Emergent constraints on climate sensitivity based on recent warming are biased low by sea-surface temperature pattern effects

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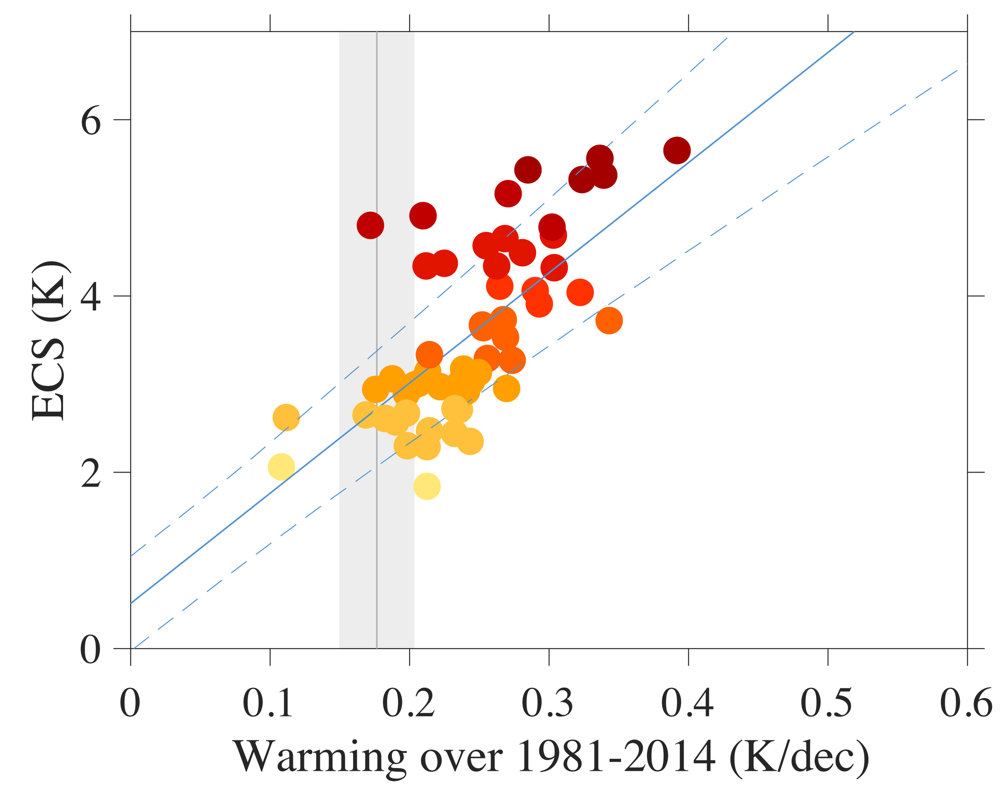
Summary

Global climate models show a tight relationship between post-1970s global warming and climate sensitivity. It has thus been proposed that observations of this recent global warming rate can be used together with model-derived estimates of the warming-sensitivity relationship to produce an emergent constraint on Earth's climate sensitivity and warming projections[1-4]. However, climate models do not reproduce the observed spatial pattern of warming, introducing a bias in the modeled warming-sensitivity relationship via the influence of sea-surface temperature patterns on radiative feedbacks. The result is that emergent constraints on climate sensitivity based on recent warming are overly-confident: high values of climate sensitivity cannot be excluded based on observed warming over recent decades. How the spatial pattern of warming evolves will influence the rate of future global warming, introducing a major uncertainty in climate projections.

