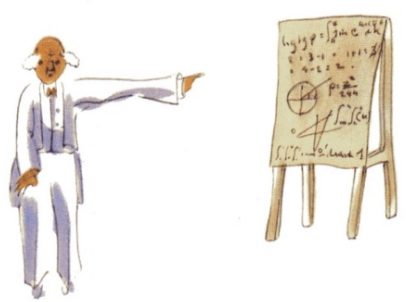
A Multilayer Canopy Model for CLM

Gordon Bonan, Ned Patton, Keith Oleson
National Center for Atmospheric Research
Boulder, Colorado, USA

Ian Harman
CSIRO Marine and Atmospheric Research



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Boulder, Colorado
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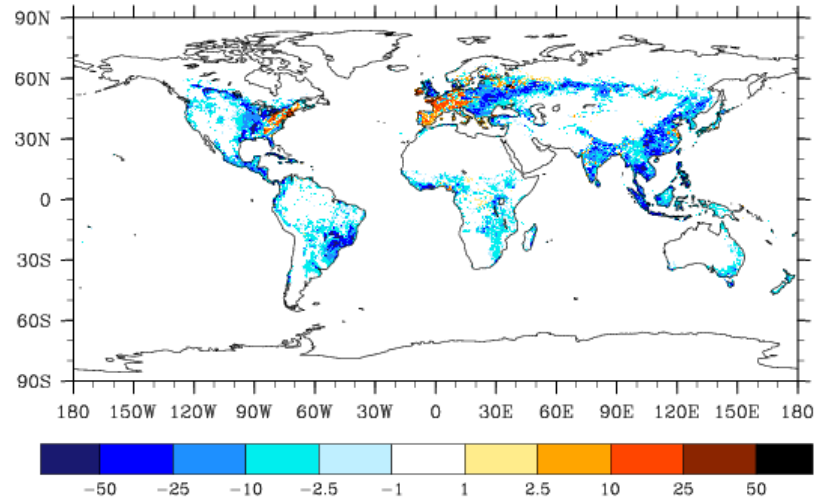
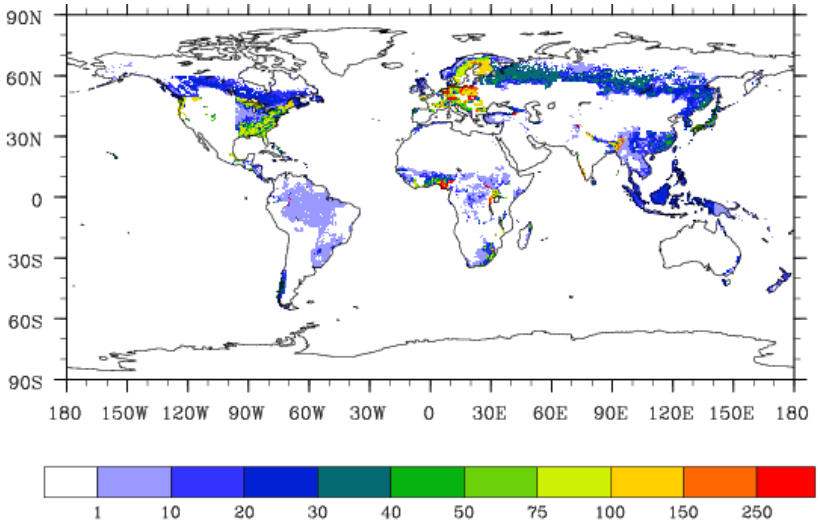
Land management

Forest management

Change in tree cover as percent of grid cell (1850 - 2005)



Cumulative percent of grid cell harvested (1850 - 2005)



Lawrence et al. (2012) J Climate 25:3071-3095

Agricultural management

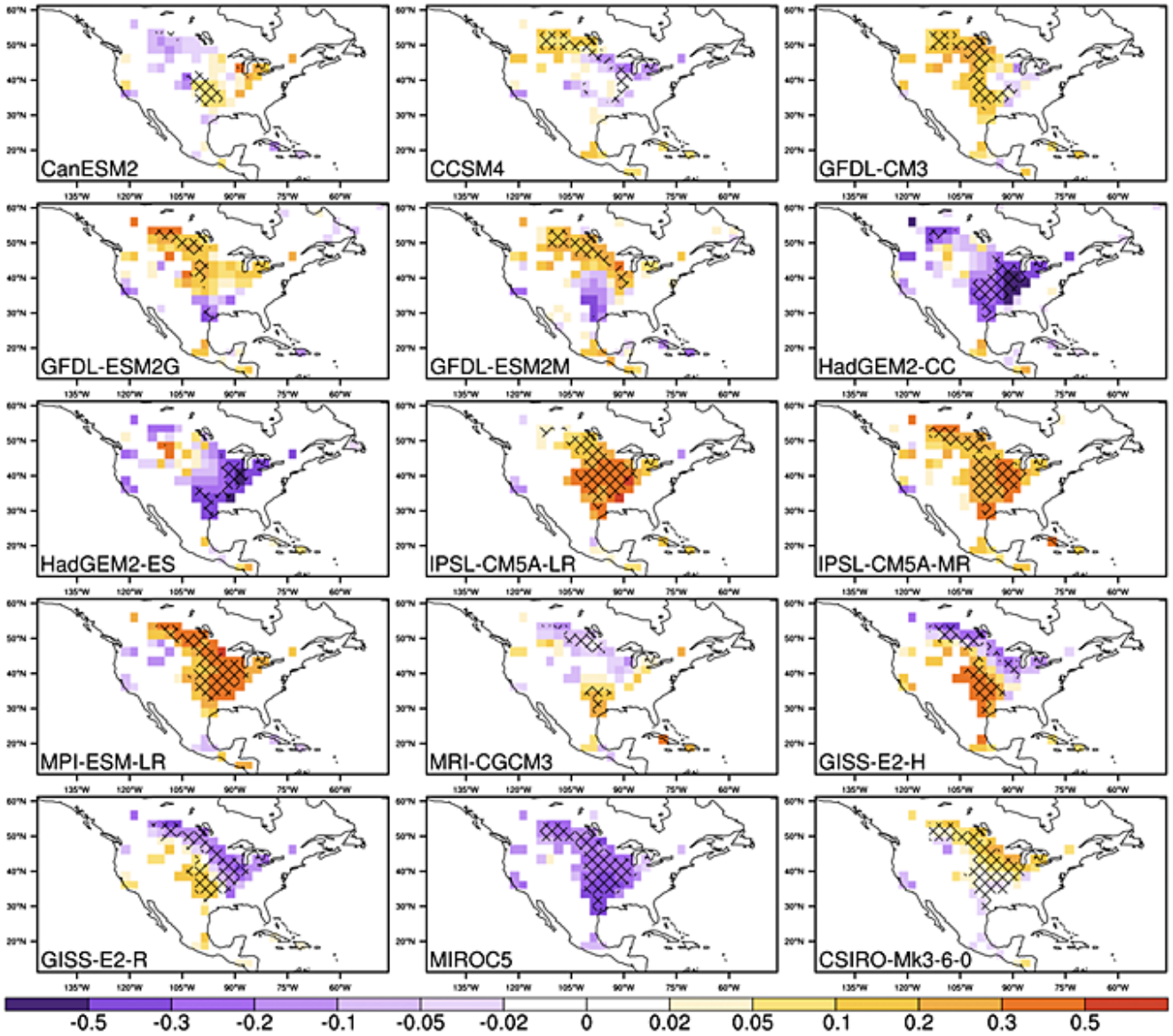
Tillage
Crop selection
Irrigation
Fertilizer use

