Aerosol and CAPE Sensitivity Simulations with the NASA WRF Bin Microphysical Model

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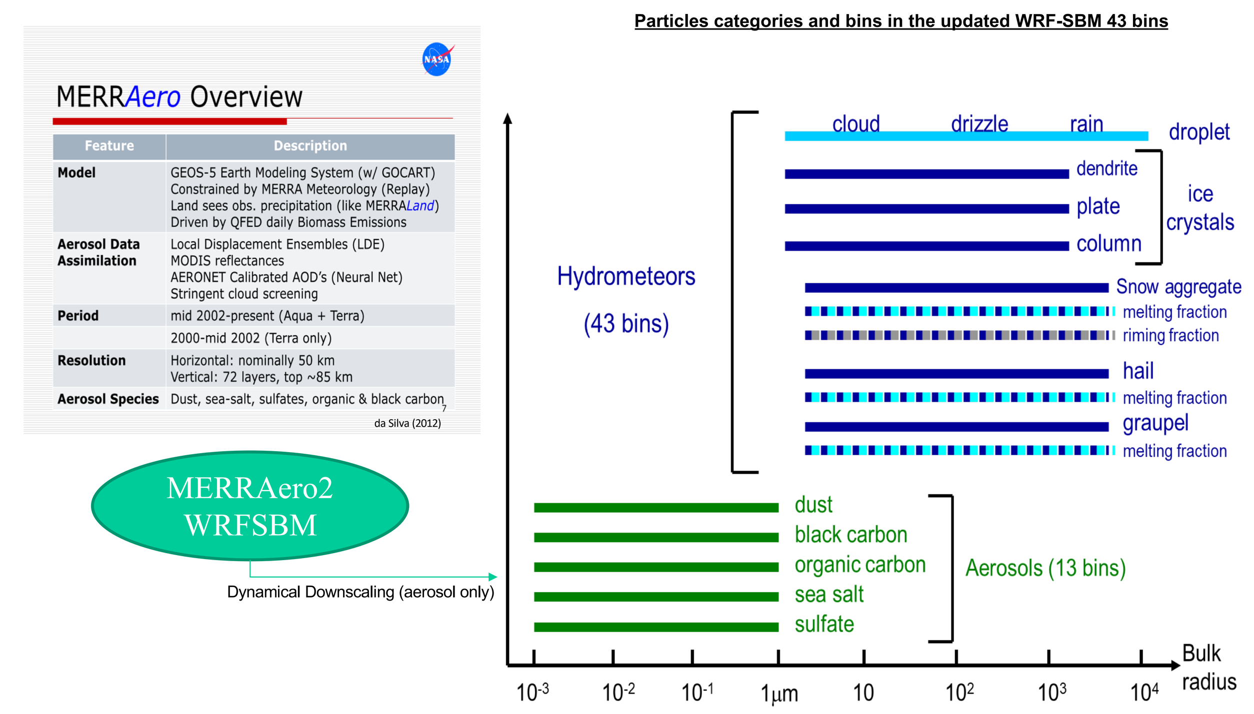
Series of sensitivity experiments were configured to investigate the effects of cloud condensation nuclei (CCN) loading on deep convective systems in tropical maritime and mid-latitude continental conditions. A new approach was adopted to change aerosol fields of two different cases (tropical and mid-latitude) in the framework of aerosol dynamic downscaling derived from large-scale aerosol simulations. The NASA WRF model using bin microphysics (SBM) was used for both control and a series of sensitivity simulations. For the mid-latitude simulation, we systematically decreased CCN concentrations and CAPE from the control run. For the tropical simulation, we systematically increased CCN concentrations and decreased CAPE compared to the control run. For both the mid-latitude and tropical cases, the accumulated surface precipitation was found to monotonically increase with CCN concentration. As expected, when CAPE decreased, accumulated surface precipitation decreased, somewhat independent of CCN concentration. For the mid-latitude simulation, supercooled liquid water increased with increasing CCN, leading to more hail production aloft. Hail formed at the expense of graupel. The large number of aerosol sensitivity experiments with the SBM are summarized in a conceptual model that explains increasing/decreasing trends of each hydrometeor type (ice, snow, graupel, hail, rain, etc), convective-stratiform precipitation rates, and the areal fractions of convective and stratiform rain. This conceptual model provides insights regarding the complex aerosol and thermodynamic impacts on convective systems in continental and maritime environments.

