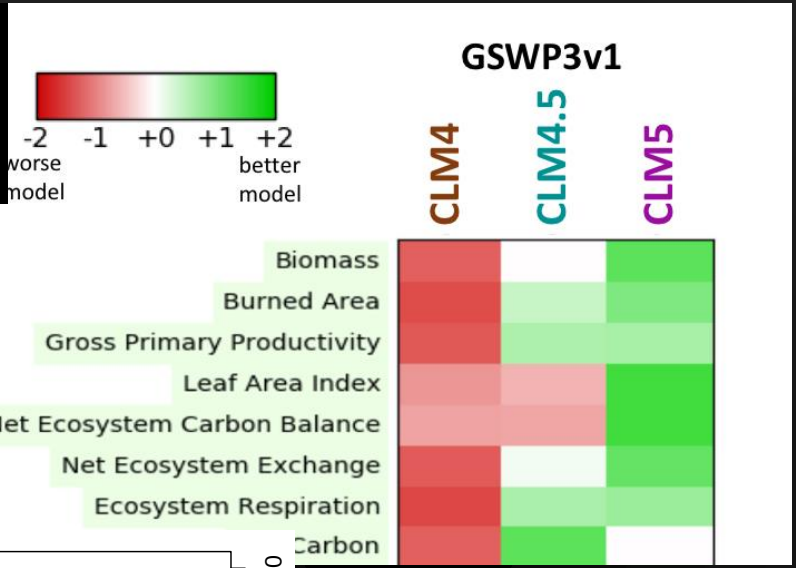
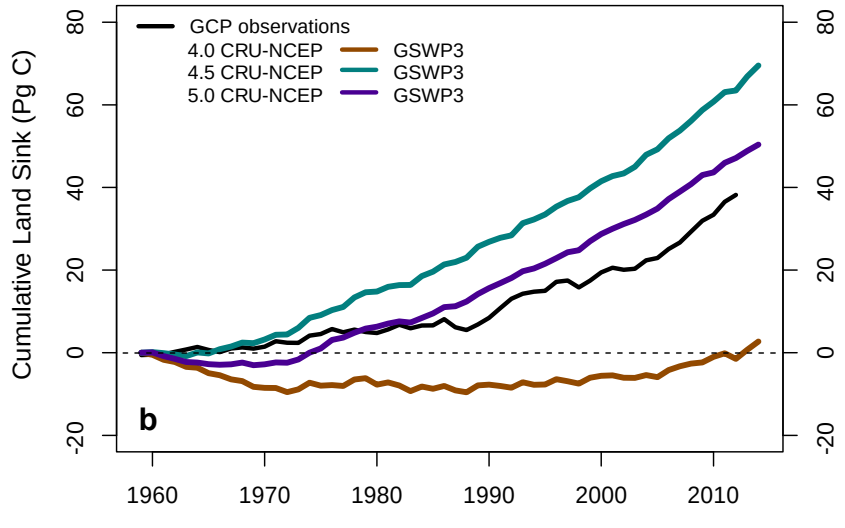
# Terrestrial C Cycle Variability

Will Wieder, TSS

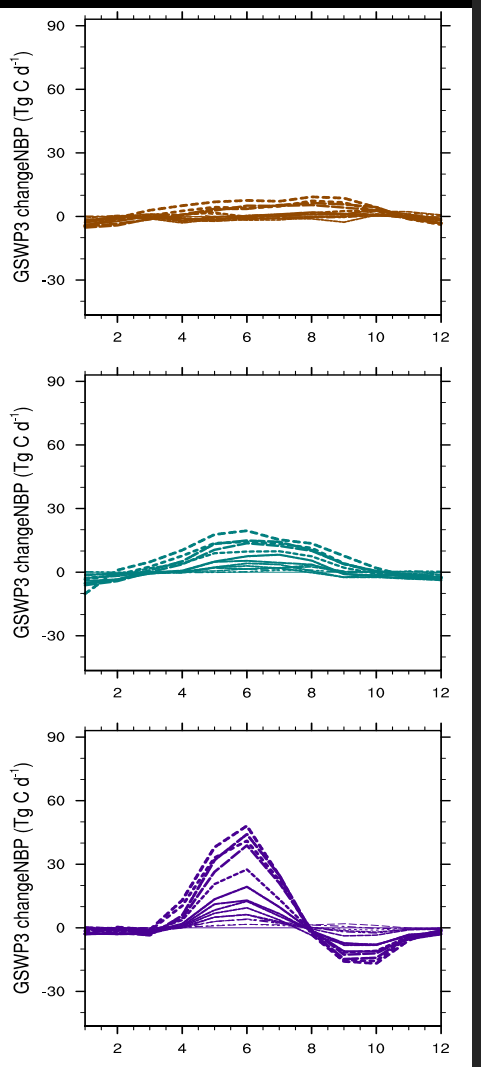
Dave Lawrence, Gordon Bonan, Danica Lombardozzi, Keith Oleson, Rosie Fisher, Gretchen Keppel-Aleks, Charlie Koven, Daniel Kennedy

# CLM5 = Better C cycle




Lawrence et al. in review;
Bonan et al. in review;
Lombardozzi et al. in review & in prep.



# Carbon cycle variability

**Sensitivity of tropical carbon to climate change constrained by carbon dioxide variability**

Peter M. Cox[1], David Pearson[2], Ben B. Booth[2], Pierre Friedlingstein[1], Chris Huntingford[3], Chris D. Jones[2] & Catherine M. Luke[1]

**Global Carbon Budget 2018**

Le Quéré et al. 2018 ESSD

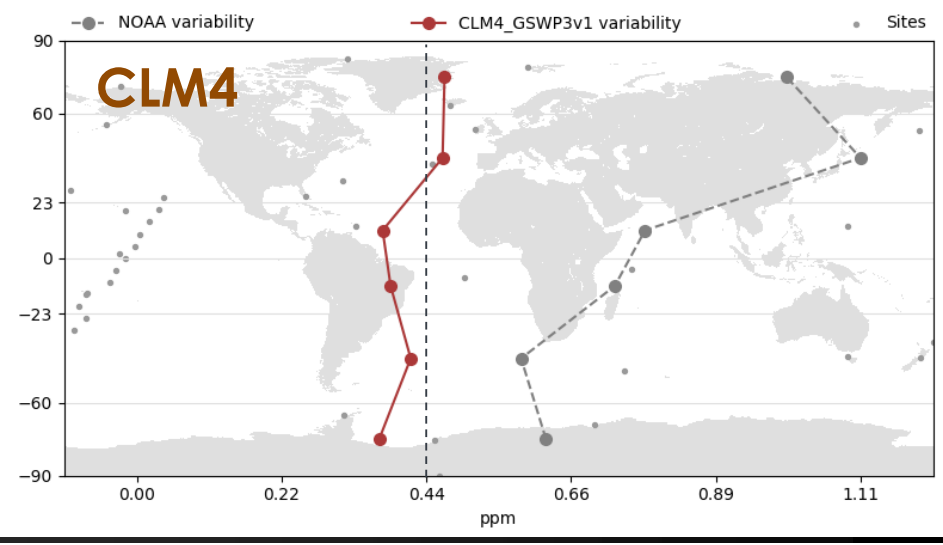
CARBON CYCLE

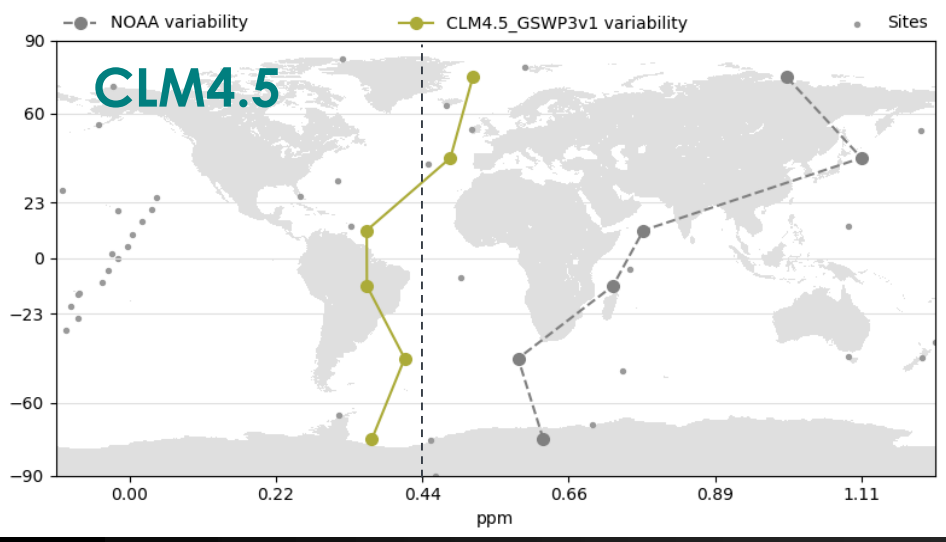
**The dominant role of semi-arid ecosystems in the trend and variability of the land $CO_2$ sink**

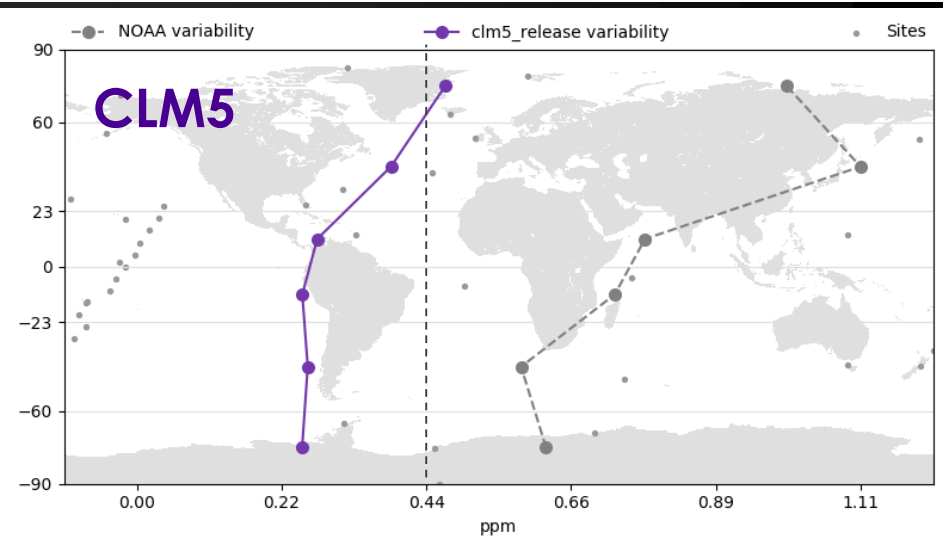
Anders Ahlström,[1,2*] Michael R. Raupach,[3†] Guy Schurgers,[4] Benjamin Smith,[1] Almut Arneth,[5] Martin Jung,[6] Markus Reichstein,[6] Josep G. Canadell,[7] Pierre Friedlingstein,[8] Atul K. Jain,[9] Etsushi Kato,[10] Benjamin Poulter,[11] Stephen Sitch,[12] Benjamin D. Stocker,[13,14] Nicolas Viovy,[15] Ying Ping Wang,[16] Andy Wiltshire,[17] Sönke Zaehle,[6] Ning Zeng[18]

# Carbon cycle variability in CLM5

- Reduced IAV of net land C exchange
- Lower GPP variability
- Stronger GPP - ER correlation

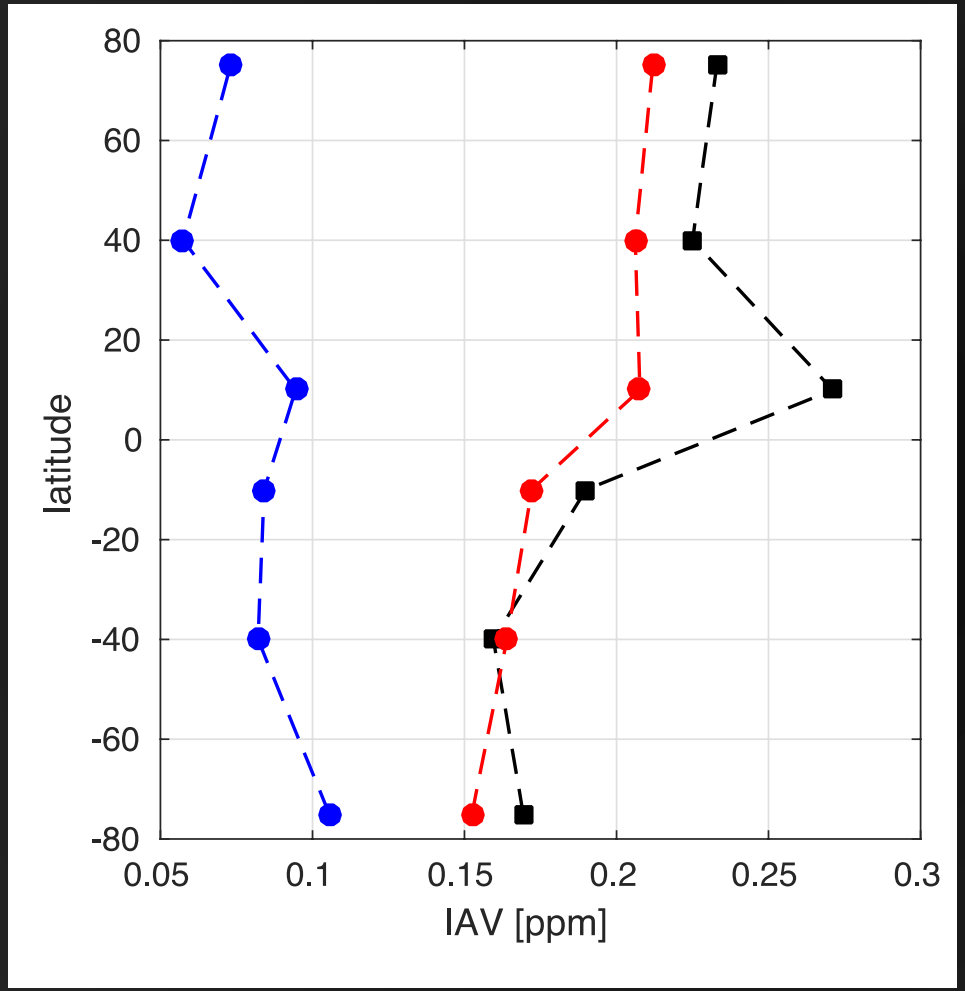


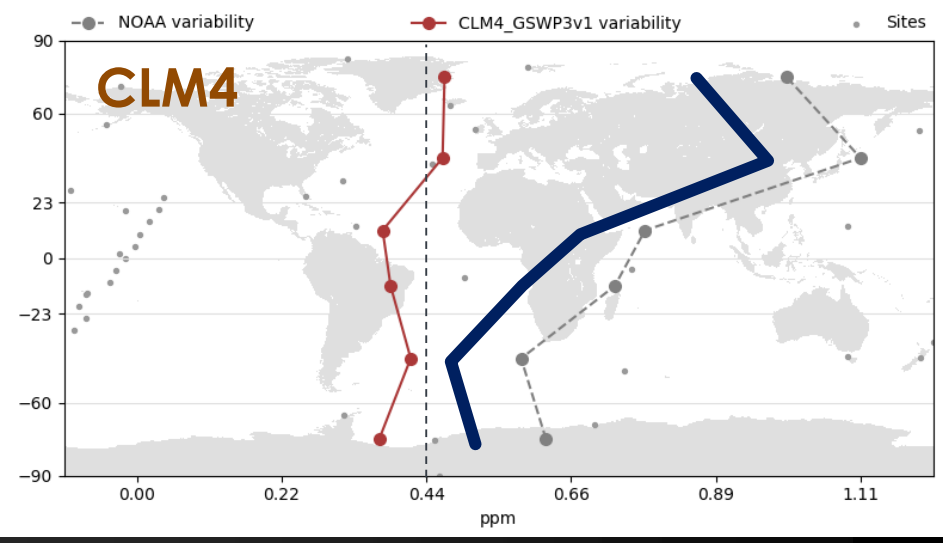

# Interannual variability of net C flux

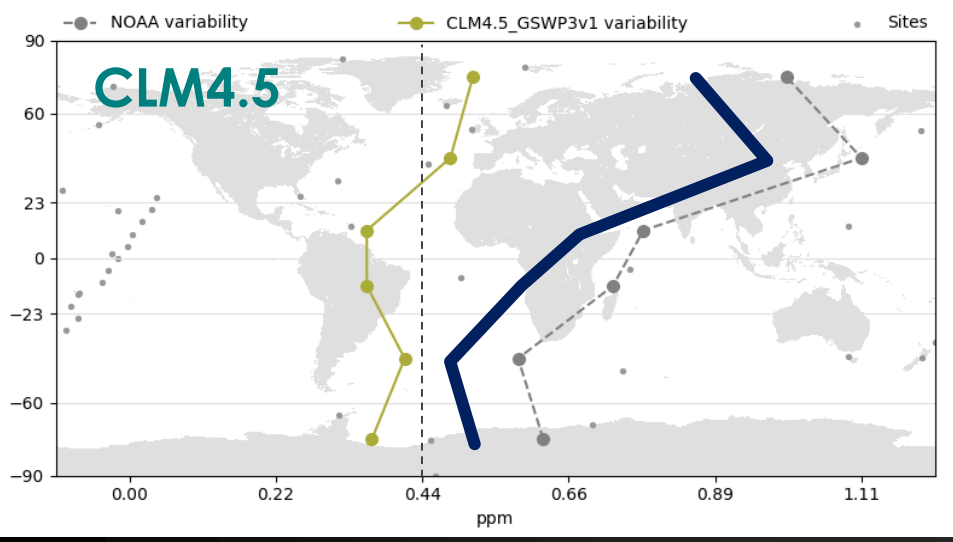
Keppel-Aleks & Collier unpublished + ILAMB!

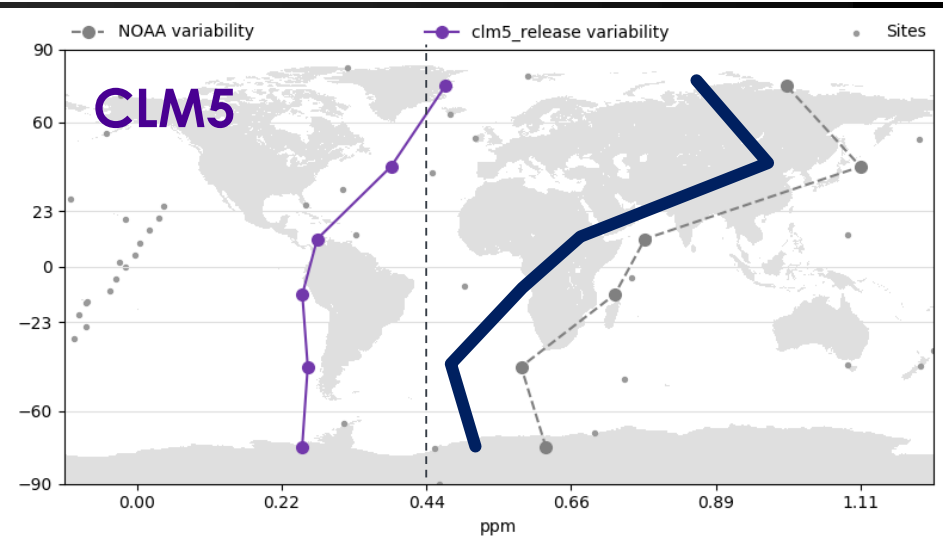



– Ocean –
– Emissions –
– Total –

Keppel-Aleks unpublished

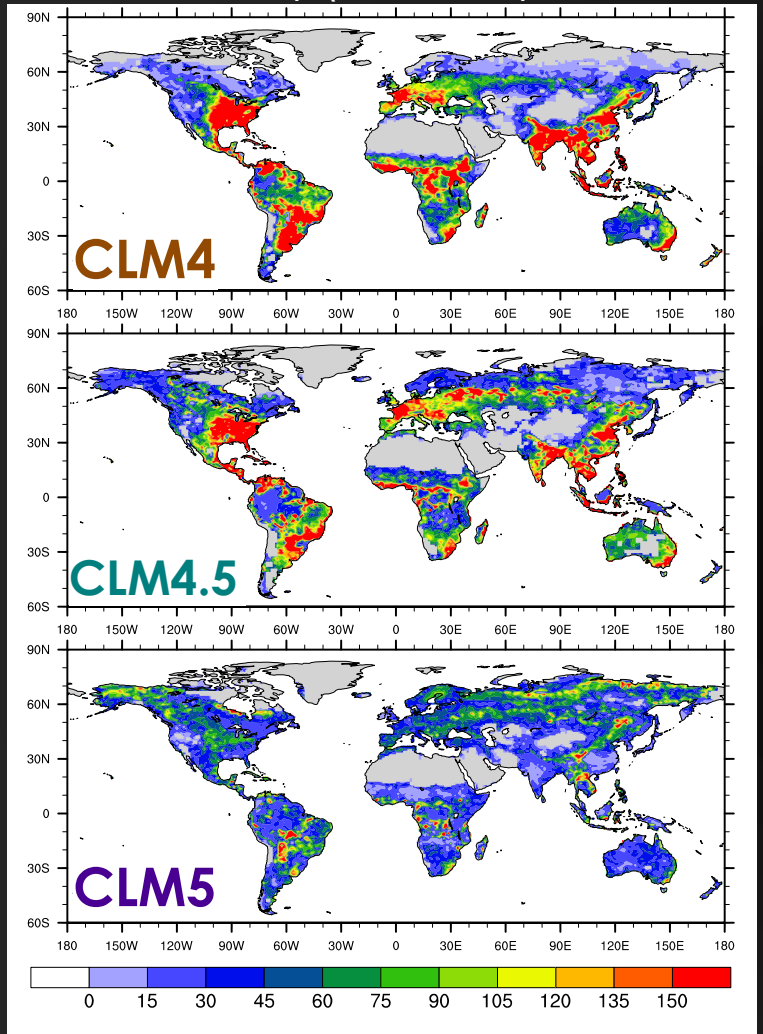


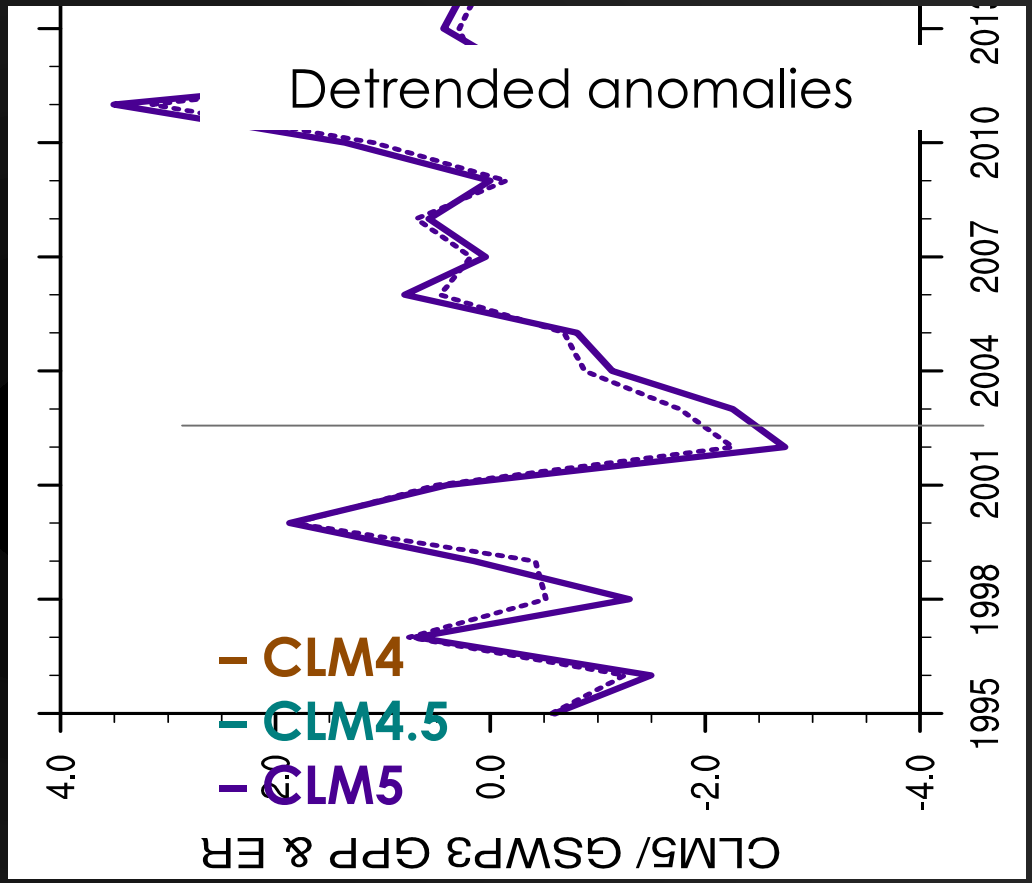



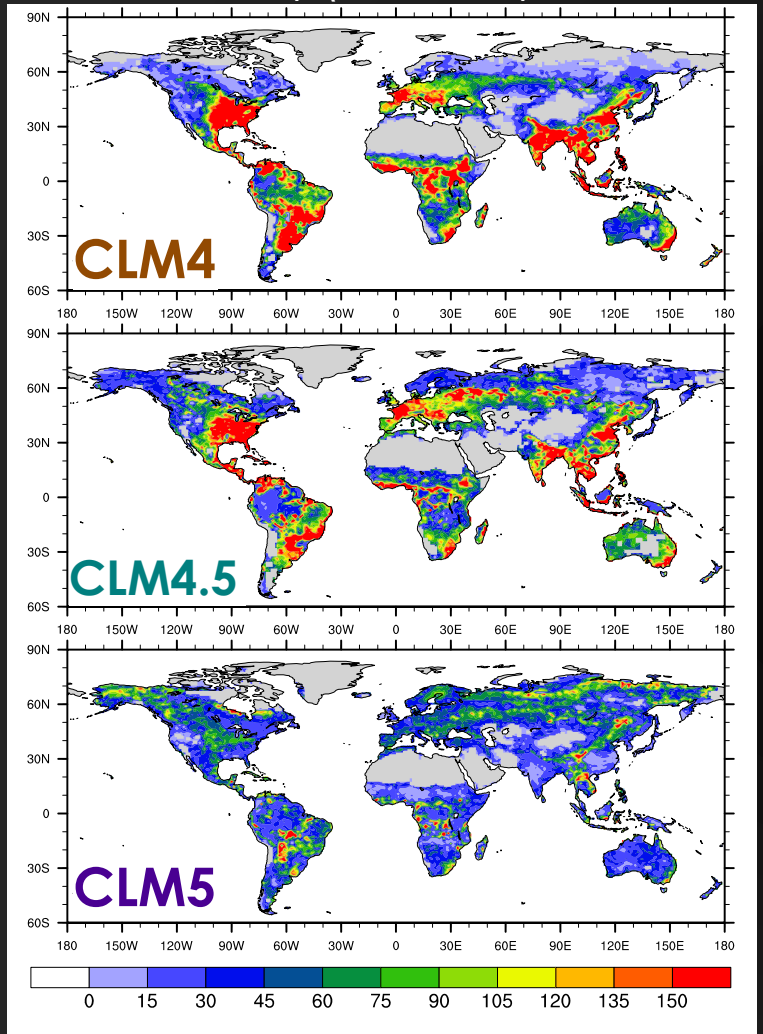

# Interannual variability of land C flux

NEE variability (SD of 25 y anomalies)

