Evaluation of biases in UFS hindcasts at S2S timescales

Benjamin W. Green[1,2], Sina Khani[1,2], and Shan Sun[2]

[1]CIRES, University of Colorado Boulder

[2]NOAA/Global Systems Laboratory

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Overview of operational global modeling at NOAA

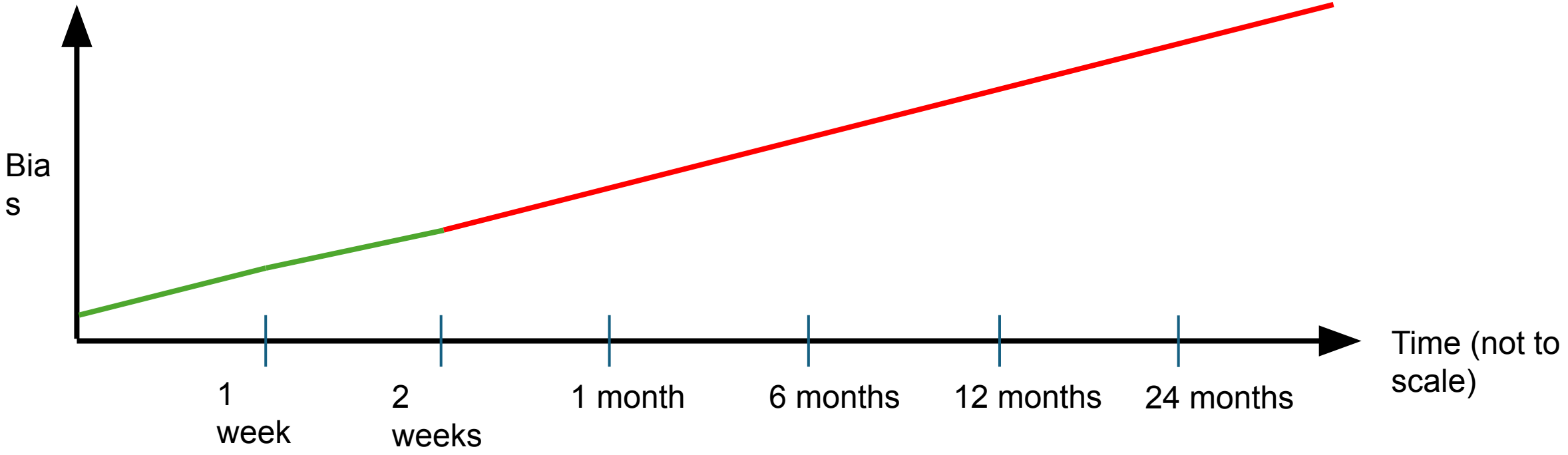
- Current (June 2023):
  - GEFSv12: UFS-based, atmosphere/wave coupled, 0-16 days*
    - *GEFS does provide forecasts out to 35 days, using CFSv2 SST
  - CFSv2: **not** UFS-based, atmosphere/ocean/wave/ice, 0-9 months

- Future (exact details subject to change):
  - GEFSv13: UFS-based, atmosphere/ocean/wave/ice coupled, 0-48 days
  - SFSv1: UFS-based, atmosphere/ocean/wave/ice coupled, 0-12 months

- Key point: Subseasonal **and** seasonal currently handled by same model (CFSv2); future will **separate seasonal forecasts from subseasonal**

Minimizing Early Model Biases and Errors

- How does bias grow over time? A conceptual sketch – variable-dependent



- We do not expect bias to grow unbounded, indefinitely

Minimizing Early Model Biases and Errors

- How does bias grow over time? A conceptual sketch – variable-dependent

- We expect biases to grow, then saturate (with [intra]seasonal oscillation)
- But what happens in the S2S time range???? We might expect patterns at 6-7 months to be quite different than 0-1 month due to seasonal cycle
- Previous work (e.g. Saurral et al. 20 their Fig. 12) shows, e.g., a "seasonal dependency of [SST] biases in ***some*** forecast systems"

Previous results: Subseasonal bias growth

- Green et al. (2023, MWR):
  - Coupled UFS; subseasonal prototypes 5, 7, and 8 (lead times out to 35 days)
  - Key finding: **Many bias patterns at weeks 3-4 are similar to those at week 1** (but with bigger amplitude) – potential shortcut for *subseasonal* model tuning

- Notice that sign of bias does not change with lead time (don't see blues changing to reds along a horizontal line)