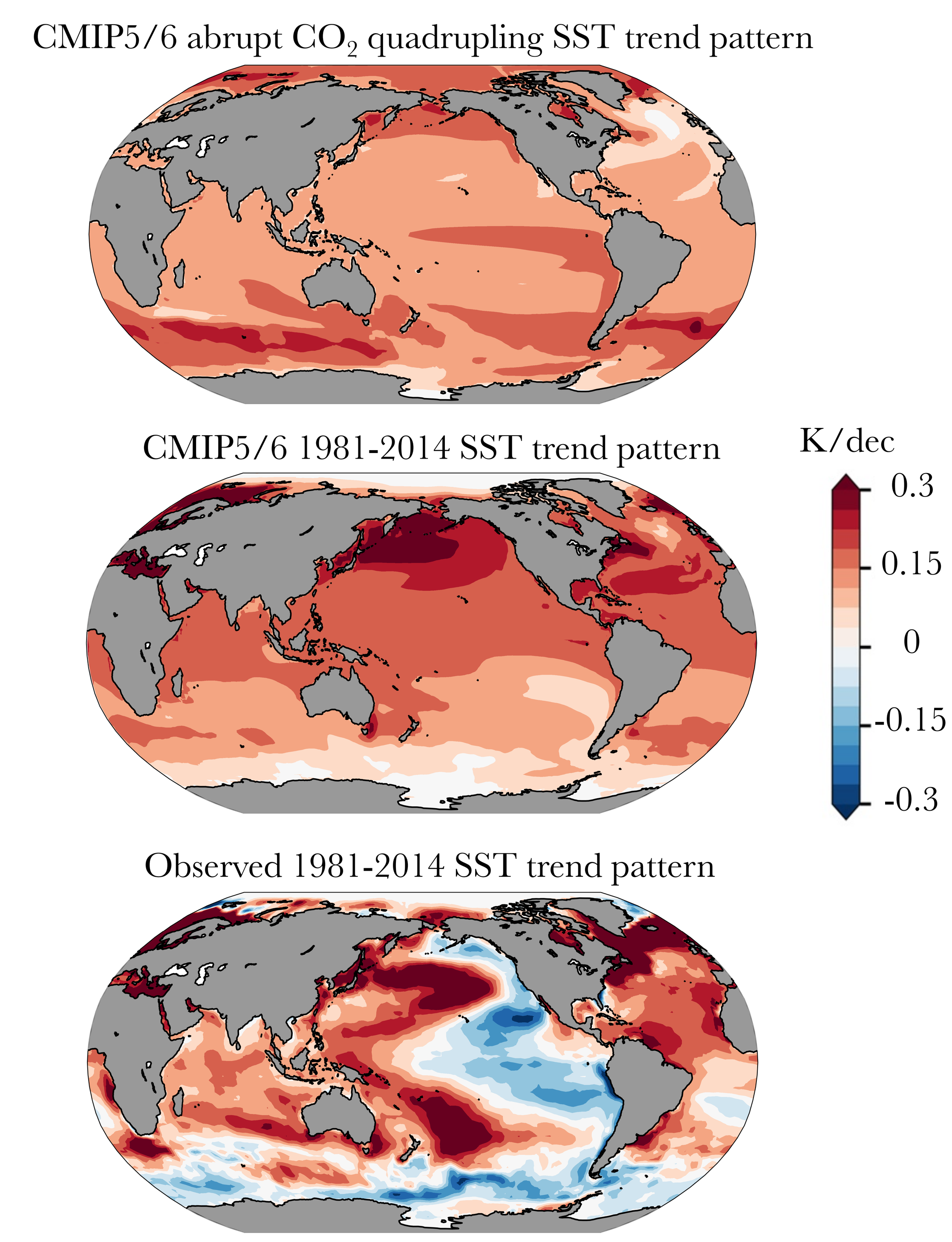
1. CMIP5/6 relationship between climate sensitivity and recent warming rate

Correlation between post-1970s warming and equilibrium climate sensitivity (ECS) or transient climate response (TCR) has been proposed as the basis for an strong emergent constraint[1-4]: ECS = 2.7°C (1.5-3.9°C) and TCR = 1.6°C (1.1-2.1°C) using HadCRUT5 over the period 1981-2014



