Global estimates of evapotranspiration for climate studies using multi-sensor remote sensing data: Evaluation of three process-based approaches

Vinukollu, R.K., Wood, E.F., Ferguson, C.R., Fisher, J.B.: *Remote sensing of the Environment*, 2011

Models

- Surface Energy balance System (SEBS)
  - *Su, 2002*
- Penman-Monteith Algorithm
  - *Mu et al., 2007*
- Priestley-Taylor Algorithm
  - *Fisher et al., 2008*

SEBS

- Partitions the available energy between the turbulent heat fluxes

$$LE = R_{\text{net}} - G - H$$

PM-Mu 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

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

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

Priestley-Taylor

$$LE = \alpha \frac{\Delta}{\Delta + \gamma} (R_{net} - G_{flux})$$

Fisher et al. (2008) developed a model introducing ecophysiological constraint functions (f-functions, unitless multipliers, (0–1) based on atmospheric moisture (VPD and RH) and vegetation indices (normalized and soil adjusted vegetation indices -NDVI and SAVI).

The driving equations in their model are:

$$LE = LE_s + LE_c + LE_i$$

$$LE_c = (1 - f_{wet}) f_g f_T f_M \alpha \frac{\Delta}{\Delta + \gamma} R_{nc}$$

$$LE_s = (f_{wet} + f_{SM}(1 - f_{wet})) \alpha \frac{\Delta}{\Delta + \gamma} (R_{ns} - G)$$

$$LE_i = f_{wet} \alpha \frac{\Delta}{\Delta + \gamma} R_{nc}$$

Assumptions

- None of the models incorporate soil moisture
- Ignored evaporation from blowing snow
- No transpiration over snow covered regions
- Canopy interception losses of precipitation

Datasets

- LST/Emissivity (T1) – AIRS/MODIS
- Albedo (T2) – MODIS (averaged BSA and WSA)
- Radiation (T1)

$$R_{net} = (1-\alpha_{MODIS}) \cdot SW_{\downarrow CERES} + LW_{\downarrow CERES} - \left(\varepsilon_{MODIS} \cdot \sigma \cdot LST^4_{AIRS}\right)$$

- Surface meteorology (T1) - AIRS
- Surface/vegetation characteristics (T2) - MODIS
- Other – MODIS snow cover product, Surface Radiation Budget dataset (for converting instantaneous to daily values, etc)

Type 1 – subdiurnal variation

Type 2 – no subdiurnal variation

Methodology

- Data are used with the three process models to estimate the instantaneous latent heat fluxes
- All models: LH flux for snow covered regions are estimated using the Penman equation. If the surface temperature is below freezing, assumed that there is no evaporation
- Instantaneous fluxes are converted to daily values by assuming that evaporative fraction is constant throughout the day $EF = \frac{LH}{A}$

Methodology - continued

- The daily ET is then extrapolated using:

$$ET_{daily} = \lambda \cdot n \cdot EF_{inst} \left(R_{net} - G\right)_{daytime}$$

