Sensitivity of ice supersaturated region's characteristics to spatial resolution in idealized squall line simulations

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The representations of squall lines in numerical simulations can be influenced by both horizontal grid spacings and microphysical schemes. In this study, we focus on evaluating the simulated characteristics of ice supersaturated regions (ISSRs), which are the birthplace of ice crystals and cirrus clouds, in a cloud-resolving model. Idealized simulations of a squall line in the NCAR CM1 model (Bryan and Morrison, 2012) are compared with the in-situ aircraft observations from the NSF Deep Convective Clouds & Chemistry (DC3) campaign. Characteristics of ISSRs, including the spatial extent and relative humidity with respect to ice (RHi), as well as the evolution of cirrus clouds (e.g., relative lifetime) are compared between 1 Hz observations (~250 m horizontal scale) and model simulations at three horizontal grid spacings: Δx = 0.25, 1 and 4 km. In addition, the double-moment microphysics scheme of Morrison et al. (2005) is used with three different set-ups: (1) using the RHi threshold (RHi_{nucl}) = 108% (default) for ice crystal formation, (2) using a new threshold of RHi_{nucl} = 130%, and (3) using a new vapor deposition rate at 1/10th of the default value.

Here we use mock aircraft to transect model domain during simulations at a similar true air speed (~250 m/s) as that of the NSF/NCAR Gulfstream-V research aircraft. Our comparisons show that higher resolution simulations provide results closer to observations than those from coarser resolutions. These better comparison results are shown in terms of representing the spatial characteristics of ISSRs, including their length distribution, the spacings between ISSRs, and the average and maximum RHi values inside ISSRs. The closest match to observations is provided by the 0.25 km run with RHi_{nucl} = 130%. Particularly, the RHi_{nucl} = 130% run provides very similar results to observations for representing positive correlations between the RHi values (both average and maximum) and the ISSR lengths, while other runs show much weaker correlations. The RHi_{nucl} = 130% run also provides more realistic simulations of ISSRs, by allowing more clear-sky ISSRs and a higher spatial ratio of ISSRs to cirrus clouds. We further compare the roles of water vapor and temperature spatial variabilities in contributing to the RHi variabilities. Model simulations have captured the dominant contributions of water vapor horizontal variability to ISSR formation in an Eulerian view, yet there are still a larger portion of the ISSRs being dominated by temperature heterogeneities in the simulations than that in the observations.

When analyzing the evolution of cirrus clouds based on the method of Diao et al. (2013), wider ranges of distributions of ice water content and ice crystal number concentration are found in observations, which indicate that more spatial heterogeneities in ice microphysical properties are captured in the observations than simulations.

Overall, the CM1 model run at 0.25 km resolution is able to present the spatial characteristics of ISSR, as well as the five evolution phases of cirrus clouds. More investigation on the RHi thresholds of ice crystal formation will help to determine whether relatively higher RHi thresholds (e.g., RHi_{nucl} = 130%) for ice crystal formation are more representative than lower ones (e.g., RHi_{nucl} = 108%) for squall line simulations.