United States Department of Agriculture

Agricultural Research Service

Time Series Evapotranspiration Mapping Using Landsat-TM and MODIS Data

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SOIL & WATER MANGEMENT RESEARCH

Project Objective

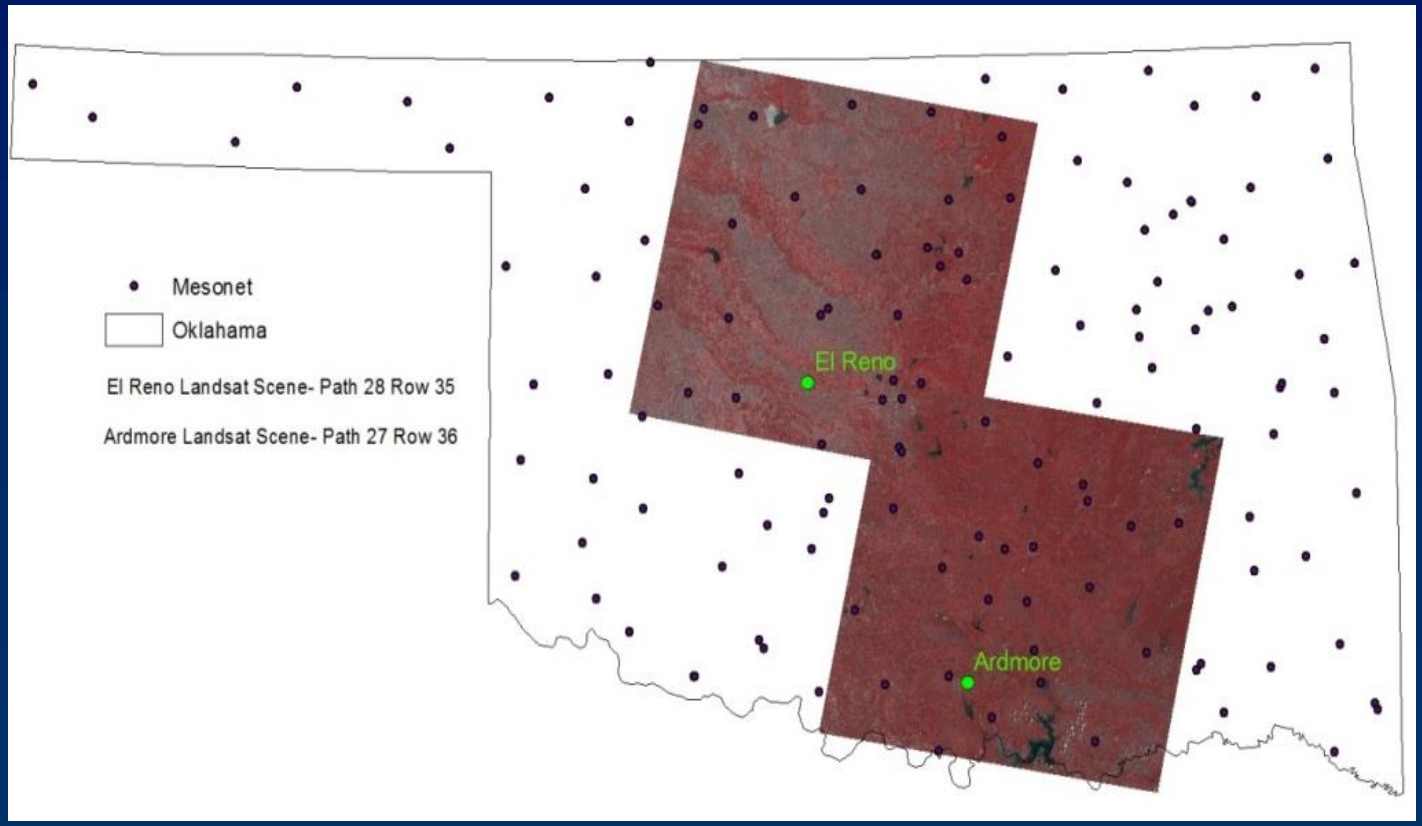
- Developing time series evapotranspiration (ET) maps using Landsat-TM and Terra-MODIS satellite data

Landsat-based ET Maps

- Two selected locations
- High resolution ET maps (30 m spatial resolution)
- Two source model (Norman et al., 1995)
- Period: 2001 – 2010
- Data used – 16-day coverage
- Products:
  - ➔ Surface temperature
  - ➔ Evaporation, transpiration and evapotranspiration (daily time-step)

