Supplementary Information for "Low Antarctic Continental Climate Sensitivity due to High Ice Sheet Orography"

Hansi A Singh[1,*] **and Lorenzo M Polvani**[2]

[1]University of Victoria, School of Earth and Ocean Sciences, Victoria, British Columbia, Canada

[2]Columbia University, Department of Applied Physics and Applied Mathematics, and Department of Earth and Environmental Science, New York City, New York, USA

[*]hansingh@uvic.ca

Supplementary Table

Supplementary Table 1 shows the globally-averaged net top-of-atmosphere (TOA) fluxes over the final 30 years of all GCM experiments described in the main text. For both the CCSM4.0 and the CESM1.1, the magnitude of the net TOA fluxes for all preindustrial experiments (PI and PI_FA) are ≤ 0.1 W/m^2, and these experiments can be assumed to be in quasi-equilibrium. The net TOA fluxes are substantially larger for all CO_2-doubling experiments (2XCO2_FA and 2XCO2), though all are < 1.0 W/m^2.

Model	Experiment	Net Top-of-Atmosphere Anomaly (W/m^2)
CCSM4.0	Control (PI)	-0.03
	CO_2-doubling (2×CO2)	0.64
	Flat Antarctic (PI_FA)	-0.11
	Flat Antarctic + CO_2-doubling (2×CO2_FA)	0.36
CESM1.1	Control (PI)	0.04
	CO_2-doubling (2×CO2)	0.77
	Flat Antarctic (PI_FA)	-0.02
	Flat Antarctic + CO_2-doubling (2×CO2_FA)	0.71

Supplementary Table 1. Globally-averaged net top-of-atmosphere fluxes (in W/m^2) for the GCM experiments utilized in this study.

Supplementary Figures

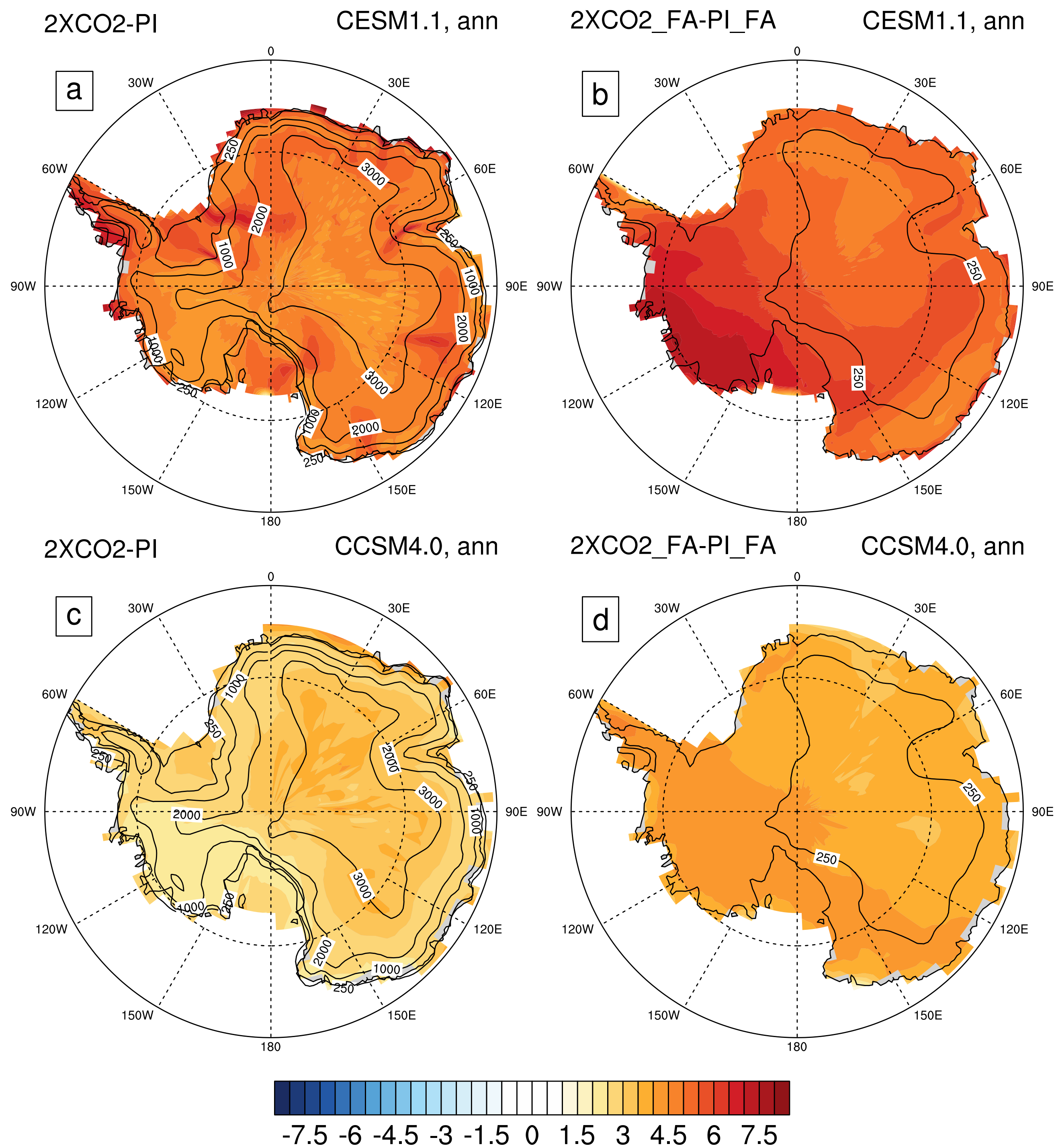
Supplementary Figure 1 shows the annual mean surface temperature change with CO_2-doubling when Antarctica is at its present-day elevation (Supplementary Figure 1, a and c) and when Antarctic orography is flattened (Supplementary Figure 1, b and d). In both the CESM1.1 and the CCSM4.0, annual mean warming with CO_2-doubling is greater when Antarctic orography is flattened than when at its present-day elevation (0.7K greater in the CESM1.1 and 0.9K greater in the CCSM4.0). Greater warming is most apparent over the West Antarctic, where CO_2-induced annual mean warming is nearly 5K greater over certain areas in both models when orography is flattened.

