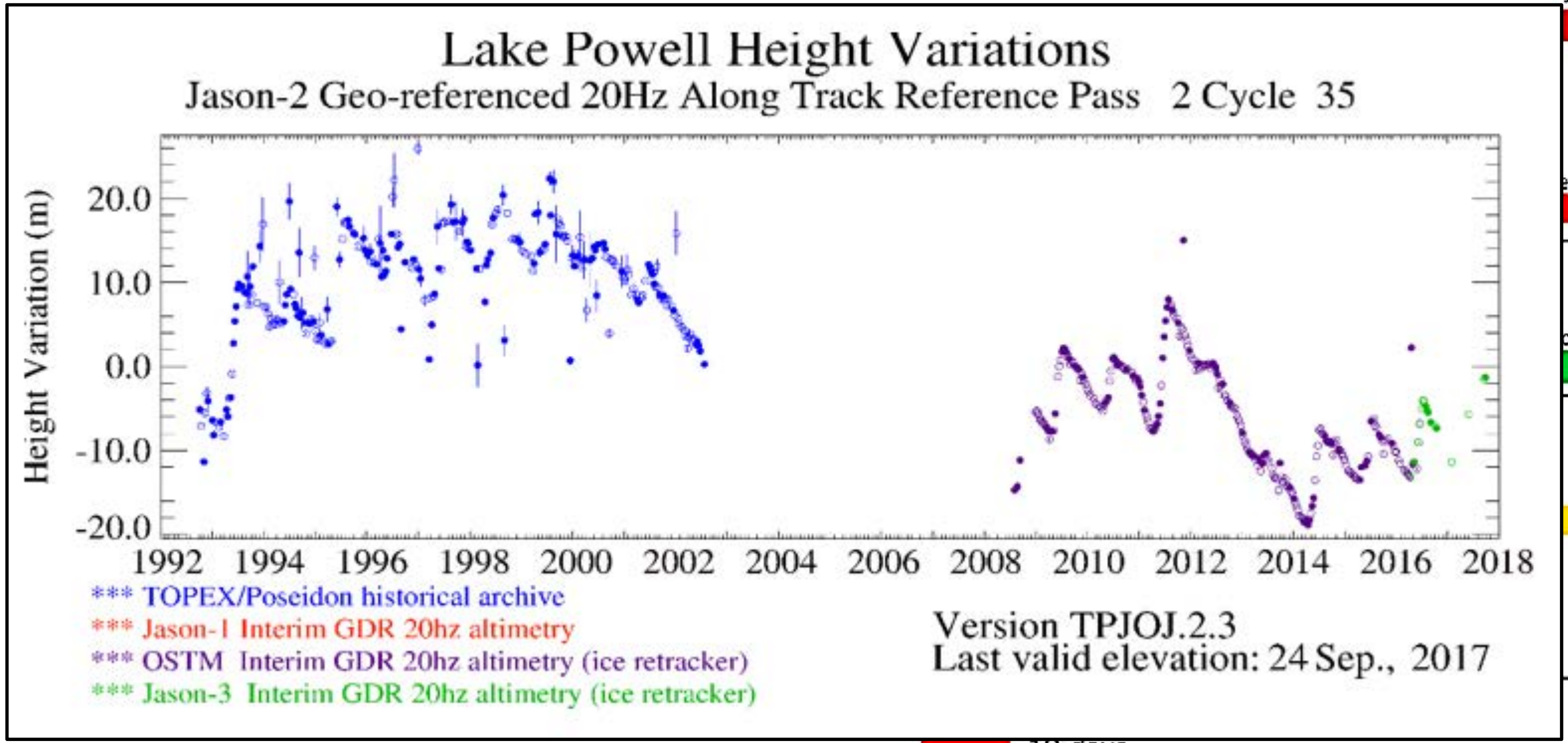
- We hardly know anything about the reservoir storage in some regions (e.g. developing regions with conflicts of interest)
- Different reservoirs are operated using different rules, but information about operating rules are usually not shared
- In situ reservoir evaporation data is extremely limited

Targeted Science Applications

- Drought and flood monitoring
- Water resources management
- Hydrological modeling
- Coupled atmospheric-hydrologic modeling
- Hydrodynamic modeling
- Ecosystem service

Water Surface Elevation from Radar Altimetry





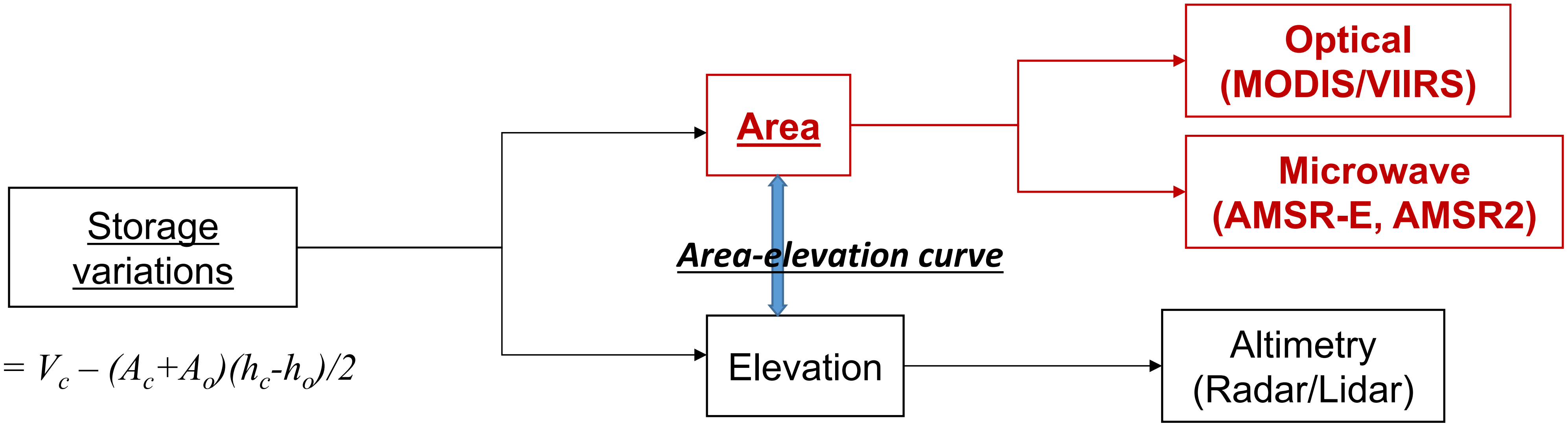
https://ipad.fas.usda.gov/cropexplorer/global_reservoir/

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



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

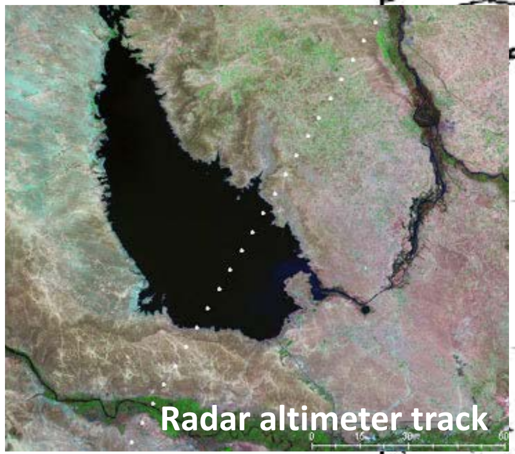
Available global reservoir storage variation datasets

Dataset	Number	Sensors	Period
Cretaux et al 2011 (Adv. Space Res)	15	Various imagers + radar altimeters	1992-2011(present)
Gao et al. 2012 (WRR)	34	MODIS + radar altimeters	1992-2010
Busker et al. 2018, (HESS)	135 (including lakes)	Landsat + radar altimeters	1984-2011

