Improvement of Convective Ice Parameterization for the NASA GISS GCM and Impacts on Cloud Ice Simulation

National Aeronautics and Space Administration
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New York, N.Y.

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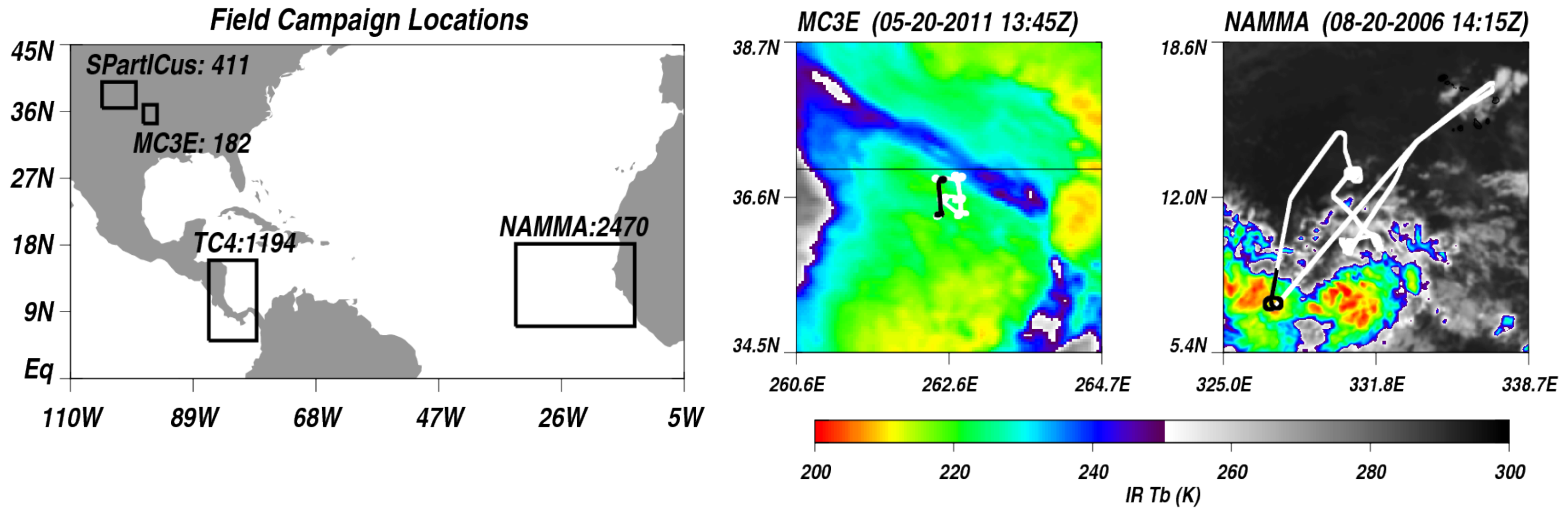
1. Introduction

Detrainment of ice from convective updrafts influences the development of stratiform anvils, impacts the radiation budget, and can affect GCM climate sensitivity. This presents a challenge for GCMs since detrainment is determined by both the vigor of convective updrafts and the microphysics occurring within the updrafts. The CMIP5 configurations of the GISS Model E2 GCM simulated an ice water path (IWP) that approached the upper limits of satellite-retrieved IWP, while the simulated upper troposphere (~200 mb) ice water content (IWC) exceeded the published upper-bounds by a factor of ~2. This was largely driven by IWC in deep-convecting regions of the tropics. Partly in response to this bias, we revisit our treatment of convective ice, and now include observations of particle size distributions (PSDs) and fall speeds from multiple DOE/ARM field campaigns in our improved convective ice parameterization.