<u>8 crop functional types</u>:

Maize (temperate, tropical)	Sugarcane
Soybean (temperate, tropical)	Cotton
Spring wheat	Rice

20th century land-cover change and climate

15 CMIP5 models: Δ JJA temperature with land-cover change



Deforestation

+ Δ albedo → cooling

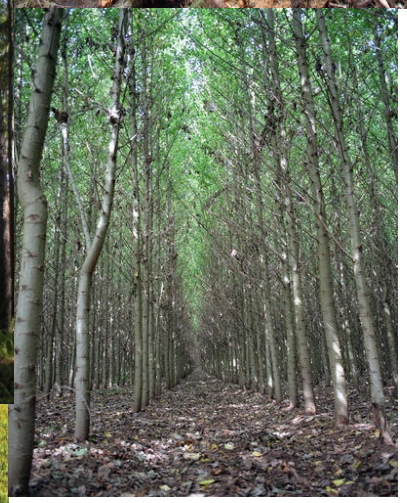
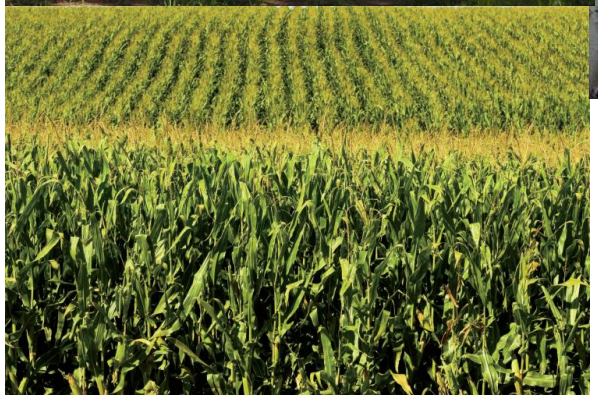
- Δ ET → warming

- Δ z_0 → warming

Kumar et al. (2013) JGR: Atm, 118, doi:10.1002/jgrd.50463

Humans, ecosystems, and climate

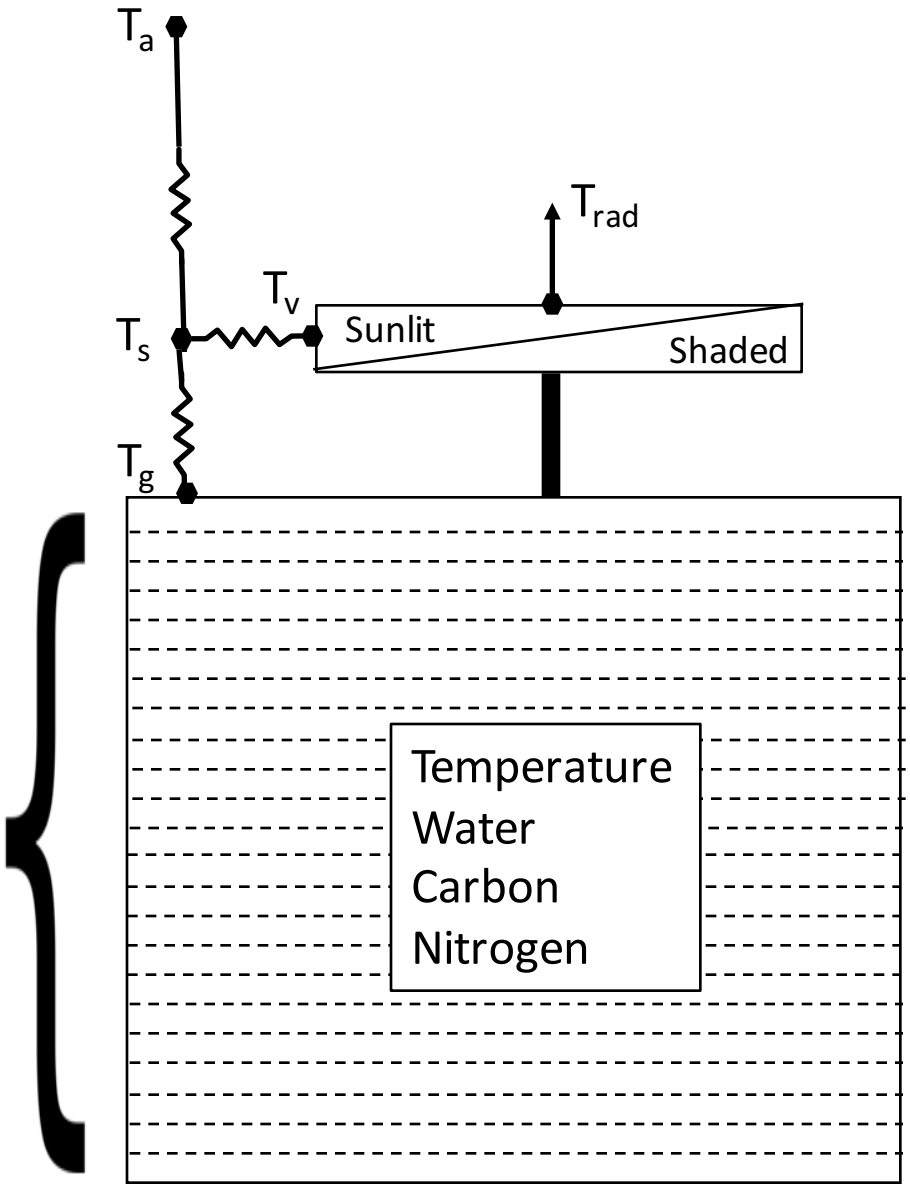


Much of the biosphere is now managed by human activities

Do the details of land-atmosphere coupling matter as we assess the climatic impacts of land management and land-cover change?

