When is a trend meaningful? Insights to carbon cycle variability from the CESM2 large ensemble

Gordon Bonan
NSF National Center for Atmospheric Research
Boulder, Colorado, USA

CESM Land Model Working Group
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With:

Clara Deser, Will Wieder, Danica Lombardozzi, and Flavio Lehner

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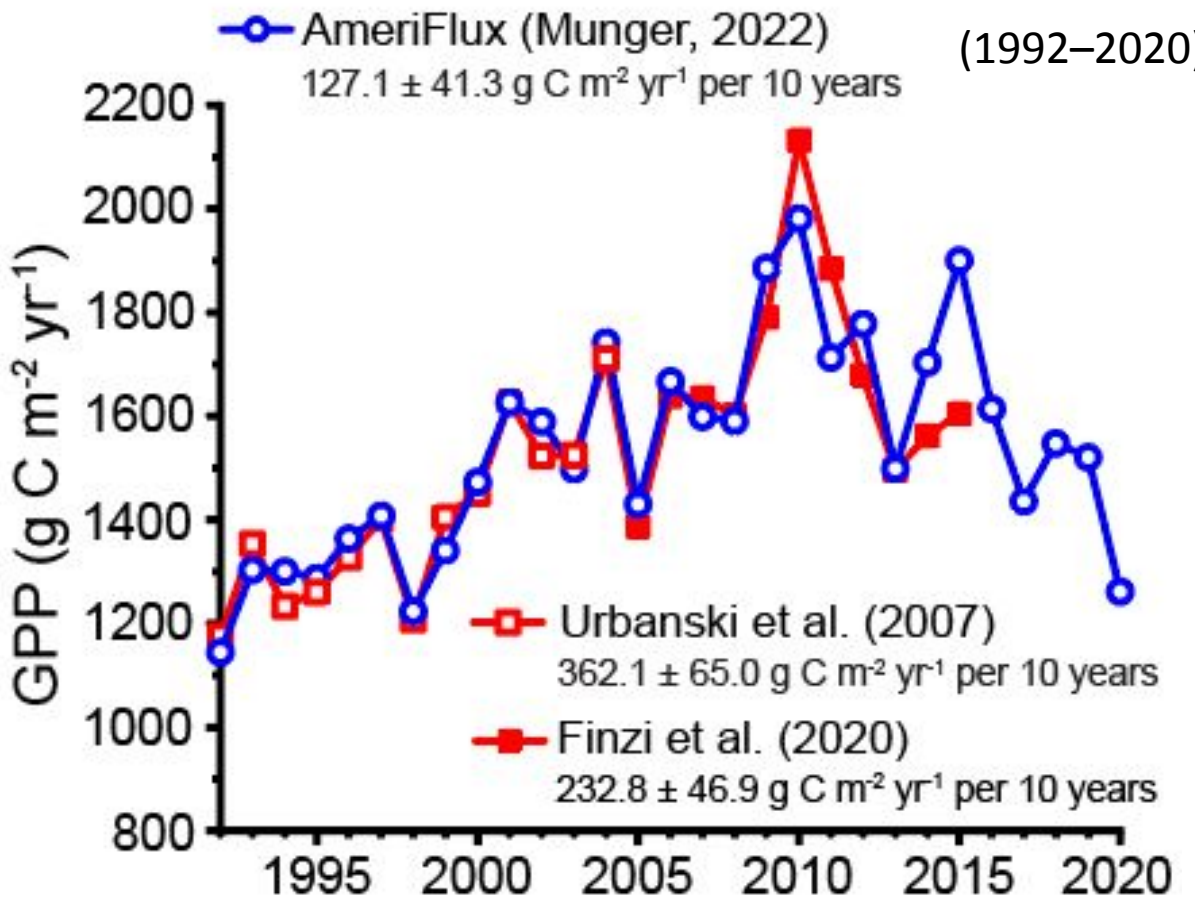
Carbon cycle trends at Harvard Forest



(1992–2020)

(1992–2004)

(1992–2015)

How does unforced variability (internal variability) affect GPP trends over the different time periods?

Initial condition large ensembles

nature climate change

PERSPECTIVE

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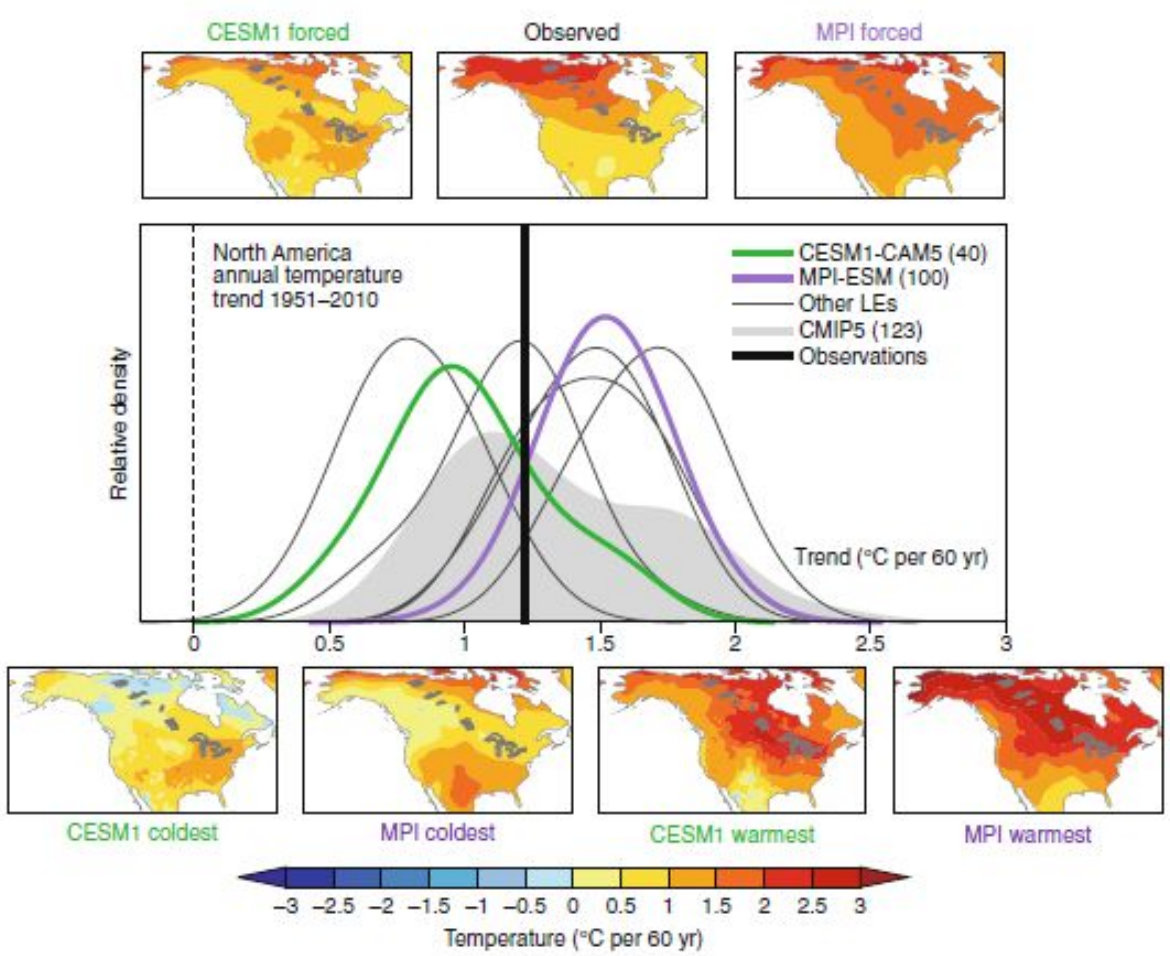
Check for updates

Insights from Earth system model initial-condition large ensembles and future prospects