Supplementary Figure 2 shows the change in winter season precipitation (both rain and snow) with CO_2-doubling when Antarctic orography is at its present-day elevation (Supplementary Figure 2, a and c) and when Antarctic orography is flattened (Supplementary Figure 2, b and d). When Antarctica is at its present-day elevation, most of the precipitation increase with CO_2-doubling occurs at the edge of the continent. On the other hand, when Antarctic Ice Sheet orography is flattened, more of the increased precipitation occurs over the interior of the continent, particularly the Eastern Pacific sector of the East Antarctic in the CESM1.1 (Supplementary Figure 2b), and over the West Antarctic in both the CESM1.1 and the CCSM4.0 (Supplementary Figure 2, b and d). As expected, the spatial pattern of the precipitation increase with CO_2-doubling closely follows that of the increase in lower tropospheric condensational heating (compare to Figure 5 in the main text).

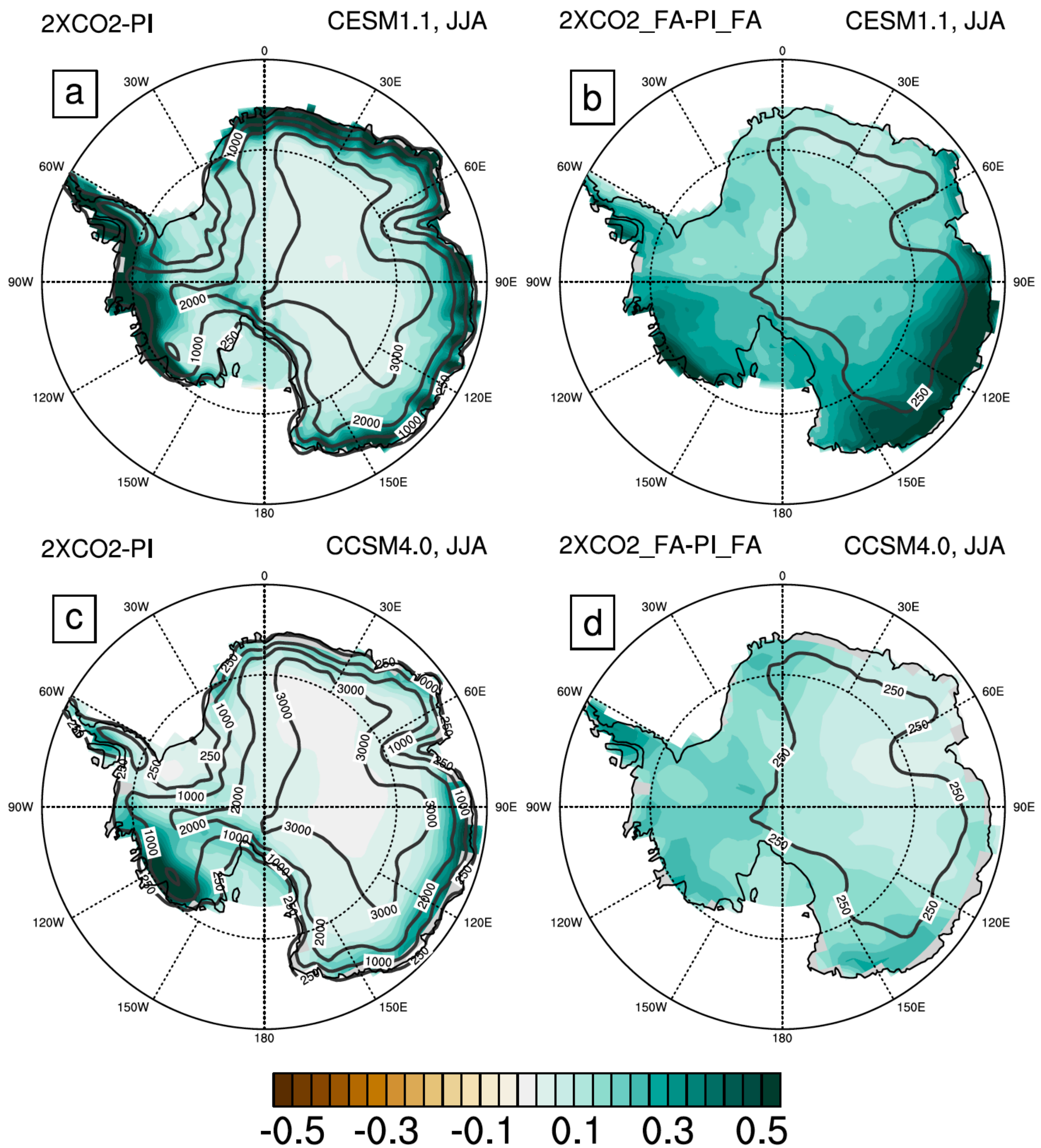
Supplementary Figure 3 shows the change in annual mean surface temperature with CO_2-doubling when Antarctic orography is at its present-day elevation (solid lines) and when Antarctic orography is flattened (dashed lines). In both models, CO_2-forced warming over the Antarctic continent is greater when Antarctic orography is flattened than when Antarctic orography is at its present-day elevation. However, differences in the remote response to CO_2-doubling are quite distinct in the two models studied: in the CESM1.1, the zonal mean temperature response to CO_2-doubling is greater when Antarctic orography is at its present-day elevation (blue solid lines lie above blue dashed lines north of 65S), while in the CCSM4.0, the zonal temperature response to CO_2-doubling is greater when Antarctic orography is flattened (green dashed line lies above green solid line).

Supplementary Figure 4 shows the atmospheric (cyan lines), oceanic (green lines), and total (red lines) energy transport response to CO_2-doubling when Antarctica is at its present-day elevation (solid lines) and when Antarctic orography is flattened (dashed lines). In the CCSM4.0, there is a greater CO_2-induced increase in poleward ocean heat transport in the mid- and high-latitude Northern Hemisphere when orography is flattened than when orography is at its present-day elevation (Supplementary Figure 4, lower panel, compare solid and dashed green lines). In the CESM1.1, on the the other hand, there is a greater decline in poleward ocean heat transport in the entire Northern Hemisphere when orography is flattened, than when orography is at its present day elevation (upper panel, compare solid and dashed green lines).

