Evaluation of a MODIS Triangle-based Algorithm for Improving ET Estimates in the Northern Sierra Nevada Mountain Range

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San Diego State University

Motivation

- Disturbances (urbanization, wildfire, and climate change) alter landscapes, land-atmosphere interactions and hydrologic behavior
- Remote sensing provides key information about pre- and post-disturbance environments
- Critical for spatial and temporal monitoring of long-term response

Goal

- Develop and test popular remote-sensing based ET methods to obtain an ET product feasible for operational use in altered systems where little gaged data exists
  - $SSEB_{op}$ (Operational Simplified Surface Energy Balance) (Senay et al., 2013)
  - MODIS MOD16* (Mu et al., 2007)
  - MODIS Triangle Method (Wang et al., 2001; Kim and Hogue, 2013)

Approach – MODIS Triangle Method

- MODIS products are used in developed independent, stand-alone algorithms and detection methods for:
  - Net Radiation (SW and LW parameters) (Kim and Hogue, 2008)
  - Evapotranspiration (ET) (Kim and Hogue, 2012a, 2012b, 2013)
- Algorithms and methods are applied over a small region in the Northern Sierra Nevada Mountain Range

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*Product downloaded from Montana's Numerical Terradynamic Simulation Group (ftp.ntsg.umt.edu/pub/MODIS/Mirror/MOD16/)

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Estimation of ET (LE)

$$\mathrm{EF} = \frac{\mathrm{LE}}{(\mathrm{Rn} - \mathrm{G})}$$

Estimation of ET (LE)

$$\boxed{\mathrm{LE} = \mathrm{EF}(\mathrm{Rn} - \mathrm{G})}$$

All values can be estimated on a regional scale for all sky conditions using only satellite based data

Estimation of ET (LE)

$$\mathrm{LE} = \mathrm{EF}(\mathrm{Rn} - \mathrm{G})$$

MODIS Products

MYD03
Geolocation

MYD05
Water Vapor

MYD06
Cloud Fraction
Cloud Optical Thickness
Surface Temperature

MYD07
Total Ozone
Air Temperature
Dew-Point Temperature

MYD11
Emissivity
LST

Net Radiation (Rn)

$$\boxed{\mathbf{R_{net}} = \boldsymbol{SW} \downarrow (\mathbf{1} - \boldsymbol{Alb})\boldsymbol{CC} + \boldsymbol{LW} \downarrow - \boldsymbol{LW} \uparrow}$$

(Bisht and Bras, 2010;
Kim and Hogue, 2008, 2013)

$$\boldsymbol{SW} \downarrow = \frac{\boldsymbol{R_s}(\mathbf{1} + \mathbf{cos}(\mathbf{2}\boldsymbol{z}))}{\mathbf{2}(\mathbf{1.085\,cos}(\boldsymbol{z}) + \mathbf{0.001}\boldsymbol{e_0}(\mathbf{2.7} + \mathbf{cos}(\boldsymbol{z})) + \mathbf{0.2})}$$

$z = zenith\ angle$

$e_0 = water\ vapor\ pressure \rightarrow f(air\ temp., dew\ point\ temp.)$

$$\boldsymbol{CC} = (\mathbf{1} - \boldsymbol{C_f}) + \left(\boldsymbol{C_f}\mathbf{exp}\left(\boldsymbol{C_{opt}}/\mathbf{cos}(\boldsymbol{z})\right)\right)$$

$C_f = cloud\ fraction$

$C_{opt} = cloud\ optical\ thickness$

$$\mathbf{LW} \downarrow = \boldsymbol{\varepsilon}_\mathbf{a}\mathbf{T_a^4} + (\mathbf{1} - \boldsymbol{\varepsilon}_\mathbf{a})\boldsymbol{\varepsilon}_\mathbf{c}\mathbf{T_c^4}$$

$\varepsilon_a = air\ emissivity$

$\varepsilon_c = cloud\ emissivity$

$T_a = air\ temperature$

$T_c = cloud\ temperature$

$$\mathbf{LW} \uparrow = \boldsymbol{\varepsilon}_\mathbf{s}\mathbf{T_s^4}$$

$\varepsilon_s = surface\ emissivity$

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Estimation of ET (LE)

$$LE = EF(Rn - G)$$

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MOD13/MYD13
NDVI

MYD43
Albedo

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z = zenith angle
e_0 = water vapor pressure → f(air temp., dew point temp.)

$$CC = (1 - C_f) + \left(C_f \exp\left(C_{opt}/\cos(z)\right)\right)$$

C_f = cloud fraction
C_{opt} = cloud optical thickness

$$LW\downarrow = \varepsilon_a T_a^4 + (1-\varepsilon_a)\varepsilon_c T_c^4$$

ε_a = air emissivity
ε_c = cloud emissivity
T_a = air temperature
T_c = cloud temperature

$$LW\uparrow = \varepsilon_s T_s^4$$

ε_s = surface emissivity
T_s = surface temperature

Ground Heat Flux (G)

(SEBAL; Bastiaanssen et al., 1998)

$$G = \frac{T_s}{Alb}(0.0038Alb + 0.0074Alb^2)(1 - 0.98NDVI^4)$$

T_s = surface temperature
Alb = Albedo

Estimation of ET (LE)

$$\mathrm{LE} = \mathrm{EF}(\mathrm{Rn} - \mathrm{G})$$

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NDVI

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$Alb = Albedo$

MYD11
LST

MOD13/MYD13
EVI

MYD03
Geolocation

Evaporative Fraction (EF)

(Wang et al., 2006; Kim and Hogue, 2013)