Experimental Design



Model Description:

The WRF-SBM is the WRF-ARW version 3.6.1 coupled with Hebrew University Cloud Model (HUCM) Spectral Bin Microphysics (SBM) 43-bin version. We updated SBM to include the typical five aerosol types (which for cloud interactions currently serve as cloud condensation nuclei). In addition, we developed a framework of dynamical downscaling of aerosols from the NASA Modern Era Retrospective analysis for Research and Applications Aerosol Reanalysis (MERRA Aerosol) into the WRF-SBM.

TWP-ICE sensitivity simulations

RunName	Case	CCN Con*	Vapor
TC1	TWP-ICE	39	100%
TC2	TWP-ICE	85	100%
TC3	TWP-ICE	215	100%
TC4	TWP-ICE	619	100%
TC5	TWP-ICE	1964	100%
TD1	TWP-ICE	39	95%
TD2	TWP-ICE	85	95%
TD3	TWP-ICE	215	95%
TD4	TWP-ICE	619	95%
TD5	TWP-ICE	1964	95%

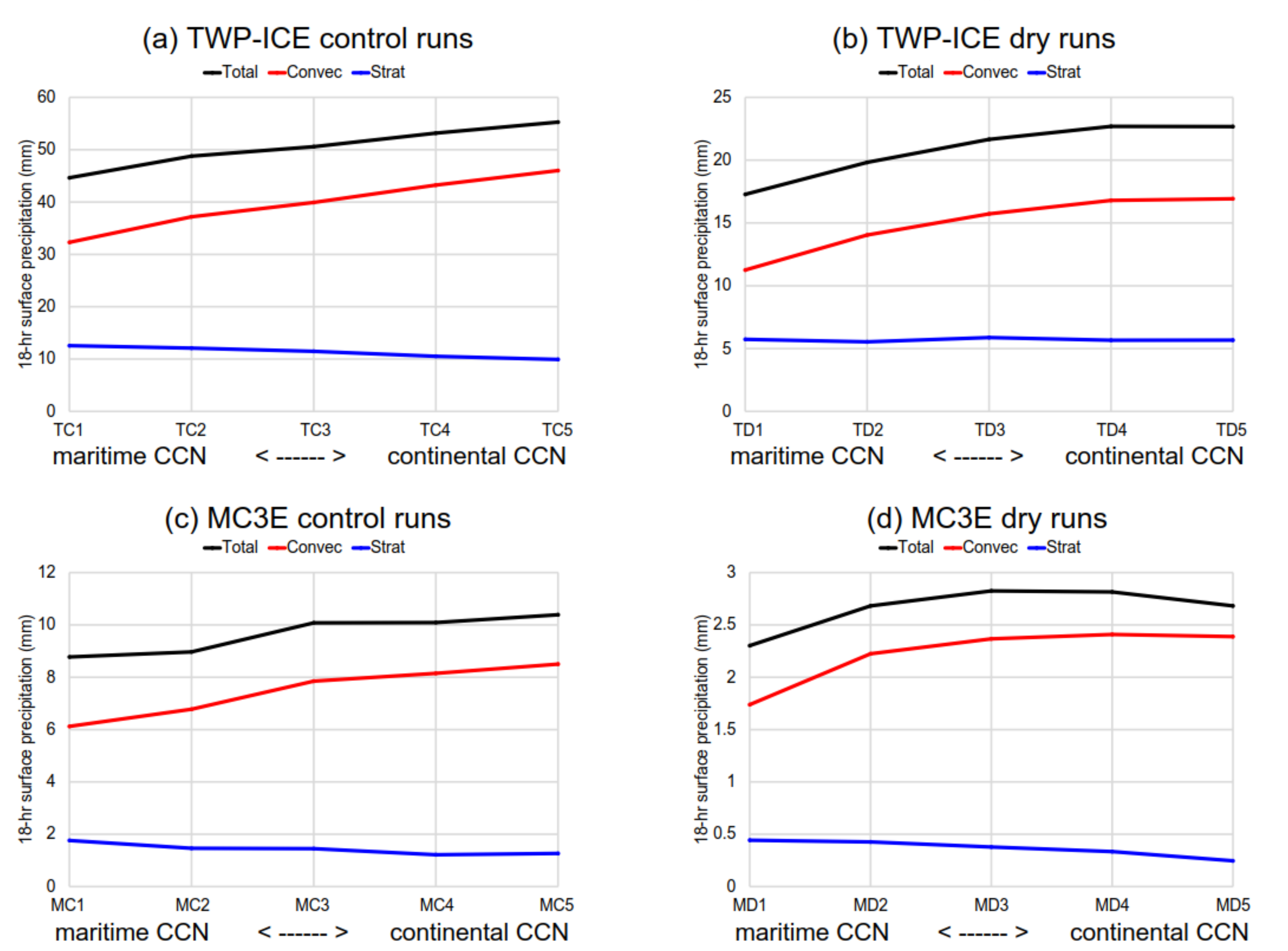
MC3E sensitivity simulations

RunName	Case	CCN Con*	Vapor
MC1	MC3E	48	100%
MC2	MC3E	88	100%
MC3	MC3E	240	100%
MC4	MC3E	661	100%
MC5	MC3E	2001	100%
MD1	MC3E	48	80%
MD2	MC3E	88	80%
MD3	MC3E	240	80%
MD4	MC3E	661	80%
MD5	MC3E	2001	80%

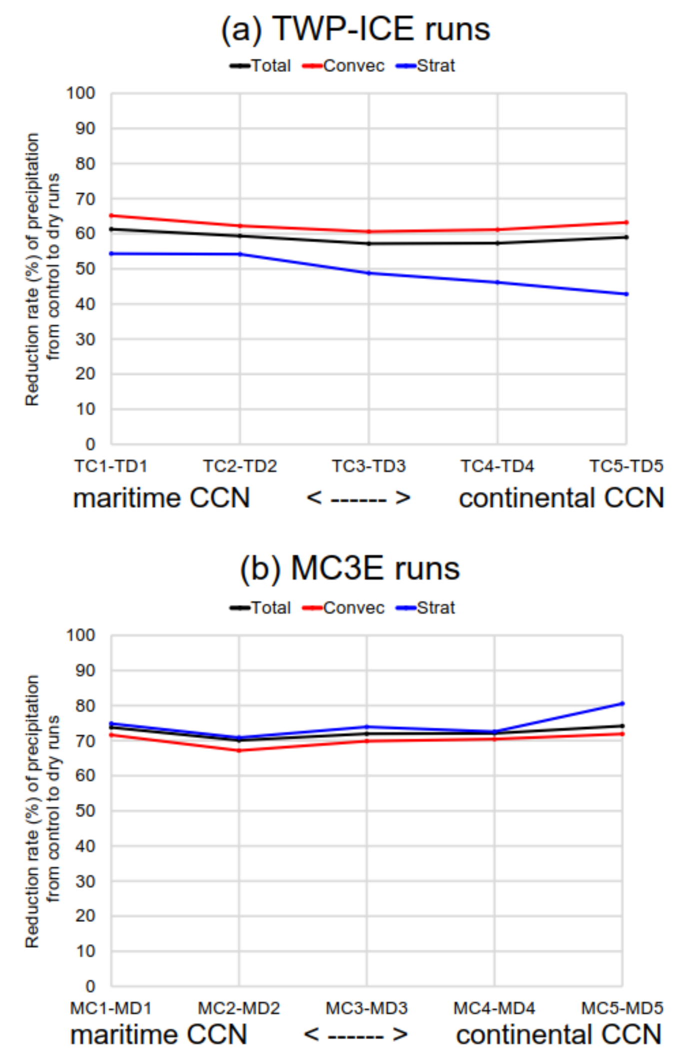
*Model domain averaged CCN concentrations for 1 % supersaturation (cm^{-3}) at 850 hPa level.

