Fluxnet-Specnet workshop 2011 Berkeley

Success and Failures with Implementing Biophysical Modeling to Upscale Carbon and Water Fluxes to the Global Scale

Youngryel Ryu
UC Berkeley
Harvard University
Seoul National University

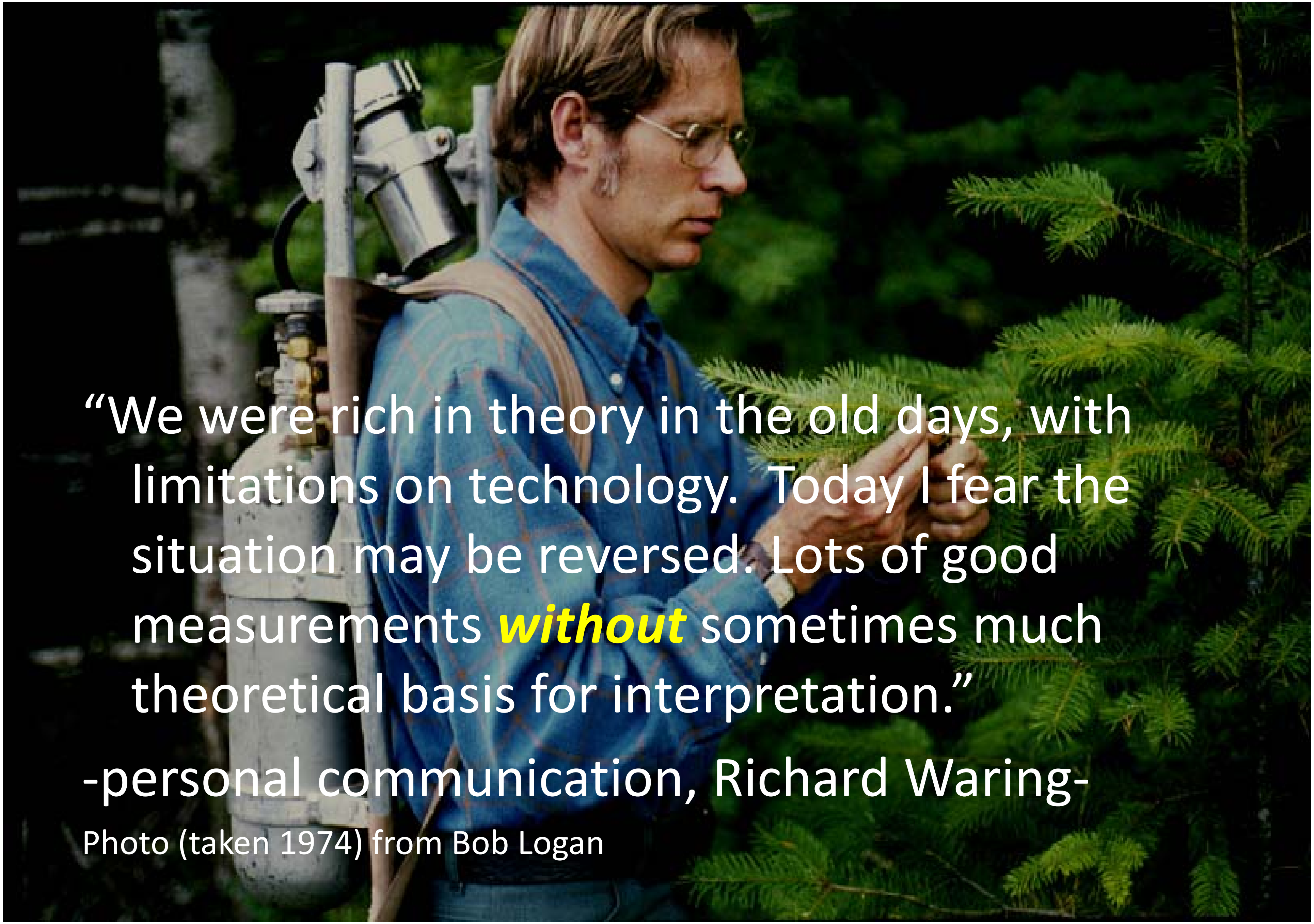

"We were rich in theory in the old days, with limitations on technology. Today I fear the situation may be reversed. Lots of good measurements ***without*** sometimes much theoretical basis for interpretation."
-personal communication, Richard Waring-
Photo (taken 1974) from Bob Logan

Fig. 4. John Norman (right) making "simultaneous" measurements of stomatal conductance and photosynthesis, using a Delta T porometer, and a home-made chamber with syringes.

Welles and Anderson 2009 AFM

Where we are?

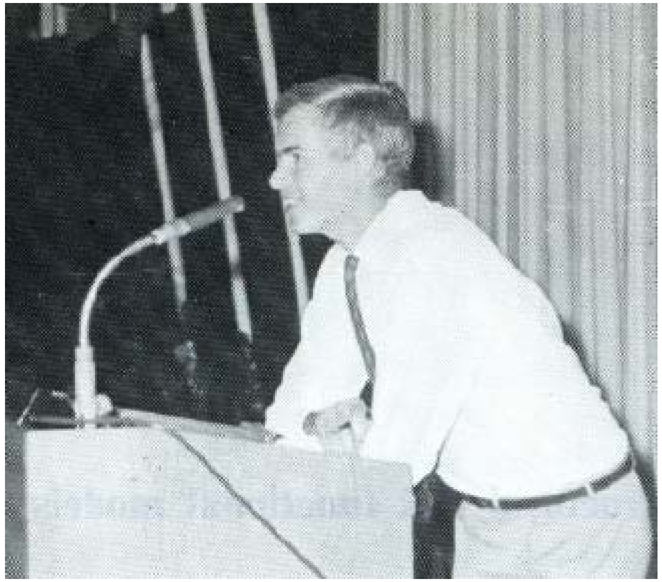
0. HISTORICAL BACKGROUND OF BIOPHYSICAL MODELING

IBP Workshop at Trebon 1969

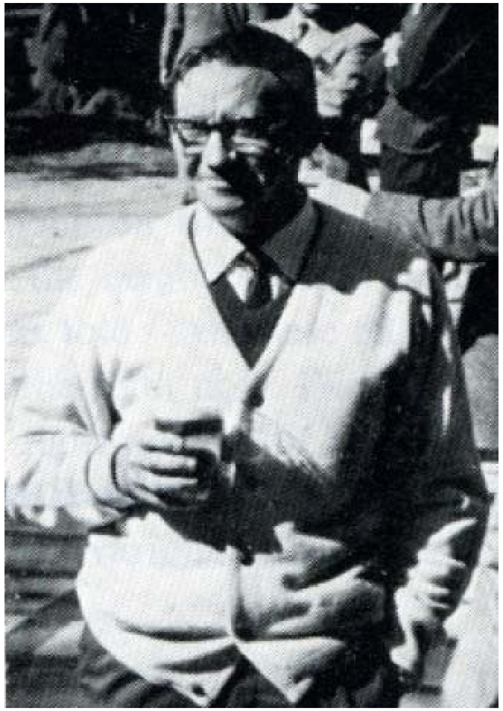
- Before the Cold War
- Scientists across continents joined
- From giants (e.g. Hendrick deWit) to junior faculty (e.g John Monteith, Paul Jarvis, Hal Mooney)

CC Nichiporovichi

CT deWit



John Monteith



OT Denmead

Paul Jarvis

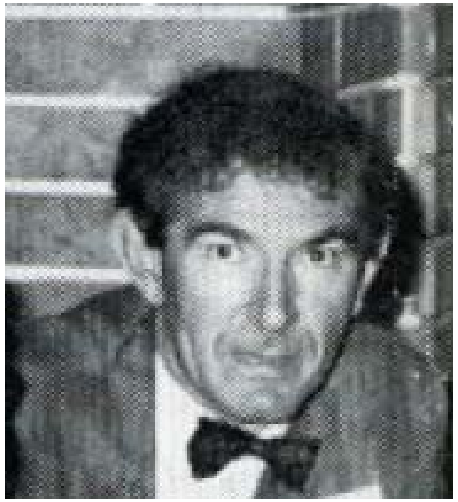
Joe Landsberg

Olle Björkman

Photos: IBP Proceedings, 1969
Identified by Drs Jarvis, Waring, Nilson, Norman, Baldocchi


Margaret Anderson


Z Uchijima


Lloyd Evans
(father of John Evans at CSIRO)


Harold Mooney


Ed Lemon


Masami Monsi
(Monsi and Saeki 1953)

Biophysical model in 1969

deWit CT

“Seven-stage simulation models by means of which eco-systems may be explained on basis of the molecular sciences are *impossible large and detailed and it is naive to pursue their construction*”

IUFRO meeting at Knoxville, 1986

- International Union of Forest Research Organizations (IUFRO)
- Organized by Luxmoore, Landsberg and Kaufmann
- Micrometeorologists and forest ecologists met!
- Biophysical model can be tested at ecosystem scale!

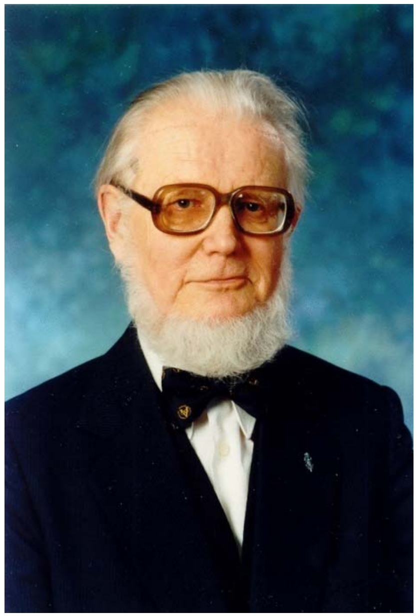
Richard Waring

"Paul Jarvis and I probably commented more than we should have, trying to get the physiologists to make better links to atmospheric science"

-personal email-

Stomata workshop at Penn Sate U, 1989

- Organized by Toby N Carlson
- **<u>Scale up</u>** of trace gas fluxes from stomata to canopy, landscape and region



Juhan Ross (grand father of canopy radiative transfer study)

