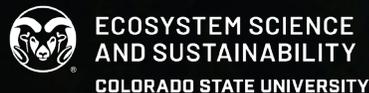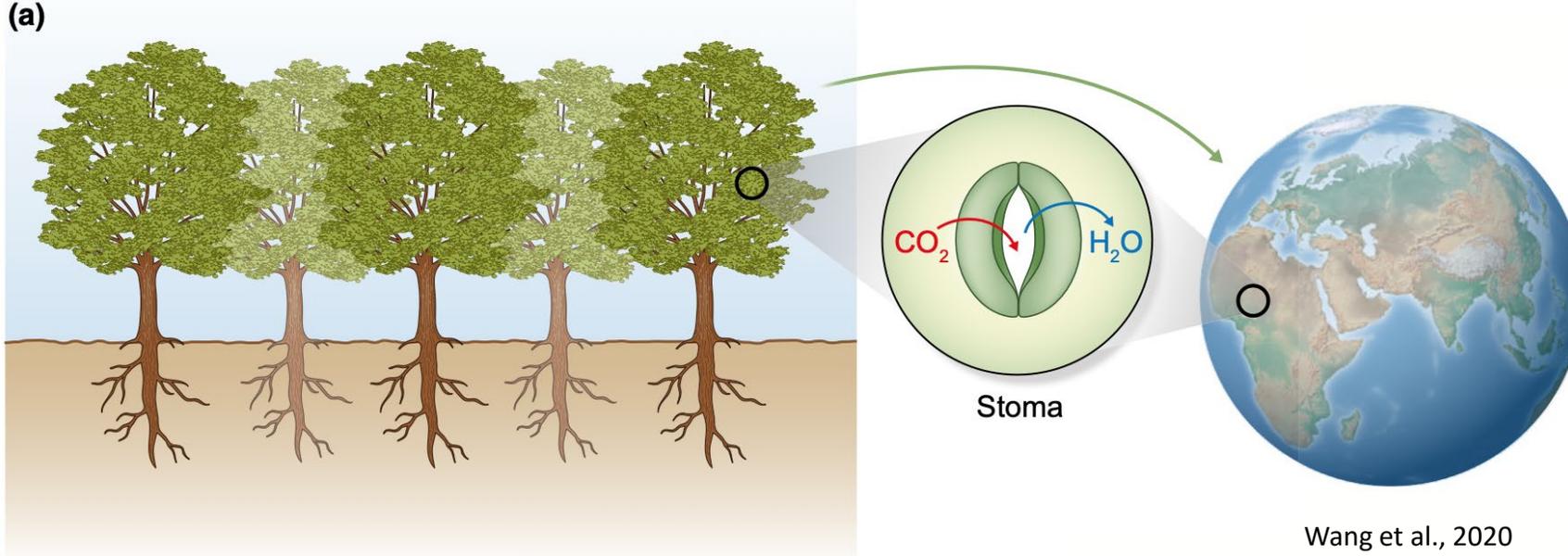# Comparing Multiple Stomatal Conductance Models in Multilayer Canopy Simulations

*Zhiyi Zhou, Danica Lombardozzi, Dave Barnard, Gordon Bonan*

Land Model and Biogeochemistry Working Group Meeting 2026
February 25, 2026

ECOSYSTEM SCIENCE AND SUSTAINABILITY
COLORADO STATE UNIVERSITY

NSF | NCAR
Operated by UCAR

USDA

# Stomatal Conductance Models – Empirical Models



(a)

$CO_2$    $H_2O$

Stoma

Wang et al., 2020

**Empirical Models**



**35 Empirical Stomatal Conductance Models**

Damour et al., 2010

# Stomatal Conductance Models – Empirical Models



(a)

CO$_2$    H$_2$O

Stoma
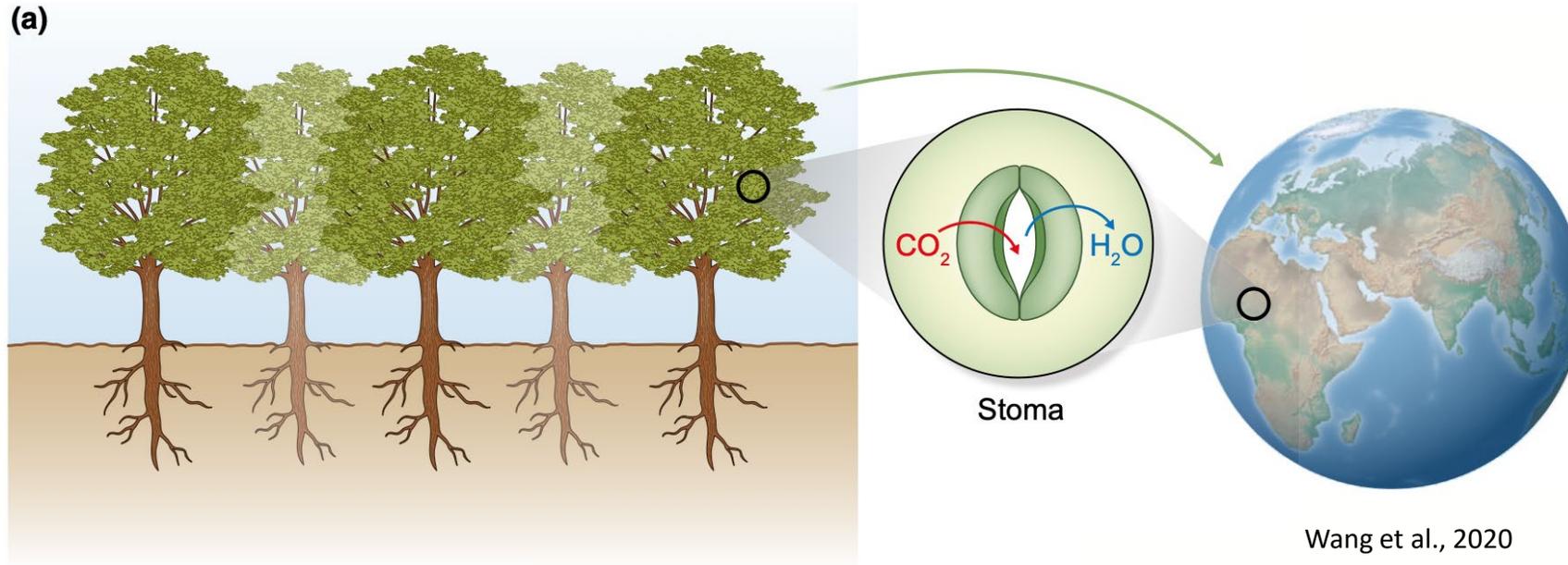
Wang et al., 2020

**Empirical Models**
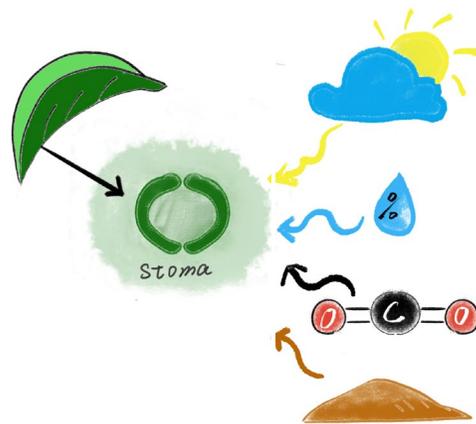
Ball et al., 1987  : $g_s = g_0 + g_1 \text{h}_\text{s} \dfrac{\text{A}_\text{n}}{c_s}$

Leuning 1995     : $g_s = g_0 + g_1 \dfrac{A_n}{(1+\frac{VPD}{D_0})(c_s - \Gamma)}$

Tuzet et al., 2003: $g_s = g_0 + 1.6 g_1 \zeta \dfrac{\text{A}_\text{n}}{c_s}$

...

# Stomatal Conductance Models – Optimization Models



$$MAX(A - \Theta)$$
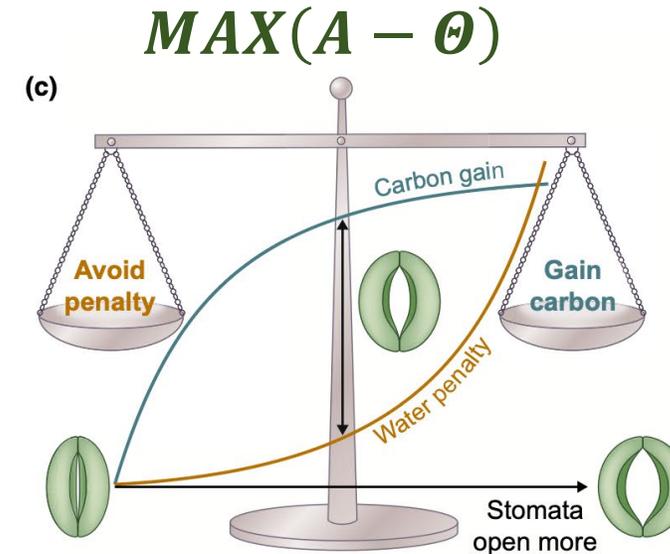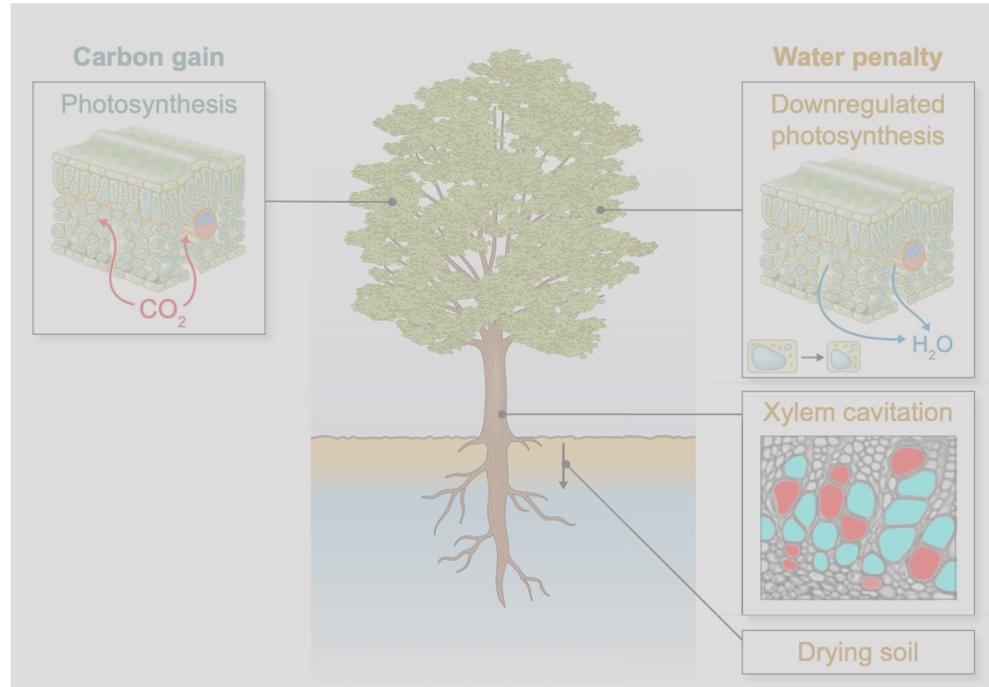
Wang et al., 2020

