Seeking guidance from active cloud observations to improve climate model subcolumn generators

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Abstract

Our objective is to test and improve cloud subcolumn generators used for greater realism of scales in the radiation schemes and satellite simulators GCMs. For this purpose, we use as guidance water content fields from active observations by the CloudSat radar (CPR) and the CALIPSO lidar (CALIOP). Cloud products from active sensors while suffering significant sampling and coverage drawbacks have the advantage of resolving both horizontal and vertical variability which is what the generators are designed to produce. Our first order goal is to test the ability of the generators to deliver realistic 2D cloud extinction (cloud optical thickness) fields using, as in GCMs, limited domain-averaged information. Our reference 2D cloud extinction fields fully resolving horizontal (along the track of the satellites) and vertical variability come from combining CloudSat's 2B-CWC-RVOD (liquid clouds) and CALIPSO-enhanced 2C-ICE (ice clouds) products. The combined fields were improved by introducing a simple scheme to fill liquid cloud extinction values identified as missing by comparing with coincident 2D (phase-specific) cloud masks provided by the CALIPSO-enhanced 2B-CLDCLASS-LIDAR CloudSat product. Our presentation will demonstrate the substantial improvements for low clouds brought by the filling scheme through comparisons with MODIS-Aqua cloud fraction distributions expressed in terms of joint cloud top pressure – cloud optical thickness histograms. Beyond global comparisons, the nature of the improvements become clearer when comparing mean joint histograms segregated by MODIS Cloud Regime (CR): improvement is by design superior for MODIS CRs dominated by low clouds. With the improved 2D extinction fields at hand, we test the skill of two subcolumn generators, one used in the COSP satellite simulator package, and one with more sophisticated cloud overlap implemented in the GEOS global model, to reproduce joint histograms that are statistically similar to the observed counterparts described above (as interpreted by COSP's MODIS simulator). Our main comparison metrics are the Euclidean distance between observed and generator-produced global or near-global mean joint histograms, and the statistics of Euclidean distances calculated for individual scenes. One full year of data is used to assess whether the more sophisticated cloud generator produces clouds with greater realism in 2D cloud variability.

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What the work is about

Evaluation two stochastic subcolumn generators:

- SCOPS of COSP (citation)
- "Raisanen" by Räisänen et al. (2004)

