SUPPLEMENTAL MATERIALS FOR

"The relative contributions of tropical Pacific sea surface temperatures and atmospheric internal variability to the recent global warming hiatus"

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1. Decomposition of DJF GMST trends

Table S1 shows the decomposition of DJF GMST trends (2002-2013; °C per 12 years) into contributions from radiative forcing, observed internal variability of Tropical Pacific SSTs, and other internal variability. The two models yield similar values for the radiatively-forced component (+0.24°C in CESM1 and +0.23°C in CM2.1), obtained from the ensemble-mean of their historical simulations (HistEM), but differ slightly in the contribution from internal tropical Pacific SST changes (-0.22°C in CESM1 and -0.27°C in CM2.1), determined from the ensemble-mean of their Pacemaker simulations (PaceEM) after subtracting the ensemble-mean of their historical simulations (HistEM). Applying the CESM1 values to the observed (MLOST) GMST cooling trend of -0.22°C, one deduces that internal variability caused GMST to cool by -0.42°C, with 50% of this internal component due to teleconnections from the tropical Pacific and 50% to variability beyond the tropical Pacific (Table S1). Applying the values from CM2.1 to MLOST, one concludes that internal variability caused a slightly larger GMST cooling trend (-0.47°C), 63% of which resulted from the tropical Pacific and 37% from additional internal variability (Table S1). Internal variability within and beyond the tropical Pacific also contribute nearly equally to the GMST trend in CESM1_#2, the most realistic of all the Pacemaker simulations across the two models (Table S1).

2. Comparison and discussion of the forced responses in CM2.1 *vs*. CESM1

It is conceivable that with a larger Pacemaker ensemble, CM2.1 could have produced a simulation that reproduces the main features of the observed pattern of SAT trends during the Hiatus, including cooling over Eurasia. However such a simulation would be dominated by the contribution from internal variability beyond the tropical Pacific ("OTHERint_70"; see Fig. S6d), as it is the only component that produces pronounced cooling over Eurasia (and to a lesser extent over North America): radiative forcing causes warming (Fig. S6b) and observed internal tropical Pacific SST trends cause a mixture of cooling and warming over Eurasia (Fig. S6c). This inference is in keeping with the results of Kosaka and Xie (2013) who noted that "… the [CM2.1] model fails to simulate the SAT and SLP changes over Eurasia [during the Hiatus], suggesting that they are due to internal variability unrelated to tropical forcing". As we have demonstrated, a different conclusion is reached with CESM1 for which tropical forcing causes substantial cooling over most of Eurasia, and radiative forcing produces muted warming and even slight cooling in central Eurasia (a similar lack of radiatively-induced warming is found over North America in CM2.1: Fig. S6b).

Differences between the models' radiatively-forced SAT trends over the NH continents may be related to differences in their radiatively-forced SLP trends (Fig. S5). In particular, CESM1 shows positive SLP trends over the Eurasian sector of the Arctic, which would dynamically induce negative SAT trends that offset thermodynamically-induced warming; CM2.1, on the other hand, shows negative SLP trends north of Eurasia, which would augment the thermodynamically-induced warming over the continent. Similar arguments hold for the opposite-signed SAT and SLP responses over North America in the two models (Fig. S5). The reasons for the different radiatively-forced SLP responses in the two models remains to be determined. However, the different radiatively-forced SAT trends in the two models are not sufficient to account for the different relationships between the realism of their simulated SAT trend patterns and GMST trends. In particular, the shapes of the scatterplots between pattern correlation (against MLOST) and GMST trend, and between rmse (against MLOST) and GMST trend, do not change appreciably if the radiatively-forced responses are switched between the two models (Fig. S7).

Finally, although the SLP and SAT patterns in "OTHERint_70" are similar in the two models, the amplitude of the cooling over the NH continents and associated positive SLP trends upstream are larger in CESM1 (Fig. 4h) compared to CM2.1 (Fig. S6d) for a one standard deviation departure of the GMST trend. This means that in CM2.1, internal variability beyond the Tropical Pacific is less likely to be of sufficient magnitude to overcome the effects of radiative forcing and observed tropical Pacific SSTA to produce a Hiatus of realistic spatial pattern.