**Penalty based on water supply**

- Cowan-Farquhar model (WUE, 1977)
- Makela model (1996)
- Manzoni model (2013)
- Prentice model (2014)
- Lu model (2016)
- Medlyn model (2011)

**Penalty based on xylem vulnerability to cavitation**

- Wolf-Anderegg-Pacala model (CM, 2016)
- Sperry model (2017)
- Eller model (SOX, 2018)
- Wang model (2020)
- Eller model (2022)

**Penalty based on nonstomatal limitation (NSL) to photosynthesis**

- Holtta model (2017)
- Dewar model (2018)

# Which Optimality Model Performs Better?



Water Supply   Xylem Vulnerability   NSL

(a) Data from Wang et al. (2019)

(b) Data from Venturas et al. (2018)

(c) Data from Anderegg et al. (2018)

MAPE (%)

Cowan–Farquhar, Manzoni, Prentice, Lu, Wolf–Anderegg–Pacala, Sperry, Eller, Dewar AP, Dewar AP*, New model

Wang et al., 2020
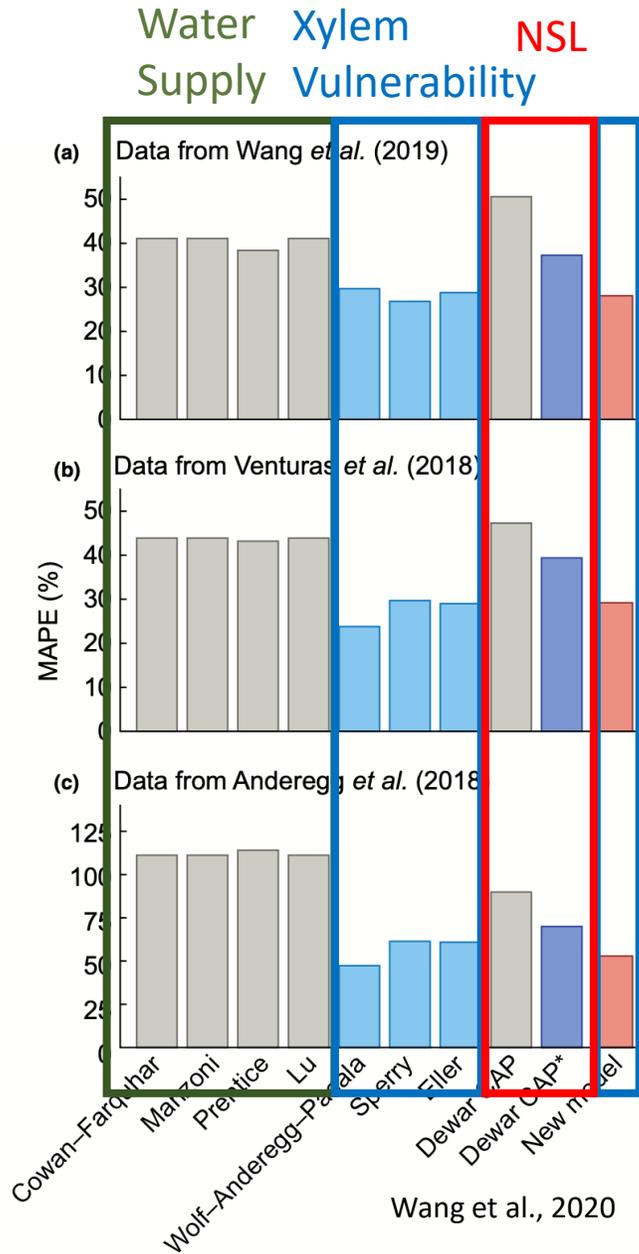
➤ **xylem-vulnerability** and **NSL** based optimization models meet > 6 criteria

➤ **Xylem-vulnerability** models show lower MAPE

**Water-supply** based models (WUE) show better predictive and functional performance than xylem-vulnerability models (SOX, CM)

Water Supply   Xylem Vulnerability

(a) Cal/val goodness-of-fit

(b) Parameter uncertainty

(c) Adequate parsimony

(d) Predictive accuracy

(e) Functional accuracy

WUE   CM   SOX

Average performance score

Bassiouni et al., 2021
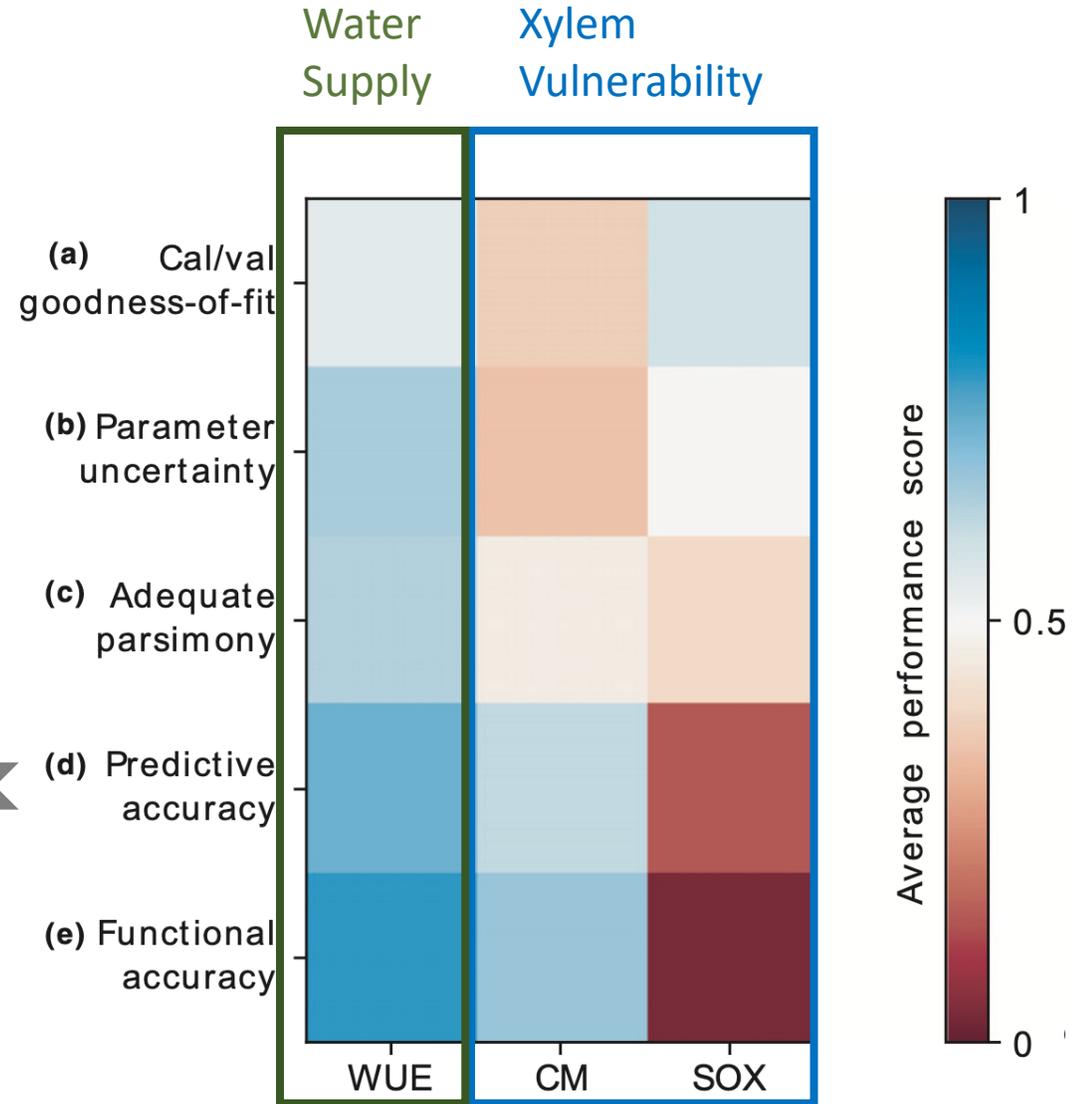
# Which Model Performs Better?
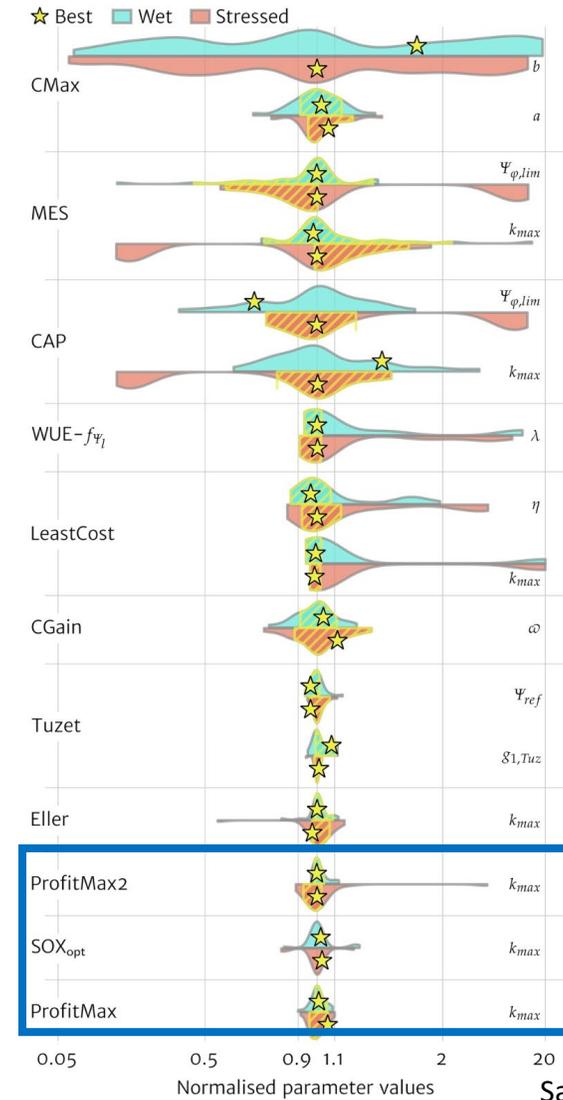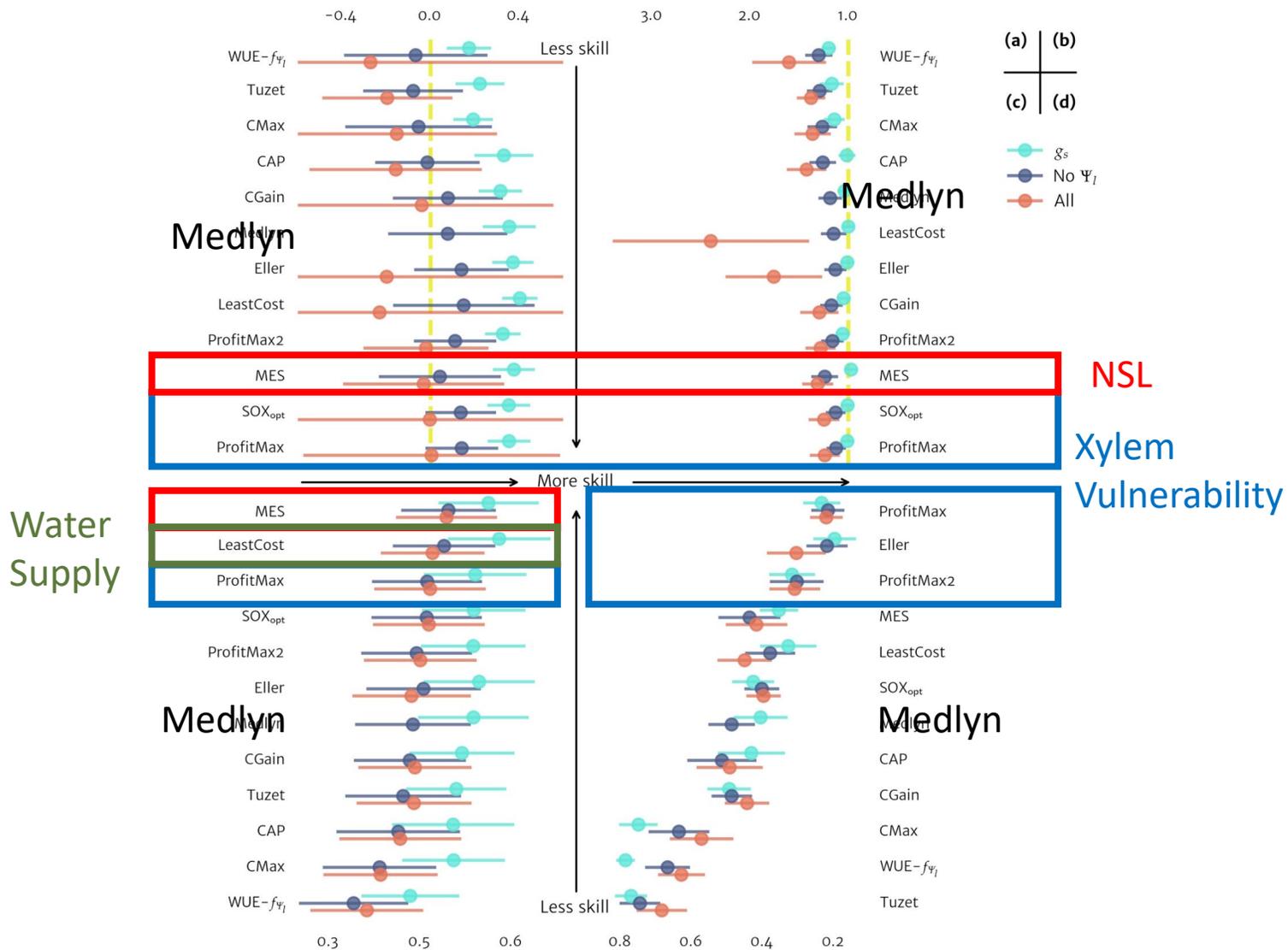


