Comparing seasonal cycle and trend-based emergent constraints on future sea ice albedo feedback

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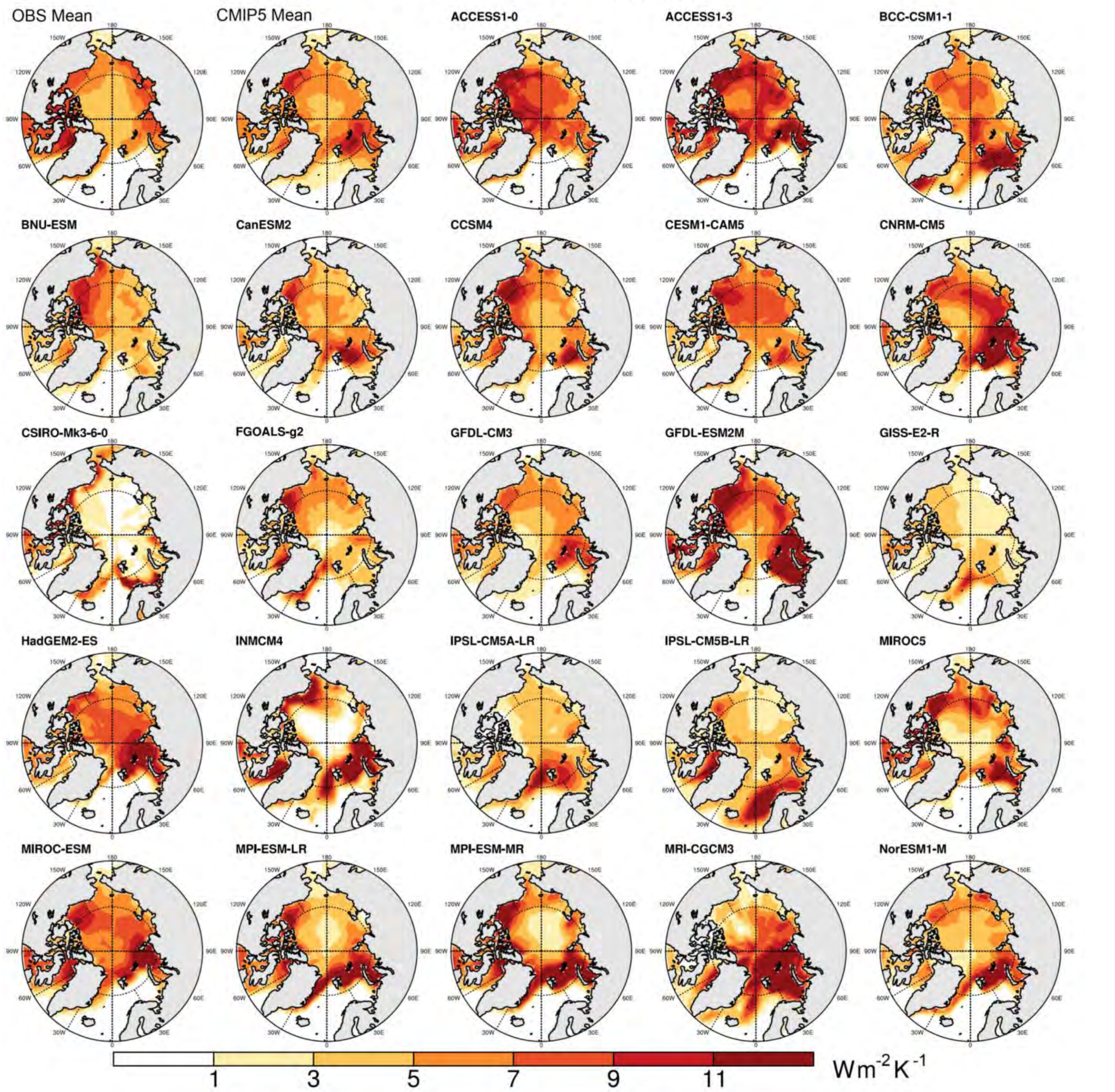
Motivation

- One of the largest sources of uncertainty in projections of Arctic climate change is the surface albedo feedback.

- Particularly the feedback stemming from sea ice retreat and thinning (i.e., sea ice albedo feedback; SIAF).

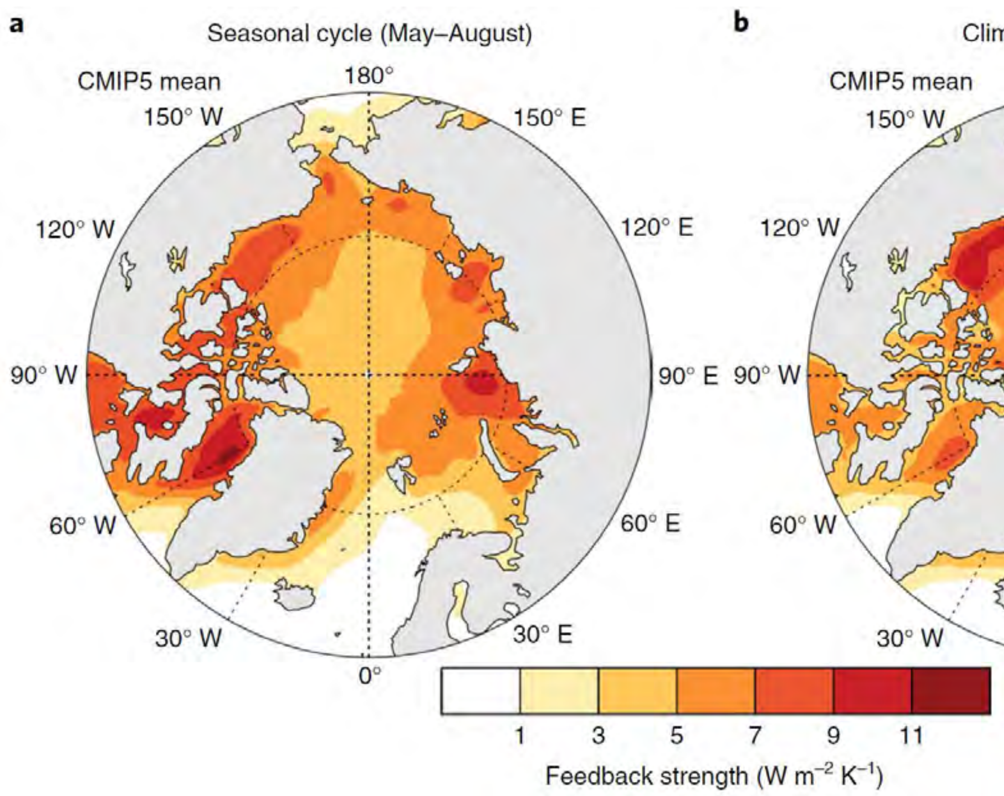
- We see a large diversity in SIAF strength under mid-century climate change across CMIP models.