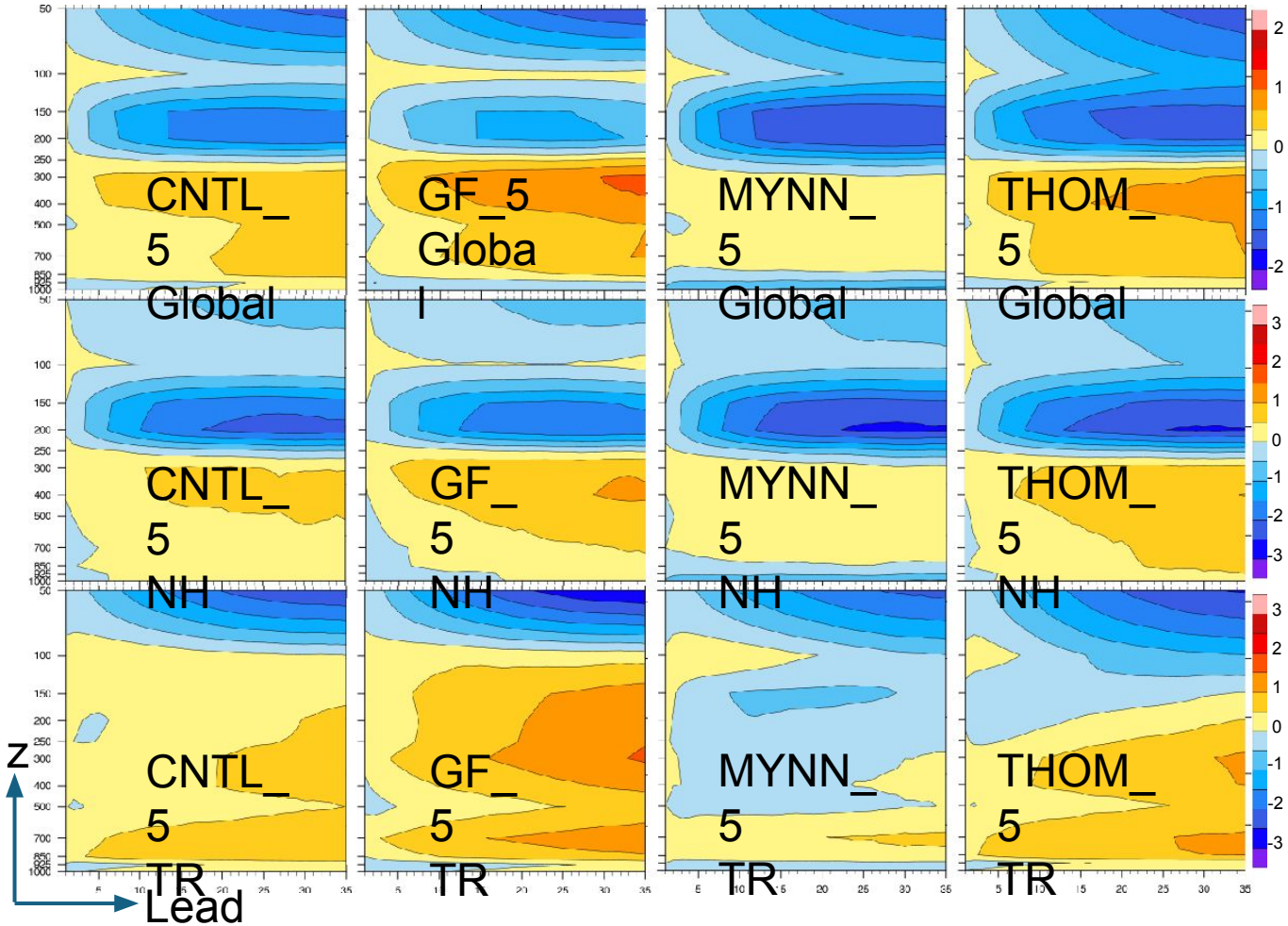
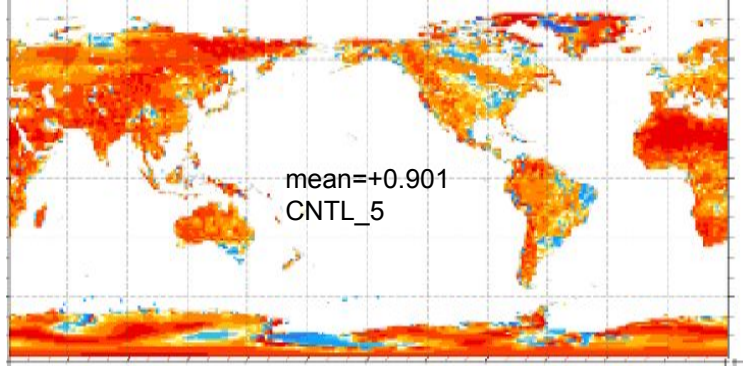


Figure 6 of Green et al. (2023)

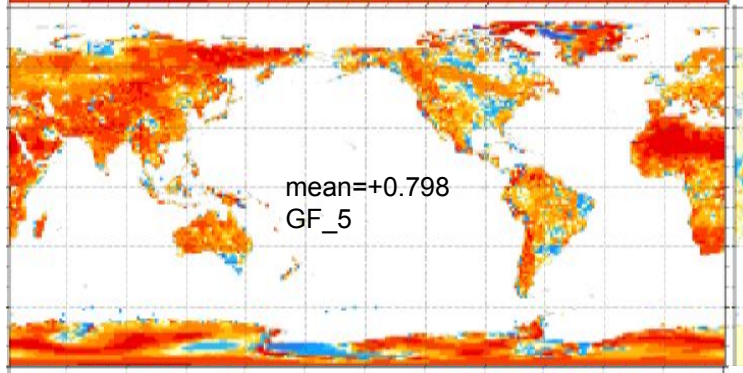
Previous results: Subseasonal bias growth

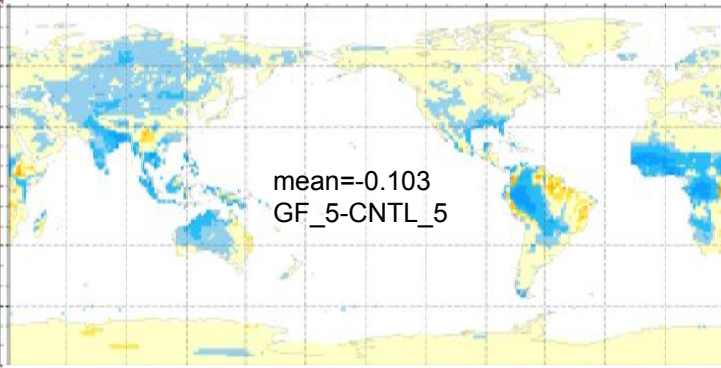
- Bias patterns in Week 1 often look similar to those in Weeks 3-4, but with bigger amplitudes
- Example from this particular study (T2m):
  - Locally cool bias in SE Australia
- Can also be seen in precip (next slide)…

