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

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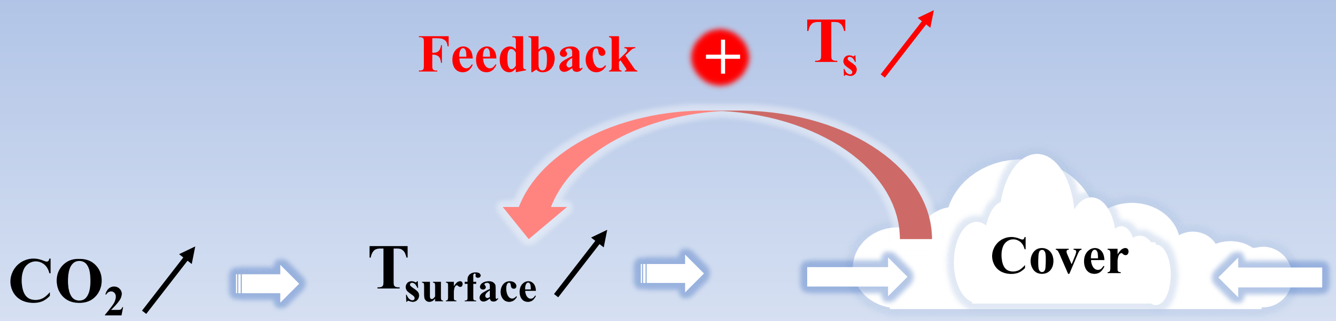
CASCCAD
The Cumulus and Stratocumulus CloudSat-CALIPSO Dataset

Future climate



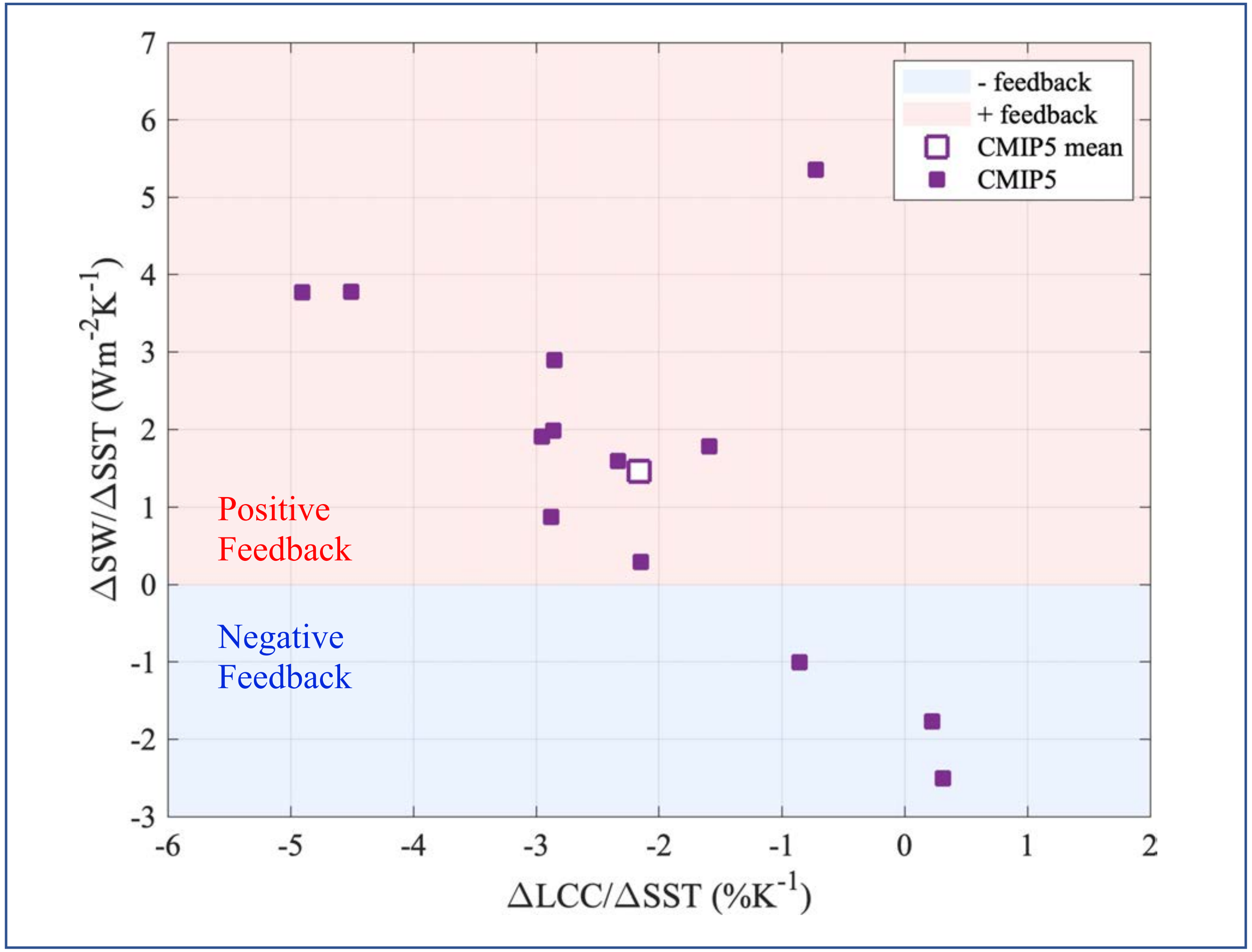
- In a warming world: clouds dissipate (cloud amount feedback)
  ➔ positive feedback T_s

- 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…)