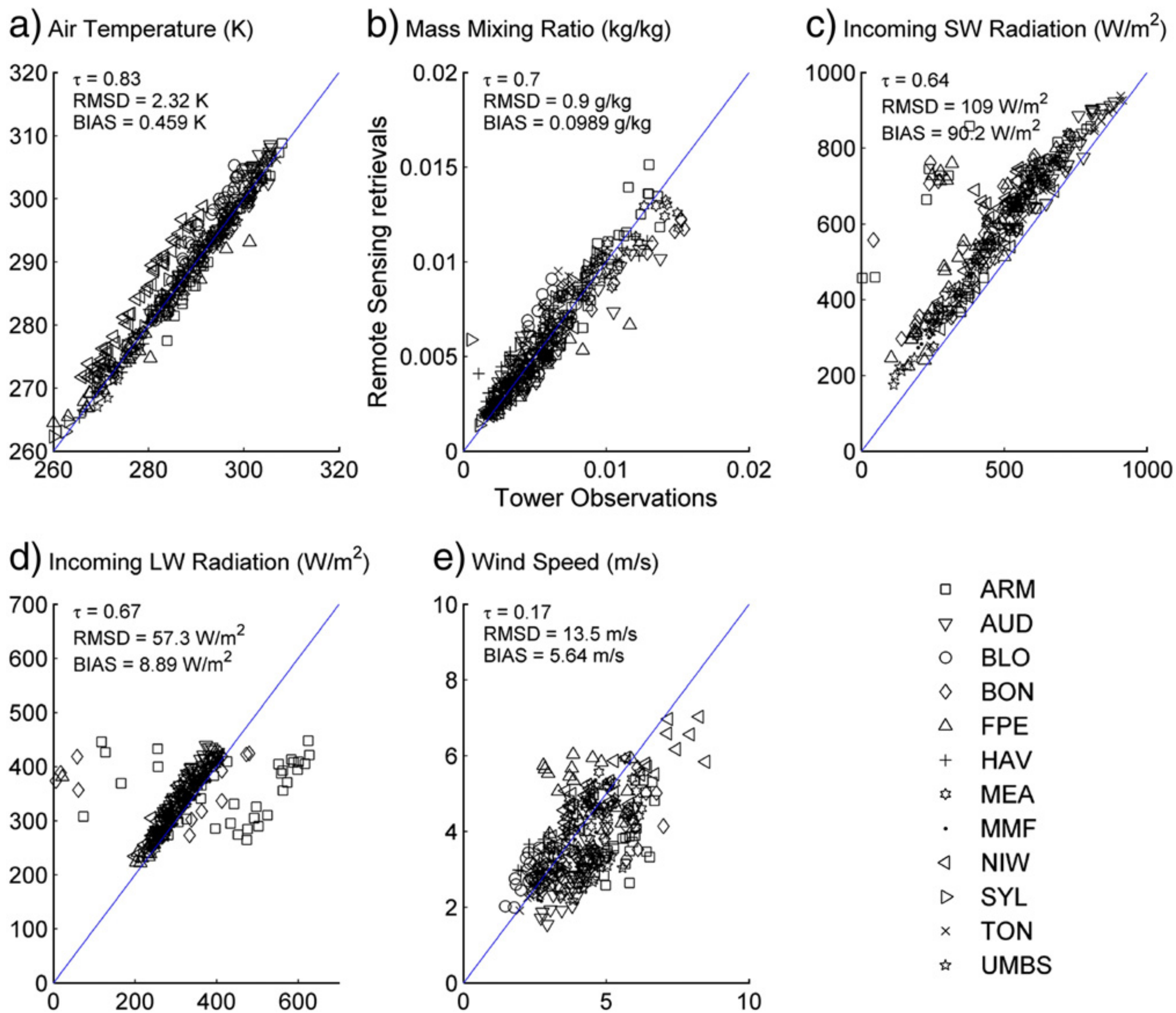
λ = latent heat of evaporation;

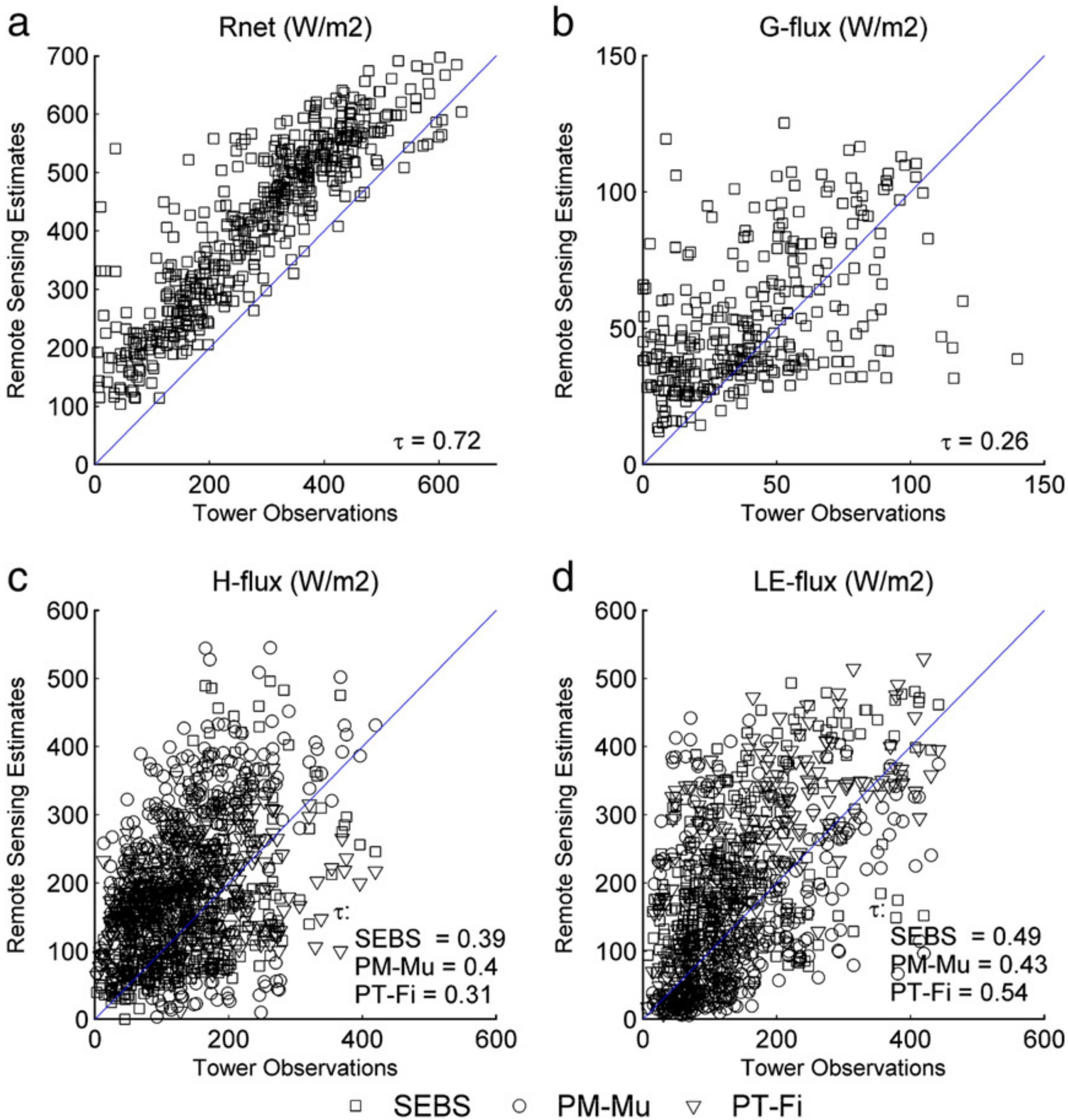
n = 1.10 – factor to include nighttime evaporation

