Lawrence Berkeley National Laboratory

ESD
EARTH SCIENCES DIVISION

The CLM4 stomatal conductance calculation revisited: the empirical Ball-Berry equation and its relationship to relative humidity and vapor pressure deficit

Jinyun Tang and Bill Riley

Funded by DOE C-Climate Feedbacks project

Lawrence Berkeley National Laboratory

ESD
EARTH SCIENCES DIVISION

The CLM4 stomatal conductance and soil resistance calculation revisited

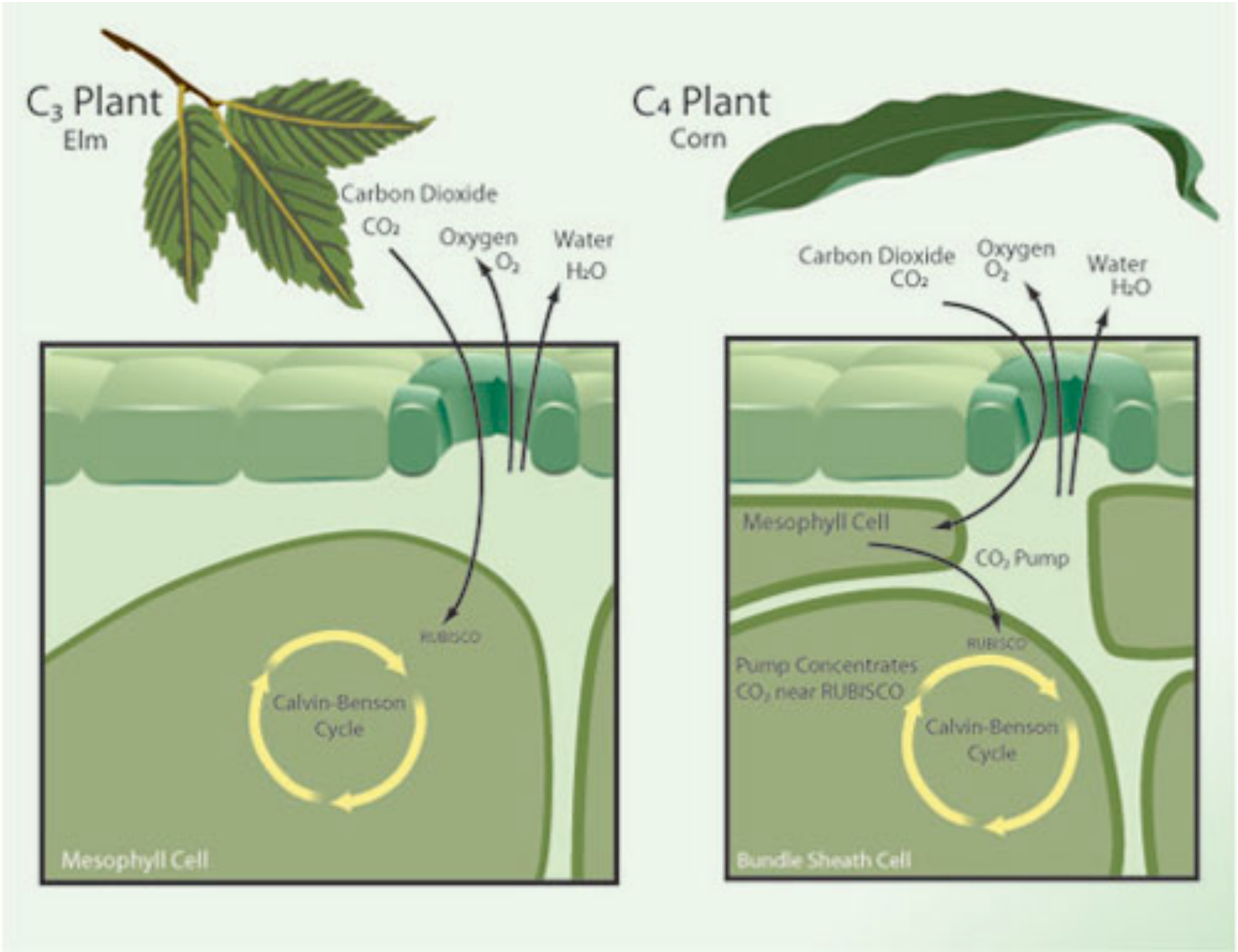
Jinyun Tang and Bill Riley

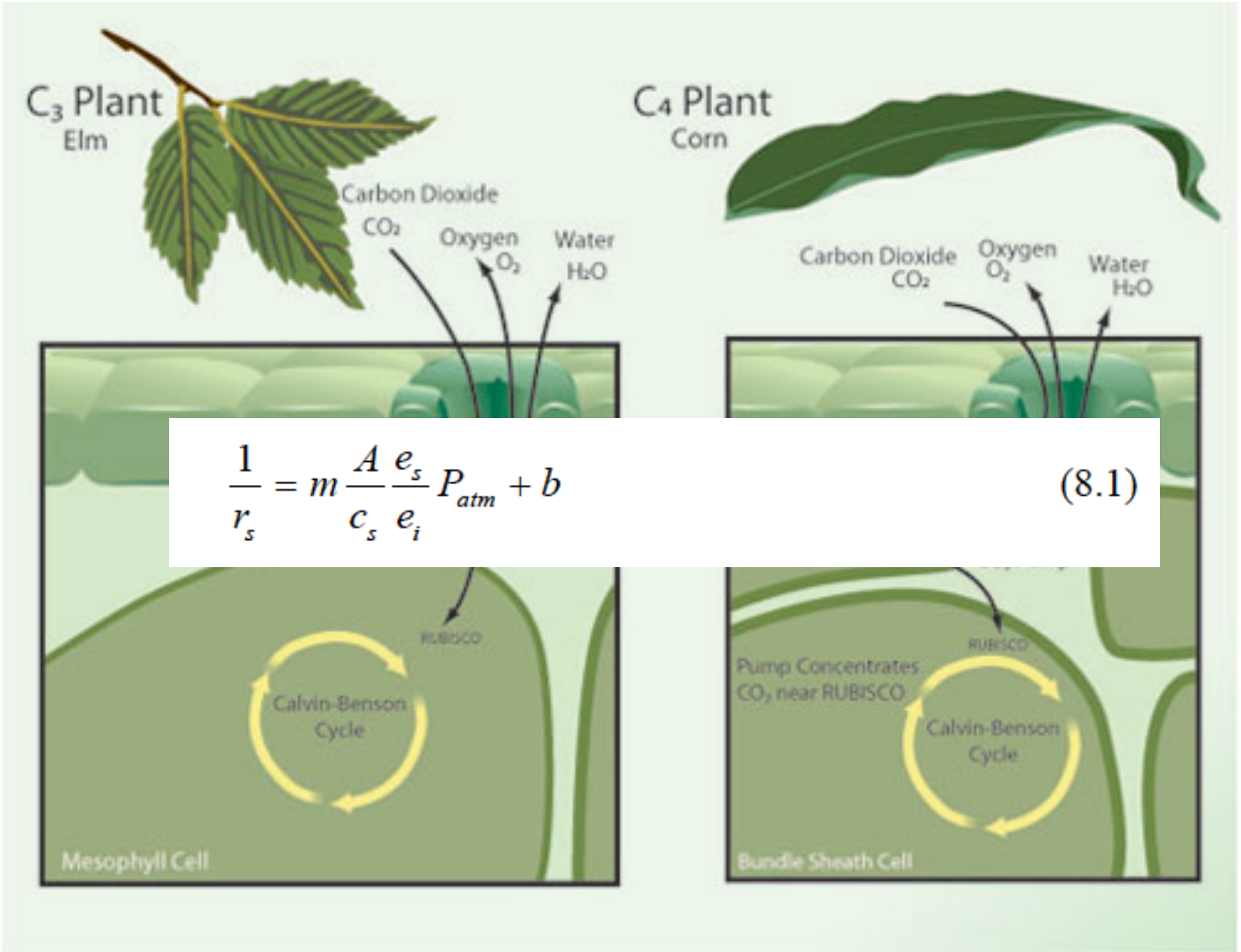
Funded by DOE C-Climate Feedbacks project

Road map

- An robust numerical implementation of stomatal conductance calculation

- A mechanistically based formulation of soil conductance for soil-atmosphere exchange of generic volatile tracers