Present-day climate CMIP5

Tropical Subsidence (ω_{500} > 10 hPa/day), ocean only

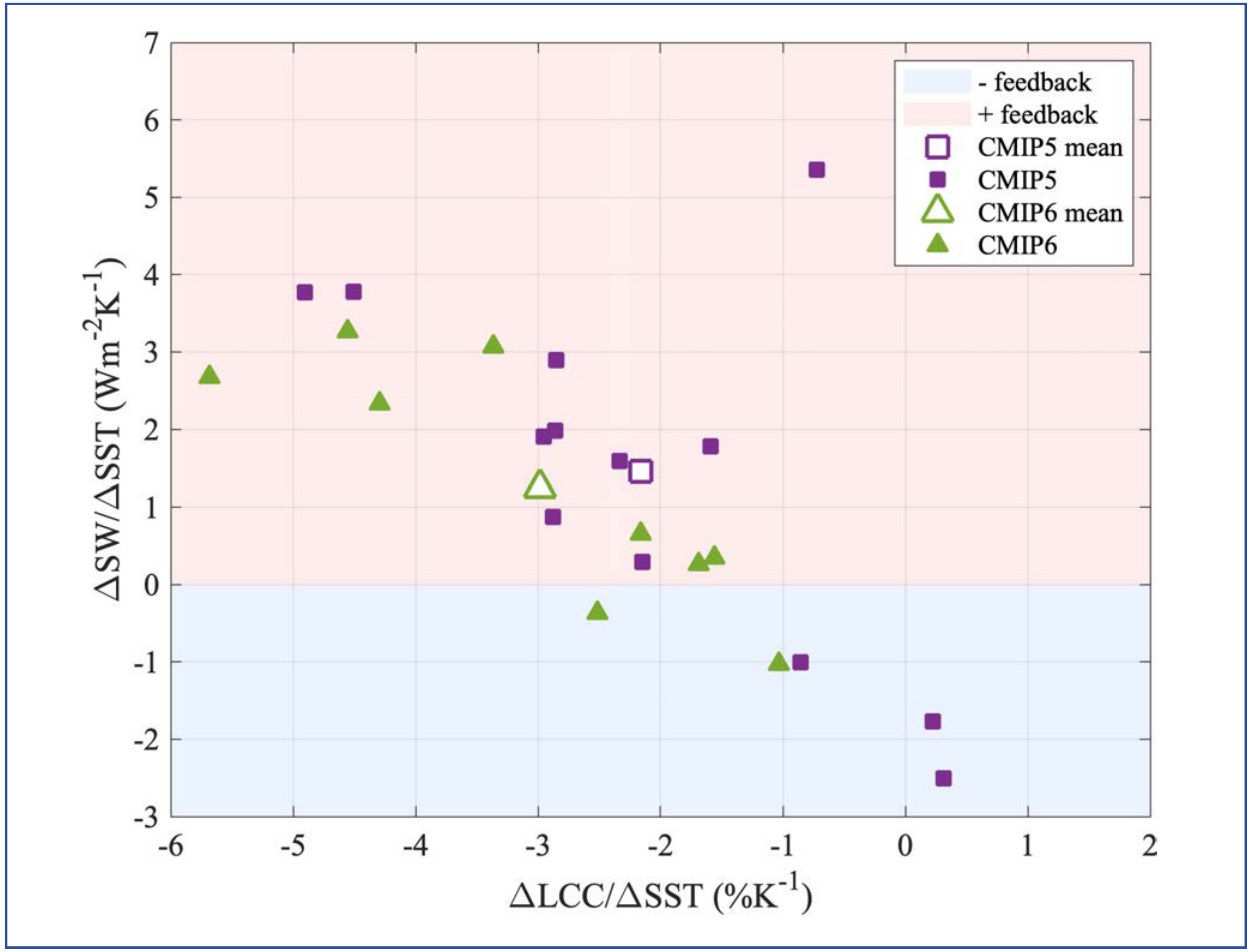


Modified from Cesana et al., 2019, ACP

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

Present-day climate CMIP6

Tropical Subsidence (ω_{500} > 10 hPa/day), ocean only

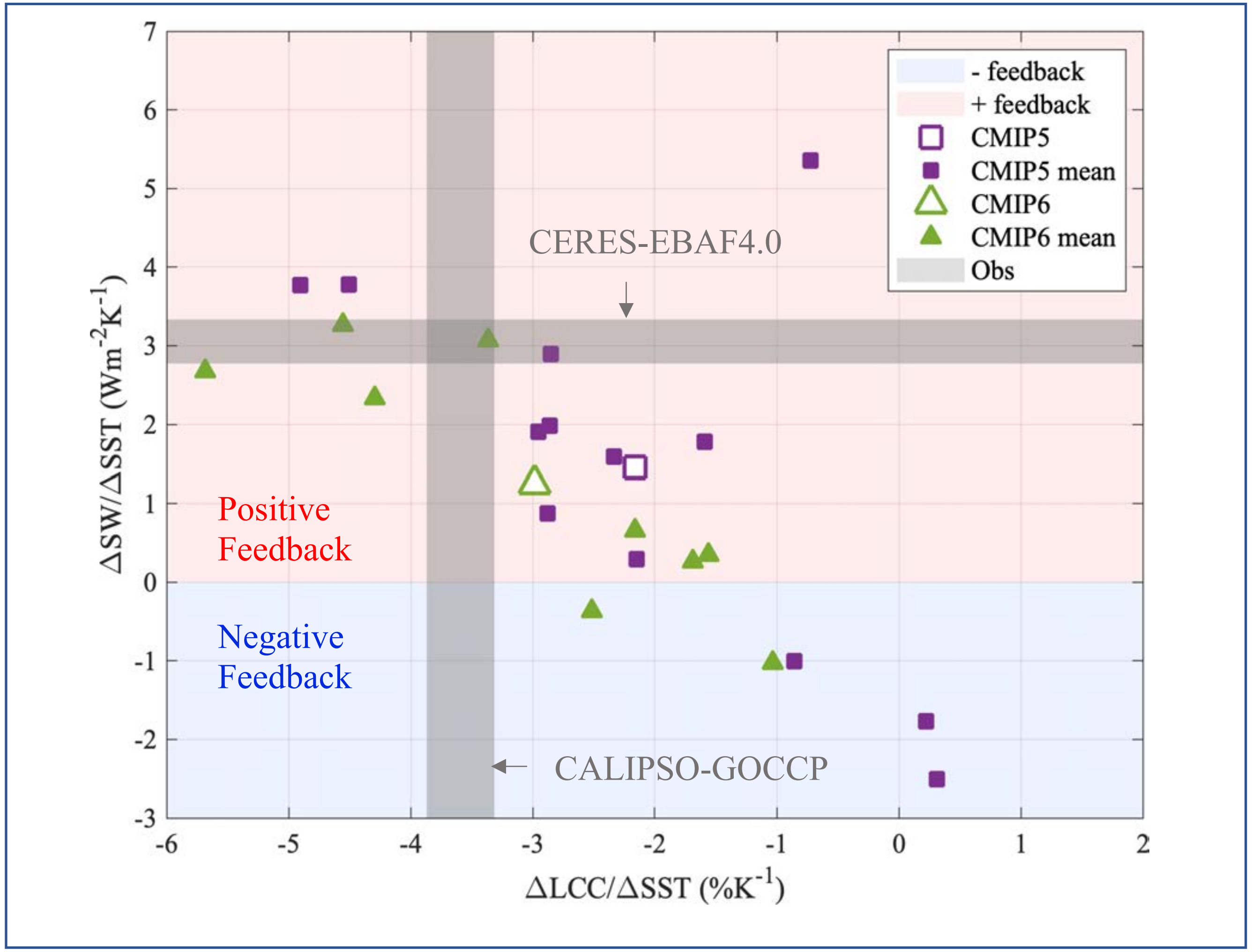


Modified from Cesana et al., 2019, ACP

- Decreasing LCC well correlated with increasing SW CRE (positive feedback)
- CMIP6 models' LCC more sensitive for the same CRE's sensitivity

Present-day climate GCMs vs. Obs

Tropical Subsidence (ω_{500} > 10 hPa/day), ocean only



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- 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?

Present-day climate GCMs vs. Obs

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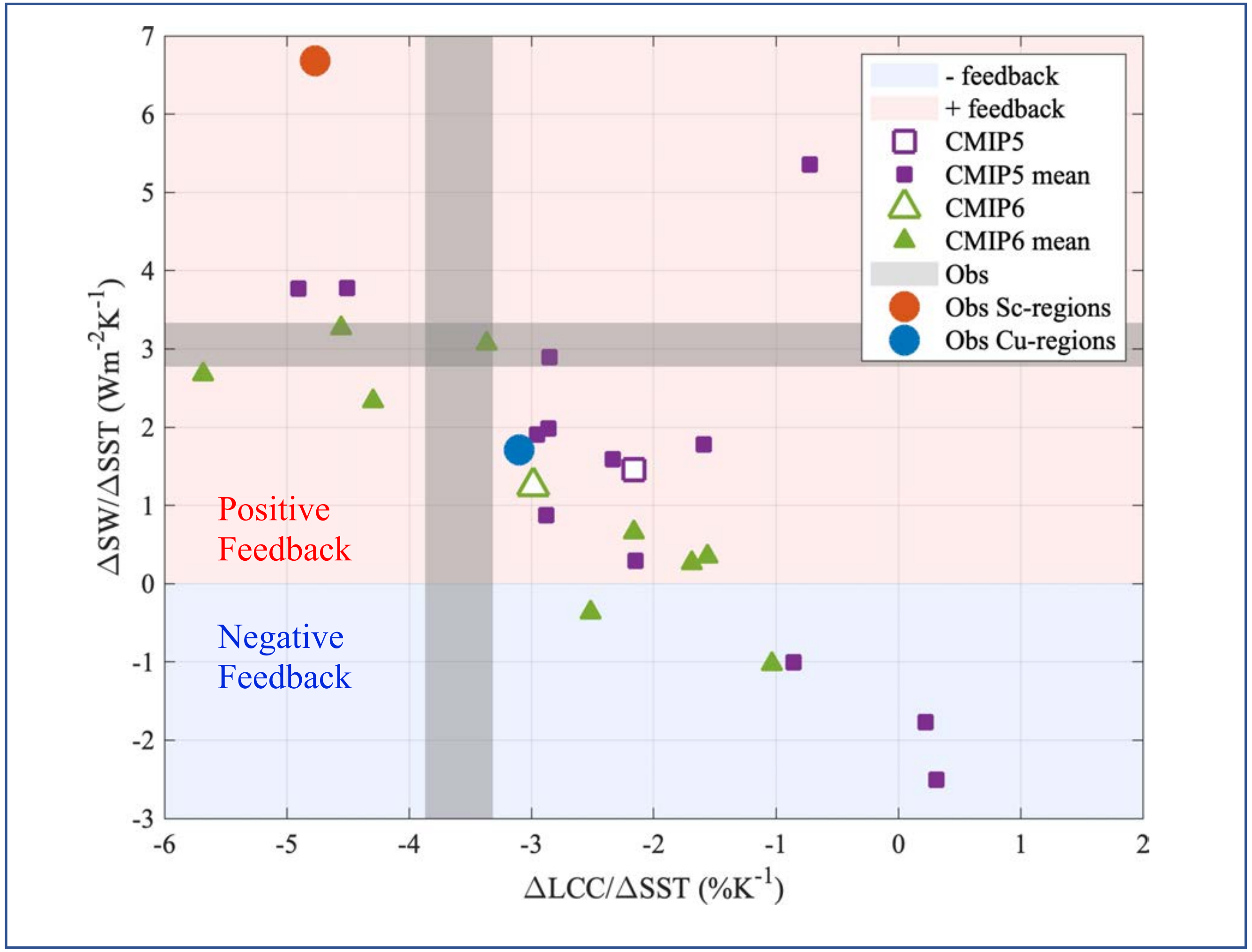