$$EF = \alpha\frac{\Delta}{\Delta + \gamma}$$

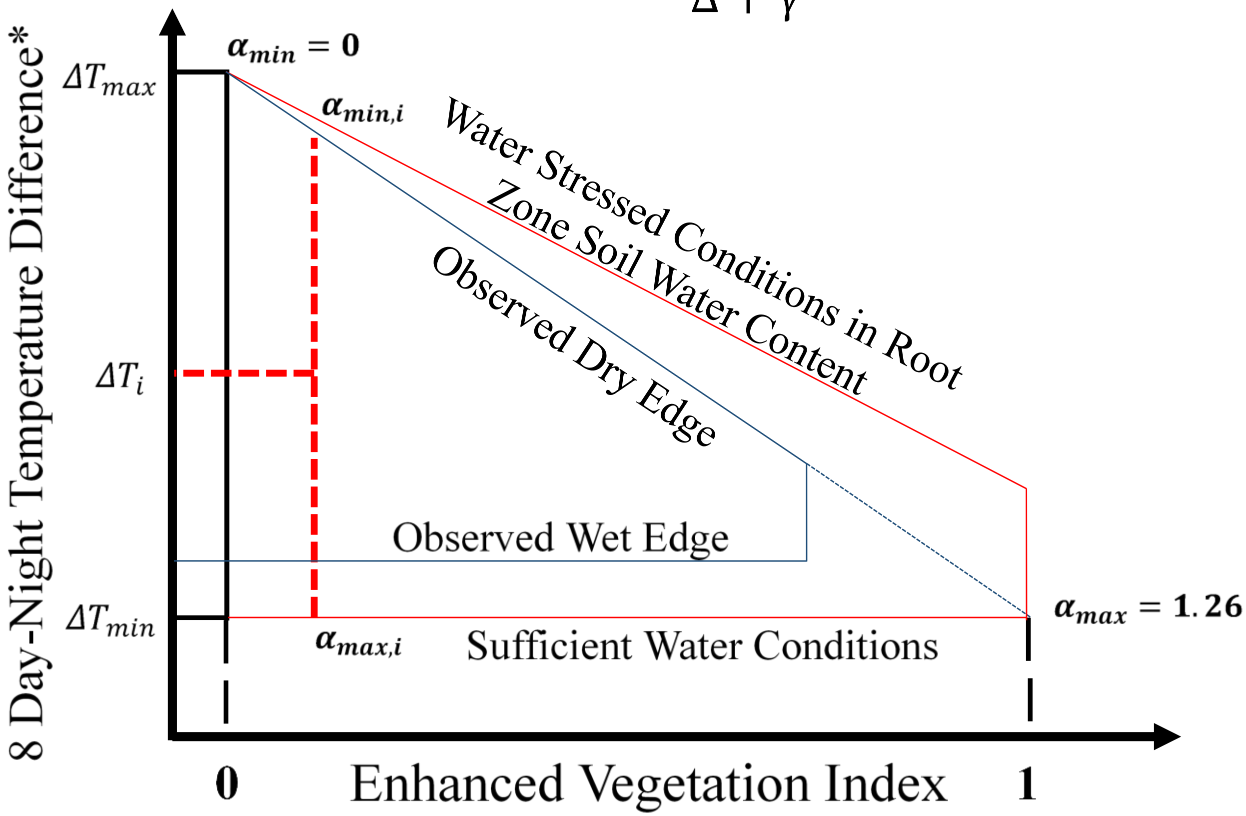
$\gamma = psychrometric\ constant$

$$\Delta = \frac{26297.77}{(T_a - 29.65)^2}\exp\left(\frac{17.67(T_a - 273.15)}{T_a - 29.65}\right)$$

$T_a = air\ temperature$

Evaporative Fraction (EF) – *Triangle Method*[+]

$$\mathrm{EF} = \alpha \frac{\Delta}{\Delta + \gamma}$$



[+]*Tang et al., 2010*
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Evaporative Fraction (EF) – *Triangle Method*[+]

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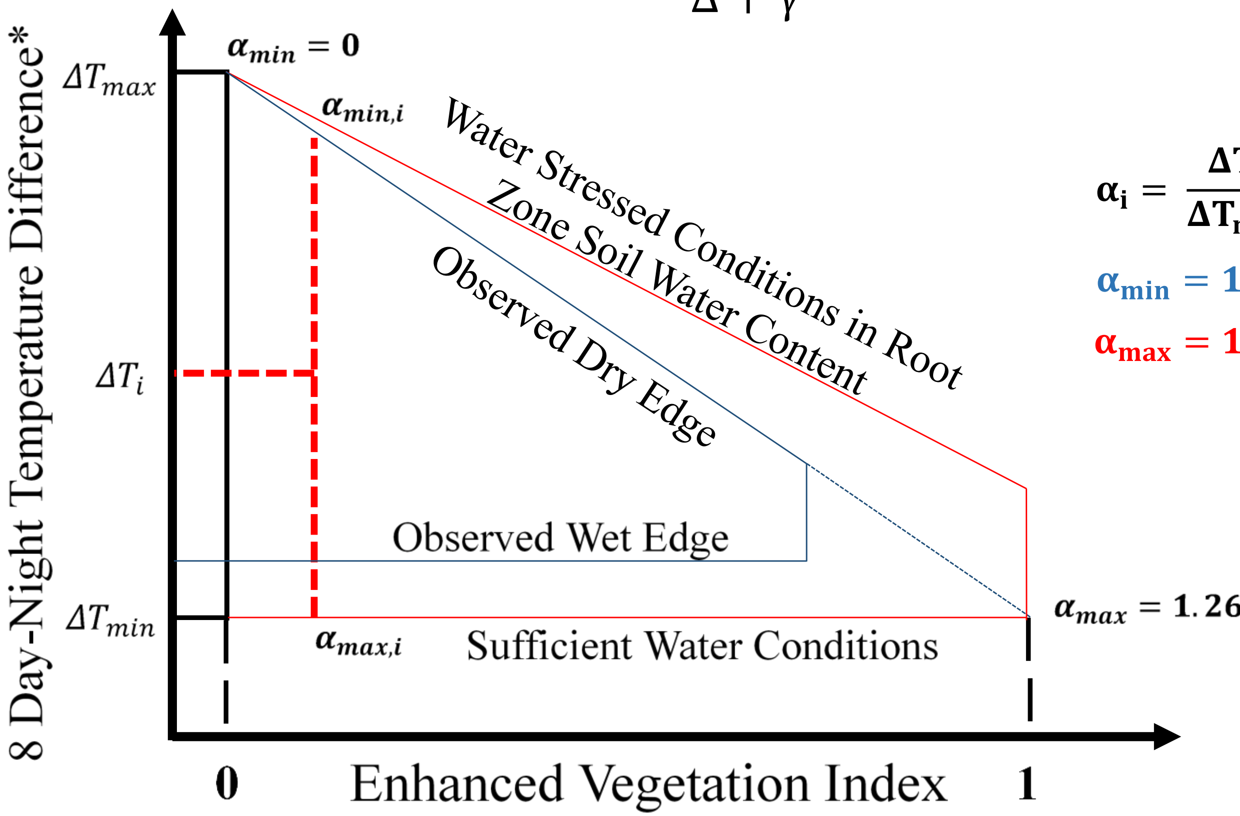
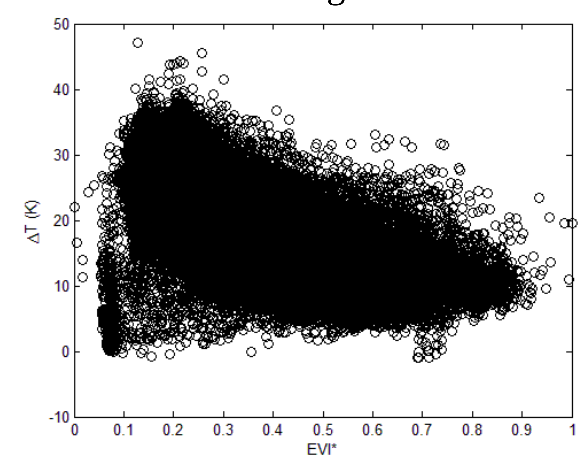


$$\alpha_i = \frac{\Delta T_{max} - \Delta T_i}{\Delta T_{max} - \Delta T_{min}}(\alpha_{max} - \alpha_{min}) + \alpha_{min}$$

$$\alpha_{min} = 1.26 f_{veg} = 1.26 \frac{EVI_i - EVI_{min}}{EVI_{max} - EVI_{min}}$$

$$\alpha_{max} = 1.26^{**}$$

Observed Triangular Domain



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Evaporative Fraction (EF) – *Triangle Method*

$$EF = \alpha \frac{\Delta}{\Delta + \gamma}$$

$$T = \left(\frac{T_s^4}{\cos\gamma}\right)^{1/4}$$

Cosine Method:
Corrects for terrain-induced angular effects

$$\alpha_i = \frac{\Delta T_{max} - \Delta T_i}{\Delta T_{max} - \Delta T_{min}}(\alpha_{max} - \alpha_{min}) + \alpha_{min}$$

