Microphysical and Radiative Impacts of the Cirrus Cloud Negative Twomey Effect in Two GCMs Based on SPARTICUS Data

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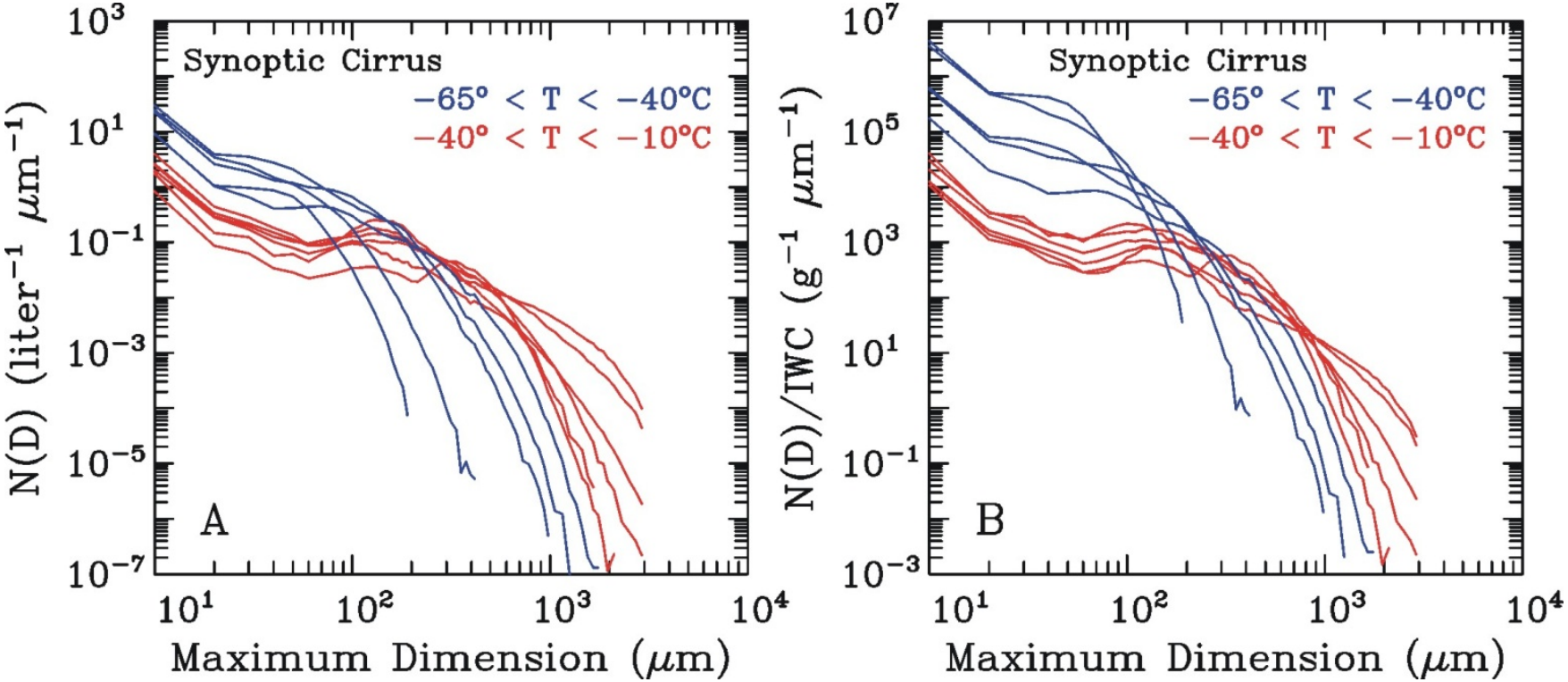
ASR
Atmospheric System Research