The CLM5 perspective of the land surface



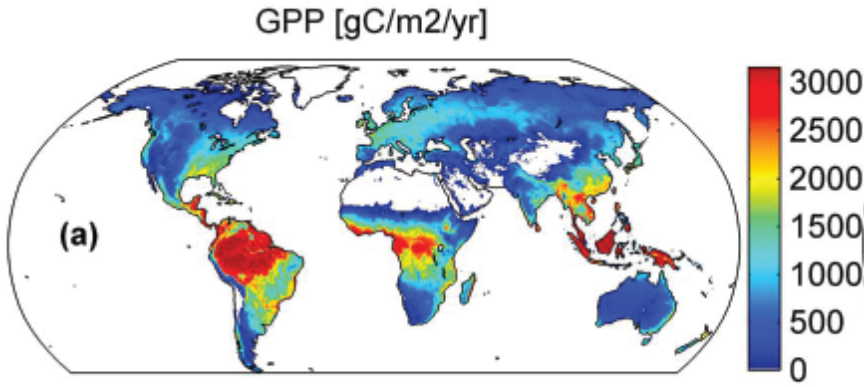
Soil/snow

12 snow layers
20 soil layers
5 bedrock layers

Multi-scale model evaluation

Canopy fluxes
Net radiation, latent heat flux, sensible heat flux, GPP

AmeriFlux, FLUXNET



Global vegetation
GPP, latent heat flux

Upscaled FLUXNET products

Canopy processes
Theory
Numerical parameterization

Profiles of light, temperature, wind, water stress, nitrogen, and leaf traits

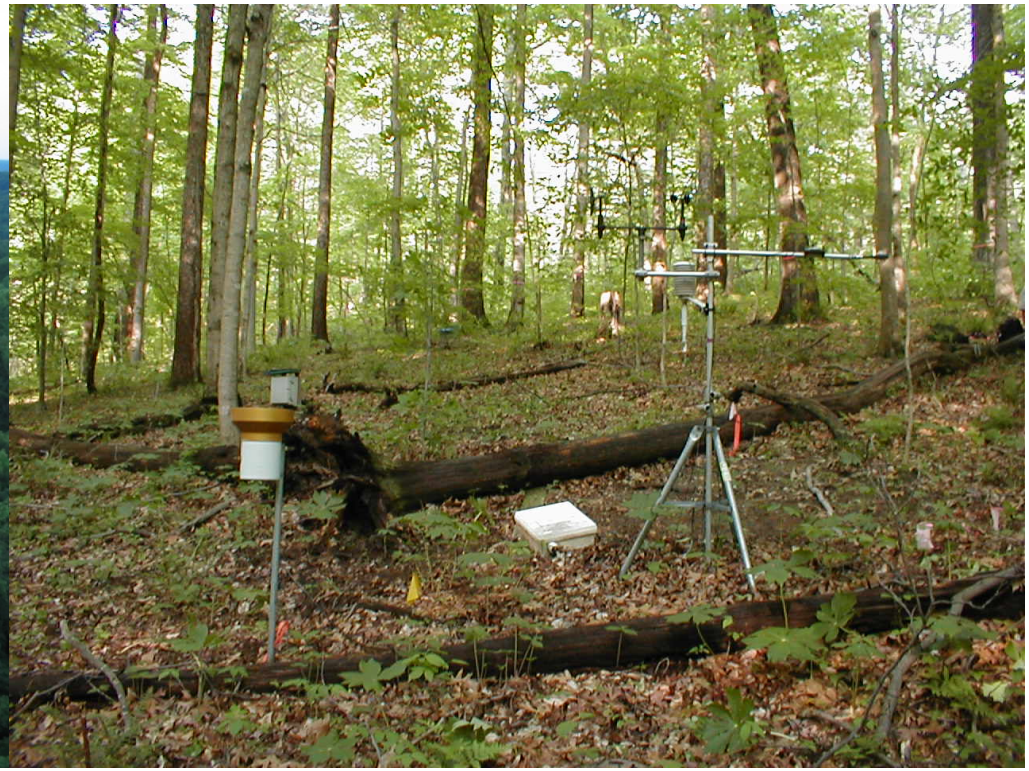
Leaf traits
Leaf N, specific leaf area, V_{cmax}

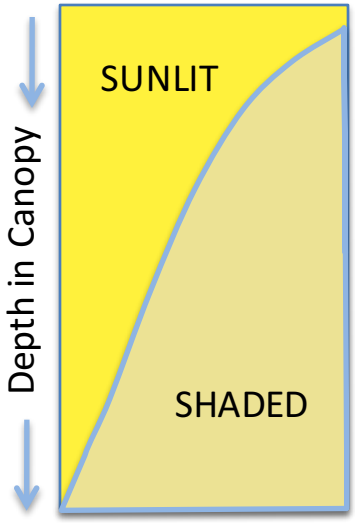
Glopnet, TRY

Consistency among parameters, theory, processes, and observations across multiple scales, from leaf to canopy to global

Two ways to model plant canopies

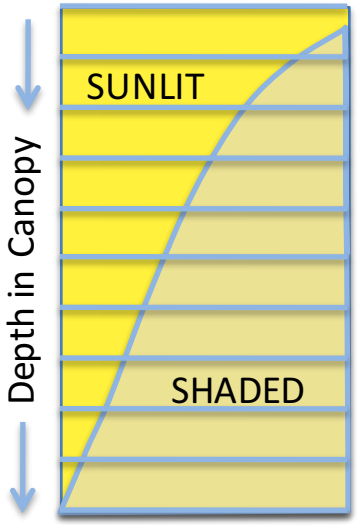
Photographs of Morgan Monroe State Forest tower site illustrate two different representations of a plant canopy: as a "big leaf" (below) or with vertical structure (right)





Big-leaf canopy

- Two "big-leaves" (sunlit, shaded)
- Radiative transfer integrated over LAI (two-stream approximation)
- Photosynthesis calculated for sunlit and shaded big-leaves

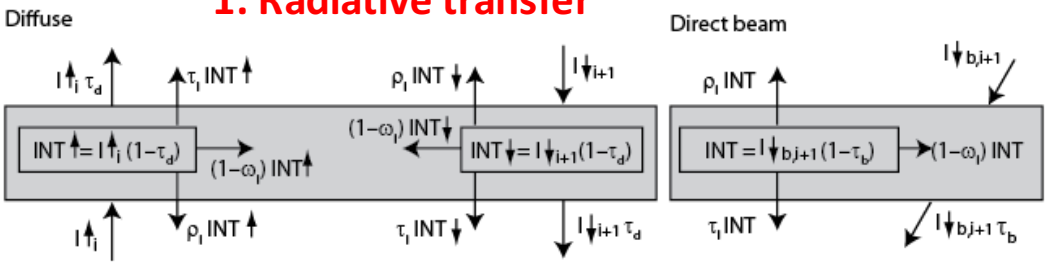


Multilayer canopy

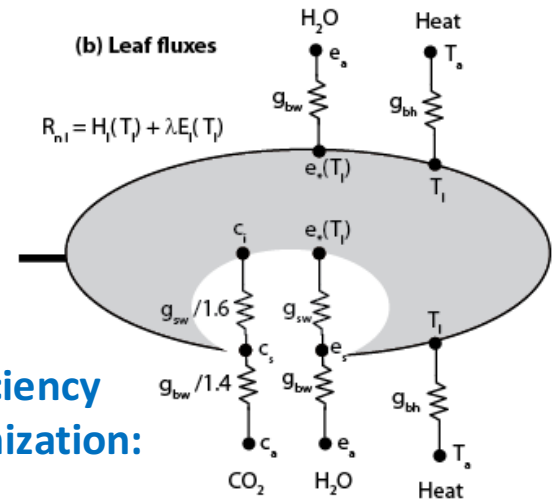
- Explicitly resolves sunlit and shaded leaves at each layer in the canopy
- Light, temperature, humidity, wind speed, H, E, A_n, g_s, ψ_L
- New opportunities to model stomatal conductance from plant hydraulics (g_s, ψ_L)

