Supporting Information for "Evaluating the representation of tropical stratocumulus and shallow cumulus clouds as well as their radiative effects in CMIP6 models using satellite observations"

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Contents of this file

Introduction

This Supporting Information to the main article evaluates the two Sc-Cu categorizations in observations (Text S1), provides full validation analysis for individual CMIP6 models using newly proposed LCC categorization (Text S2) and finally compares the two Sc-Cu categorizations when employed in climate models (Text S3).

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Text S1.

1. Evaluation of the two Sc-Cu categorizations in observations

In this section we assess the performance of the two Sc-Cu categorizations when applied to observational LCC dataset (CALIPSO-GOCCP) validated against benchmark cloud-type components derived from CASCCAD.

Figures S1 and S2 evaluate geographical distributions of Sc- and Cu- cloud cover as well as frequency of occurrence comparing the new categorization exploiting dynamic LCC threshold with the traditional discrimination relying on fixed EIS threshold. Both categorizations capture prominent Sc decks typically found off the west coast of the continents and Cu clouds in trade wind regions over the open ocean. We notice only minor differences between the performance of the two Sc-Cu discriminations as explained in the following. There is a band of stratiform type of clouds which occassionally form in the Pacific Ocean within the Intertropical Convergence Zone slightly northward of the equator. These stratiform clouds are properly captured by the LCC categorization, whereas they are attributed to the Cu-component when the EIS categorization is employed. The observed histograms of Sc- and Cu-cloud cover, on the other hand, are better captured with the EIS categorization, because LCC categorization partly mixes Sc and Cu clouds. We examined several other metrics evaluating temporal evolution and spatial variability of cloud-type cloud cover, whereby both Sc-Cu categorizations performed similarly well.

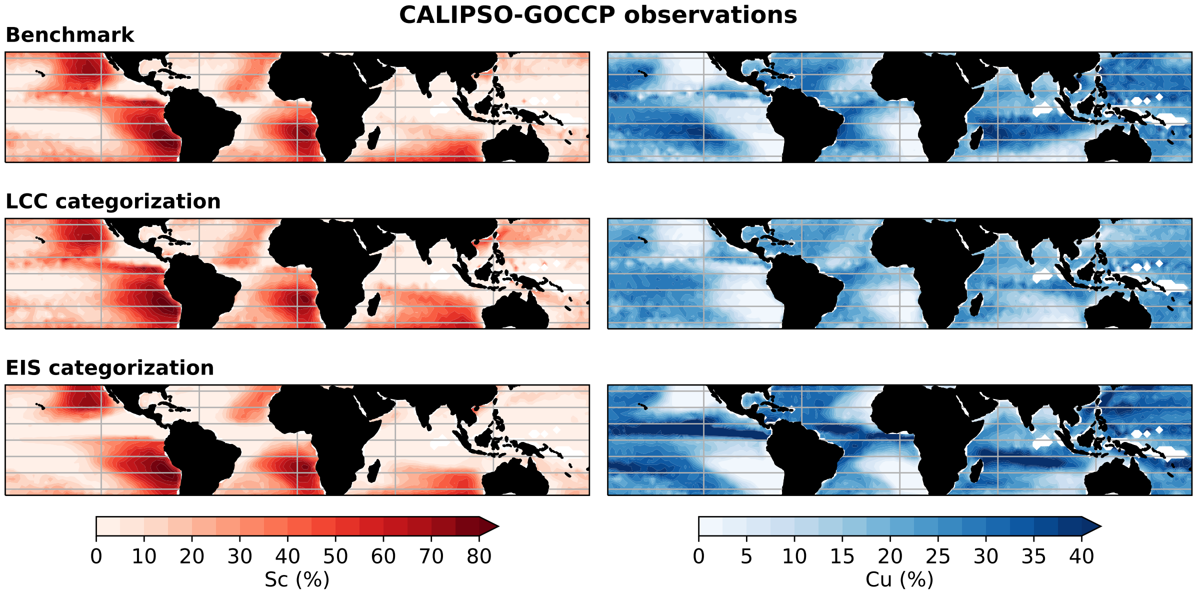

Figure S1: Geographical distributions of Sc- and Cu-cloud cover obtained with the two approaches to discriminate Sc from Cu.