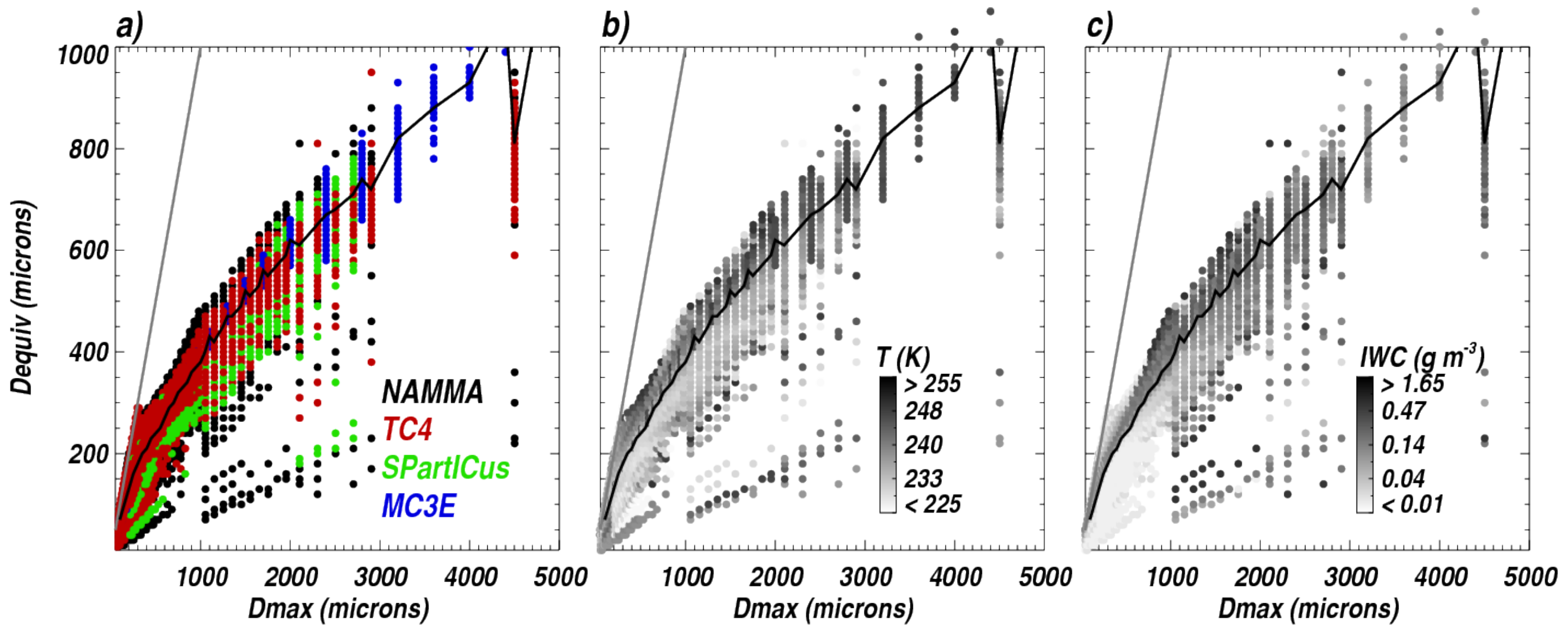
2. Field Campaign Sources



- ❖ Isolate deep convective outflow using infrared (IR) and microwave imagery, and existing literature noting flight legs coincident with anvils/adjacent to deep convective turrets.
- ❖ Final number of flight segments used for each campaign is shown in the **top left panel**.
- ❖ Example flight segments used are shown in the **top center/right panels** (black lines segments only).

◆ *Flight safety measures prevent most convective core penetration where graupel is found. Therefore, the PSD data we use inform only the less-dense/"fluffier" ice (cloud ice + snow) component of the GCM convective ice parameterization.*

