The Impact of SST Biases on Projections of Anthropogenic Climate Change: A Greater Role for Atmosphere-only Models?

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Supplementary Material

The supplementary material provides detailed description on model simulations and the calculation of internal precipitation variability, as well as additional comparison between the fully coupled and uniform AGCM simulations.

1. CGCMs from CMIP5

In addition to the CESM model, we use 15 additional CGCMs archived in CMIP5 (Table S1) to calculate the climatological SST and pattern of SST change used in the "modelSST", "ensemblePattern" and "modelPattern" simulations. Five CGCMs provide extended historical SST during year 1982-2011, which is used for the "modelSST" simulations. For the rest of the models, climatological SST is taken from the 1pctCO2 simulation during year 11-40 when the CO_2 level is similar to the observation during 1982 to 2011.

For the CMIP5 CGCMs, changes in SST are calculated as the difference between the last 20 years (year 121-140) and the first 20 years of the 1pctCO2 simulation. These SST changes represent the same intensity of external forcing (3.3xCO_2) as the coupled CESM simulation, in which the SST changes are calculated as the difference between year 131-160 and year 11-40.

2. Applying the likely patterns and range of amplitudes of SST change

In performing AGCM simulations of regional climate change, changes in SST need to be taken from CGCM simulations. Thanks to the Coupled Model Intercomparison Project

(CMIP), SST outputs from most CGCMs for the standard climate change experiments are easily accessible.

During the past generations of climate models, the pattern of SST change has evolved very little, despite the substantial improvement in model resolution and parameterization. In Figure S2, we show the ensemble mean pattern of SST change from the 1pctCO2 experiment from the CMIP3 and CMIP5 archives. The pattern of SST change is very similar between CMIP3 and CMIP5, with a global spatial correlation of 0.929 and tropical spatial correlation of 0.931. In addition, Knutti and Sedlacek (2013) showed that neither the amplitude nor the uncertainty in climate sensitivity has evolved much from CMIP3 and CMIP5. Therefore, both the pattern and range of amplitudes of SST change are fairly robust and should not change substantially, at least in the near future.

Due to the insensitivity of land climate to the pattern of SST change, the current multi-model mean pattern of SST change should be sufficient for AGCM projections. Regarding the global mean SST change, one may take it from the corresponding individual CGCM or the multi-model mean (the "most likely" global mean SST change). However, the latter may result in an inconsistency between the SST warming and the amplitude of radiative forcing for an individual model. Therefore, it may be wise to apply the same global mean SST change as that of each individual CGCM, and make the "best estimate" of projection by averaging the multi-model AGCM simulations.

Here, we also show that taking the global mean SST change from a low-resolution CGCM for a high-resolution AGCM simulation should not result in inconsistency, since resolution has very little impact on the global mean SST change. We compare the global mean SST changes in the low-resolution and mid-resolution IPSL-CM5A and MPI-ESM models, both of which are archived in CMIP5. The difference in the global mean SST change resulted from different resolutions is 0.30% of the actual global mean SST change for the IPSL-CM5A model and 0.28% for the MPI-ESM model, which is substantially smaller than the inter-model spread.

Reference

Knutti, R. & Sedlacek, J. Robustness and uncertainties in the new CMIP5 climate model projections. *Nat. Clim Change* **3,** 369–373 (2013).

Table S1. CGCMs used to calculate the ensemble mean pattern of SST change. Also shown here is the spatial correlation of 1) CGCMs' climatological SST V.S. the observed climatological SST and 2) CGCM's relative SST change V.S. the ensemble mean relative SST change, as well as the corresponding RMS of the climatological SST biases and δSST differences (as shown in the parentheses). The SST changes are first normalized by each model's global mean SST change. The units of the RMS are "K" and "K/K" for the climatological SST and SST change, respectively. An asterisk indicates that the model's climatological SST is taken from the historical simulation (year 1982-2011).

	Global		Tropical (30°S-30°N)	
	Clim SST	δSST	Clim SST	δSST
CESM	0.991 (1.50)	0.57 (0.28)	0.92 (1.21)	0.60 (0.11)
bcc-csm1-1	0.992 (1.56)	0.76 (0.18)	0.92 (1.50)	0.81 (0.07)

