Supporting Information for "Linking Atmospheric Cloud Radiative Effects and Tropical Precipitation"

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Text S1: Regions of the Tropics and Distributions of CRH

The latitude and longitude boundaries for the six tropical regions used in the main text are recorded in Tbl. S1. The regions were selected to give a range of underlying sea surface temperature (SST) and column relative humidity (CRH) distributions (see Fig. S1). The Indo-Pacific warm pool, south Pacific convergence zone, Pacific ITCZ and Atlantic ITCZ regions are characterized by time-mean low-level moisture convergence which favors deep convection. In contrast, the Atlantic and Pacific cold tongue regions are characterized by

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cold upwelling SSTs and are situated under the descending branch of the Hadley cells. The cold SSTs and subsiding motion both tend to suppresses deep convection and favor the formation of marine stratocumulus clouds.

Probability density functions (PDFs) of column relative humidity (CRH) are included in the six panels of Fig. S1. The CRH appears to follow a bimodal distribution, with a "humid peak" near 80% and a "dry peak" near 40%. The Indo-Pacific and ITCZ regions have a single mode near the humid peak, while the cold tongue regions have a single moad near the dry peak. Only the SPCZ region exhibits the bimodal behavior of the wider tropical belt.

Text S2: ACRE Binned by CRH for Six Tropical Regions

Fig. S2 shows the net ACRE binned by the CRH for the six regions specified in the main text and in Tbl. S1. Each panel shows a rapid increase in magnitude above a threshold of about 60%. This is consistent with the curve of the ACRE vs. CRH over the entire tropical belt from 30°S to 30°N (see Fig. 1.d in the main text).

As mentioned in the main text, the curves for the cold tongue regions (Fig. S2.e and S2.f) each show the influence of marine stratus clouds. These clouds occur in relatively dry conditions under the subsiding branches of the hadley cells. Because they are bright, they reflect a large amount of solar radiation and have a large negative ACRE. This is illustrated in Fig. S2.e and S2.f as the, negative extrema near 20$ CRH that is absent in the other panels. This likely contributes to the error in the estimation method in these regions (Fig. S2 of the main text).

Text S3: Composite ENSO Analysis of Estimated ACRE

The time series analysis of the main text (Fig. 3) suggests that the estimation method may be more biased in the Pacific ITCZ, Indo-Pacific Warm Pool or Pacific cold tongue regions during different phases of ENSO variability.

To investigate this, we repeat the calculation of Pearson's R^2 correlation for each of the six regions, composited by ENSO phase. We use the Oceanic Niño Index (ONI, National Weather Service (2020)) as our metric for ENSO phase. An El Niño occurs when the ONI exceeds 0.5 K for 5 consecutive months, while a La Niña occurs when the ONI is less than -0.5 for 5 consecutive months. Fig. S3 shows a time series of the ONI aligned with the 19-year period used in the main texts. El Niño (La Niña) periods are colored red (blue). For the sake of completeness the analysis is repeated for each of the six regions (Figs. S4 through S9), but we focus only on the Pacific ITCZ (Fig. S4) and Indo-Pacific warm pool (Fig. S5), which show the most clear dependence on ENSO.

The top left panel of Fig. S4 shows the correlation between the estimated (y-axis) and observed (x-axis) monthly ACRE anomalies in the Pacific ITCZ region, with data points colored according to the ENSO phase. A first look shows a relationship between ENSO phase as ACRE anomaly in this region: El Niño conditions (red) support enhanced convection due to warmer SSTs in the eastern equatorial Pacific, leading to positive ACRE anomalies, while La Niña conditions (blue) suppress convection due to cooler SSTs, leading to negative anomalies. In the Indo-Pacific regions (Fig. S5), the opposite occurs. In this region, El Niño is associated with *cooler* SSTs, while La Niña is associated with *warmer* SSTs. The result is that El Niño (red) months in Fig. S5 are associated with negative ACRE anomalies, and La Niña (blue) months are associated with positive ACRE anomalies.

The R^2 correlation is 0.401 during La Niña in the Pacific ITCZ, while it is above 0.7 during the neutral and Niño phases in that region (bottom row of Fig. S4). This suggests that the estimation method is less accurate in this region during La Niña due to a lower frequency of organized convection at the expense of marine stratus clouds. The R^2 correlations do not seem to vary with ENSO in the Indo-Pacific region, or in any of the other regions. There is a slight difference in the Atlantic Cold Tongue region, but this is likely due to noise, as the anomalies all centered around zero during each ENSO phase (Bottom row of Fig. S9)

References

National Weather Service. (2020, December). *Cold & warm episodes by season.* https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php. Retrieved from https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php (Accessed: 2020-12-22)