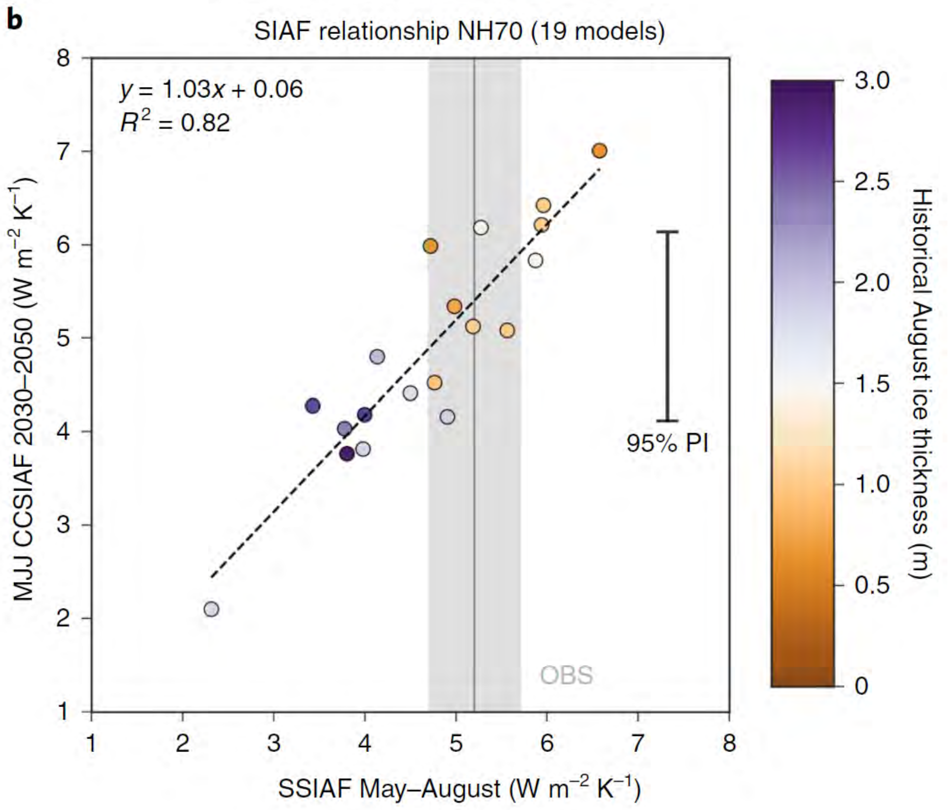
$$\mathrm{SAF}(t) = \frac{\partial Q_{\mathrm{net}}}{\partial \alpha_s}(t)\frac{\Delta \alpha_s(t)}{[\Delta T_s](t)}.$$



