Yale 耶鲁大学–南京信息工程大学大气环境中心
Yale-NUIST Center on Atmospheric Environment

An Energy Partitioning Perspective on Lake Evaporation Variations to Climate Change

Wei Wang[1], Xuhui Lee[1,2], Lei Zhao[3], Zachary M. Subin[4]

1. Yale-NUIST Center on Atmospheric Environment, Nanjing University of Information Science & Technology, Nanjing, 210044, China;
2. School of Forestry and Environmental Studies, Yale University, New Haven, Connecticut, 06511, USA
3. Woodrow Wilson School of Public and International Affairs, Princeton University, Princeton, NJ, 08544, USA
4. Princeton Environmental Institute, Princeton University, Princeton, NJ 08544, USA

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Outline

- Motivation
- Scientific questions and hypothesis
- Model and data
- Preliminary results
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  - Interannual variations
  - Energy partitioning vs. air temperature
  - Freshwater flux
  - Evaporation comparison between lake and surrounding land
- Next steps

Motivation

- **Hypothesis I** – the lake evaporation rate will increase as air temperature rises, at a rate of 7% K^{-1} predicted by the Clausius-Clapeyron equation (*Held and Soden, 2006; Huntington, 2006; Wentz et al., 2007; Alessandri et al., 2012, Roderick et al., 2014*). **Hypothesis II** – lake evaporation variabilities are controlled by the variabilities in the surface solar radiation (*Ohmura and Wild, 2002; Liu and Zeng, 2004; Fu et al., 2009*).
- Changes in global water evaporation can be decomposed into two parts: one associated with the the net change in radiative flux and the other due to the variability of energy partitioning (*Held and Soden, 2006*).

Surface energy balance and the Priestley-Taylor (PT) model

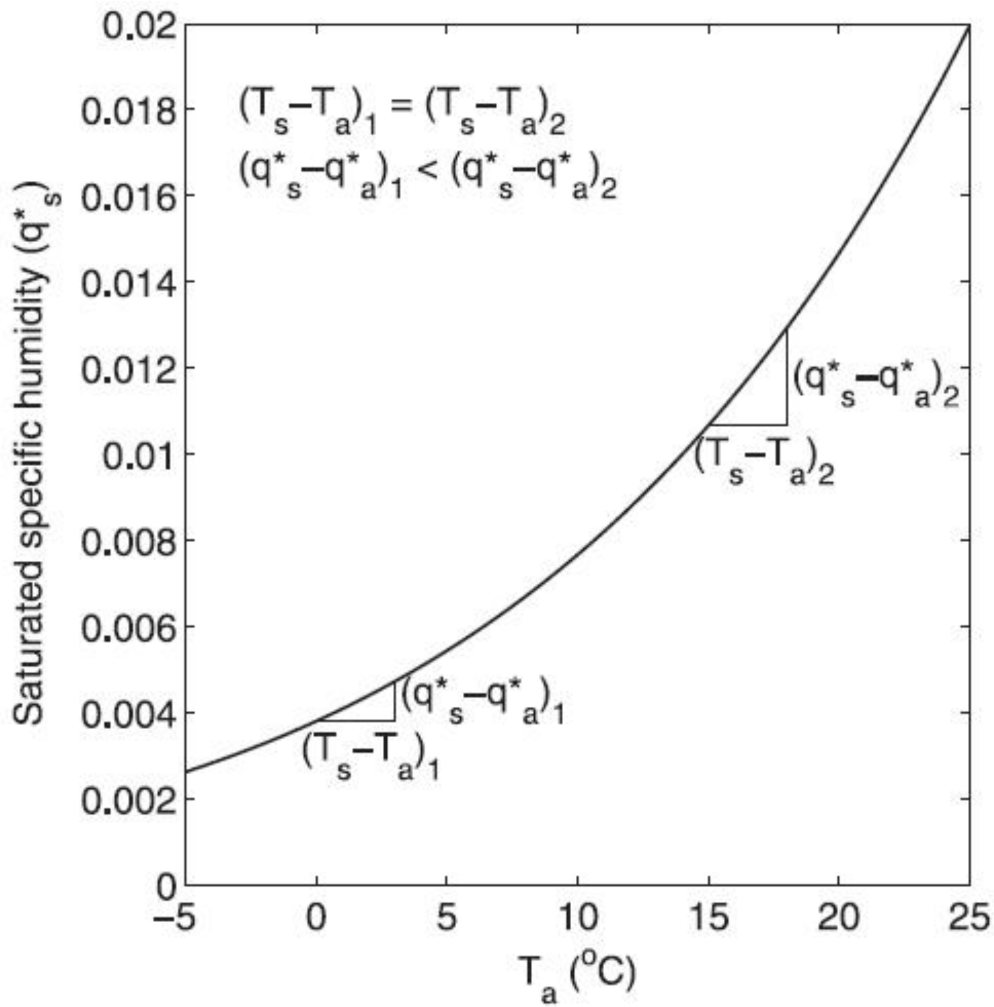
$$\beta = \frac{H}{\lambda E} \quad EF = \frac{\lambda E}{R_n - G}$$

$$R_n - G = H + \lambda E$$

$$\lambda E = \alpha \frac{\Delta}{\Delta + \gamma}(R_n - G)$$

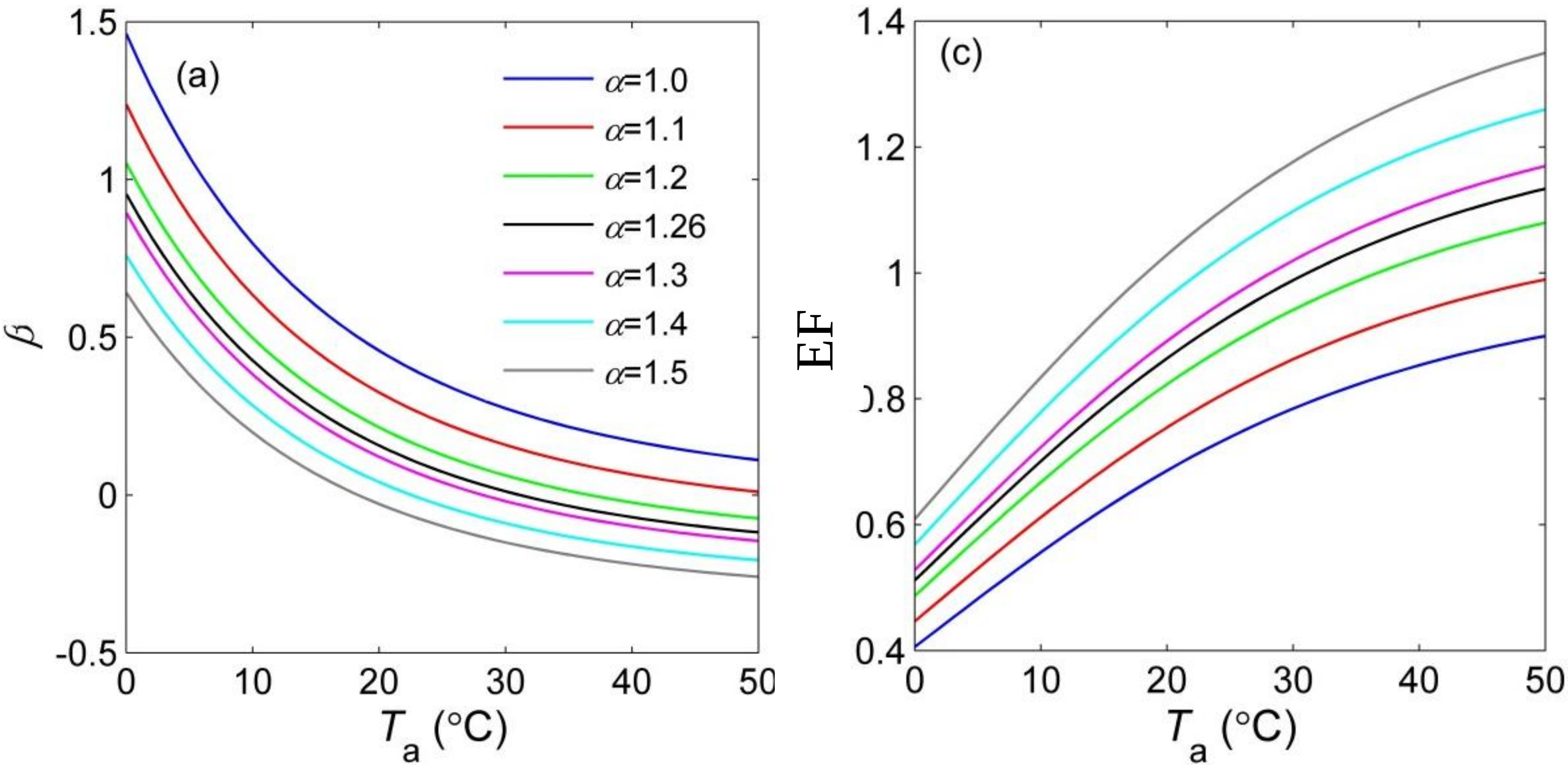
$$\beta = \frac{1}{\alpha}\frac{\gamma}{\Delta} + \frac{1}{\alpha} - 1$$

$$EF = \frac{1}{1+\beta}$$



(Priestley and Taylor, 1972; Monteith, 1981; Brutsaert, 1982; Garratt, 1992)

