CESM Dominates CMIP6 Ensemble in Pareto Optimal Evaluation of Tropical Low Cloud Simulation

Mengxi Wu[1], Hui Su[1,2], J. David Neelin[3], Ni Dai[1], Leo Donner[4], Charles Seman[4], Kathleen A. Schiro[5]

[1]Joint Institute for Regional Earth System Science & Engineering, University of California, Los Angeles
[2]Department of Civil and Environmental Engineering, Hong Kong University of Science and Technology
[3]Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles
[4]Geophysical Fluid Dynamics Laboratory, Princeton University
[5]Department of Environmental Sciences, University of Virginia

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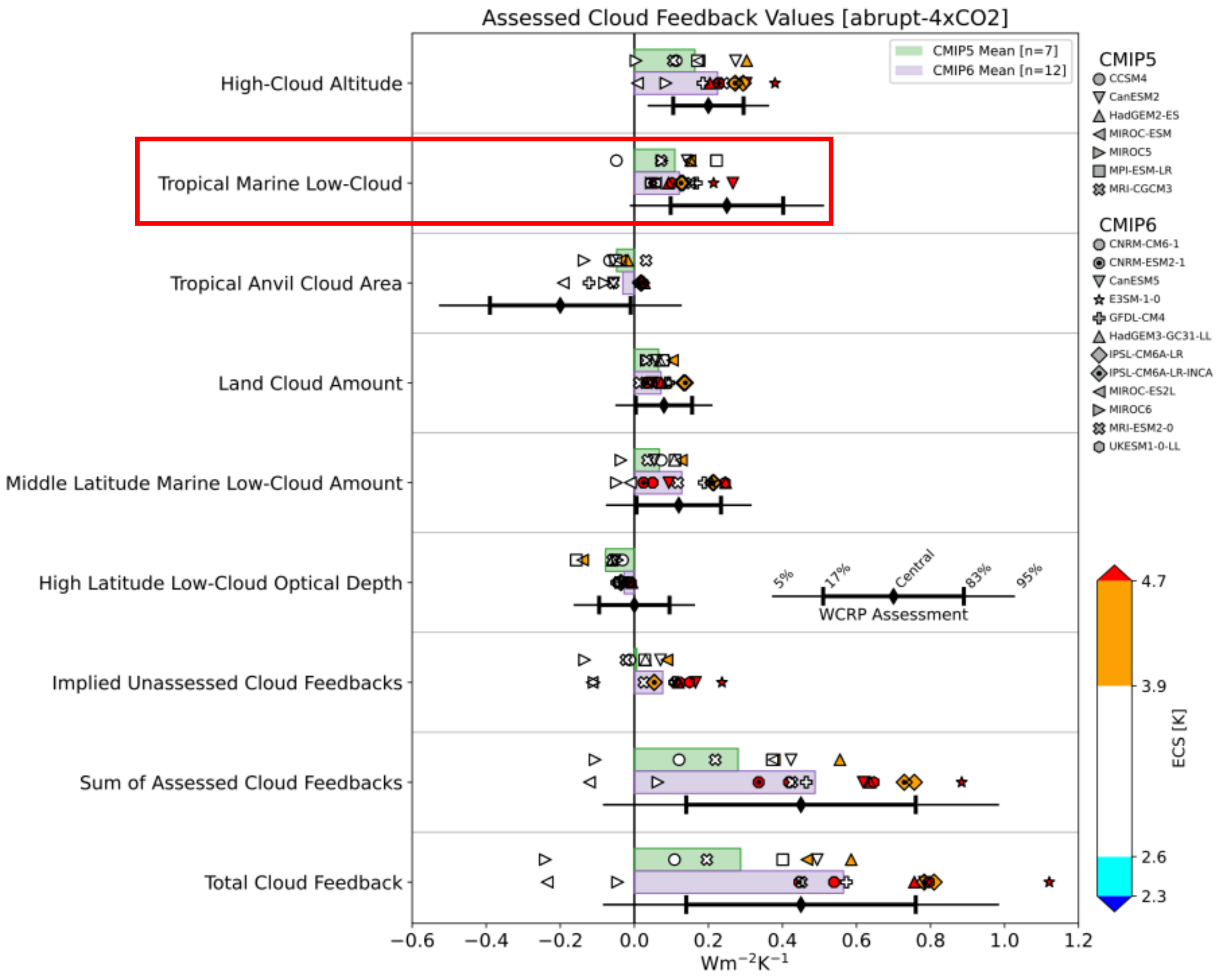
Motivation

Tropical marine low clouds remain to be an important source of the uncertainty in the total cloud feedback.



