Modulation of El Niño Decay by Negative High Cloud Feedback

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Introduction

The El Niño-Southern Oscillation (ENSO) is the most dominant interannual variability in the tropical area, with its decay phase exerting profound impacts on global weather. ENSO decay phase is driven not only by ocean dynamics but also by complex atmospheric processes. While the cooling effect of low clouds has been extensively studied, the role of high clouds in modulating El Niño's decay phase remains undervalued.

Using reanalysis datasets and the Coupled Model Intercomparison Project Phase 6 (CMIP6) models, this study investigates how high-cloud radiative effects regulate El Niño's decay rate.

Data

Historical experiments from 32 CMIP6 models

Observations: SST from NOAA ERSST; Cloud amount and radiation fluxes from ERA5; Niño3.4 calculated from ERSST provided by NOAA

Method

- **El Niño:** Niño3.4 exceeds 0.4°C for at least five consecutive months.
- **Cloud feedback (λ_{cloud}):** the ratio of the spatially averaged surface cloud radiative effect (Sfc CRE) anomaly to the spatially averaged SST anomaly during Max+0 to Max+2. (**Spatial Domain Selection:** regions with large variability in Sfc CRE, instead of a fixed basin-wide average.)
- $\textit{Decay rate} = \dfrac{Niño3.4_{end} - Niño3.4_{peak}}{Time_{end} - Time_{peak}}$

(the definitions of peak and end time shown in Fig. 1)

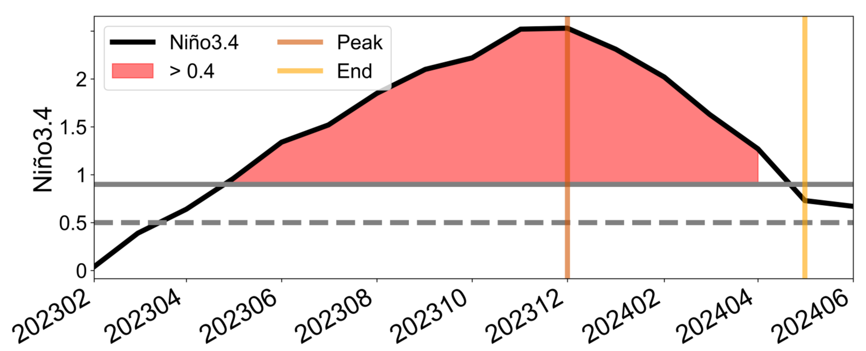

Fig. 1 Niño3.4 from Feb 2023 to June 2024.

CESM2 (BHIST from 1850 to 1949)

- **Control:** micro_mg_dcs=200μm
- **Long_Cld_Lifetime:** micro_mg_dcs=400μm

micro_mg_dcs governs the autoconversion of cloud ice to snow. Increasing micro_mg_dcs delays the conversion of ice to snow, leading to longer cloud lifetimes.