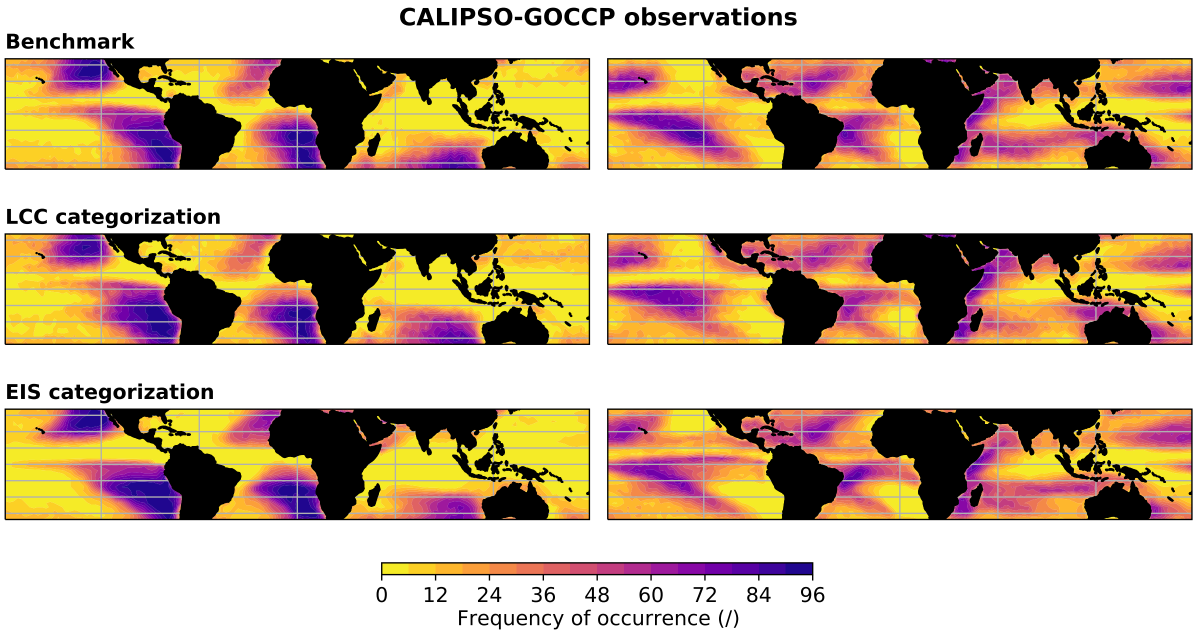

Figure S2: Geographical distributions of frequency of occurrence of Sc (left) and Cu (right) obtained with the two approaches to discriminate Sc from Cu. Note that througout this work we utilize 8 years of monthly data (January 2007 – December 2014).

Text S2.

2. Full validation analysis for individual CMIP6 models using Sc-Cu categorization based on LCC threshold

In this section we present full validation results for individual CMIP6 models. The Sc- and Cu-components of LCC and shortwave CRE are thereby obtained using the new categorization based on LCC threshold.

