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Improving the treatment of subgrid cloud variability in warm rain simulation in CESM2

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Representing subgrid variability of cloud properties has always been a challenge in global climate models (GCMs). In microphysics schemes, the effects of subgrid cloud variability on warm rain process rates calculated based on mean cloud properties are usually accounted for by scaling process rates by an enhancement factor (EF) that is derived from the subgrid variance of cloud water. In our study, we find that the EF derived from Cloud Layers Unified by Binormals (CLUBB) in Community Earth System Model Version 2 (CESM2) is severely overestimated in most of the oceanic areas, which leads to the strong overestimation in the autoconversion rate. Through an EF formula based on empirical fitting of MODIS, we improve the EF in the liquid phase clouds. Results show that the model has a more reasonable relationship between autoconversion rate, cloud liquid water content (LWC), and droplet number concentration (CDNC) in warm rain simulation. The annual mean liquid cloud fraction (LCF), liquid water path (LWP), and CDNC show obvious increases for marine stratocumulus, where the probability of precipitation (POP) shows an obvious decrease. The annual mean LCF, cloud optical thickness (COT), and shortwave cloud forcing (SWCF) match better with observation. The sensitivity of LWP to aerosol decreases obviously. The sensitivities of LCF, LWP, cloud top droplet effective radius (CER), and COT to aerosol are in better agreement with MODIS, but the model still underestimates the response of cloud albedo to aerosol. These results indicate the importance of representing reasonable subgrid cloud variabilities in the simulation of cloud properties and aerosol-cloud interaction in climate models.