These generators are used in GCMs to emulate subgrid cloud variability

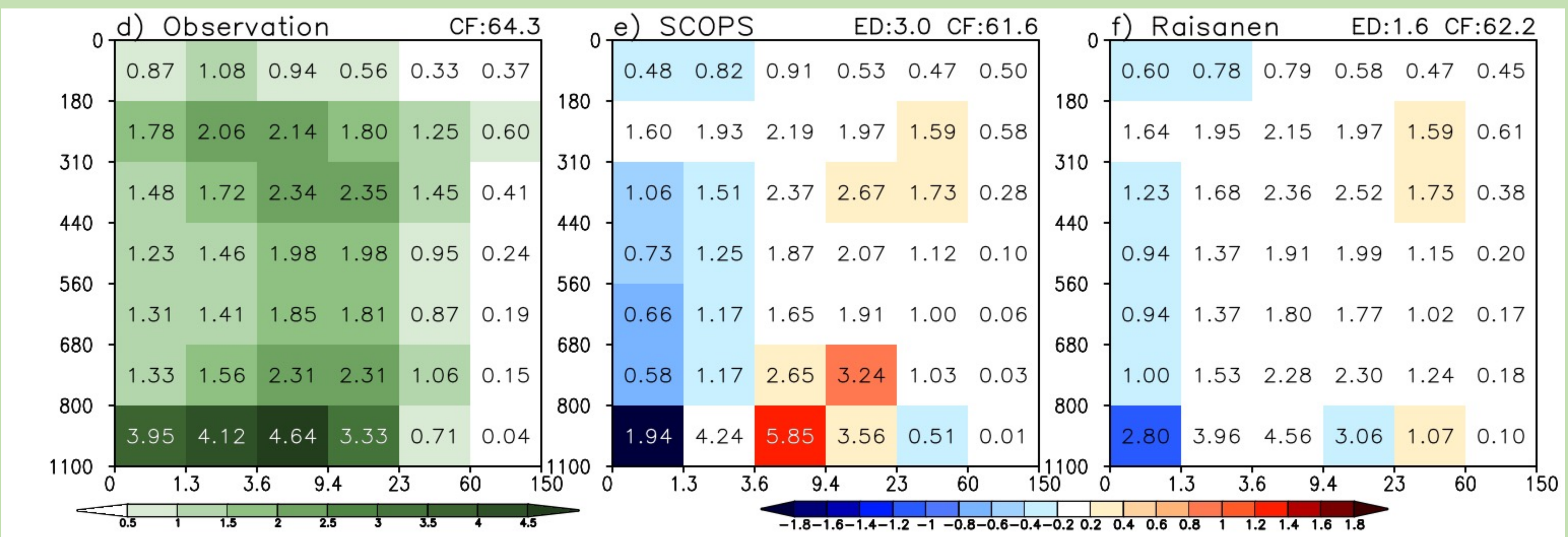
Datasets and methods

Subgrid variability "truth": *Modified* CloudSat-CALIPSO (CC) dataset combining two CC cloud products providing one-year ocean-only two-dimensional (height-distance) cloud optical depth variability of liquid, ice, and mixed phase clouds when blended at scales ~200 m (vertical) and ~ 2 km (horizontal). Dataset is segmented to 100-subcolumn individual "scenes". Mean properties of the cloud fields are passed as input to generators to produce scene-level cloud subgrid variability.

Evaluation: Comparison of cloud fraction (CF) joint histograms in cloud top pressure (CTP) – cloud optical thickness (TAU) space: individual scenes and grand-averages.

