Estimation of evapotranspiration using satellite TOA radiances

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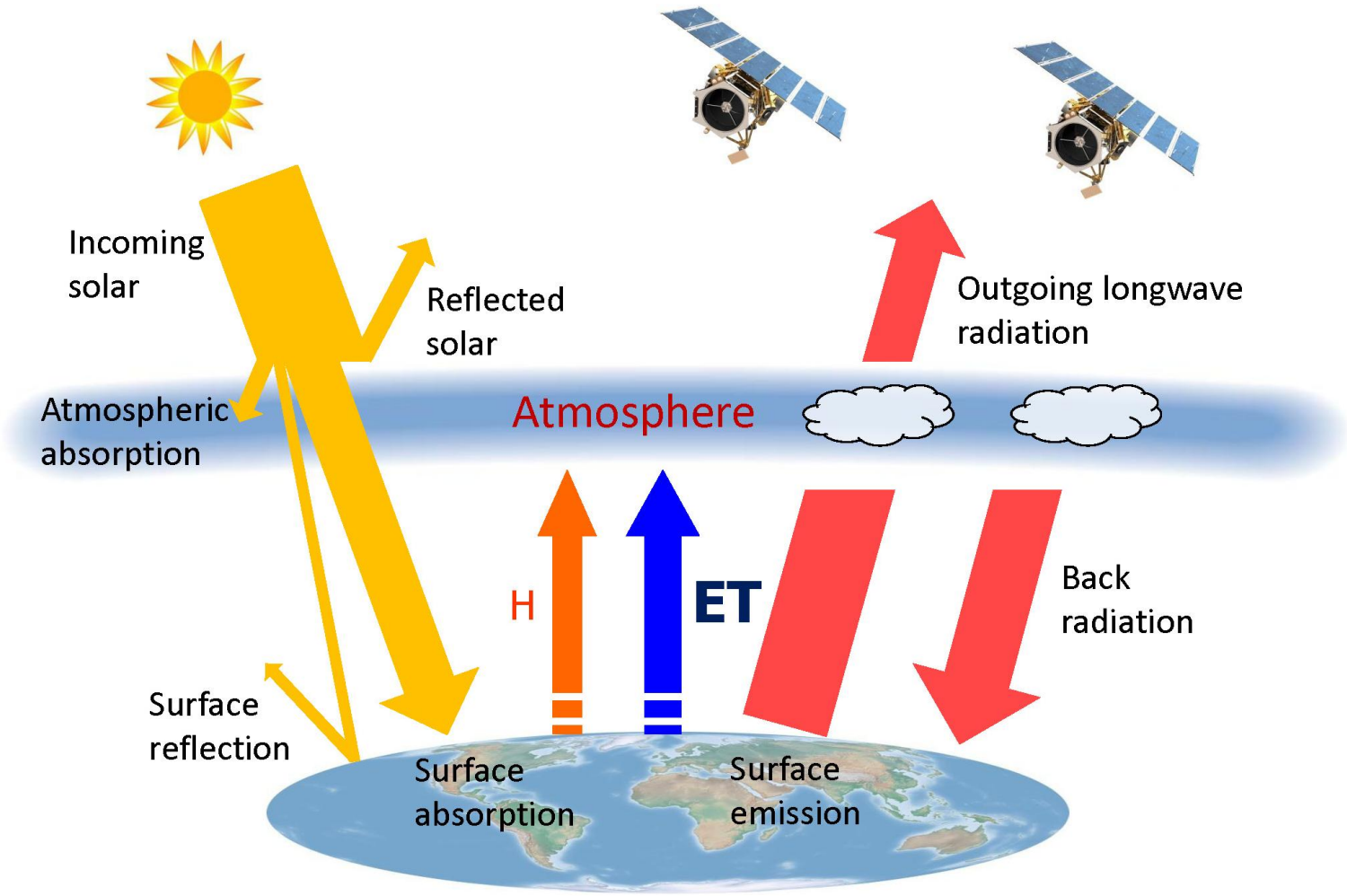
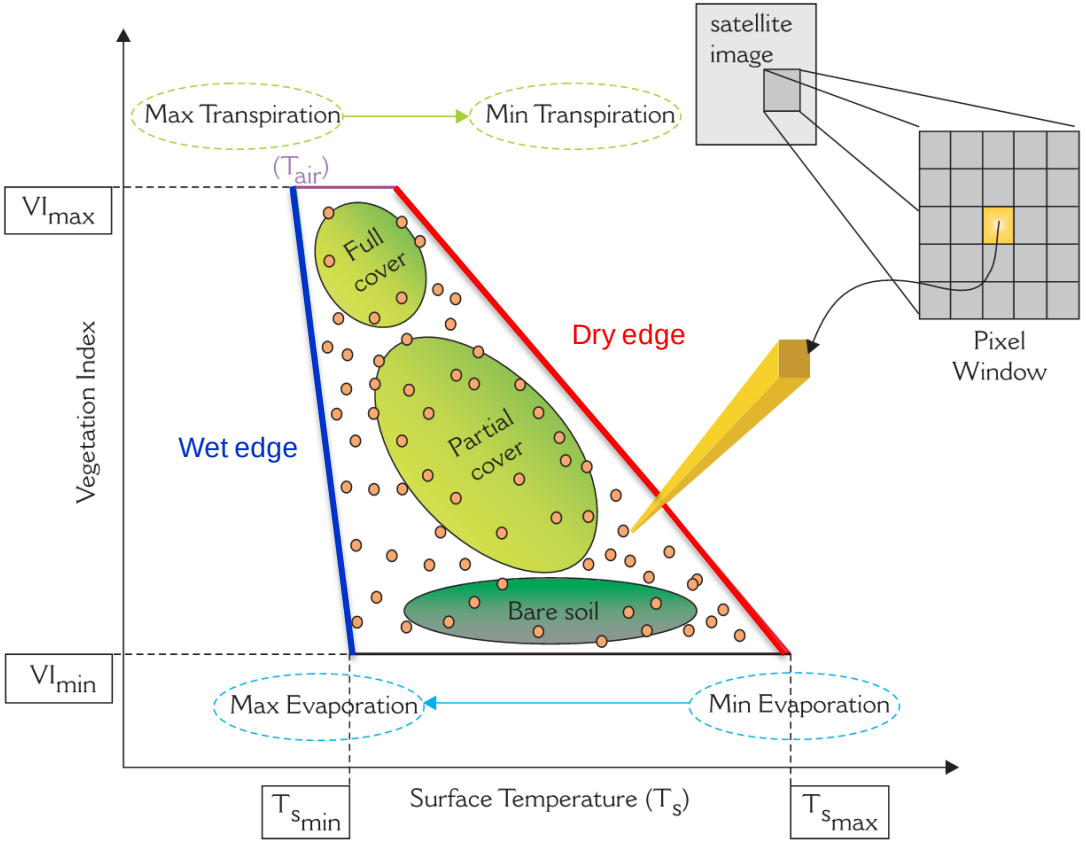
Satellite top of atmosphere radiances



Surface temperature/vegetation index feature space



Petropoulos et al. (2009)

$$ET = EF(R_n - G)$$

$$EF = \phi_{\max} \frac{T_{\max} - T_s}{T_{\max} - T_{\min}} \frac{\Delta}{\Delta + \gamma}$$

$$NDTI = \frac{T_{\max} - T_s}{T_{\max} - T_{\min}}$$

Research questions

1. Is it possible to estimate NDTI using TOA radiances?
2. How representative is instantaneous EF for daytime EF?
3. How accurate is the daytime EF estimated from TOA radiances?
4. Is it possible to estimate daytime ET from TOA radiances?

1. Is it possible to estimate NDTI using TOA radiances?*

*** Peng, J.**, Liu, Y., and Loew, A.: Uncertainties in Estimating Normalized Difference Temperature Index From TOA Radiances, *IEEE Transactions on Geoscience and Remote Sensing*, 51(5):2487 – 2497, 2013.

