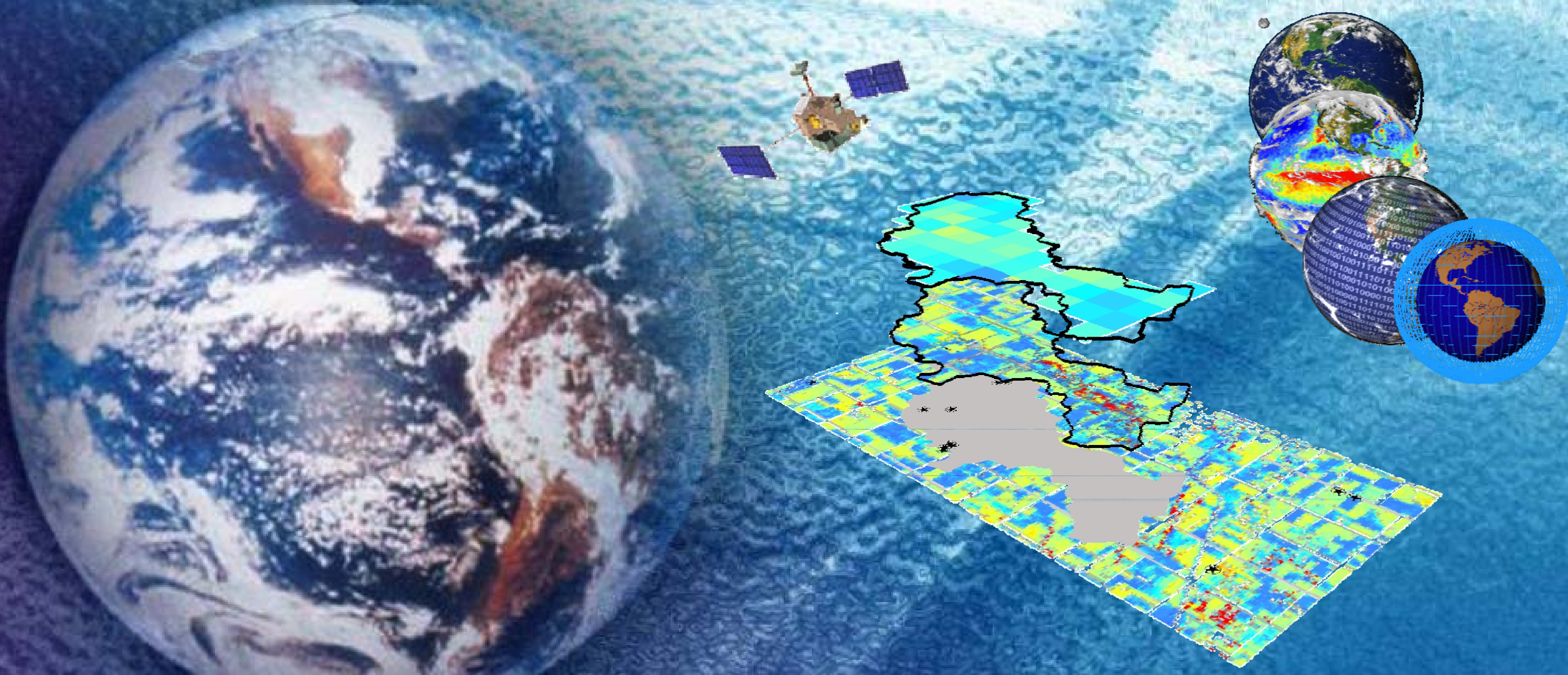

Globally distributed evapotranspiration using remote sensing and CEOP data

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Introduction

The Need:

Evapotranspiration (ET) provides the link between the energy and water budgets at the land surface, and is a critical variable for GEWEX and CEOP. Remote sensing is the only feasible method for estimating ET over large regions, but developing a globally robust algorithm is a significant challenge.

The Work:

The purpose of this analysis is to evaluate the potential of various approaches over different climatic conditions and land cover classifications; and

To evaluate the potential for using operational products in achieving routine prediction of evapotranspiration.

The Relevance to GEWEX/CEOP

A Goal of GEWEX:

"Determine the hydrological cycle and energy fluxes by means of global measurements of atmospheric and surface properties."

