Science opportunities and software engineering needs of the CLM-ml multilayer canopy

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CESM Land Model Working Group
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Background

Big-leaf models are incorrect but useful

CLM-FATES uses a hybrid canopy

- FATES: multilayer for vegetation demography
- CLM: big-leaf for fluxes and coupling with CAM

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

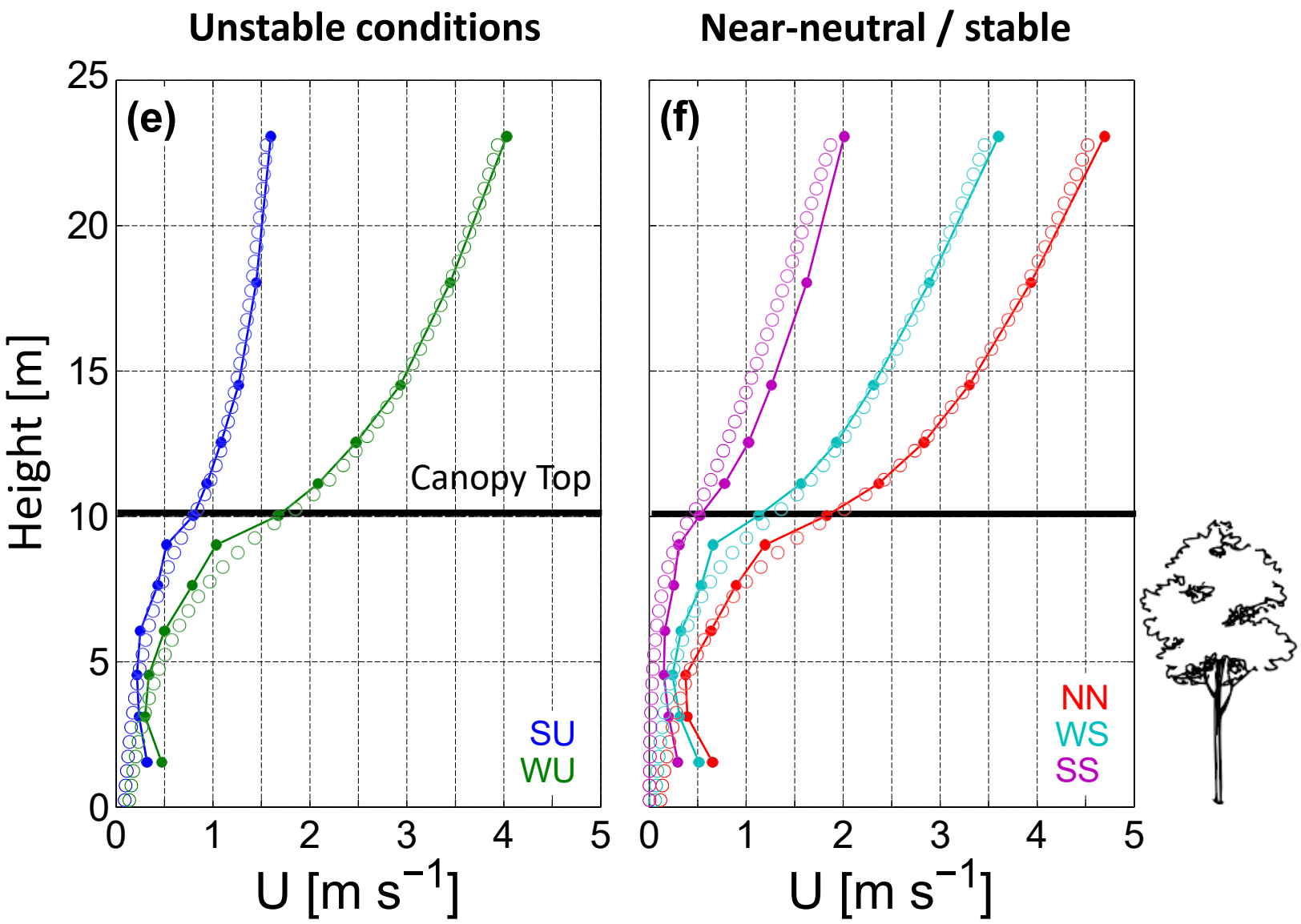
Bonan, Williams et al. (2014) *Geosci. Model Dev.*, 7, 2193-2222

Bonan, Patton, Harman, et al. (2018) *Geosci. Model Dev.*, 11, 1467-1496

Bonan, Patton, Finnigan, et al. (2021) *Agric. For. Meteorol.*, 306, 108435

Bonan, Burns & Patton (2026) *Agric. For. Meteorol.*, 378, 110960

CHATS: Wind speed (May 2007)



