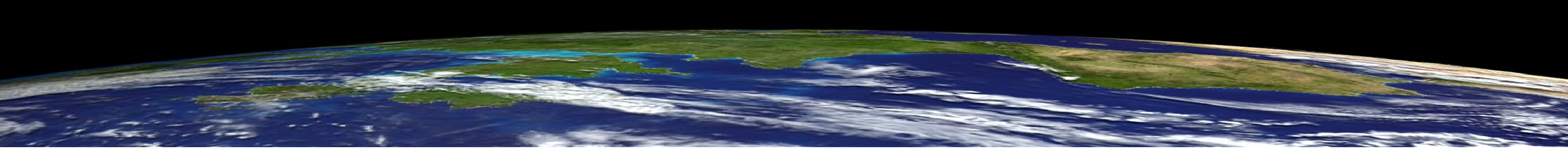

Improving the maize growth processes in the Community Land Model: implementation, evaluation and future work

Kaiyu Guan (UIUC), Bin Peng (UIUC), Min Chen (PNNL), Dave Lawrence (NCAR), Yadu Pokhrel (MSU), and Yaqiong Lu (NCAR)

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NCAR CESM WORKING GROUP MEETING, Mar 1, 2017

Outline

1) Motivation and CLM-APSIM-MAIZE Concepts
2) Implementation, parameter sensitivity, and site-level calibration
3) Some thoughts on large-scale validation and future work

Two groups of crop models

- **Agronomy crop models**: such as APSIM, DSSAT, EPIC, and DAYCENT. These agronomy crop models usually have a longer history, and were primarily developed at the site level by agronomists.
- **Crop models in the Earth system models**: such as CLM-Crop, Ag-IBIS, SiBcrop, ISAM, and LPJ-ML, in which modeling of photosynthesis, and energy and water balance are typically coupled.

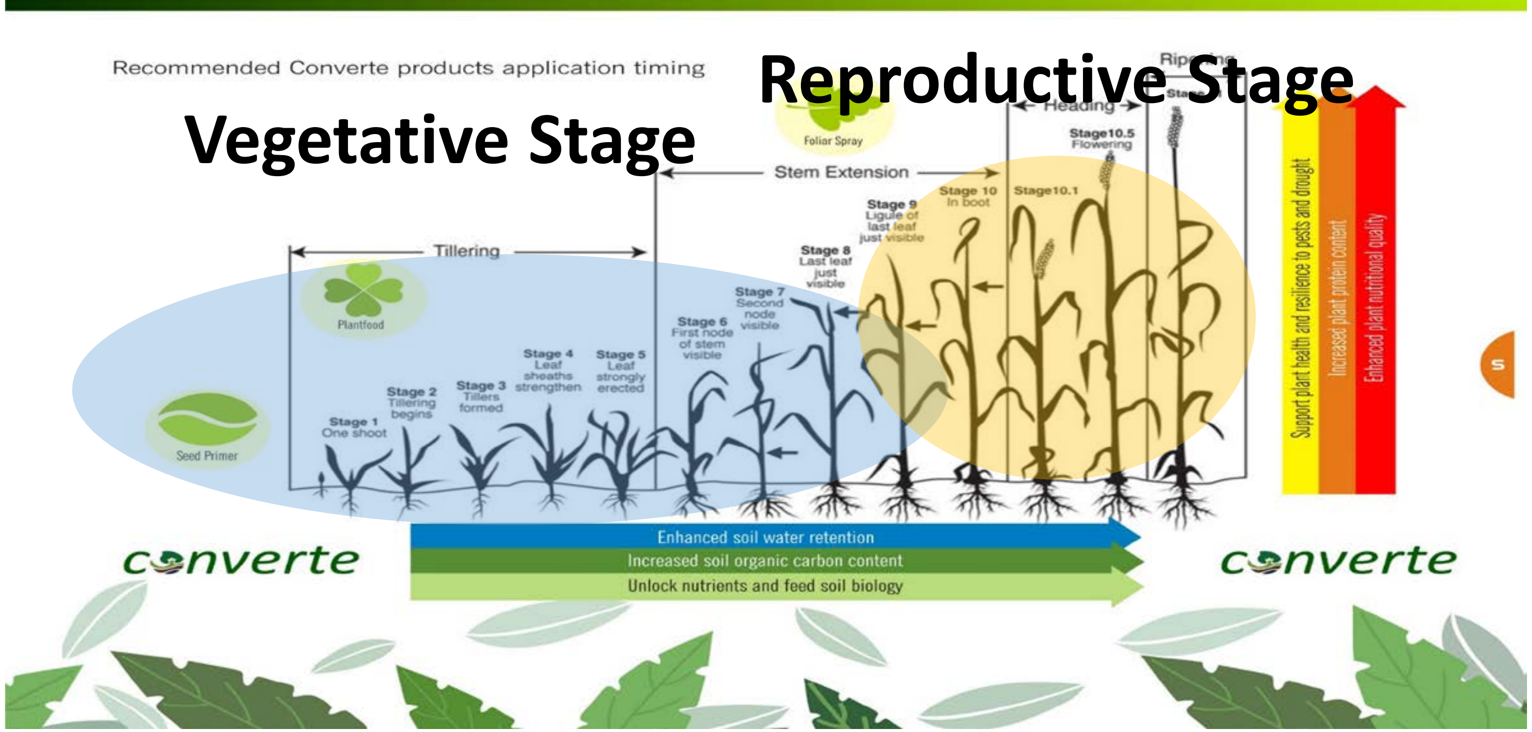
Current maize routine in CESM/CLM

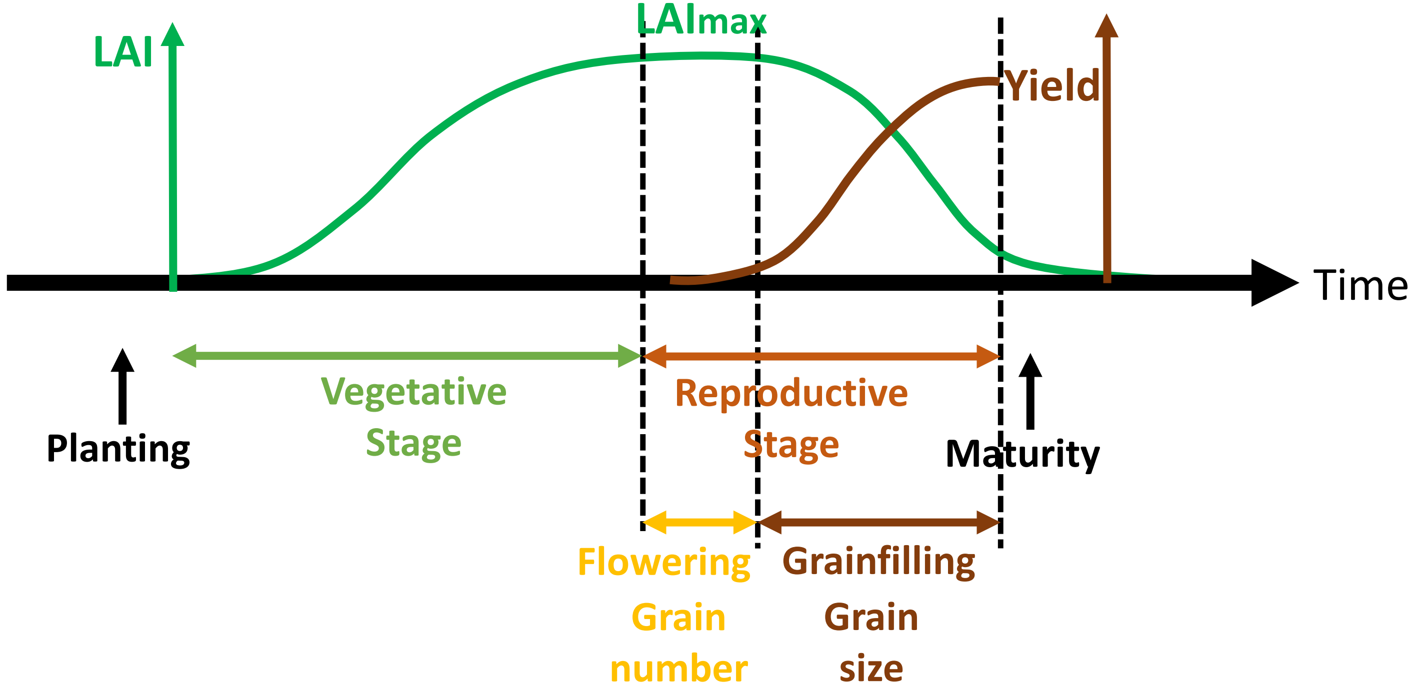
- Algorithm originated from **Agro-IBIS** (Kucharik et al., 2003)

- **Four stages**: plating, emergence, grain filling, maturity-harvest
  --> missing some critical stages (such as **flowering**)

- No other explicit stresses to phenology and allocation except those to photosynthesis (CLM4.5 has water, nitrogen and temperature stresses to photosynthesis)
  --> heat stress is still missing

- The phenology is determined by the linearly-accumulated GDD which leads to a linear phenology response to temperature


Recommended Converte products application timing
Vegetative Stage
Reproductive Stage
Tillering
Stem Extension
Heading
Ripening
Foliar Spray
Plantfood
Seed Primer
Stage 1 One shoot
Stage 2 Tillering begins
Stage 3 Tillers formed
Stage 4 Leaf sheaths strengthen
Stage 5 Leaf strongly erected
Stage 6 First node of stem visible
Stage 7 Second node visible
Stage 8 Last leaf just visible
Stage 9 Ligule of last leaf just visible
Stage 10 In boot
Stage10.1
Stage10.5 Flowering
Support plant health and resilience to pests and drought
Increased plant protein content
Enhanced plant nutritional quality
Enhanced soil water retention
Increased soil organic carbon content
Unlock nutrients and feed soil biology
converte
converte


LAI
LAImax
Yield
Time
Planting
Vegetative Stage
Reproductive Stage
Maturity
Flowering
Grainfilling
Grain number
Grain size

CLM-APSIM-MAIZE model

Kaiyu Guan, Bin Peng (UIUC), Min Chen (PNNL), Dave Lawrence & Yaqiong Lu (NCAR), Yadu Pokhrel (MSU)

The motivation of CLM-APSIM is to combine the strengths of both CLM and APSIM models