Stronger El Niño → Stronger Cooling of high clouds → Faster decay

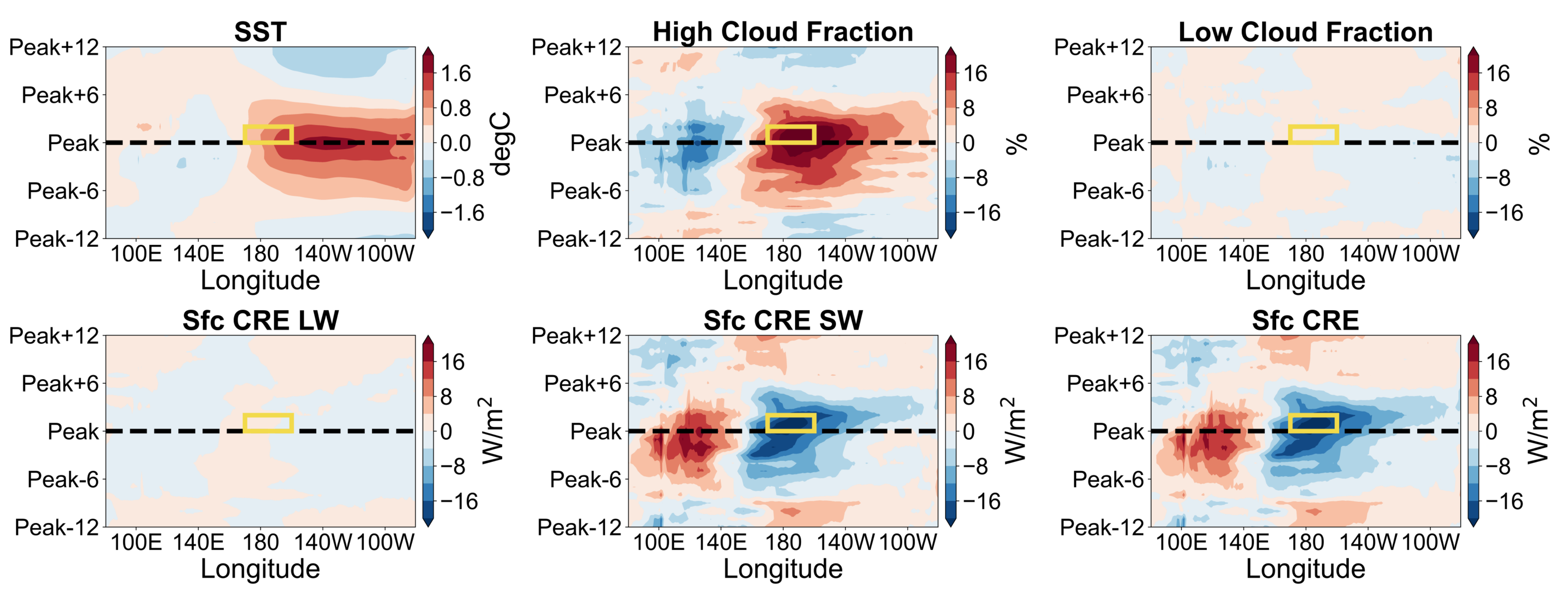

Fig. 2 Hovmöller diagrams of equatorial anomalies averaged over 5°S–5°N, shown relative to the El Niño peak. The time axis spans from Peak−12 to Peak+12 months). The yellow box highlights the region (170°E–160°W, Peak to Peak+2) with the large variability in Sfc CRE for cloud feedback calculation.

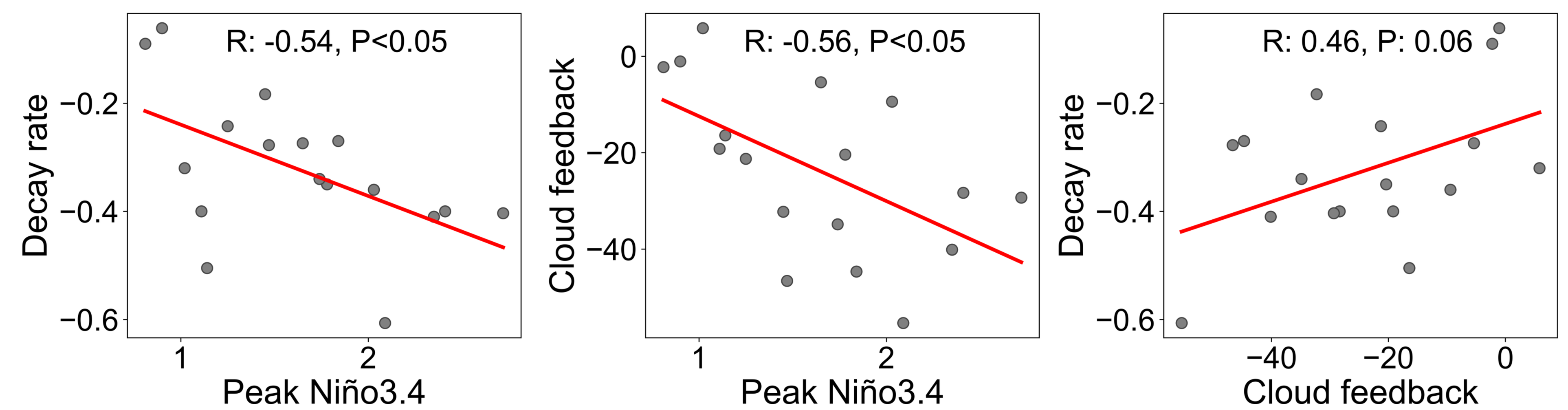

Fig. 3 Scatter plots of peak Niño3.4, cloud feedback, and decay rate. Red lines indicate linear regression fits across historical El Niño events.