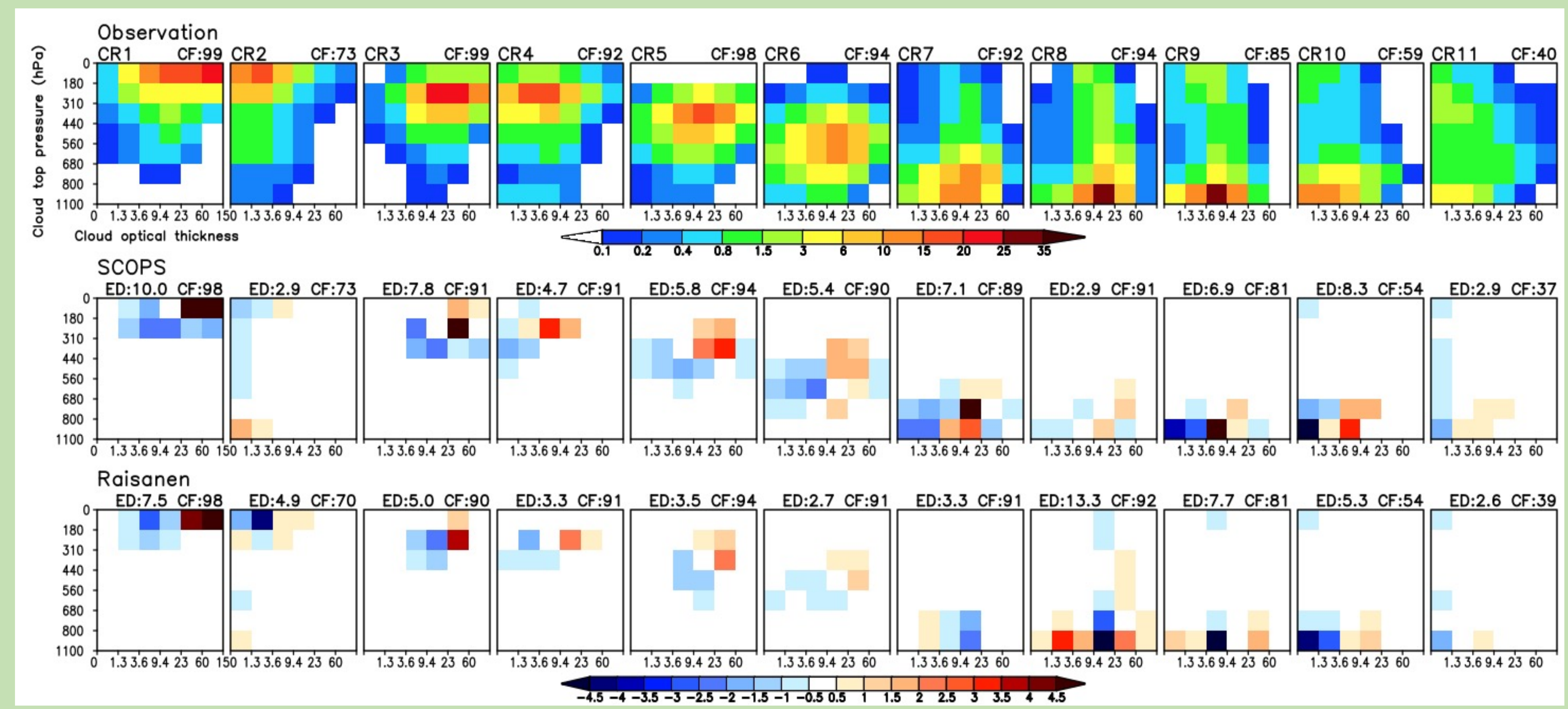
Overall performance

Global Joint Histograms



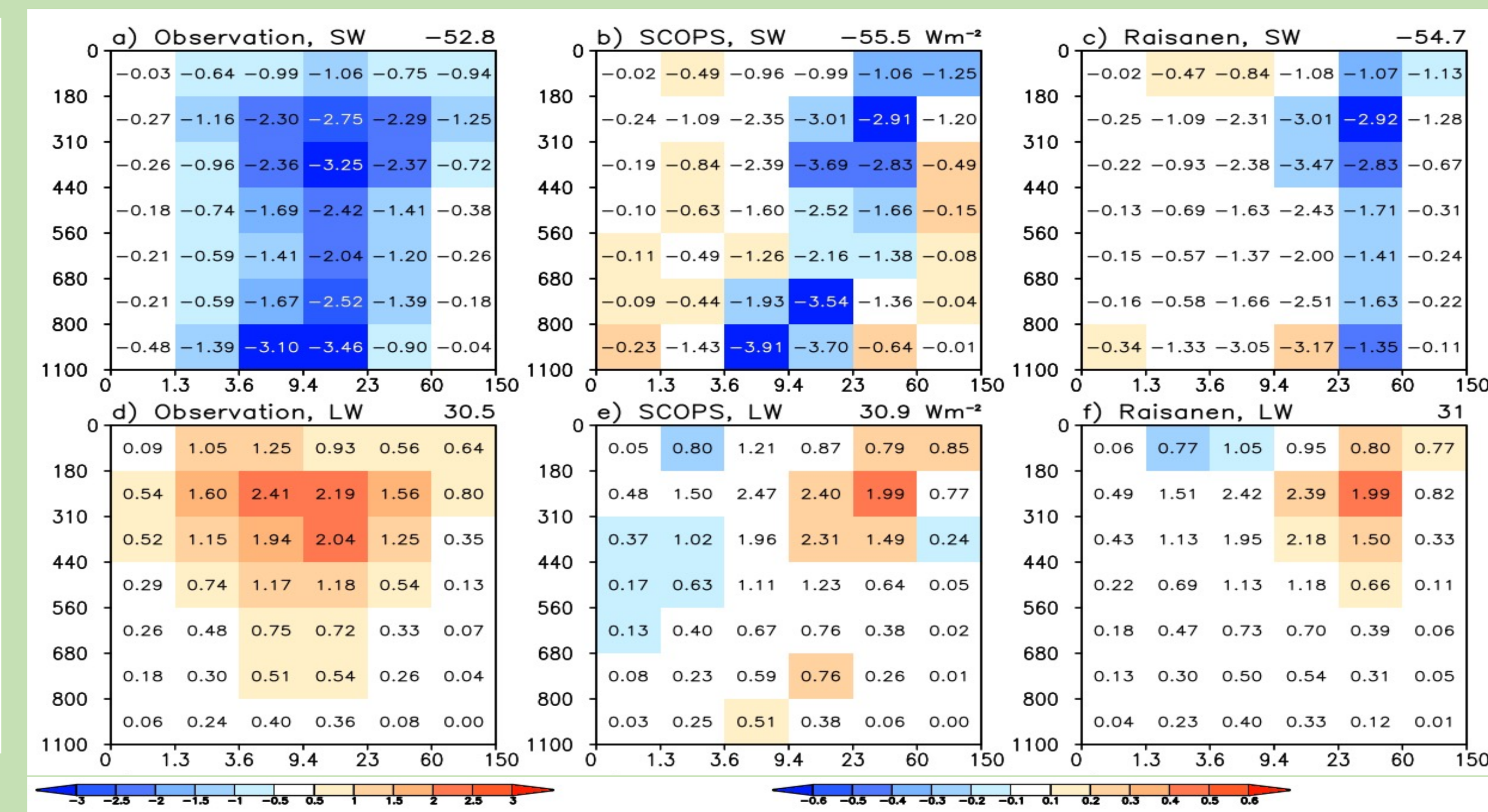
The all-encompassing measure of quality of simulated joint histograms is the Euclidean Distance (ED) from the observed histogram. According to that metric, for the global oceans ***the Raisanen generator performs better*** (ED = 1.6 < ED = 3.0 for SCOPS; compare the right and middle panels where the numbers show bin CF values and the colors errors). Raisanen's total vertically projected CF is slightly closer to observations (but both generators are good). The underestimation by the generators suggest that they ***overlap clouds slightly more maximally than in observations*** which probably also explains the underestimate of optically thin (TAU < 3.6) clouds: the greater vertical cloud alignment of maximum overlap reduces the probability of optically thin clouds. The colored bins in the panel (e) and (f) joint histograms are CTP-TAU combinations of biggest bin CF errors.