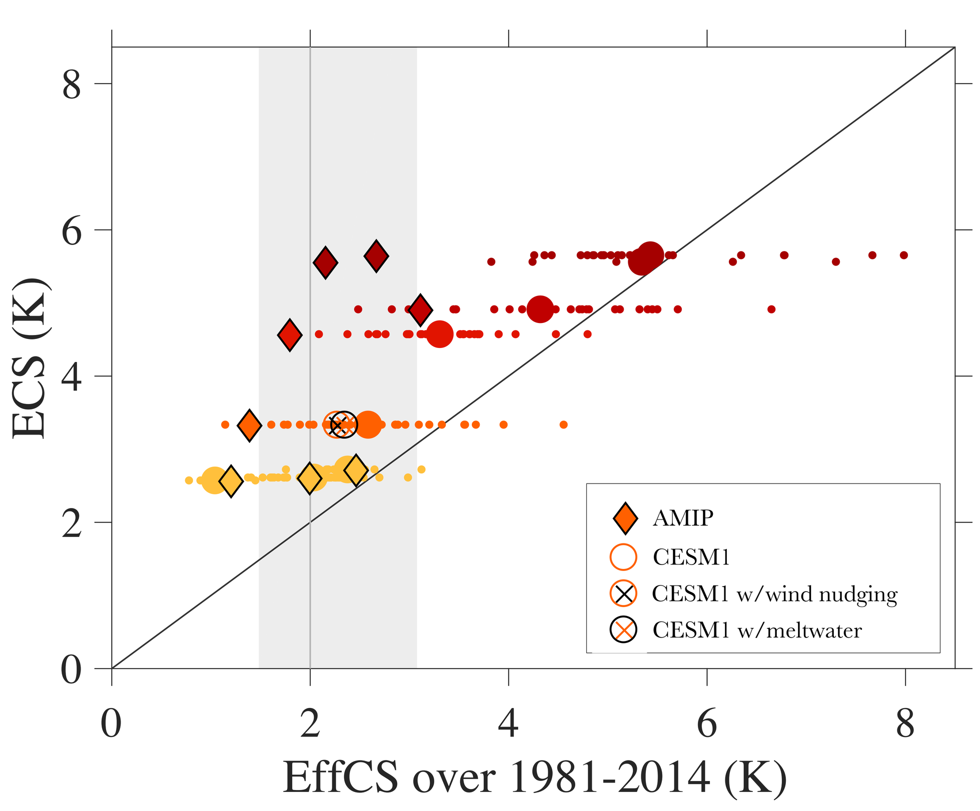
2. CMIP5/6 historical and abrupt4xCO2 warming patterns are similar, but both are different from observed warming patterns[5]

The stark differences in SST trend patterns between CMIP5/6 and observations suggests there is a pattern effect to account for in emergent constraints based on recent warming



3. CMIP5/6 *effective* climate sensitivity (EffCS) values in historical simulations are similar to ECS values in abrupt4xCO2 simulations

That CMIP5/6 historical EffCS is similar to ECS forms the basis for the emergent constraint, but relies on there being similar historical and abrupt4xCO2 patterns of warming – which is true in models but not in nature