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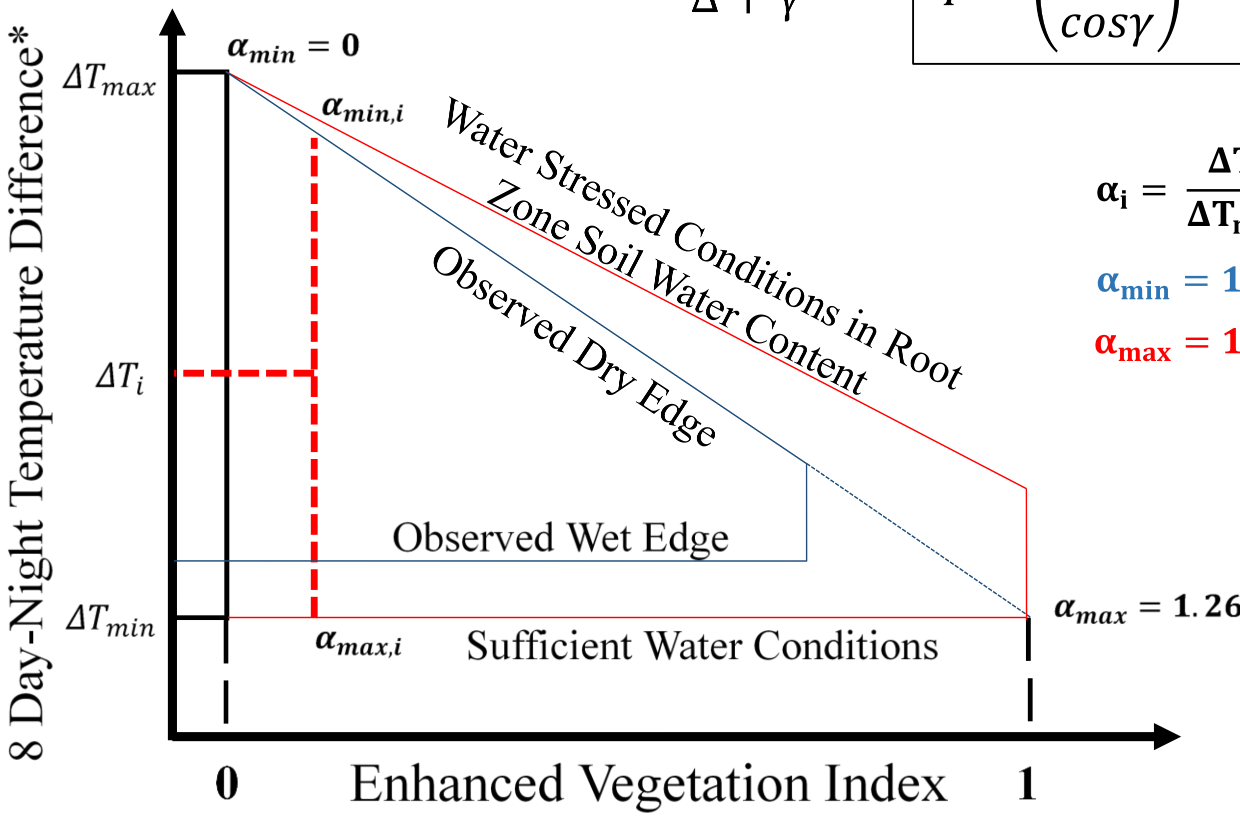
$\alpha_{max} = 1.26$**



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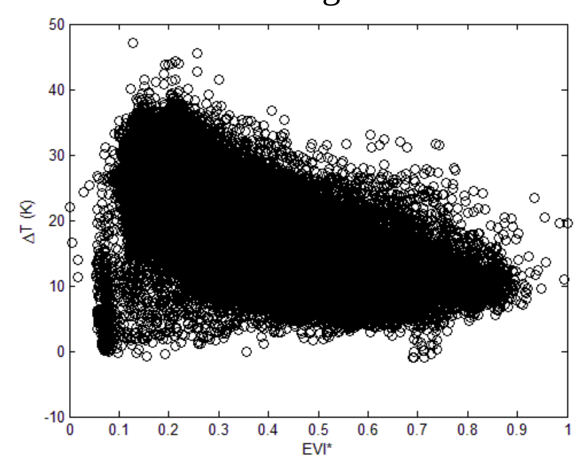

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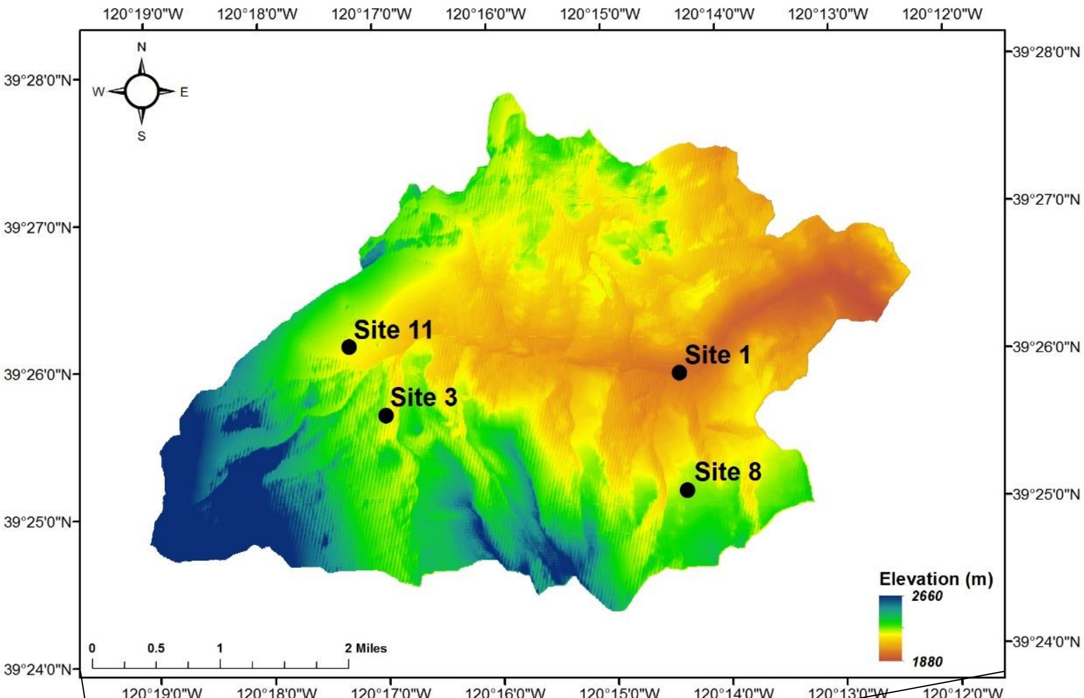
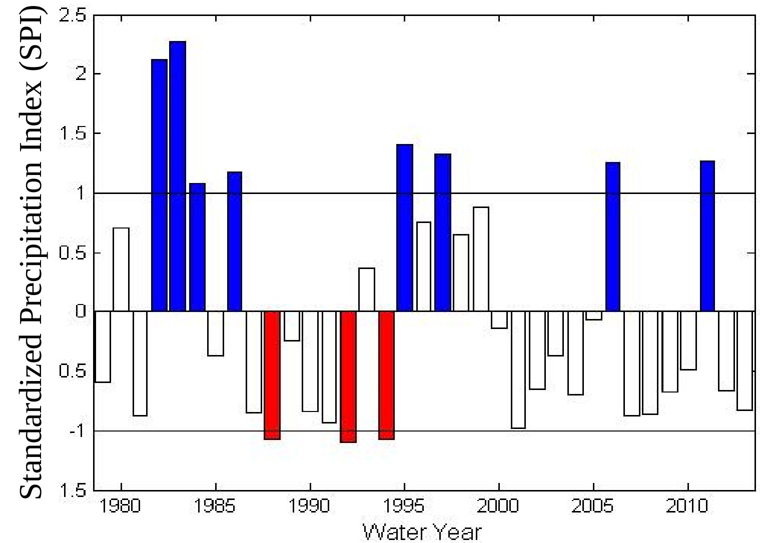
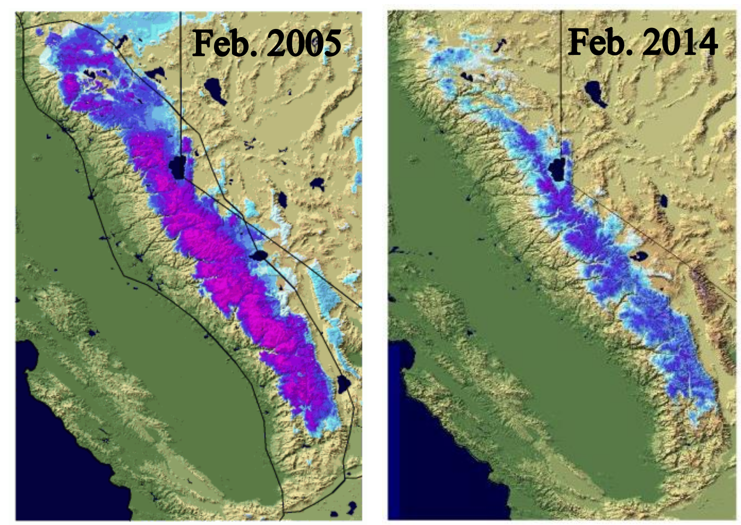
Study Area – *Sagehen Watershed*