Improving the Spatial Coverage of the Product

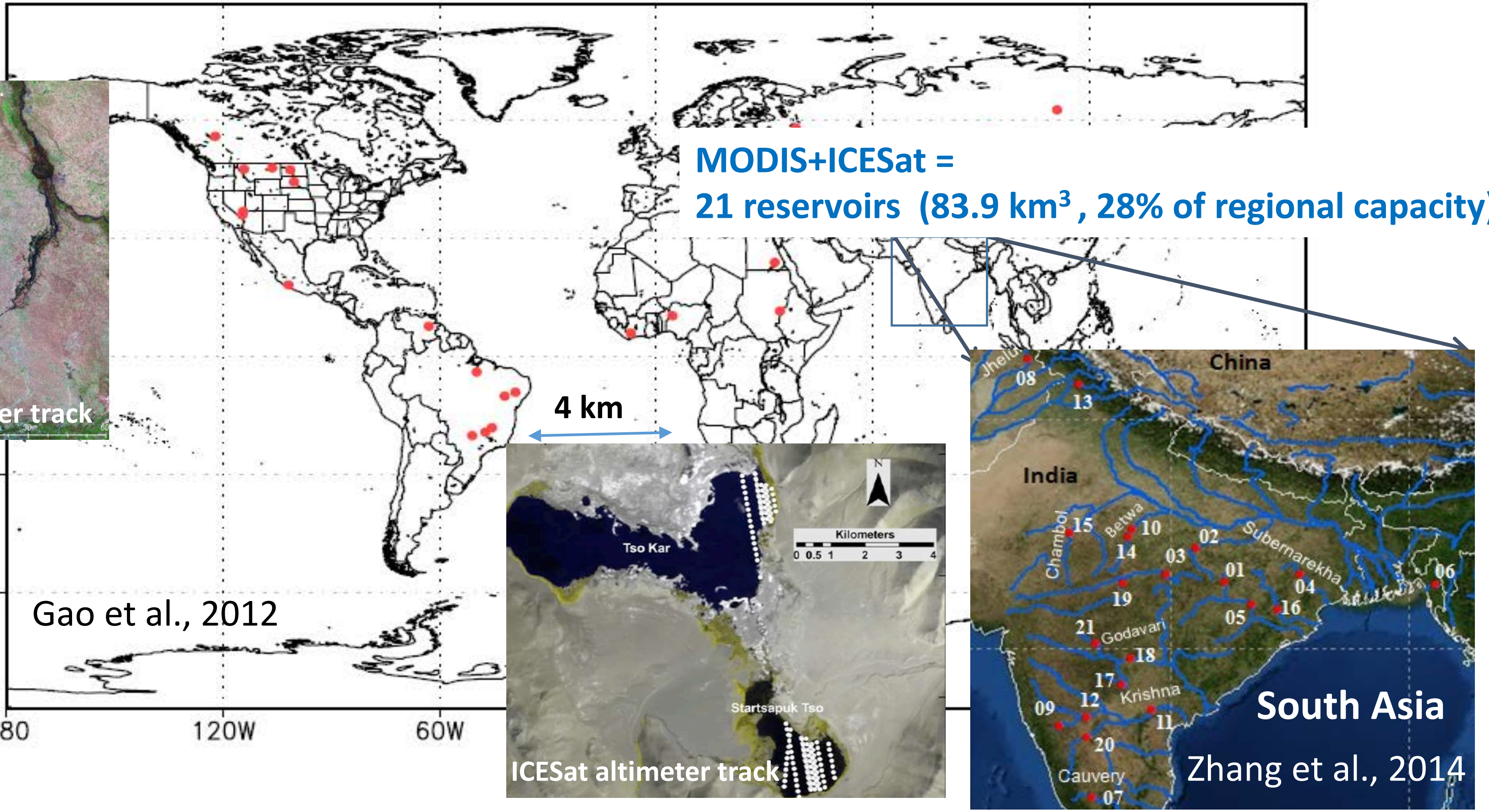
MODIS + Radar altimeter = 34 reservoirs (1164 km^3 , 19% of global capacity)

60 km



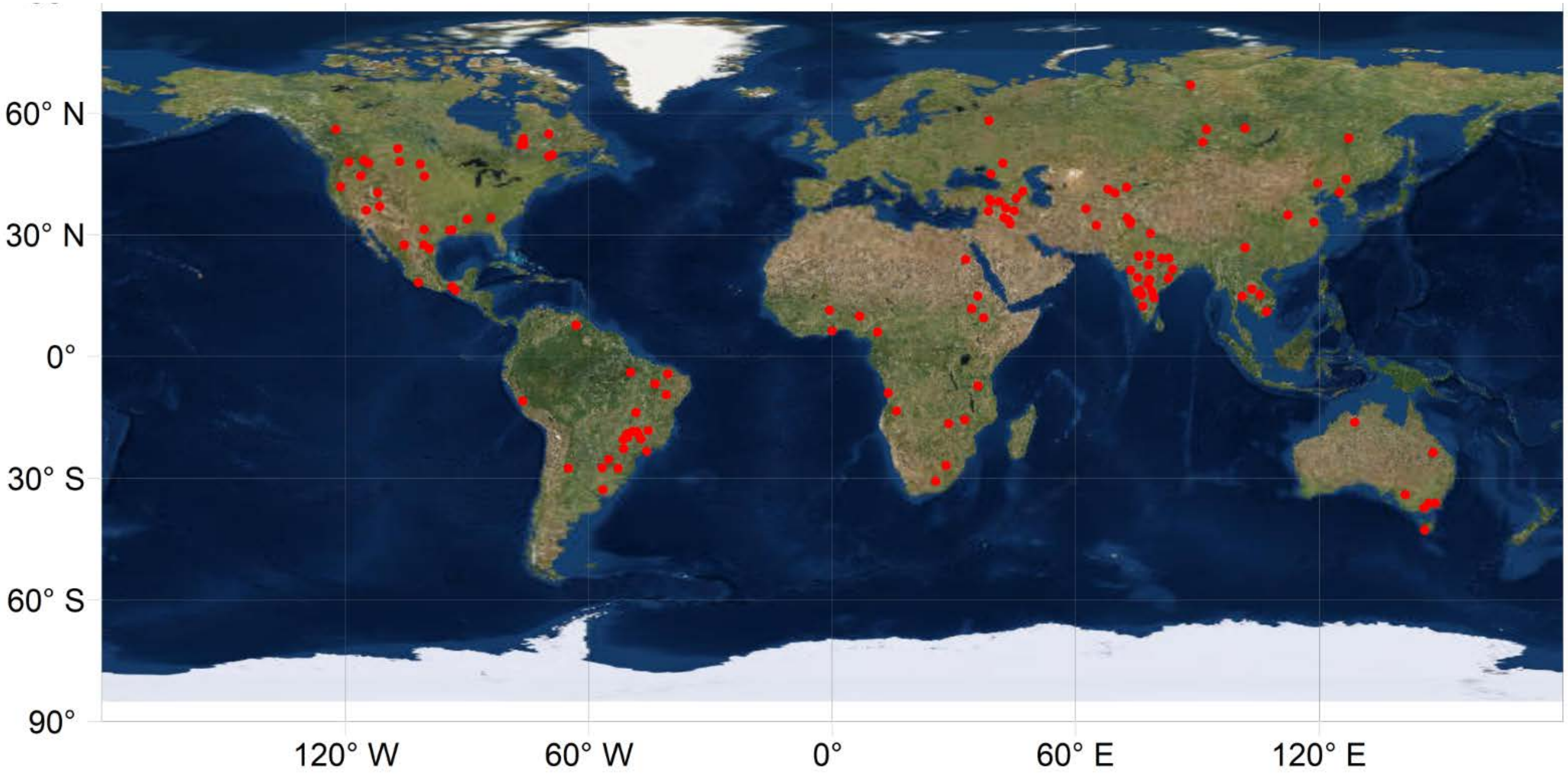
MODIS+ICESat =
21 reservoirs (83.9 km^3 , 28% of regional capacity)

4 km



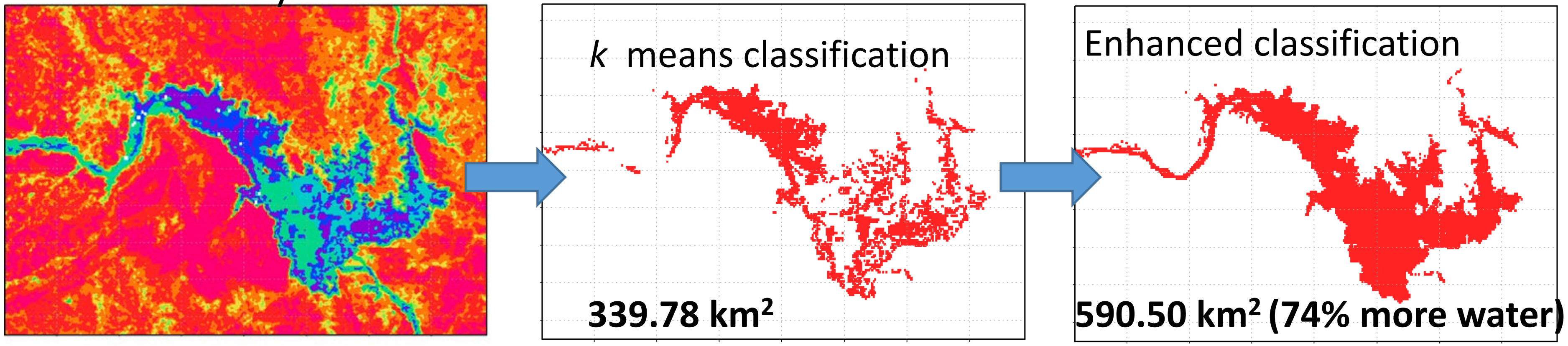
Improving the Spatial Coverage of the Product