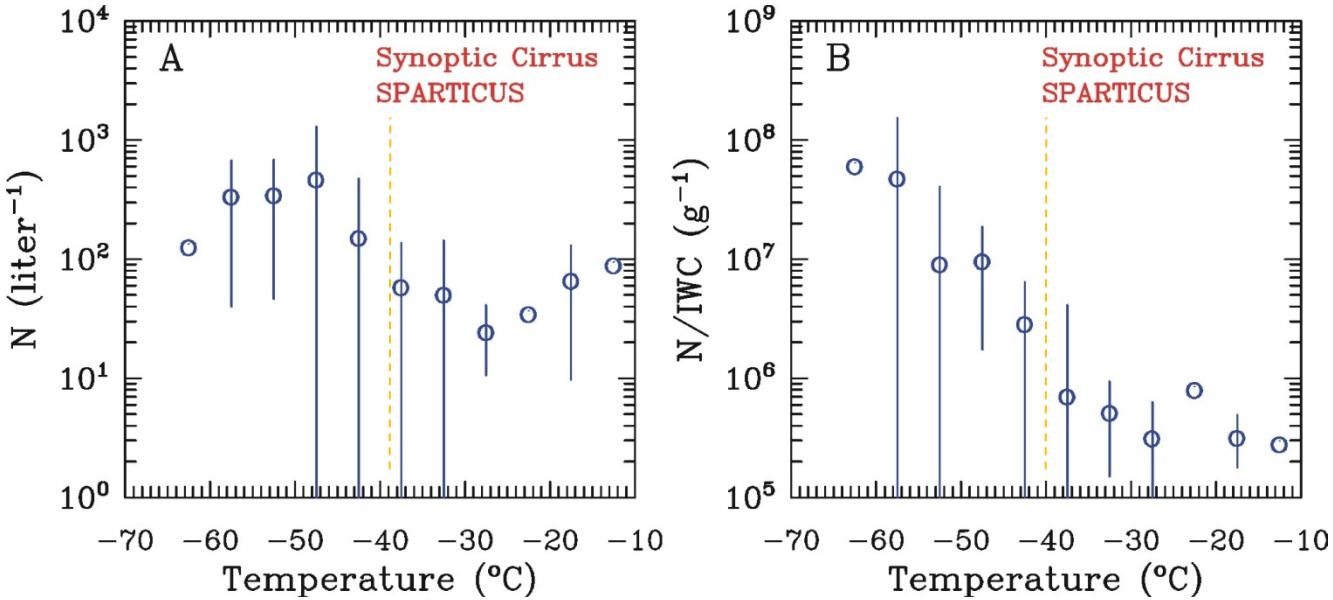
ARM

DRI
Desert Research Institute

Temperature Dependence of Synoptic SPARTICUS PSD



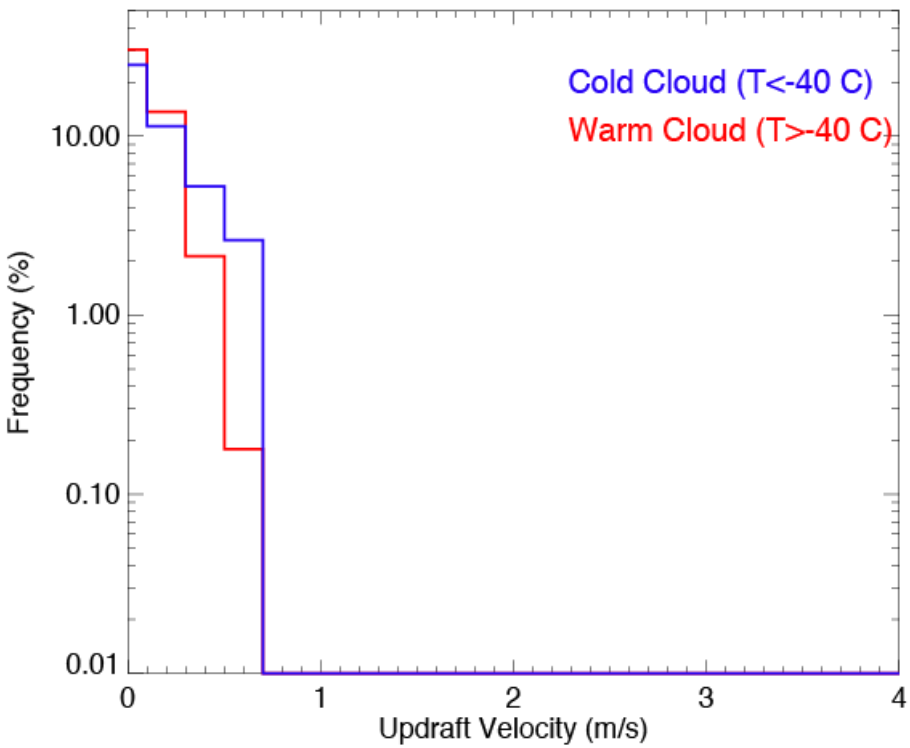
Evidence of homogeneous freezing nucleation?

