Cloud and surface albedo feedbacks reshape 21st-Century warming in successive generations of an Earth System Model

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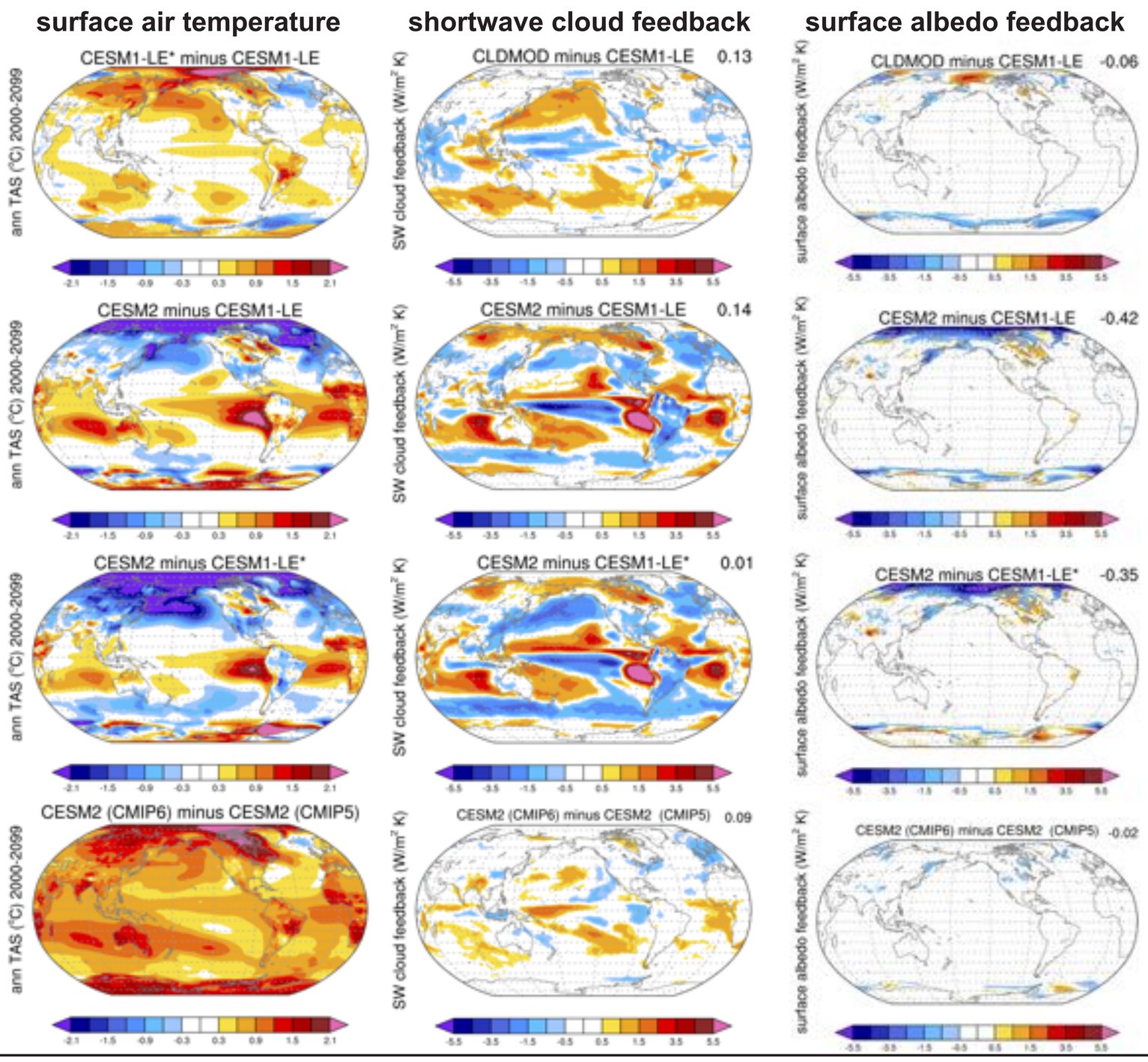
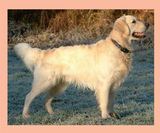
The Problem

The relative importance of radiative feedbacks and emissions scenarios in controlling surface warming patterns is challenging to quantify across model generations and intercomparison projects. We analyze three variants of the Community Earth System Model (CESM) with differing equilibrium climate sensitivities (ECS) under identical CMIP5 historical and high-emissions scenarios. To illustrate the role of scenario uncertainty, we also analyze the CESM2 under the nominally equivalent CMIP6 scenarios. Shortwave feedbacks are estimated with the APRP method; longwave feedbacks are estimated with the radiative kernel method.