Robustness of the cooling effect of high clouds across CMIP6 models

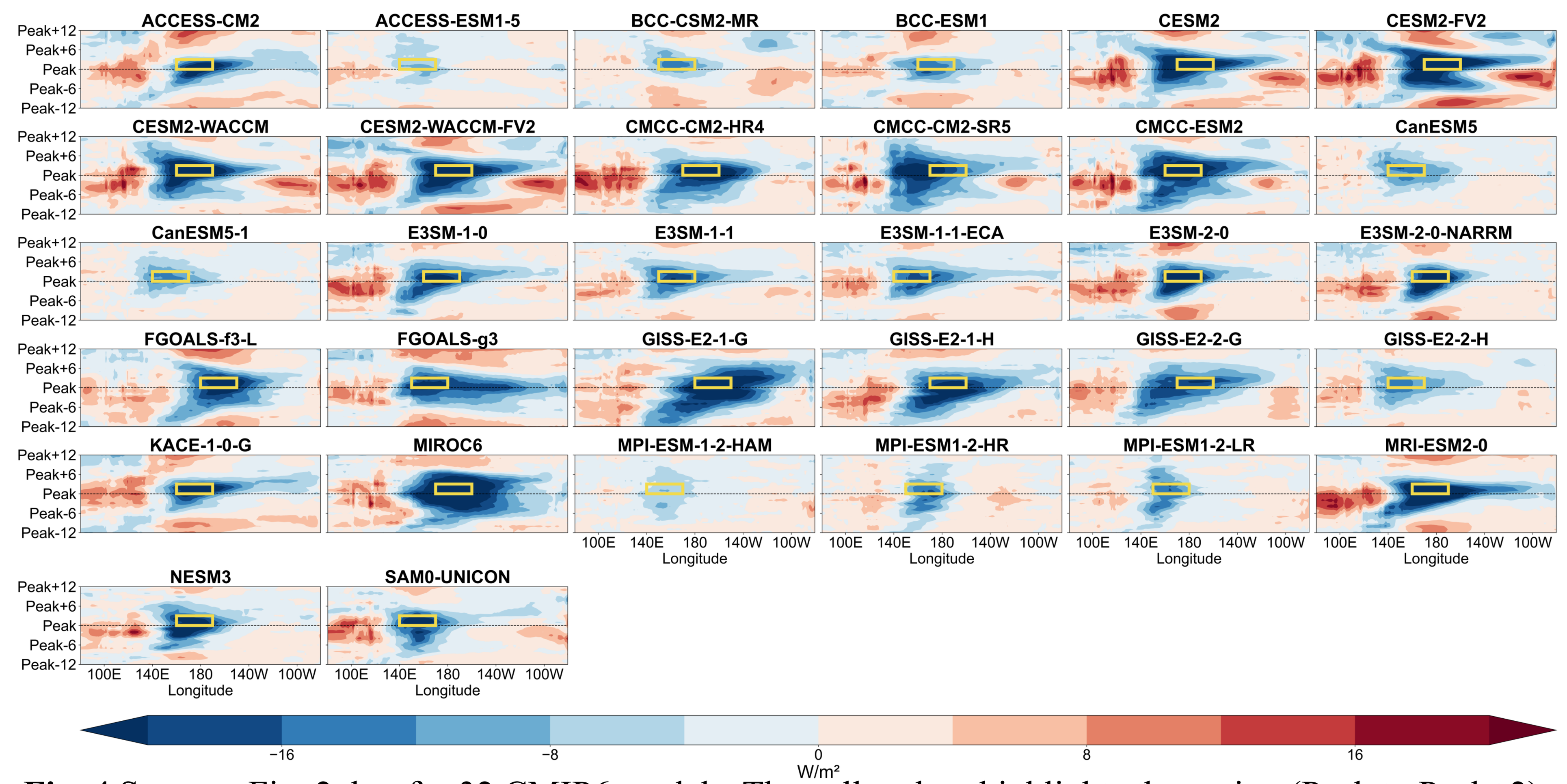

Fig. 4 Same as Fig. 2, but for 32 CMIP6 models. The yellow box highlights the region (Peak to Peak+2) with the large variability in Sfc CRE for further analysis, with the exact region varying by model.