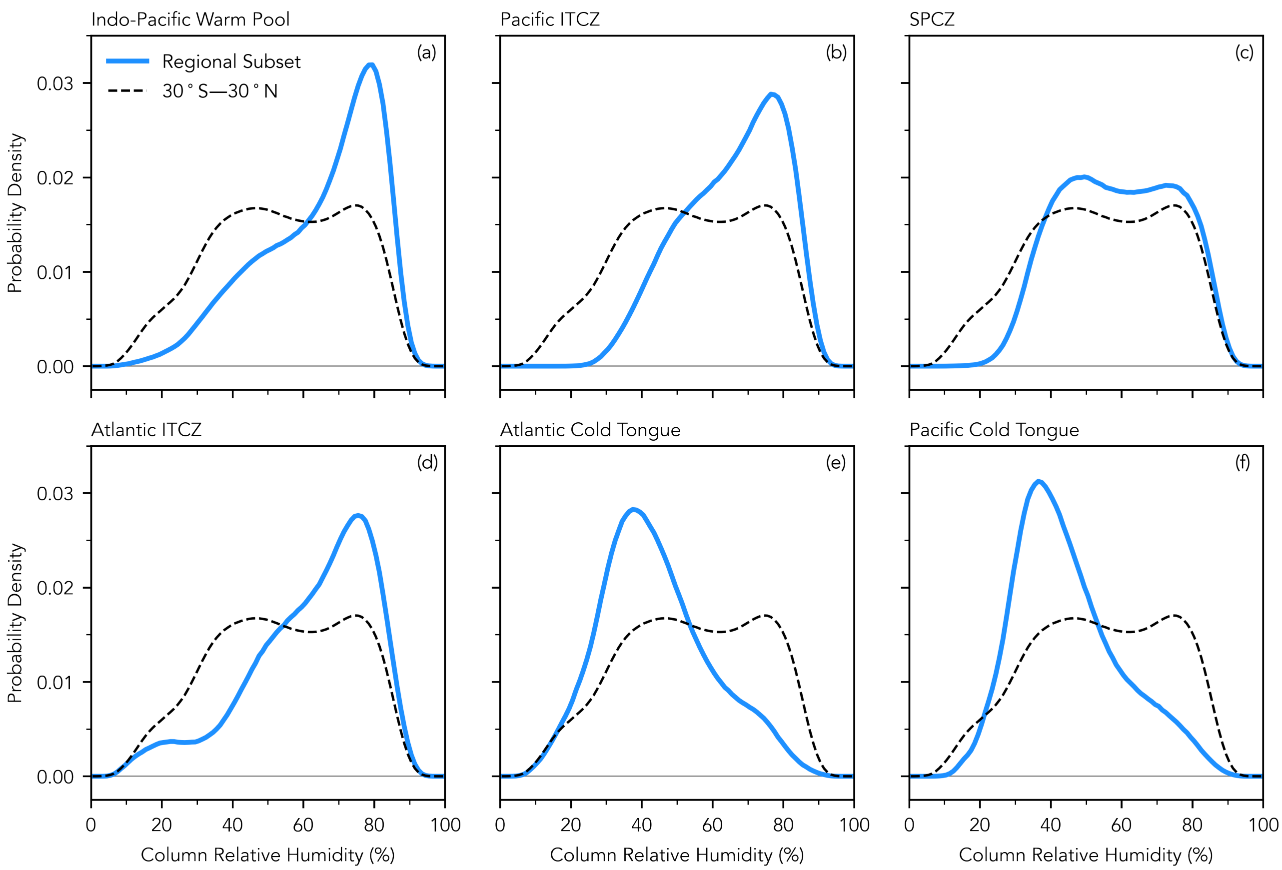

Figure S1. **(a)** Probability density functions of column relative humidity for the Indo-Pacific warm pool (red line) and over the entire 30°S-30°N tropical belt. **(b)-(f):** same as **(a)**, but for, respectively, the pacific ITCZ, the SPCZ, the Pacific cold tongue, the Atlantic ITCZ, and the Atlantic cold tongue.