C. Deser[1,2] ✉, F. Lehner[1,2], K. B. Rodgers[2,3,4], T. Ault[2,5], T. L. Delworth[2,6], P. N. DiNezio[2,7], A. Fiore[2,8], C. Frankignoul[2,9], J. C. Fyfe[2,10], D. E. Horton[2,11], J. E. Kay[2,12,13], R. Knutti[2,14], N. S. Lovenduski[2,12,15], J. Marotzke[2,16], K. A. McKinnon[2,17], S. Minobe[2,18], J. Randerson[2,19], J. A. Screen[2,20], I. R. Simpson[1,2] and M. Ting[2,8]

Internal variability: uncertainty in initial atmospheric and oceanic states produces different climate trajectories, each with its own random sequence of unforced variability and each an equally plausible realization of climate change

50 members of the CESM2 LE (1850–2100) that differ only in initial conditions for 1850



Rodgers et al. (2021) Earth Syst. Dynam., 12, 1393–1411

CESM2 Initial Condition Large Ensemble

MACRO
(20 members)

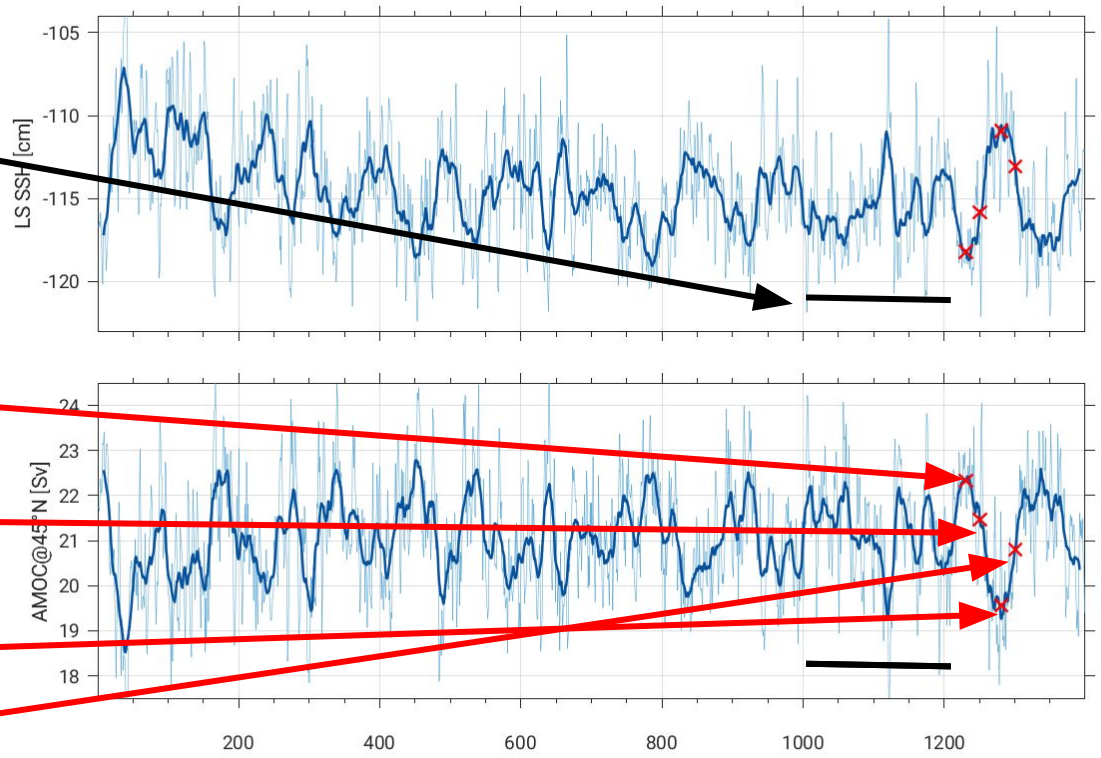
Different climate states (10 years apart)
between years 1001 and 1191

MICRO 1231
(20 members)

MICRO 1251
(20 members)

MICRO 1281
(20 members)

MICRO 1301
(20 members)

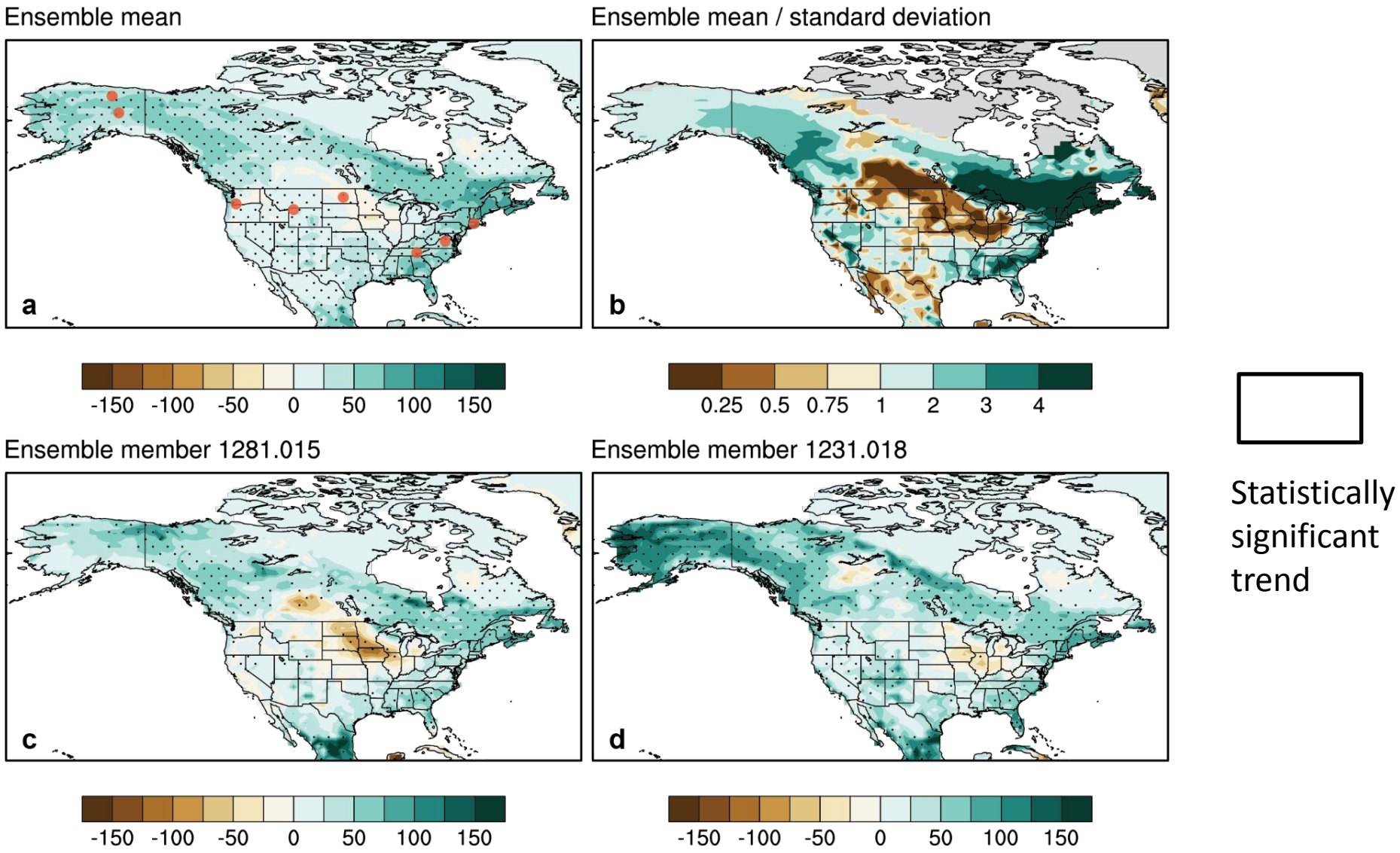


See:
Rodgers et al. (2021) Earth Syst. Dynam., 12, 1393–1411

4 sets of 20 members, initialized from 4 different climate states (years 1231, 1251, 1281, 1301)