Thackeray and Hall 2019

Motivation

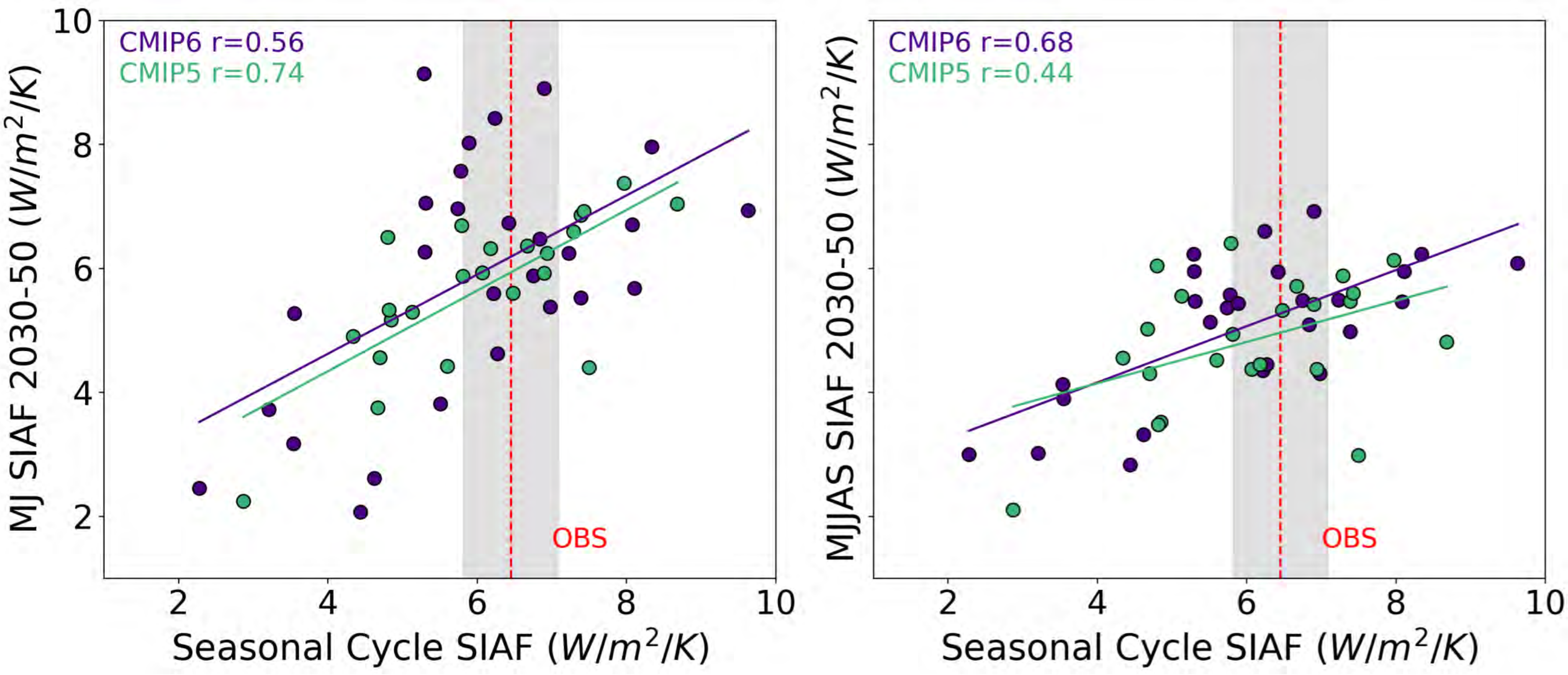




- We showed that model spread in climate change SIAF can be reduced through an emergent constraint (EC) using a measure of SIAF derived from climatological summer sea ice retreat.
  - Computed using climatological albedo and temperature for August and May along with a blend of 5 radiative kernels.
- The EC was improved when GCMs with unrealistically thin summer sea ice were removed.

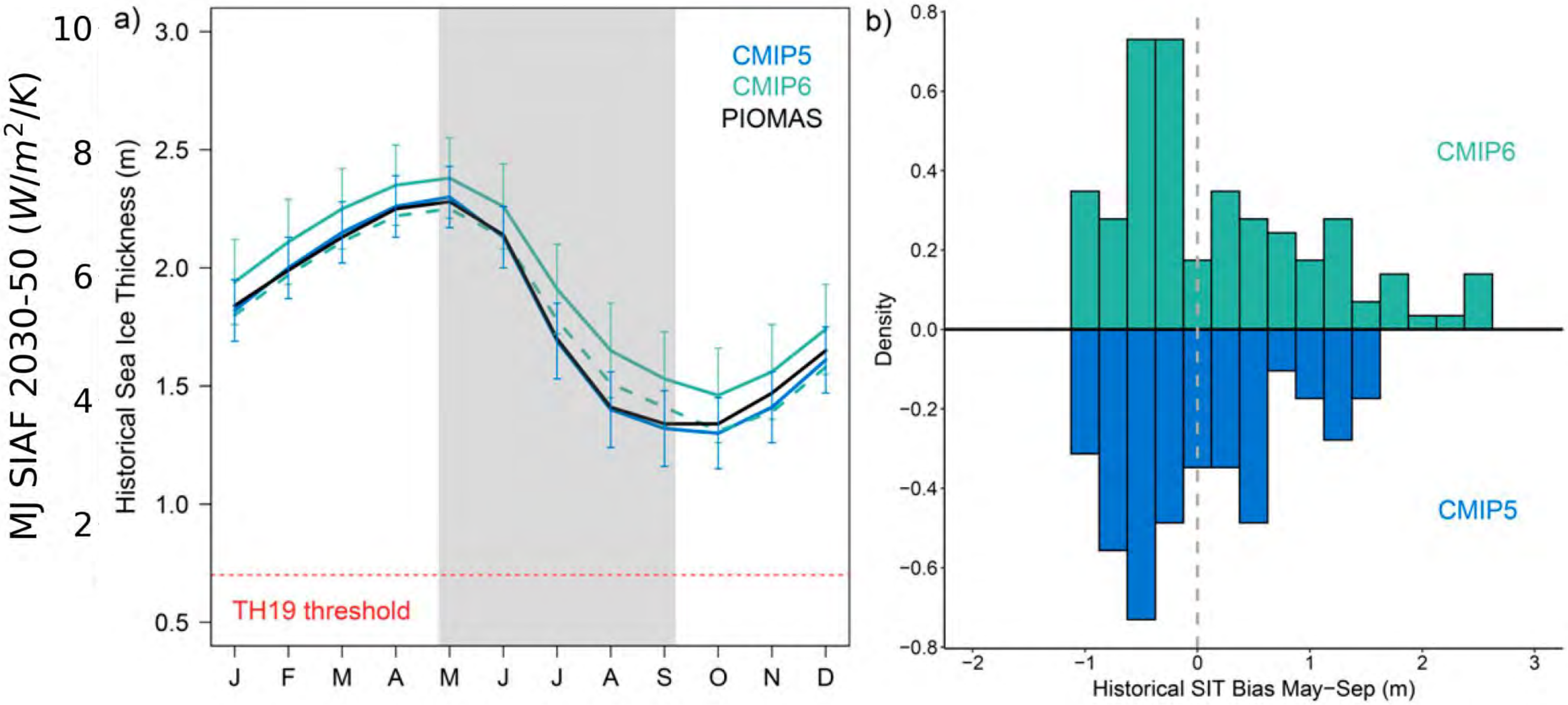
Thackeray and Hall 2019

CMIP6 showed differences from CMIP5



- However, these relationships were slightly different in CMIP6 (seasonal cycle better explained the whole summer SIAF: tied to fewer very low SIT models), which brings up questions about whether other observables might perform better.