In summary, it is possible that with a larger Pacemaker ensemble, CM2.1 might have produced a realistic simulation of the Hiatus SAT trend pattern in boreal winter, but it would be dominated by the contribution from internal variability beyond the Tropical Pacific rather than a combination of observed Tropical Pacific SSTA, other internal variability and radiative forcing as in CESM1, and would be less likely to occur than inCESM1.

Reference

Kosaka, Y., and S. P. Xie (2013), Recent global-warming hiatus tied to equatorial Pacific surface cooling, *Nature, 501*, 403–407, doi:10.1038/nature12534.

Table S1. Decomposition of the DJF GMST trend (2002-2013; °C per 12 years) in observations (MLOST) and the most realistic Tropical Pacific Pacemaker simulation (CESM #2) into contributions from radiative forcing, observed internal variability of Tropical Pacific SSTs, and other internal variability. PaceEM refers to the ensemble-mean of the 10 Pacemaker simulations with CESM1 and CM2.1. HistEM refers to the ensemble-mean of the 40 (20) Historical simulations with CESM1 (CM2.1). Percentages are with respect to the total internal variability (i.e., non radiatively-forced). For MLOST, the first number is derived from the CESM1 simulations and the second value in parentheses is derived from the CM2.1 simulations.

	Actual	PaceEM	HistEM	PaceEM - HistEM	Actual - PaceEM
OBS (MLOST)	-0.20	---	---	--- 50% (63%)	-0.22 (-0.16) 50% (37%)
CESM #2	-0.24	+0.02	+0.24	-0.22 46%	-0.26 54%
CM2.1	---	-0.04	+0.23	-0.27	---
Comments	*Total*	*Radiatively Forced + TPAC Internal*	*Radiatively Forced*	*TPAC Internal*	*OTHER Internal*

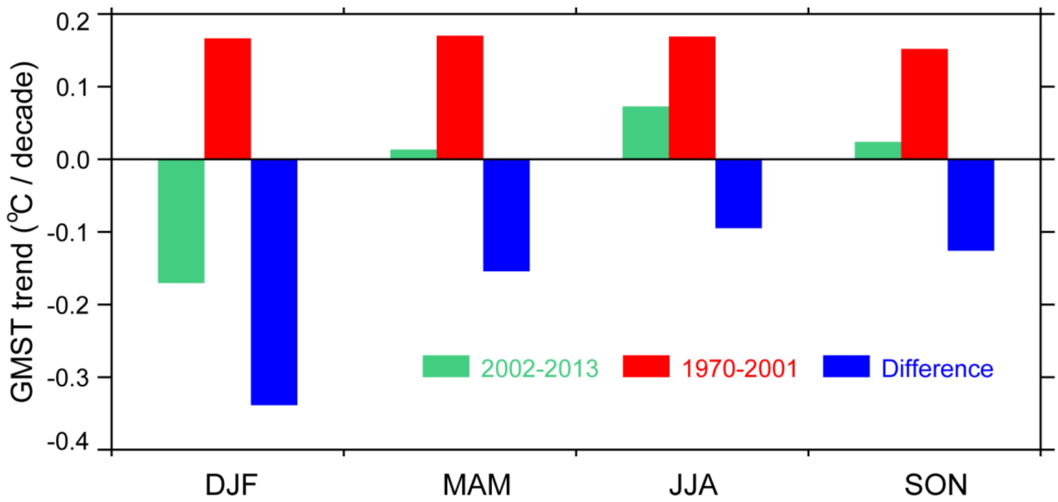

Figure S1. Observed (MLOST) DJF GMST trends (2002-2013; °C/decade) by season during 2002-2013 (green), 1970-2001 (red) and their difference. Note that all trend values are in °C/decade to facilitate comparison.