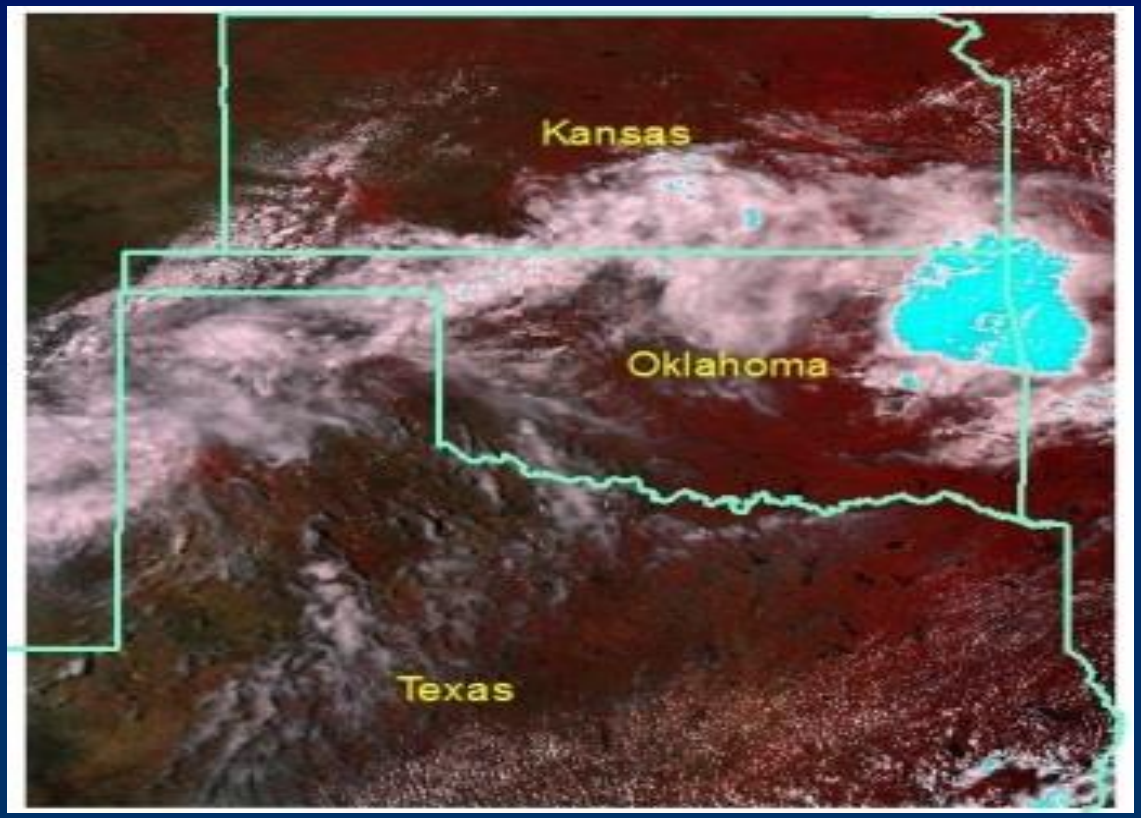
Landsat-Based ET maps

- Intensive field experiment locations
- Landsat scenes used



MODIS-based ET Maps

- Study area



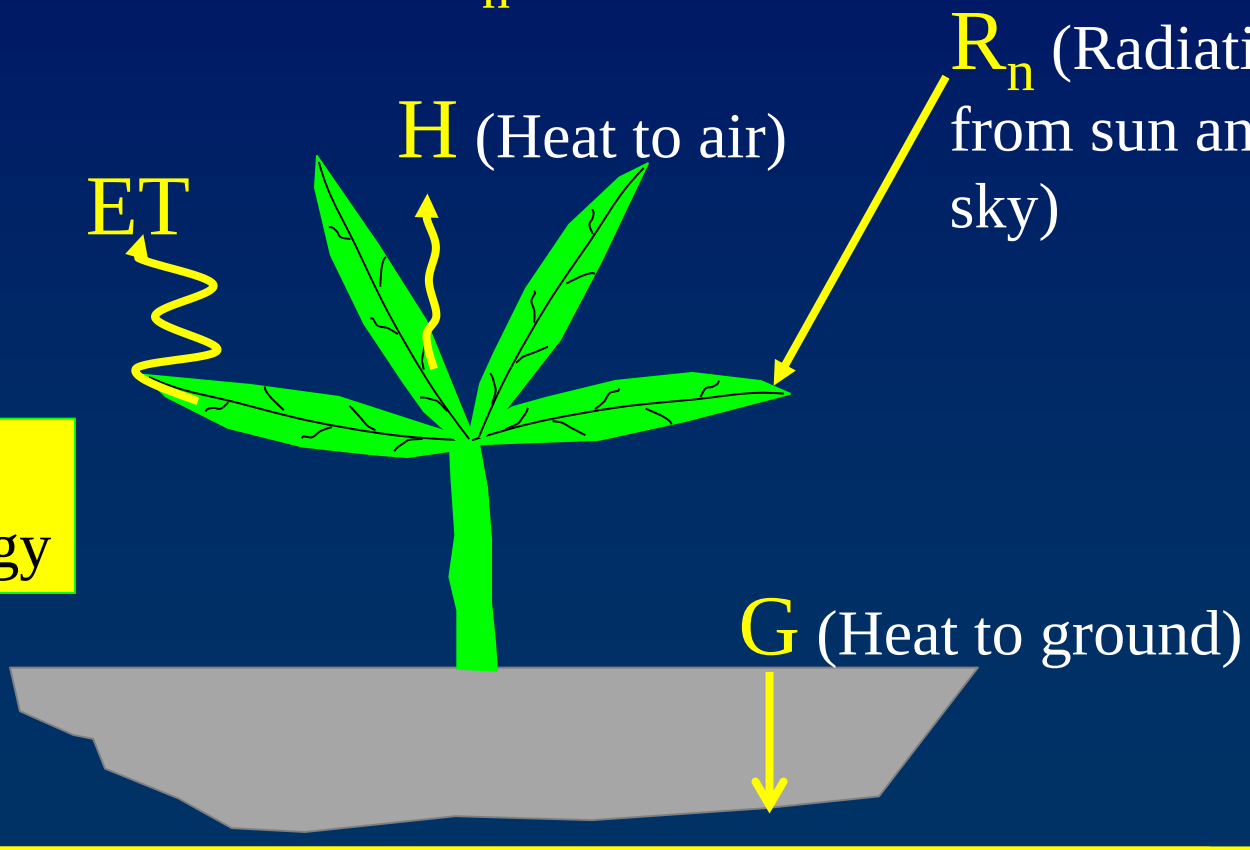
MODIS-based ET Maps

- Medium resolution ET maps (250 m)
- Surface Energy Balance System (Su, 2002)
- Period: 2001 – 2010
- Data used: Daily coverage
- Products:
  - ➔ Surface temperature (daily time series)
  - ➔ Evapotranspiration (daily time series)

Energy Balance Equation

- ET is calculated as a residual of the energy balance equation

$$ET = R_n - G - H$$



Basic Truth:
ET consumes energy

Soil Heat Flux (G)

- Bastiaanssen (1995)

$$G/R_n = T_s (0.0038 + 0.0074\alpha)(1 - .98NDVI^4)$$

- Tasumi et al. (2003)

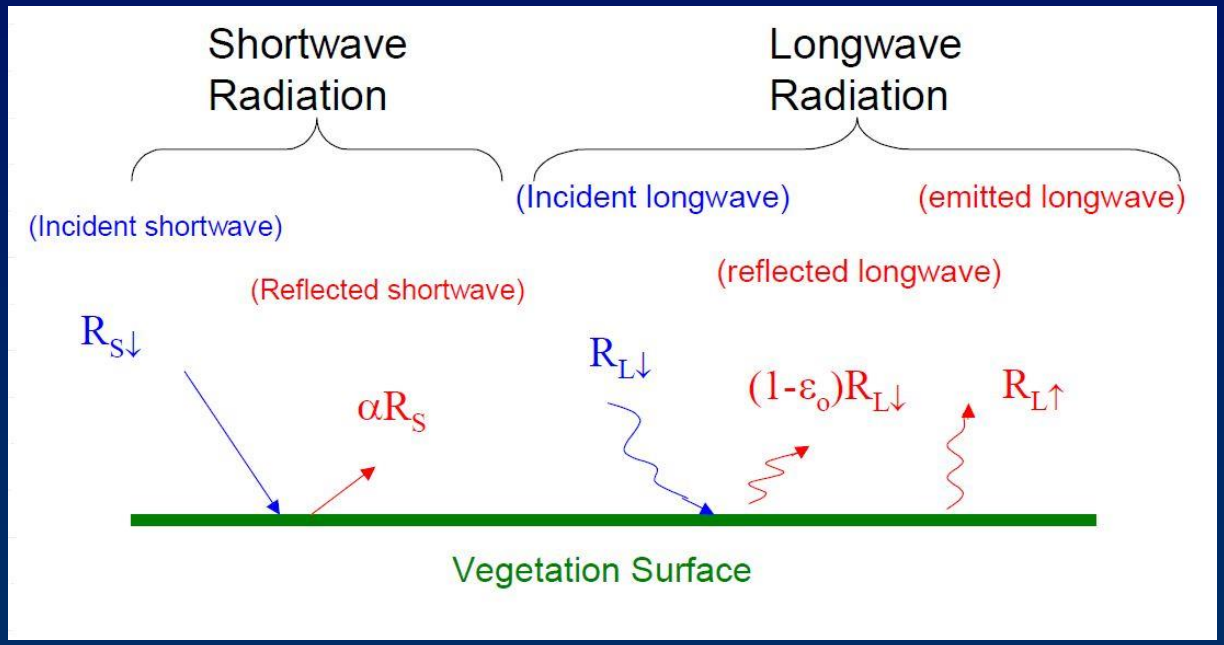
$$G/R_n = 0.05 + 0.18 \exp(-0.521\ LAI) \quad \text{for LAI} > 0.5$$

$$G/R_n = 1.80\ (T_s - 273)/\ R_n + 0.084$$

for LAI < 0.5 (~bare soil)

$$G = G/R_n \times R_n$$

Net Radiation (R_n)



$$R_n = (1-\alpha)R_{S\downarrow} + R_{L\downarrow} - R_{L\uparrow} - (1-\varepsilon_o)R_{L\downarrow}$$

Sensible Heat Flux (H)

$$H = (\rho \times c_p \times dT) / r_{ah}$$

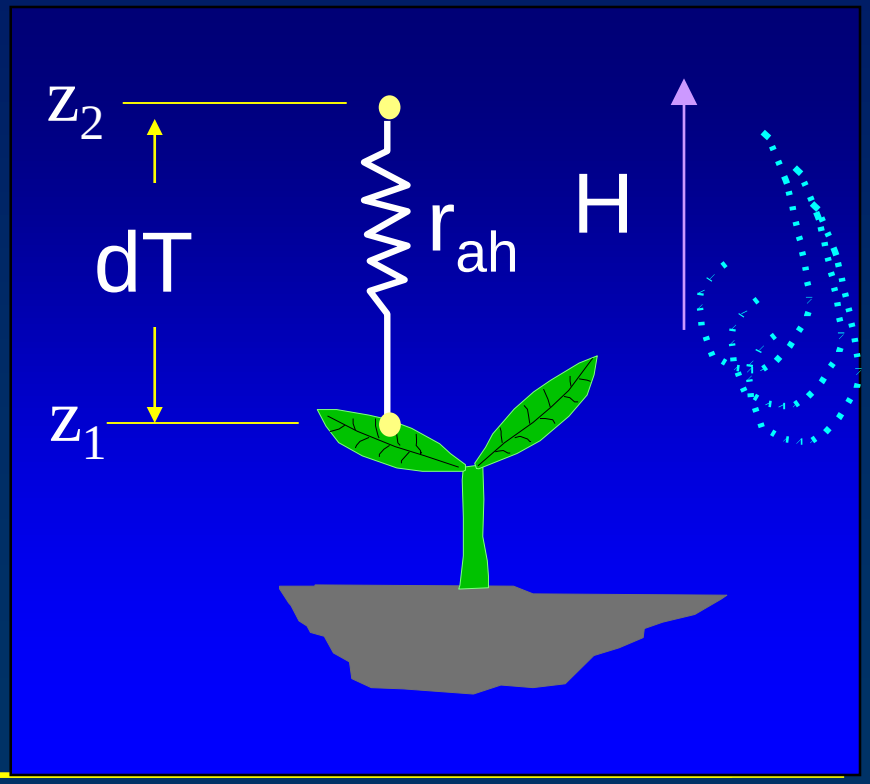
dT = the near surface temperature difference (K)

r_{ah} – Aerodynamic resistance to heat transport

$$r_{ah} = \frac{\ln\left(\frac{z_2}{z_1}\right)}{u_* \times k}$$

U_* - Friction velocity

k – von karmon constant (0.41)