CMIP6 showed differences from CMIP5

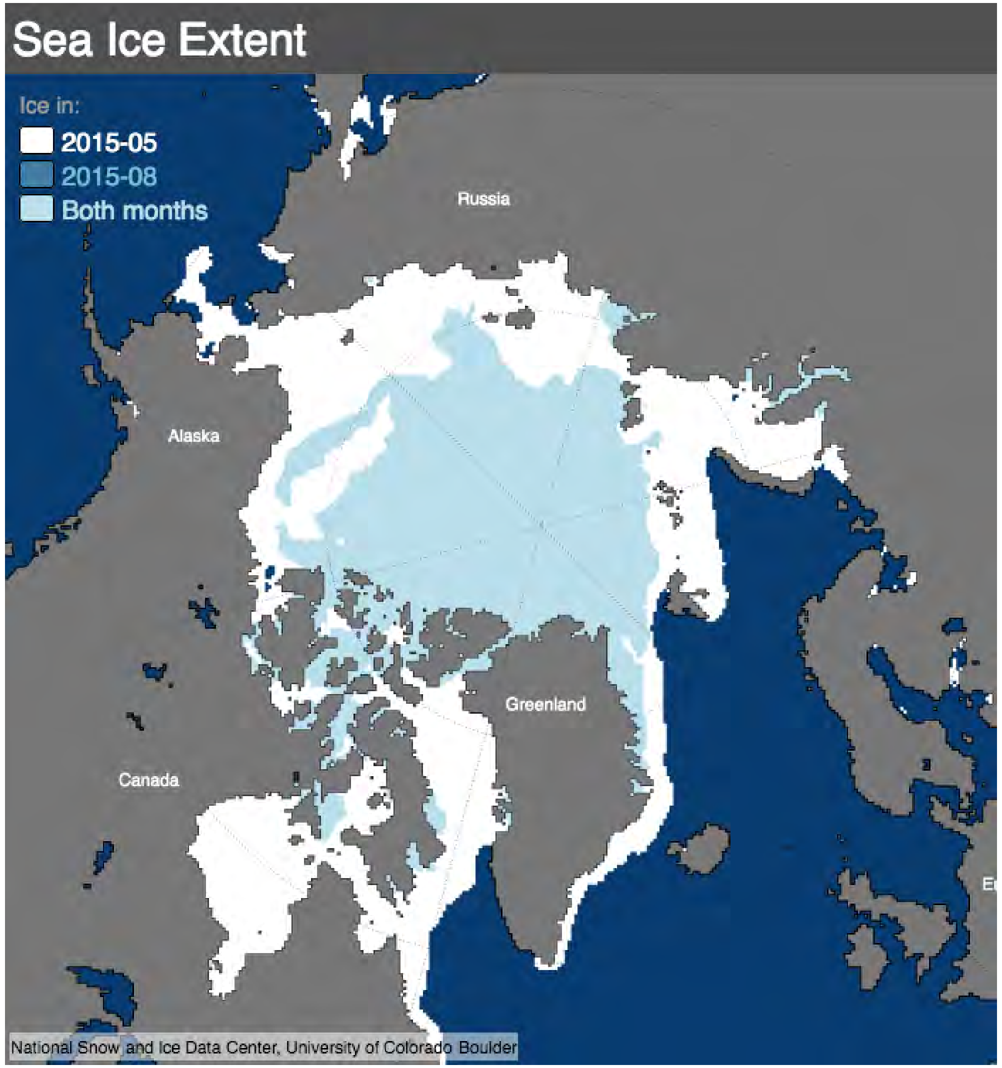


- However, these relationships were slightly different in CMIP6 (seasonal cycle better explained the whole summer SIAF: tied to fewer very low SIT models), which brings up questions about whether other observables might perform better.

Datasets

- **Model data:** 41 GCMs from CMIP5+CMIP6
- **Radiative kernels:** blend of 5 kernels

- **Albedo data:** APP-x (1982-2020), CLARA-A2 (1982-2015: updating to version 3*)
- **Temperature data:** MERRA2 (1980-2020), NCEP-II (1980-2020).