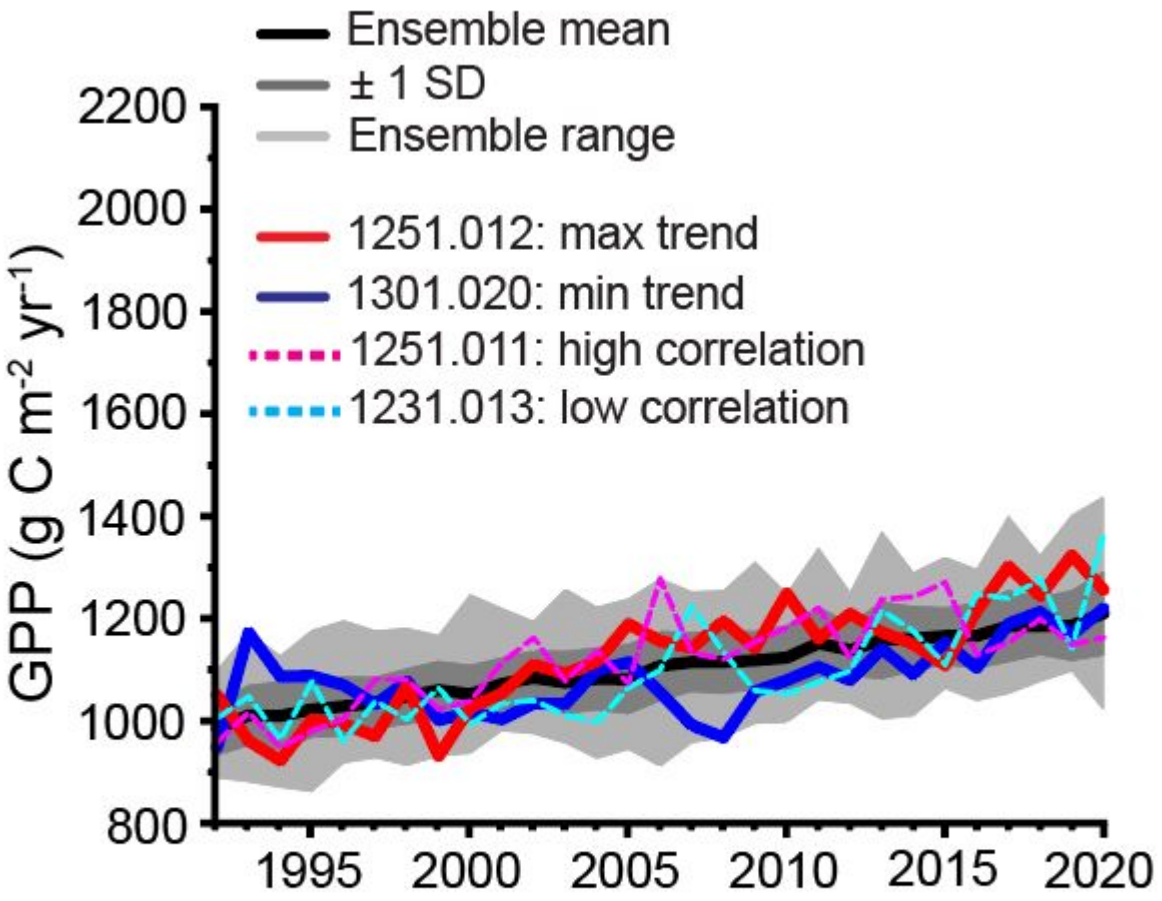
The 20 members differ by initial perturbation of order 10^{-14} to the air temperature field

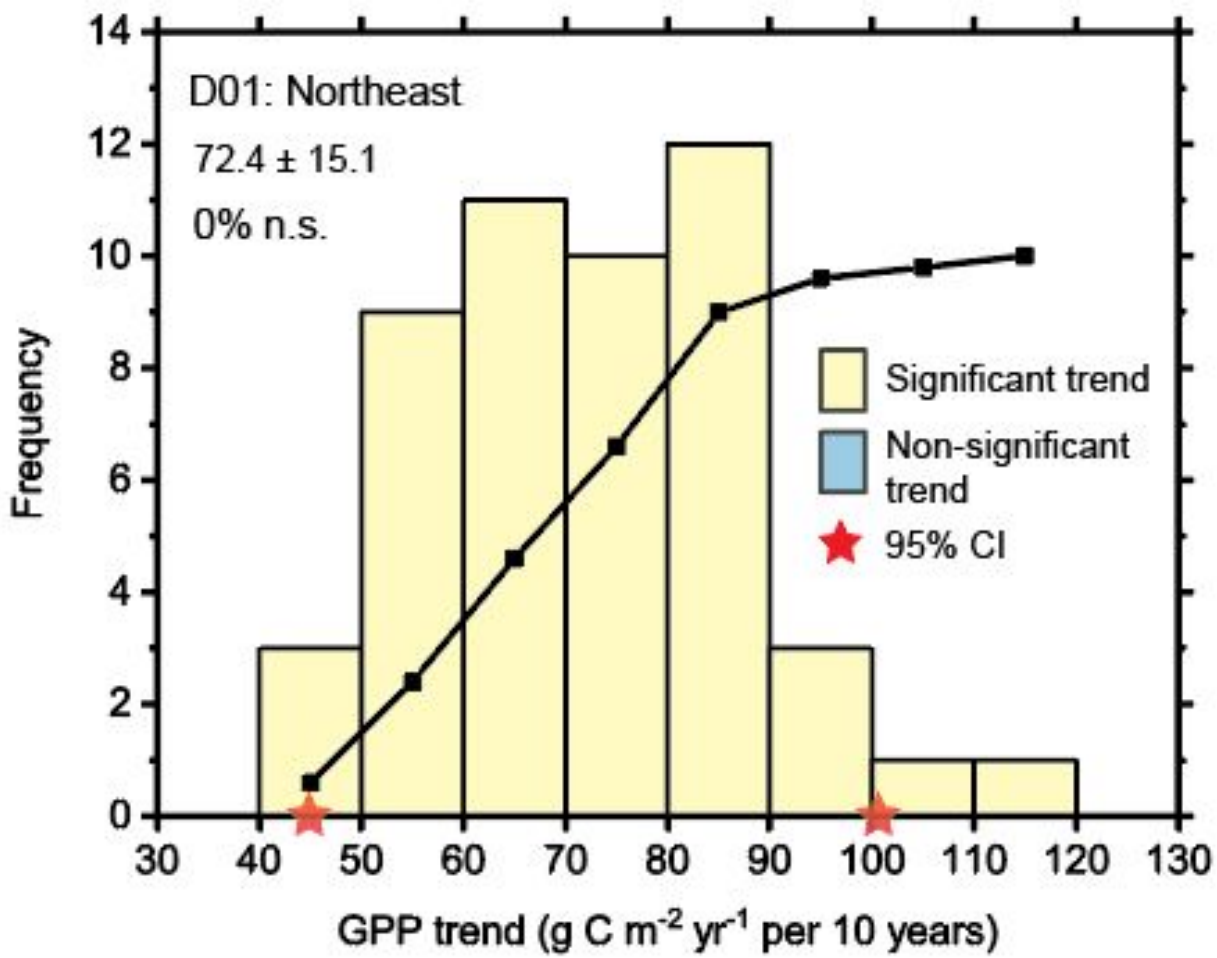
Gross primary production (1991–2020)