Using TOA Radiance directly instead of surface temperature products

$$\frac{T_{\max} - T_s}{T_{\max} - T_{\min}} \rightarrow \frac{L_{max} - L_s}{L_{\max} - L_{\min}}$$

Valor and Caselles (1996)

Planck's law
Radiance transfer equation

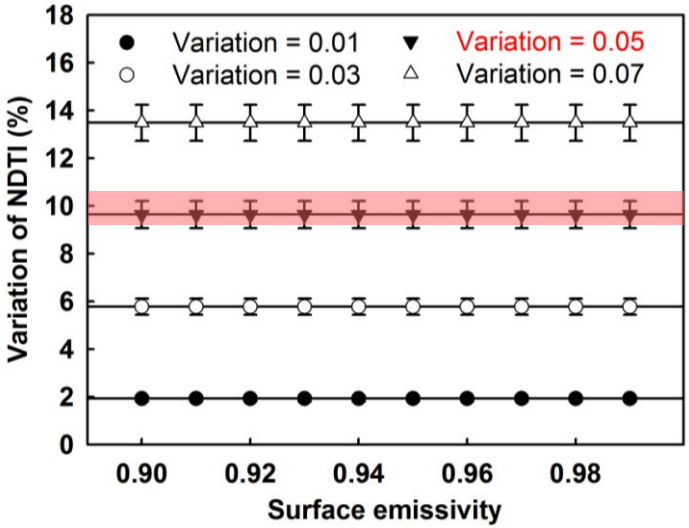
Theoretical Derivation

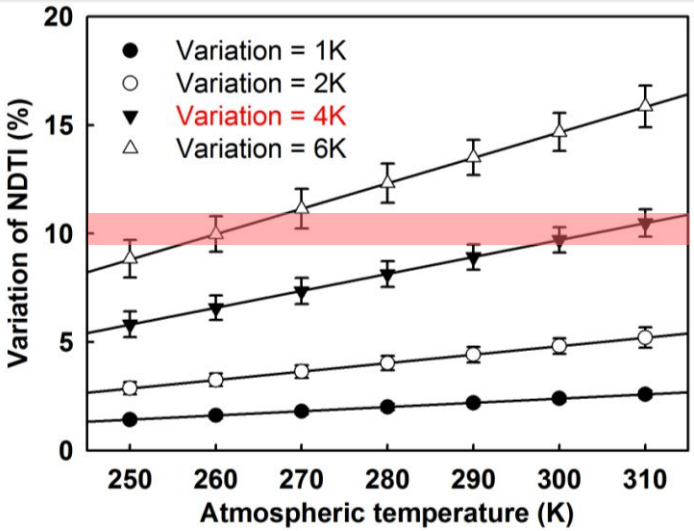
$$\frac{T_{max}-T_s}{T_{\max}-T_{\min}}=\frac{\dfrac{L_i^{\max}-(1-t_i^{\max})[1+(1-\varepsilon_i^{\max})t_i^{\max}]B_i(T_a^{\max})}{t_i^{\max}\varepsilon_i^{\max}}-\dfrac{L_i^{s}-(1-t_i^{s})[1+(1-\varepsilon_i^{s})t_i^{s}]B_i(T_a^{s})}{t_i^{s}\varepsilon_i^{s}}}{\dfrac{L_i^{\max}-(1-t_i^{\max})[1+(1-\varepsilon_i^{\max})t_i^{\max}]B_i(T_a^{\max})}{t_i^{\max}\varepsilon_i^{\max}}-\dfrac{L_i^{\min}-(1-t_i^{\min})[1+(1-\varepsilon_i^{\min})t_i^{\min}]B_i(T_a^{\min})}{t_i^{\min}\varepsilon_i^{\min}}}$$

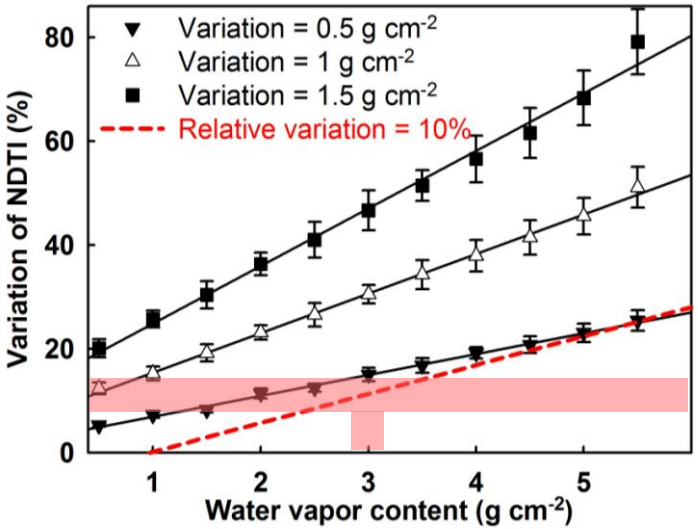
If surface emissivity, atmospheric temperature and water vapor are constant over the study area, then:

$$\frac{T_{max}-T_s}{T_{\max}-T_{\min}}=\frac{L_{max}-L_s}{L_{\max}-L_{\min}}$$

Sensitivity analysis







Spatial variation

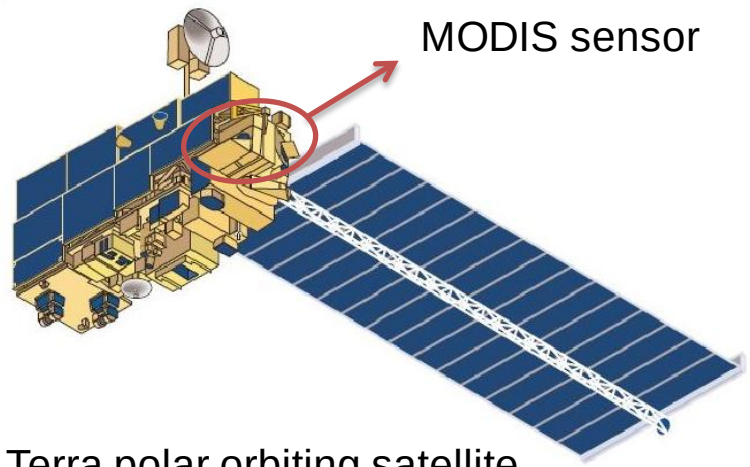
Emissivity < 0.05

Atmospheric temperature < 4 K

Water vapor < 10%

NDTI uncertainty < 10%

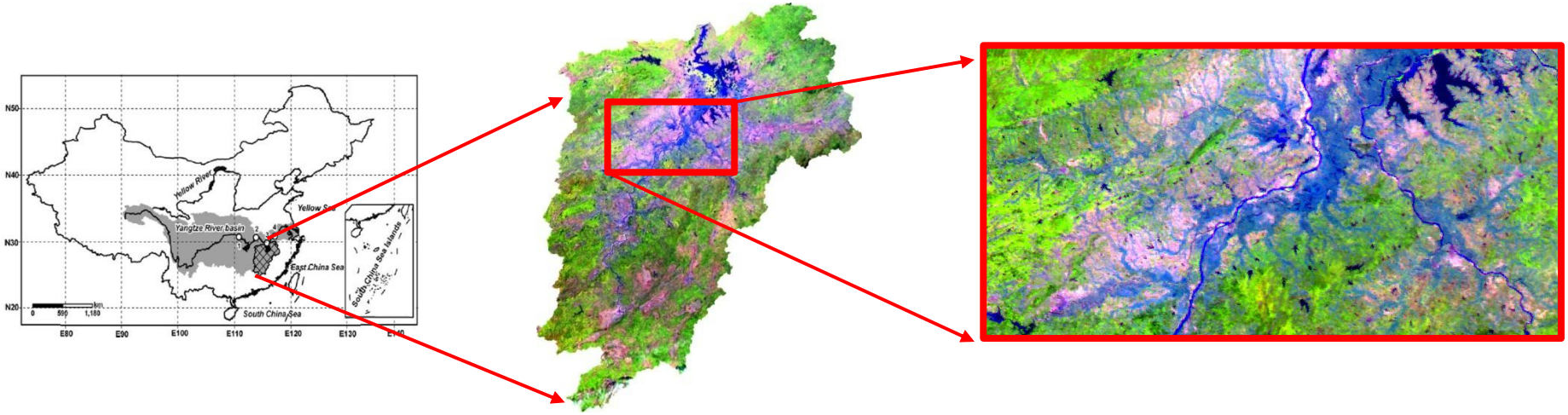
MODIS data and study area



Terra polar orbiting satellite

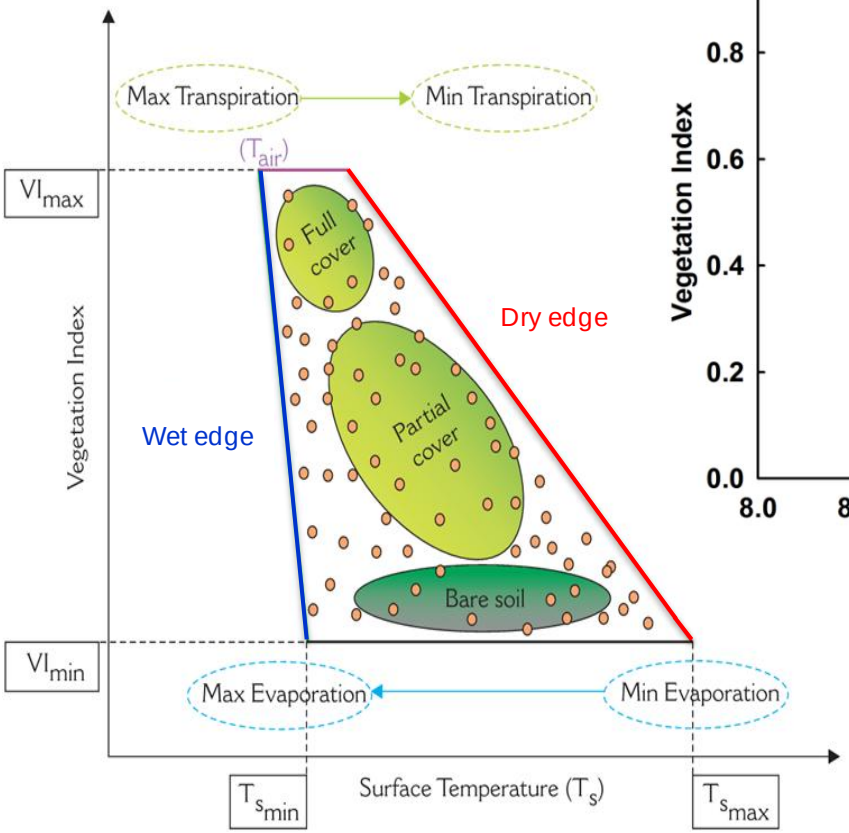
MODIS
(Moderate Resolution Imaging Spectroradiometer)

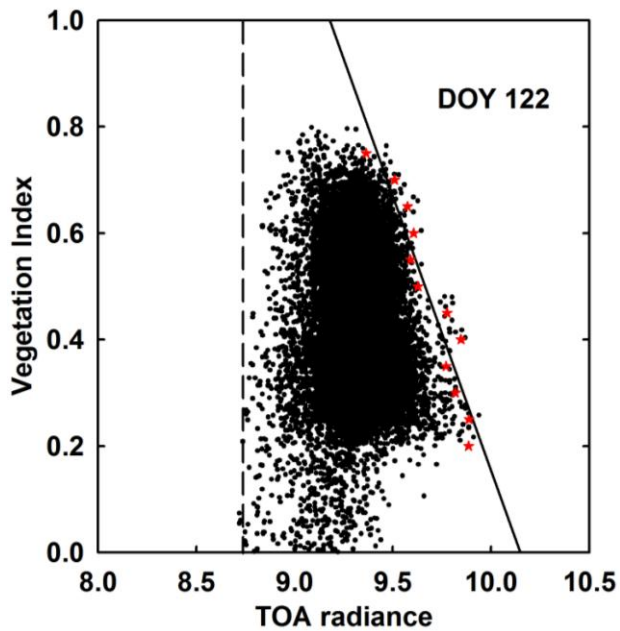
MODIS data	Category	Parameters used
MOD02	Level 1	TOA radiance
MOD09	Level 2	Surface reflectance
MOD11	Level 2	Surface temperature

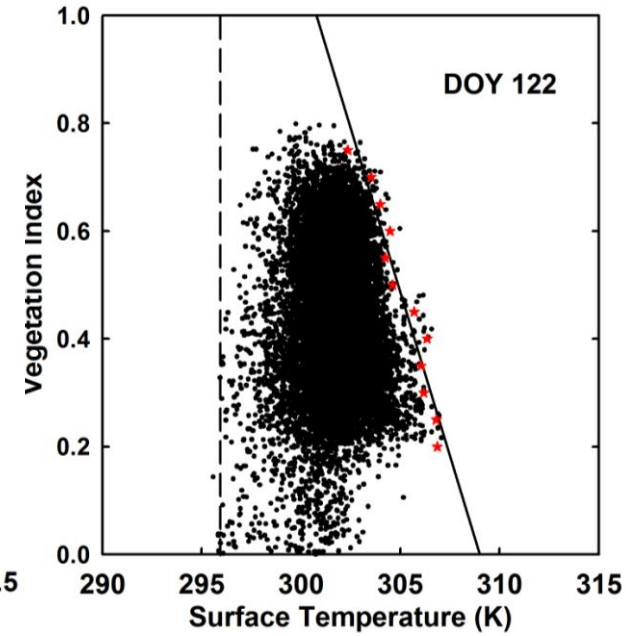


Study area: Poyang Lake basin, southeast of China

Surface temperature/vegetation index feature space





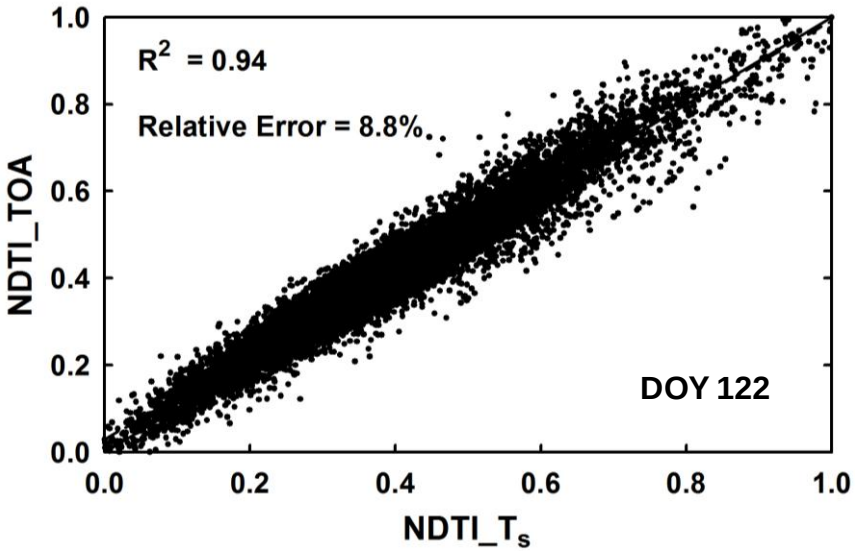


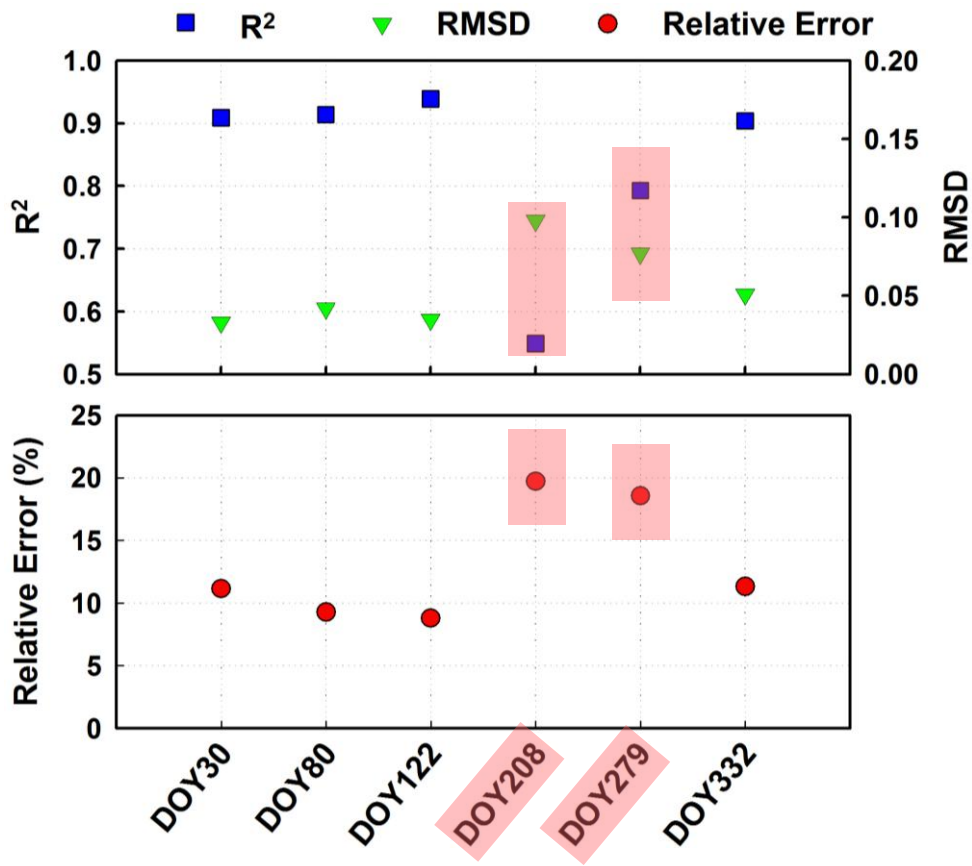
$$\frac{L_{max} - L_s}{L_{\max} - L_{\min}}$$

$$\frac{T_{\max} - T_s}{T_{\max} - T_{\min}}$$

Petropoulos et al. (2009)

