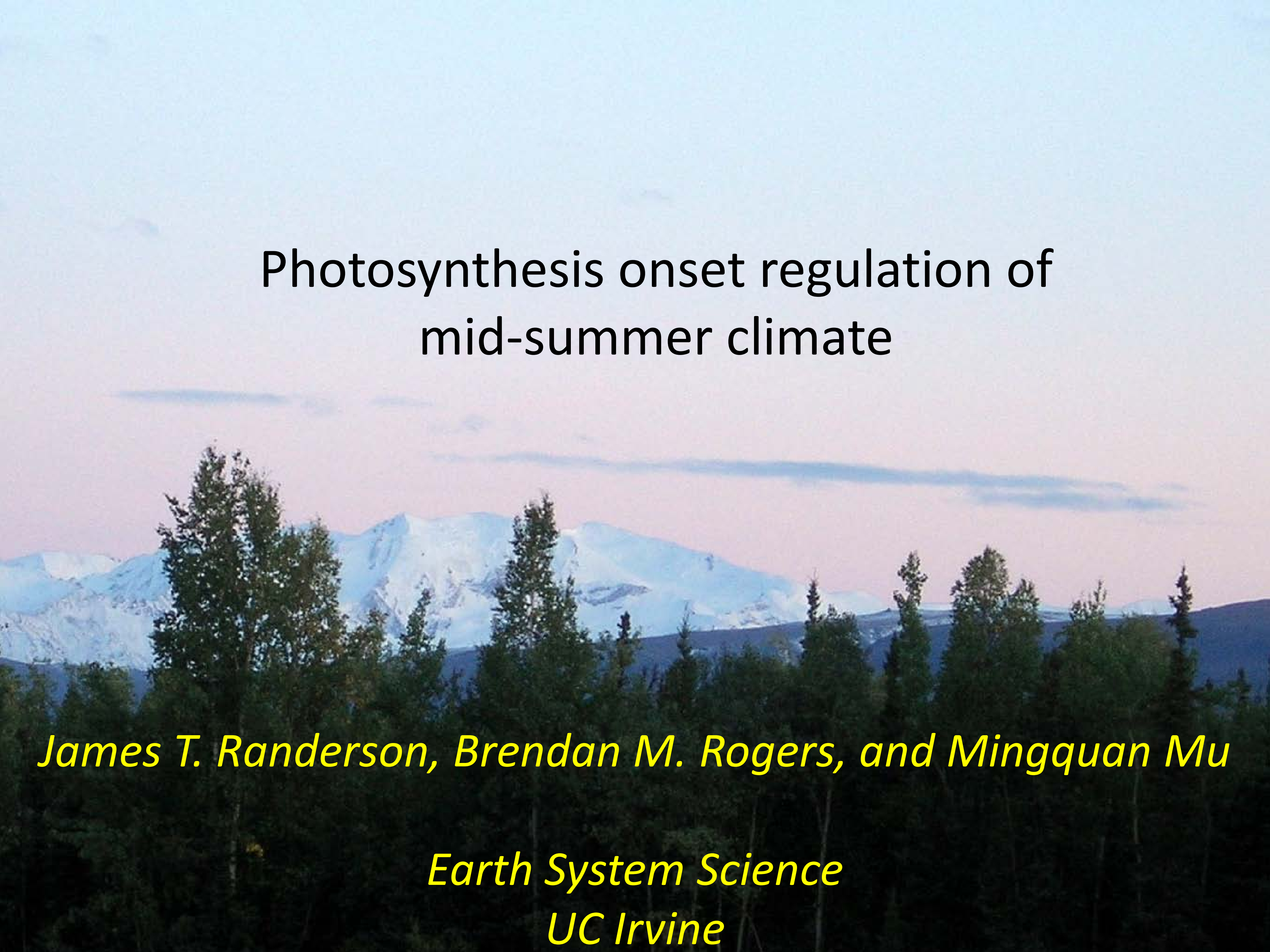

Photosynthesis onset regulation of mid-summer climate

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The False Spring of 2012, Earliest in North American Record

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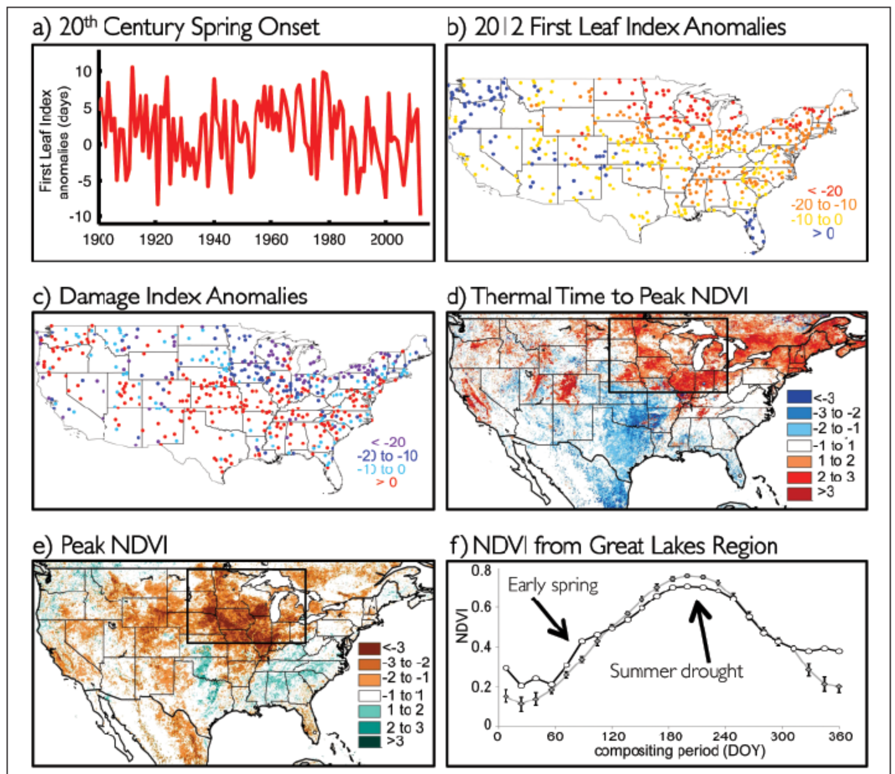
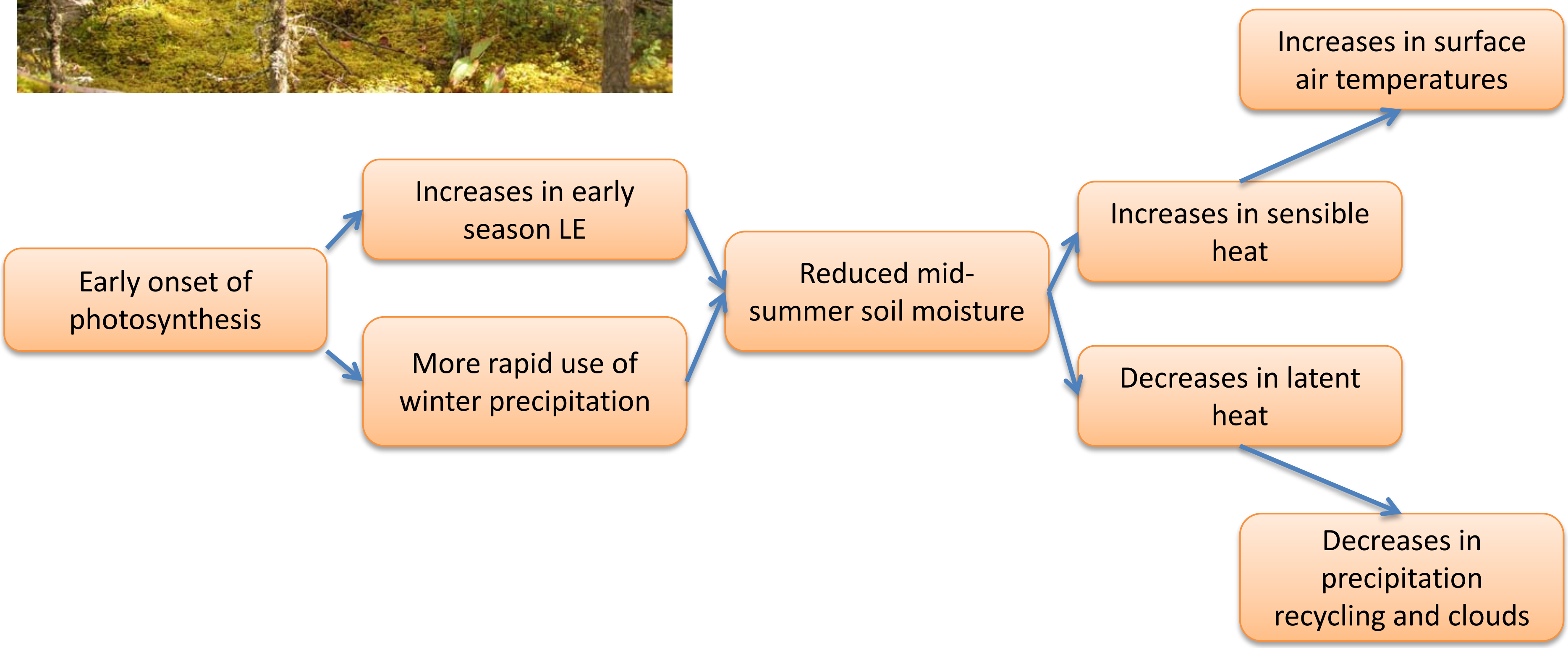
Phenology—the study of recurring plant and animal life cycle stages, especially their timing and relationships with weather and climate—is becoming an essential tool for documenting, communicating, and anticipating the consequences of climate variability and change. For example, March 2012 broke numerous records for warm temperatures and early flowering in the United States [*Karl et al.*, 2012; *Elwood et al.*, 2013]. Many regions experienced a "false spring," a period of weather in late winter or early spring sufficiently mild and long to bring vegetation out of dormancy prematurely, rendering it vulnerable to late frost and drought.