- Interception losses are added to the ET estimate , and daily sensible heat flux is calculated from energy balance equation

$$H_{daily} = R_{net-daily} - G_{daily} - \lambda ET_{daily}$$

Algorithm and data evaluation: Scatter plots of tower data vs. satellite data (monthly mean)





Monthly mean remote sensing estimates :

(a) net radiation (Rnet);
(b) soil heat flux (G-flux);
(c) sensible heat flux (H-flux); and
(d) latent heat flux (LE-flux), as compared

with ground observations from flux towers for years 2003–2006

Possible causes of discrepancy

1. Fluxes from remote sensing are instantaneous retrievals, while flux tower data are averaged over 1-hour period

2. Difference in spatial scales between the satellite footprints and the tower footprint + heterogeneity of the surface

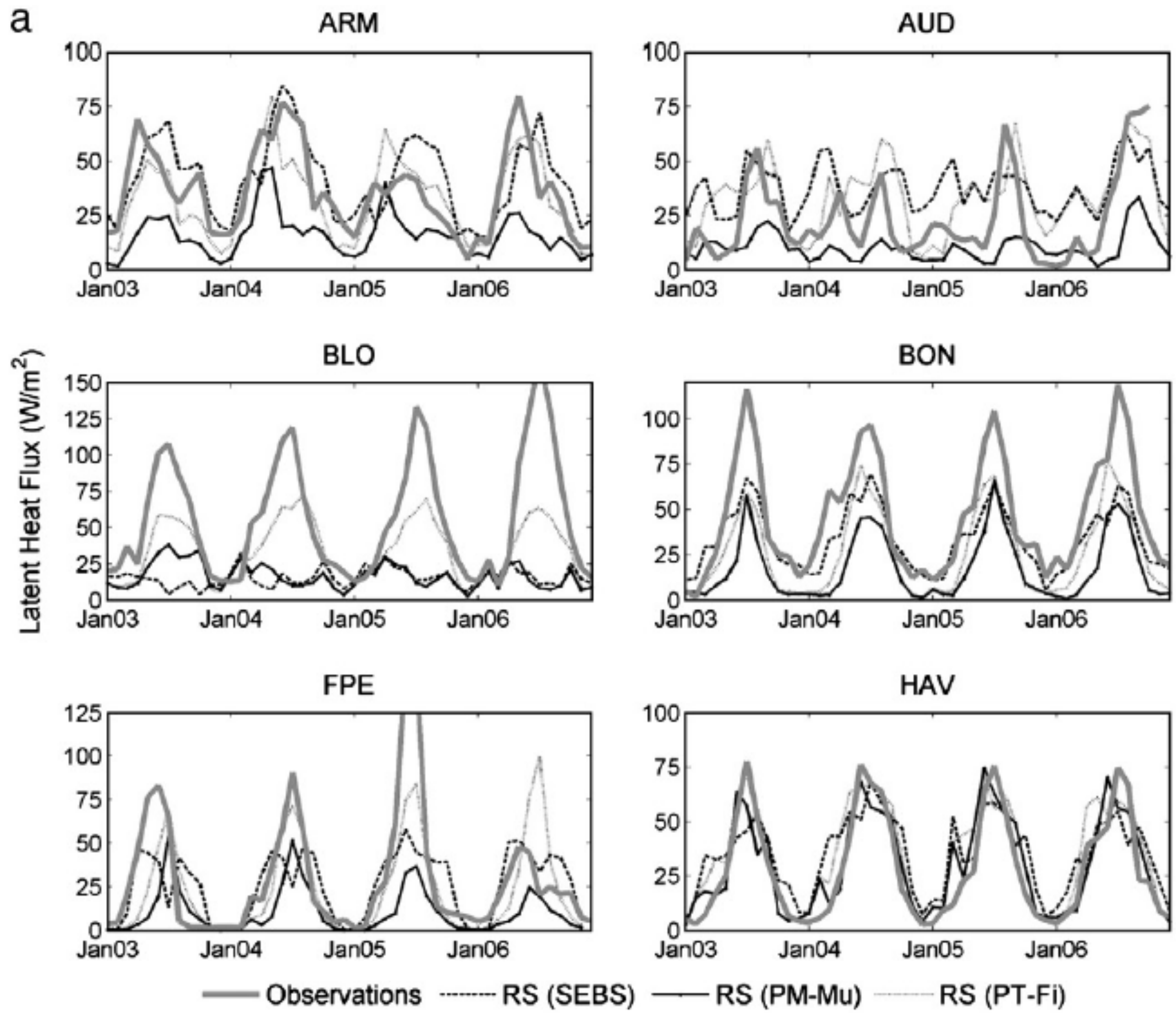
3. Lack of energy balance closure for tower data