Site	Elevation (m)	Vegetation
Site 1	1940	Shrub/Scrub
Site 3	2130	Shrub/Scrub
Site 8	2080	Shrub/Scrub
Site 11	2110	Shrub/Scrub



Snow Depth (NOAA NOHRSC)



Study Area – *Sagehen Watershed*

- USFS GTR 237: Managing Sierra Nevada Forests to restore natural forest structure (North et al., 2012)
- Sagehen Experimental forest management prototype for the Sierra Nevada
  - Treatments started summer 2014
- Evaluate variability in fuel treatments and corresponding water yield response
- Understand altered annual and seasonal water budgets

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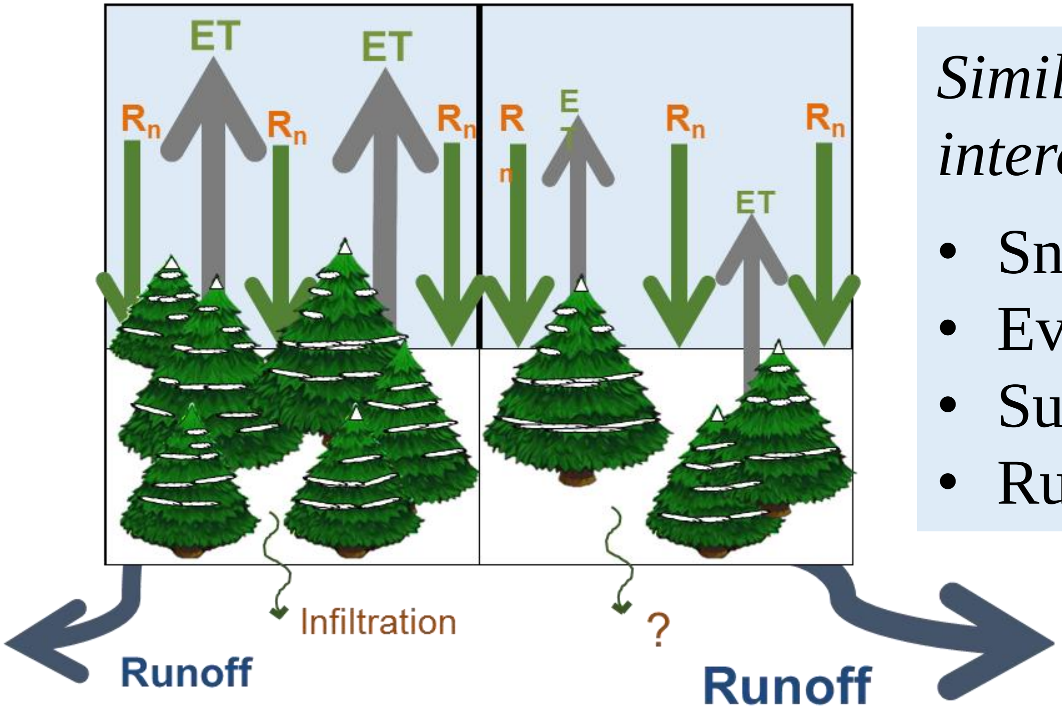

Similar R_n, less canopy, and less interception will alter:

- Snow Regimes (melt & timing)
- Evapotranspiration (ET)
- Sublimation
- Runoff and Water Yield

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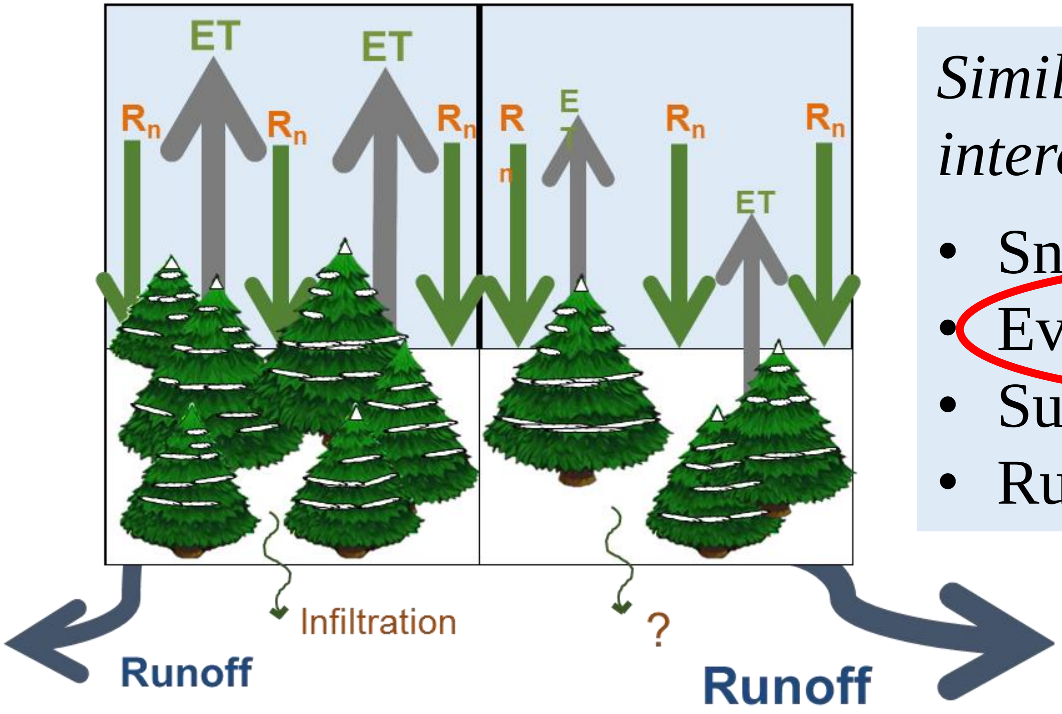