Statistically significant trend

Statistical distribution of GPP trends





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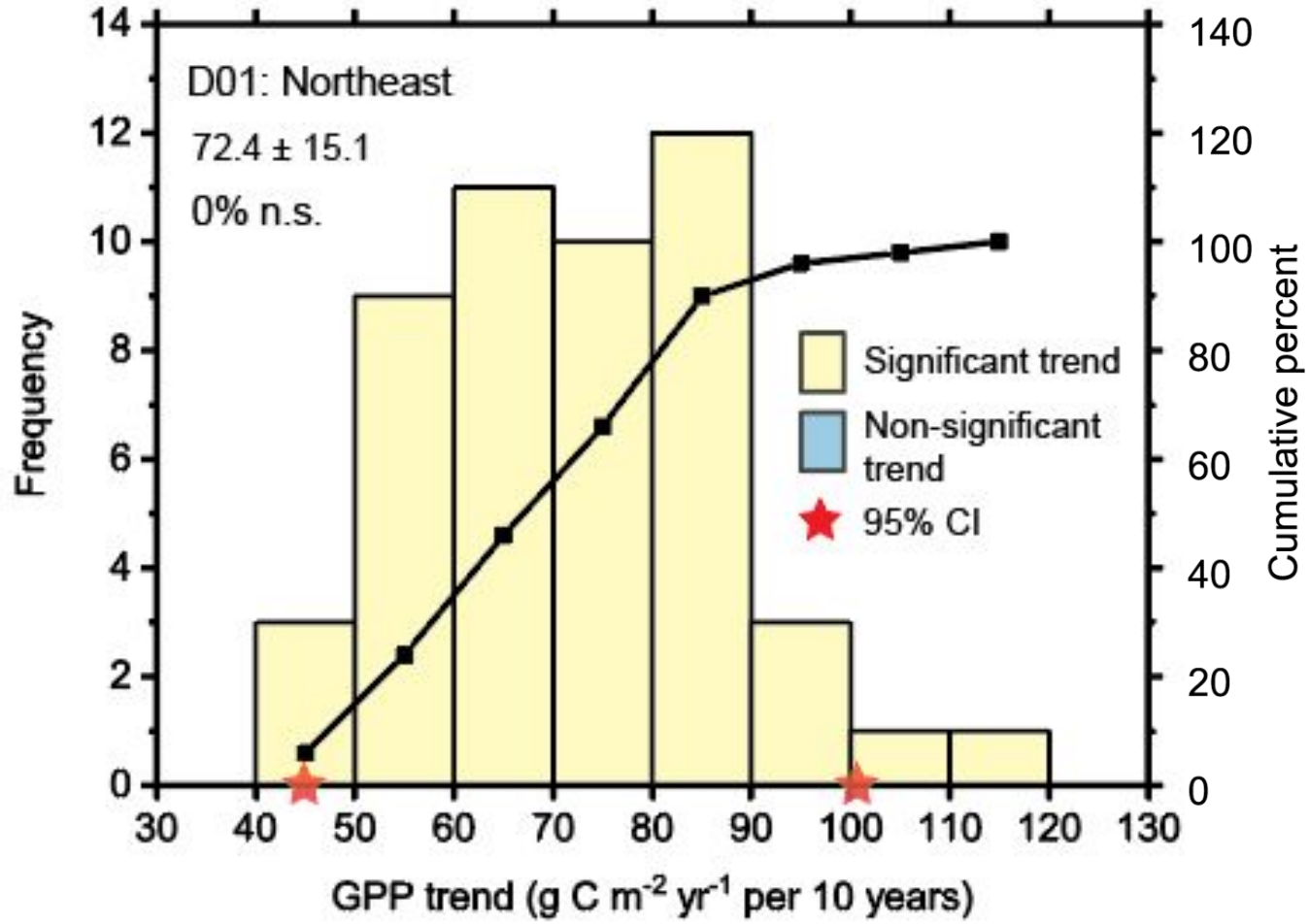
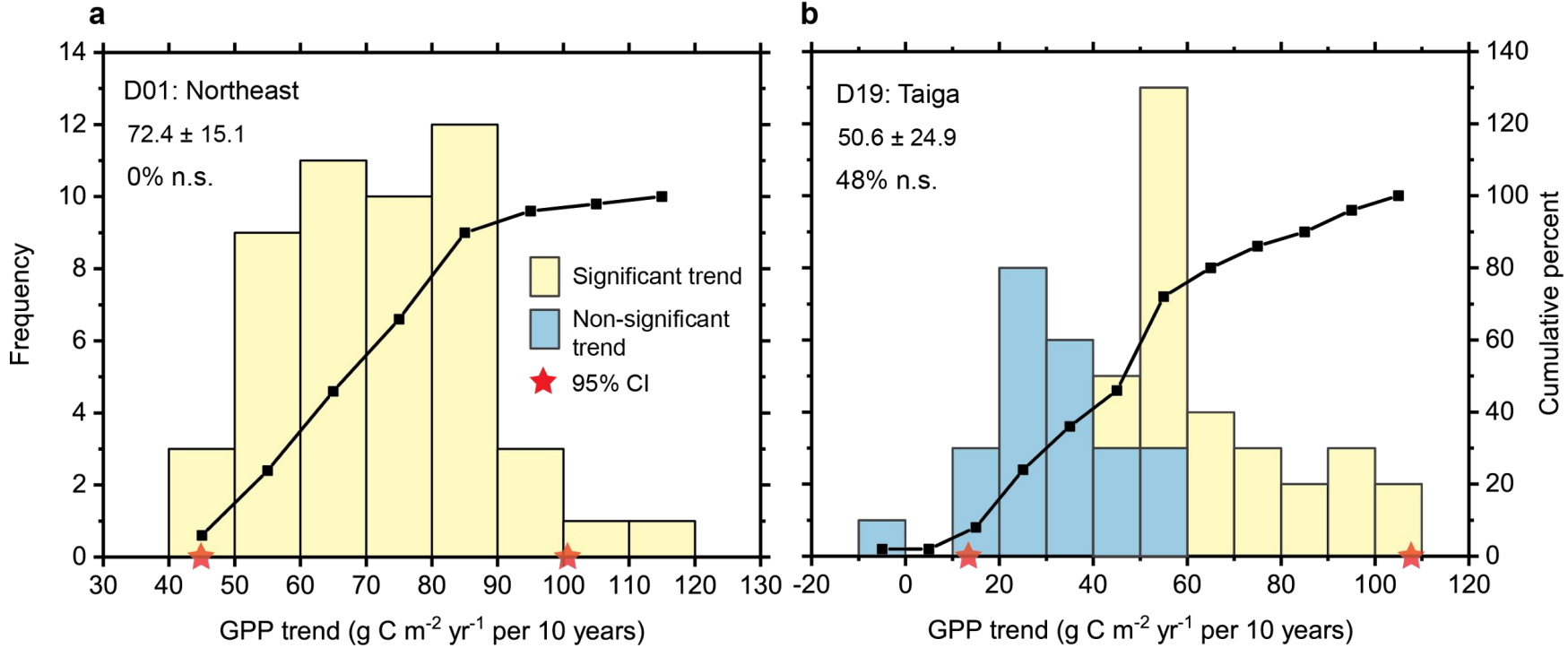
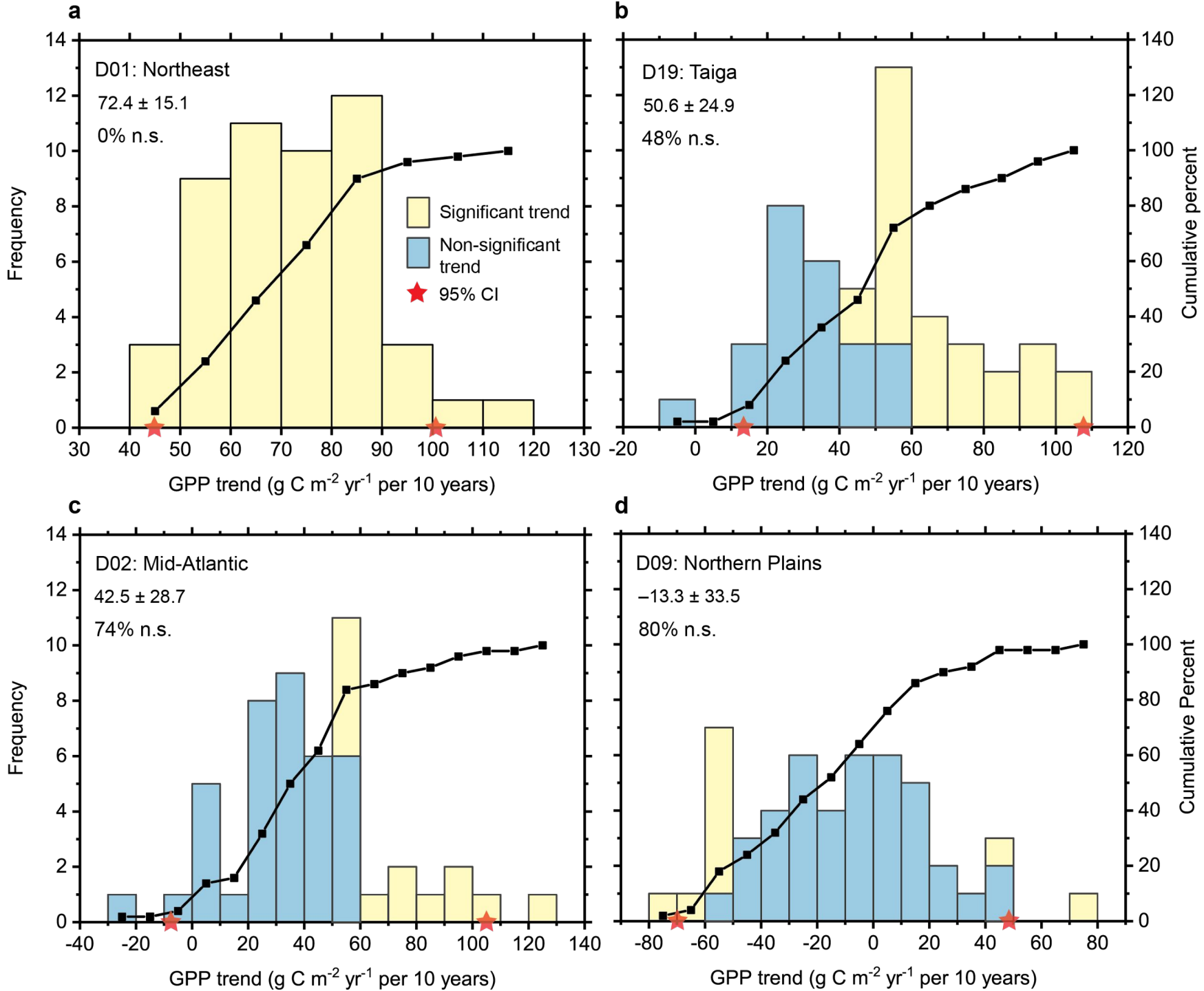



