Constraints on the Pattern Effect Using Observations: A Low Cloud Feedback Perspective

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Introduction

Model evidence for the "pattern effect" assumes that global climate models faithfully simulate how marine clouds respond to varying SST patterns and associated meteorological perturbations.

We use an observational framework to quantify how marine low clouds have responded to SST patterns since 1870 and meteorological trends since ~1980.

Method to Constrain Cloud Feedback

Low cloud feedback at each 5° x 5° grid box over 60°S - 60° N oceans =

$$\frac{dR(\theta,\phi,t)}{dT} = \sum_{i=1}^{6} \frac{\partial R(\theta,\phi)}{\partial x_i} \frac{dx_i(\theta,\phi,t)}{dT}$$

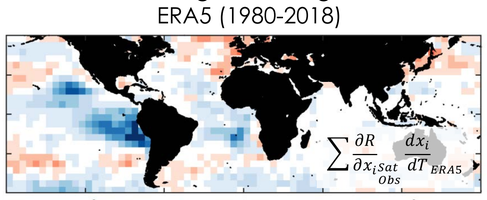
R = unobscured low cloud radiative effect
x_i = cloud-controlling factor (CCF) (SST, EIS, etc.)
T = global mean surface temperature
θ = latitude, ϕ = longitude, t = time

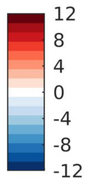
$\frac{\partial R}{\partial x_i}$ **Observation-based *meteorological cloud radiative kernels* developed by Scott et al. (2020) and applied in Myers et al. (2021).** Multi-linear regression of interannual monthly anomalies of satellite-derived R on observed x_i.

$\frac{dx_i}{dT}$ **Change in cloud-controlling factor with planetary warming.** Reanalyses (1980-2018) & CMIP6 AMIP-piForcing experiments (1870-2014) are used to estimate how each CCF has changed historically. Using abrupt4xCO2 runs to estimate this term yields the feedback from increasing CO_2 derived by Myers et al. (2021).

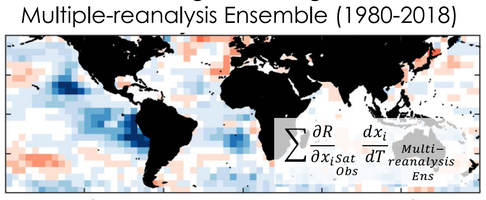
Marine Low Cloud Feedback on Two Timescales

Constrained by Sat. Obs. and Meteorological Changes from ERA5 (1980-2018)

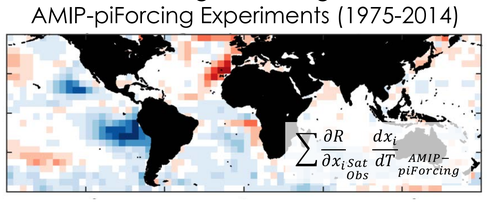


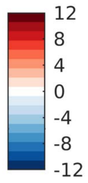


Constrained by Sat. Obs. and Meteorological changes from Multiple-reanalysis Ensemble (1980-2018)

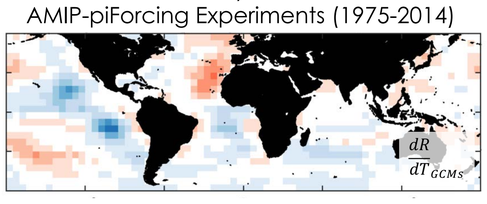


Constrained by Sat. Obs. and Meteorological Changes from AMIP-piForcing Experiments (1975-2014)

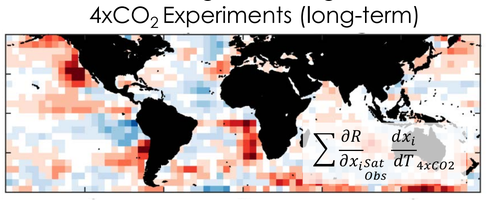


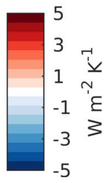


Simulated by Six GCMs in AMIP-piForcing Experiments (1975-2014)

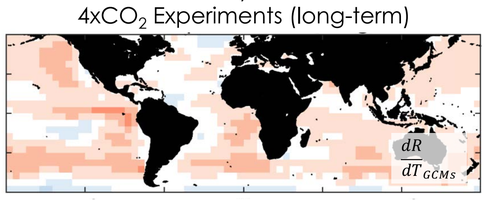


Constrained by Sat. Obs. and Meteorological Changes from 4xCO$_2$ Experiments (long-term)





Simulated by 11 GCMs in 4xCO$_2$ Experiments (long-term)



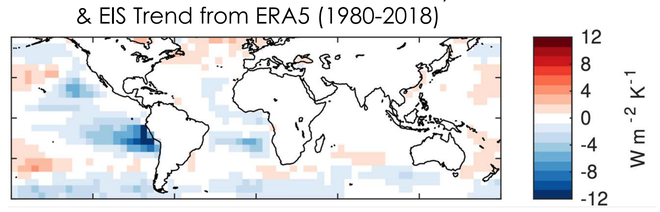
In general, recent historical cloud feedbacks are much more stabilizing than the long-term feedbacks arising from increasing CO_2, especially over eastern subtropical Pacific.