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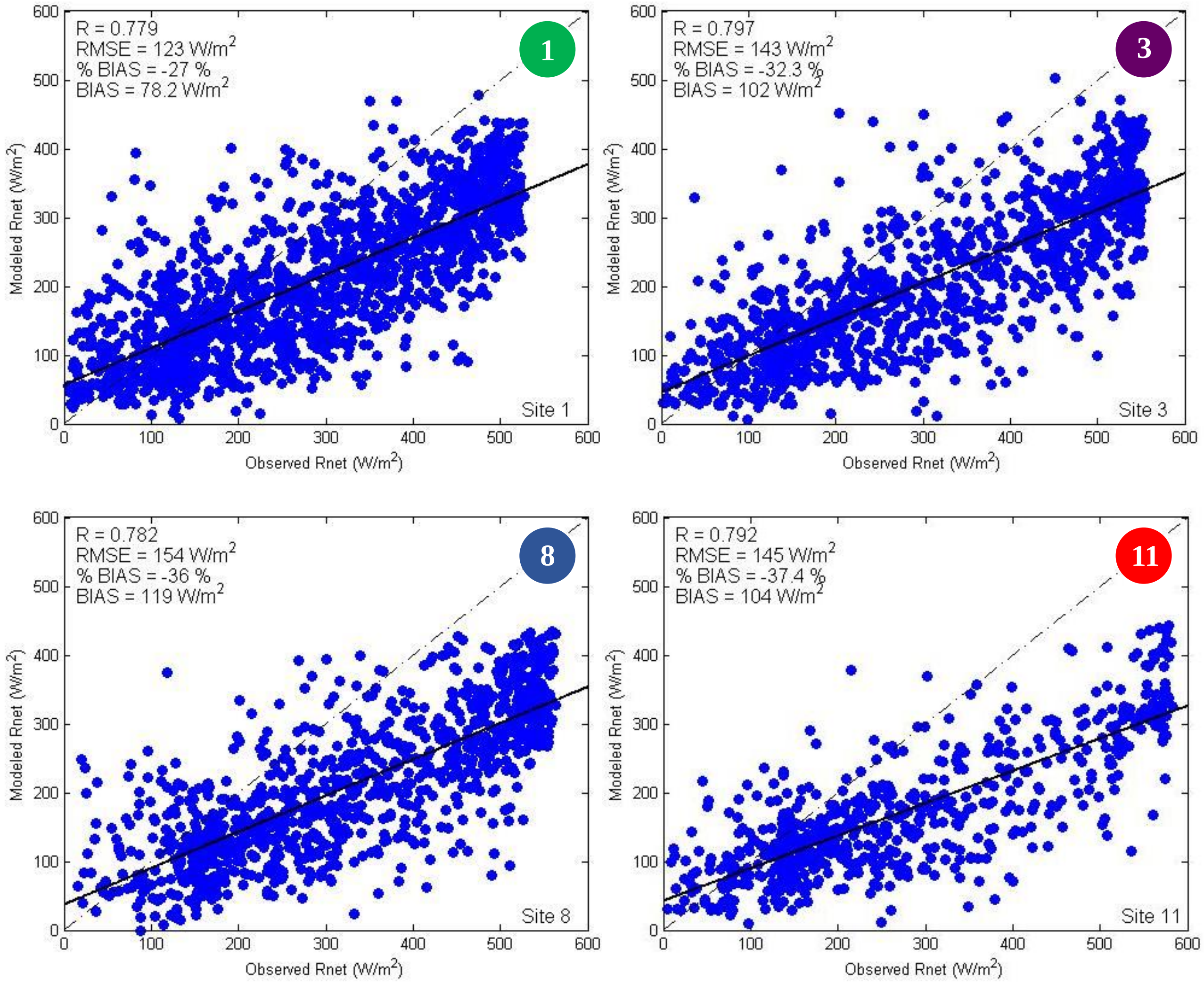
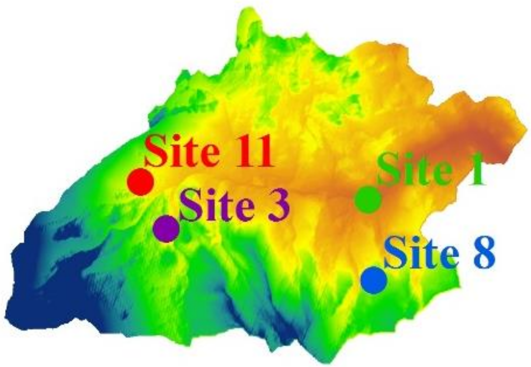
Validation - Net Radiation (R_{net})

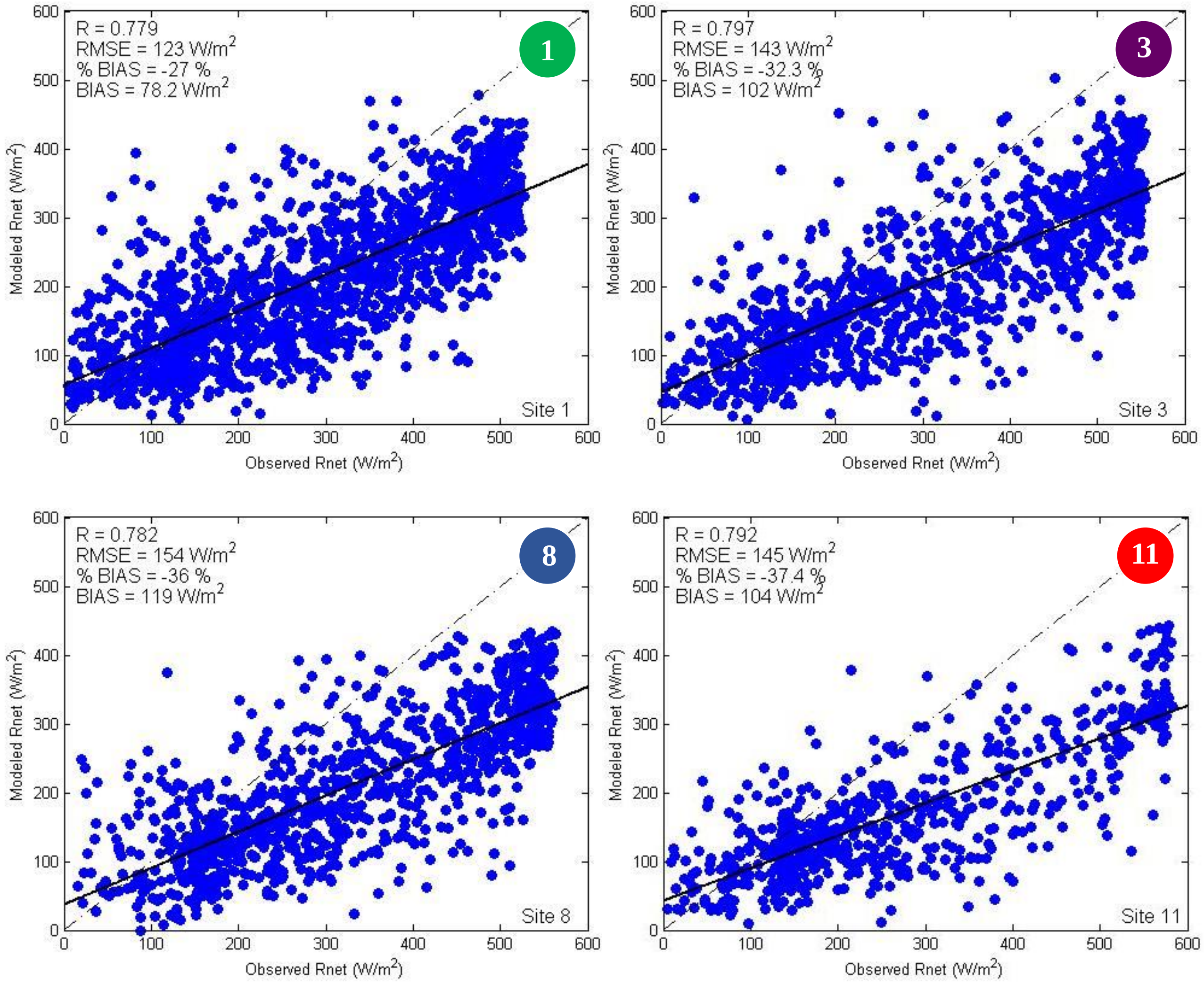


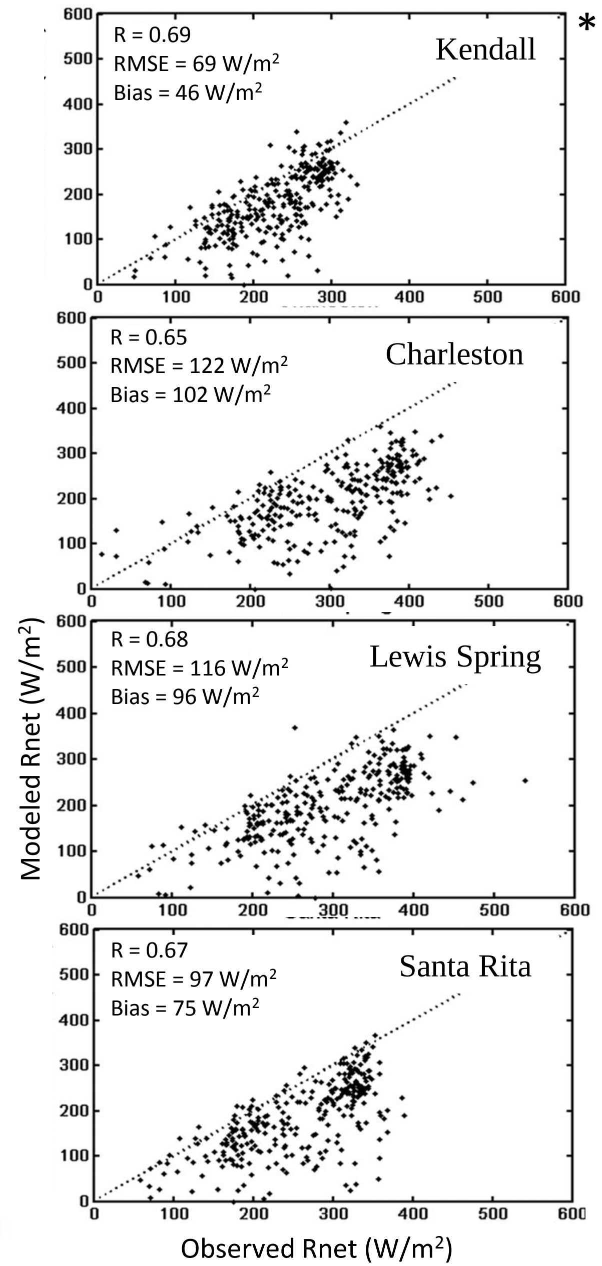
- *Daily*
- *250m Resolution*
- *Years 2010 - 2014*



