

**Supplemental Material for**  
**Impact of Mountains on Tropical Circulation in Two Earth System Models**

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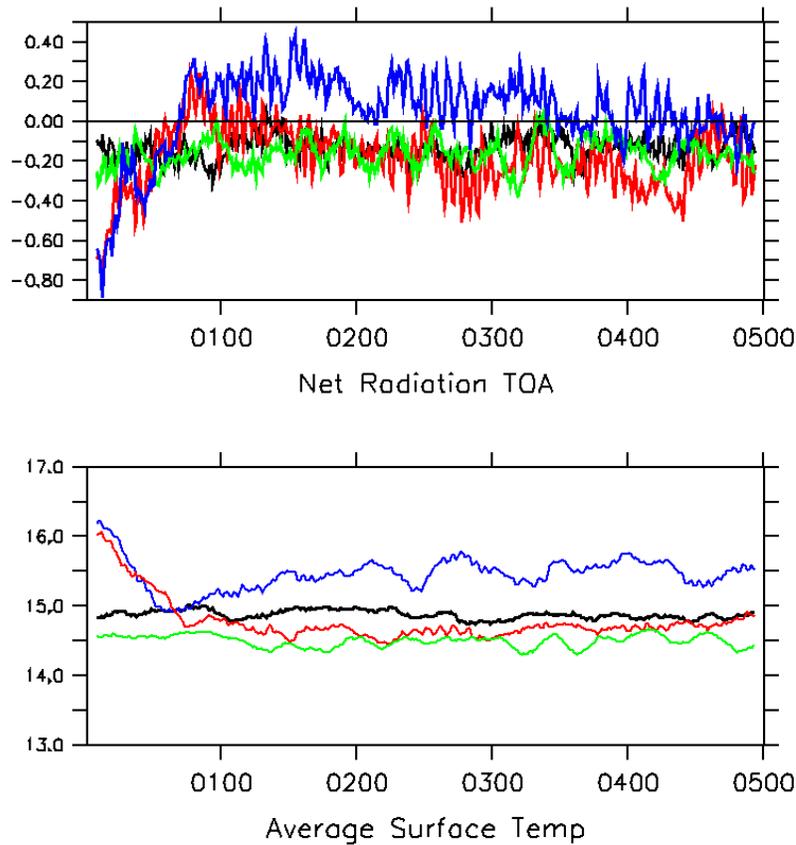
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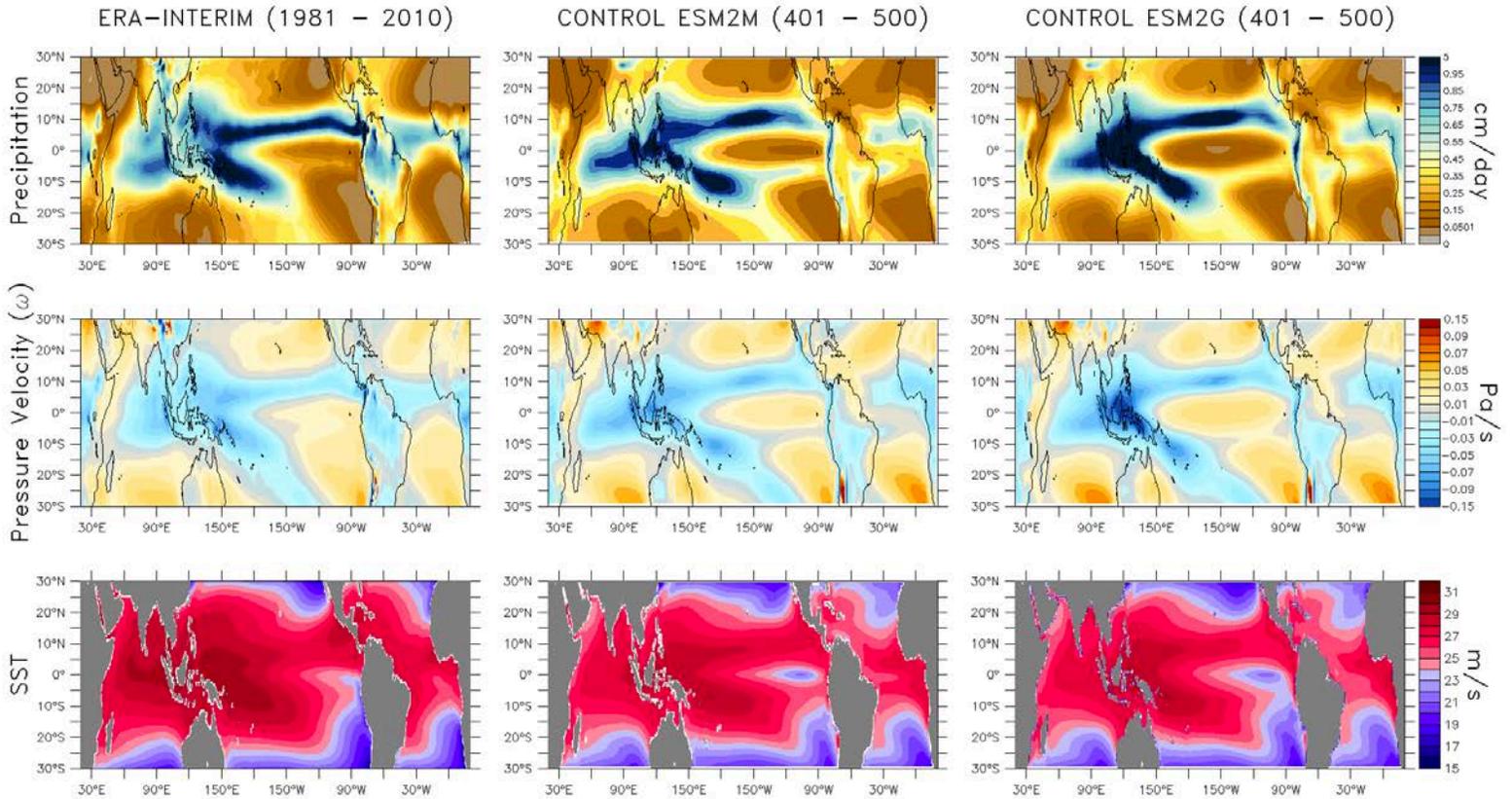
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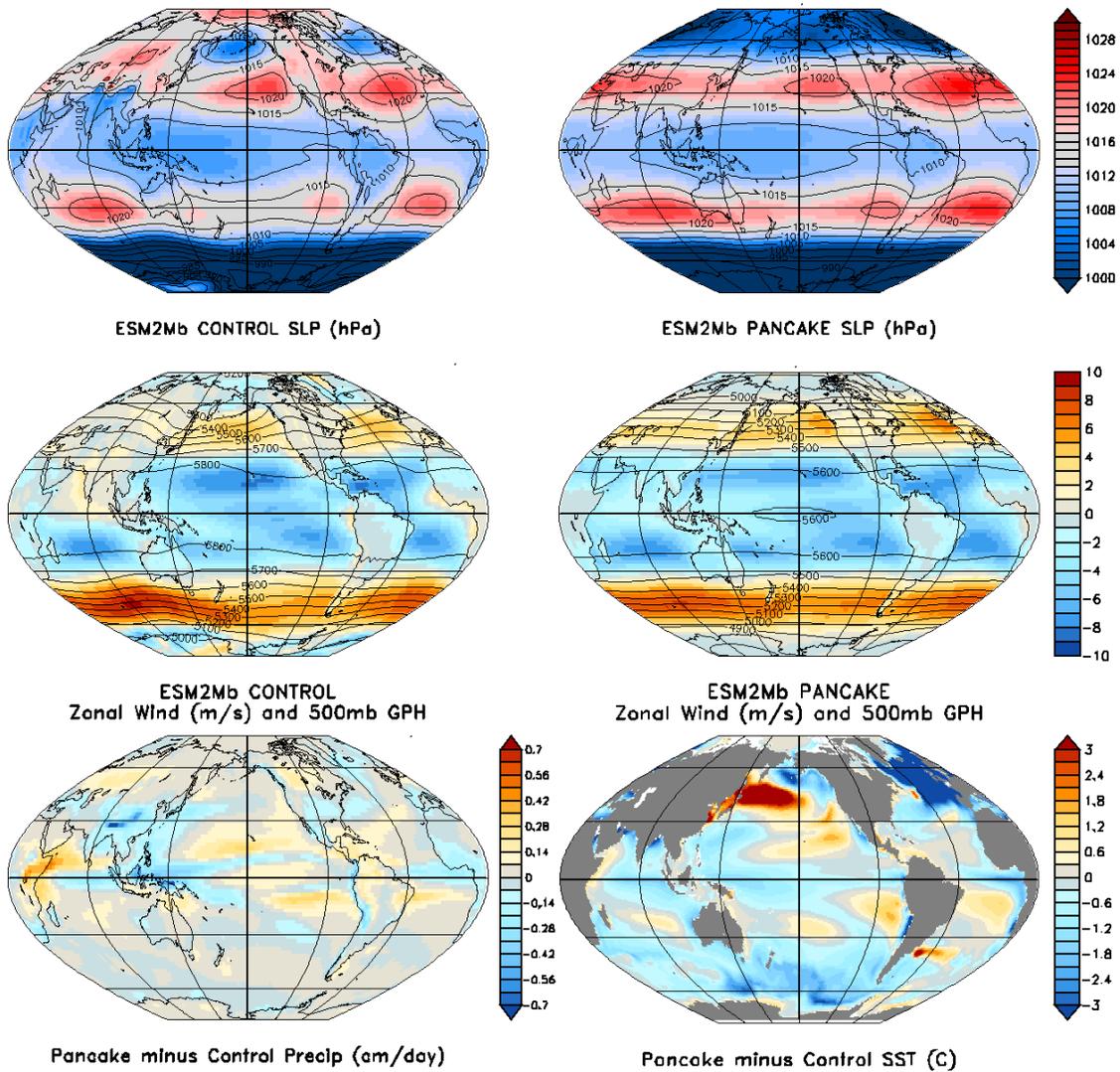