MODIS + Radar altimeter & ICESat = 180 reservoirs (2880 km^3 , 46.5% of global capacity)

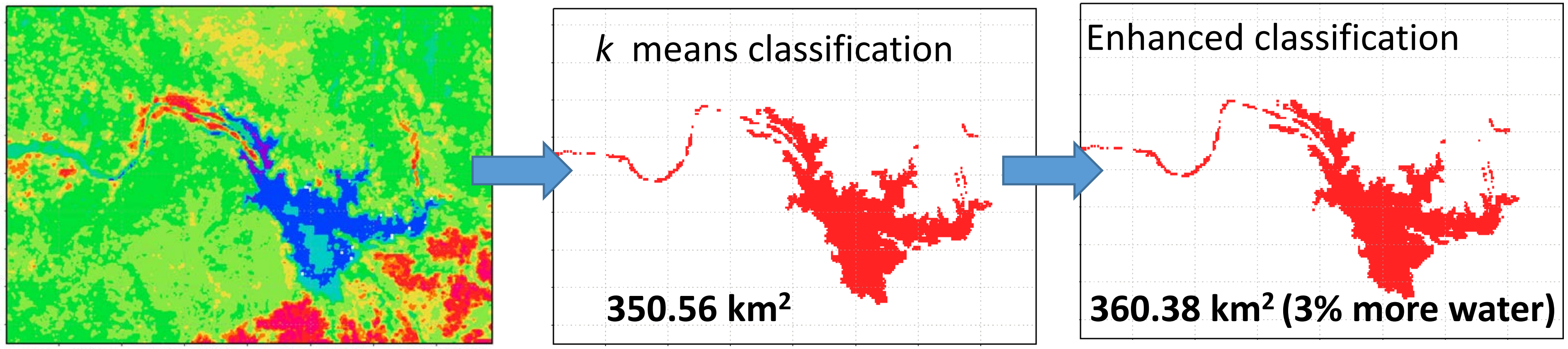


Reservoir Area from MODIS

MODIS NDVI on day 273 in 2005



MODIS NDVI on day 097 in 2005



Zhang et al., 2014

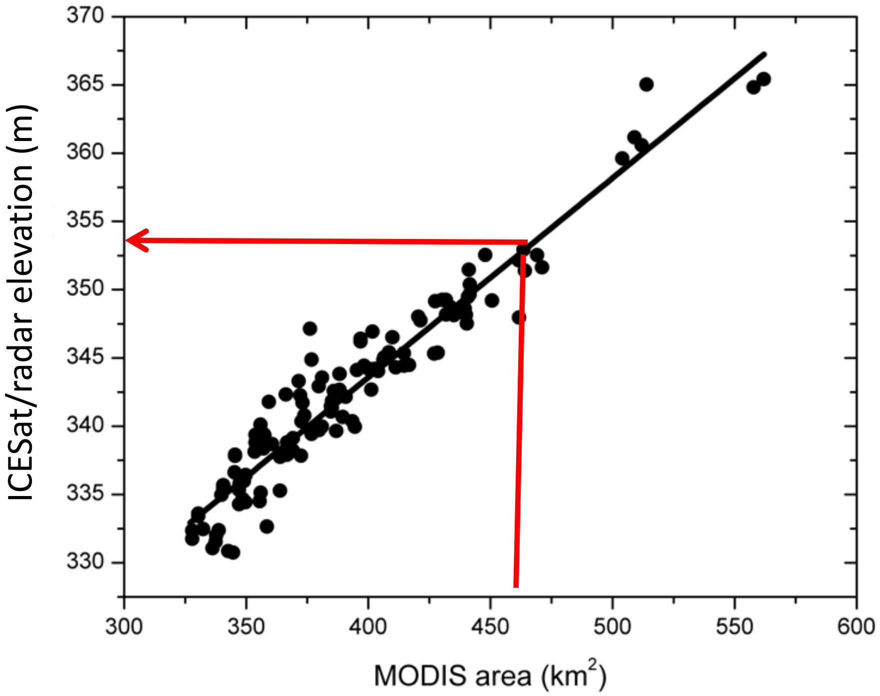
Towards a Continuous Storage Data Record