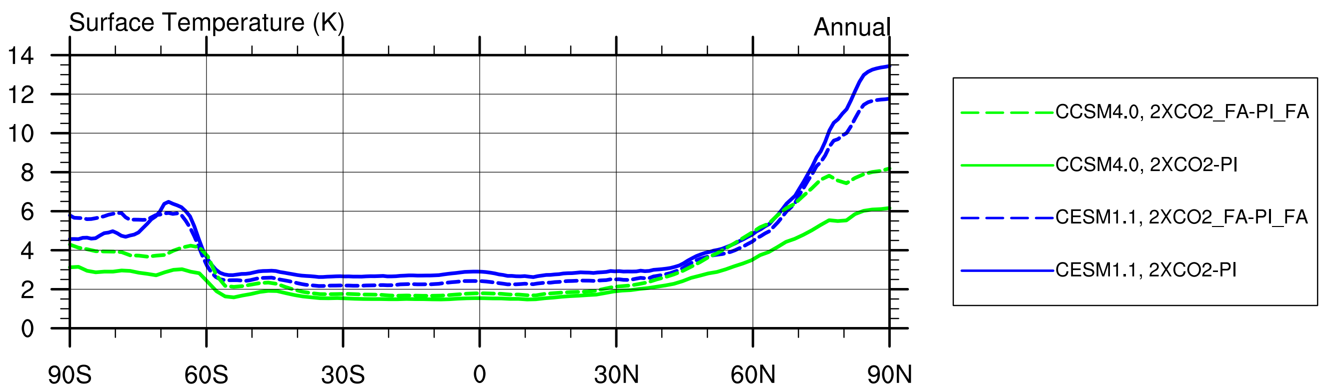
Supplementary Figure 5 shows the surface temperature change over the Southern Ocean with CO_2-doubling (colors), and the accompanying change in sea ice fraction (contours). We note a greater decline in sea ice area with CO_2-doubling in the CCSM4.0 with flattened Antarctic orography than with present-day orography (compare panels d and c in Supplementary Figure 5), but a smaller decline in the CESM1.1 (compare panels b and a in Supplementary Figure 5). Such differences in sea ice decline may be due, in part, to differences in the mean climate state in the PI and PI_C experiments in each model.