A multilayer canopy model for CLM

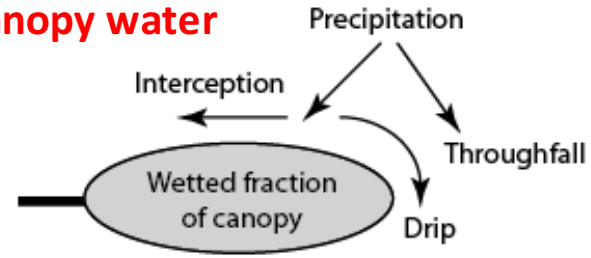
1. Radiative transfer



2. Leaf fluxes (CO_2, H, E)



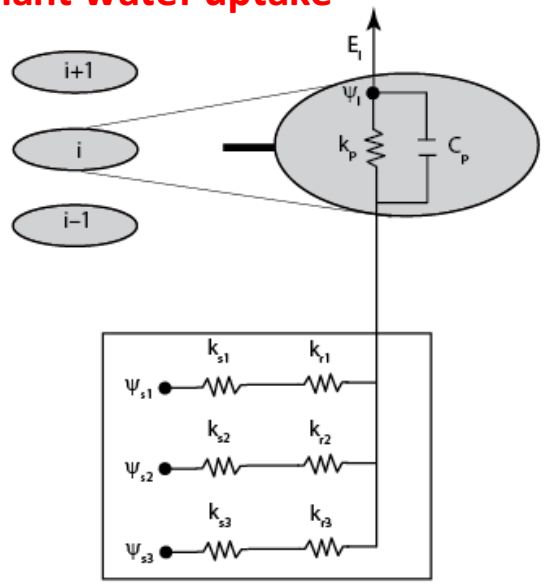
4. Canopy water



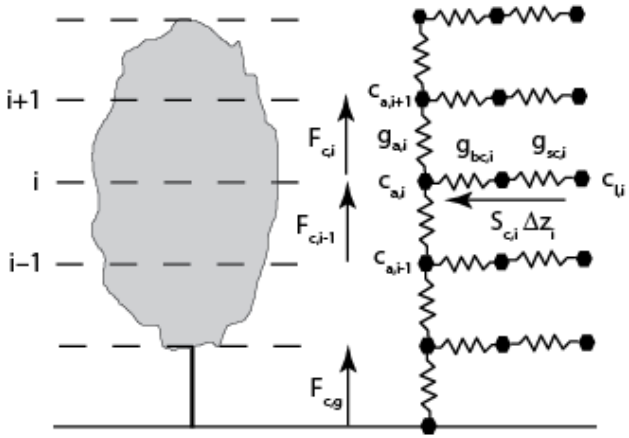
Water-use efficiency stomatal optimization:

$\Delta A_n/\Delta E_l > \iota$ and $\psi_L > \psi_{Lmin}$

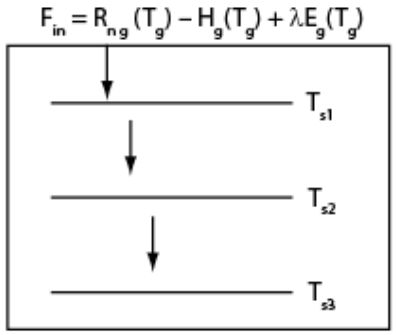
3. Plant water uptake



6. Above and within canopy turbulence and scalar profiles



5. Soil fluxes



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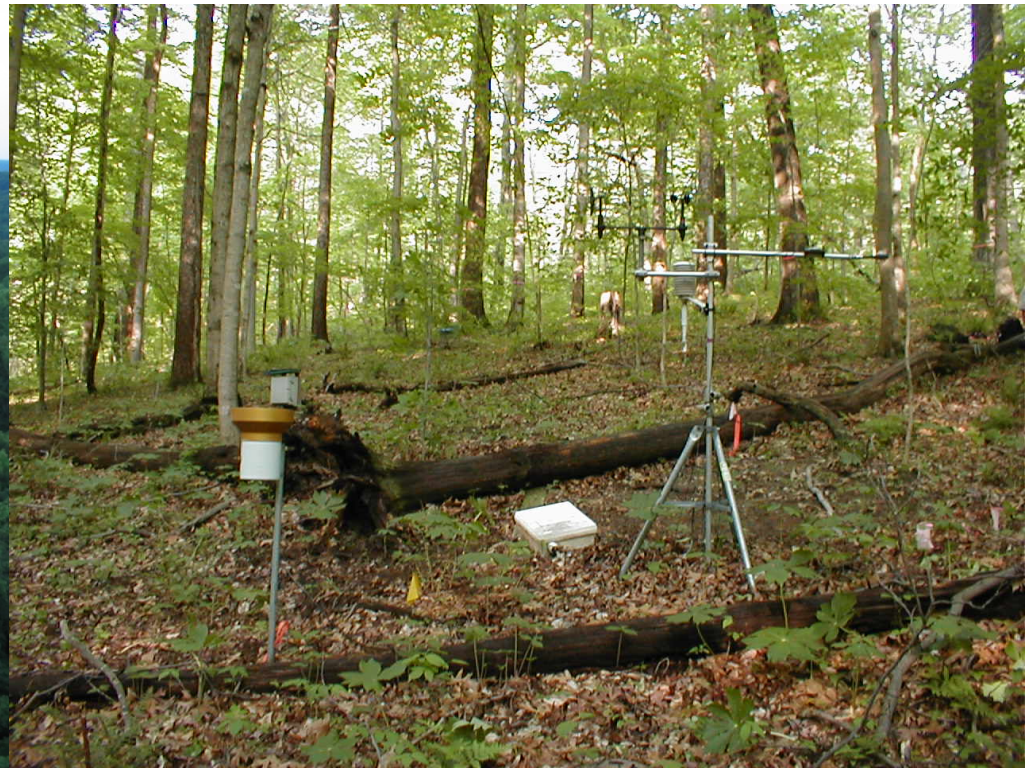


AmeriFlux
3 deciduous broadleaf forests
3 evergreen needleleaf forests
51 site x years

CLM4.5 → multilayer model

Multilayer canopy improved relative to CLM4.5 (H, GPP)

Ball-Berry → stomatal optimization

$\Delta A_n/\Delta E_l$ and ψ_L optimization improved relative to Ball-Berry. Especially apparent at US-Me2 (drought-stressed)

