Shallow Cumulus and Stratocumulus Cloud Feedbacks inferred from CALIPSO-CloudSat Observations

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Future climate

- In a warming world: clouds dissipate (cloud amount feedback) ➔ positive feedback $T_s$

- Low clouds: major source of uncertainty in climate projections (e.g., Bony and Dufresne, 2005)

Evaluate their interannual variability (e.g., Myers and Norris, 2015; Qu et al., 2014, 2015…)

$T_{surface}$ ➔ $T_s$ ➔ Feedback ➔ $CO_2$ ➔ Cover
Present-day climate CMIP5

*Tropical Subsidence ($\omega_{500} > 10$ hPa/day), ocean only*

- Decreasing LCC well correlated with increasing SW CRE (positive feedback)

Modified from Cesana et al., 2019, ACP
Present-day climate CMIP6

Tropical Subsidence ($\omega_{300} > 10$ hPa/day), ocean only

- Decreasing LCC well correlated with increasing SW CRE (positive feedback)

- CMIP6 models’ LCC more sensitive for the same CRE’s sensitivity

Modified from Cesana et al., 2019, ACP
- Decreasing LCC well correlated with increasing SW CRE (positive feedback)

- CMIP6 models’ LCC more sensitive for the same CRE’s sensitivity

- Both underestimated

*Who is the culprit? Cu? Sc?*

*Modified from Cesana et al., 2019, ACP*
Present-day climate GCMs vs. Obs

Tropical Subsidence ($\omega_{500} > 10$ hPa/day), ocean only

- Decreasing LCC well correlated with increasing SW CRE (positive feedback)

- CMIP6 models’ LCC more sensitive for the same CRE’s sensitivity

- Both underestimated

Who is the culprit? Cu? Sc?

⇒ Lack of Sc?
⇒ Too many Cu?

Modified from Cesana et al., 2019, ACP
Can Sc and Cu clouds be reliably identified in satellite observations?

... and be used to evaluate (and better constrain) climate models (parameterizations)?
**Question:**
Can these clouds be reliably identified in satellite observations?

**Findings:**

- Using CloudSat-CALIPSO or CALIPSO-only (GOCCP) to identify the different types Sc & Cu
- Method based on the cloud morphology: height, horizontal extent, vertical variability and horizontal continuity.
- Cu and Sc are geographically separated more distinctly than suggested by previous satellite observations.
- Vertical structure

**Why does it matter?**
Can be used to identify the interannual cloud feedback as a constraint for climate model development.


Download: [https://data.giss.nasa.gov/clouds/casccad/](https://data.giss.nasa.gov/clouds/casccad/)
“Real” Cu and Sc Interannual Variability

No LTS, EIS or $\omega_{500}$ thresholds
Not regionally based

- In tropical subsidence regimes, Sc and Cu cloud covers are very similar
“Real” Cu and Sc Interannual Variability

No LTS, EIS or $\omega_{500}$ thresholds
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- In tropical subsidence regimes, Sc and Cu cloud covers are very similar
- Sc clouds drive most of the interannual variability of the low clouds
- Cu clouds increase with increasing surface temperatures
“Real” Cu and Sc Interannual Variability

No LTS, EIS or $\omega_{500}$ thresholds
Not regionally based

\[
dLCC/dSST = \partial LCC/\partial SST + \partial LCC/\partial EIS \cdot dEIS/dSST
\]

- In tropical subsidence regimes, Sc and Cu cloud covers are very similar
- Sc clouds drive **most** of the interannual variability of the low clouds
- Cu clouds **increase** with increasing surface temperatures (mostly due to EIS)
"Real" Profiles of Cu and Sc Interannual Variability

- The total change is largely driven by Sc, consistent with the change in cloud cover
- Cu cloud cover sensitivity to SST is the result of compensating effects: decrease/increase at the top/bottom
- Cu CF decreases over its full vertical extent in response to EIS increase
No Cu or Sc cloud fraction outputs in either CMIP5 or CMIP6 models… but:

• $R_{S_{Cu}}$: Ratio of Cu to all low clouds in CALIPSO observations
  • $R_{S_{Cu}} \geq 0.5 \rightarrow Sc$
  • $R_{S_{Cu}} < 0.5 \rightarrow Cu$

• Mask applied every month to CMIP6 models’ LCC and profiles of cloud fraction for the overlapping AMIP period 2007 – 2014 to diagnose Sc-dominated and Cu-dominated cloud fractions
• Similarly, the mask is applied to the CALIPSO LCC to diagnose Sc- and Cu-dominated cloud fractions
Model Evaluation: Cu and Sc LCCs

SC: \( R_{\text{Scu}} \geq 0.5 \)

Cu: \( R_{\text{Scu}} < 0.5 \) with \( R_{\text{Scu}} = \frac{\text{LCC}_\text{strati}}{\text{LCC}_\text{all}} \) in CALIPSO observations

- Underestimation \( \sim \) uniformly distributed between Cu and Sc

- Sc clouds drive most of the interannual variability of the low clouds (consistent with Obs)

- Large biases in Cu sensitivities to SST and EIS (particularly \( \partial \text{Cu}/\partial \text{EIS} \)
Model Evaluation: Cu and Sc CF Profiles

**Sc:** \( R_{\text{Scu}} \geq 0.5 \)  \hspace{1cm} **Cu:** \( R_{\text{Scu}} < 0.5 \) \hspace{1cm} with \hspace{1cm} \( R_{\text{Scu}} = \frac{\text{LCC}_{\text{strati}}}{\text{LCC}_{\text{all}}} \) in CALIPSO observations
Summary

We study the interannual variability of low, Sc and Cu clouds using CALIPSO-GOCCP CASCCAD observations and we find that:

- In tropical subsidence regimes, Sc and Cu cloud covers are very similar
- Sc clouds drive most of the interannual variability of the low clouds
- Cu clouds increase with increasing surface temperatures (mostly due to EIS)

We use this new dataset to diagnose and evaluate Cu and Sc clouds in CMIP6 models:

- Underestimation ~ uniformly distributed between Cu and Sc
- Sc clouds drive most of the interannual variability of the low clouds (consistent with Obs)
- Large biases in Cu sensitivities to SST and EIS (particularly ∂Cu/∂EIS)

Why?

Do the models overestimate the amount of stratiform clouds in Cu regimes?
- No change in the amount
- Larger interannual variability of the low clouds in CMIP6
- Due to less sensitivity to SST and far more to EIS
Low-cloud change vs CRESW change

a. Mean state

b. d/dSST
c. δ/δSST
d. δ/δEIS