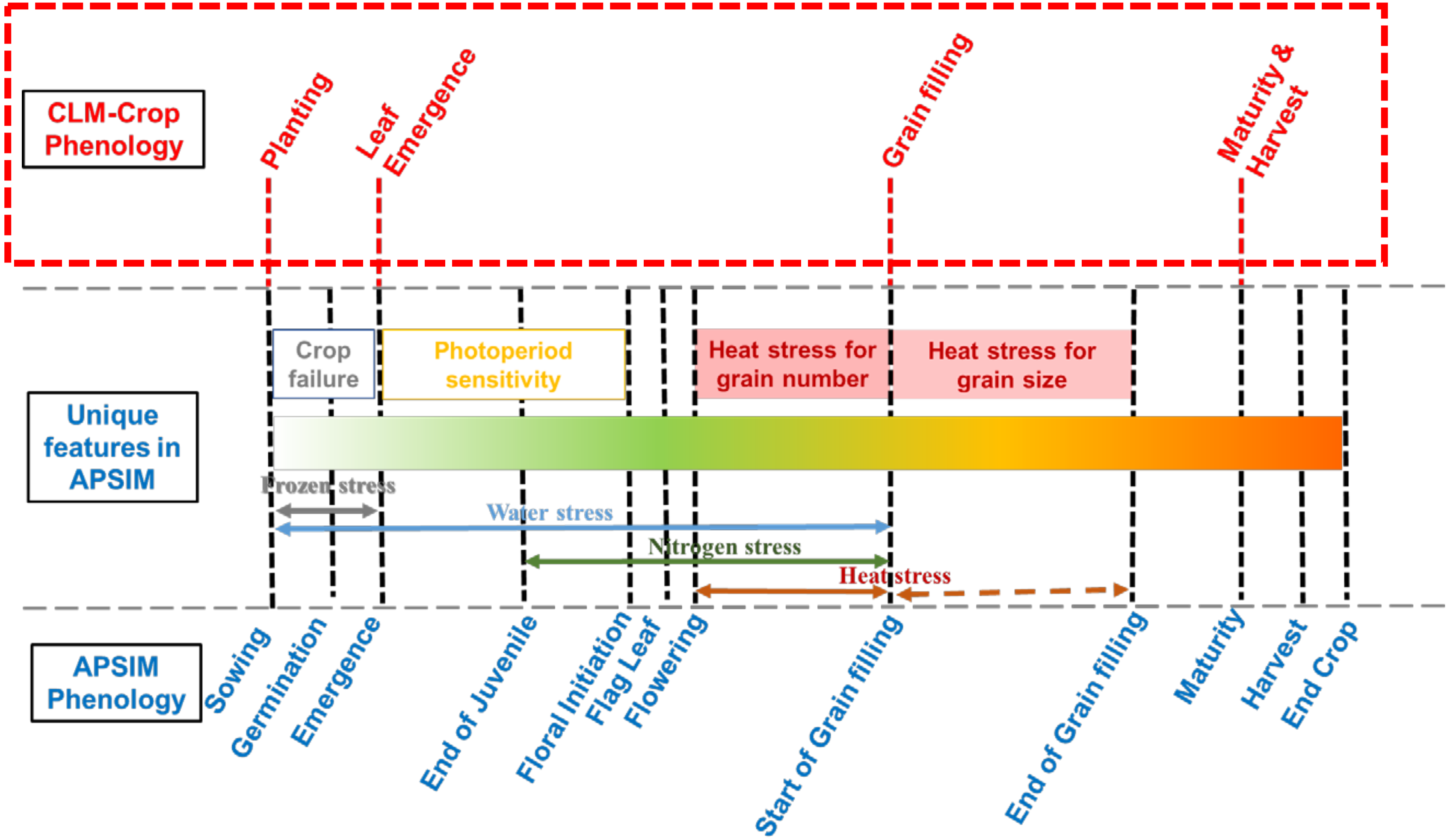


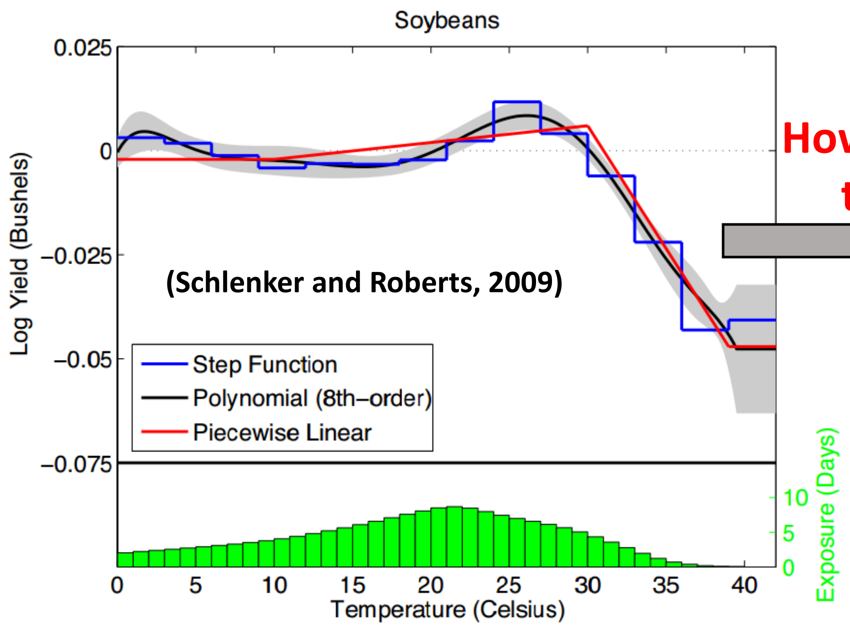
Fig 1. Conceptual diagram showing the differences between original CLM and CLM-APSIM models in phenology development and unique features in CLM-APSIM on environmental stresses.

However, there are many more strengths in the CLM framework (no need to say too much here)

Model	Strength	Weakness
CLM	● Complex soil and canopy hydrology ● Multi-layer canopy radiative transfer ● Physical-based stomatal conductance and photosynthesis ● Explicitly calculate canopy temperature ● More process-driven CO_2 fertilization effects ● More others	● Missed critical stages ● Lack of stress terms ● Linear accumulation of thermal time
APSIM	● More detailed growth stages ● Stage-dependent stress terms ● Piece-wise linear response of thermal time ● More detailed management practices	● RUE-based photosynthesis ● Oversimplified soil hydrology

And also, CLM can be readily coupled in CESM!

Furthermore:
what about crop responses to climate change?



How to attribute this slope?

Possible Mechanisms:

1. Photosynthesis and Respiration
2. Growth rate and shortening of growing season
3. Heat stress during reproductive stage (Harvest Index)
4. Larger atmospheric water demands

……

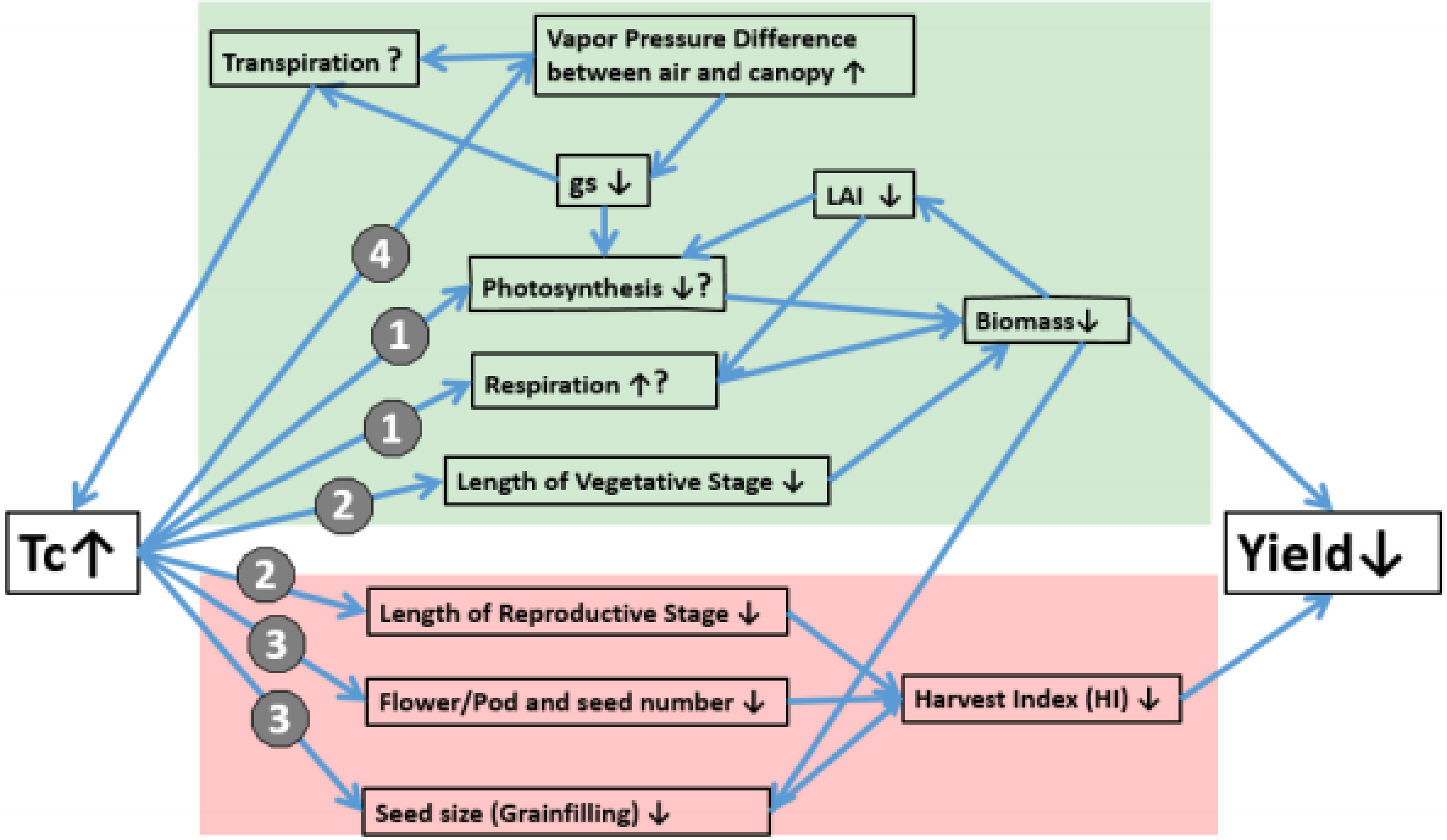


Fig. 3. The conceptual diagram of different processes that are involved in crop responses to higher canopy temperature (Tc), which also contains all the major hypotheses, with "↑" indicating a hypothesized increase, "↓" indicating a hypothesized decrease, and "?" indicating unclear direction of change. The processes in the green box are mostly related to biomass production, while those in the red box are mostly related to the Harvest Index.

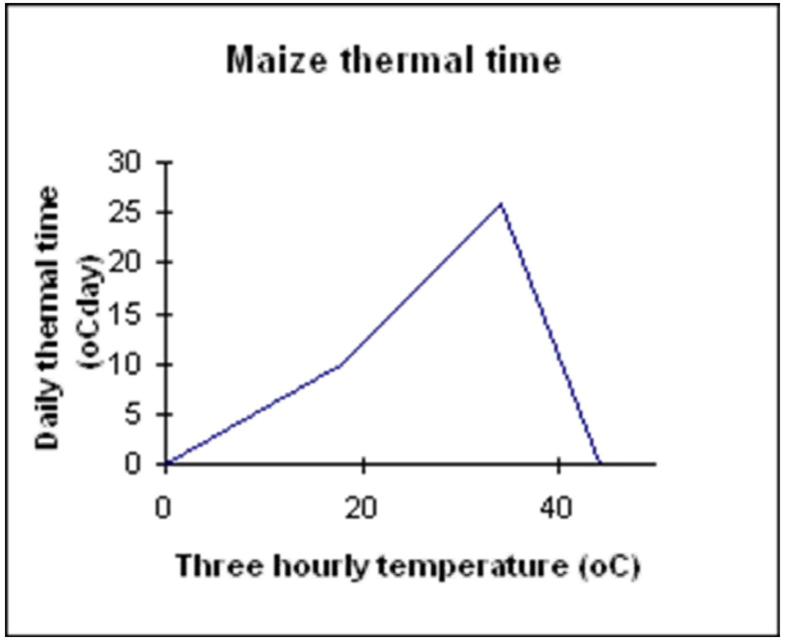
USDA NIFA Newly funded project: **"Parsing multiple mechanisms of high temperature impacts on soybean yield combining infrared heating experiments and process-based modeling"**
(PI: Kaiyu Guan; Co-PI: Lisa Ainsworth, Carl Bernacchi)

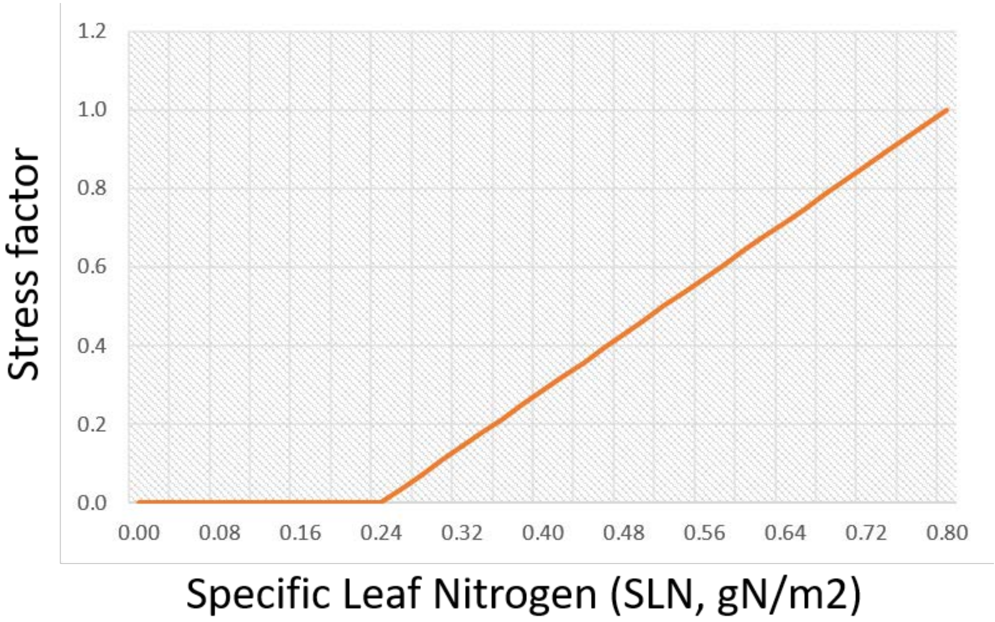
So, this is why we put the APSIM Maize into the CLM!