Bonan et al. (2014) Geosci. Model Dev. 7:2193-2222

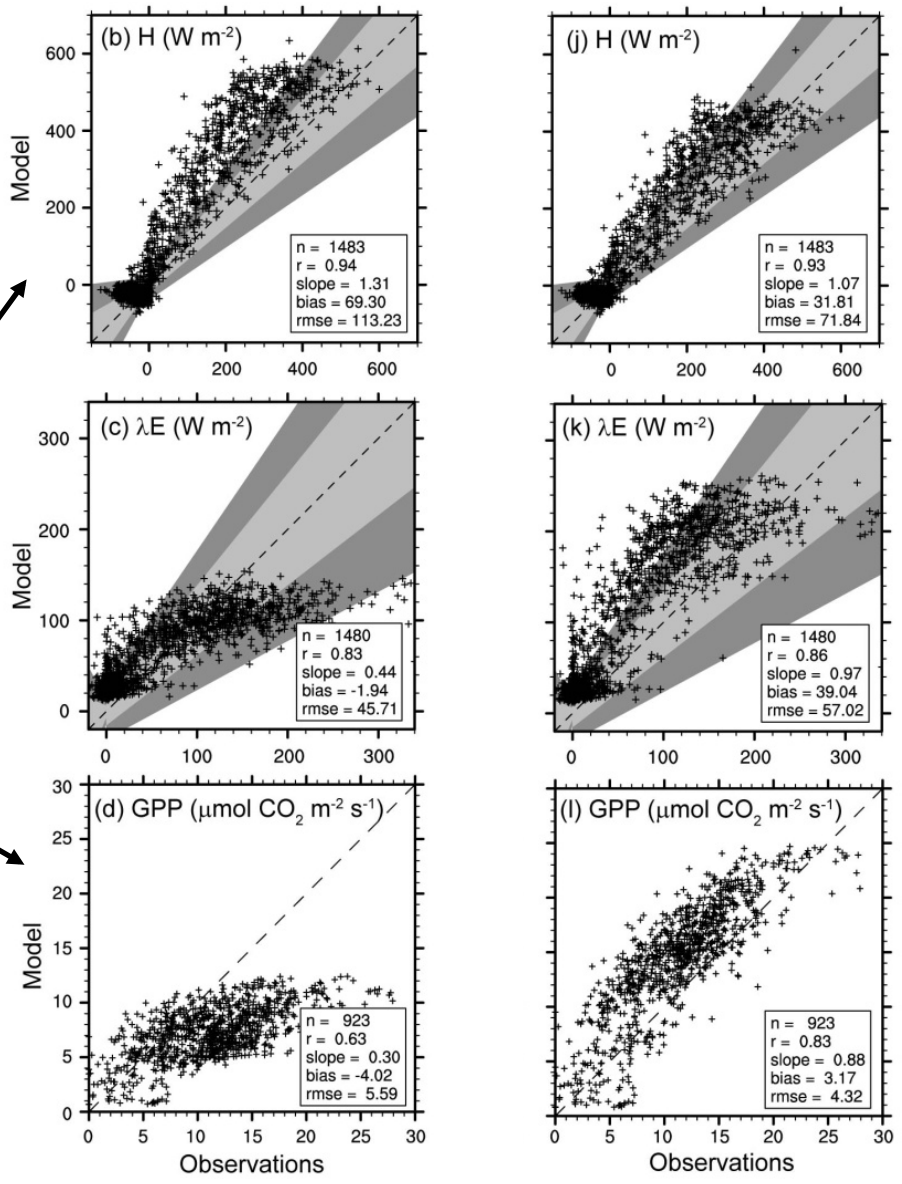
Drought stress: US-Me2, July 2002 (Ponderosa pine)

Shown are scatter plots of model (vertical axis) and observed (horizontal axis) 30-min fluxes for the month of July 2002

CLM4.5 Ball-Berry parameterization overestimates sensible heat flux, underestimates mid-day peak latent heat flux, and systematically underestimates GPP

Ball-Berry with β factor

$\Delta A_n/\Delta E_l$ and ψ_L optimization



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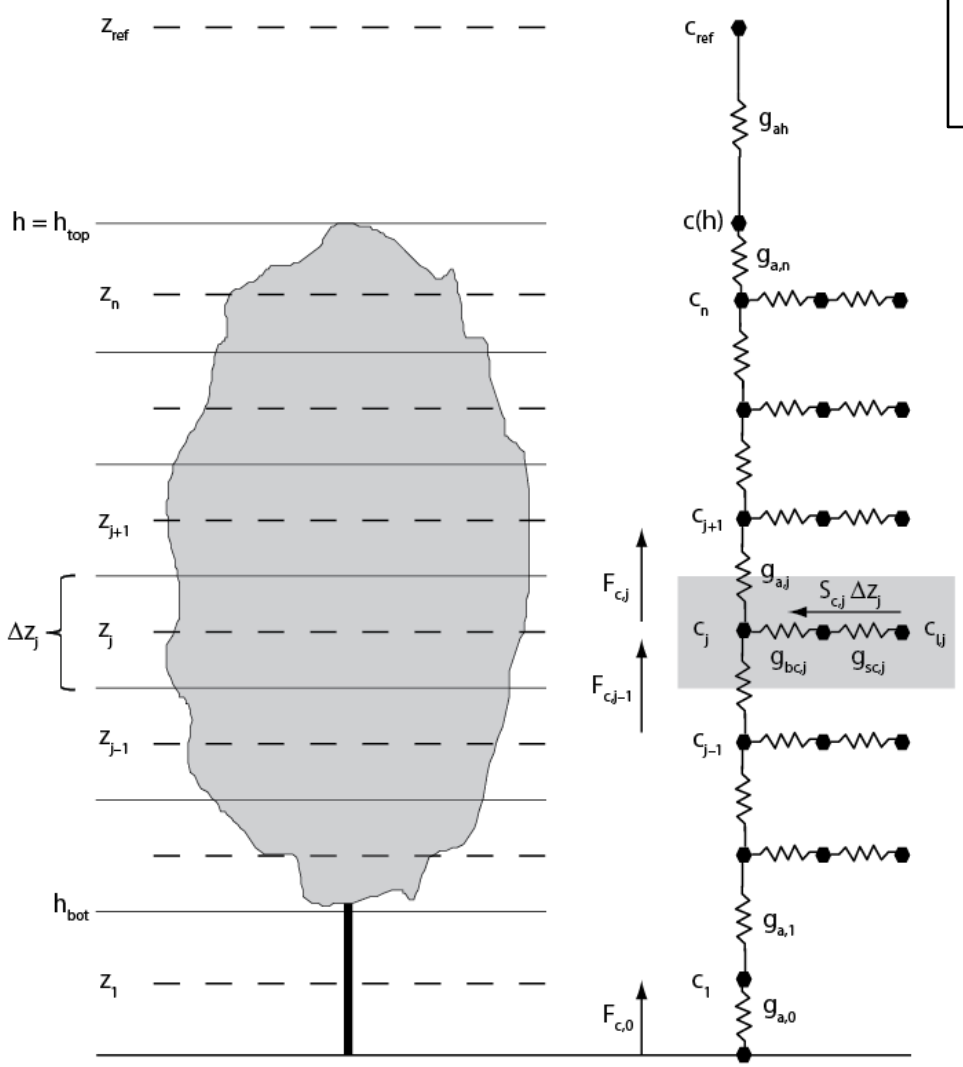
Scalar profiles



Coupling challenge: scalar profiles depend on source (leaf, soil) fluxes but these fluxes depend on scalar profiles

Leaf energy balance

$$c_L \frac{\partial T_L}{\partial t} = R_n - H_L(T_L) - \lambda E_L(T_L)$$

Conservation equation for heat

$$\rho_m c_p \frac{\partial T(z)}{\partial t} + \frac{\partial H(z)}{\partial z} = H_L(z)$$