Sabot et al., 2022

**Xylem-vulnerability based optimization models show strong promise for climate-vegetation modeling**

# Questions

- **Leaf-level Model -> Canopy-Level Model**

**How Do These Stomatal Conductance (gs) Models Behave in** Multilayer Canopy Model?

# Multilayer Canopy Model (CLM-ml)

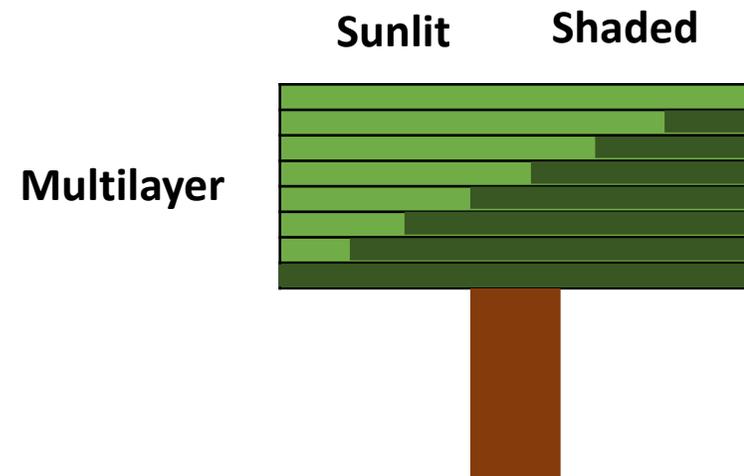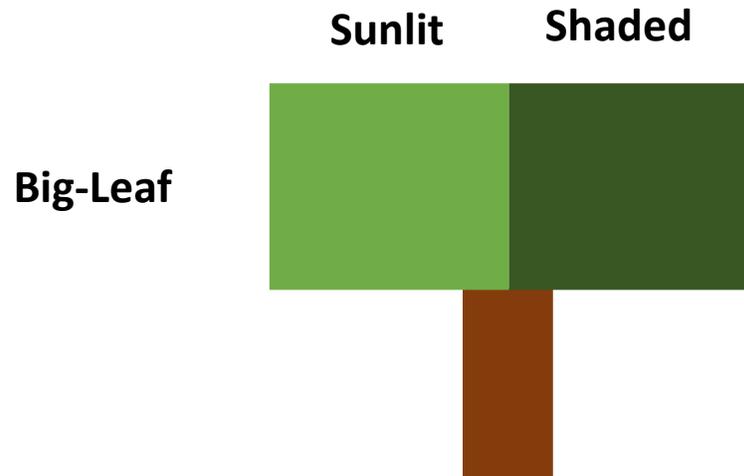| CLM-ml v1 (Bonan et al., 2018) | Stomatal Conductance (gs) Model in CLM-ml |
|---|---|

Canopy structure
- Multilayer canopy (28-54 layers, height-dependent)
- Beta distribution for leaves; uniform for stems

Scalar & turbulence
- Conservation-based scalar profiles
- Roughness sublayer parameterization

Plant hydraulics and capacitance

- **Ball et al., 1987 :** $g_s = g_0 + g_1 A_n \frac{h_s}{c_s}$

- **Medlyn et al., 2011 :** $g_s = g_0 + 1.6\left(1 + \frac{g_1}{\sqrt{D}}\right)\frac{A_n}{C_a}$

- **Cowan and Farquhar (WUE) 1977 :** $max(A - \lambda E)$ or $\frac{\partial A}{\partial E} = \lambda$

- **Sperry et al., 2017:** $max\left(A - A_{max}\left(1 - \frac{k}{k_{max}}\right)\right)$

- **Wang et al., 2020:** $max\left(A - A\frac{E_{leaf}}{E_{crit}}\right)$

- **Potaky et al., 2025:** $g_s = \frac{1.6}{(1-x)(c_a - \Gamma^*)}\left(f_0 \frac{x}{x + \frac{y}{z}} - R_d\right)$