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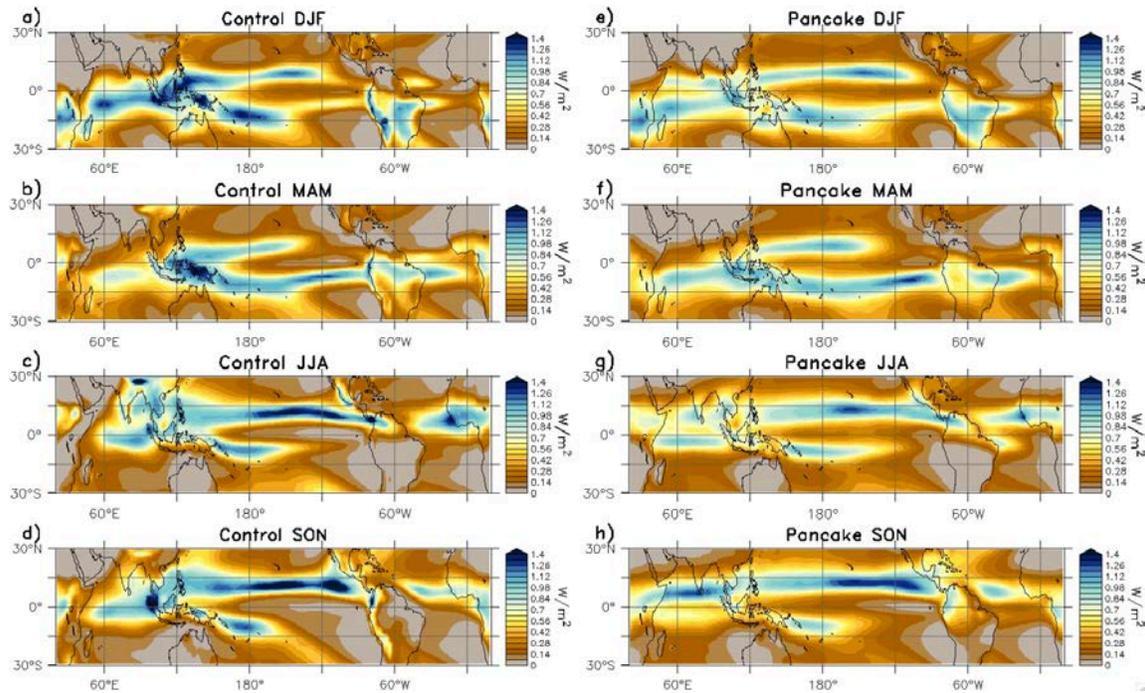
**Figure S1.** Average annual global net radiation at the top of the atmosphere (top) and surface air temperature (bottom). Black line is ESM2Mb CONTROL; red line is ESM2Mb PANCAKE; Green line is ESM2G CONTROL; blue line is ESM2G PANCAKE. Negative net radiation values indicate more outbound long-wave radiation than incoming short-wave solar radiation. Lines are smoothed with a box car smoother with a 15 point time filter (15 years). By model year 200 CONTROL and PANCAKE exhibit net radiative fluxes of  $< 0.5 \text{ W/m}^2$ , and surface air temperature trends are  $< 0.5^\circ\text{C/century}$ , which we interpret to mean that the simulations have reached a state of quasi-equilibrium.