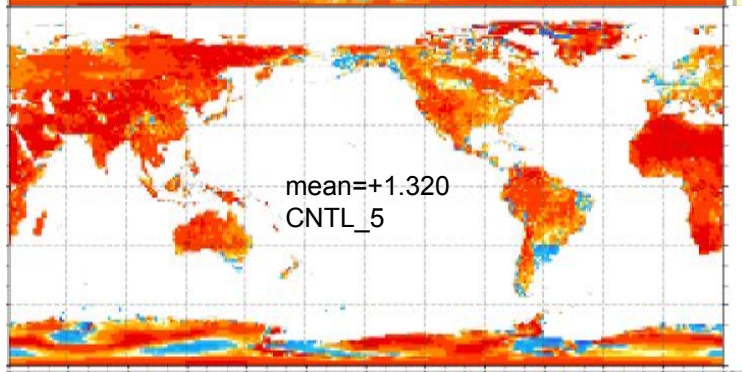


Week 1 T2m bias

From Fig. 1 of Green et al. (2023)

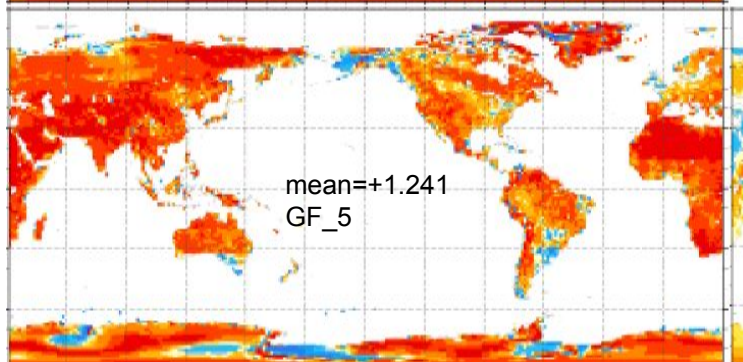


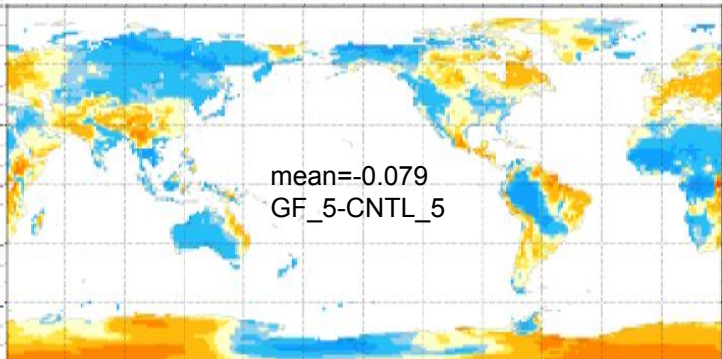




Weeks 3+4 T2m bias

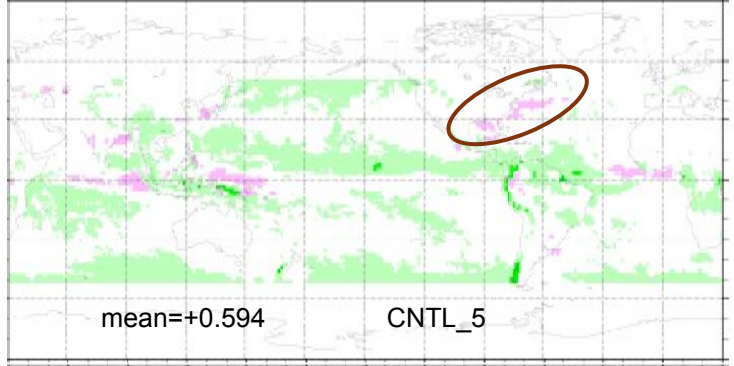
From Fig. 2 of Green et al. (2023)





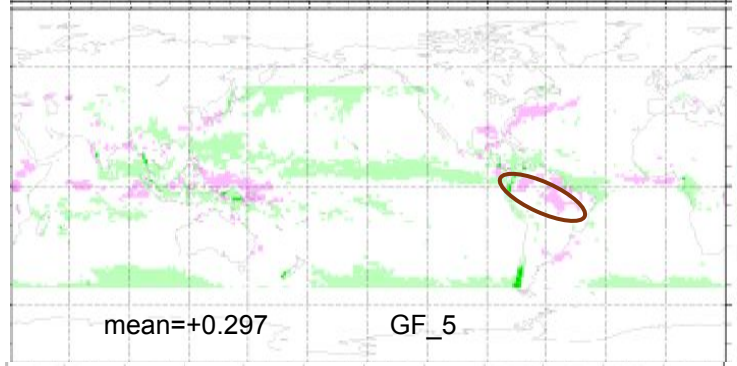
Previous results: Subseasonal bias growth

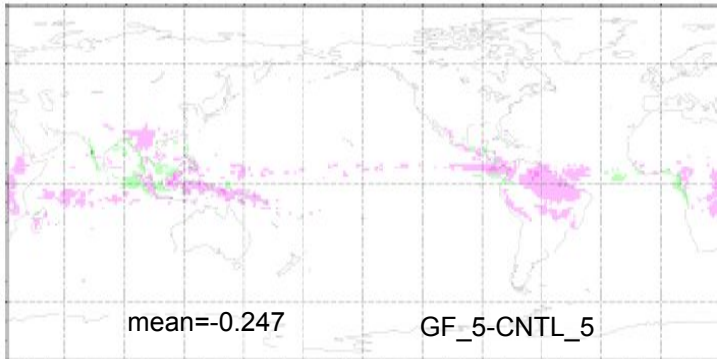
- Bias patterns in Week 1 often look similar to those in Weeks 3-4, but with bigger amplitudes
- Examples from this particular study (QPF):
  - Dry bias off US East Coast
  - Dry bias in Amazon region ("GF_5" experiment)
- But what about **seasonal** bias evolution? Dependent on model and variable?