- **Buckley et al., under review :** $g_s = \frac{sr(\psi_s - \psi_c)}{1 + sr\frac{\Delta w}{K}}$
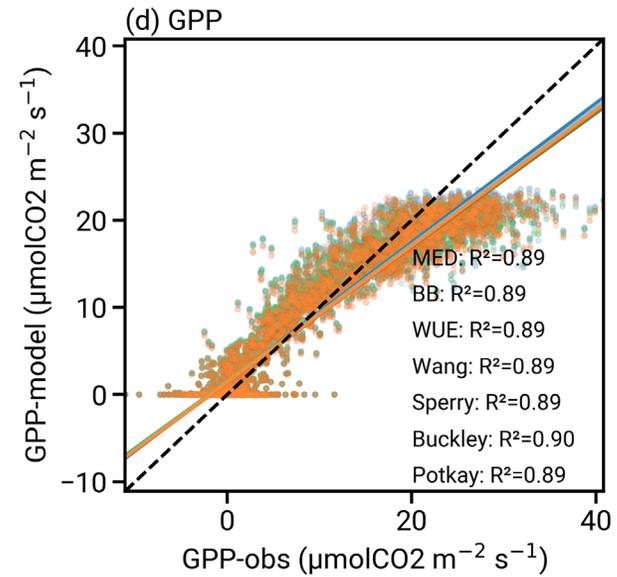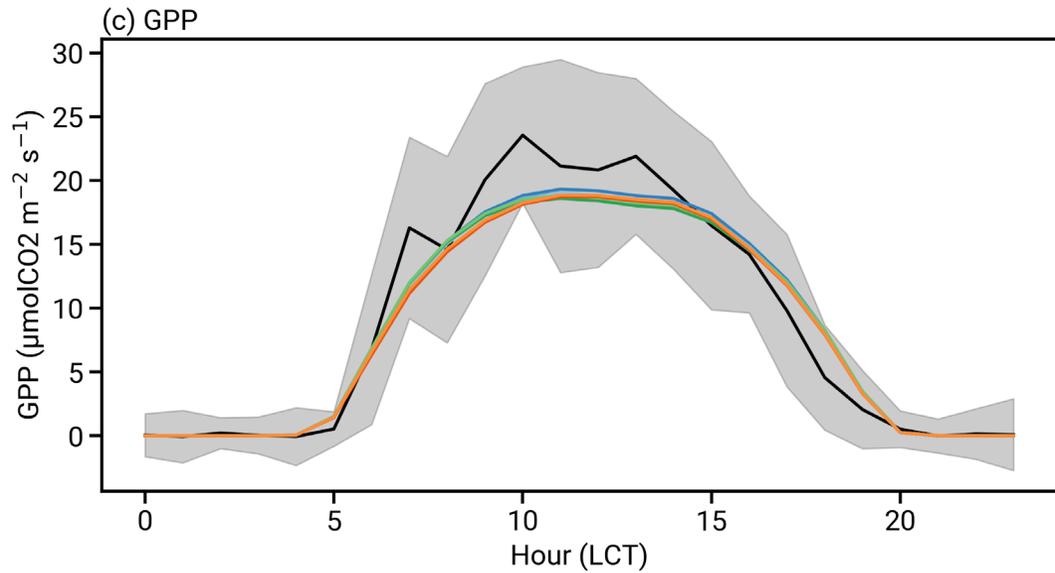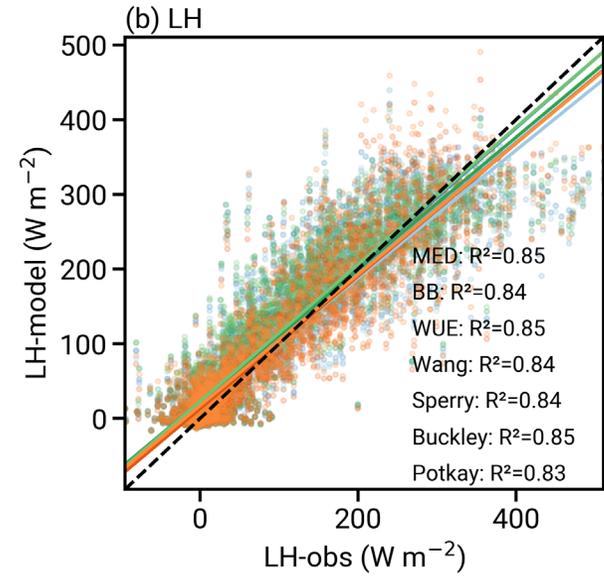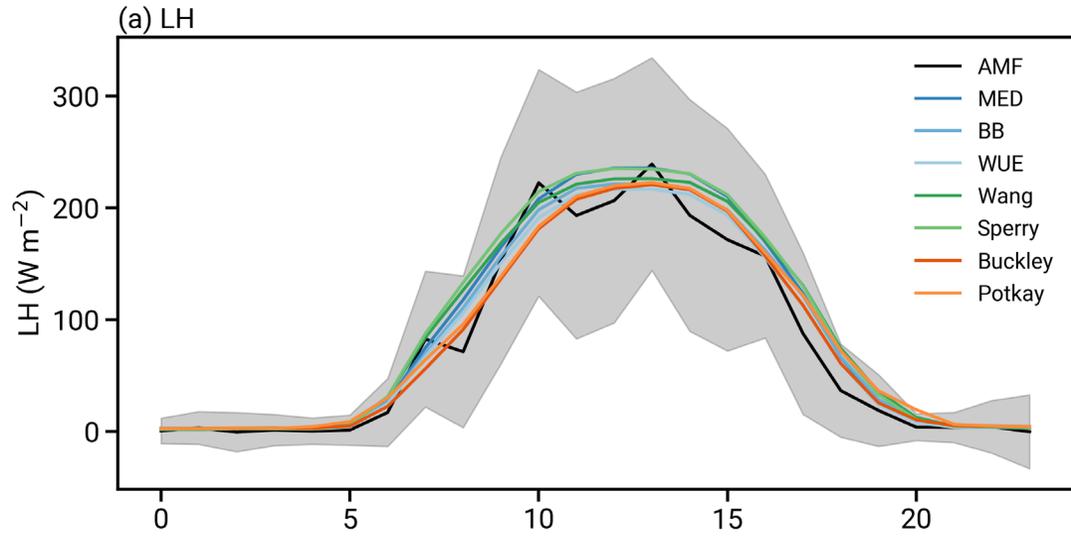
# Diurnal Cycle of LH and GPP over US-UMB



(a) LH

(c) GPP
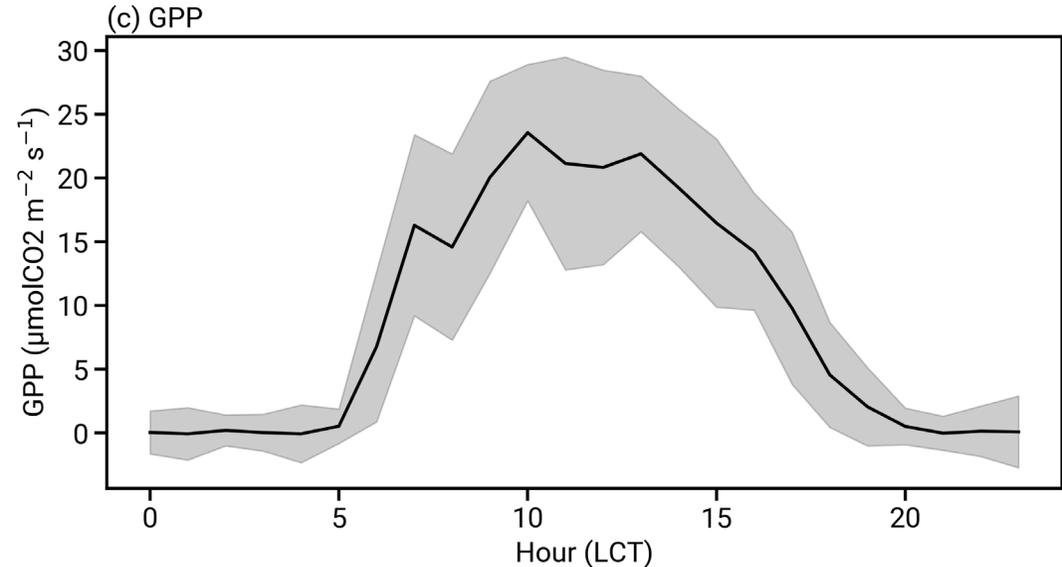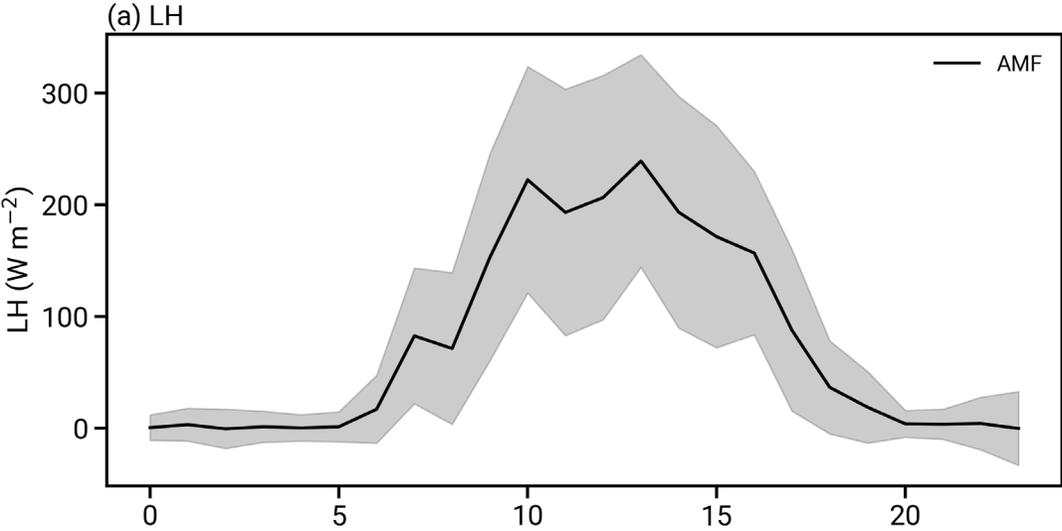
AmeriFlux site: US-UMB
University of Michigan Biological Station