C3 Plant
Elm
Carbon Dioxide
CO2
Oxygen
O2
Water
H2O
RUBISCO
Calvin-Benson
Cycle
Mesophyll Cell
C4 Plant
Corn
Carbon Dioxide
CO2
Oxygen
O2
Water
H2O
Mesophyll Cell
CO2 Pump
RUBISCO
Pump Concentrates
CO2 near RUBISCO
Calvin-Benson
Cycle
Bundle Sheath Cell



$$\frac{1}{r_s} = m\frac{A}{c_s}\frac{e_s}{e_i}P_{atm} + b \qquad (8.1)$$

Stomatal resistance solution

$$\frac{e_a' - e_i}{(r_b + r_s)} = \frac{e_a' - e_s}{r_b} = \frac{e_s - e_i}{r_s} \qquad (8.23)$$

$$c_s = c_a - 1.37 r_b P_{atm} A \qquad (8.25)$$

$$\left(\frac{mAP_{atm} e_a'}{c_s e_i} + b \right) r_s^2 + \left(\frac{mAP_{atm} r_b}{c_s} + b r_b - 1 \right) r_s - r_b = 0. \qquad (8.27)$$

$$c_i = c_s - 1.65 r_s P_{atm} A \qquad (8.28)$$

Fixed-point iteration

$$c_i^{n+1} = f\left(c_i^n\right)$$

Contracting condition

$$\left|c_i^{n+1} - c_i^n\right| = \left|f\left(c_i^n\right) - f\left(c_i^{n-1}\right)\right| < \left|c_i^n - c_i^{n-1}\right|$$

Fixed-point iteration

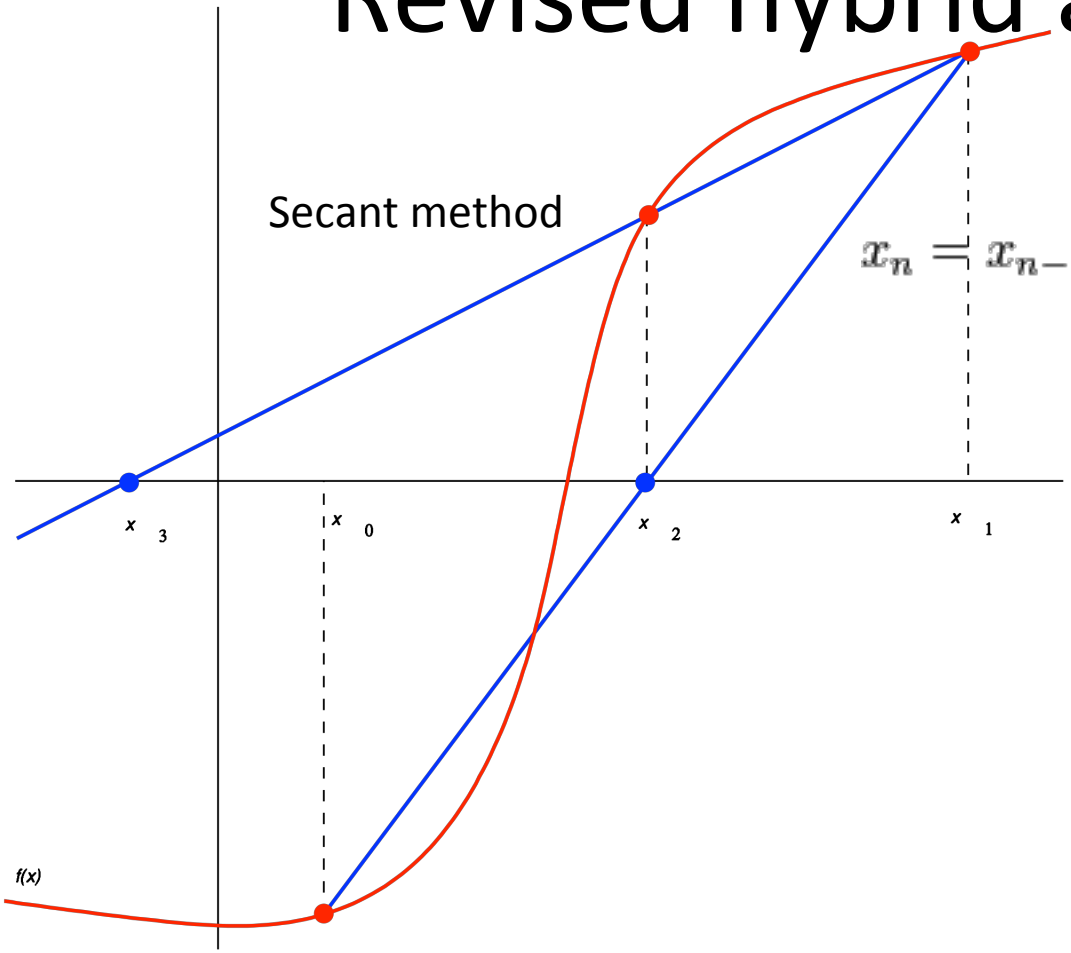
$$c_i^{n+1} = f\left(c_i^n\right)$$

Contracting condition

$$\left|c_i^{n+1} - c_i^n\right| = \left|f\left(c_i^n\right) - f\left(c_i^{n-1}\right)\right| \not\leq \left|c_i^n - c_i^{n-1}\right|$$