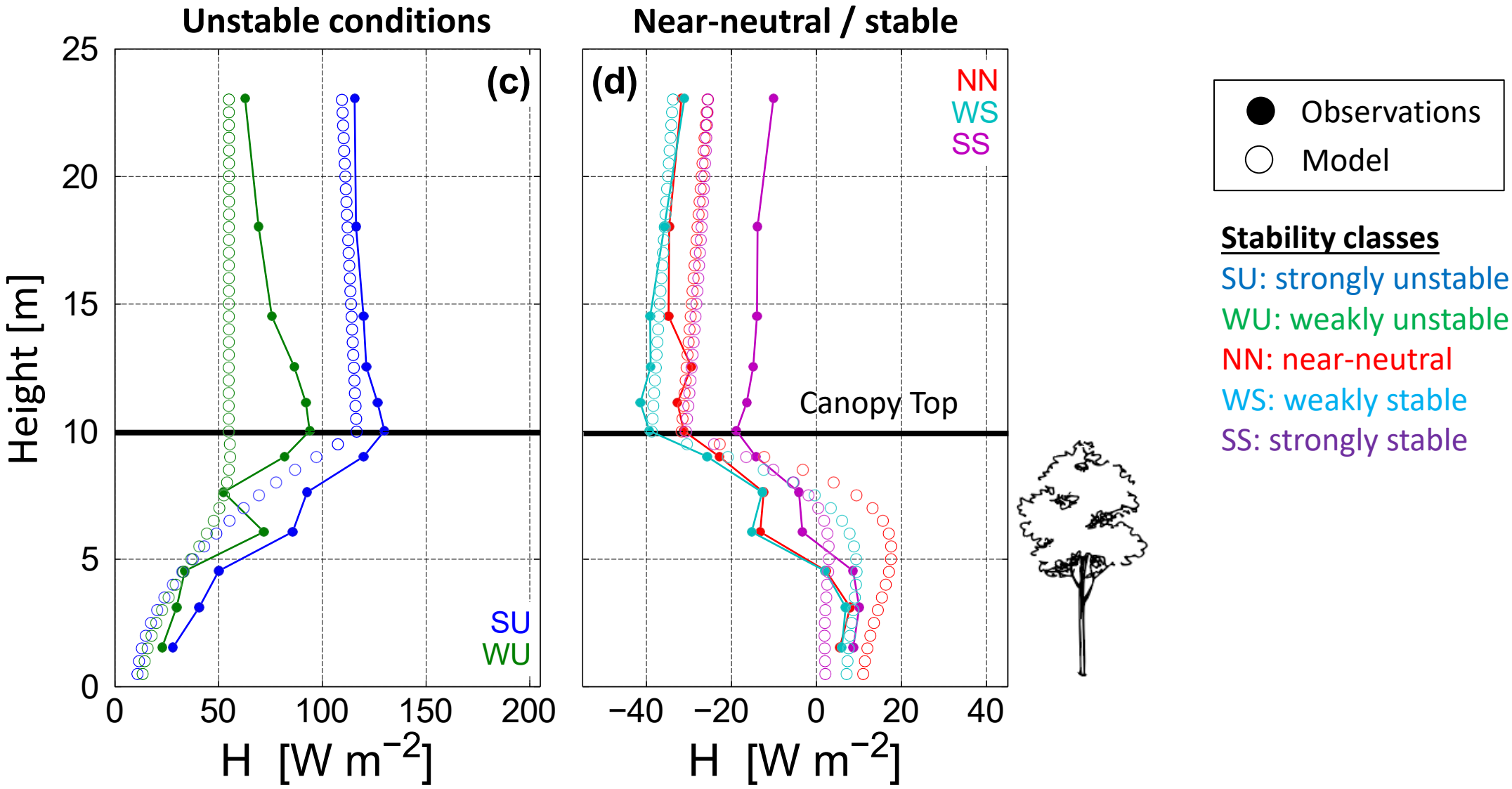
Observations
Model

Stability classes

SU: strongly unstable
WU: weakly unstable
NN: near-neutral
WS: weakly stable
SS: strongly stable

Bonan, Burns & Patton (2026) Agric. For. Meteorol., 378, 110960

CHATS: Sensible heat flux (May 2007)



Bonan, Burns & Patton (2026) Agric. For. Meteorol., 378, 110960

Profile data

Martin Béland (Université Laval)

US-Ha1: Harvard Forest

US-HBK: Hubbard Brook Experimental Forest

Image Credit: Harvard Forest

Sean Burns (CU/NCAR)