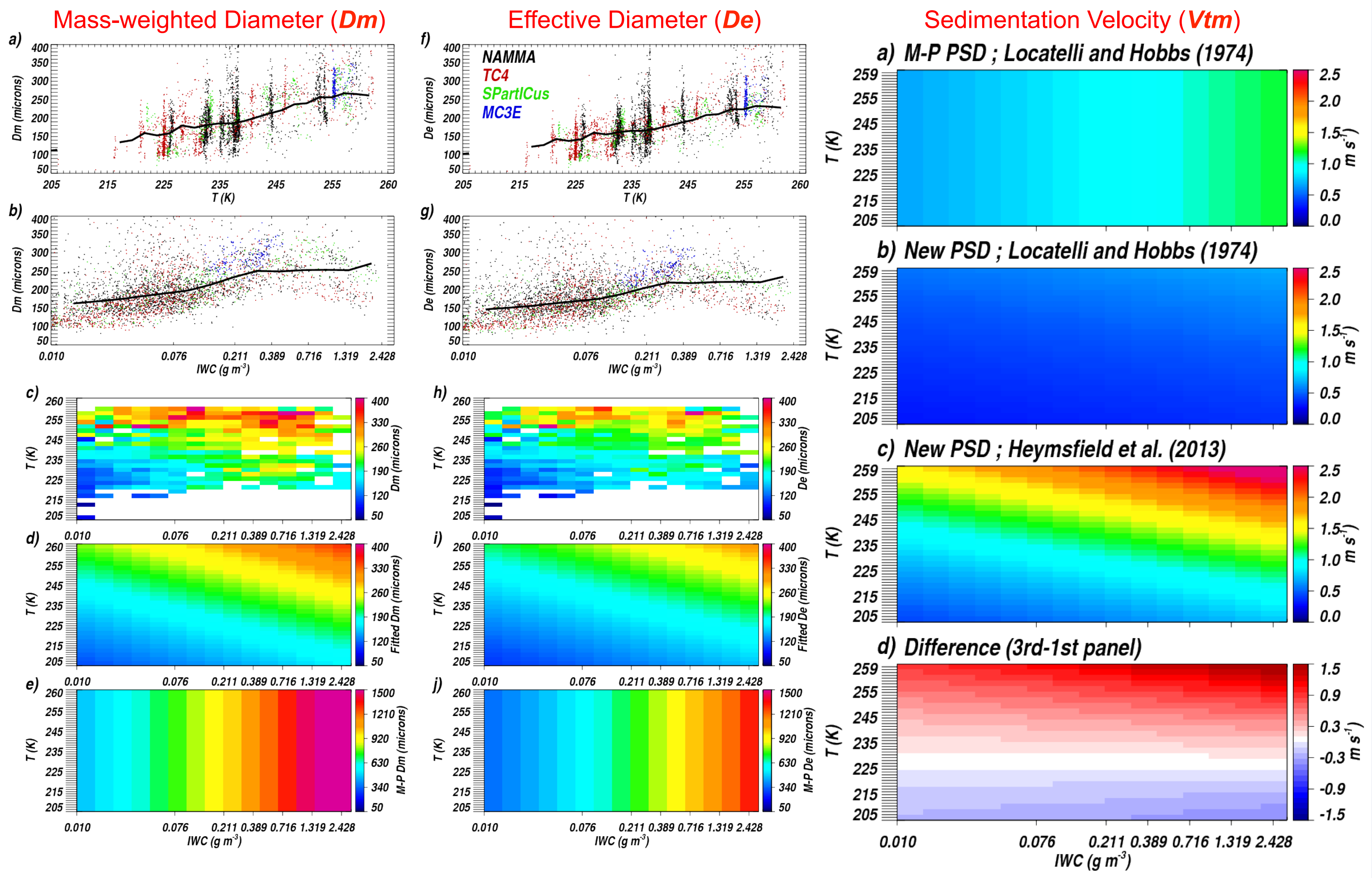
3a. Convective Ice Parameterization



- ❖ Use projected-area and particle mass distributions as a function of maximum diameter (***Dmax***).
- ❖ Adopt normalized particle size distribution concept [e.g. Testud et al. (2002); Delanoë et al. (2005)] to describe ice PSDs, and assume a gamma function shape for PSDs.
- ❖ Computation of PSD moments is made simpler upon conversion of ***Dmax*** to melted equivalent diameter (***Dequiv***). In general, for a given ***Dmax***, particles at colder temperatures collapse to smaller ***Dequiv***. Overall smaller particles are also associated with lower IWC.