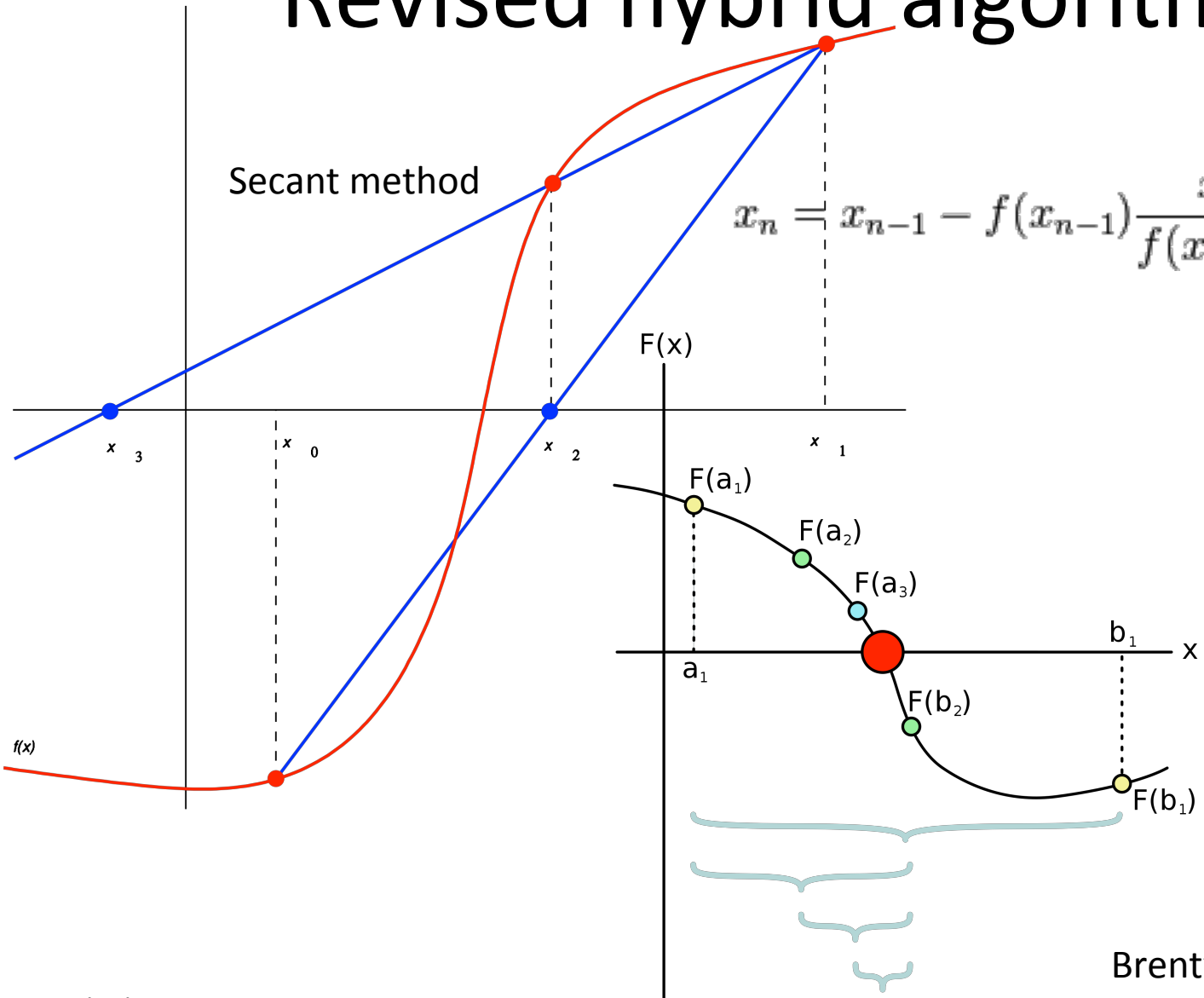
Sun et al., 2012

Revised hybrid algorithm



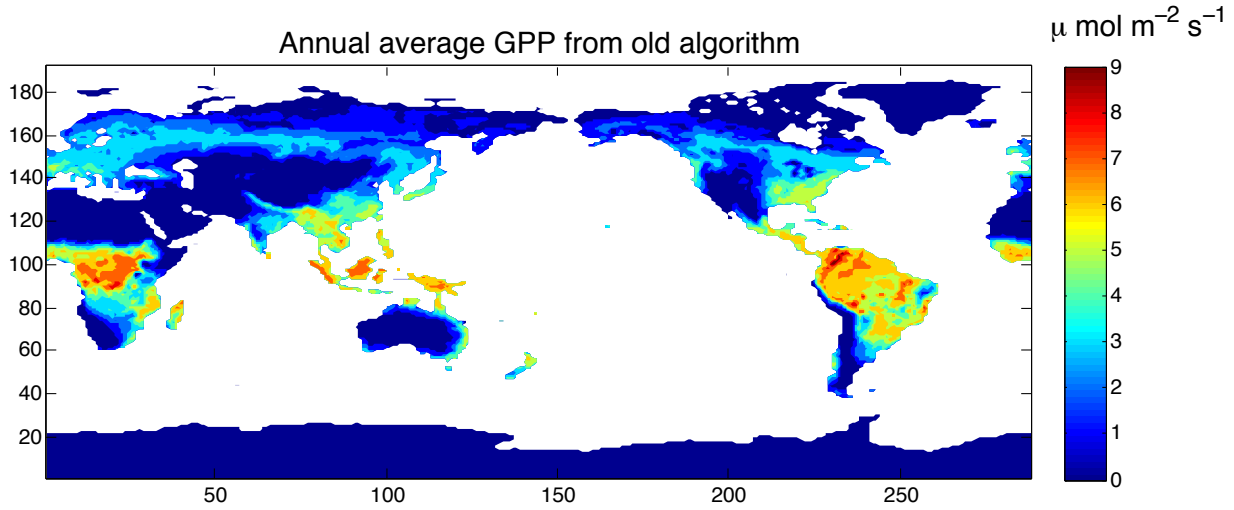
$$x_n = x_{n-1} - f(x_{n-1}) \frac{x_{n-1} - x_{n-2}}{f(x_{n-1}) - f(x_{n-2})}$$