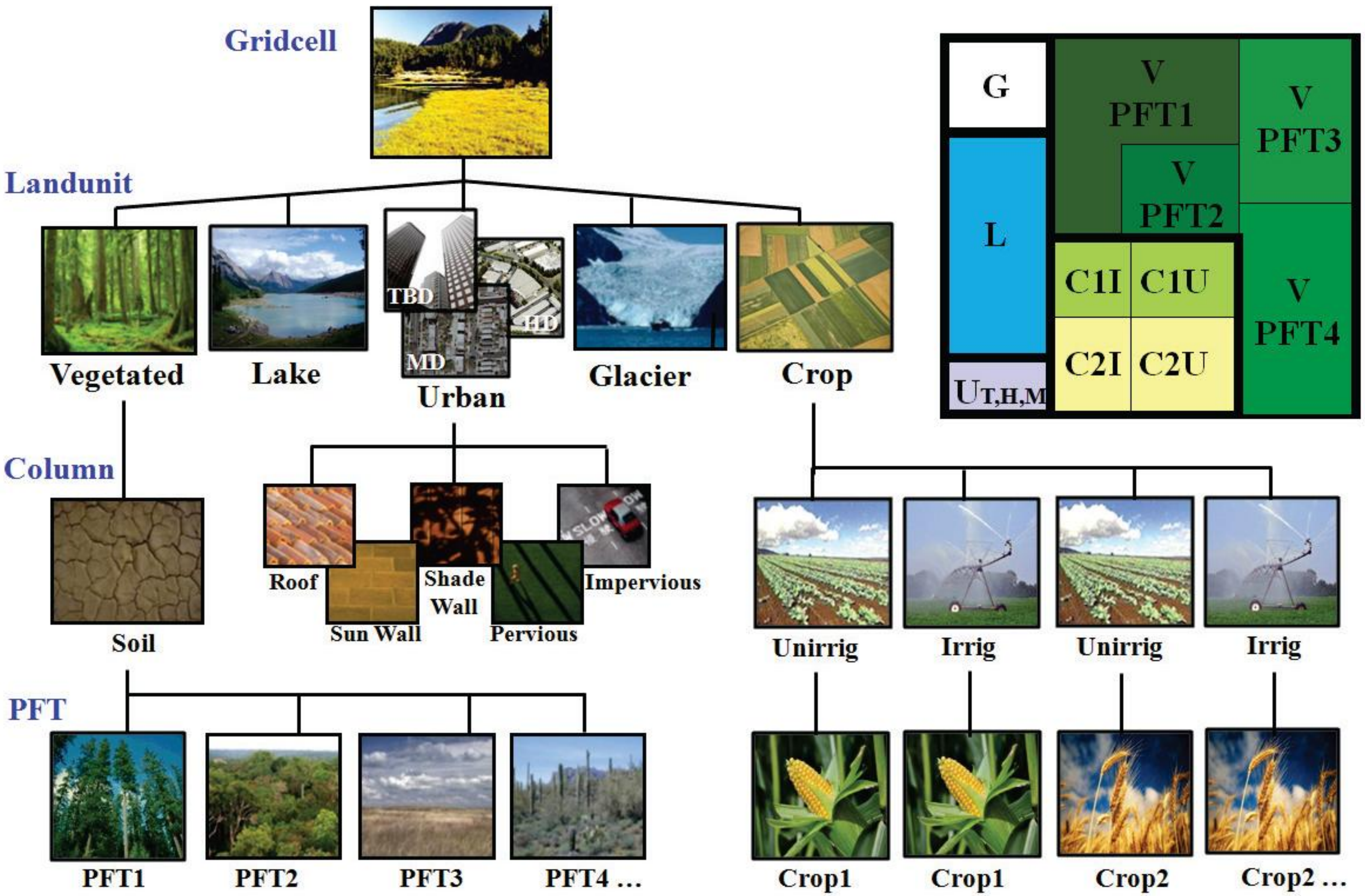
Relationship between β (EF) and T_a by PT model



Scientific questions and Hypothesis

- What is the main driver of the interannual variations in lake evaporation? Air temperature or solar radiation?
- How are about the mechanisms underlying lake evaporation variability caused by energy partitioning?
- The lake evaporation interannual variability are primarily explained by air temperature through its effect on energy partitioning (Bowen ratio or evaporative fraction), not by surface solar radiation.

Configuration of the CLM subgrid hierarchy



(Oleson et al., 2013)

Surface flux solution in CLM4.5-LISSS (Lake, Ice, Snow, and Sediment Simulator)

$$\beta \vec{S}_g - \vec{L}_g - H_g - \lambda E_g - G = 0$$

$$H_g = -\rho_{atm} C_p \frac{\left(\theta_{atm} - T_g\right)}{r_{ah}}$$

$$E_g = -\frac{\rho_{atm}\left(q_{atm} - q_{sat}^{T_g}\right)}{r_{aw}}$$

(Oleson et al., 2013)

Global Lake Database version 2 used in CLM4.5-LISSS

Lake type	Number	With depth	Fraction %	<5 m	<5 m fraction %	<10 m	<10 m fraction %
Freshwater	13155	8378	63.69	2247	26.82	6180	**73.76**
Saline	221	144	65.16	100	69.44	118	**81.94**
All	13376	8522	63.71	2347	27.54	6298	**73.90**

Global lake coverage: 2.3 million km^2.

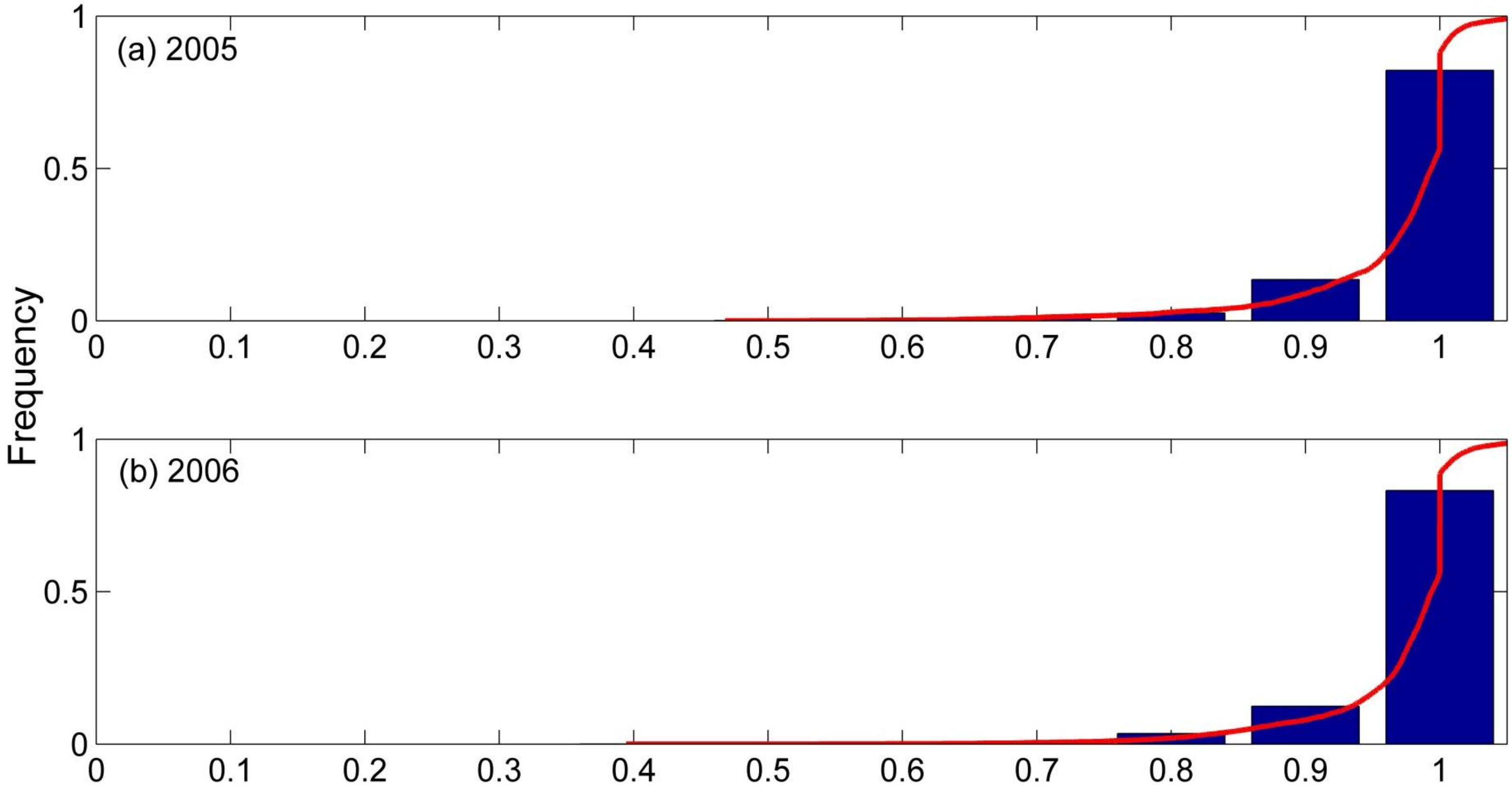
(Lehner and Doll, 2004; Kourzeneva et al., 2009, 2010, 2012)

CLM4.5-LISSS simulations

- Historical simulation: 1991-2010, monthly, 10-yr spin-up, 0.9^{o} (latitude) x 1.25^{o} (longitude), by Zack Subin, be validated;
- Future simulation: 2005-2100, monthly (primary files), daily (secondary files), 100-yr spin-up, RCP8.5, 0.9^{o} (latitude) x 1.25^{o} (longitude), by Lei Zhao, research;
- Latent heat: ground + canopy + transpiration