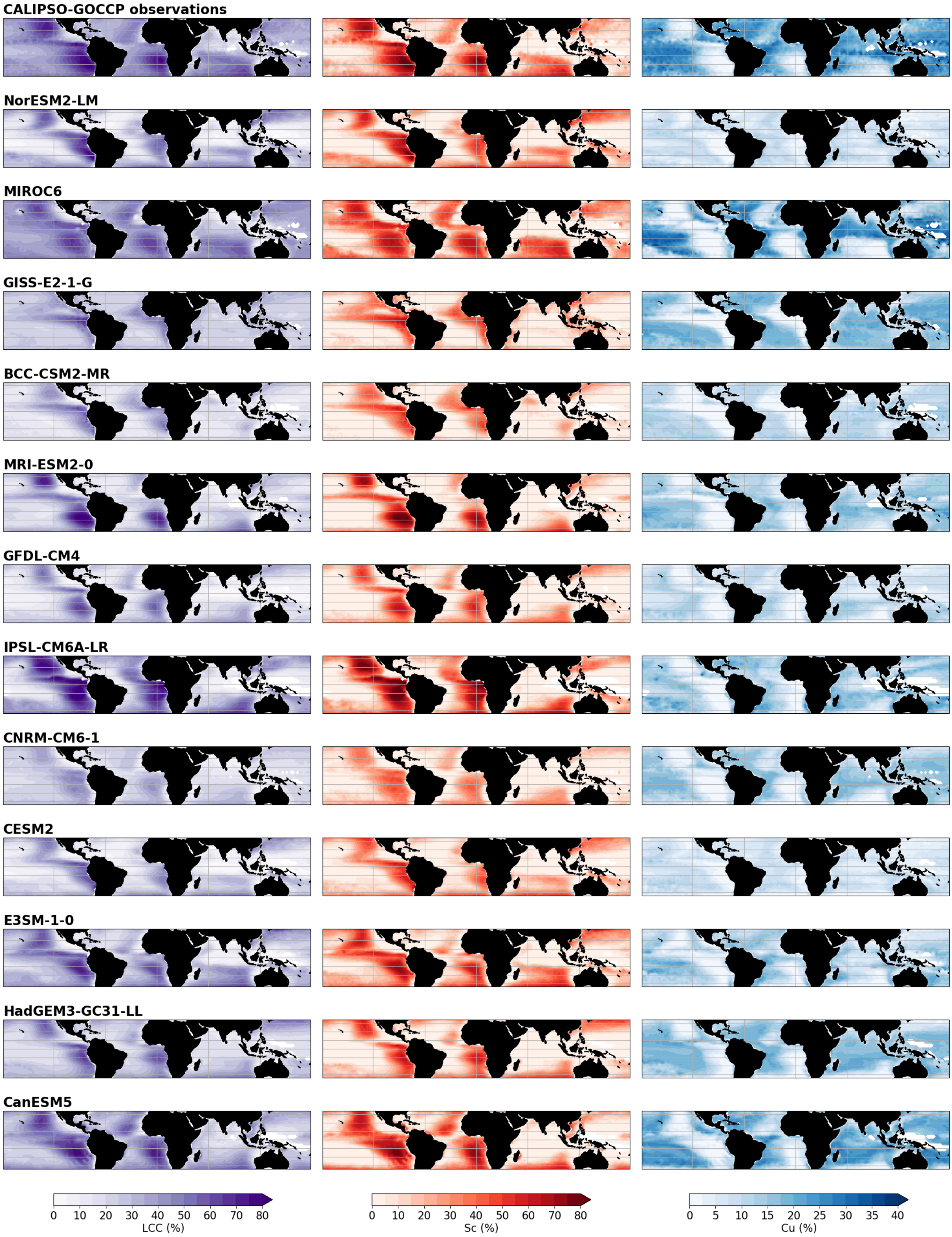

Figure S3: Geographical distributions of LCC in subsidence areas over tropical oceans as well as separately in Sc- and Cu-regions.