As global climate warms, increasingly warmer springs may combine with the random climatological occurrence of advective freezes, which result from cold air moving from one region to another, to dramatically increase the future risk of false springs, with profound ecological and economic consequences [e.g., *Gu et al.*, 2008; *Marino et al.*, 2011; *Augspurger*, 2013]. For example, in the false spring of 2012, an event embedded in long-term trends toward earlier spring [e.g., *Schwartz et al.*, 2006], the frost damage to fruit trees totaled half a billion dollars in Michigan alone, prompting the federal government to declare the state a



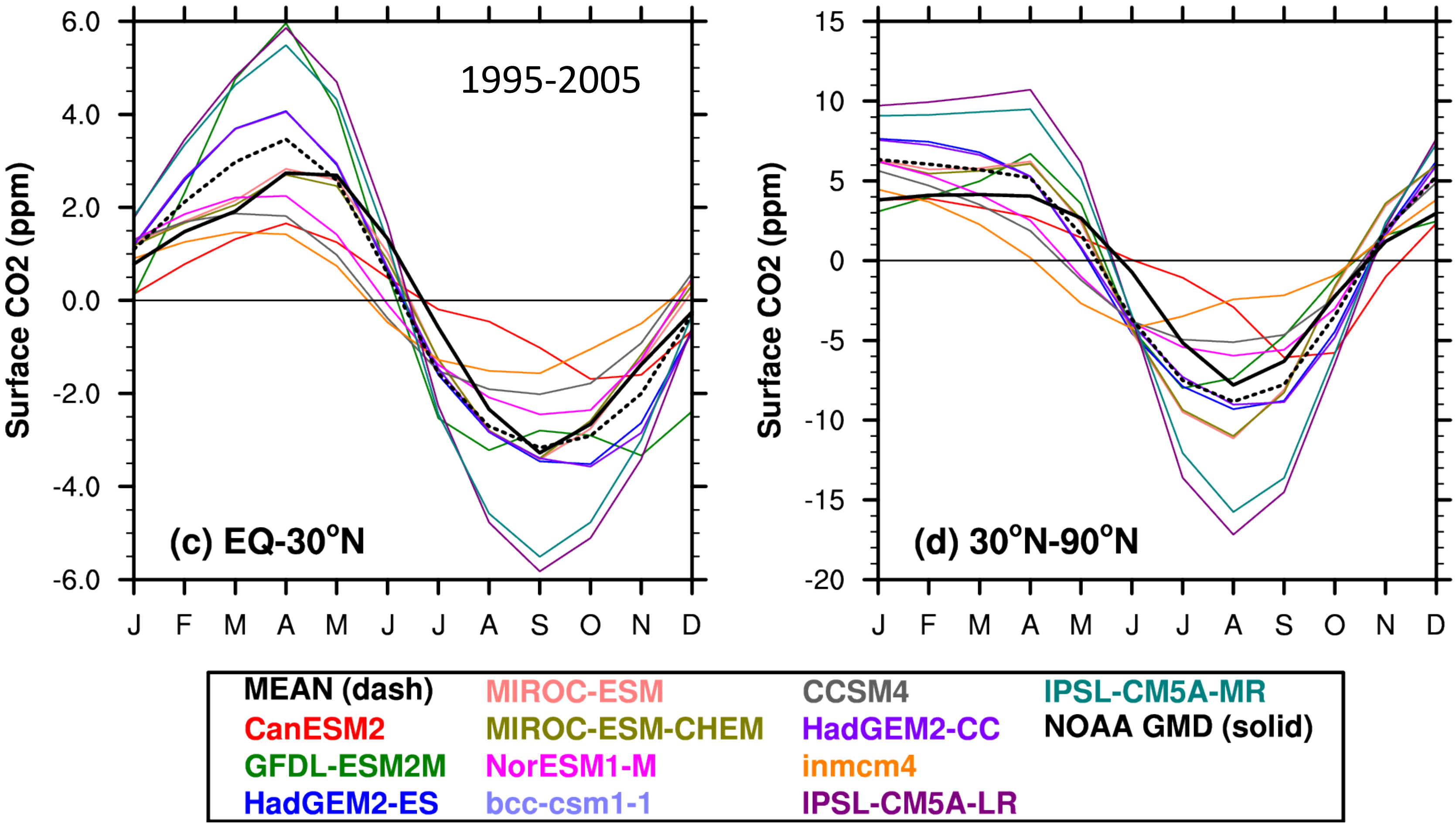
Ault et al.

How much of mid-summer climate variability can be explained by spring onset of photosynthesis?

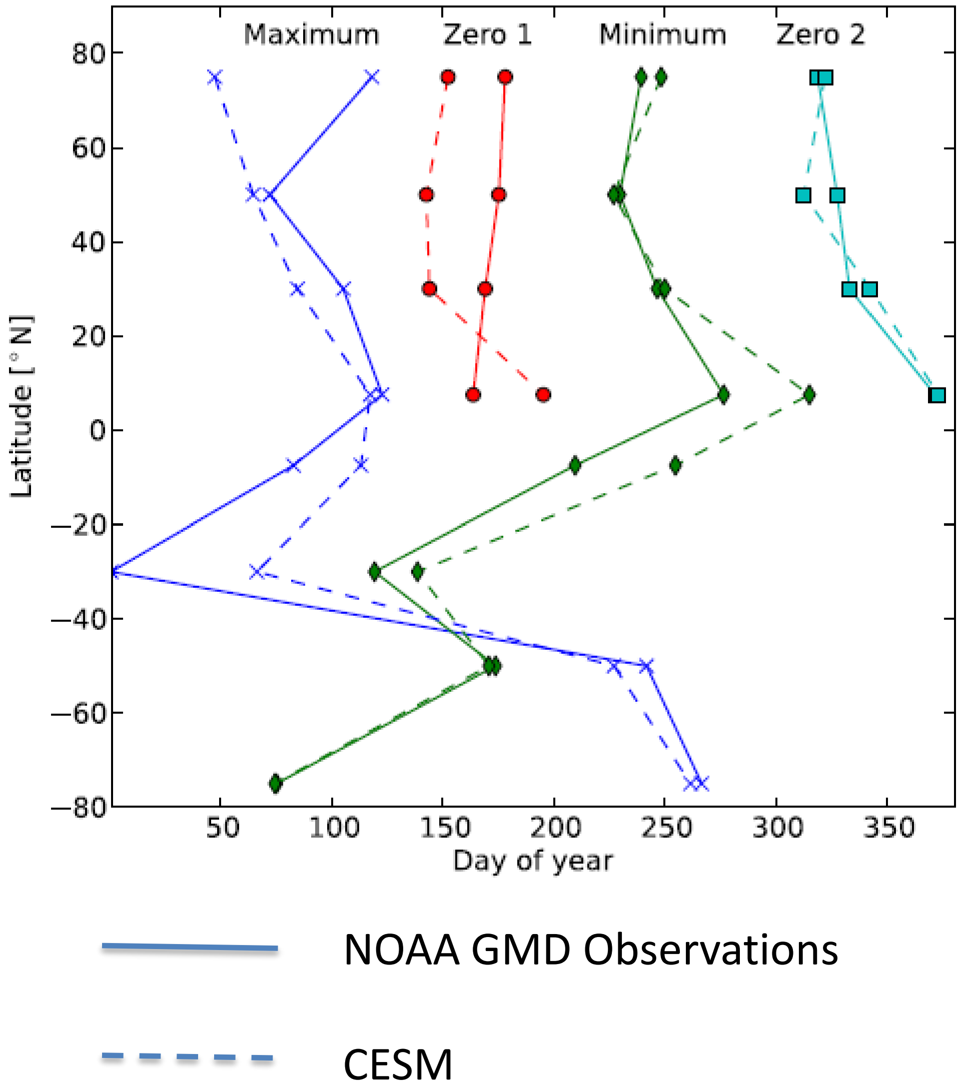


Atmospheric CO_2 is drawn down too early in spring in most CMIP5 Earth system models

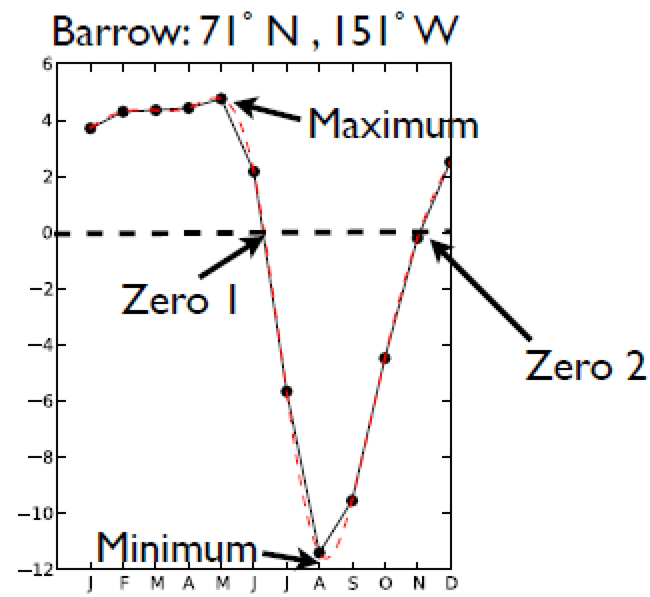
- GEOS-Chem with CMIP5 net biosphere production (NBP) and prescribed ocean and fossil fuel fluxes, sampled at NOAA GMD stations and compared with observations (1995-2005)