  Sensible heat: ground + canopy

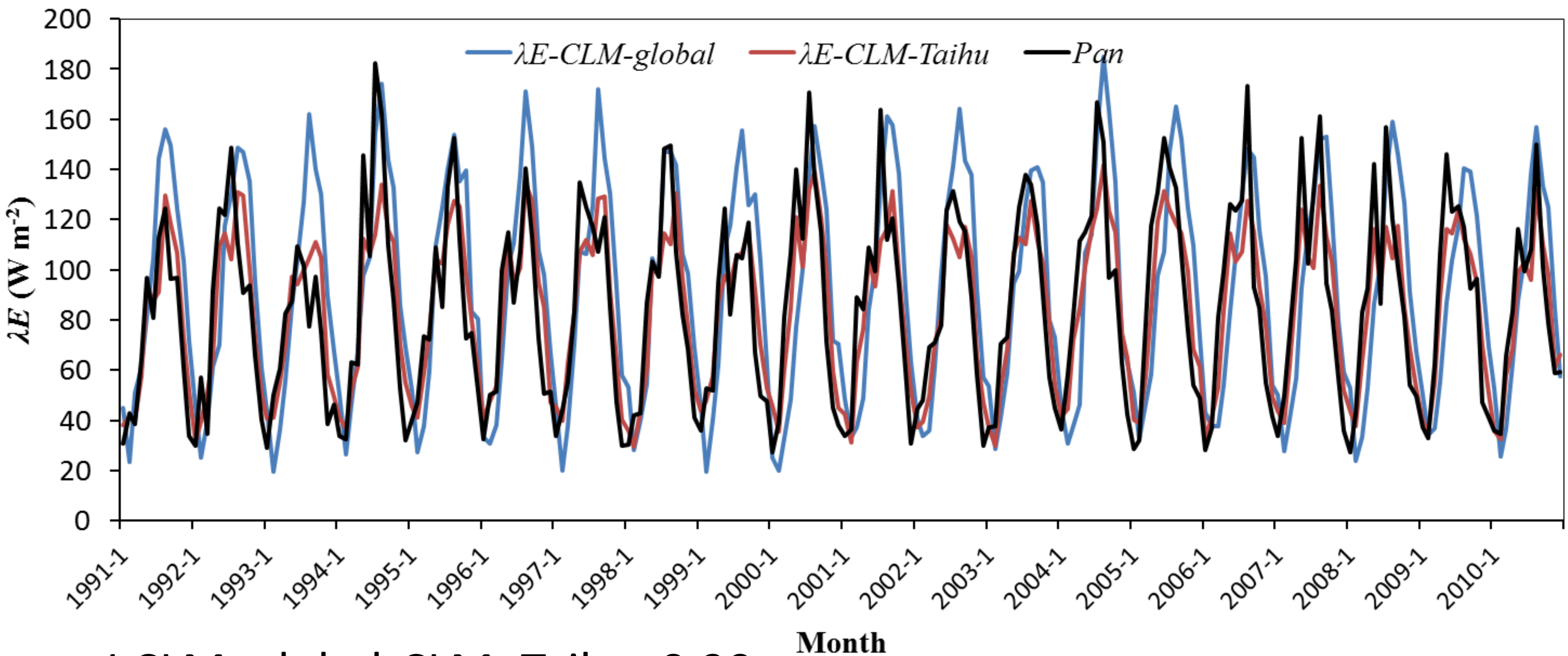
Why open water evaporation?



Global open lake evaporation: 2.16 x 10^{15} kg yr^{-1}

Year round lake evaporation: 2.18 x 10^{15} kg yr^{-1}

Validation of monthly evaporation simulations at Lake Taihu



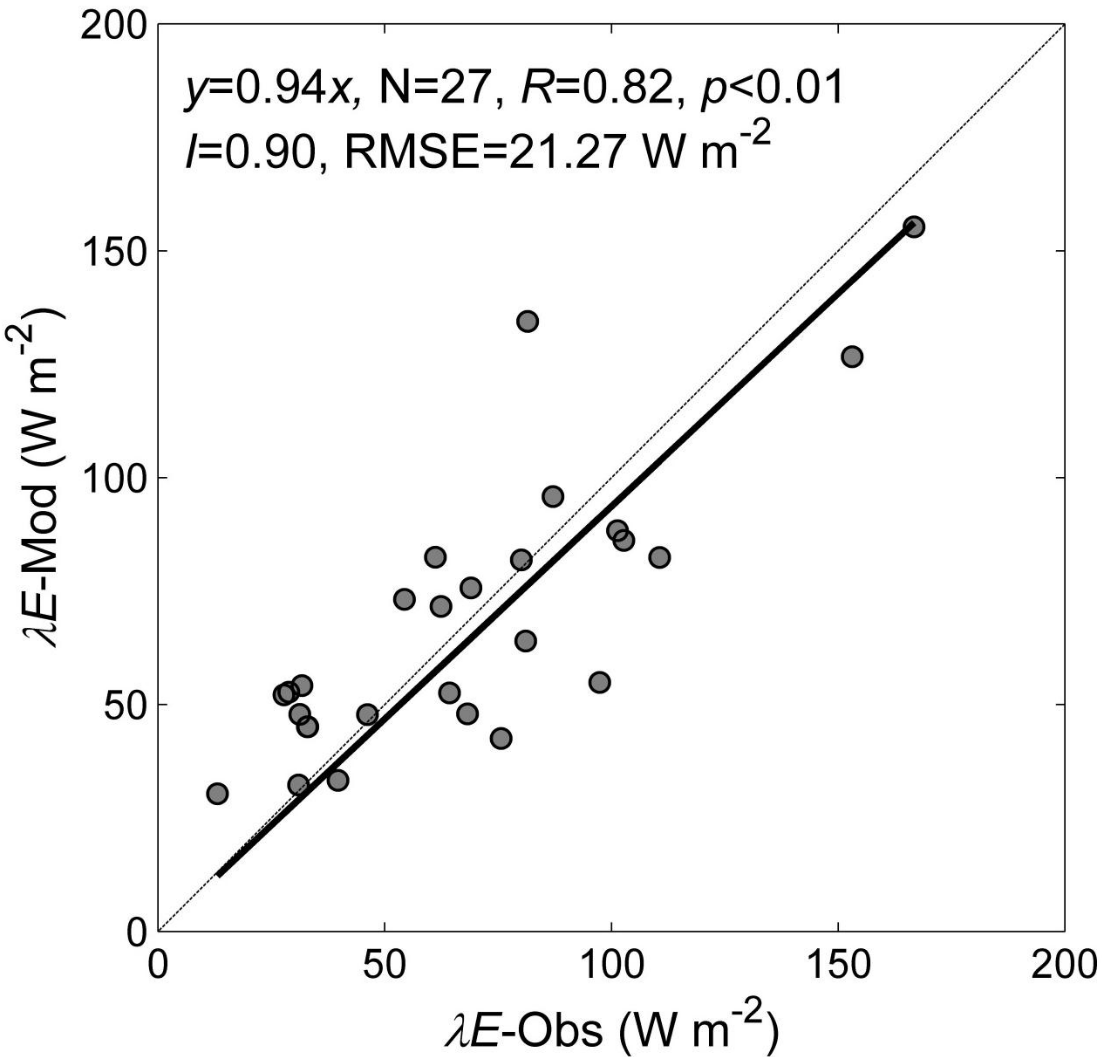
l-CLM_global-CLM_Taihu: 0.90

l-CLM_global-Pan: 0.83

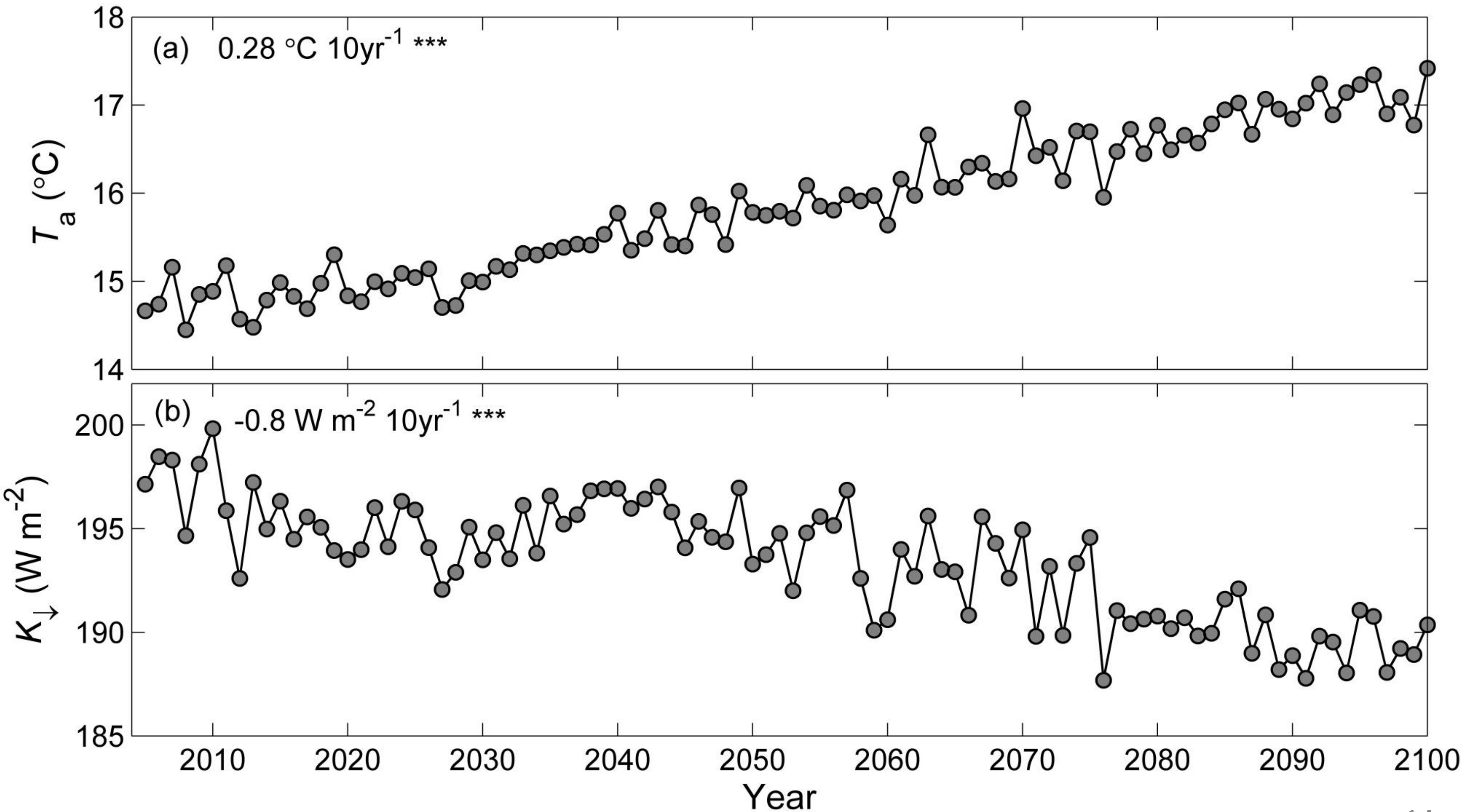
RMSE-CLM_global-CLM_Taihu: 23.10 mm.month^{-1}