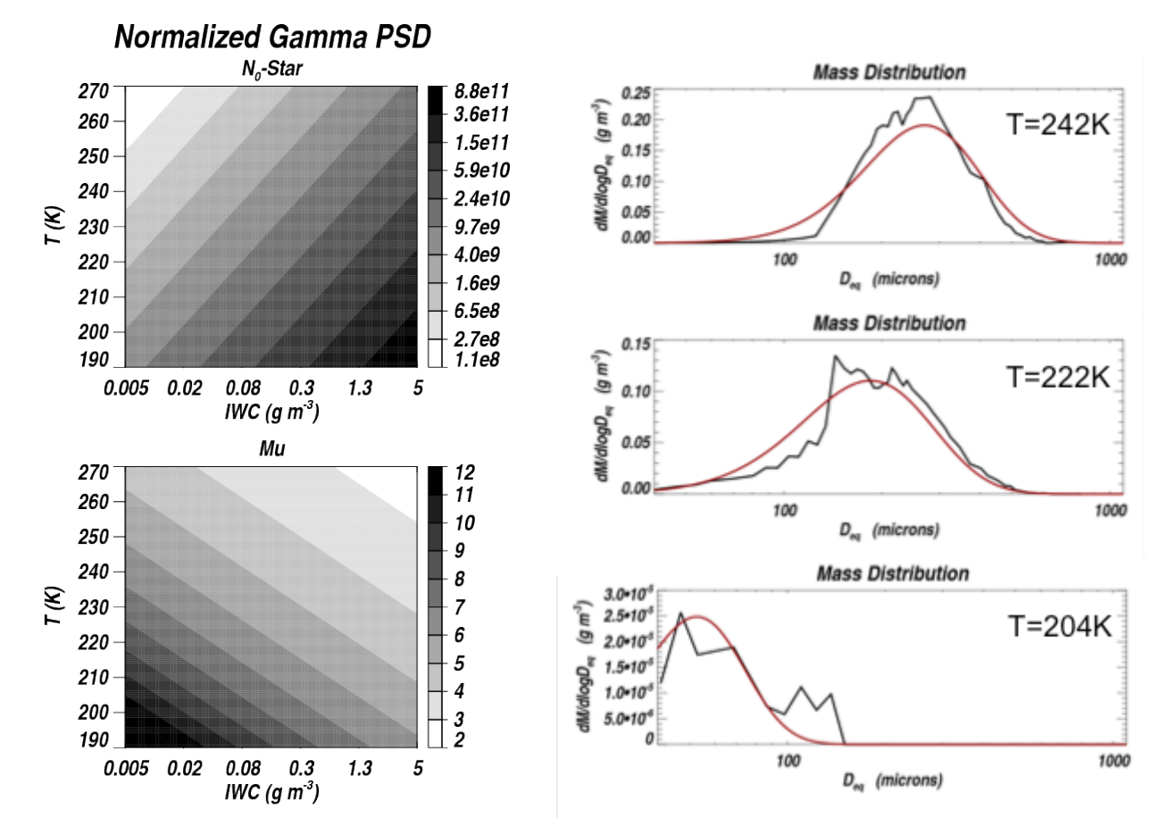
◆ *We aim to retain this physical variation in particle sizes as a function of temperature (T) and IWC in the convective ice parameterization.*

3b. Convective Ice Parameterization (Continued)