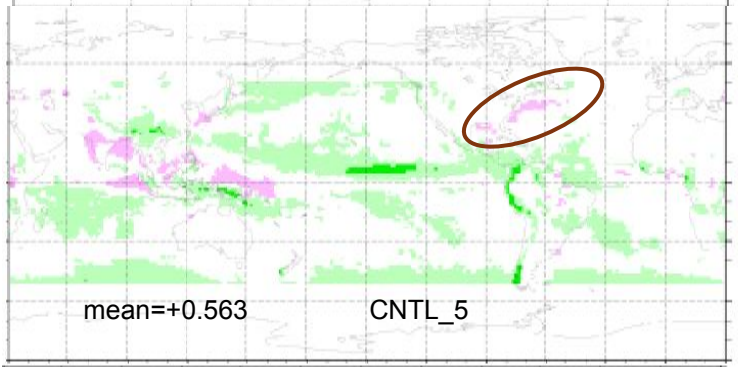


Week 1 QPF bias

From Fig. 3 of Green et al. (2023)

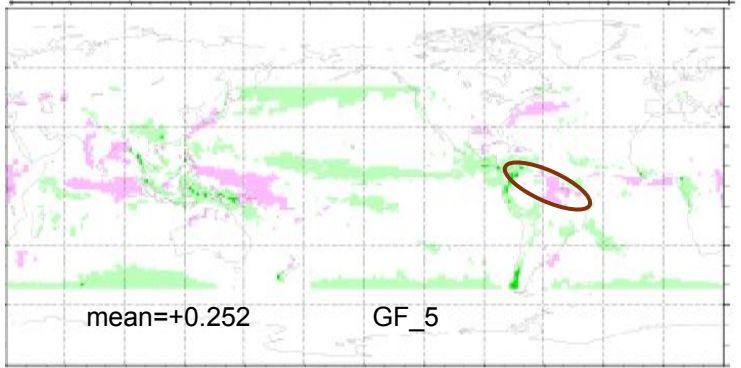


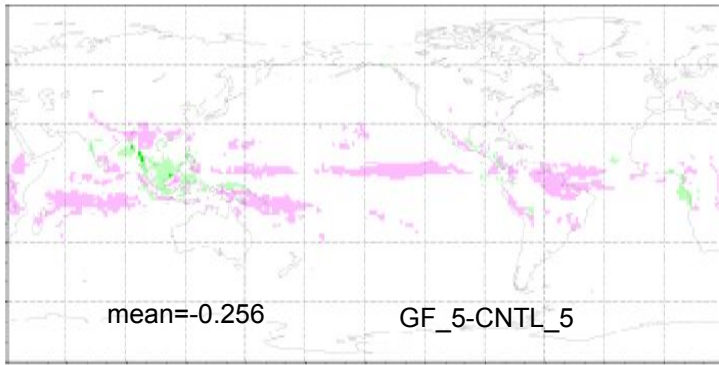




Weeks 3+4 QPF bias

From Fig. 4 of Green et al. (2023)





Ongoing work: Seasonal prediction with UFS

- "SFS" is still in very early stages of development

- In this talk, focus on a set of 12-month-long coupled UFS runs:
  - Initialized every May 21-25 (5-member time-lagged ensemble) from 1991-2022 (**32 yrs**)
  - Resolution: 1° atmosphere and ocean

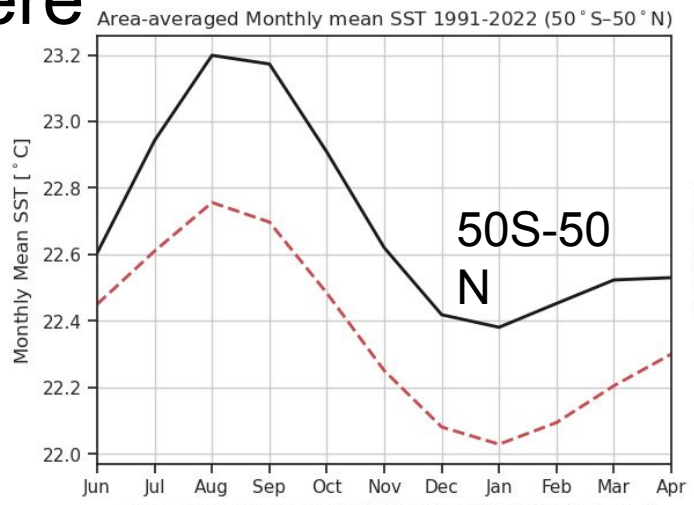
- Look at monthly averages: captures annual cycle without daily/weekly noise

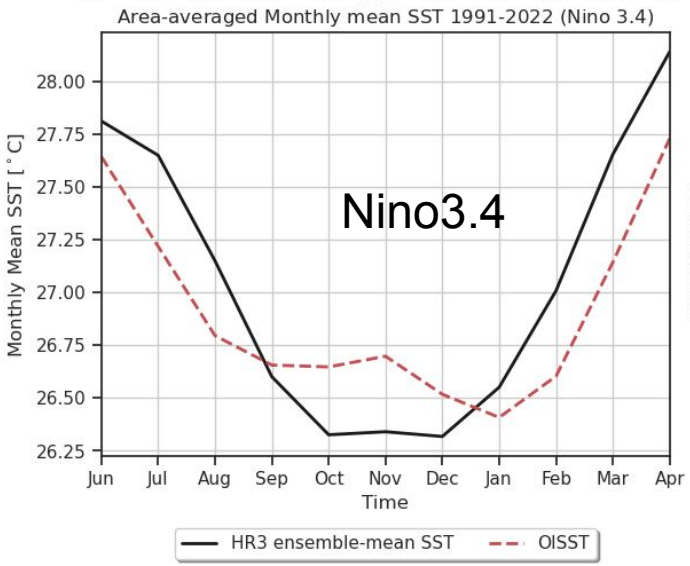
- Caveat (same with subseasonal): code base is changing rapidly; some specific results may be "fleeting"