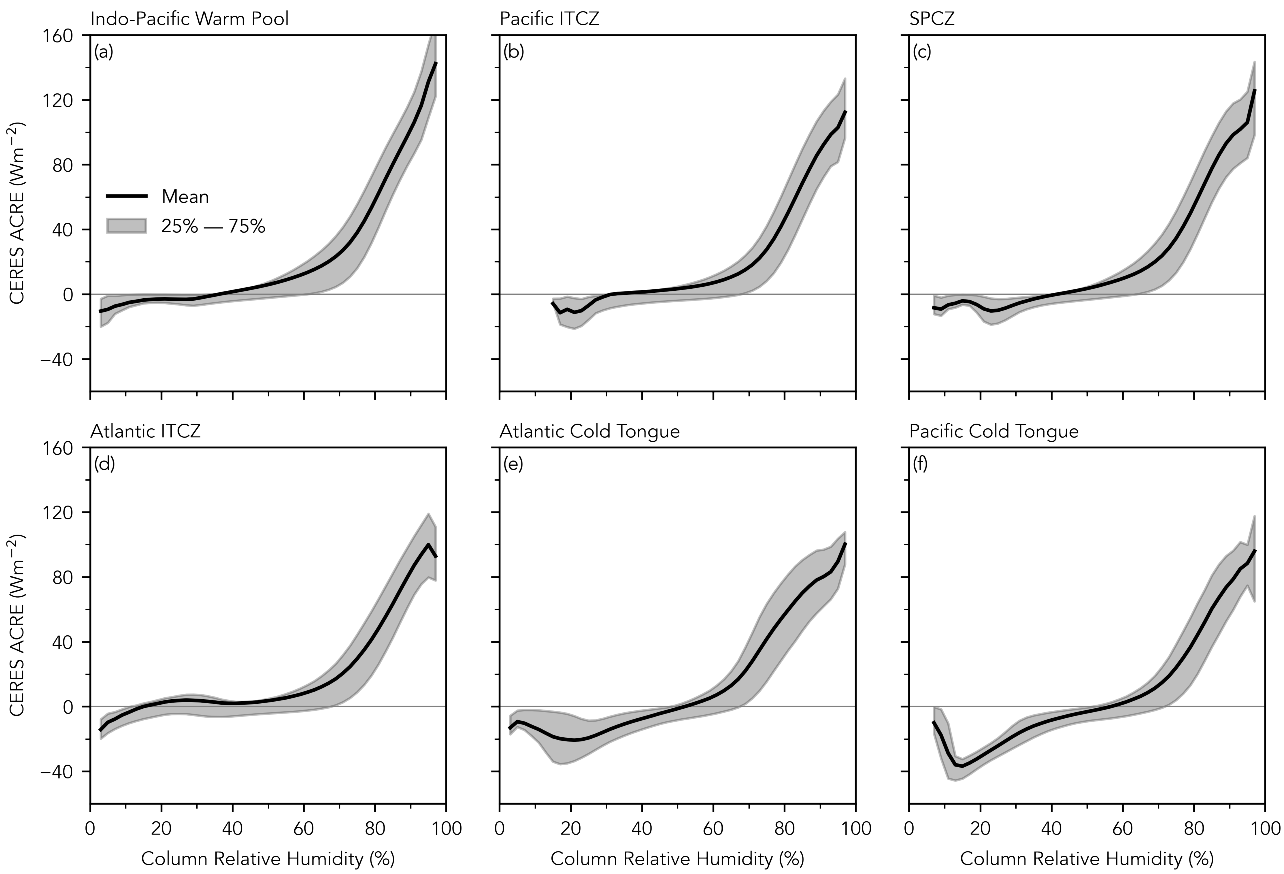

Figure S2. Net (longwave plus shortwave) ACRE binned by the CRH for the six tropical regions specified in Fig. 1.a of the main text.

Table S1. Pearson's R^2 correlation between ACRE calculated from CERES observations and ACRE estimated from ERA5 CRH at monthly and daily time-scales for each of the six tropical sub regions. Also included are the latitude and longitude boundaries for each region.

	Regional Extent	Monthly R^2	Daily R^2
Indo-Pacific Warm Pool	70°E-170°W, 20°S-20°N	0.775	0.624
Pacific ITCZ	150°E-100°W, 0°-15°N	0.753	0.569
SPCZ	150°E-130°W, 30°S-0°	0.616	0.486
Pacific Cold Tongue	130°W-95°W, 30°S-0°	0.56	0.39
Atlantic ITCZ	55°W-15°E, 5°S-15°N	0.653	0.507
Atlantic Cold Tongue	40°W-20°E, 30°S-5°N	0.515	0.421