Conservation equation for water vapor

$$\rho_m \frac{\partial w(z)}{\partial t} + \frac{\partial E(z)}{\partial z} = E_L(z)$$

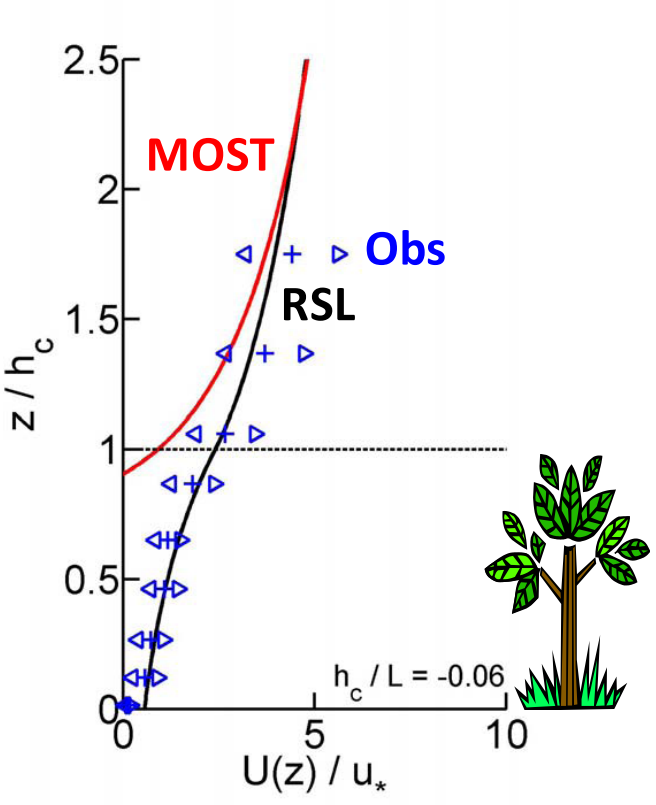
Soil surface balance

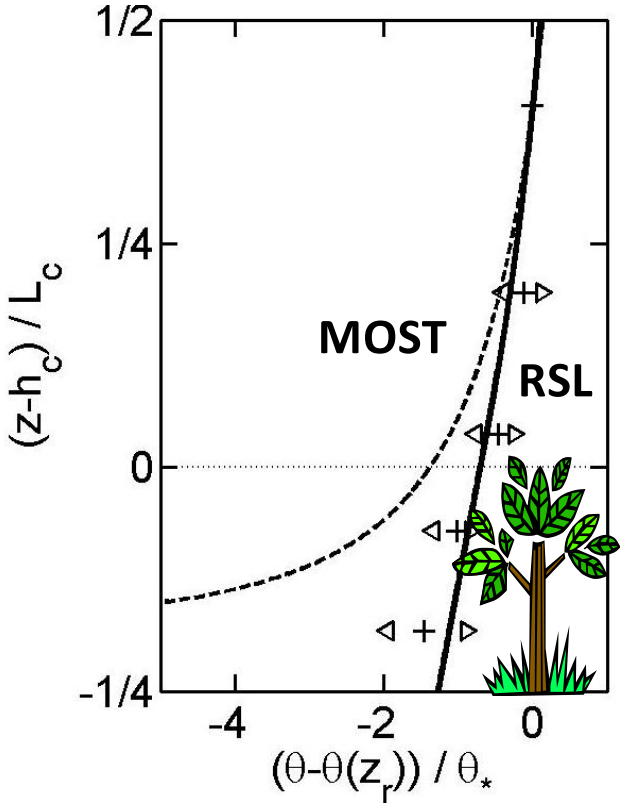
$$R_n - H(T_g) - \lambda E(T_g) - G(T_g) = 0$$

Canopy turbulence and the roughness sublayer

Profiles from the CSIRO flux station near Tumbarumba

CLM (and most other models) use MOST, which fails above and within plant canopies





Key collaborators:
Ned Patton (NCAR)
Ian Harman (CSIRO Marine and Atmospheric Research)

Harman & Finnigan (2007) Boundary-Layer Meteorol. 123:339-363
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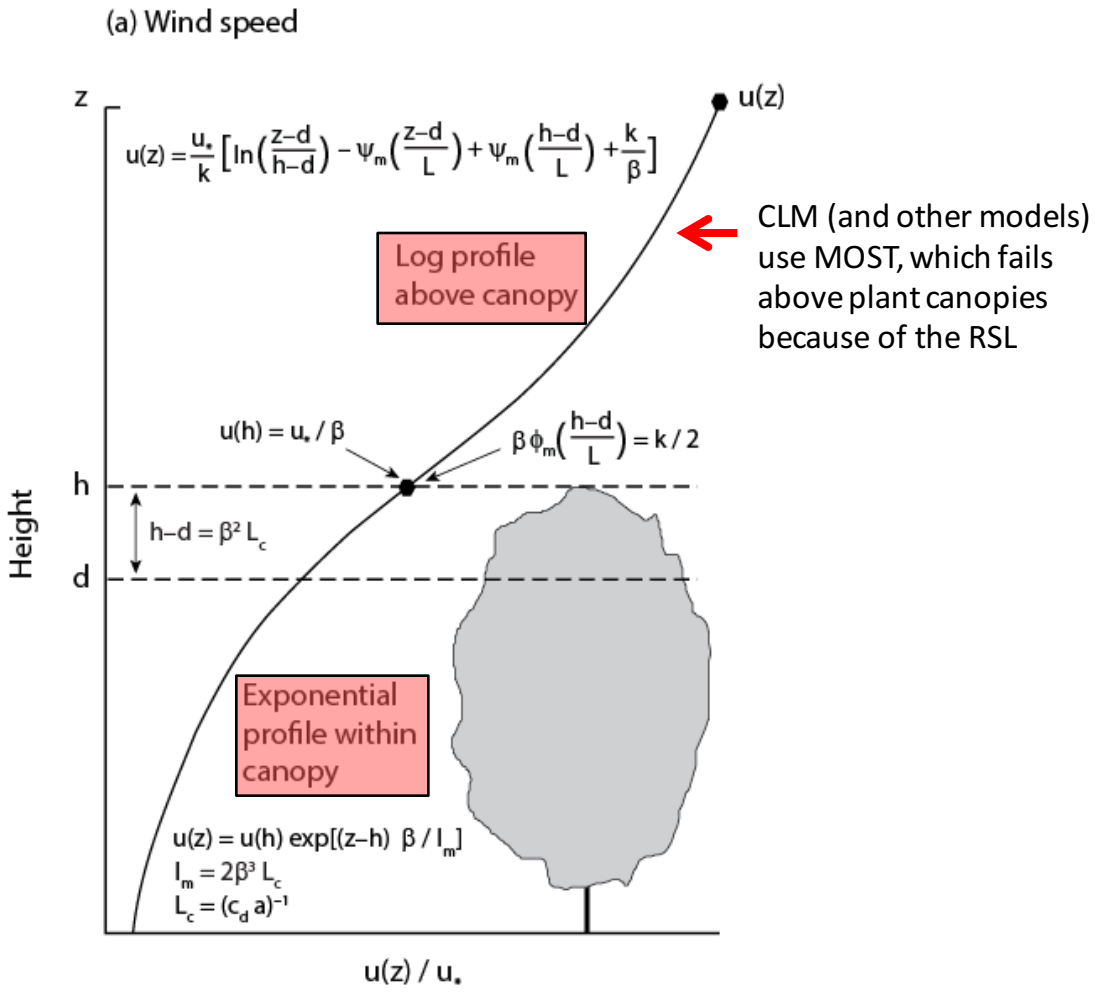
Coupling above and within plant canopies