Zelinka et al. (2022)

Observed low cloud responses to local and remote SST

Conceptual model:

(e.g., Zhou et al. 2017)

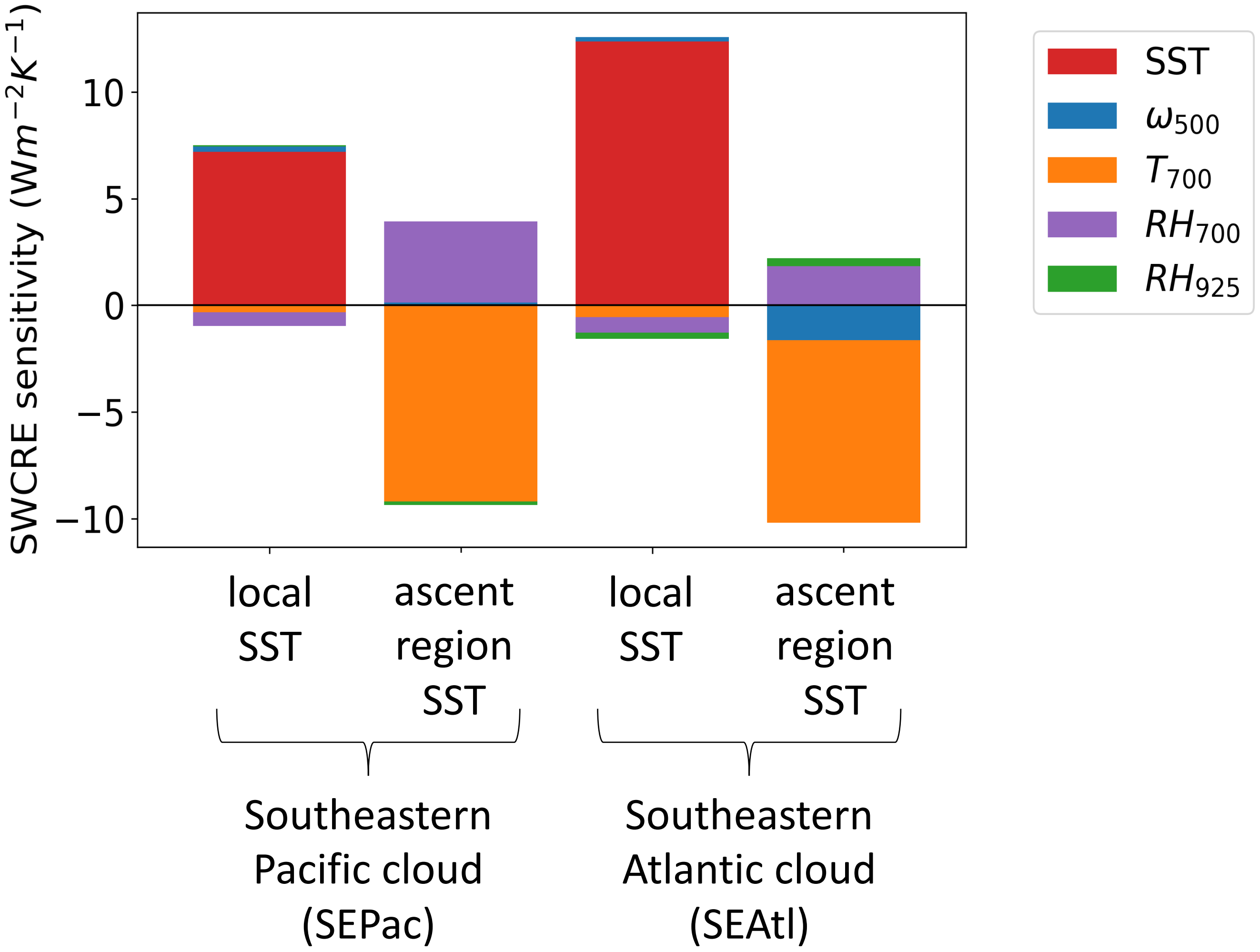
Ascent region SST

⇒ deep convection

⇒ T_{700} (WTG)