Comparison of the NDTI_T_s and NDTI_TOA





Spatial variation

Emissivity < 0.01

Atmospheric temperature < 1 K

Water vapor < 10%

5.9 (DOY208), 3.9 (DOY279)
Water Vapor (g cm^{-2})

2. How representative is instantaneous EF for daytime EF?*

*** Peng, J**., Borsche, M., Liu, Y., and Loew, A.: How representative are instantaneous evaporative fraction measurements of daytime fluxes?, *Hydrology and Earth System Sciences*, 17(10): 3913-3919, 2013.

The assumption of constant EF during daytime

Instantaneous NDTI from TOA radiances

$$EF = \phi_{\max} \frac{L_{max} - L_s}{L_{\max} - L_{\min}} \frac{\Delta}{\Delta + \gamma}$$

Instantaneous EF

?

Daytime EF

FLUXNET measurements

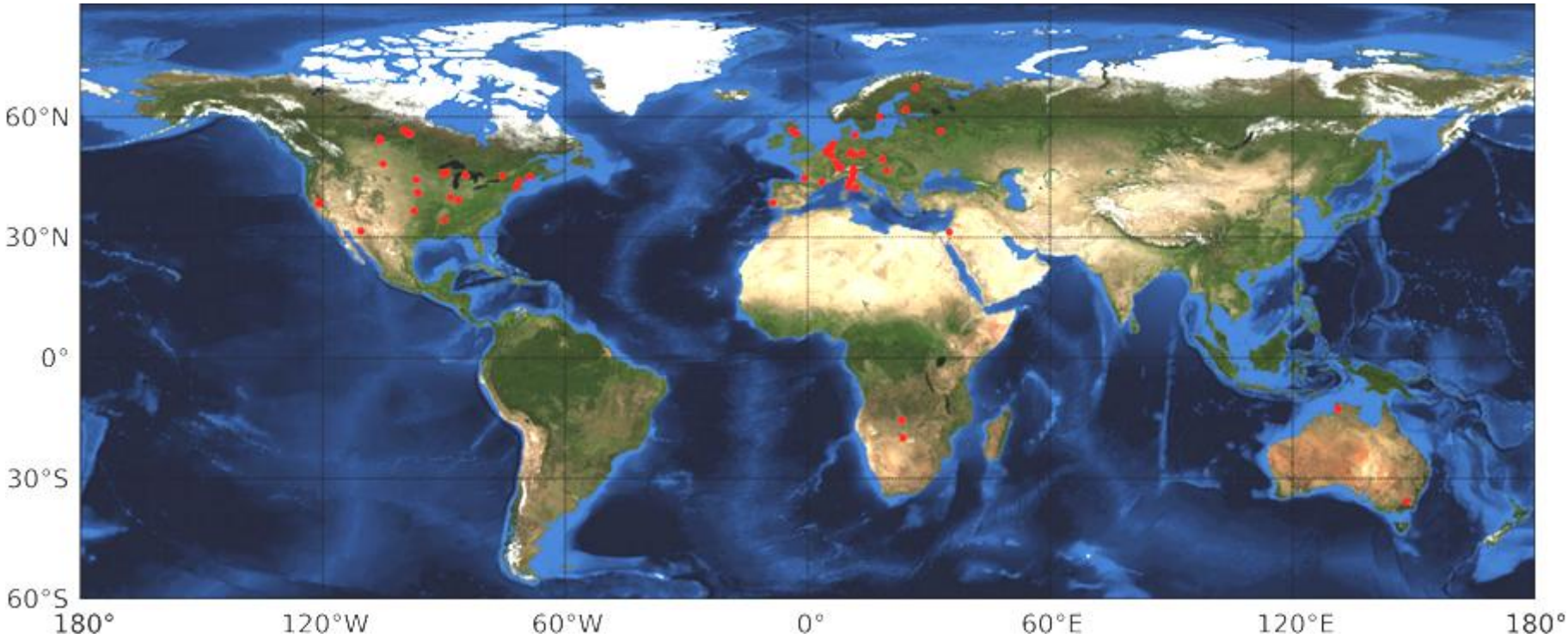
FLUXNET A global network of eddy covariance towers, providing measurements of water and energy fluxes

Flux tower

Eddy covariance instrument

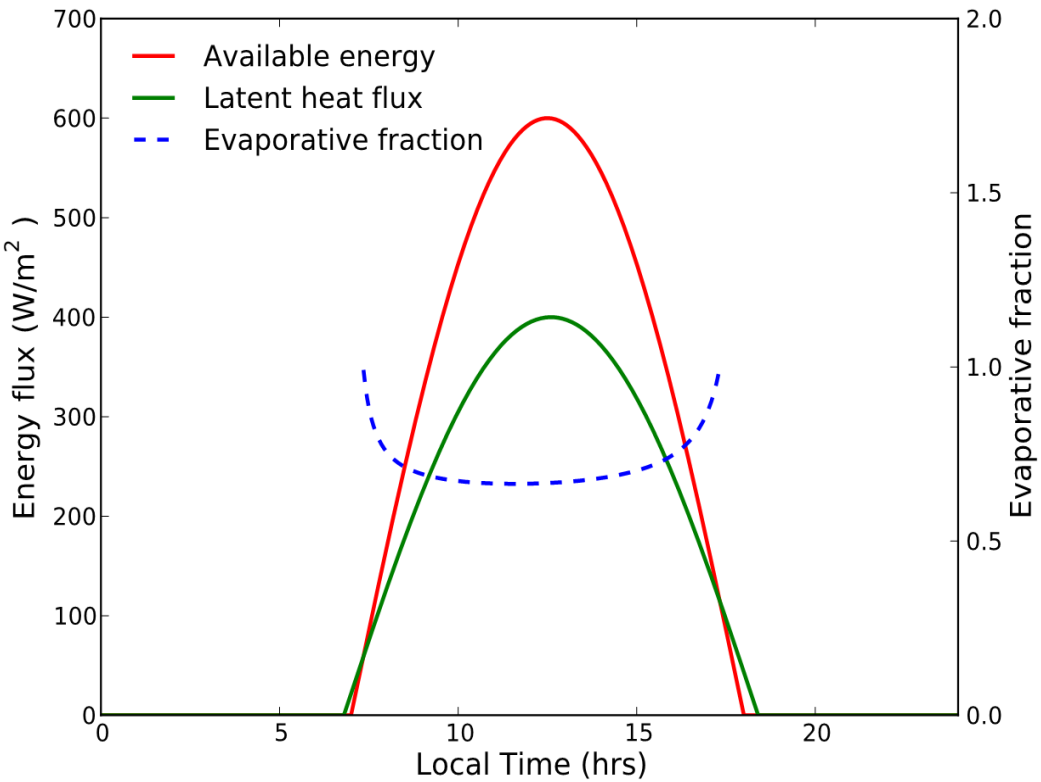
http://hpwren.ucsd.edu/news/20080516/

The FLUXNET sites used in this study



72 sites across a wide range of ecosystems and climates are used in this analysis