CLM (and other models) use MOST, which fails above plant canopies because of the RSL

First-order closure

$$H(z) = -\rho_m c_p K_c(z) \frac{\partial T(z)}{\partial z}$$

$$E(z) = -\rho_m K_c(z) \frac{\partial w(z)}{\partial z}$$

$$K_c(z) = l_m l_c \frac{\partial u(z)}{\partial z}$$

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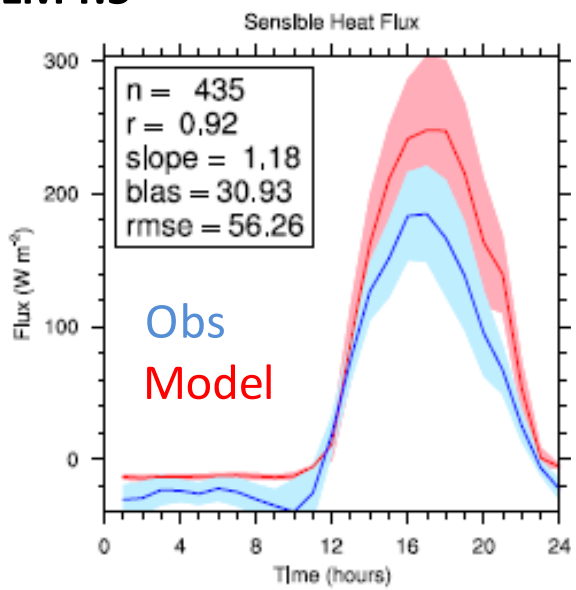
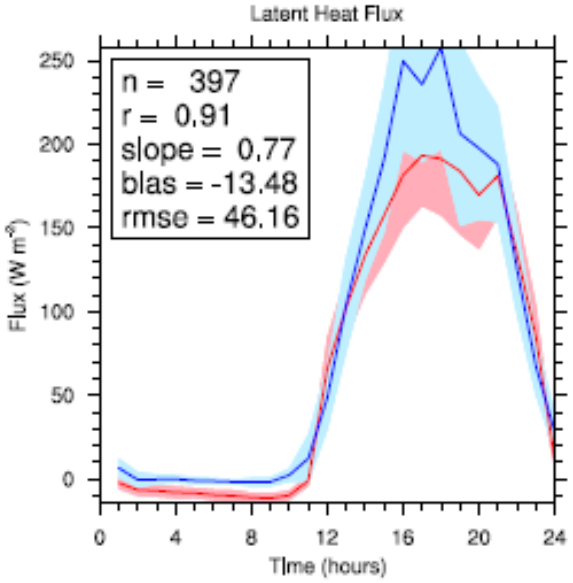
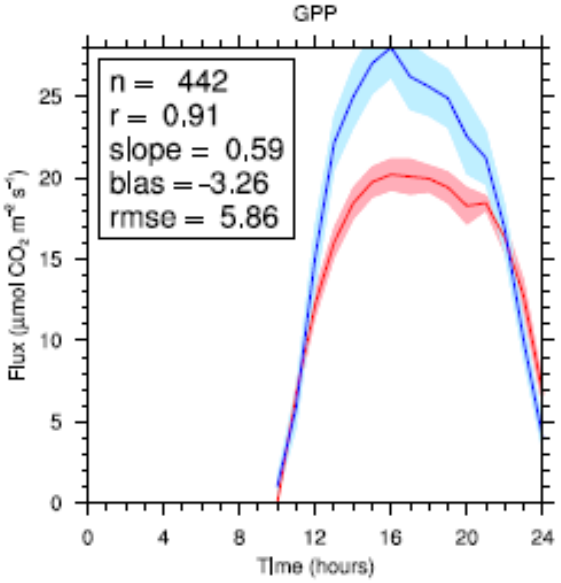
Center for Multiscale Modeling of Atmospheric Processes
CMMAP
Reach for the sky.

US-Ha1, July 2001 (DBF)