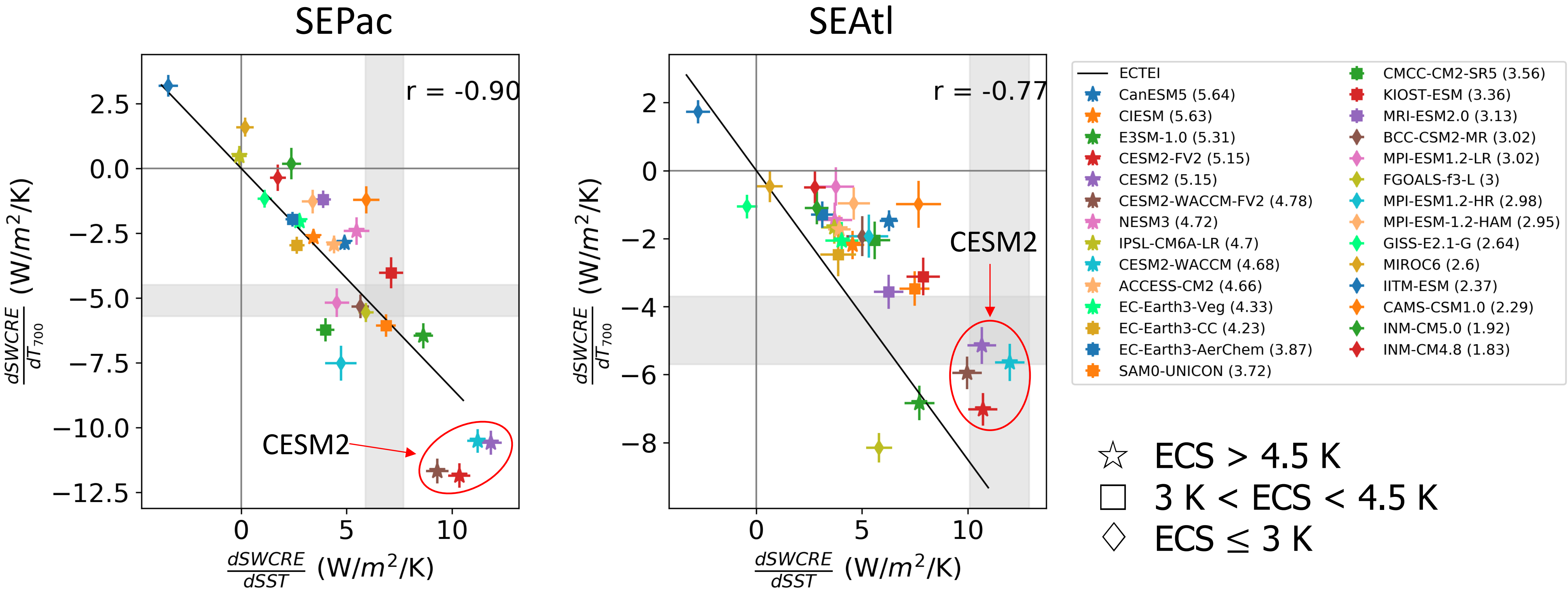
⇒ EIS

⇒ LCC



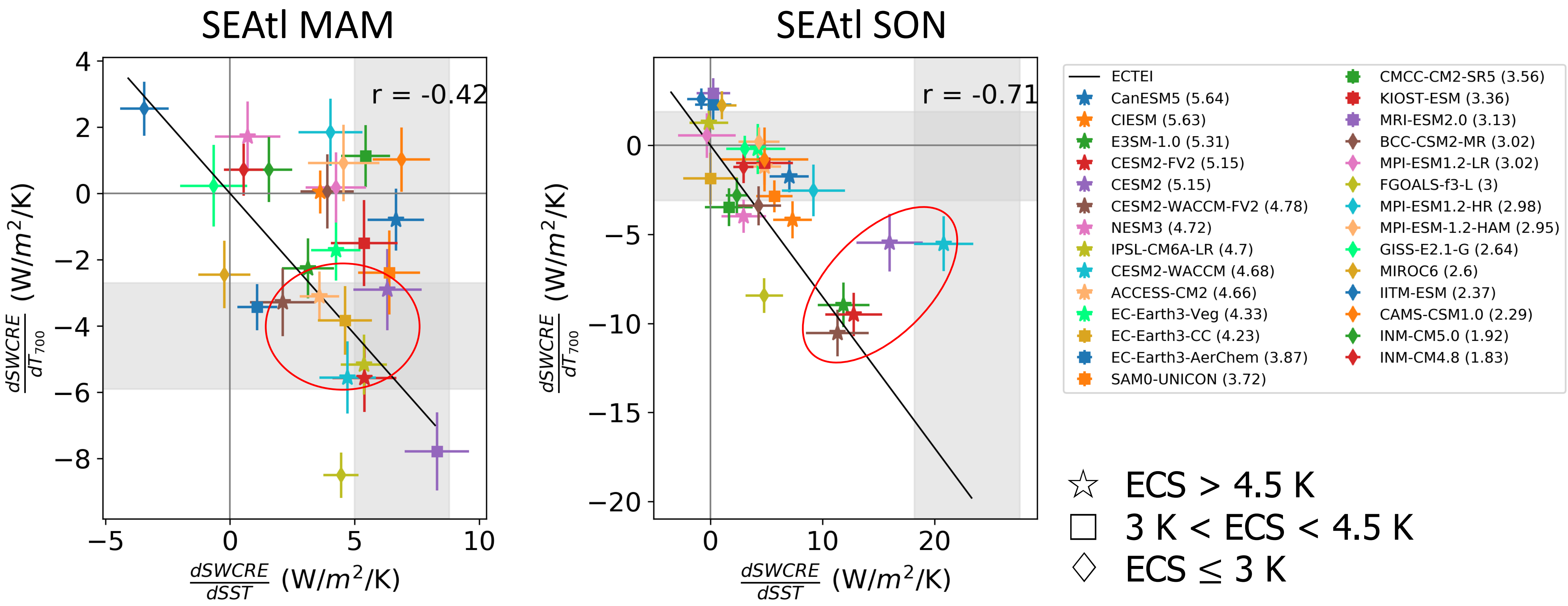
Relationship between SWCRE sensitivities to SST and T_{700}

- $\Delta SWCRE = k_{SST}\Delta SST + k_{T700}\Delta T_{700} + \varepsilon$
- $ECTEI = EIS - \beta \frac{L}{c_p}(q_{sfc} - q_{700})$. (Kawai et al., 2017)