Biophysical model

IBP workshop, Trebon 1969

↓

IUFRO workshop, Knoxville 1986

↓

Stomata workshop, PennSU 1989

Fluxnet data

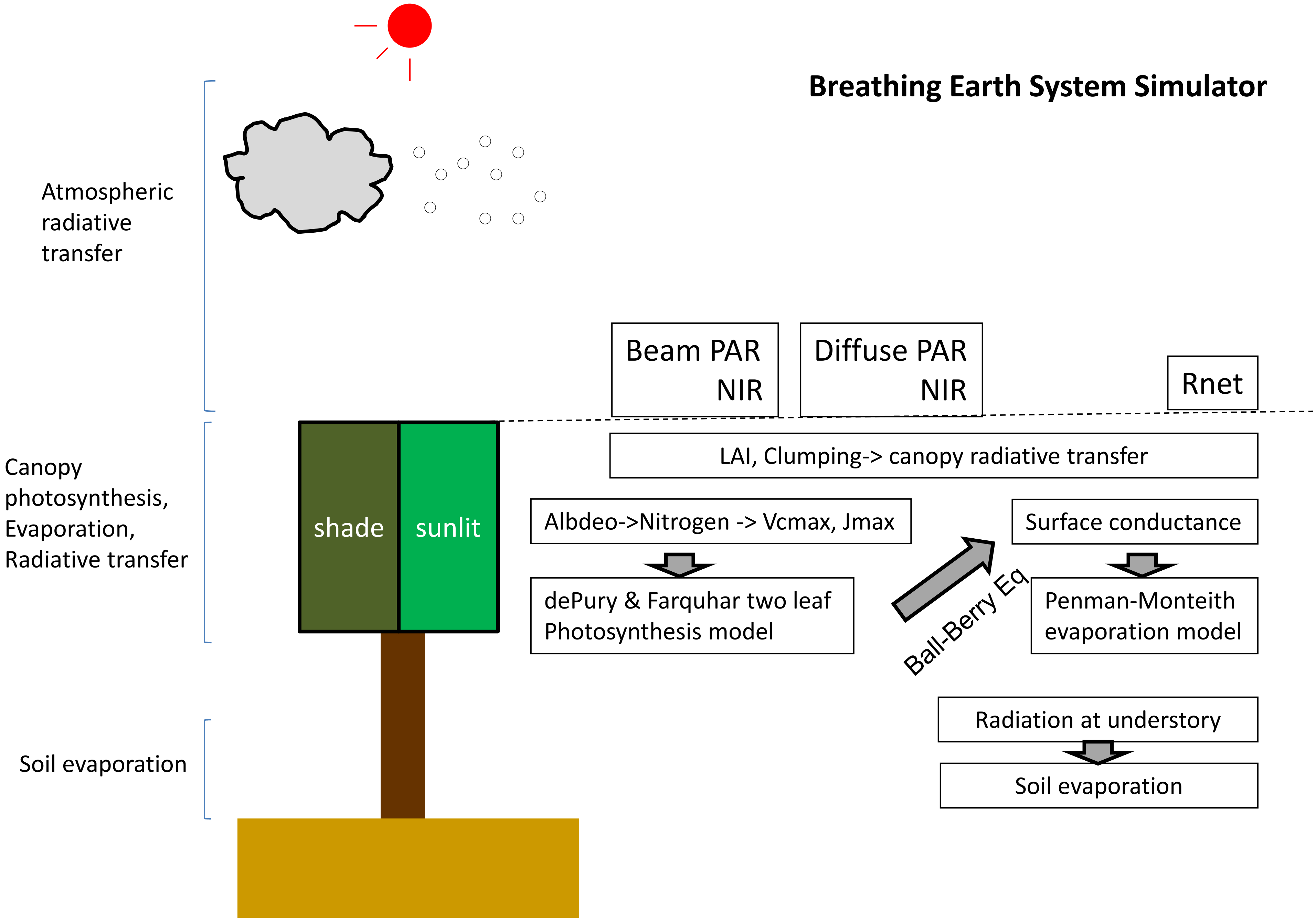
Marconi Fluxnet workshop, 2000

↓

LaThuile Fluxnet workshop, 2007

APPROACH

1. MODEL:
BREATHING EARTH SYSTEM SIMULATOR (BESS)

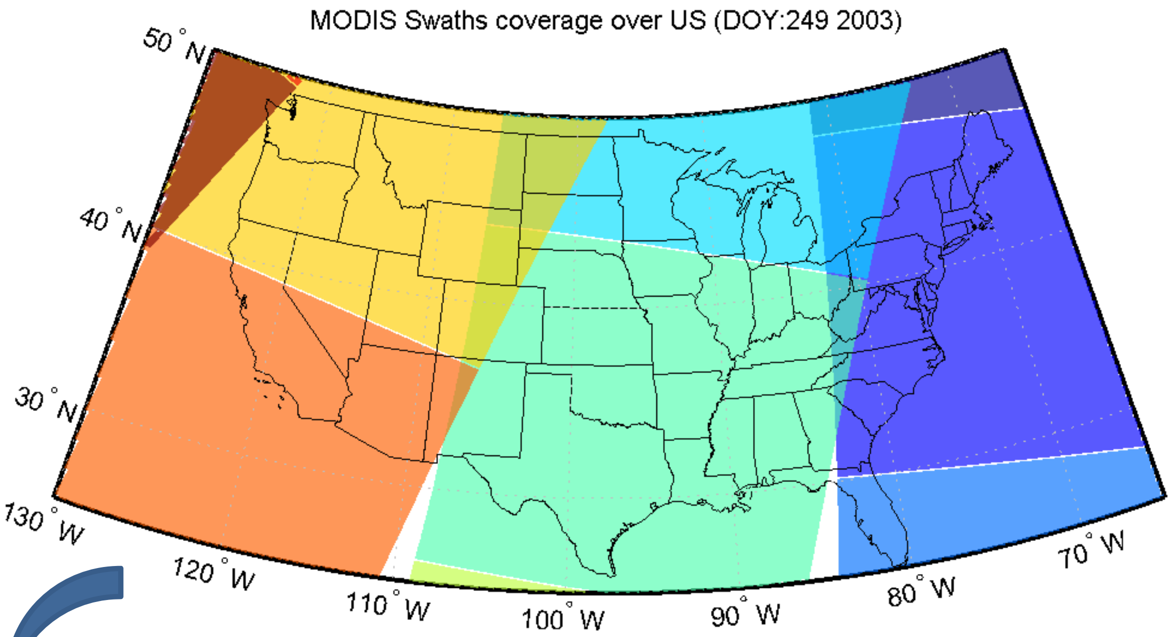


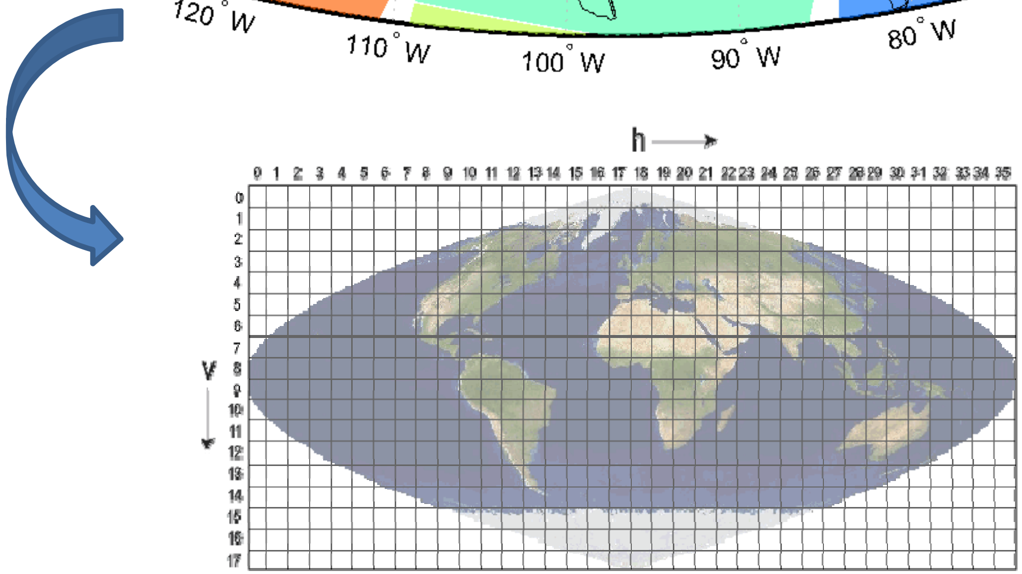
Ryu et al (in review) Global Biogeochemical Cycles

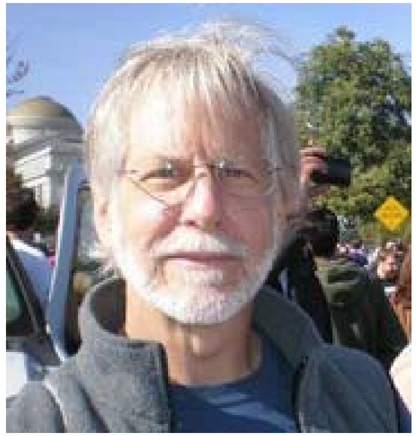
Key point: 1. Atmospheric radiative transfer model at 1 km resolution

- Monte Carlo approach developed by Iwabuchi (2006) and Kobayashi and Iwabuchi (2008)
- Develop LUT
- Forcing data from MODIS atmospheric/land products
- Producing “instantaneous” 1 km radiation fields, for PAR, NIR with beam and diffuse components, under both clear and cloudy skies, at globally.

Gridding L2 MODIS Atmospheric products

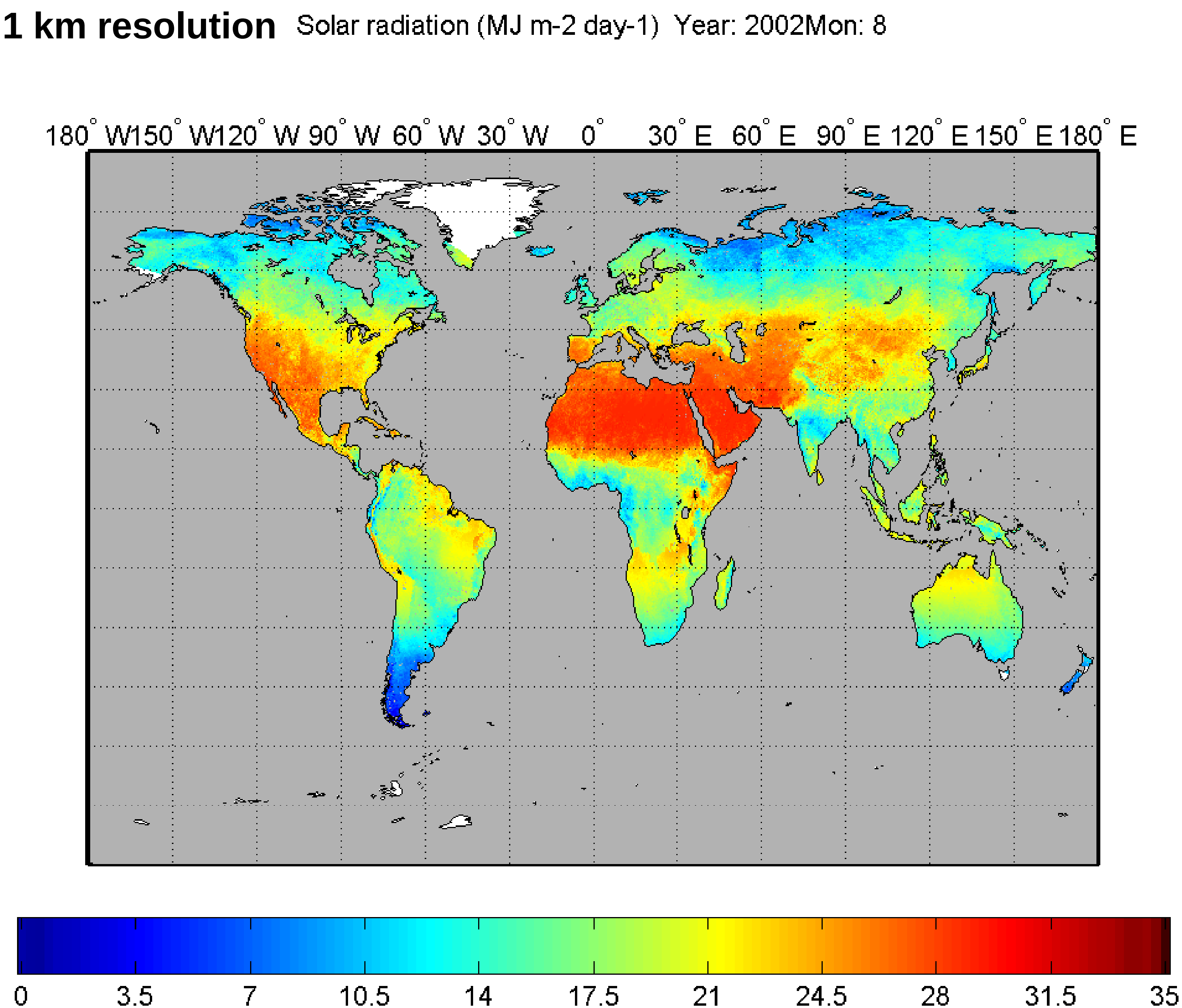






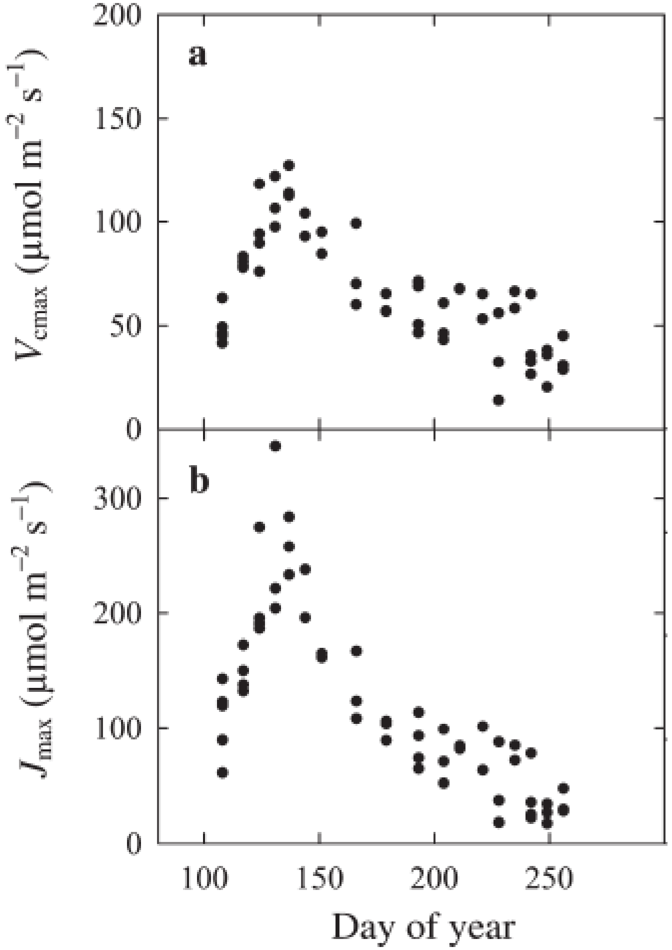
Robert Wolfe

Petr Votava


1 km resolution
Solar radiation (MJ m-2 day-1) Year: 2002Mon: 8
180° W
150° W
120° W
90° W
60° W
30° W
0°
30° E
60° E
90° E
120° E
150° E
180° E
0
3.5
7
10.5
14
17.5
21
24.5
28
31.5
35

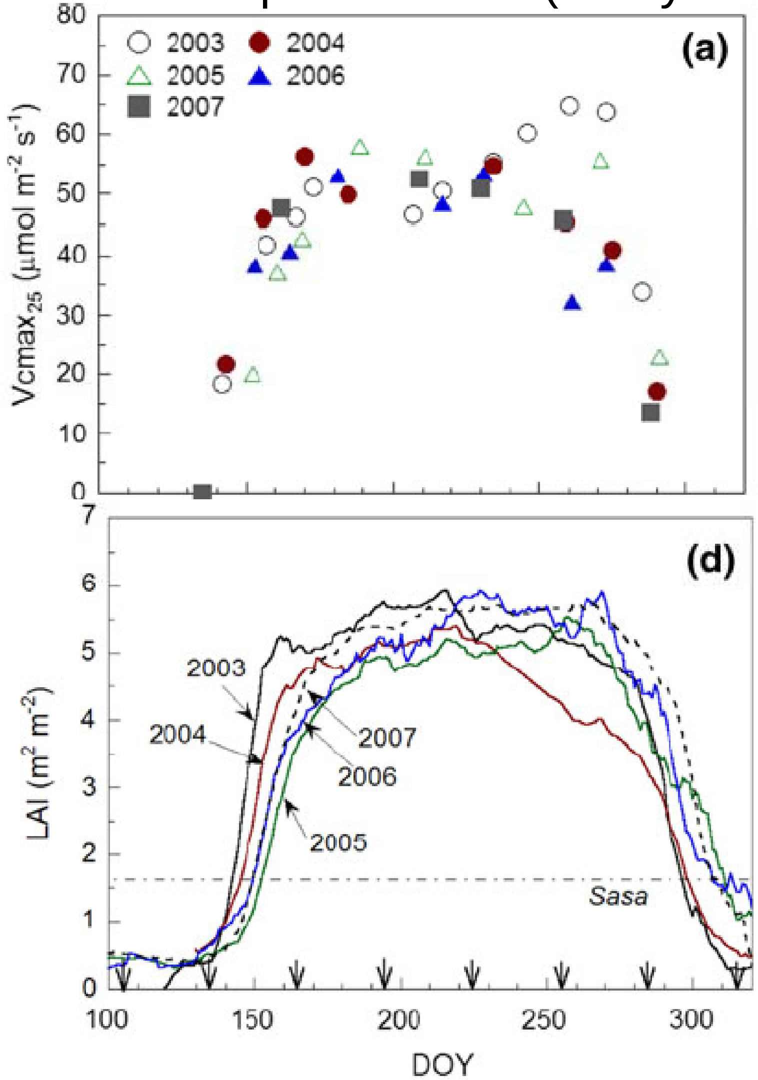
Key point: 2. Vcmax@25C is not constant.

Oak savanna (Tonzi)



Xu and Baldocchi 2003

Cool temperate forest (Takayama)



Muraoka et al 2010

Seasonal pattern of Vmax@25 follows the seasonal pattern of LAI (modified version of Houborg et al 2009 AFM)

$$V_{\max}{}^{25C} = a \times PeakV_{\max}{}^{25C} + (1-a) \times PeakV_{\max}{}^{25C} \times \frac{L_c - L_{\min}}{L_{\max} - L_{\min}}$$

Key point: 3. Two-leaf energy balance, photosynthesis, leaf temperature are coupled

$$d\Delta T^2 + e\Delta T + f = 0.$$

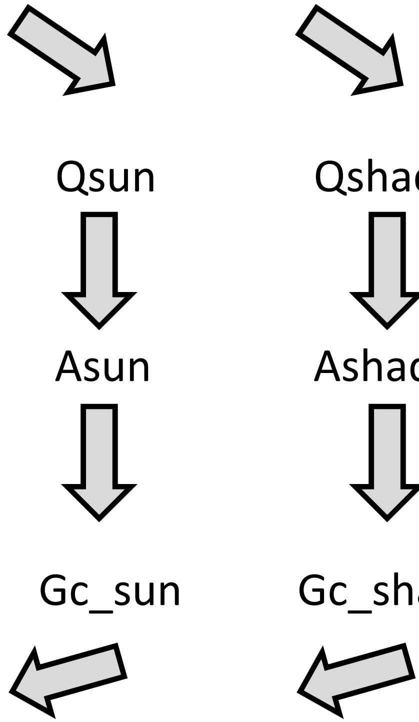
$$d = 6\varepsilon\sigma T_{\mathrm{a}}^2 + \frac{\rho_{\mathrm{a}}\lambda G_{\mathrm{w}} m_{\mathrm{v}}}{2 m_{\mathrm{a}} P}\frac{\mathrm{d}^2 e_{\mathrm{s}}(T_{\mathrm{a}})}{\mathrm{d}T^2}$$

$$e = 4\varepsilon\sigma T_{\mathrm{a}}^3 + \frac{\rho_{\mathrm{a}}\lambda G_{\mathrm{w}} m_{\mathrm{v}}}{m_{\mathrm{a}} P}\frac{\mathrm{d} e_{\mathrm{s}}(T_{\mathrm{a}})}{\mathrm{d}T} + \rho C_p G_{\mathrm{a}}$$

$$f = \varepsilon\sigma T_{\mathrm{a}}^4 + \frac{\rho_{\mathrm{a}}\lambda G_{\mathrm{a}} m_{\mathrm{v}}(e_{\mathrm{s}}(T_{\mathrm{a}}) - e_{\mathrm{a}})}{m_{\mathrm{a}} P} + -Q + G_{\mathrm{soil}}.$$

Quadratic form of leaf energy balance

PawU and Gao (1988)



Q: absorbed radiation
A: photosynthesis
Gc: canopy conductance

Key point: 4. Temporal upscaling of fluxes from snap-shots to 8-day mean daily sum estimates

Satellite overpass time

30 min

Rg at TOA

$$SF_d(t) = \frac{1800s \times \lambda E(t)}{\int_d \lambda E(t)dt} \approx \frac{1800s \times R_{gPOT}(t)}{\int_d R_{gPOT}(t)dt}$$