Area-elevation relationship

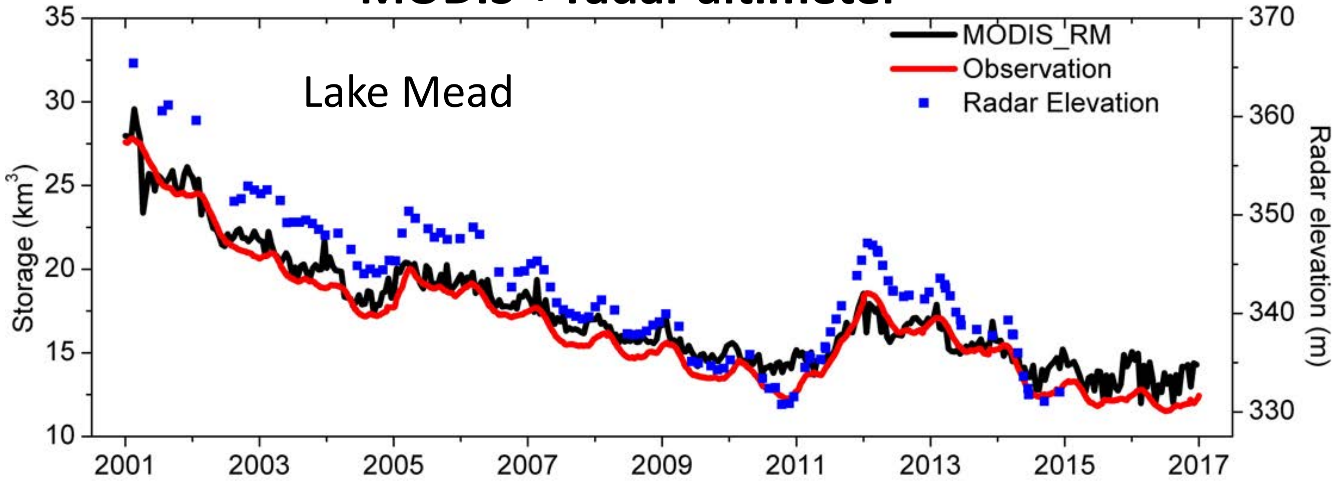
$$h = f(A)$$

Storage Estimation

$$V = g(A)$$

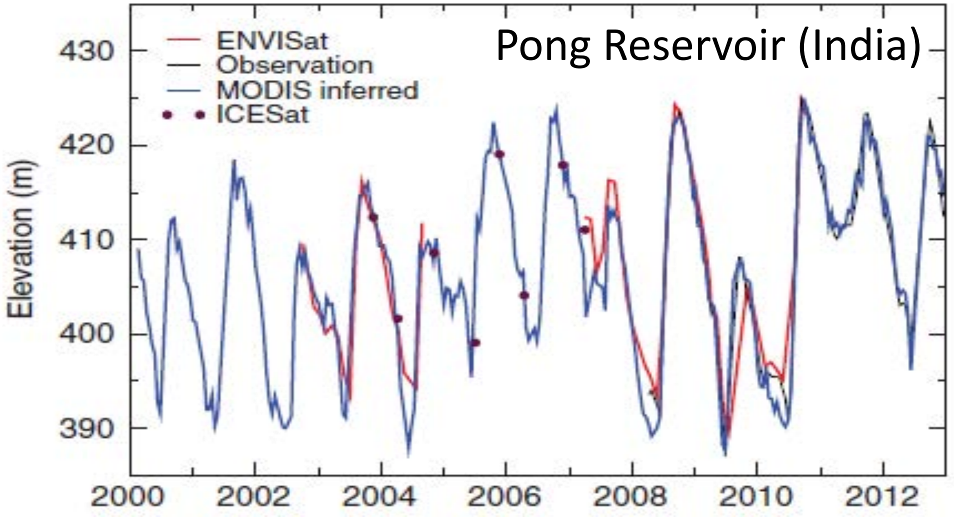


MODIS + radar altimeter



Li et al, 2017

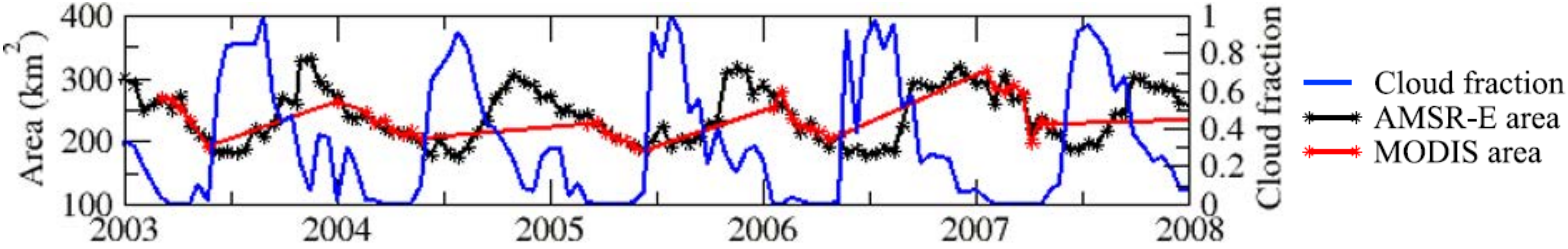
MODIS + ICESat



Gao, 2015

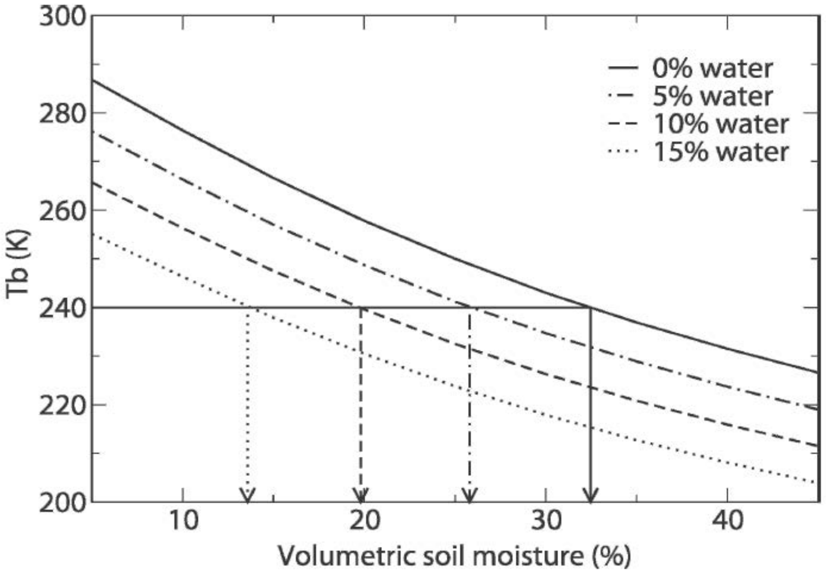
Monitoring Reservoir Storage under All-Weather Conditions

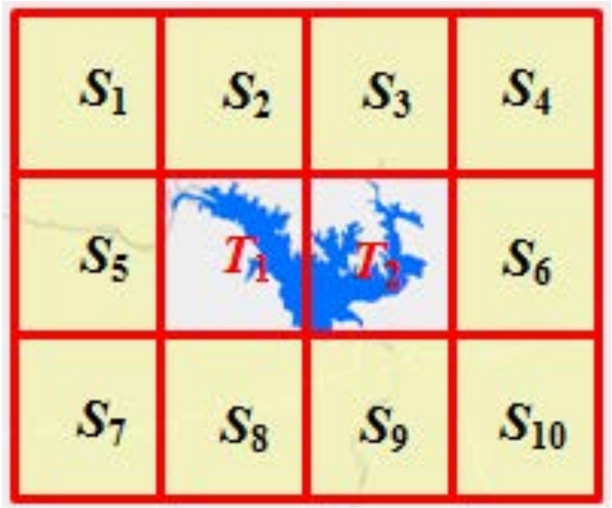
MODIS and AMSR-E at 16-day



Rengali Reservoir (India)

Zhang and Gao, 2016





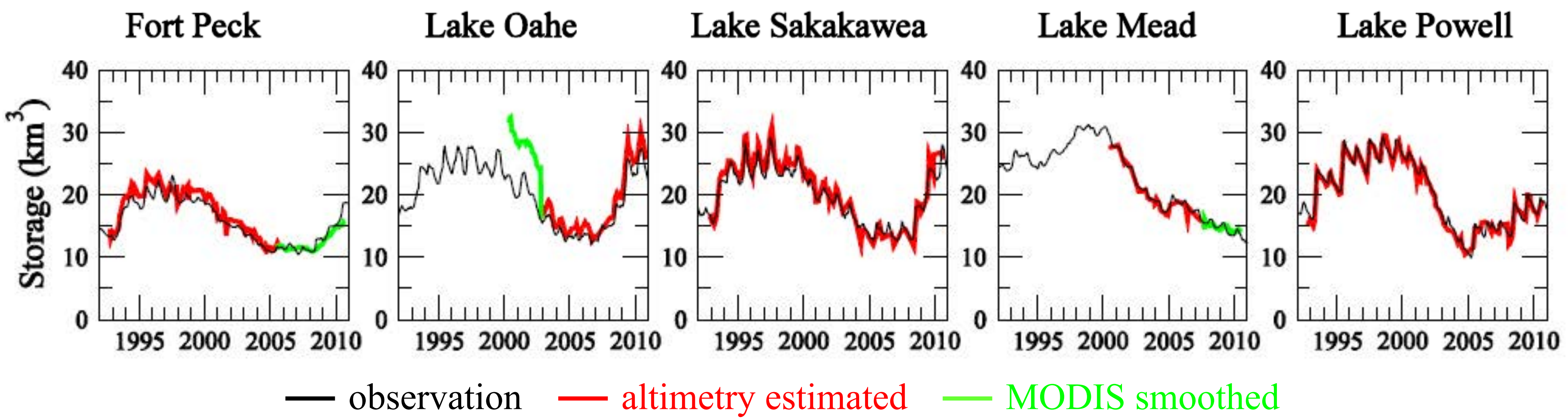
$$WHR = \frac{\sum_{i=1}^{N_T} W_i \times TbH(T_i)}{\sum_{j=1}^{N_S} W_j \times TbH(S_j)}$$

Gao et al., 2006, JHM

Validation Results

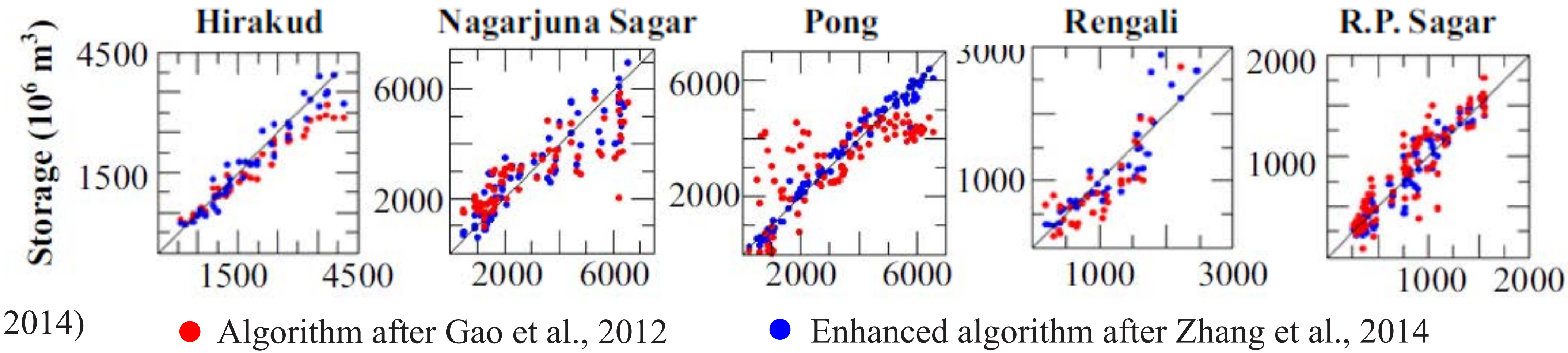
MODIS
+
radar

(Gao et al., 2012)