US-NR1: Niwot Ridge Forest

Image Credit: Sean Burns

Other sites

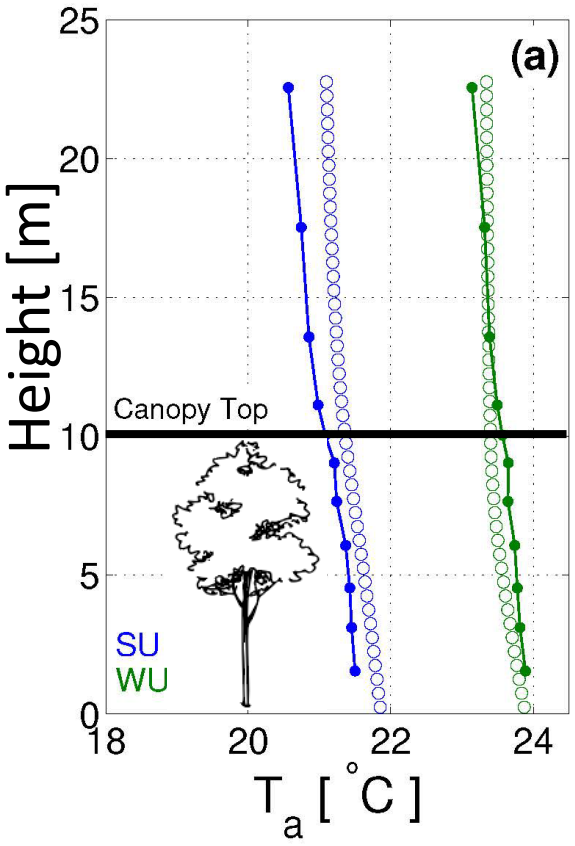
US-UMB: Univ. of Mich. Biological Station

NEON

more …

How does canopy structure shape temperature profiles?

Walnut orchard



Patton et al. (2011) *BAMS*, 92, 593-611

Bonan, Burns & Patton (2026) Agric. For. Meteorol., 378, 110960

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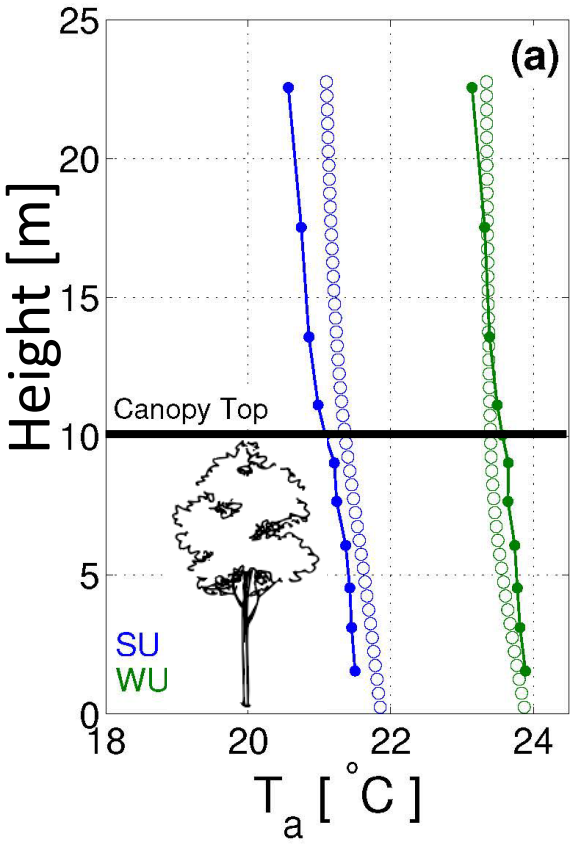
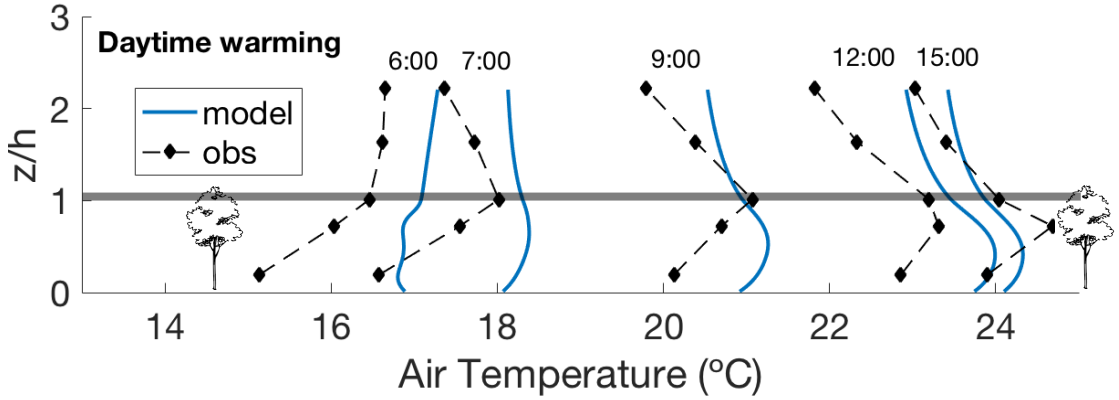