Sensitivity of basic precipitation and microphysical components

Surface precipitation sensitivity to aerosol change



Sensitivity to CAPE & aerosol change

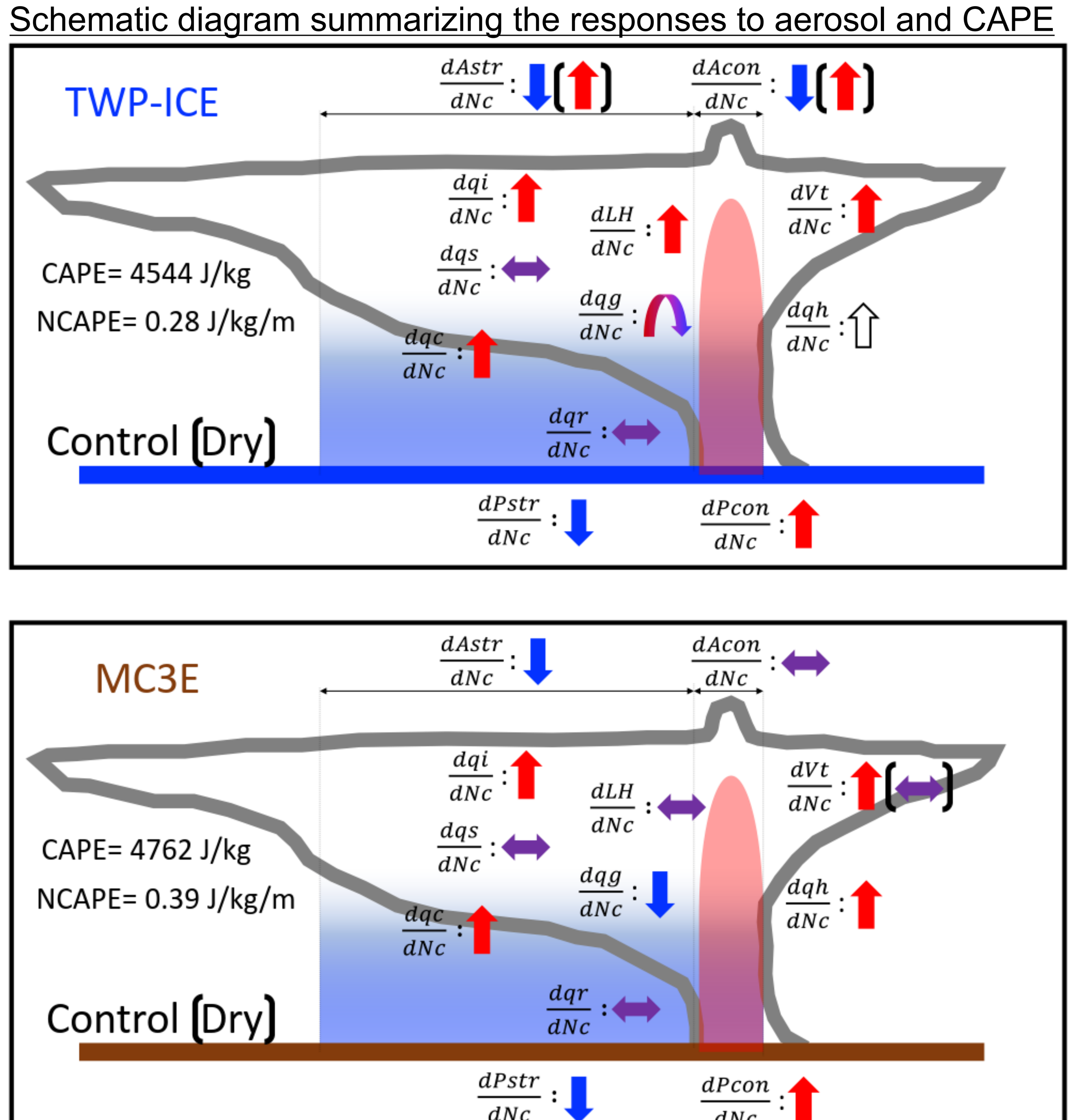


In TWP-ICE simulations, the total of convective and stratiform precipitation is smallest in most clean and highest in most polluted aerosol conditions. The convective precipitation is positively corrected with the aerosol concentration, while the stratiform precipitation is nearly constant.

The increase in aerosol concentration slightly decreases the reduction rates in stratiform precipitation from the control to CAPE-reduced run.

In MC3E simulations, overall tendency in the precipitation changes due to the aerosol change is the same as in TWP-ICE simulations, but the reduction rates in stratiform precipitation increases with increase in the aerosol concentration.