https://flux.org.ohio-state.edu/tower-fisheye-2/

# LH and GPP Simulations in CLM-ML



(a) LH

(b) LH

MED: R²=0.85

BB: R²=0.84

WUE: R²=0.85

Wang: R²=0.84

Sperry: R²=0.84

Buckley: R²=0.85

Potkay: R²=0.83

(c) GPP

(d) GPP

MED: R²=0.89

BB: R²=0.89

WUE: R²=0.89

Wang: R²=0.89

Sperry: R²=0.89

Buckley: R²=0.90

Potkay: R²=0.89
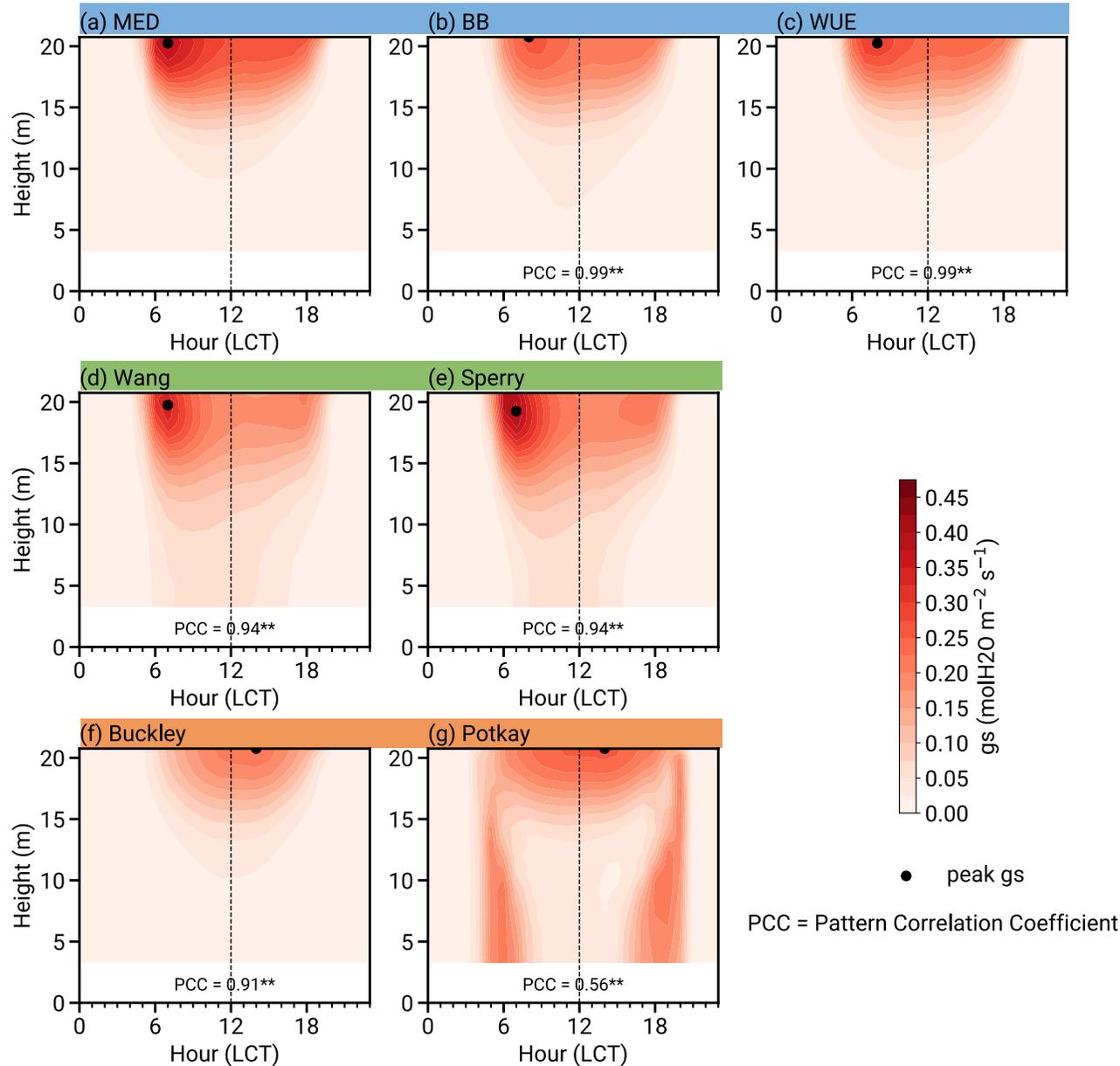
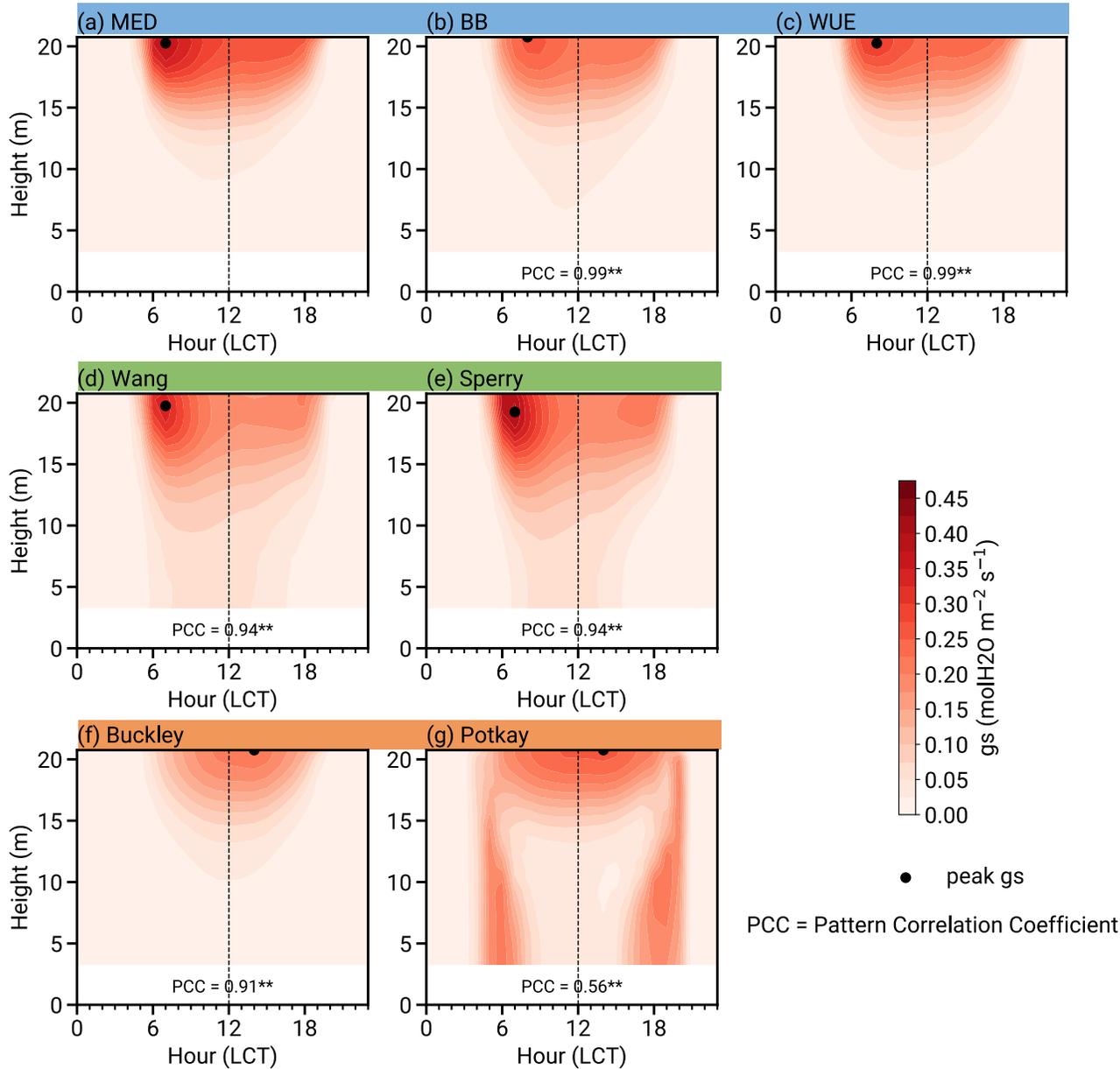# Simulated Vertical Profiles of gs in CLM-ML



(a) MED
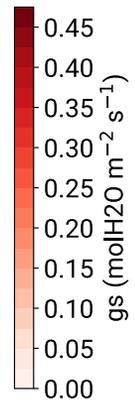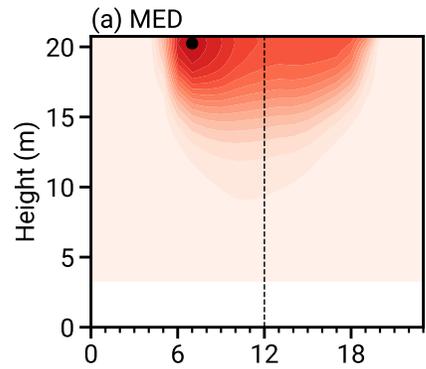
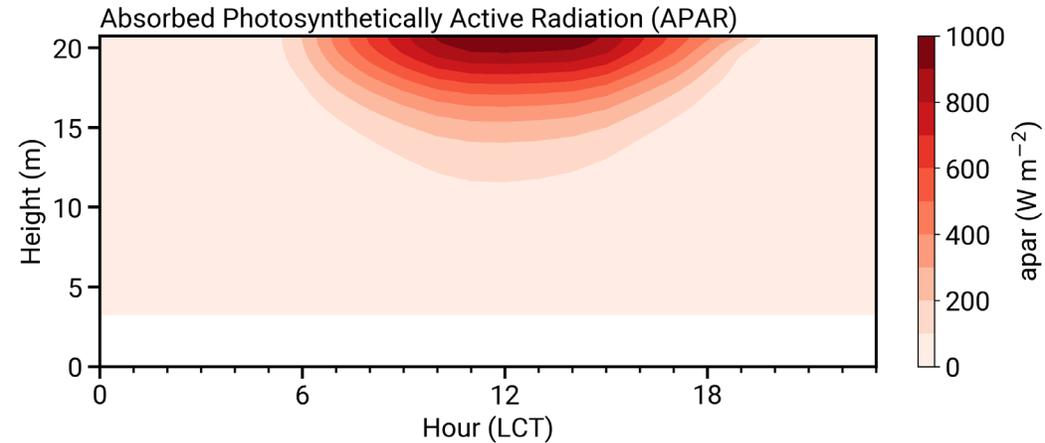# Simulated Vertical Profiles of gs in CLM-ML



- **gs Peak timing:**
  AM (*Med, BB, WUE*, *Wang, Sperry*)
  *vs.*
  PM (*Buckley, Potkay*)