Diurnal variations of surface fluxes and EF



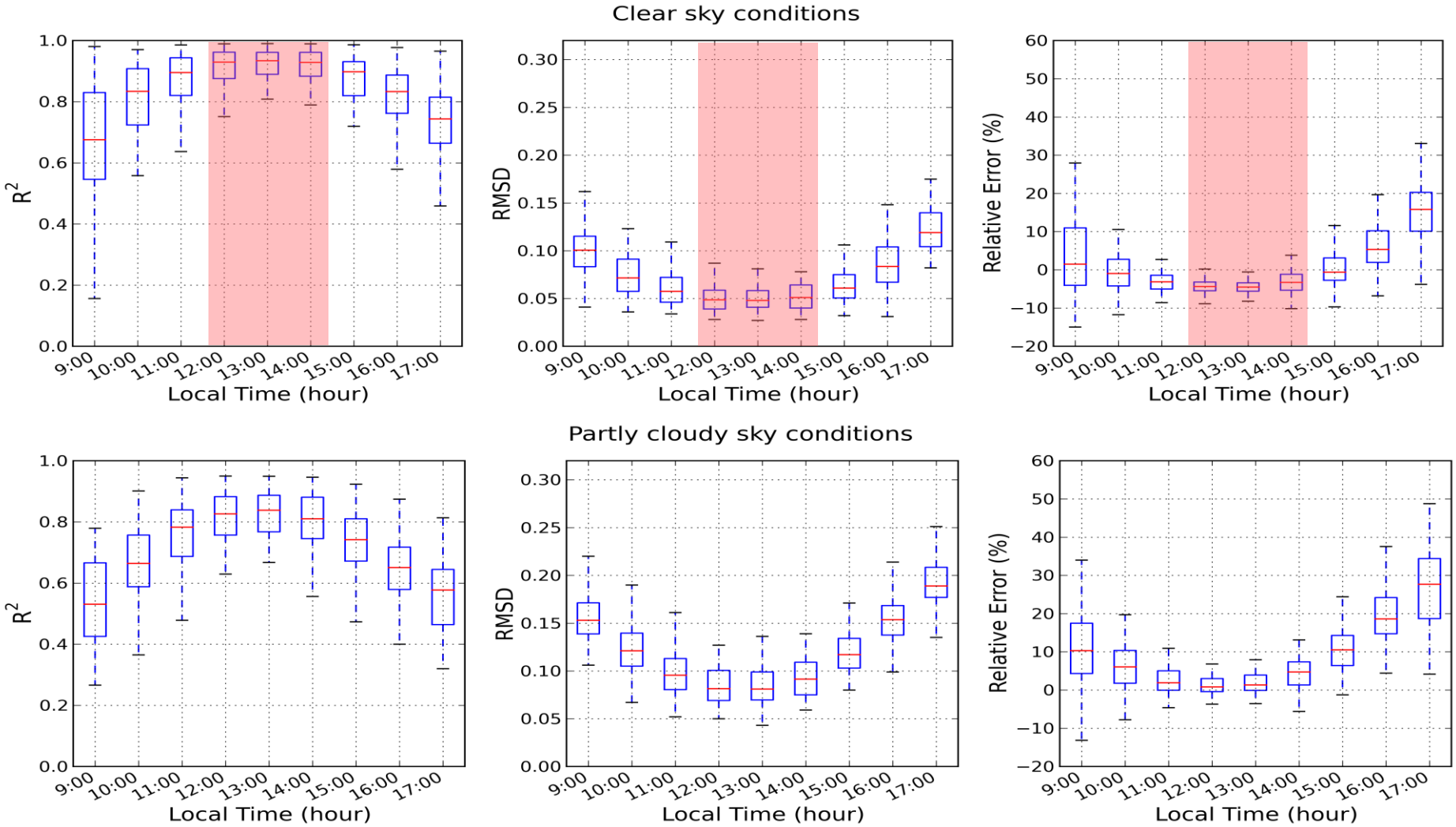
Instantaneous EF:

$$EF(t) = \frac{LE(t)}{LE(t) + H(t)}$$

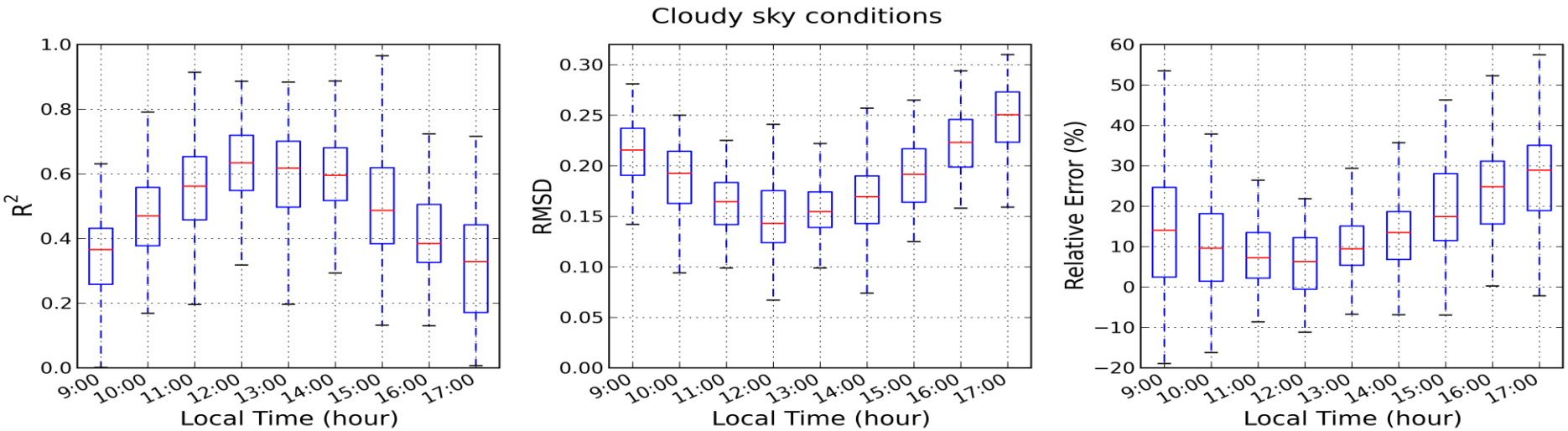
Daytime EF:

$$EF_{daytime} = \frac{\int_{t_1}^{t_2} LE(t)\, dt}{\int_{t_1}^{t_2} [H(t) + LE(t)]\, dt}$$