Day (1-8)

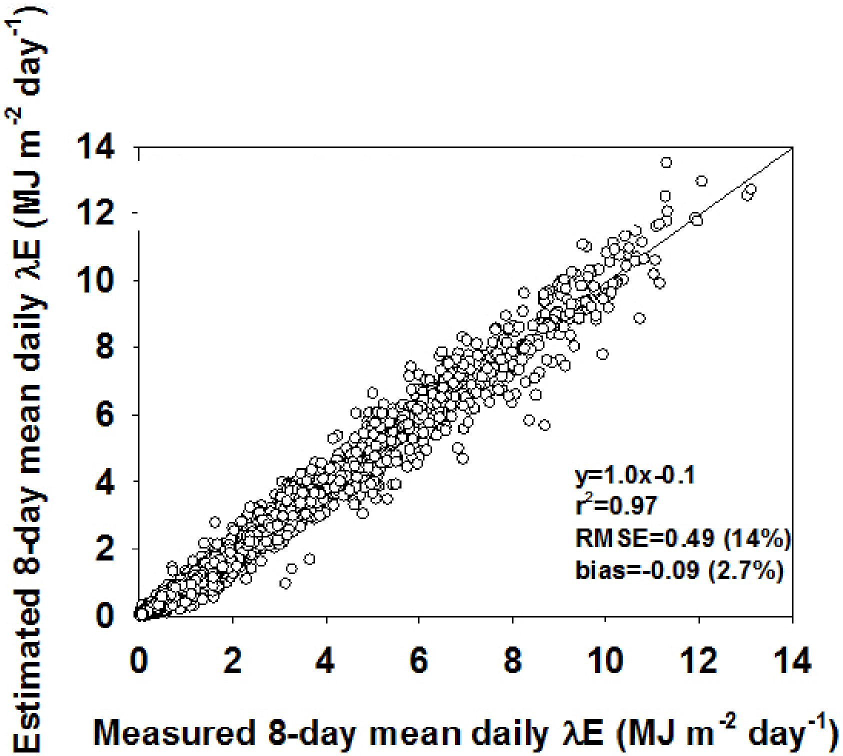
Instantaneous LE

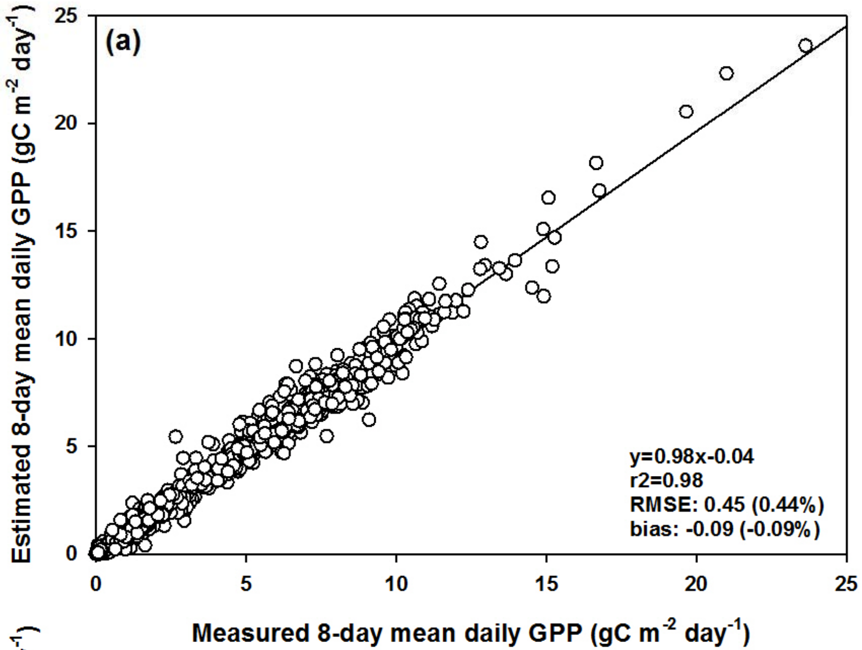
$$\lambda E_{8day} = \frac{1}{8}\sum_{d=1}^{8}\frac{1800s \times \lambda E(t_d)}{SF_d(t_d)}$$

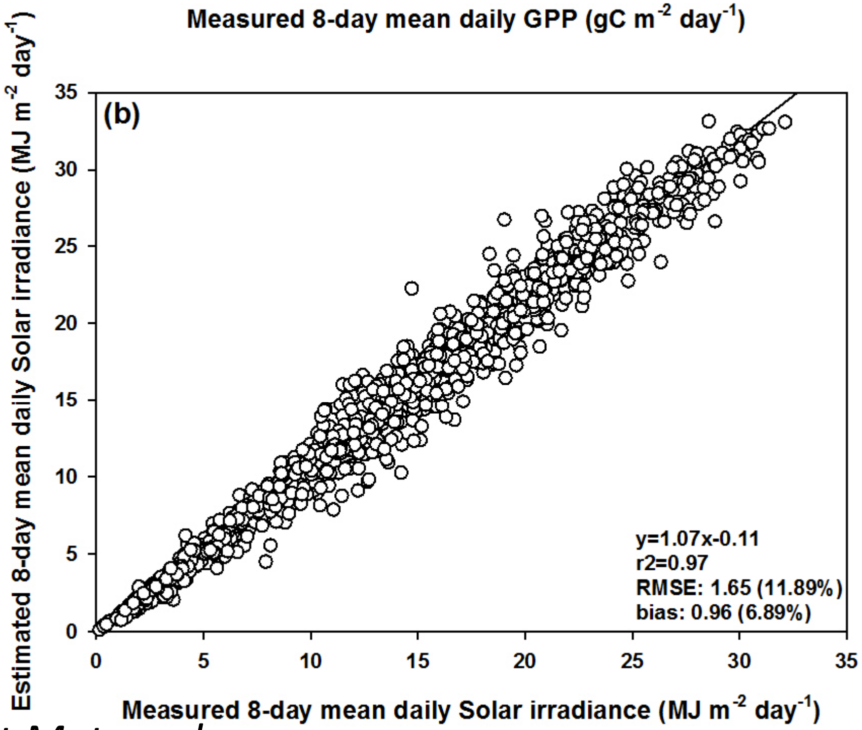
R_{gPOT} =f(latitude, longitude, time)

Ryu et al (in minor revision) *Agricultural and Forest Meteorology*

Tested the scheme using 33 flux tower data from the Arctic to the Tropics







Ryu et al (in minor revision) *Agricultural and Forest Meteorology*

Key point: 5. Working in the Cloud computing

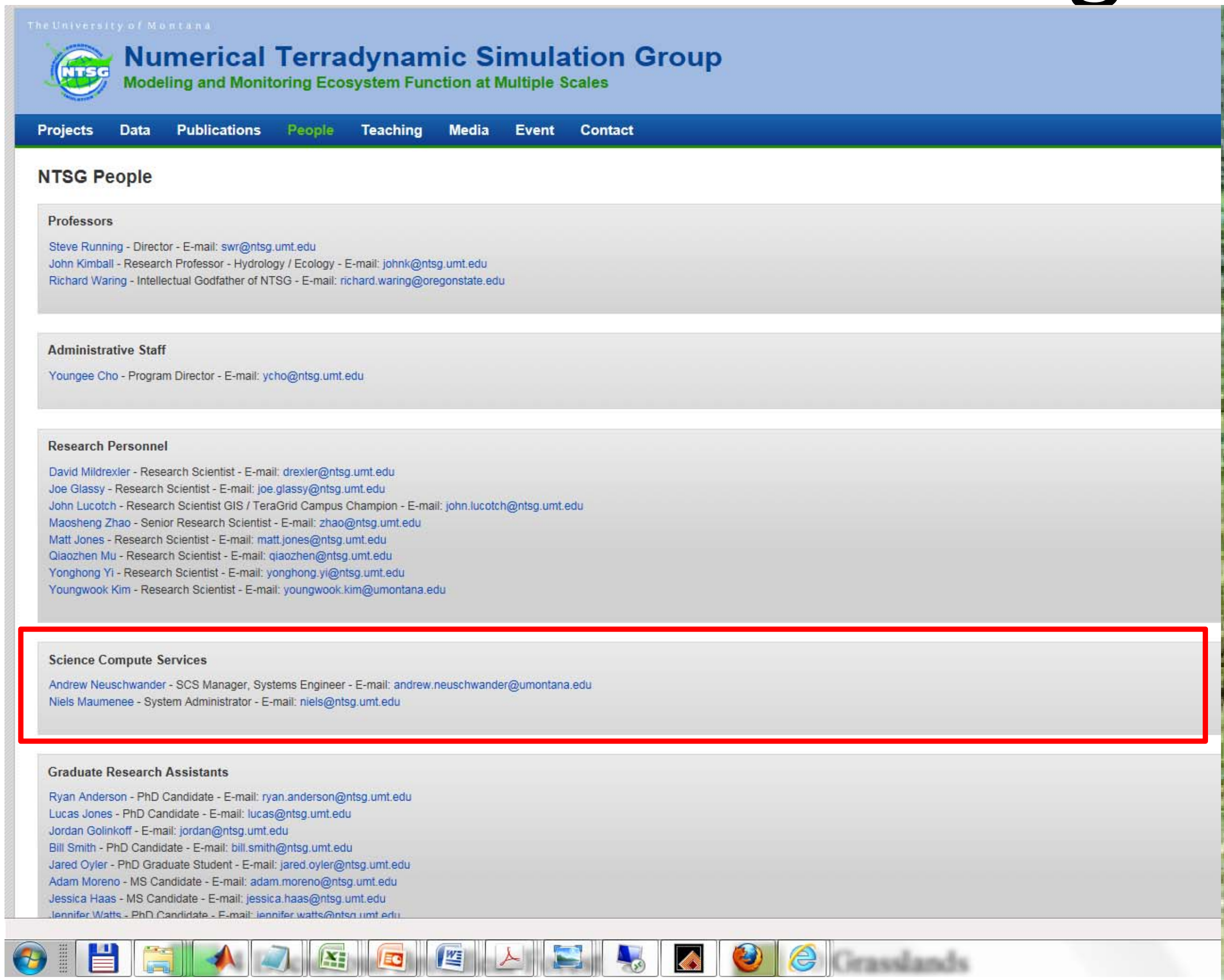
Some numbers that I learned from this project

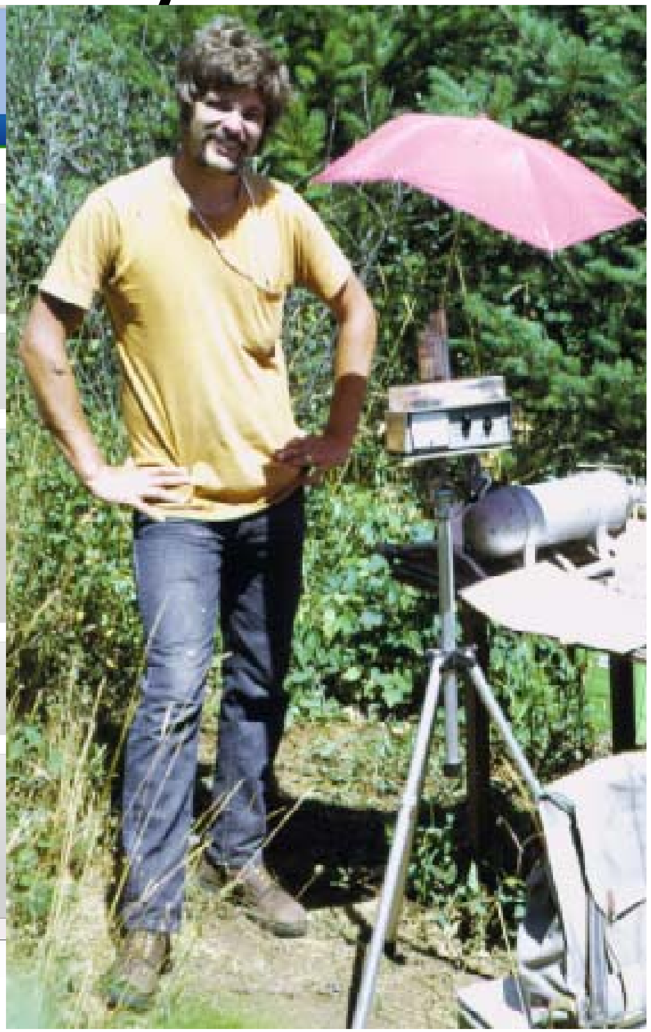
- Global 1-year calculation for ET and GPP: 9000 CPU hours
- That is, 375 days.
- 1-year calculation takes 1 year with 1 CPU!

- 8 TB downloaded from NASA ftp server
- 940 TB moved across the Cloud computing system

How to do global RS study?

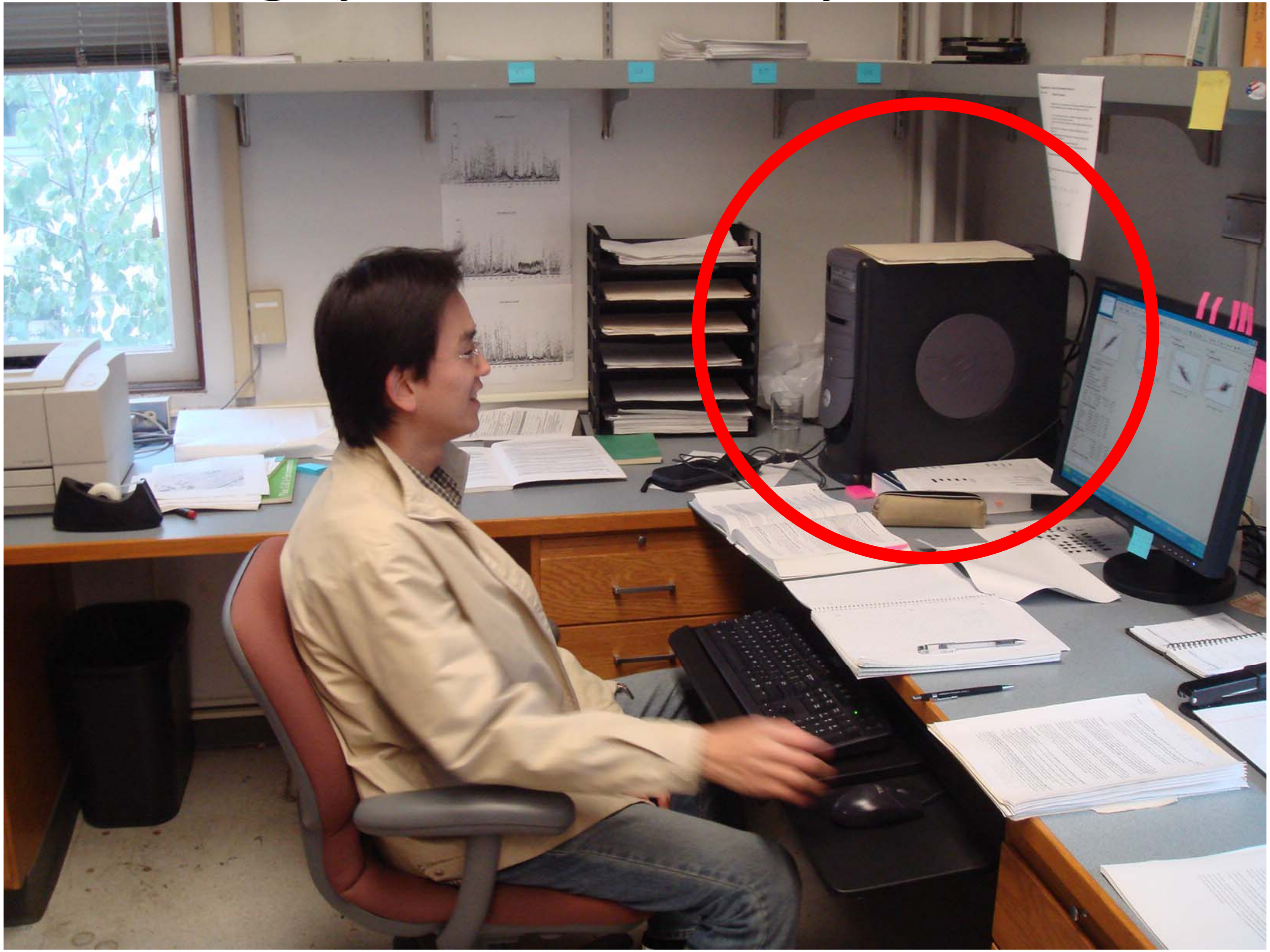
Computer facility is a key in global remote sensing study