RMSE-CLM_global-Pan: 31.93 mm month^{-1}

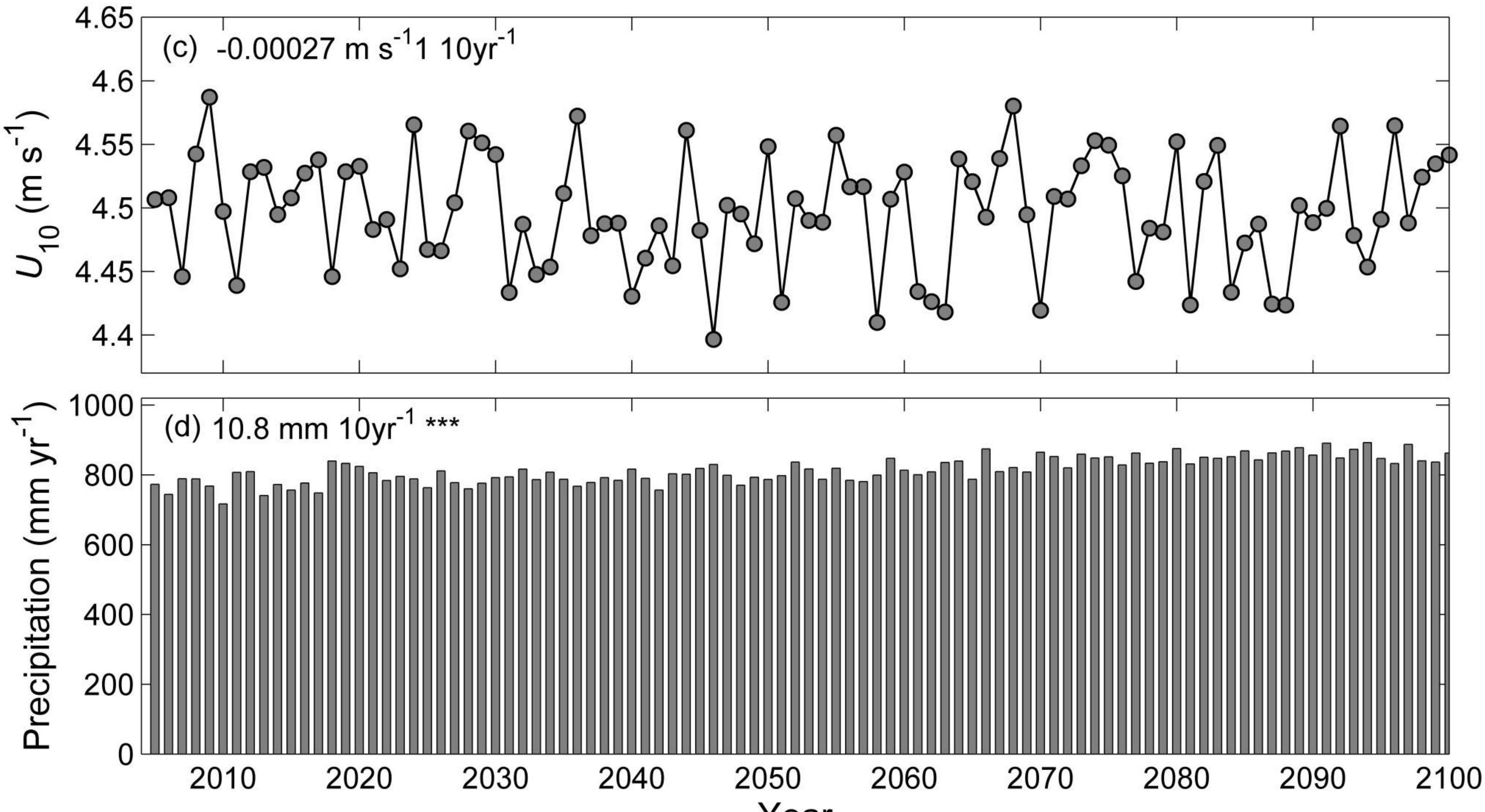
Validation of annual evaporation simulations at 27 lakes



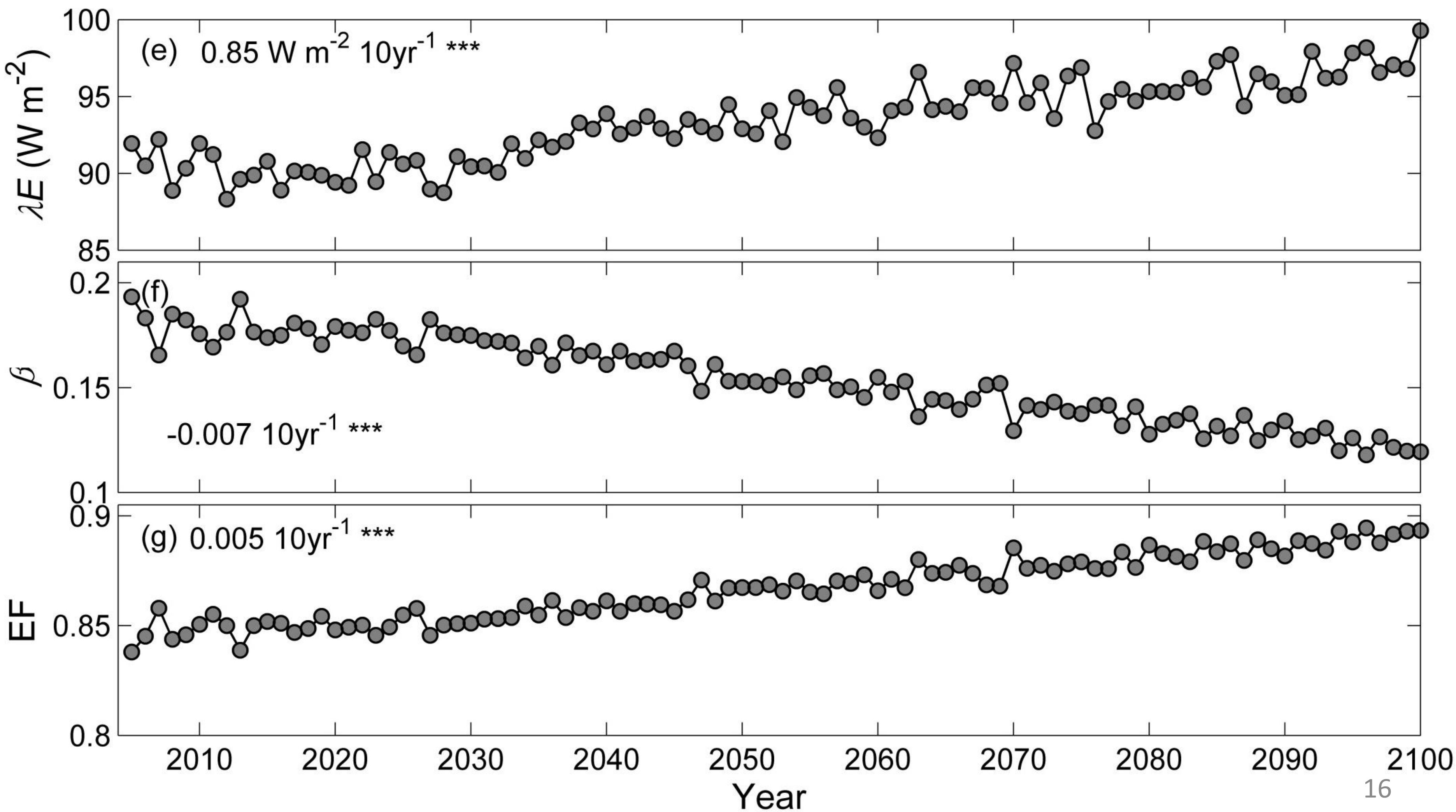
Interannual variations in global lake mean air temperature and solar radiation