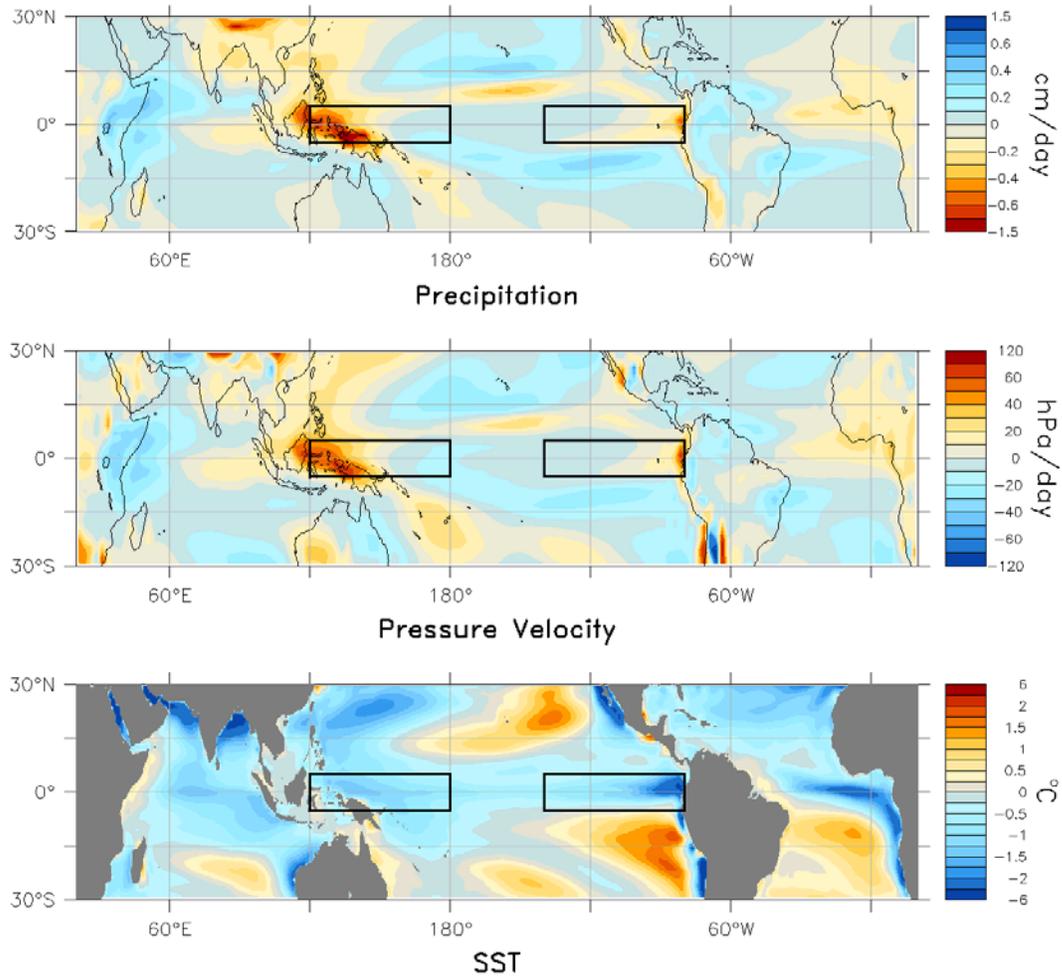
**Figure S2.** Precipitation, pressure velocity ( $\omega$ ) at 500mb, and sea-surface temperatures for reanalysis data (January 1981 – December 2010) and control models used in this study (100-year means; see Methods for details). ERA-INTERIM reanalysis data (column 1) for precipitation (row 1), vertical wind (row 2) and sea-surface temperatures (row 3) are similar to those fields in the CONTROL model for EMS2Mb (column 2) and ESM2G (column 3).