SEBS

- R_n and G are calculated as in the SEBAL
- Estimation of the evaporative fraction based on energy balance at limiting cases – Wet & Dry limit for each pixel

At Dry-limit, the latent heat is assumed to be zero due to the limitation of soil moisture.

$$LE_{dry} = R_n - G_0 - H_{dry} \equiv 0$$

$$H_{dry} = R_n - G_0$$

At Wet-limit, evaporation takes place at potential rate

$$LE_{wet} = R_n - G_0 - H_{wet}$$

$$H_{wet} = R_n - G_0 - LE_{wet}$$

SEBS

Su (2002)

$$\lambda E = \frac{\Delta . r_e . (R_n - G) + \rho . c_p . (e_{sat} - e)}{r_e . (\gamma + \Delta) + \gamma . r_i}$$

Menenti, 1984

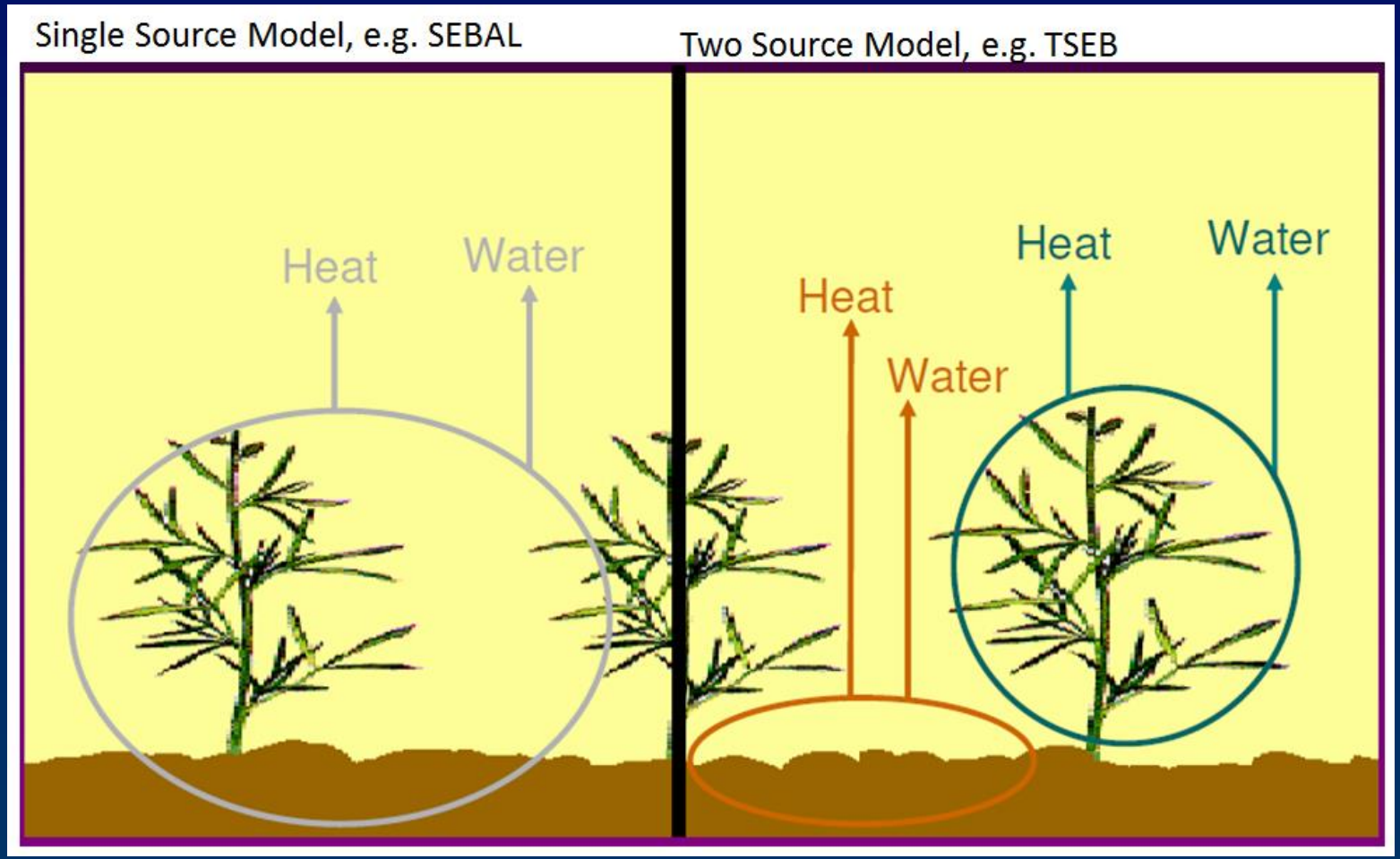
$$H_{wet} = \frac{(R_n - G) - \frac{\rho . c_p . (e_{sat} - e)}{r_{ew} . \gamma}}{\left(1 + \frac{\Delta}{\gamma}\right)}$$

SEBS

Su (2002)

$$LE = \Lambda_r . LE_{Wet}$$

Two Source Model



TSM (Two Source Model)

$$\mathrm{Rn}_c + \mathrm{Rn}_s + G + H_c + H_s + \lambda E_c + \lambda E_s = 0$$

$$T_{\mathrm{RAD}}(\theta) = \left\{ f(\theta) T_C^4 + [1 - f(\theta)] T_S^4 \right\}^{1/4}$$

Two Source Model

$$Rn_c = Rn[1 - \exp(-\beta LAI)]$$

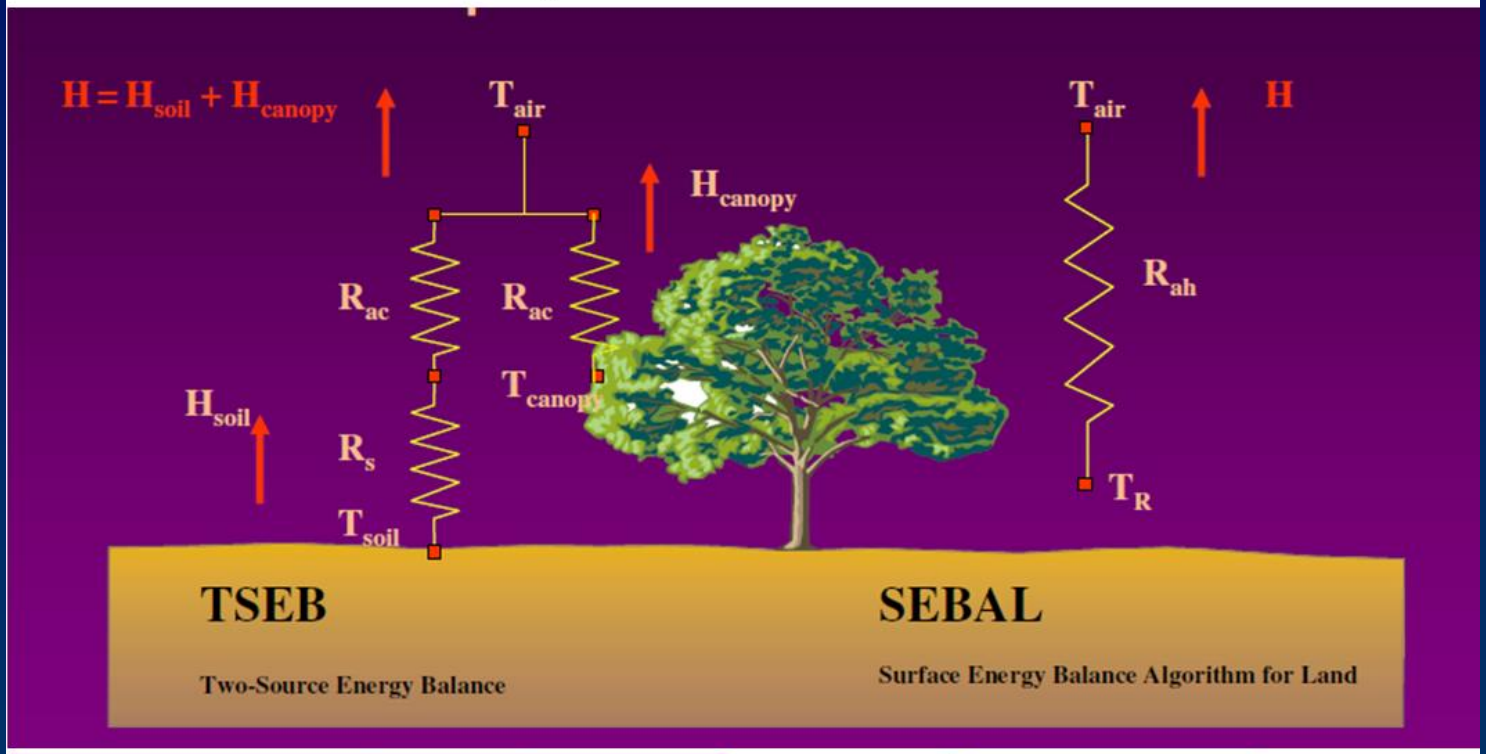
$$R_{ns} = cR_n \exp(-\beta \,.\, LAI)$$