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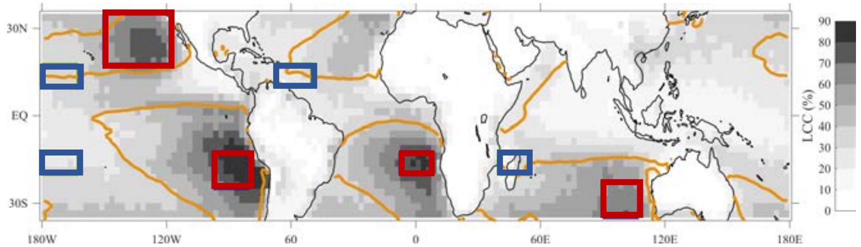

- Decreasing LCC well correlated with increasing SW CRE (positive feedback)
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Who is the culprit? Cu? Sc?

➔ *Lack of Sc?*

➔ *Too many Cu?*

Can Sc and Cu clouds be reliably identified in satellite observations?

... and be used to evaluate (and better constrain) climate models (parameterizations)?

The Cumulus and Stratocumulus CloudSat-CALIPSO Dataset (CASCCAD)

CASCCAD
The Cumulus and Stratocumulus CloudSat-CALIPSO Dataset

Download: https://data.giss.nasa.gov/clouds/casccad/

Question:

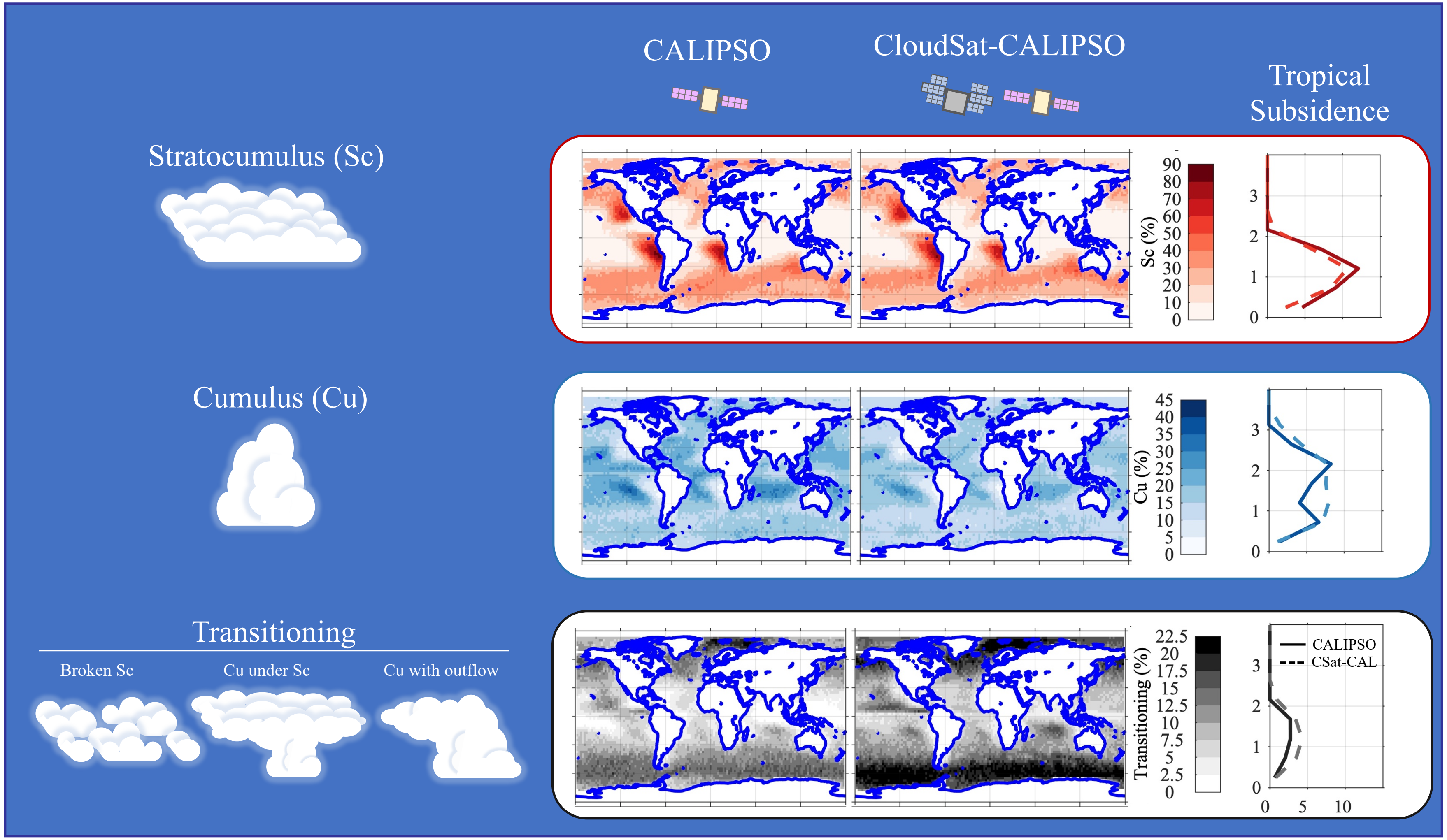
Can these clouds be reliably identified in satellite observations?

Findings:

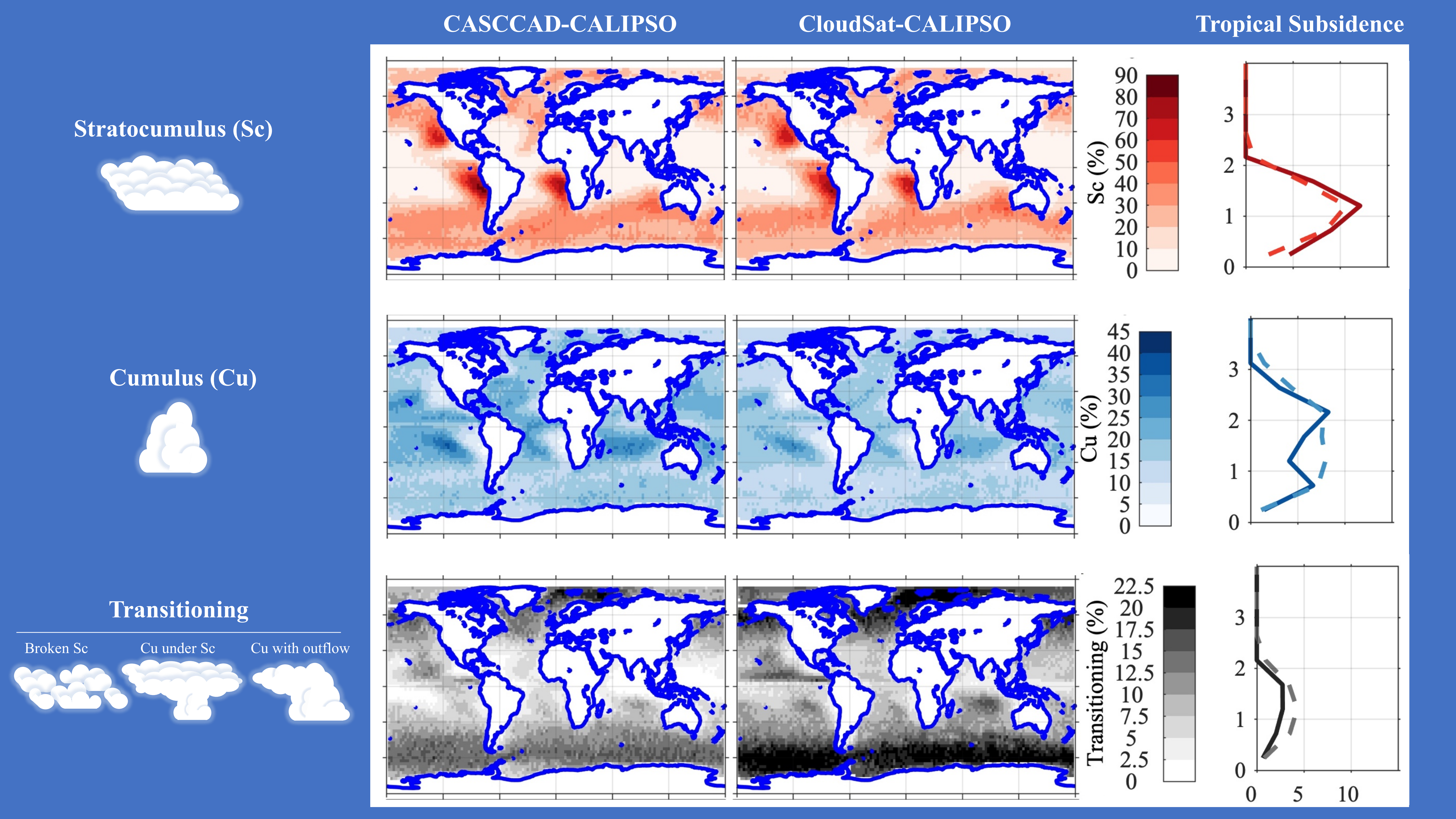
- Using CloudSat-CALIPSO or CALIPSO-only (GOCCP) to identify the different types Sc & Cu
- Method based on the cloud morphology: height, horizontal extent, vertical variability and horizontal continuity.
- Cu and Sc are geographically separated more distinctly than suggested by previous satellite observations.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