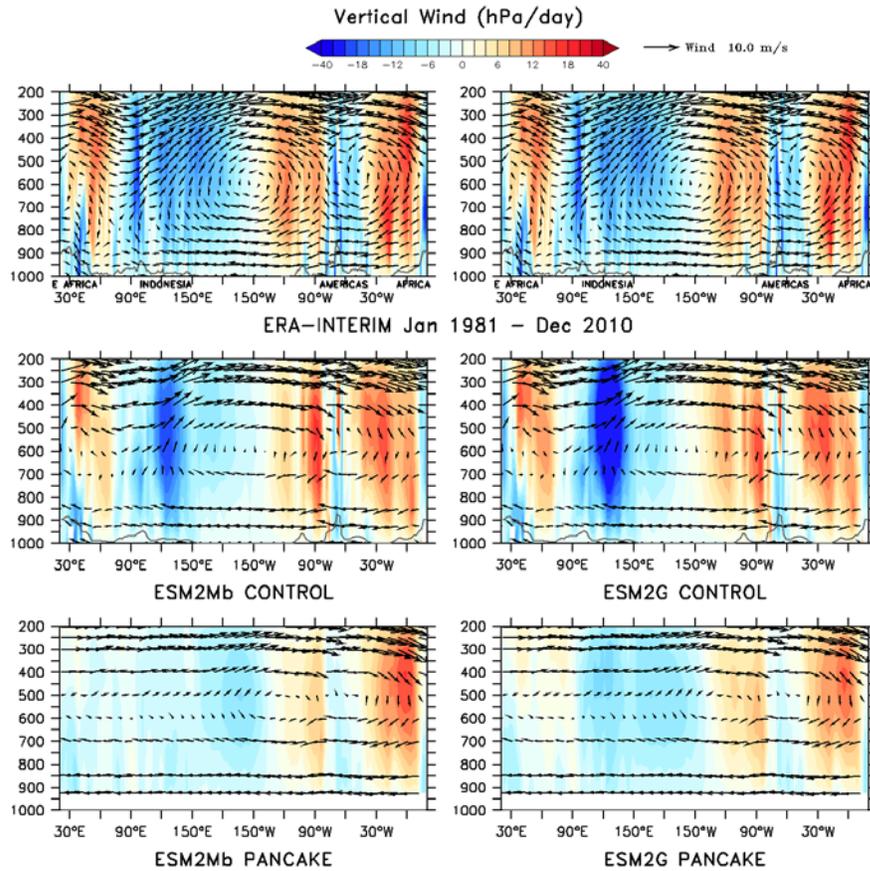
**Figure S3.** Top: Mean sea-level pressure; Middle: zonal surface wind speed (m/s, shaded) and height of 500mb geopotential height (contours); Bottom: PANCAKE minus CONTROL for precipitation (left) and sea-surface temperatures (right). All data is from model years 401-500. PANCAKE SLP is scaled by a factor of 1.026 to account for global change in SLP due to removal of orography.