or

$$R_{ns} = R_n - R_{nc}$$

TSM - Energy Balance

Sensible Heat flux parameterization TSM and SEBAL



$$H = H_{canopy} + H_{soil} = \rho C_P \left[\frac{(T_{canopy} - T_{air})}{R_{ac}} + \frac{(T_{soil} - T_{air})}{R_s + R_{ac}} \right]$$

$$H = \rho C_P \frac{(T_R - T_{air})}{R_{ah}}$$

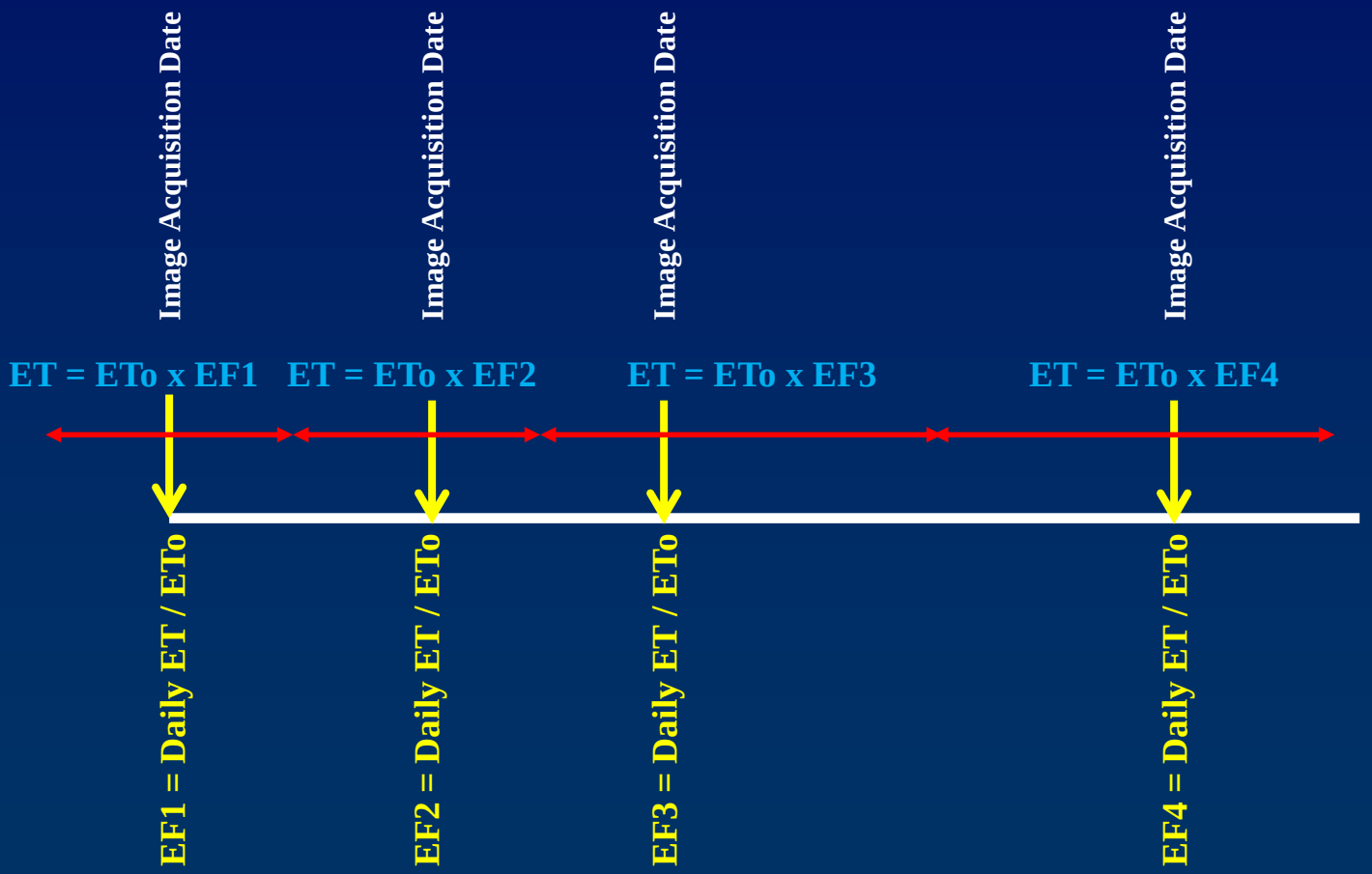
Instantaneous ET to Daily ET

- **Evaporative Fraction Method**

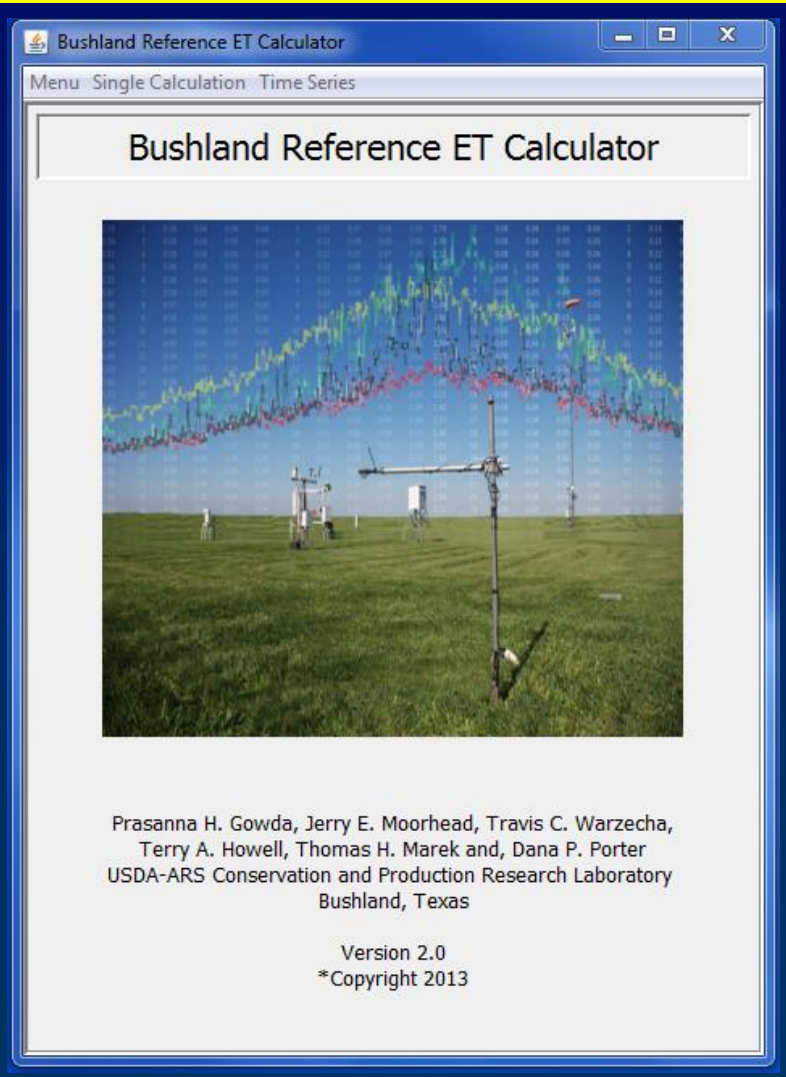
$$ET_{d6} = \left(ET_i / (ET_o)_i\right) \times (ET_o)_d$$

Time Series Daily ET

- Calculation of daily ET (2001-2010)