A Goal of CEOP:

"Use a new generation of remote sensing satellites…(for)… comprehensive and quantitative monitoring of the energy and water cycle from local to global scales."

NASA MOD-16 Evapotranspiration

- Princeton University funded to research a MODIS based ET product (July, 2004)
- Initial algorithm is based primarily on the SEBS[1] model, although other approaches are being explored – (can one model work in all environments/all conditions?)
- The goal is a global product – but locally validated – hence the need for thorough evaluation – CEOP sites!!!
- Princeton needs to partner with other groups to investigate the best approach/es of utilizing satellite (e.g. MODIS through model intercomparisons, field experiments etc…

[1] Su, B. (2002). The surface energy balance system (SEBS) for the estimation of turbulent heat fluxes. Hydrol. Earth Sys. Sci. 6(1): 85-99

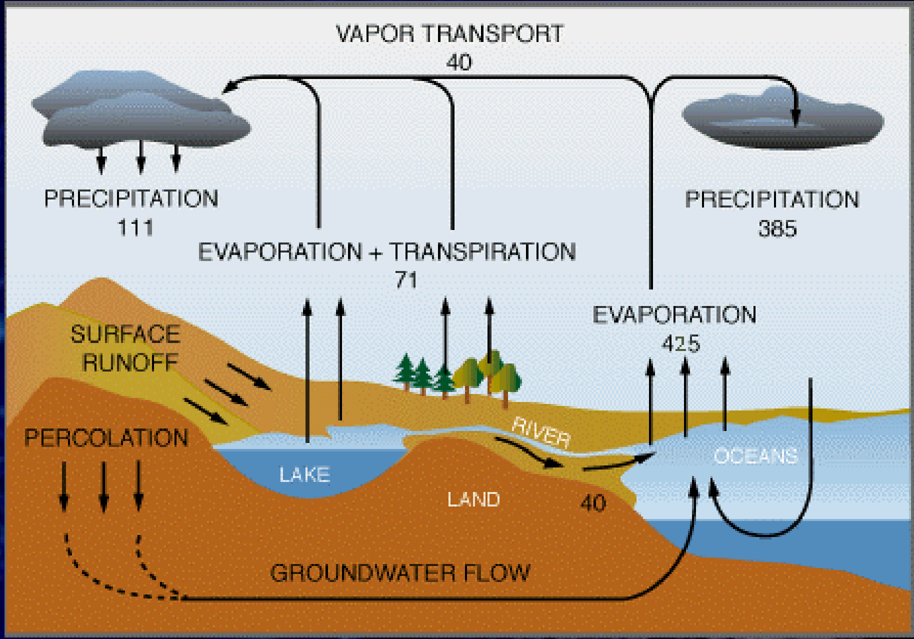
Modeling Evapotranspiration

Use the Surface Energy Balance Model (SEBS) to determine daily/pentad/monthly ET predictions.

- Combining available land surface information, meteorological, surface temperature, vegetation, radiation data

- Make use of available MODIS products – supplemented with other sources of data

- Undertake comparisons with other approaches over varied environments…



SEBS Model Description

SEBS calculates H using similarity theory

$$u = \frac{u_*}{k}\left[\ln\left(\frac{z-d_0}{z_{0m}}\right) - \Psi_m\left(\frac{z-d_0}{L}\right) + \Psi_m\left(\frac{z_{0m}}{L}\right)\right]$$

$$L = -\frac{\rho C_p u_*^3 \theta_v}{kgH}$$

$$H = k u_* \rho C_p (\theta_0 - \theta_a)\left[\ln\left(\frac{z-d_0}{z_{0h}}\right) - \Psi_h\left(\frac{z-d_0}{L}\right) + \Psi_h\left(\frac{z_{0h}}{L}\right)\right]^{-1}$$

Wind, air temperature, humidity
(aerodynamic roughness,
thermal dynamic roughness)

Various sub-modules for calculating needed components…

SEBS basic equations/structure

(Su, 2002, HESS, 6(1),85-99)

Energy Balance: $$R_n = G_0 + H + \lambda E$$

Estimated using incoming $\boldsymbol{R_s}$, downward $\boldsymbol{R_l}$ and surface temperature.