a
D01: Northeast
72.4 ± 15.1
0% n.s.
Significant trend
Non-significant trend
95% CI
Frequency
GPP trend (g C m-2 yr-1 per 10 years)
b
D19: Taiga
50.6 ± 24.9
48% n.s.
Cumulative percent
GPP trend (g C m-2 yr-1 per 10 years)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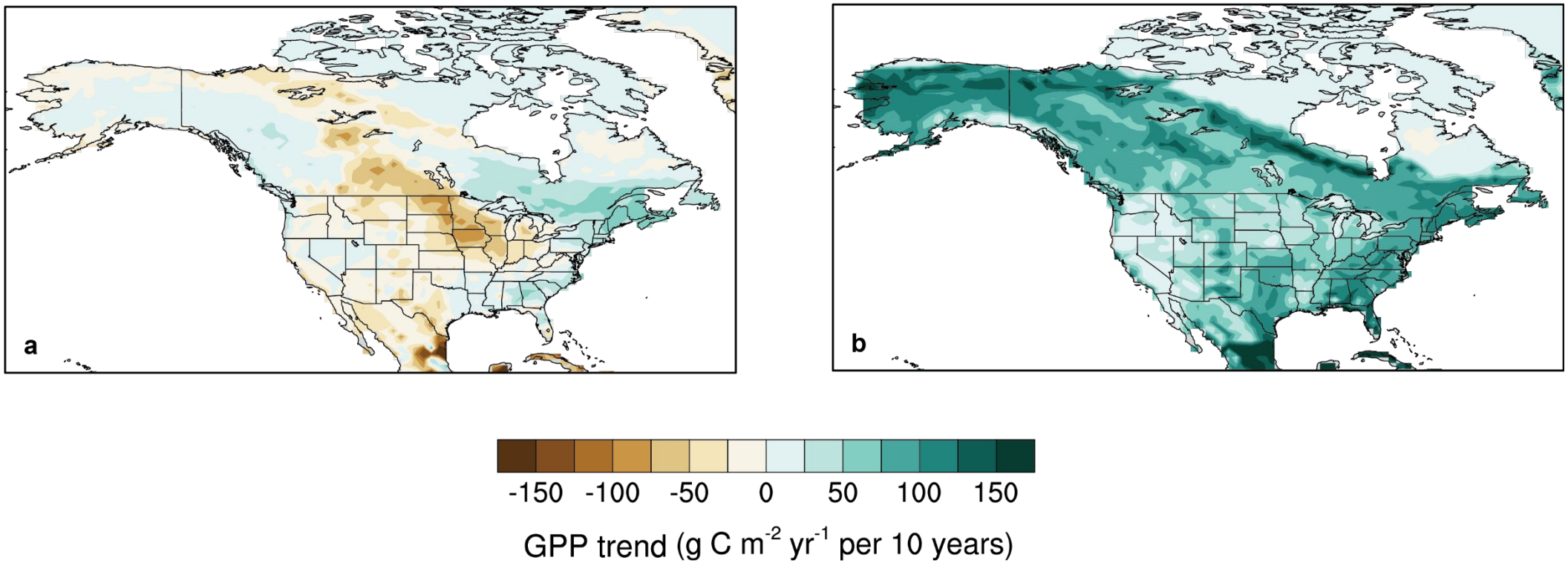
D19: Taiga
50.6 ± 24.9
48% n.s.
Cumulative percent
GPP trend (g C m-2 yr-1 per 10 years)
c
D02: Mid-Atlantic
42.5 ± 28.7
74% n.s.
Frequency
GPP trend (g C m-2 yr-1 per 10 years)
d
D09: Northern Plains
–13.3 ± 33.5
80% n.s.
Cumulative Percent
GPP trend (g C m-2 yr-1 per 10 years)

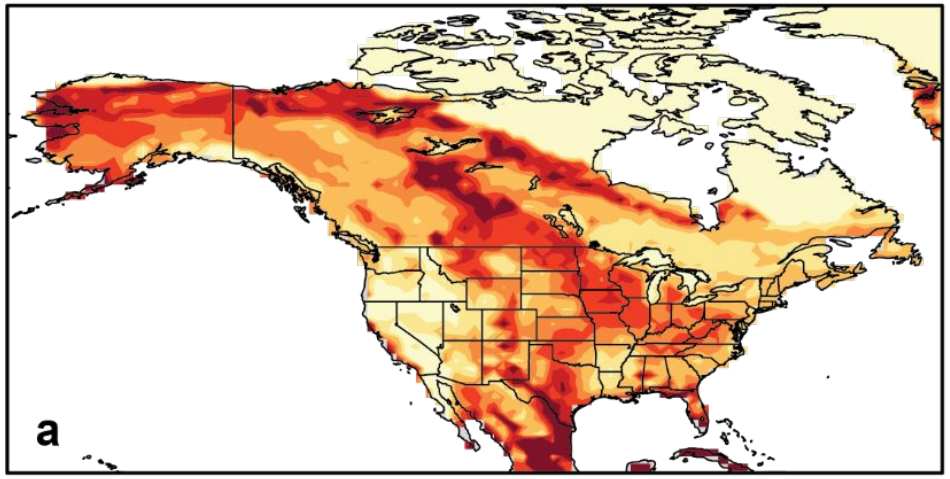
95% confidence interval of trend

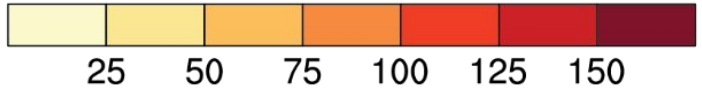


95% CI: range of trends (*n* = 48) after excluding the smallest and largest trends for each grid cell