Steve Running in 1972
Photo by Bob Rogan

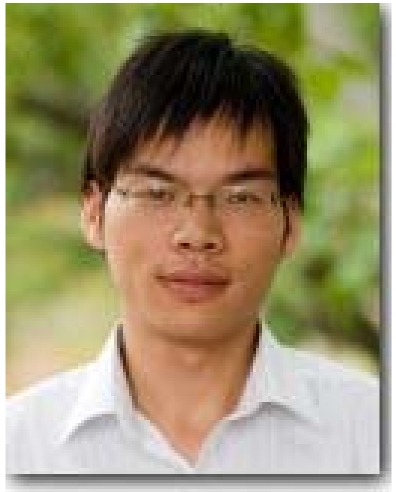
Youngryel was lonely with 1 PC



We made a team, MODIS-Azure, with Computer Scientists Microsoft kindly funded

Catharine van Ingen

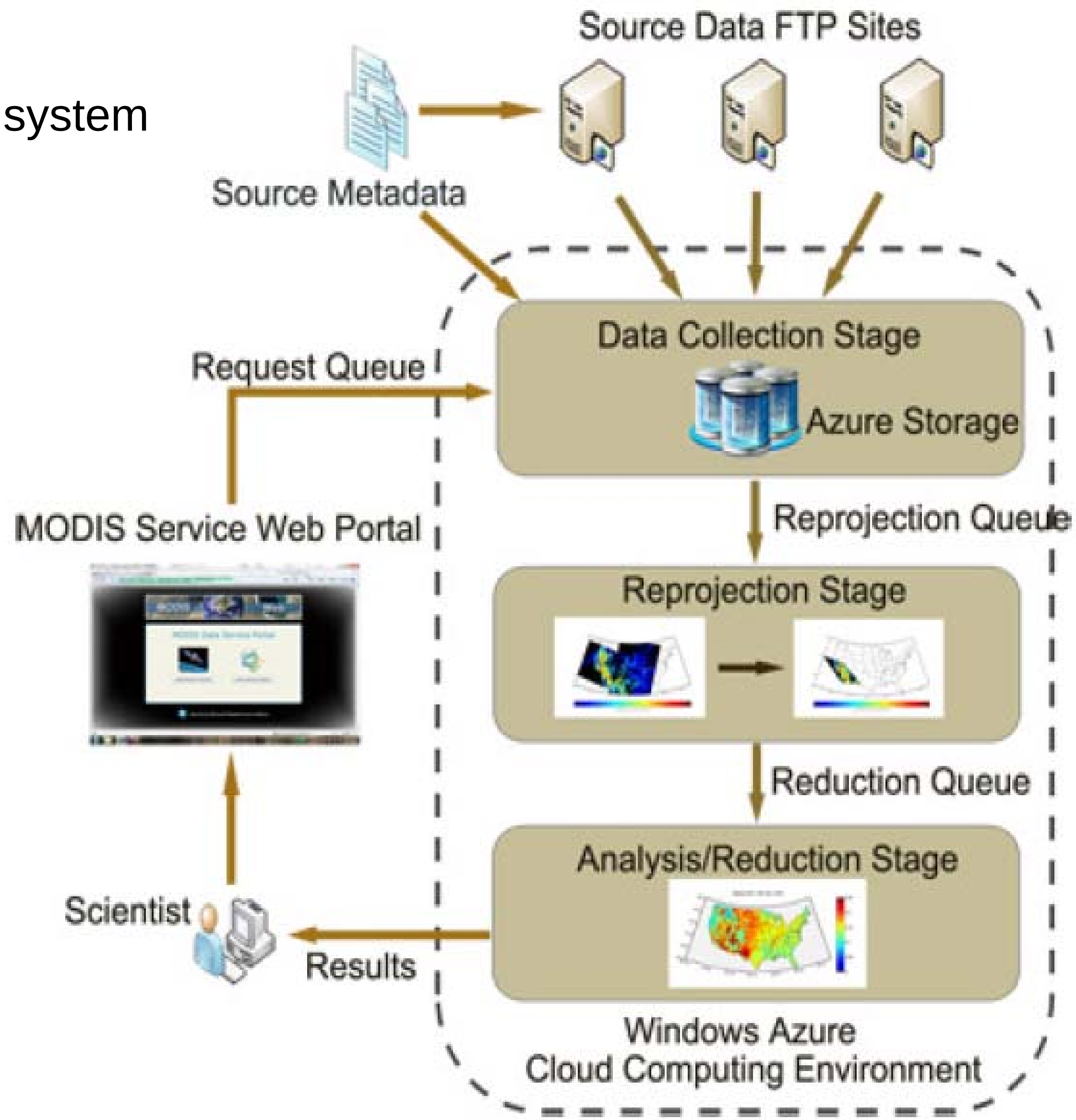
Deb Agarwal



Jie Li

Kieth Jackson

MODIS-Azure system



Li et al 2010. *IEEE e-Science 2010 Conference*
Li et al 2010. *IEEE International Parallel and Distributed Processing Symposium*
Hey et al 2011. *International Journal of High Performance Computing*

Data preparation

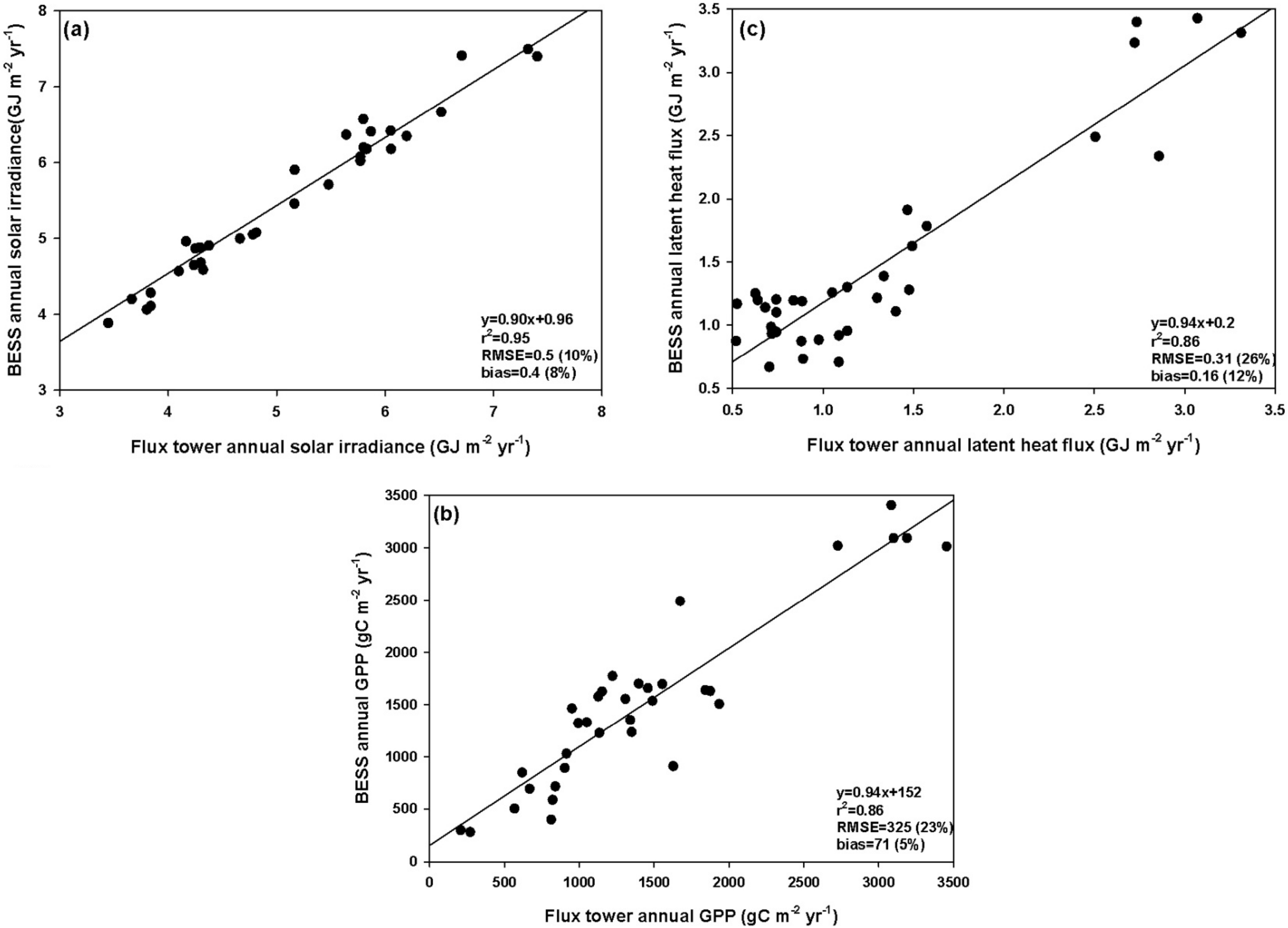
- MODIS
  - MOD04 (aerosol)
  - MOD05 (precipitable water)
  - MOD06 (cloud)
  - MOD07 (atmospheric profile)
  - MOD11 (land surface temperature)
  - MCD12 (land cover)
  - MCD15 (LAI)
  - MCD43 (albedo)

Data preparation

- Global climate map (Koeppen-geiger)
- Global foliar clumping index map (Chen et al 2005 RSE, updated by Pisek 2010)
- Global C4 map (Still et al 2003 GBC)
- NCEP (to fill the data gaps in MODIS)