Energy Balance Closure

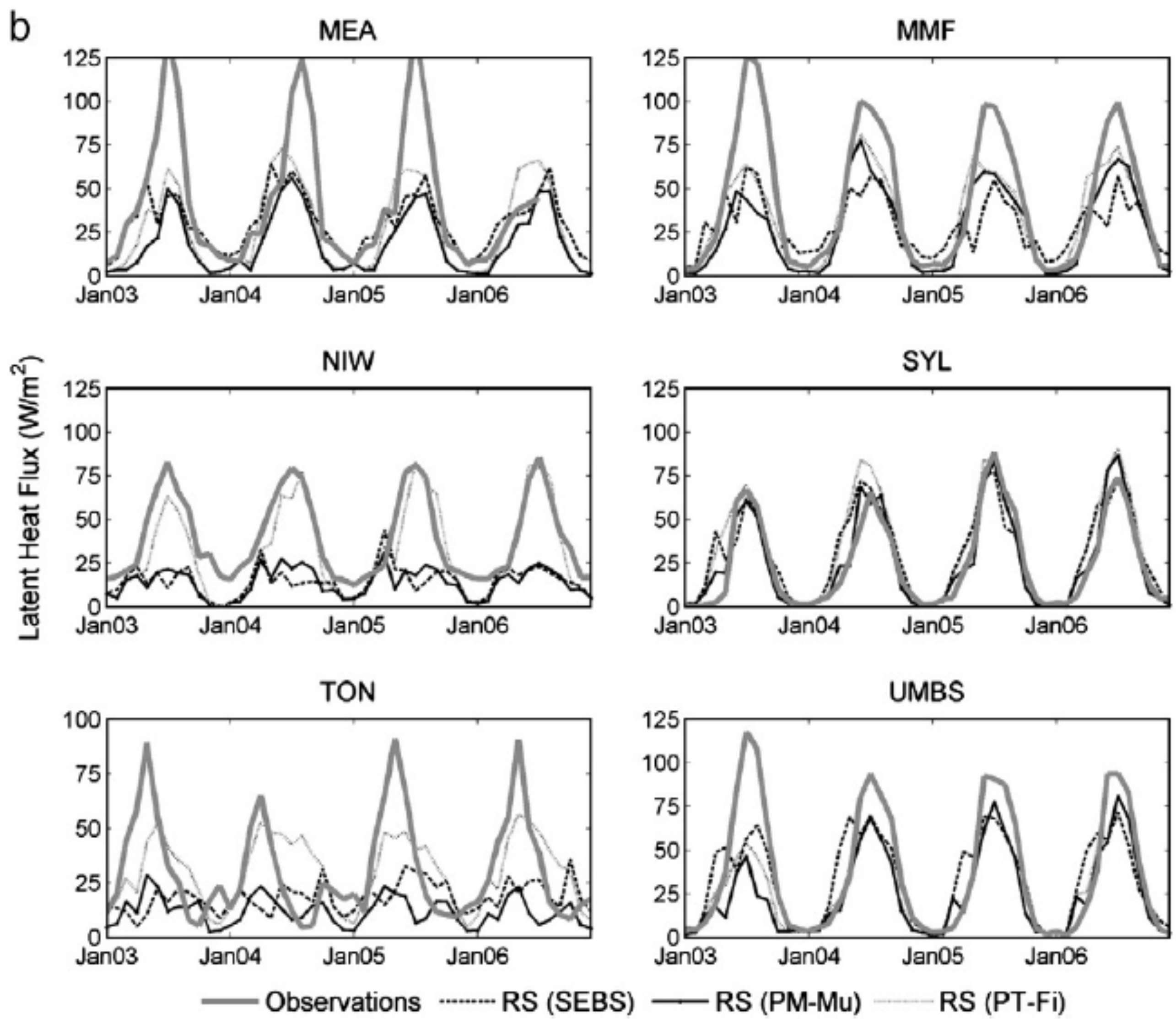
Yearly $\dfrac{SH + LE}{R_{NET} - G}$

Tower	Elev. (m)	Lat	Lon	Closure
ARM SGP – Main (ARM)	314	36.61	−97.49	0.68
Audubon (AUD)	1469	31.59	−110.51	0.70
Blodgett Forest (BLO)	1315	38.90	−120.63	0.55
Bondville (BON)	219	40.01	−88.29	0.56
Fort Peck (FPE)	634	48.31	−105.10	0.64
Harvard (HAV)	340	42.54	−72.17	NA