Preliminary results: Seasonal prediction with UFS

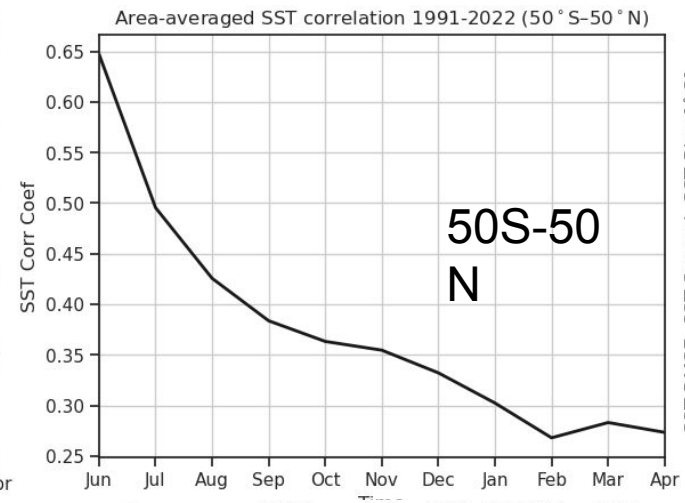
- SST shown here
- Results look “reasonable”
- Time-lagged ensemble is quite under-dispersive (better ensemble strategies coming!)
- What about bias maps?