Parameterized using fractional vegetation

SEBS basic equations/structure

(Su, 2002, HESS, 6(1),85-99)

Energy Balance: $$R_n = G_0 + H + \lambda E$$

$$\lambda E_{dry} = R_n - G_0 - H_{dry} \equiv 0, \quad or$$
$$H_{dry} = R_n - G_0$$

$$\lambda E_{wet} = R_n - G_0 - H_{wet},$$
$$H_{wet} = \left(\left(R_n - G_0\right) - \frac{\rho C p}{r_{ew}} \bullet \frac{e_s - e}{\gamma} \right) \Big/ \left(1 + \frac{\Delta}{\gamma} \right)$$

Limiting cases:

Dry: latent heat → 0 due to soil moisture limitations

Wet: latent heat → potential rate

SEBS basic equations/structure

(Su, 2002, HESS, 6(1),85-99)

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$$H_{wet} = \left((R_n - G_0) - \frac{\rho C p}{r_{ew}} \bullet \frac{e_s - e}{\gamma} \right) \Big/ \left(1 + \frac{\Delta}{\gamma} \right)$$

Define relative evaporation Λ_r

$$\Lambda_r = \frac{\lambda E}{\lambda E_{wet}} = 1 - \frac{\lambda E_{wet} - \lambda E}{\lambda E_{wet}} = 1 - \frac{H - H_{wet}}{H_{dry} - H_{wet}}$$

SEBS basic equations/structure

(Su, 2002, HESS, 6(1),85-99)

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Define evaporative fraction Λ_r

$$\Lambda = \frac{\lambda E}{R_n - G} = \frac{\Lambda_r \cdot \lambda E_{wet}}{R_n - G}$$

Estimation of Daily Evapotranspiration

Knowing H, solve for Λ_r

$$\Lambda_r = 1 - \frac{H - H_{wet}}{H_{dry} - H_{wet}}$$

Knowing Λ_r , solve for Λ

$$\Lambda = \frac{\lambda E}{R_n - G} = \frac{\Lambda_r \cdot \lambda E_{wet}}{R_n - G}$$

Re-write H and λE

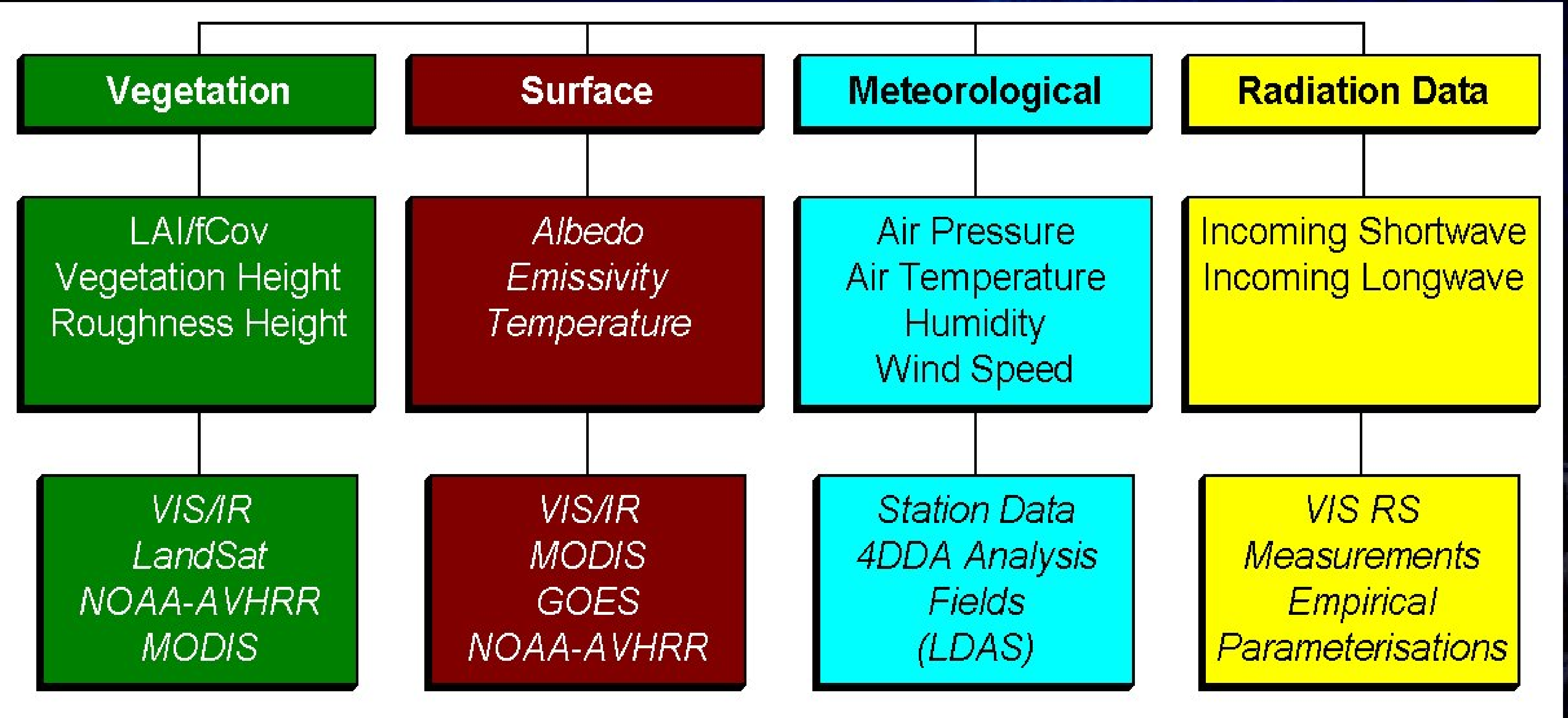
$$H = (1 - \Lambda) \cdot (R_n - G)$$
$$\lambda E = \Lambda \cdot (R_n - G)$$