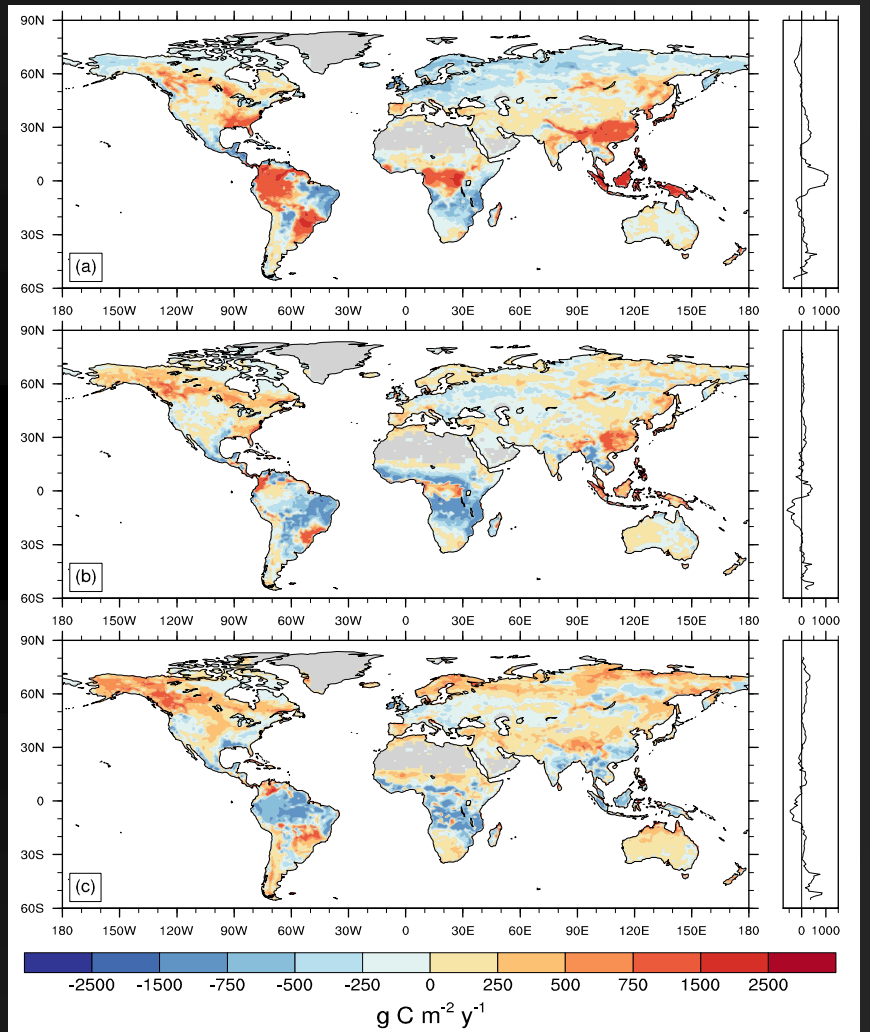


# NEE variability (SD of 25 y anomalies)




# GPP Bias

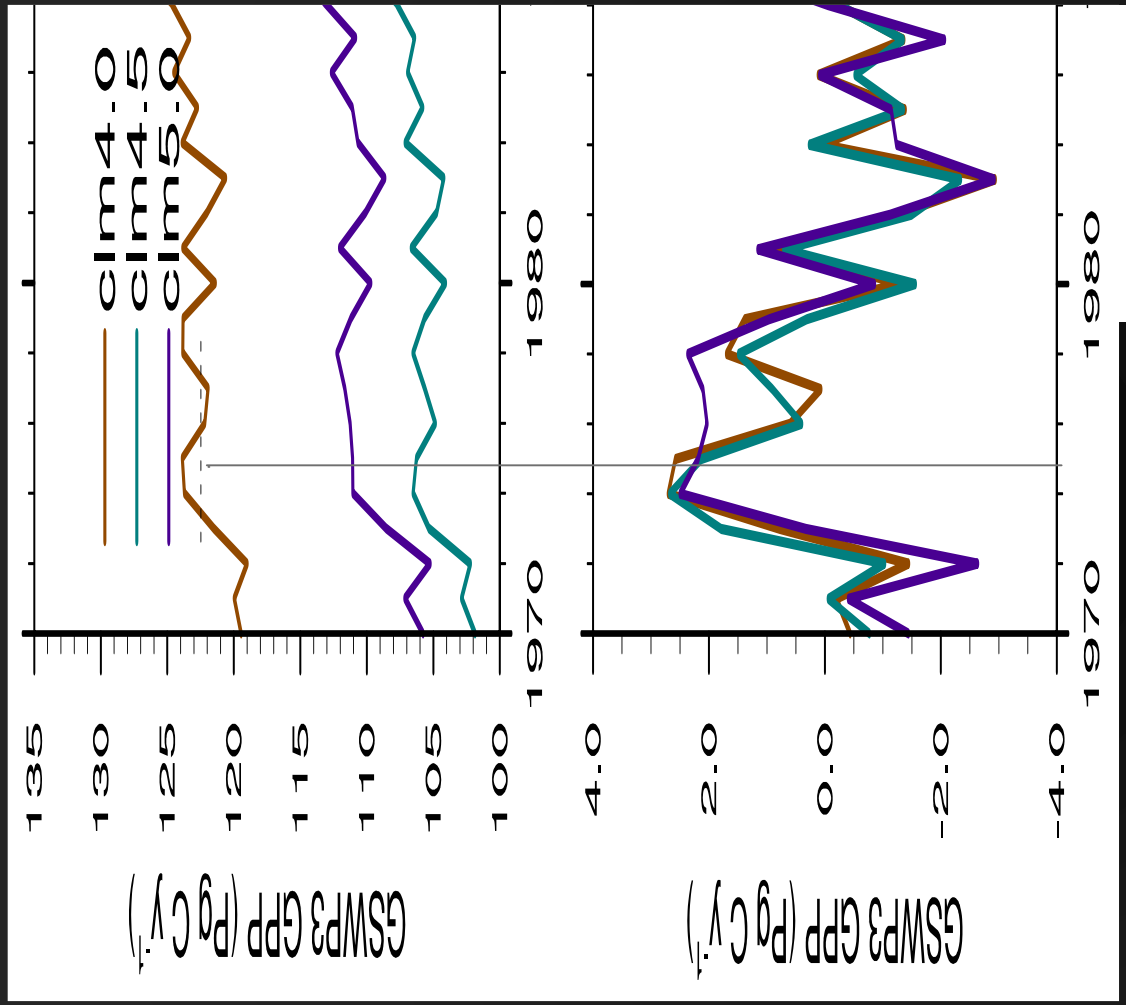


# Modest changes to CLM5



Culprits:

PHS
Soil HR
AR fluxes
FUN
Roots
Hydrology
Medlyn conduct.
LUNA
Bugs
Crops
Allocation
Parameterization
…



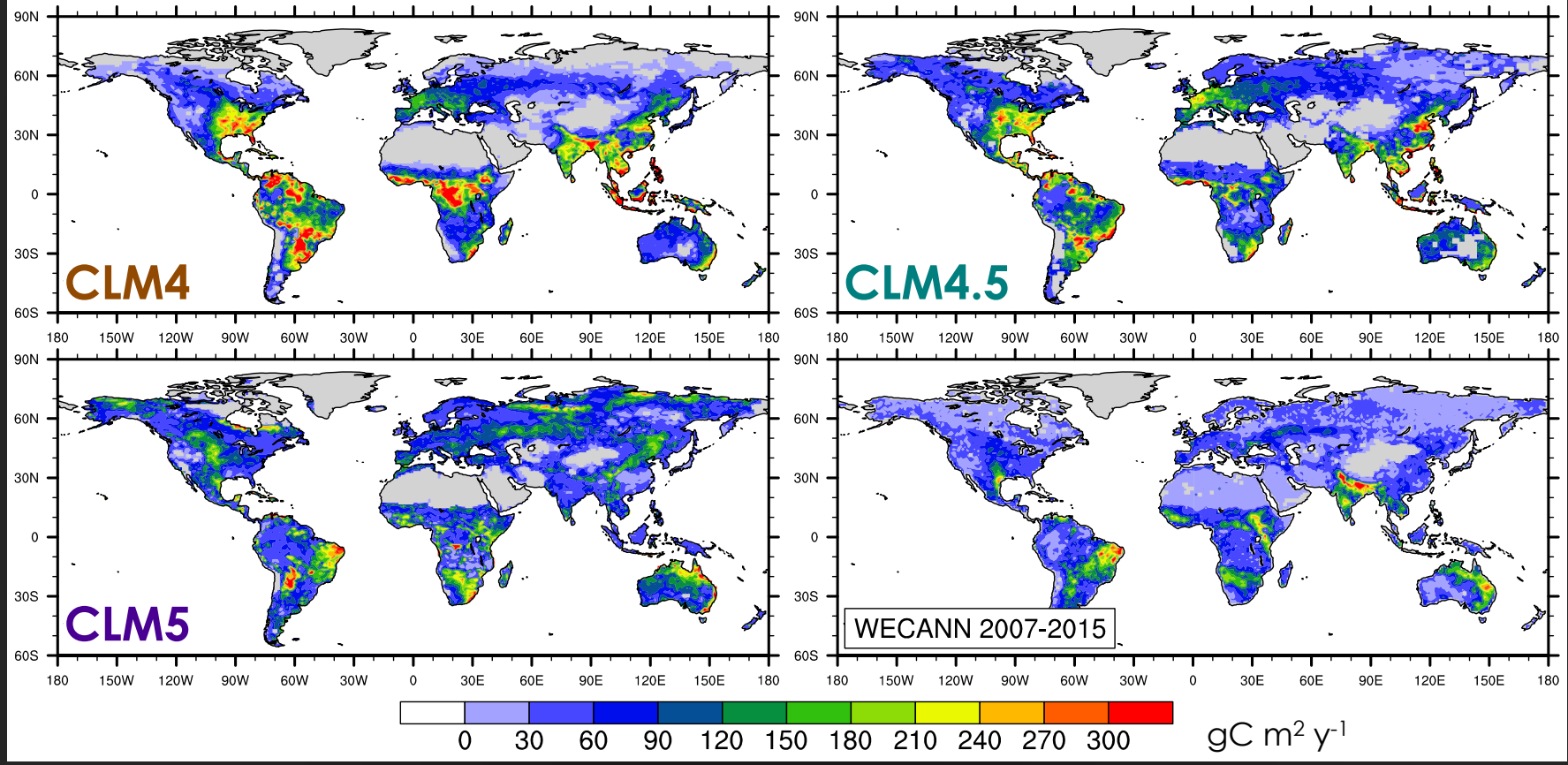

Detrended GPP anomalies

**– CLM4 –**

**– CLM4.5 –**

**– CLM5 –**

# GPP variability (SD of 25 y anomlaies, 1990-2014)



## Fluxes:

**NEP = GPP – ER**

**ER = AR + HR**

NPP = GPP – AR

NEP = NPP – HR

NEE = NEP – Fire

NBP = NEE – LULCC

## Culprits:

~~**PHS**~~

Soil HR

AR fluxes

FUN

**Roots**

**Hydrology**

**Medlyn conduct.**

**LUNA**

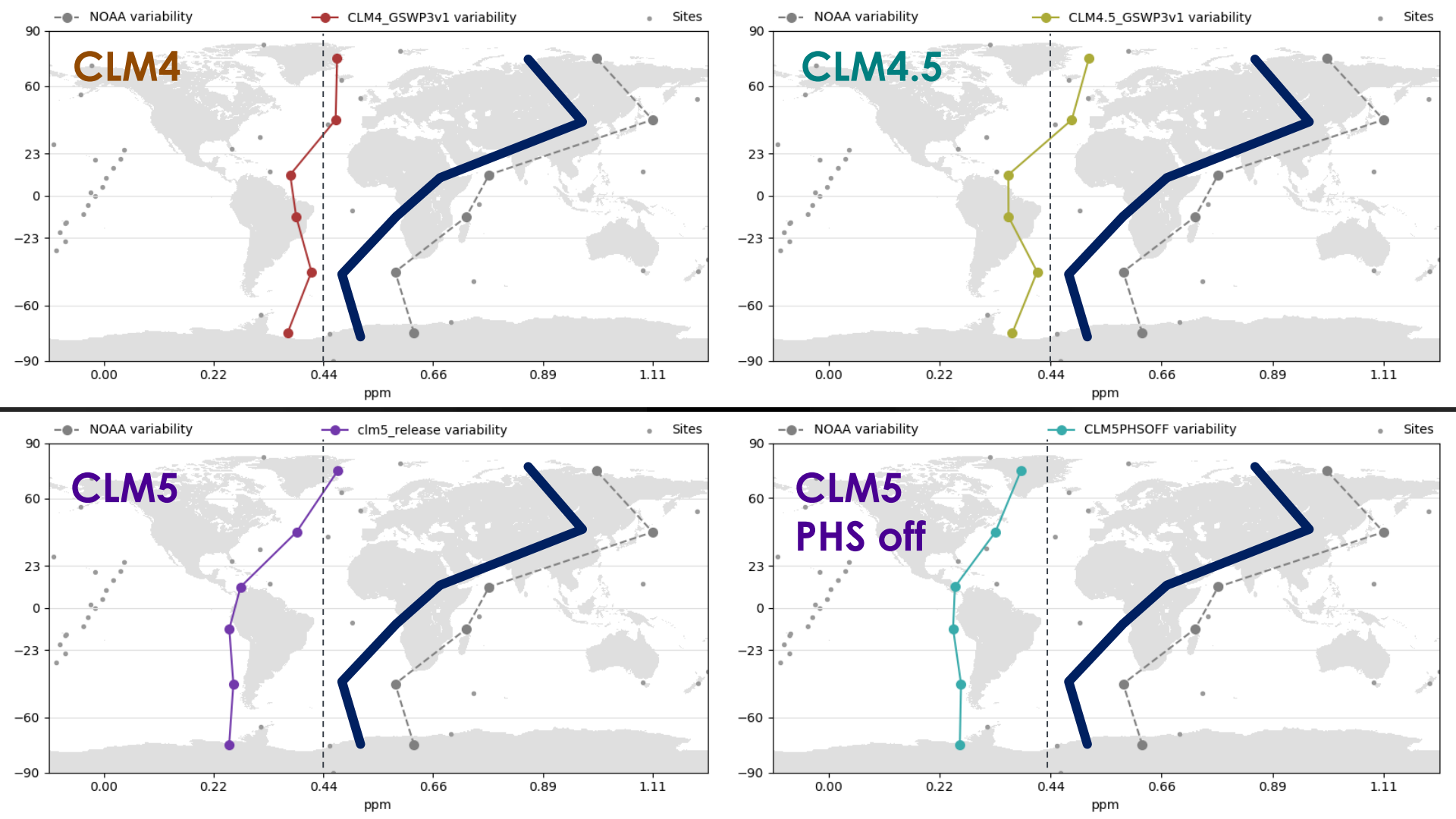
Bugs

~~**Crops**~~

Allocation

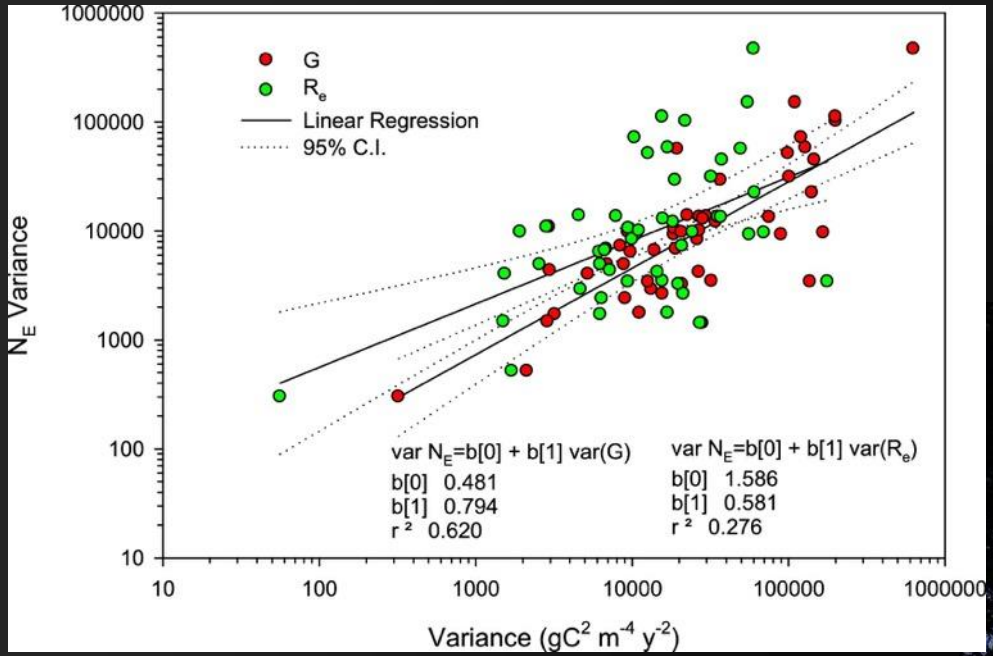
**Parameterization**

…


NOAA variability
CLM4_GSWP3v1 variability
Sites
CLM4
90
60
23
0
−23
−60
−90
0.00
0.22
0.44
0.66
0.89
1.11
ppm
NOAA variability
CLM4.5_GSWP3v1 variability
Sites
CLM4.5
ppm
NOAA variability
clm5_release variability
Sites
CLM5
ppm
NOAA variability
CLM5PHSOFF variability
Sites
CLM5
PHS off
ppm

# Carbon cycle variability in CLM5

- Reduced IAV of net land C exchange
  *Track GPP biases*
- Lower GPP variability
  *Not related to PHS or crops*
- Stronger GPP - ER correlation