Diagnostics of the phase of the annual cycle of atm. CO_2

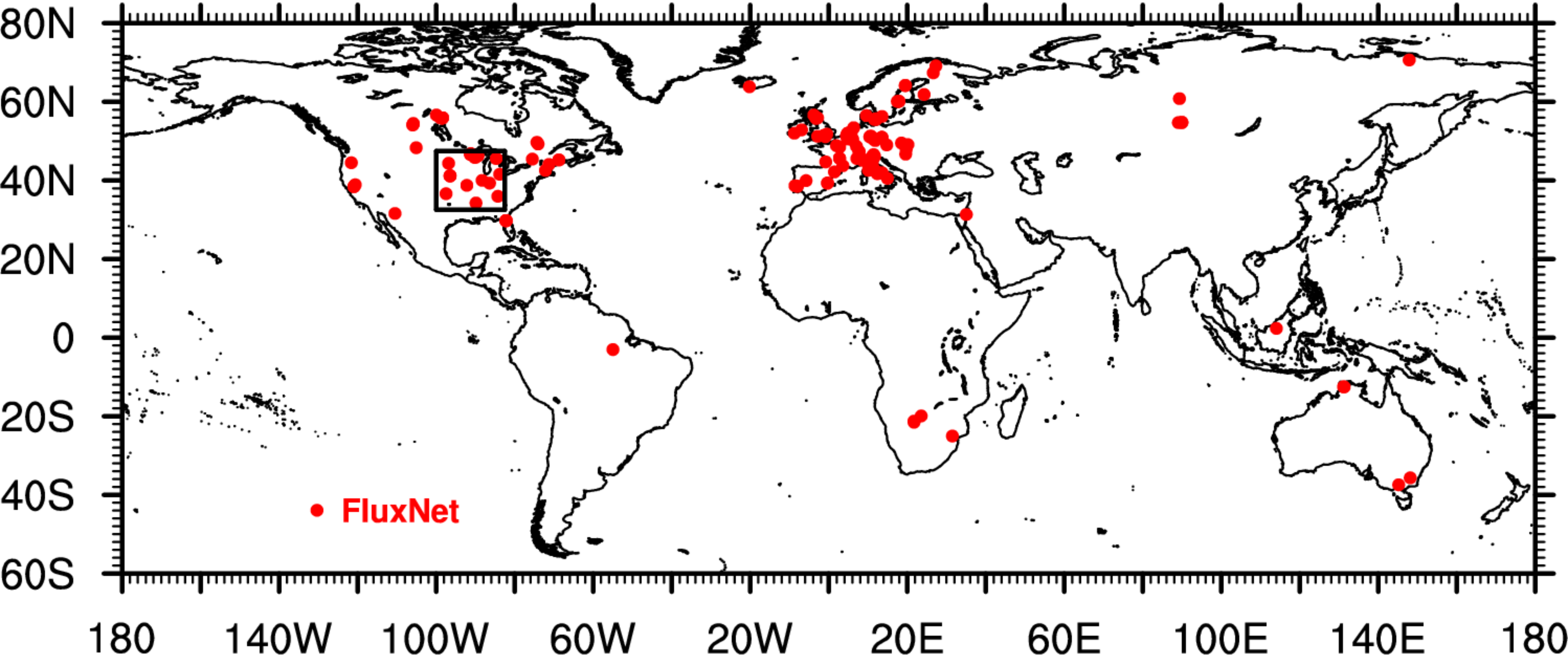


The onset of the growing season occurs too early in CESM.



Keppel-Aleks et al. (J. of Climate, 2013)

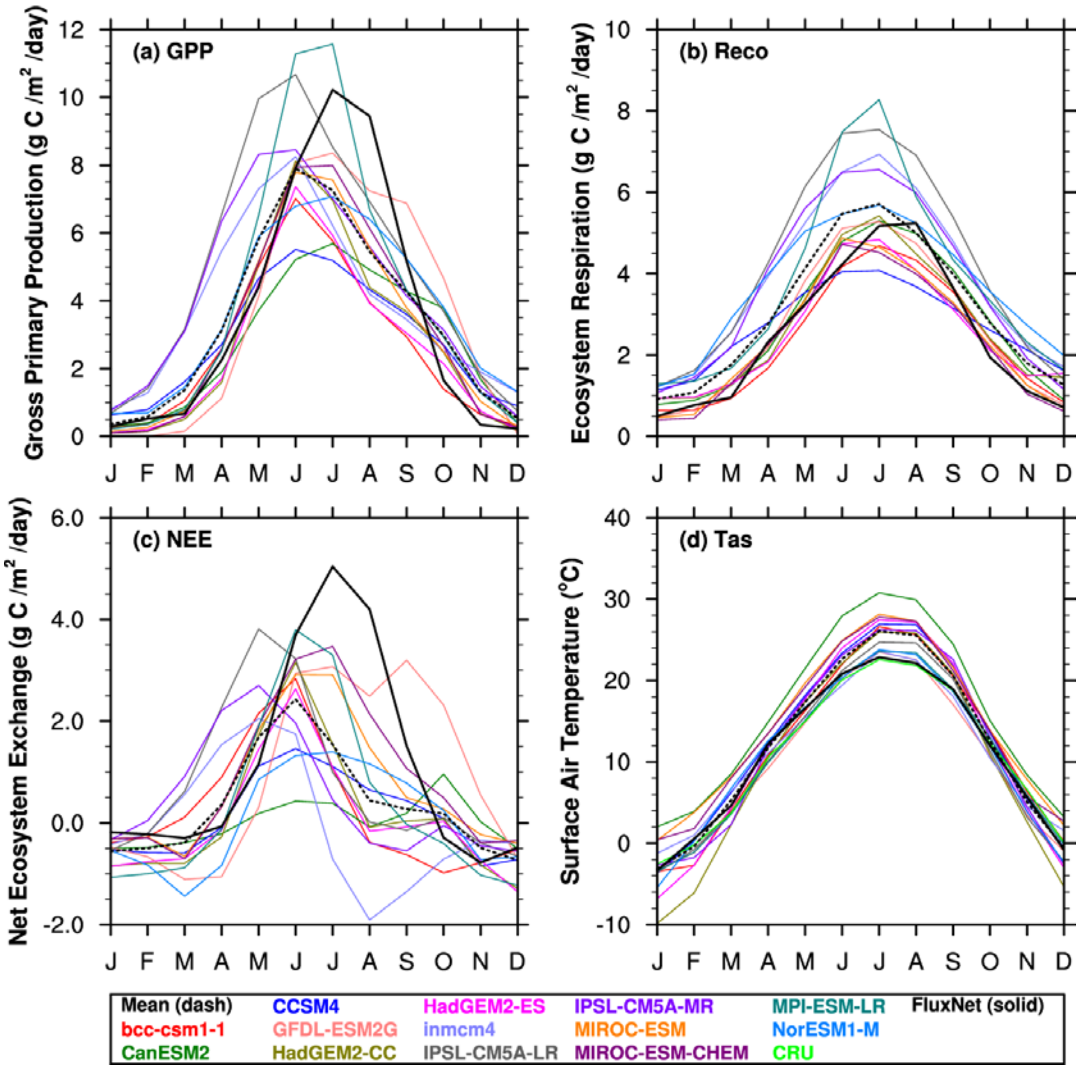
What are the causes of the early season uptake bias?
Eddy covariance observations from FLUXNET provide constraints



GPP appears to be the primary culprit for the early NEE uptake and CO_2 drawdown

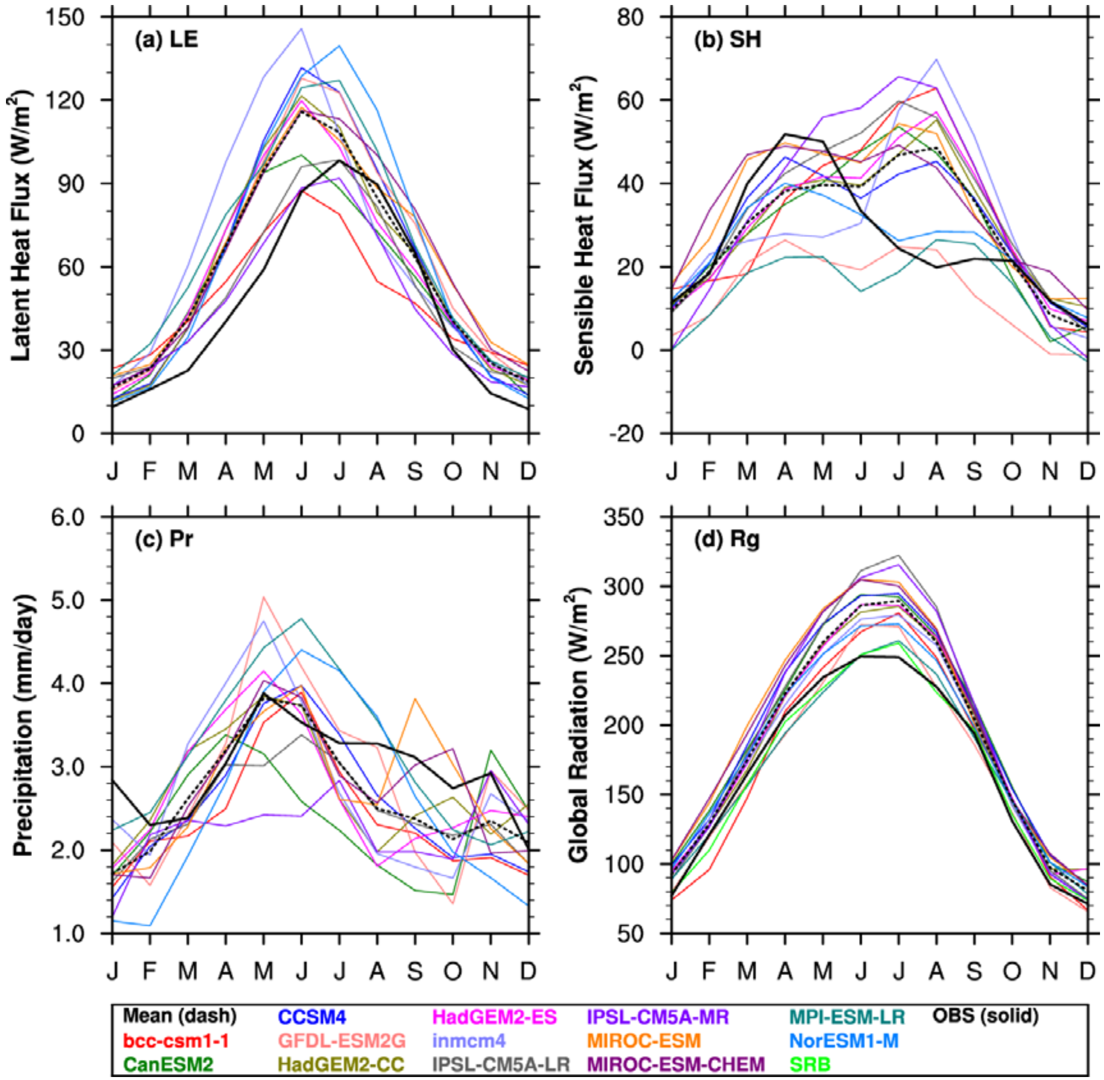
- Fluxnet sites in North America between 35N and 45N