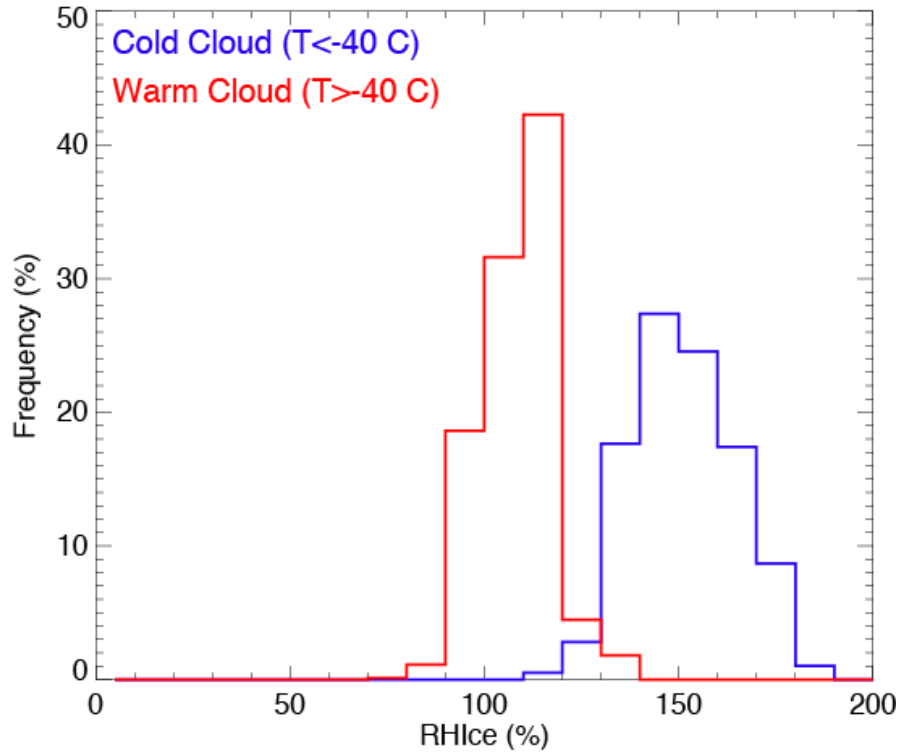


Ignoring aggregation & advection, the ratio N/IWC appears related to the nucleation rate coefficient J (# g^{-1} s^{-1}): $N/IWC \equiv \int_{t_o}^{t_f} J(t)\,dt$