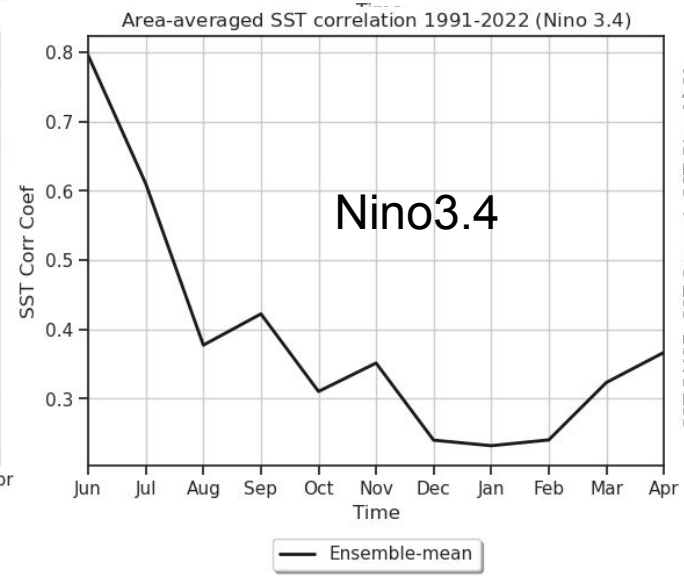
Mean SST



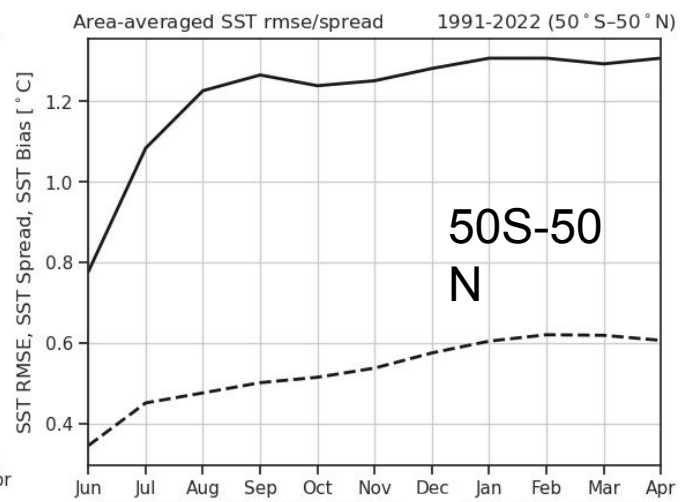


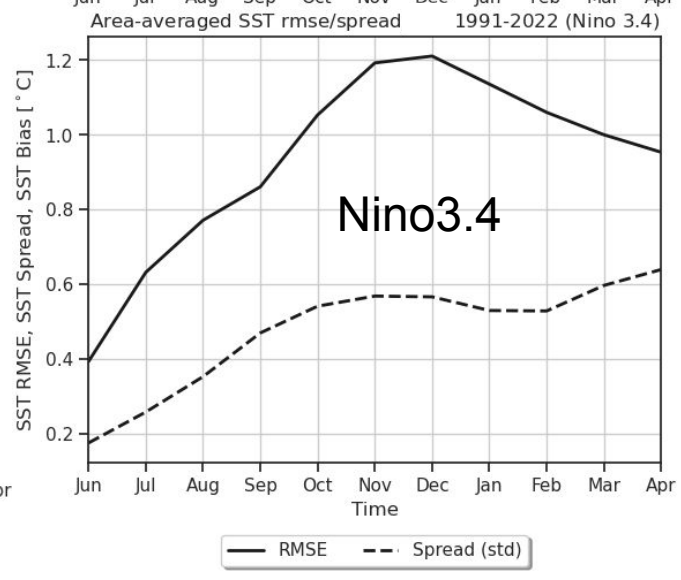
Correlation





RMSE & Spread

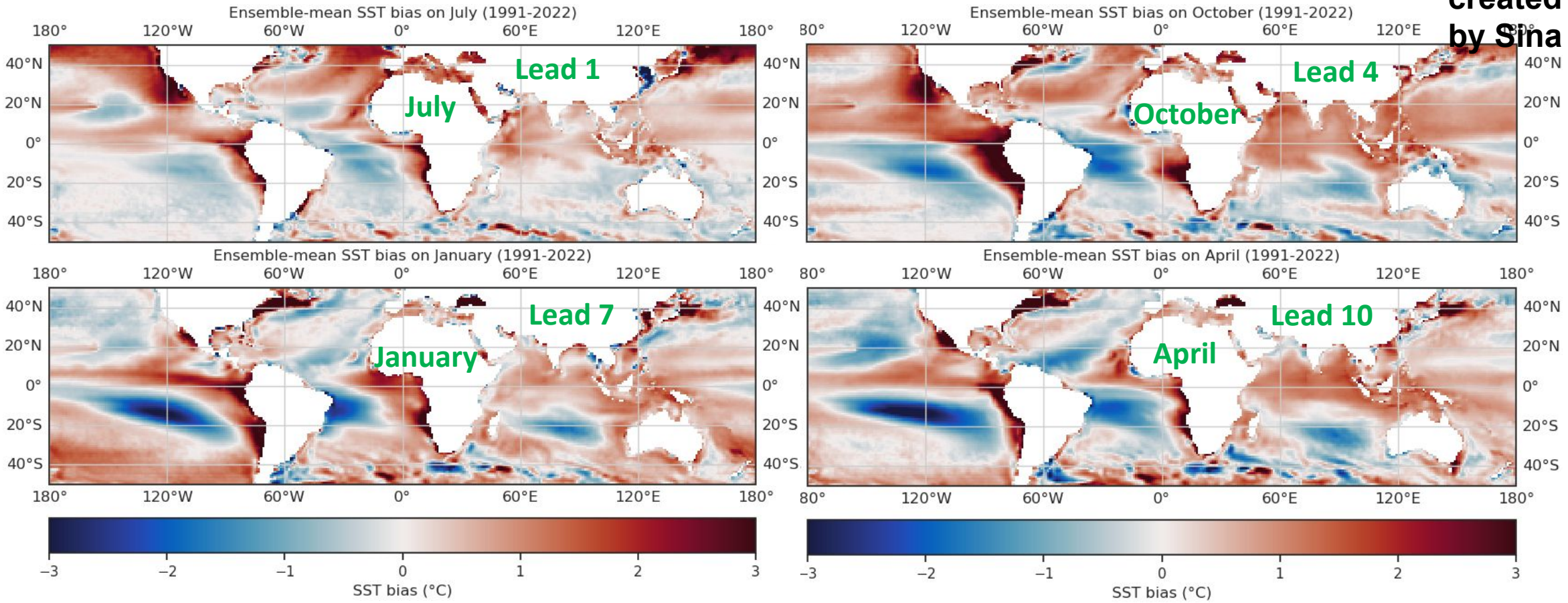




Figures created by Sina Khani

SST biases: Late May ICs

Figures created by Sina Khani

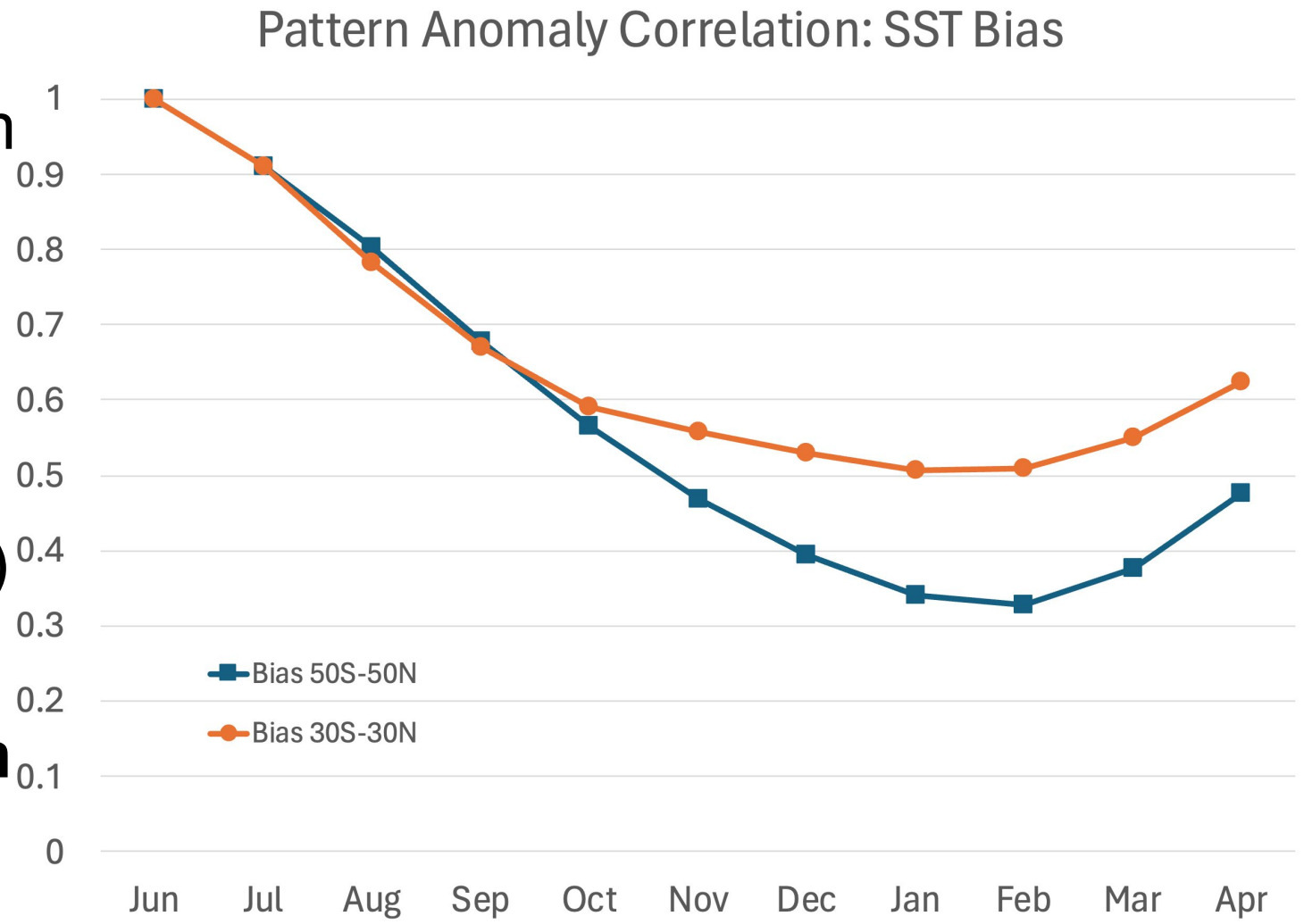


- Some regions have persistent bias patterns (SE Pacific cool bias)
- Other regions have time-varying bias patterns (N Atlantic)
- How can bias evolution be **quantified**?

Quantification of bias evolution

- Use anomaly correlation: Correlation between bias map of Lead Month 0 (June) and bias map every other lead month (separately)

- Correlation reaches a minimum at Lead Month 8 (February)
  - Note: Lead Month 6 (December) is halfway through solar cycle from initializations (late May)
- Bias correlations **increase** in Lead Months 9&10 (Mar & Apr)