Difference maps (21st Century; historical + RCP 8.5)



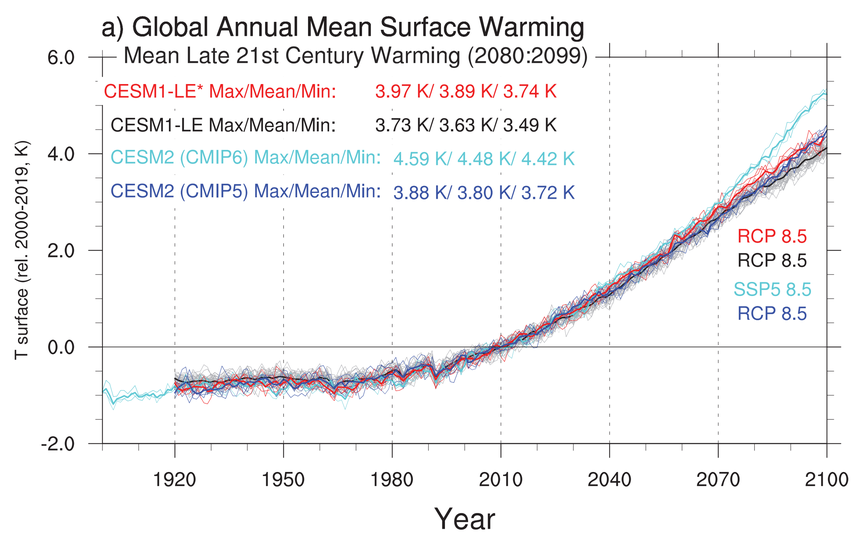
3 Models; same scenarios



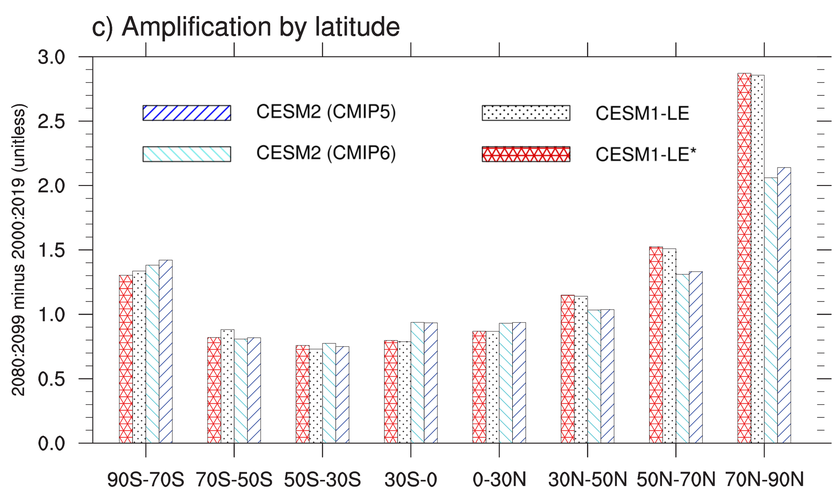
CESM1-LE: ECS of 4.0K; very stable model; used in Large Ensemble (Kay et al., 2016 BAMS); mean-state biases include Southern Ocean Absorbed Shortwave Radiation (ASR)

CESM1-LE*: ECS of 5.6K resulting from corrected ASR biases via increasing super-cooled cloud liquid (Kay et al., 2016 J Clim.)