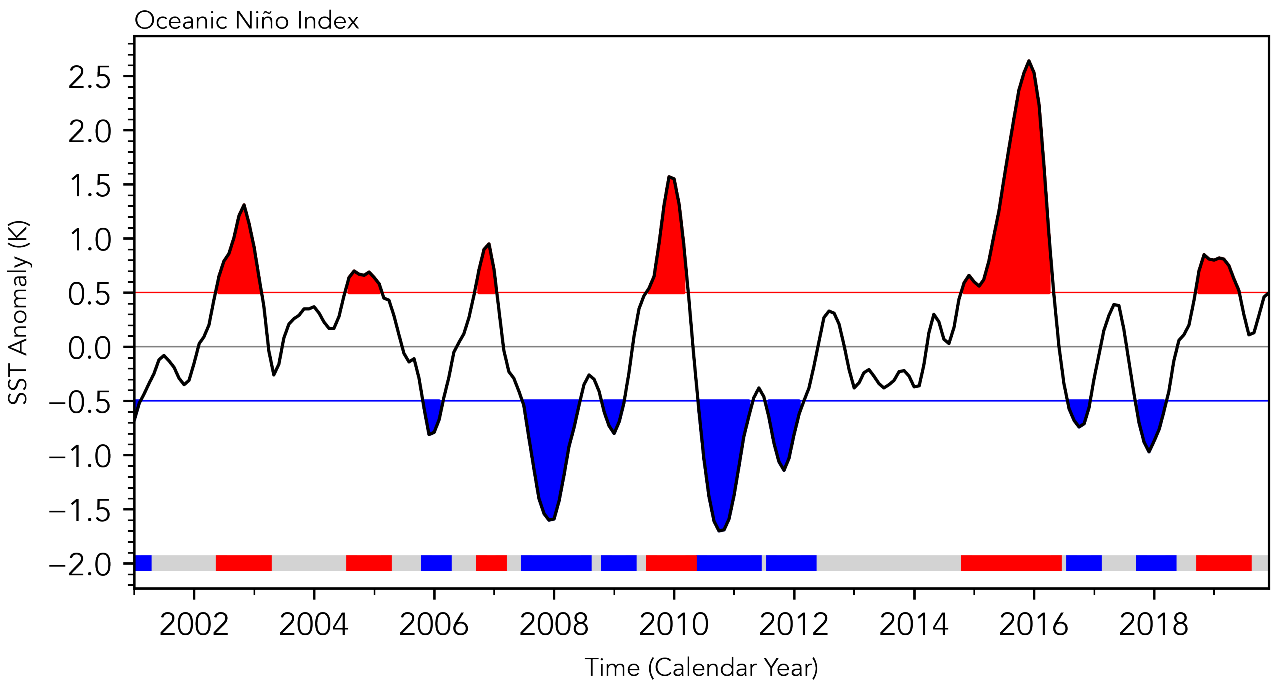

Figure S3. Oceanic Niño index, showing centered, 3-month running average SST anomaly over the Ni no 3.4 region of the eastern Pacific.