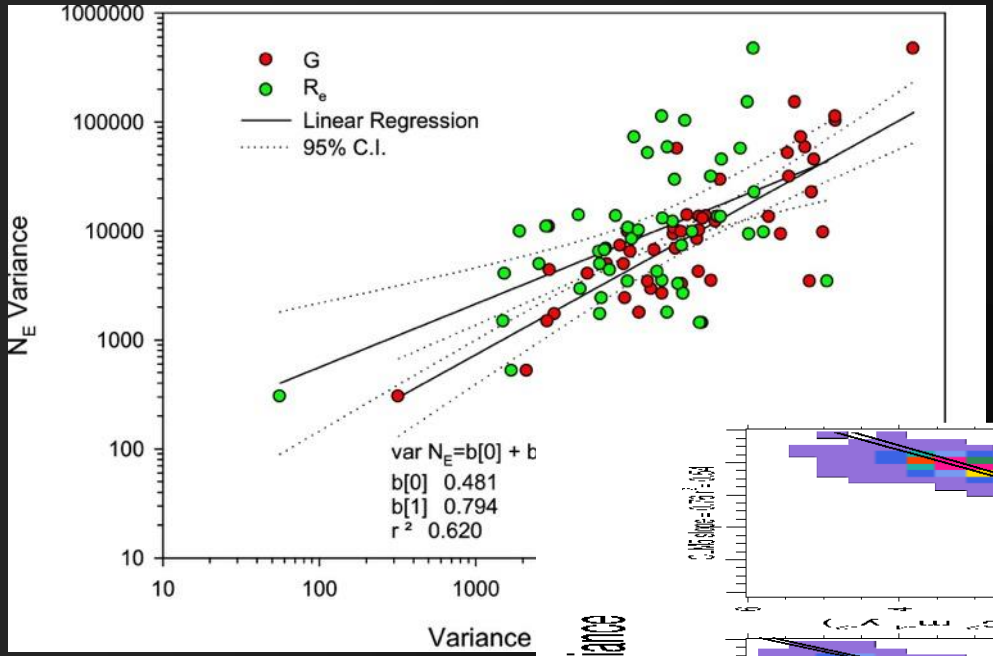


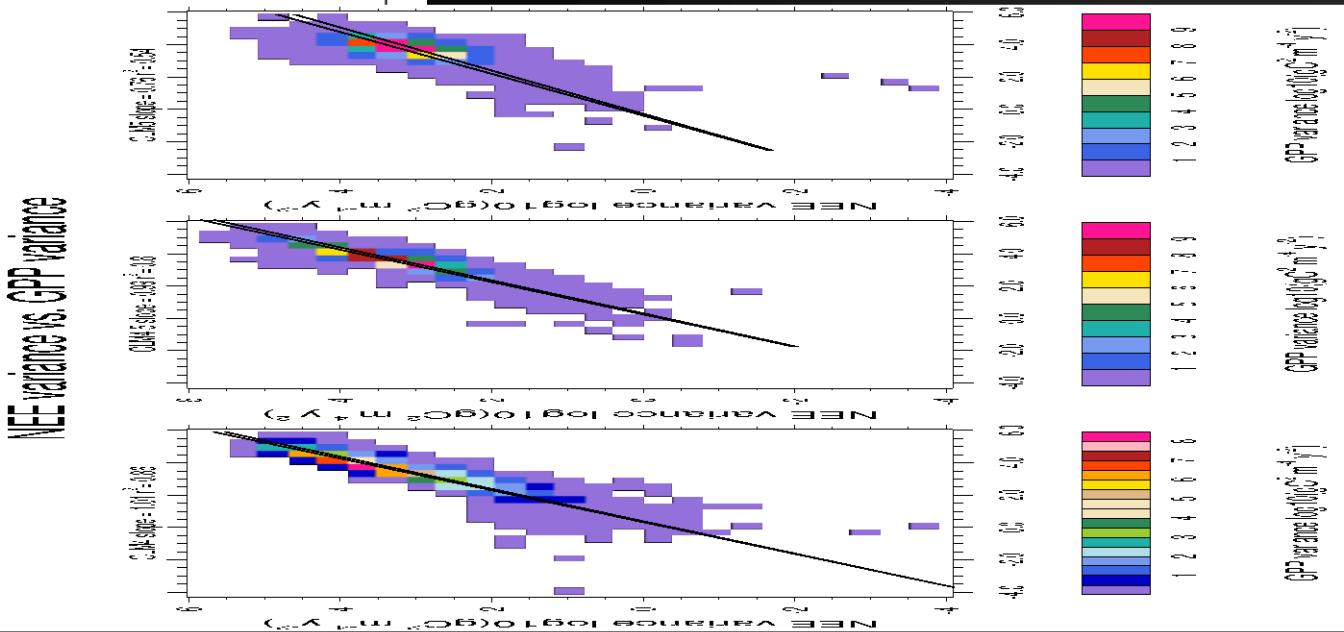

Variance in **NEE** is correlated with variance in **GPP** and ER

Baldocchi et al. 2018

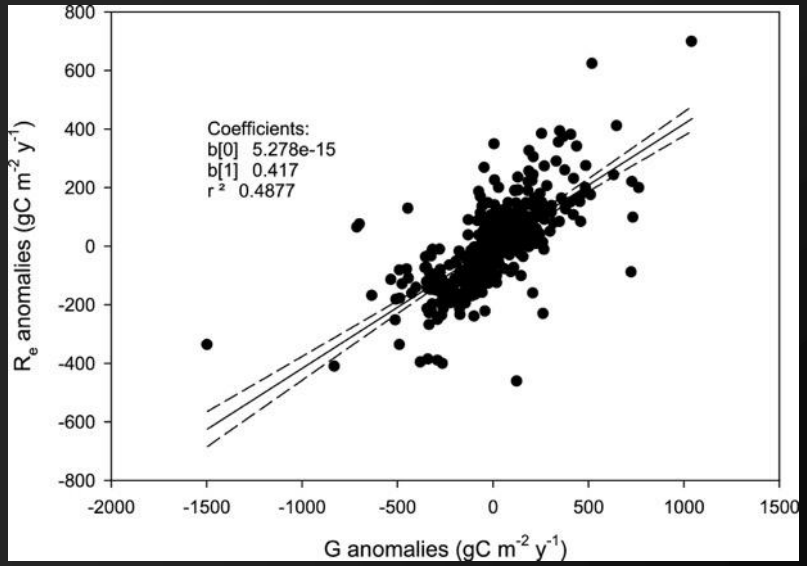
# Corr(NEE, GPP)

| | Obs. | CLM4 | CLM4.5 | CLM5 |
|---|---|---|---|---|
| Slope | **0.79** | 1.01 | 0.99 | **0.76** |
| R2 | **0.62** | 0.86 | 0.8 | **0.54** |



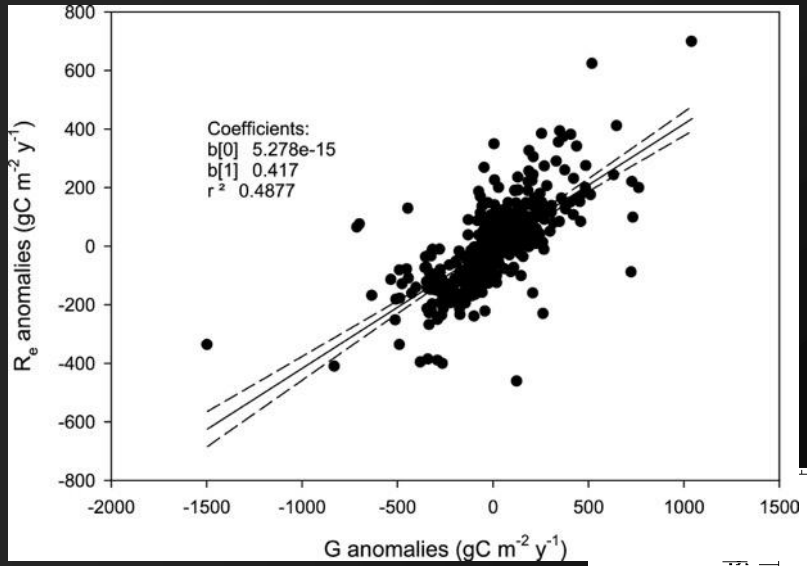

Baldocchi et al. 2018



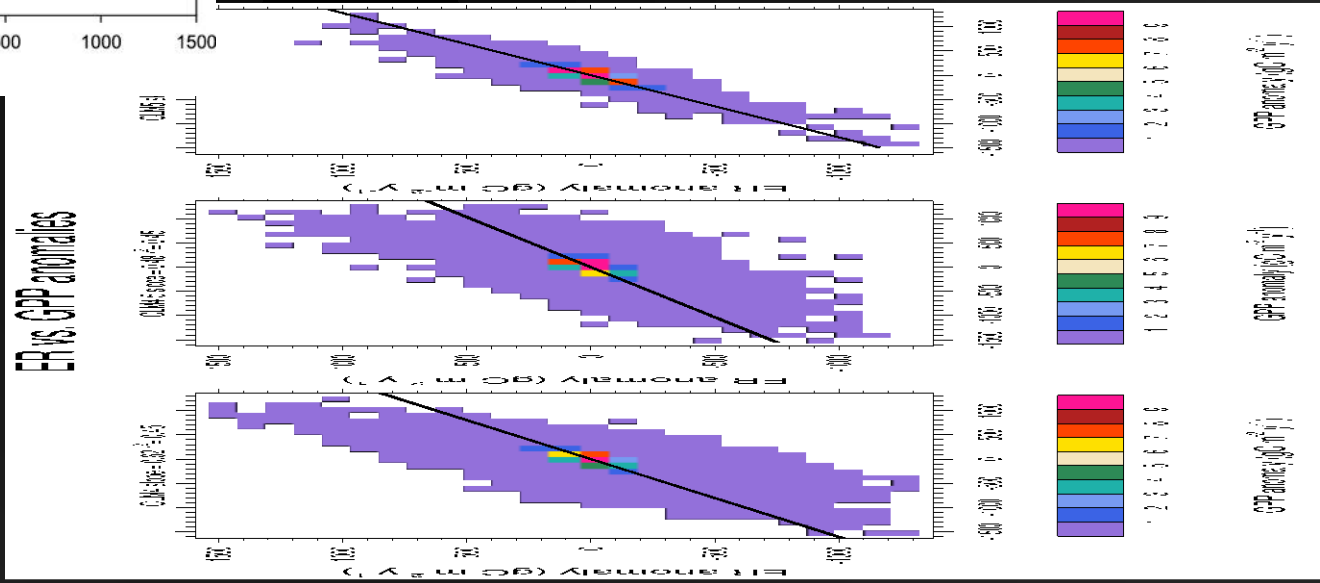

# Auto correlation of **GPP** and **ER** anomalies

Baldocchi et al. 2018

# Corr(GPP, ER)



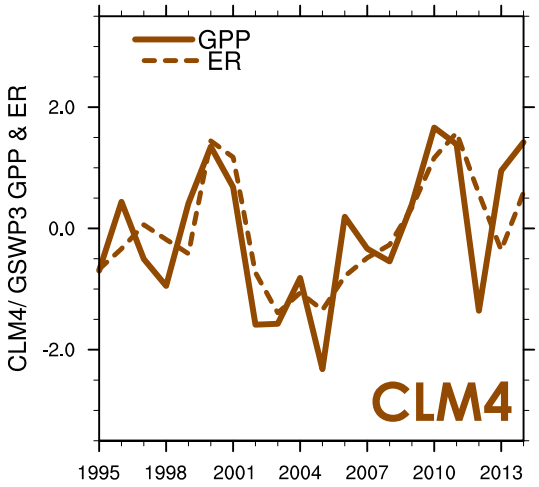

| | **Obs.** | CLM4 | **CLM4.5** | CLM5 |
|---|---|---|---|---|
| Slope | **0.42** | 0.62 | **0.48** | 0.78 |
| R2 | **0.49** | 0.45 | **0.45** | 0.8 |

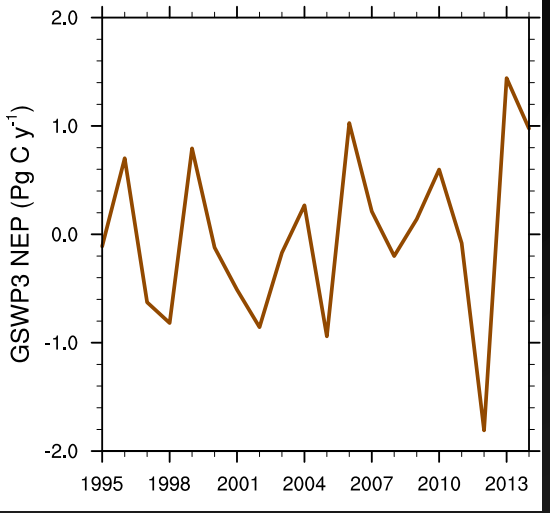



# GPP-ER correlation

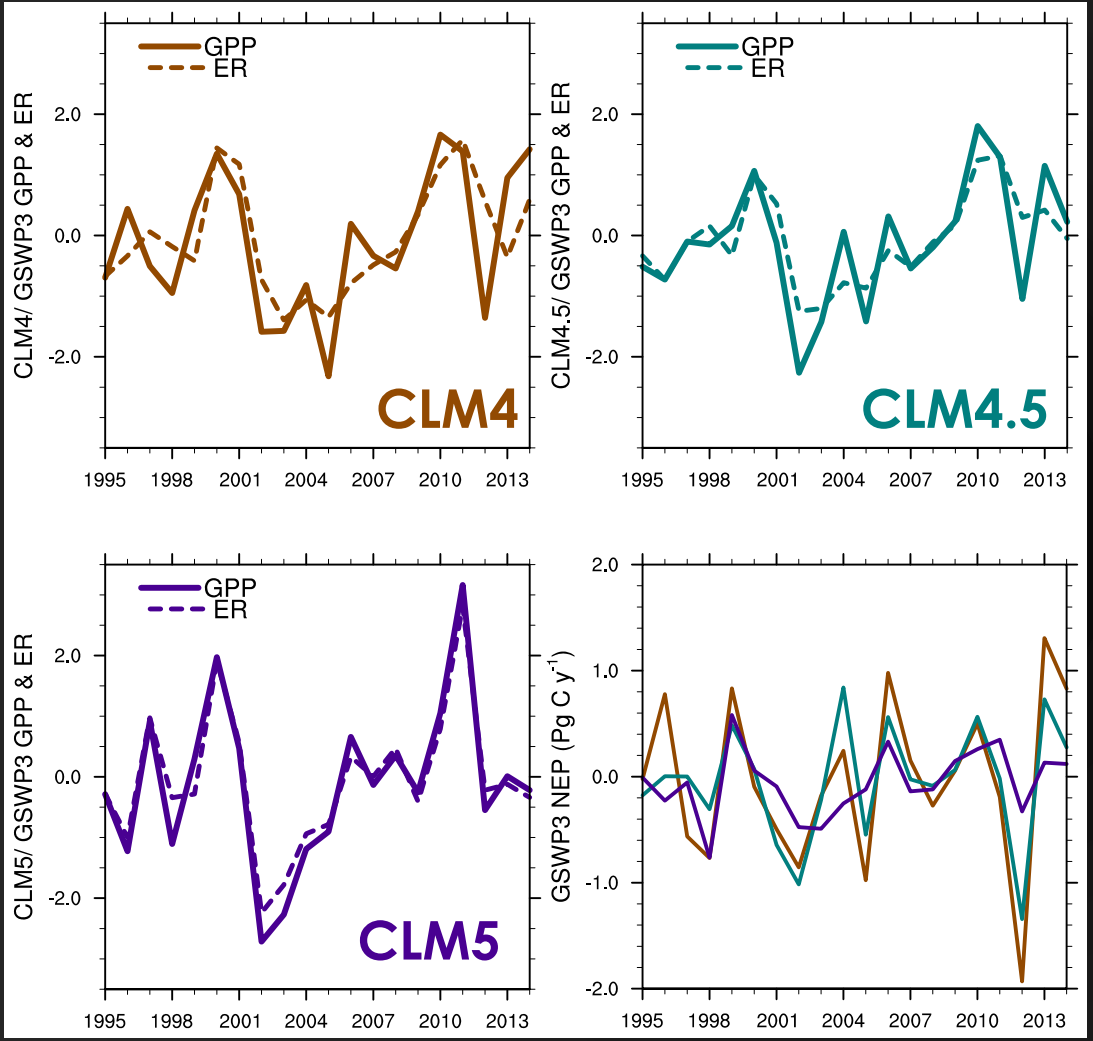
Baldocchi et al. 2018

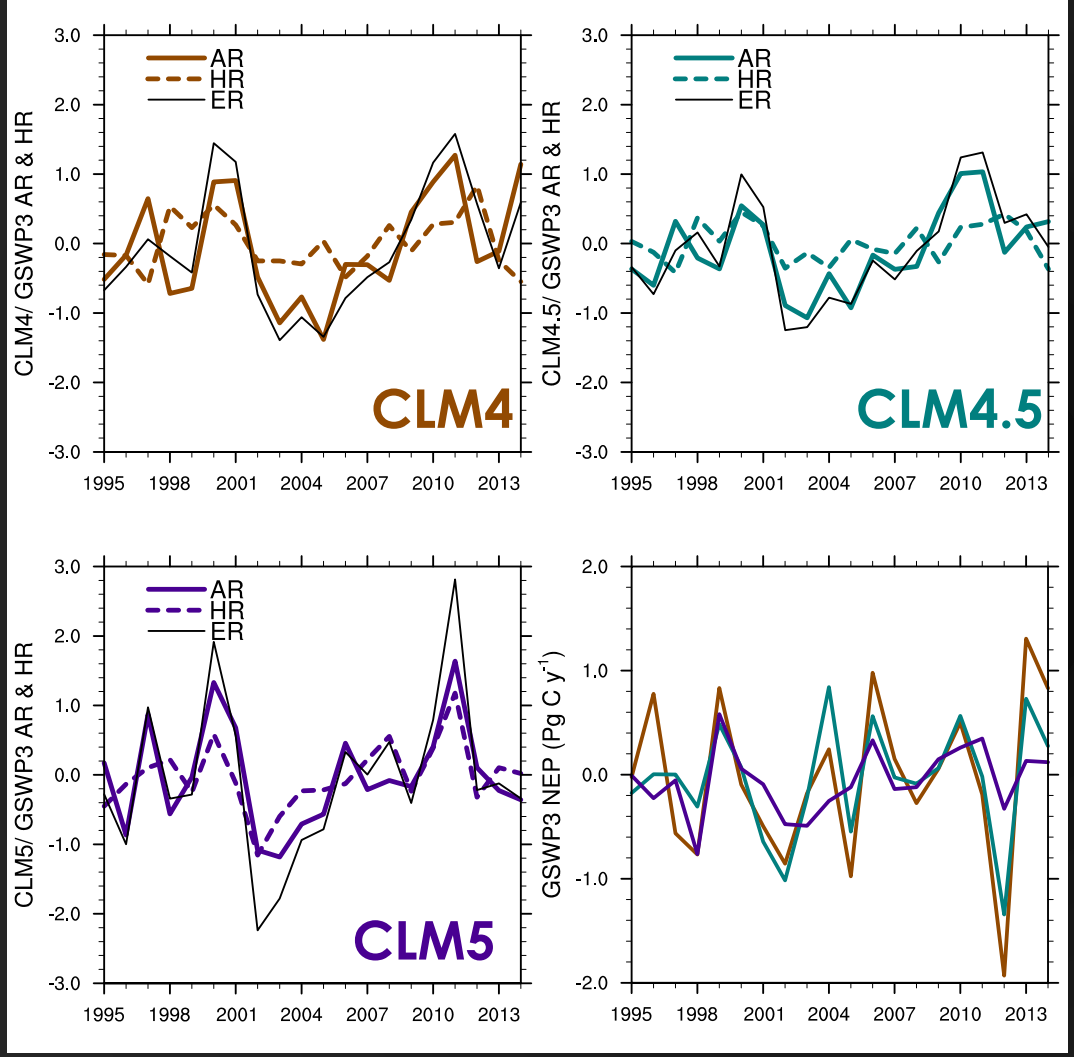
# GPP-ER anomalies



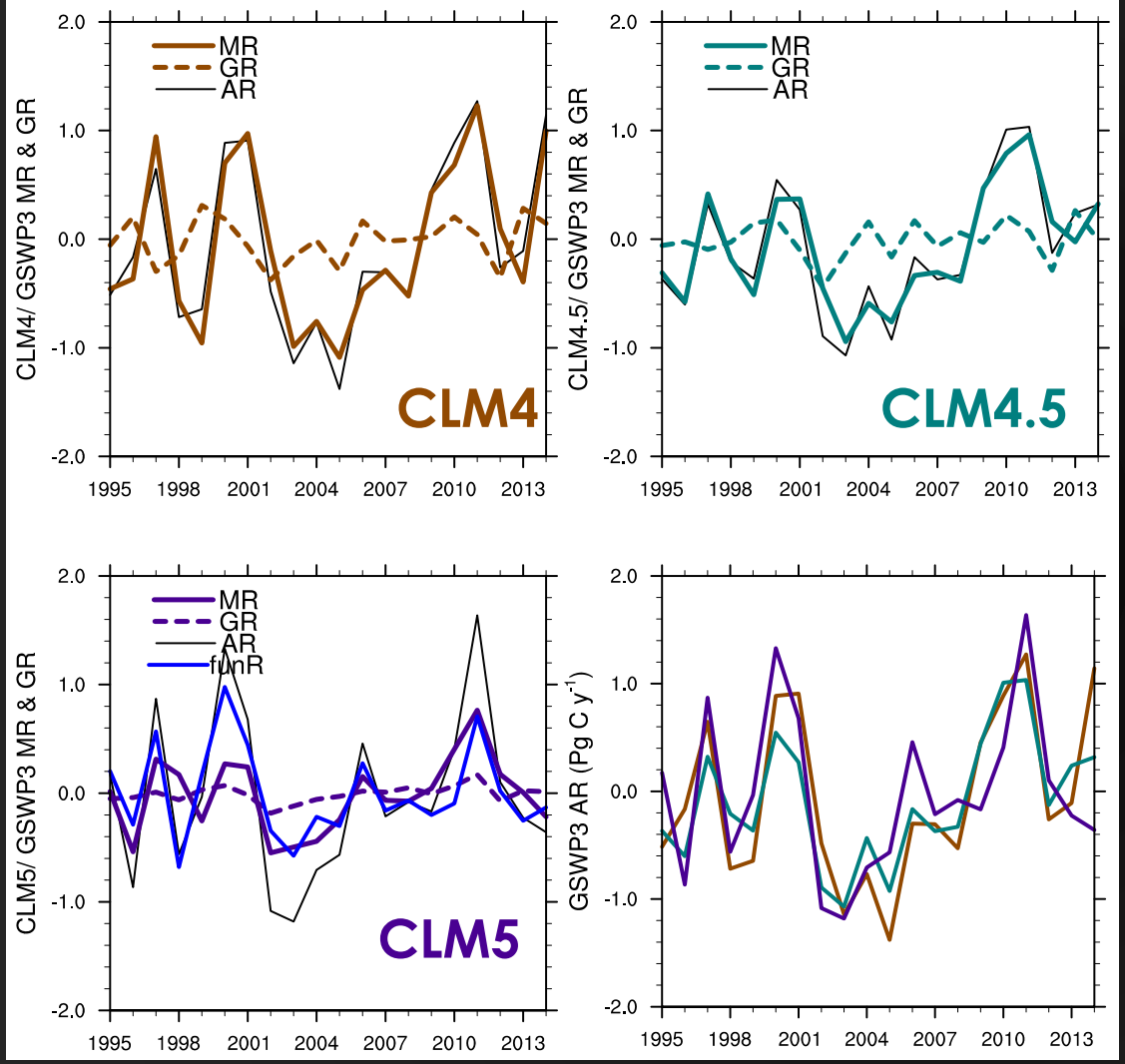
# GPP-ER anomalies






ER component anomalies

Dominated by Autotrophic respiration

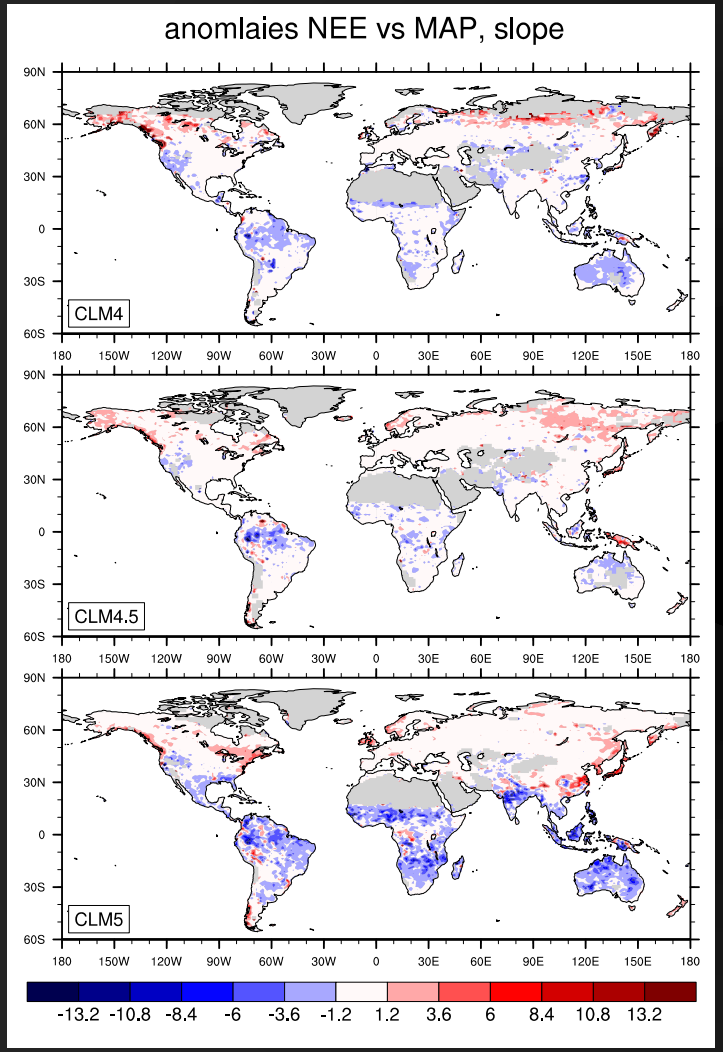


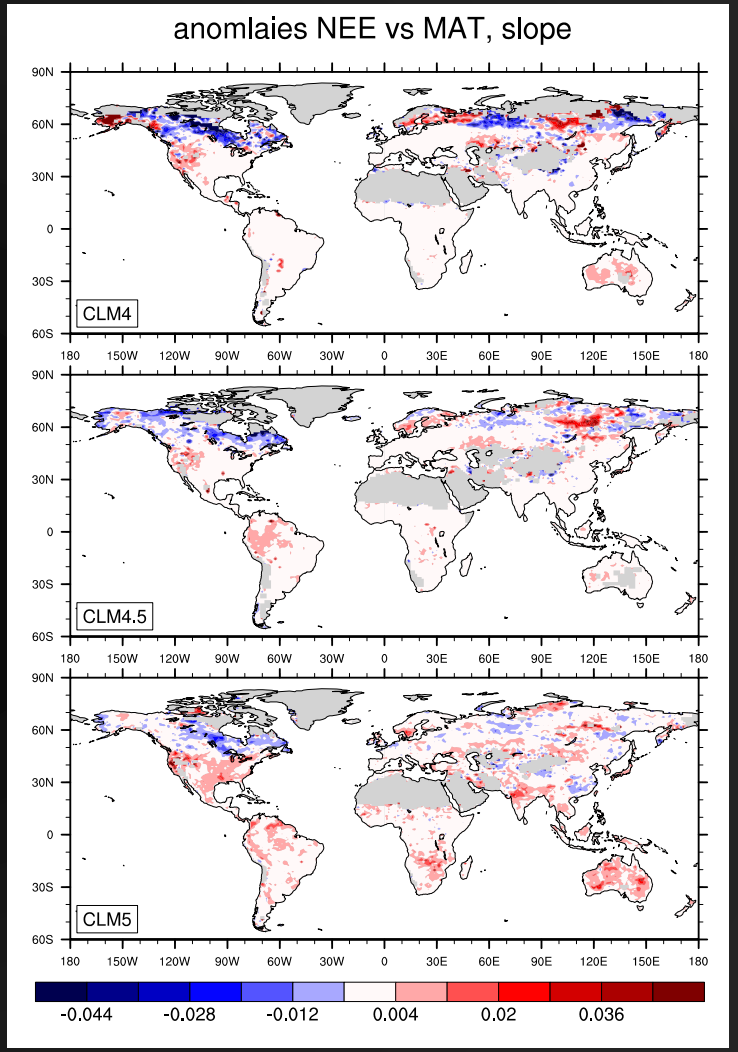

AR component anomalies

Dominated by FUN

# Carbon cycle variability in CLM5

- Reduced IAV of net land C exchange
  *Track GPP biases*
- Lower GPP variability
  *Not related to PHS or crops*
- Stronger GPP - ER correlation
  Related to FUN?