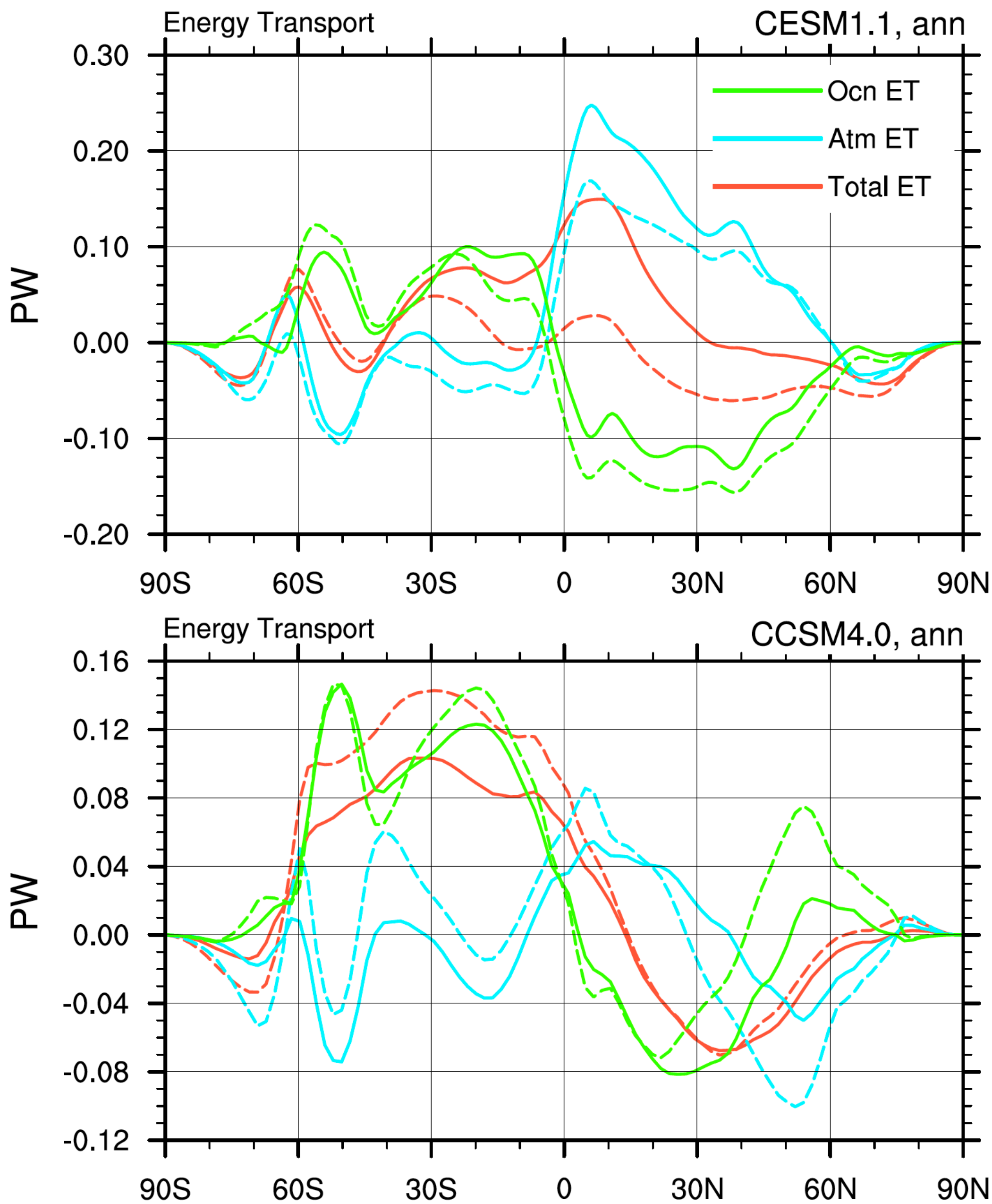
Supplementary Figure 1. Annual Mean Surface Temperature Change with CO_2-Doubling: Annual mean surface temperature change over the Antarctic continent (in K; colors) with CO_2-doubling in the (a, b) CESM1.1 and (c, d) CCSM4.0 when (a, c) Antarctic orography is at its present-day height, 2XCO2 minus C, and when (b, d) Antarctic orography is flattened to 10% of its present-day height, FA2XCO2 minus FAC. Contours show the surface elevation (in m).