Revised hybrid algorithm

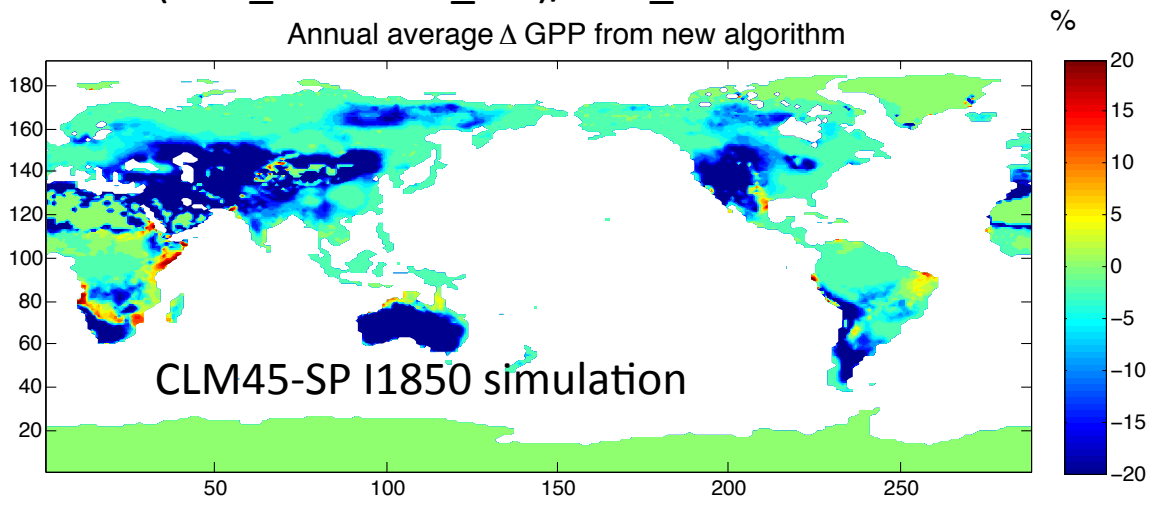


Brent's bisection method

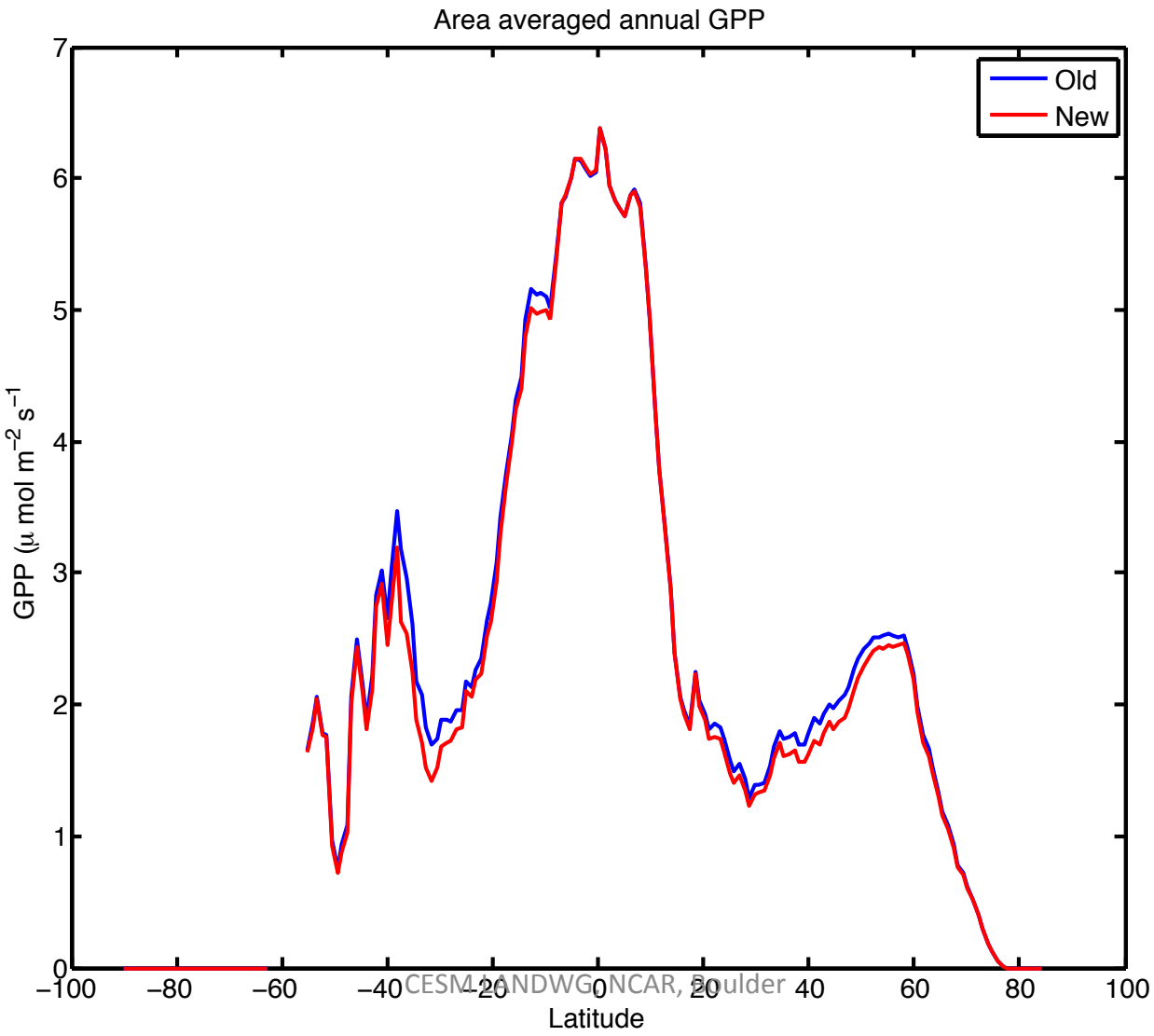
Change in annual GPP



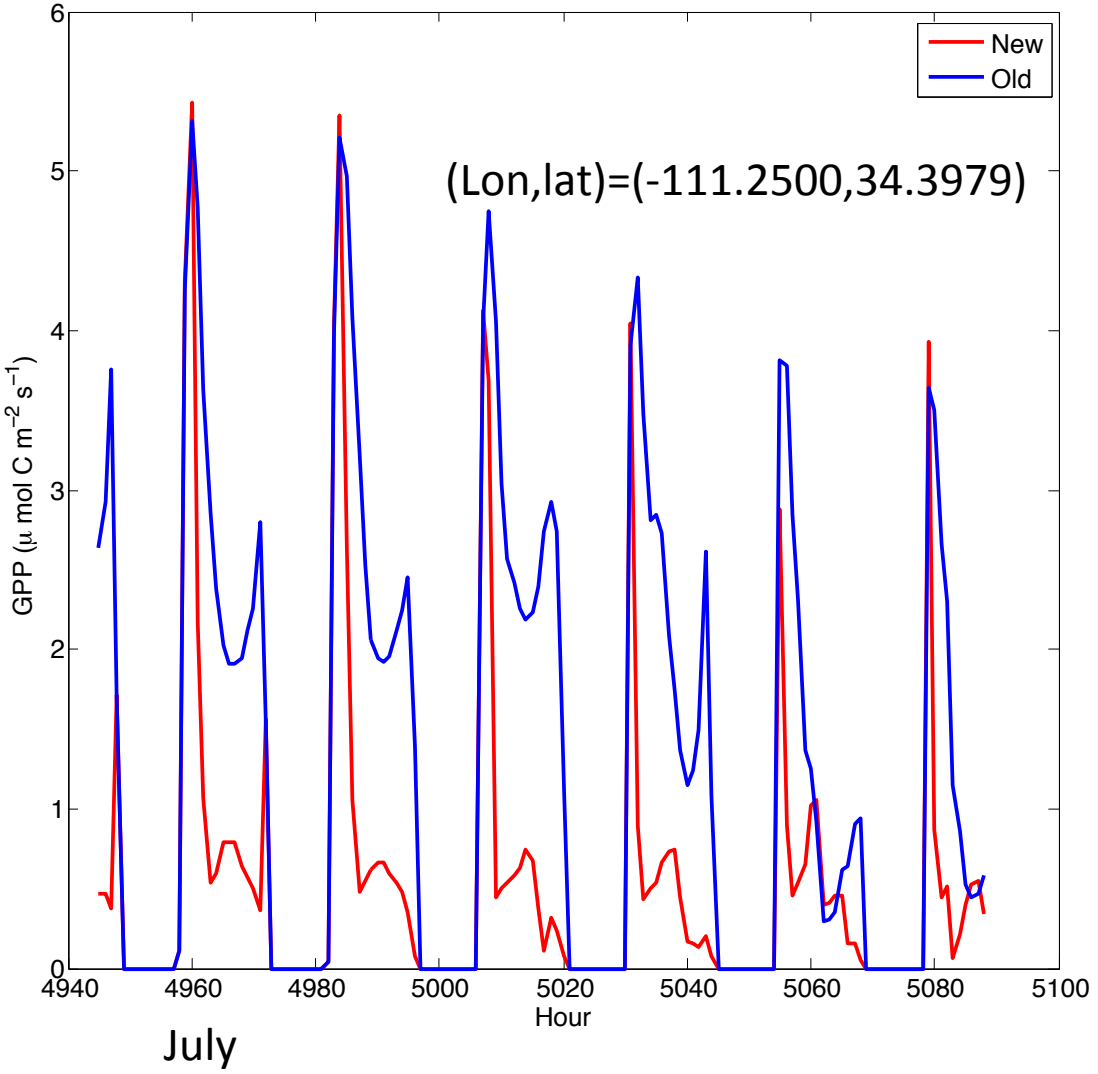
(GPP_new-GPP_old)/GPP_oldx100%



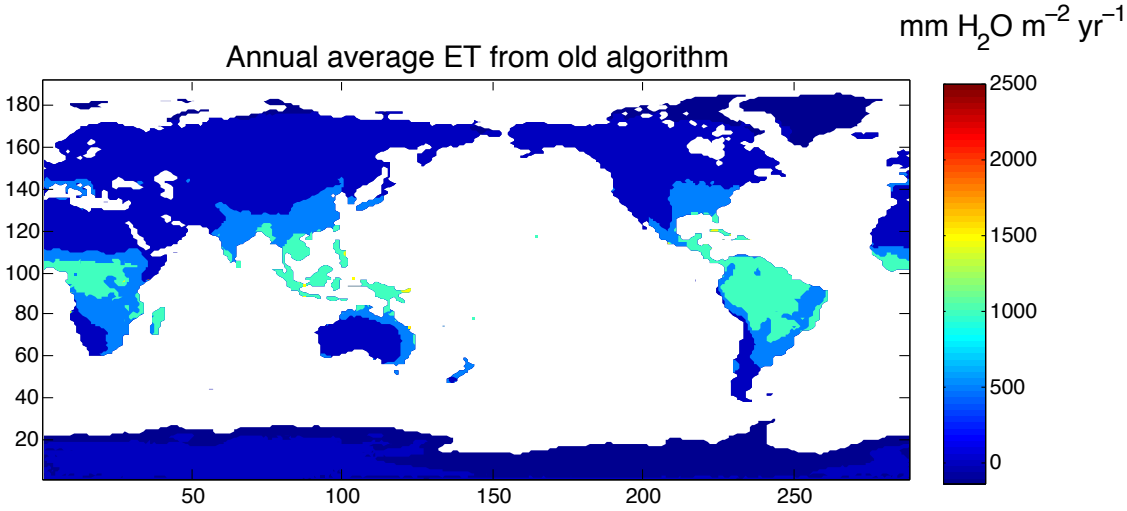
Change in GPP



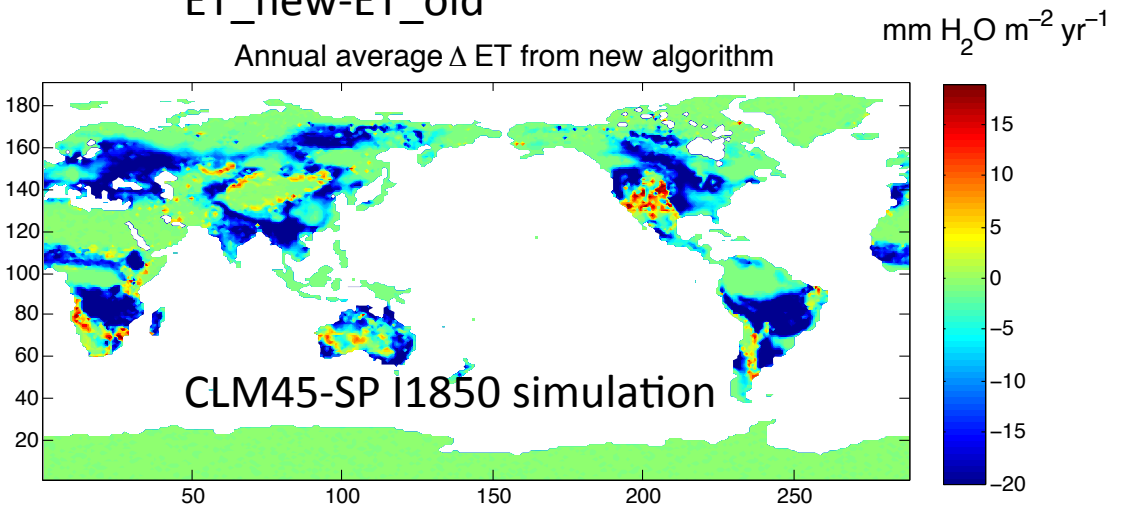
Diurnal cycle



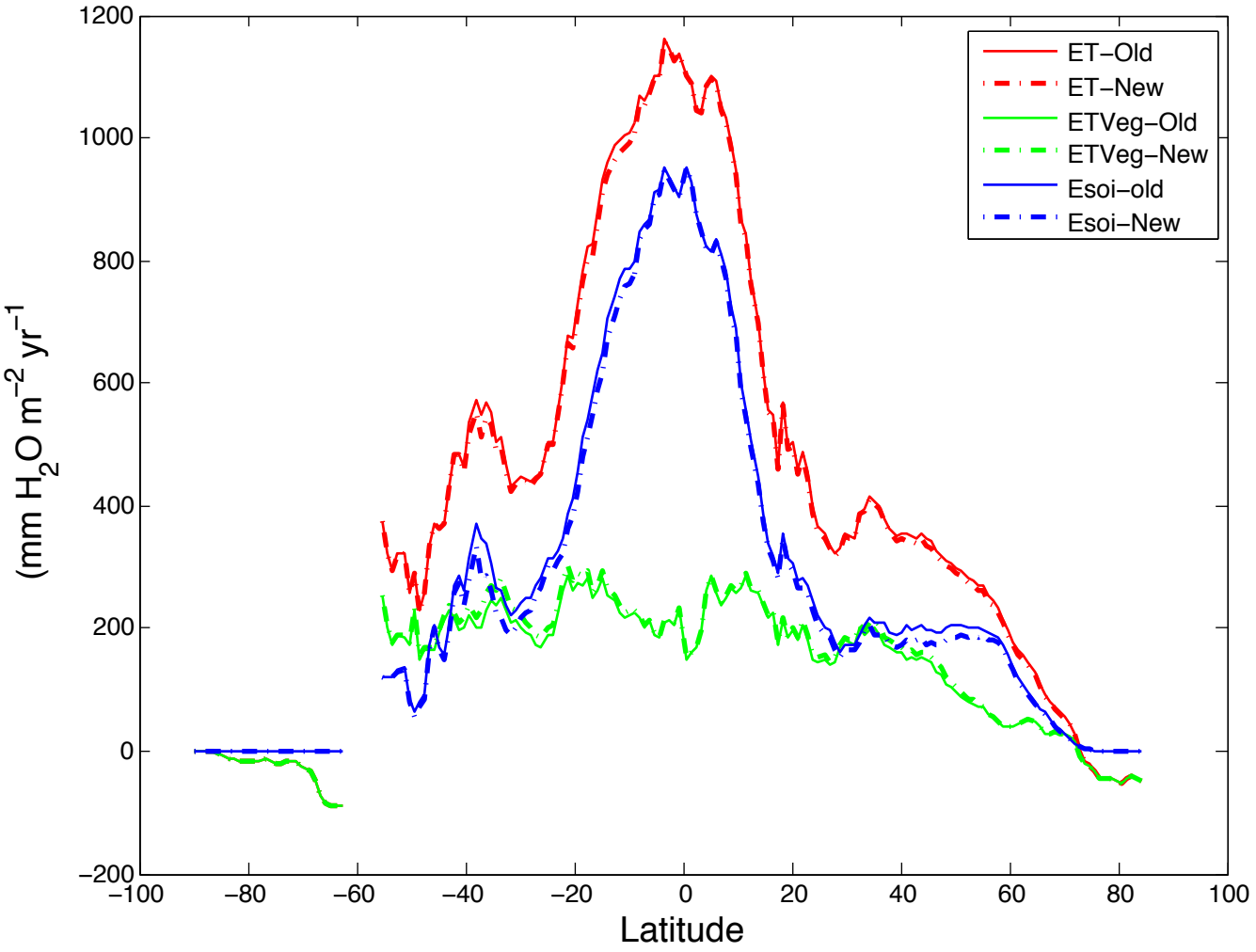
Change in ET



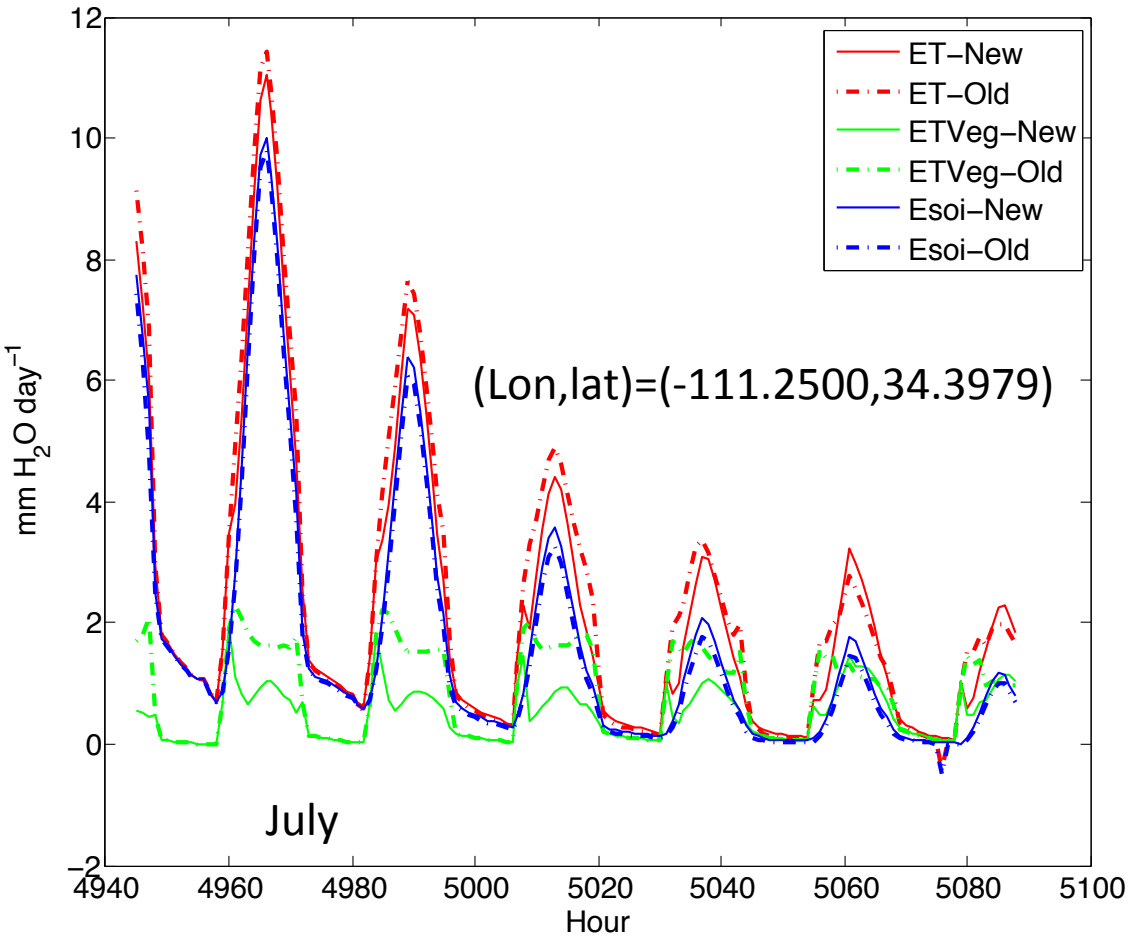
ET_new-ET_old



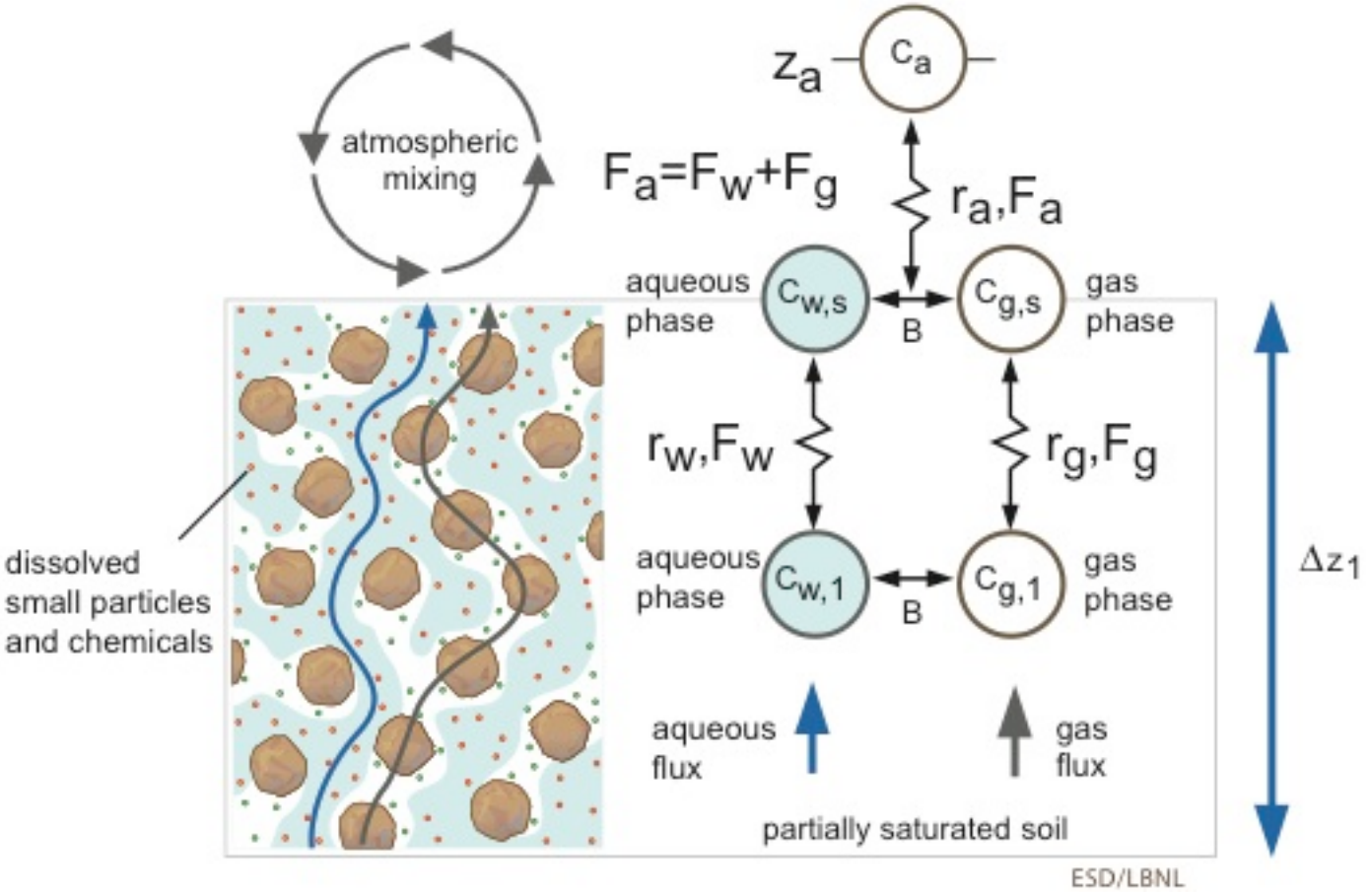
Change in ET


ET−Old
ET−New
ETVeg−Old
ETVeg−New
Esoi−old
Esoi−New
(mm H2O m−2 yr−1
Latitude
1200
1000
800
600
400
200
0
−200
−100
−80
−60
−40
−20
0
20
40
60
80
100