- Implications for **bias reduction**



Conclusions and Future Work

- Evidence at both subseasonal and seasonal timescales that **bias patterns can persist with increasing lead time**
  - Limiting factor: annual cycle
  - Influence of annual cycle likely varies between variables **and models** (source of bias)

- Model developers may be able to **leverage persistence of bias patterns** in their work: in some instances, shorter runs may be sufficient without having to spend lots of CPU always making very long integrations

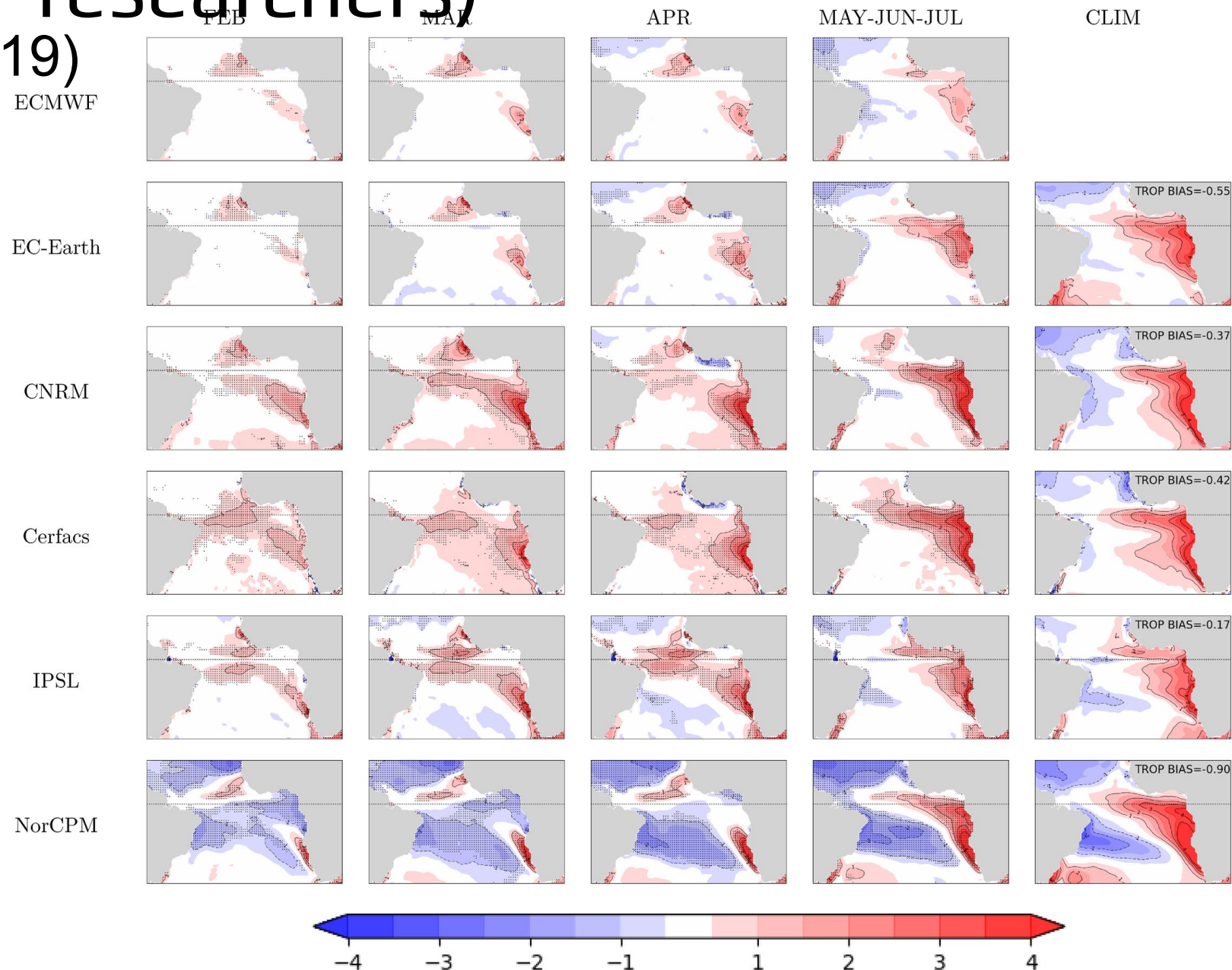
- Future work: Investigate **root causes** of SST biases in seasonal UFS
  - Following Saurrai et al. (2021) finding that *different modeling systems have different seasonality of bias patterns*, explore seasonality of biases in fields such as radiation and wind stress