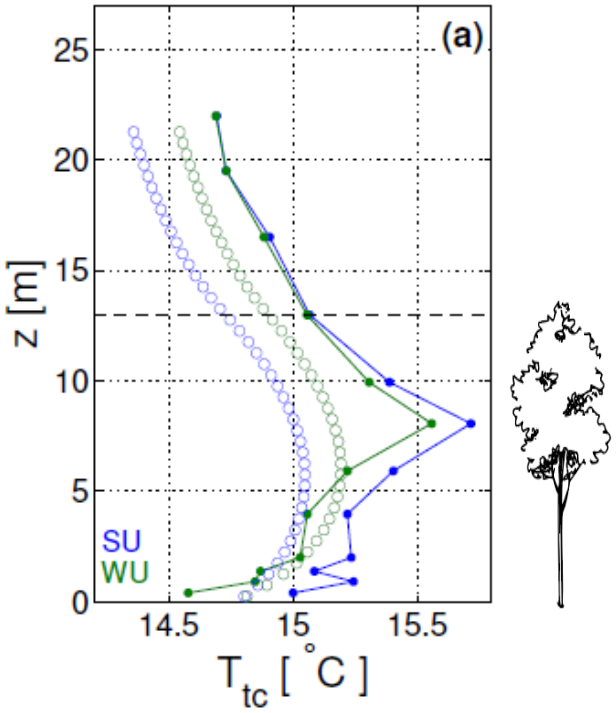
Bonan, Burns & Patton (2026) Agric. For. Meteorol., 378, 110960

US-UMB



Wozniak, Bonan, et al. (2020) *JGR: Biogeosci.*, 125, e2020JG005658

US-NR1



Sean Burns (unpublished)

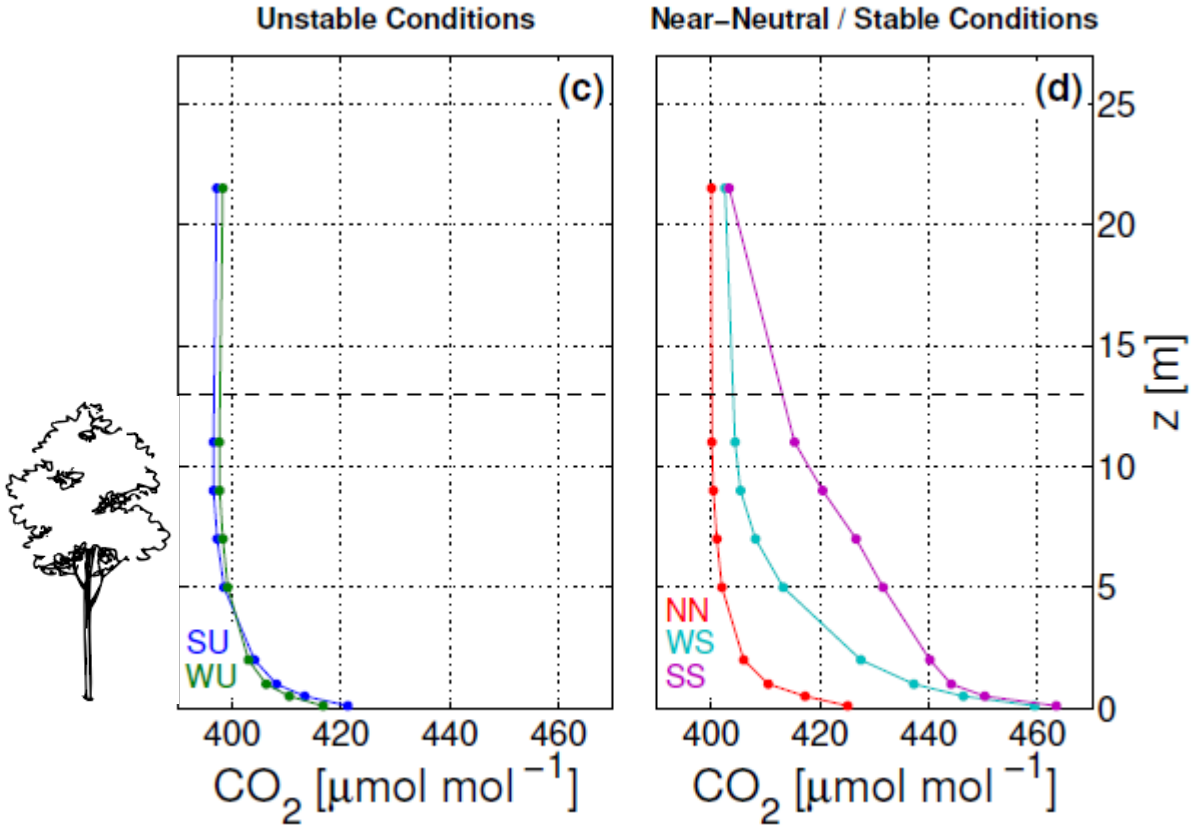
Observations

Model

CO_2 profiles

Sean Burns (CU/NCAR)

US-NR1: Niwot Ridge Forest



Martin Béland (Université Laval)