Model grid cells extracted and sampled at all measurement sites during the times obs. were available



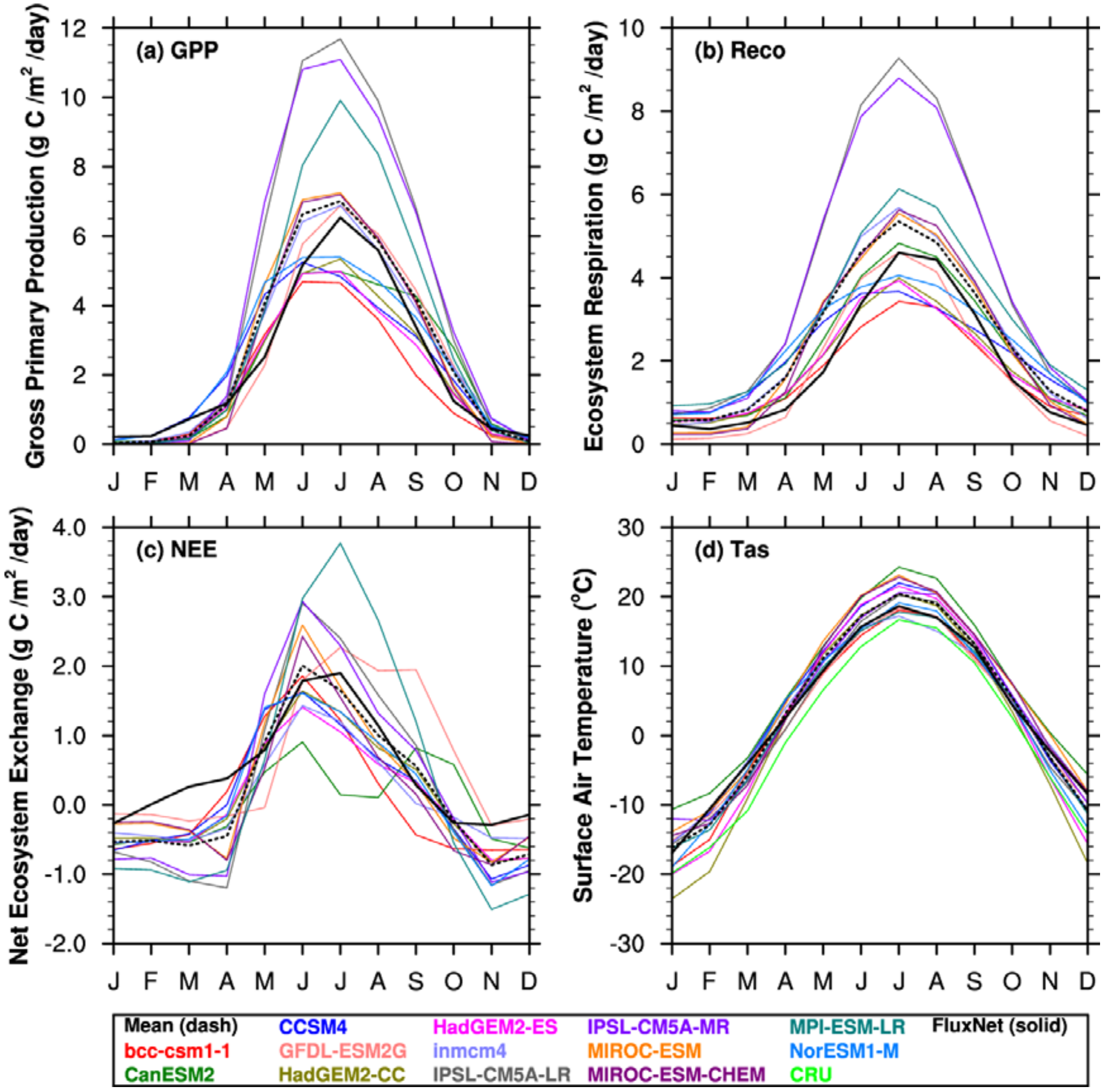
Early onset of photosynthesis may have consequences for the seasonal dynamics of surface energy exchange

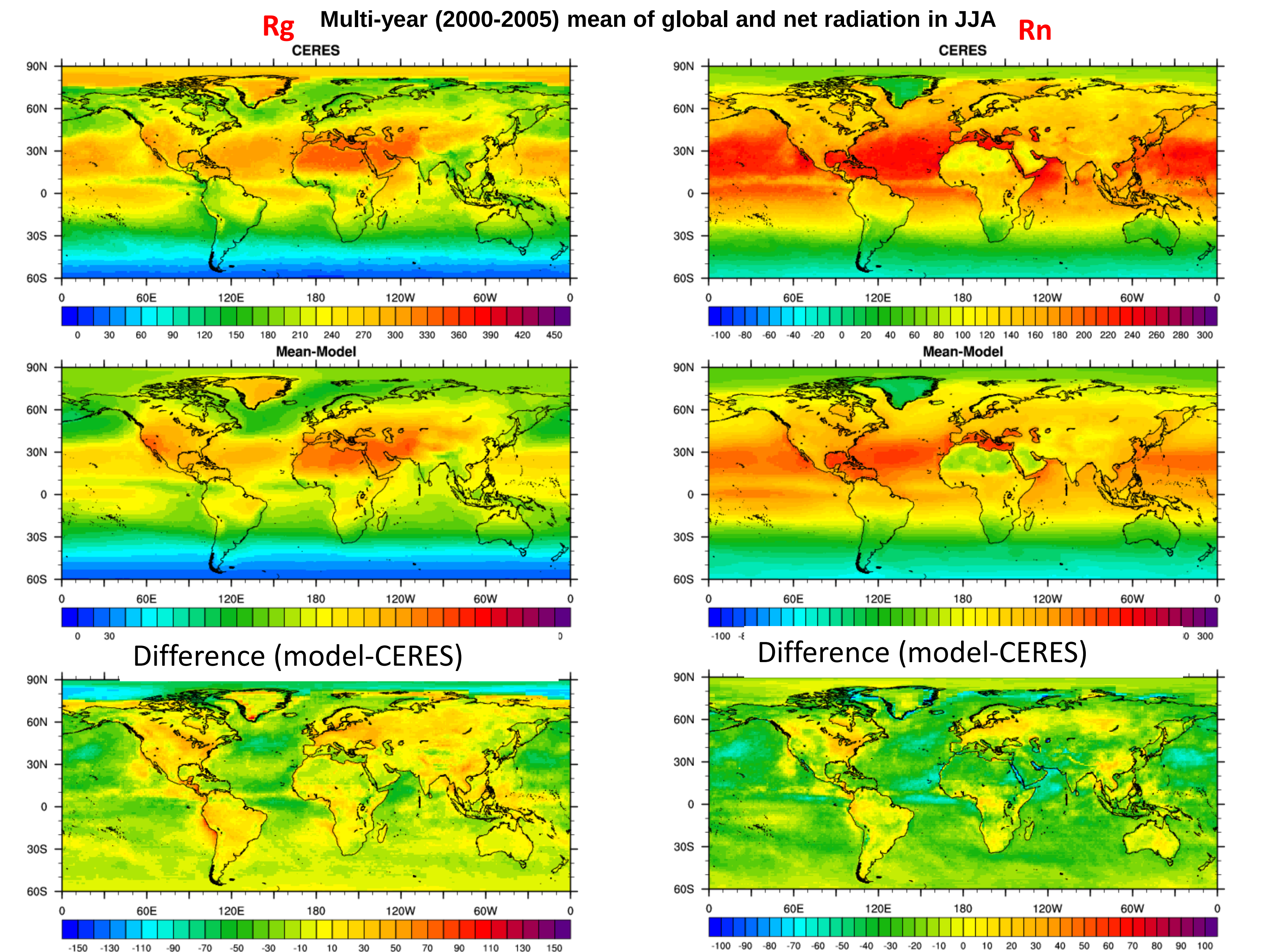
- Fluxnet sites in North America between 35N and 45N



Strength of the early season uptake bias varies by region

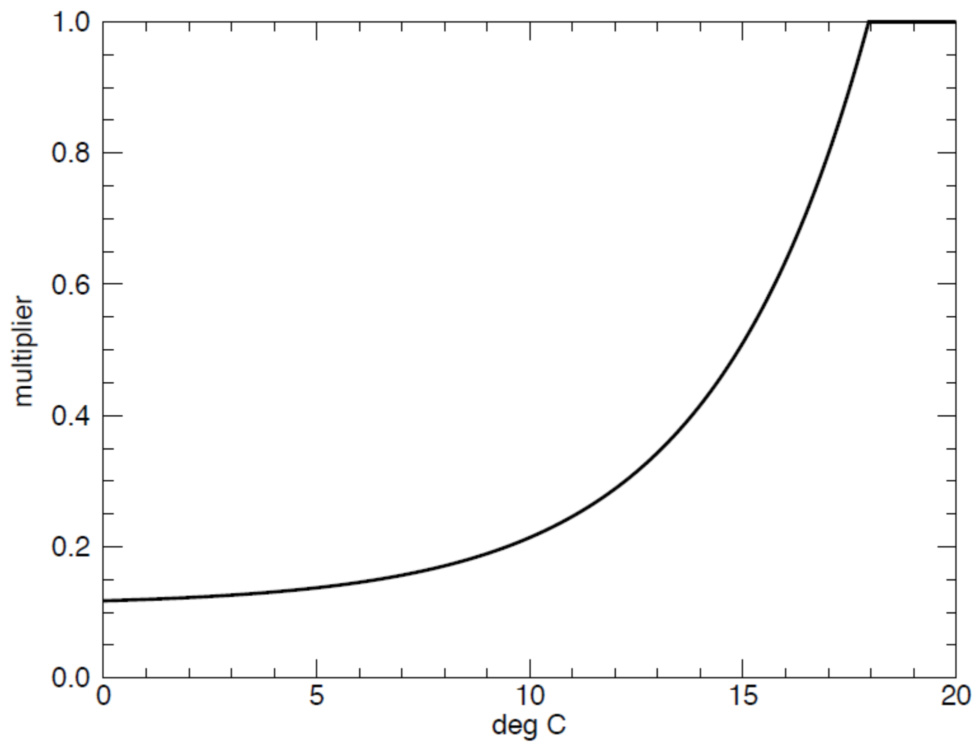
- Fluxnet sites in North America between 45N and 60N