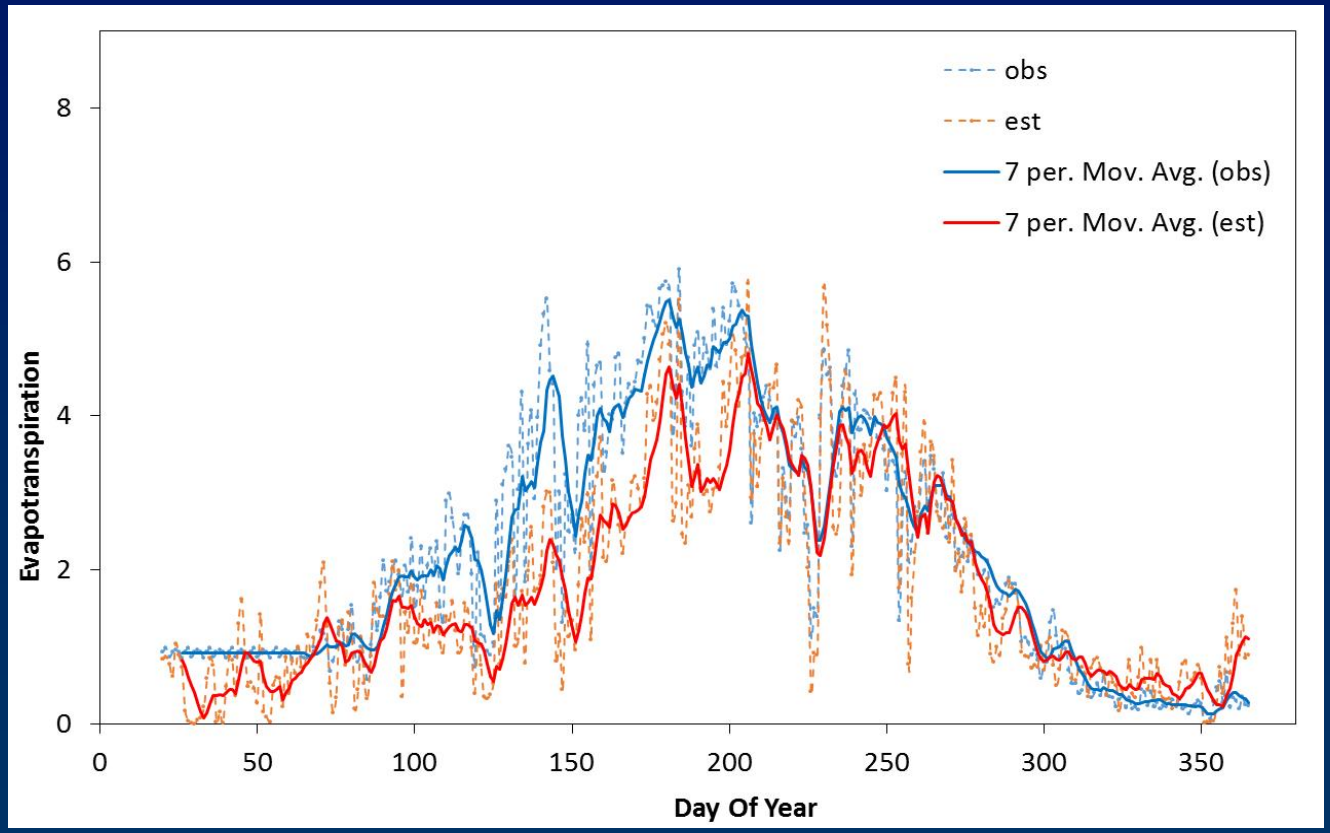


ET_0 Calculation



Landsat ET – Accuracy Assessment

- El Reno Control Site (2005)



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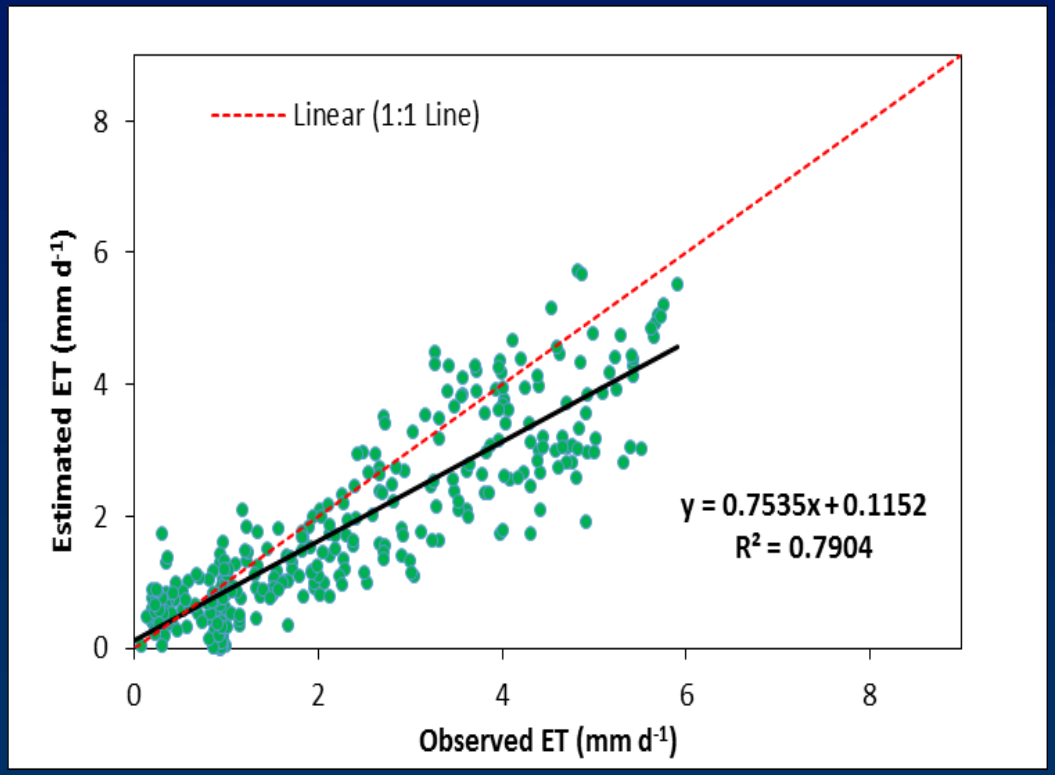

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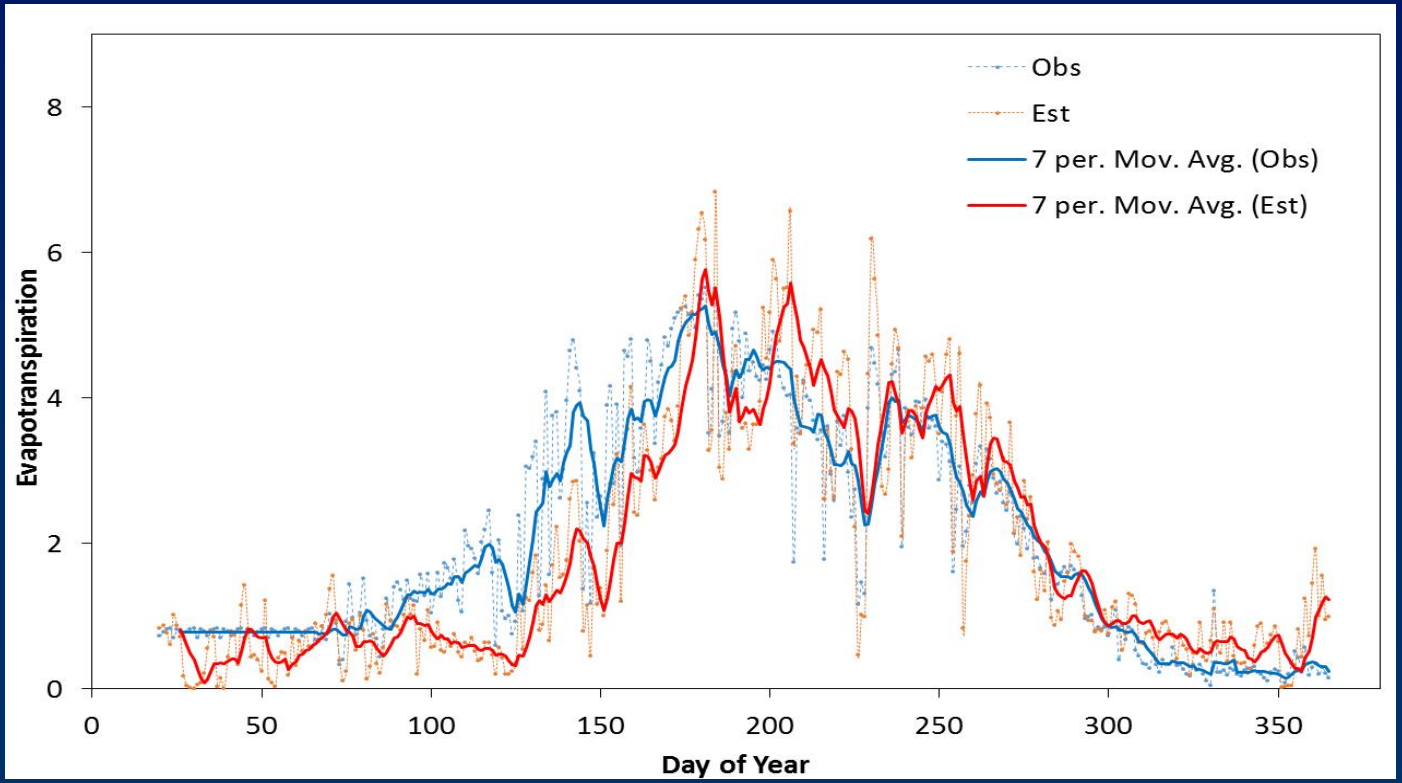