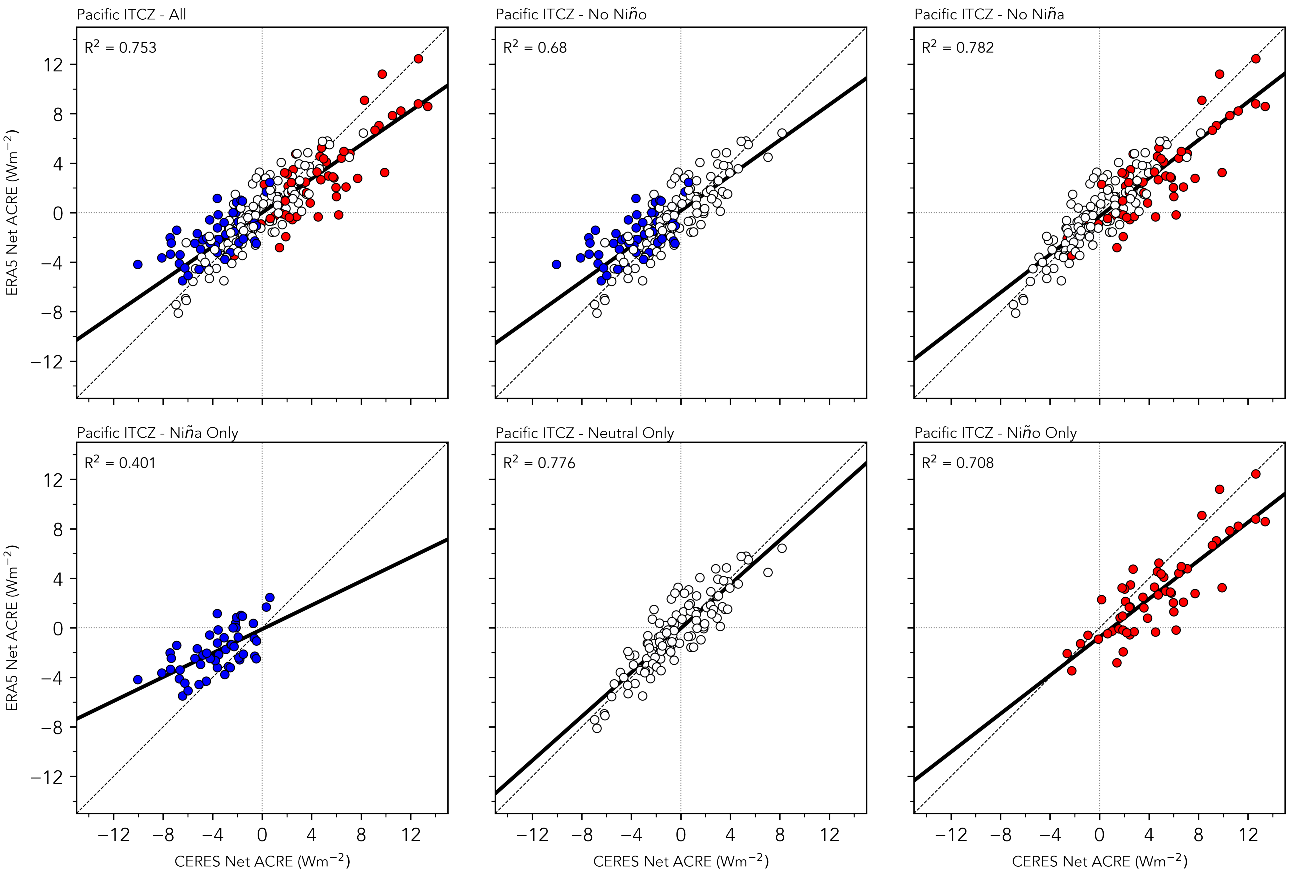

Figure S4. Correlation between ACRE observed from CERES fluxes (horizontal) with ACRE estimated from ERA5 CRH for the Pacific ITCZ region, as described in the main text. The color of the dots in each panel indicates the ONI phase (See Fig. S3) associated with each data point: red indicates El Niño, white indicates neutral, and blue indicates La Niña. **Top Left:** Correlation for all months. **Top Center:** Correlation for neutral and Niña. months only. **Top Right:** Correlation for Niño and neutral months only. **Bottom Left:** Correlation for Niña months only. **Bottom Center:** Correlation for neutral months only. **Bottom Right:** Correlation for Niño months only. In each panel, the thick black line shows the line of best fit (least-squares regression), and the dashed diagonal line shows a perfect one-to-one correlation.