Rg
Multi-year (2000-2005) mean of global and net radiation in JJA
Rn
CERES
Mean-Model
Difference (model-CERES)
90N
60N
30N
0
30S
60S
0
60E
120E
180
120W
60W
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450
-100 -80 -60 -40 -20 0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
-150 -130 -110 -90 -70 -50 -30 -10 10 30 50 70 90 110 130 150
-100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100

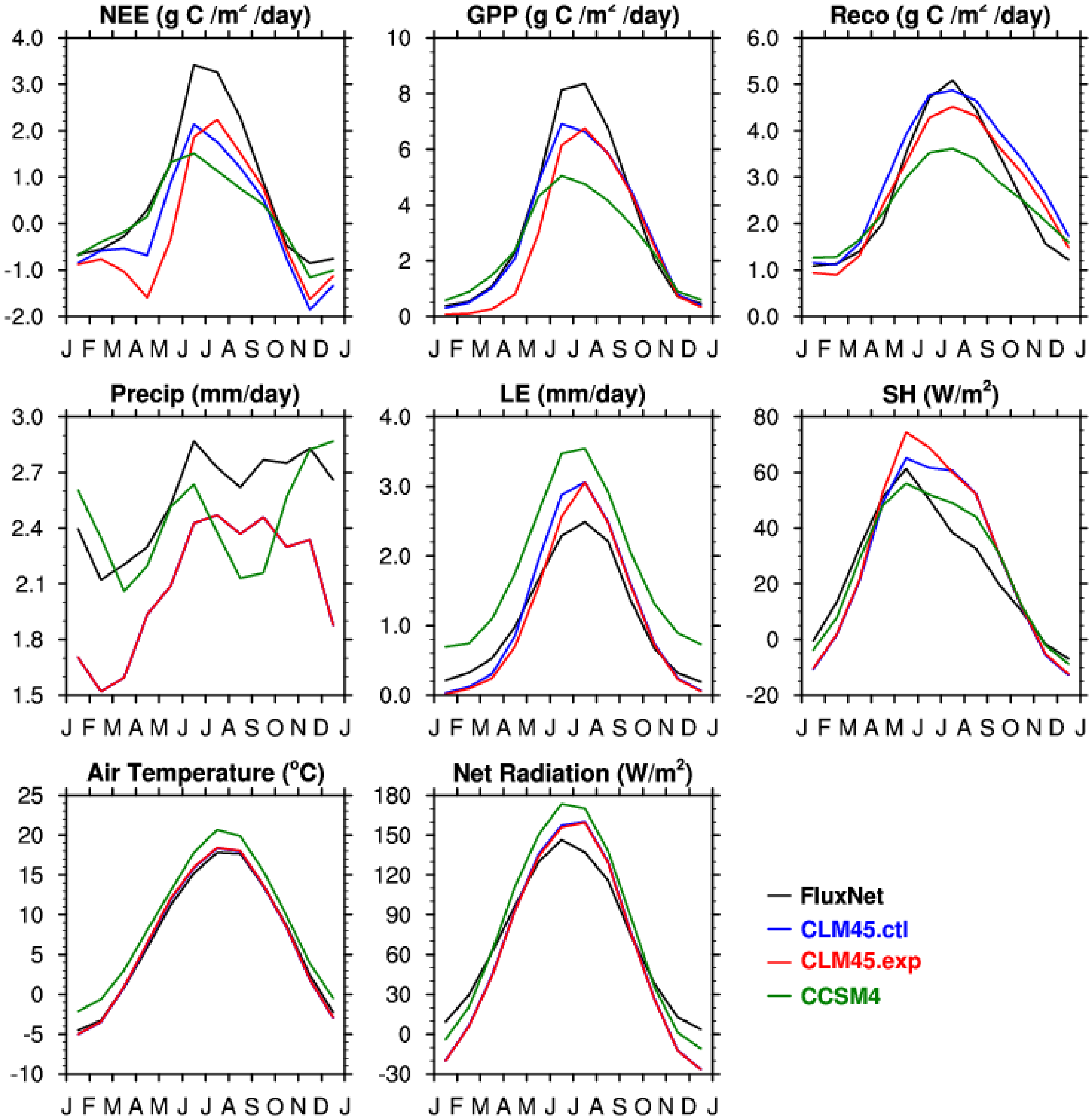
Modify CLM4.5 to simulate delayed recovery from cold-hardening and false-spring avoidance

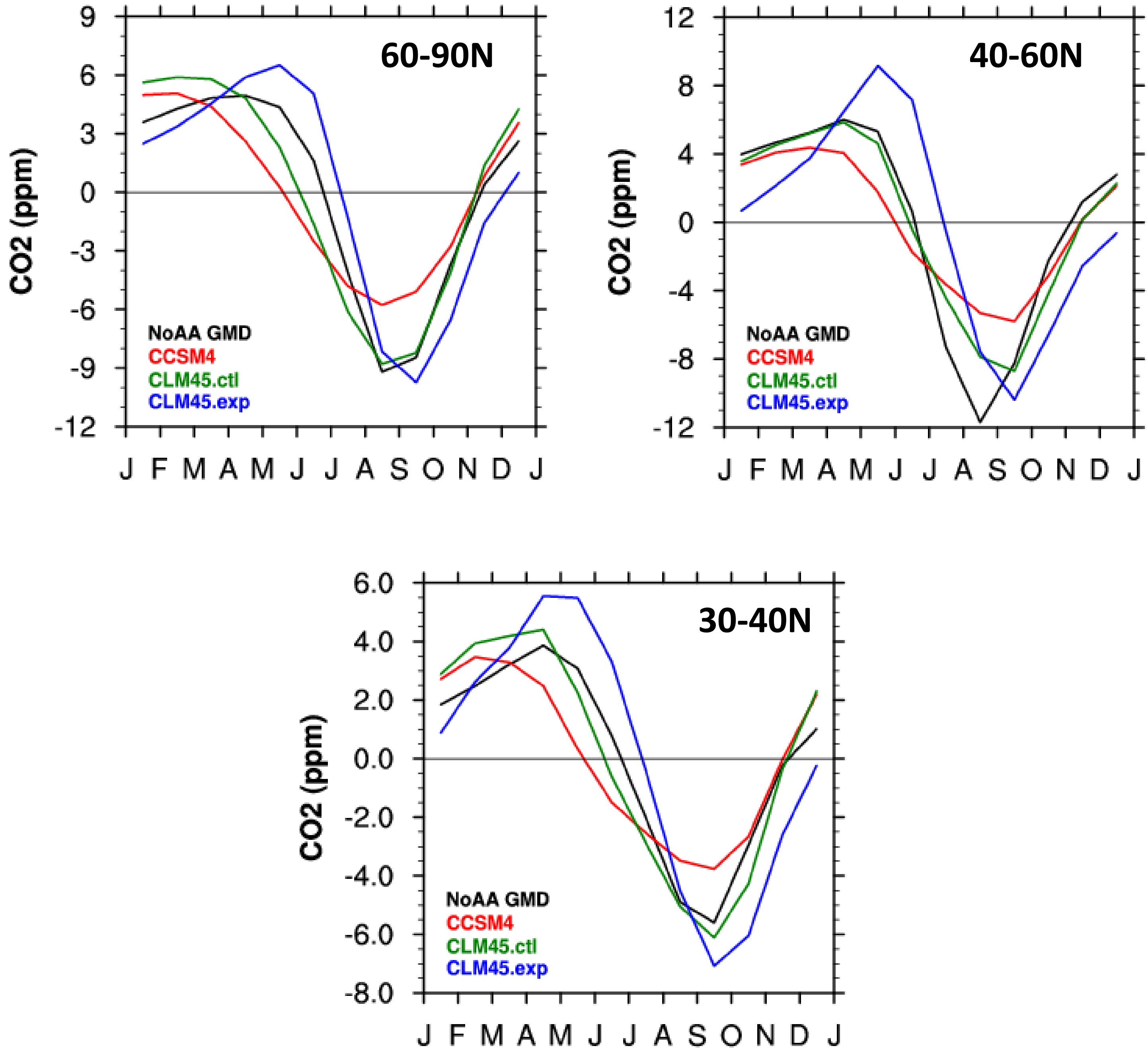


Clm tag: clm4_0_60
Vcmax modified during January to June by applying the above scalar using 10 day mean 2m air temperature

CLM45 Simulations vs. FluxNet

40-60N




60-90N
CO2 (ppm)
9
6
3
0
-3
-6
-9
-12
J F M A M J J A S O N D J
NoAA GMD
CCSM4
CLM45.ctl
CLM45.exp
40-60N
CO2 (ppm)
12
8
4
0
-4
-8
-12
J F M A M J J A S O N D J
NoAA GMD
CCSM4
CLM45.ctl
CLM45.exp
30-40N
CO2 (ppm)
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
J F M A M J J A S O N D J
NoAA GMD
CCSM4
CLM45.ctl
CLM45.exp