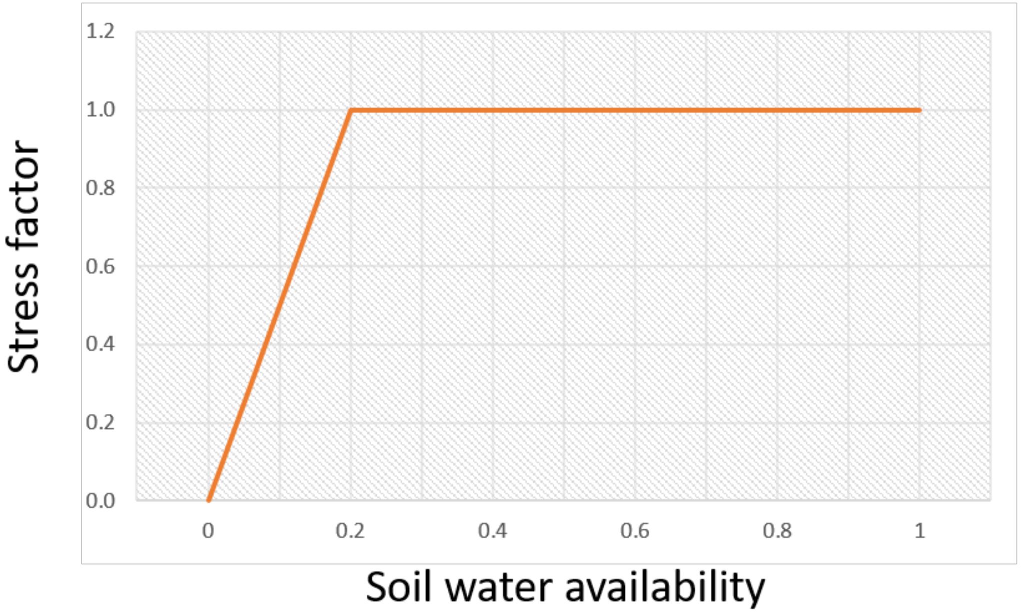
Let’s see how we did it.

CLM-APSIM-Maize Implementation

- Phenology scheme from APSIM (12 stages)
- Phenology driven by Thermal Time (TT)
- Soil moisture, nitrogen, temperature and heat stress terms from APSIM to maize phenology

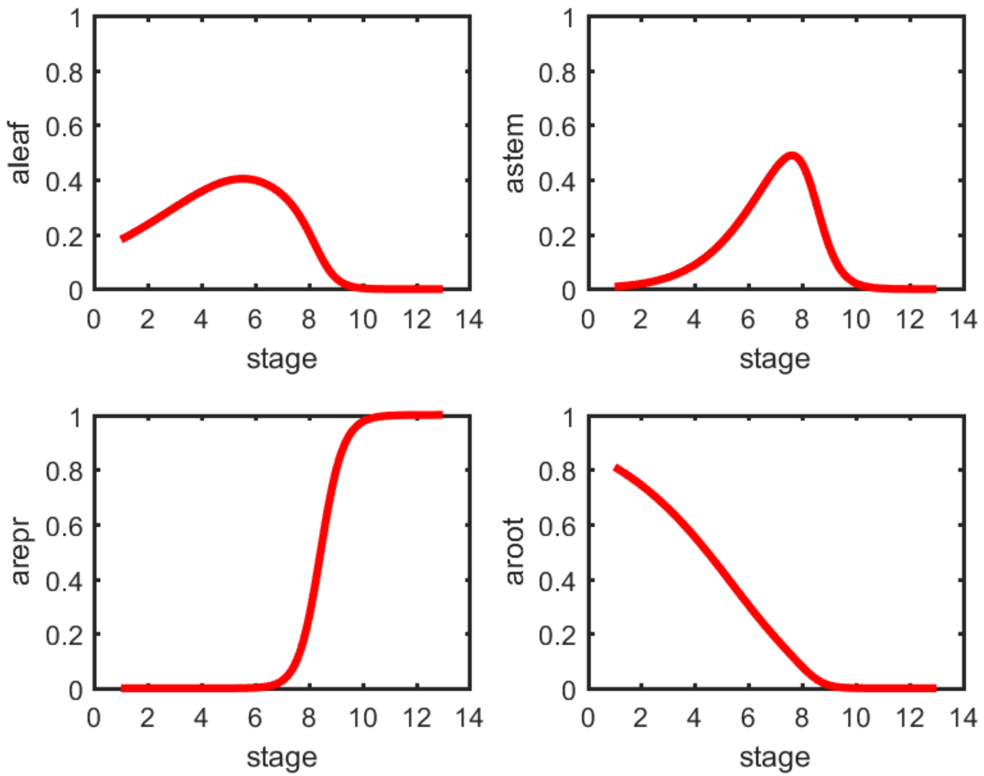






CLM-APSIM-Maize Implementation

- Stage-dependent potential allocation coefficient under unstressed condition
- Water, nitrogen and light stress to carbon allocation in vegetative stages
- Additional supply-demand type stress (due to grain number) to grain carbon allocation in grain filling stage



$$\begin{cases} a_{leaf} = exp(\alpha_{leaf} + \beta_{leaf} \times stage)/\Delta \\ a_{stem} = exp(\alpha_{stem} + \beta_{stem} \times stage)/\Delta \\ a_{root} = exp(\alpha_{root} + \beta_{root} \times stage)/\Delta \\ a_{repr} = 1/\Delta \end{cases}$$

Where $\Delta = \sum_{i=root,stem\ and\ leaf} exp(\alpha_i + \beta_i \times stage) + 1$

$$a_{leaf} = a_{leaf,p}/[1 + \omega(3 - LS - WS - NS)]$$

$$a_{stem} = [a_{stem,p} + \omega(1 - LS)]/[1 + \omega(3 - LS - WS - NS)]$$

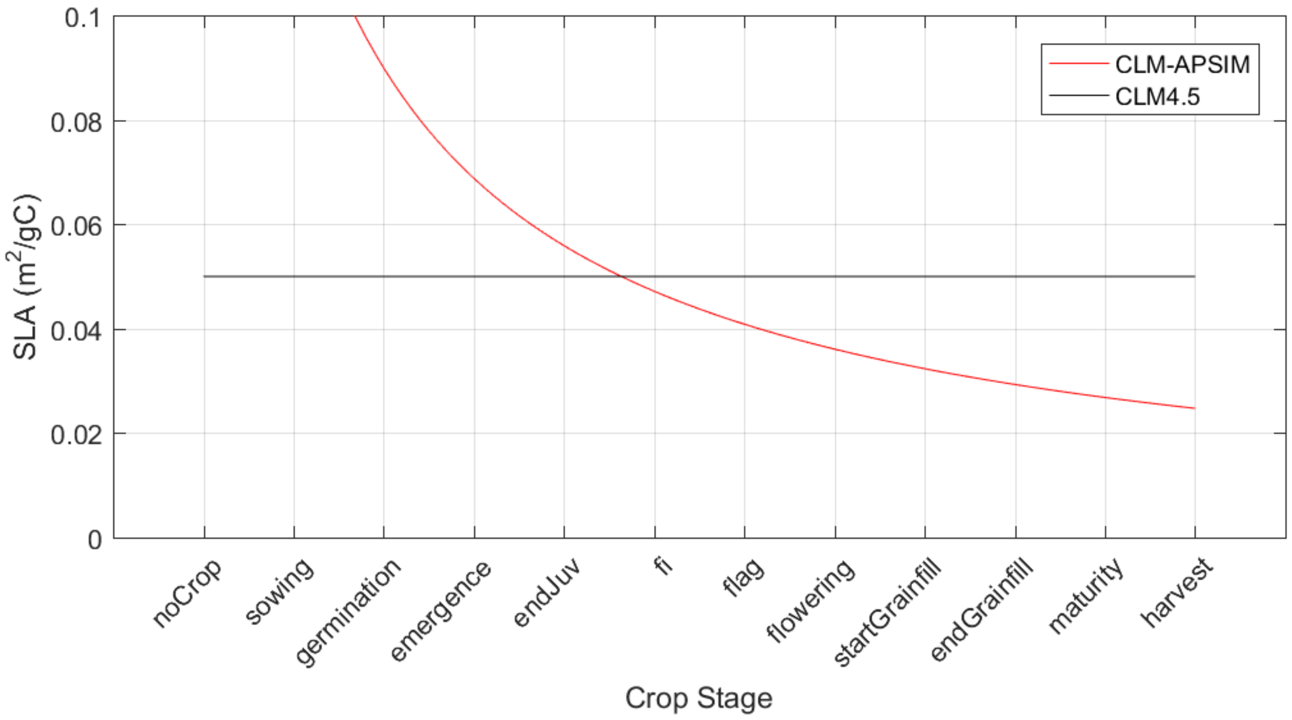
$$a_{root} = [a_{root,p} + \omega(2 - WS - NS)]/[1 + \omega(3 - LS - WS - NS)]$$

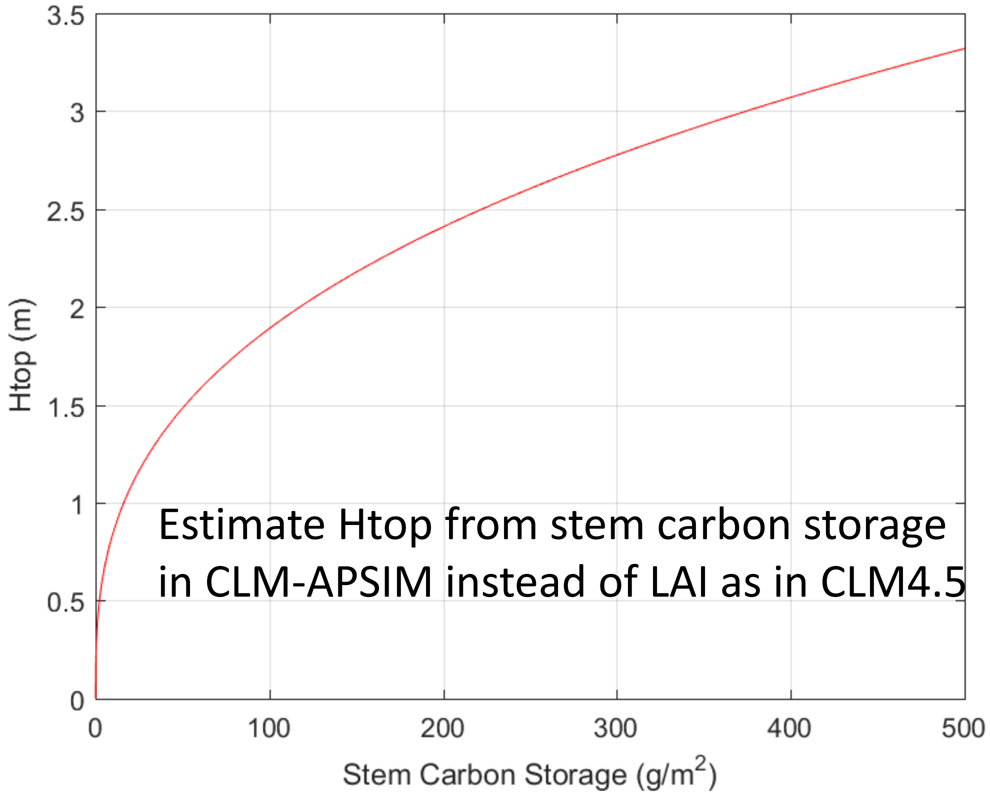
$$a_{grain} = \frac{min[(C2Grain) \times (1 - a_{root}), C2Grain\_demand]}{availC},$$