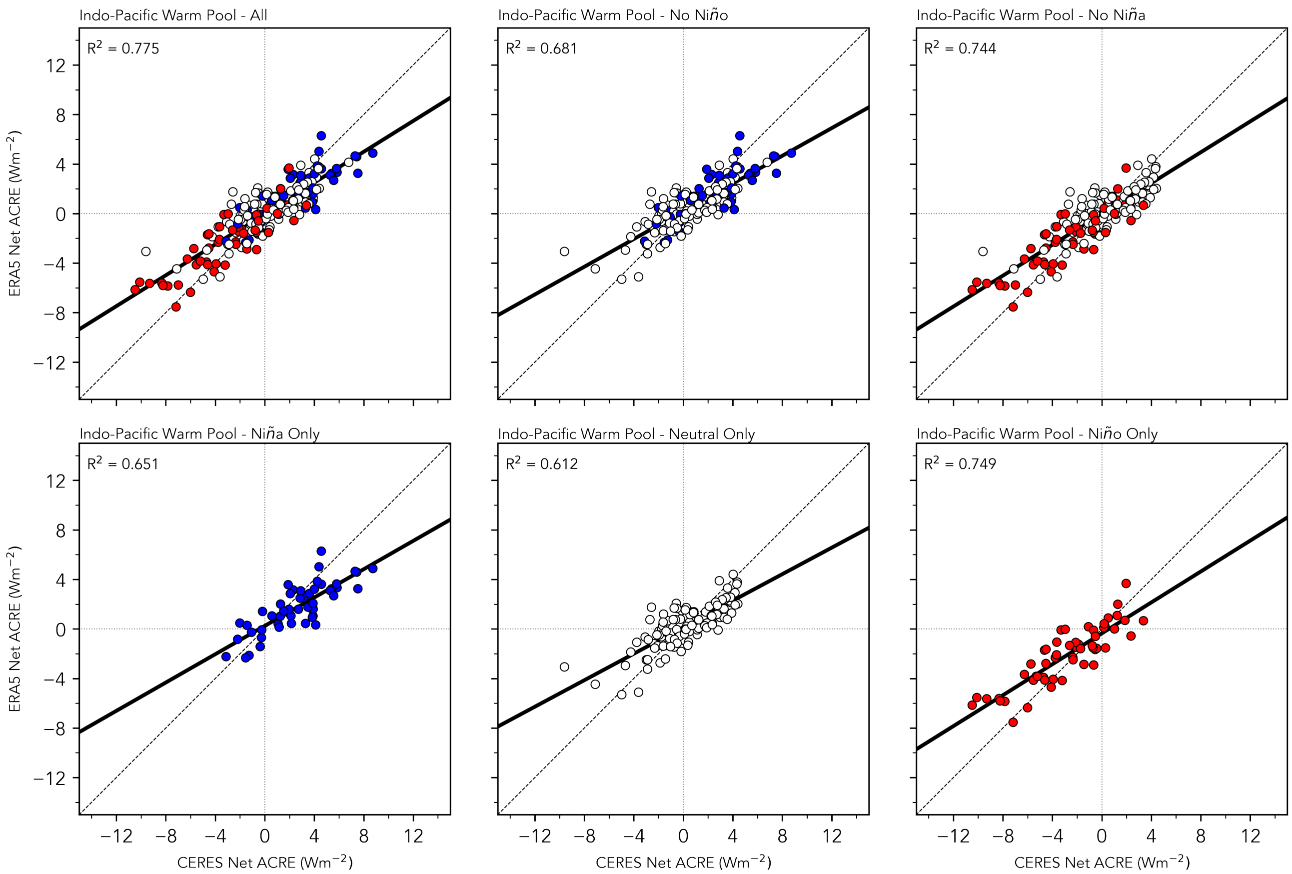

Figure S5. Same as Fig. S4, but for the Indo-Pacific Warm Pool

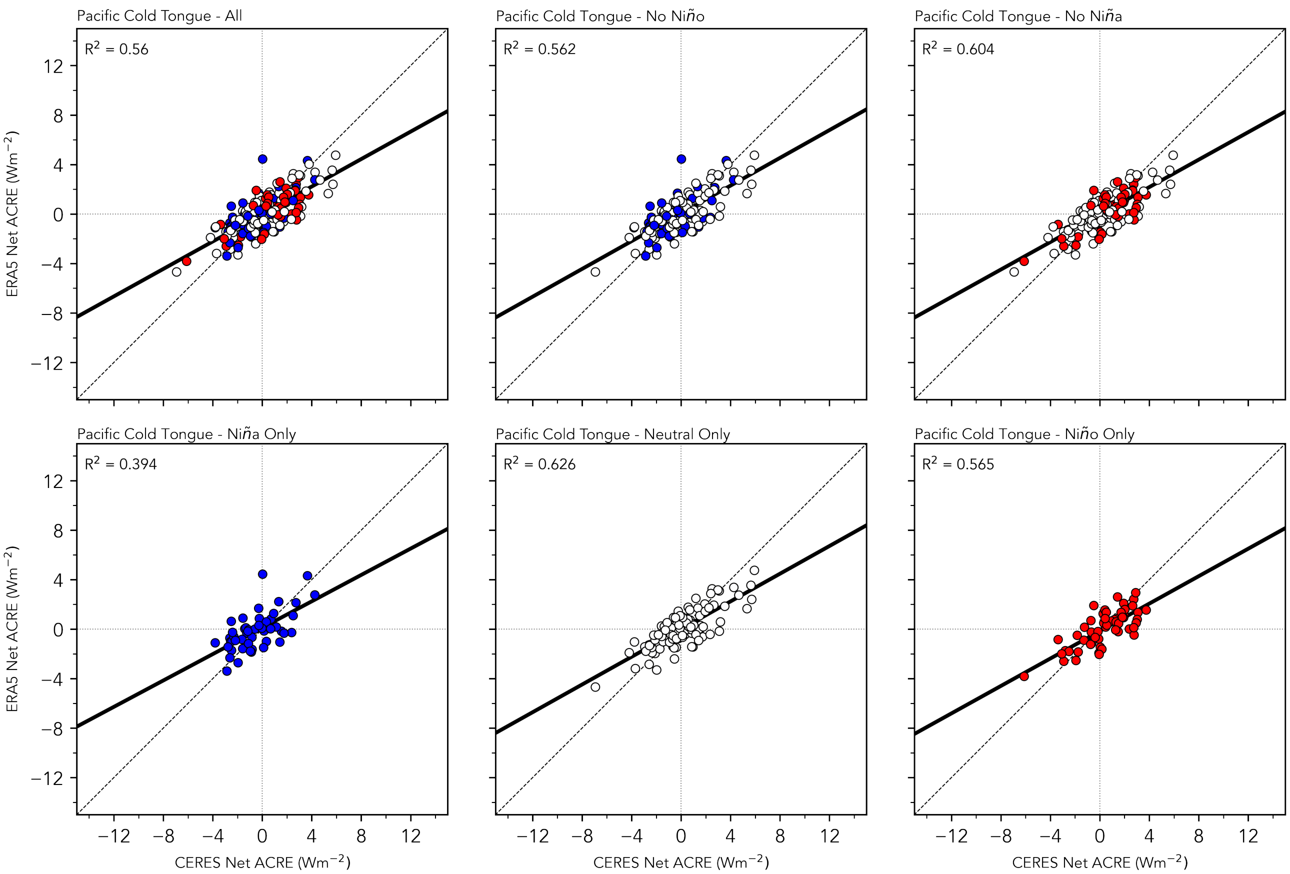