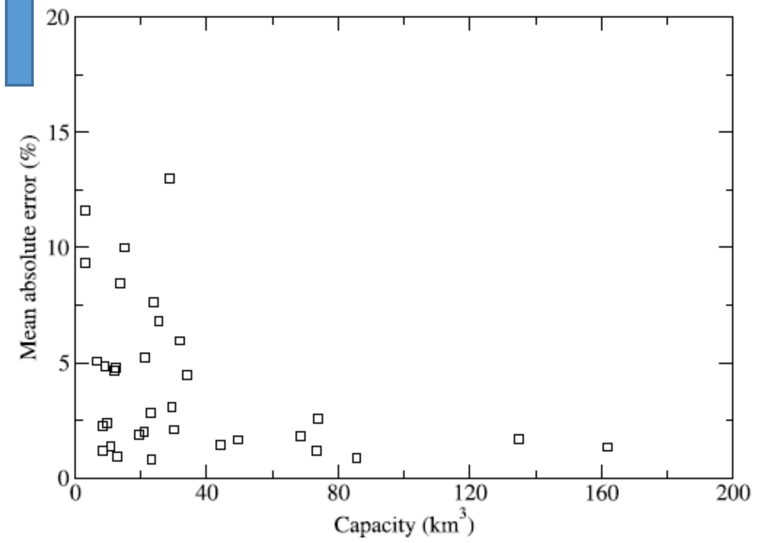
ICESat
+
radar

(Zhang et al., 2014)



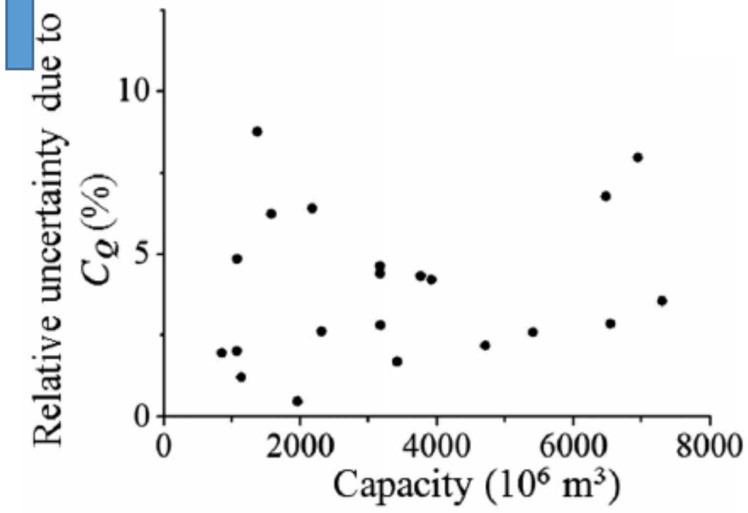
Uncertainty Analysis

Uncertainties due to
MODIS area + radar elevation

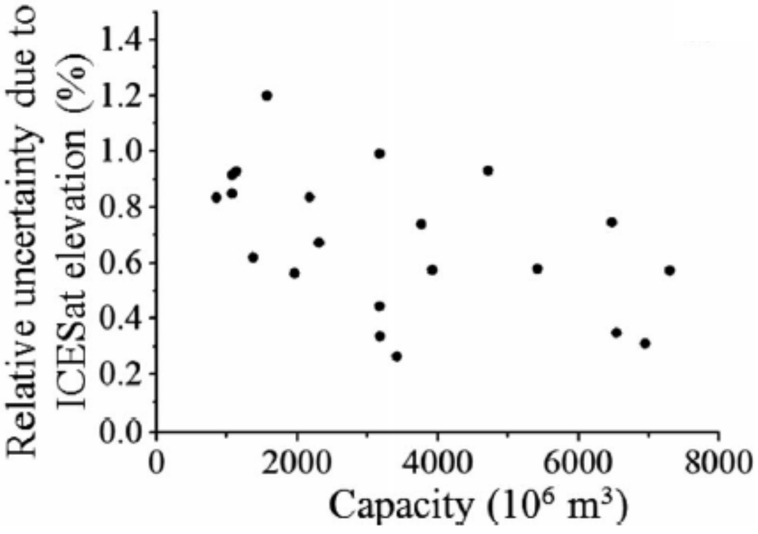


Gao et al., 2012

Uncertainties due to
MODIS area

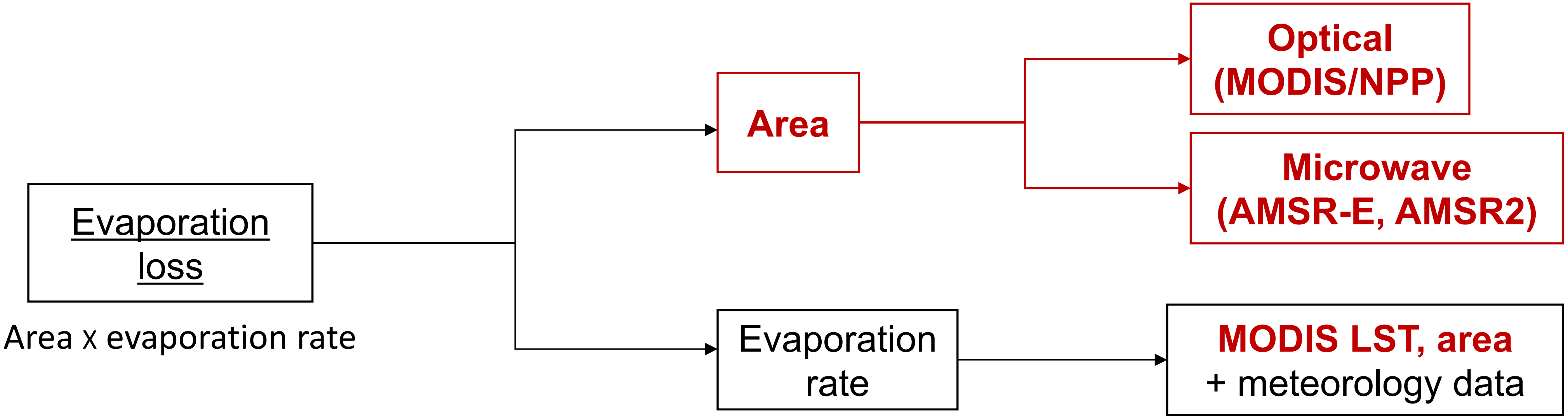


Uncertainties due to
ICESat elevation



Zhang et al., 2014)