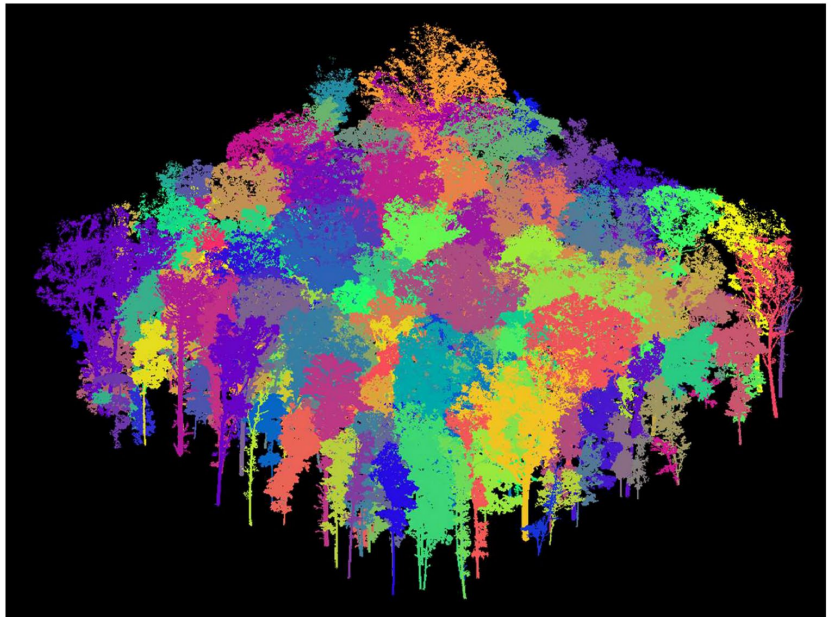
US-Ha1: Harvard Forest

CANVEG2 model

Conservation equation

$$\rho_m \frac{\partial c(z)}{\partial t} + \frac{\partial F_c(z)}{\partial z} = S_c(z)$$

