# Estimating evapotranspiration in the North American Monsoon region using flux tower and satellite data

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# Estimating Land Surface Evaporation Using Remotely Sensed Data

- 2 Fundamentally different approaches:
  - 1. LE deduced from surface energy balance
    - (Bastiaanssen et al. 1998 - SEBAL)
  - 2. LE modeled
    - (Cleugh et al., 2007 , Mu et al., 2007)
- Both of these approaches rely (at least partially) on ground data

# Remote Sensing - Penman - Monteith Model
(Cleugh et al. 2007)

$$\lambda E = \frac{sA + \dfrac{\rho C_p (e_{sat} - e)}{R_a}}{s + \gamma\left(1 + \dfrac{R_s}{R_a}\right)}$$

**s** = slope of the curve relating saturation water vapor pressure to temperature ($de_{sat}/dT$)
**A** = available energy ($R_{net}$ – G) - measured
ρ = air density
**$C_p$** = specific heat capacity of dry air (1005 J/kg K)
**$e_{sat}$** = saturation water vapor pressure
**e** = water vapor pressure
γ = psychrometric constant
**$R_s$** = surface resistance
**$R_a$** = aerodynamic resistance

# RS - PM Model

(Cleugh et al. 2007)

$$\lambda E = \frac{sA + \frac{\rho C_p (e_{sat} - e)}{R_a}}{s + \gamma\left(1 + \frac{R_s}{R_a}\right)}$$

$$e_{sat} = 6.11 \exp\left(\frac{L}{R_v}\left(\frac{1}{273} + \frac{1}{T}\right)\right)$$

$$s = \frac{de_{sat}}{dT} = \frac{Le_{sat}}{R_v T^2}$$

$$\gamma = \frac{M_a}{M_v}\frac{C_p P_{air}}{L}$$

$$R_a = \frac{1}{k^2 U}\left[\ln\left(\frac{z-d}{z_{0H}}\right) - \Psi_H\left(\frac{z-d}{L}\right)\right]\left[\ln\left(\frac{z-d}{z_0}\right) - \Psi_M\left(\frac{z-d}{L}\right)\right]$$

L – constant
$R_v$ – constant
T – measured
$M_a$ – constant
$M_v$ – constant
$C_p$ – constant
P – measured
$R_s$ - ?

# Surface resistance algorithm

Important: Surface conductance = (surface resistance)$^{-1}$

- Reasoning: Remotely-sensed vegetation indices such as NDVI and the derived measures of canopy cover such as LAI and fractional land cover (Fc), are an adequate surrogate for Rs.
- If there is sufficient soil moisture for vegetation to develop, this will be manifested as a signal in NDVI, fc or LAI on timescales that match plant growth, i.e. weeks to months.
- Low values of Gs are expected at low LAI and when low levels of soil moisture limits evaporation, while Gs will be high for well-watered surfaces with high LAI.
- simple linear relationship proposed:

$$1/R_s = G_s = cL \cdot LAI + G_{s,\ min}$$

# Surface resistance algorithm - continued

$1/R_s = G_s = c_L \cdot LAI + G_{s, min}$

LAI = Leaf Area Index = is the ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows

Gs, min = surface conductance controlling soil evaporation and the conductance through the leaf cuticle