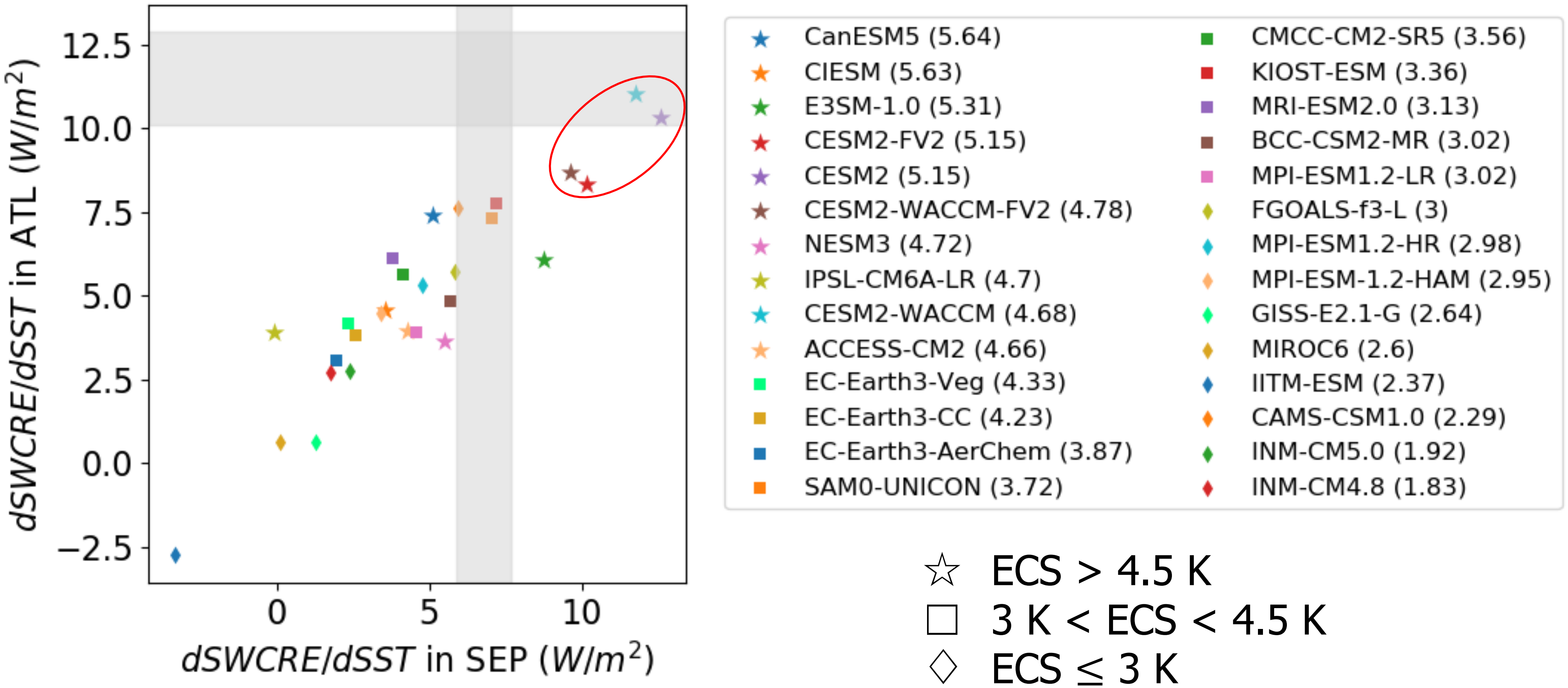


Seasonality associated with WTG

The correlation between SEAtl T_{700} and Pacific warm pool T_{700} drops below 0.5 during SON, while it can reach 0.8 during MAM.