Figure S6. Same as Fig. S4, but for the Pacific cold tongue

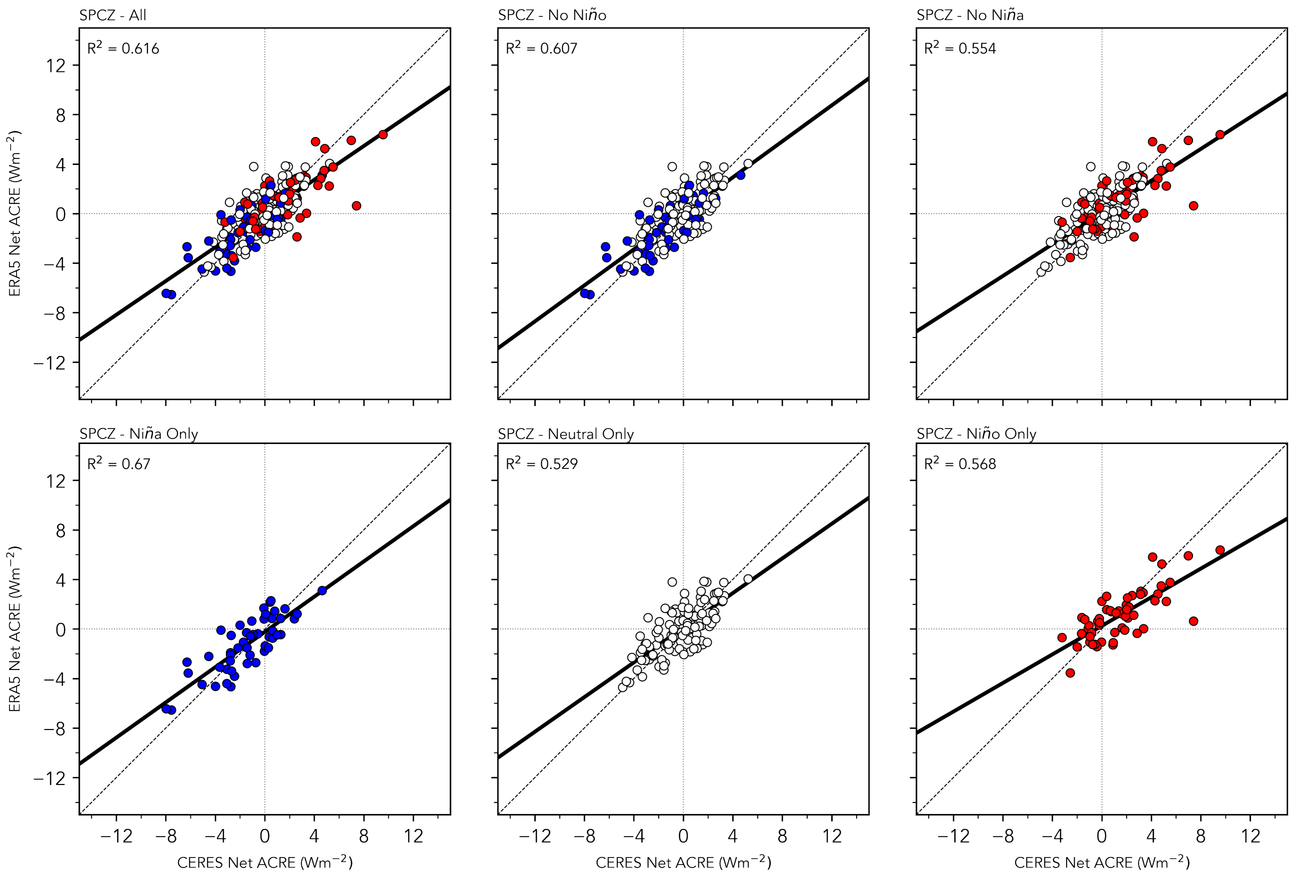

Figure S7. Same as Fig. S4, but for the Atlantic ITCZ region

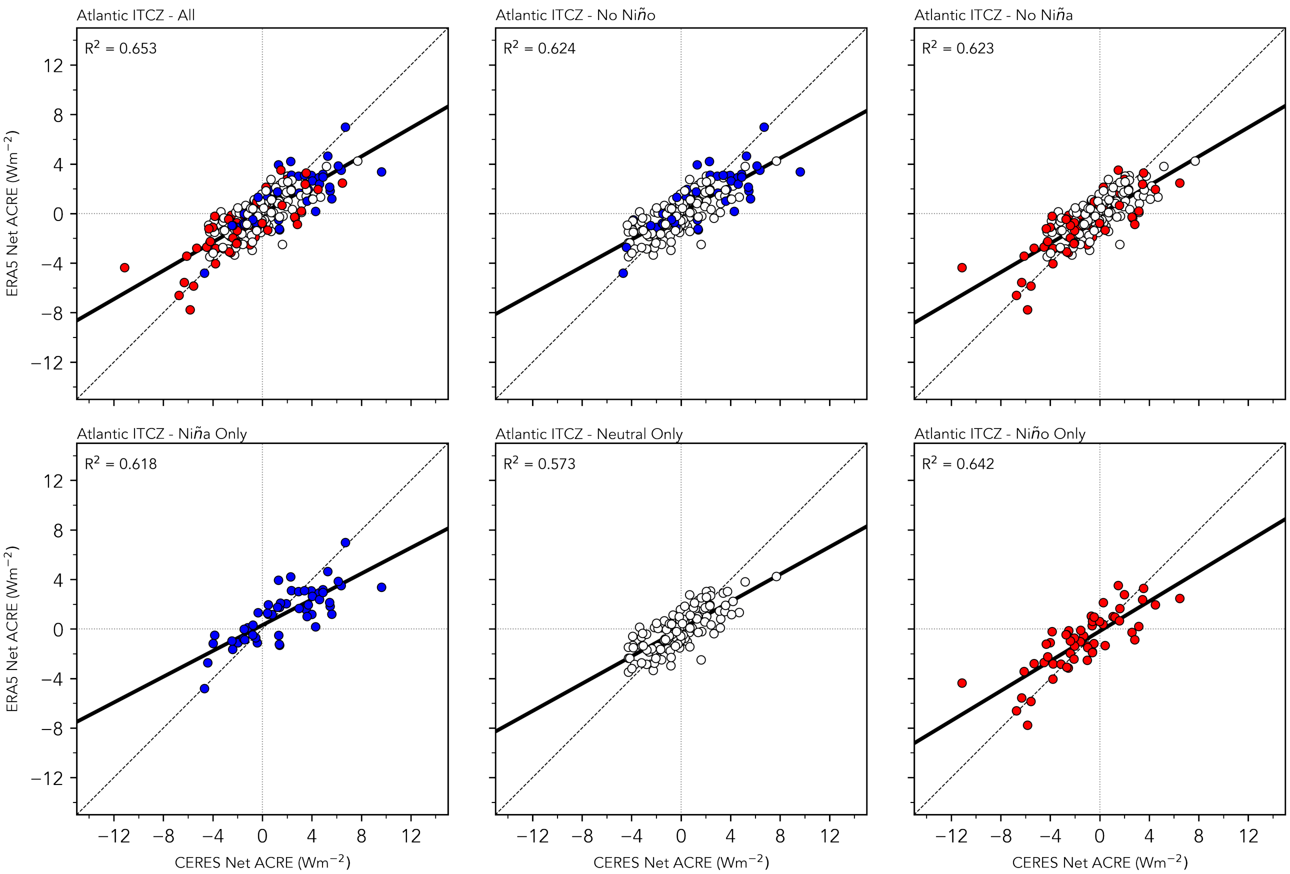