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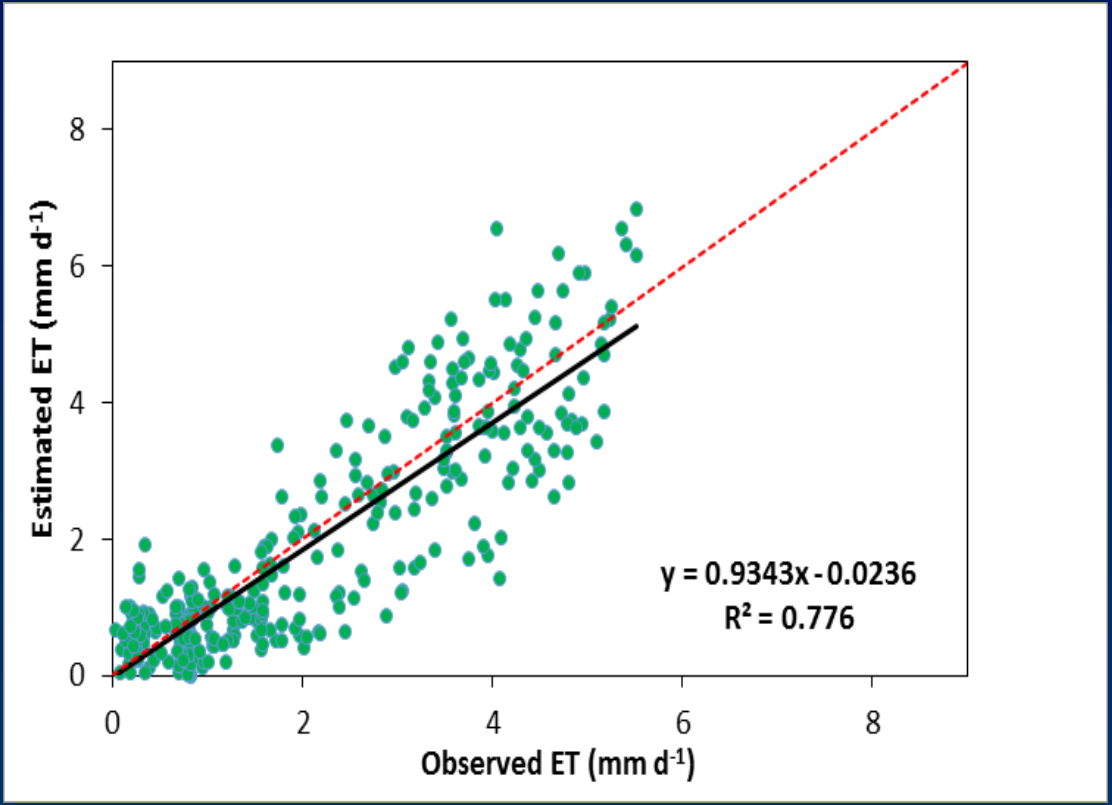

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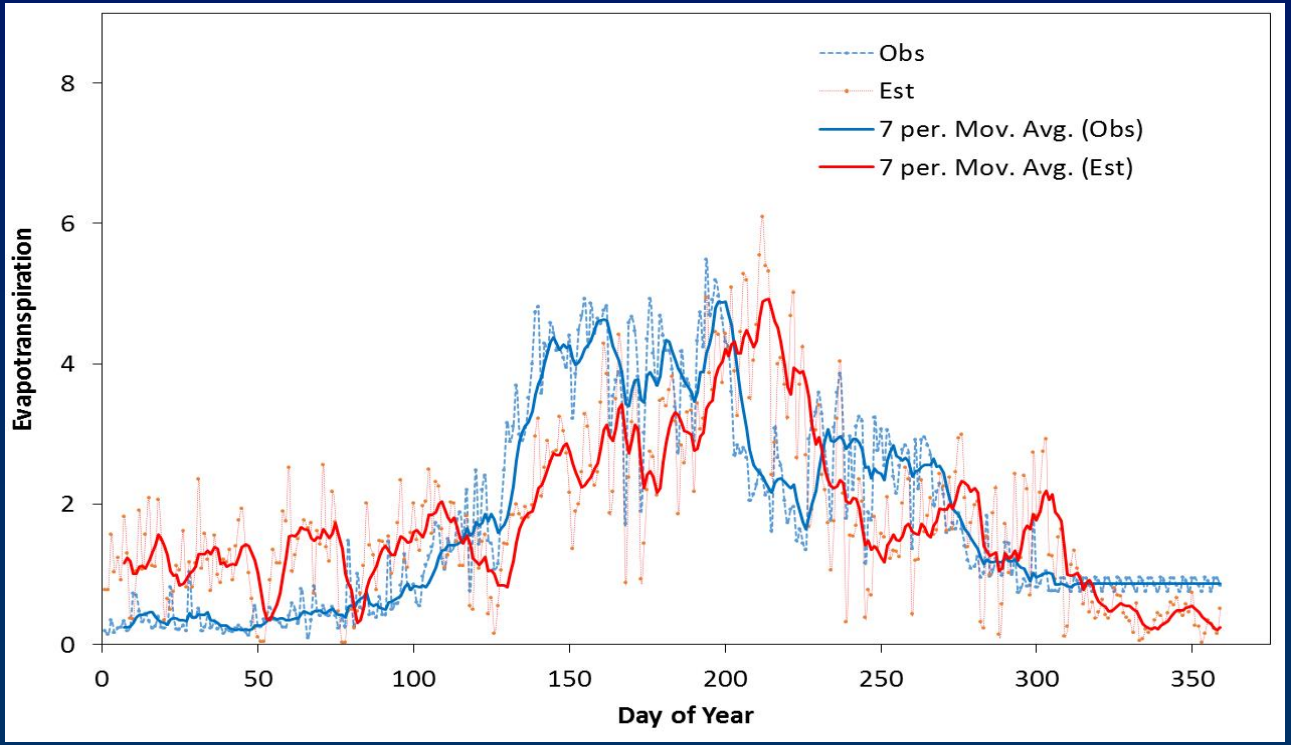