Estimate daily E using N measurements

$$E_{daily} = 8.64 \times 10^7 \times \overset{N}{\underset{0}{\Lambda}} \times \frac{\overline{R_n} - \overline{G_0}}{\lambda \rho_W}$$

SEBS Model Description

- CEOP observations used to assess estimates of evapotranspiration determined using different approaches.
- Forcing data from validation tower sites supplemented with MODIS data to produce estimates of surface fluxes.



Evaluating SEBS Model Results

Predictions are only as good as the evaluation data!!!

- Issues of measurement accuracy, frequency, type…
- Intensive field experiments offer excellent detail, but are temporally limited
- Continuous measurements are usually spatially sparse…

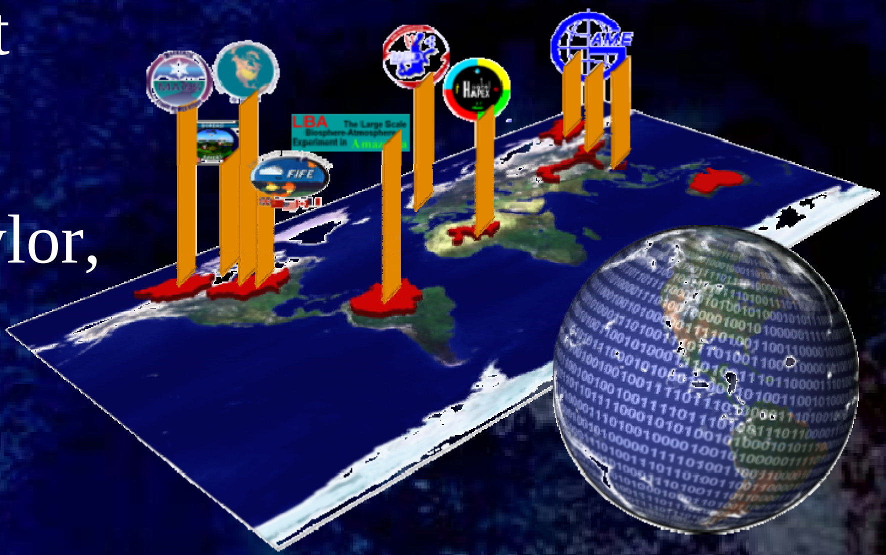
What is the best/most efficient combination of these.