Why does it matter?

Can be used to identify the interannual cloud feedback as a constraint for climate model development.

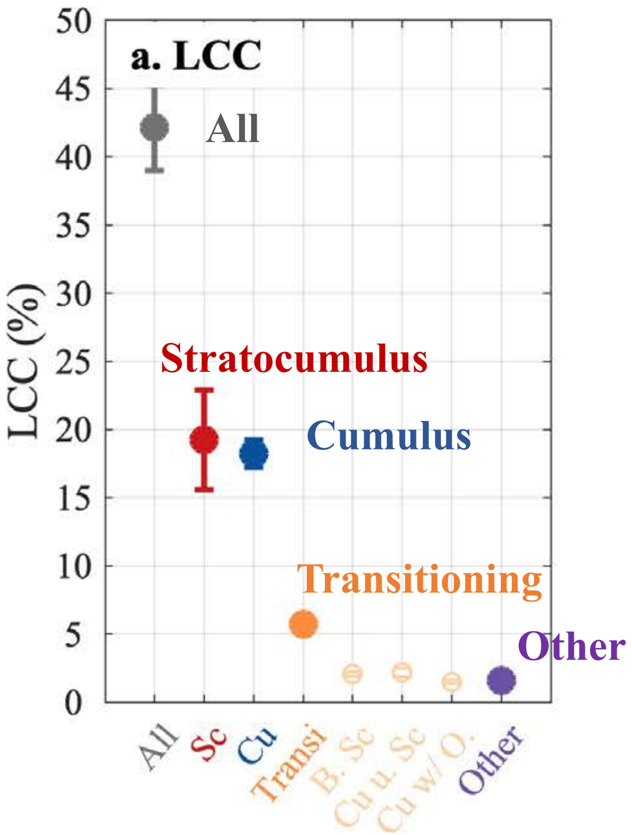


Cesana, G., Del Genio, A. D., and Chepfer, H.: The Cumulus And Stratocumulus CloudSat-CALIPSO Dataset (CASCCAD), Earth Syst. Sci. Data Discuss., doi: 10.5194/essd-2019-73, accepted, 2019.


CASCCAD-CALIPSO
CloudSat-CALIPSO
Tropical Subsidence
Stratocumulus (Sc)
Cumulus (Cu)
Transitioning
Broken Sc
Cu under Sc
Cu with outflow
Sc (%)
90
80
70
60
50
40
30
20
10
0
Cu (%)
45
40
35
30
25
20
15
10
5
0
Transitioning (%)
22.5
20
17.5
15
12.5
10
7.5
5
2.5
0
3
2
1
0
0
5
10

“Real” Cu and Sc Interannual Variability

No LTS, EIS or ω_{500} thresholds
Not regionally based



- In tropical subsidence regimes, Sc and Cu cloud covers are very similar

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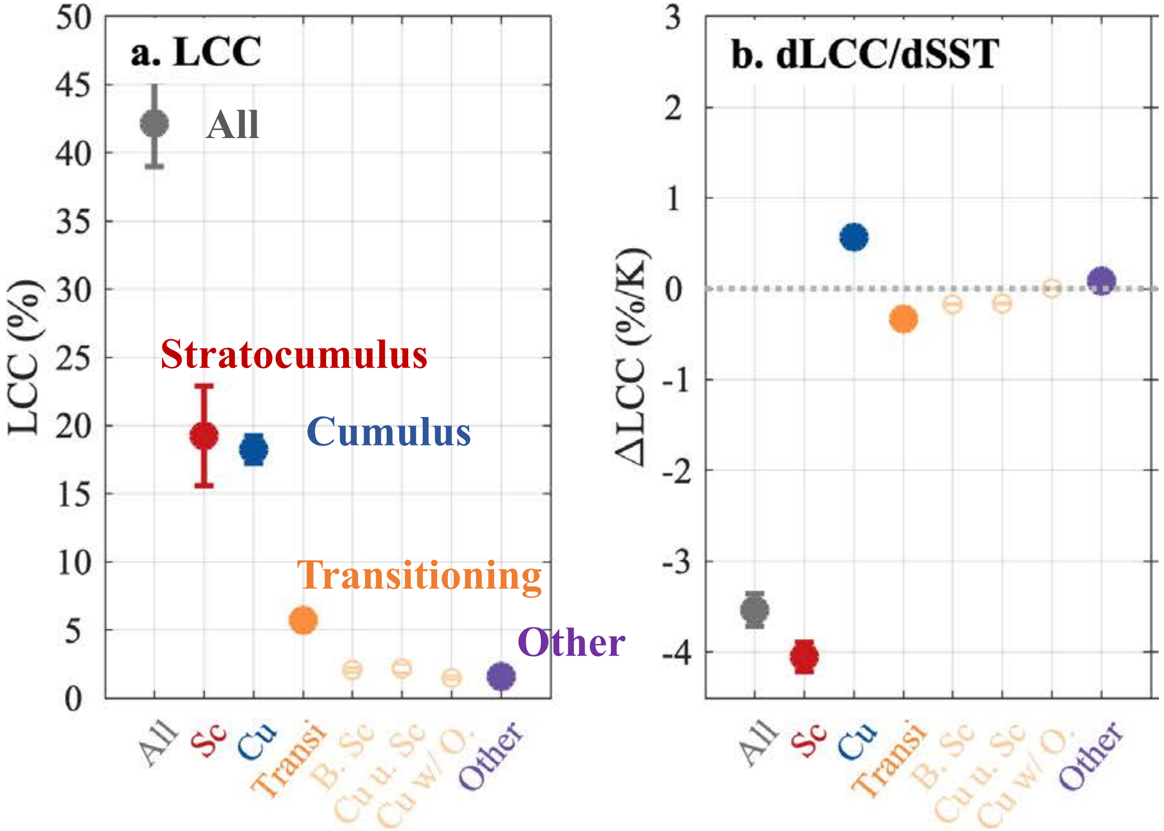
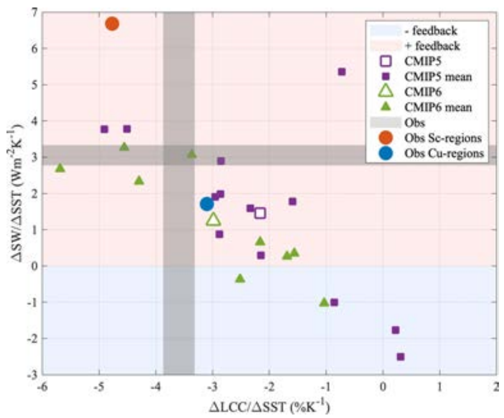