Reservoir Evaporation Estimation



RESERVOIR EVAPORATION IN THE WESTERN UNITED STATES

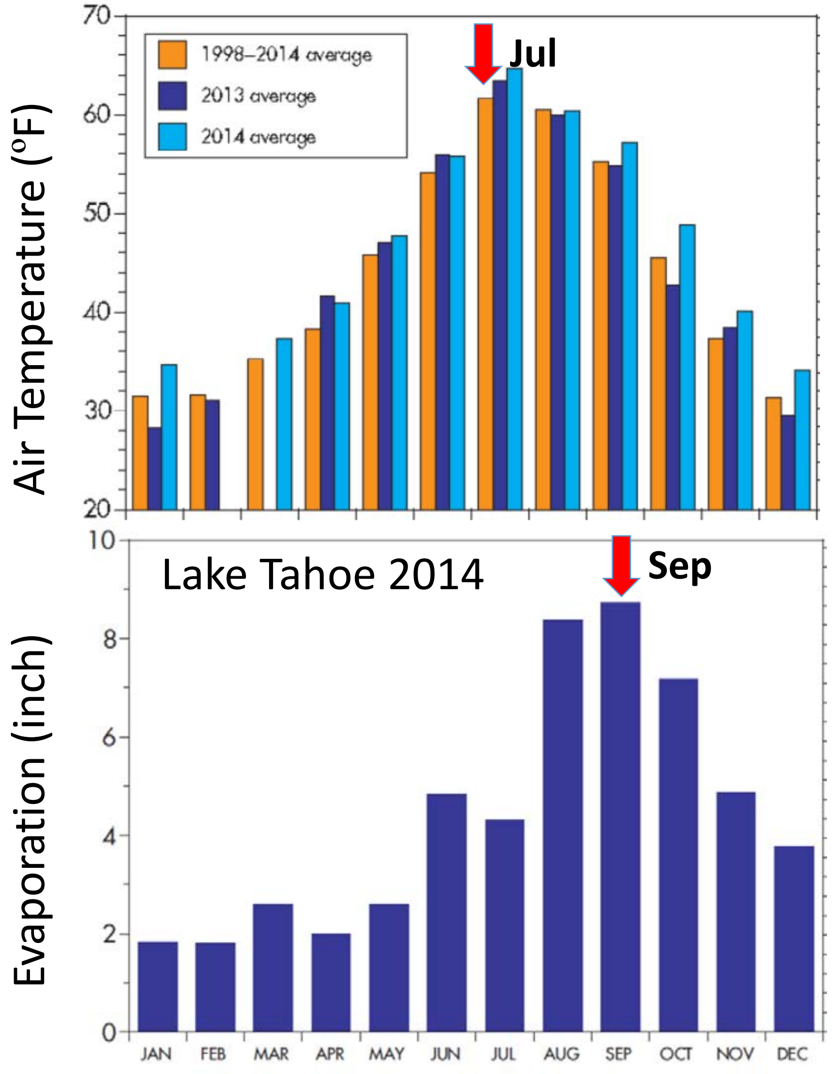
Current Science, Challenges, and Future Needs

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.

Heat Storage Effect on the Evaporation Rate



Heat storage effect:

Spring and Summer – absorb heat

Fall and Winter – release heat

Penman Equation

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

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})

Improving the Estimation of Reservoir Evaporation Rate

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

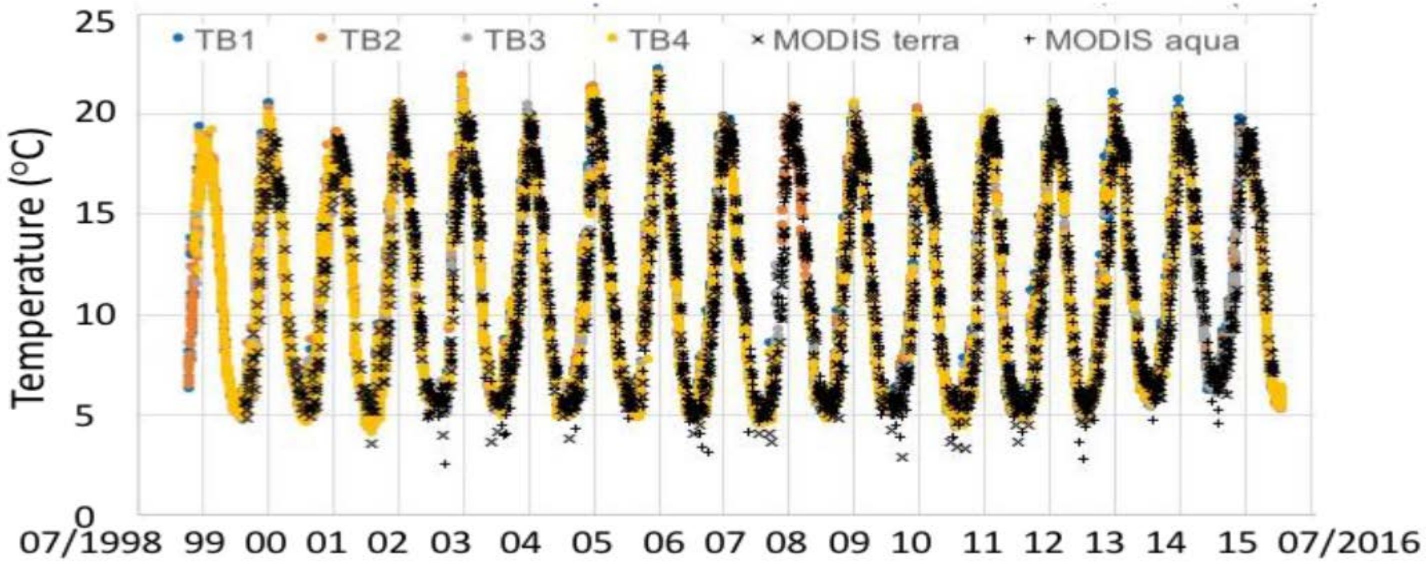
$$\Delta U = h\rho c[T_w(t) - T_w(t - \Delta t)]$$

Tw from MODIS LST

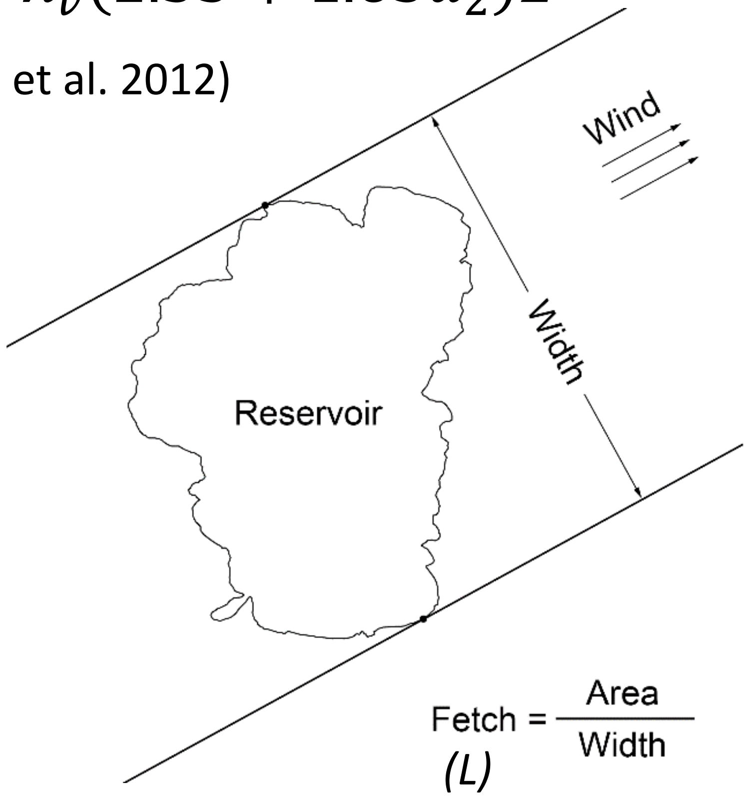
$$f(u_2) = \lambda_v (2.33 + 1.65 u_2) L^{-0.1}$$

(McJannet et al. 2012)