Mead – Rainfed (MEA)	363	41.18	−96.44	0.85
Morgan Monroe (MMF)	275	39.32	−86.41	0.24
Niwot Ridge (NIW)	3050	40.03	−105.55	0.80
Sylvania Wilderness (SYL)	540	46.24	−89.35	0.65
Tonzi (TON)	177	38.43	−120.97	0.42
UMBS (UMBS)	234	45.56	−84.71	NA

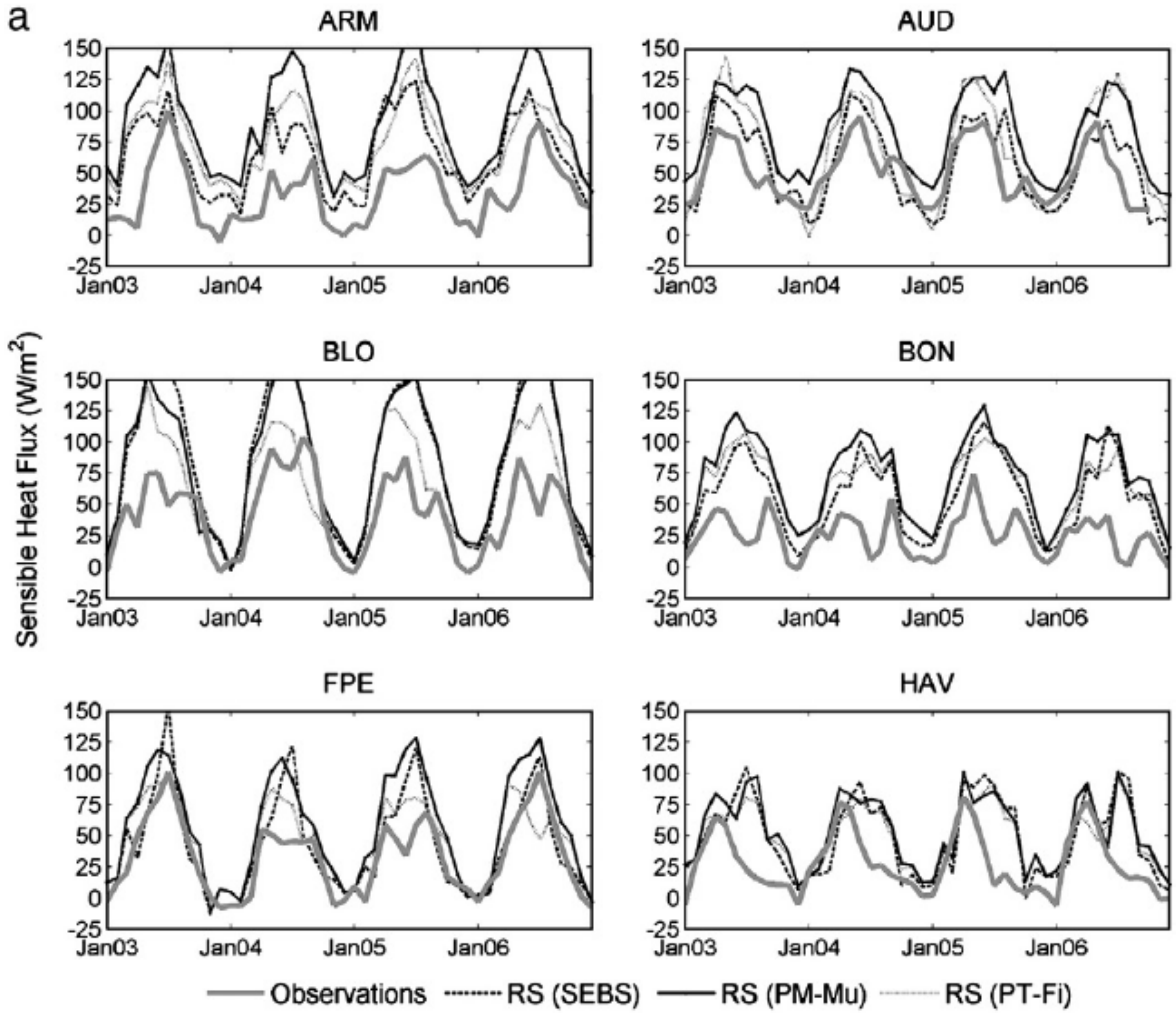
Results – comparison against tower data: Latent heat flux