anomlaies NEE vs MAP, slope
CLM4
CLM4.5
CLM5
90N
60N
30N
0
30S
60S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
-13.2 -10.8 -8.4 -6 -3.6 -1.2 1.2 3.6 6 8.4 10.8 13.2


anomlaies NEE vs MAT, slope
CLM4
CLM4.5
CLM5
90N
60N
30N
0
30S
60S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
-0.044 -0.028 -0.012 0.004 0.02 0.036

**Correcting biases**

- GPP, LAI

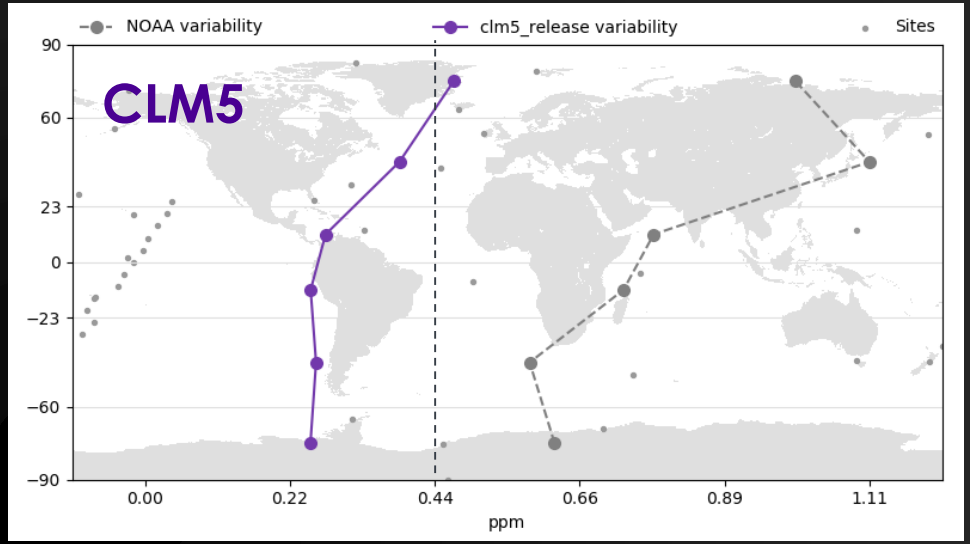
**Improving assumptions**

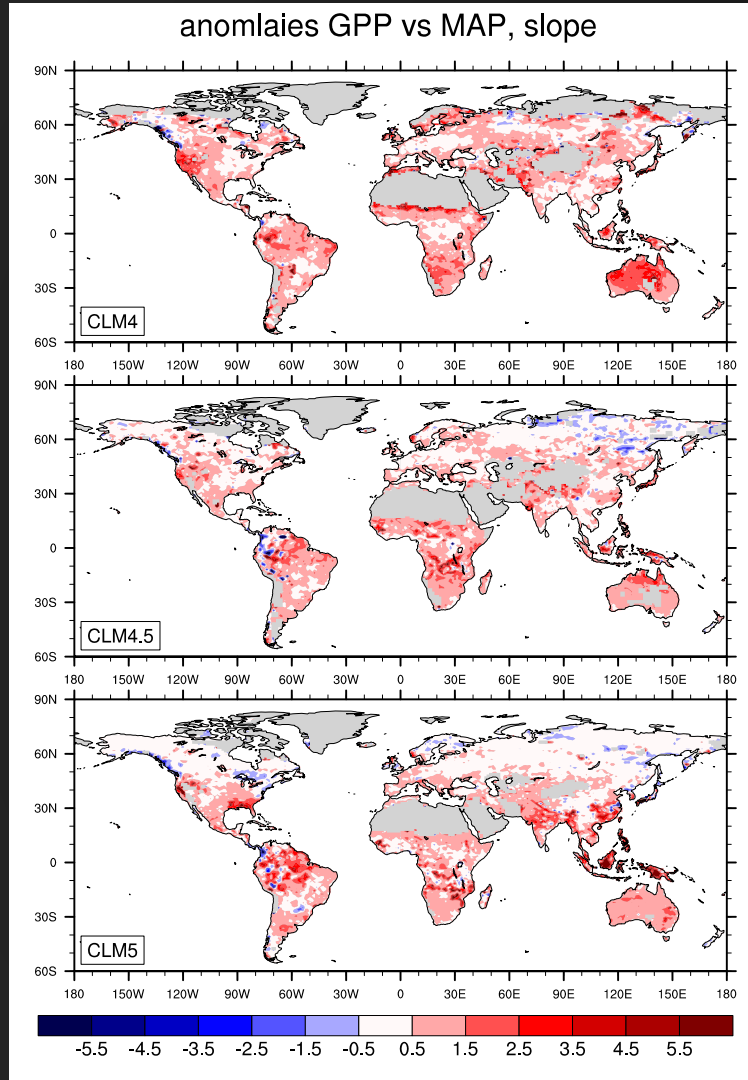
- PHS
- Temp. – AR function
- Moisture – HR corrections
- FUN

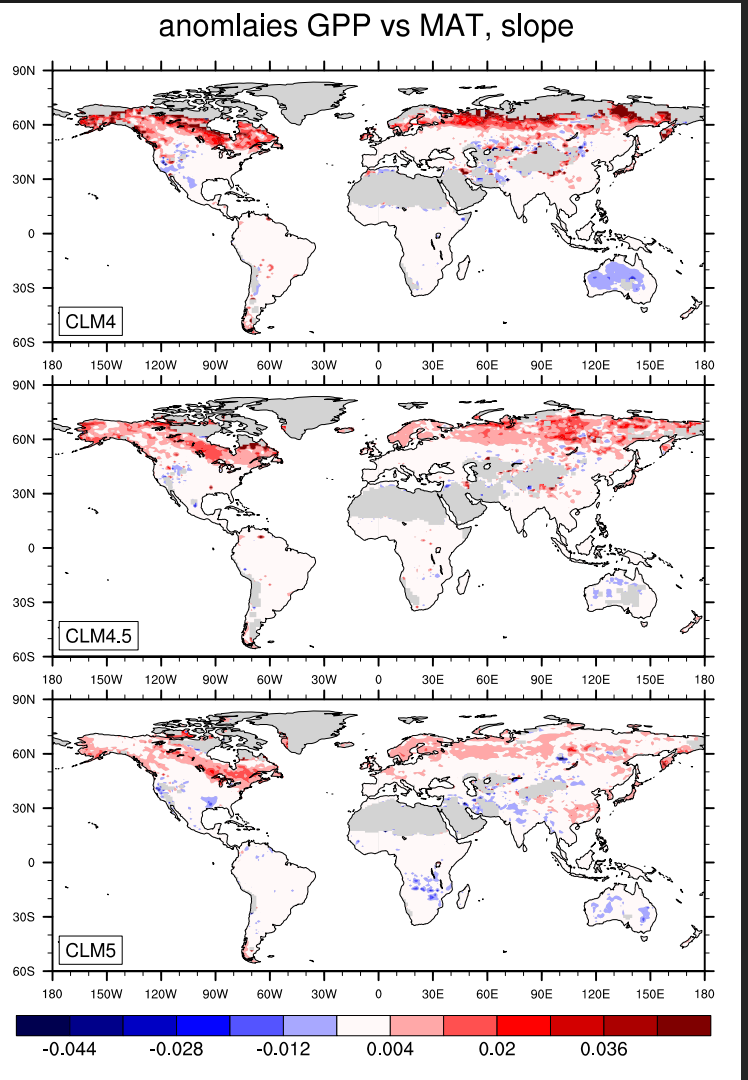
**Unintended consequences**

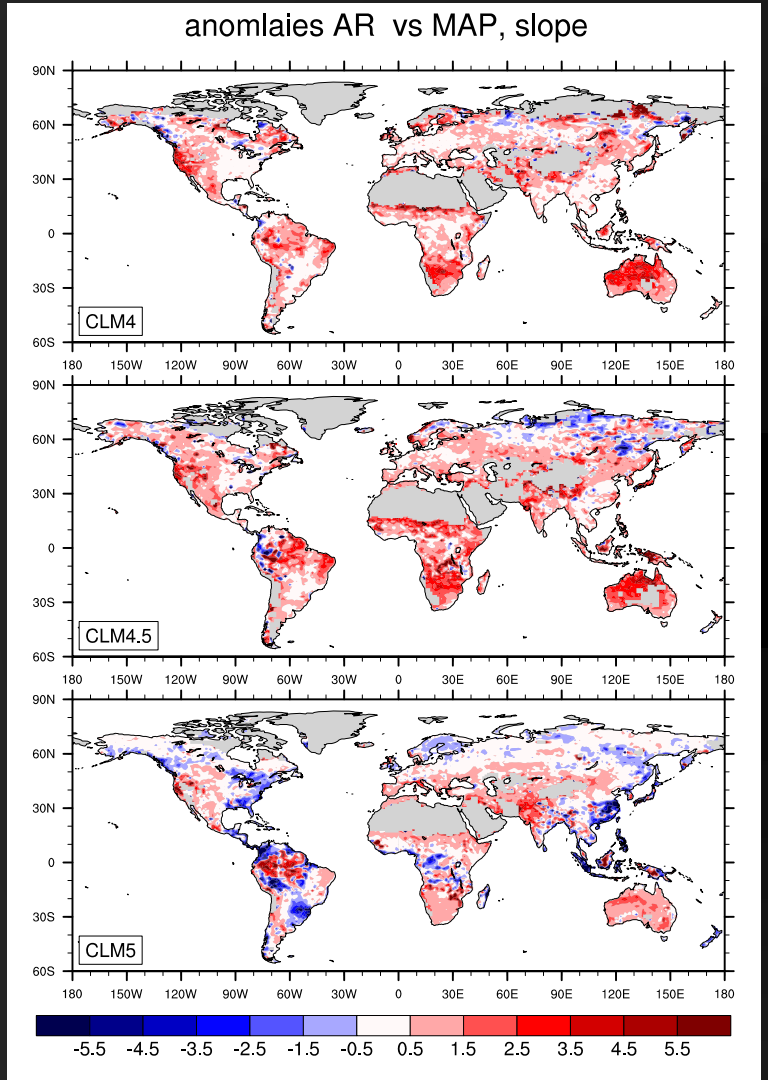
**How best to increase IAV w/o degrading simulations?**

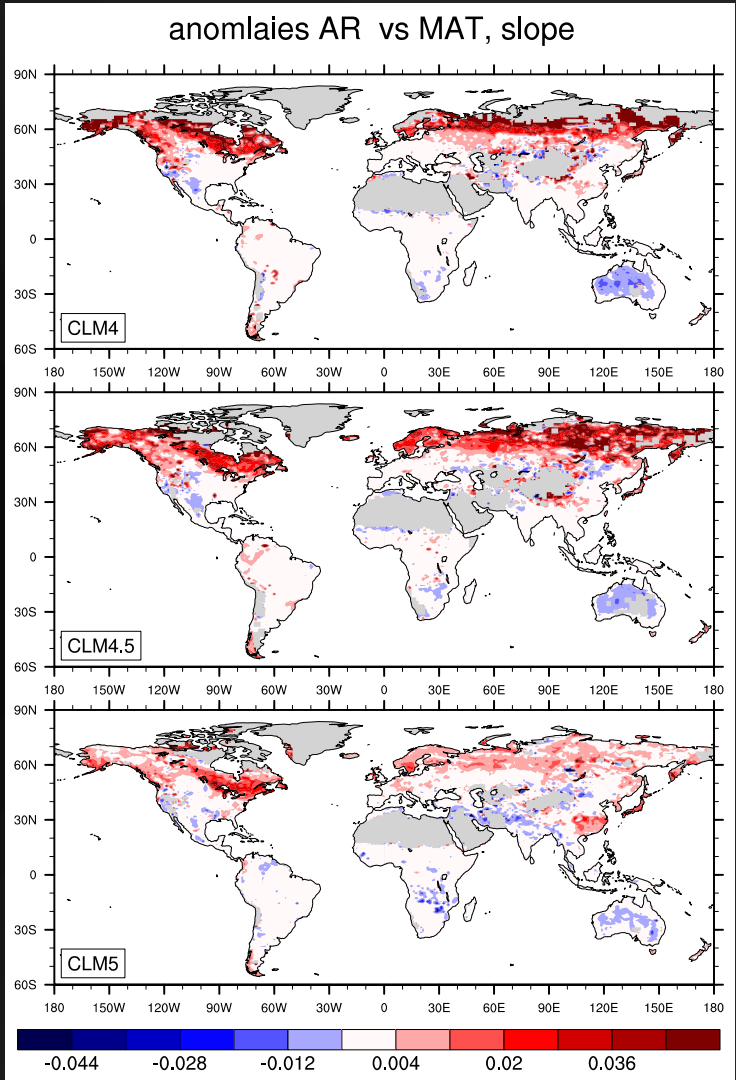
appropriate climate sensitivities?

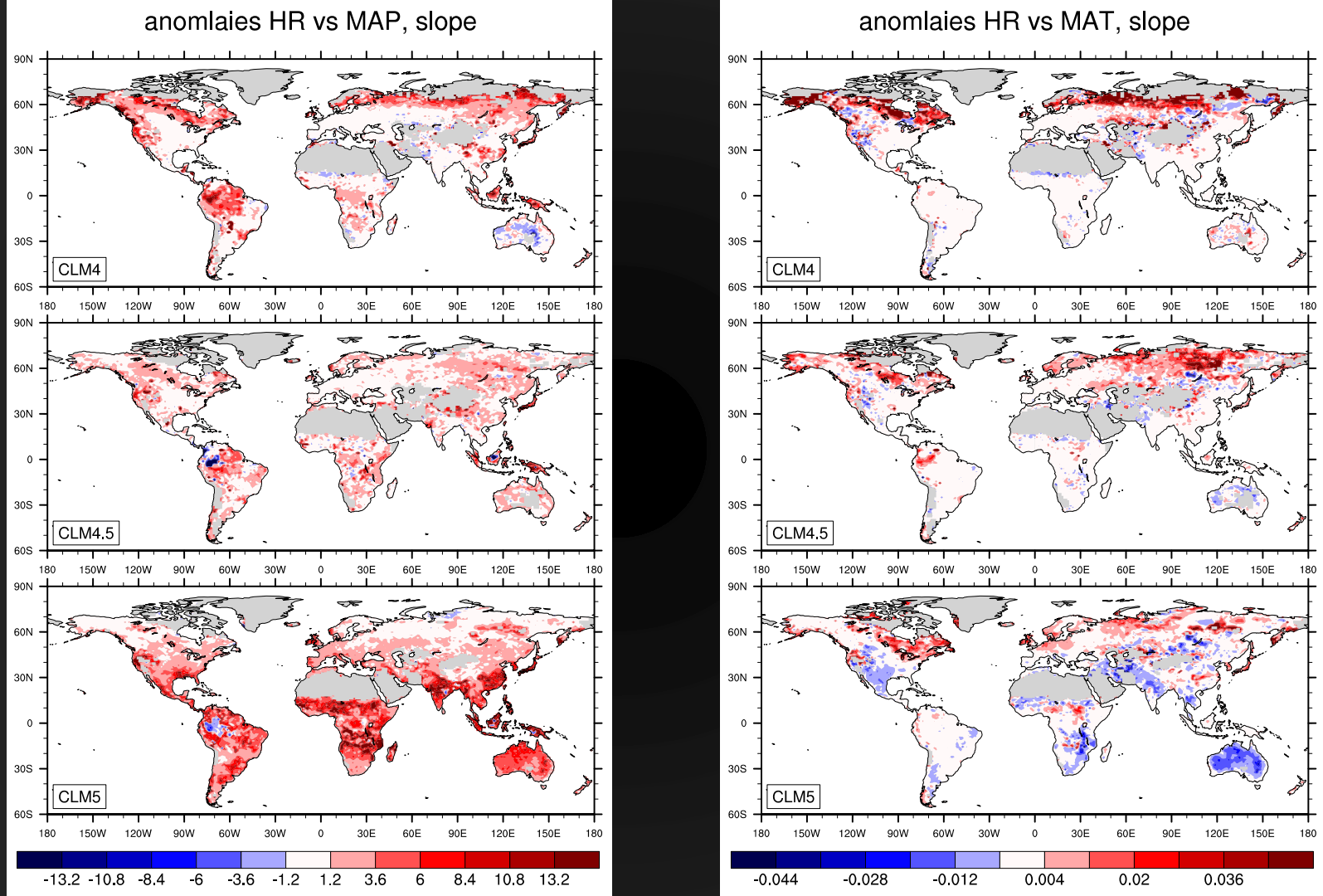



anomlaies GPP vs MAP, slope
CLM4
CLM4.5
CLM5
90N
60N
30N
0
30S
60S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
-5.5 -4.5 -3.5 -2.5 -1.5 -0.5 0.5 1.5 2.5 3.5 4.5 5.5


anomlaies GPP vs MAT, slope
CLM4
CLM4.5
CLM5
90N
60N
30N
0
30S
60S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
-0.044 -0.028 -0.012 0.004 0.02 0.036


anomlaies AR vs MAP, slope
90N
60N
30N
0
30S
60S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
CLM4
CLM4.5
CLM5
-5.5 -4.5 -3.5 -2.5 -1.5 -0.5 0.5 1.5 2.5 3.5 4.5 5.5


anomlaies AR vs MAT, slope
90N
60N
30N
0
30S
60S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
CLM4
CLM4.5
CLM5
-0.044 -0.028 -0.012 0.004 0.02 0.036


anomlaies HR vs MAP, slope
anomlaies HR vs MAT, slope
CLM4
CLM4.5
CLM5
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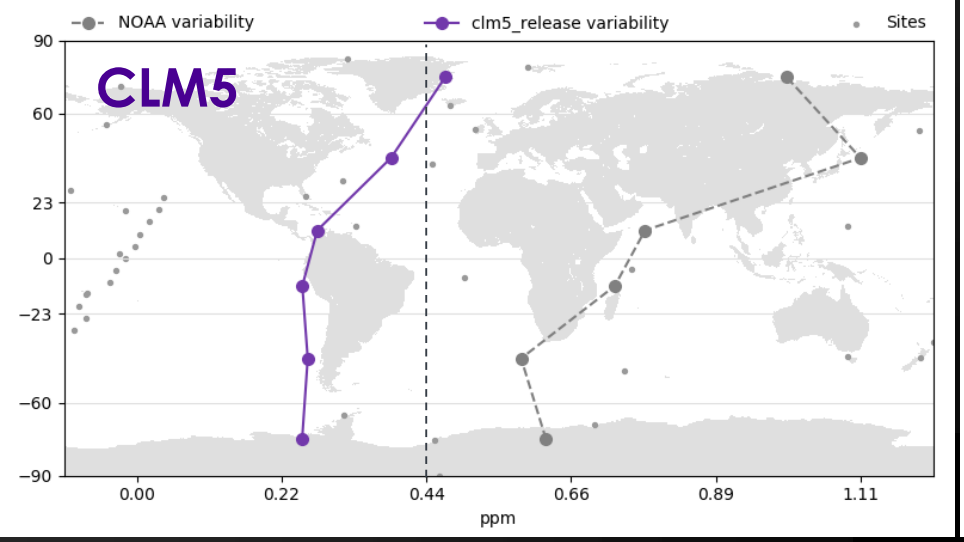
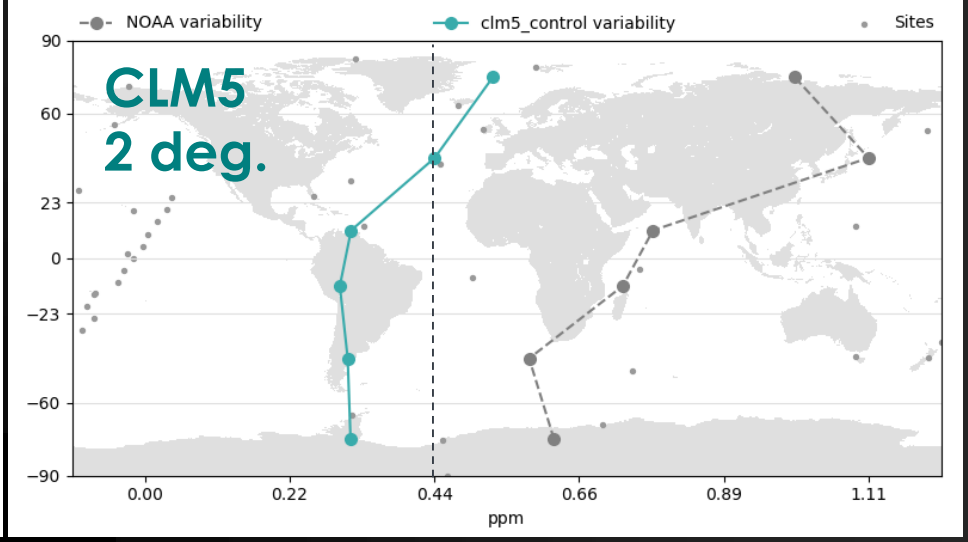
60N
30N
0
30S
60S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
-13.2 -10.8 -8.4 -6 -3.6 -1.2 1.2 3.6 6 8.4 10.8 13.2
-0.044 -0.028 -0.012 0.004 0.02 0.036


NOAA variability
clm5_release variability
Sites
CLM5
90
60
23
0
−23
−60
−90
0.00
0.22
0.44
0.66
0.89
1.11
ppm