95% confidence interval of trend

Full ensemble

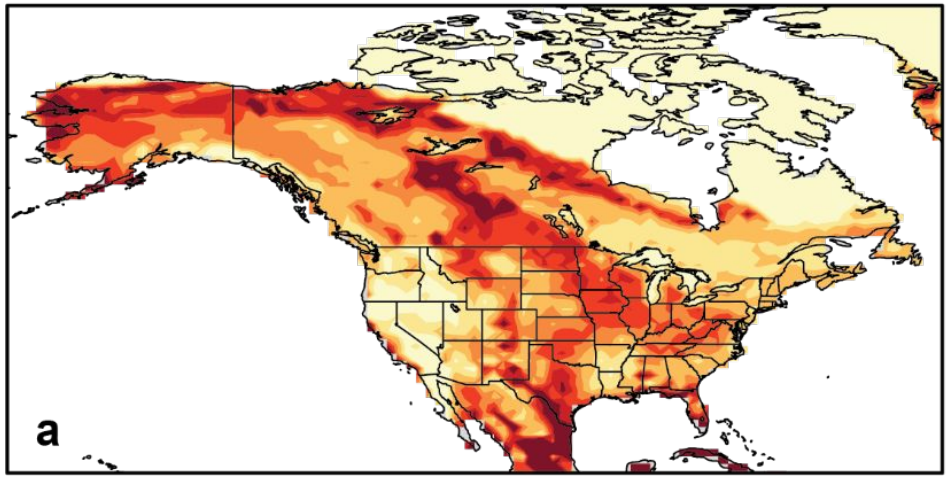




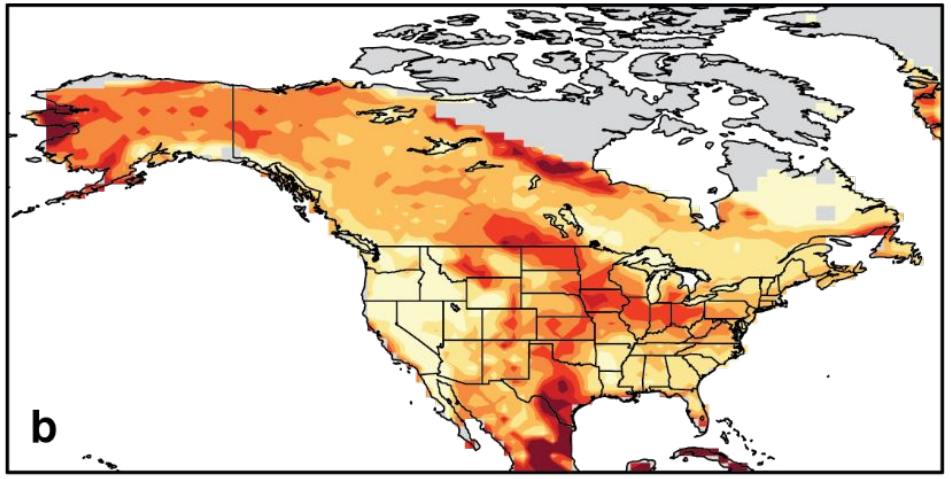
95% confidence interval (g C m^{-2} yr^{-1} per 10 years)

95% confidence interval of trend

Full ensemble



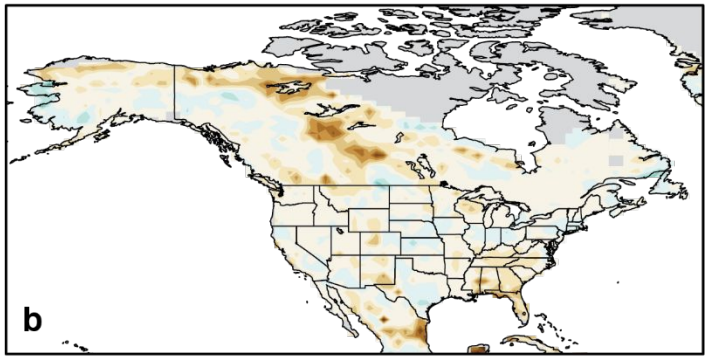
Ensemble member 1251.013

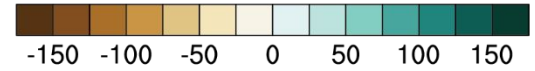


95% CI obtained from linear regression (b_1 ± 2.048*s.e.) for ensemble member 1251.013

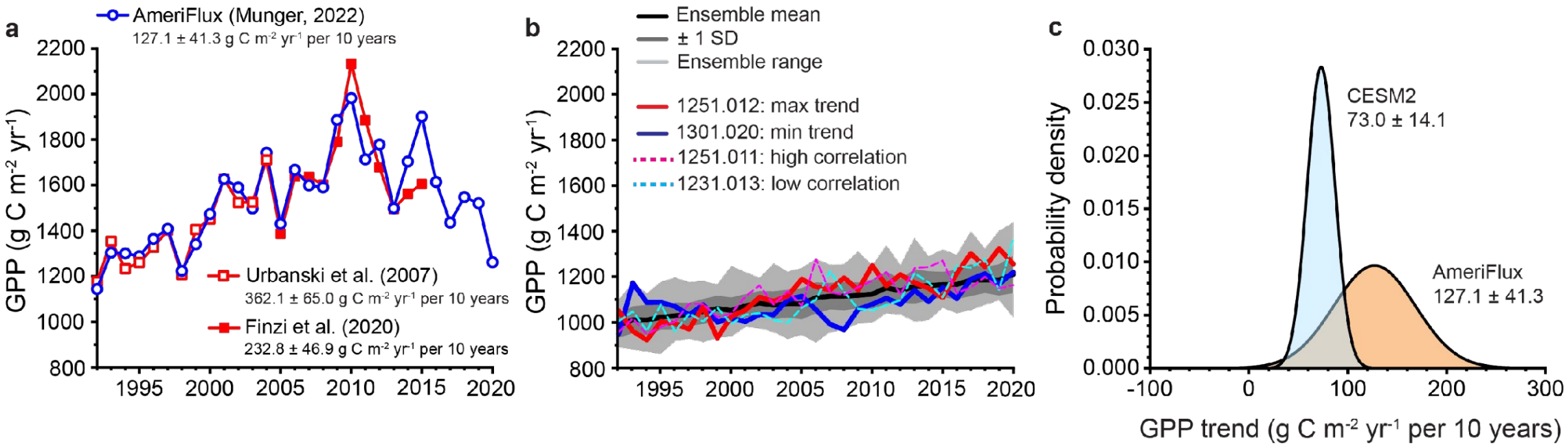
95% confidence interval (g C m^{-2} yr^{-1} per 10 years)

The standard error of the regression slope (from a single ensemble member) estimates the spread across all ensemble members