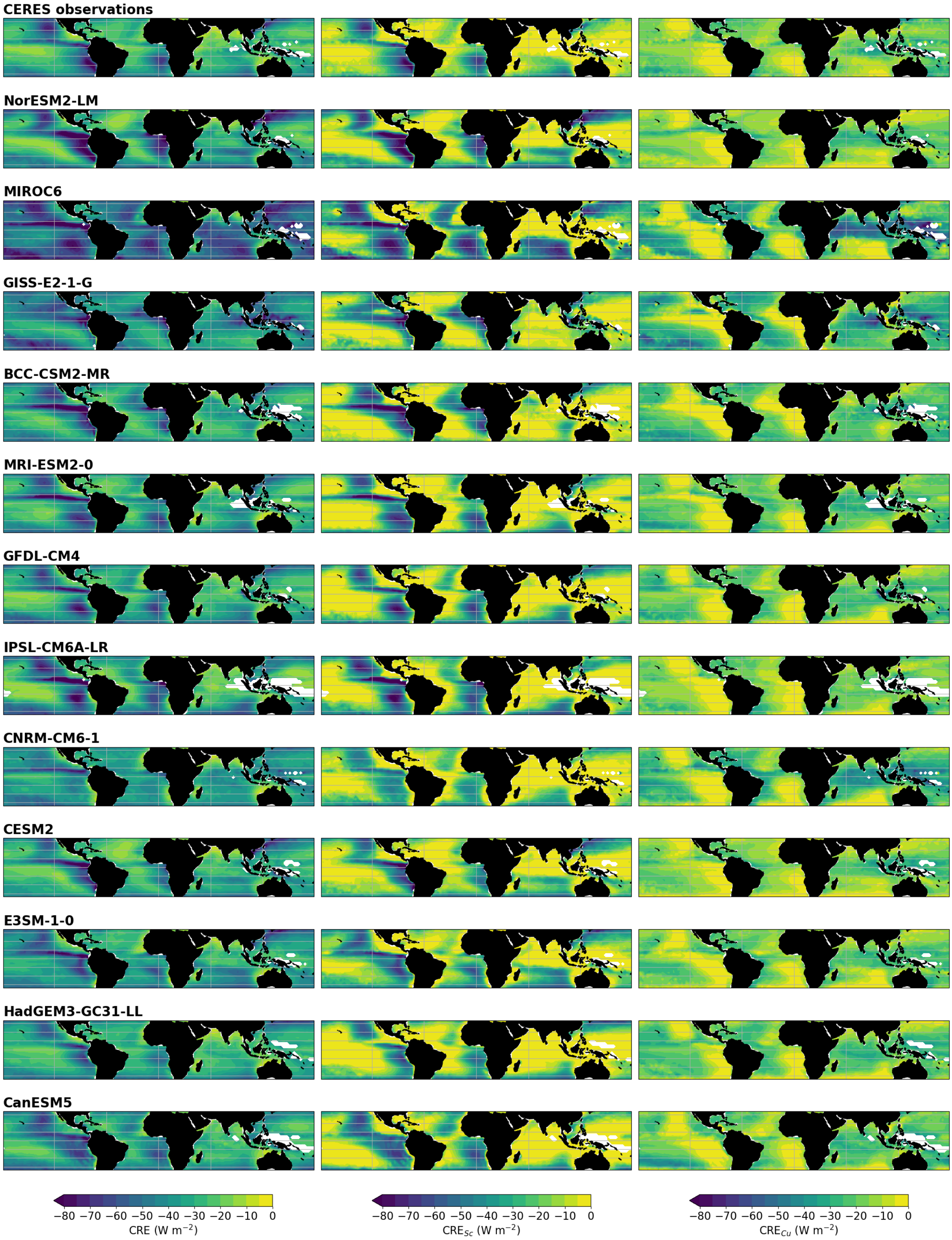

Figure S4: Geographical distributions of shortwave CRE in subsidence areas over tropical oceans as well as separately in Sc- and Cu-regions.