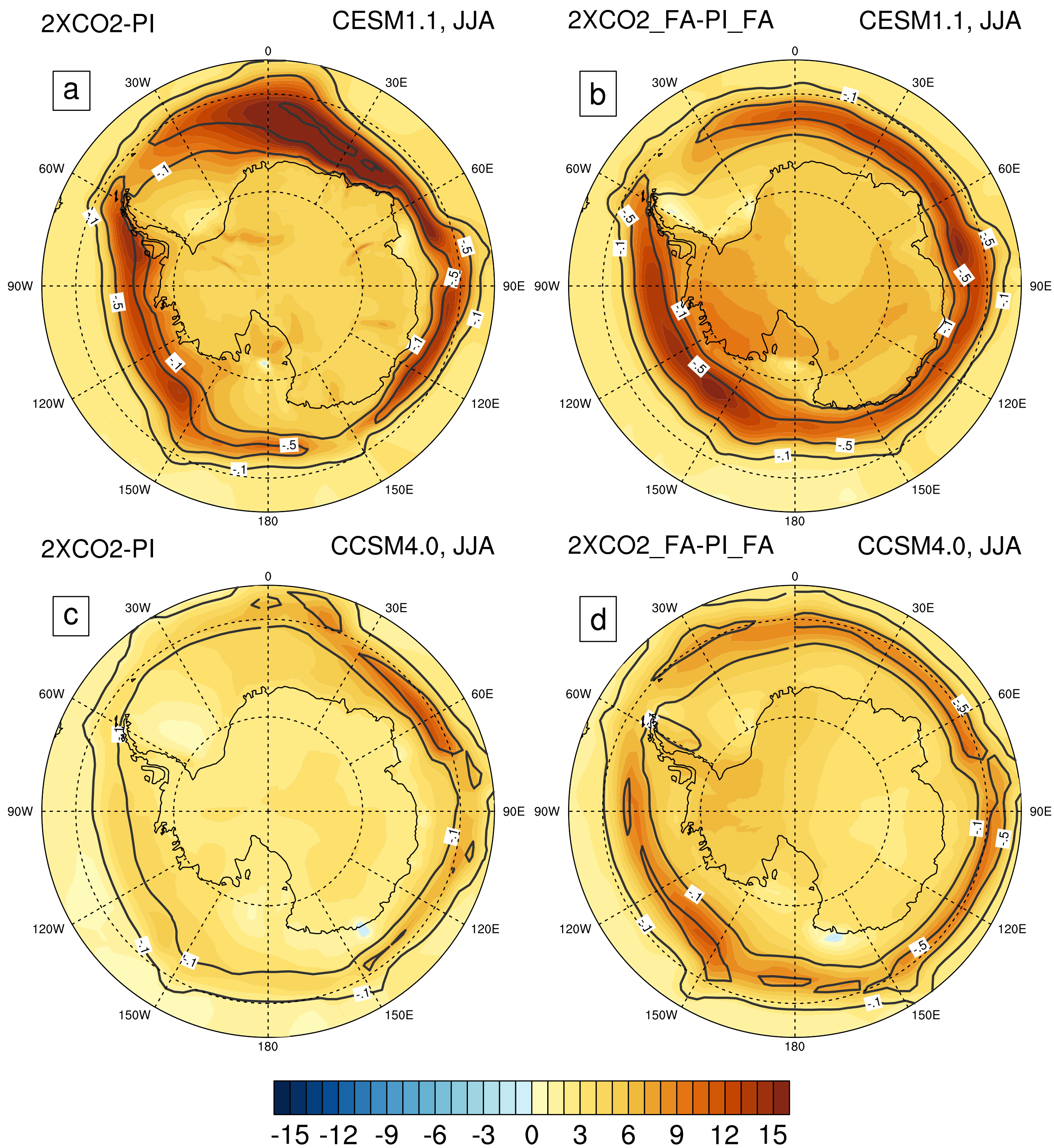
Supplementary Figure 2. Winter Season Precipitation Change with CO_2-Doubling: Change in winter season precipitation over the Antarctic continent (in mm/day; colors) with CO_2-doubling in the (a, b) CESM1.1 and (c, d) CCSM4.0 when (a, c) Antarctic orography is at its present-day height, 2XCO2 minus PI, and when (b, d) Antarctic orography is flattened to 10% of its present-day height, 2XCO2_FA minus PI_FA. Contours show the surface elevation (in m).



Supplementary Figure 3. Annual Zonal Mean Surface Temperature Change with CO_2-Doubling: Zonal mean surface temperature response to CO_2-doubling in the CESM1.1 (blue lines) and the CCSM4.0 (green lines), when Antarctic orography is at its present-day height (i.e. 2XCO2 minus PI; solid lines) and when Antarctic orography is flattened to 10% of its present-day height (i.e. 2XCO2_FA minus PI_FA; dashed lines).



Supplementary Figure 4. Annual Energy Transport Change with CO_2-Doubling: Change in atmospheric (cyan lines), oceanic (green lines), and total (red lines) annual mean energy transport (in PW) with CO_2-doubling in the (a) CESM1.1 and (b) CCSM4.0, when Antarctic orography is at its present-day height (i.e. 2XCO2 minus PI; solid lines) and when Antarctic orography is flattened to 10% of its present-day height (i.e. 2XCO2_FA minus PI_FA; dashed lines).



Supplementary Figure 5. Winter Season Temperature and Sea Ice Change with CO_2-doubling: Change in winter season surface temperatures (in K; colors) and sea ice fraction (contours at -0.1, -0.5, and -0.9) with CO2-doubling in (a, b) CESM1.1 and (c, d) CCSM4.0 when (a, c) Antarctic orography is at its present-day height, 2XCO2 minus PI, and when (b, d) Antarctic orography is flattened to 10% of its present-day height, 2XCO2_FA minus PI_FA.