Global product – but locally validated

Global Evaluation - CEOP Data

Coordinated Enhanced Observation Period provides globally distributed data sets from which estimates of ET can be produced. Located over a variety of landscapes and hydro-climatologies they offer:

- Data to assess global scale application
- Allow comparison of different model output
- SEBS, modified Priestley-Taylor, modified Penman-Monteith[#] and GLDAS model output

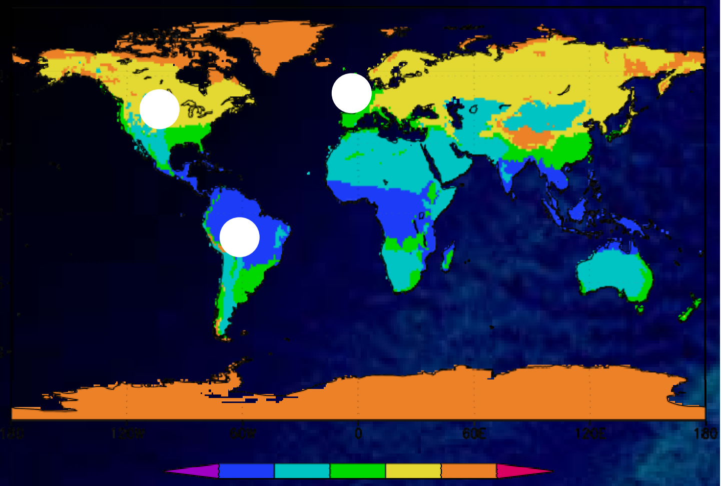


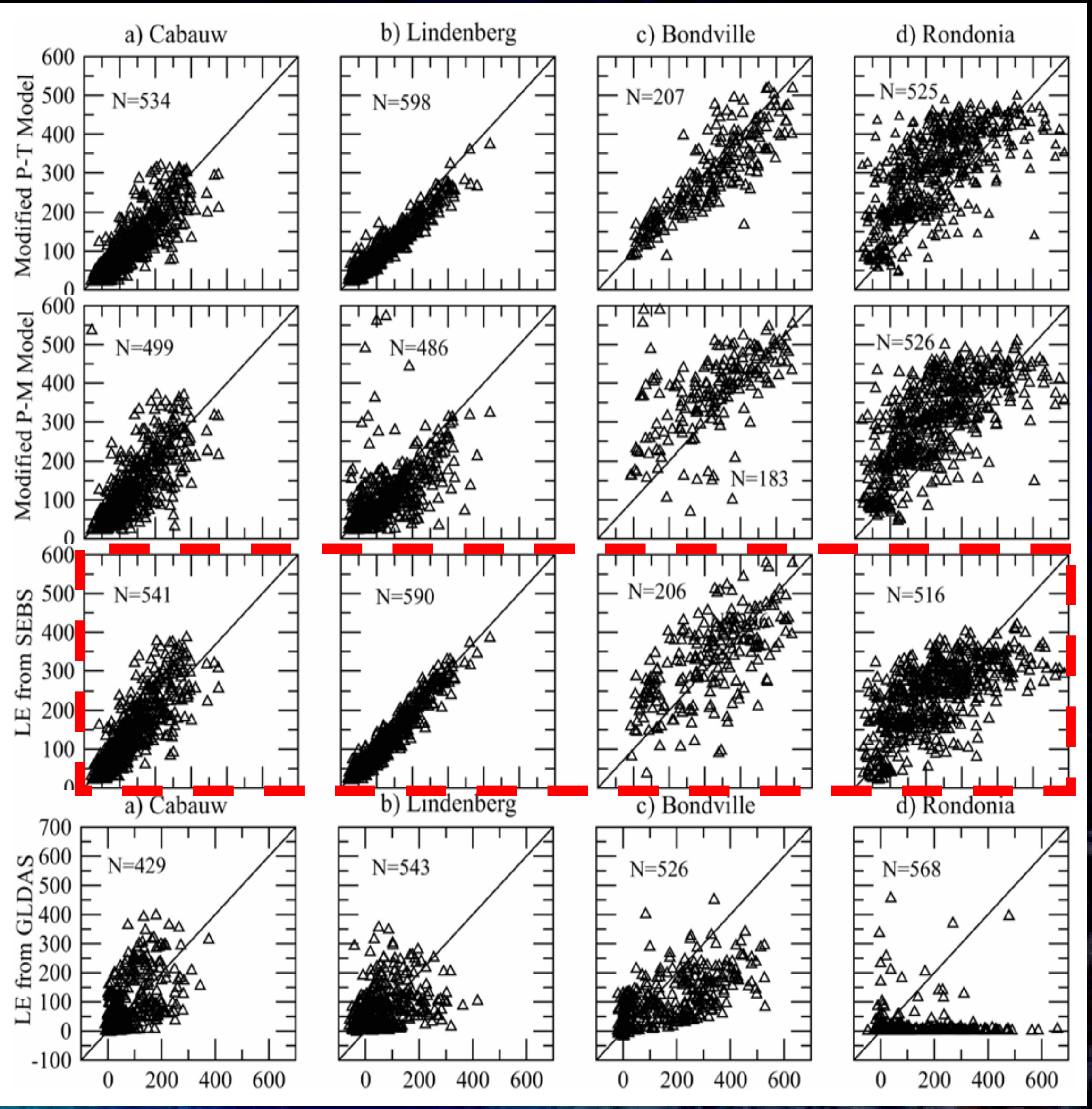
[#] Boegh, E. et al. (2002). Evaluating evapotranspiration rates and surface conditions using Landsat TM to estimate atmospheric and surface resistance. Remote Sensing of Environment, 79(2-3): 329-343.