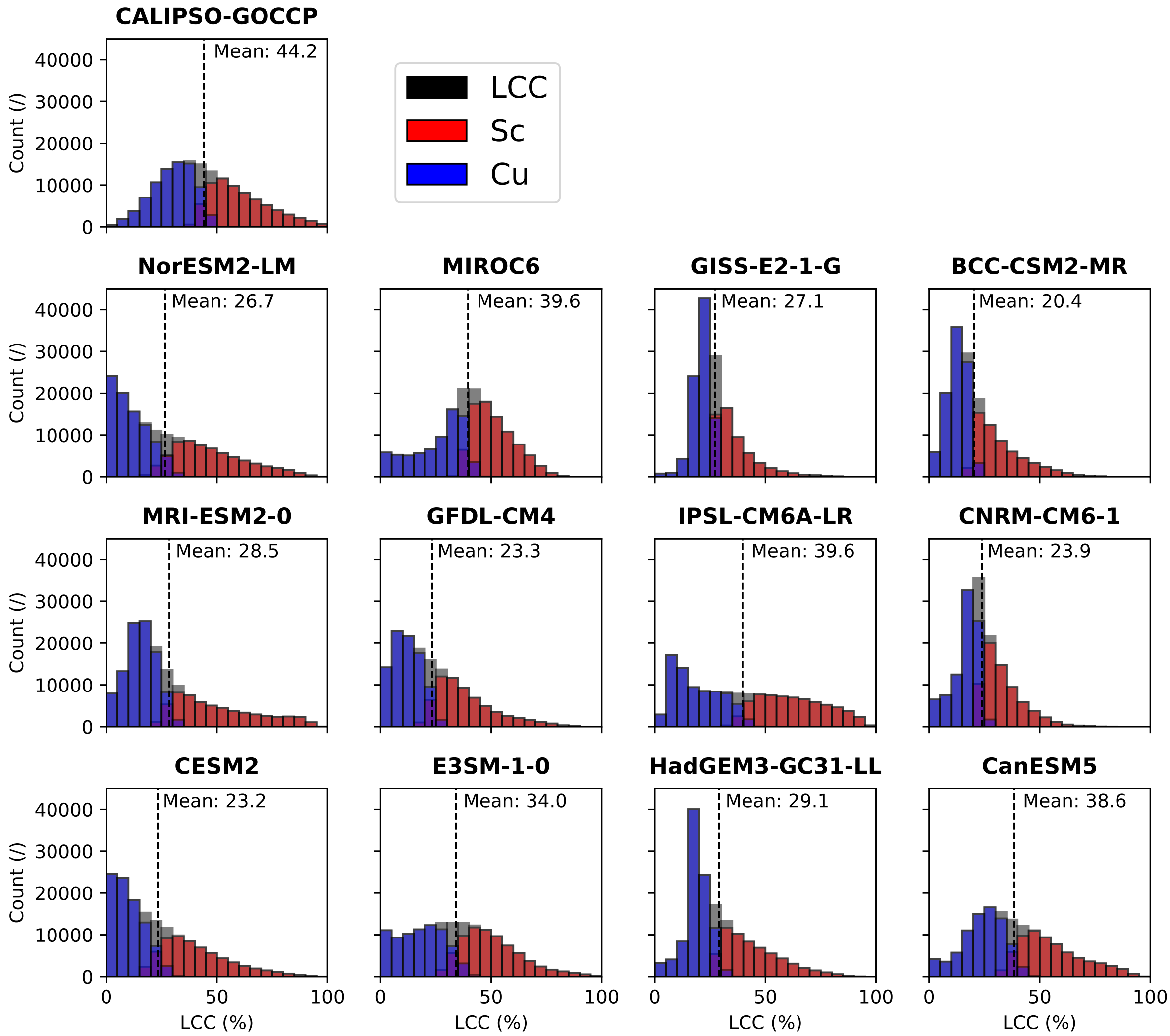

Figure S5: Histograms of LCC in subsidence areas over tropical oceans as well as separately in Sc- and Cu-regions.

Text S3.

3. Comparison of the two Sc-Cu categorizations in climate models

In this section we compare the two approaches to discriminate Sc from Cu when applied to climate models. As exposed in Main article the traditional categorization based on a fixed EIS threshold has limitations when applied to climate models, which markedly underestimate EIS compared to reanalyses.

Figures S6 and S7 visualize geographical distributions of Sc- and Cu-cloud cover as well as frequency of occurrence comparing the two Sc-Cu categorizations in CMIP6 models. Consistent with our aforementioned considerations we notice that the EIS categorization generally assigns a smaller amount of low cloudiness to the Sc component compared to the LCC categorization throughout major portions of tropical oceans. Consequently, the Cu cloud cover is larger when the EIS categorization is applied compared to its counterpart acquired with the LCC categorization. This problem is especially pronounced in MIROC6 and IPSL-CM6A-LR. Whereas it is out of the scope of the present work to directly evaluate the two categorizations in other models than in the GISS model, an interesting point can be made regarding IPSL-CM6A-LR. As discussed in Main article, scientists at IPSL utilized CALIPSO-GOCCP observations as target when tuning the model. Remarkably, in IPSL-CM6A-LR the LCC categorization brings Sc- and Cu-cloud cover which show a good match with benchmark components derived from CASCCAD/CALIPSO-GOCCP. The EIS categorization, on the contrary, leads to a significant misrepresentation of low-cloud regimes in IPSL-CM6A-LR.

