An Observation-Based Approach to Assess Tropical Stratocumulus and Shallow Cumulus Clouds and Feedbacks in CMIP6 and CMIP5 models

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SW tropical low-cloud feedback explains part of the spread in simulated climate sensitivity.
Reducing the uncertainty in low-cloud feedback would reduce its contribution to the spread in ECS.
Large increase of the extratropical low-cloud feedback…

Zelinka et al. (2020)
Small increase of the tropical low-cloud feedback…

Low Cloud Feedback in CMIP5 and CMIP6 models

- 0.23 (Wm$^{-2}$K$^{-1}$) for All CMIP6 (n=46)
- 0.29 (Wm$^{-2}$K$^{-1}$) for All CMIP5 (n=29)

Low Cloud Feedback (W/m$^2$/K)

Latitude (°N)
But the increase is also substantial when focusing on a fixed subset of CMIP6 and CMIP5 models.
Observationally inferred low-cloud feedback is driven by stratocumulus clouds

Observed low-cloud feedback

d. 0.56 W/m²/K

f. 0.44 W/m²/K

e. 0.12 W/m²/K

Cesana and Del Genio (2021)
Objectives

1. Evaluate Sc and Cu in two CMIP generations

2. How changes in Sc and Cu cloud properties between CMIP generations affect low-cloud feedback
How to discriminate Sc and Cu clouds in climate models?

We use mean tropical cloud fraction to distinguish Sc and Cu

Cesana, Del Genio, Chepfer (2019)
Sc and Cu are discriminated at each time step based on the tropical mean low cloud fraction.
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Our novel Sc-Cu discrimination method works very well with observations
Our novel Sc-Cu discrimination method works very well with observations. Better than an EIS-based method.
Our novel Sc-Cu discrimination method also works in GISS-E3 model.
1. Evaluate Sc and Cu in two CMIP generations
CMIP6 models collectively underestimate both Sc and Cu, especially over the Sc decks.
Their SW radiative effect also improved, yet too bright overall.
Most CMIP models favor Cu over Sc regime frequency…
Almost all CMIP models underestimate Both Sc and Cu in-regime cloud fraction
2. How changes in Sc and Cu cloud properties between CMIP generations affect low-cloud feedback
How to characterize Sc and Cu feedbacks?

We weight the low cloud feedback by the Sc and Cu cloud fractions:

\[
\text{Feedback}_{\text{Sc or Cu}} = \text{Feedback}_{\text{Low}} \times \text{CF}_{\text{Sc or Cu}}
\]
How to characterize Sc and Cu feedbacks?
We weight the low cloud feedback by the Sc and Cu cloud fractions:

Truth: CASCCAD

CF-Rebuilt GOCCP
CMIP6 models substantially improved their depiction of Sc cloud feedback.
Increased Sc between CMIP generations is correlated with increased low-cloud feedback
If the mean CMIP6 Sc had matched the observations, their mean low-cloud feedback would have been twice as large.
Future climate:
We will incorporate constraints on how clouds respond to climate change in our development process by using unique expertise of observational cloud feedbacks.

<table>
<thead>
<tr>
<th>Model</th>
<th>Stratocumulus</th>
<th>Shallow Cumulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>CERES &amp; CASCCAD</td>
<td>-0.54 Wm$^{-2}$K$^{-1}$</td>
<td>0.13 Wm$^{-2}$K$^{-1}$</td>
</tr>
<tr>
<td>GISS-E2.1</td>
<td>-0.2 Wm$^{-2}$K$^{-1}$</td>
<td>-0.03 Wm$^{-2}$K$^{-1}$</td>
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<tr>
<td>GISS-E3</td>
<td>0.55 Wm$^{-2}$K$^{-1}$</td>
<td>0.13 Wm$^{-2}$K$^{-1}$</td>
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<tr>
<td>IPSL6A</td>
<td>0.11 Wm$^{-2}$K$^{-1}$</td>
<td>0.19 Wm$^{-2}$K$^{-1}$</td>
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</tbody>
</table>

Change of sign between GISS versions
IPSL better Sc in present climate but poor response in future climate.
Summary

- Large-scale cloud fraction can be used to distinguish Sc and Cu cloud amount and feedback in observations and simulations.

- CMIP6 models better simulate Sc and Cu cloud amount, pattern, SW radiative effect, and feedback.

- More Sc partly explain increased low-cloud feedback in CMIP6.

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