Figure S8. Same as Fig. S4, but for the SPCZ region

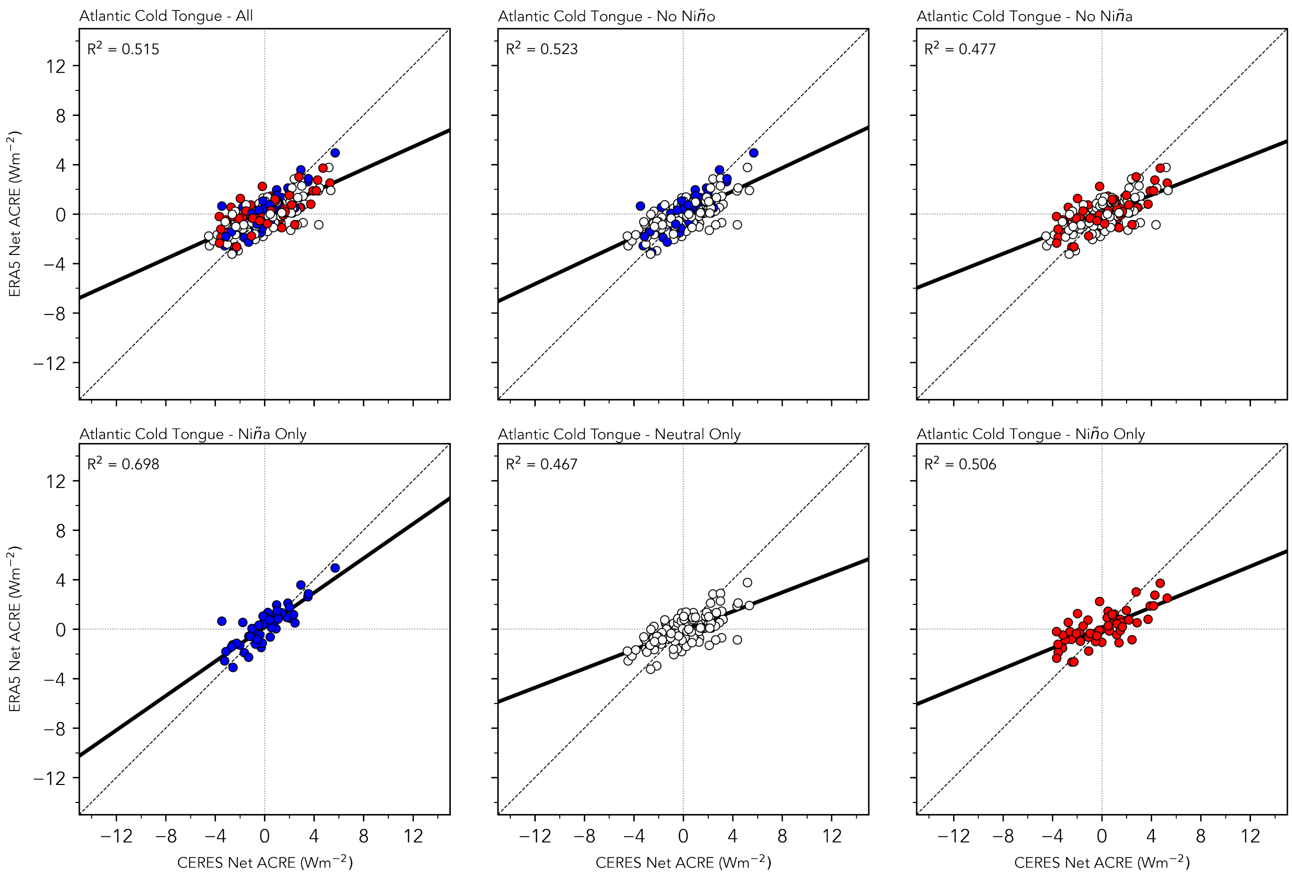

Figure S9. Same as Fig. S4, but for the Atlantic cold tongue region