- *Model systematically underestimates surface net radiation*

Validation - Net Radiation (R_{net})





**Kim and Hogue, 2013

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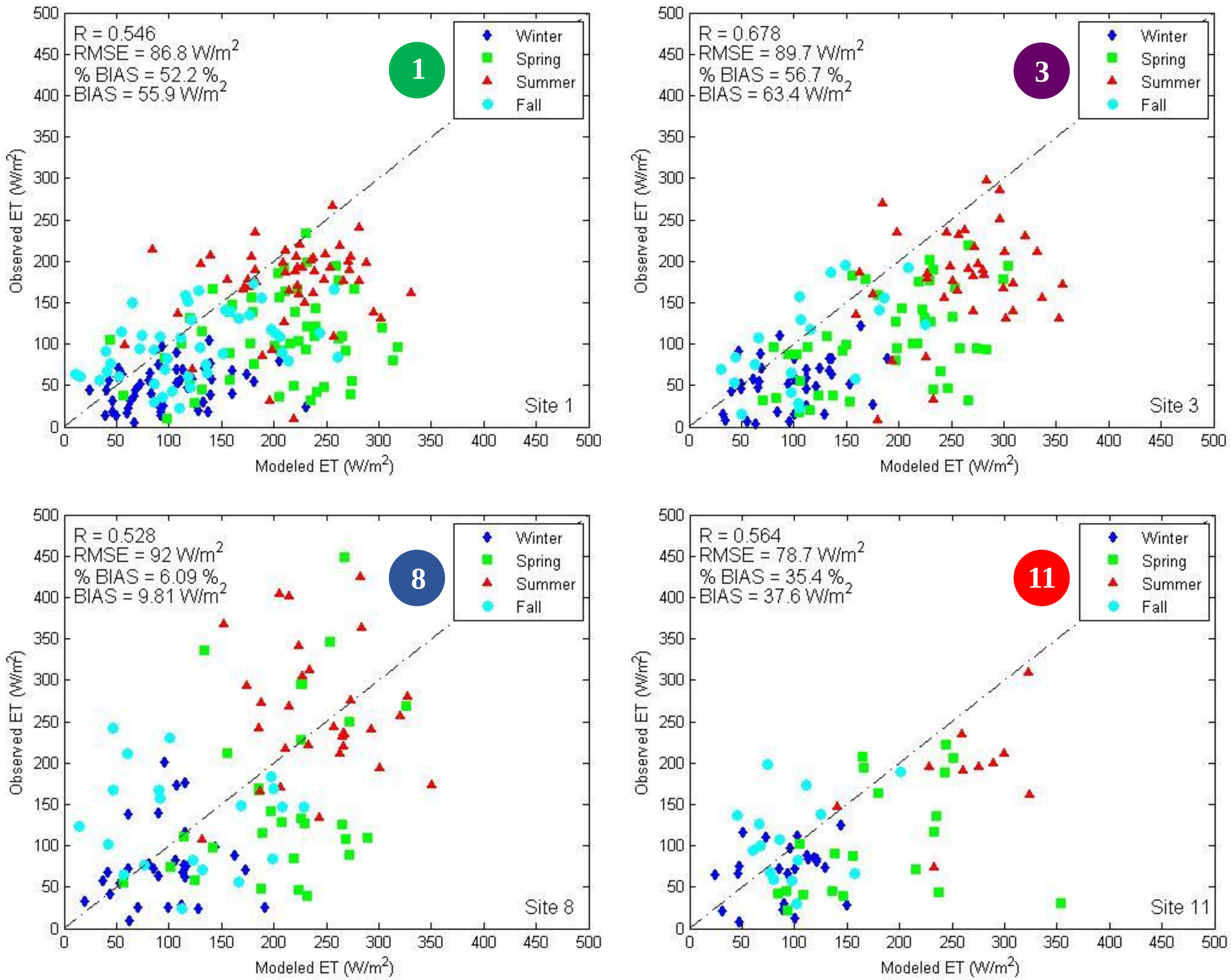
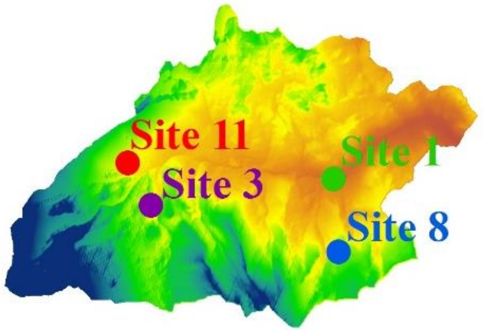
Validation – 8 day Average Actual ET



- Slight over-estimations (Sites 1 & 3)
- Fraval Sandy Loam – moderately deep and well-drained



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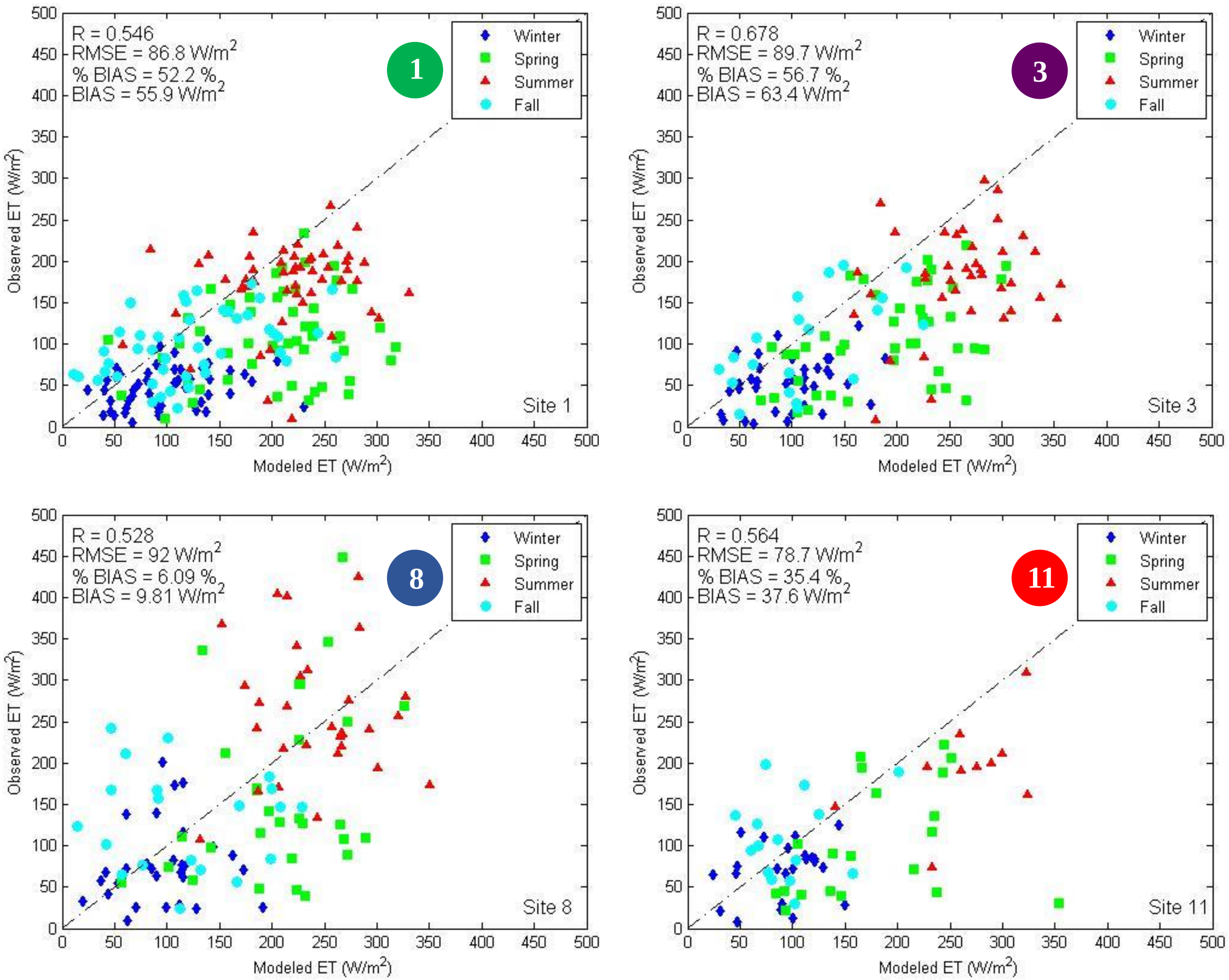