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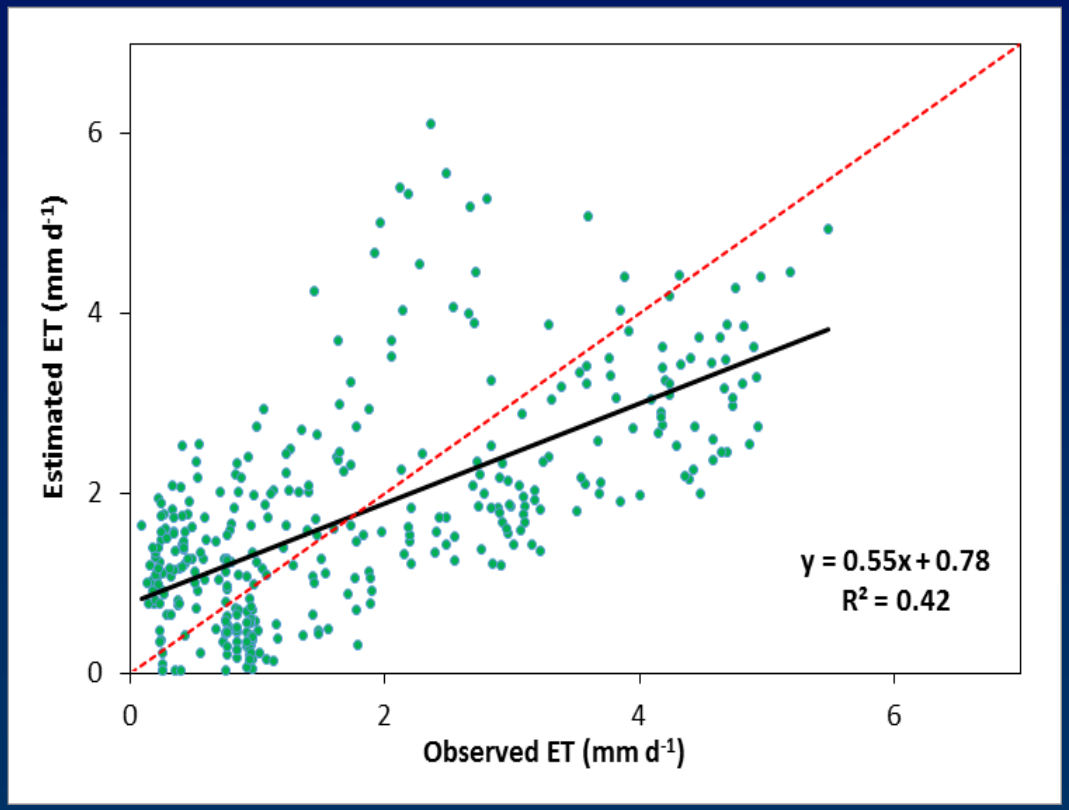

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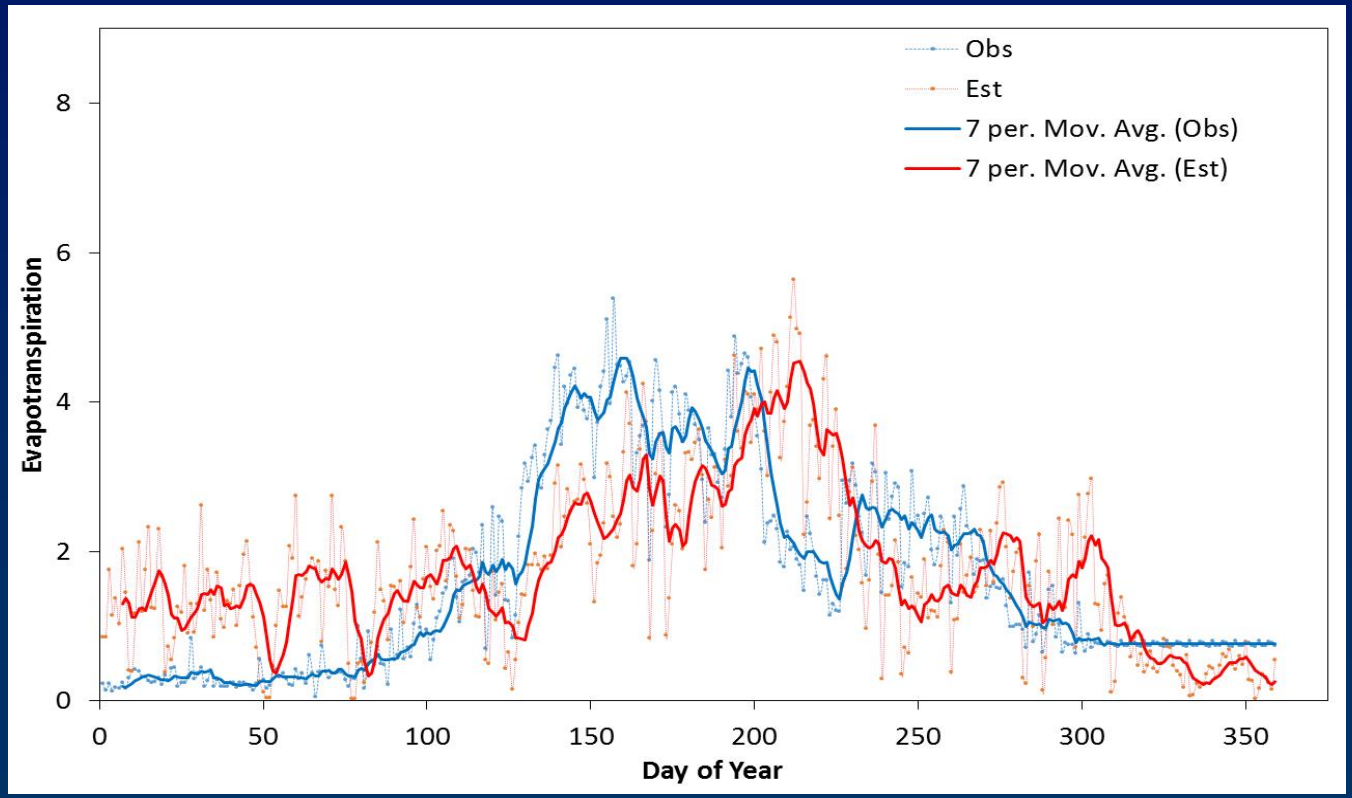