Schematic diagram summarizing the responses to aerosol and CAPE

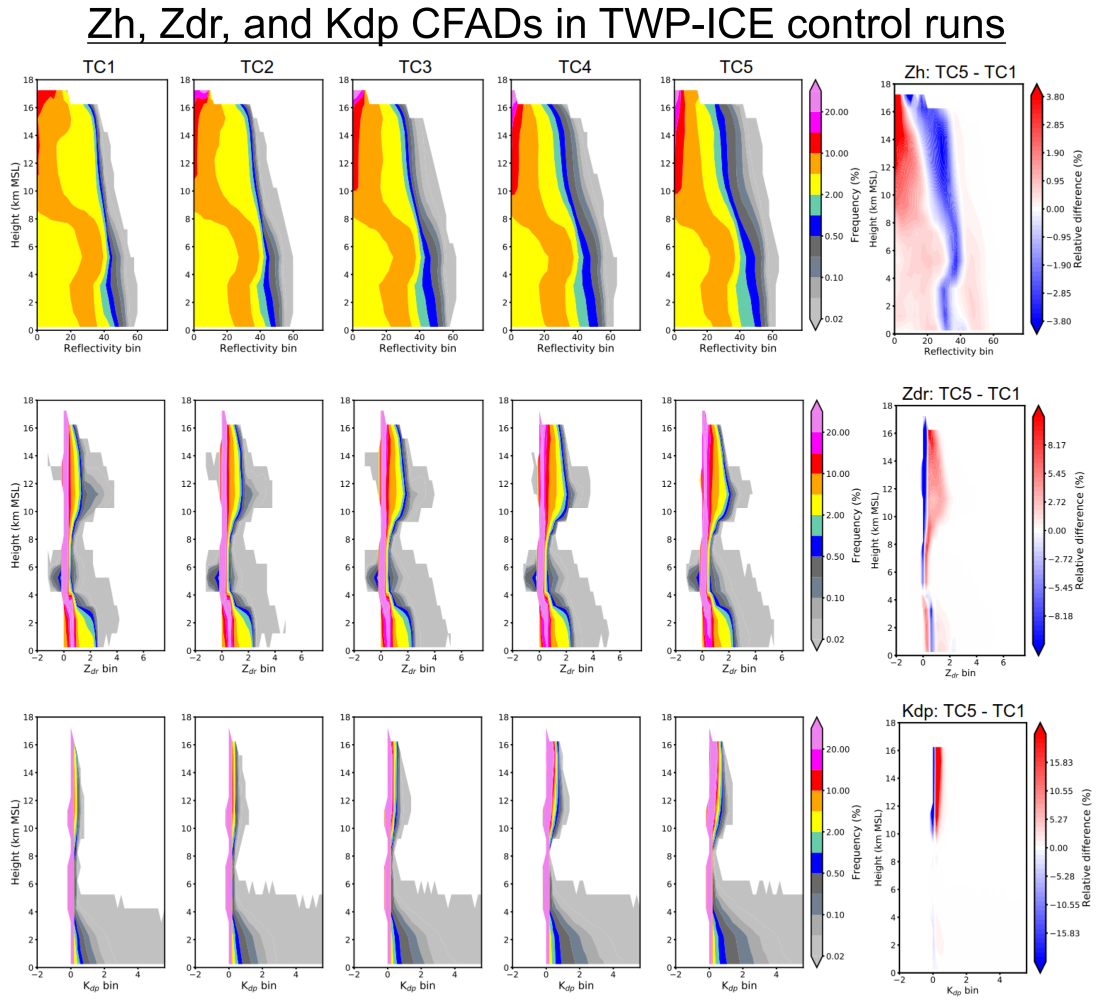


A_{str}: stratiform cloud area; A_{con}: convective cloud area; *qi*, *qs*, *qg*, *qh*, *qc*, *qr*: mixing ratios of cloud ice, snow, graupel, hail, cloud water, and rain, respectively; *LH*: net latent heating due to cloud microphysics processes; *Vt*: magnitudes of up/downdrafts; P_{str}: surface precipitation amounts from the stratiform cloud area; P_{con}: those from the convective cloud area; *Nc*: CCN concentration.