$$when\ startGrainFill \leq stage \leq maturity$$

CLM-APSIM-Maize Implementation

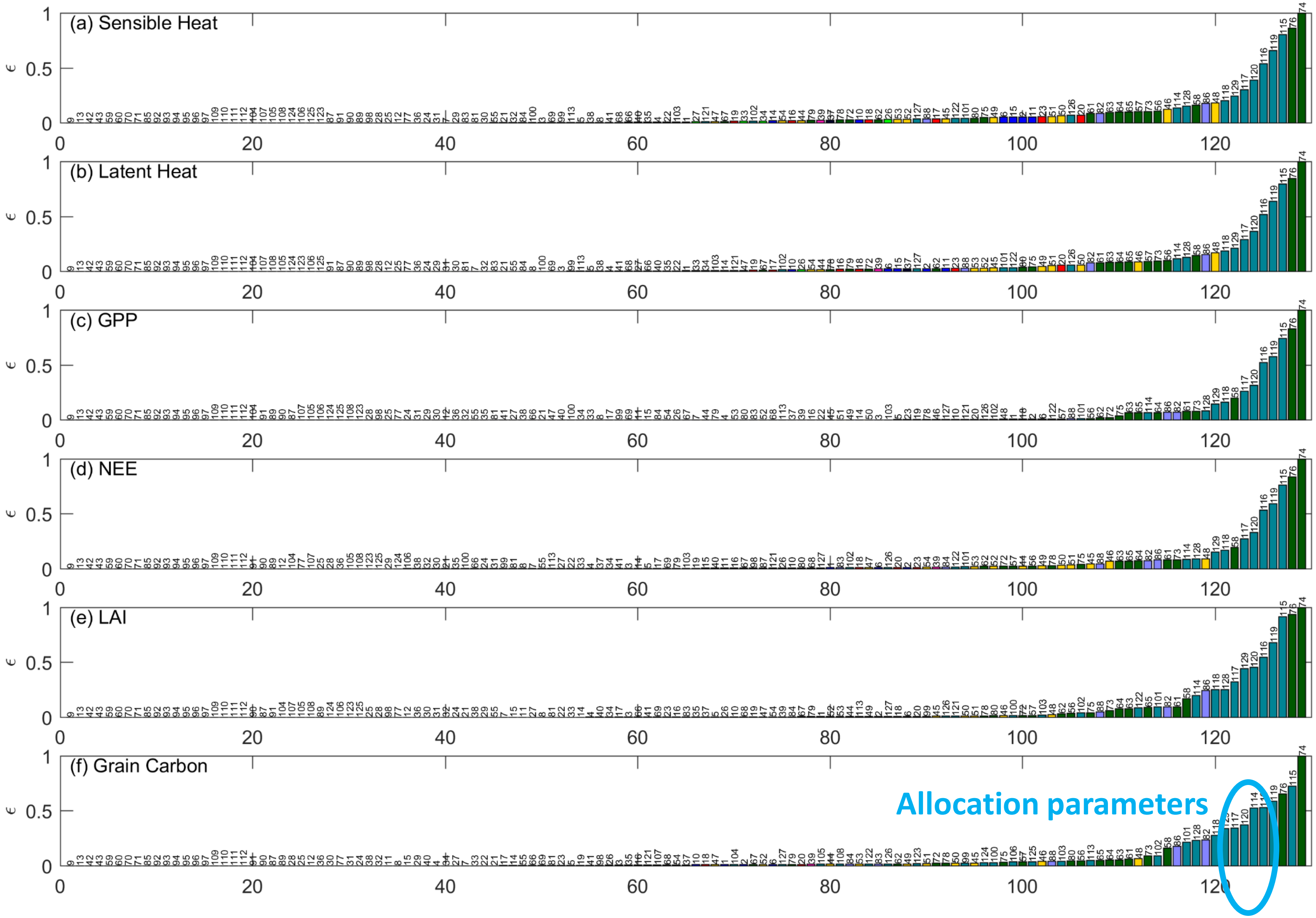
- Explicit simulation of grain number and grain size
- Dynamic specific leaf area (SLA) (stage-dependent)
- Improved LAI and canopy height estimation scheme





Estimate Htop from stem carbon storage in CLM-APSIM instead of LAI as in CLM4.5

Parameter sensitivity analysis of CLM-APSIM-Maize



Morris parameter screening:

$$\varepsilon = \sqrt{\mu^{*2} + \sigma^2}$$

We normalized ε to (0, 1].

Color of bar represents parameter categories:

Forest Green color: Photosynthesis-related parameters

(74->S2, 76->S4)

For C_4 plants,

$$V_{c\max} = V_{c\max 25}\left[\frac{Q_{10}^{(T_v - 298.15)/10}}{f_H(T_v)\, f_L(T_v)}\right]$$

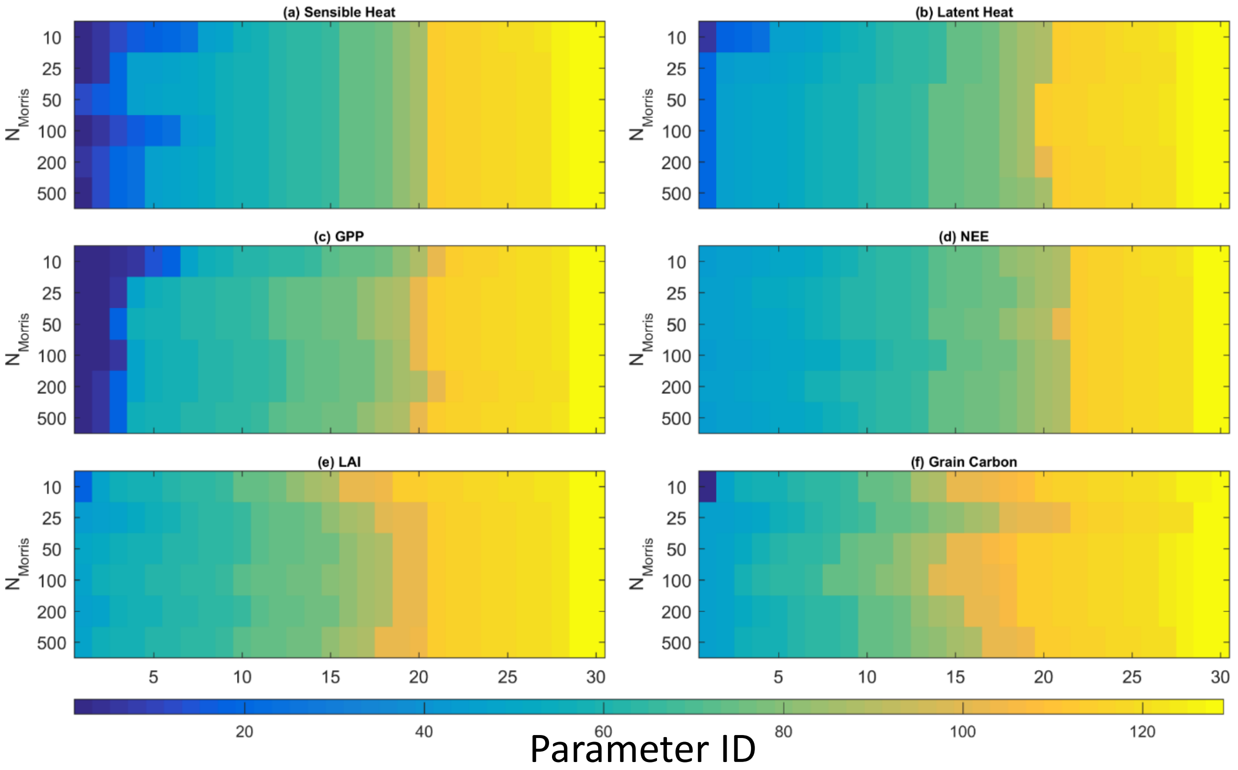
$$f_H(T_v) = 1 + \exp\left[s_1(T_v - s_2)\right]$$

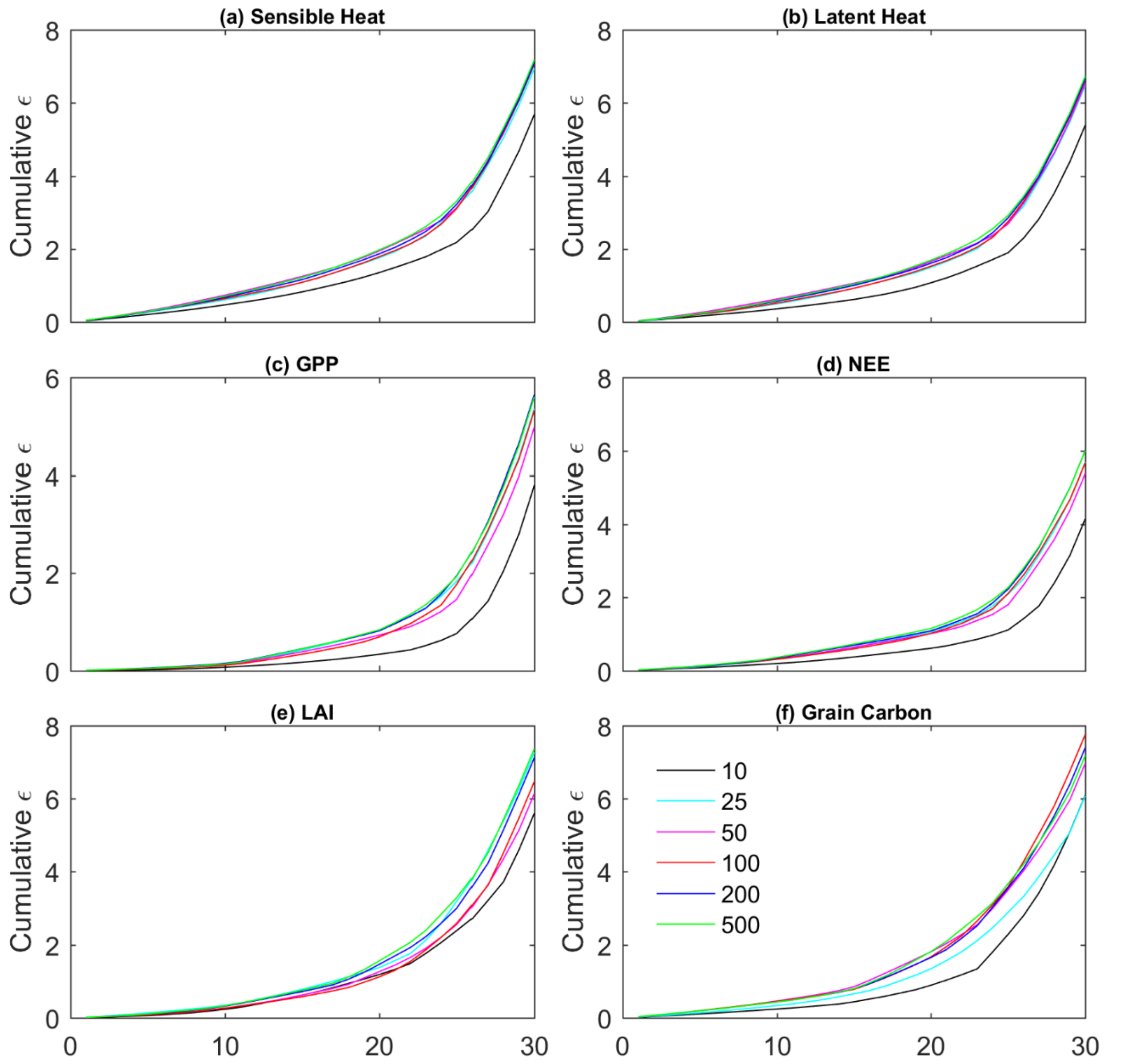
$$f_L(T_v) = 1 + \exp\left[s_3(s_4 - T_v)\right]$$

with $Q_{10} = 2$, S1 = 0.3 K^{-1} , **S_2 = 313.15 K**, S_3 = 0.2 K^{-1} , and **S_4 = 288.15 K**