Biomass heat storage: CANVEG2



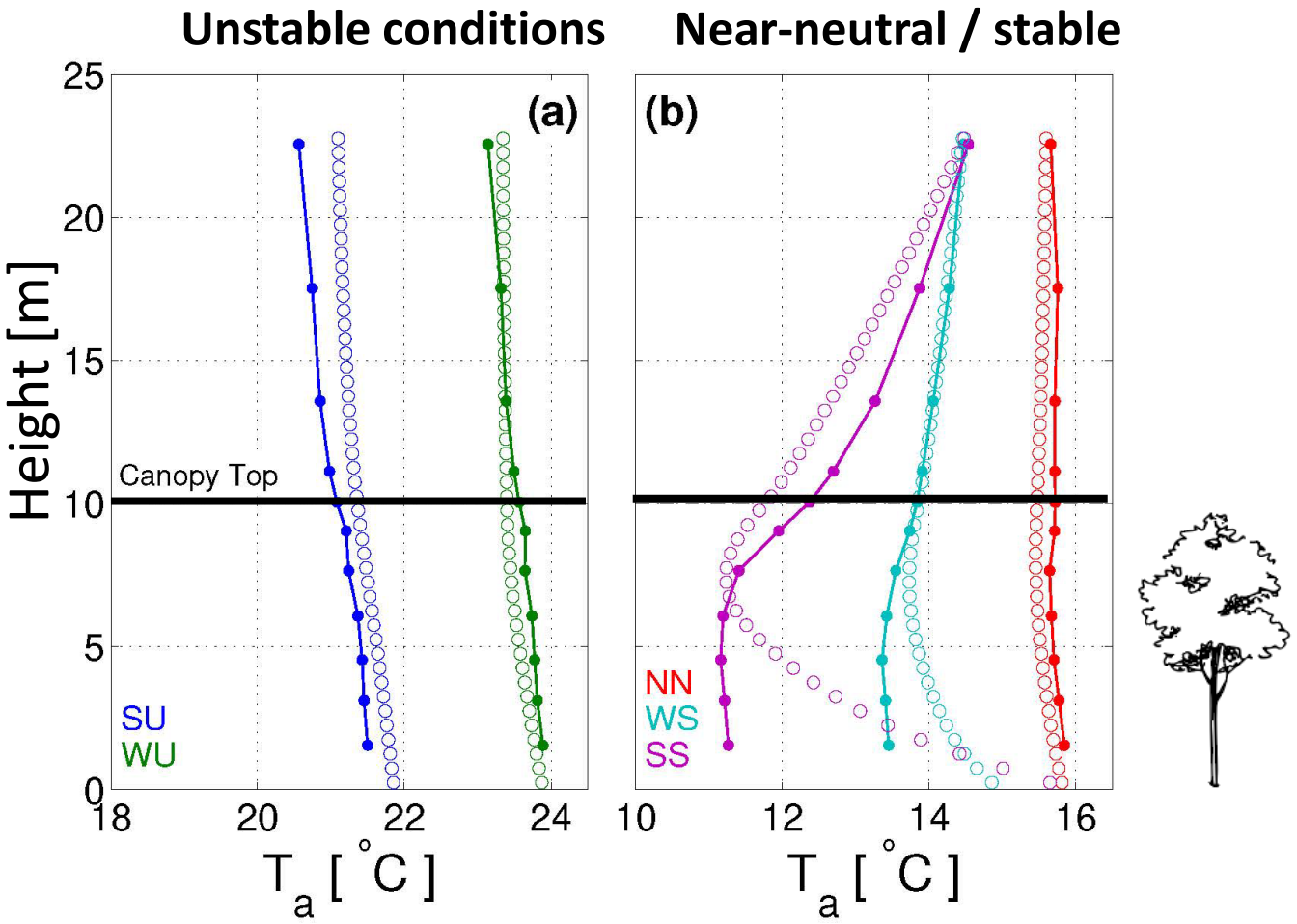
Harvard Forest

Ground lidar

NIR absorbed radiation

Béland (2025) Agric. For. Meteorol., 375, 110883

Model biases



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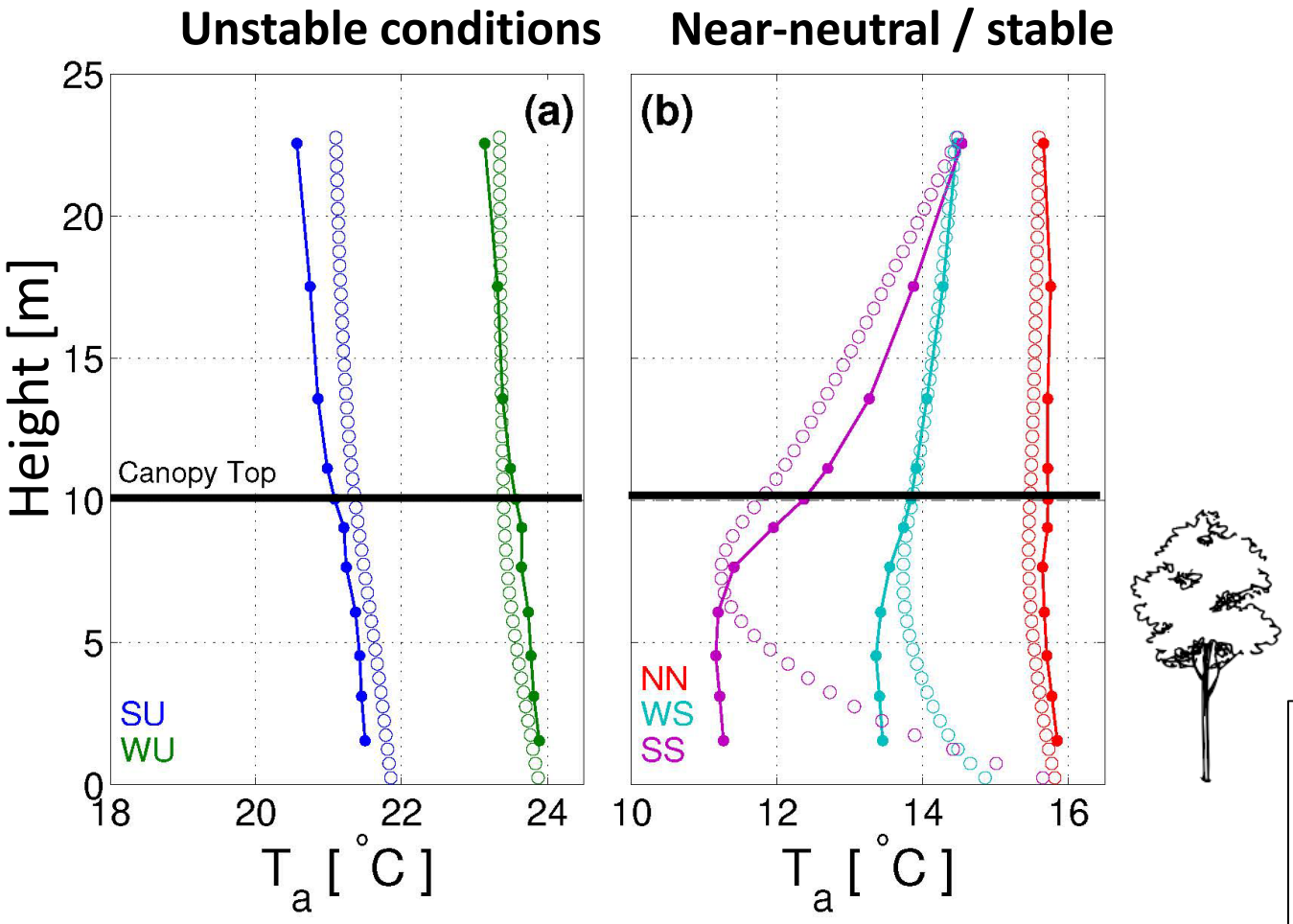

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CLM-ml: First-order turbulence closure

CANVEG2: Dispersion matrix (Lagrangian)

Martin Béland (Université Laval)