$c_L$ = mean surface conductance per unit leaf area index

Parameters that need to be determined empirically

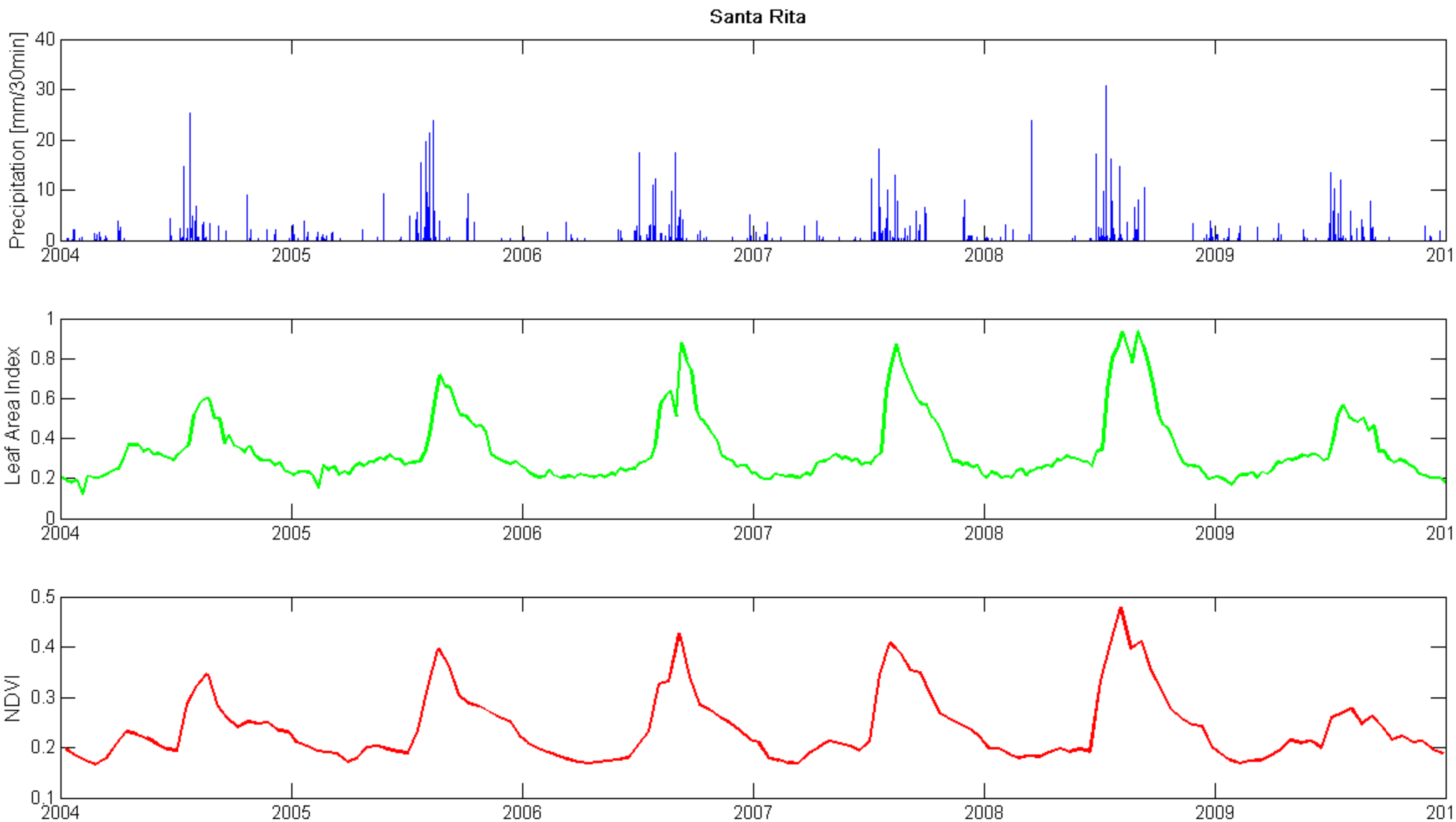
Remotely sensed

# Application of the RS -PM ET algorithm to the NAM region

- Test site: Santa Rita Mesquite, AZ ( *31.82 N, 110.86 W*)
- Approach:
  - Use flux tower data for $R_{net}$, G, $T_{air}$, $P_{air}$
  - Use MOD15A2 LAI product ( 1 km, 8-day composite) spatially averaged over a 7x7 km subset around the test site
- Tower data averaged daily over daylight hours, then averaged further over 8 days to match the MODIS compositing period
- Parameter values:

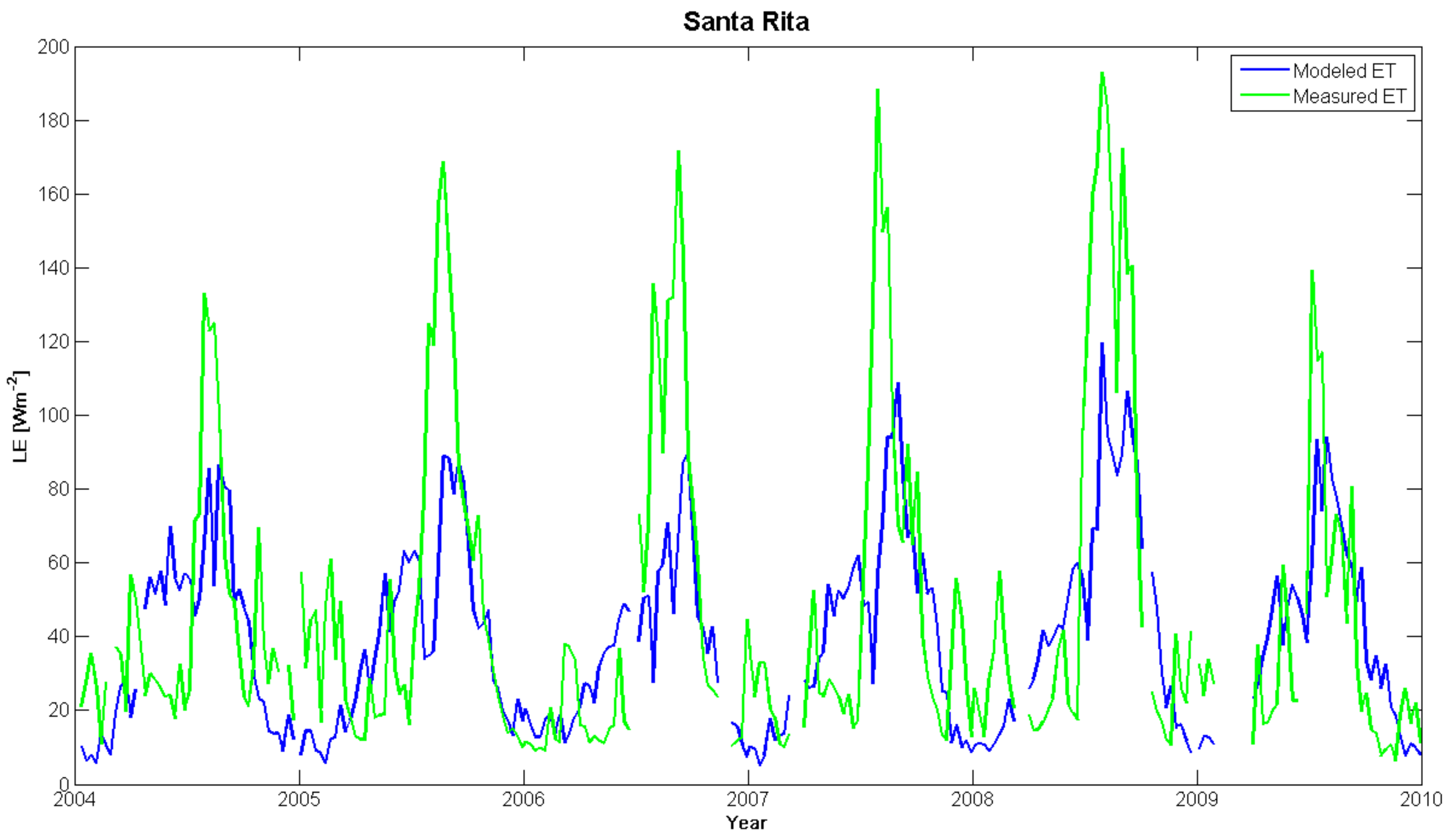
$$1/Ra = 0.05\ ms^{-1}$$

$$c_L = 0.0019$$

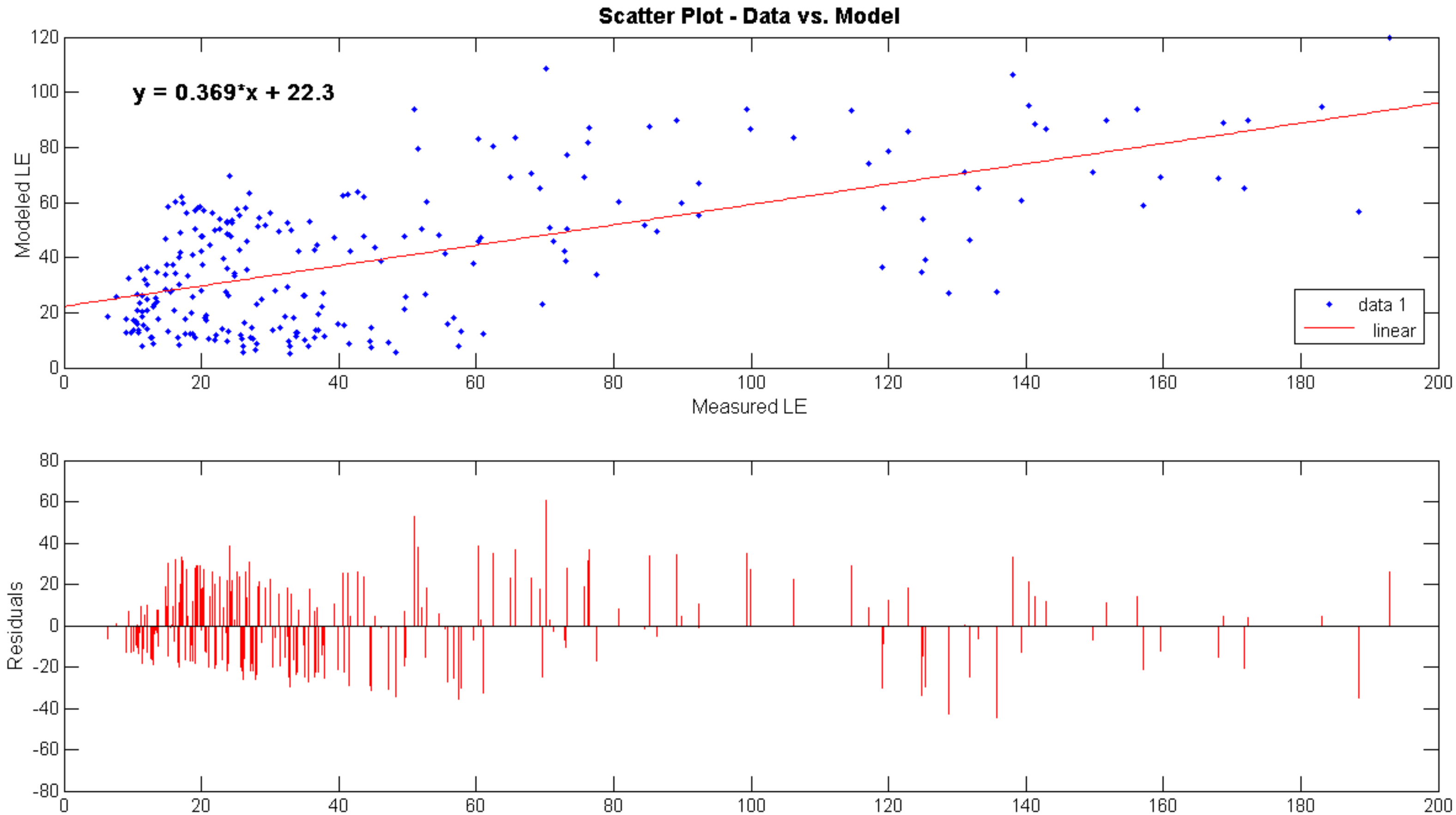


Santa Rita
Precipitation [mm/30min]
40
30
20
10
0
2004
2005
2006
2007
2008
2009
2010
Leaf Area Index
1
0.8
0.6
0.4
0.2
0
2004
2005
2006
2007
2008
2009
2010
NDVI
0.5
0.4
0.3
0.2
0.1
2004
2005
2006
2007
2008
2009
2010

# (Very) Preliminary Results




RMSE = 32.6



Scatter Plot - Data vs. Model
y = 0.369*x + 22.3
Modeled LE
Measured LE
data 1
linear
Residuals

# Revised RS-PM Algorithm
(Mu et al., 2007)

- Added the calculation of soil evaporation (not just canopy evaporation)
- Added vapor pressure deficit and minimum air temperature constraints on stomatal conductance
- Used EVI instead of NDVI to compute vegetation fraction

# Revised RS-PM Algorithm

## Canopy Evaporation

$$\lambda E_{can} = \frac{sA_C + \frac{\rho C_p (e_{sat} - e)}{R_a}}{s + \gamma \left(1 + \frac{R_s}{R_a}\right)}$$

$$Rs = \frac{1}{C_c} = (C_s \cdot LAI)^{-1}$$

$$C_S = c_L \cdot m(T\min) \cdot m(VPD)$$

*m* = multiplier that limits potential stomatal conductance by min $T_{air}$ and when VPD is high