Parameter sensitivity analysis of CLM-APSIM-Maize

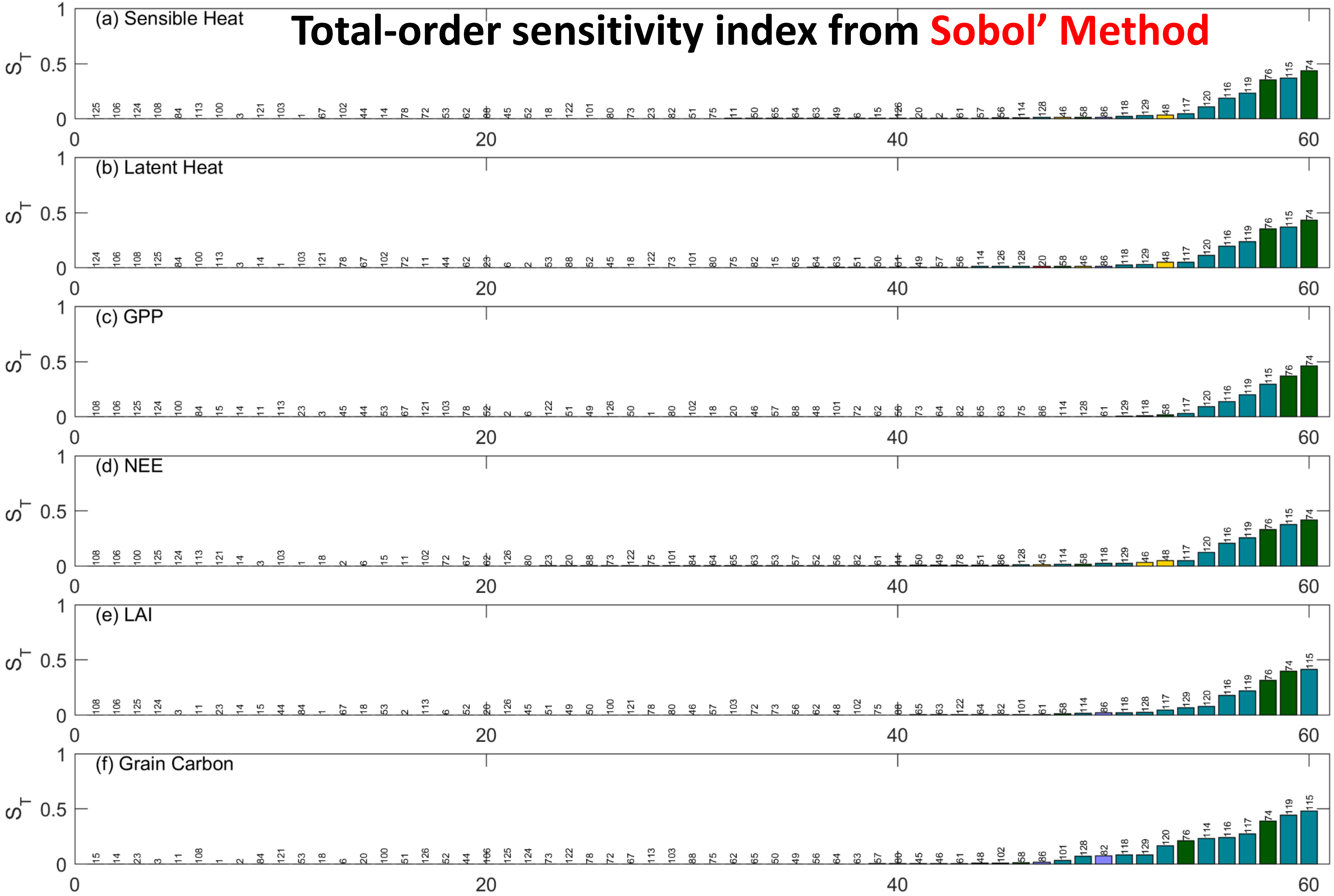
The ascending sorted parameter ID of the screened most sensitive 30 parameters (left) and the accumulated main effect of these 30 parameters (right)





- **The results of Morris method converged when N>=50**
- **60 parameters emerged in the all the subplots of left figure and were identified as sensitive parameters and used for Sobol' analysis**

Parameter sensitivity analysis of CLM-APSIM-Maize



46: parameter for porosity of the mineral soil

48: parameter for saturated matric potential of the mineral soil

74: S2 in Vcmax

76: S4 in Vcmax

82: leaf C:N in vegetative stage

114: Total Thermal Time for reproductive stages

115: alpha for leaf

116: beta for leaf

117: alpha for stem

118: beta for stem

119: alpha for root

120: beta for root

128: kappa for dynamic SLA

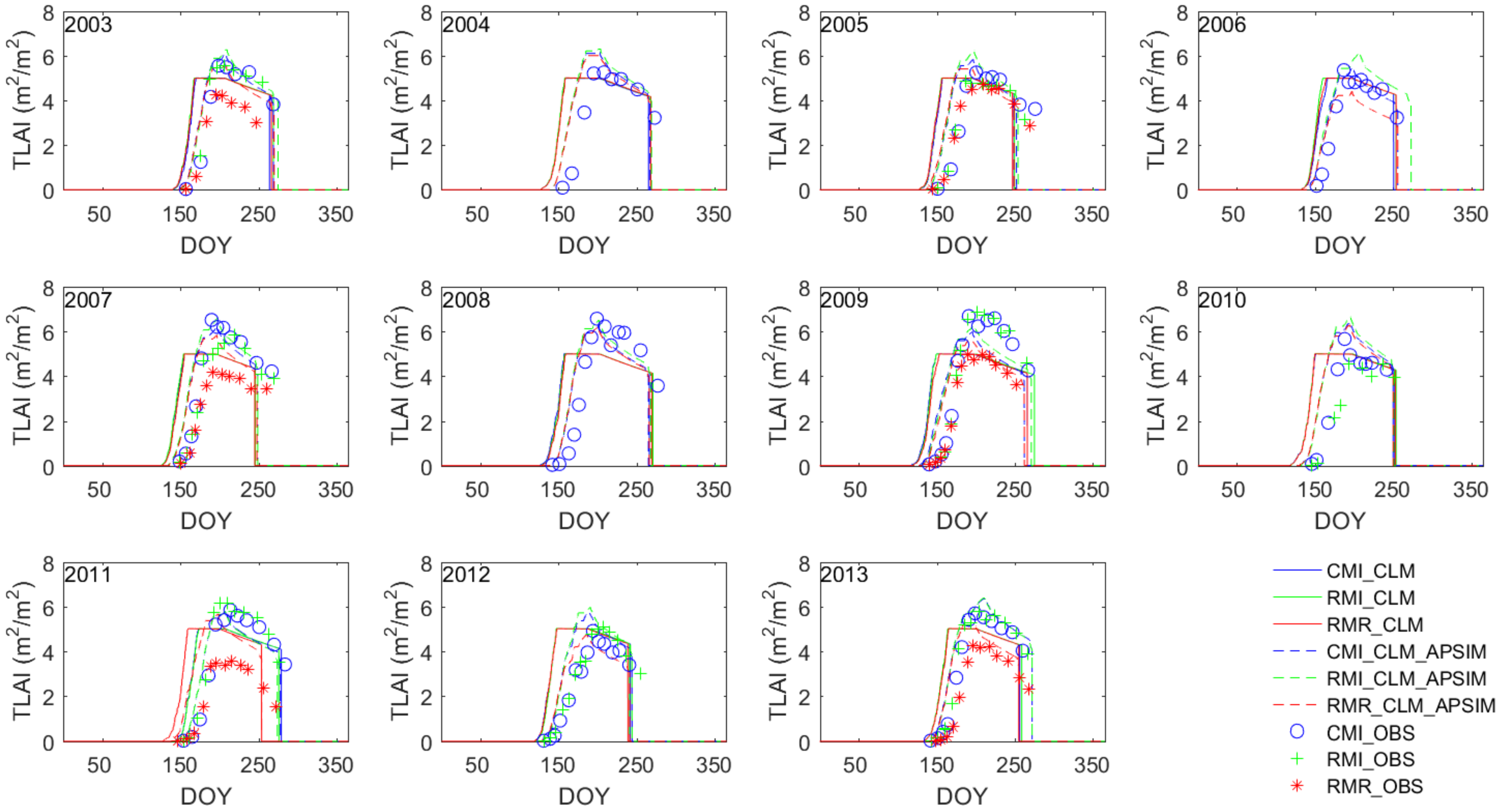
129: lambda for dynamic SLA

CLM-APSIM model evaluation

7 sites located in the US Corn Belt

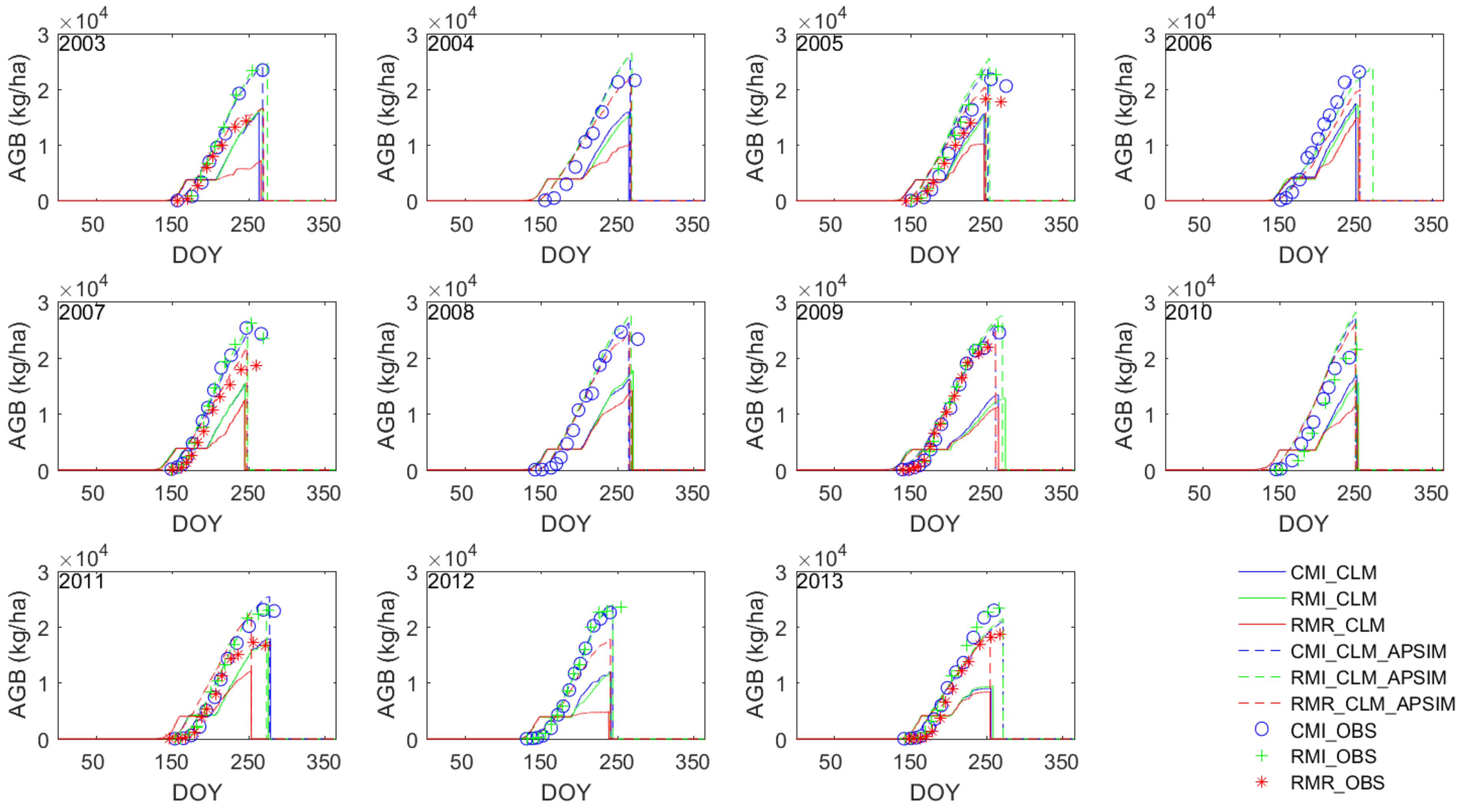
Site Name	Latitude	Longitude	Location	Available Year	Crop Types and Management
US-Ne1	41.1651	-96.4766	Mead, NE	2001-2013	Irrigated, Continuous corn
US-Ne2	41.1649	-96.4701	Mead, NE	2001-2013	Irrigated, Corn at odd years and soybean at even years before 2009, Corn after 2009
US-Ne3	41.1697	-96.4397	Mead, NE	2001-2013	Rainfed, Corn at odd years and soybean at even years
US-Bo1	40.0062	-88.2904	Bondville, IL	2005-2008	Rainfed, corn in 2005 and 2007, soybean in 2006 and 2008
US-IB1	41.8593	-88.2227	Batavia, IL	2007-2009	Rainfed, Corn at even years and soybean at odd years
US-Br1	41.6915	-93.6914	Brooks, IA	2007-2011	Rainfed, Corn at odd years and soybean at even years
US-Ro1	44.7143	-93.0898	Rosemount, MN	2007-2010	Rainfed, Corn at odd years and soybean at even years