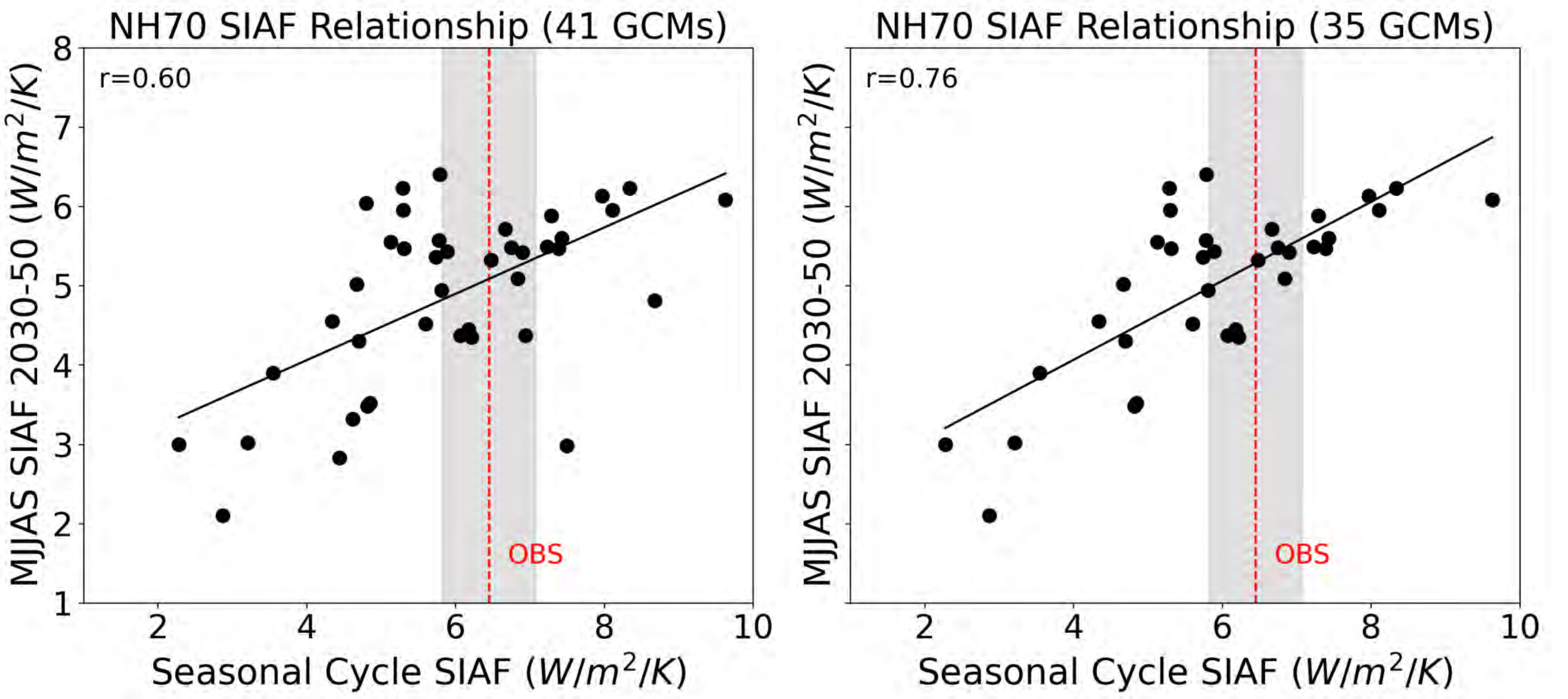


Observable Metrics

EC Name	Type	Description
Seasonal SIAF (1980-2015)	Seasonal Cycle	Thackeray and Hall 2019: Surface albedo feedback calculated from albedo and temperature climatologies for May and August and a blend of 5 radiative kernels.

- The seasonal SIAF metric was chosen for its resemblance to the established snow albedo feedback EC, but it is possible that other types of seasonal or trend metrics may prove to be even more robustly tied to SIAF.
- Here, we explore the use of 4 possible metrics for constraining the mid-century summer (MJJAS) SIAF across the Arctic.

Seasonal SIAF relationship sensitive to initial SIT