NOAA variability
clm5_control variability
Sites
CLM5
2 deg.
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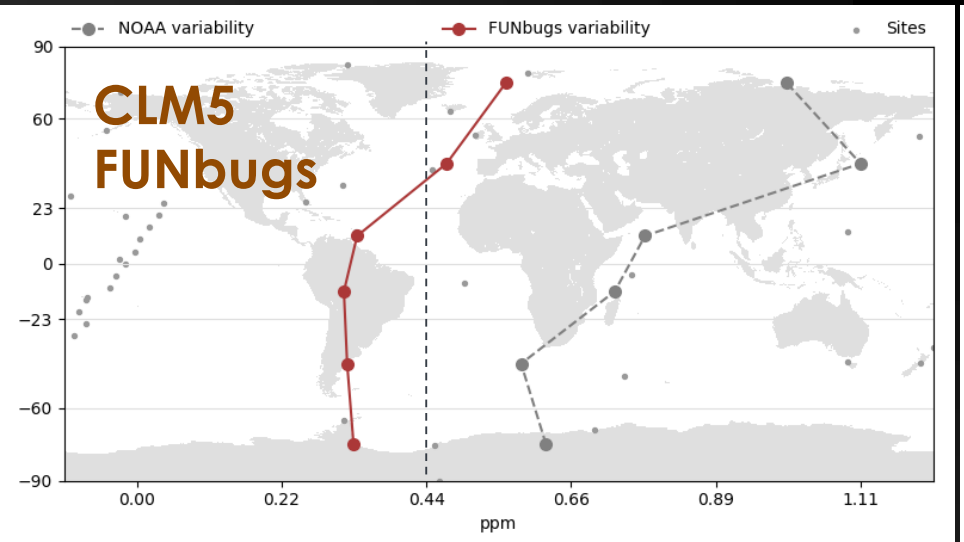
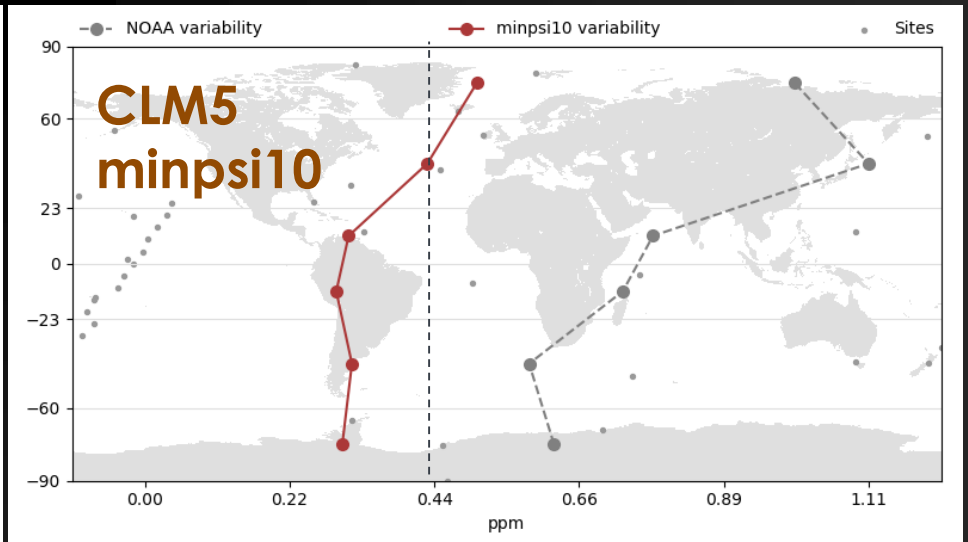
23
0
−23
−60
−90
0.00
0.22
0.44
0.66
0.89
1.11
ppm


NOAA variability
FUNbugs variability
Sites
CLM5
FUNbugs
90
60
23
0
−23
−60
−90
0.00
0.22
0.44
0.66
0.89
1.11
ppm


NOAA variability
minpsi10 variability
Sites
CLM5
minpsi10
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23
0
−23
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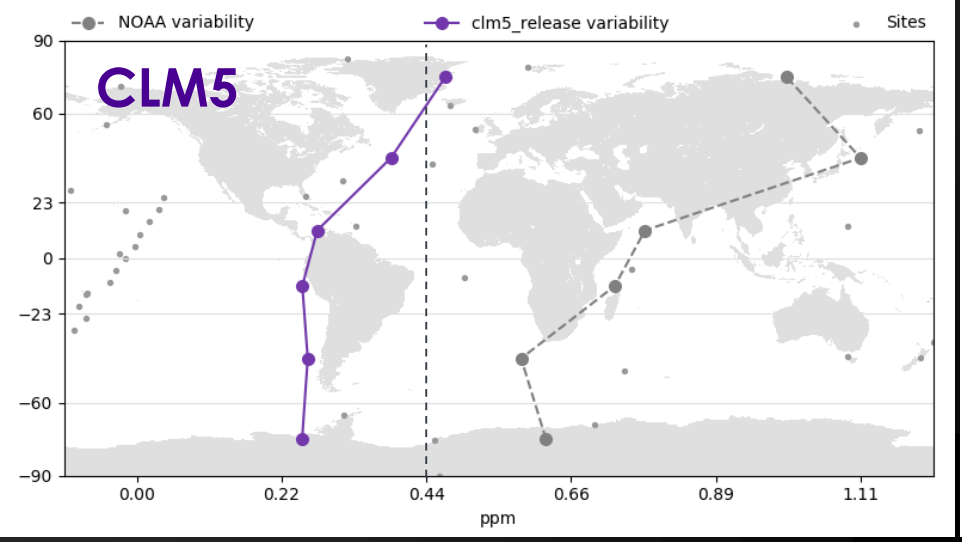
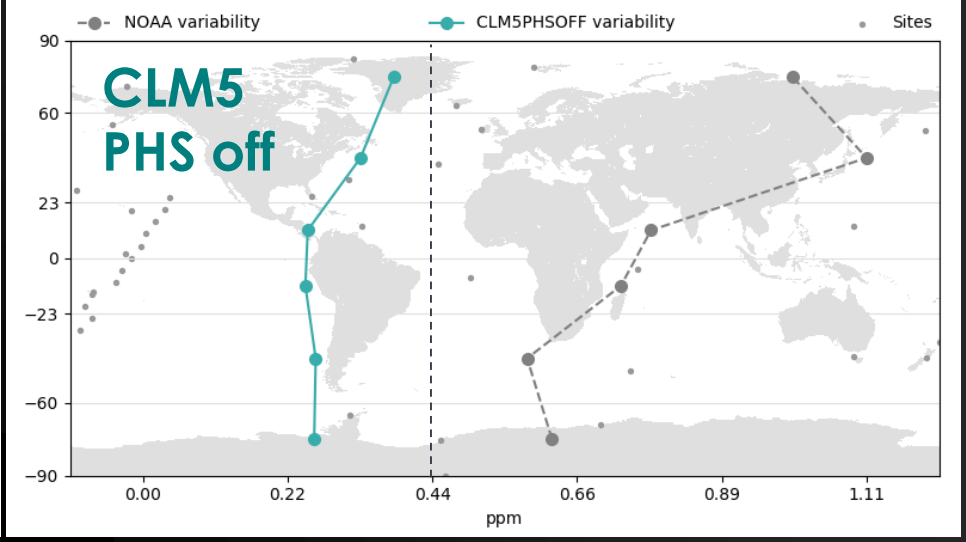
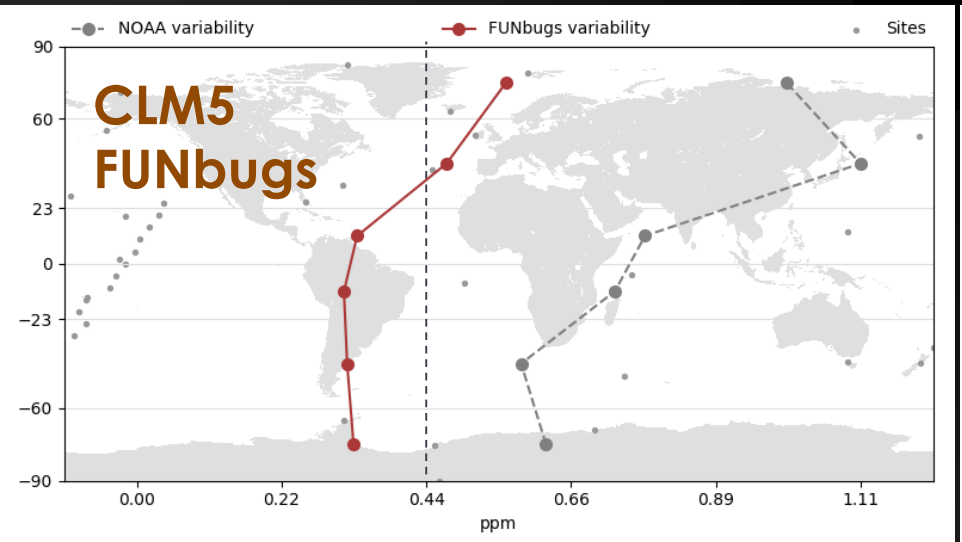
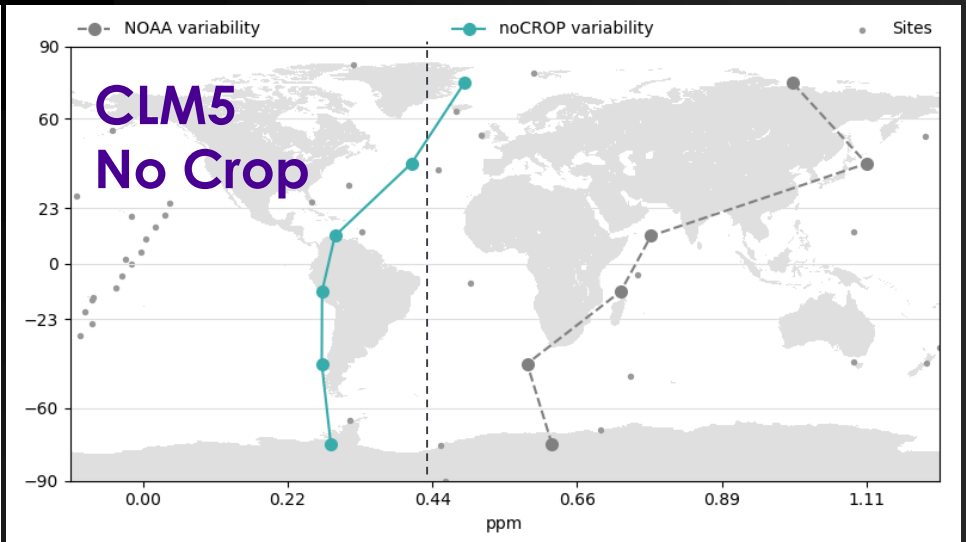
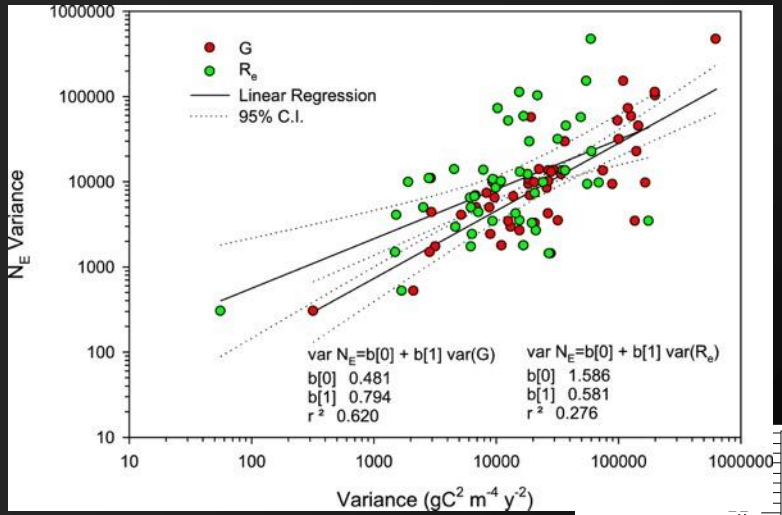
−90
0.00
0.22
0.44
0.66
0.89
1.11
ppm


NOAA variability
clm5_release variability
Sites
CLM5
90
60
23
0
−23
−60
−90
0.00
0.22
0.44
0.66
0.89
1.11
ppm

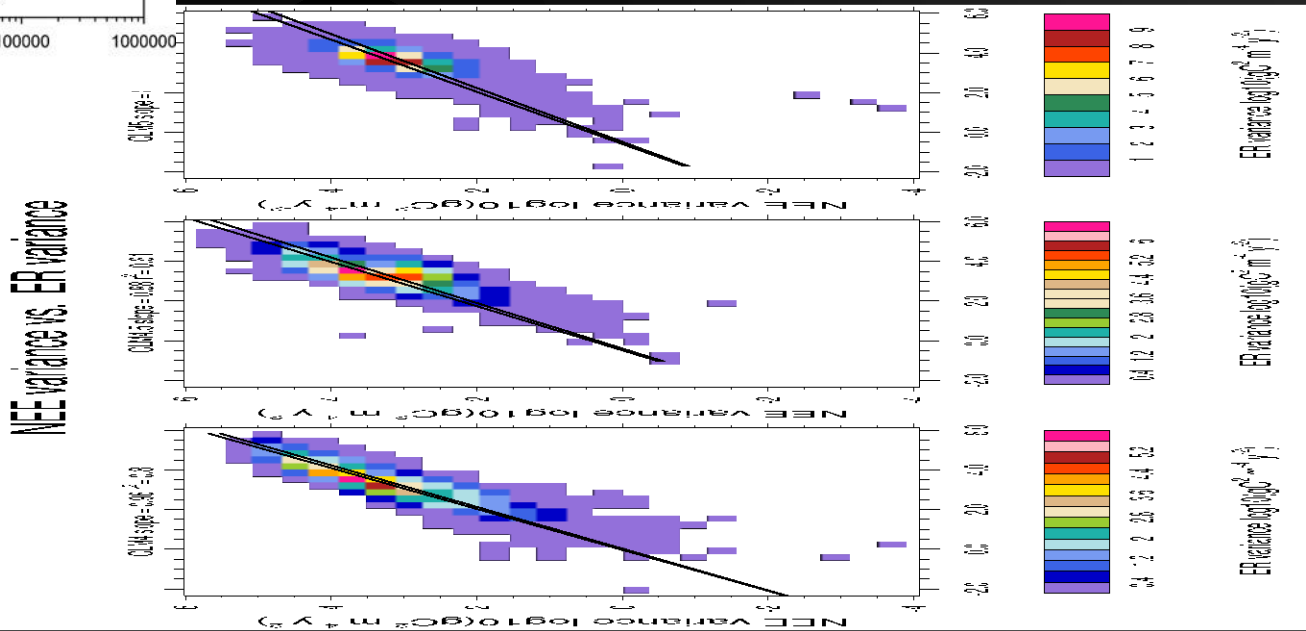

NOAA variability
CLM5PHSOFF variability
Sites
CLM5
PHS off
90
60
23
0
−23
−60
−90
0.00
0.22
0.44
0.66
0.89
1.11
ppm


NOAA variability
FUNbugs variability
Sites
CLM5
FUNbugs
90
60
23
0
−23
−60
−90
0.00
0.22
0.44
0.66
0.89
1.11
ppm

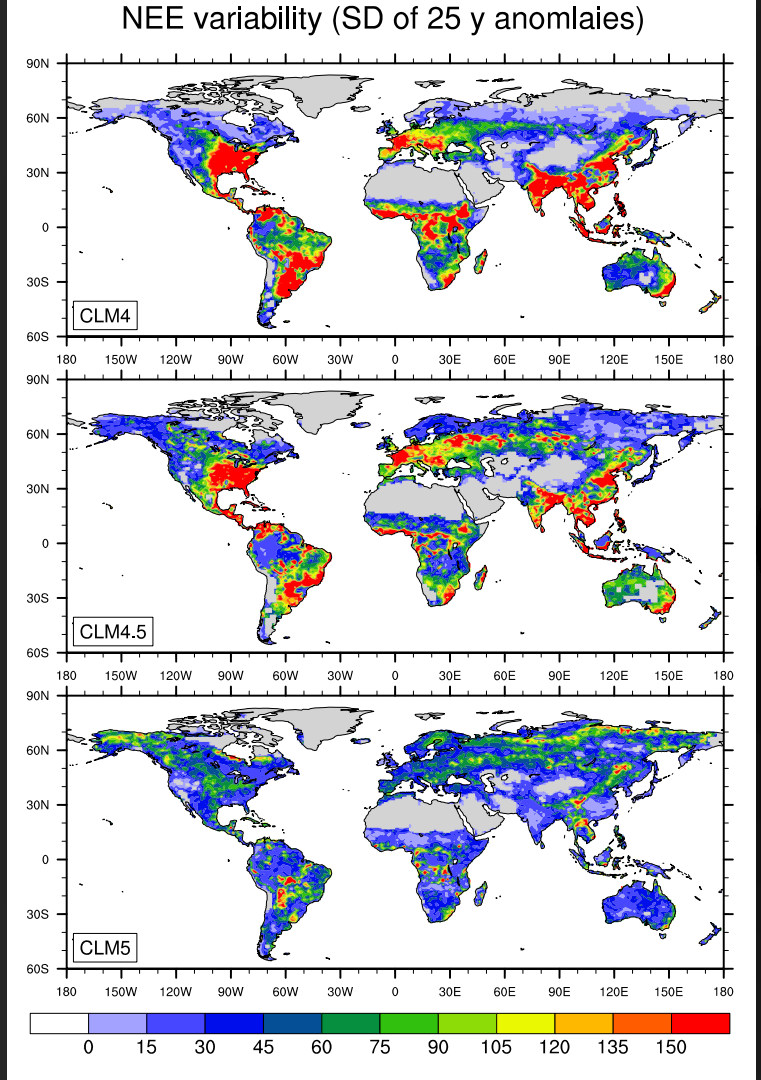

NOAA variability
noCROP variability
Sites
CLM5
No Crop
90
60
23
0
−23
−60
−90
0.00
0.22
0.44
0.66
0.89
1.11
ppm




| | Obs. | CLM4 | CLM4.5 | CLM5 |
|---|---|---|---|---|
| Slope | **0.58** | 0.96 | 0.88 | **0.75** |
| R2 | **0.28** | 0.8 | 0.61 | **0.53** |




Baldocchi et al. 2018




**Correcting biases**

- GPP

**Improving assumptions**

- Temp. – AR function
- Moisture – HR corrections
- FUN

**Unintended consequences…?**

## Correcting biases

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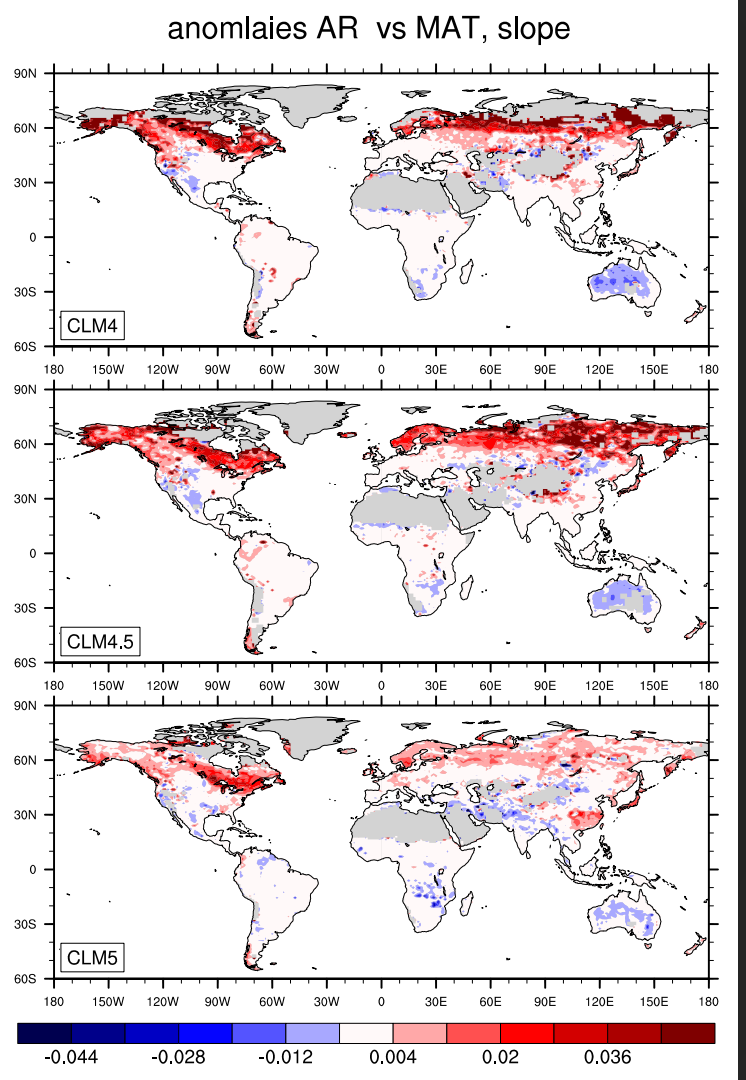