ET Predictions with CEOP Tower Data

Time series of GLDAS
~ 0.25º 3-hrly time step

4 sites at global locations:
Netherlands, Germany,
USA, Brazil



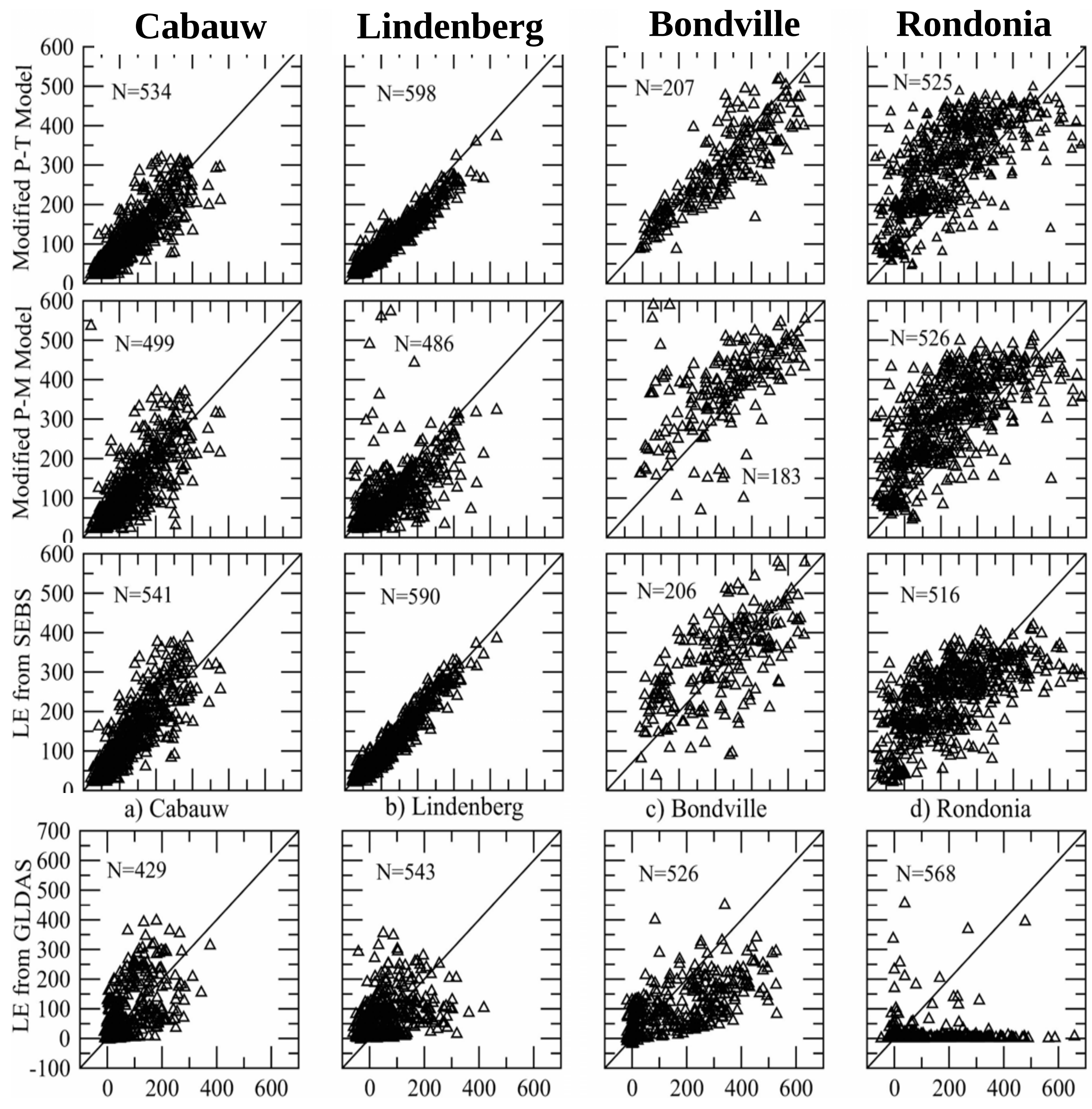


Priestley-Taylor

Penman-Monteith

SEBS based

GLDAS – Model Output



ET Predictions with CEOP Data

Bias	SEBS	Mod-PT	Mod-PM	GLDAS
Cabauw	4.75	-17.67	-10.09	8.23