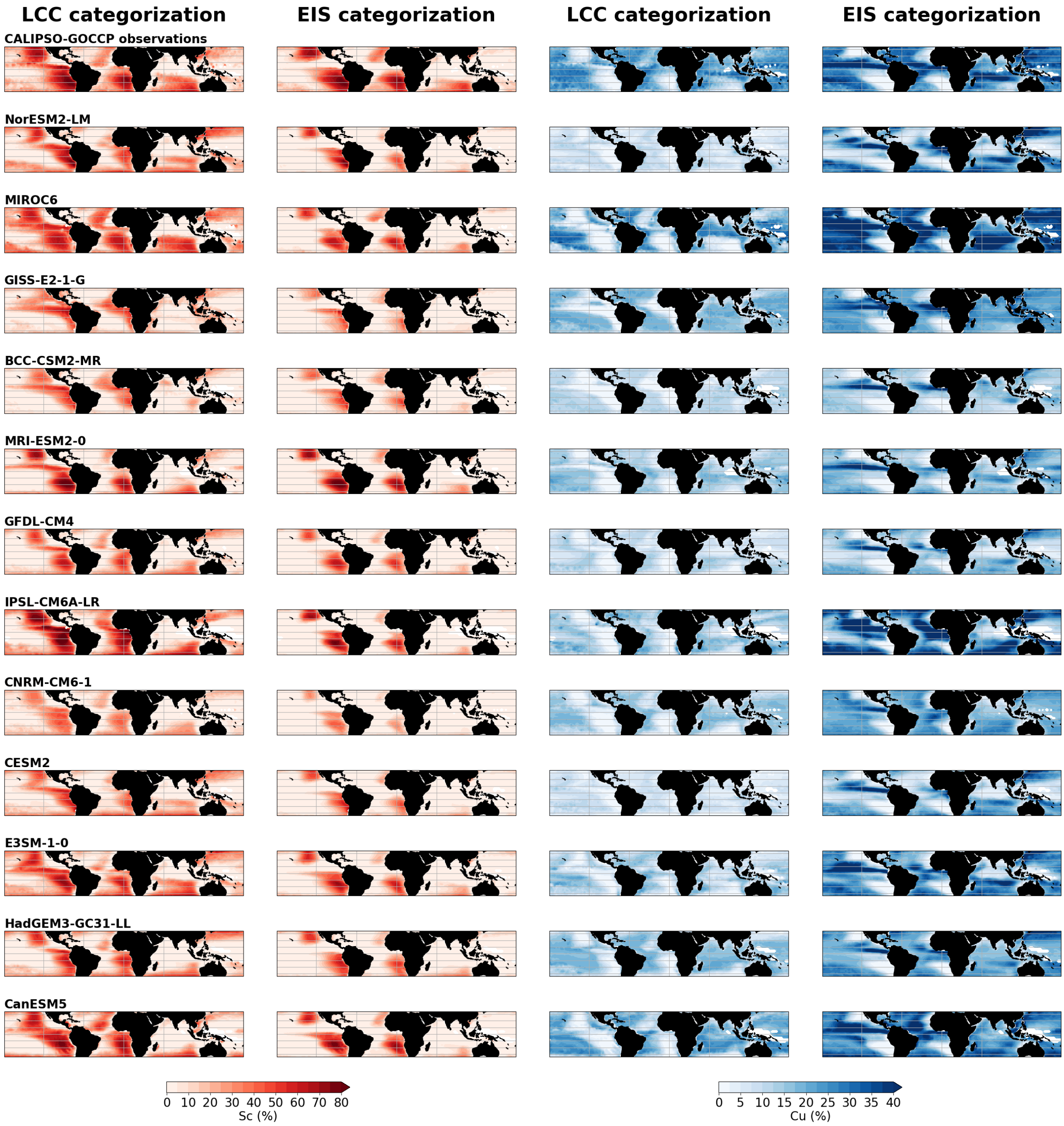

Figure S6: Geographical distributions of Sc- and Cu-cloud cover obtained with the two approaches utilizing either dynamic LCC or fixed EIS threshold to discriminate Sc from Cu.