Results

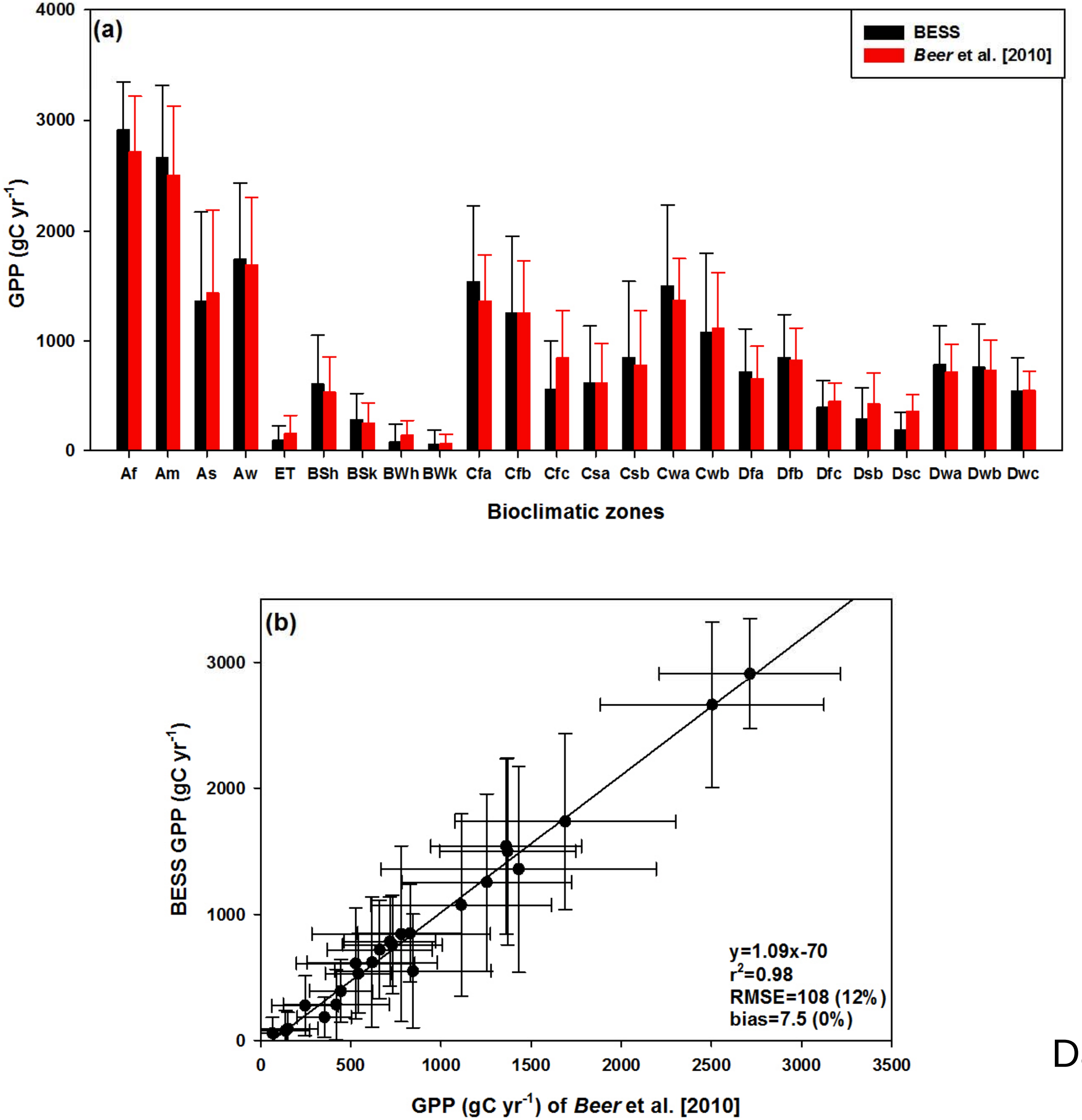
COMPARISON AGAINST FLUXNET DATA (1 KM SCALE) AT 32 SITES FROM ARCTIC TO TROPICS



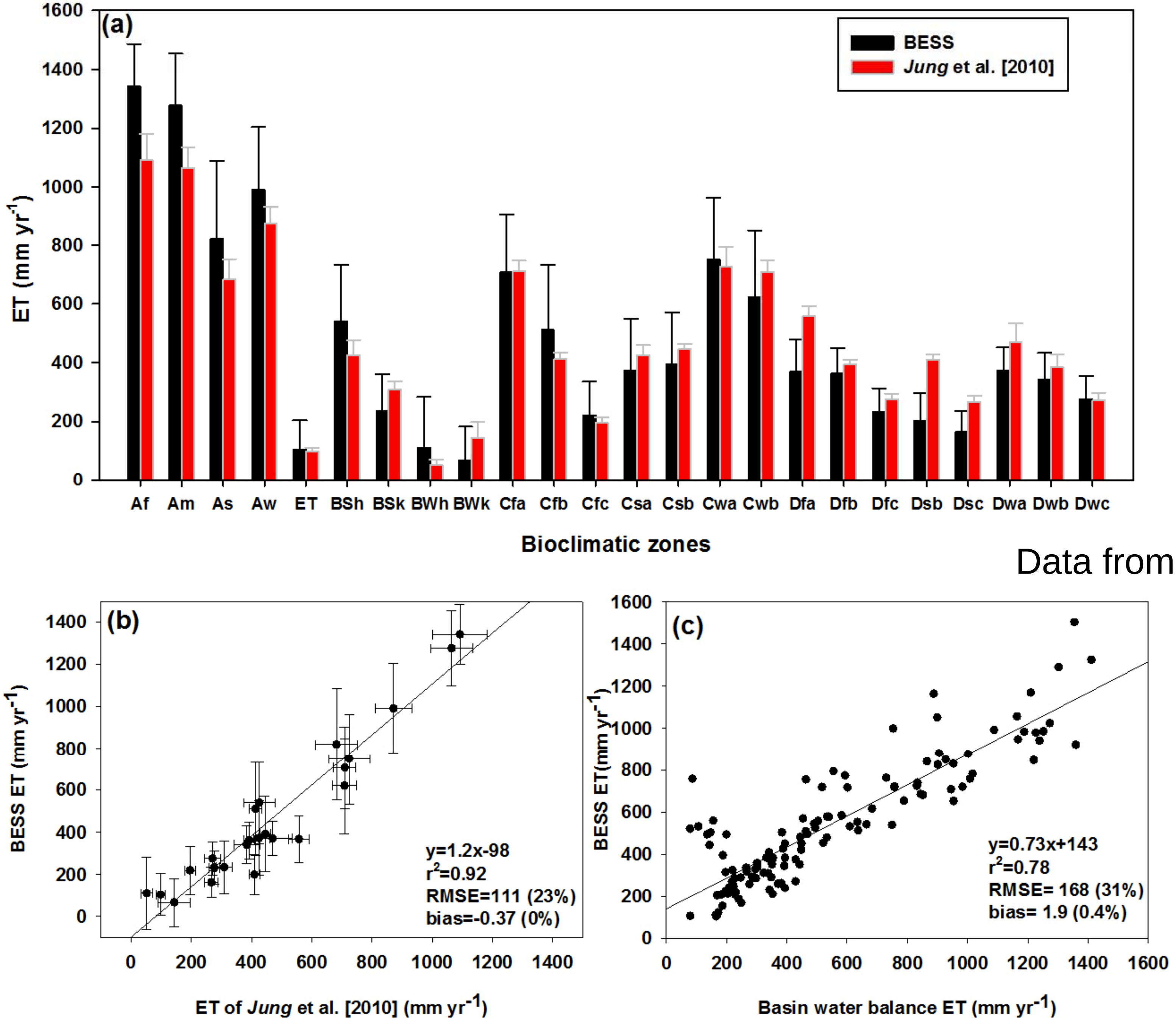
Ryu et al (In review) GBC

Results

COMPARISON AGAINST DATA-DRIVEN PRODUCTS



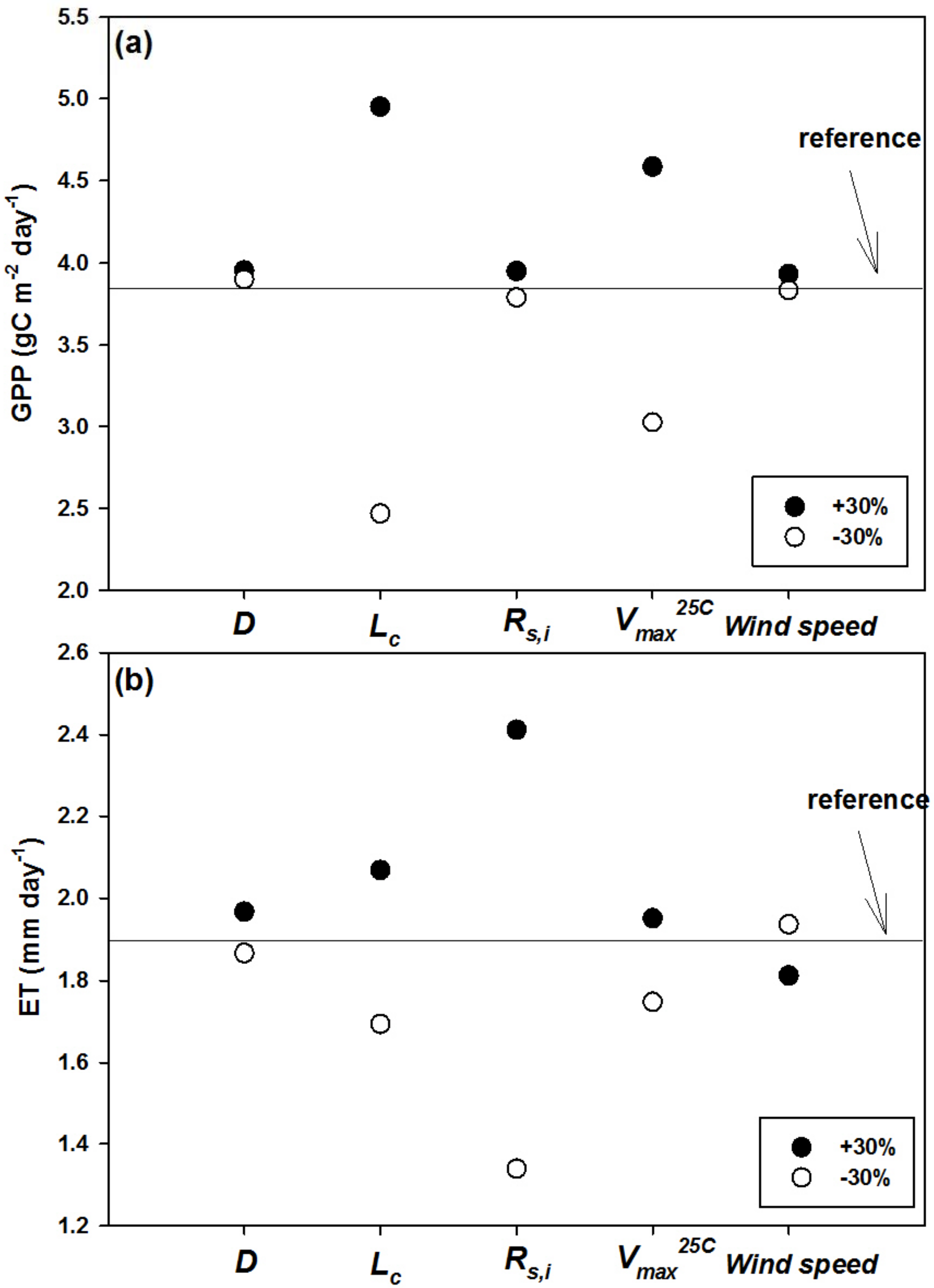
Data from Beer



Data from Jung

Results

SENSITIVITY ANALYSIS

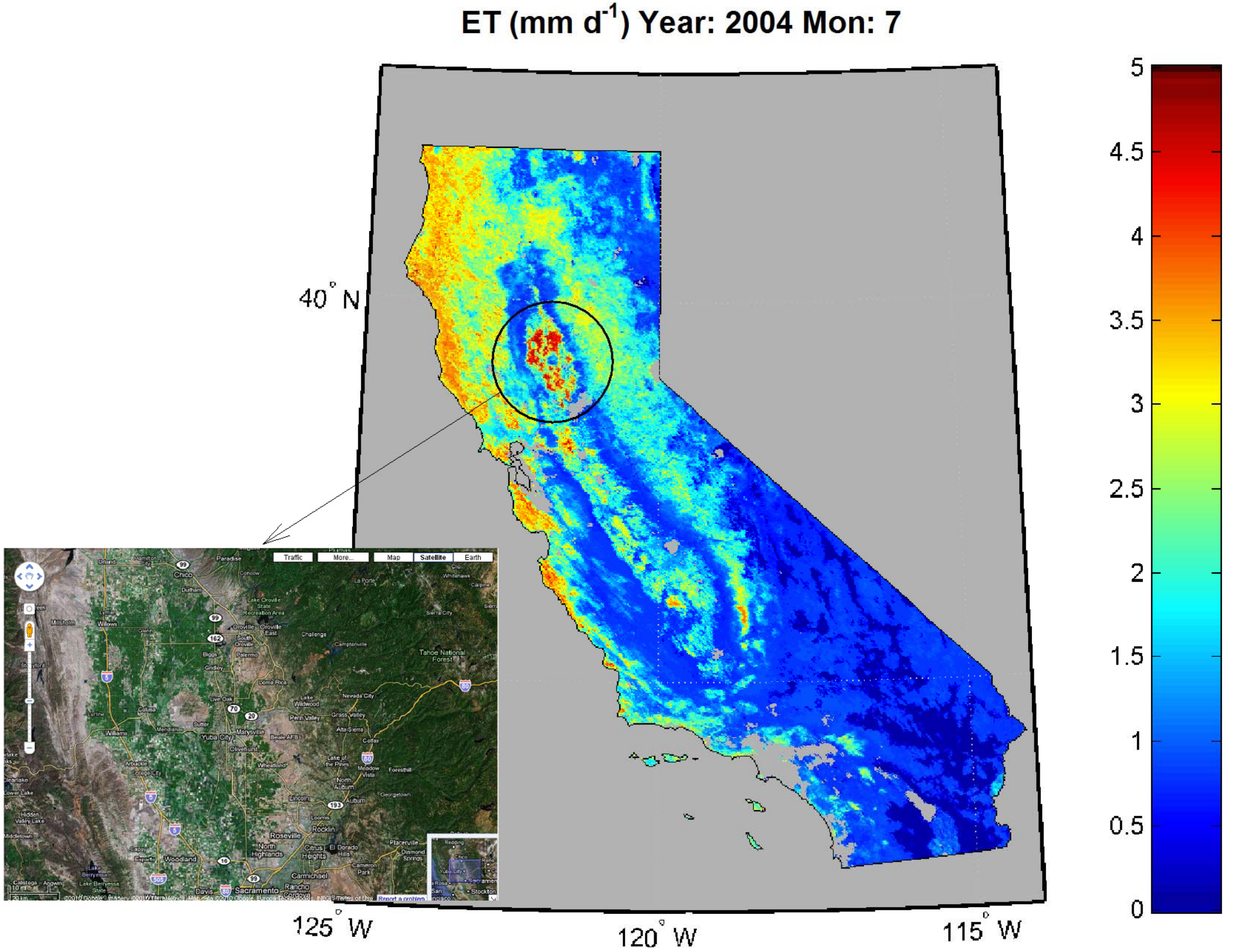


(a)
GPP (gC m-2 day-1)
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
reference
+30%
-30%
D
Lc
Rs,i
Vmax25C
Wind speed
(b)
ET (mm day-1)
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
reference
+30%
-30%
D
Lc
Rs,i
Vmax25C
Wind speed

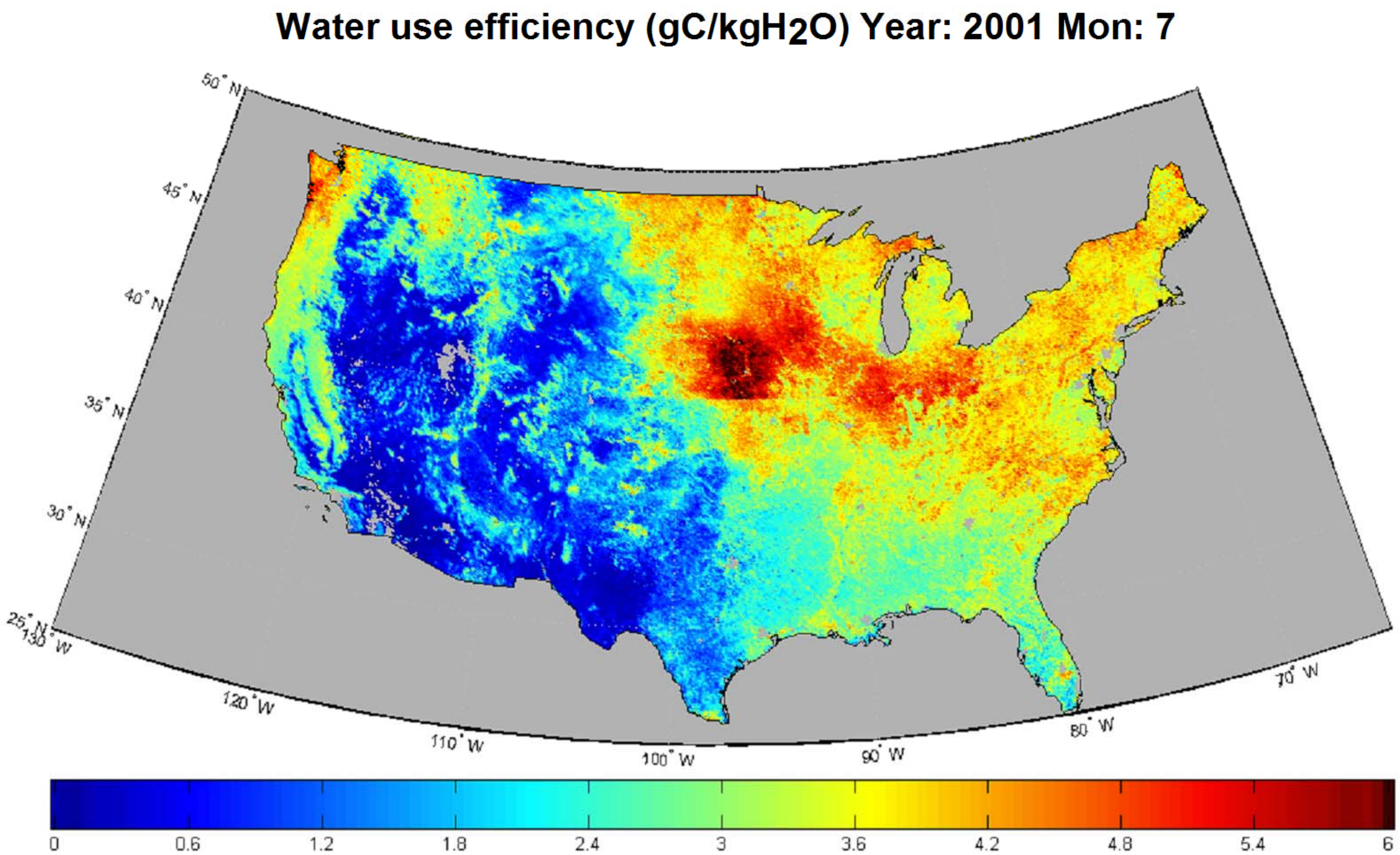
Results

SUCCESS OF BIOPHYSICAL MODEL FROM LOCAL TO GLOBAL SCALE

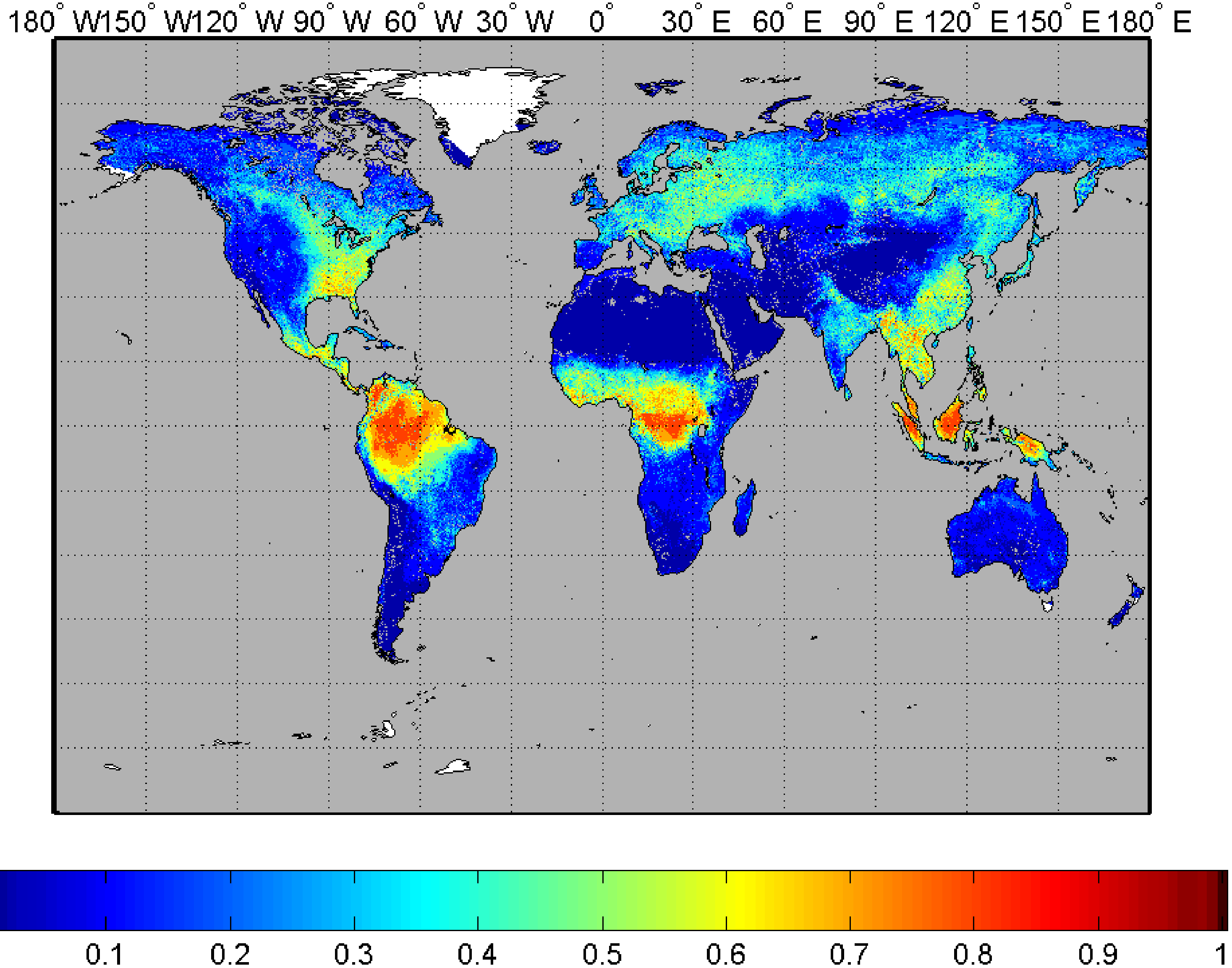
1 km resolution ET map, with 1 km forcing data