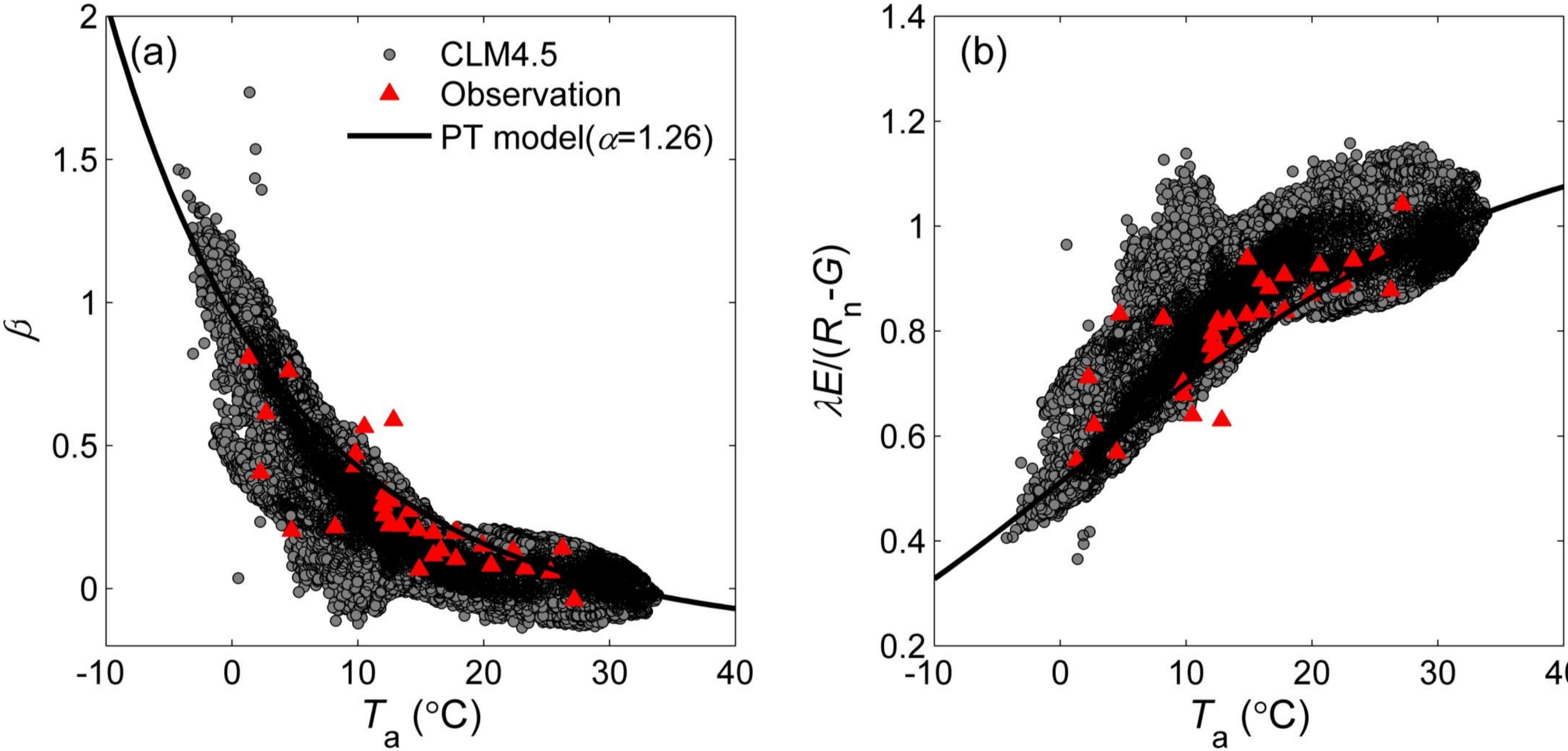
Interannual variations in global lake mean wind speed and precipitation



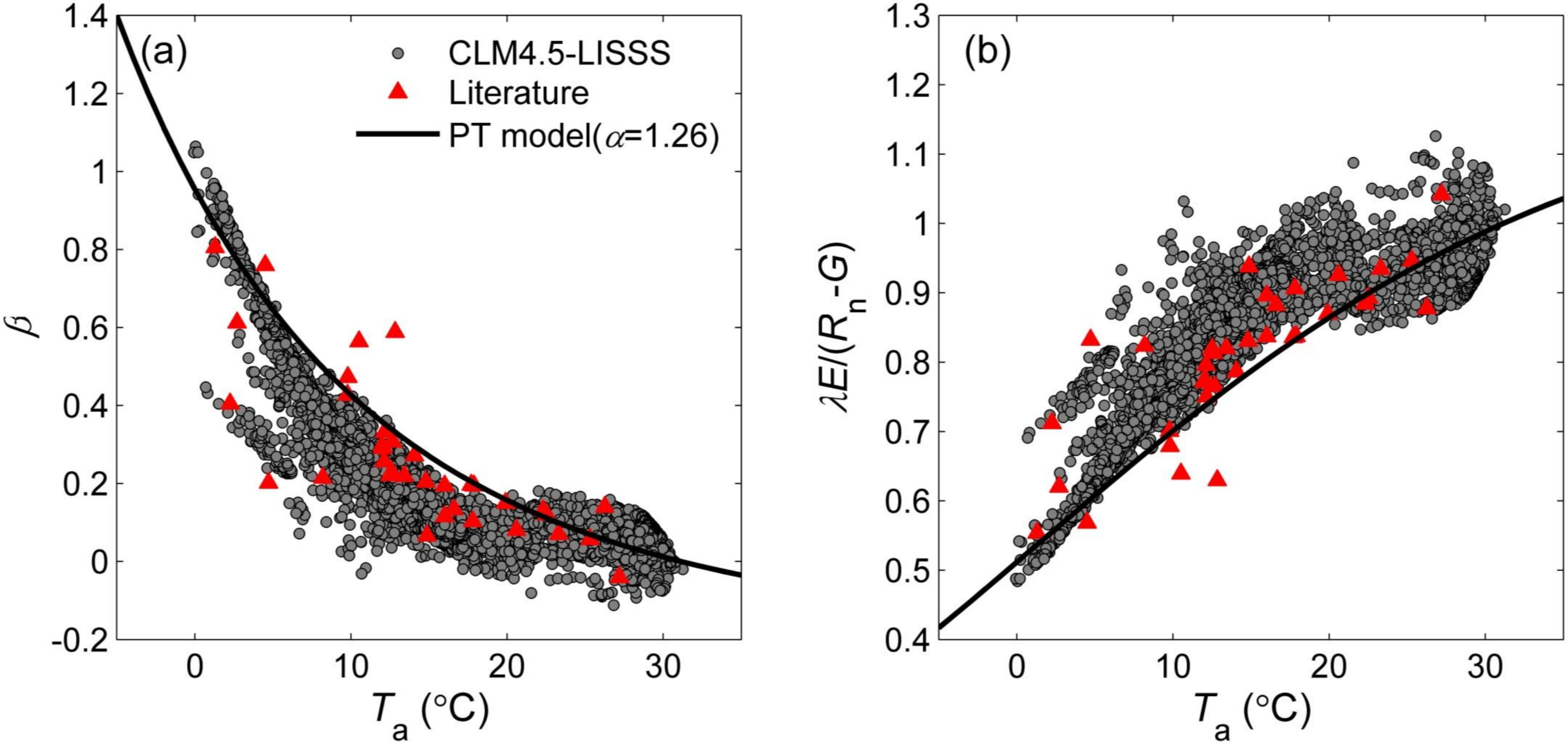
Interannual variations in global lake mean latent heat, β and EF



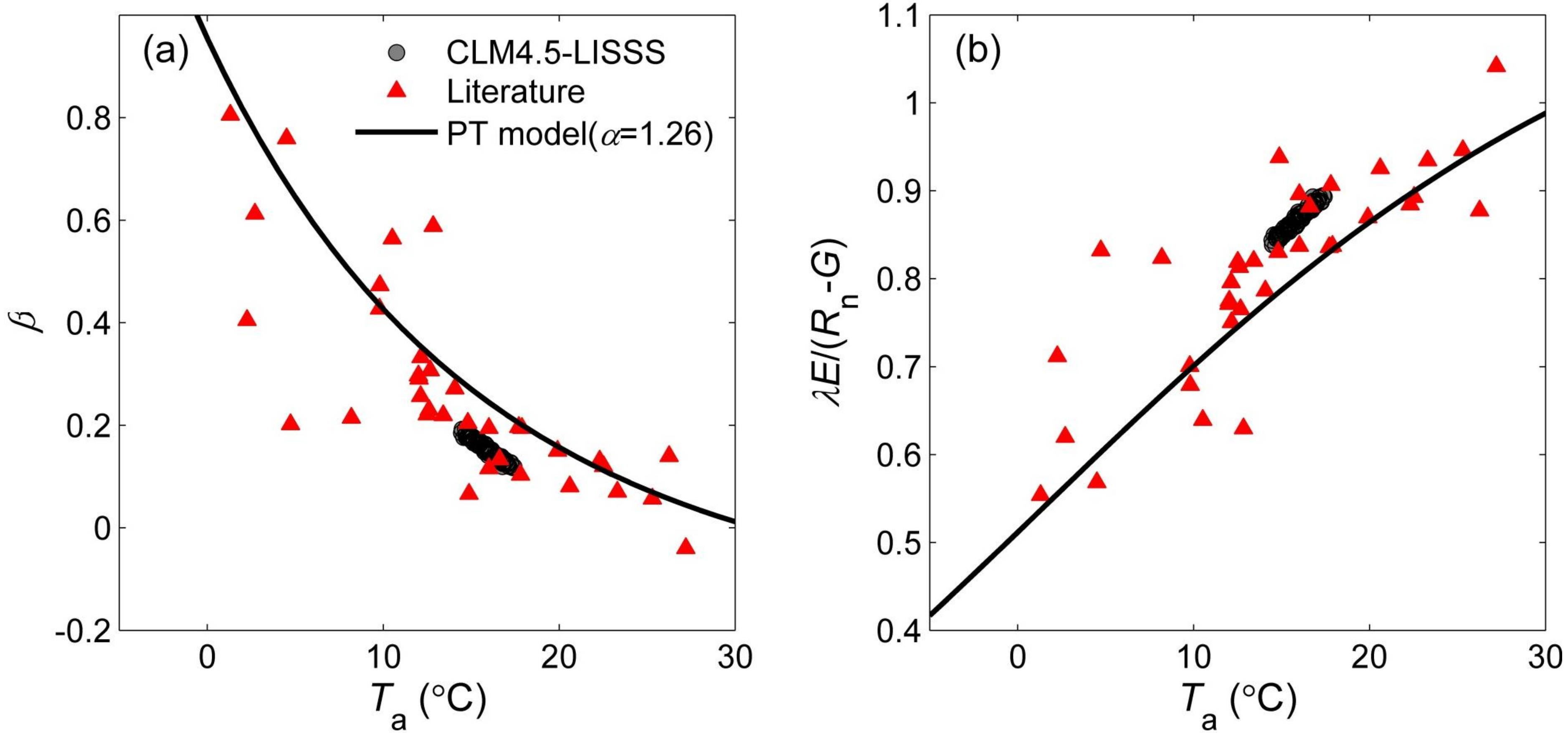
β (EF) varying with air temperature every lake-year