Tilden Meyers (NOAA)

Sreenath Paleri (Texas A&M)

Microclimate ecology

Received: 26 May 2023 | Revised: 16 February 2024 | Accepted: 6 March 2024

DOI: 10.1111/geb.13834

Global Ecology and Biogeography

WILEY

PERSPECTIVE

Microclimate, an important part of ecology and biogeography

Ecological Modelling 451 (2021) 109567

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Microclimc: A mechanistic model of above, below and within-canopy microclimate

Ilya M.D. Maclean, Writing – Original Draft Preparation; Writing – Review & Editing [a,*], David H. Klinges, Validation; Writing – Original Draft Preparation; Writing – Review & Editing [b,c]

Software engineering needs

CLM6 code is not modular. No clean interface to surface fluxes

a. CanopyFluxes, SoilFluxes, BareGroundFluxes, SoilTemperature, BiogeophysPreFluxCalcs, …
b. z_0 & d: 5 subroutines in 4 modules

Many CLM6 modules do things in addition to the stated intent

a. SoilTemperature: urban surfaces
b. CanopyFluxes: moisture stress, human heat stress indices, …

Duplication of code for specific model needs (CLM6, FATES, CLM-ml)

a. Photosynthesis and stomatal conductance
b. Radiative transfer
c. Other: CANVEG2 (wood), Noah-MP (3-D radiation)

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The kraken devouring the ship

Colossal octopus attacking a ship
(Pierre Denys de Montfort, 1801)

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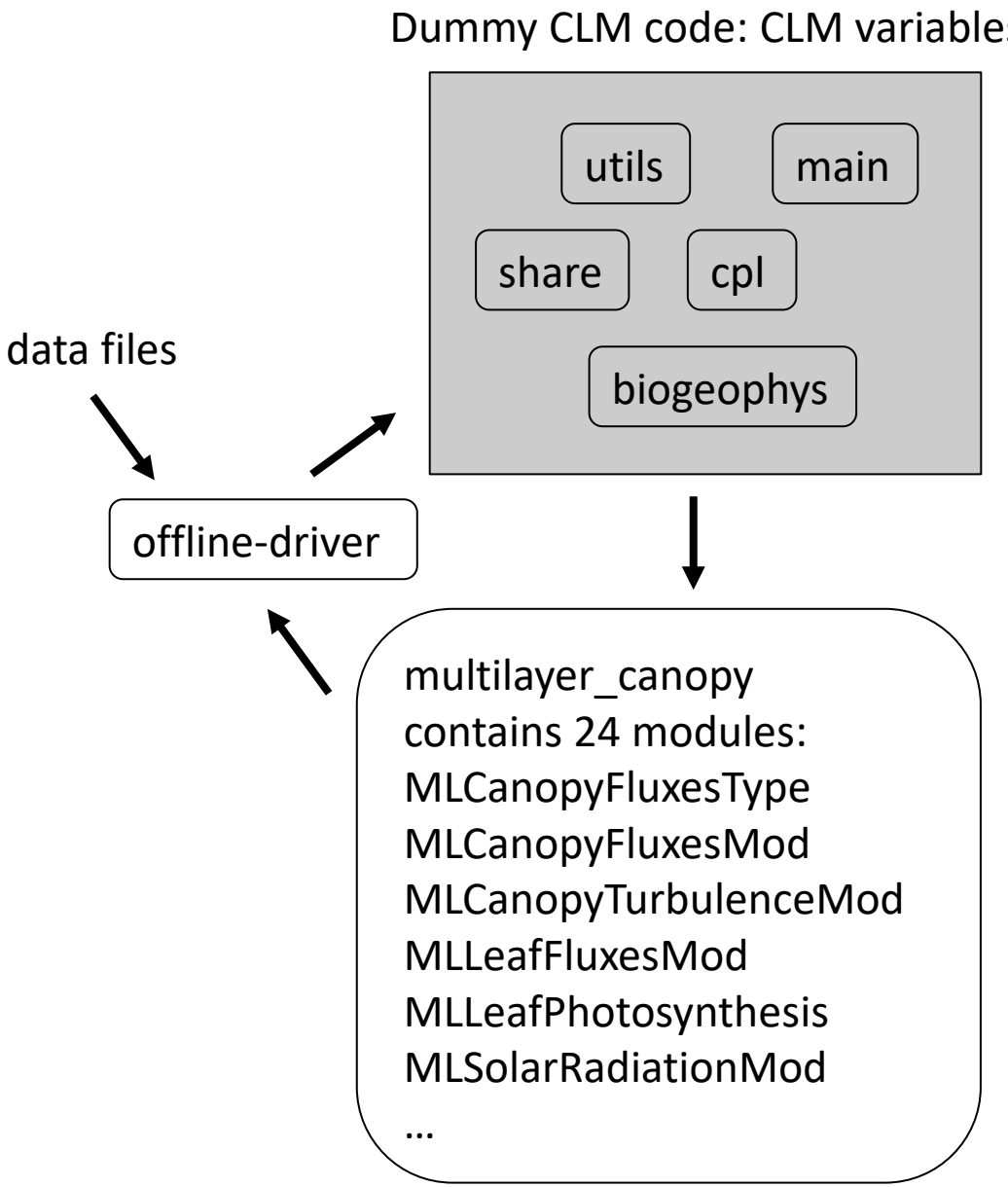
The Gordian knot