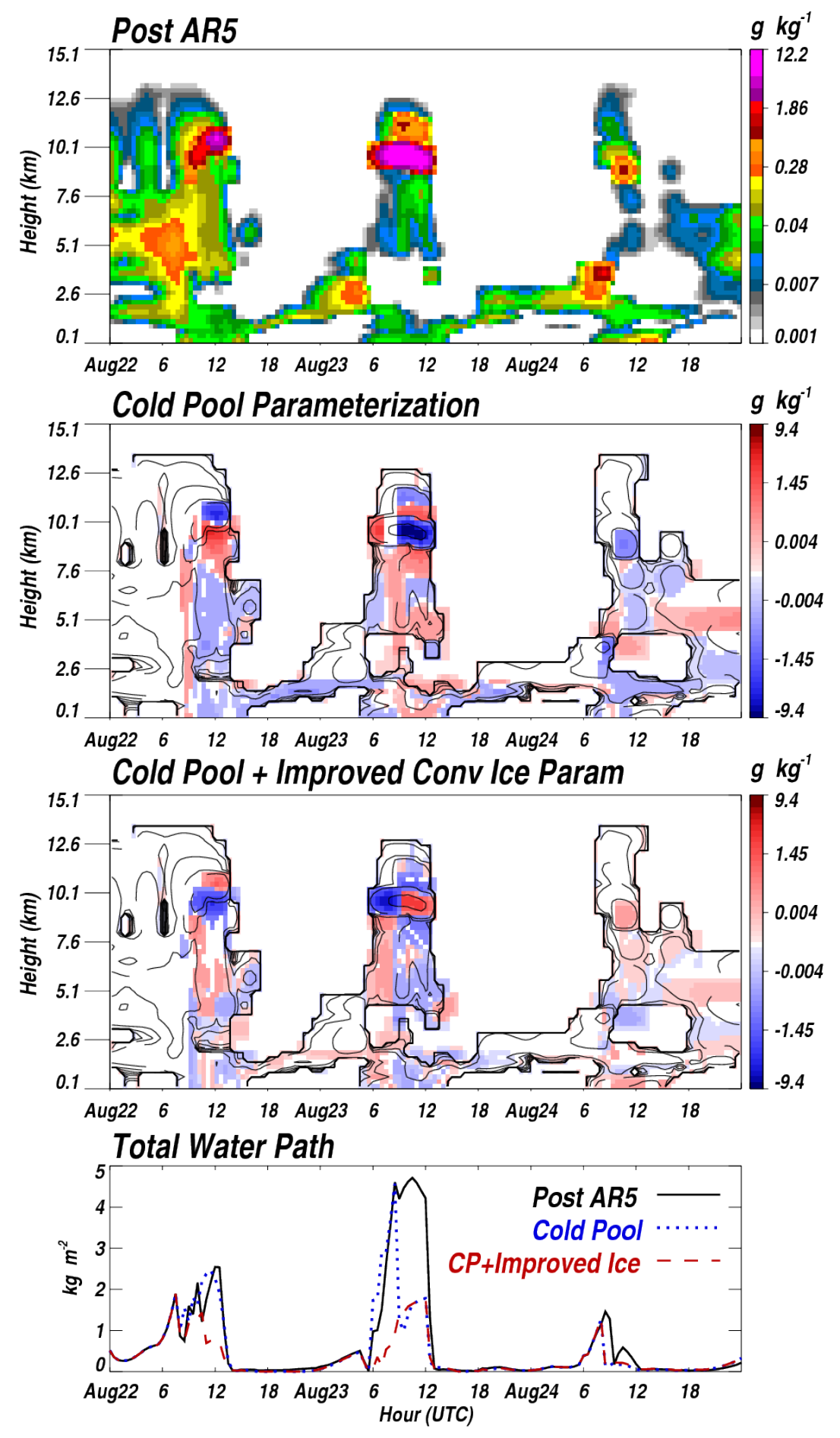


- ❖ With a normalized PSD, only two parameters are needed to solve for the gamma PSD shape parameters.
- ❖ With our eye on parameterization, we aim to choose two parameters that are related to variables already diagnosed in the convective plume (e.g. T or IWC). We settle upon ***Dm*** and ***De*** (both highly correlated [r ~ 0.85] with T and IWC); the PSD can now be analytically determined.
- ❖ ***Dm*** and ***De*** from our prior assumed Marshall-Palmer PSD are **shown above**. Now, particles are smaller, and sizes vary explicitly with T. **Fit parameters/sample fits to in situ obs are shown below.**
- ❖ Smaller particles alone imply an increase in detrained ice; however, new terminal fall velocity formulations (Heymsfield et al. 2013) counteract this and result in greater fall speeds (**top right column**).