Diurnal cycle



Resistance for soil-atmosphere exchange of volatile chemicals



Tang and Riley, HESS, 2013

The mechanistic bulk resistance for soil-atmosphere exchange

$$r_T = r_a + \frac{\Delta z_1}{2D_1\left(\mathrm{B}\theta_1 + \varepsilon_1\right)}$$

$$D_1 = \frac{\mathrm{B}\theta_1 D_w + \varepsilon_1 D_g}{\mathrm{B}\theta_1 + \varepsilon_1}$$

$$D_w = D_{w,m} + D_{w,\psi}$$

$$D_{w,\psi} = K\left[\frac{\partial \psi}{\partial \theta} + \left(1 + \frac{\partial \psi}{\partial T}\frac{\partial T}{\partial z}\right)\frac{\partial z}{\partial \theta}\right]$$

The mechanistic bulk resistance for soil-atmosphere exchange

$$r_T = r_a + \frac{\Delta z_1}{2D_1\left(\mathrm{B}\theta_1 + \varepsilon_1\right)}$$

$$D_1 = \frac{\mathrm{B}\theta_1 D_w + \varepsilon_1 D_g}{\mathrm{B}\theta_1 + \varepsilon_1}$$

$$D_w = D_{w,m} + D_{w,\psi}$$

$$D_{w,\psi} = K\left[\frac{\partial \psi}{\partial \theta} + \left(1 + \frac{\partial \psi}{\partial T}\frac{\partial T}{\partial z}\right)\frac{\partial z}{\partial \theta}\right]$$

The mechanistic bulk resistance for soil-atmosphere exchange

$$r_T = r_a + \frac{\Delta z_1}{2D_1\left(\mathrm{B}\theta_1 + \varepsilon_1\right)}$$

$$D_1 = \frac{\mathrm{B}\theta_1 D_w + \varepsilon_1 D_g}{\mathrm{B}\theta_1 + \varepsilon_1}$$

$$f_W = \frac{\mathrm{B}\theta_1 D_w}{\mathrm{B}\theta_1 D_w + \varepsilon_1 D_g}$$