- *Early AM & late PM lower canopy:*
  *Higher gs in Potkay*

# Why Do Different gs Models Peak at Different Times of Day?
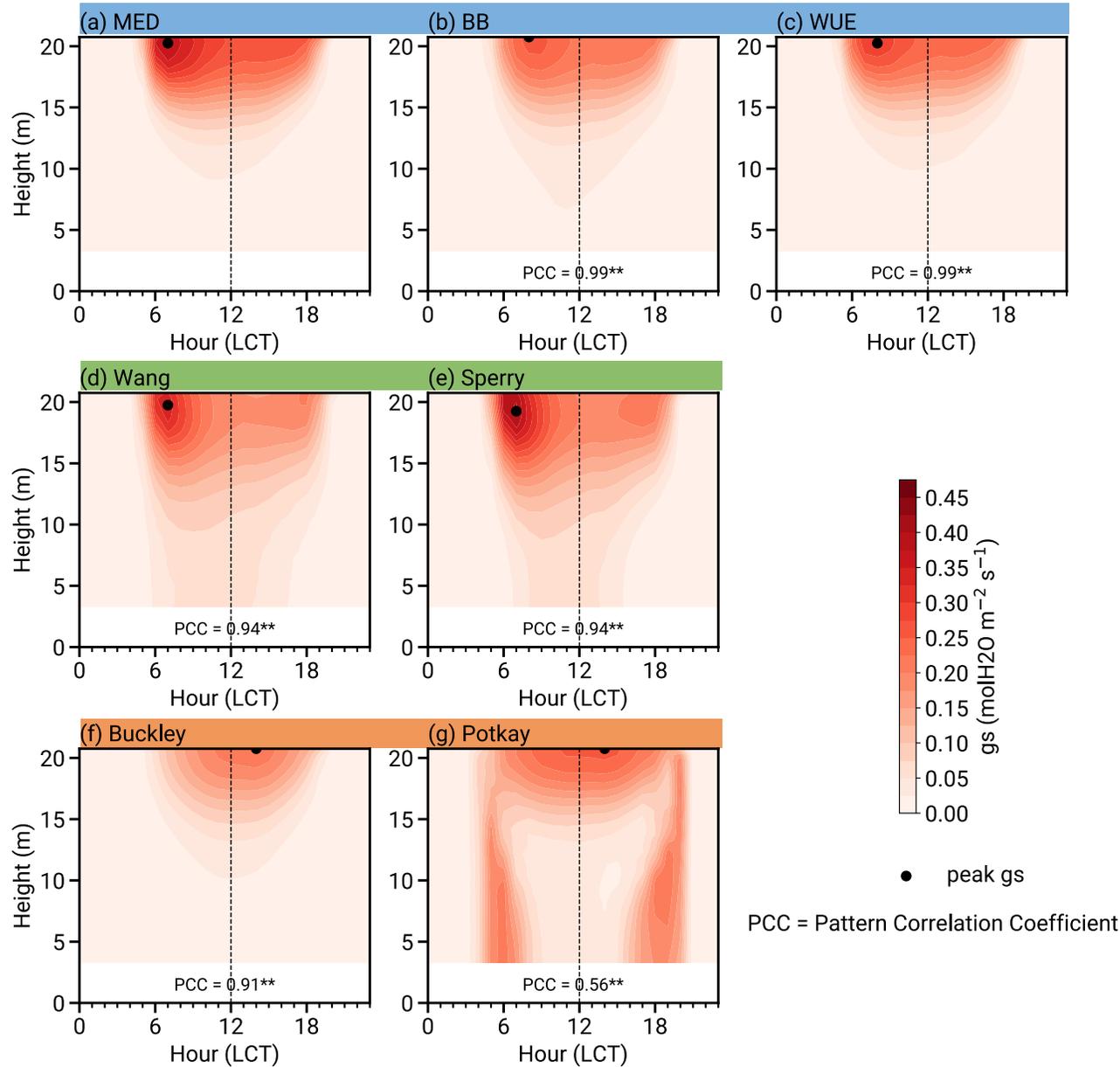


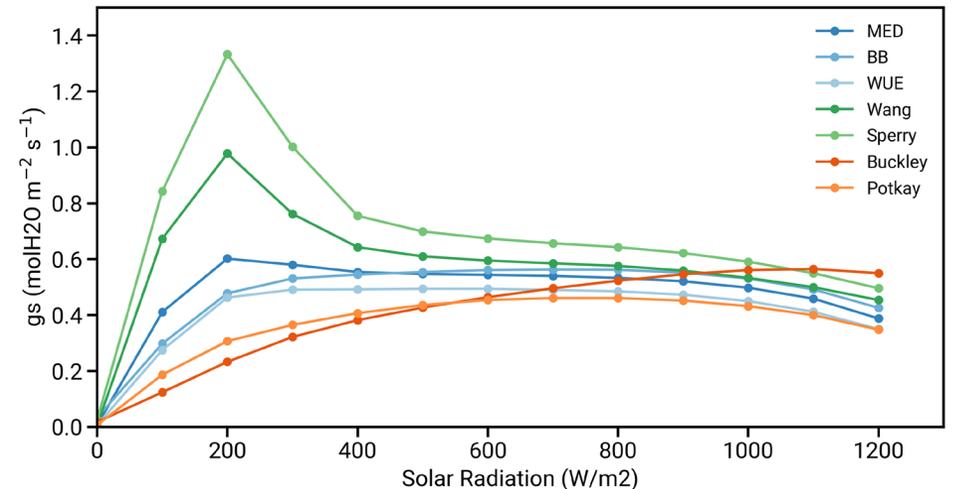AM (*Med, BB, WUE*, *Wang, Sperry*)
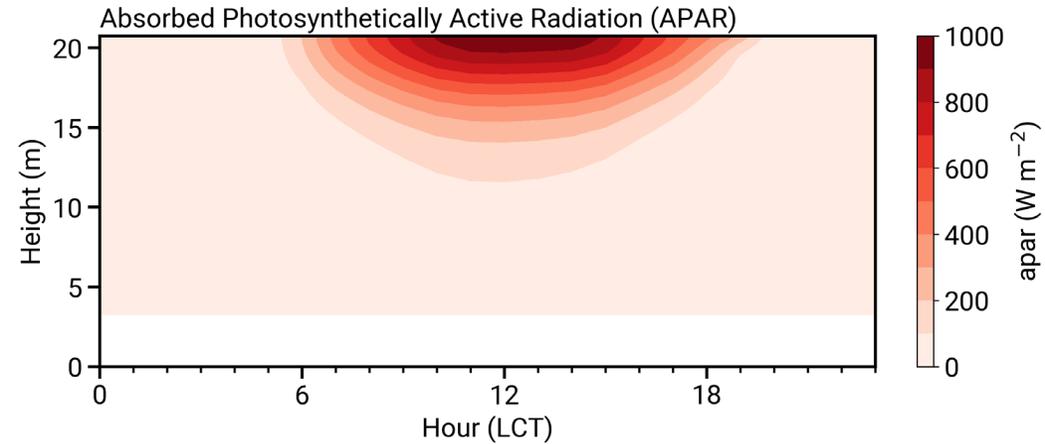*vs.*
PM (*Buckley, Potkay*)
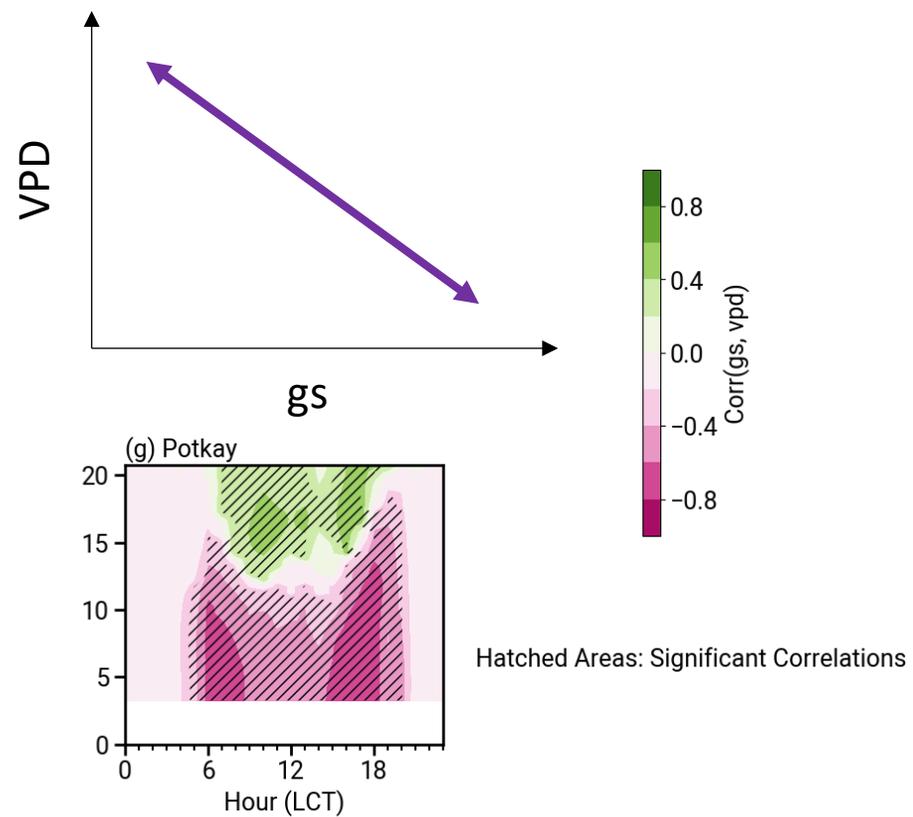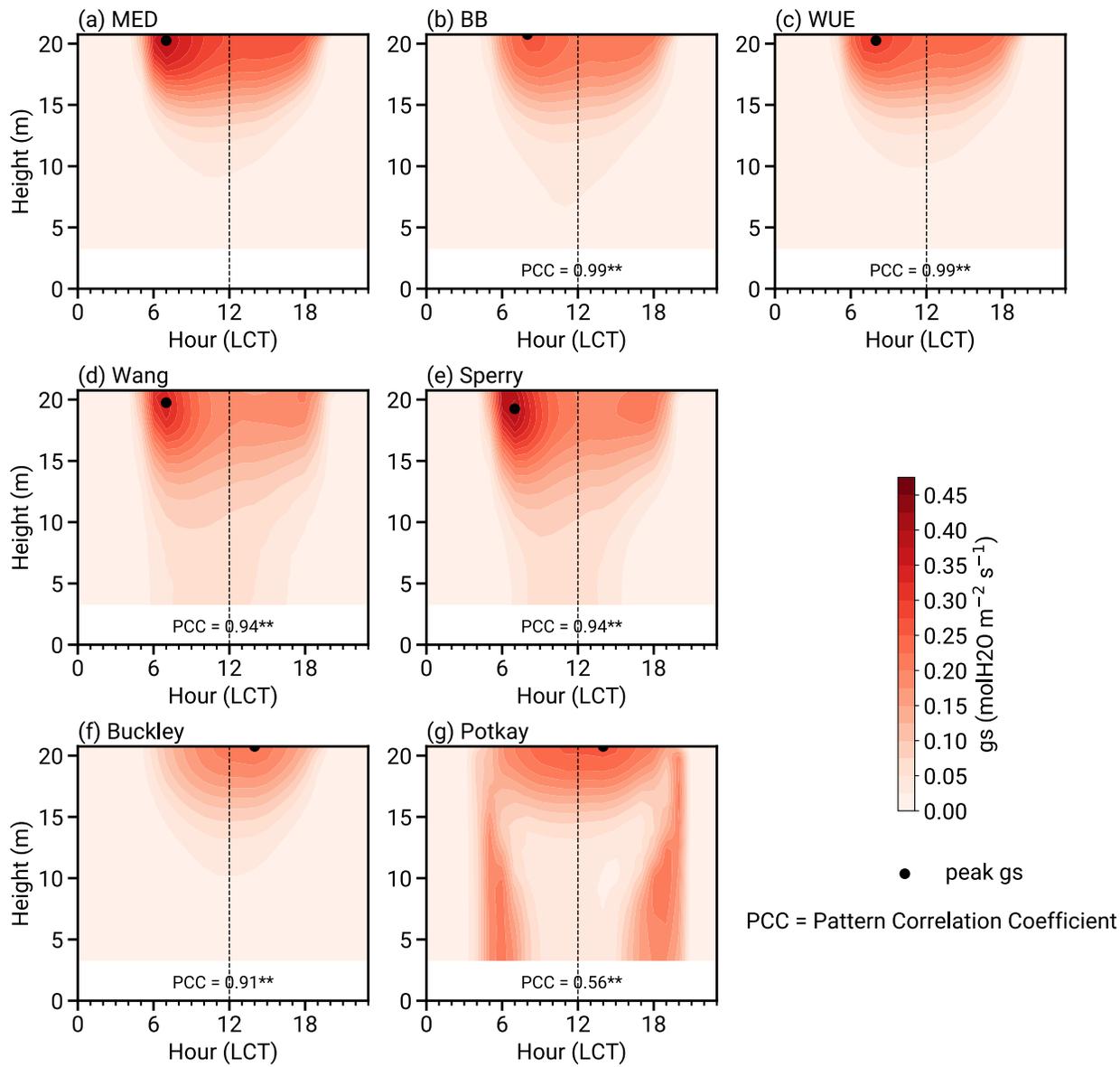
*gs-light response curve?*