Comparison between instantaneous and daytime average EF

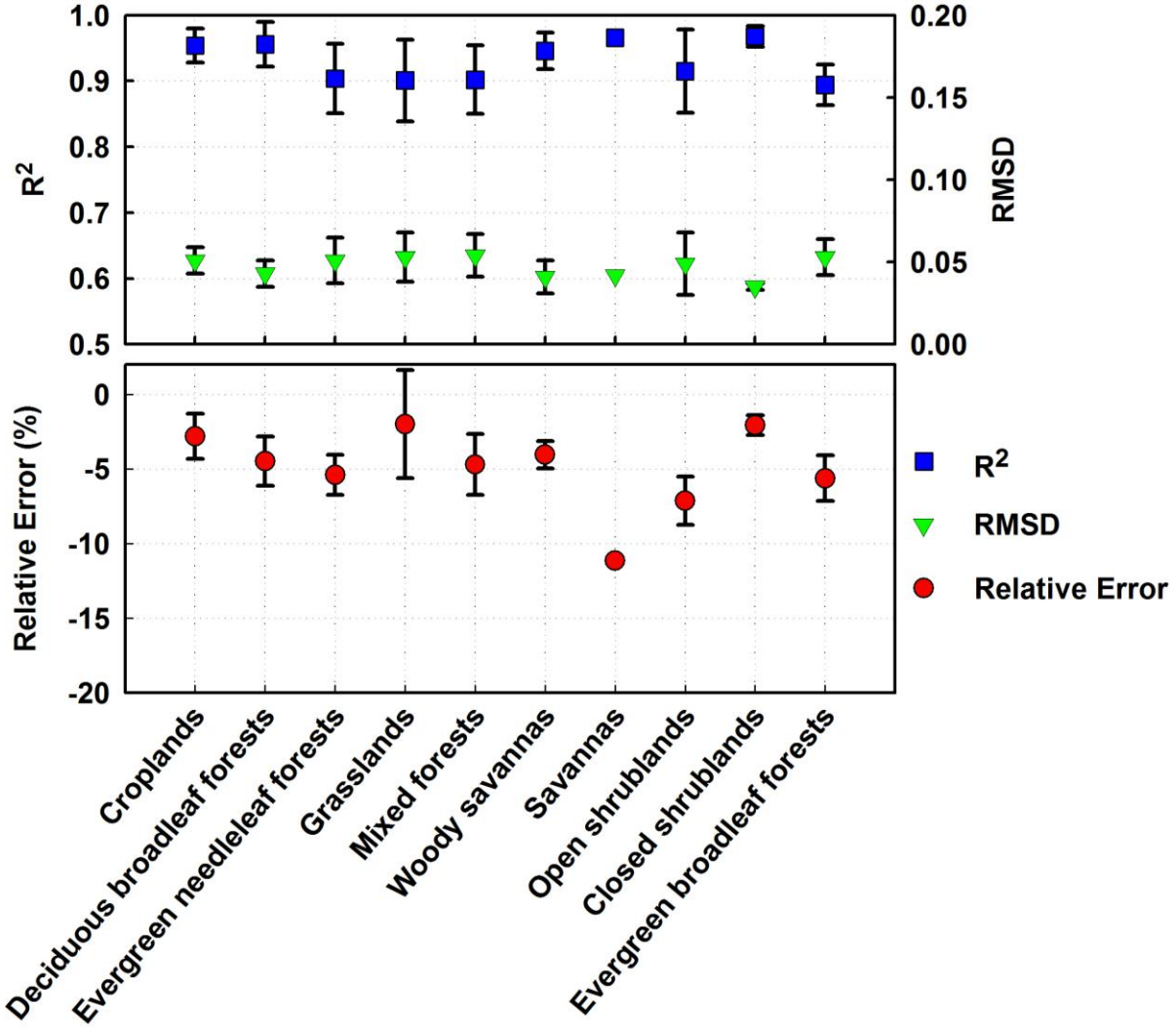


Comparison between instantaneous and daytime average EF



- The EF constant assumption is strictly true only for clear sky conditions.
- The effects of cloudiness need to be considered, when the EF constant assumption is applied under cloudy conditions.

Influence of biome types on EF constant assumption



3. How accurate is the daytime EF estimated from TOA radiances?*

*** Peng, J**., Loew, A.: Evaluation of Remote Sensing Based Evaporative Fraction from MODIS TOA radiances using Tower Eddy Flux Network Observations, *Under review in Remote sensing*

Using FLUXNET measurements to validate daytime EF from MODIS TOA radiances

Daytime EF from FLUXNET

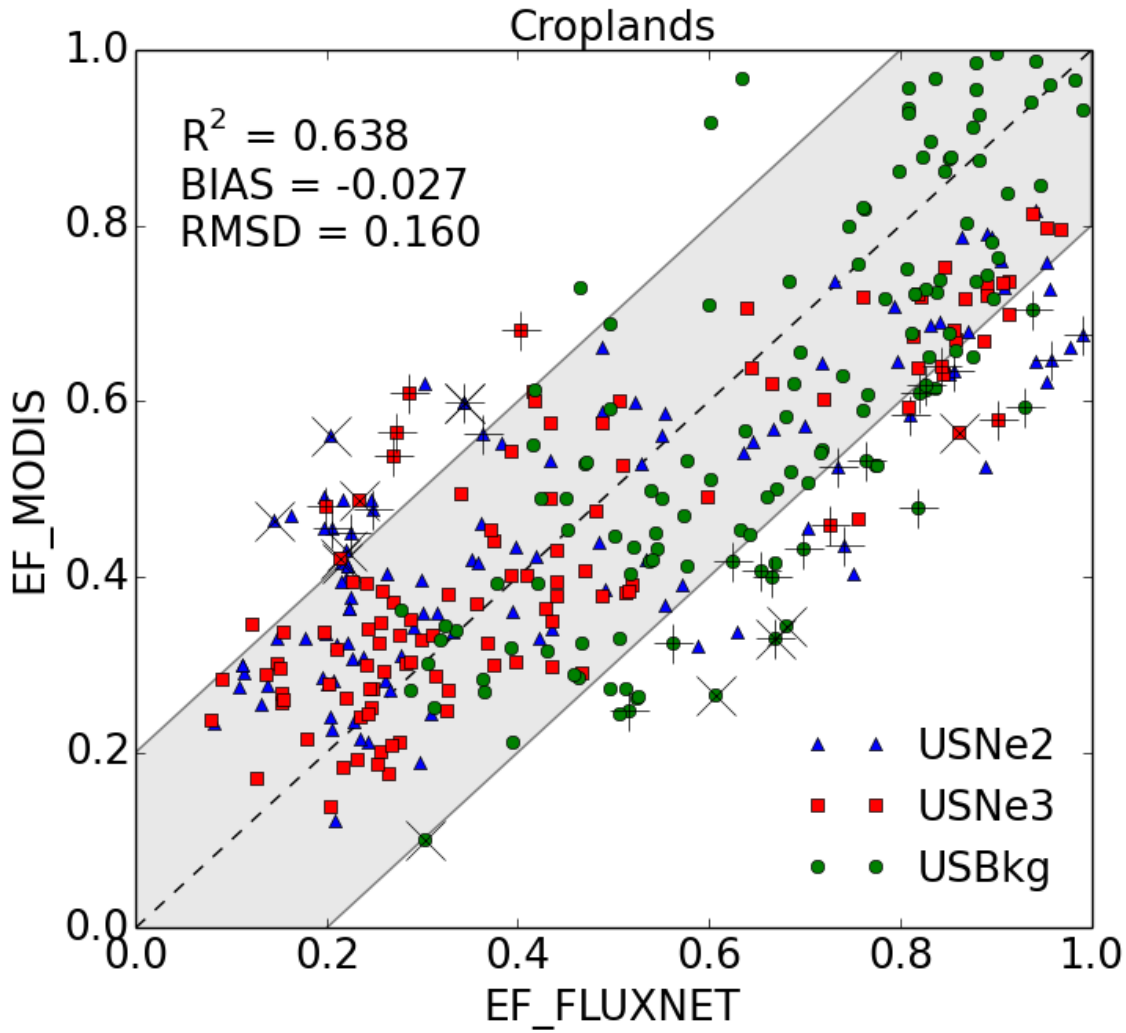
$$EF_{daytime} = \frac{\int_{t_1}^{t_2} LE(t)\,dt}{\int_{t_1}^{t_2} [H(t) + LE(t)]\,dt}$$

Validate

Daytime EF from MODIS TOA radiances

$$EF = \phi_{\max} \frac{L_{max} - L_s}{L_{\max} - L_{\min}} \frac{\Delta}{\Delta + \gamma}$$