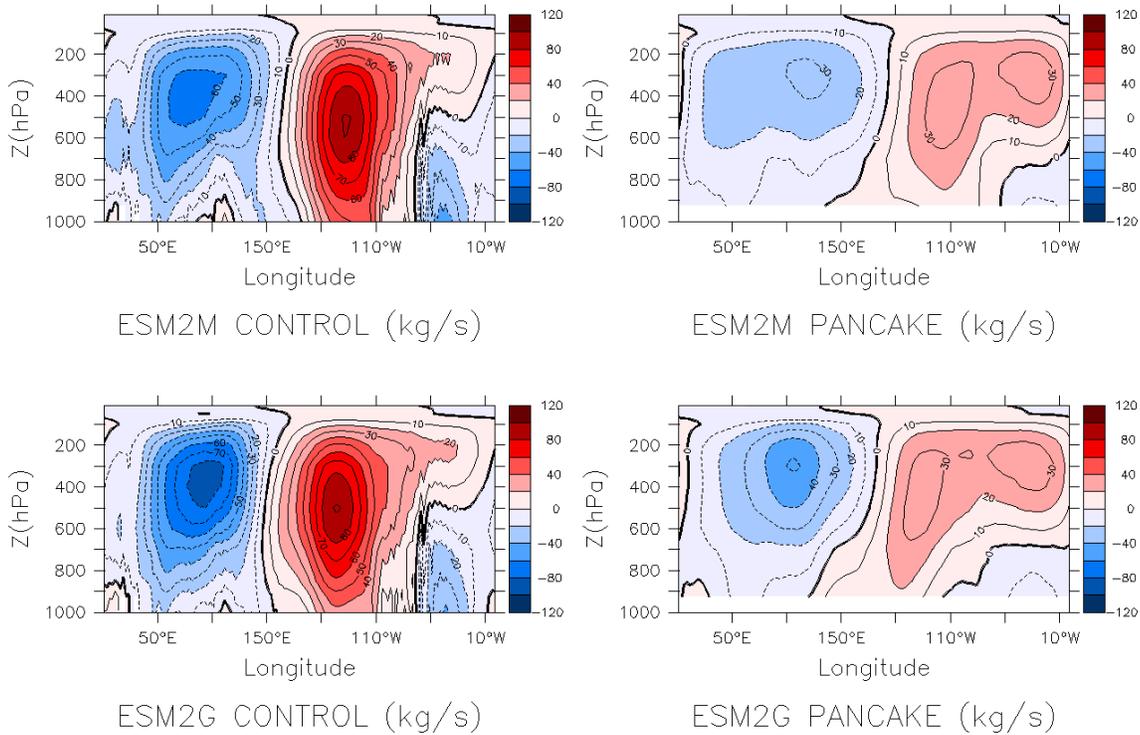
**Figure S4.** Seasonal precipitation for ESM2Mb CONTROL (left) and PANCAKE (right). DJF = December, January, February; MAM=March, April, May; JJA=June, July, August; SON=September, October, November. All data from model years 401-500.



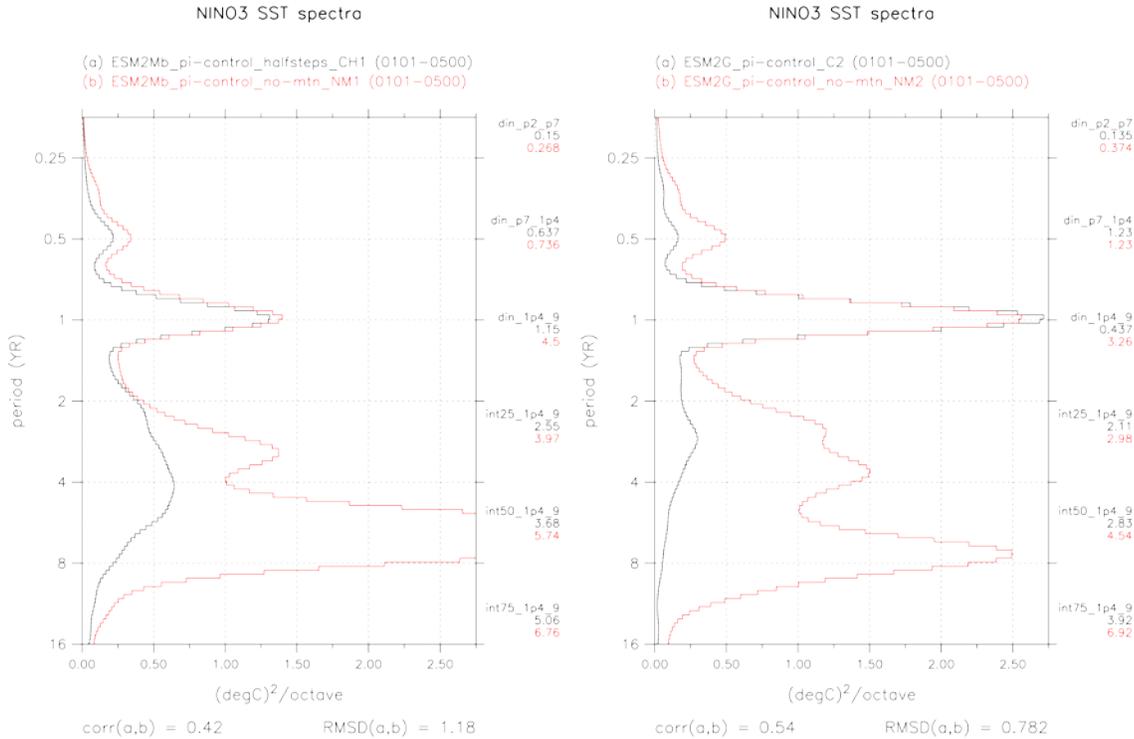
**Figure S5.** ESM2G Differences (PANCAKE – CONTROL) for precipitation (top), pressure velocity  $\omega$  (middle), and sea-surface temperature (bottom). PANCAKE has more dispersed, less focused rain over Indonesia and an associated weakening of the Walker circulation. Values for  $\omega$  are from 500 hPa. Negative (blue) values are in the “up” direction. Results for  $\omega$  do not change significantly when different pressure levels, or an average of pressure levels, are used to represent the “middle of the troposphere.” Rectangles in bottom image show regions used to