# Why Do Different gs Models Peak at Different Times of Day?



AM (*Med, BB, WUE*, *Wang, Sperry*)
vs.
PM (*Buckley, Potkay*)

# Why the Potkay Model Shows High Lower-Canopy gs at Both Ends of the Day

(a) MED

(b) BB — PCC = 0.99**

(c) WUE — PCC = 0.99**

(d) Wang — PCC = 0.94**

(e) Sperry — PCC = 0.94**

(f) Buckley — PCC = 0.91**

(g) Potkay — PCC = 0.56**

gs (molH2O m$^{-2}$ s$^{-1}$)

• peak gs

PCC = Pattern Correlation Coefficient

VPD vs gs

Corr(gs, vpd)
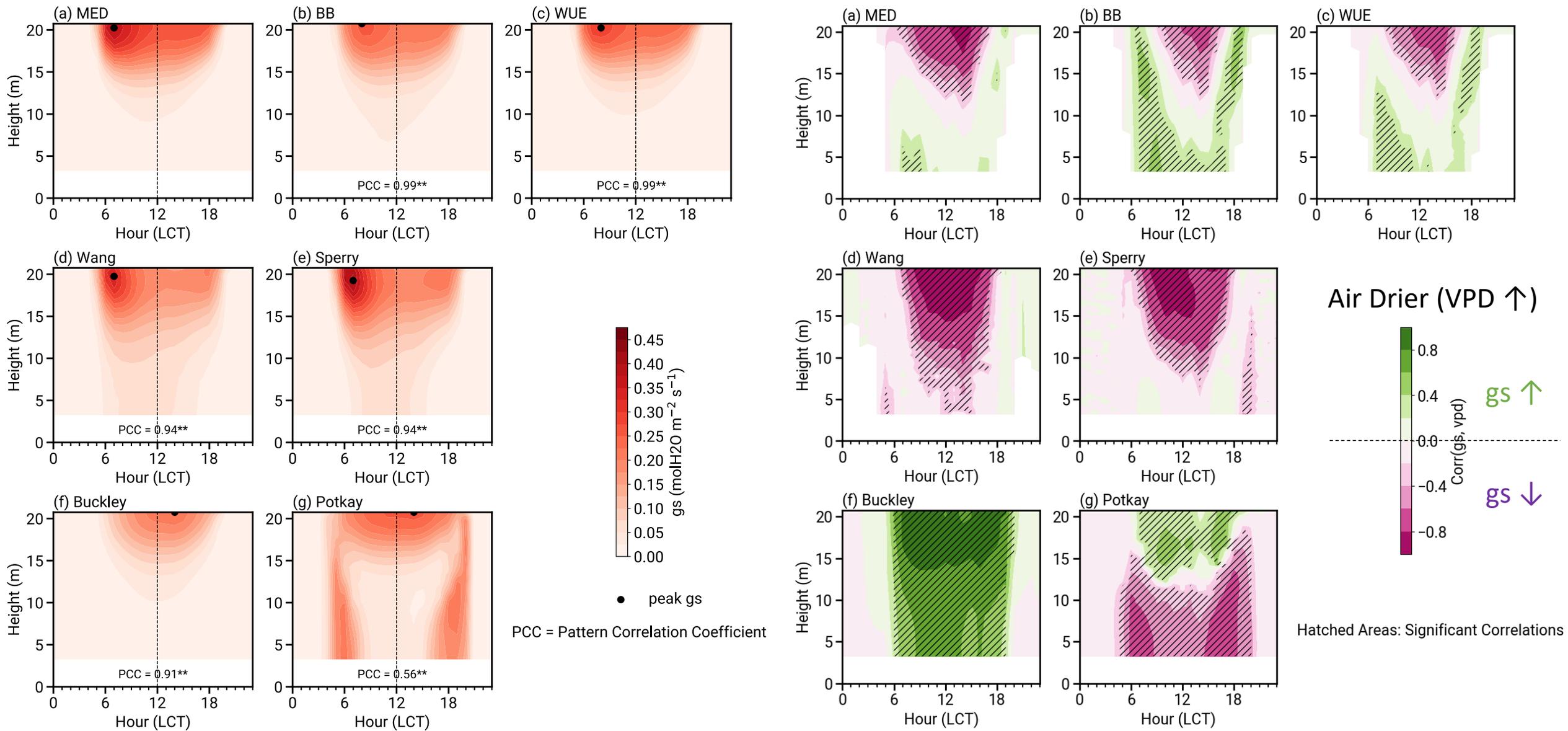
(g) Potkay

Hatched Areas: Significant Correlations

# Why the Potkay Model Shows High Lower-Canopy gs at Both Ends of the Day
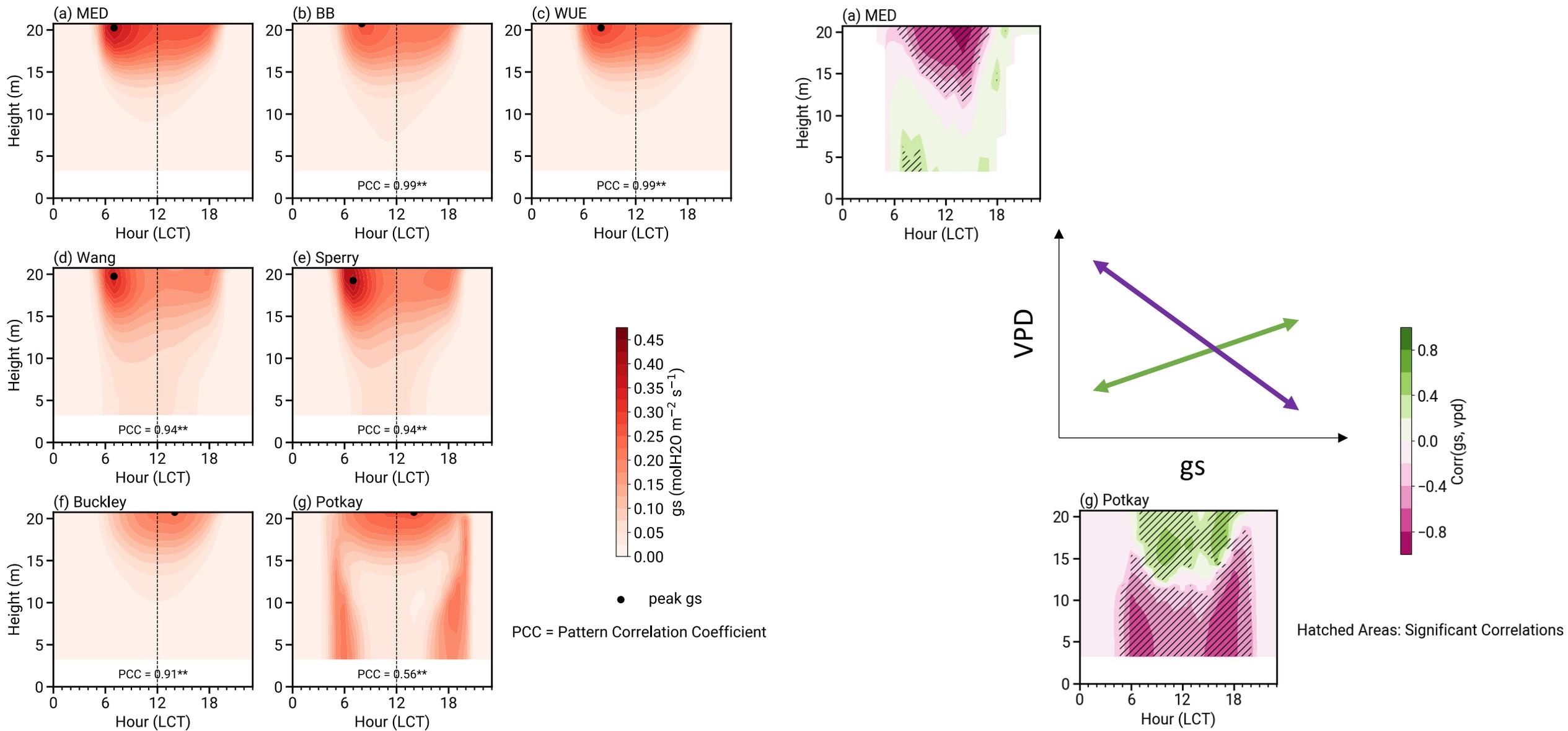
# Why the Potkay Model Shows High Lower-Canopy gs at Both Ends of the Day

# Conclusions and Future Directions

- All tested stomatal conductance models within CLM-ML show good skill in simulating canopy-level LE and GPP.

- Peak gs timing differs across stomatal models, largely reflecting differences in their light-response curve.

- The Potkay model shows strong sensitivity to VPD, resulting in elevated gs in the lower canopy during early morning and late afternoon.