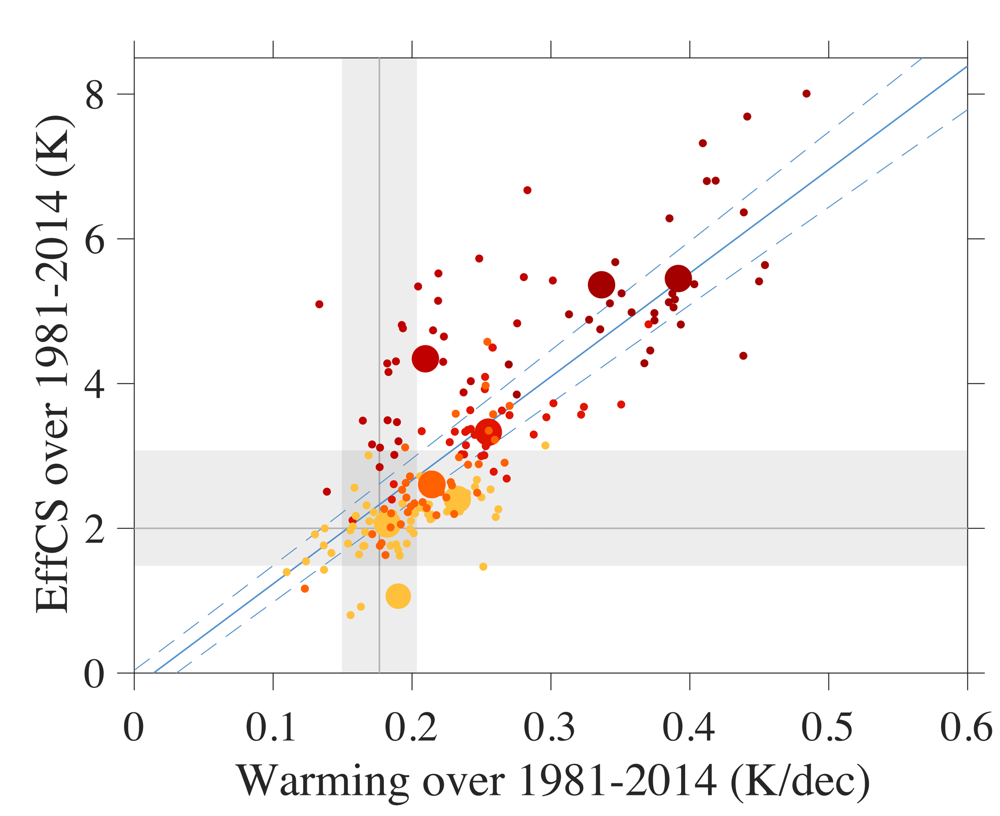


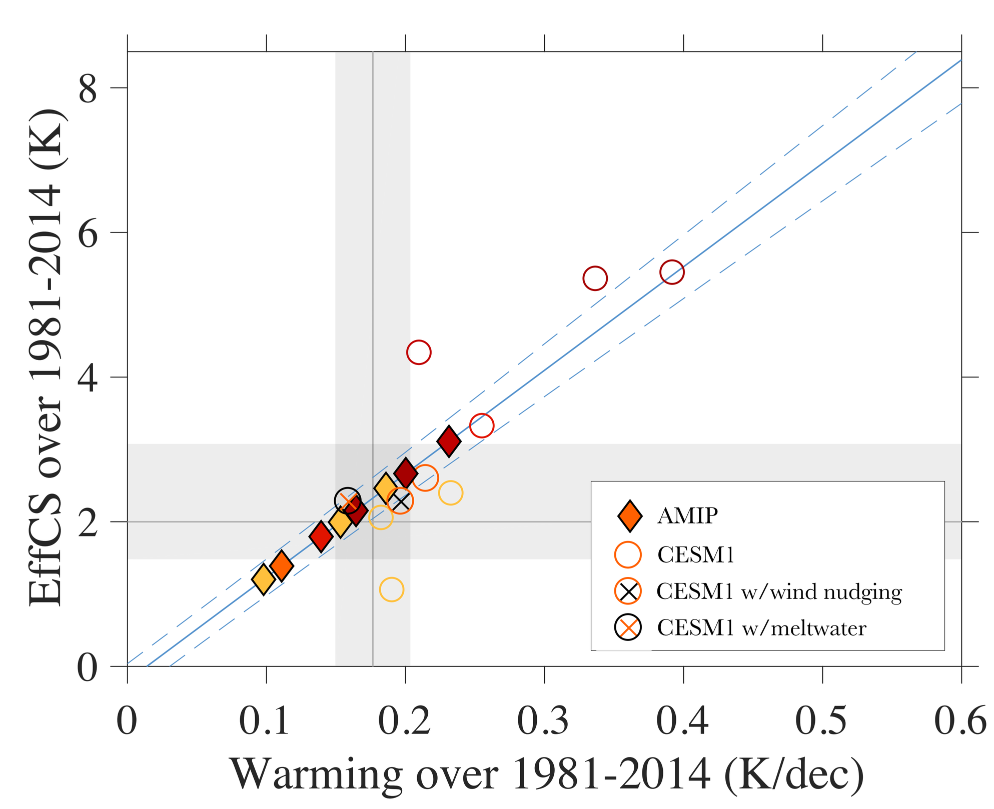
... there is large spread in EffCS across ensemble members due to internal variability, and both AMIP simulations[5] (using observed SST trend pattern, diamonds) and observed energy budget constraints[6] (shading) suggest a value of EffCS close to 2°C over this period – even for high ECS models

Note: Historical EffCS is calculated using RFMIP simulations for 8 CMIP5/6 models for which multiple ensemble members are available; see Dong et al. (2021) for details