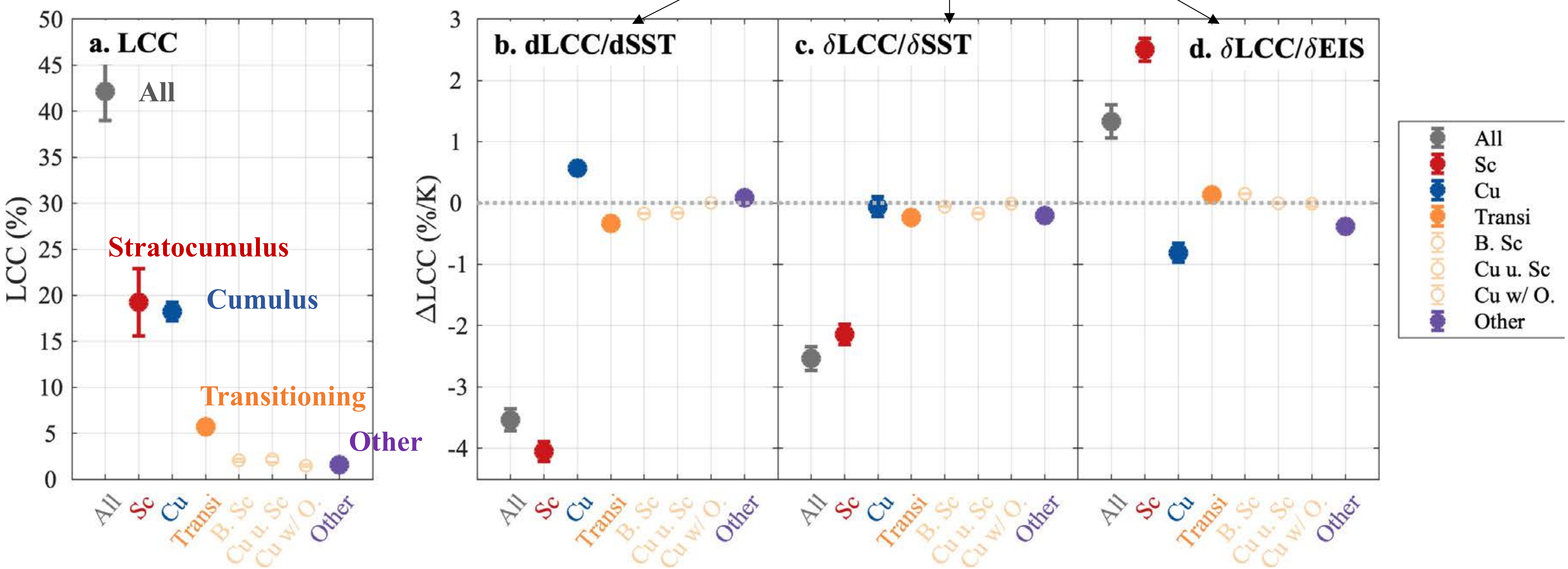


- In tropical subsidence regimes, Sc and Cu cloud covers are very similar
- Sc clouds drive **most** of the interannual variability of the low clouds
- Cu clouds **increase** with increasing surface temperatures

“Real” Cu and Sc Interannual Variability

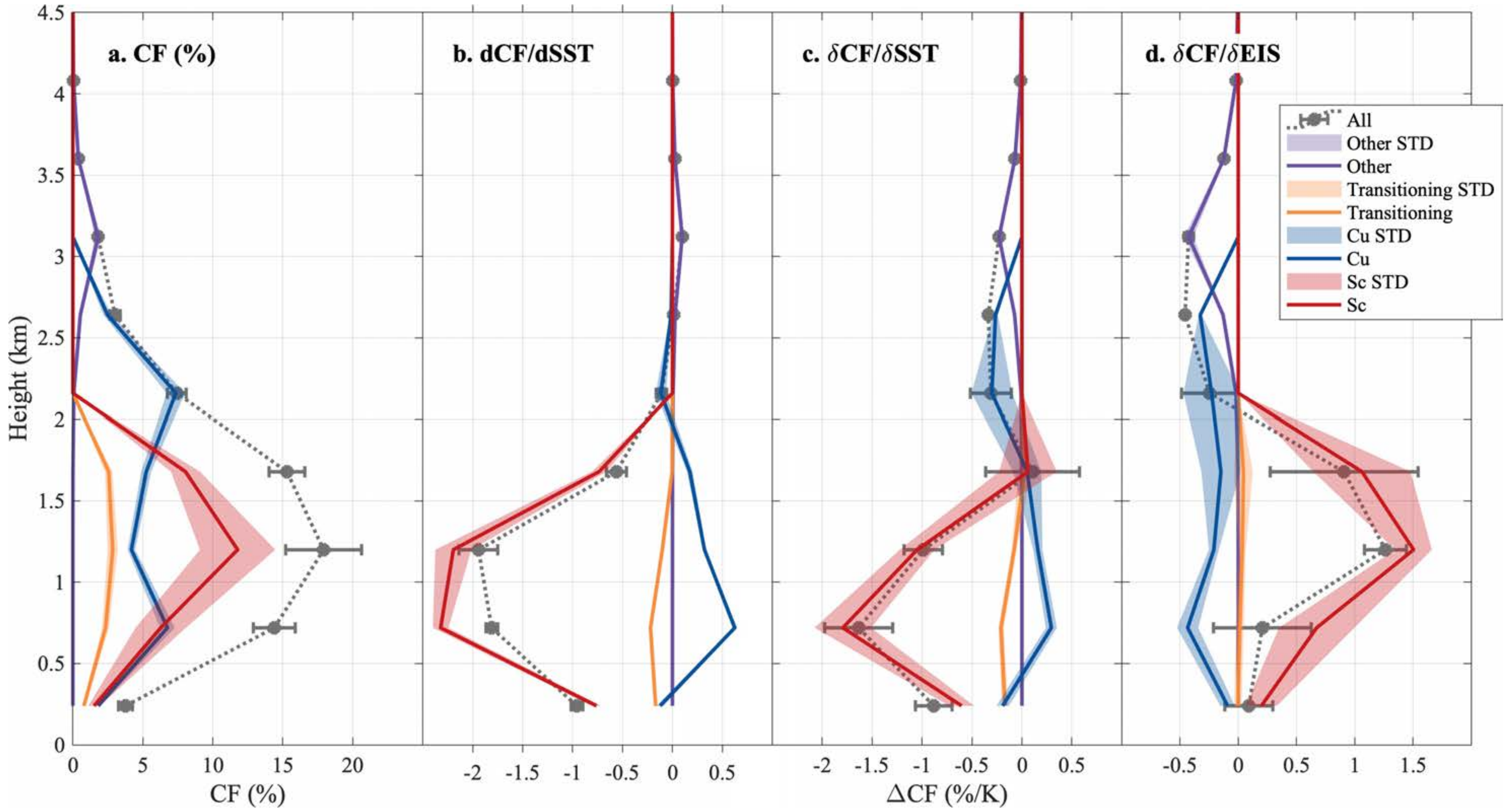
No LTS, EIS or ω_{500} thresholds
Not regionally based

$dLCC/dSST = \partial LCC/\partial SST + \partial LCC/\partial EIS \; . \; dEIS/dSST$ - 0.74



- 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)