Lake Tahoe

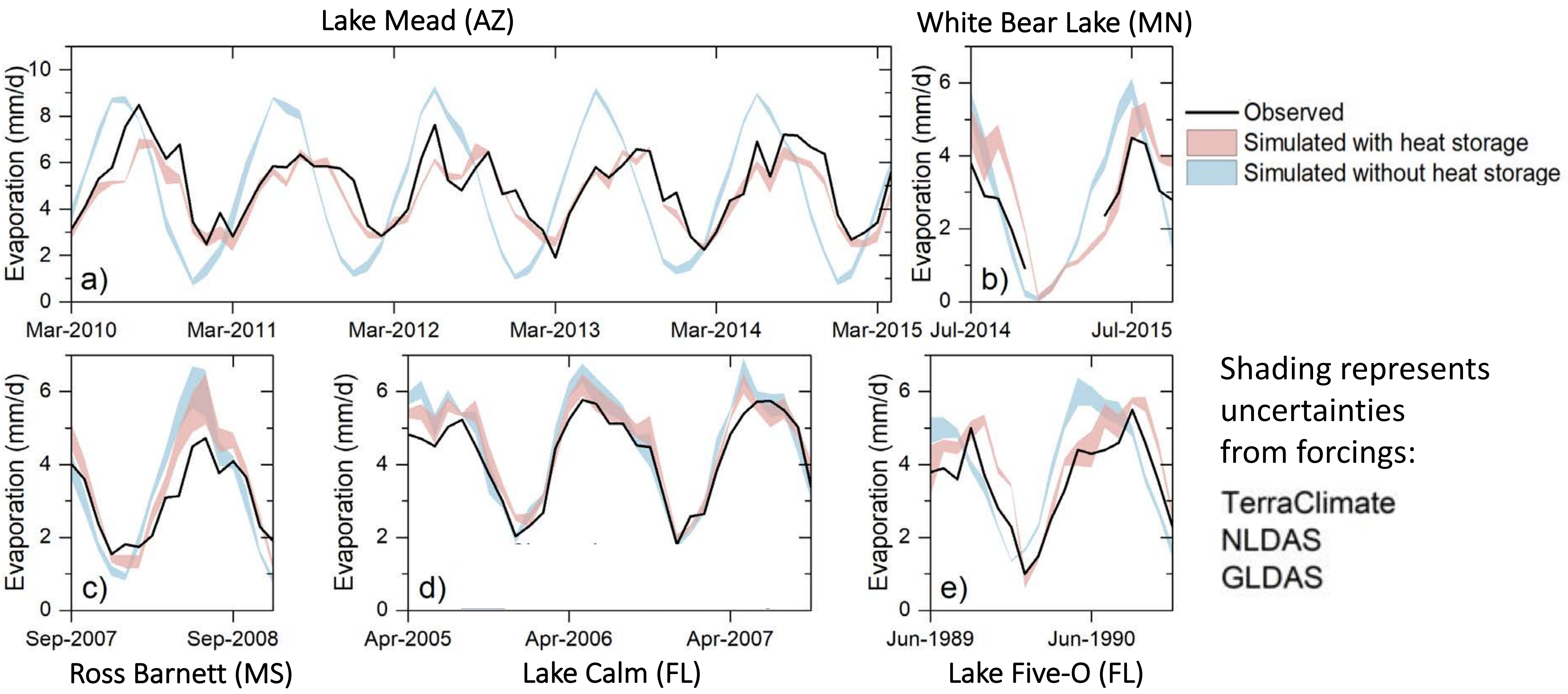


(Friedrich et al., 2017)



Dynamic MODIS Area

Validation Results & Uncertainties

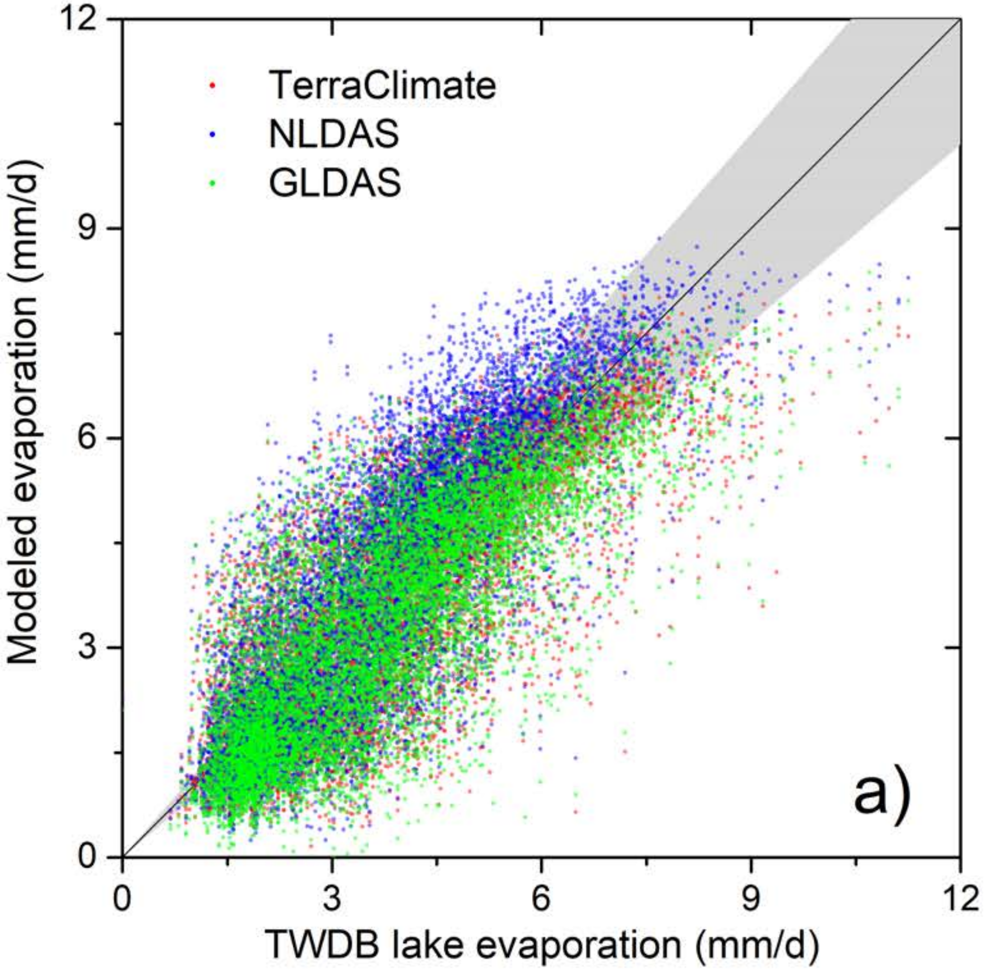


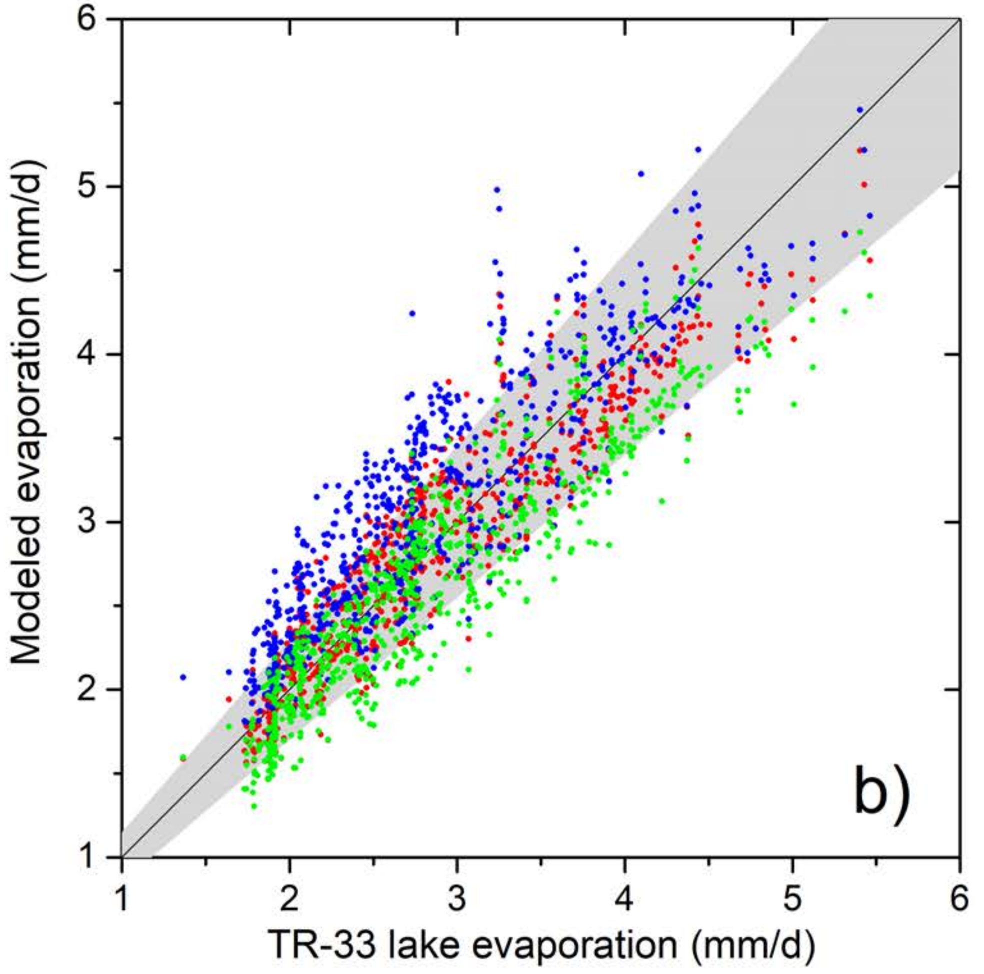
Shading represents uncertainties from forcings:

TerraClimate
NLDAS
GLDAS

a-c: Eddy covariance; d-e: Bowen ration

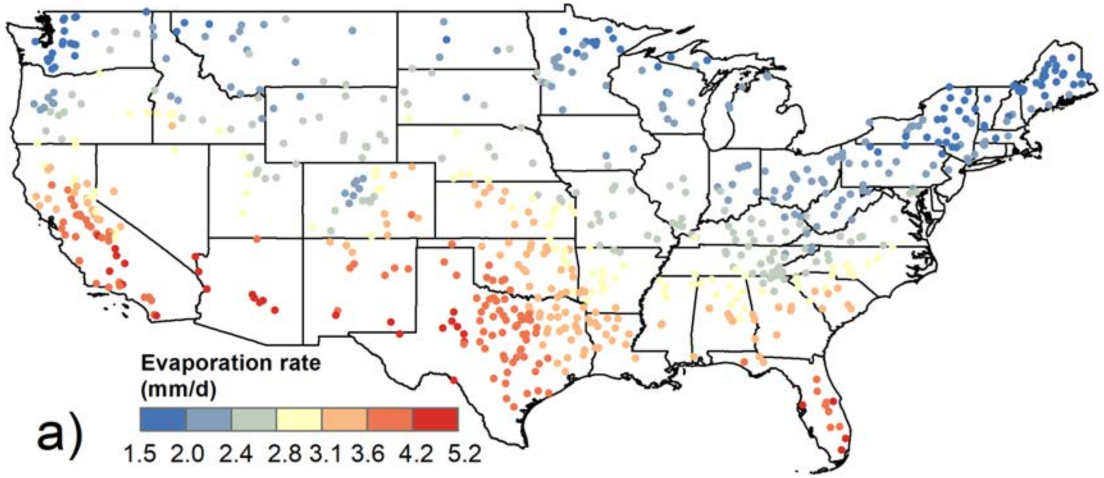
Validation Results & Uncertainties

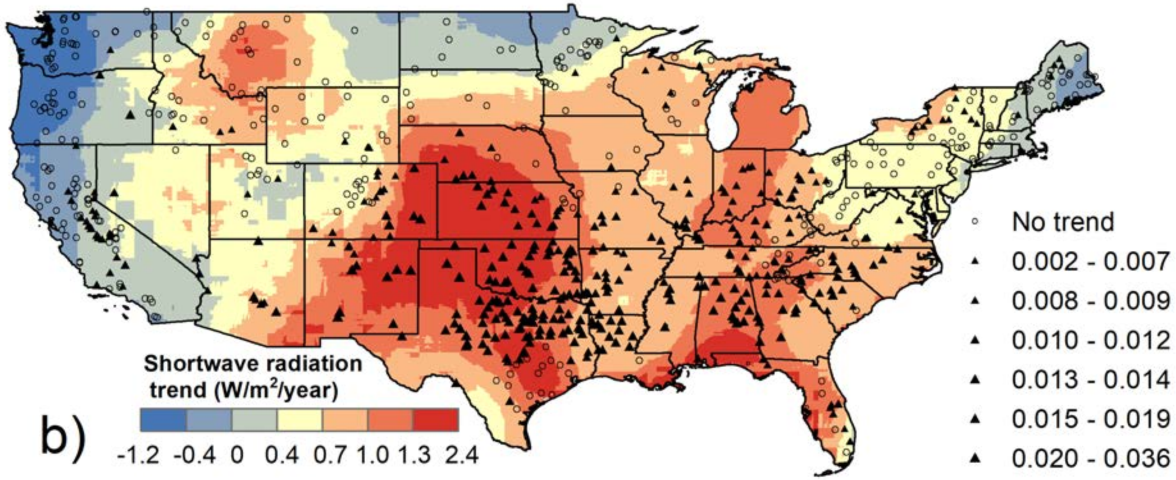


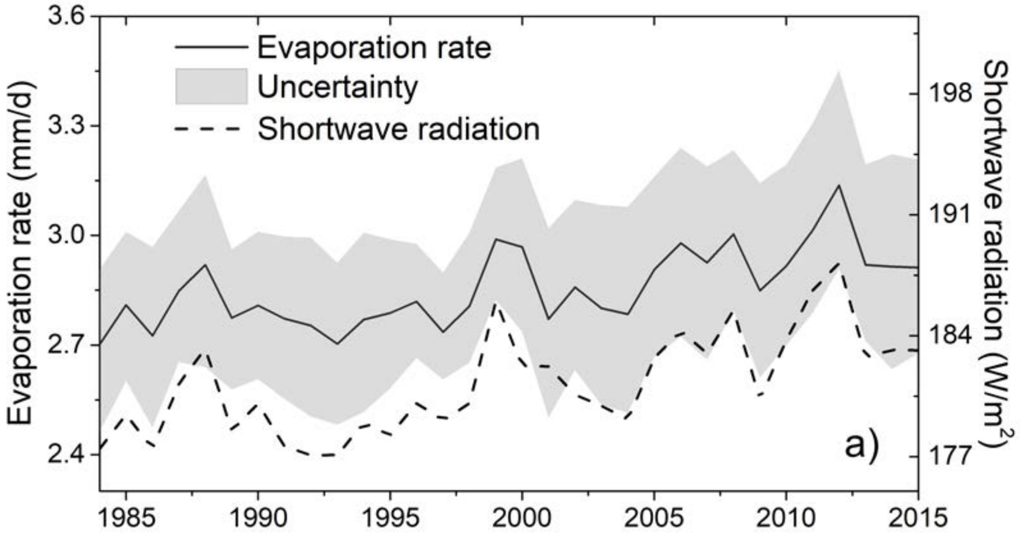


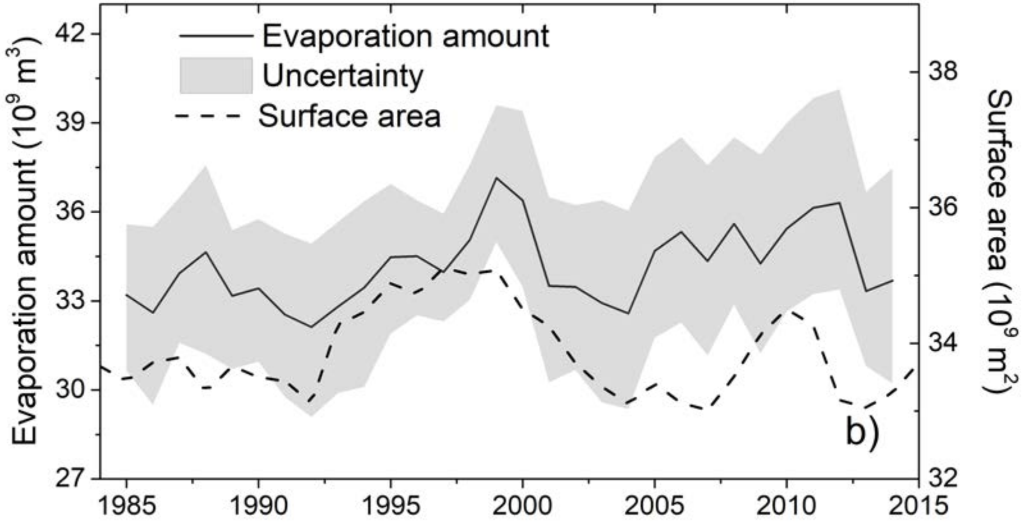
Trends of Reservoir Evaporation

1984-2015









Zhao and Gao, to be submitted.

Planed Schedule of Activities

Tasks	Yr1				Yr2				Yr3			
Task 1: Identifying reservoirs and extracting elevation												
Task 2: Developing the reservoir product series												
Task 2.1 Reservoir area, storage, and elevation products												
Task 2.2 Reservoir evaporation rate and loss products												
Task 3: Validating the algorithms and product series												
Task 3.1 Validating the reservoir storage algorithm and product												
Task 3.2 Validating the reservoir evaporation algorithm and product												
Task 4: Characterizing errors and uncertainties												
Task 5: Developing the ATBD and delivering the products												

Summary

✓ Long term, consistent, remotely sensed reservoir storage and evaporation products can be used to support many applications.

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

✓ The estimation of reservoir evaporation rate can be improved using the Penman Equation, with the heat storage and fetch considered. The lake heat storage can be estimated using MODIS/VIIRS LST, while the fetch is a function of the dynamic lake area.

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

✓ More comprehensive uncertainty analyses are needed for the final product.