calculate dSLP as the difference between average sea-level pressures in an equatorial region of the east (140°W-80°W, 5°S-5°N) and the west Pacific (120°E-180°E, 5°S-5°N).



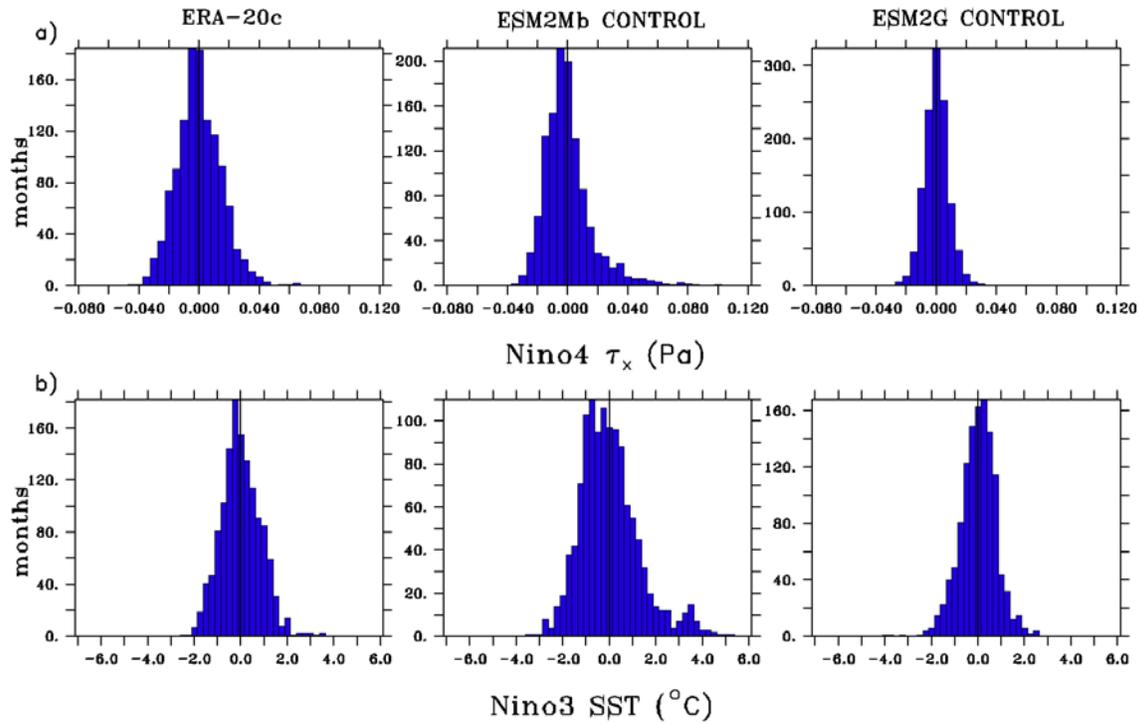
**Figure S6.** Walker Circulation. All values are averaged over the entire tropics (30°S-30°). Pressure velocities are shaded (blue/negative values are in the up direction) and vectors are zonal wind ( $u$ ) and vertical wind ( $w$ ) for Walker circulation. Top: ERA-INTERIM Reanalysis data from Jan 1981-Dec 2010. Middle: CONTROL. Bottom: PANCAKE. Means from model years 401-500 are shown. Grey curve on each plot near the abscissa shows approximate topography from observations (top, from etopo40) and the respective models. Continents are labeled below the abscissa in the top row. The vertical wind speed ( $w$ ) was calculated from the pressure velocities and scaled  $\times 1000$ .



