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Supporting Online Material for

Observational and Model Evidence for Positive Low-Level Cloud Feedback

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Supporting Online Material

The International Satellite Cloud Climatology Project (ISCCP) is an archive of cloud data retrieved from geostationary and polar-orbiting weather satellites. Since these satellites were not designed for climate monitoring, the nominal cloud record suffers from spurious variability associated with changes in instrumentation, sensor degradation, shifts in orbit, and other problems. For example, systematic changes in satellite view angle cause artificial variations in retrieved cloud cover because clouds are more difficult to detect when closer to nadir due to a shorter optical path length through the cloud (S1). We removed this effect by linearly regressing out that portion of cloud variability associated with local changes in satellite view angle. Another problem is that the ISCCP satellite intercalibration process was imperfect, leading to similar changes in cloud cover across the entire view area of a satellite that were inconsistent with high-quality surface observations (S2, S3). We removed this effect by regressing out from each individual grid box time series the time series of standardized cloud cover anomalies averaged over the entire view area of successive satellites. This procedure removes any real cloud cover variability occurring on near-hemispheric spatial scales but should have little impact on our regression patterns that focus on differences between regions. We call the resulting data “adjusted ISCCP cloud cover”.

The ISCCP Flux Dataset was constructed by applying a sophisticated radiative transfer model to ISCCP cloud data (S4). The parameter we use is “cloud radiative effect”, the change (from clear sky conditions) in downward radiation flux at the surface produced by the presence of clouds. We applied the two procedures described above to obtain “adjusted ISCCP cloud radiative effect”.

One additional problem is that the ISCCP retrieval method underestimates cloud top pressure in the presence of strong temperature inversions, which are a common feature in stratocumulus regions. This caused some low-level clouds to be mistakenly identified as mid-level clouds. Because natural mid-level clouds are rare in stratocumulus regions, we added ISCCP mid-level cloud cover to low-level cloud cover to obtain a better measure of true low-level cloud. Previous studies of the SE Pacific stratocumulus region have noted that surface observations of low-level cloud cover are in better agreement with the sum of ISCCP middle plus low-level cloud cover than low-level cloud cover alone (S5).

No corrections were applied to the COADS data even though there is a suspicious increase in global cloudiness that appears mostly associated with low-level cumulus types (S6, S7). If the global total cloud cover data are detrended to remove this, we find that the first EOF (Fig S3) has a spatial pattern that shows the same features as the patterns shown in Fig. 3 in the main text. The time series in Fig S3 also shows the 1976 and late-1990’s climate shifts that dominate the timeseries in the NE Pacific. For the analysis performed in the main text, the COADS data were not detrended, and the similarity of spatial and temporal variability with that shown in Fig S2 indicates that (1) the subtropical stratocumulus regions are not affected by spurious trends and (2) that the cloud fluctuations in the NE Pacific are part of the dominant mode of global cloud variability.

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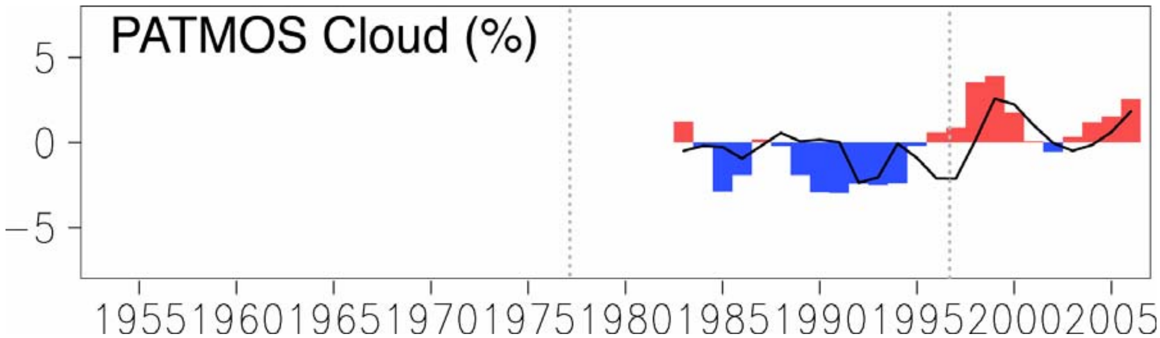