Conflict between individual index-based constraints



☆ ECS > 4.5 K

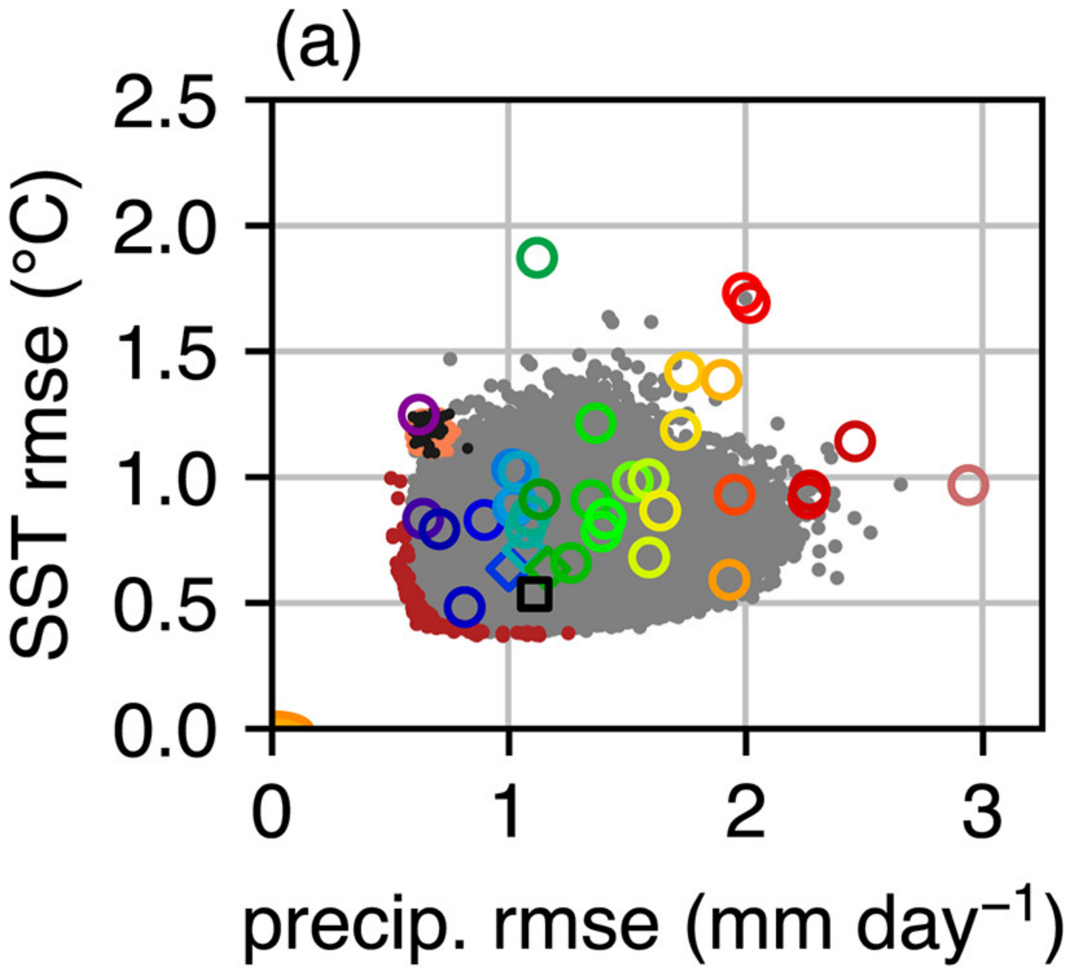
□ 3 K < ECS < 4.5 K

◇ ECS ≤ 3 K

Pareto optimality with multiple objectives