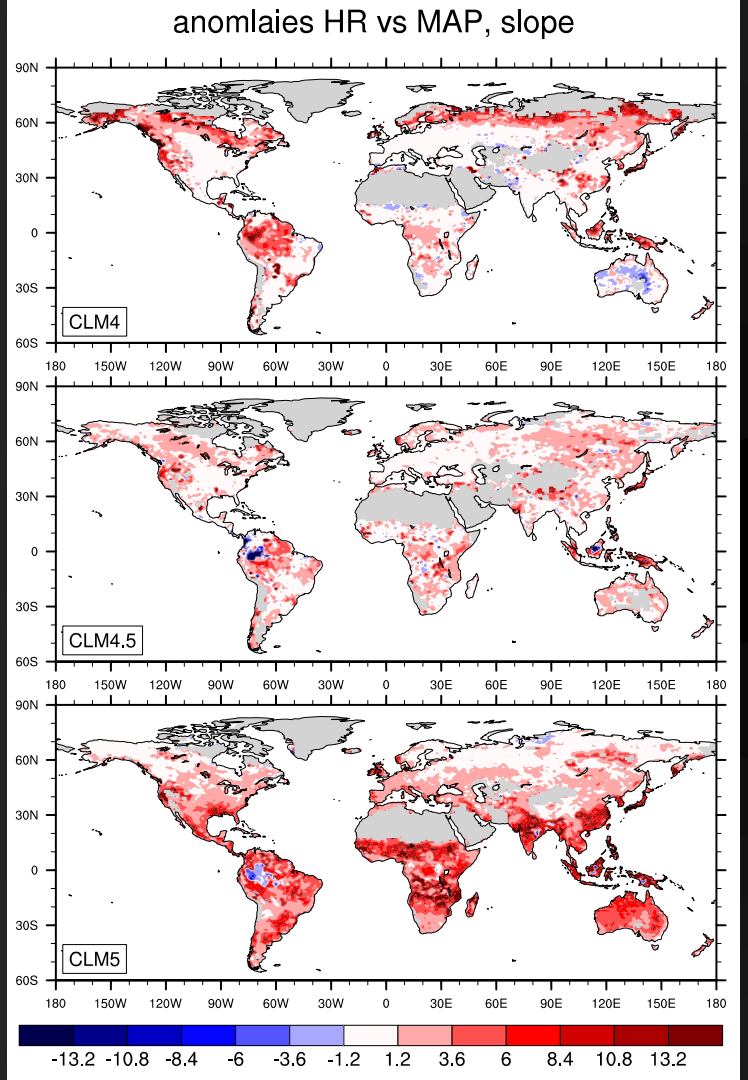


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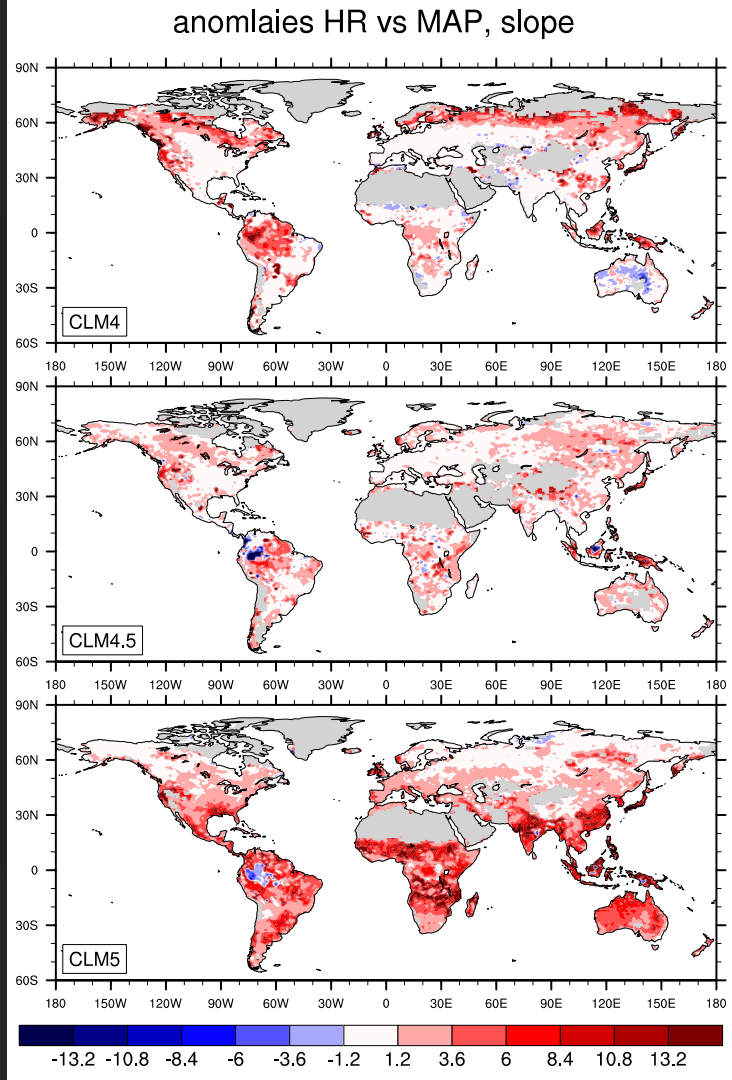
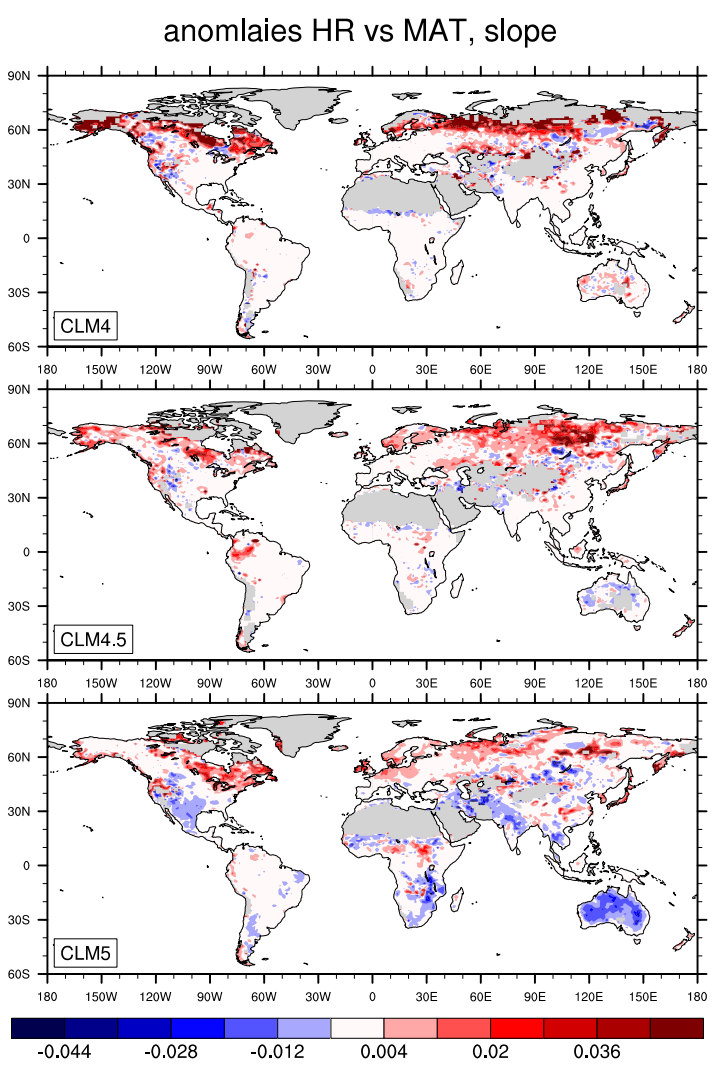
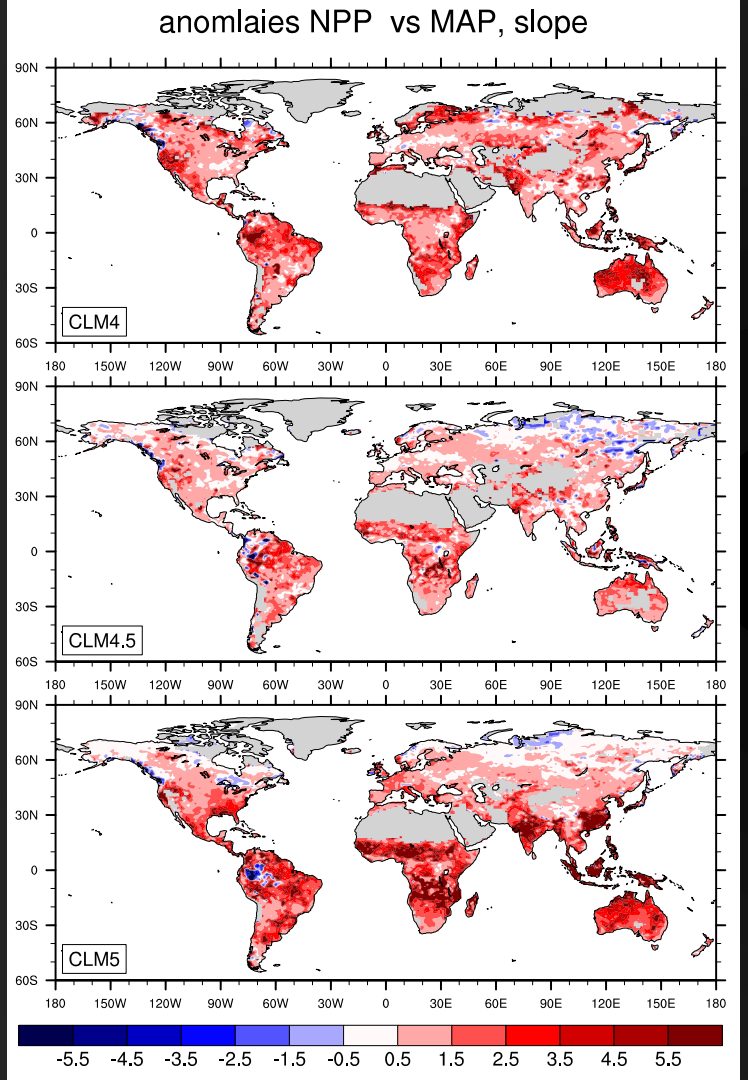

anomlaies HR vs MAP, slope
CLM4
CLM4.5
CLM5
90N
60N
30N
0
30S
60S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
-13.2 -10.8 -8.4 -6 -3.6 -1.2 1.2 3.6 6 8.4 10.8 13.2


anomlaies HR vs MAT, slope
CLM4
CLM4.5
CLM5
90N
60N
30N
0
30S
60S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
-0.044 -0.028 -0.012 0.004 0.02 0.036




**Correcting biases**

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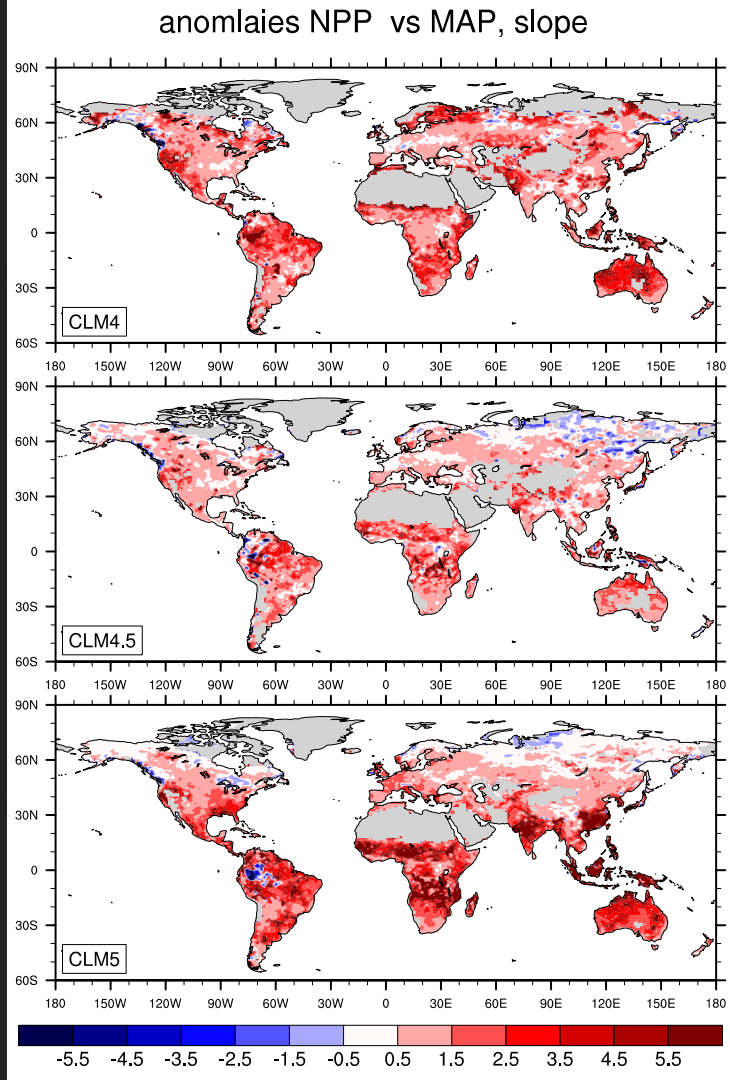
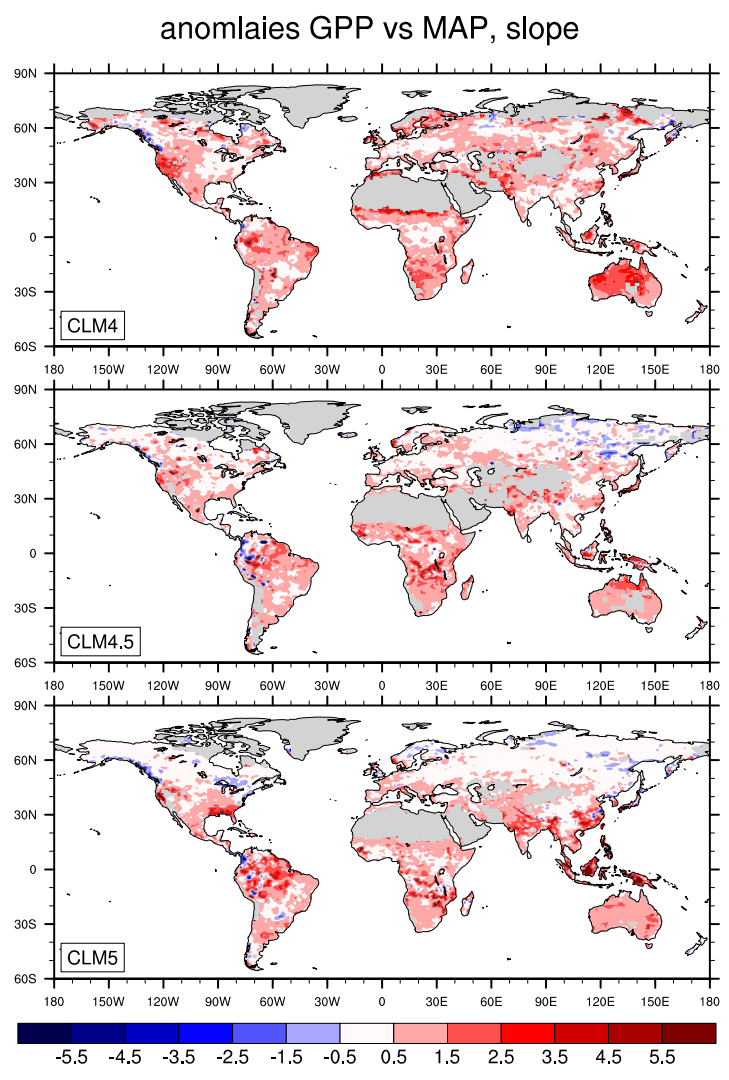
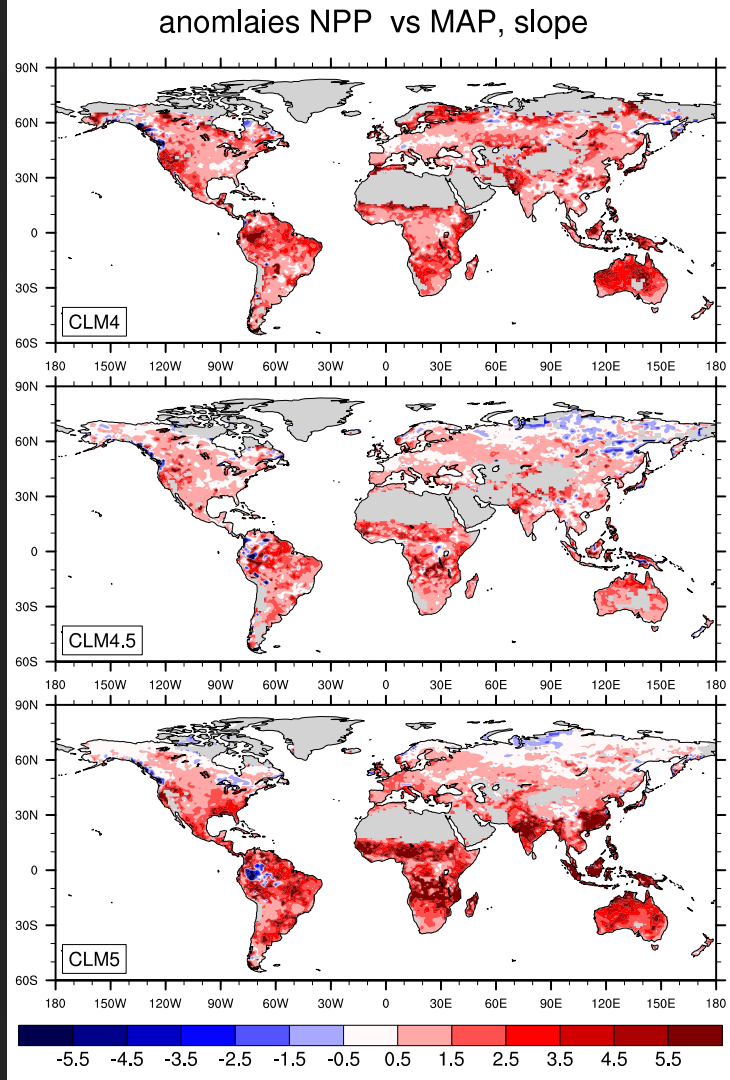
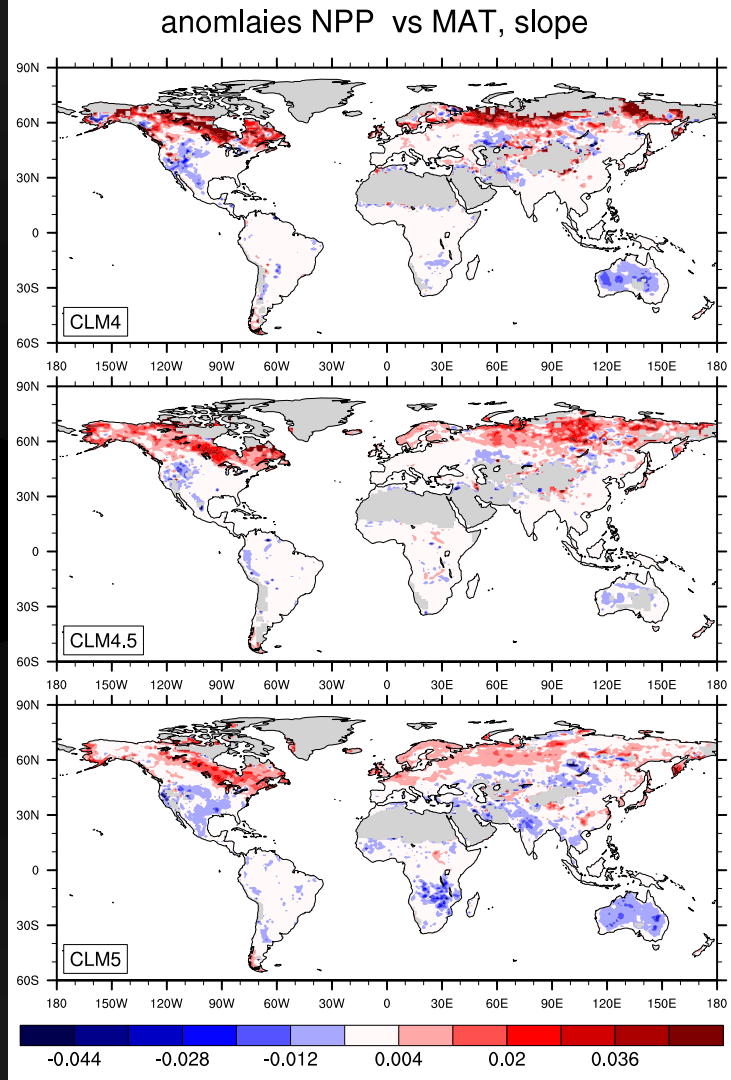
- FUN?

**Unintended consequences…?**


anomlaies NPP vs MAP, slope
90N
60N
30N
0
30S
60S
CLM4
CLM4.5
CLM5
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
-5.5 -4.5 -3.5 -2.5 -1.5 -0.5 0.5 1.5 2.5 3.5 4.5 5.5


anomlaies GPP vs MAP, slope
90N
60N
30N
0
30S
60S
CLM4
CLM4.5
CLM5
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
-5.5 -4.5 -3.5 -2.5 -1.5 -0.5 0.5 1.5 2.5 3.5 4.5 5.5


anomlaies NPP vs MAP, slope
90N
60N
30N
0
30S
60S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
CLM4
CLM4.5
CLM5
-5.5 -4.5 -3.5 -2.5 -1.5 -0.5 0.5 1.5 2.5 3.5 4.5 5.5


anomlaies NPP vs MAT, slope
90N
60N
30N
0
30S
60S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
CLM4
CLM4.5
CLM5
-0.044 -0.028 -0.012 0.004 0.02 0.036

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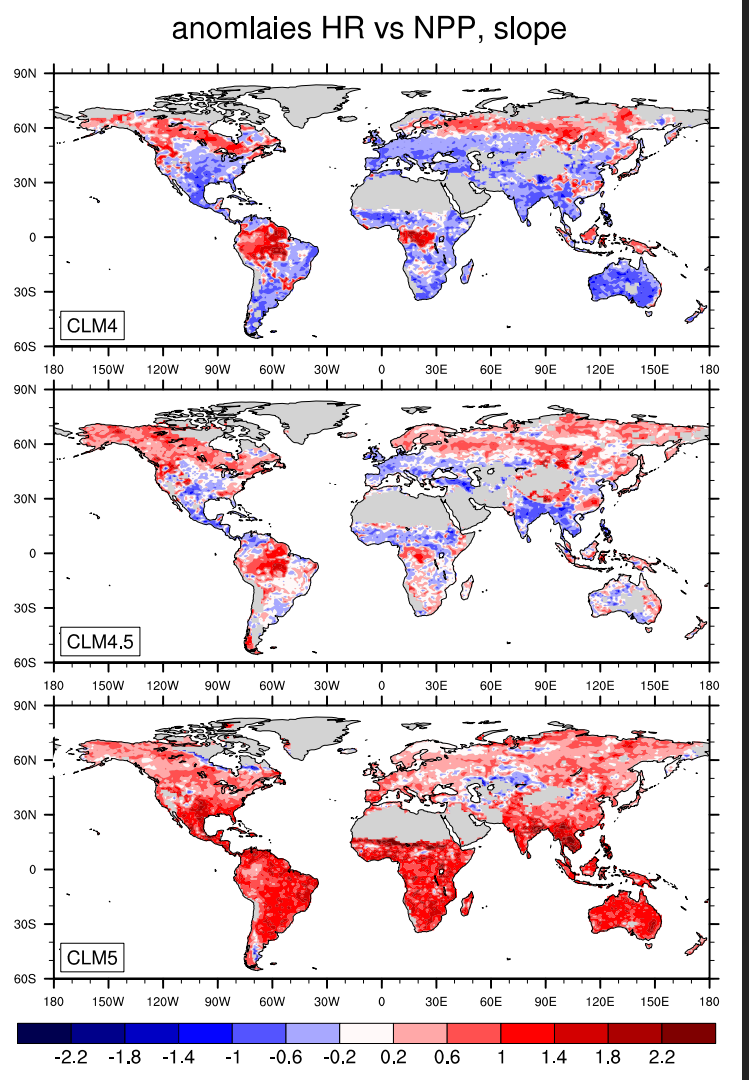
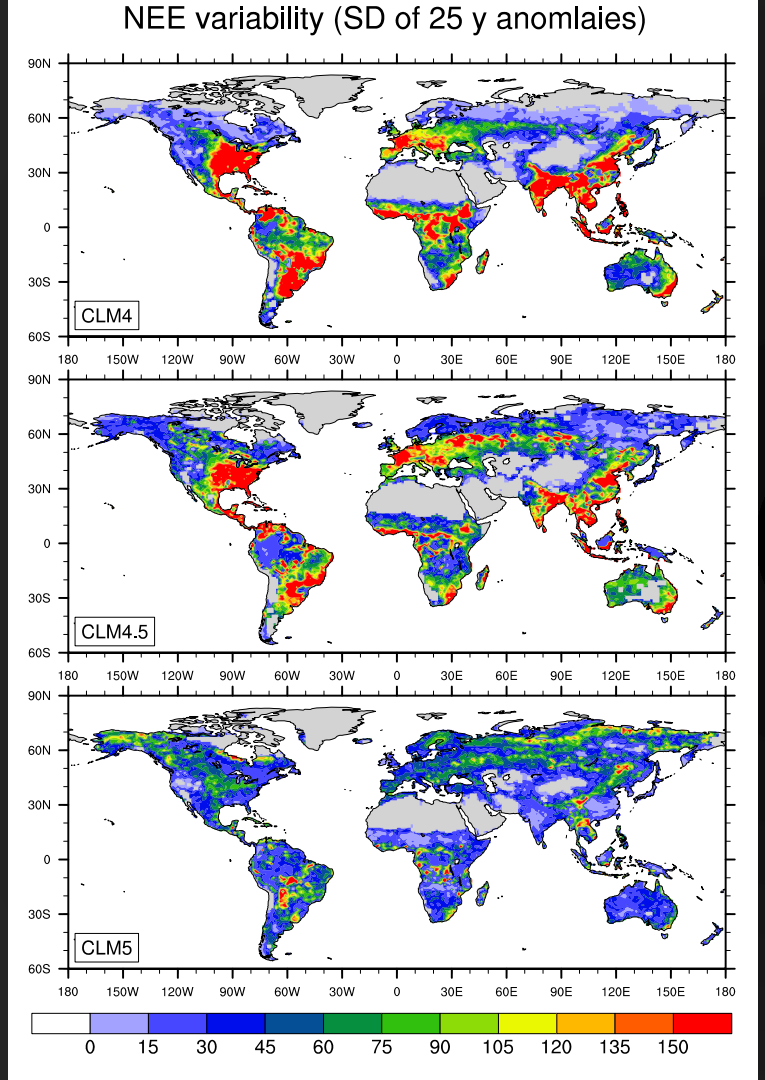
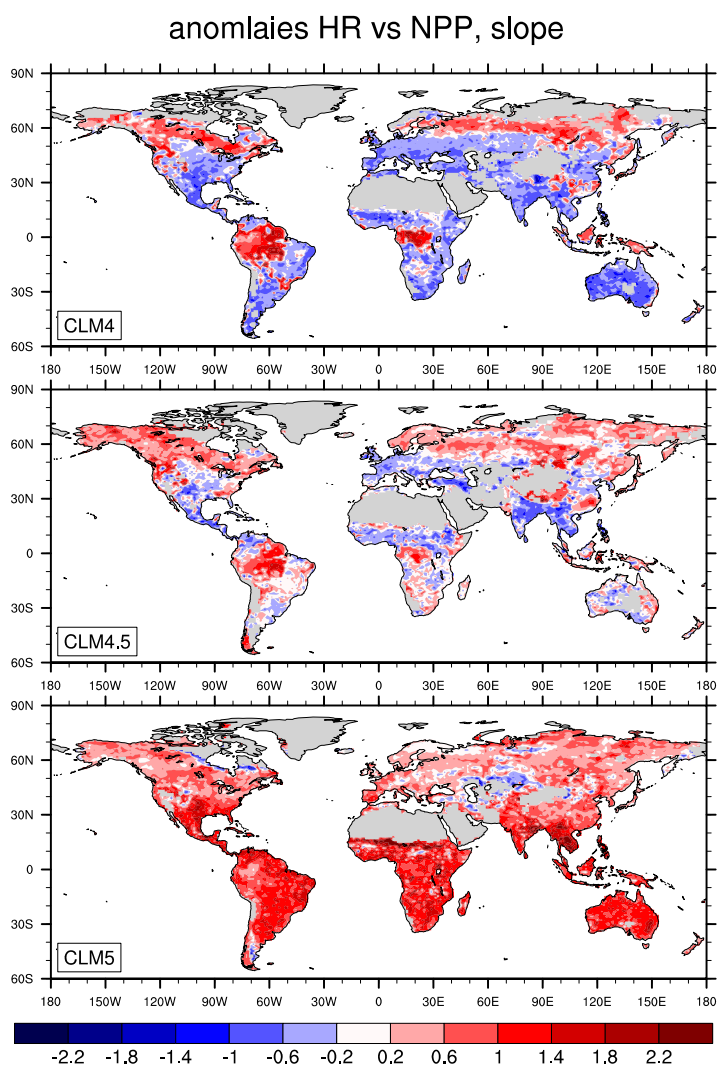
- FUN?