## Soil Evaporation

$$\lambda E_{soil} = \lambda E_{soil\_Pot} \left(\frac{RH}{100}\right)^{\frac{e_{sat}-e}{100}}$$

$$\lambda E_{soil\_Pot} = \frac{sA_{soil} + \frac{\rho C_p (e_{sat} - e)}{R_a}}{s + \gamma \frac{R_{tot}}{R_a}}$$

# Revised RS-PM Algorithm

- A – available energy is linearly partitioned between canopy and soil surface using vegetation fraction:

$$A_C = F_C \cdot A$$
$$A_{Soil} = (1 - F_C) \cdot A$$

- Vegetation Fraction:

$$F_C = \frac{EVI - EVI_{min}}{EVI_{max} - EVI_{min}}$$

- $R_a$, $R_s$, $R_{tot}$ - Aerodynamic resistance, surface resistance, total aerodynamic resistance to vapor transport (= $R_a + R_v$) respectively

# Conclusions

- RS – PM algorithm produces ET estimates that match the seasonality of the measured ET, but **not** the magnitude
- Modeled ET is consistently lower than measured ET
- RMSE = 32.6 W/m^2 – comparable to the results in the article
- But, $R^2$ = 0.369 (low!)

# Future work

- Plenty of room for improvement:
- For RS – PM algorithm:
  - Optimize $c_L$
  - Use local meteorology-dependent $R_a$ instead of a fixed value
- Use Revised RS – PM

Thank you!