Hence, the processes responsible for recent historical marine low cloud changes are distinct from those associated with a long-term increase in CO_2.

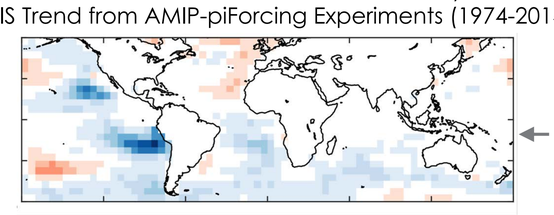
Sat. Obs. above = MODIS and CERES

Driver of Recent Negative Cloud Feedback – Increasing EIS

EIS-induced Cloud Feedback Constrained by Sat. Obs. & EIS Trend from ERA5 (1980-2018)



EIS-induced Cloud Feedback Constrained by Sat. Obs. & EIS Trend from AMIP-piForcing Experiments (1974-2014)

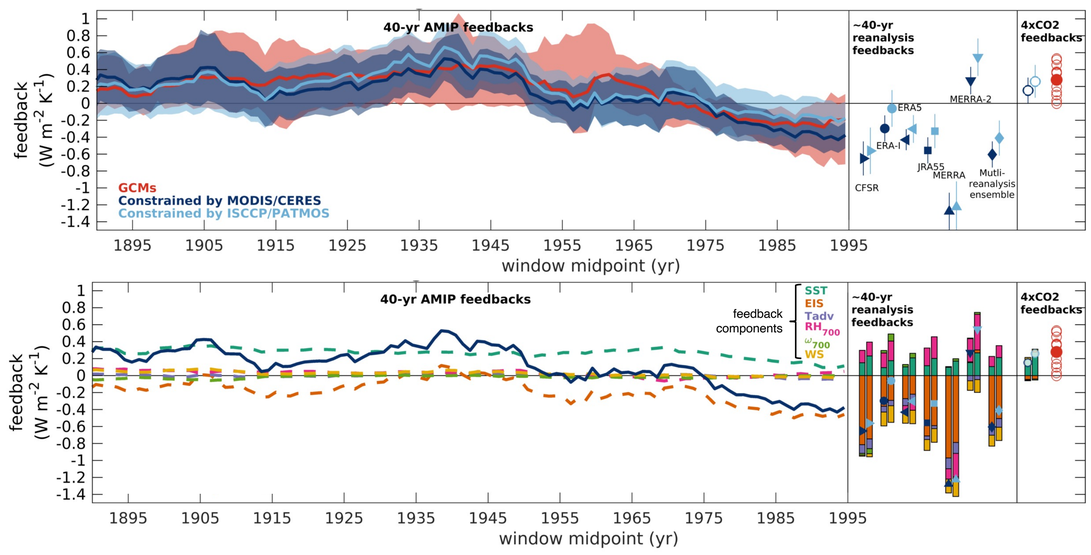


Forced by historical SSTs

Implies that changes in marine clouds over the last several decades have been driven by changes in the pattern of SST and the resulting increase in EIS.

Consistent with Zhou et al. (2016) and Cesana et al. (2021)

Near-Global Multi-Decadal Feedbacks



Multi-decadal variations in the low cloud feedback constrained by observations are largely consistent with variations in the feedbacks produced by GCMs forced by historical SST patterns.

The feedback closely tracks that induced by the evolution of EIS, consistent with the large negative EIS-induced feedback inferred from reanalyses.

Recent cloud feedbacks are anomalous relative to the previous ~100 years, consistent with Andrews et al. (2018) and (2022).

Conclusions

Historical (1980-2018) marine low cloud feedback is negative.

Large increase in inversion strength over eastern subtropical Pacific induced this feedback.

GCMs forced by historical SSTs reproduce these climate changes

Processes controlling historical marine cloud changes are distinct from those associated with an increase in carbon dioxide.

References
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Cesana, G. V., & Del Genio, A. D. (2021), *Nature Climate Change*, *11*(3), 213-218
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