Comparison between estimated and measured daytime EF



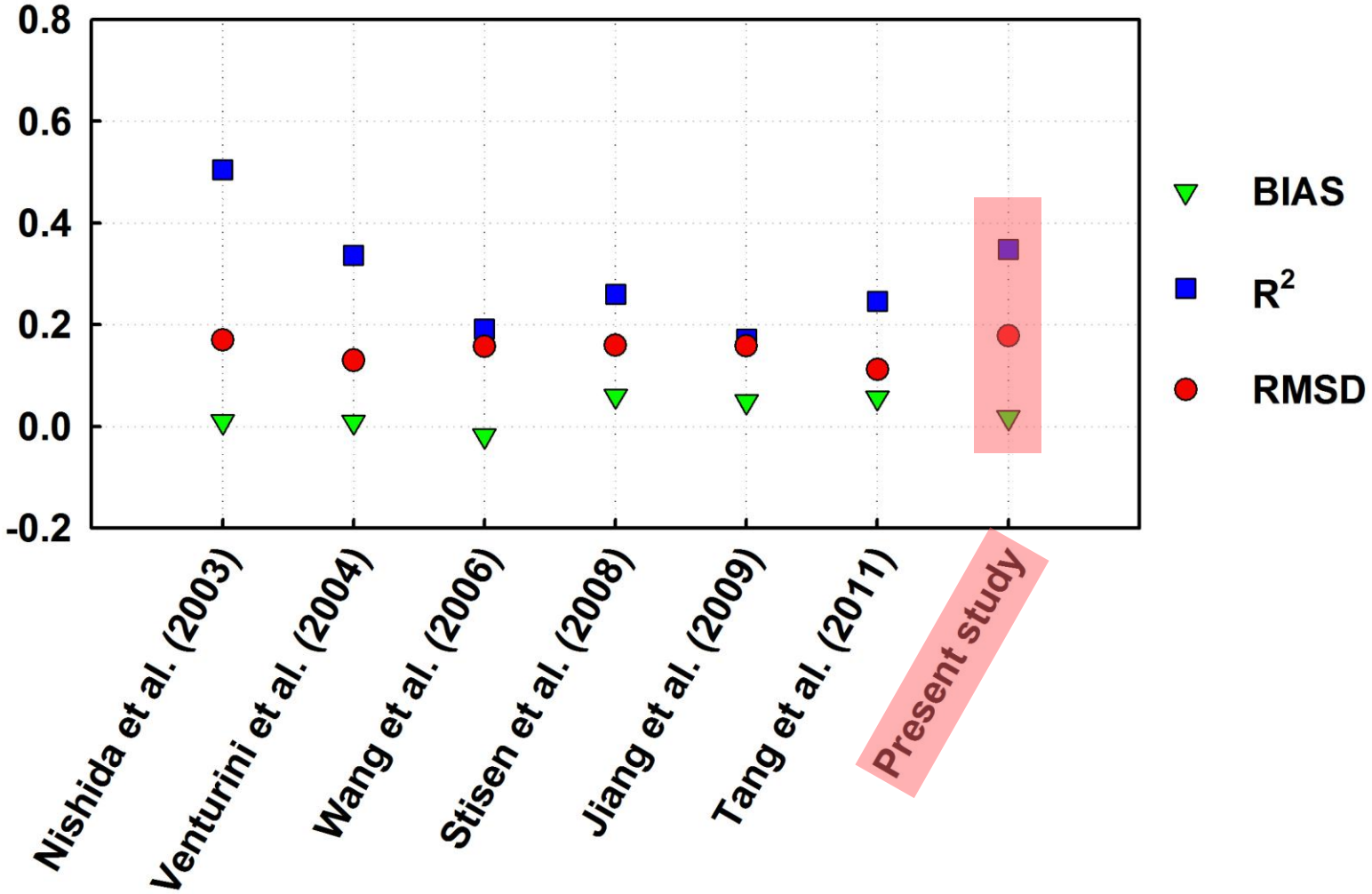
‘+’ marker

Influenced by precipitation

‘x’ marker

Outside growing season

Accuracy assessment of the estimated daytime EF in the literature



4. Is it possible to estimate daytime ET from TOA radiances?*

* **Peng, J**., Liu, Y., Zhao, X., and Loew, A.: Estimation of evapotranspiration from MODIS TOA radiances in the Poyang Lake basin, China, *Hydrology and Earth System Sciences*, 17(4):1431-1444, 2013.

Estimation of daytime ET

Daytime EF from TOA radiances

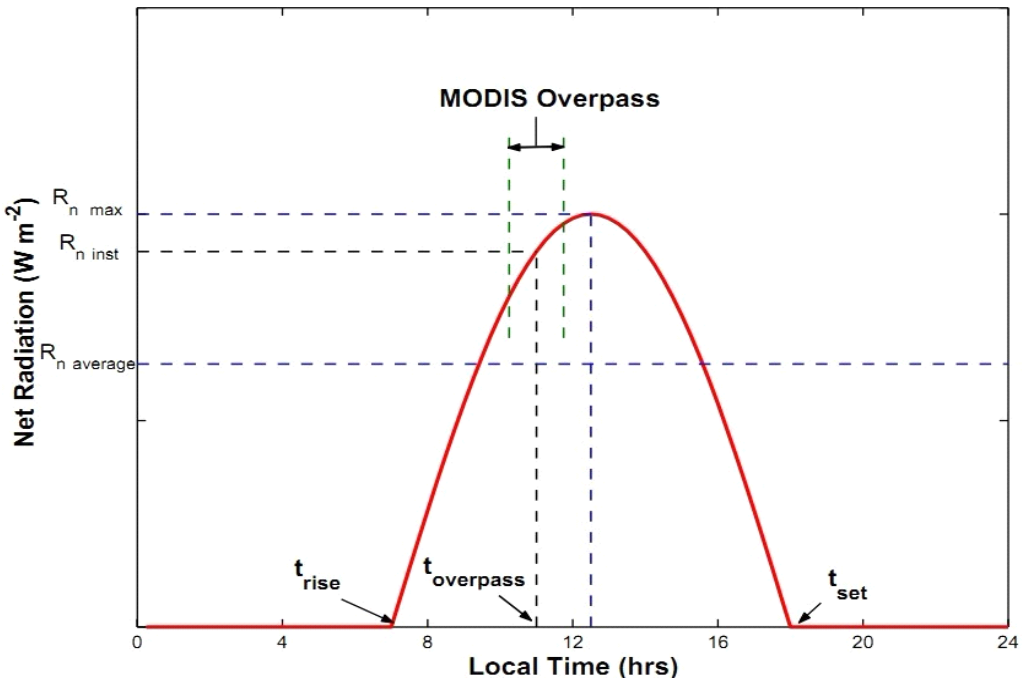
$$ET = EF(R_n - G)$$

Daytime ET from TOA radiances

Tang et al. (2006)
Wang et al. (2009)

Estimation of daytime ET

$$ET^{daytime} = EF^{daytime} \cdot R_n^{daytime}$$



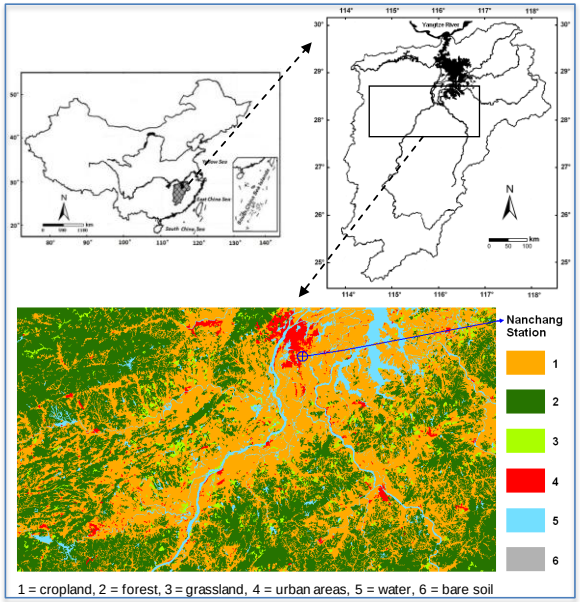
Sinusoidal model with MODIS overpass
from Bisht et al. (2005)

Assessment strategy

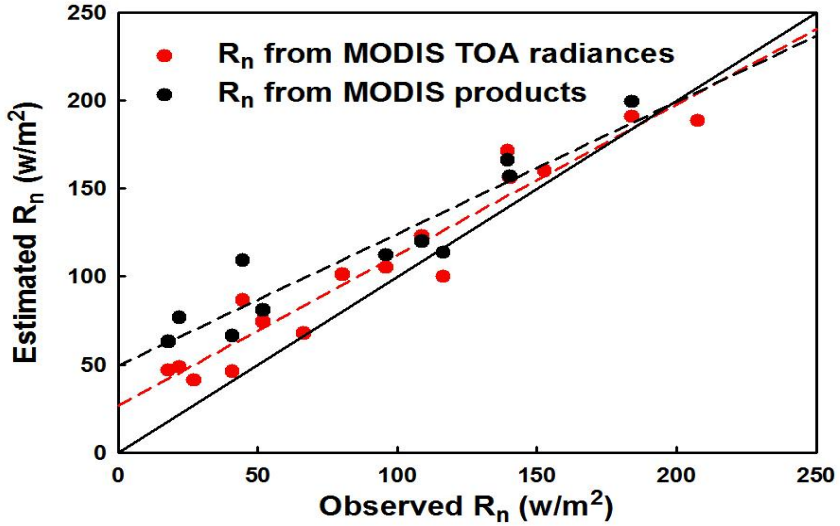
MODIS TOA radiances → Daytime R_n, EF and ET