- For the Thackeray and Hall (2019) method, we once again remove the GCMs with unrealistically thin summer SIT (defined as <0.6m in August).
- This metric suggests a mid-century summer SIAF of 5.2+/-0.8 $W/m^2/K$ (vs. 5.1 +/- 1.0).

Observable Metrics

EC Name	Type	Description
Seasonal SIAF (1980-2015)	Seasonal Cycle	Thackeray and Hall 2019: Surface albedo feedback calculated from albedo and temperature climatologies for May and August and a blend of 5 radiative kernels.
Albedo Climatology (2010-2020)	Seasonal Cycle	Arctic albedo change from May to Aug calculated for each year. Average across the most recent decade (2010-2020).

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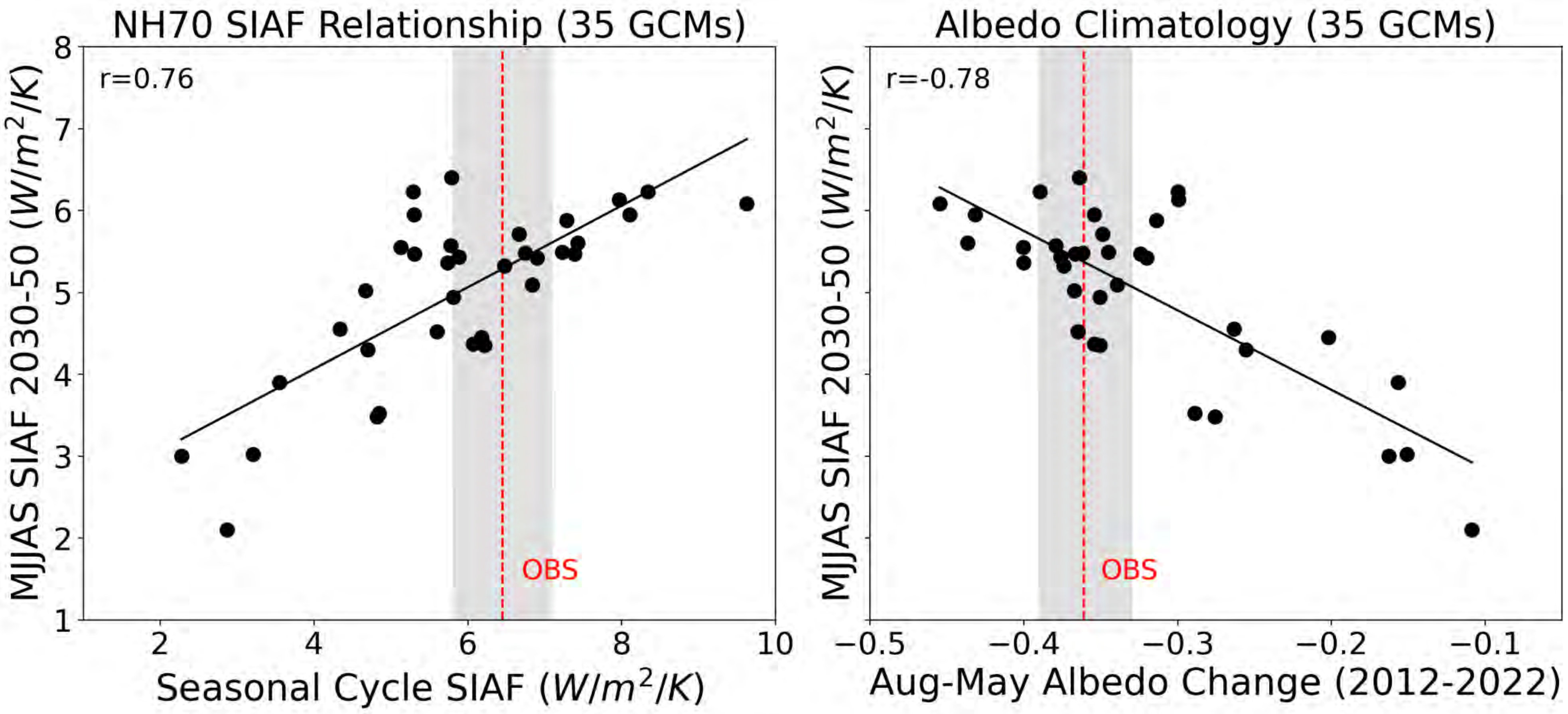
Seasonal Cycle Metrics