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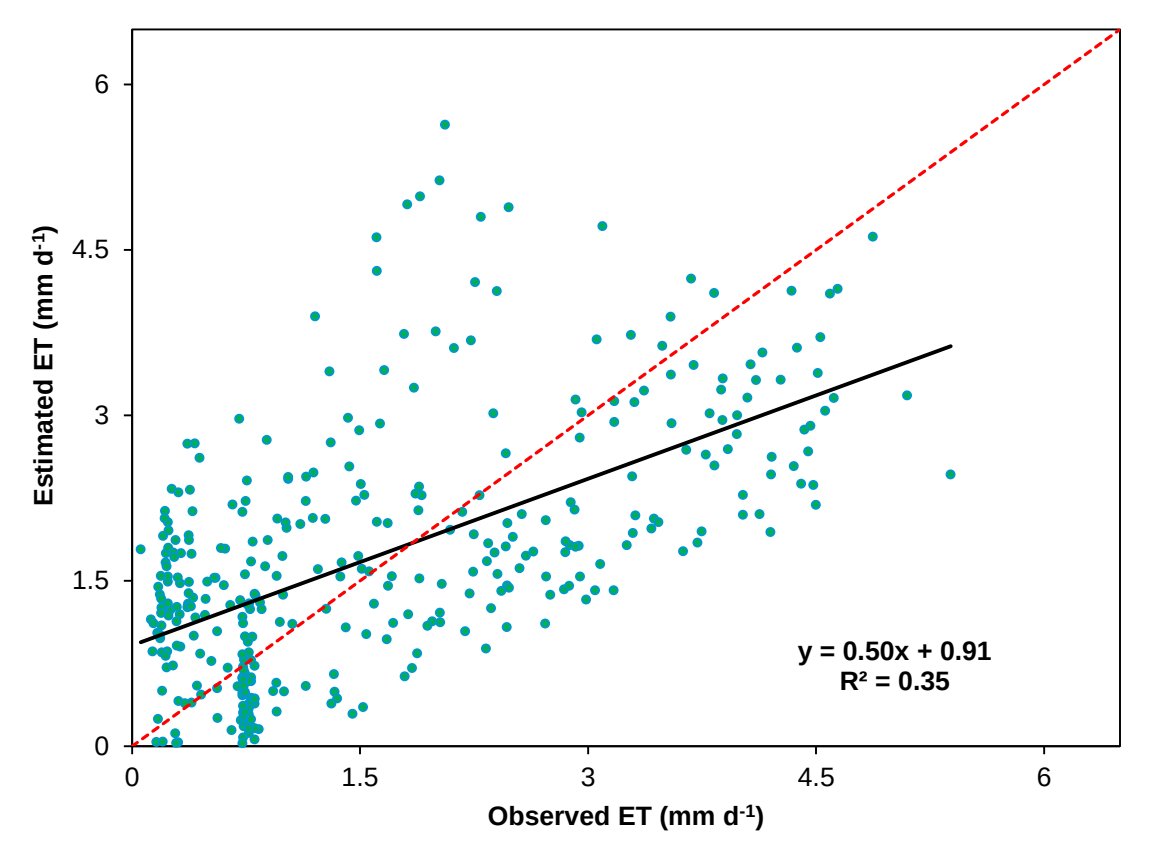
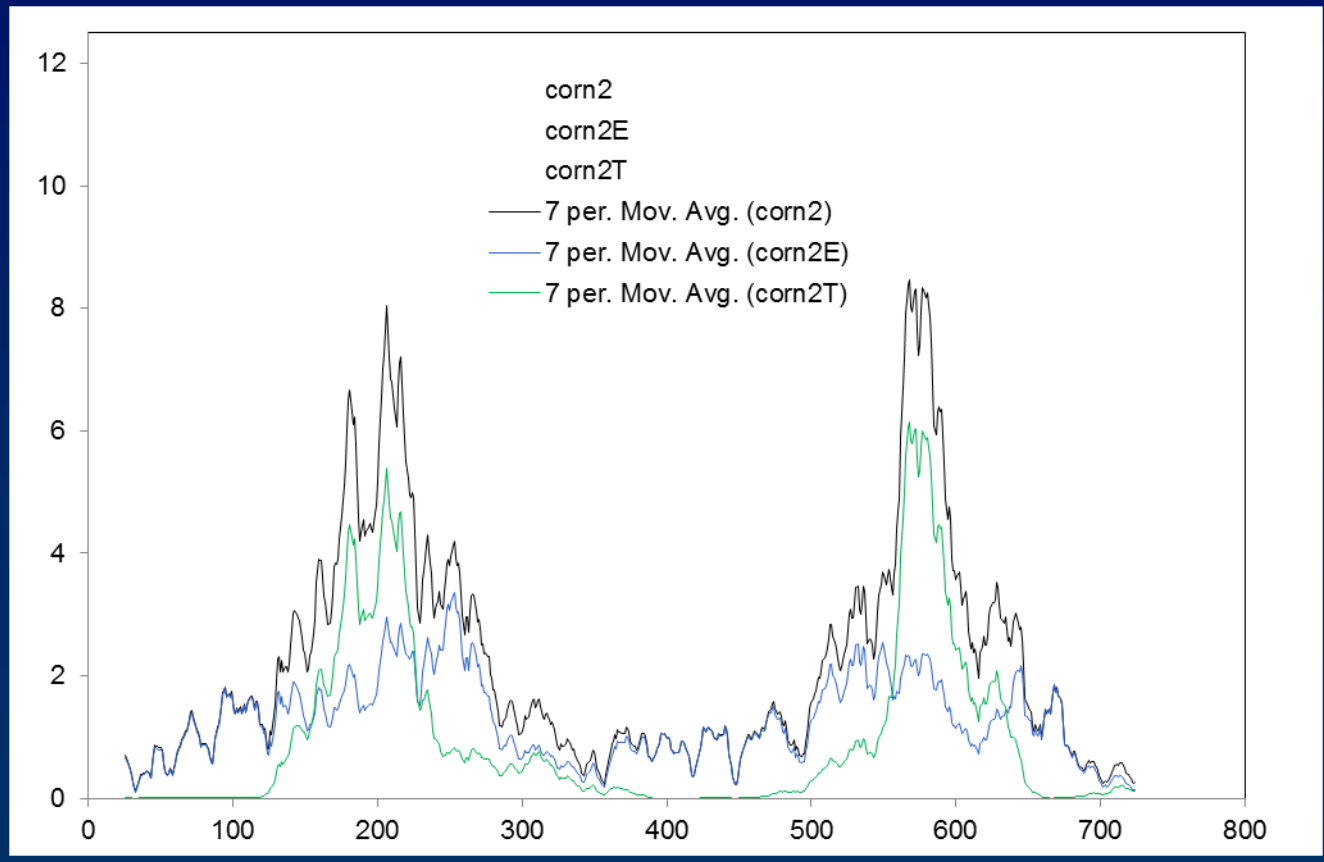


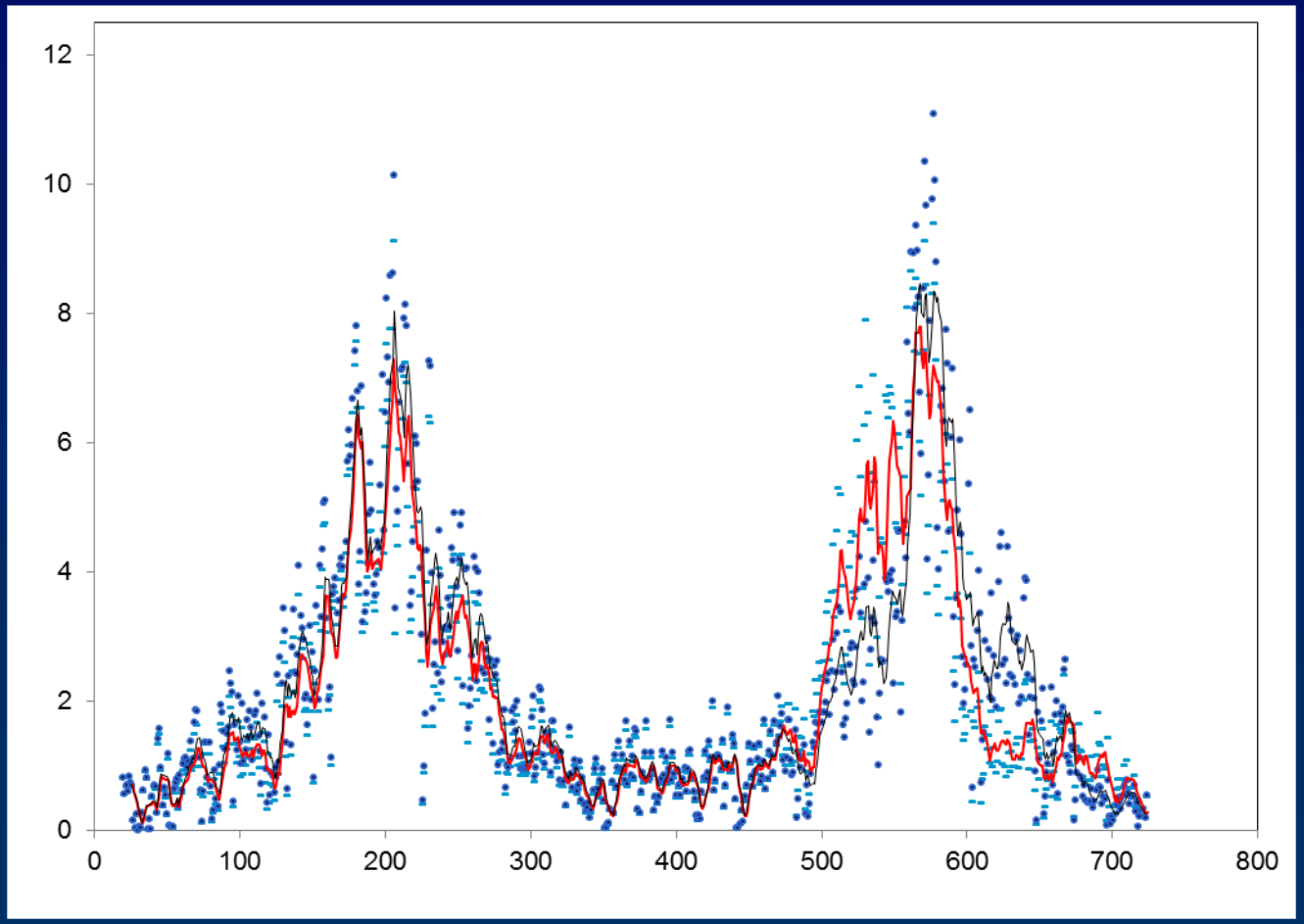
Performance Statistics

N	Mean (mm d^{-1})	Mean (mm d^{-1})	MBE (mm d^{-1})	% MBE (%)	RMSE (mm d^{-1})	% RMSE (%)	MAE (mm h^{-1})	MAPD (%)	NSE	R^2
ElReno Control 2005	2.2	1.8	-0.43	-19.4	0.87	38.9	0.65	29.5	0.71	0.79
ElReno Burn 2005	2.0	1.8	-0.15	-7.7	0.80	39.8	0.62	30.7	0.73	0.77
ElReno Control 2006	1.8	1.8	-0.03	-0.5	1.1	62.8	0.92	51.9	0.38	0.42
ElReno Burn 2006	1.6	1.7	0.07	6.2	1.1	68.6	0.90	55.6	0.28	0.35

Actual E, T and ET



Actual ET vs Potential ET



Summary

- Development of Landsat-TM based time series ET database is complete
  - ➔ Available Products
    - Surface temperature maps
    - E, T, and ET maps (2001-2010)
- Accuracy of ET maps depended upon availability of cloud-free Landsat images in a given year
- MODIS-based ET maps will be available in December 2014