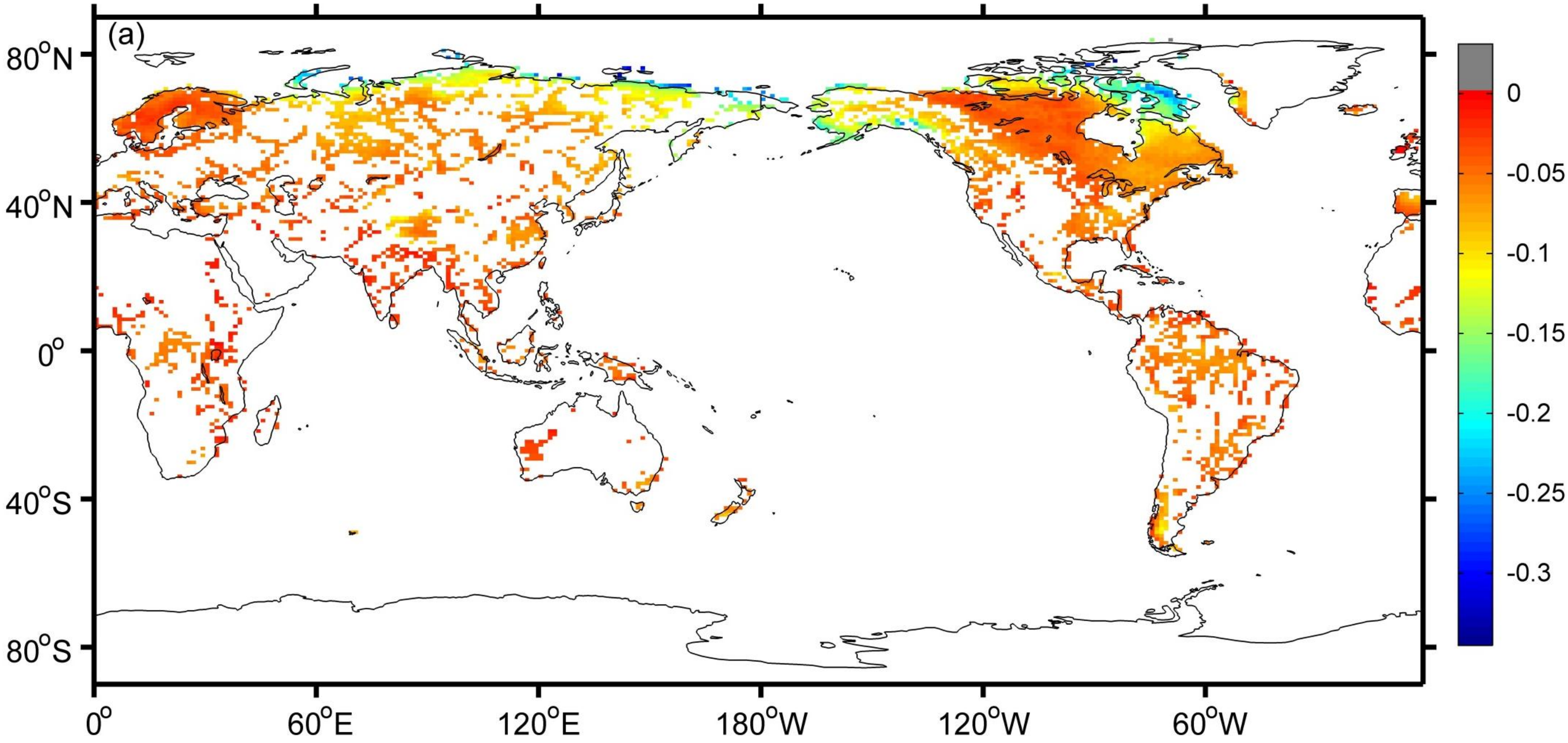
β (EF) varying with air temperature every lake 2005-2100 mean



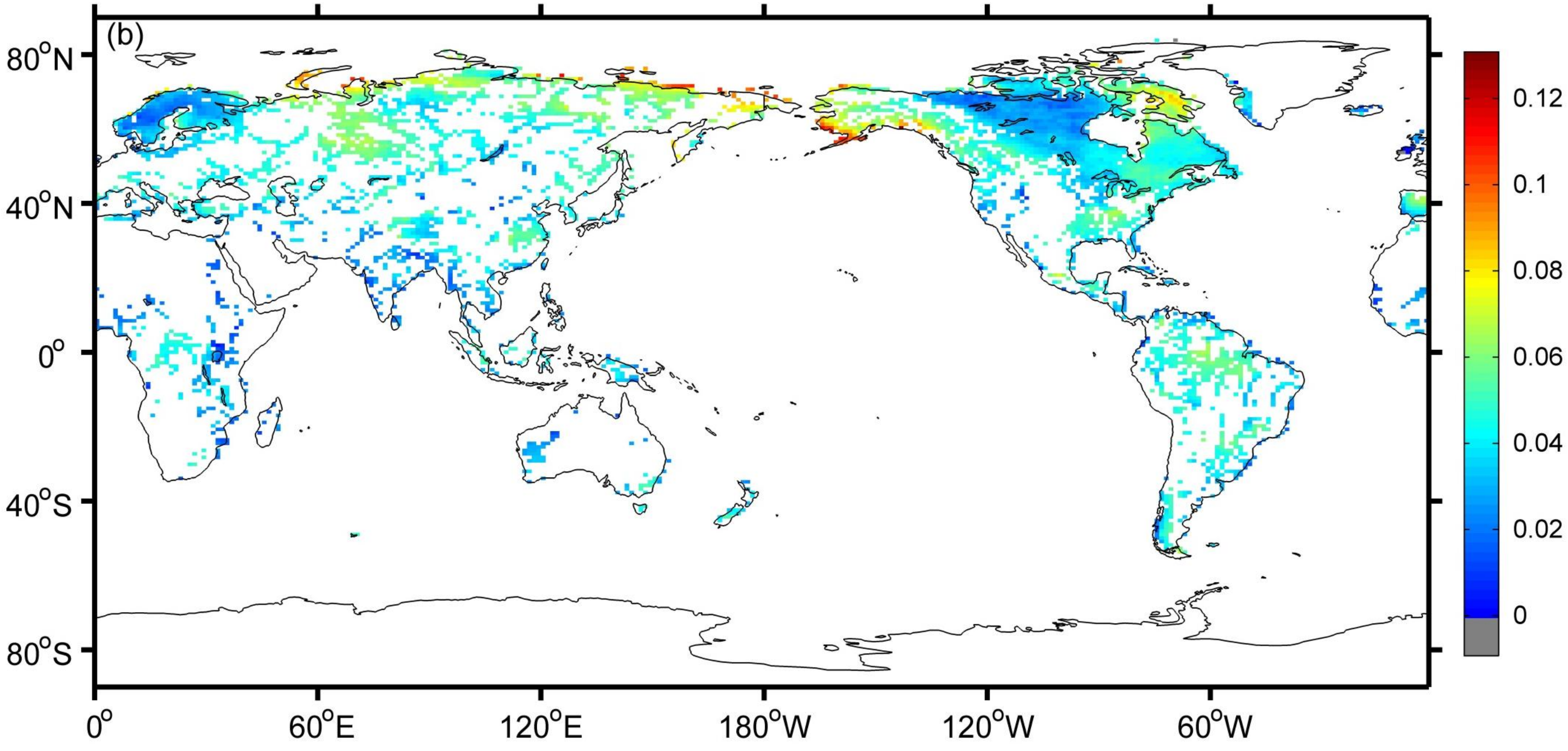
β (EF) varying with air temperature 2005-2100 global lake mean



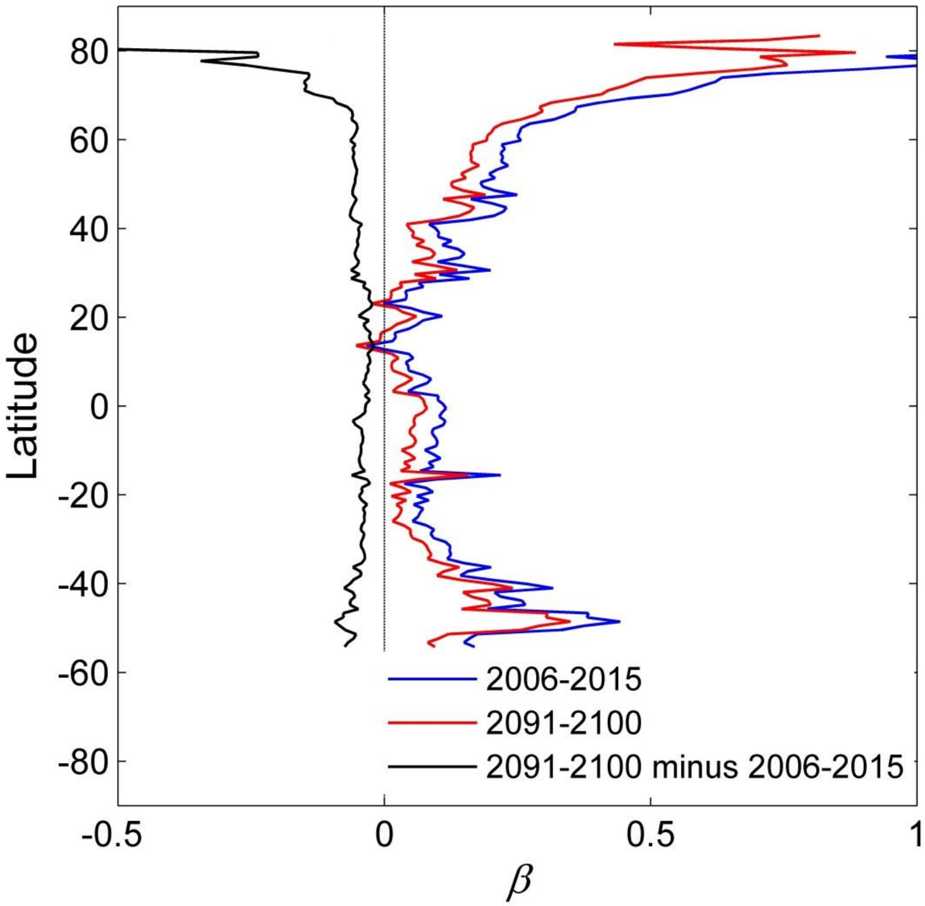
β difference 2091-2100 mean minus 2006-2015 mean