CLM-ml: software design



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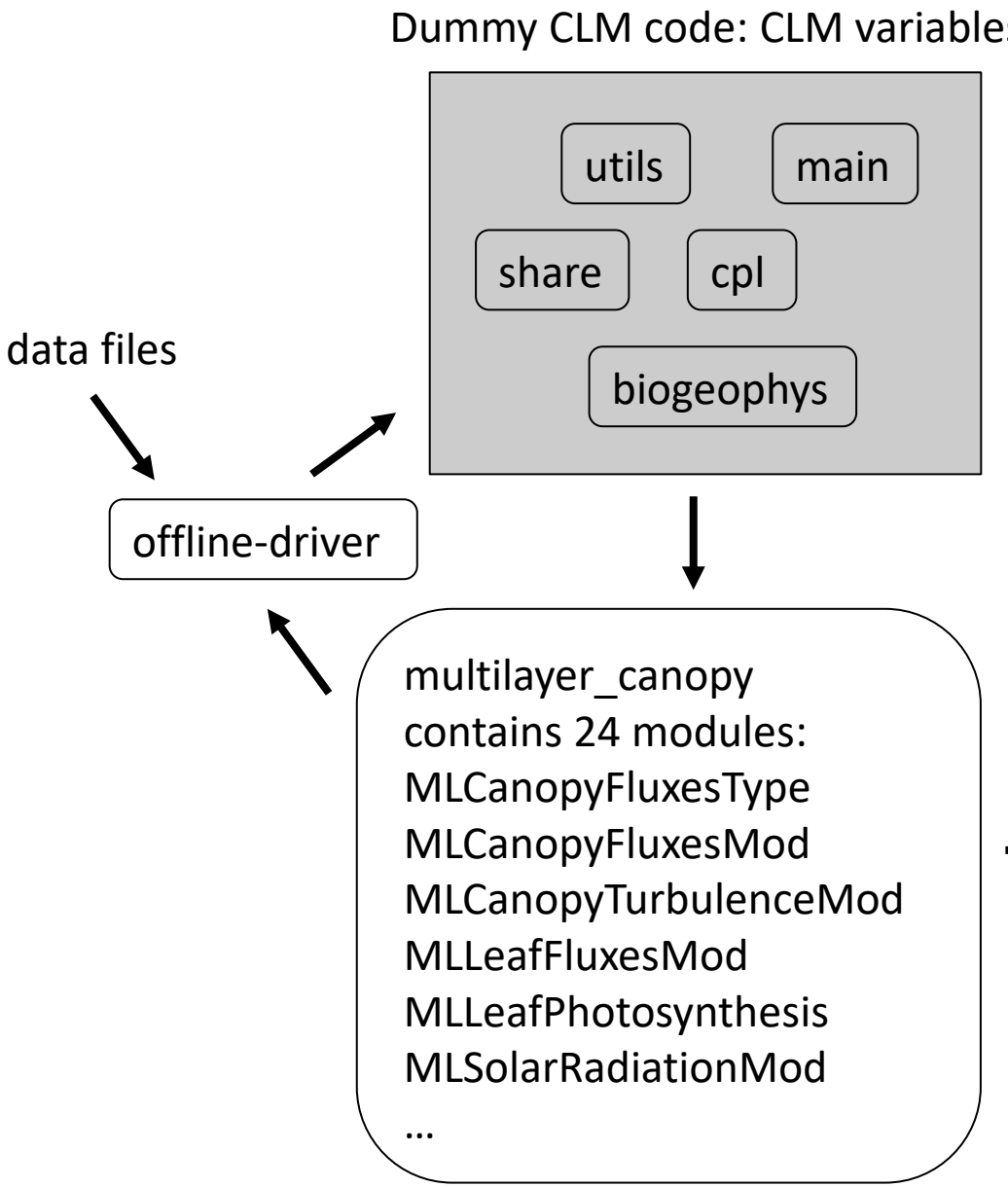

Protype coupling with CLM: runs parallel to existing surface fluxes

```
subroutine clm_drv
…
call CanopyInterceptionAndThroughfall
…
call SurfaceRadiation
…
call BareGroundFluxes
call CanopyFluxes
…
call SoilTemperature
call SoilFluxes
call MLCanopyFluxes
…
```

https://github.com/slevis-lmwg/ctsm/tree/multilayer_canopy

How can the LMWG contribute?

Lots of interesting science

Research model

- Flux tower case studies
- Process studies
- Very much a hands-on model

Cutting the Gordian knot