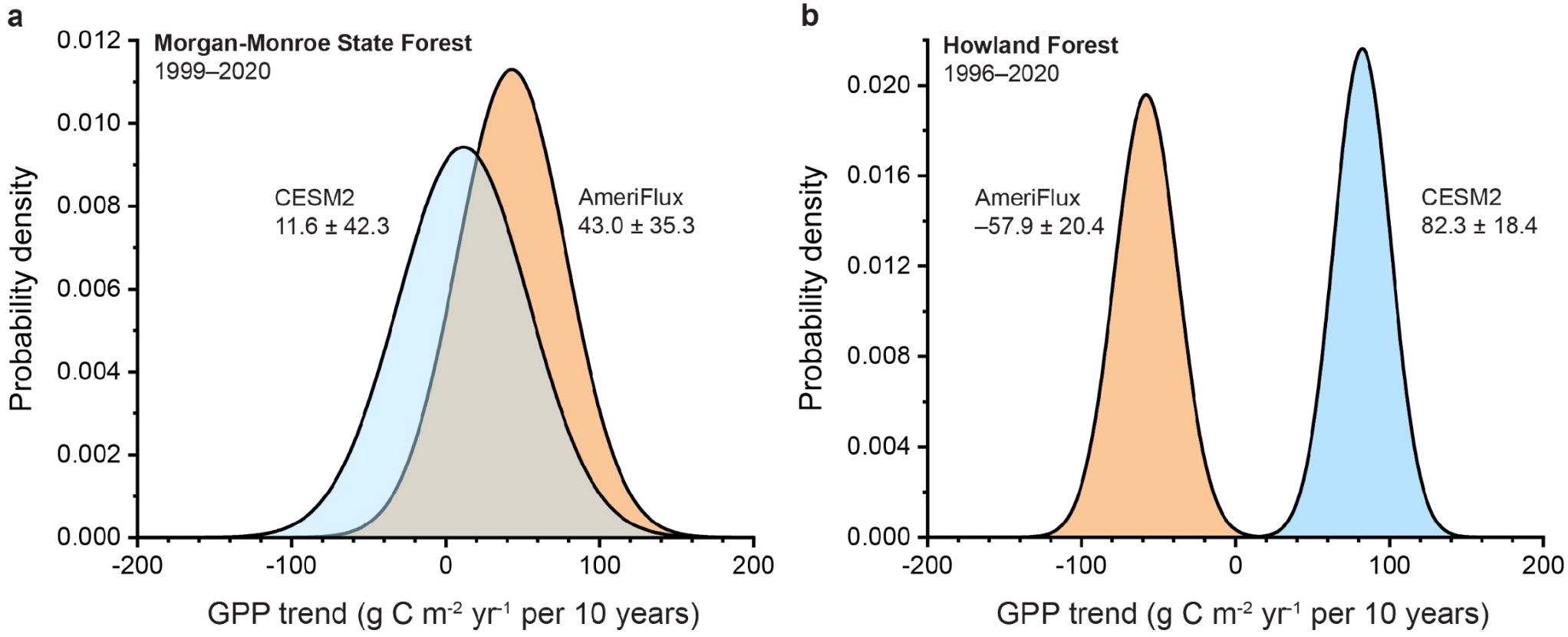


How do observations compare with models?



- CLM5 is biased low in terms of absolute GPP but has a trend that is not dissimilar to the observations
- The internal variability of CESM2 (14.1 g C m^{-2} yr^{-1} per 10 years) is less than the observations (41.3)

How do observations compare with models?



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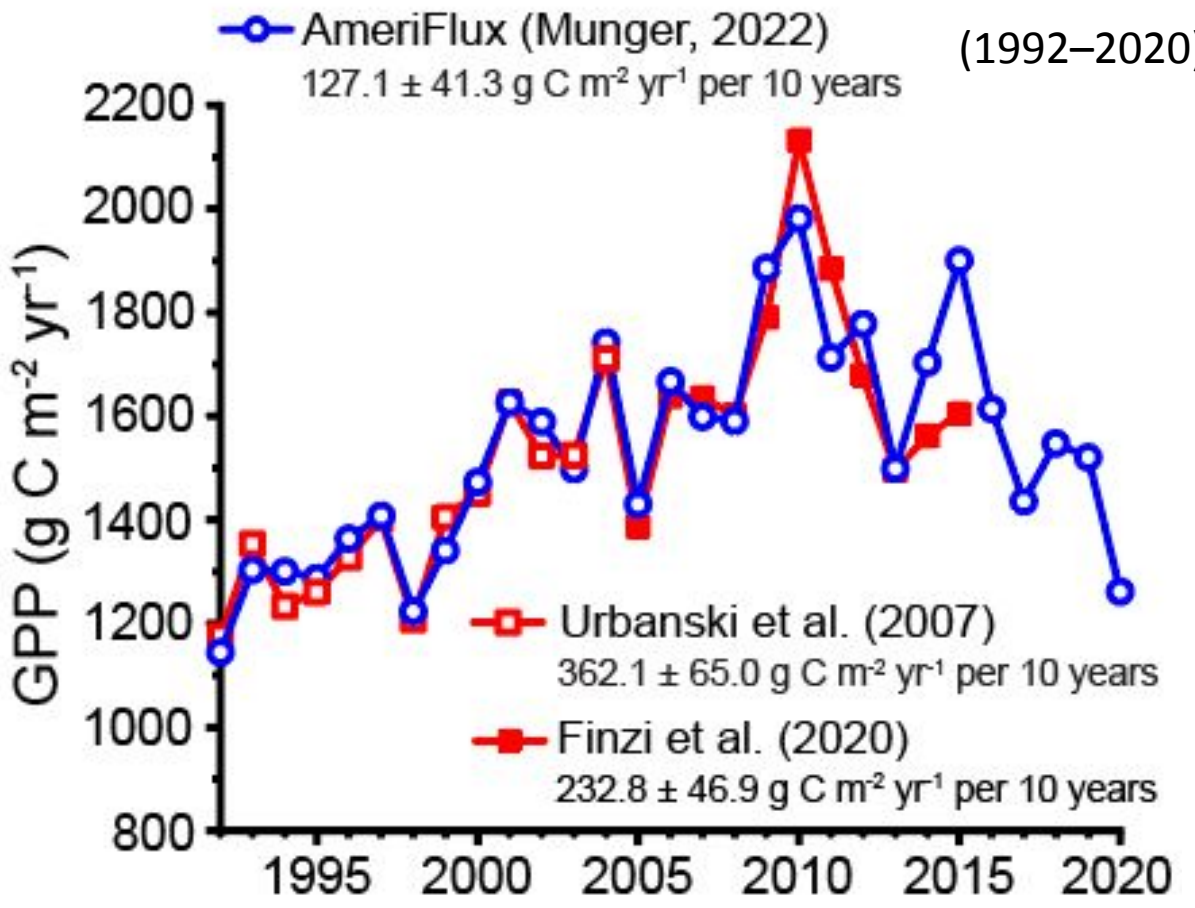
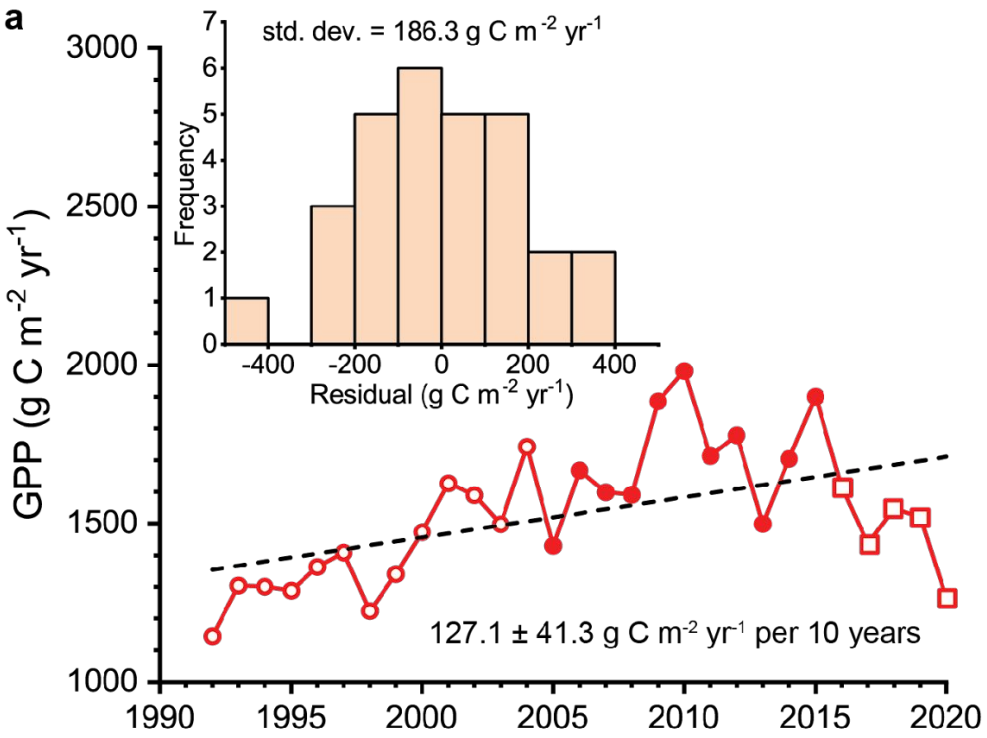


How does unforced variability (internal variability) affect GPP trends over the different time periods?