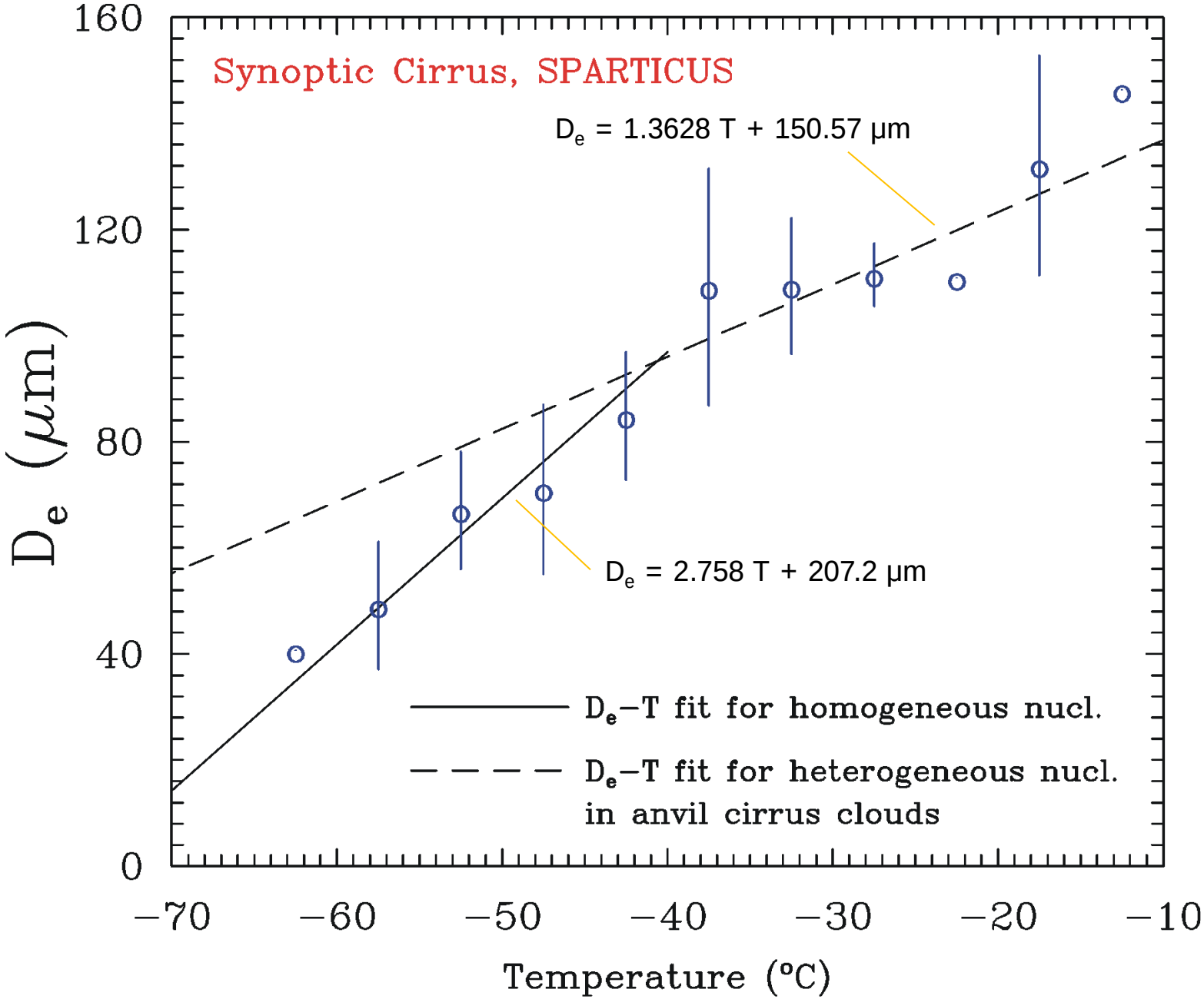
where t_o = ice initiation and t_f = sampling time of ascending parcel.