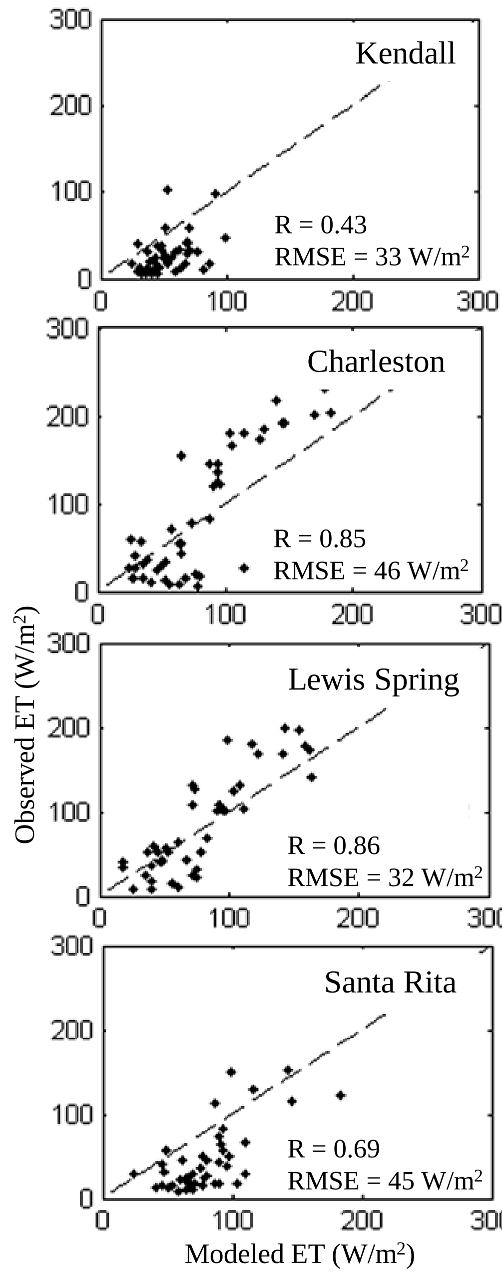

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**Kim and Hogue, 2013

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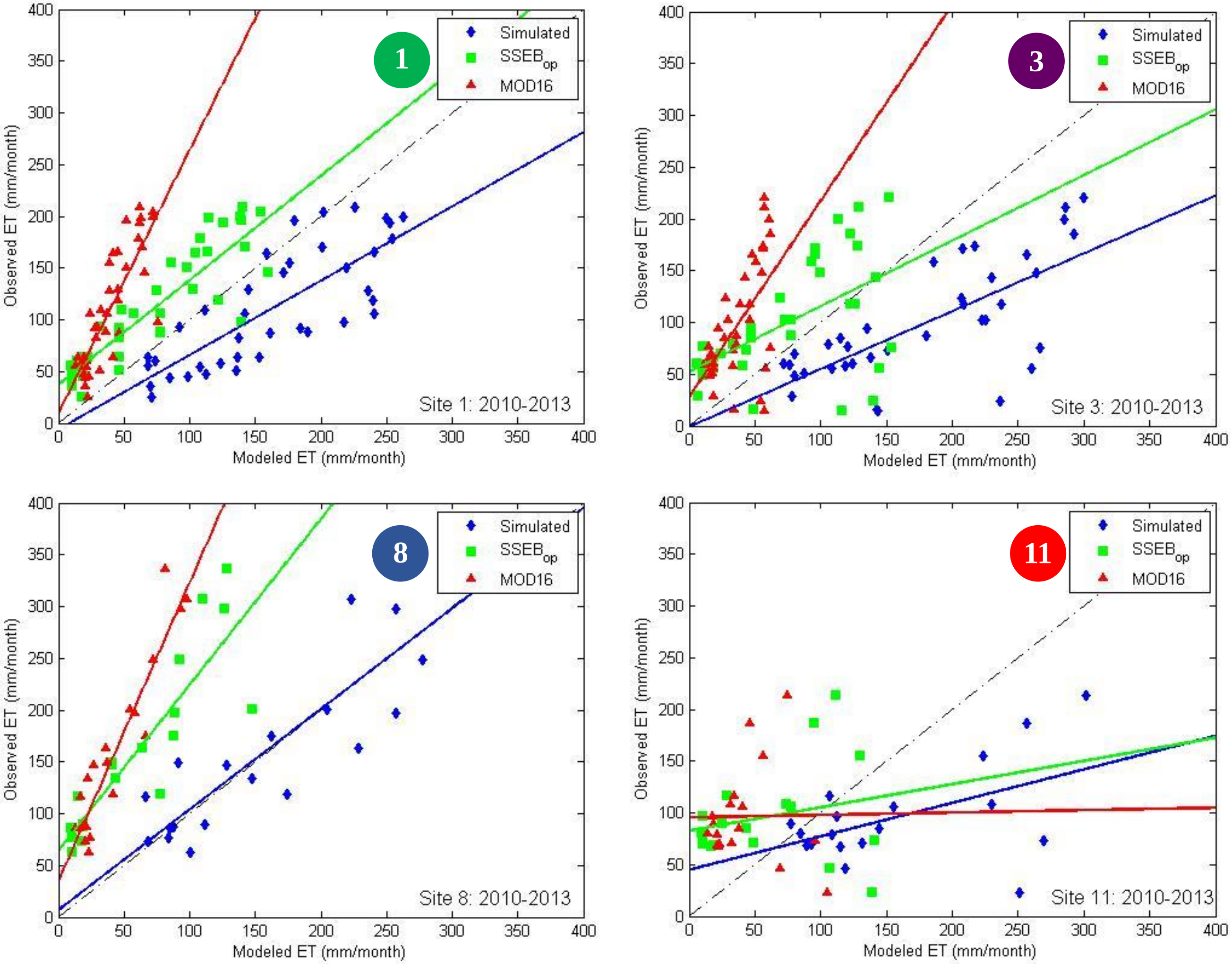
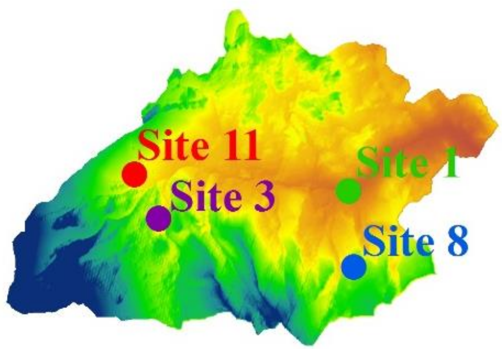
Validation – Monthly Actual ET