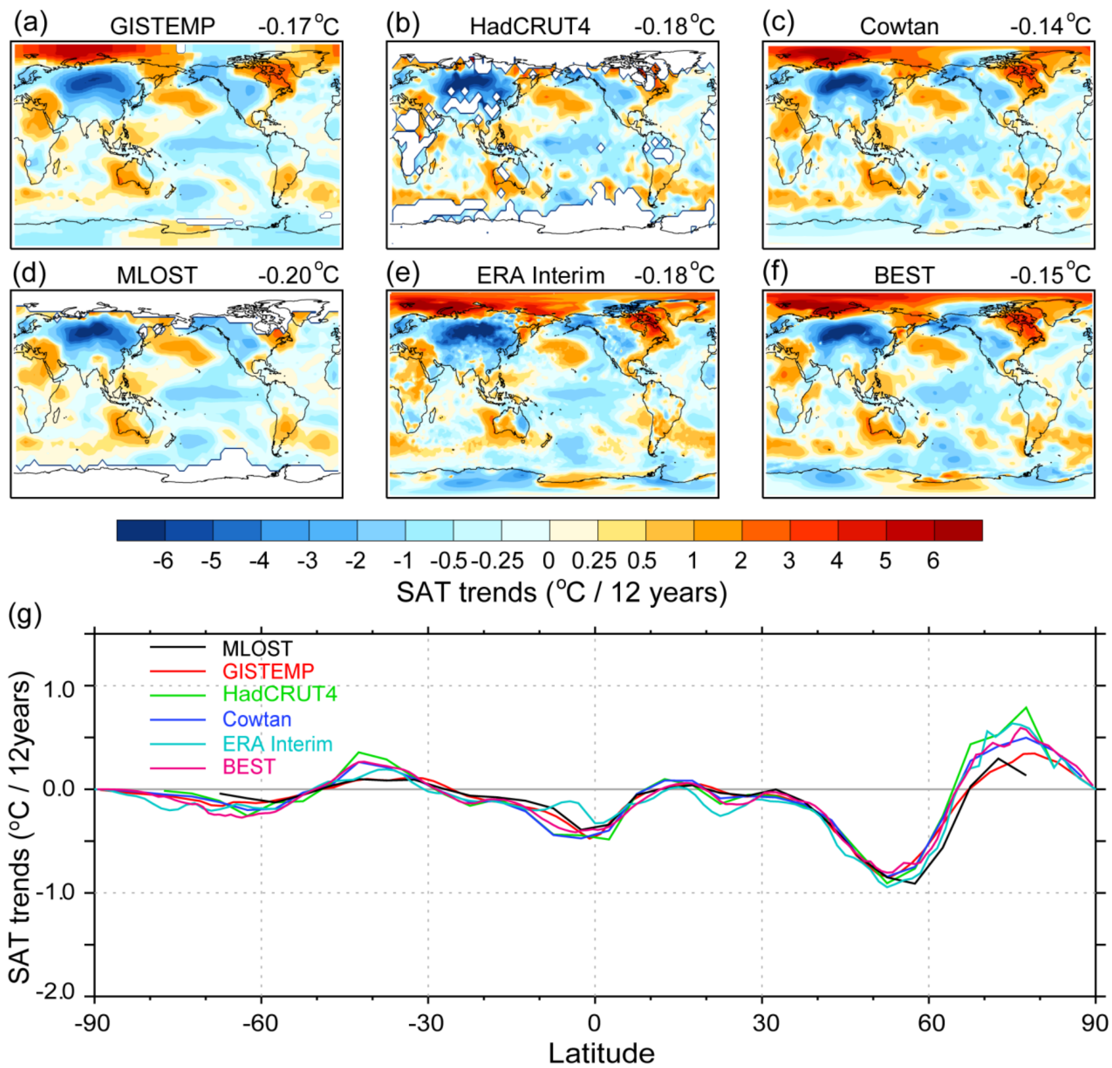

Figure S2. DJF SAT trends (2002-2013; °C/12 years) from 6 different observational data sets: (a) GISTEMP; (b) HadCRUT4; (c) Cowtan and Way; (d) MLOST; (e) ERA Interim; (f) BEST. Values in the upper right corner denote the GMST trend (°C/12 years). (g) Zonal-mean SAT trends,weighted by cosine of latitude, for each data set.