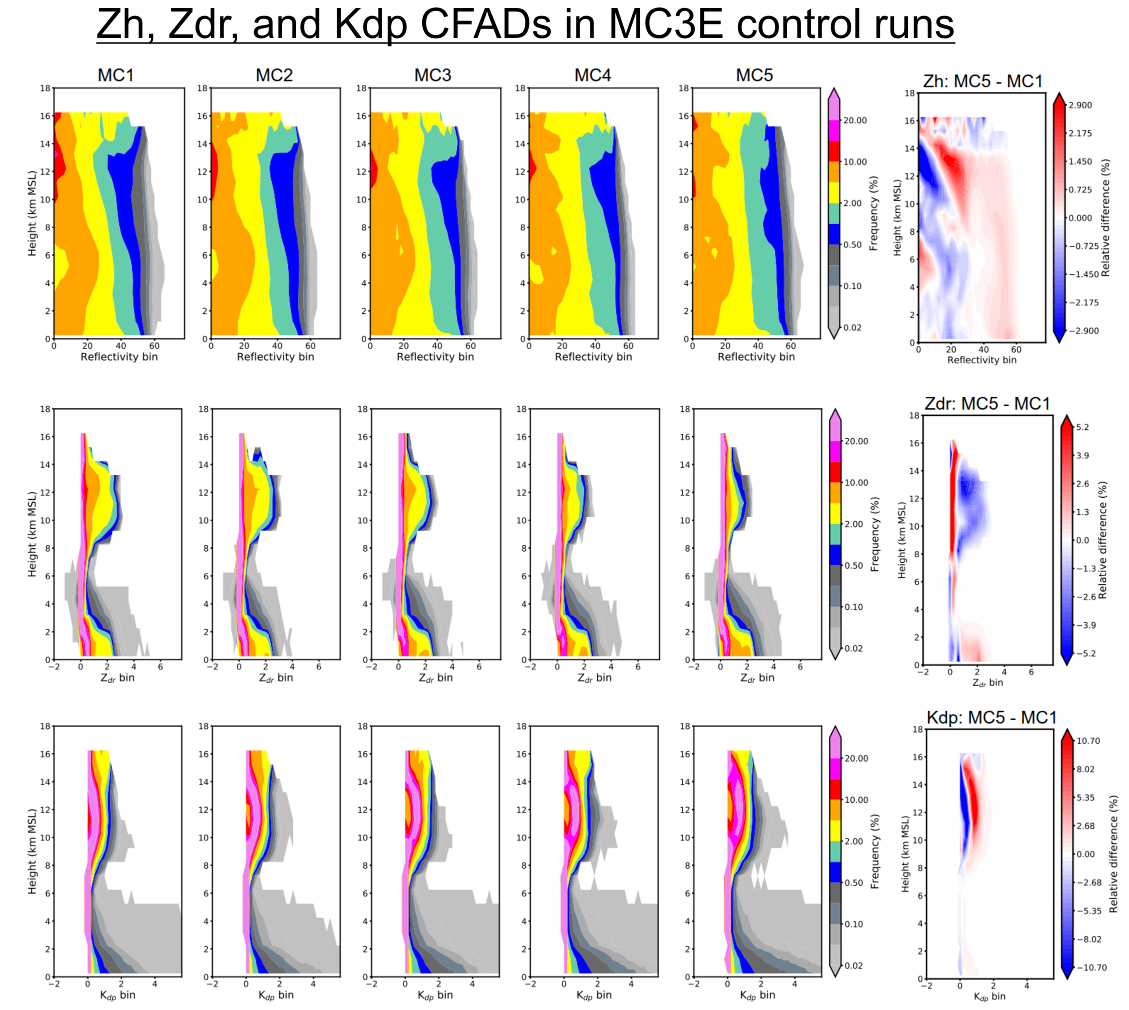
- The effects on surface precipitation were similar overall for the TWP-ICE and MC3E cases and in the control and vapor (CAPE) reduced runs.
- The precipitation from convective areas increases in response to CCN increases, and its change has a more significant impact on the total precipitation than stratiform precipitation.
- The increase in CCN loading yielded the opposite impacts on the changes in the areal coverages of convective and stratiform clouds in the TWP-ICE control and vapor-reduced runs, while they were similar in the MC3E runs.
- Changes in supercooled water due to CCN loading had different impacts on the cloud microphysics in the TWP-ICE and MC3E simulations. The dry middle troposphere in the continental case focused the riming of supercooled water on a limited number of non-rimed particles; consequently, rimed particles transitioned to hail. In contrast for the maritime case, increased supercooled water led to increased riming that was dispersed over more abundant non-rimed particles, leading to less dense rimed particles like graupel.