- In addition to the seasonal SIAF constraint, we also find that the most recent decadal average of seasonal albedo change (Aug-May) is informative of future SIAF.
- The relationship shown here, also improves when the GCMs with the thinnest ice are removed.

Observable Metrics

EC Name	Type	Description
Seasonal SIAF (1980-2015)	Seasonal Cycle	Thackeray and Hall 2019: Surface albedo feedback calculated from albedo and temperature climatologies for May and August and a blend of 5 radiative kernels.
Albedo Climatology (2010-2020)	Seasonal Cycle	Arctic albedo change from May to Aug calculated for each year. Average across the most recent decade (2010-2020).
Albedo Trend (1982-2020)	Trend	The trend in summer mean (MJJAS) surface albedo across the Arctic is divided by the contemporaneous trend in temperature.
SIAF Trend (1980-2015)	Trend	Similar to TH19, but SIAF is calculated for each year of the timeseries. The trend is then computed over recent decades.

- The seasonal SIAF metric was chosen for its resemblance to the established snow albedo feedback EC, but it is possible that other types of seasonal or trend metrics may prove to be even more robustly tied to SIAF.
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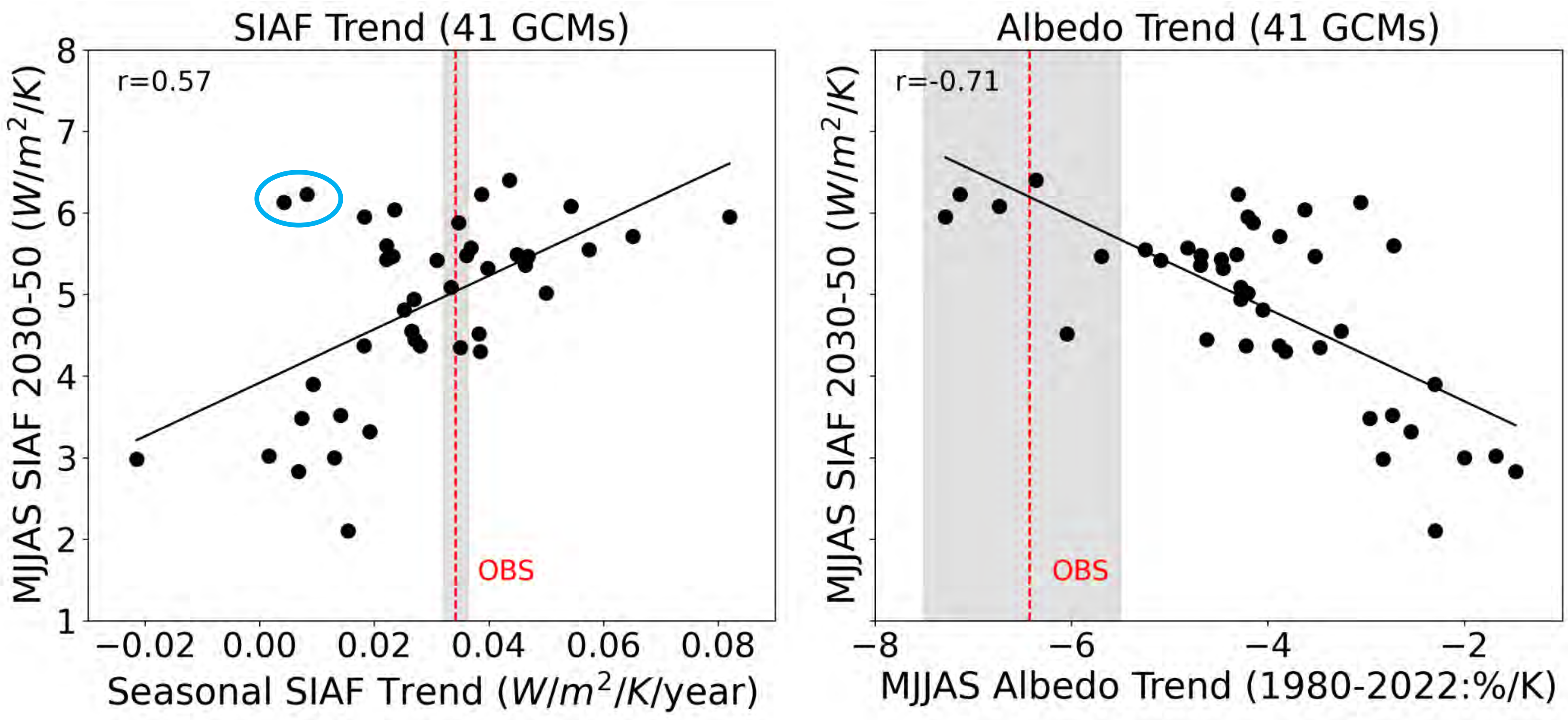
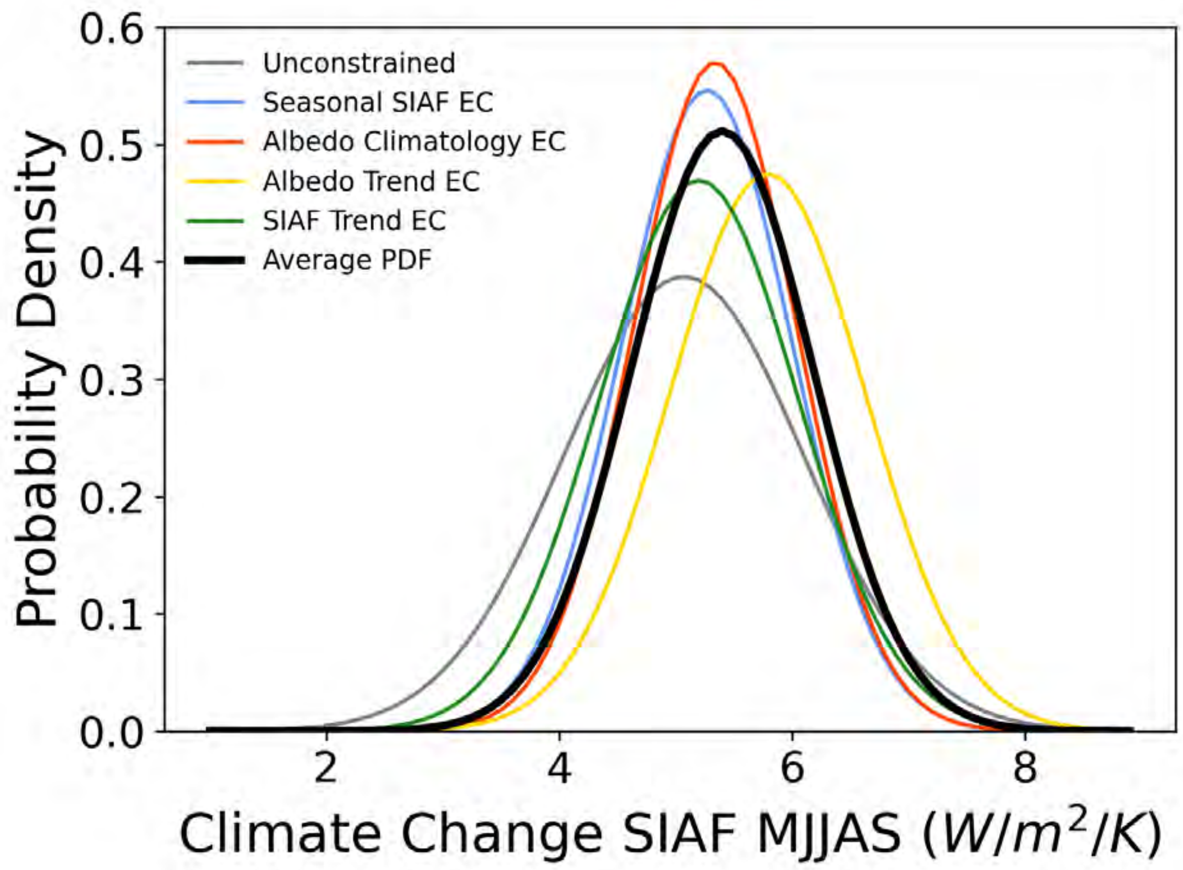
Trend metrics are sensitive to historical warming