Next Steps and Conclusions

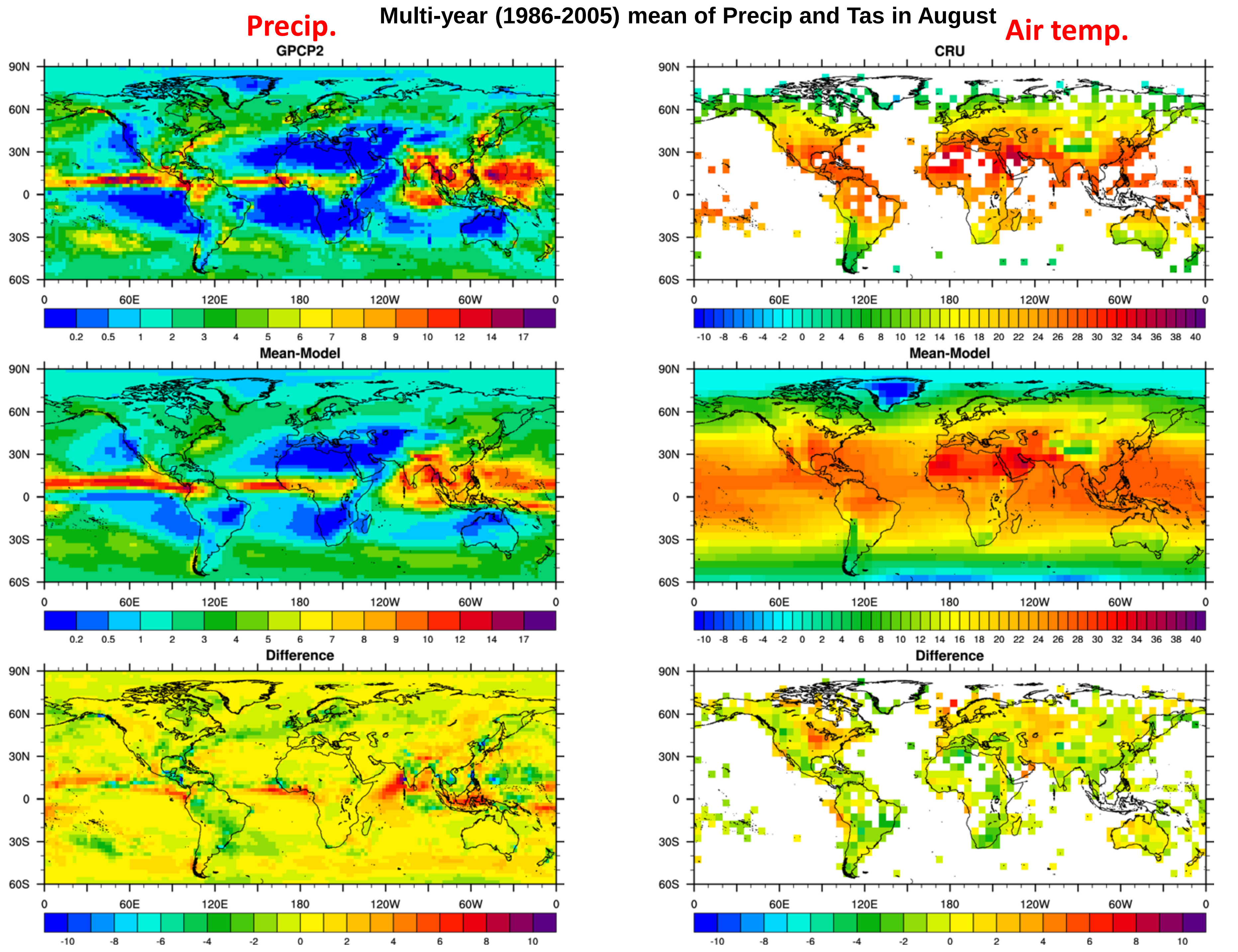
- Evaluate CLM4.5 GPP onset experiments in CAM5 with a slab ocean to look at mid-summer climate responses
- - examine canopy evaporative fraction
- - soil temperatures and controls on spring ET

- Early season onset bias will have important consequences for the representation of mid-summer drought stress in evergreen conifer ecosystems (Monson et al. 2005) and for fire behavior (Westerling et al. 2006) in ESMs

- The timing of photosynthesis initiation in spring may influence regional climate in mid-summer, with early onset of GPP causing higher air temperatures and reduced precipitation recycling

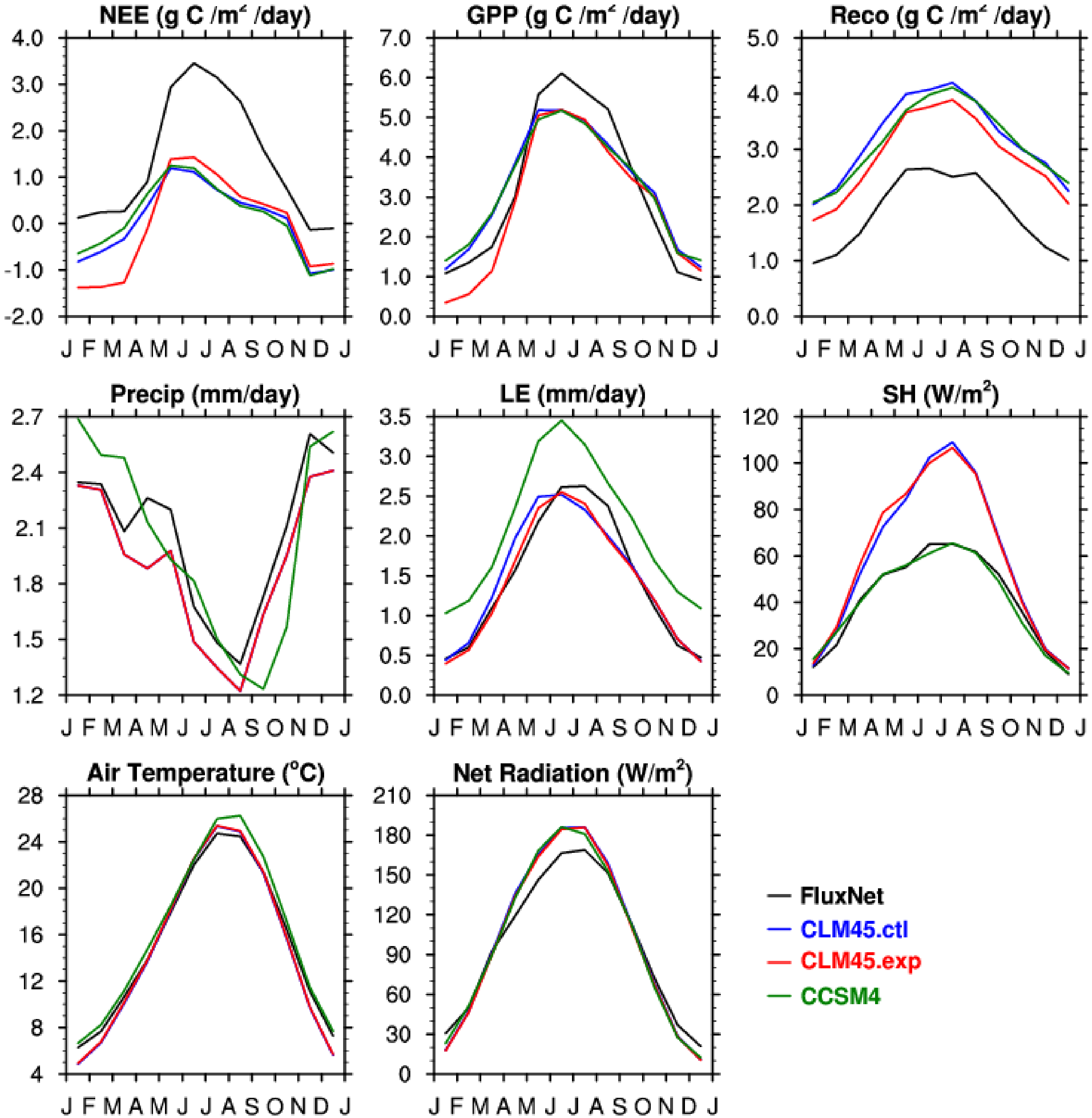
- Cold hardening and temperature acclimation algorithms need to be integrated with existing photosynthesis and stomatal conductance models
  - Unpackaging membrane and protein systems increases vulnerability to late spring frost events
  - Need to combine with improvements in phenology (Richardson et al., 2012)

- Next steps: we need to improve our understanding of how the existing photosynthesis timing biases influence the representation of climate-induced drought stress during the 21st century