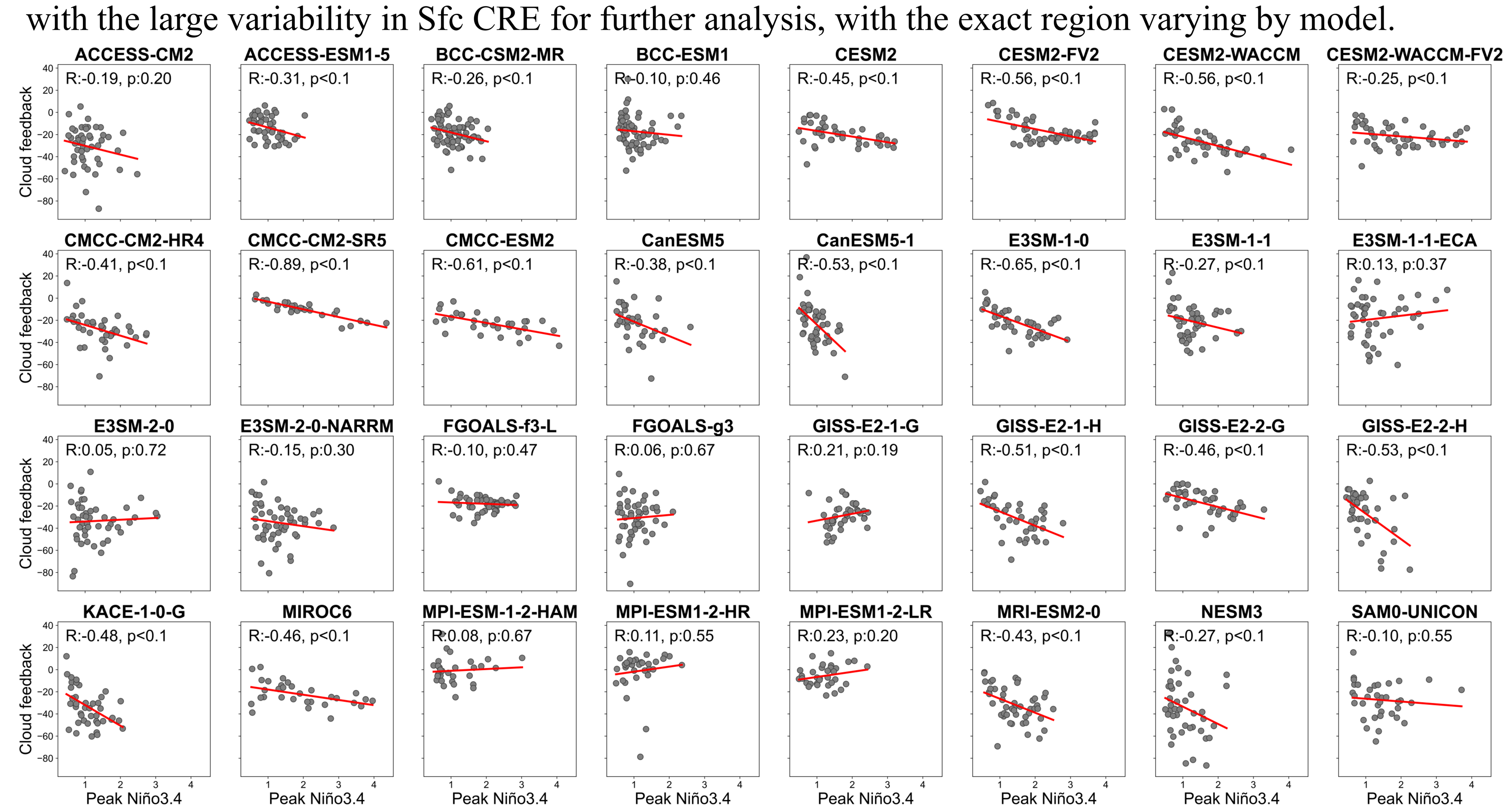

Fig. 5 Same as Fig. 3, but for 32 CMIP6 models. 20 models successfully capture the relationship between the Niño3.4 peak and cloud feedback.

Longer cloud lifetime enhances negative cloud feedback and accelerates El Niño decay.