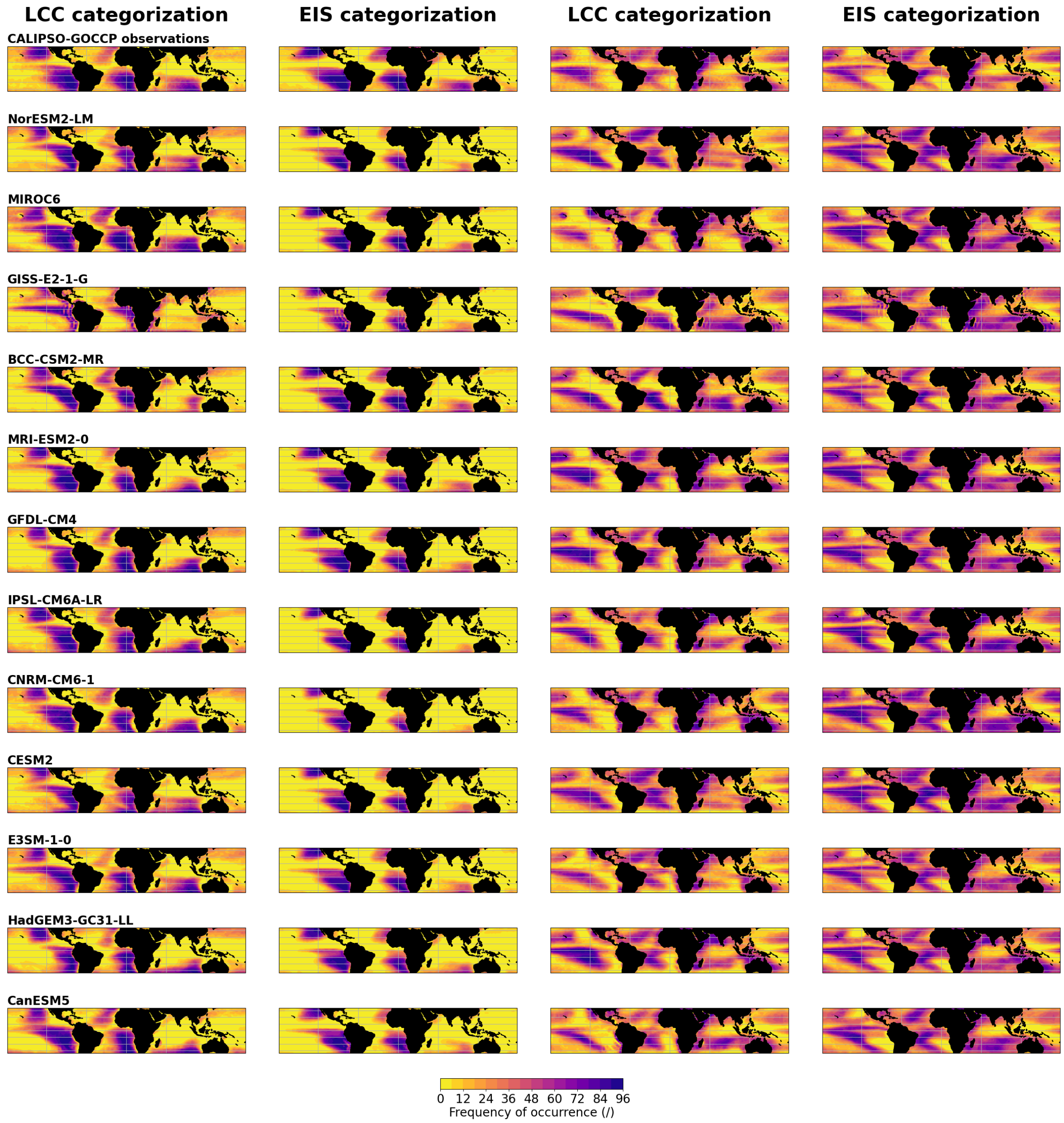

Figure S7: Geographical distributions of frequency of occurrence of Sc (left) and Cu (right) obtained with the two approaches to discriminate Sc from Cu. Note that througout this work we utilize 8 years of monthly data (January 2007 – December 2014).

In summary, the two categorizations generally brought quantitatively different conclusions when applied to a set of twelve CMIP6 models, therefore caution has to be taken how LCC is splitted when establishing low-cloud regimes in climate models. The disparity between the outcome of the two Sc-Cu discriminations depends on the GCM as well as on the evaluation metric.