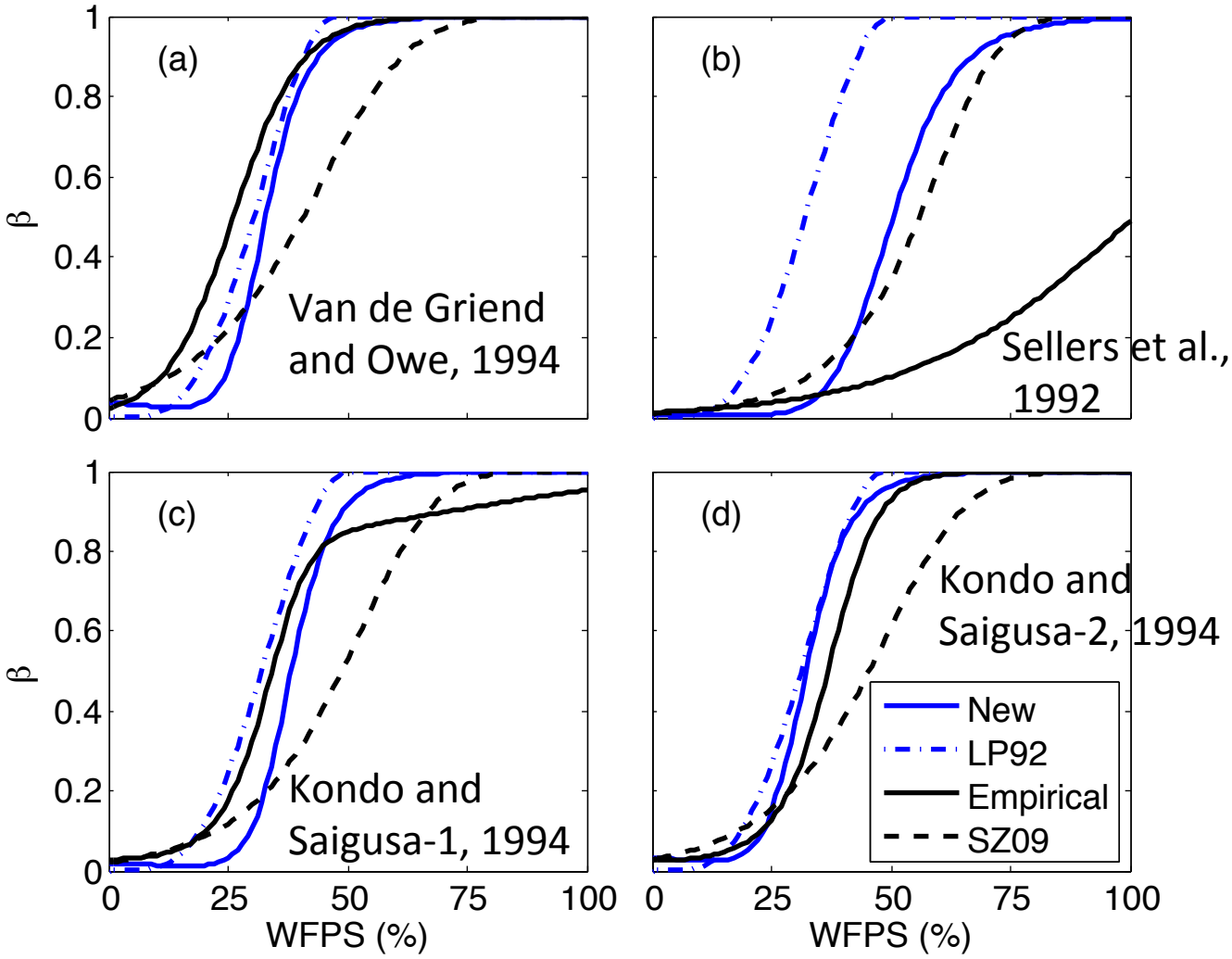
$$D_w = D_{w,m} + D_{w,\psi}$$

$$f_g = \frac{\varepsilon_1 D_g}{\mathrm{B}\theta_1 D_w + \varepsilon_1 D_g}$$

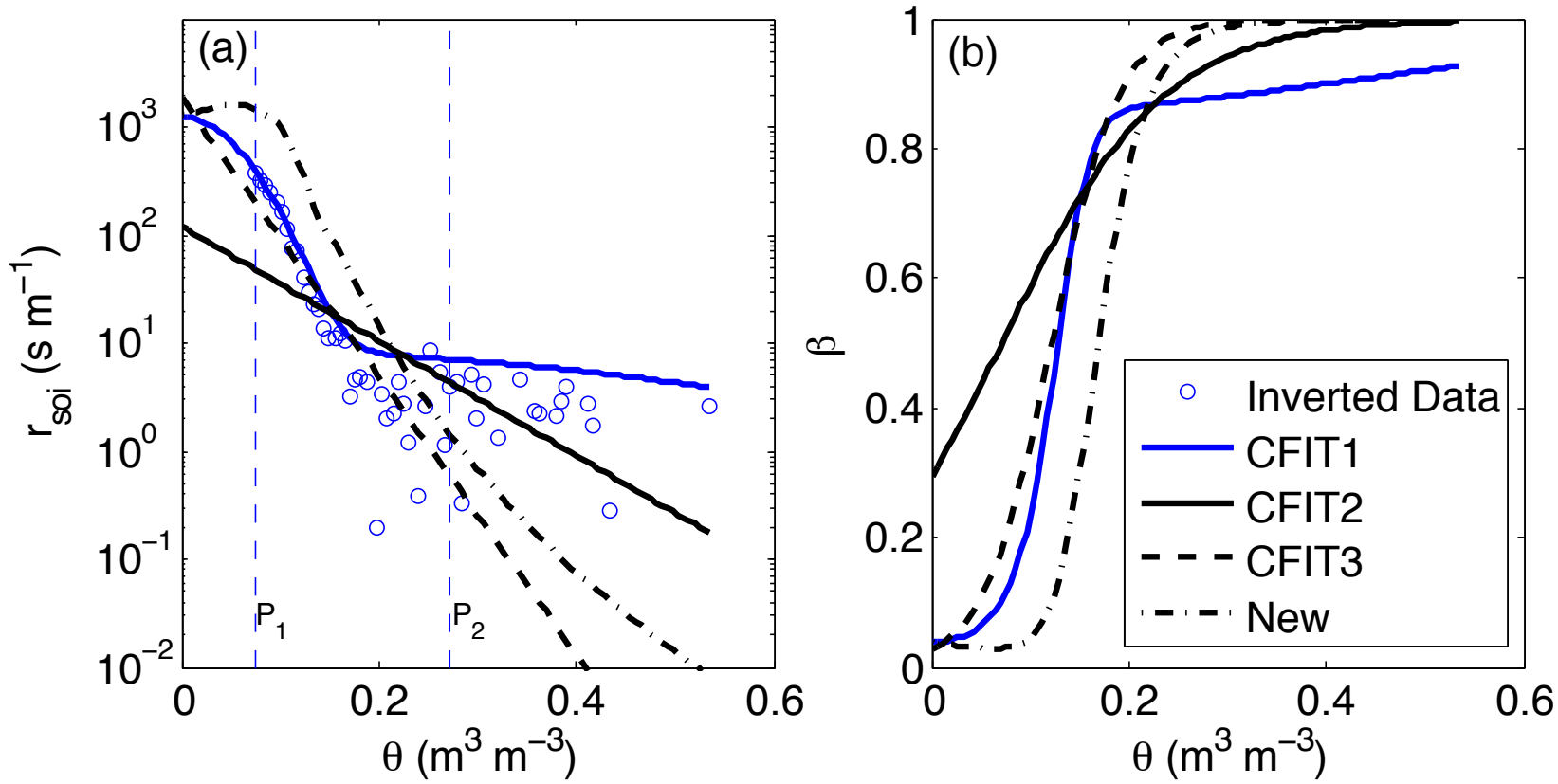
$$D_{w,\psi} = K\left[\frac{\partial \psi}{\partial \theta} + \left(1 + \frac{\partial \psi}{\partial T}\frac{\partial T}{\partial z}\right)\frac{\partial z}{\partial \theta}\right]$$