Joint histograms by Cloud Regime



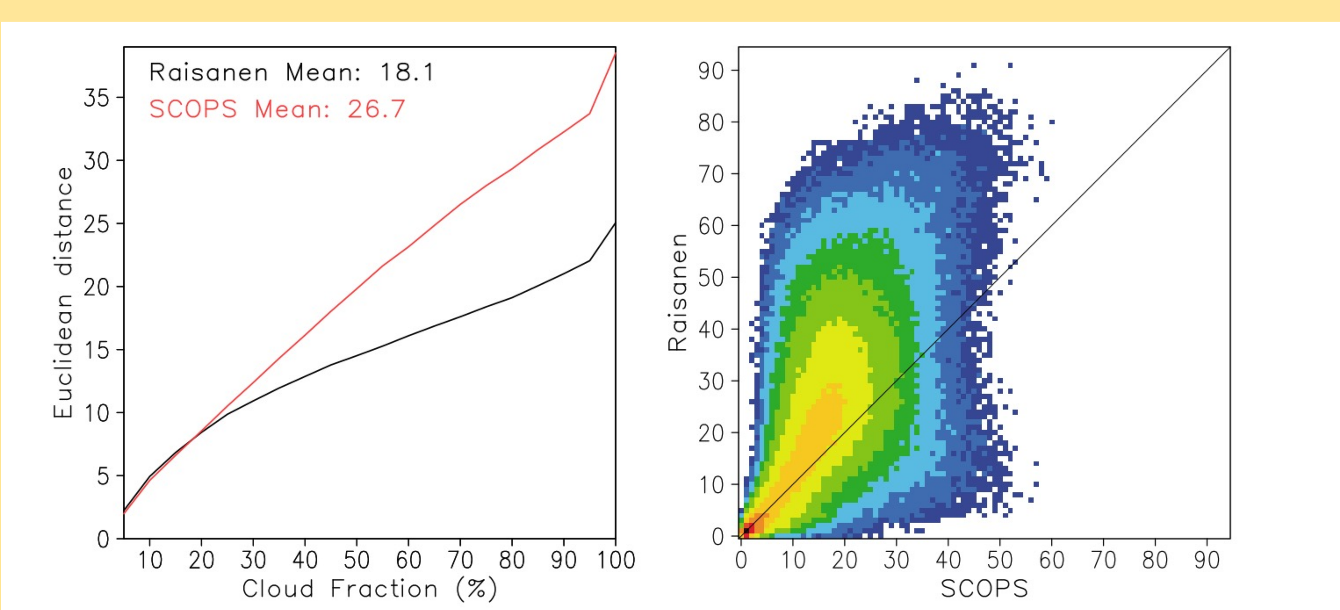
The global ocean joint histogram comparison can be refined by taking into account the MODIS Cloud Regime (Cho et al. 2021) coinciding with the 100-subcolumn scene. ***Both generators are capable of closely reproducing on average the mean CF of each CR, but again with a systematic underestimation*** (worst for CR3). ***The Raisanen generator performs overall better***, as it gives lower EDs for 8 out of 11 CRs. However, Raisanen is notably inferior for CR8 even though it reproduces the mean CF of this CR quite well. CR8 along with CR9 appear to go against Raisanen's trend of optical thin cloud underestimation; on the other hand, SCOPS's underestimation of optically thin cloud is persistent across all CRs.

Global Cloud Radiative Effect (CRE)



The bin CF errors (panels (e) and (f) on the left) ***can be converted to SW and LW CRE errors by multiplying with pseudo-Cloud Radiative Kernels*** (CRKs) calculated for the 2007 global oceans from the monthly version of the new CERES FluxByCldTyp product (Sun et al. 2021). Global SW CRE errors (panel top) are larger for SCOPS (2.7 Wm^{-2}) than for Raisanen (1.9 Wm^{-2}) , but the LW CRE errors about the same (~0.5 Wm^{-2}). ***The distribution of SW CRE errors (colors) broadly tracks the distribution of CF errors***, except for the radiatively inconsequential optically thin clouds. Binned LW CRE errors outside the ±0.15 Wm^{-2} are sporadic occur mainly for high clouds.

Performance at individual scene level



EDs of simulated joint histograms from their observational counterparts can also be calculated for individual 100-subcolumn scenes. When plotted as a function of scene CF the average ***EDs of the Raisanen generator remain consistently below those from the SCOPS*** generator above CF≈20%. The density plot of EDs from the two generators shows a much larger population above the diagonal (where SCOPS ED exceeds Raisanen ED).

The bottom line

Both generators tend to underestimate optically thin clouds and overestimate some cloud types of moderate and high optical thickness, but one of them (Raisanen) clearly produces cloud fields closer to observations. Associated radiative flux errors can be as high as 3 Wm^{-2} in the SW part of the spectrum.

References

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