Figure S1: Time series of annual mean values of PATMOS-X (S8, S9) total cloud cover (black line) and low-level cloud cover from the split-window method (bars) averaged over the NE Pacific (115-145 W, 15-25 N). The time mean of each field is removed, and a 1-2-1 smoothing is applied. Units are percent cloud cover.

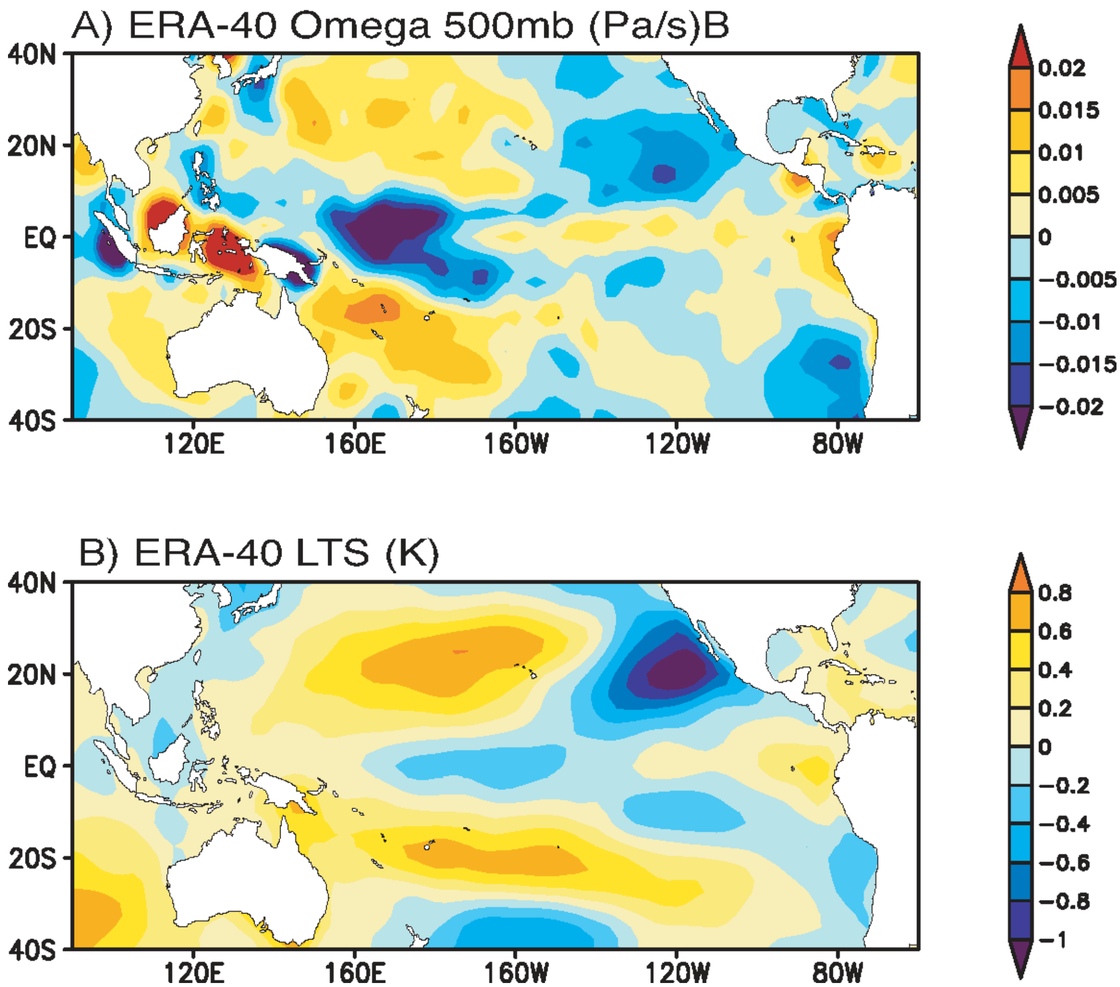

Figure S2: Regression of climate variables on the time series of NE Pacific SST (from Figure 1c). Values are shown per degree change in the NE Pacific index. (a) 500 mb vertical velocity from ERA40 (units of Pa/sec). (b) Lower-tropospheric