Beta factors

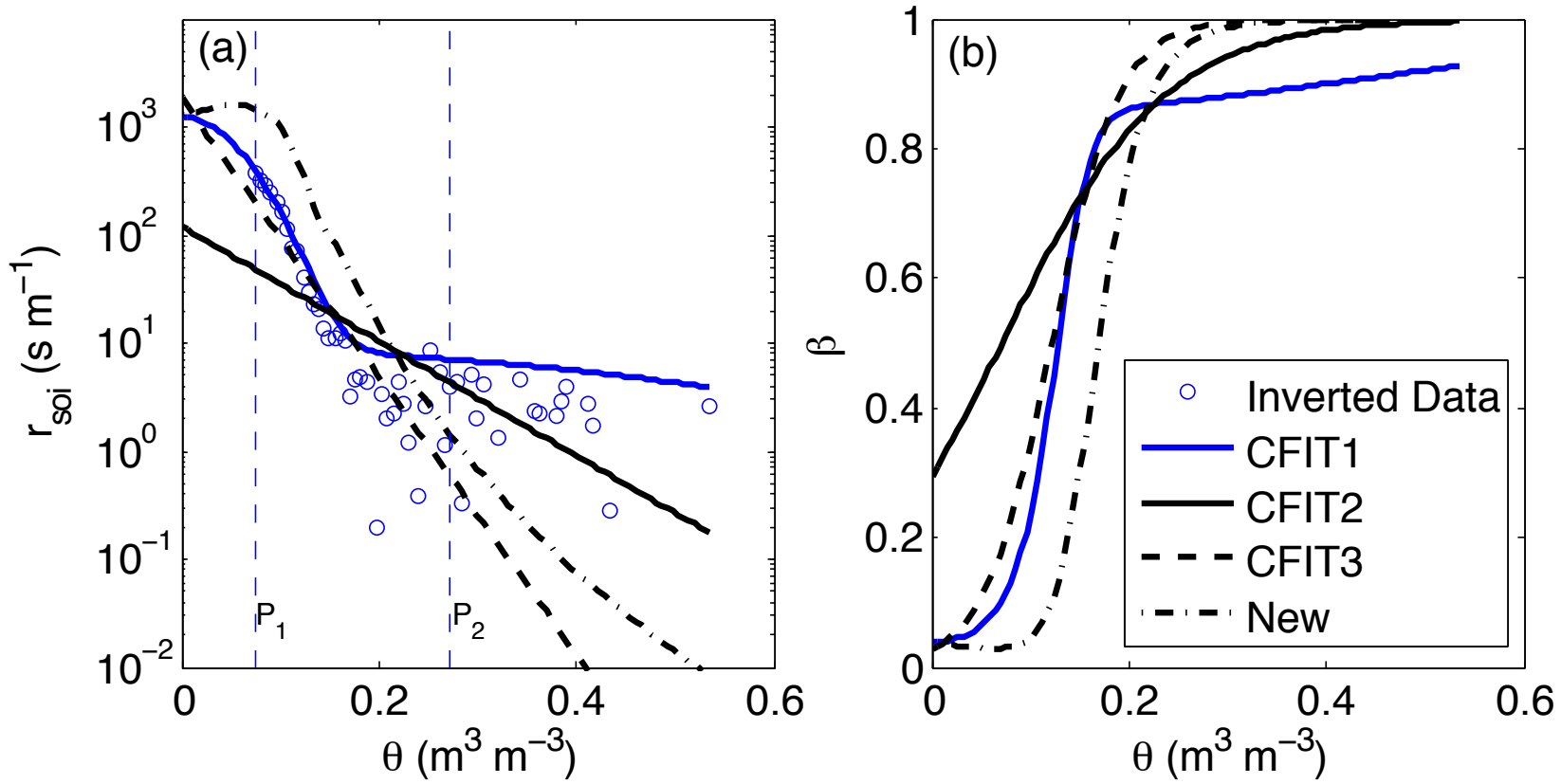
$$\beta = \frac{E_a}{E_p}$$



Data error sensitivity

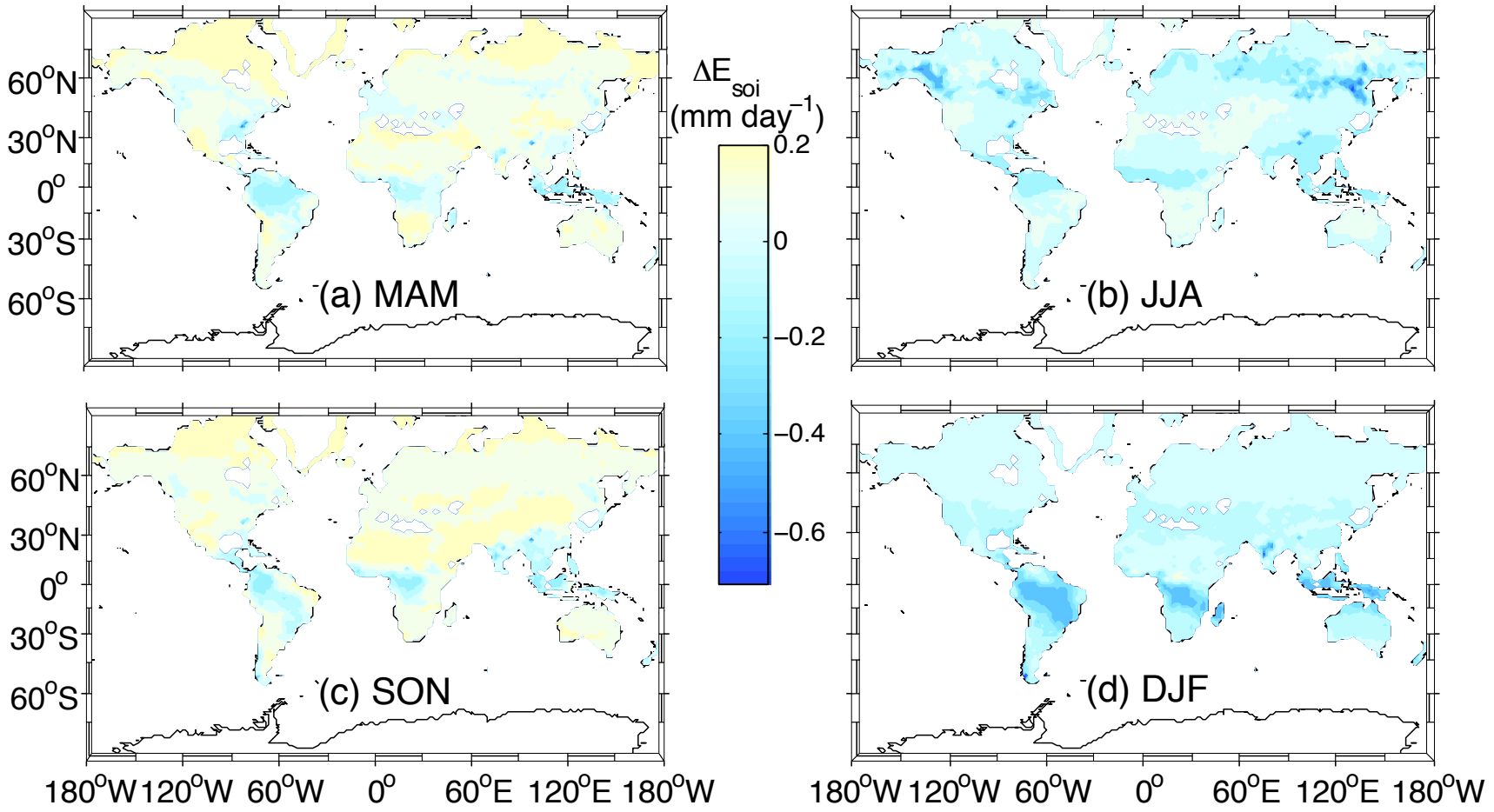


Data error sensitivity



Empirical data are very likely severely error convolved

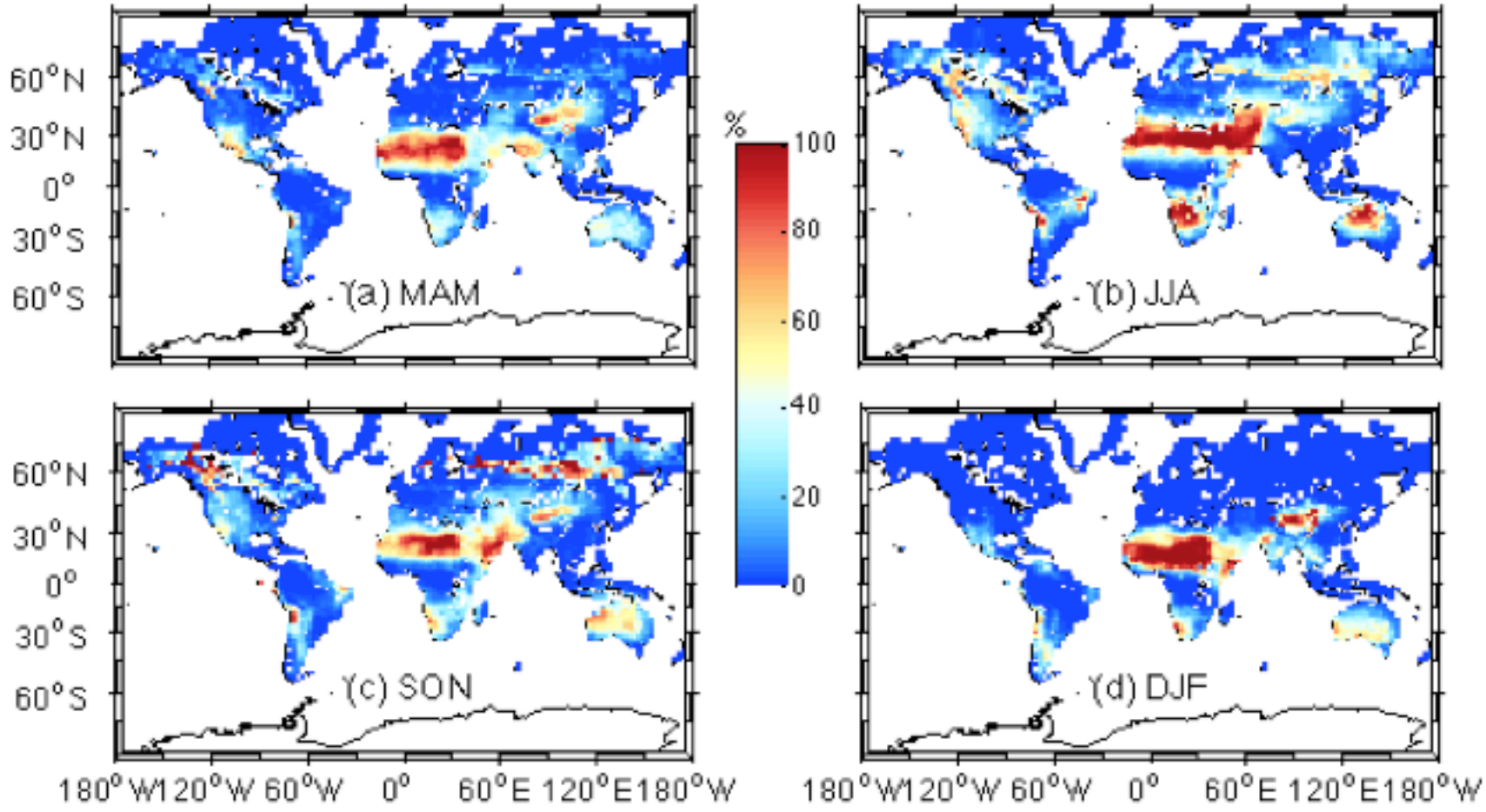
Change in soil evaporation



5-yr average difference, CLM4SP, I-2000

Tang and Riley, JAMES, In review

Soil evaporation partitioning



5-yr average difference, CLM4SP, I-2000

Tang and Riley, JAMES, In review

Summary

- The revised numerical algorithm improved the stomatal resistance calculation.

- The mechanistically based soil resistance improved the physical understanding of soil evaporation.