Linking water and carbon, directly

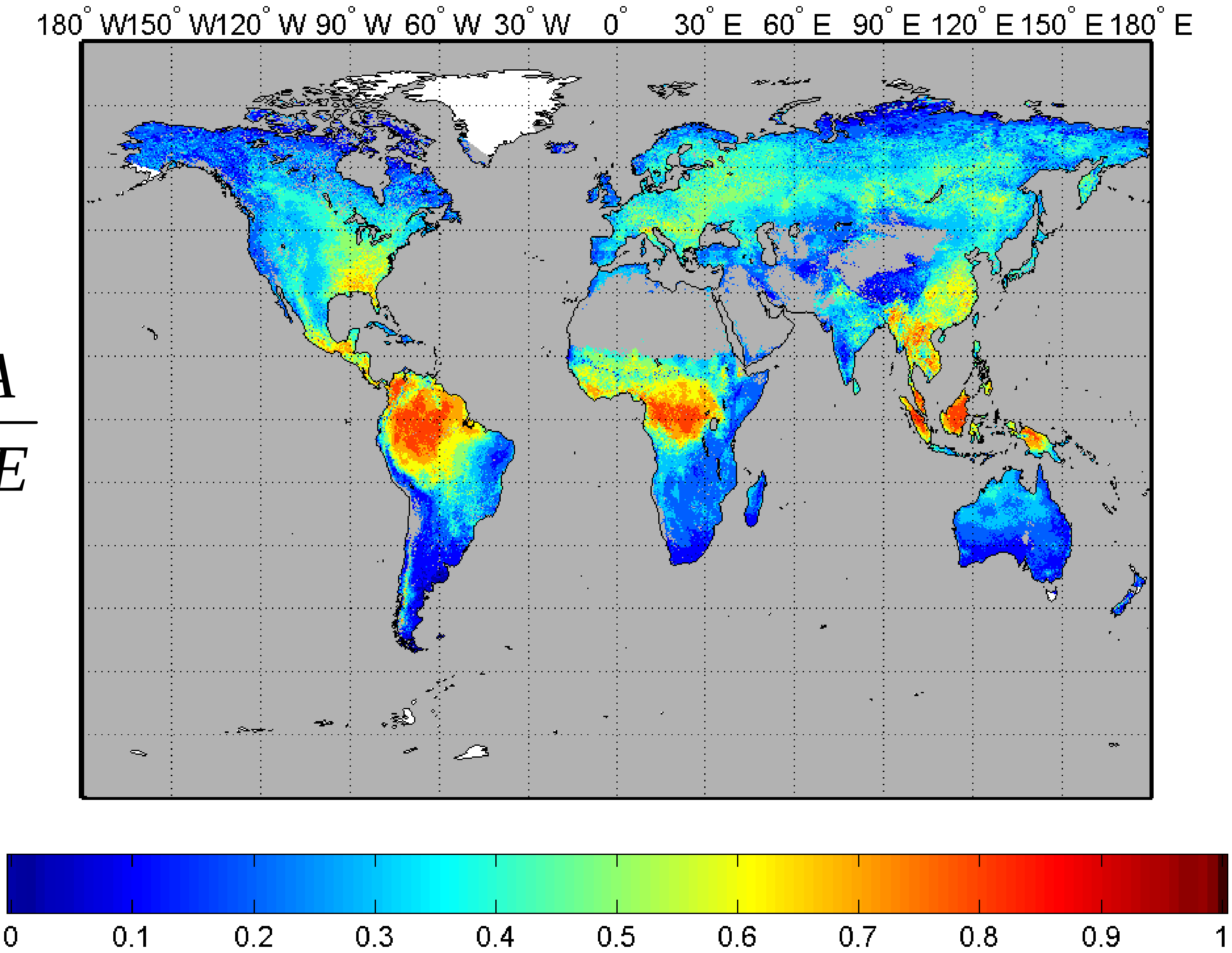


Linking land and atmosphere (decoupling factor by Jarvis and McNaughton 1986) in July, 2003



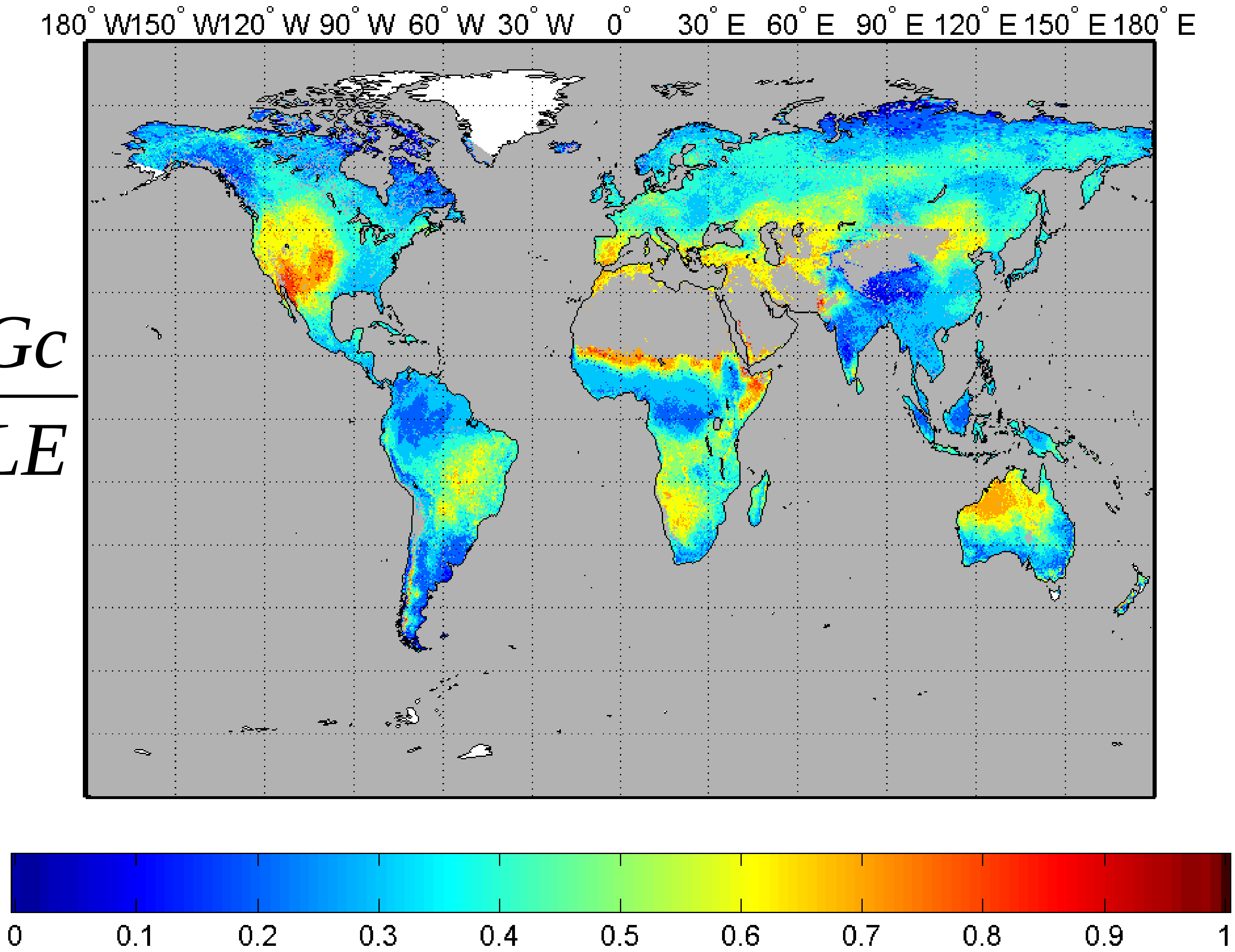
Sensitivity of ET on available energy (July, 2003)

$$\frac{\partial LE}{\partial A}\frac{A}{LE}$$

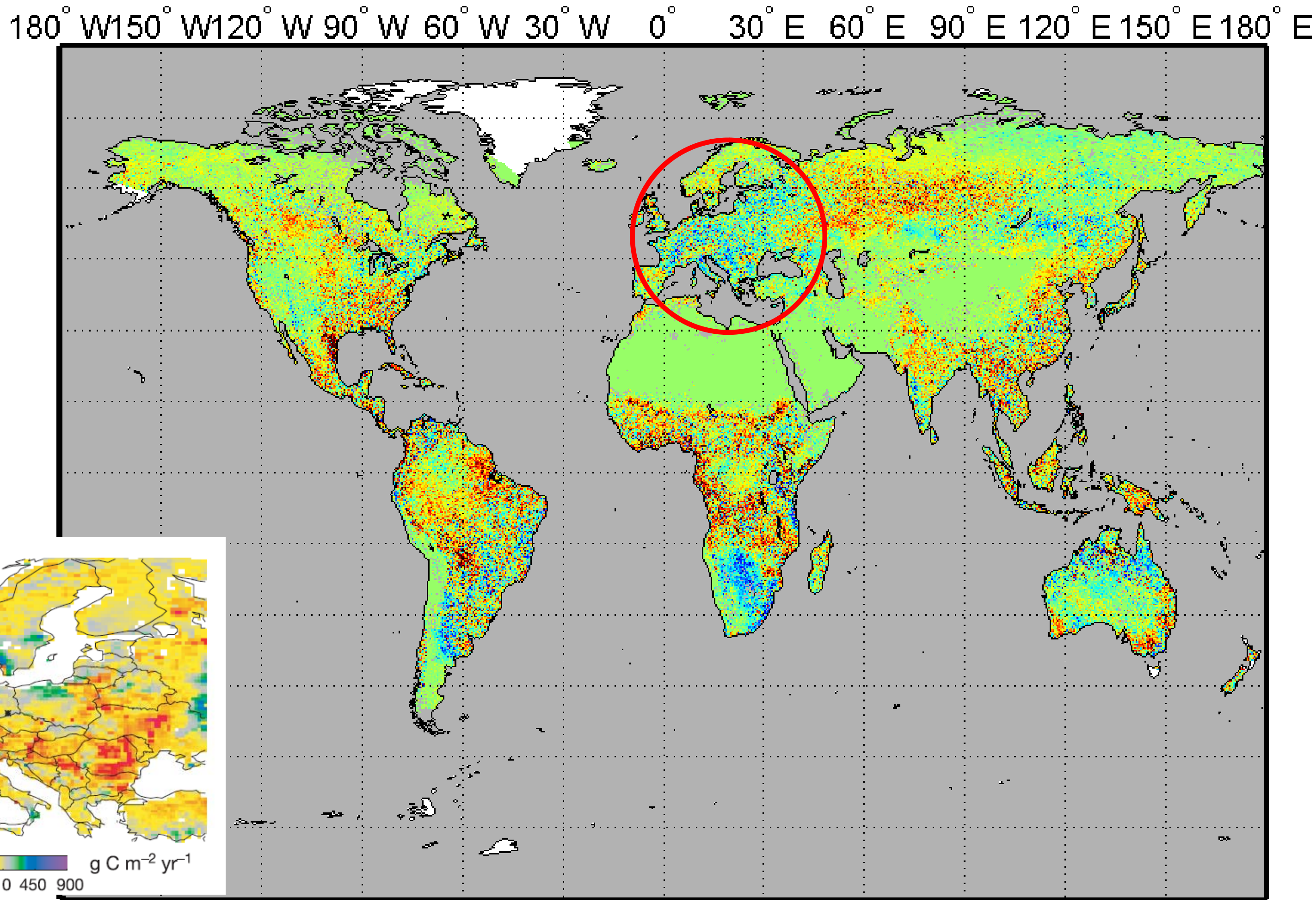


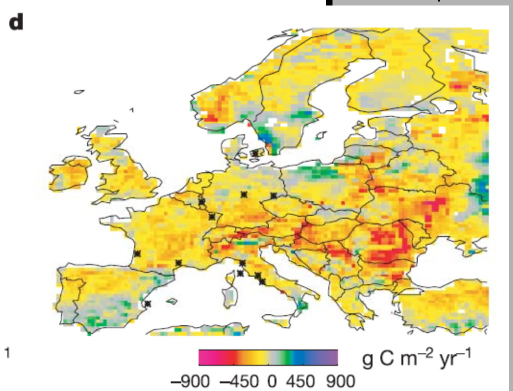
Sensitivity of ET on canopy conductance (July, 2003)

$$\frac{\partial LE}{\partial Gc}\frac{Gc}{LE}$$

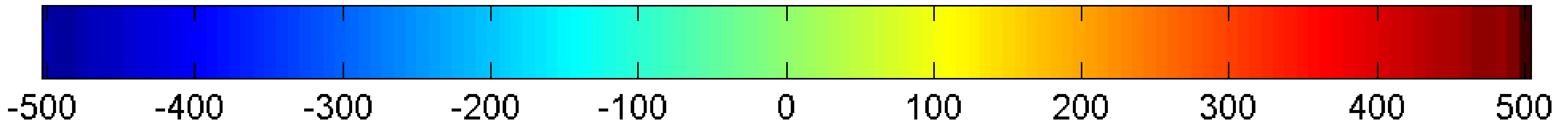


Interannual variation of GPP
Difference of annual GPP (2003yr – mean of 2001-2002)