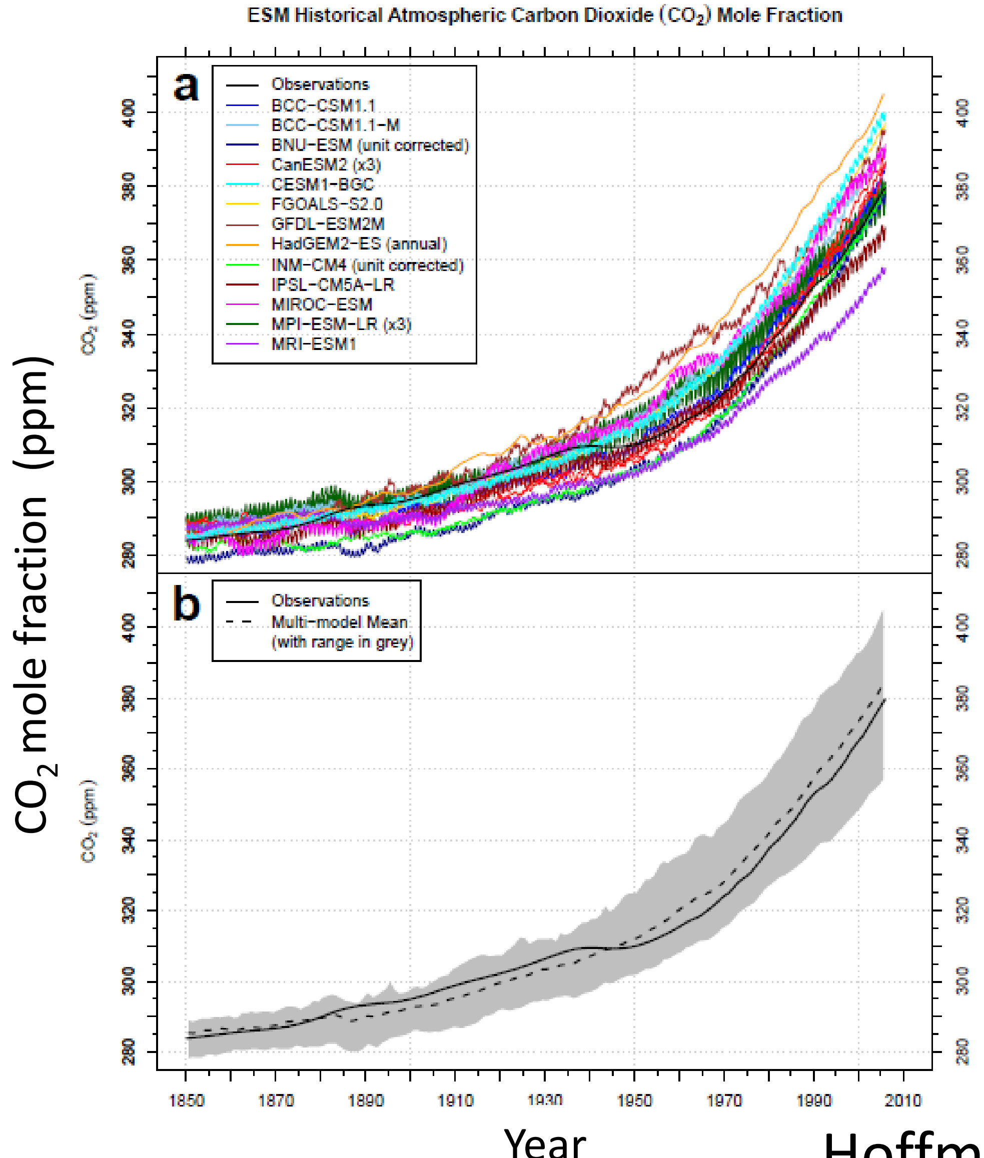

Multi-year (1986-2005) mean of Precip and Tas in August
Precip.
Air temp.
GPCP2
CRU
Mean-Model
Mean-Model
Difference
Difference
90N
60N
30N
0
30S
60S
0
60E
120E
180
120W
60W
0
0.2 0.5 1 2 3 4 5 6 7 8 9 10 12 14 17
-10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
-10 -8 -6 -4 -2 0 2 4 6 8 10

30-40N

CLM45 Simulations vs. FluxNet

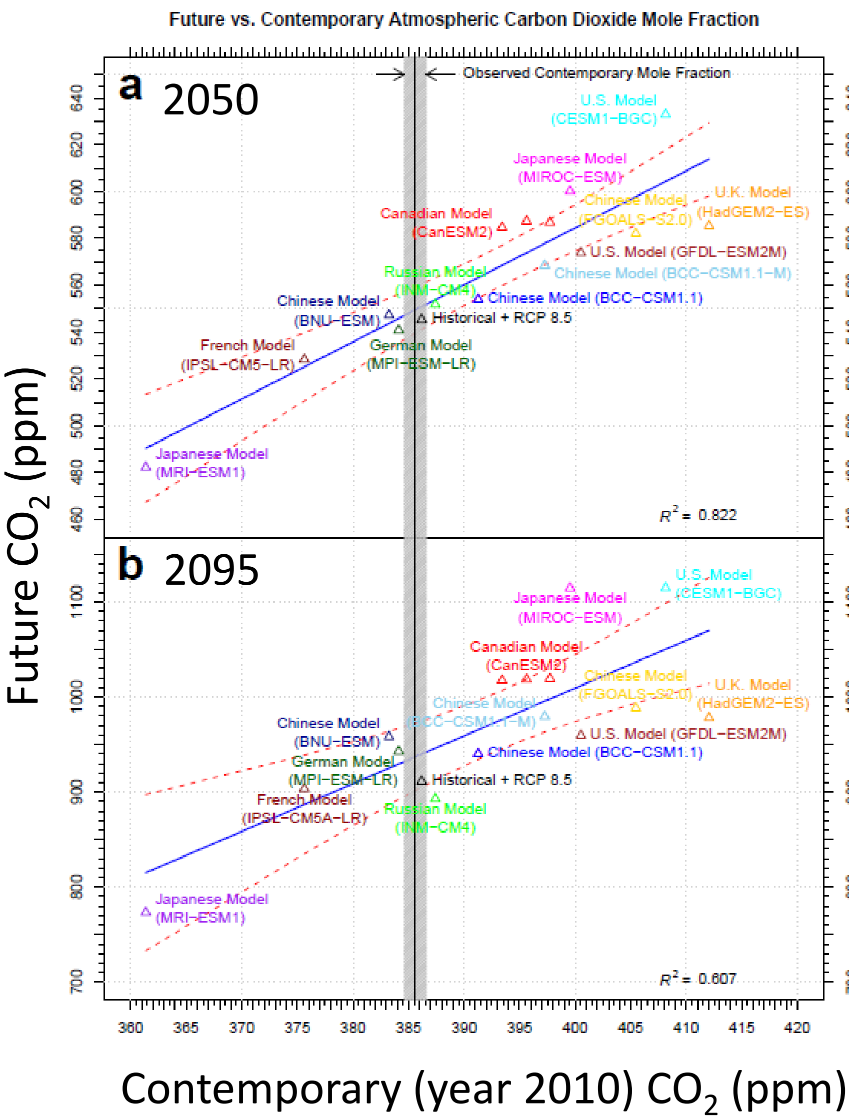


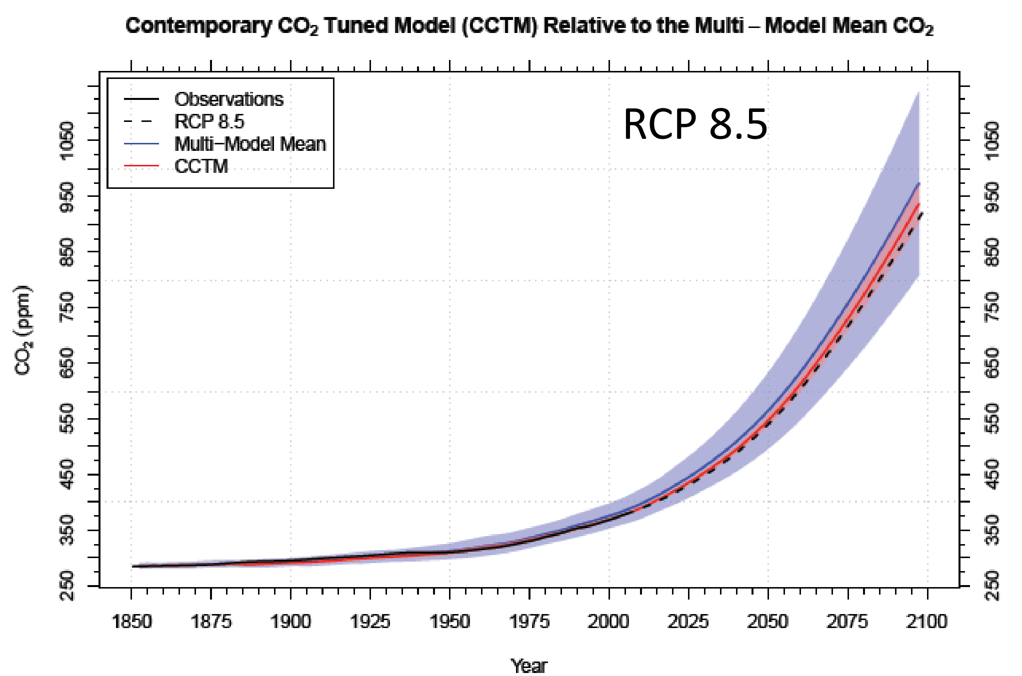
Most CMIP5 ESMs have a positive bias in atmospheric CO_2 by the end of the observational era