Conditional probability distribution of observed trends

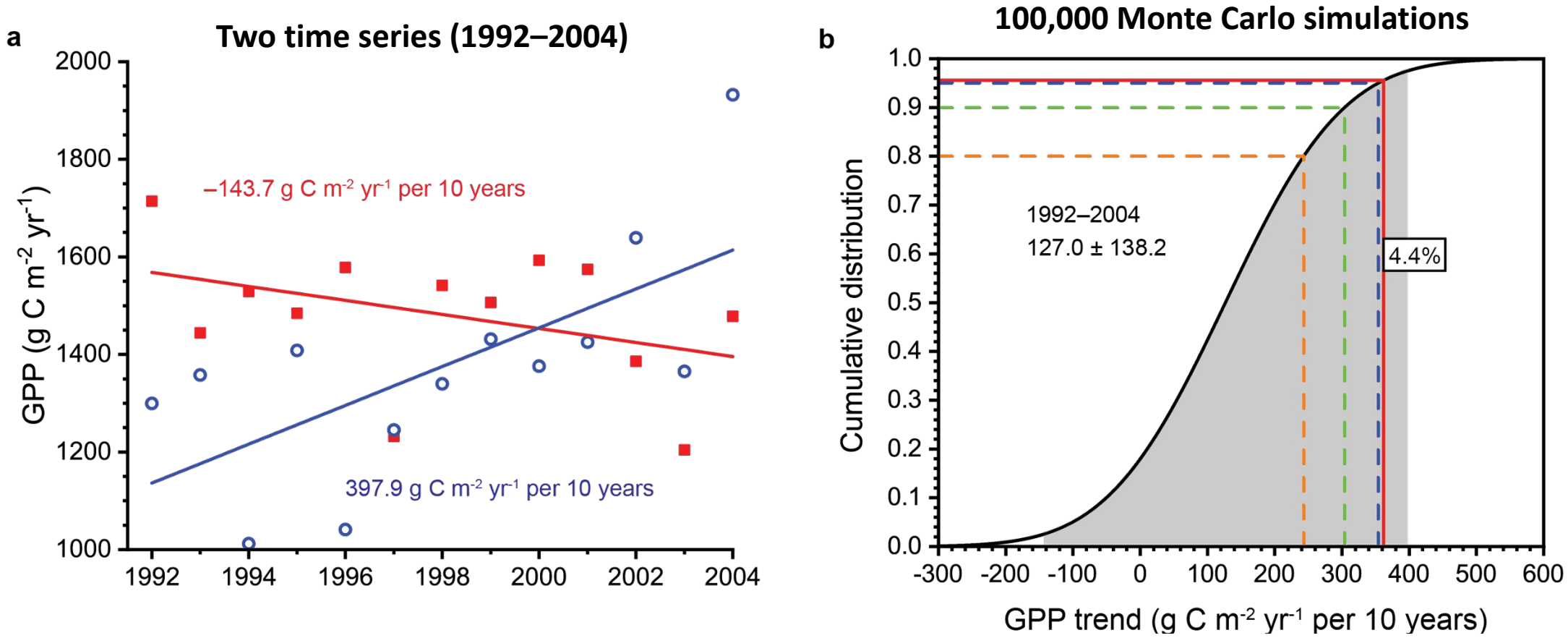


Monte Carlo simulations

If the forced trend over 1992–2020 is 127.1 ± 41.3 g C m^{-2} yr^{-1} per 10 years, what is the probability of attaining a trend of 362.1 when sampled over 1992–2004 and 232.8 when sampled over 1992–2015?

GPP for each year 1992–2004 and 1992–2015 is chosen as a random deviate about the 1992–2020 forced trend

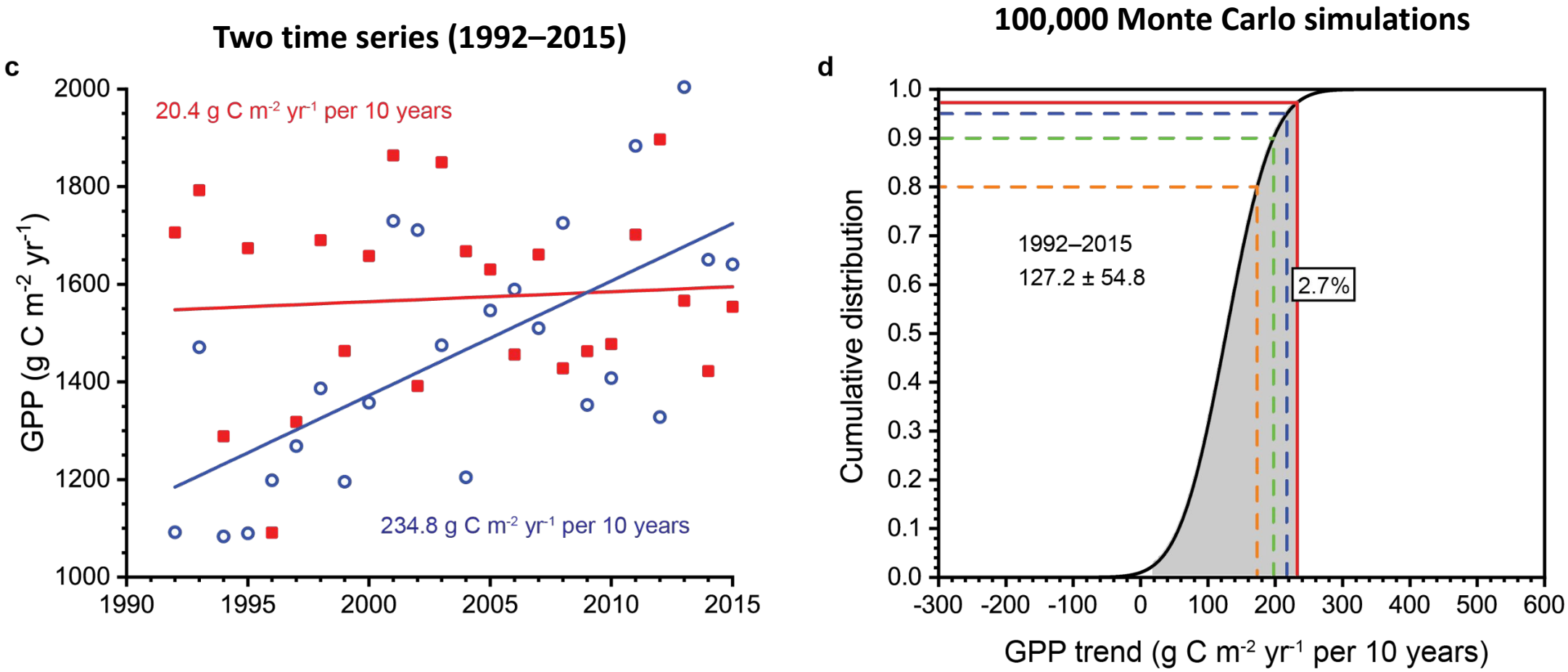
1992–2004



If the forced trend is 127.1 g C m^{-2} yr^{-1} per 10 years:

- 95% CI for 1992–2004 is –144 to 398 g C m^{-2} yr^{-1} per 10 years
- 4.4% chance that a trend equals or exceeds the observed trend (362.1)

1992–2015



If the forced trend is 127.1 g C m^{-2} yr^{-1} per 10 years:

- 95% CI for 1992–2015 is 20 to 235 g C m^{-2} yr^{-1} per 10 years
- 2.7% chance that a trend equals or exceeds the observed trend (232.8)

Concluding thoughts

Observations

- Need a better understanding of how internal variability affects trends
- Standard error of regression trend (slope) is a measure of internal variability (i.e., not just the trend!)
- The observational record is but one realization of many possible alternatives in which the sequence of internal variability could have unfolded differently

Model development

- CLM (land-only): GPP is sensitive to climate realizations. Does model development need to use an ensemble forcing approach?
- CESM (coupled): One realization may give false positive or false negative trends. Is CESM correctly sampling internal variability?
- CMIP: Are differences due to model structure, parameters, or internal variability?
- Uncertainty reduction?