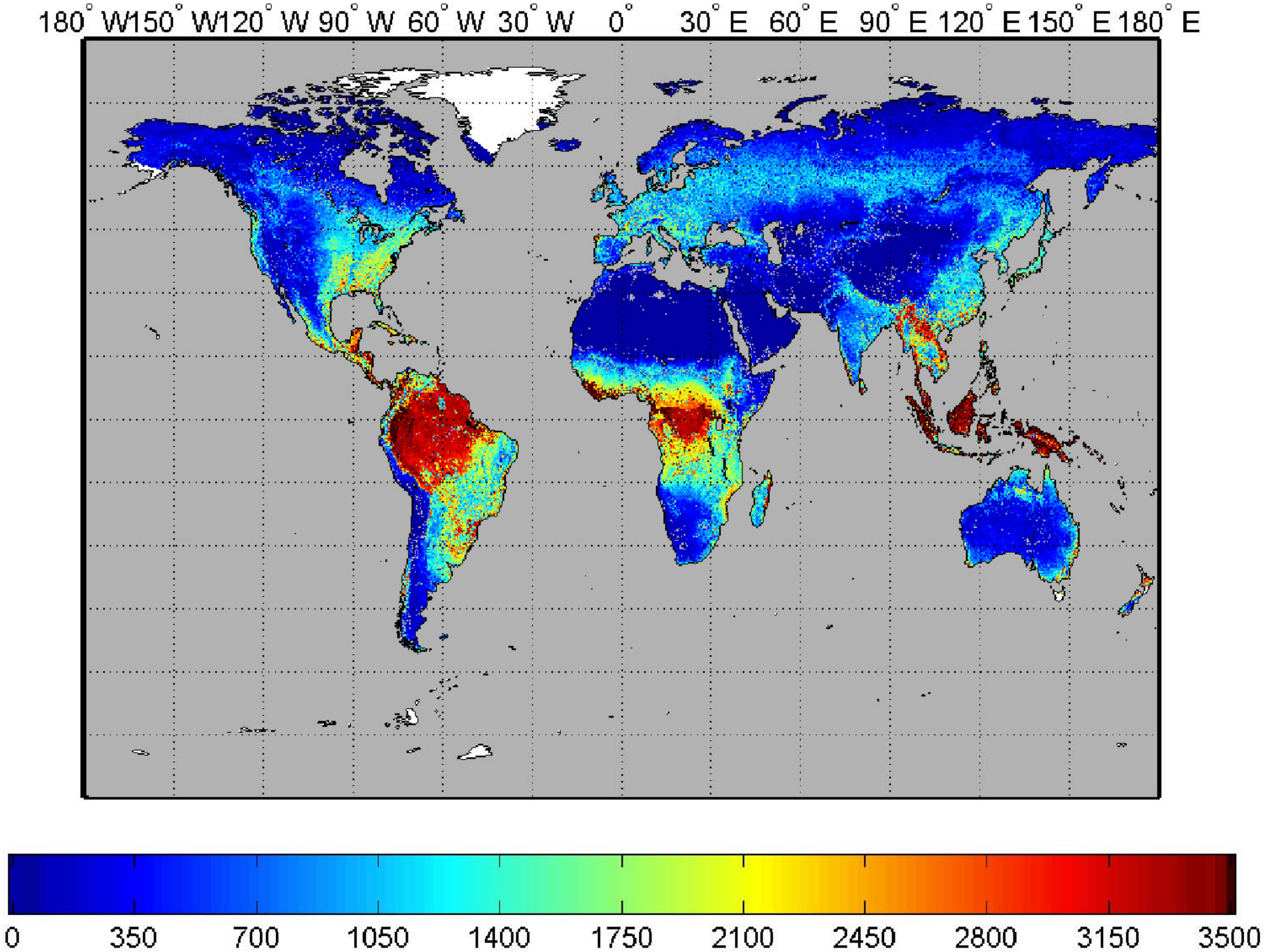


Ciais et al 2005 Nature



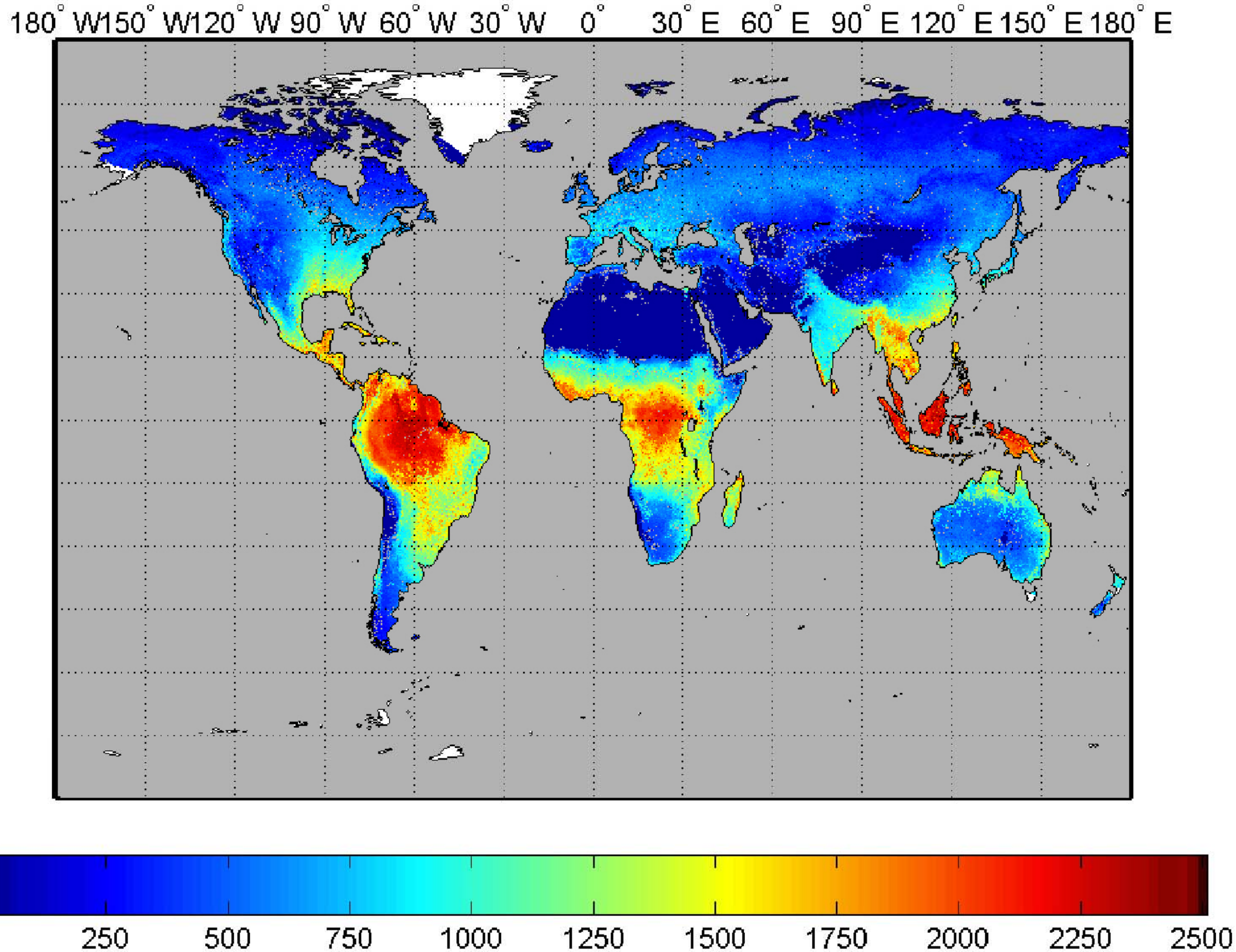
GPP anomaly (gC m-2 yr-1)

Mean annual GPP (PgC yr^{-1}) between 2001 and 2003



118±26 PgC yr^{-1}

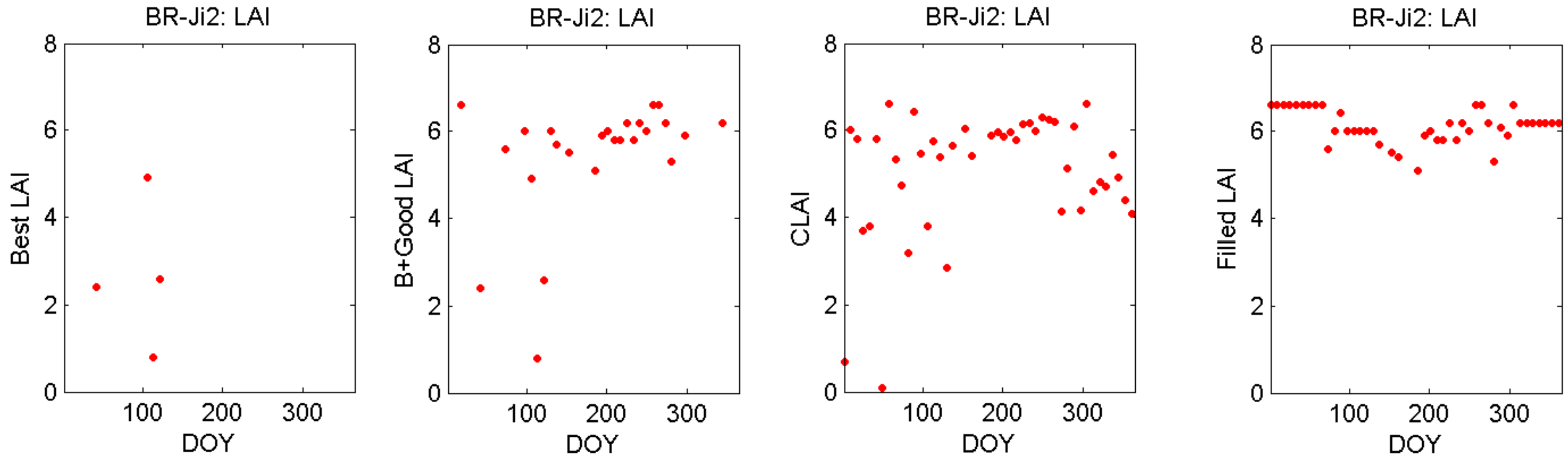
Mean annual ET (mm yr^{-1}) between 2001 and 2003



63,000±13,100 km^3 yr^{-1}

FAILURES OR LIMITATION

LAI in the tropics



"Main (RT) method used, best result possible (no saturation)" - Best

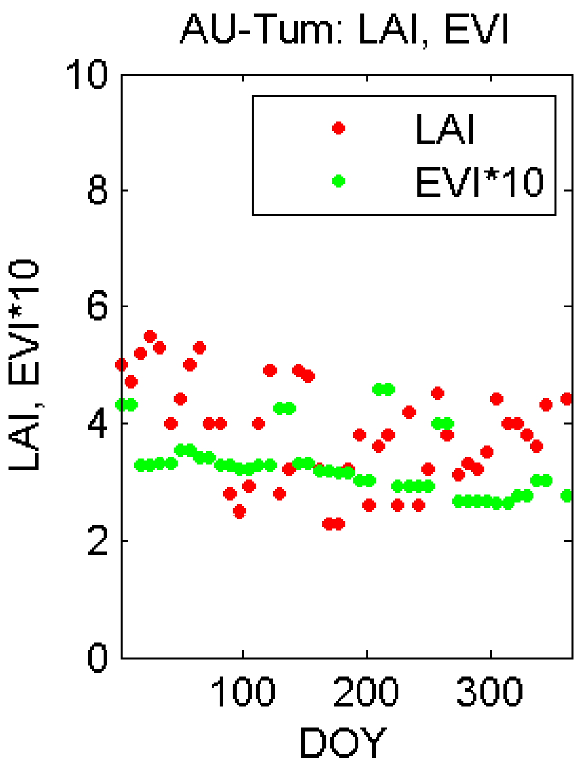
"Main (RT) method used with saturation. Good,very usable "- Good

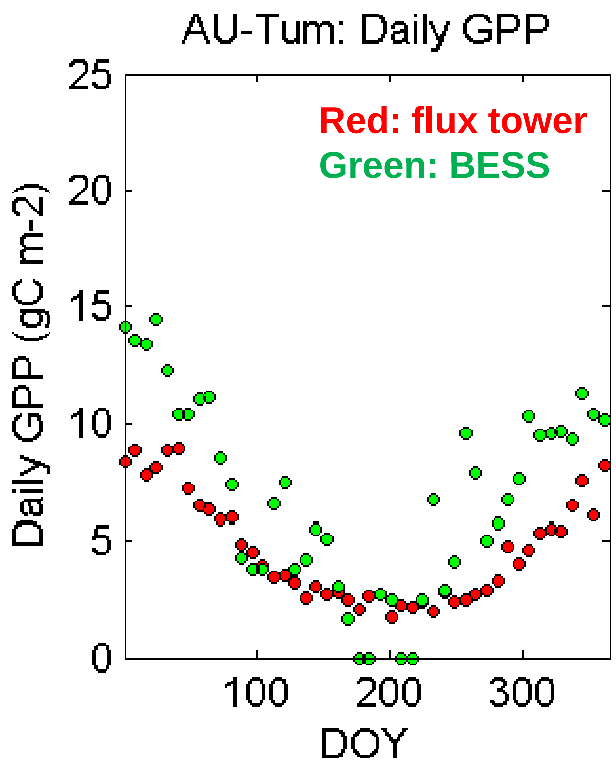
5 year mean LAI for Best+Good

Select max(Best or Good, 5 year mean)
Replace LAI value which is <80% of the max LAI over 6 week interval

?

LAI

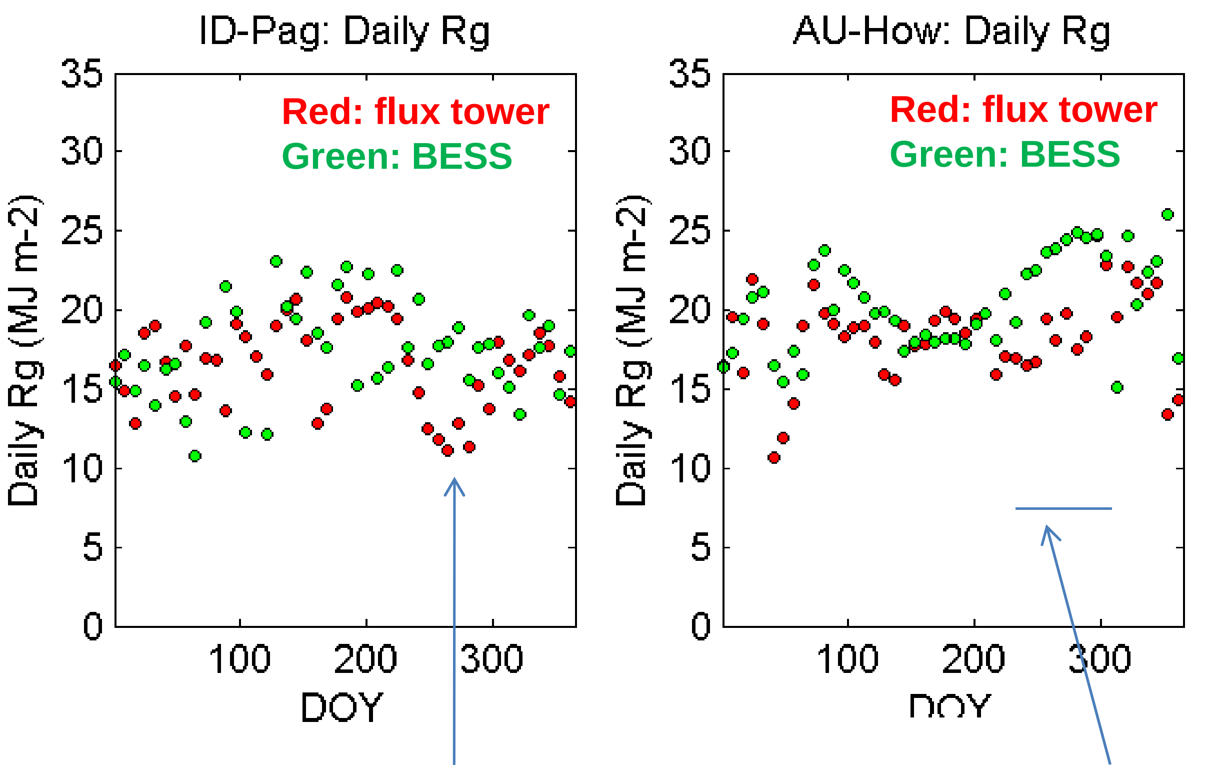




In-situ peak LAI ~2.5

(Leuning et al 2006 AFM)