◆ We develop a formulation that relates the fall speed in ***Dequiv*** space to that in ***Dmax*** space, and **all particles with fall speeds greater than (less than) the GCM parameterized convective updraft velocity precipitate (detrain).**



4. Model E2 Simulation Setup



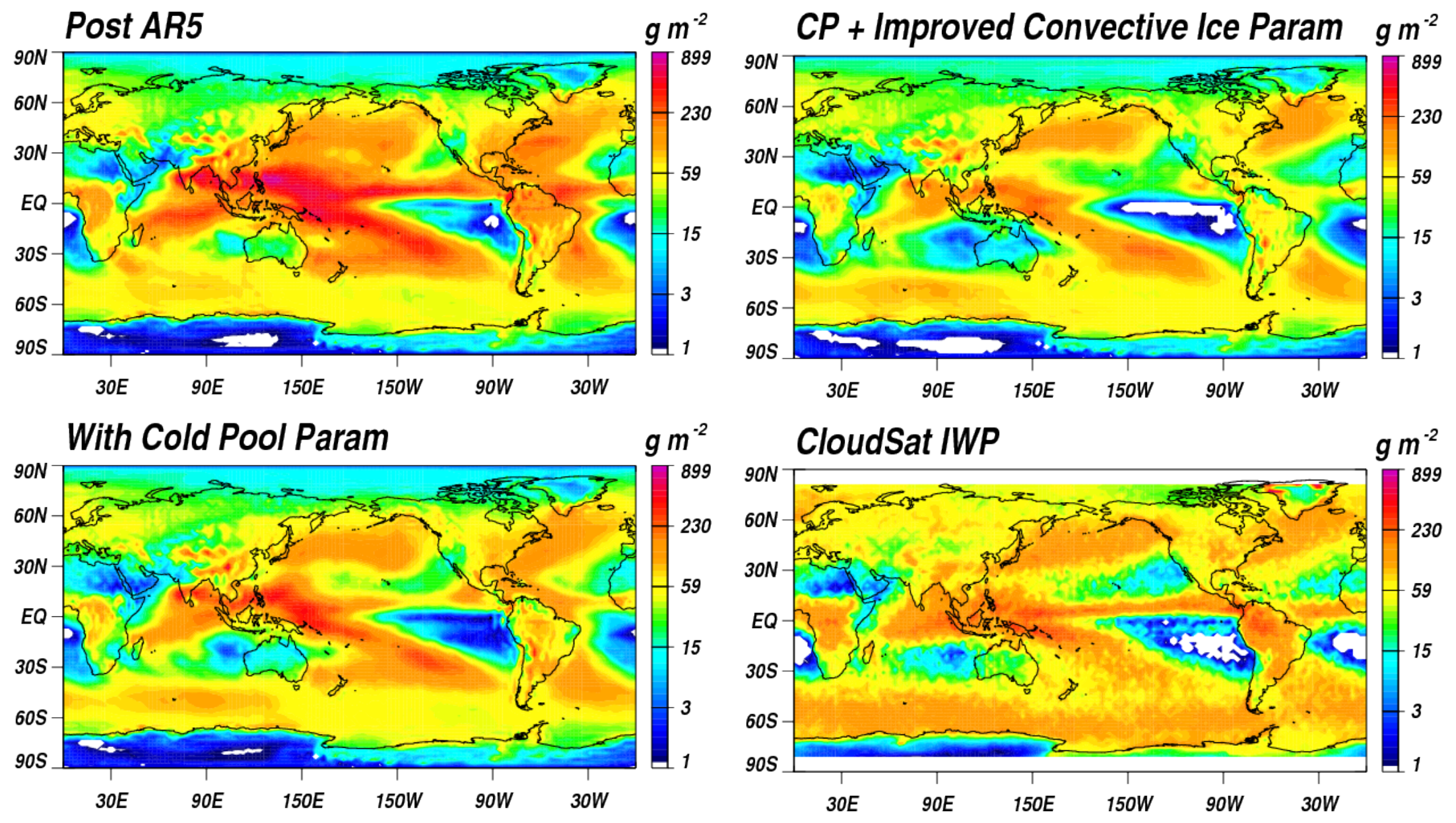
- ➢ We test the convective ice parameterization in the GISS SCM and GCM (AMIP-style only). Control GCM: "Post AR5" model (Stanfield et al. 2014). For completeness, a Cold Pool-configured GCM (Del Genio et al. 2015) simulation is also shown since impacts on IWC simulation were substantial.
- ➢ Snapshot of SCM experiment is **shown to the left** (SGP site; period of Aug 2005 for which convection was often locally forced). We show total water content (TWC), but impacts on TWC are mostly driven by changes in IWC. With each parameterization improvement, average IWP decreases.