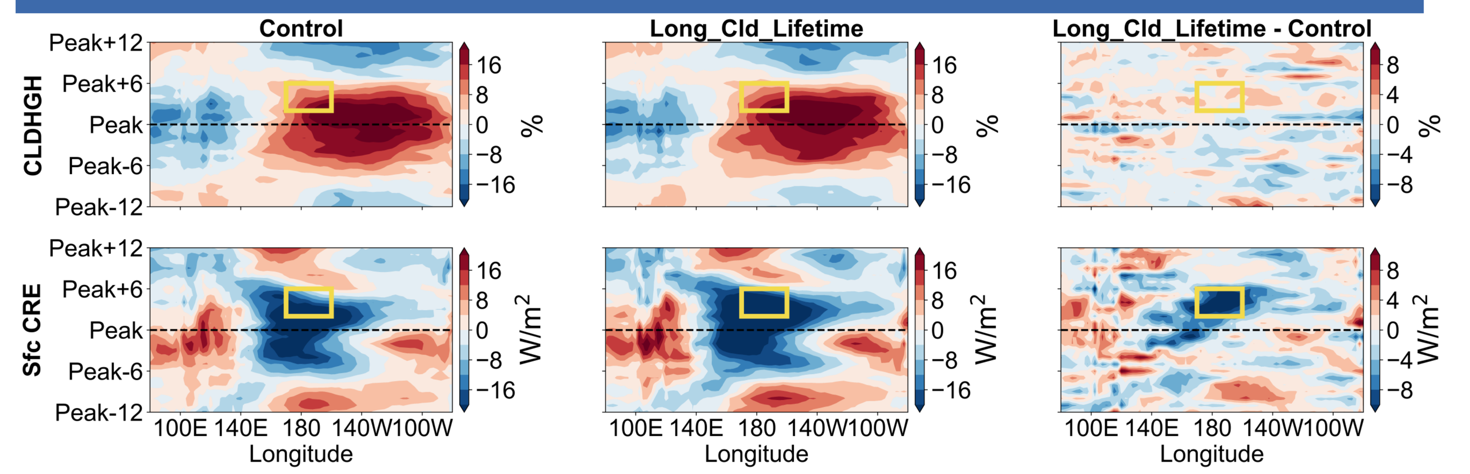

Fig. 6 Same as Fig. 2. The yellow box highlights the region (170°E–160°W, Peak+2 to Peak+6) with the large difference in Sfc CRE between Long_Cld_Lifetime and Control.

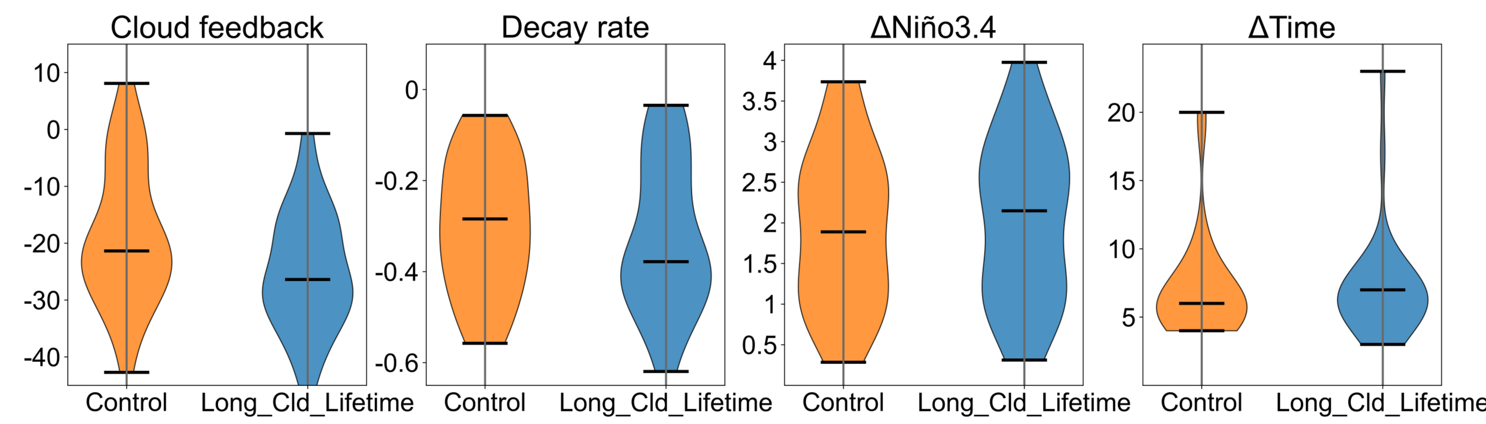

Fig. 7 Violin plots comparing the distributions of negative high cloud feedbacks, decay rates, $Niño3.4_{end} - Niño3.4_{peak}$ and $Time_{end} - Time_{peak}$(from left to right) between Control (orange) and Long_Cld_Lifetime (blue) experiments. The horizontal lines within each violin indicate the maximum, median, and minimum values.

Summary

- Observations reveal stronger El Niño events induce stronger high cloud feedback in the central Pacific, which accelerates the decay phase.
- The cooling mechanism is robust across 32 CMIP6 models. Despite inter-model spreads, the majority of models successfully capture this negative high cloud feedback during the El Niño decay phase.
- Sensitivity experiments confirm that extending cloud lifetime intensifies the surface cooling effect and accelerates the El Niño decay rate. However, the impacts on peak Niño3.4 amplitude and the duration of decay phase are less pronounced, suggesting that the expected reduction in event duration is partially offset by a slight increase in peak Niño 3.4 amplitude.

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