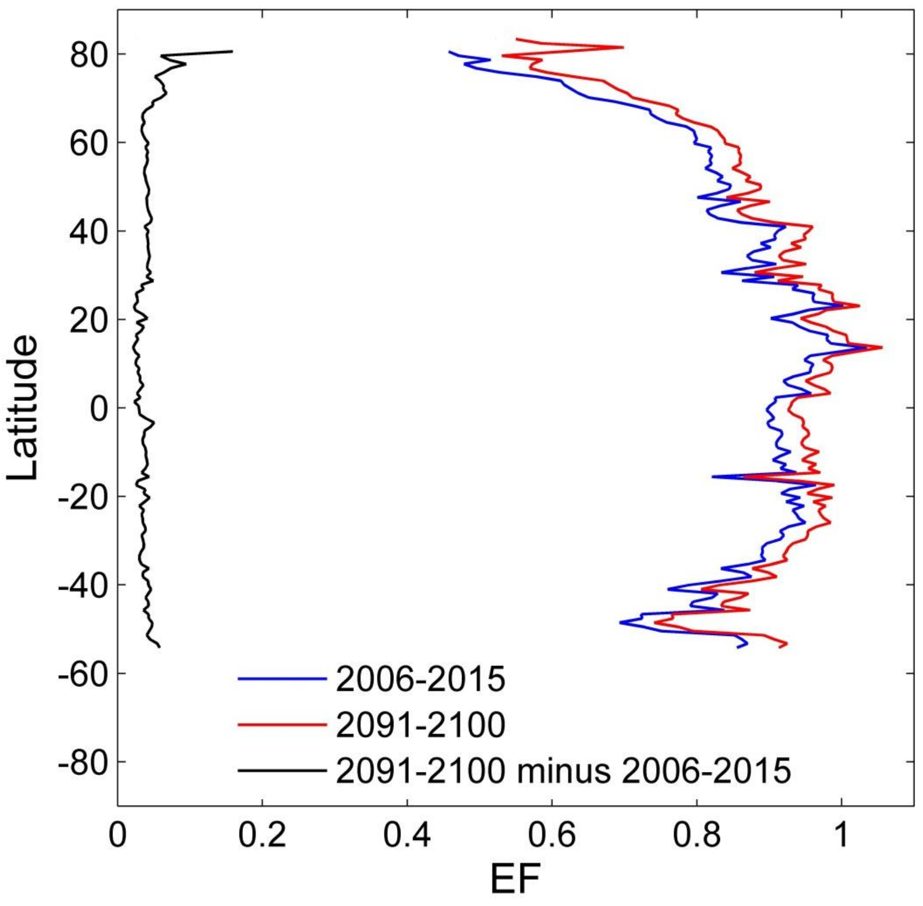


EF difference
2091-2100 mean minus 2006-2015 mean

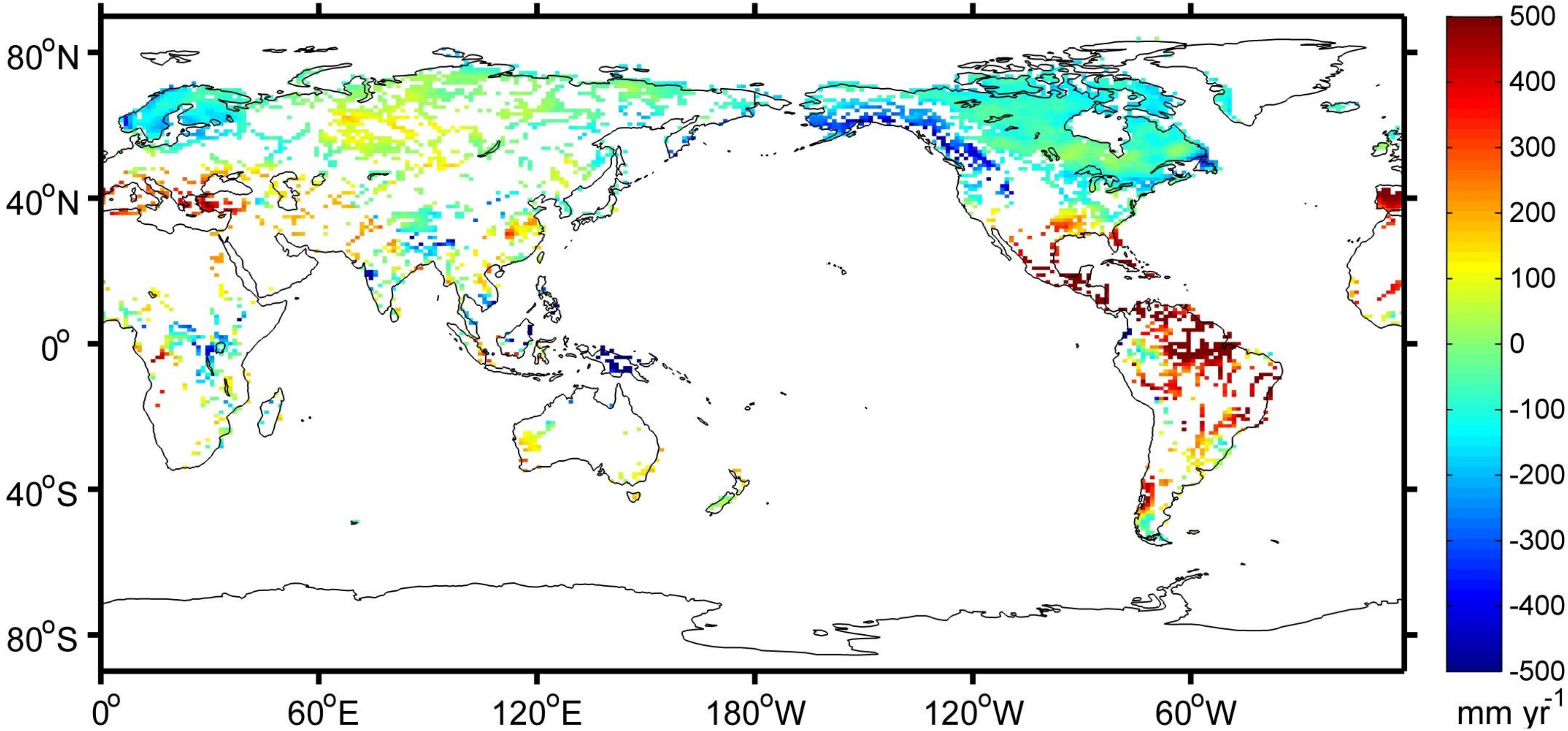


Zonal mean of β (EF)