◆ ***IWC decreases in the cold pool GCM result from the regulated occurrence of the weakly entraining plume (which produces most of the upper trop IWC). Greater mass sedimentation with the conv. ice parameterization results in further decreases in upper-tropospheric IWC.***

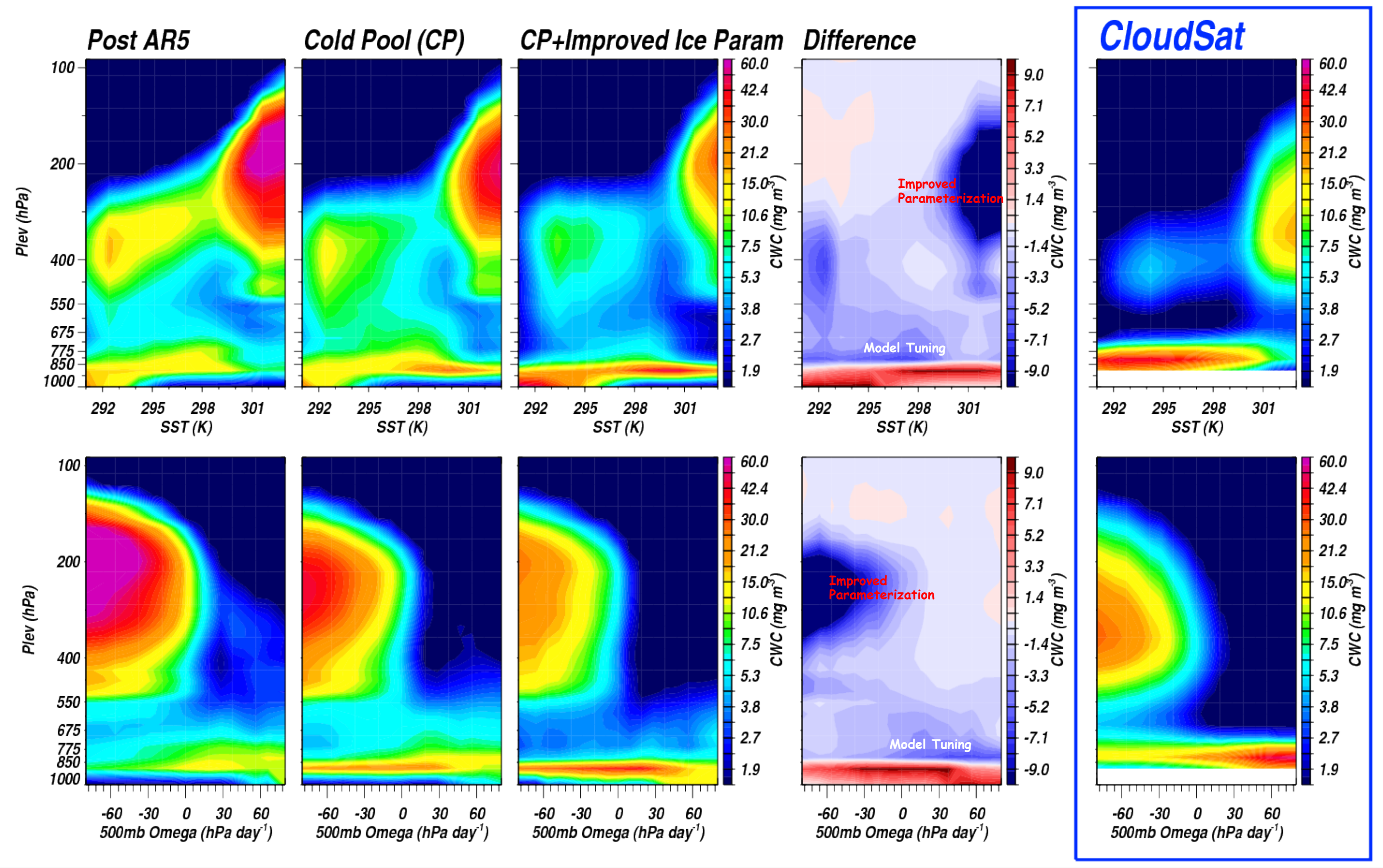
5. Impacts on GCM IWC Simulation

We perform 5-yr prescribed SST (2005–2009) runs with each GCM configuration. Each improvement in the GCM leads to a decreasing IWP climatology:

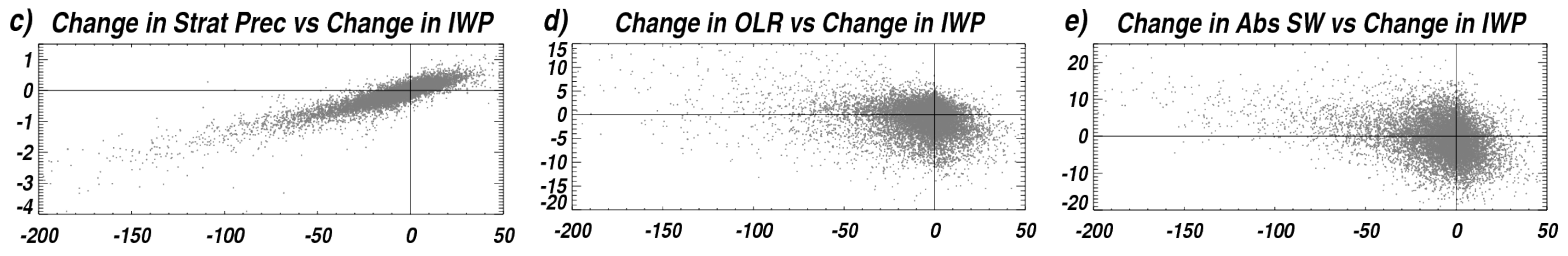
Post AR5:	103 g/m²
Cold Pool:	70 g/m²
CP+ Conv. Ice:	54 g/m²



❖Regime-sorting of IWC (bottom panels) confirms that largest decreases in IWP are due to decreases in IWC in deep convection regions (high SST, upward mid-trop vertical velocity).



6. Impacts on Other Parameters



(CP + New Ice) minus CP Simulated IWP (g m^{-2})

Scatterplots of grid-box changes in parameters as a function of the change in grid-box IWP. Unsurprisingly, stratiform rainfall decreases (global: 1.72 to 1.53 mm day^{-1}) as IWP decreases. OLR and absorbed shortwave radiation (Abs SW) changes are more weakly correlated with changes in IWP. Despite decreases in IWC, the highest-IWC clouds remain optically thick (i.e. optical thickness saturates at large water paths). Thus, there is some reason to expect a more muted change in radiation fields. However the impacts on radiation require further analysis to be fully understood.

7. Future Work

Because PSDs and terminal velocities are representative of regions adjacent to deep convective turrets, future improvements to the parameterization should include a better representation of dense ice/graupel PSDs and fall velocities characteristic of convective updraft cores. Ground-based multiple-frequency Doppler radar analyses of deep convection columns, or field campaigns such HAIC-HIWC, during which aircraft sampled regions of deep convection, higher IWC, and denser ice, will prove useful in such an endeavor. The parameterization developed here will serve as a starting point for simulating stratiform anvil cloud, the successful modeling of which requires information on the coupling between temperatures, detrained condensate, PSDs, fall speeds and radiation for these cloud types. The overall goal is to have a parameterization that responds in a physically plausible way to a climate change so that the complete deep convective contribution to cloud feedback is understood.