**Figure S7.** Walker Circulation Zonal Wind Anomaly Mass Streamfunctions (years 401-500) for PANCAKE Experiments. Mass streamfunction  $\psi_M$  calculations (kg/s) of Walker circulation between 30°S-30°N for ESM2Mb (top) and ESM2G (bottom), CONTROL (left) and PANCAKE (right). Solid lines represent clockwise circulation. Streamfunction calculations carried out based on zonal wind anomalies (zonal wind  $u$  minus the zonal mean  $|\bar{u}|$ , left). Units are  $10^9$  kg/s. The fractional difference in overturning circulations are listed in Supplementary Table 1.



**Figure S8.** Nino3 region ( $150^{\circ}\text{W}$ - $90^{\circ}\text{W}$ ,  $5^{\circ}\text{S}$ - $5^{\circ}\text{N}$ ) SST spectra for ESM2Mb (left) and ESM2G (right) calculated for model years 101-500. Based on previous work with a closely related model that reported the spread along the abscissa between multiple spectra generated from time-averaging over various time intervals (Wittenberg 2009), we estimate that time-averaging over four centuries limits the spread to  $<1^{\circ}\text{C}^2/\text{octave}$ , much less than the difference between the CONTROL and PANCAKE spectra for a given time frequency in both models.



**Figure S9.** Distribution of monthly oceanic zonal wind stress anomalies (a) in the Nino4 region ( $160^{\circ}\text{E}$ - $150^{\circ}\text{W}$ ,  $5^{\circ}\text{S}$ - $5^{\circ}\text{N}$ ) and SSTs (b) in the Nino3 region ( $150^{\circ}\text{W}$ - $90^{\circ}\text{W}$ ,  $5^{\circ}\text{S}$ - $5^{\circ}\text{N}$ ) for ERA-20c reanalysis years 1900-1999 (left), ESM2Mb CONTROL (middle) and ESM2G CONTROL (right), model years 401-500. The zero anomaly line is shown.

**Table S1.** Fractional Changes to Walker and Hadley Circulations. Fractional change calculated for model years 401-500 as (PANCAKE – CONTROL) / CONTROL and reported as percents.

Type of calculation	Relevant Region	Fractional Change	
		ESM2Mb	ESM2G
dSLP	Difference between 5°S:5°N 140°W:80°W 5°S-5°N 120°E-180°E	-41.70%	-43.46%
Walker streamfunction (using zonal wind u)	30°S-30°N, 0°-360°E	-46.55%	-45.81%
Walker streamfunction (using vertical wind w)	30°S-30°N, 0°-360°E	-40.38%	-31.22%
Walker streamfunction (using zonal wind u zonal anom)	30°S-30°N, 0°-360°E	-59.30%	-50.94%
Walker streamfunction (using vertical wind w zonal anom)	30°S-30°N, 0°-360°E	-35.08%	-36.22%
Walker as maximum deviation in ascending pressure velocity from zonal mean at 500mb	10°S-10°N, 130°E-90°W	-37.35%	-59.76%
Hadley streamfunction (using meridional wind v)	30°S-30°N, 0°-360°E	-1.93%	0.97%