*CanESM2	0.994 (1.62)	0.86 (0.15)	0.95 (1.71)	0.82 (0.09)
*CNRM-CM5	0.991 (1.95)	0.57 (0.21)	0.91 (1.47)	0.68 (0.09)
CSIRO-Mk3-6-0	0.992 (1.25)	0.72 (0.26)	0.94 (1.22)	0.74 (0.12)
GFDL-CM3	0.995 (1.77)	0.84 (0.19)	0.94 (1.43)	0.90 (0.07)
*GISS-E2-H	0.986 (3.13)	0.68 (0.23)	0.87 (2.34)	0.71 (0.12)
*HadGEM2-ES	0.993 (1.71)	0.81 (0.19)	0.94 (1.15)	0.90 (0.08)
inmcm4	0.990 (2.25)	0.59 (0.24)	0.91 (1.61)	0.43 (0.13)
IPSL-CM5A-LR	0.989 (1.46)	0.87 (0.19)	0.91 (1.15)	0.78 (0.09)
IPSL-CM5B-LR	0.978 (2.46)	0.65 (0.23)	0.85 (1.71)	0.82 (0.08)
MIROC5	0.991 (1.98)	0.85 (0.25)	0.91 (1.20)	0.79 (0.13)
MPI-ESM-LR	0.993 (1.50)	0.88 (0.21)	0.93 (1.31)	0.84 (0.08)
MPI-ESM-MR	0.994 (1.59)	0.85 (0.20)	0.94 (1.52)	0.82 (0.09)
*MRI-CGCM3	0.985 (2.27)	0.79 (0.22)	0.87 (1.77)	0.81 (0.12)
NorESM1-M	0.993 (1.55)	0.81 (0.27)	0.90 (1.23)	0.56 (0.19)

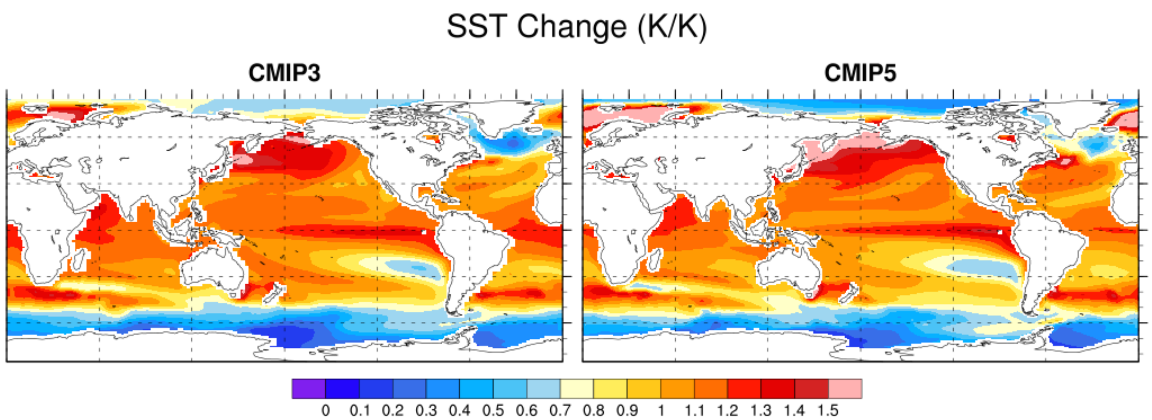

Figure S1. Ensemble mean changes in SST from CMIP3 and CMIP5 taken from the 1pctCO2 simulation. Changes are normalized by each model's global mean SST change before averaged across models. 14 models are used to calculate the CMIP3 ensemble mean: CCCma, CCSM3, CNRM-CM3, GFDL-CM2.0, GFDL-CM2.1, GISS-ER, INGV-SXG, inmcm3, IPSL-CM4, MIROC3.2-medres, MPI-OM, MRI-CGCM2.3.2, PCM and UKMO-HadGEM1.

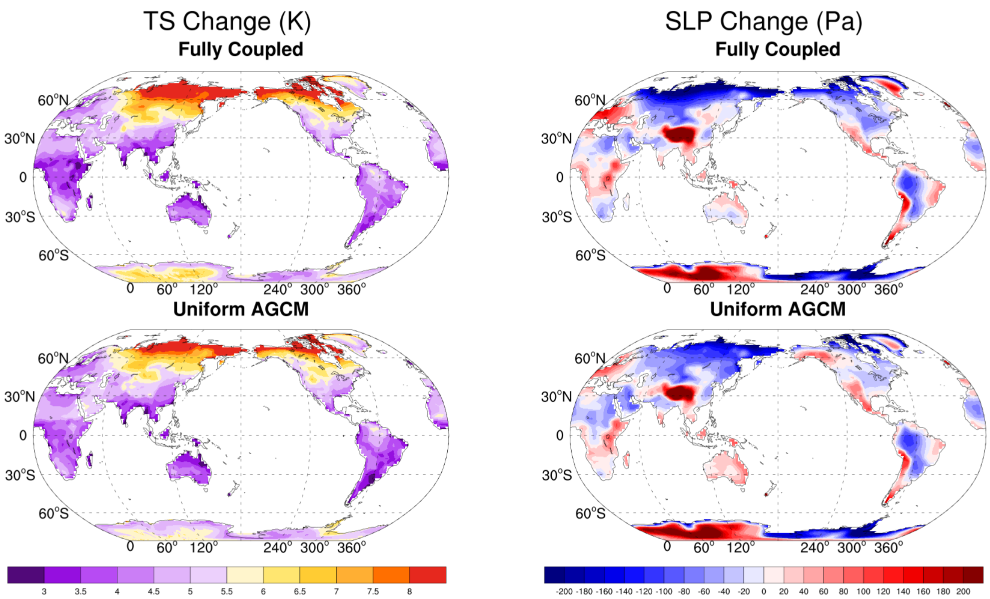

Figure S2. Changes in land surface temperature (TS, left) and SLP (right) from the CESM simulations. (top) the fully coupled simulation and (center) the uniform AGCM simulation. The spatial correlation between the fully coupled and uniform AGCM simulations is 0.96 and 0.91 for TS and SLP, respectively.