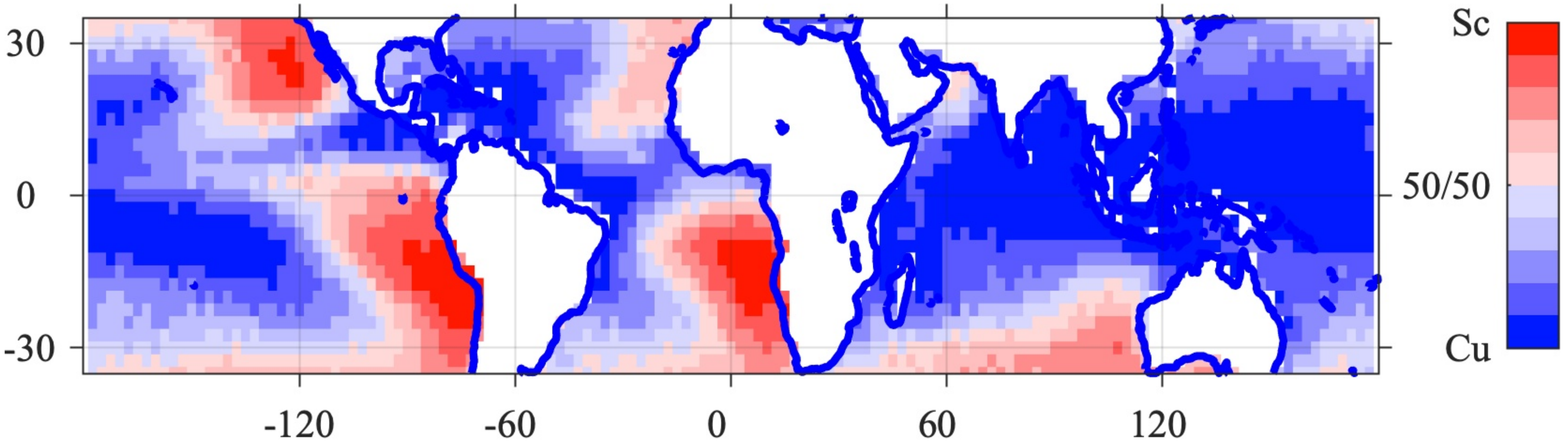
“Real” Profiles of Cu and Sc Interannual Variability



- 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

How Can We Use This Information For Multi-Model Evaluation?

"Stratiform – Cu ratio"



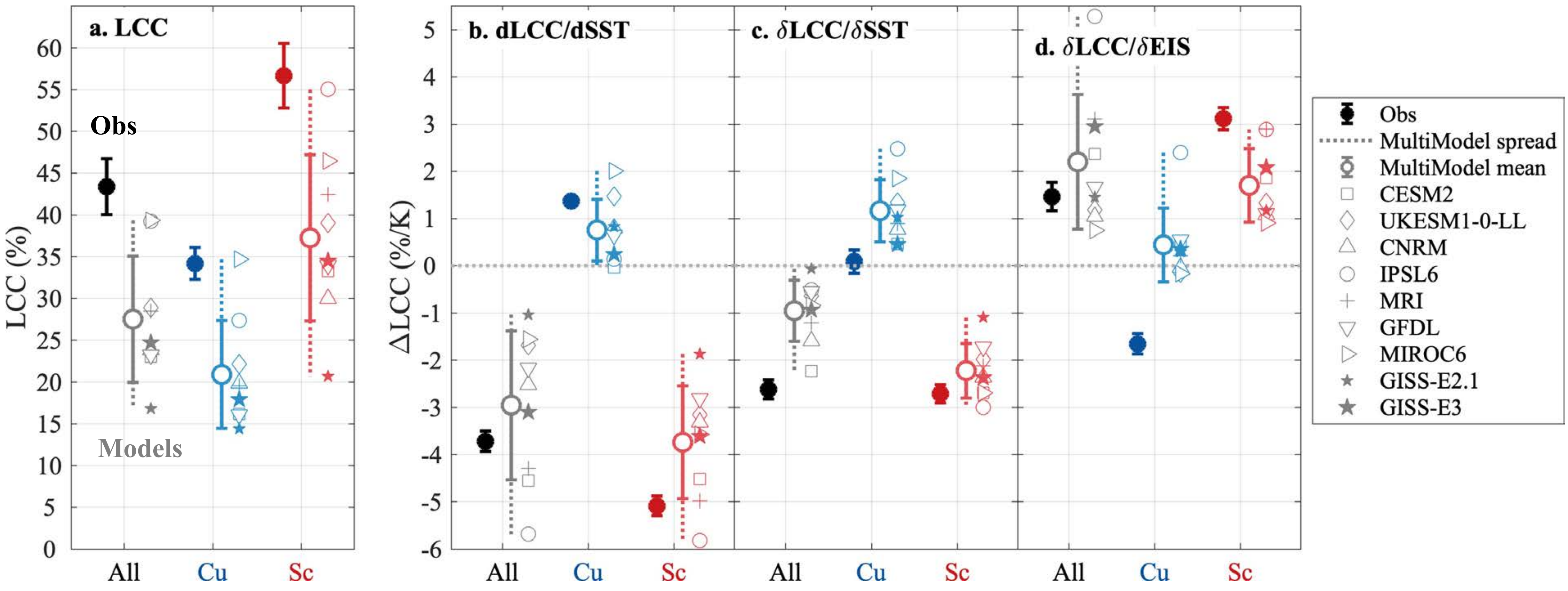
No Cu or Sc cloud fraction outputs in either CMIP5 or CMIP6 models… but:

- R_{Scu} : Ratio of Cu to all low clouds in CALIPSO observations
- $R_{Scu} \geqslant 0.5$ ➔ **Sc**
- $R_{Scu} < 0.5$ ➔ **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

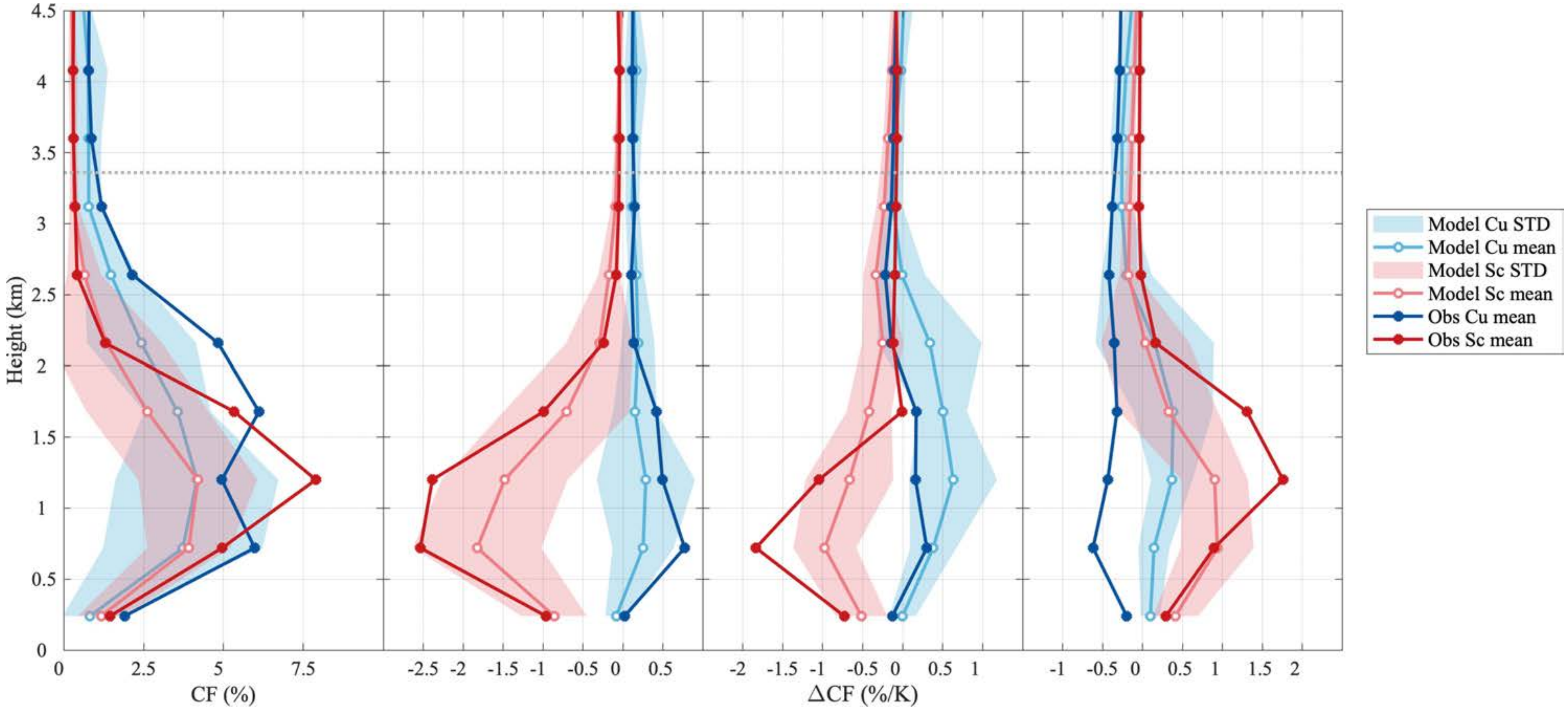
Sc: $R_{Scu} \geqslant 0.5$ **Cu**: $R_{Scu} < 0.5$ with $R_{Scu} = LCC_{strati} / LCC_{all}$ in CALIPSO observations



- 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)

Model Evaluation: Cu and Sc CF Profiles

Sc: $R_{Scu} \geqslant 0.5$ **Cu**: $R_{Scu} < 0.5$ with $R_{Scu} = LCC_{strati} / LCC_{all}$ 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 <u>most</u> of the interannual variability of the low clouds
- Cu clouds <u>increase</u> 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 $\partial Cu/\partial EIS$)

Why?