**Unintended consequences.**



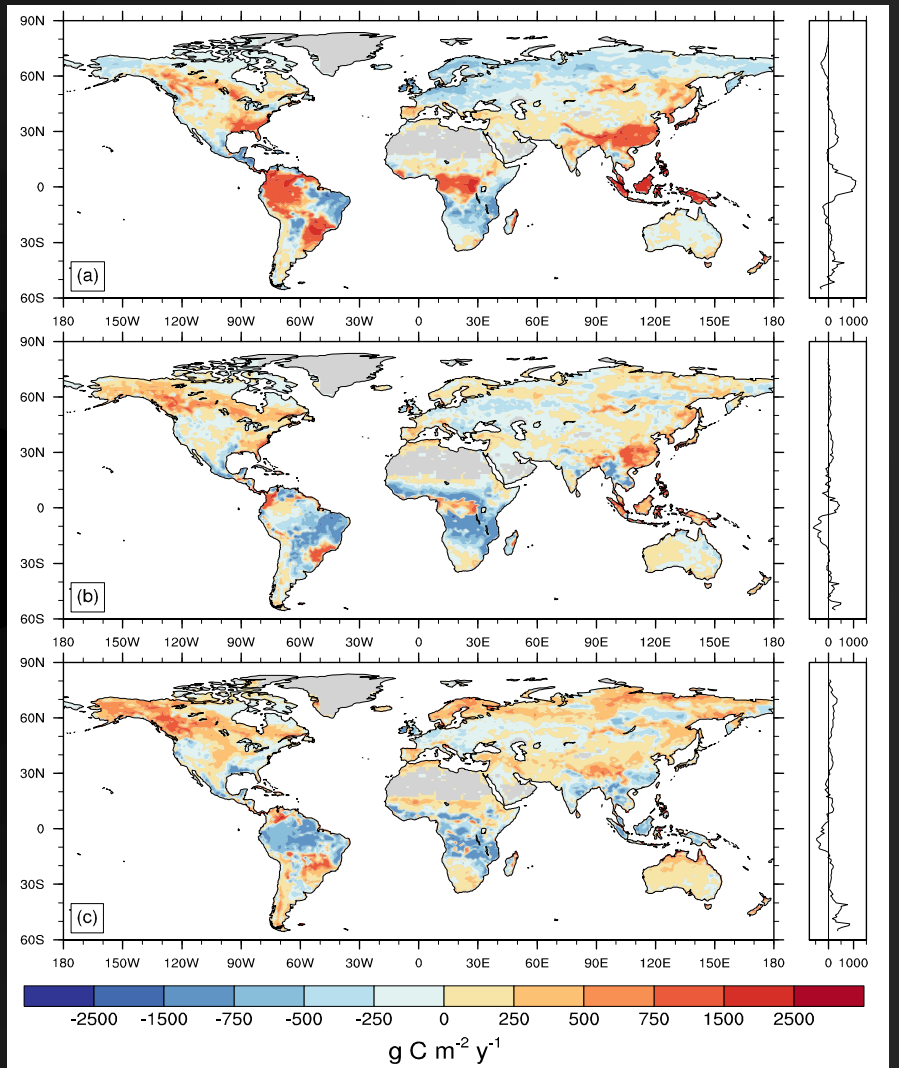

NEE variability (SD of 25 y anomlaies)
CLM4
CLM4.5
CLM5
90N
60N
30N
0
30S
60S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
0 15 30 45 60 75 90 105 120 135 150

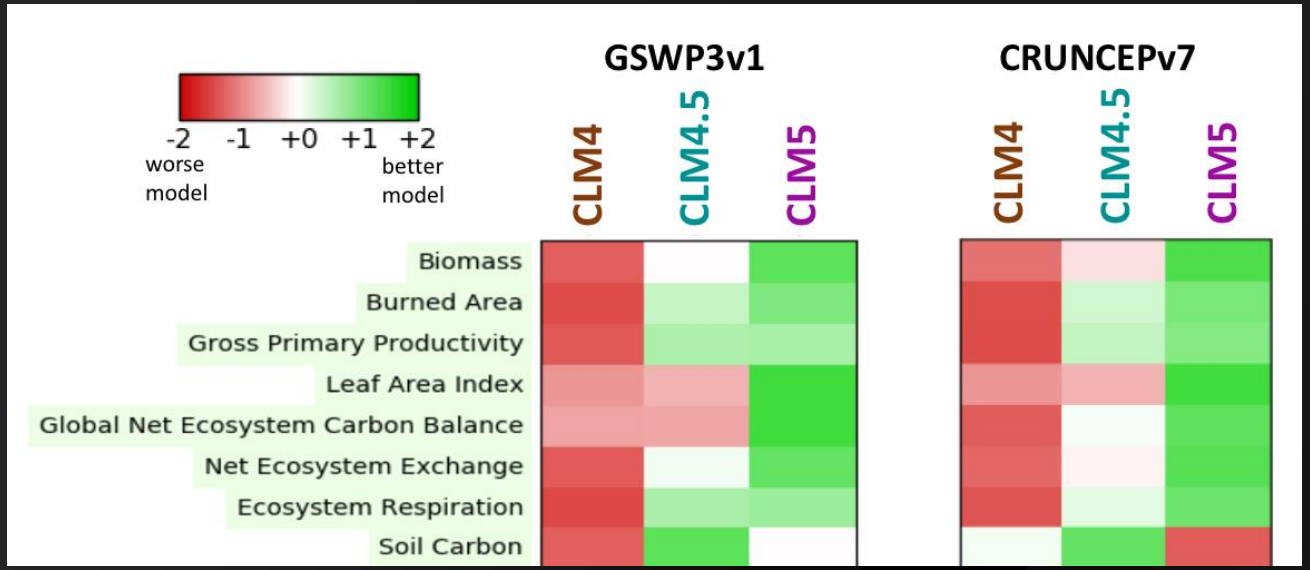

anomlaies HR vs NPP, slope
CLM4
CLM4.5
CLM5
90N
60N
30N
0
30S
60S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
-2.2 -1.8 -1.4 -1 -0.6 -0.2 0.2 0.6 1 1.4 1.8 2.2

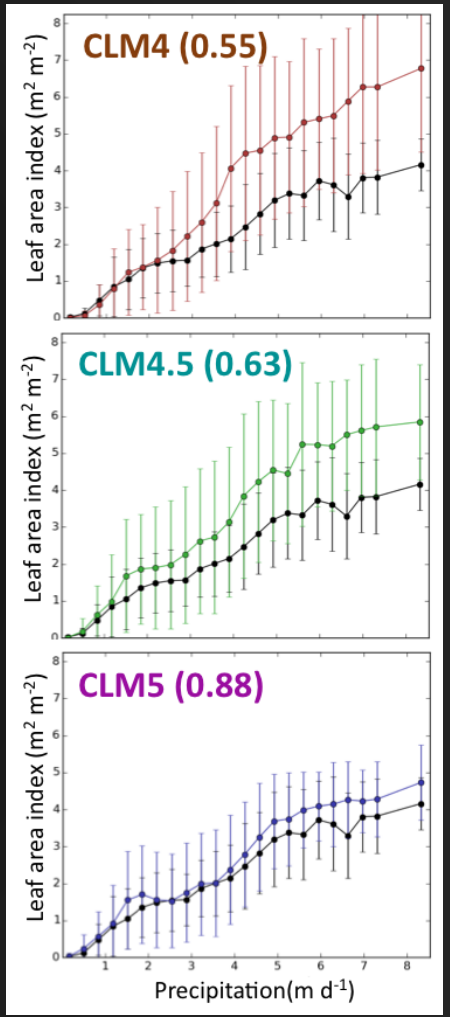
# GLOBAL BIASES - GPP
[ILAMB, FLUXNET]

GPP Biases
[relative to FLUXNET MTE]

Overall reduction in bias
Poleward shift in C cycle





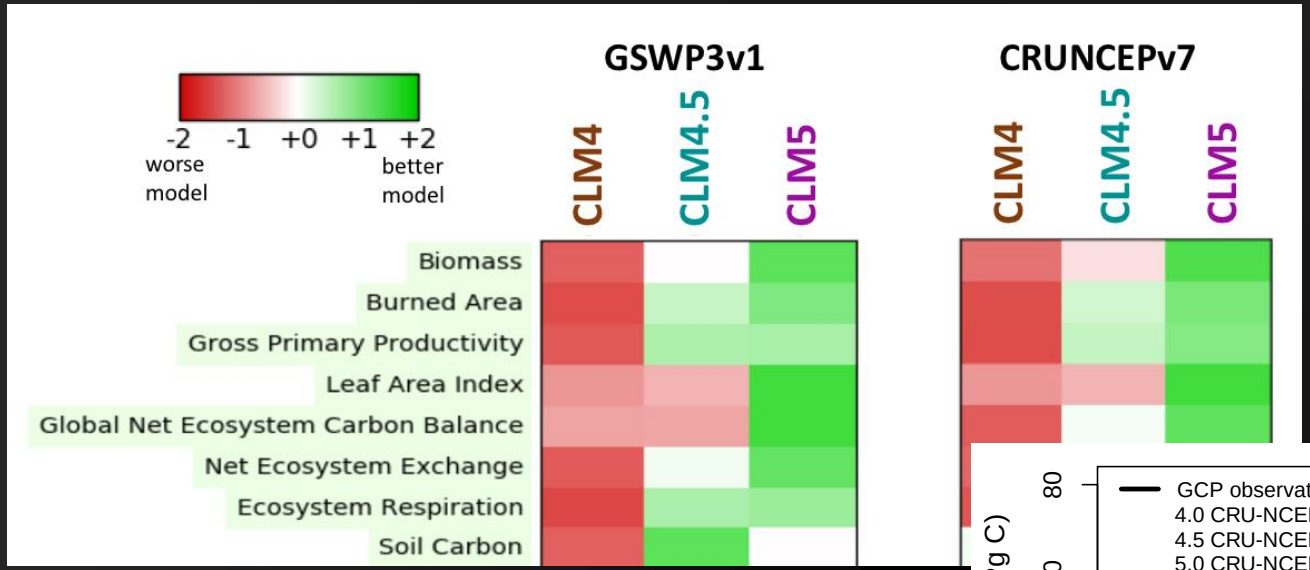



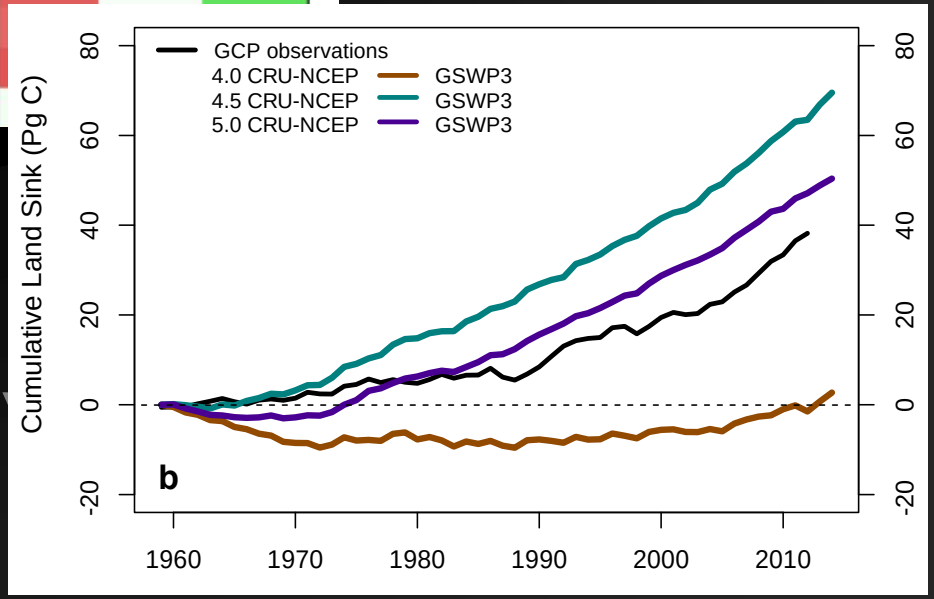

# Reduced biases

## Historical trends

## Amplification of annual cycle

Lawrence et al. in review



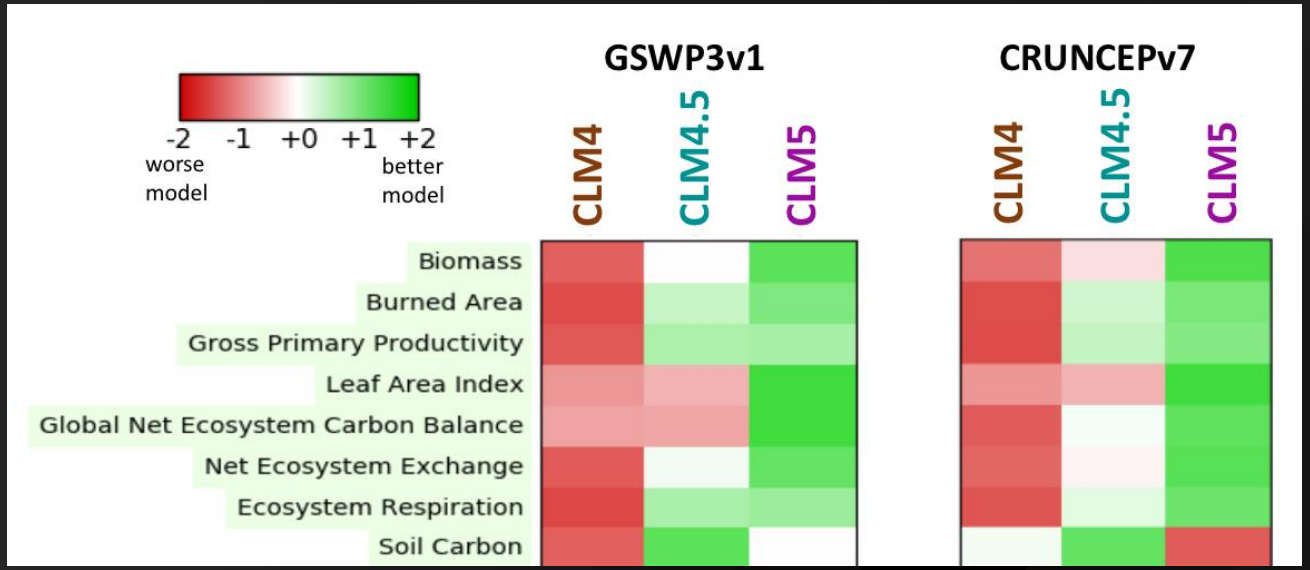



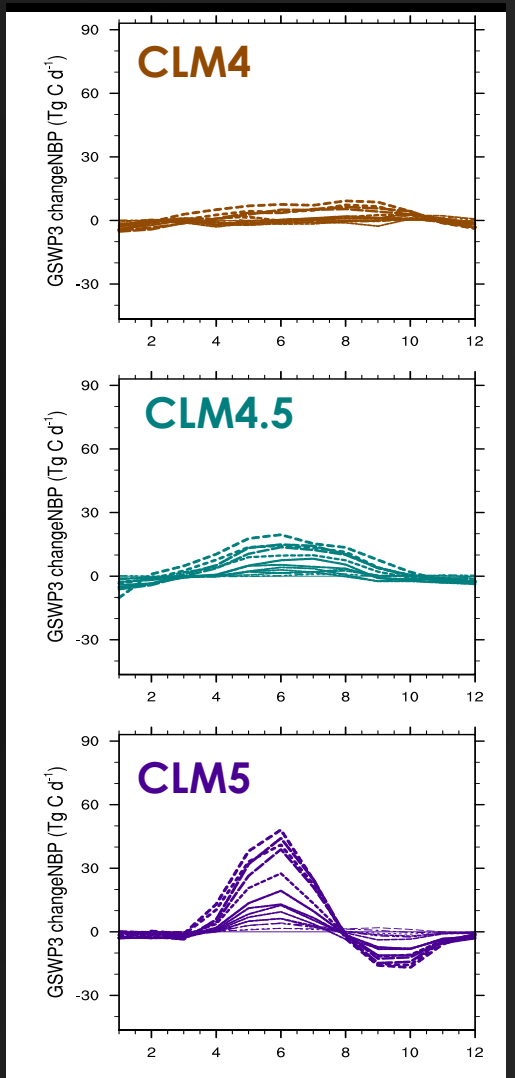

Reduced biases

Historical trends

Amplification of annual cy

Lawrence et al. in review
Bonan et al. in review




Reduced biases

Historical trends

Amplification of annual cycle

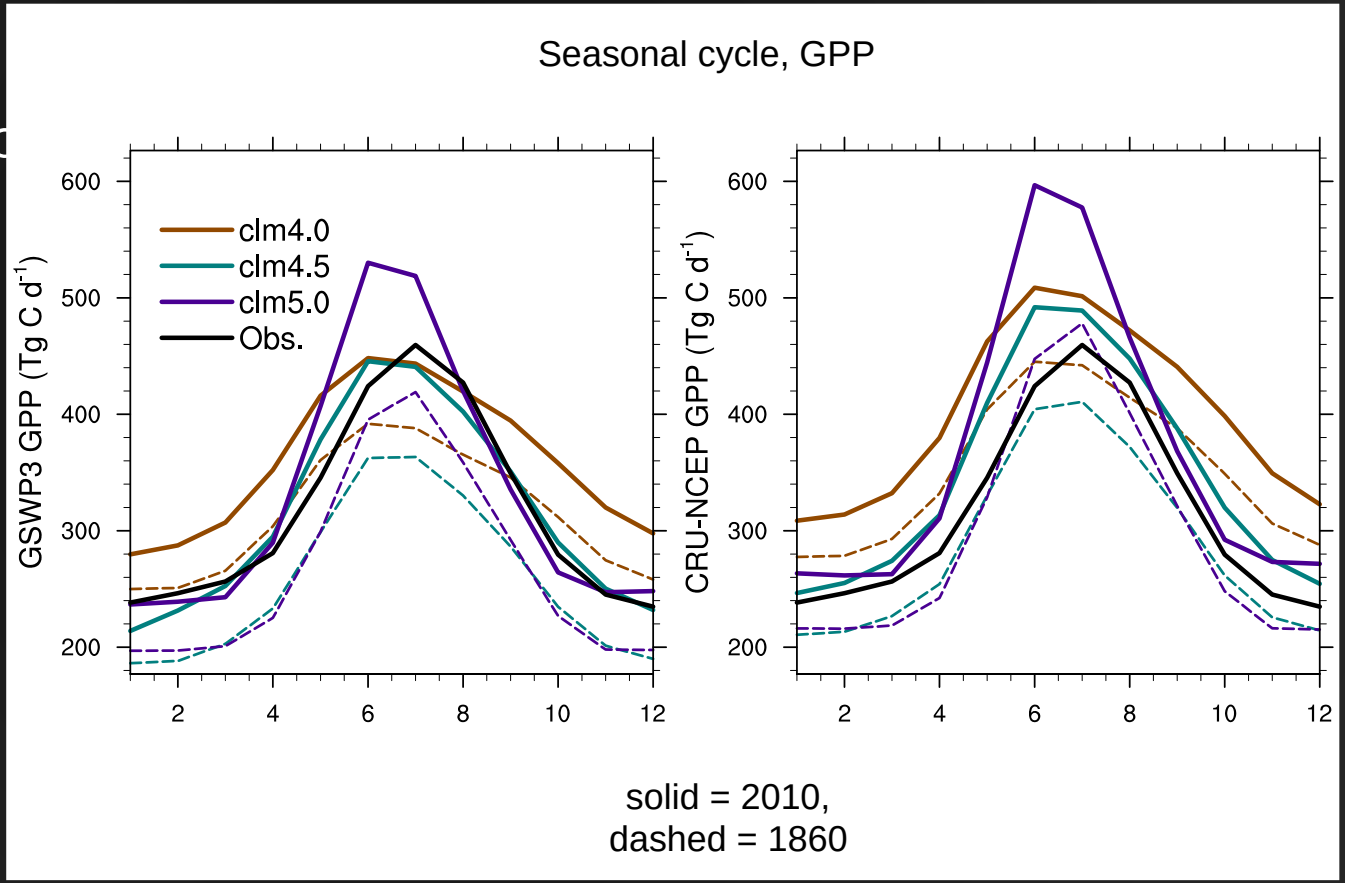
Lawrence et al. in review

Lombardozzi et al. in review & in prep.