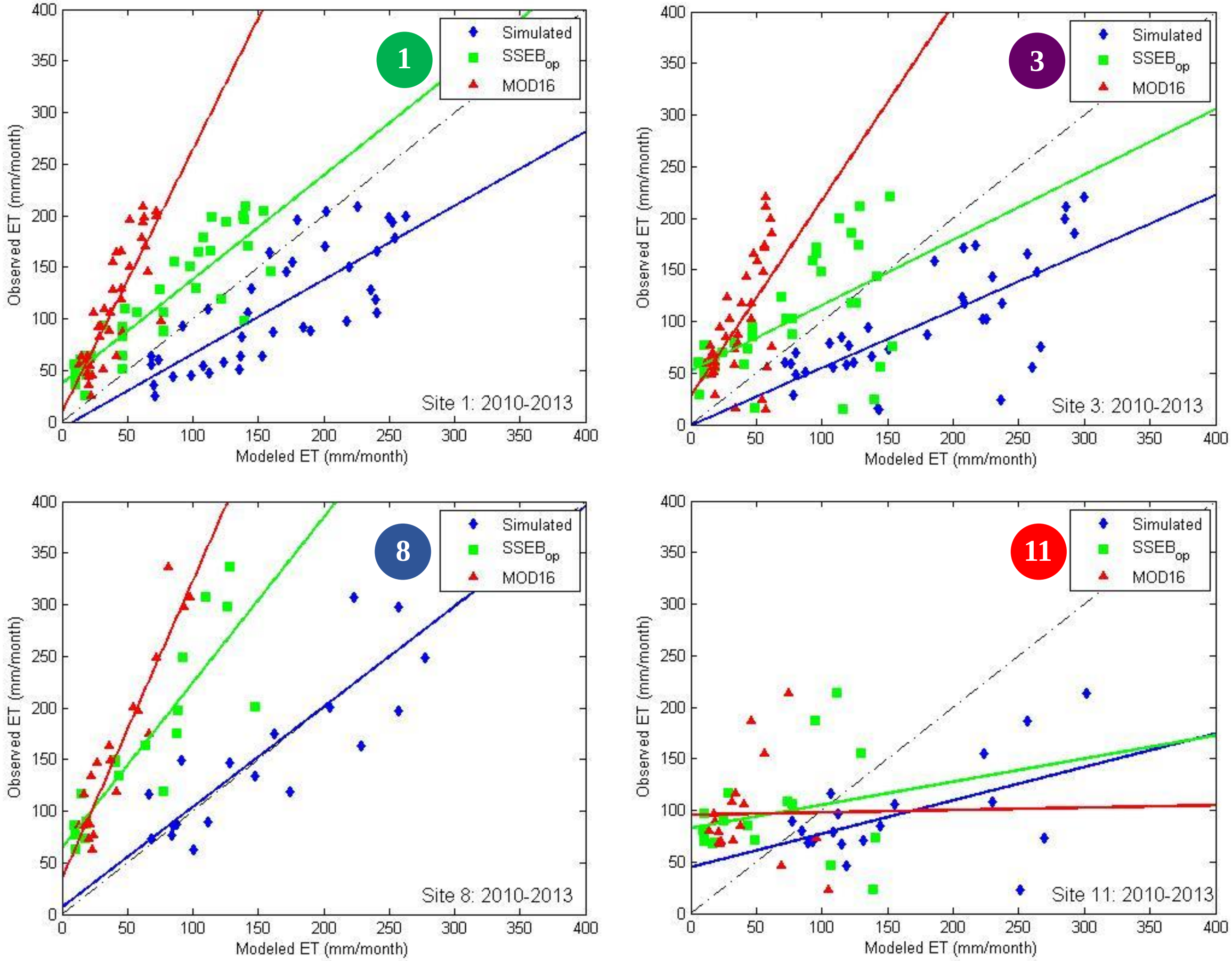


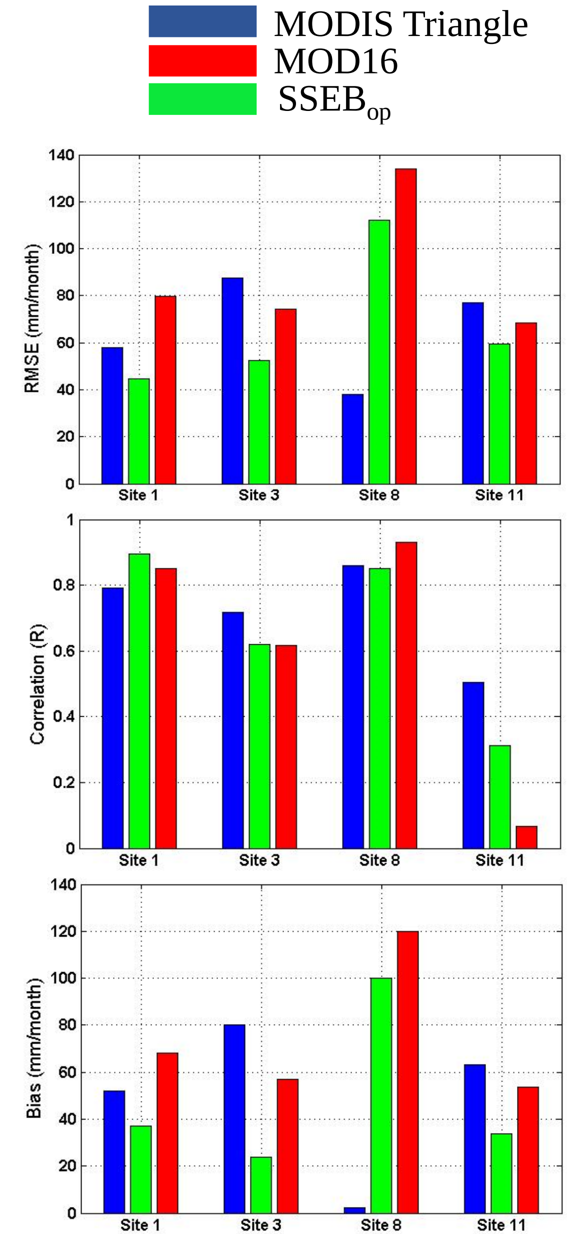
- Monthly total ET (mm/month)
- 1 km Resolution



- Poor Performance by MOD16
- SSEBop and MODIS Triangle Method show improved estimations to that of MOD16

Validation – Monthly Actual ET





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Concluding Remarks

- ET is arguably one of the most difficult hydrologic components to estimate given its dependence on a range of climatological parameters (i.e. solar radiation, temperature, wind speed, vapor pressure, etc.).
- Methods show the ability to accurately estimate ET with improved spatial and temporal scale in remote data sparse regions.
- Methods also show promise in an ability to monitor land cover change and disturbances such as regional treatments using remotely sensed products.
- The continuation of rapid landscape alterations due to climate change, urbanization and forest fire, among others, provide the motivation to continue improving remote sensing techniques in estimation of ET and other hydro-meteorological parameters for operational use.

Thank You!

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Relevant Group Work

Spies, R., K. Franz, T.S. Hogue and A. Bowman, 2014: Distributed hydrologic modeling using satellite-derived potential evapotranspiration, Journal of Hydrometeorology (in press)

Kim, J. and T.S. Hogue, 2013: Evaluation of a MODIS triangle-based evapotranspiration algorithm for semi-arid regions, Journal of Applied. Remote Sensing, 7, 073493, doi:10.1117/1.JRS.7.073493

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