Backup: Differences between this work and other work

- No study to our knowledge correlates Lead 0 bias w/ Lead Month 1,2,… bias
- Ma et al. (2021):
  - Aggregate all IC months together (only late May ICs looked at here)
  - Correlate monthly biases with "**long-term**" (40+ year) biases
- Huang et al. (2007): Focus on S. Atlantic; did not quantify bias v. lead time
- Voldoire et al. (2019): Focus on Atlantic, only looked at first 6 months (nb: Fig. 2 shows different models have different SST bias evolutions)
- Siongco et al. (2020):
  - Focus on Pacific
  - Other similarities to Ma et al. (2021)
- Hermanson et al. (2018): Only look at first 4 months
- Saurral et al. (2021): Only looked at first 5 months for seasonal

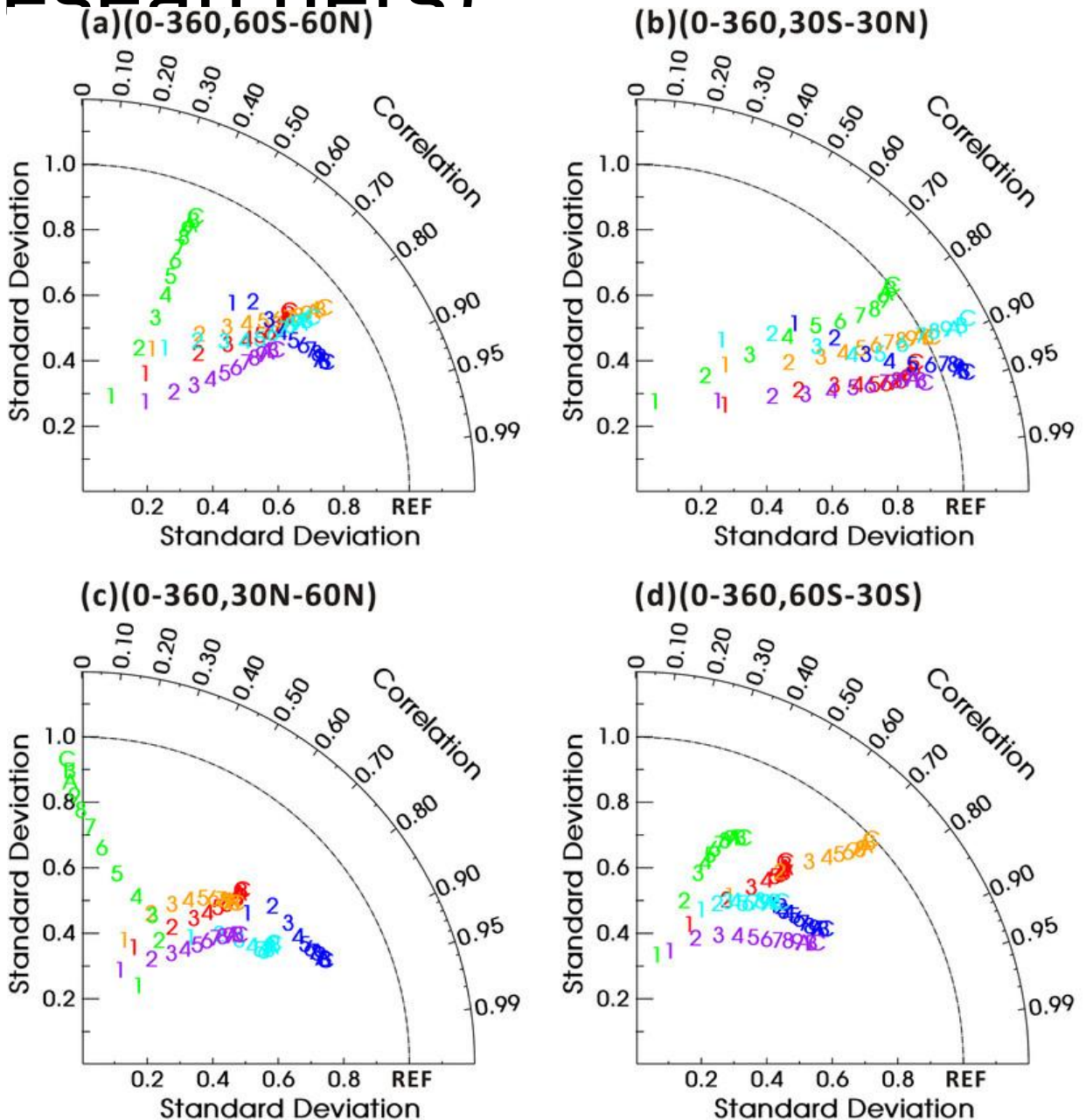
Backup: Seasonal SST bias evolution (other researchers)

- Fig. 2 of Voldoire et al. (2019)



Backup: Seasonal SST bias evolution (other researchers)

- Fig. 7 of Ma et al. (2021)



Ongoing work: Quantification of bias evolution

- Use anomaly correlation: Correlation between bias map of Lead Month 0 (June) and bias map every other lead month (separately) over 50S-50N
- Correlation reaches a minimum at Lead Month 8 (February)
  - Note: Lead Month 6 (December) is halfway through solar cycle from initializations (late May)
- Bias correlations **increase** in Lead Months 9&10 (Mar & Apr)
- Very new result, more work needed (e.g., correlations using reanalysis data only)
- Implications for **bias reduction**