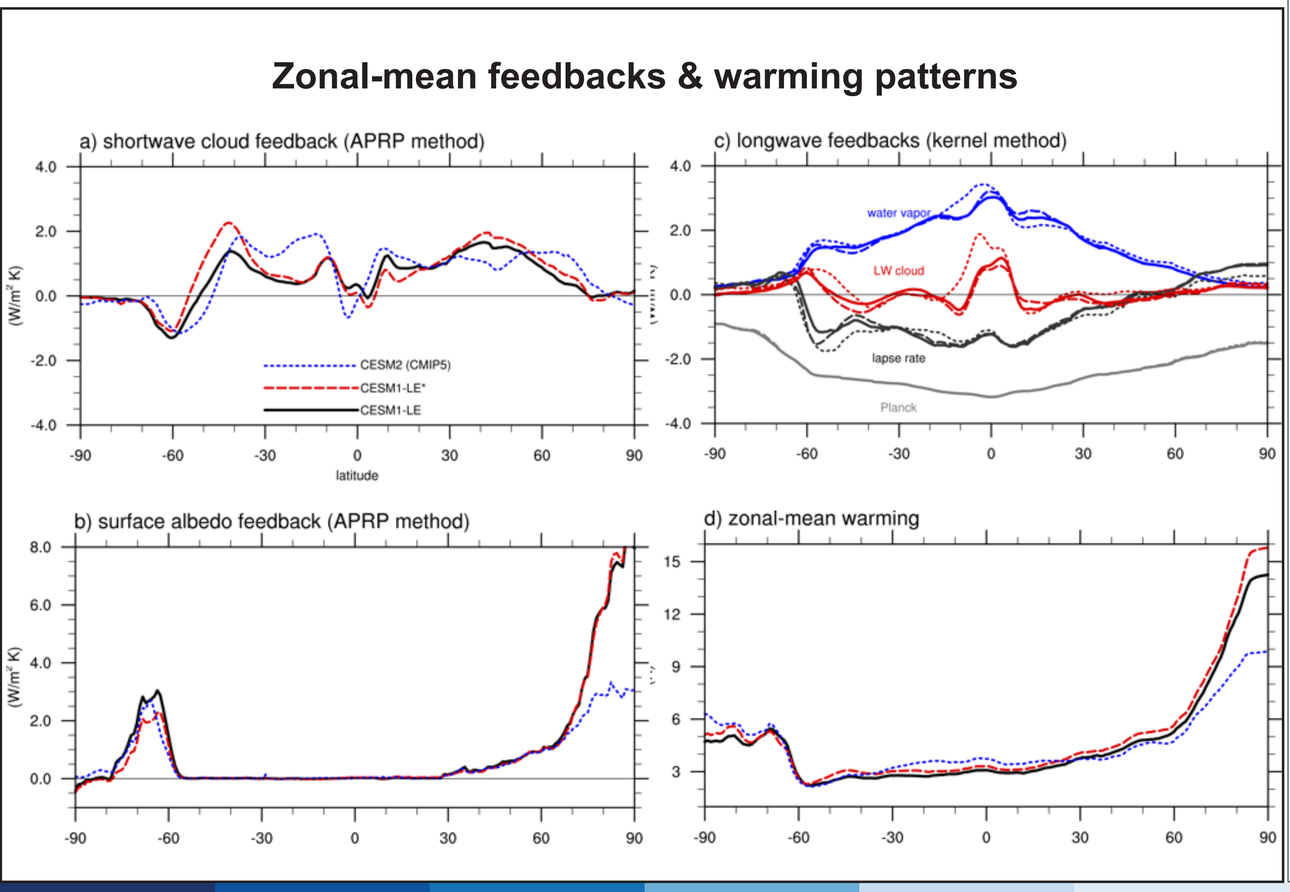
CESM2: ECS of 5.3K, largely arising from enhanced cloud feedbacks and corrected mean-state biases (Gettleman et al., 2019 GRL)



zonally-shifted warming



Zonal-mean feedbacks & warming patterns



Key Points

- Higher Equilibrium Climate Sensitivity (ECS), from CESM1 to CESM1* and CESM1 to CESM2, and associated with more positive cloud feedbacks, slightly increases 21st-Century global-mean warming in a common high-emissions scenario.

- Compared to CESM1, CESM2 has significantly stronger warming in the tropics and subtropics, and significantly weaker warming in the middle and high northern latitudes.

- This redistribution of warming is attributed to model structural differences in radiative feedbacks (clouds, surface albedo, lapse rate), not to forcing scenario differences. Similar CESM1 vs CESM2 behavior is seen in sensitivity experiments such as 1% CO_2 per year experiments (Bacmeister et al., 2020 JAMES).

- ECS is an indicator of model structural differences that matter greatly for the regional patterns of warming, but is not a great predictor of transient, global-mean warming.

- Comparing nominally equivalent CMIP5 and CMIP6 scenarios with CESM2, we find that these scenario differences matter more for transient global-mean warming than do the CESM1 vs CESM2 structural differences.

- Process-based studies are needed in order to have more confidence in the regional patterns of warming and associated feedbacks.