# ANNUAL CYCLE
## [FLUXNET]

- Higher amplitud
- Crops!
- [Boreal GPP…]

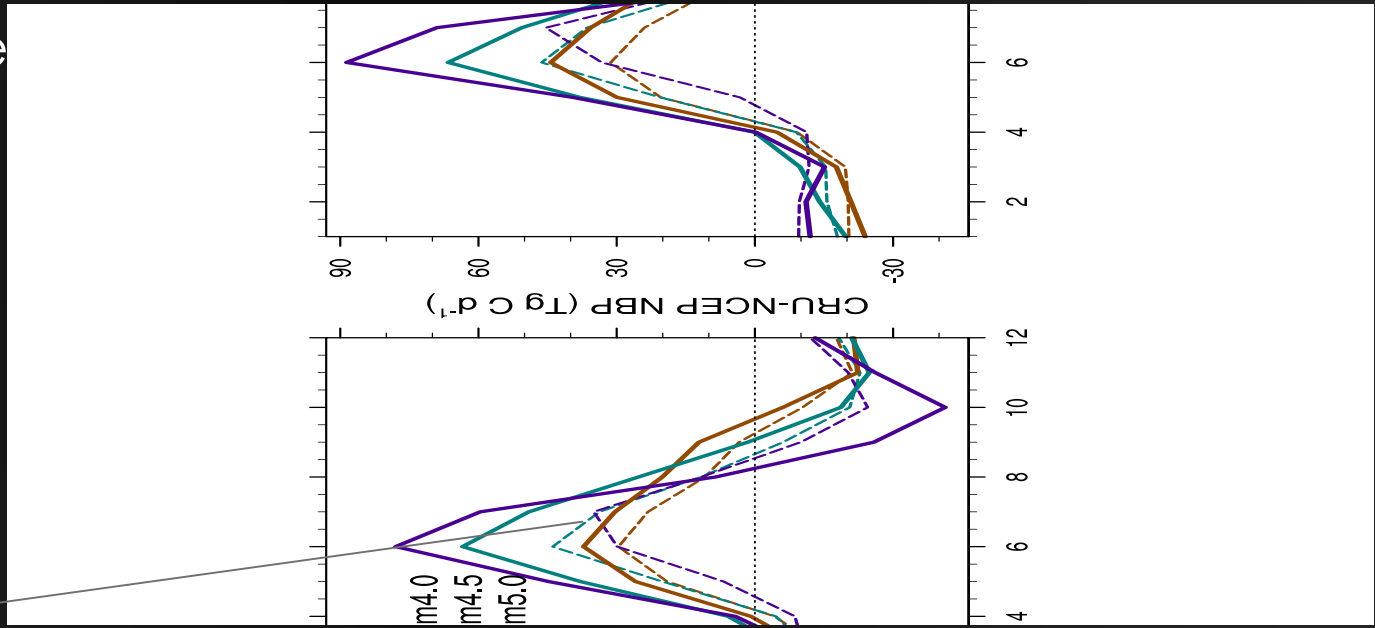
- Early Bias



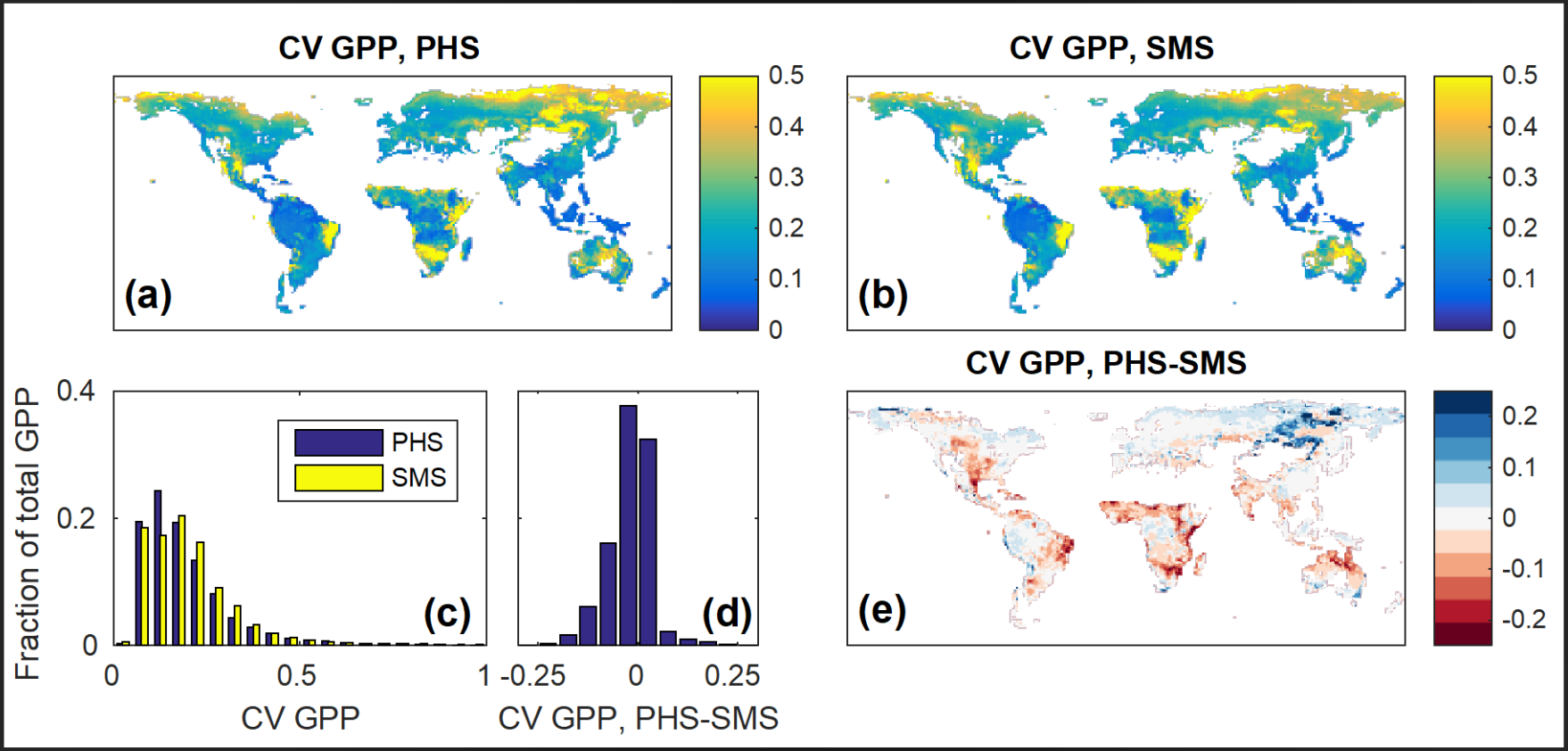
# ANNUAL CYCLE

Higher amplitude
Crops!
[Boreal GPP…]

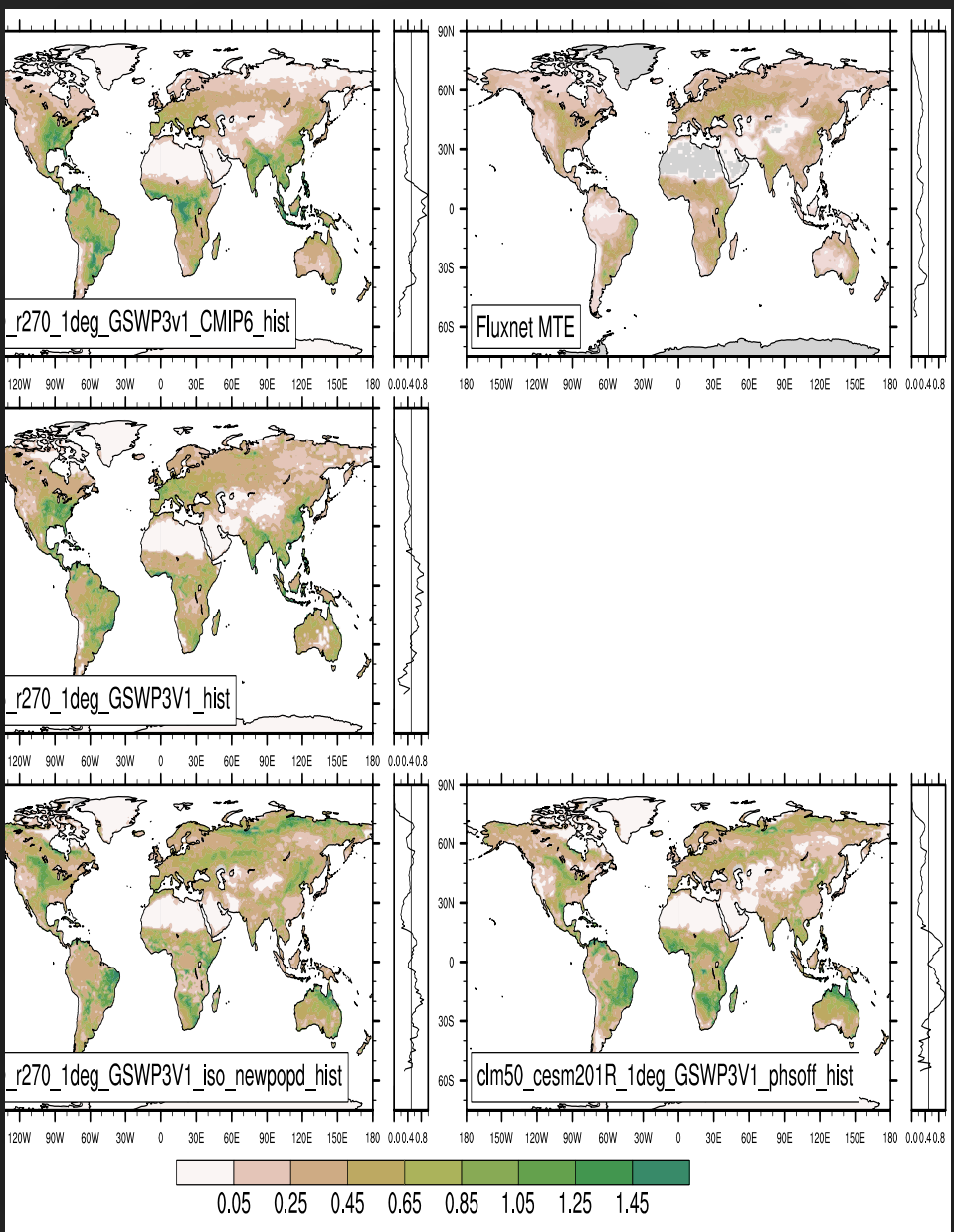
Seasonality?

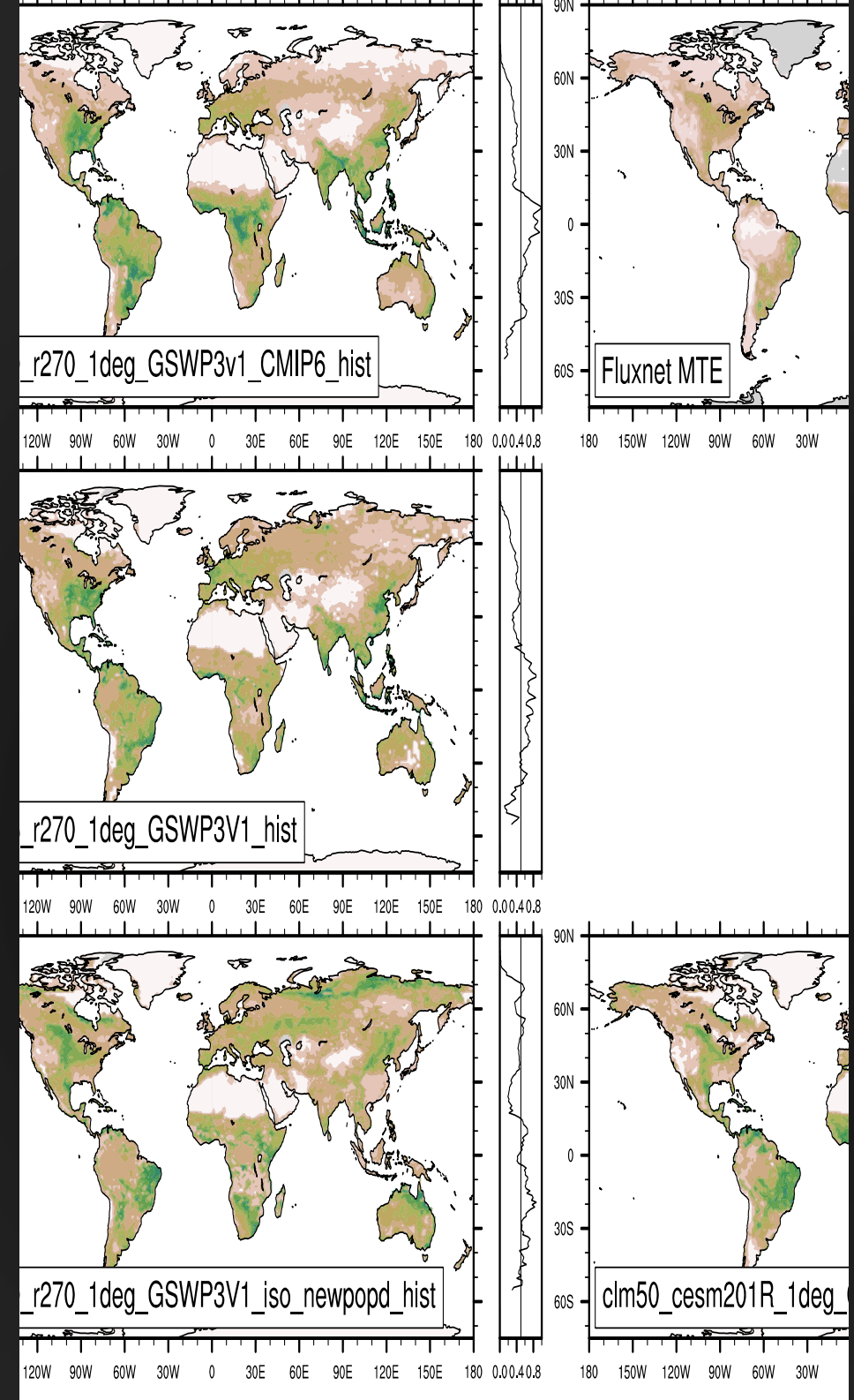


# INTERANNUAL VARIABILITY – REDUCED WITH PHS?

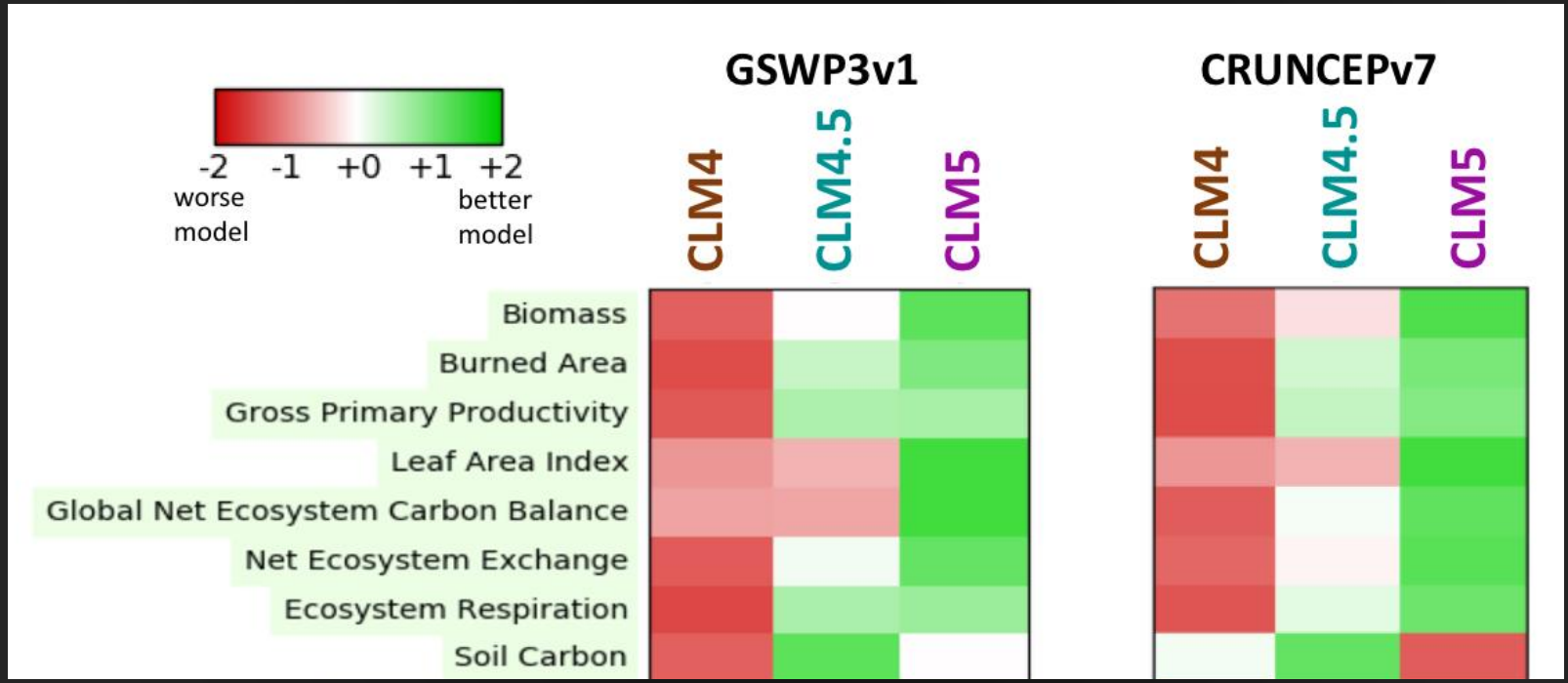



Kennedy & others


_r270_1deg_GSWP3v1_CMIP6_hist
Fluxnet MTE
_r270_1deg_GSWP3V1_hist
_r270_1deg_GSWP3V1_iso_newpopd_hist
clm50_cesm201R_1deg_GSWP3V1_phsoff_hist
90N
60N
30N
0
30S
60S
120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
0.0 0.4 0.8
0.05 0.25 0.45 0.65 0.85 1.05 1.25 1.45

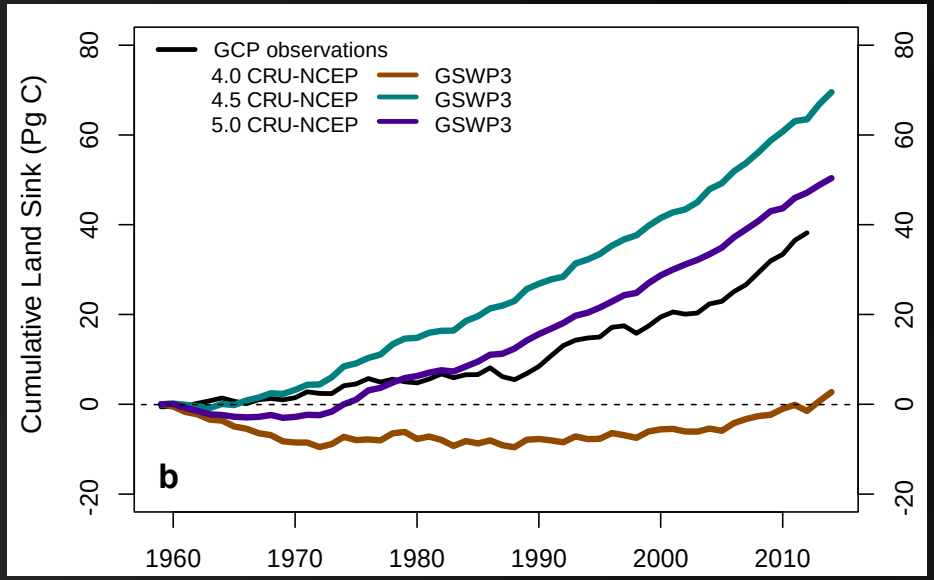

_r270_1deg_GSWP3v1_CMIP6_hist
Fluxnet MTE
_r270_1deg_GSWP3V1_hist
_r270_1deg_GSWP3V1_iso_newpopd_hist
clm50_cesm201R_1deg_
90N
60N
30N
0
30S
60S
120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
180 150W 120W 90W 60W 30W
0.0 0.4 0.8
0.05 0.25 0.45 0.65 0.85 1.05 1.25 1.45

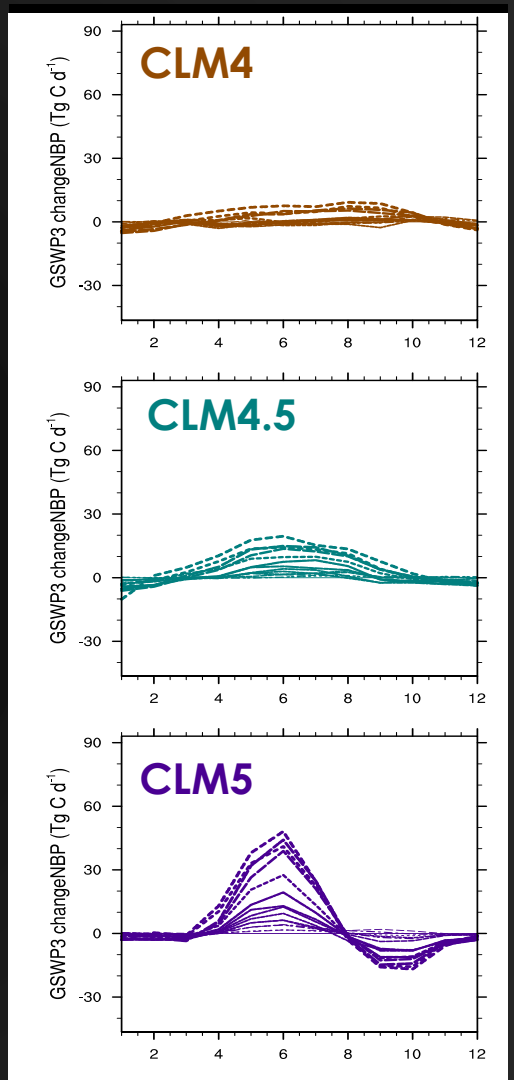
# CLM5 = BEST C cycle!




Lawrence et al. in review

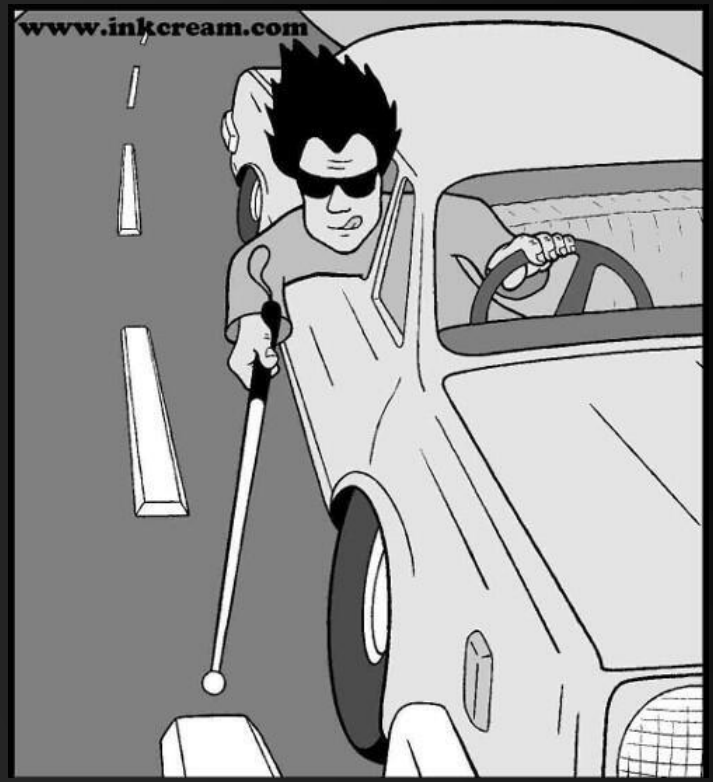
# Reduced biases
# Historical trends
# Amplification of annual cycle



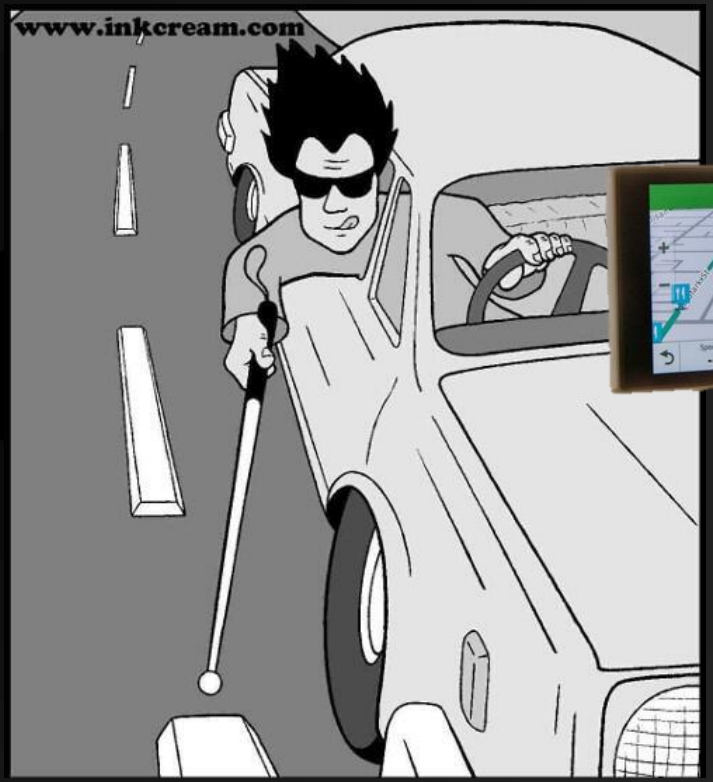




Lawrence et al. in review; Bonan et al. in review;
Lombardozzi et al. in review & in prep.

# CLM4 & CMIP5




# CLM5 & CMIP6




**ILAMB**