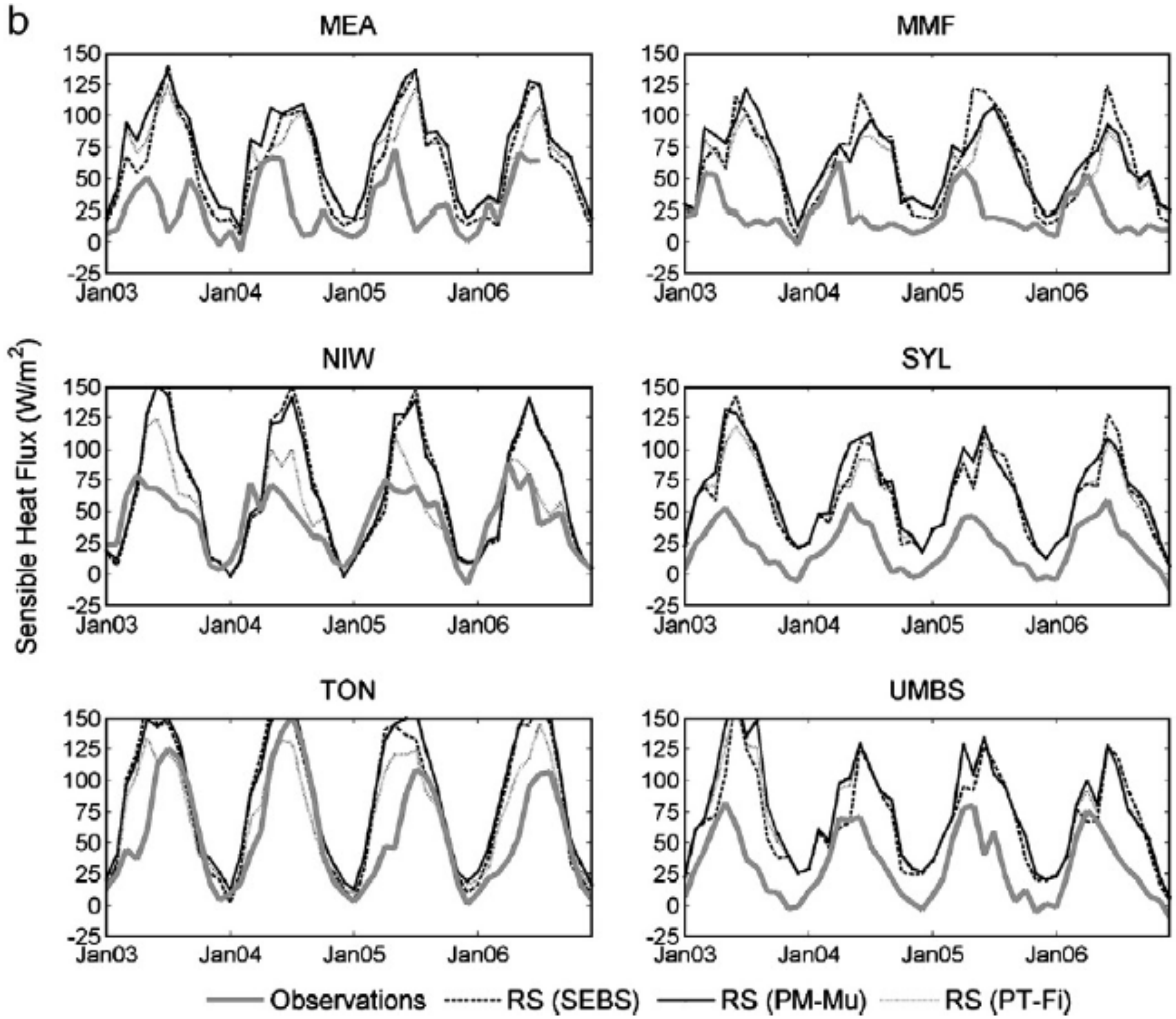
Latent heat flux - continued



Comparison against tower data: Sensible heat flux

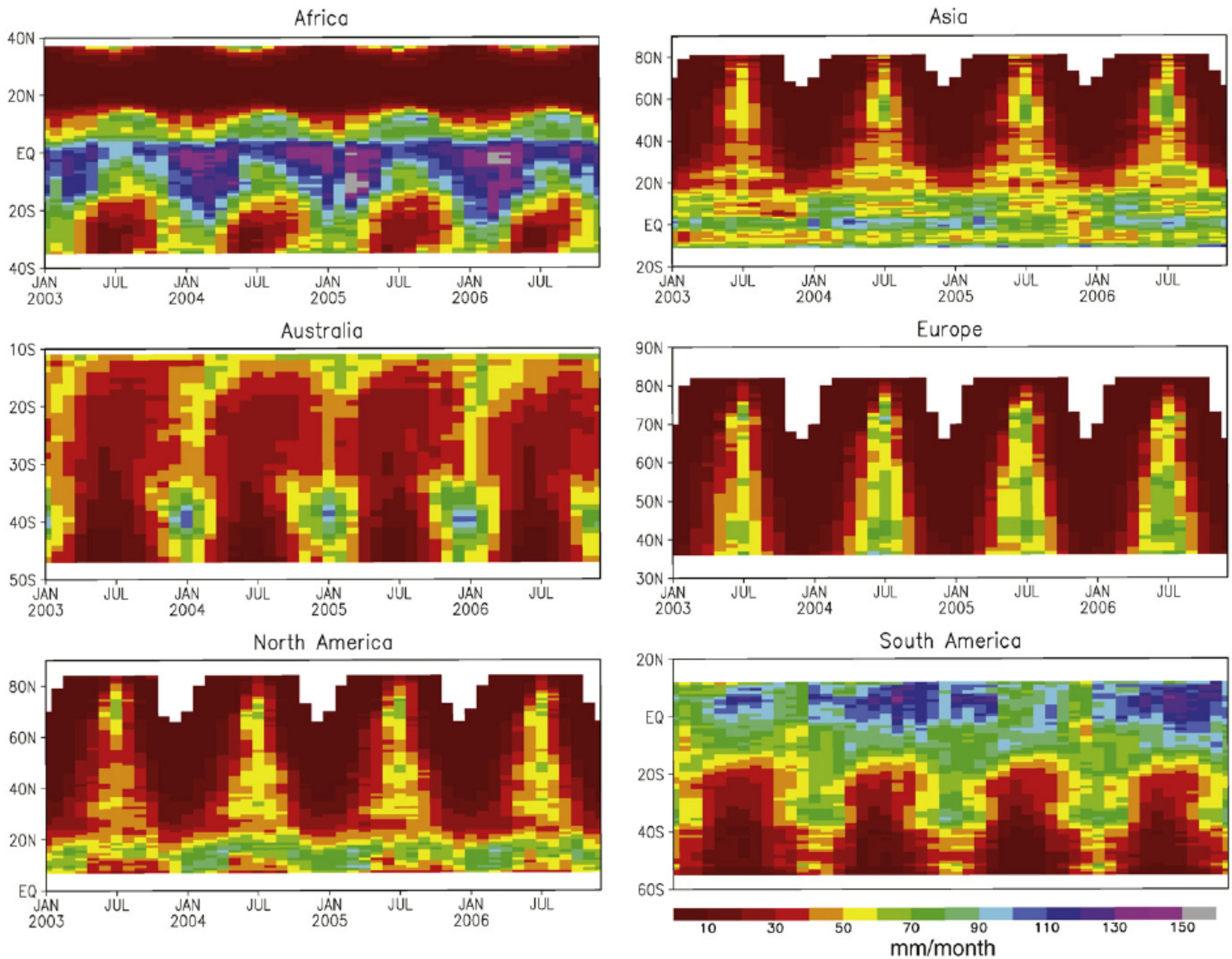


Sensible heat flux - continued

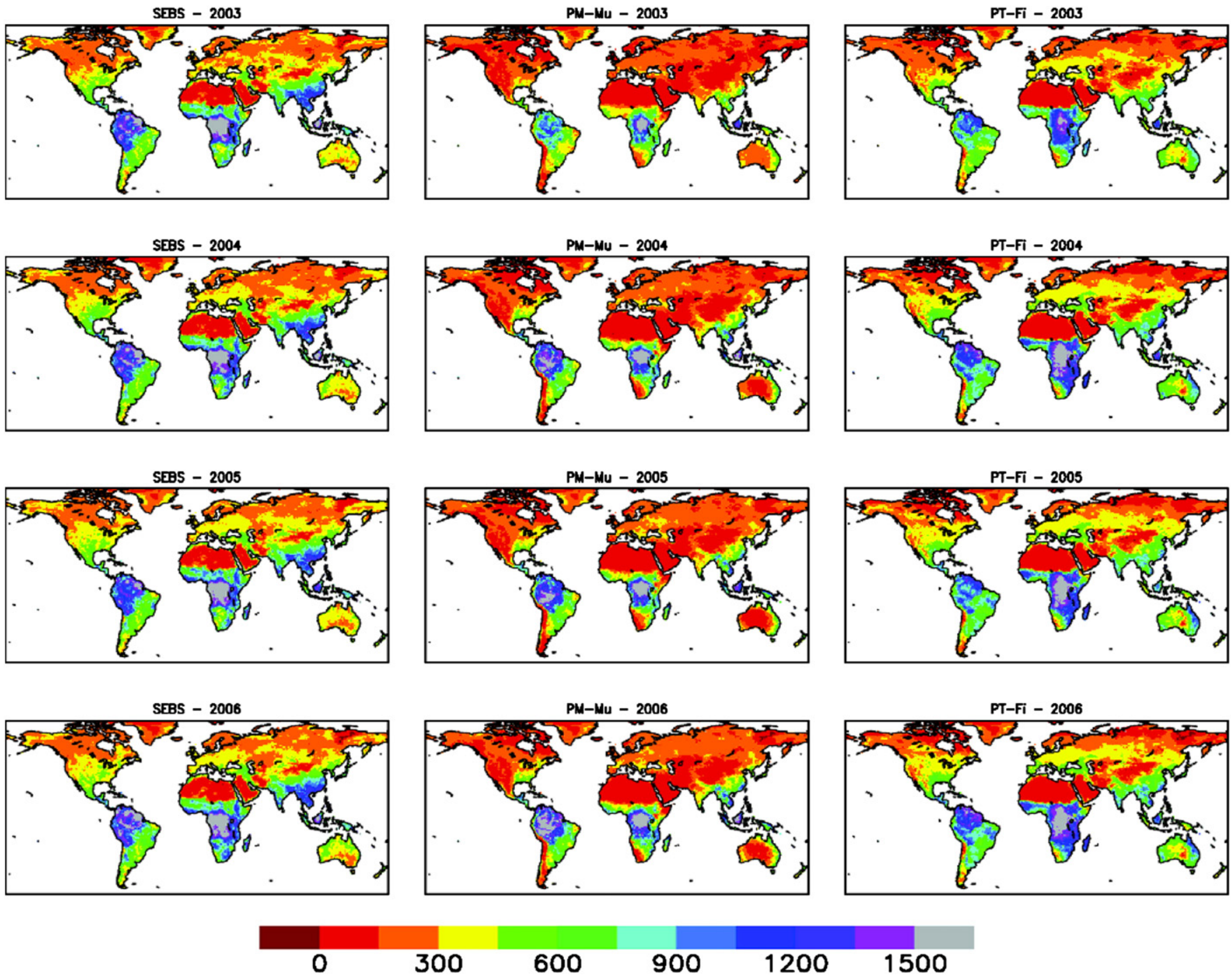


Continental/global scale

- Results presented in a zonal monthly Hovmöller diagram of the mean (of the 3 models used) evapotranspiration (mm/month) for the 6 continents.


Africa
40N
20N
EQ
20S
40S
JAN 2003
JUL
JAN 2004
JUL
JAN 2005
JUL
JAN 2006
JUL
Asia
80N
60N
40N
20N
EQ
20S
Australia
10S
20S
30S
40S
50S
Europe
90N
80N
70N
60N
50N
40N
30N
North America
South America
60S
10
30
50
70
90
110
130
150
mm/month

Global annual ET for years 2003 through 2006


SEBS - 2003
PM-Mu - 2003
PT-Fi - 2003
SEBS - 2004
PM-Mu - 2004
PT-Fi - 2004
SEBS - 2005
PM-Mu - 2005
PT-Fi - 2005
SEBS - 2006
PM-Mu - 2006
PT-Fi - 2006
0
300
600
900
1200
1500

Conclusions

Small scale comparison

- Correlations of 0.43-0.54 in the instantaneous LE fluxes between remote sensing and tower fluxes
- Correlations of 0.51-0.65 in monthly ET, RMSD: 20-27 W/m^2

Regional / global scale comparison

- Basin sale comparison – RS ET estimates vs. evaporation from climatological precipitation and basin discharge - agree well
- Global scale – compared to VIC surface model and ERA interim reanalysis data – had higher Kendall's T coefficient and lower bias
- PM-Mu algorithm provides a lower estimate of ET compared to SEBS and PT-Fi. (Examples: central Asia, Australia, Europe, Western US)