Hoffman et al. B41C-0291

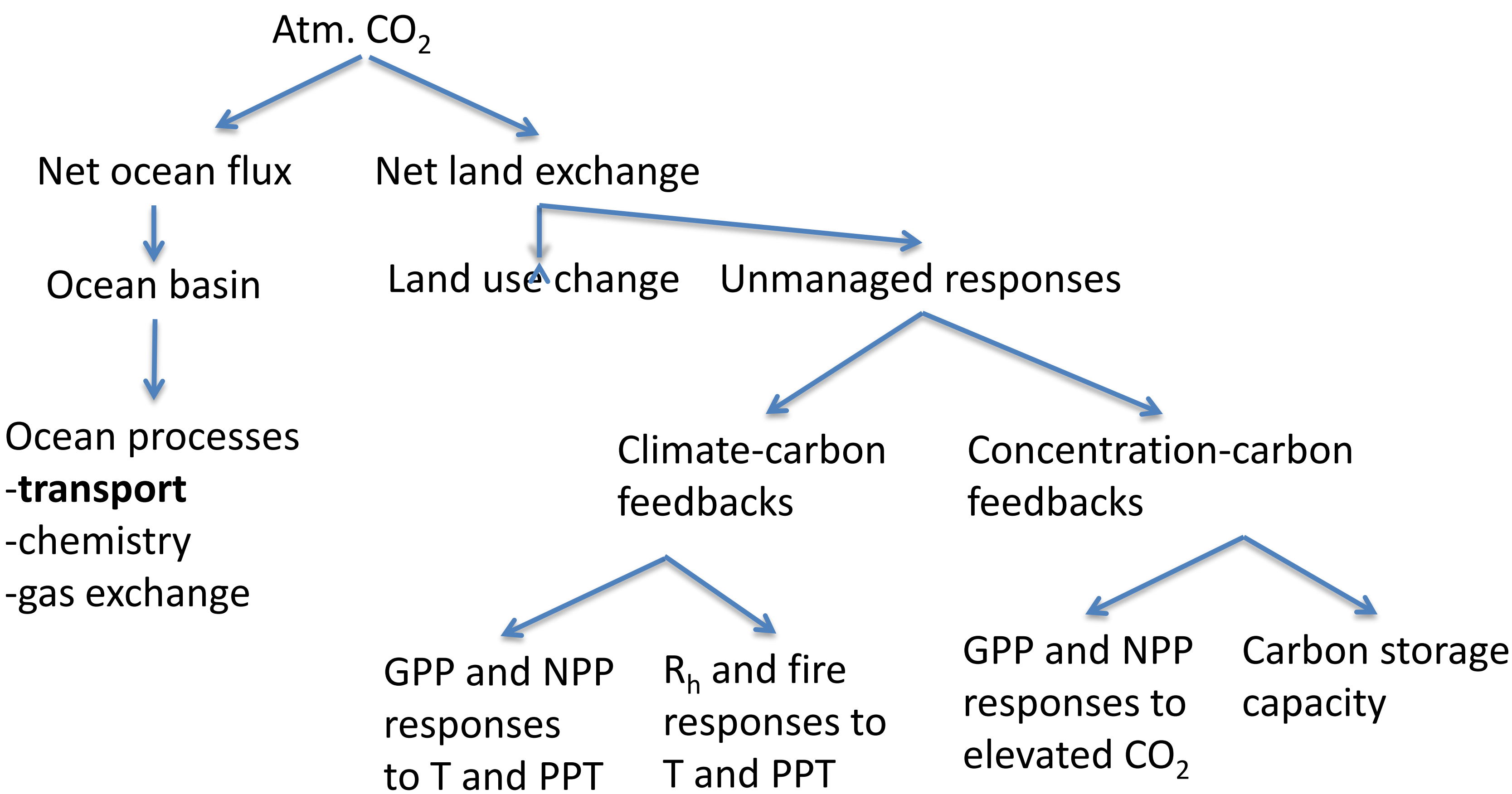
Multi-model estimates and contemporary observations can be used to reduce uncertainties in future scenarios



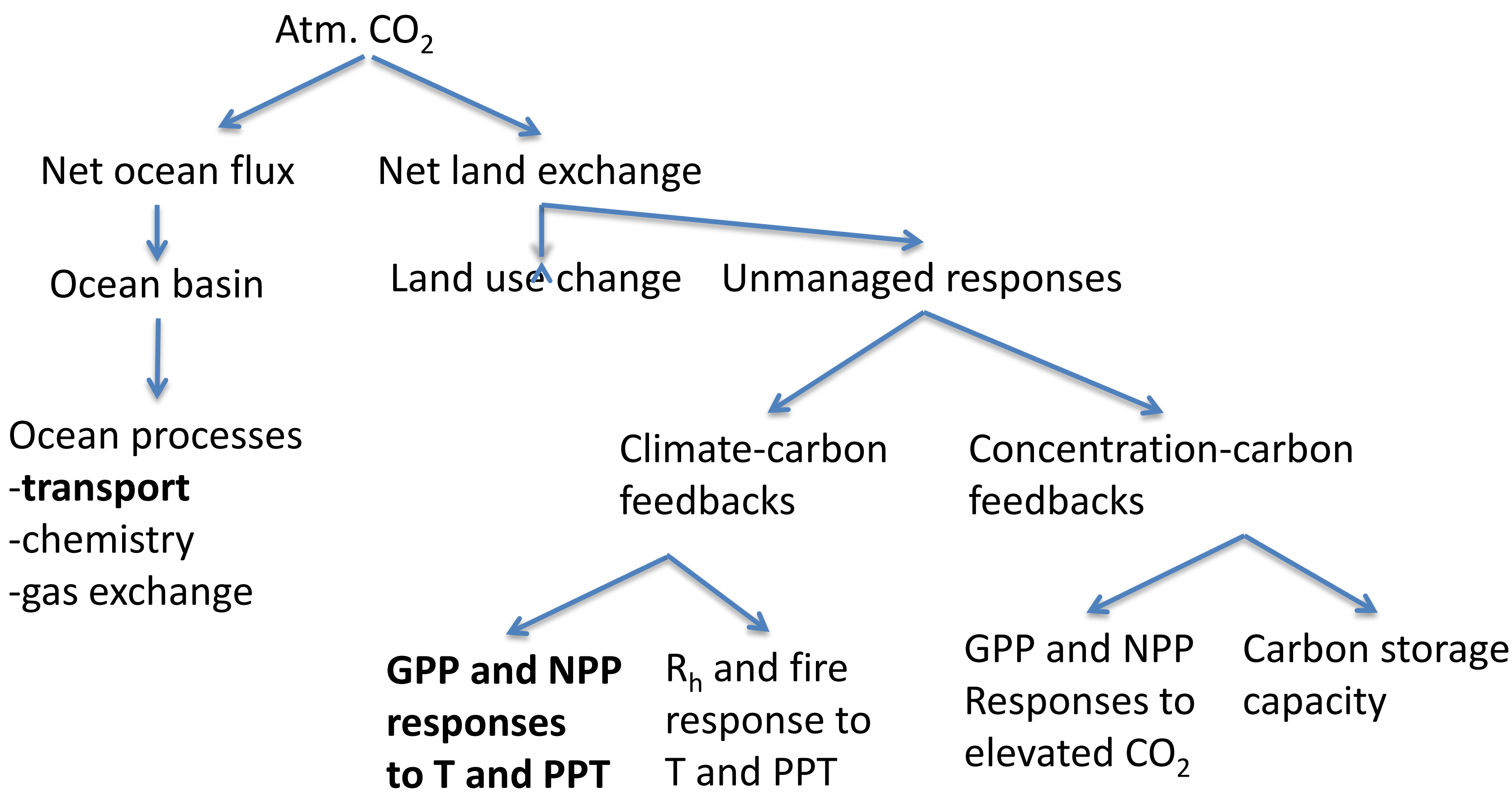


Hoffman et al. B41C-0291

Bias Attribution Hierarchy

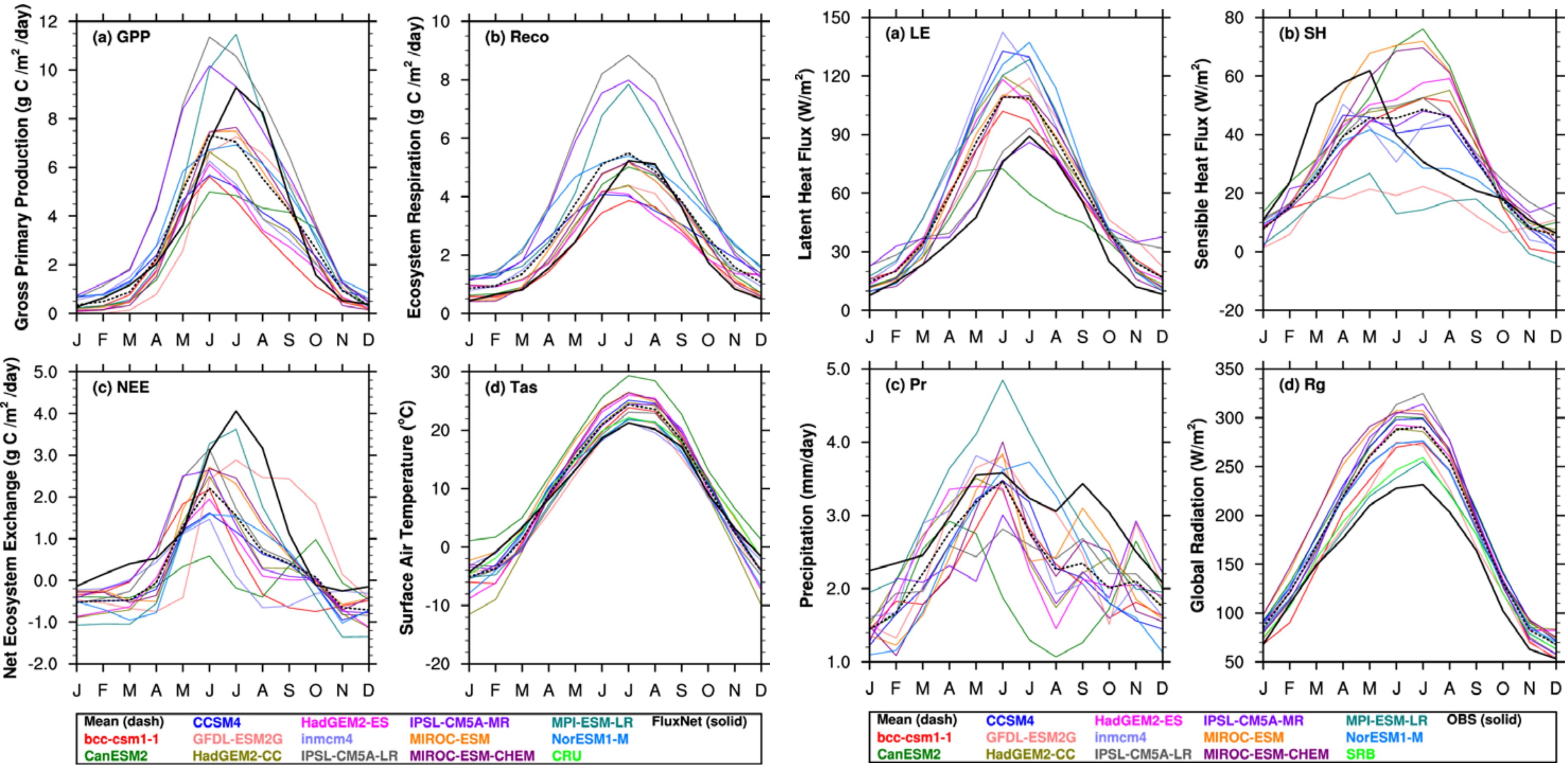


Bias Attribution Hierarchy



Strength of the early season uptake bias varies by region

- Fluxnet sites in the central U.S.



Strength of the early season uptake bias varies by region

- Fluxnet sites in Eurasia between 35N and 45N