Do the models overestimate the amount of stratiform clouds in Cu regimes?

CASCCAD ← poster

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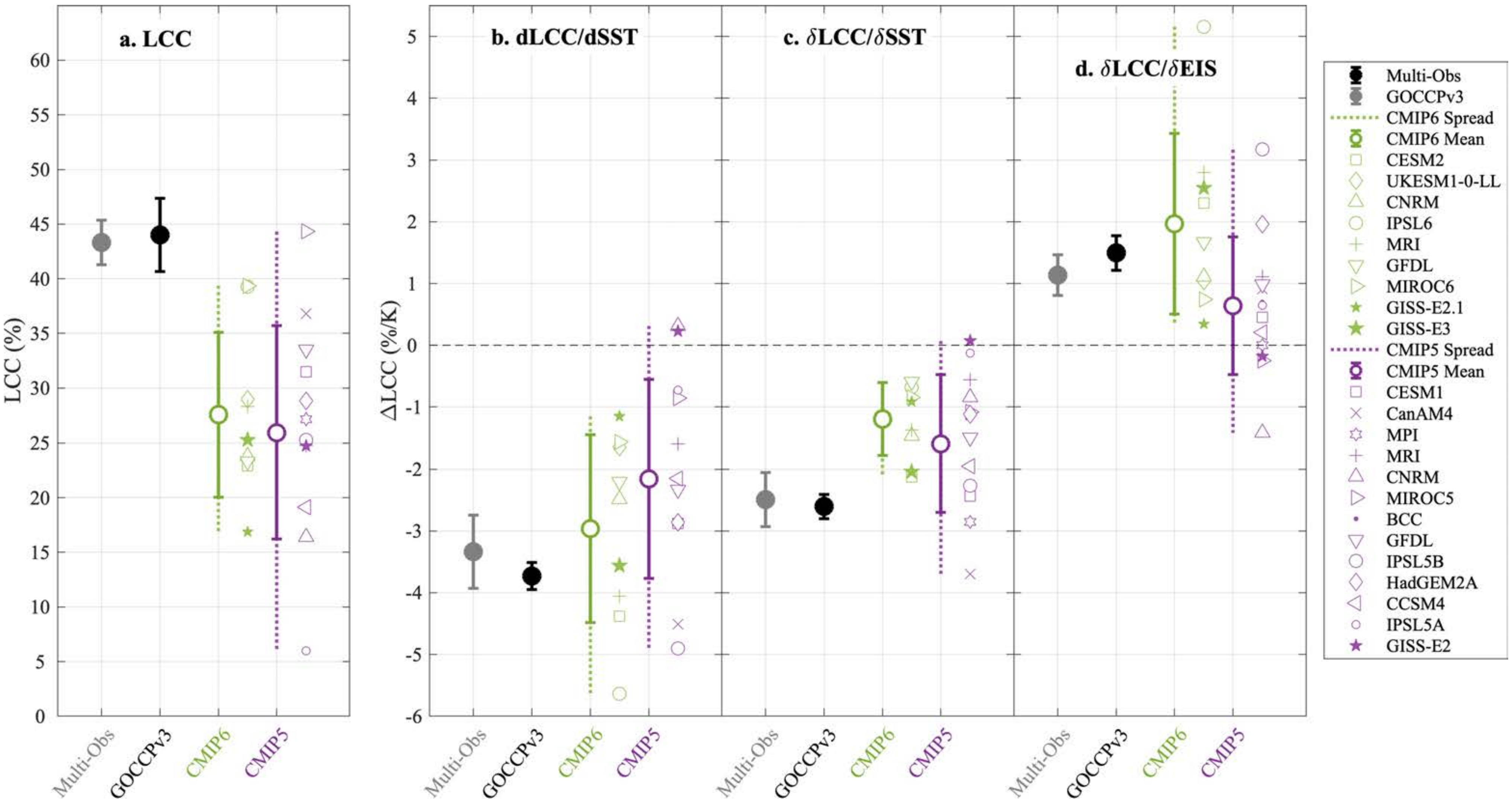
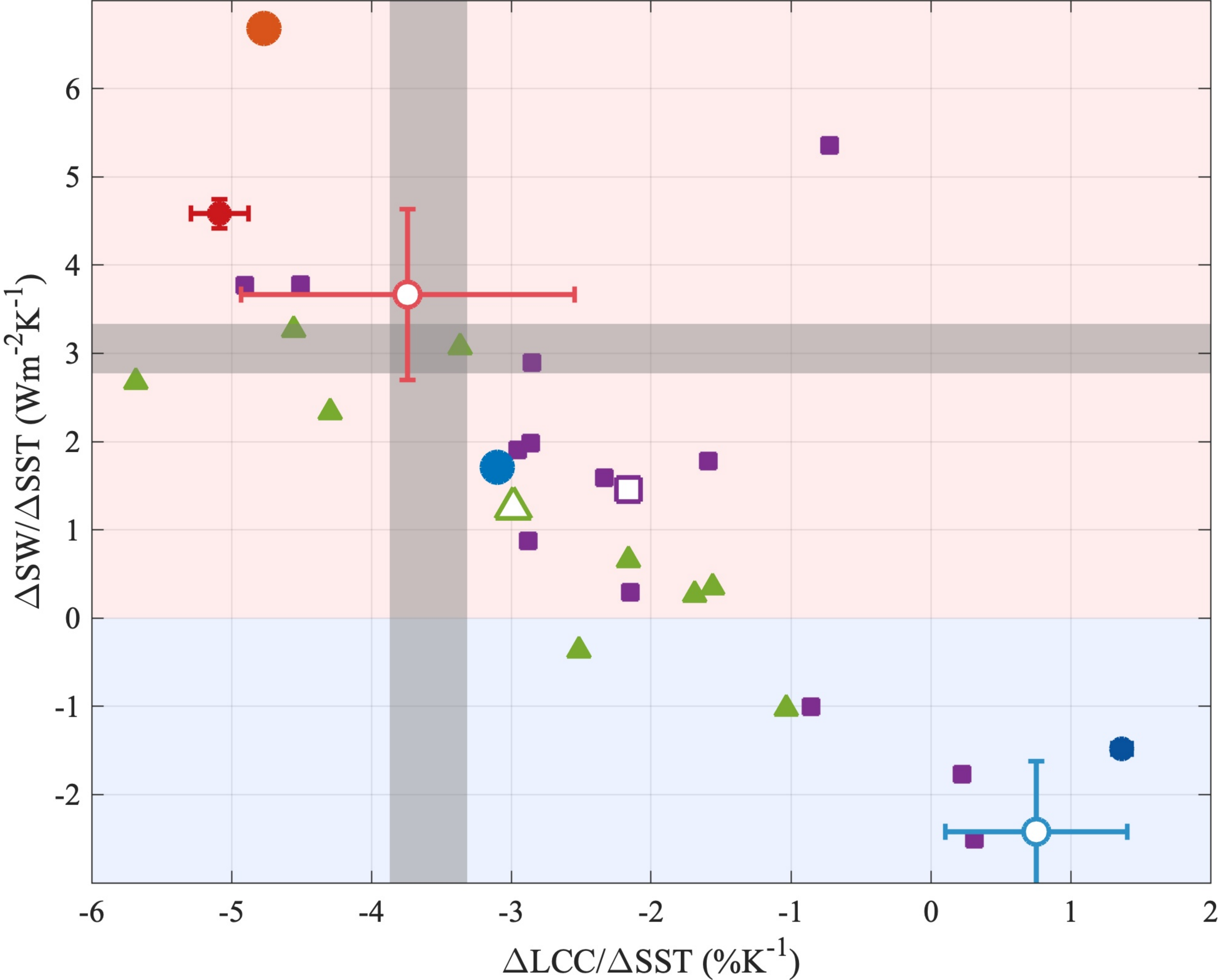
Acknowledgments
NASA Grant: NNH15ZDA001N