stability (θ_{700}-SST) from ERA40 (K). While one may question the fidelity of the vertical velocity, the pattern shown in (a) is reproduced with the NCEP-NCAR reanalysis and also appears in surface wind divergence (not shown).

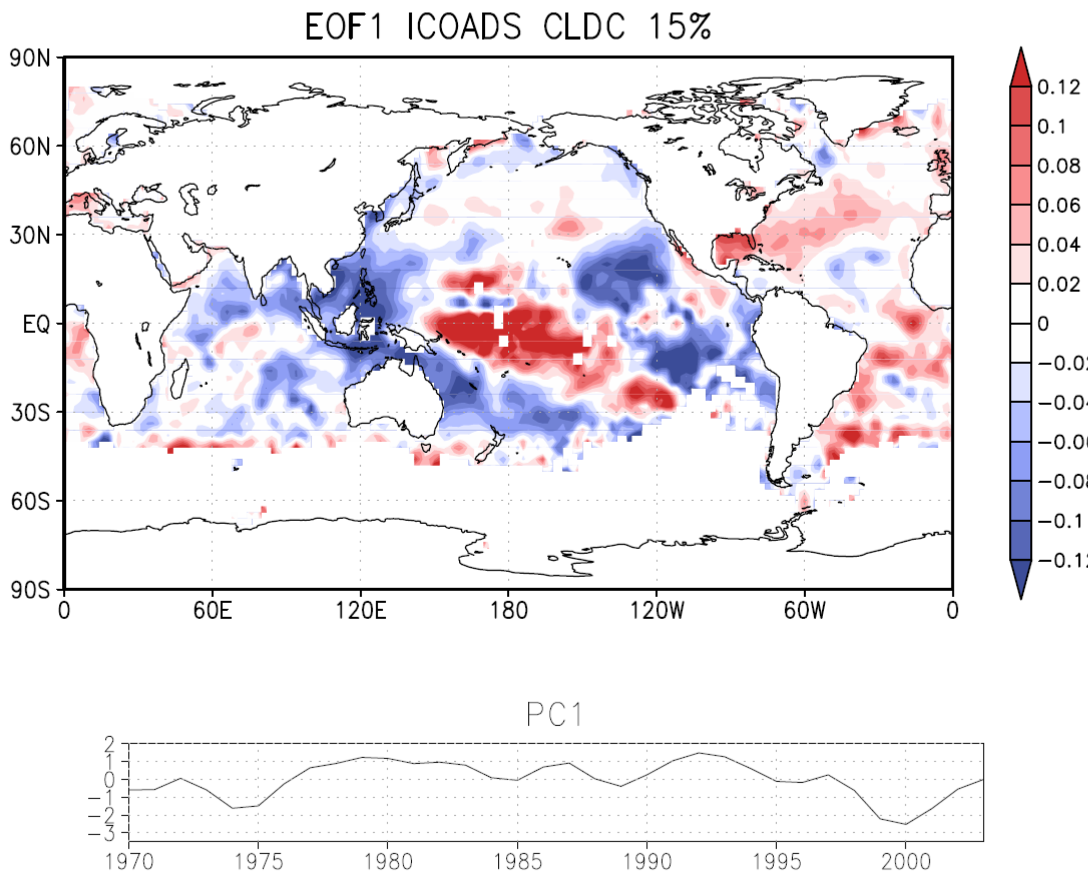

Figure S3: First EOF (15 % variance) (top panel) and principal component (bottom panel) of the detrended, global COADS total cloud cover. As in the figures in the main text, a 1-2-1 filter is applied before the EOF analysis. We do not include cloud data prior to 1970 because of insufficient global coverage.