- Some trend-based metrics are reasonably well correlated with future SIAF. In this case, GCMs with weak historical warming dampen the relationship strength.
- Likely need to use multiple realizations for trend-based metrics.

Constrained PDFs support TH19 results

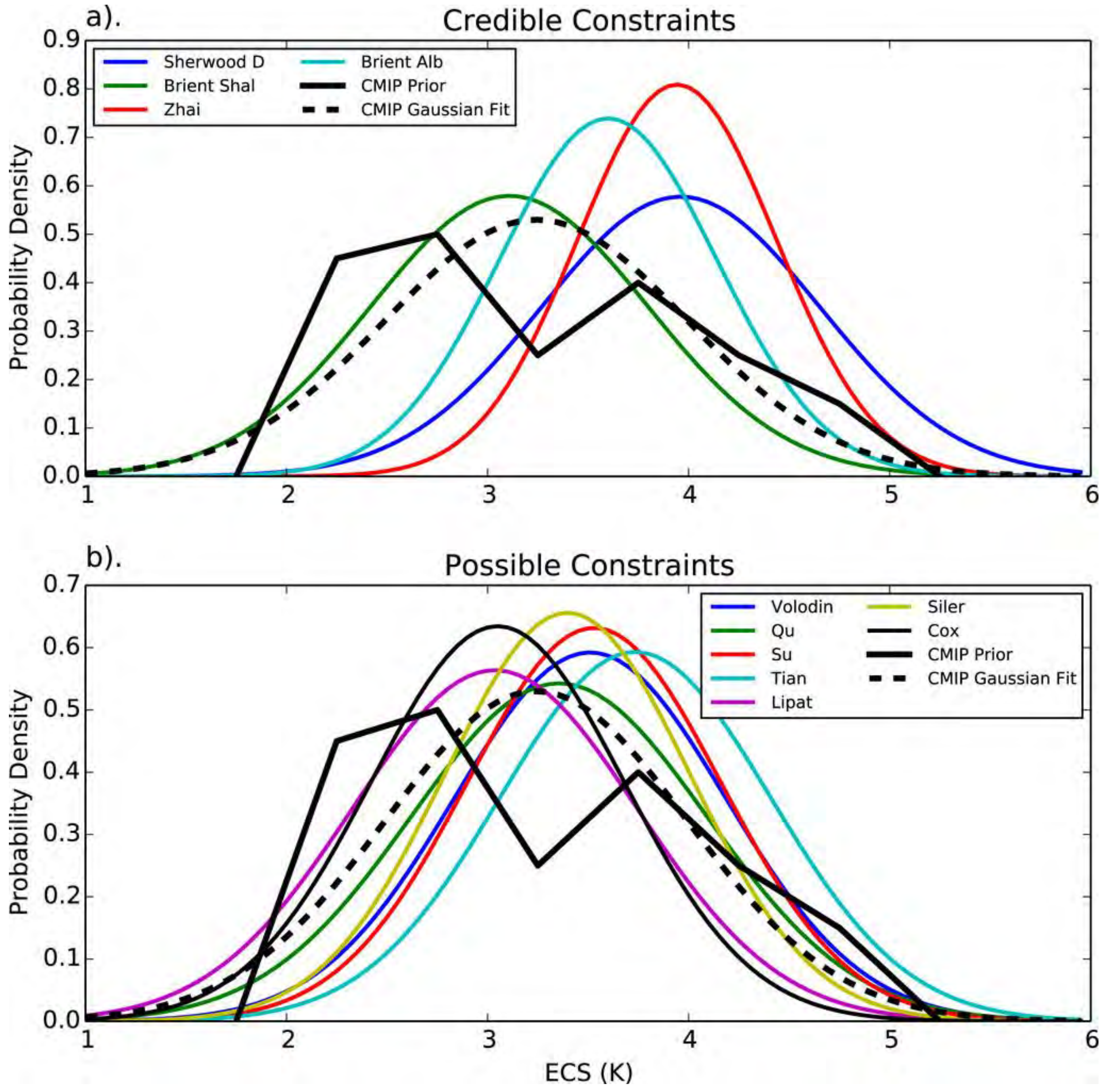


95% prediction intervals are calculated following Bowman et al. 2018, which accounts for correlation strength and the ratio of observational to model uncertainty.

- **The constrained PDFs all point to SIAF being larger than the unconstrained mean (5.07 ±1.03), which supports the findings of TH19 (average = 5.40±0.78 $W/m^2/K$).**
- The albedo trend EC is the most unique from the others (5.79±0.84), it also supports prior findings that GCMs underestimate observed sea-ice loss over recent decades.

Can we better combine constraints on SIAF?

- Bretherton and Caldwell (2020) introduced the concept of combining constraints for climate sensitivity because numerous constraints had been proposed for it.
- They state that combining constraints is only useful if those constraints provide some independent information.
- To assess interdependence of constraints, they suggest computing partial correlation coefficients between each set of constraints.
- Weights can then be calculated to determine the relative value of each constraint.



Bretherton and Caldwell 2020

Relevance to Global Feedbacks

Feedback Parameter α_x (W m^{-2} °C^{-1})	CMIP5 GCMs	CMIP6 ESMs	AR6 Assessed Ranges			
	Mean and 5–95% Interval	Mean and 5–95% Interval	Central Estimate	*Very likely* Interval	*Likely* Interval	Level of Confidence
Planck	–3.20 [–3.3 to –3.1]	–3.22 [–3.3 to –3.1]	**–3.22**	–3.4 to –3.0	–3.3 to –3.1	*high*
WV+LR	1.24 [1.08 to 1.35]	1.25 [1.14 to 1.45]	**1.30**	1.1 to 1.5	1.2 to 1.4	*high*
Surface albedo	0.41 [0.25 to 0.56]	0.39 [0.26 to 0.53]	**0.35**	0.10 to 0.60	0.25 to 0.45	*medium*
Clouds	0.41 [–0.09 to 1.1]	0.49 [–0.08 to 1.1]	**0.42**	–0.10 to 0.94	0.12 to 0.72	*high*
Biogeophysical and non-CO_2 biogeochemical	Not evaluated	Not evaluated	**–0.01**	–0.27 to 0.25	–0.16 to 0.14	*low*
Residual of kernel estimates	0.06 [–0.17 to 0.29]	0.05 [–0.18 to 0.28]				
Net (i.e., relevant for ECS)	–1.08 [–1.61 to –0.68]	–1.03 [–1.54 to –0.62]	**–1.16**	–1.81 to –0.51	–1.54 to –0.78	*medium*
Long-term ice-sheet feedbacks (millennial scale)				>0.0		*high*

- For consistency with past work, our constrained central estimates can be rescaled to better understand the contribution of SIAF to the global albedo feedback: 0.10±0.02 W/m²/K.
- This is slightly smaller than the value we reported in TH19 (0.13±0.02 W/m²/K), mainly tied to methodological changes.
- Computed by multiplying the summer value by (1) the ratio of annual to summer mean SIAF, (2) the ratio of the Arctic domain to global area (~0.03), and (3) the ratio of Arctic to global mean surface warming (~2.16 for 2030-50 in CMIP5).

Summary

- Expanding on Thackeray and Hall (2019), we test the robustness of a variety of observable albedo metrics for constraining mid-century Arctic sea-ice albedo feedback.

- Two metrics capturing the seasonal cycle are well correlated with future SIAF when GCMs with the thinnest ice pack are discarded. Two alternative trend-based metrics are proposed, and they generally support the findings of TH19.

- An EC based on these four metrics suggests a 24% reduction in model spread and that mid-century SIAF is slightly stronger than expected.

- Further work needed to explore the areas of the Arctic that are driving each relationship. Also, to account for cross-correlation between constraints. Although it should be noted that none of the ECs have a significant partial correlation coefficient (albedo trend and SIAF trend metrics are most similar).

Thanks for listening!

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