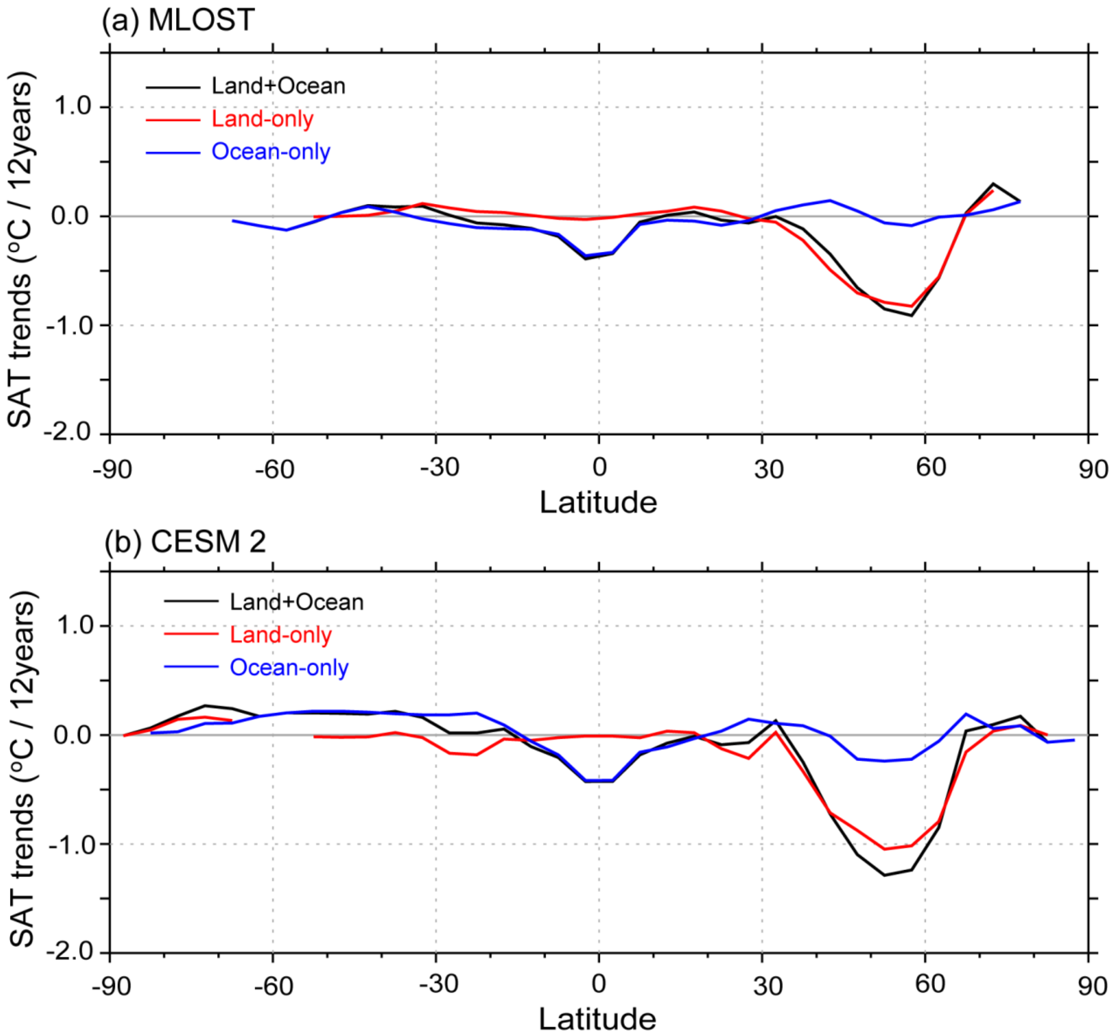

Figure S3. Zonal-mean DJF SAT trends (2002-2013; °C/12 years) weighted by cosine of latitude for (a) MLOST and (b) CESM1 Pacemaker simulation # 2. Black curves include land and ocean grid boxes; red curves only land grid boxes; and blue curves only ocean grid boxes.