Sensitivity of polarimetric radar components

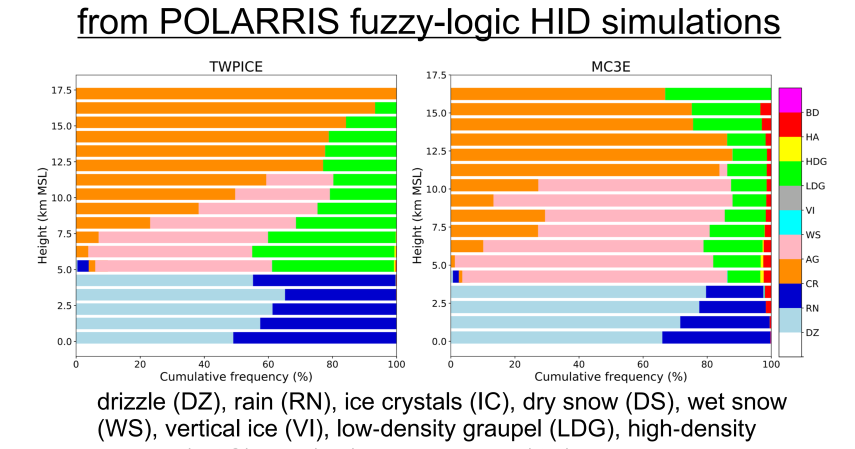
Zh, Zdr, and Kdp CFADs in TWP-ICE control runs



Zh, Zdr, and Kdp CFADs in MC3E control runs



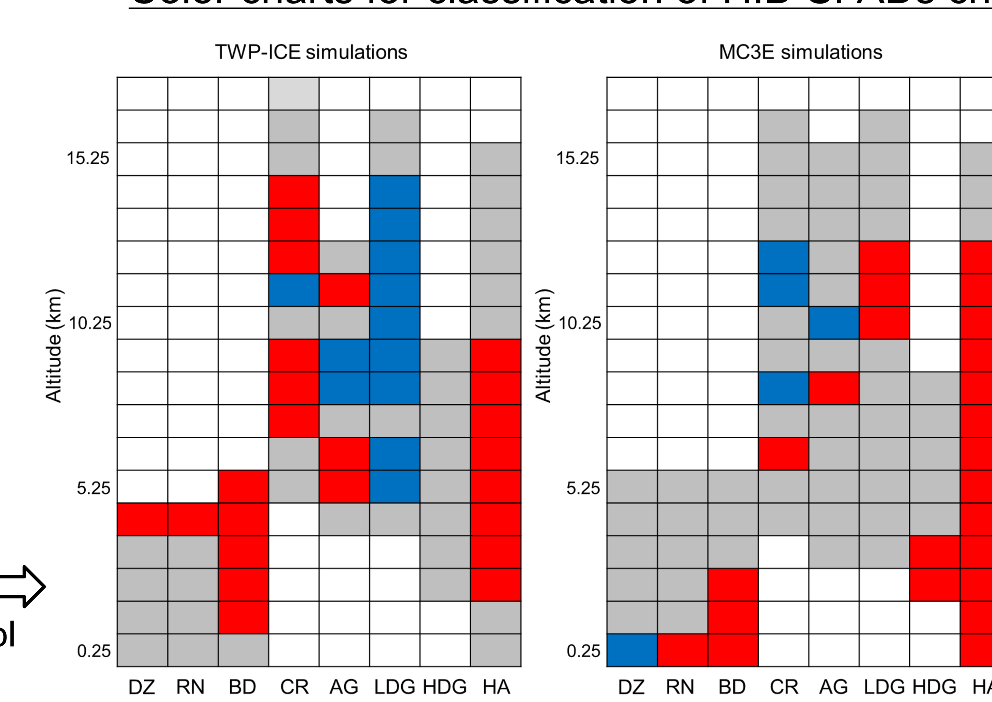
HID stacked frequency by altitude diagrams (SFADs) from POLARRIS fuzzy-logic HID simulations



drizzle (DZ), rain (RN), ice crystals (IC), dry snow (DS), wet snow (WS), vertical ice (VI), low-density graupel (LDG), high-density graupel (HDG), hail (HA), and big drops (BD)

The 5 sets of simulation results for different aerosol conditions are analyzed in the form of the color-coding chart.

Color charts for classification of HID SFADs change to aerosol



Color coding criteria
"1": least polluted run.
"5": most polluted run.

Red: "1" has min and "5" has max.
Blue: Opposite of "Red".
Gray: Others

Acknowledgements: This work was funded by Department of Energy (DOE) Atmospheric System Research (ASR) program (Project managers: Drs. Shaima Nasiri and Ashley Williamson) in support of the project entitled, "Investigation of Hydrometeor Distributions in Continental and Maritime Storm Systems: Application of Cloud-Resolving Simulations, a Polarimetric Scanning Radar Simulator and Polarimetric Radar Observations" (DE-SC0014371).

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