Improved Simulation of LAI



Note: (1) We use <u>observed sowing date</u> for three Mead site for both CLM and CLM-APSIM;
(2) We use dynamic Specific Leaf Area (SLA) and removed maximum LAI constraint;
CLM4.5 has earlier phenology than observations and CLM-APSIM

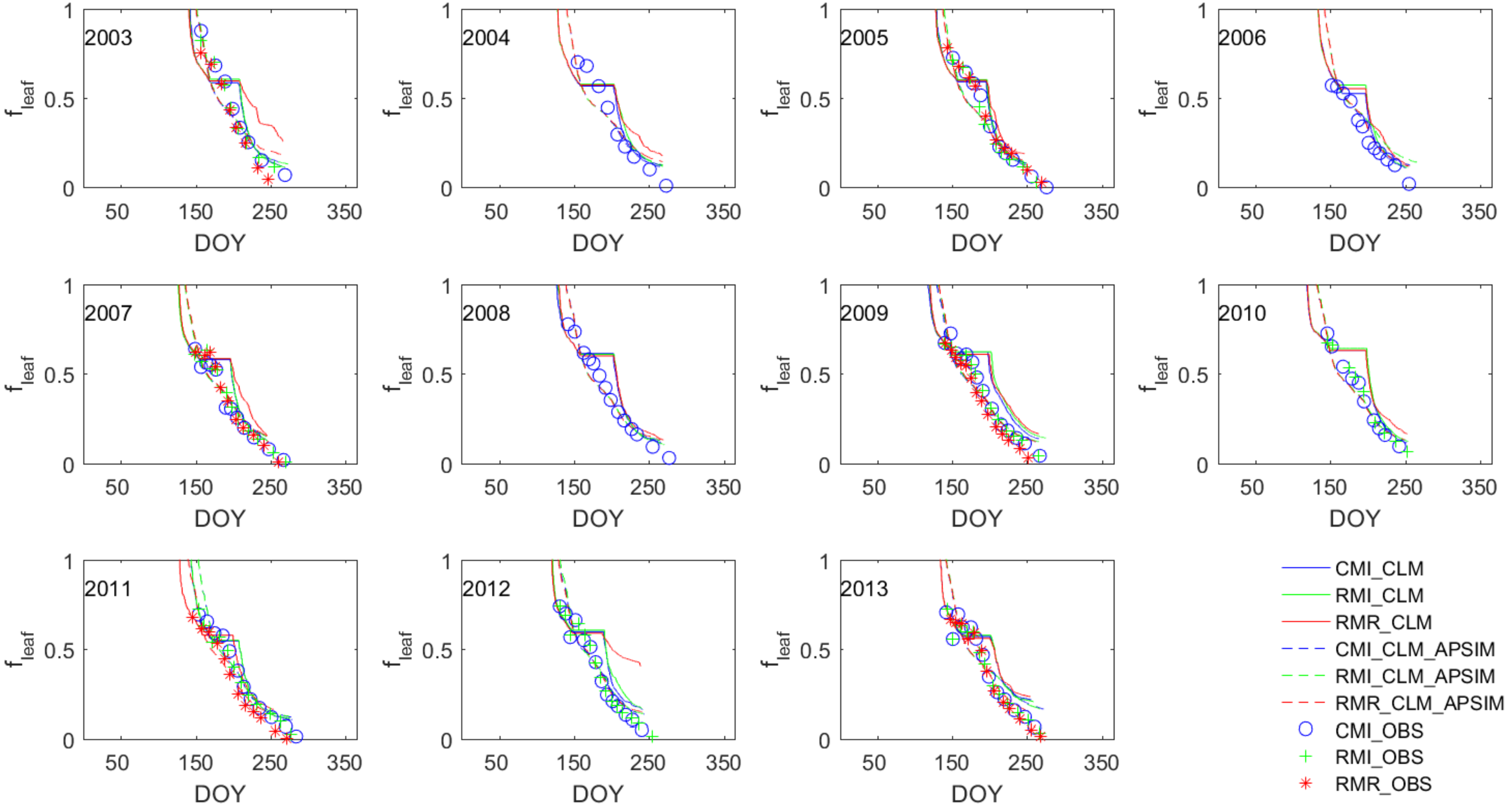
Improved simulation of AGB



CLM allocation scheme seriously underestimate the AGB and overestimate the BGB

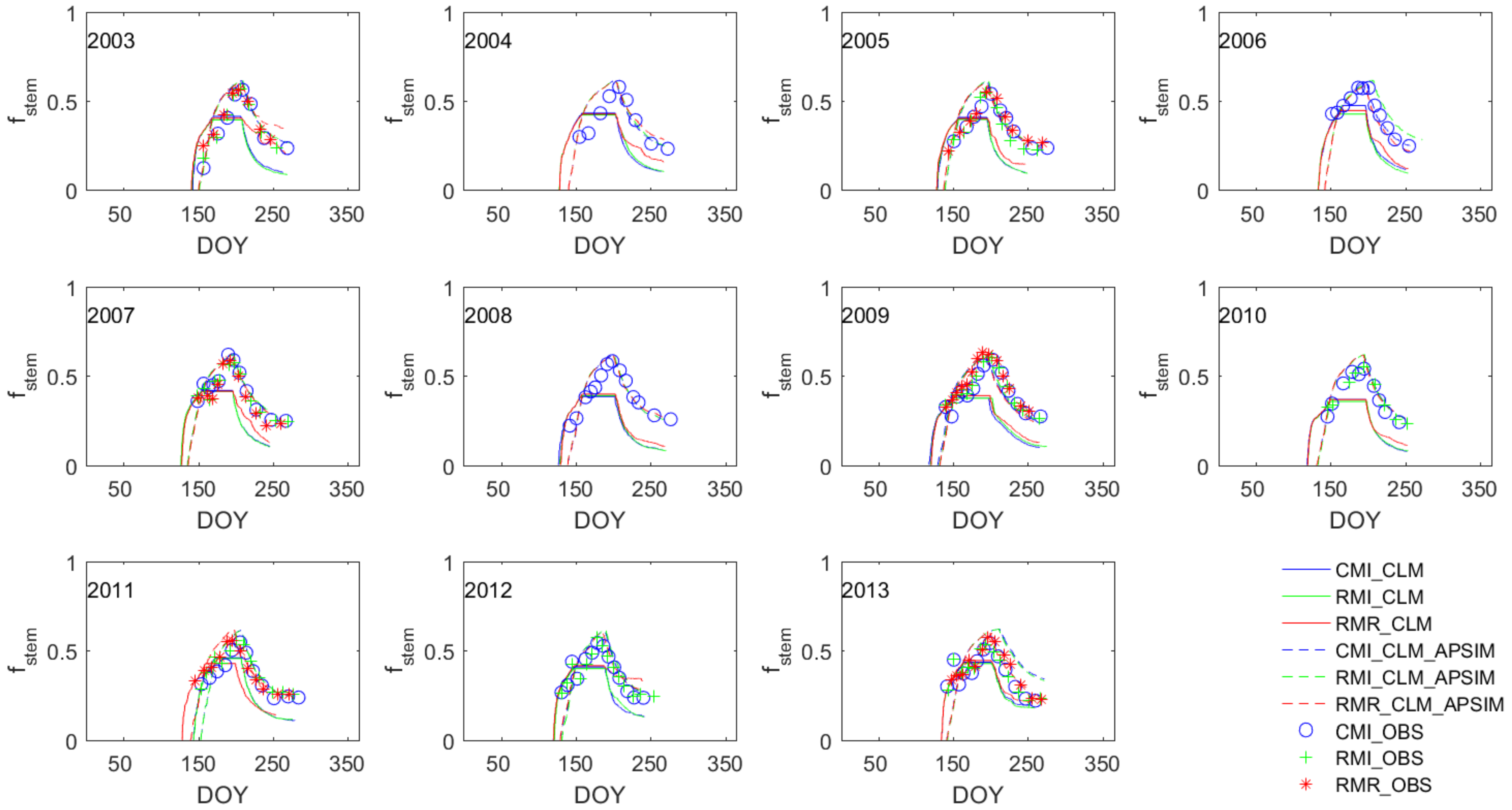
=> Apparent “right” yield simulation with wrong mechanism in CLM4.5

Improved Carbon Allocation: leaf carbon fraction in AGB



CLM allocation scheme produces discontinued leaf fraction in AGB and overestimate the leaf fraction in reproductive stage