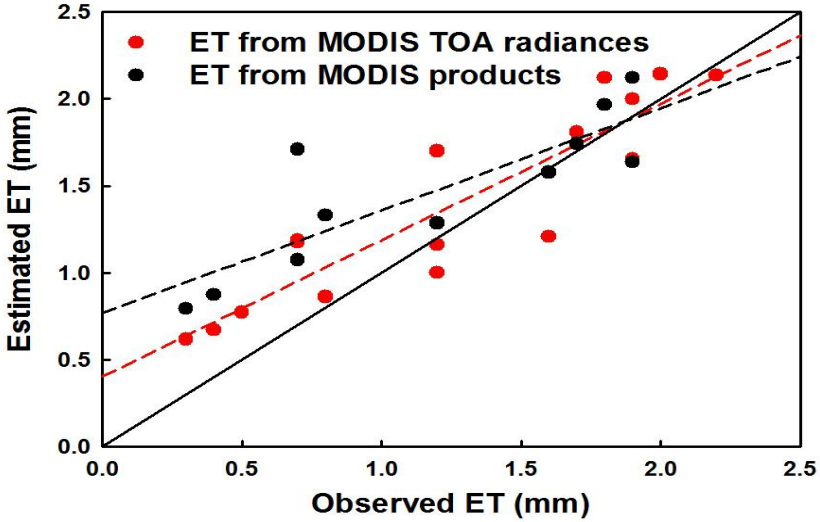
In situ measurements → Validation/Comparison

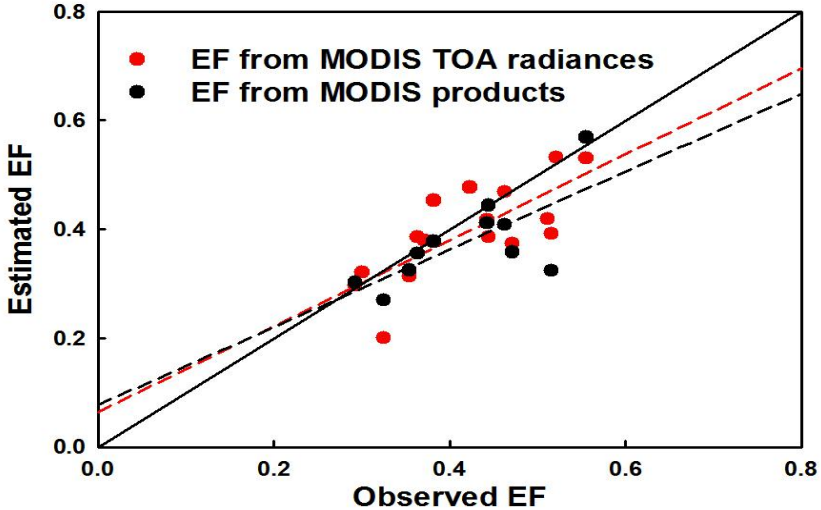
MODIS products → Daytime R_n, EF and ET

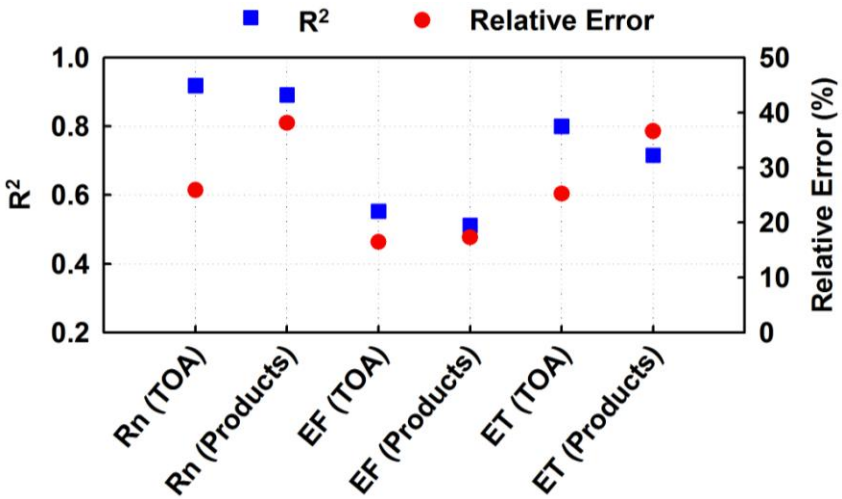


Comparisons between estimates and observations

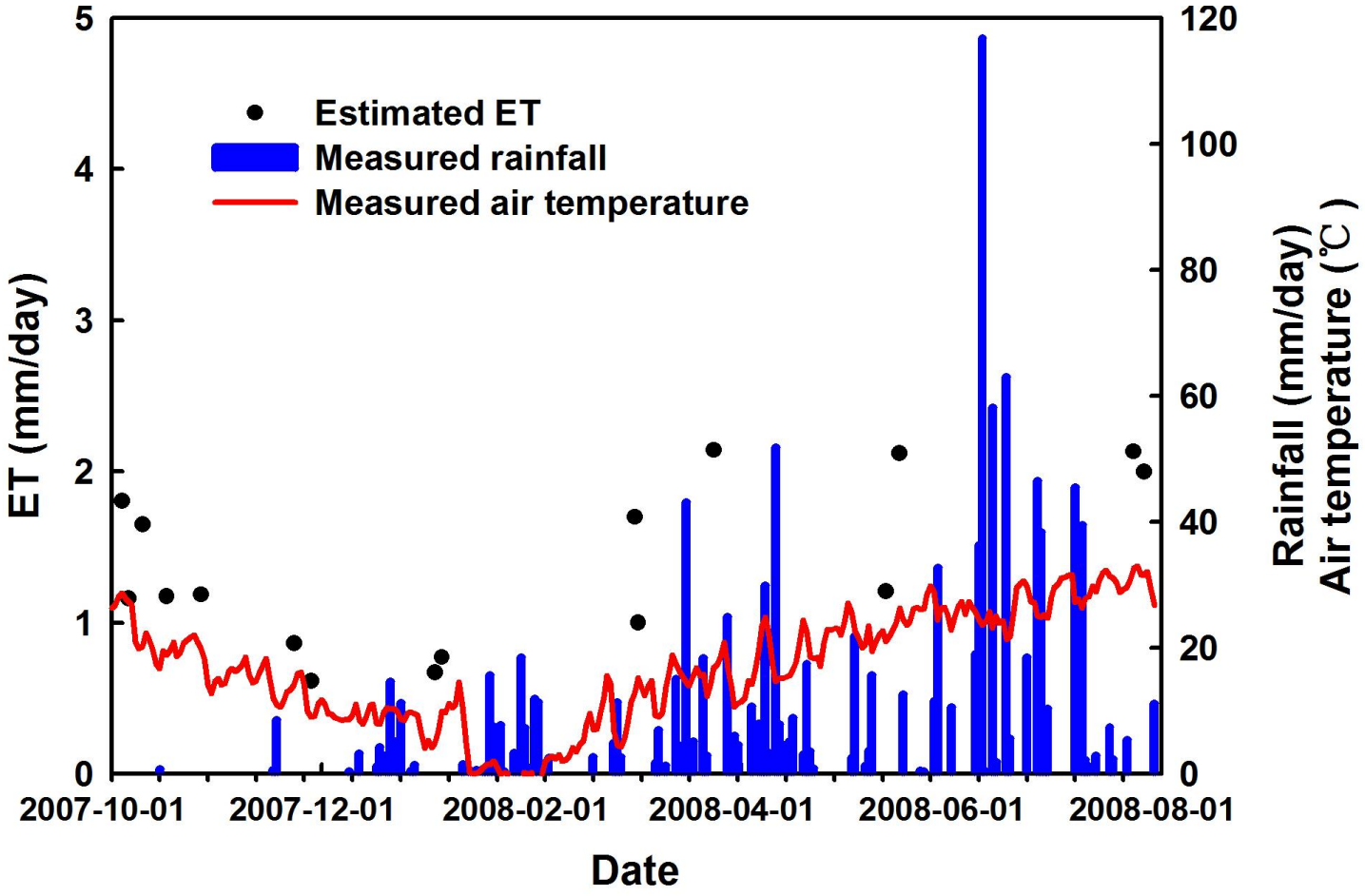








Seasonal variation of estimated daytime ET



Conclusions

1. The NDTI can be estimated using TOA radiances with an accuracy of 90% under certain conditions.

2. The EF constant assumption works well under clear sky conditions over a wide range of ecosystems and climates.

3. The accuracy of the EF estimated from TOA radiances is comparable with those satellite products based estimates.

4. The direct use of TOA radiances to estimate daytime ET is feasible and applicable.

Outlook

1. Estimate ET under full sky conditions through integrating data from different satellite systems, such as passive microwave and geostationary sensors.

2. Validate the ET estimated from TOA radiances over basin scale by constructing water balance equation from ground-based measurements.

3. Inter compare ET estimates from different satellite based methods and land surface models.

Thank you very much!