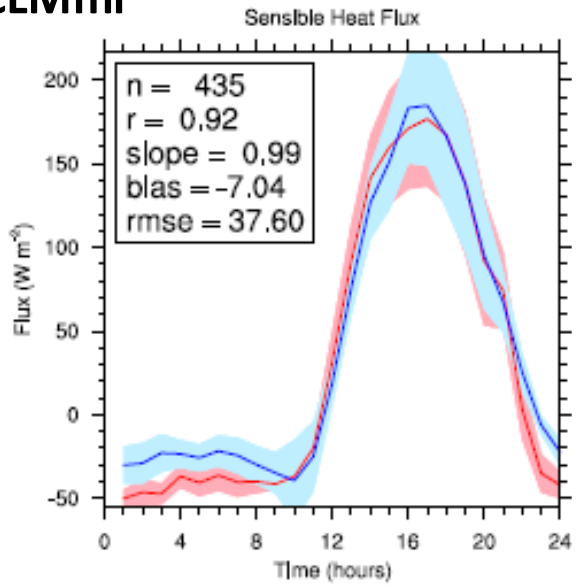
CLM4.5

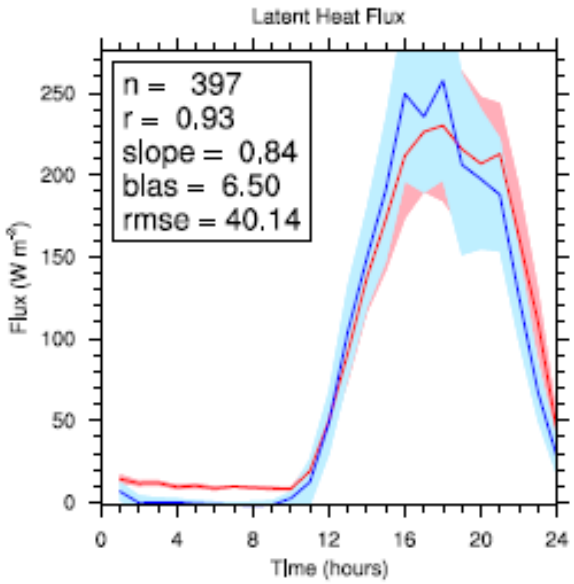


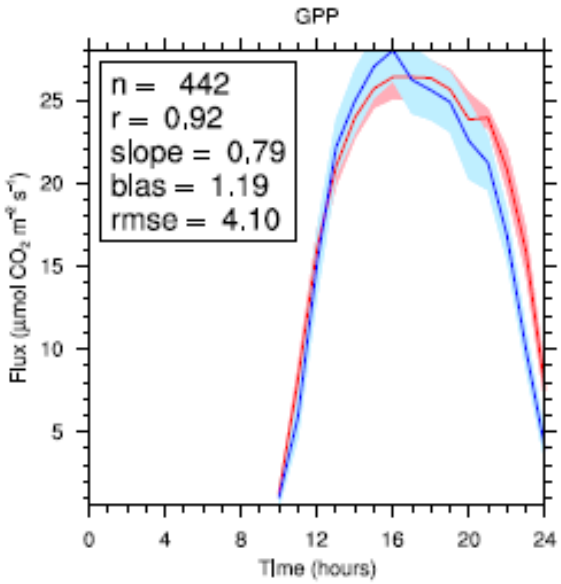




CLMml

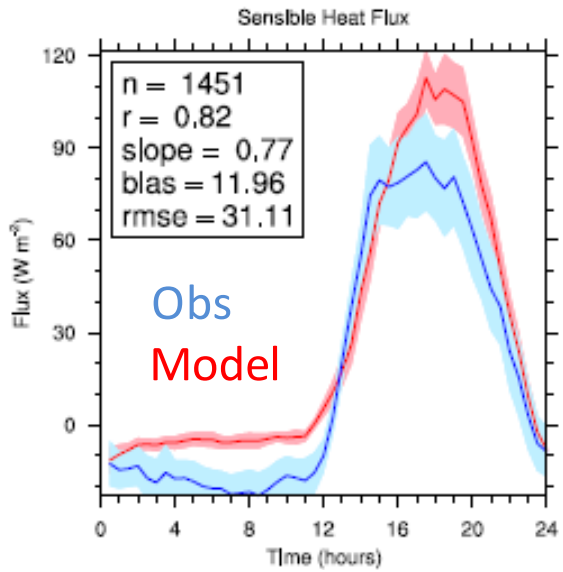


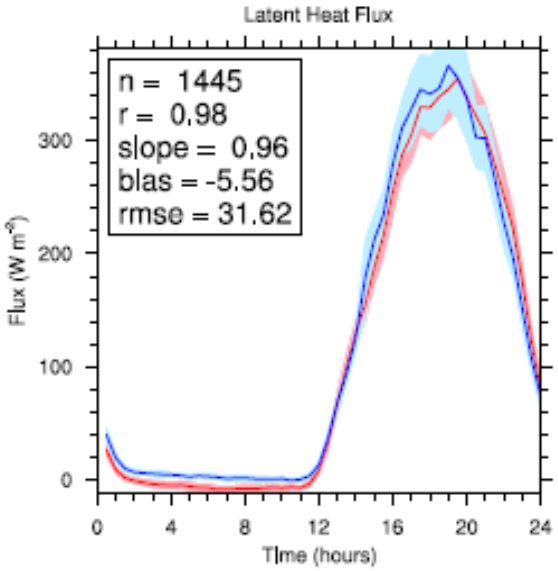




US-Bo1, July 1999 (crop)

CLM4.5





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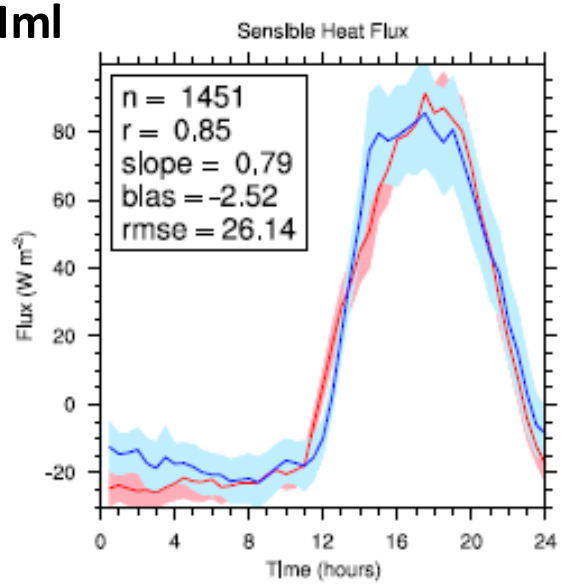
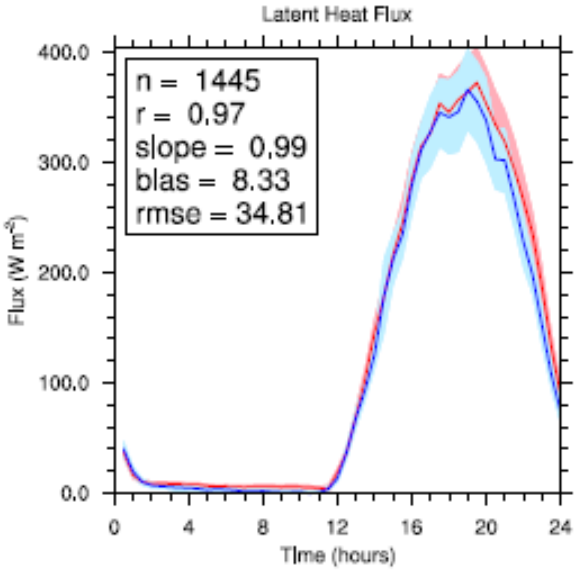
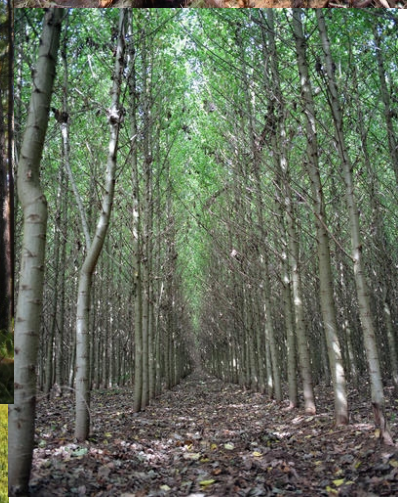
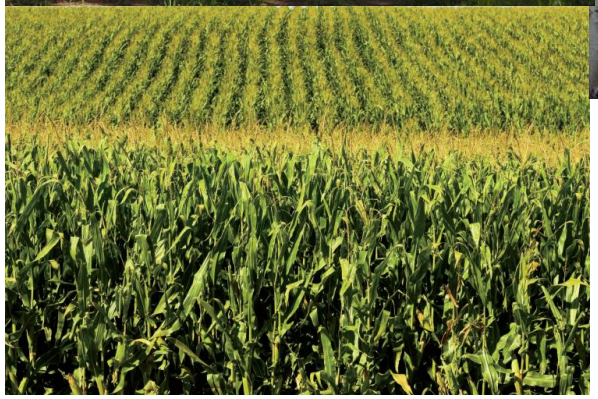




Humans, ecosystems, and climate



Earth system model paradigm

+ Δ albedo → cooling

- Δ ET → warming

- Δ z_0 → warming

Observational analyses

MODIS: albedo, ET, T_{rad}

Flux tower: T_s

Process modeling

Let the answer emerge from a theory rather than being imposed *a priori* in a model