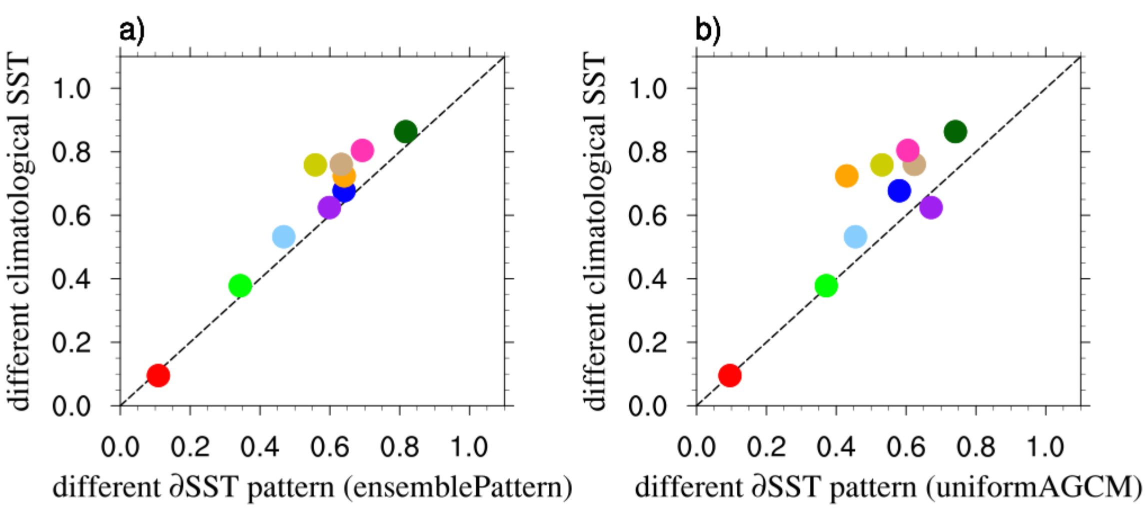

Figure 3S. The same as Fig. 4, but for the RMS of projection difference instead of correlation. The results are normalized by the RMS of change from the coupled simulation.

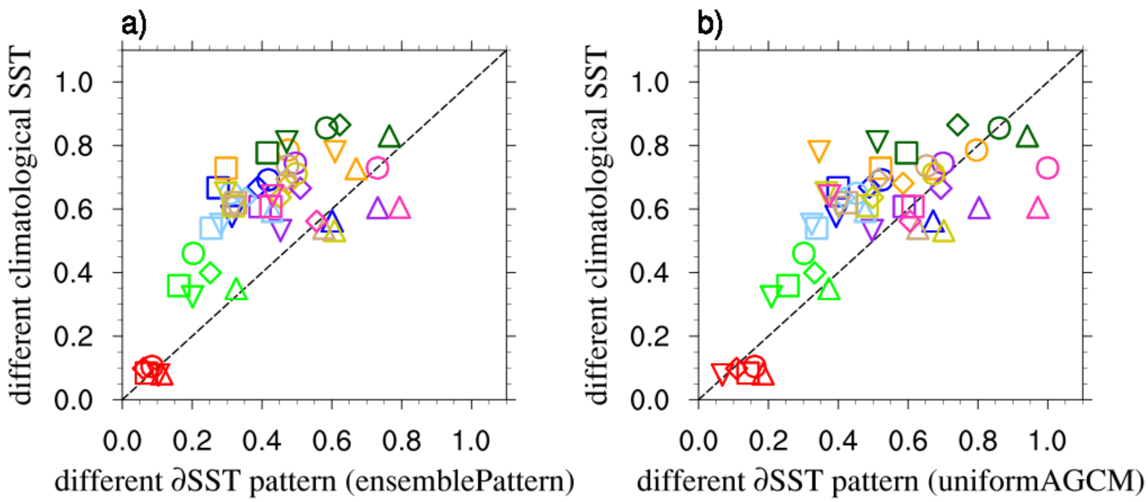

Figure 4S. The same as Fig. 5, but for the RMS of projection difference instead of correlation. The results are normalized by the RMS of change from the coupled simulation.