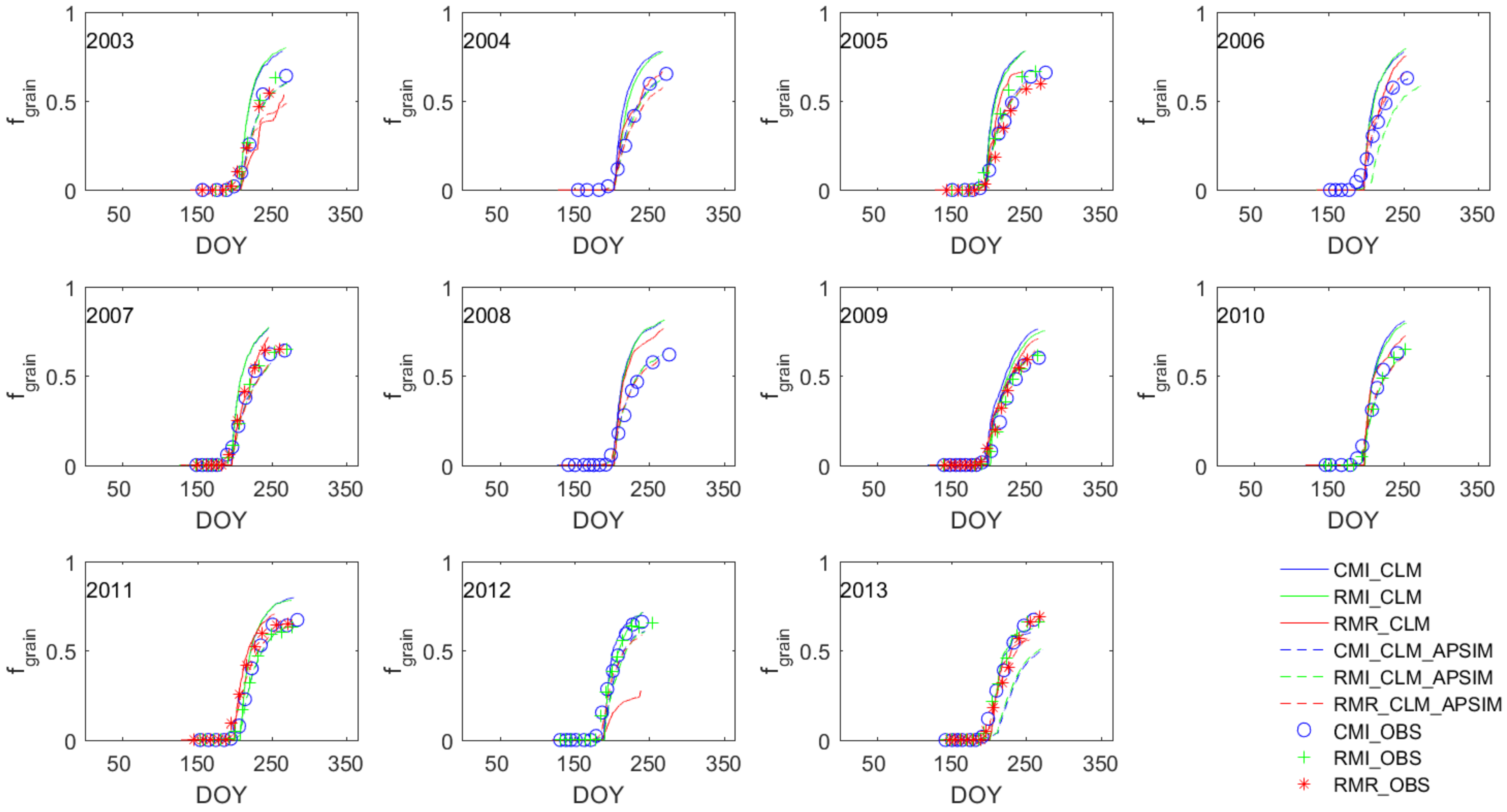
Improved Carbon Allocation: stem carbon fraction in AGB



CLM allocation scheme underestimate the stem carbon fraction in AGB

=>Apparent "right" yield simulation with wrong mechanism in CLM4.5

Improved Carbon Allocation: grain carbon fraction in AGB



CLM allocation scheme overestimate the grain carbon fraction in AGB

=>Apparent "right" yield simulation with wrong mechanism in CLM4.5

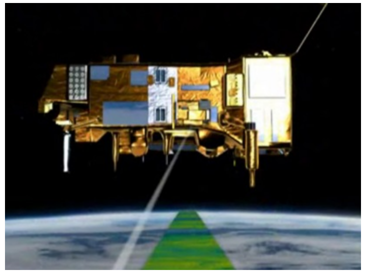
We plan to spatially parameterize our model from some novel and existing satellite data

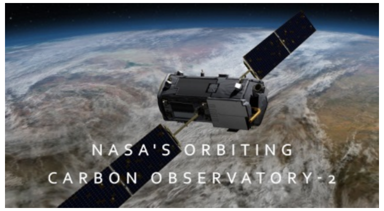
Including (to name a few)

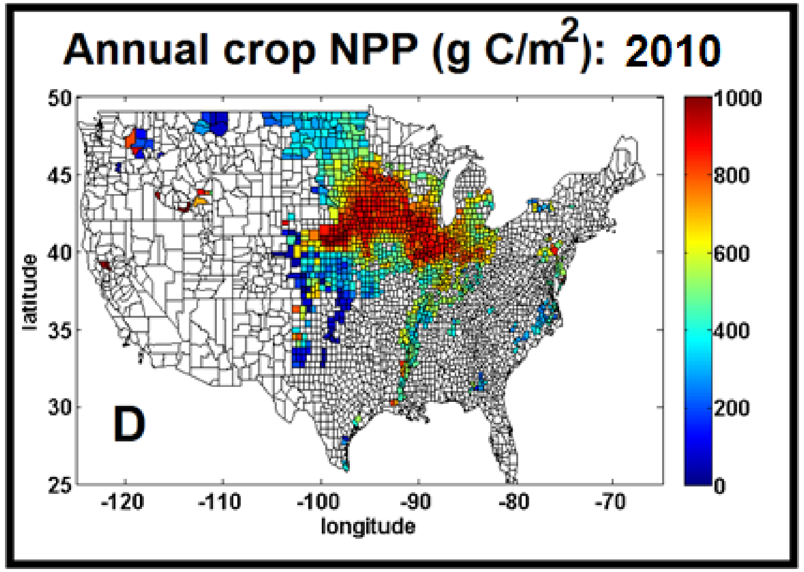
- Solar-induced fluorescence (GOME-2, OCO-2)
- SMAP root-zone soil moisture product
- MODIS LAI or VI
- etc.

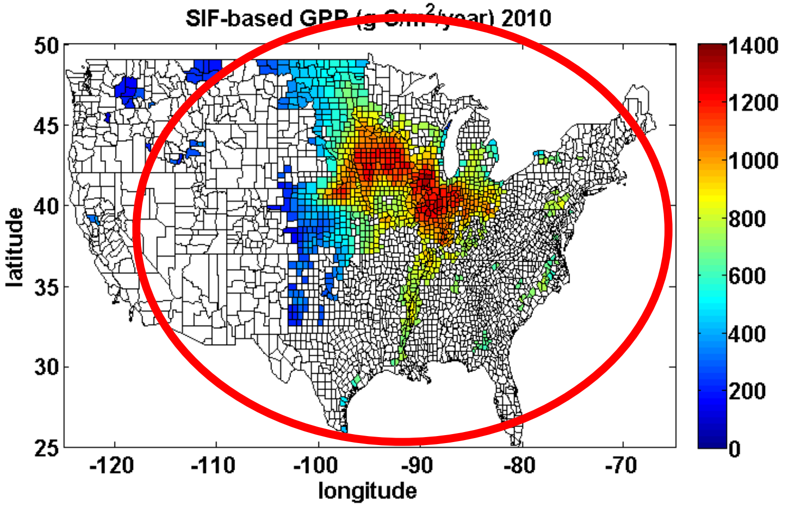
Sun-induced chlorophyll fluorescence (SIF)

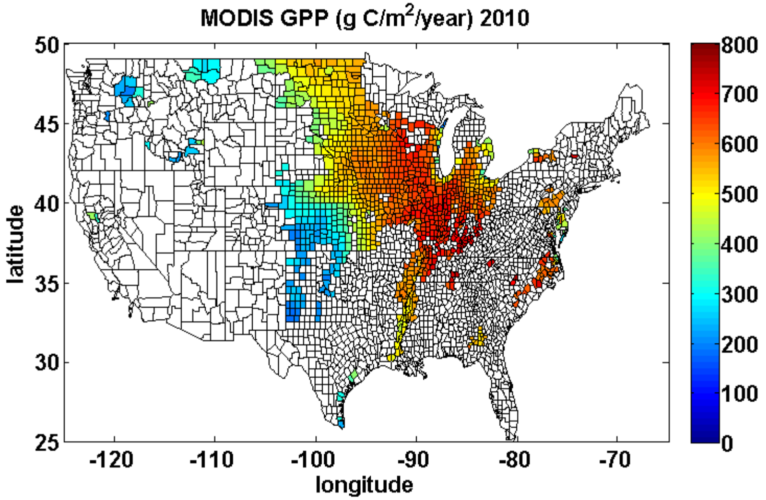
SIF best captures the spatial pattern in crop yield.





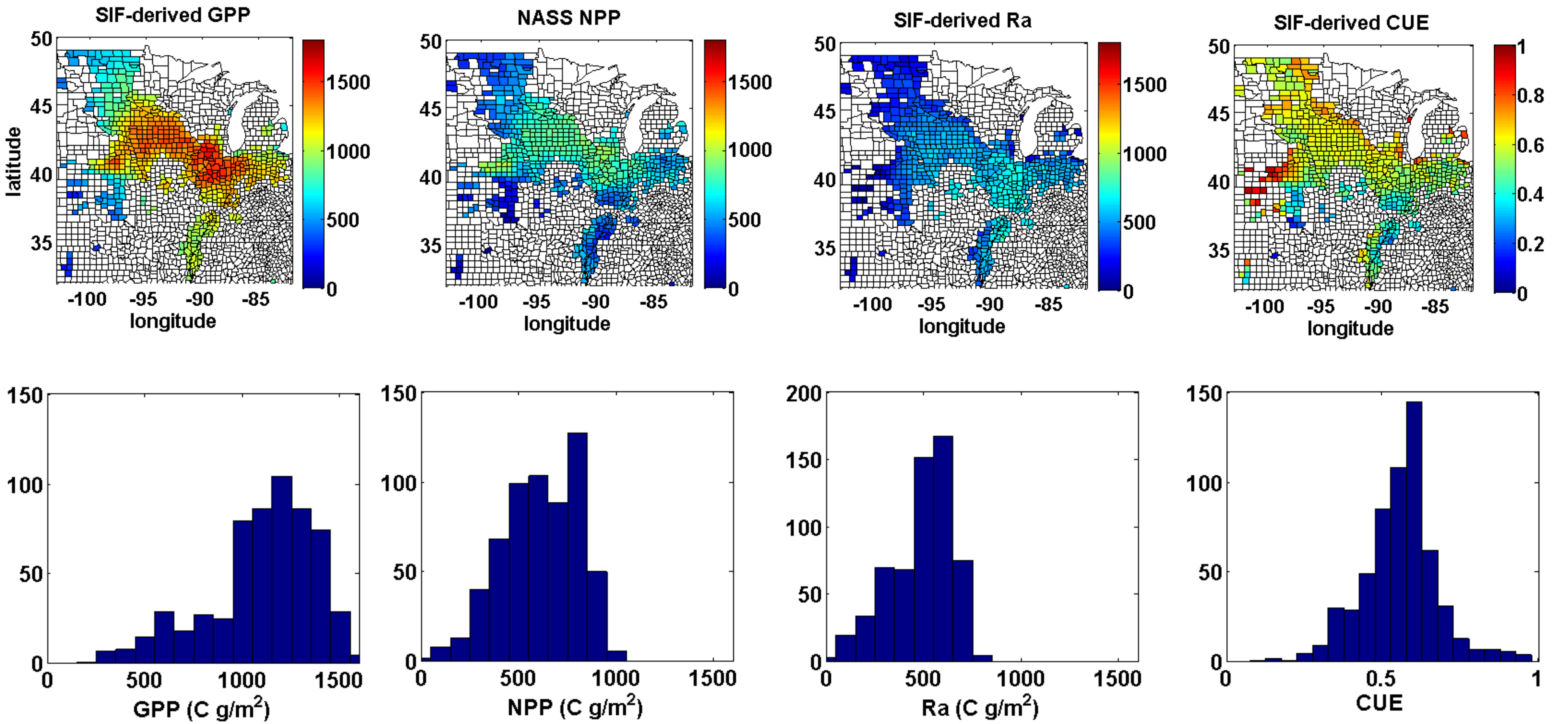






(Guan et al., "Improving the monitoring of crop productivity using spaceborne solar-induced fluorescence", Global Change Biology, 2015)

Plant respiration (Ra)=GPP-NPP
Carbon Use Efficiency (CUE)=NPP/GPP



(Guan et al., "Improving the monitoring of crop productivity using spaceborne solar-induced fluorescence", Global Change Biology, 2015)

Long-term measurements of solar-induced fluorescence (SIF)