Pareto optimal:

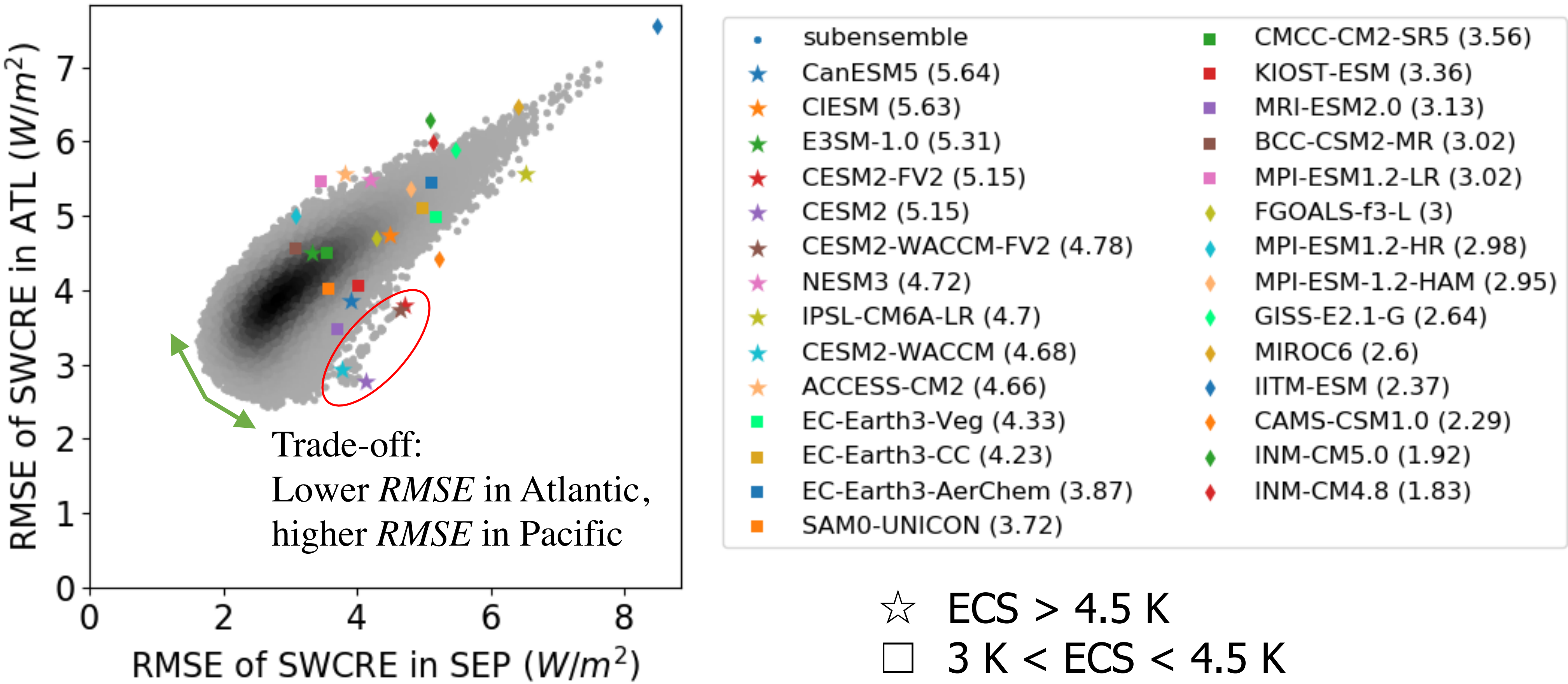
There is no alternative which is better in all dimensions, i.e., we cannot improve in one dimension without worsening in some other dimensions.