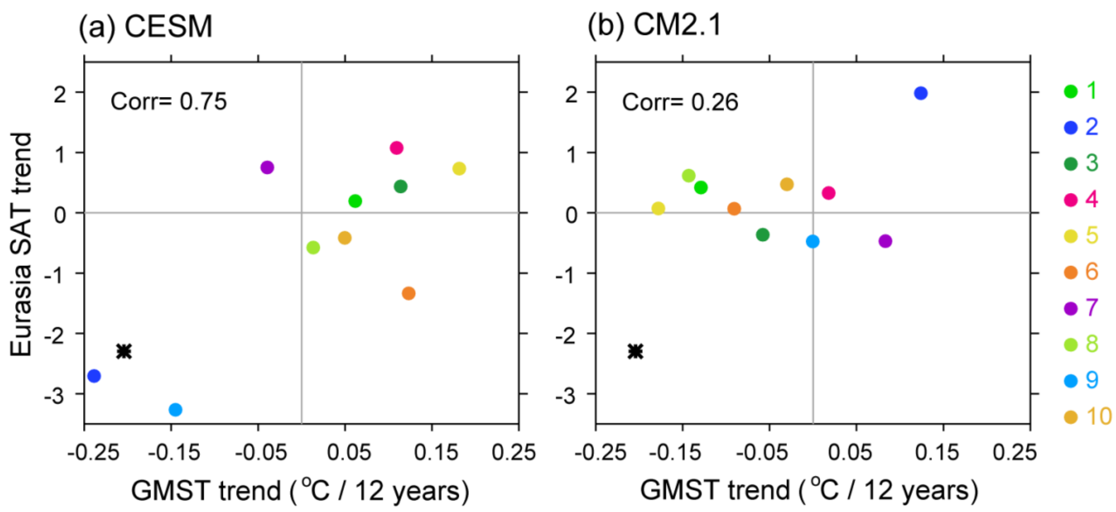

Figure S4 Scatterplots of DJF SAT trends over Eurasia (30°-70°N, 40°-145°E) and DJF GMST trends in the (a) CESM1 and (b) CM2.1 Pacemaker ensembles. Color-coding for the 10 Pacemaker simulations in each model is given in the legend to the right. Black symbols are for observations (MLOST).

