Remote pathway to tropical marine low cloud feedbacks via weak temperature gradient in observations and models

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INTRODUCTION & OBJECTIVES

• Climate models suggest a less negative feedback parameter in response to increased atmospheric CO₂ compared with that in the historical period as a result of the SST patterns (Andrews, Gregory & Webb 2015; Dong et al. 2019; Gregory & Andrews 2016).

• Rising SST in the tropical ascent region warms the free troposphere through convection and the weak temperature gradient (WTG; Sobel & Bretherton 2000; Sobel, Nilsson & Polvani 2001). This remote SST effect strengthens the capping inversion of the stratocumulus layer and favors a higher low cloud cover and a more negative shortwave cloud radiative effect (SWCRE) (Andrews & Webb 2018; Bluch-Johnson, Rugenstien & Abbot 2020; Dong et al. 2019; Fuglestveder 2019; Zhou, Zelinka & Klein 2016, 2017). In this project, we aim to quantify the local and remote SST effects on the tropical marine low cloud feedback from observations and model simulations. We will also demonstrate the differences among a set of perturbed physics experiments (PPEs) where the parameters of deep convection, such as the entrainment rate, are modified.

DATA

• We defined three tropical (30°N - 30°S) marine stratocumulus regions where the stratocumulus fraction is over 50% in the CloudSat-CALIPSO CASCAD dataset (Cesana, Del Genio & Chepfer 2019), namely the Southeastern Pacific (SEP), the Northeastern Pacific (NEP) and the southeastern Atlantic (ATL) (gray contours in Figure 1).

• The influence of WTG is strongest in SEP and weakest in NEP (Figure 1).

• We used monthly time series of SWCRE computed from CERES_SYN1deg-Month_Terra-Aqua-MODIS_Ed4.1 and monthly time series of cloud controlling factors (CCFs), including SST, air temperature at 700 mb (T_{700}), relative humidity at 925 mb (RH_{925}) and 700 mb (RH_{700}) and vertical velocity at 500 mb (\omega_{500}), from ERA5 reanalysis.

• Convective parameters are perturbed in the NOAA GFDL AM4 model and the NCAR CAM5 model. The table below summarizes these experiments.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Description</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2, 3, 4, 5</td>
<td>ε₁</td>
<td>Reference entrainment rate at RH = 40%</td>
<td>0.5, 0.7, 0.9, 1.1, 1.3 (km⁻¹)</td>
</tr>
<tr>
<td>1, 2, 3, 4, 5</td>
<td>ε₁</td>
<td>NCAR CAM5 (1996-2005)</td>
<td></td>
</tr>
<tr>
<td>6, 7, 8</td>
<td>α</td>
<td>Downdraft fraction</td>
<td>0.25, 0.5, 0.75</td>
</tr>
<tr>
<td>9, 10, 11</td>
<td>τ</td>
<td>Convective timescale</td>
<td>30, 120, 180 (min)</td>
</tr>
</tbody>
</table>

METHOD

• The sensitivity of SWCRE to local and remote ascent area SSTs are linearly decomposed into a set of CCFs, namely local SST, T_{700}, \omega_{300}, RH_{925} and RH_{700}:

\[
\frac{dSWCRE}{dSST_{a}} = \frac{\partial SWCRE}{\partial SST_{a}} \frac{dSST_{a}}{dSST_{a}} + \frac{\partial SWCRE}{\partial T_{700}} \frac{dT_{700}}{dSST_{a}} + \frac{\partial SWCRE}{\partial \omega_{300}} \frac{d\omega_{300}}{dSST_{a}} + \frac{\partial SWCRE}{\partial RH} \frac{dRH}{dSST_{a}}
\]

• The influence of WTG is strongest in SEP and weakest in NEP (Figure 1).

• We applied a linear framework to decompose the local and remote pathways to tropical marine low cloud feedback in observations and model PPEs.

• The local pathway is dominated by the local SST effect, while the remote pathway is dominated by a T_{700} effect via WTG.

• In regions where the WTG influences more, the sensitivity of SWCRE to the remote WTG-stability pathway is also higher.

• Both NOAA GFDL AM4 and NCAR CAM5 can simulate this remote pathway reasonably well in SEP where the WTG influences most, and the differences between these two models are always greater than the differences due to perturbed convective parameters.

• This remote WTG-stability pathway may help constrain the long-term tropical marine low cloud feedback and the equilibrium climate sensitivity (Figure 5).

• However, there is a large decadal variability in the strength of this remote pathway in CMIP6 models (e.g., MRI-ESM2.0 in Figure 4) which adds to the uncertainty.

RESULTS

CONCLUSIONS & IMPLICATIONS

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