Langenbrunner & Neelin (2017)

Result of Pareto optimization

$$RMSE = \sqrt{\frac{1}{n} \sum_{space/time} \left[(k_{SST}^{model} - k_{SST}^{obs}) \Delta SST + (k_{T700}^{model} - k_{T700}^{obs}) \Delta T_{700}^{model} \right]^2}$$



☆ ECS > 4.5 K
□ 3 K < ECS < 4.5 K
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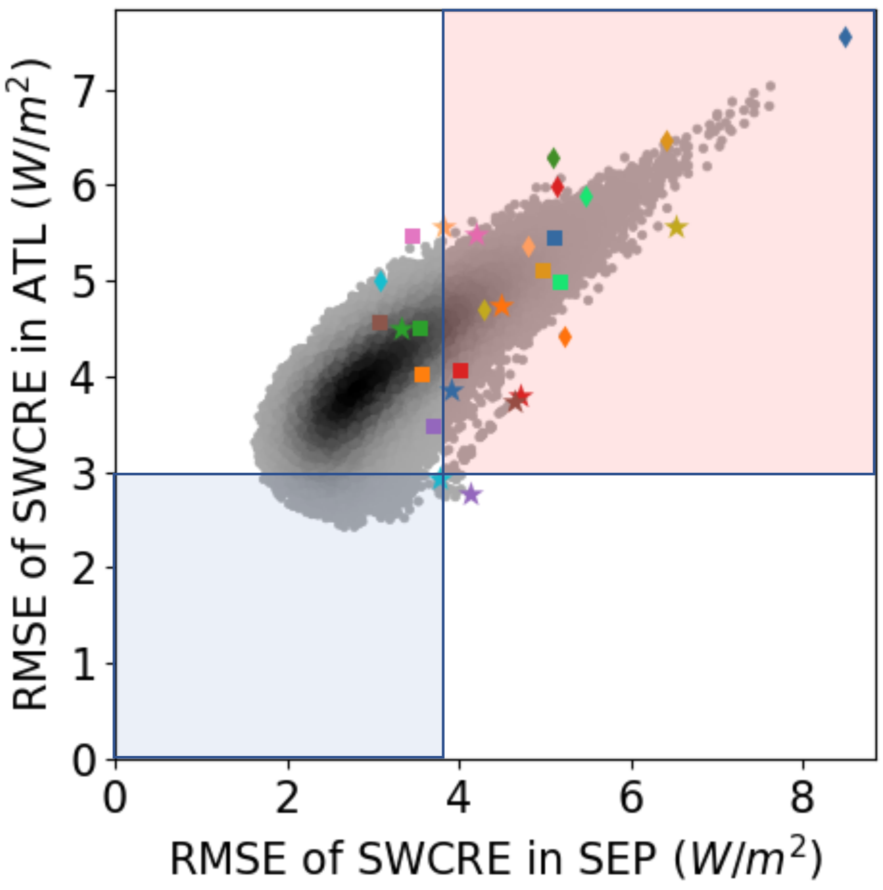
Pareto evaluation of individual models

Probability weight of individual model or model subensemble:

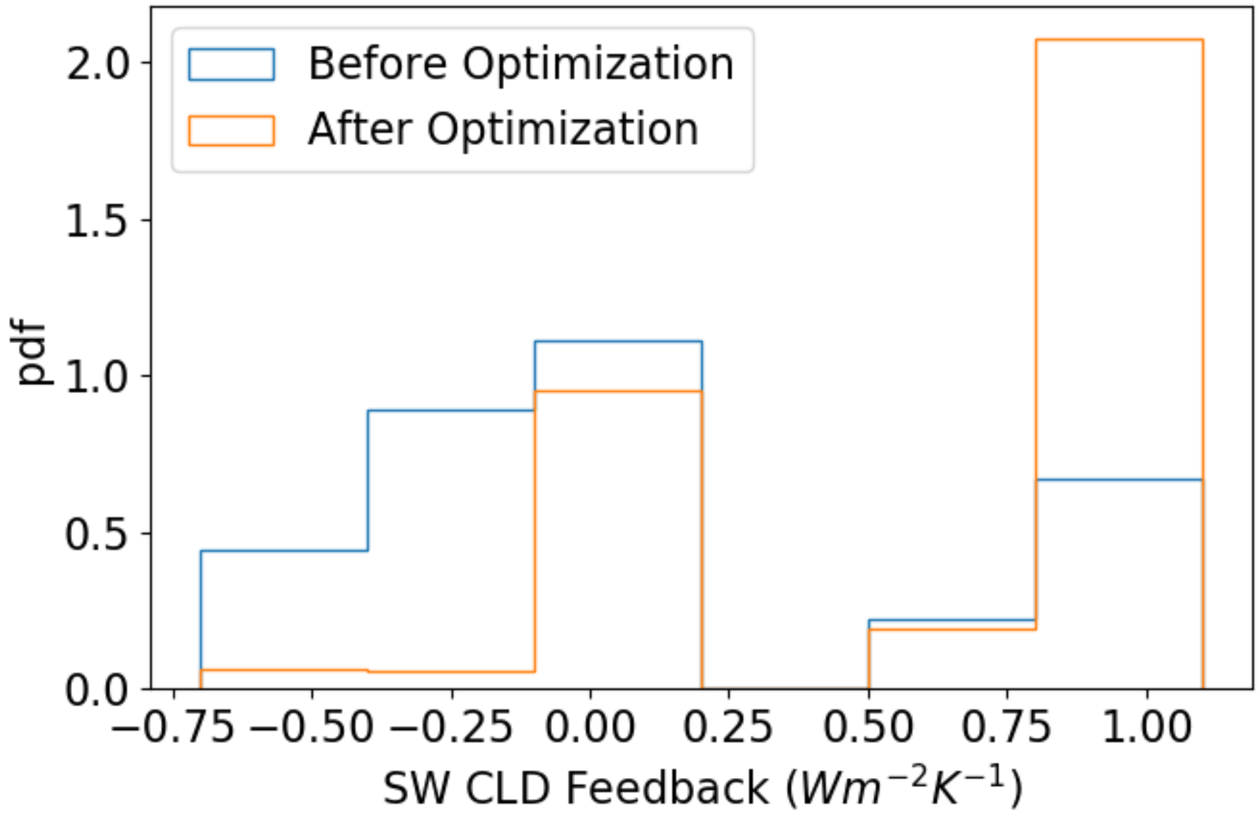
- Data points in the red quadrant are worse than the chosen model.
- Data points in the blue quadrant are better than the chosen model.

$$weight = \frac{red}{red + blue} \in [0, 1]$$



Update SW cloud feedback pdf using Pareto optimization

- Data before Pareto optimization from Zelinka et al. (2020).
- Pareto optimization results in very low likelihood of a negative SW cloud feedback.
- CESM2 and CESM2-WACCM dominate the increased probability of SW cloud feedback > 0.5 $Wm^{-2}K^{-1}$.



Conclusion

1. Using SST and T_{700} as cloud controlling factors can explicitly account for the tropical marine low cloud feedback due to remote warming in ascent regions.
2. Many models and the ECTEI index agree well with the observed SWCRE sensitivity to SST and T_{700} when and where the WTG approximation holds well.
3. CESM2 models outperform other models for SEAtl with much higher sensitivities, especially CESM2 and CESM2-WACCM.
4. The Pareto optimization suggest a positive and possibly large shortwave cloud feedback.