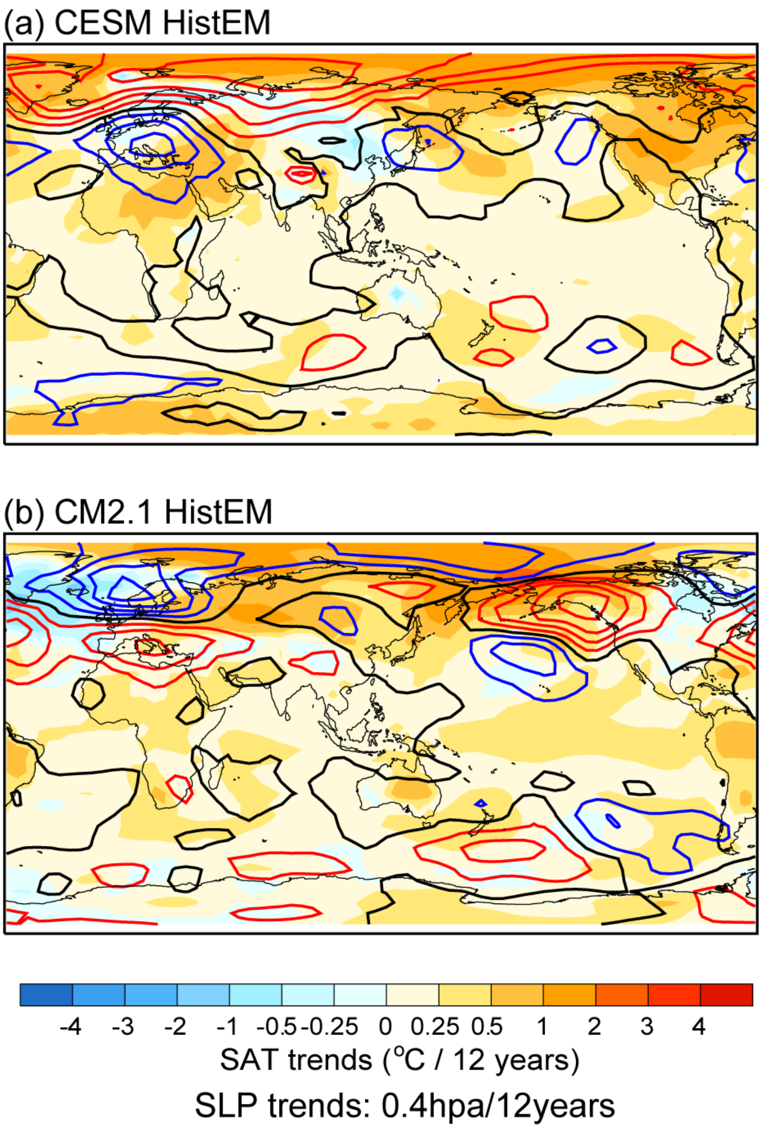

Figure S5. DJF SAT (color shading; °C/12 years) and SLP (contours; hPa/12 years) trends (2002-2013) for: (a) the ensemble-mean of the 40 CESM1 Historical simulations, and (b) the 20 CM2.1 Historical simulations. Contour interval is 0.4 hPa /12 years, with positive (negative) values in red (blue) and the zero contour in black.