- The analysis is based on only one temperate broadleaf site; extending the evaluation across diverse ecosystems is necessary.

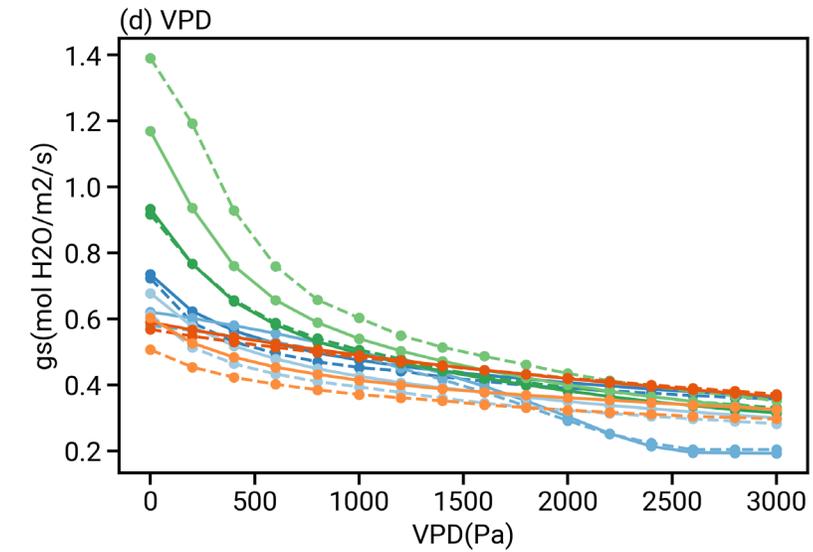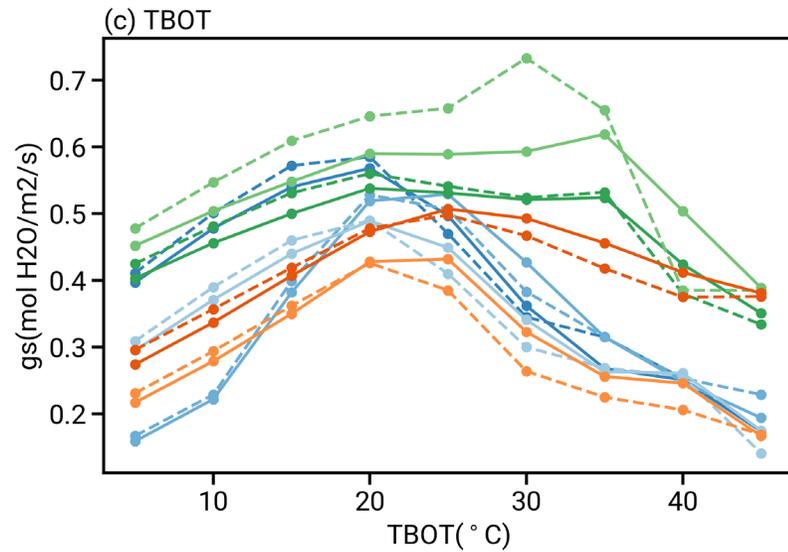- Parameter uncertainty must be quantified when comparing differences among gs models.

Thank you!
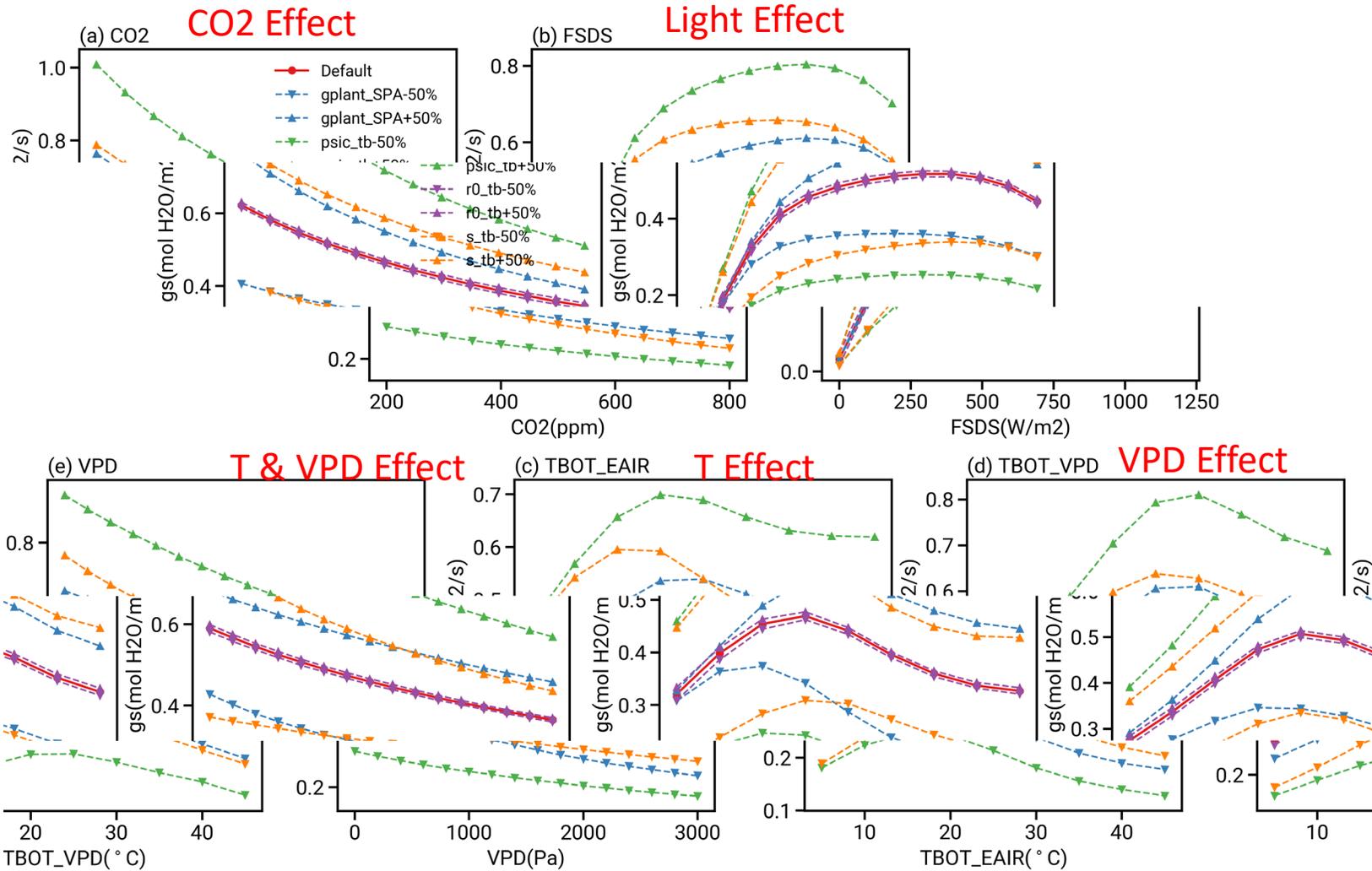Please feel free to reach out : zhiyi.zhou@colostate.edu

(a) CO2

(b) FSDS

(c) TBOT

(d) VPD

Legend: MED, BB, WUE, Wang, Sperry, Buckley, Potkay
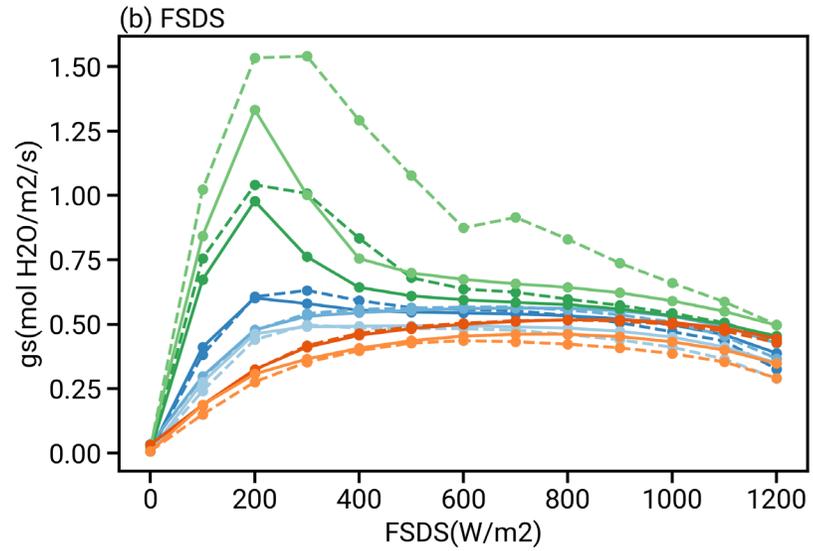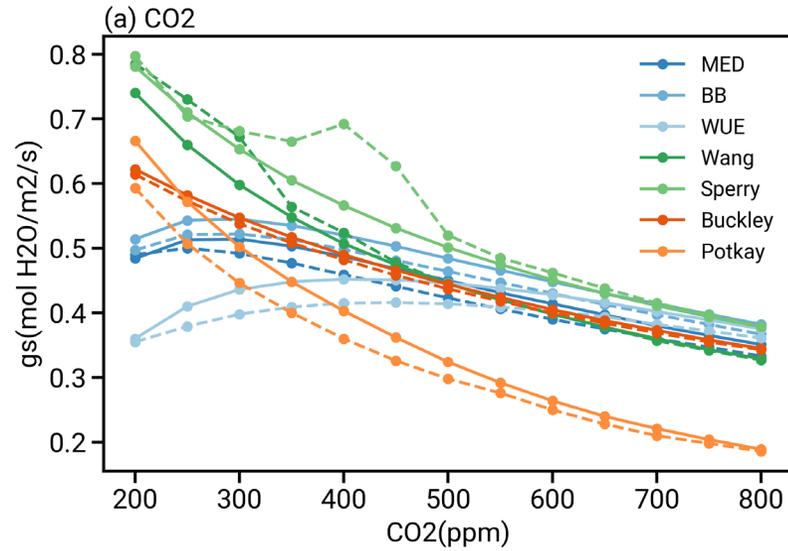
Multilayer — Bigleaf

*Thank you!*
*Please feel free to reach out : zhiyi.zhou@colostate.edu*

# Parameter Test on gs Response Curve



+50%(-50%): parameters increased (decreased) by 50% relative to default values