Solar radiation in the Tropics

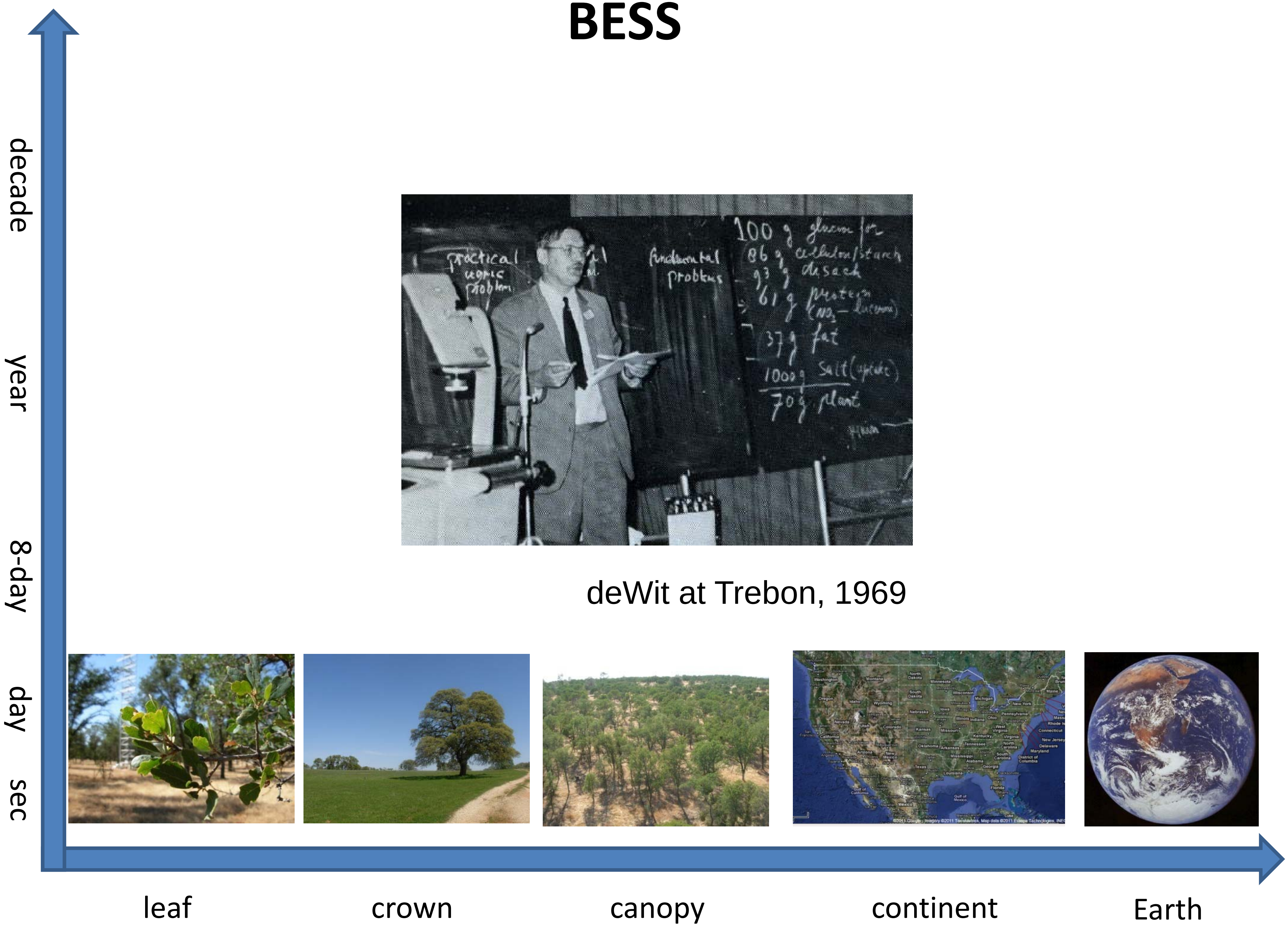


Intense fire

Frequent fires

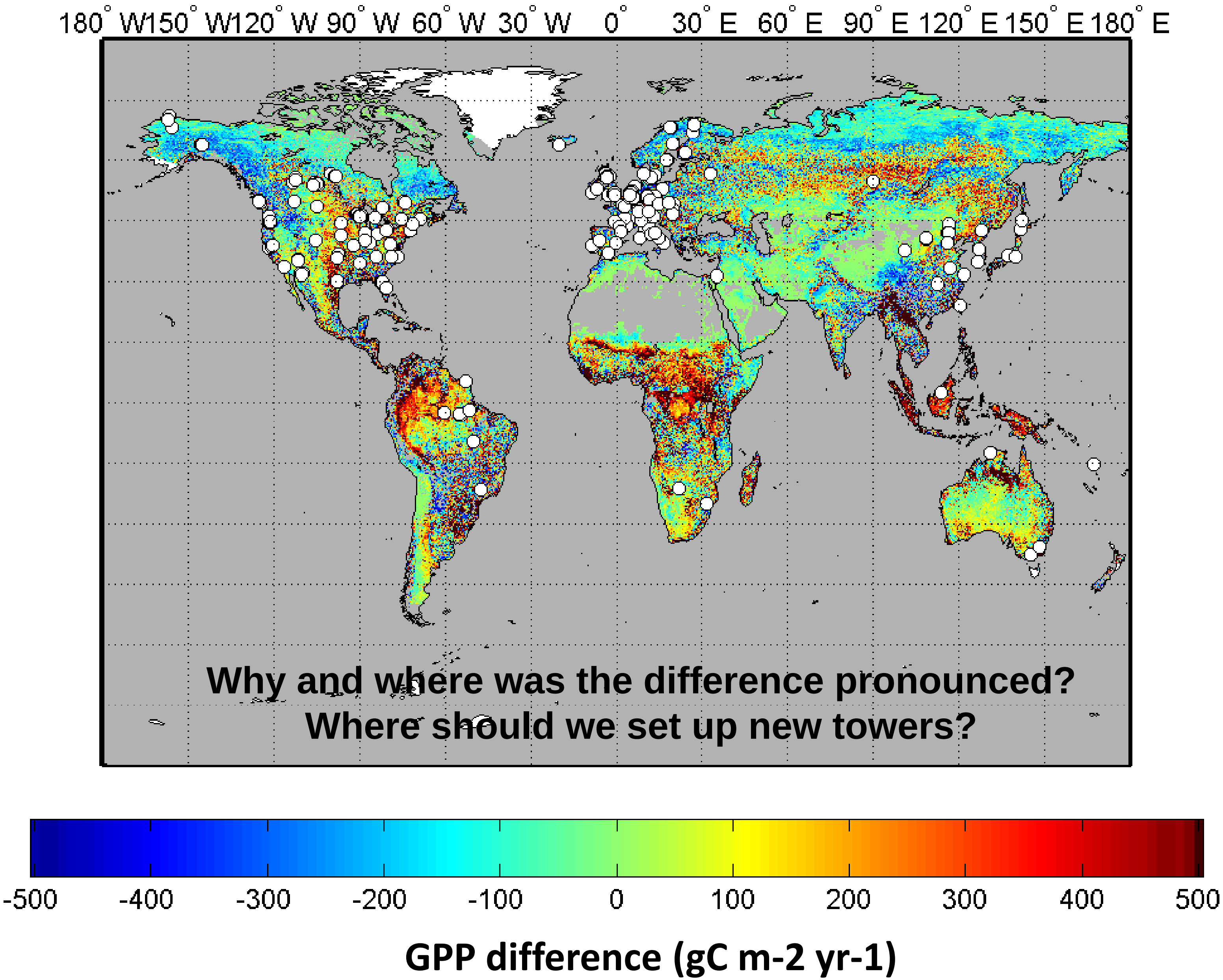
CONCLUDING REMARKS

BESS

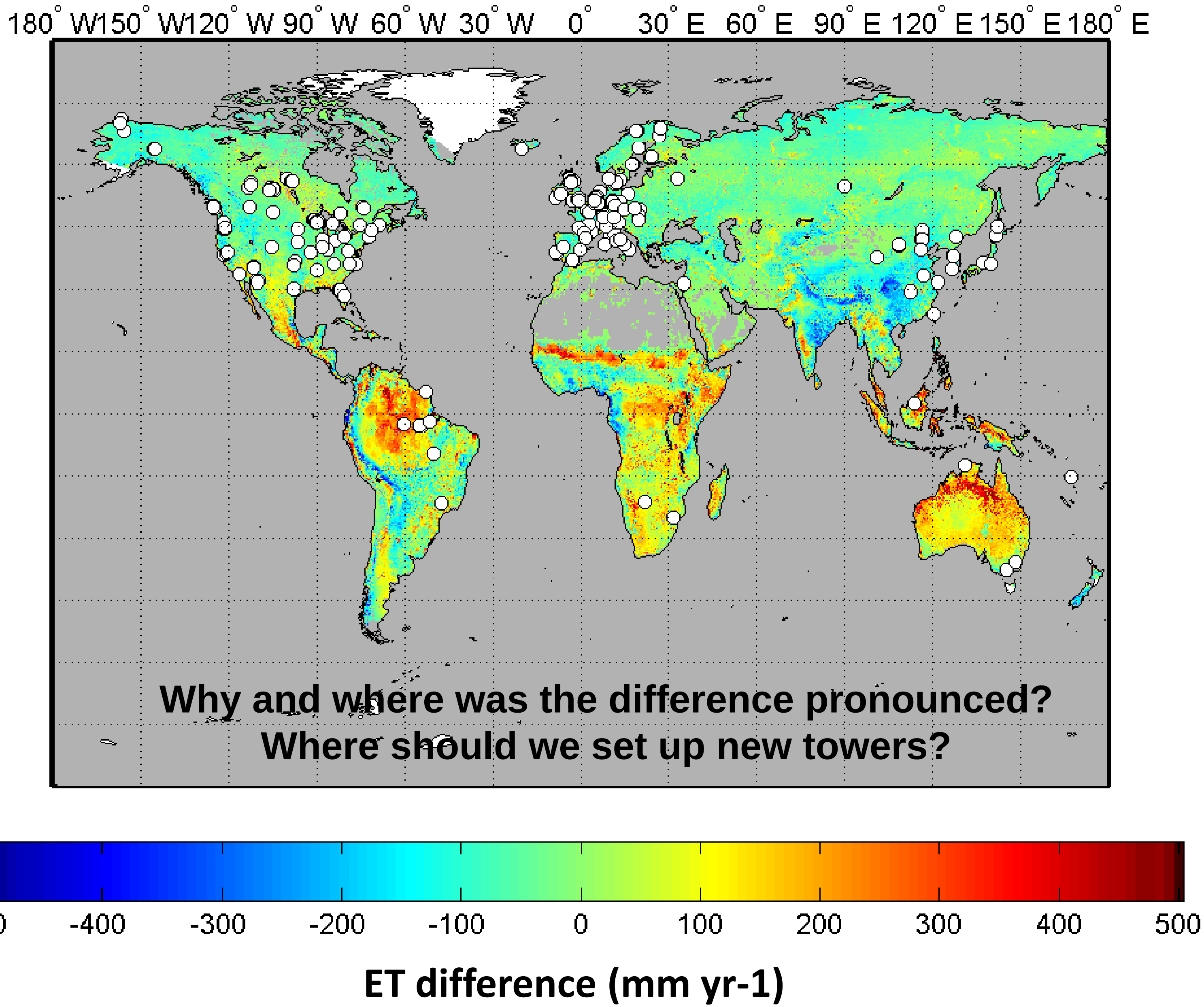


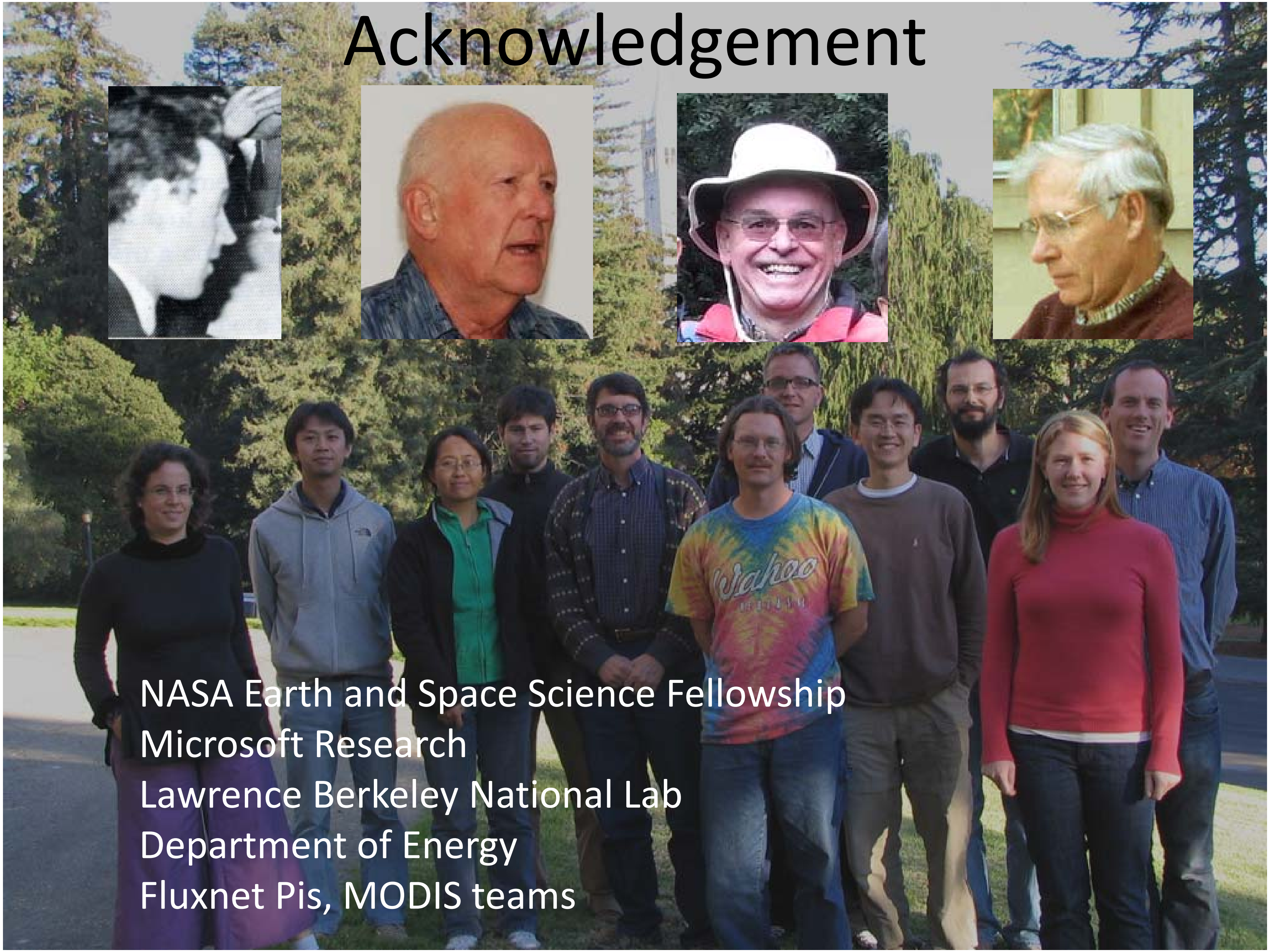
deWit at Trebon, 1969

GPP difference (BESS minus Beer et al 2010)



ET difference (BESS minus Jung et al 2010)

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Fluxnet Pis, MODIS teams