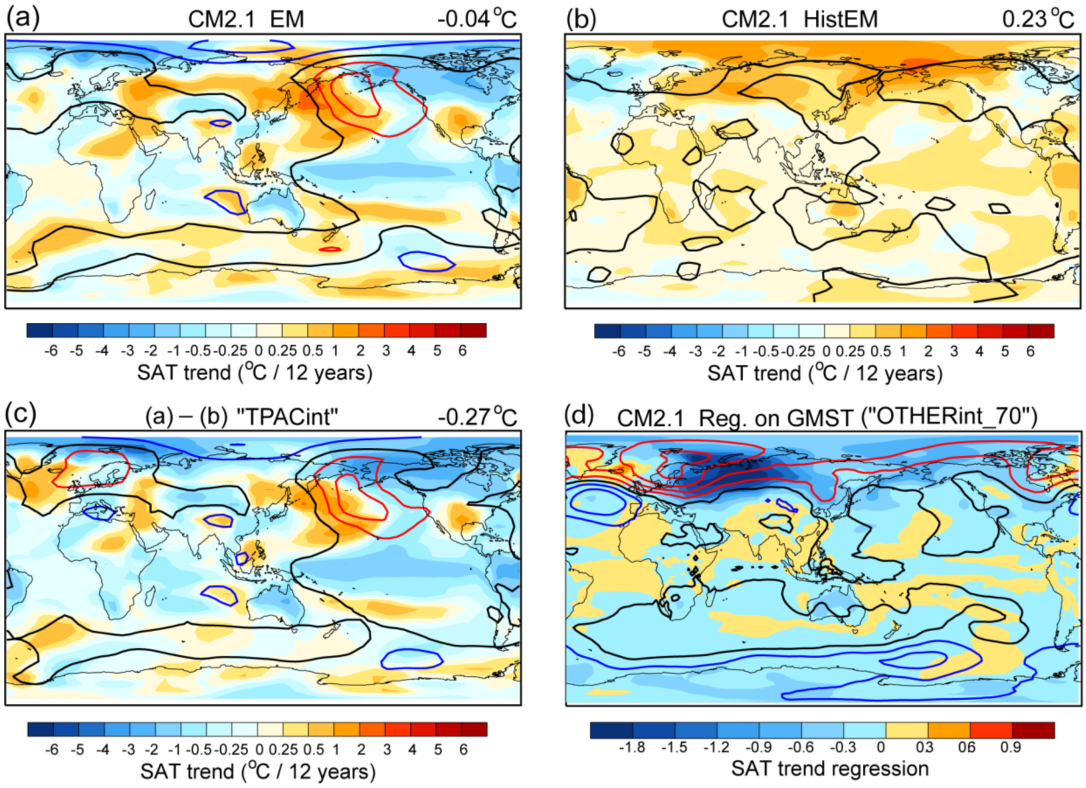

Figure S6. DJF SAT (color shading; °C/12 years) and SLP (contours; hPa/12 years) trends (2002-2013) for: (a) the ensemble-mean of the 10 CM2.1 Pacemaker simulations (CM2.1 EM); (b) the ensemble-mean of the 20 CM2.1 Historical simulations (CM2.1 HistEM); (c) (a) minus (b), termed "TPACint" in the text. Values in the upper right corner denote the GMST trend (°C/12 years). (d) Twelve-year trend regressions of SAT (°C per unit standard deviation of GMST; color shading) and SLP (contour interval = 0.5 hPa per unit standard deviation of GMST) regressions on standardized GMST trends from the CM2.1 Pacemaker ensemble over the period 1920-2013 after removing the ensemble mean trend for each 12-year segment (termed "OTHERint_70" in the text). See text for details.

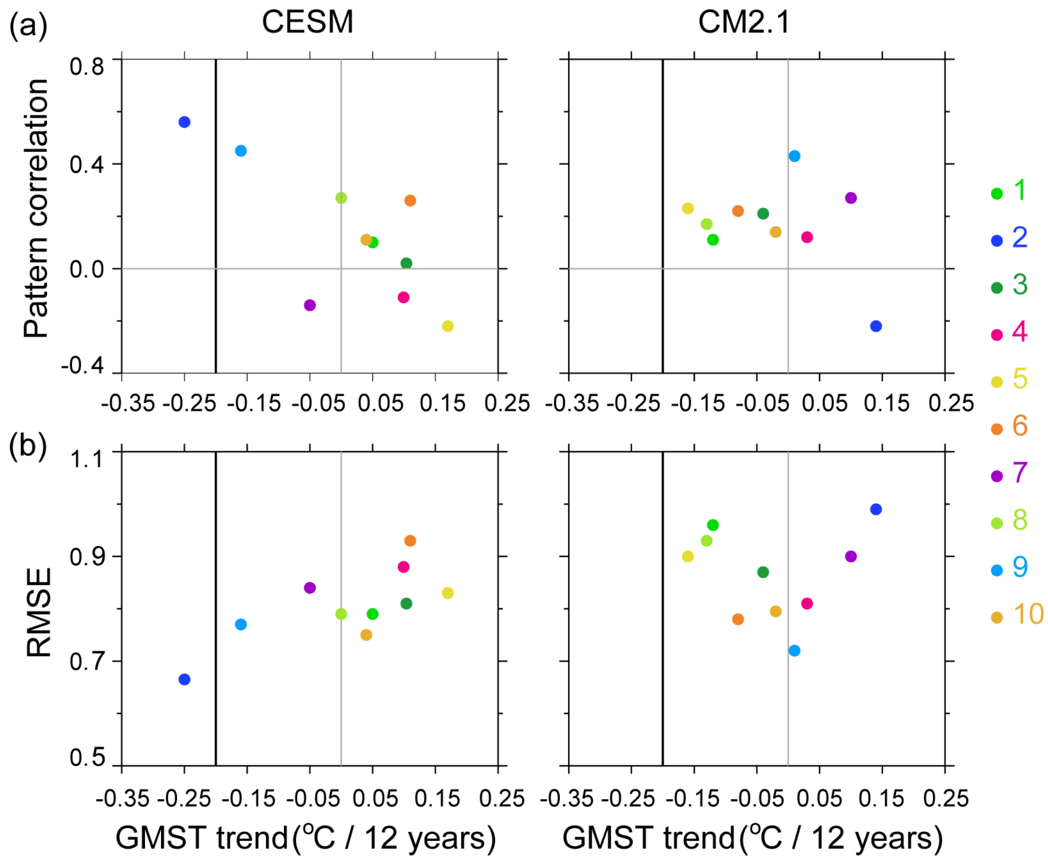

Figure S7. As in Fig. 3 in the main text but after switching the models' responses to radiative forcing (i.e., subtracting CESM1 HistEM from and adding CM2.1 HistEM to each CESM1 Pacemaker ensemble member, and subtracting CM2.1 HistEM from and adding CESM1 HistEM to each CM2.1 Pacemaker ensemble member). Note that the x-axis has been expanded from that in Fig. 3 to accommodate the new values in CESM1.