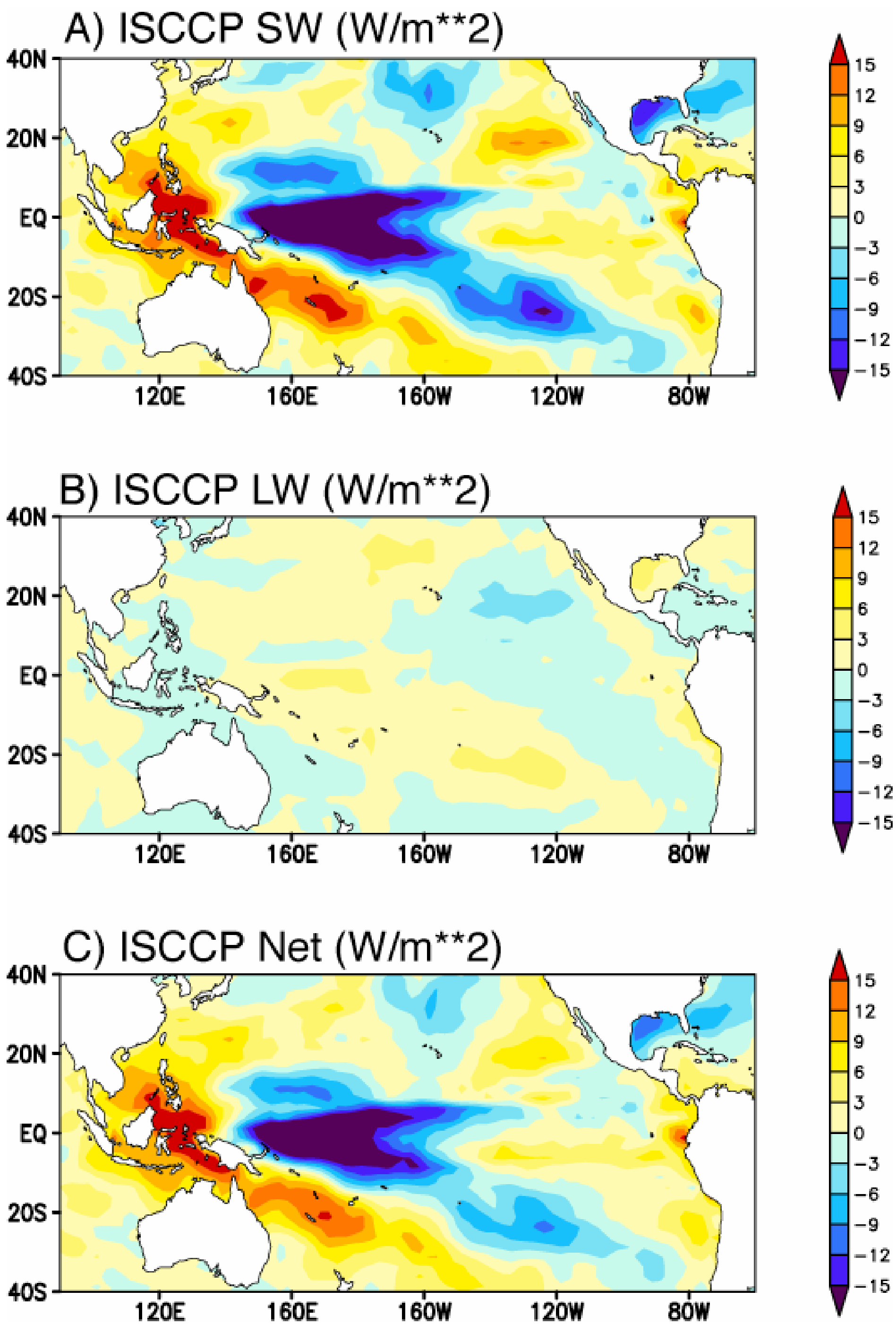

Figure S4: Regression of adjusted ISCCP cloud radiative effect and surface latent heat flux on the time series of NE Pacific SST (from Figure 1c). All panels are in units of Wm^{-2} per degree change in the SST index, and sign is positive into the surface. (a) Downward surface shortwave. (b) Downward surface longwave. (c) Net downward surface radiation.

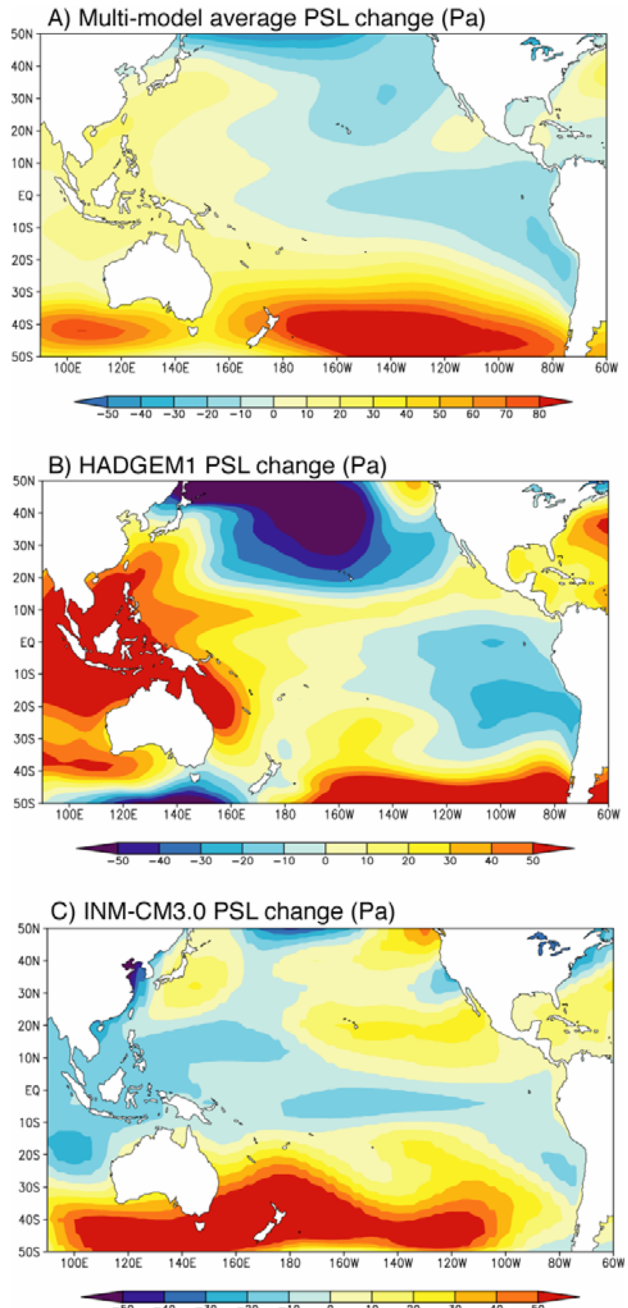

Figure S5: (a) Multi-model mean change in sea level pressure in 2xCO2 – present climate. All twenty-three available models are used to compute this. These data are taken from the 1pctto2x experiment which was initialized from year 410 of the PIcntrl experiment. CO2 was increased 1% per year, compounded, until doubling, (year 480) and then held fixed (at 710 ppm) for another 150 years. The differences shown in this figure were calculated by taking the last 50 years of the simulation with CO2 held at 710 ppm and subtracting years 1-70 of the simulation. (b) Same as (a) but for only the HadGEM1 model and (c) for the INM-CM3.0 model.