4. There is a strong correlation between historical EffCS and warming over recent decades, suggesting that CMIP5/6 biases in SST trend patterns have contributed to their too-high rate of recent warming

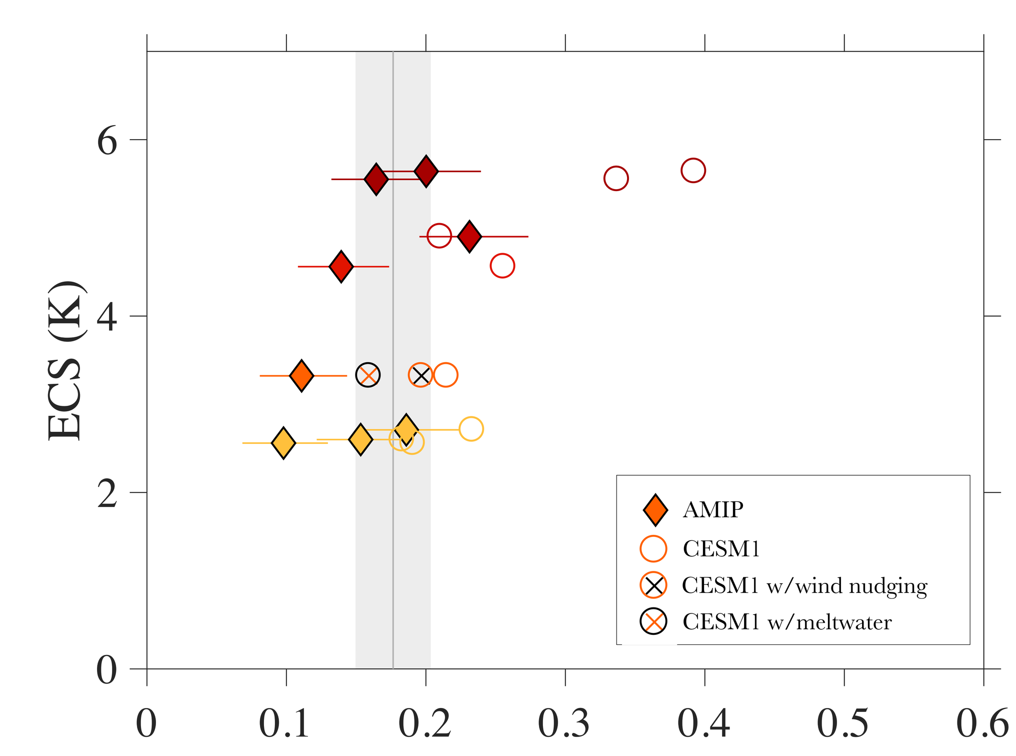
A common bias in the modeled correlation between ECS and warming rate, due to biases in warming patterns, biases the emergent constraint – but by how much?





5. Correcting for CMIP5/6 SST trend pattern biases relative to observations suggests that even high ECS (and TCR) models cannot be excluded by the emergent constraint

Using AMIP values of EffCS combined with the CMIP5/6 relationship between EffCS and warming rate suggests that CMIP5/6 models would have warmed near the observed rate had they produced the correct SST trend pattern over 1981-2014; these findings are corroborated by energy balance model simulations (not shown) and coupled model (CESM1-CAM5) simulations that better replicate observed patterns via tropospheric wind nudging or Antarctic meltwater fluxes (see work by Yue Dong!)



Key points

- CMIP5/6 historical simulations do not reproduce observed SST trend patterns; the same atmosphere models driven by observed patterns give lower effective climate sensitivity (EffCS) values that are consistent with the observed global warming rate and energy budget constraints
- The inability of CMIP5/6 models to replicate observed warming patterns results in a bias in the modeled correlation between recent global warming and climate sensitivity; the proposed emergent constraint thus produces estimates of ECS, TCR, and projected global warming that are biased toward low values
- Correcting for this bias means that observed warming does not exclude high values of ECS (or TCR)
- The results also suggest that how the spatial pattern of warming evolves will strongly influence the future global warming rate, and is thus a major uncertainty in climate projections; more work is needed to understand the causes of model-observation differences in historical warming patterns and build confidence in the warming patterns projected for the future

References

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