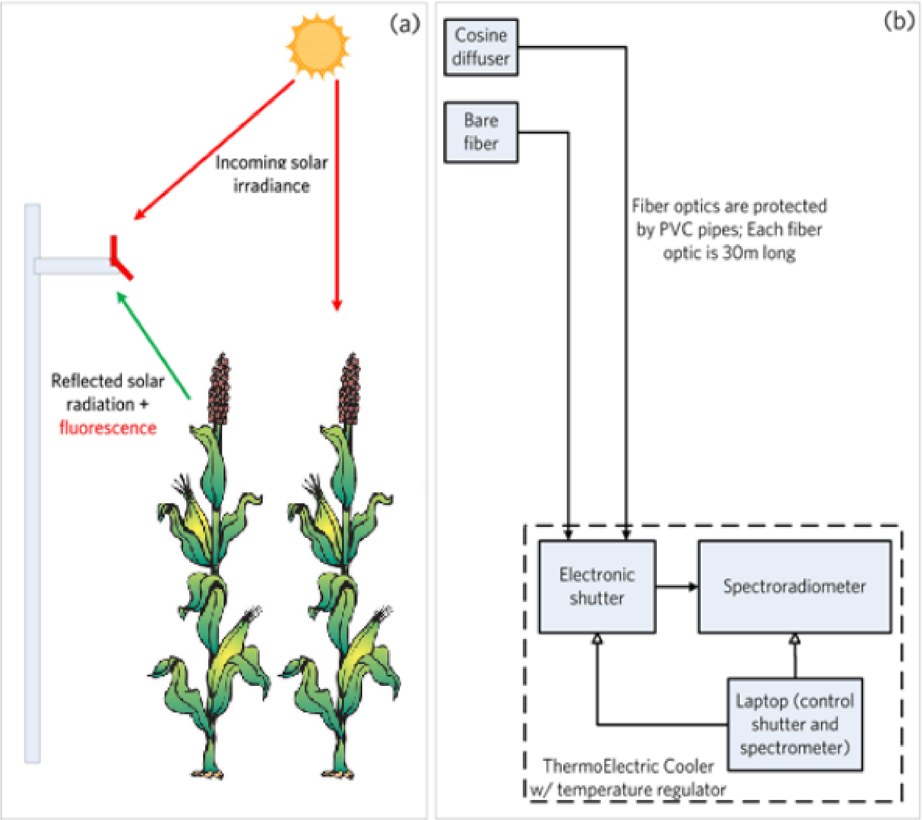
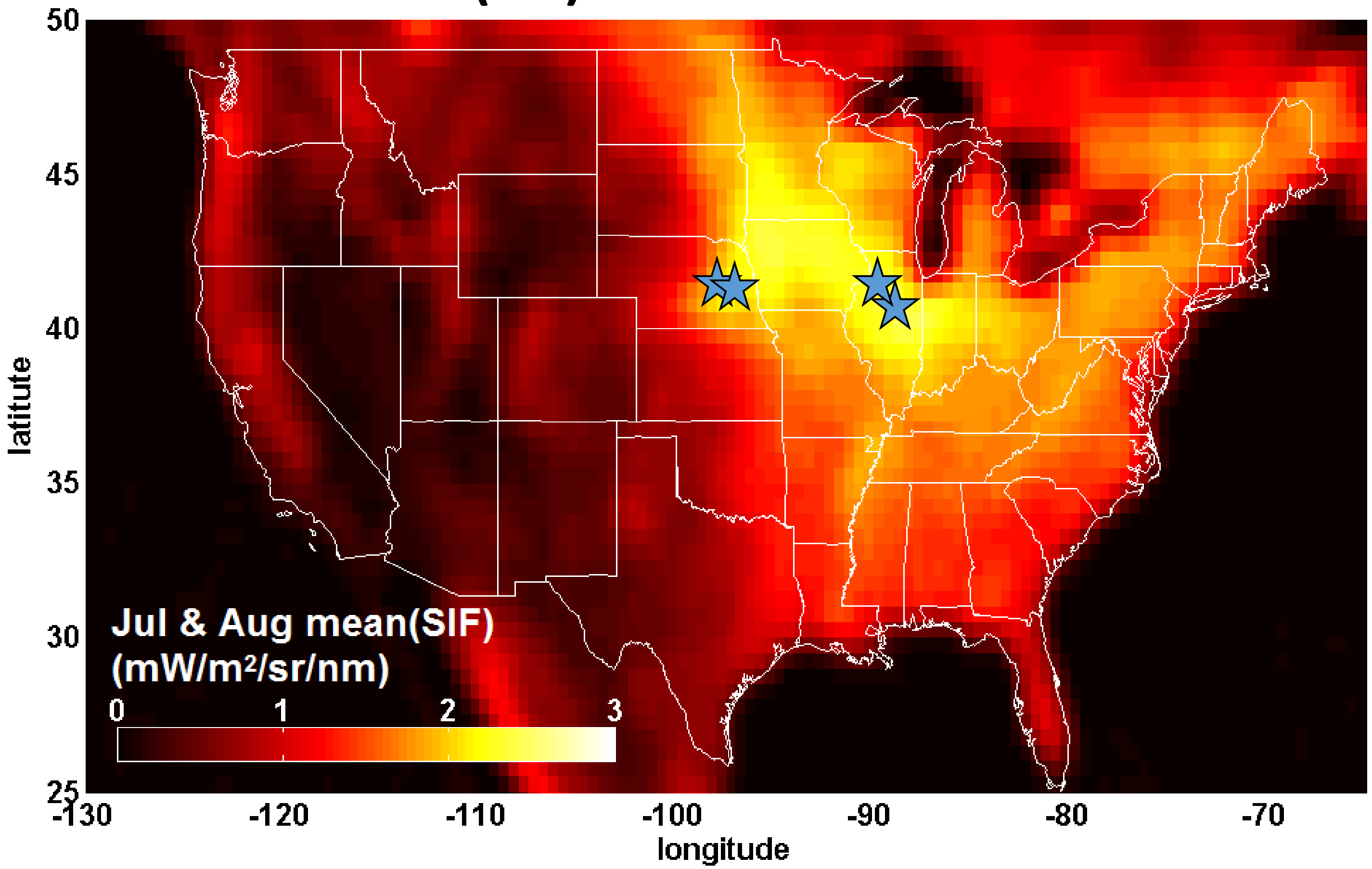


Fig 5. The design of FluoSpec2 designed by Dr. Xi

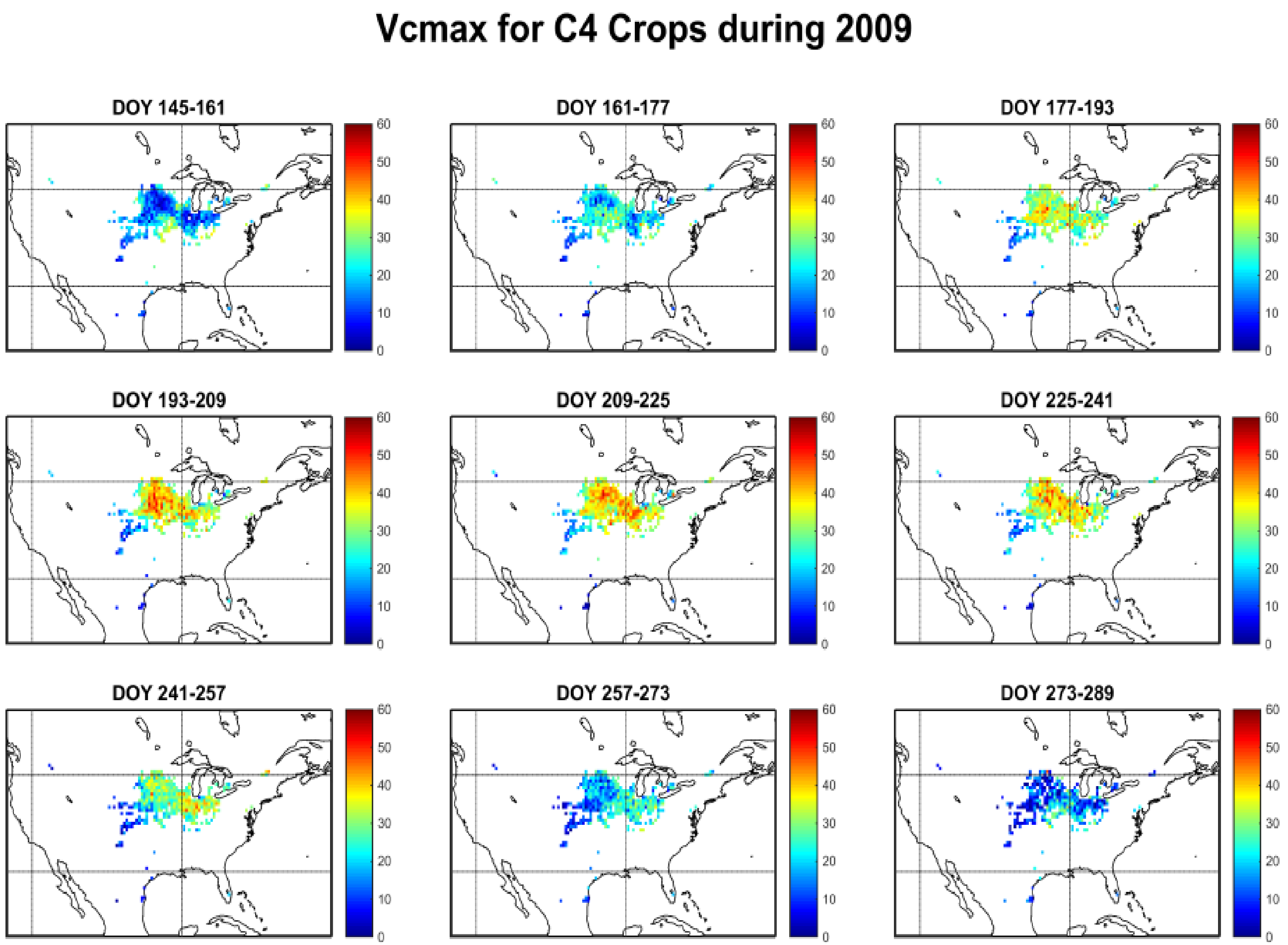


(Guan et al., NASA New Investigator Award, 2016)

Our SIF systems at the Energy Farm
(postdoc: Guofang Miao)

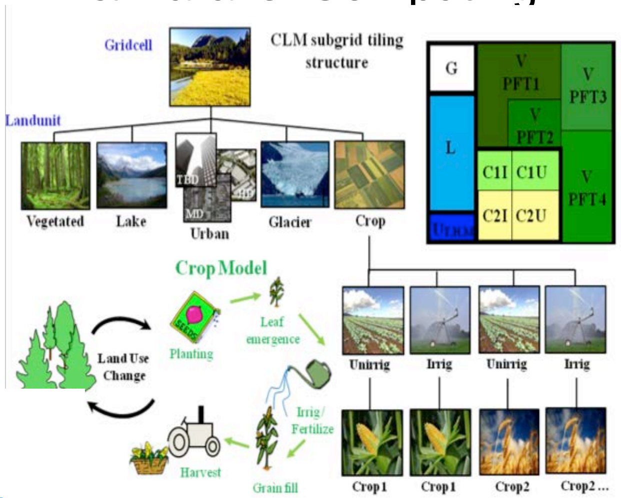
Real-time phenocam:
Soybean: http://172.22.47.177/
Corn: http://172.22.47.175/

Use SIF to spatially improve the Vcmax parameterization (Zhang, Guan et al., in review)



Remote Sensing

Numerical Modeling
& Parallel Computing



Monitoring Food Production and Security

Field Studies

Integrating field work, satellite, and supercomputing for monitoring and modeling crop production at continental scales

Dr. Kaiyu Guan
(kaiyug@Illinois.edu)
Nature Resources and Environmental Sciences & National Center for Supercomputing Applications, University of Illinois at Urbana Champaign