Lindenberg	-9.27	-19.84	-24.11	16.77
Bondville	14.2	-21.56	52.28	-38.13
Rondonia	8.43	71.8	74.66	-65.23

RMS	SEBS	Mod-PT	Mod-PM	GLDAS
Cabauw	47.45	45.16	58.49	76.62
Lindenberg	21.78	29.93	71.93	79.8
Bondville	96.95	63.32	115.53	107.37
Rondonia	93.81	118.69	118.96	142.21

SEBS with "Operational" Data

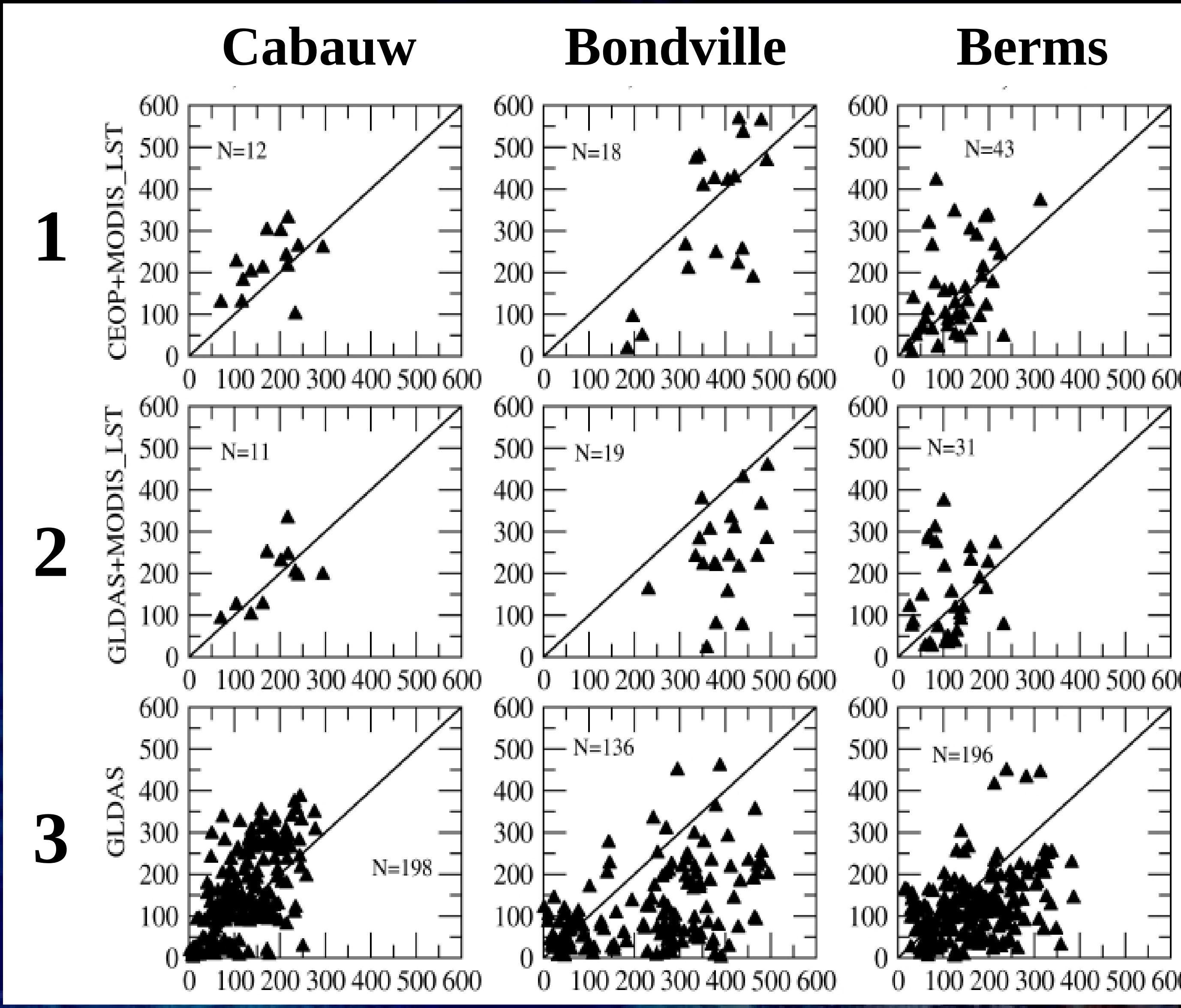
Run SEBS for the EOP-1 with:

1.CEOP data + MODIS

2.GLDAS + MODIS

3.GLDAS model output

Results are limited by lack of coincident sensor/observation data



SEBS with Operational Data

Mean ET	W/m²	Cabauw	Bondville	Berms
CEOP/MODIS	*CEOP*	210.37	362.62	128.15
	SEBS	273.62	318.19	152.52
GLDAS/MODIS	*CEOP*	186.56	395.45	113.57
	SEBS	189.59	239.78	145.17
GLDAS	*CEOP*	122.76	229.96	167.13
	GLDAS	156.53	114.95	117.91

- Mean values approximate reasonably well (within 20%), but instantaneous data are somewhat variable
- Bondville (corn) indicates particular difficulty – issues of representative flux measurement, site characteristics, capturing vegetation dynamics with RS data
- Berms – considering it is forested – illustrates pleasing results

Scale Issues in ET Modeling

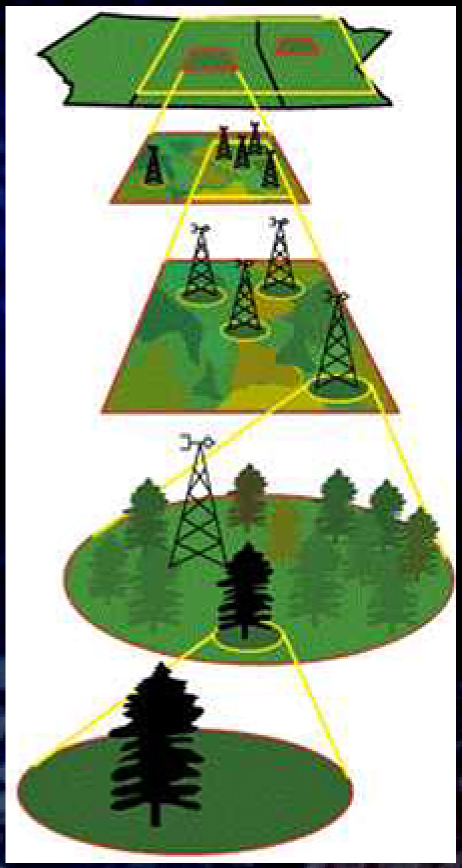
How does our ability to predict ET relate to the scale of the observations??

What is the role of surface heterogeneity?

How do different model forcings scale
– surface temp, vegetation, meteorology?

Is there a relationship with other hydrological variables – or do the time scales of the process reduce their influence?

How do you get information *between* satellite overpasses



Summary and Conclusions

1. The potential of remotely sensing ET using SEB-like approaches (micro-meteorological approaches) depends on having accurate input data: radiation, surface meteorology, and surface characterization.

2. Surface heterogeneity, especially over cropped regions, pose particular problems. There is little experience over forested regions, especially mixed forests as in Rondonia. Really an issue of SCALE.

3. There is a critical need for data to <u>evaluate</u> the RS-based estimates.

4. The best estimates will come through an assimilation approach merging the above estimates with LSM estimates.

Thank you.

Any question?