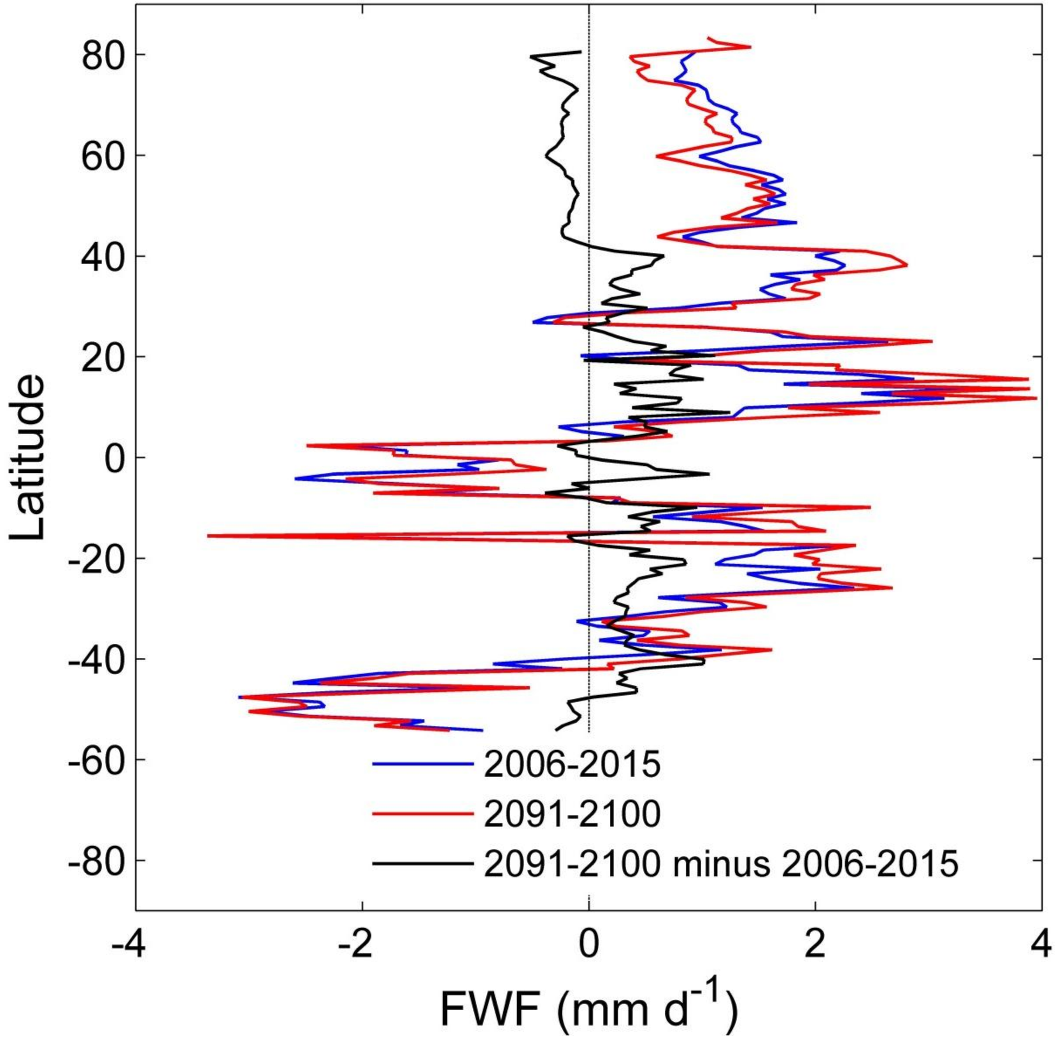




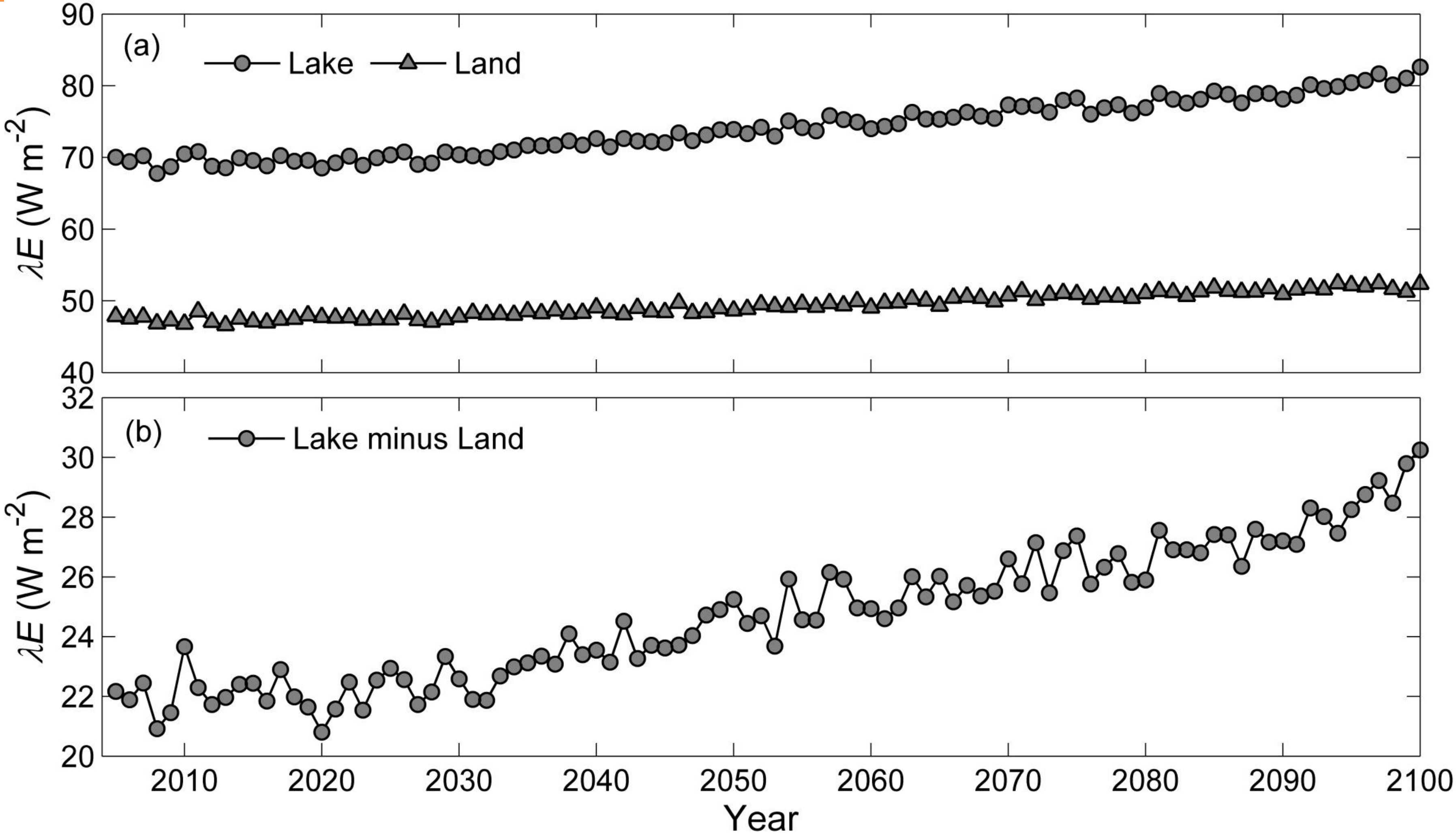
Freshwater flux (Evaporation minus Precipitation) difference 2091-2100 mean minus 2006-2015 mean



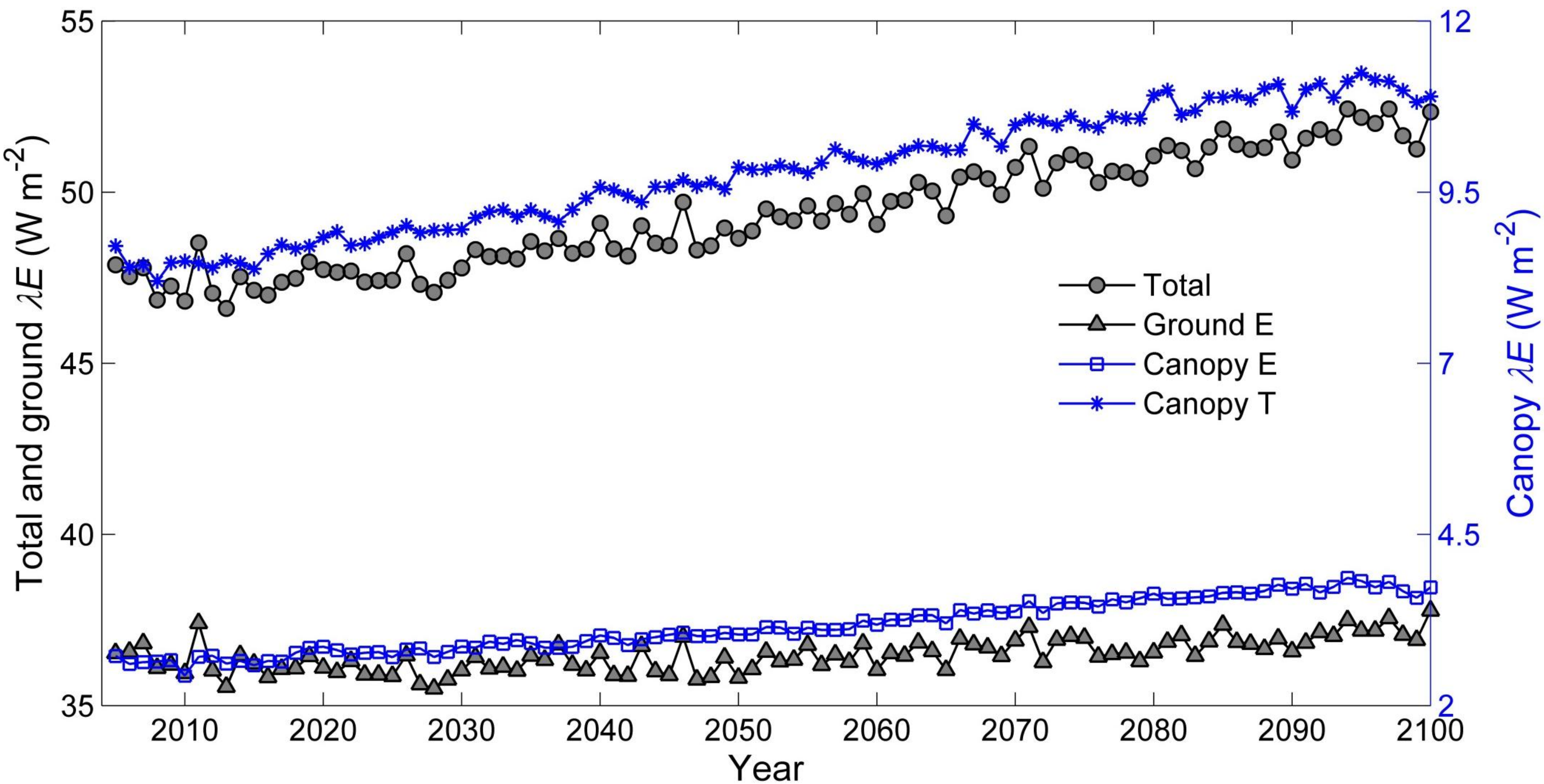
Zonal mean of FWF



Evaporation comparison between lake and surrounding land



Partitioning of latent heat flux over land



Next steps

- Intensive validation of CLM4.5-LISSS simulations against in-situ observations.

Geophysical Research Letters

RESEARCH LETTER
10.1002/2015GL066235

Rapid and highly variable warming of lake surface waters around the globe

- Application of the PT model according to the heat flux regimes with corrected PT coefficient.

Boundary-Layer Meteorol
DOI 10.1007/s10546-015-0031-

NOTES AND COMMENT

On the variability of the Priestley-Taylor coefficient over water bodies

Shmuel Assouline,[1] Dan Li,[2] Scott Tyler,[3] Josef Tanny,[1] Shabtai Cohen,[1] Elie Bou-Zeid,[4] Marc Parlange,[5] and Gabriel G. Katul[6]

On the Application of the Priestley–Taylor Relation on Sub-daily Time Scales

Xiaofeng Guo[1] · Heping Liu[2] · Kun Yang[3,4]