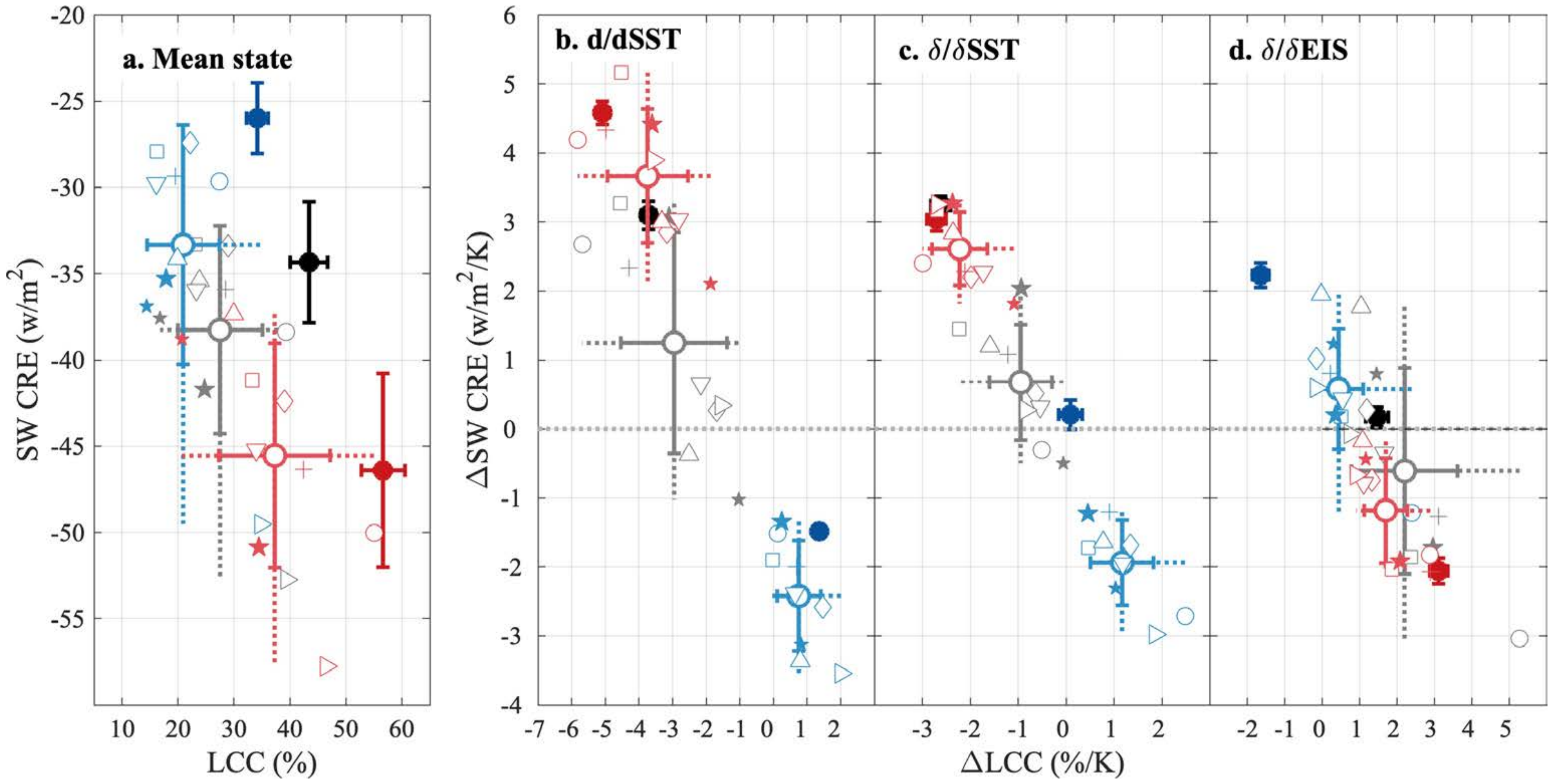


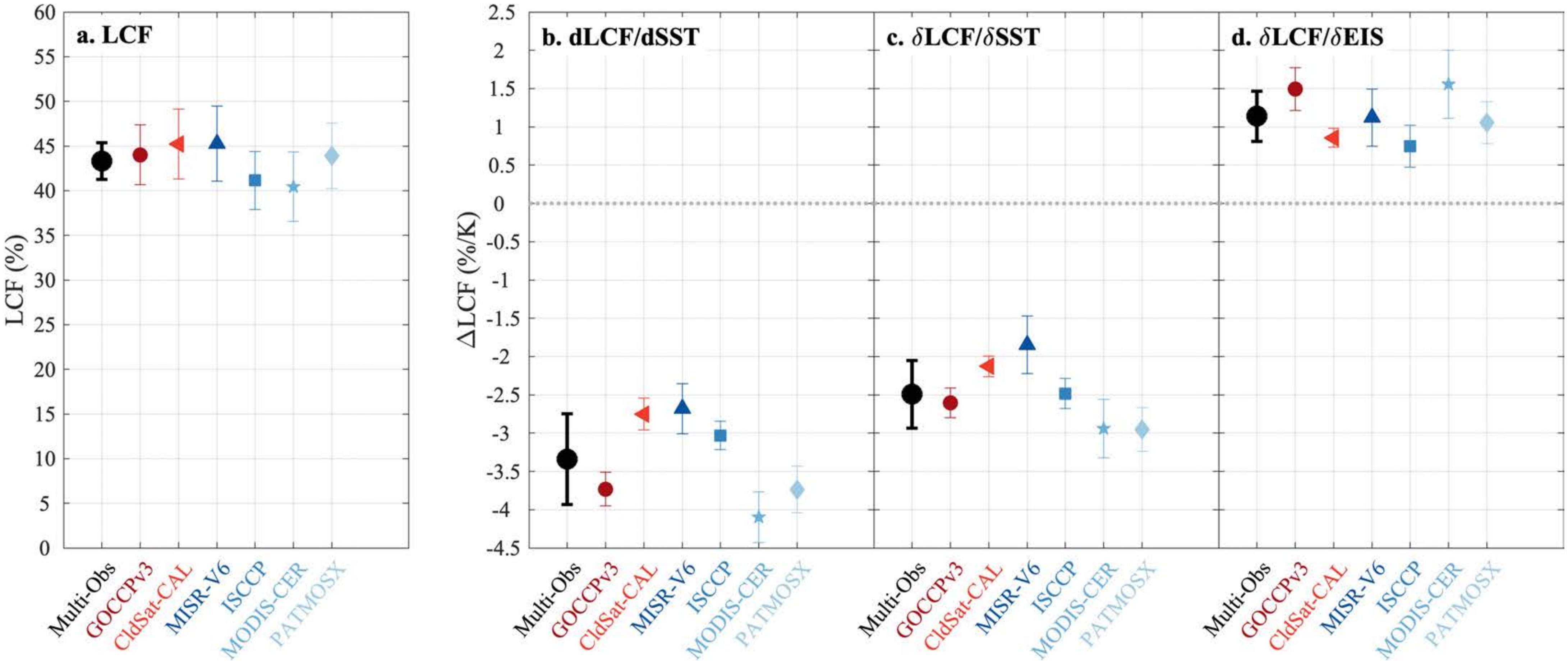
- No change in the amount
- Larger interannual variability of the low clouds in CMIP6
- Due to less sensitivity to SST and far more to EIS



ΔSW/ΔSST (Wm-2K-1)
ΔLCC/ΔSST (%K-1)
6
5
4
3
2
1
0
-1
-2
-6
-5
-4
-3
-2
-1
0
1
2

Low-cloud change vs CRESW change




a. LCF
LCF (%)
b. dLCF/dSST
c. δLCF/δSST
d. δLCF/δEIS
ΔLCF (%/K)
Multi-Obs
GOCCPv3
CldSat-CAL
MISR-V6
ISCCP
MODIS-CER
PATMOSX