Synoptic Cirrus PDFs for Updraft Velocity and RHi

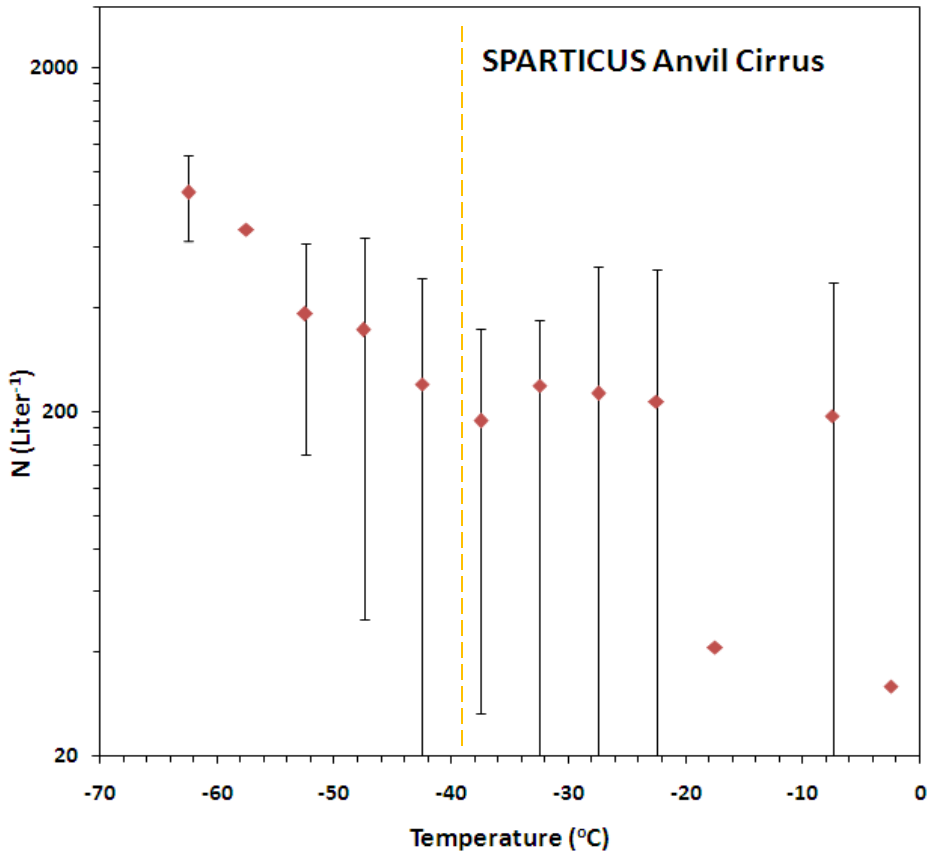


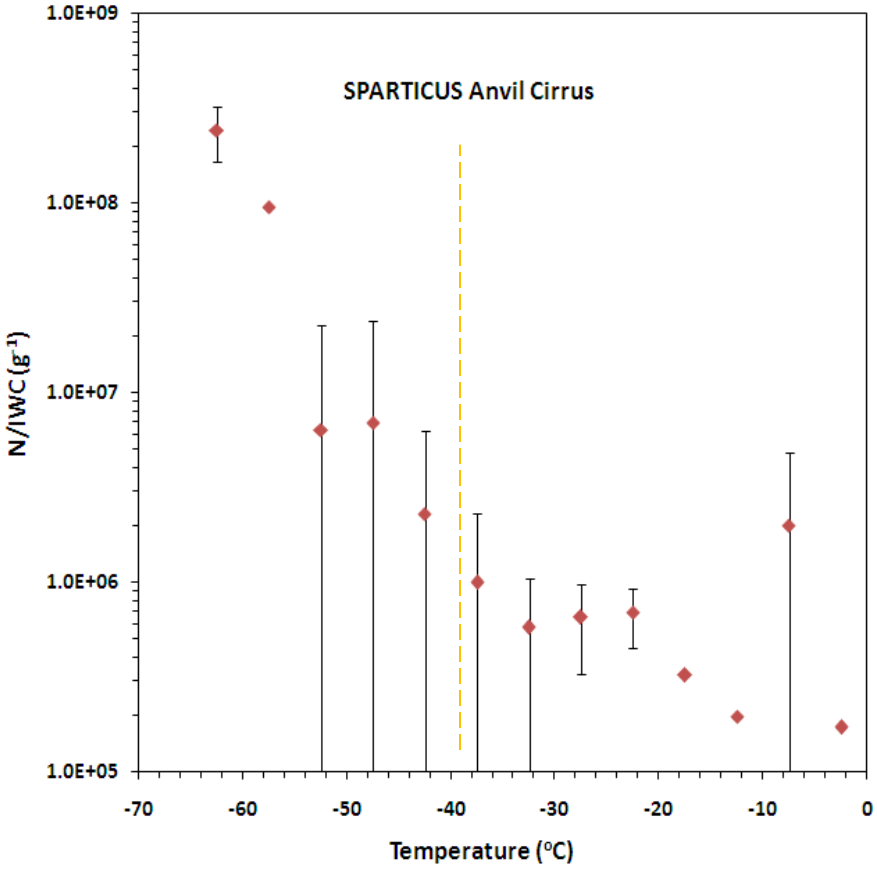


Updraft PDF confirms proper discrimination in selection of synoptic cirrus cases. RHi PDF shows remarkable separation between heterogeneous nucleation region (warm cloud) and region where homogeneous nucleation may occur. While homogeneous nucleation requires RHi > 140%, RHi may be < 140% when sampling ice crystals produced through homogeneous nucleation.


Synoptic Cirrus, SPARTICUS
D_e = 1.3628 T + 150.57 μm
D_e = 2.758 T + 207.2 μm
D_e–T fit for homogeneous nucl.
D_e–T fit for heterogeneous nucl. in anvil cirrus clouds
D_e (μm)
Temperature (°C)
160
120
80
40
0
−70
−60
−50
−40
−30
−20
−10

ANVIL CIRRUS: Temperature dependence of ice particle number concentration (N) and N/IWC





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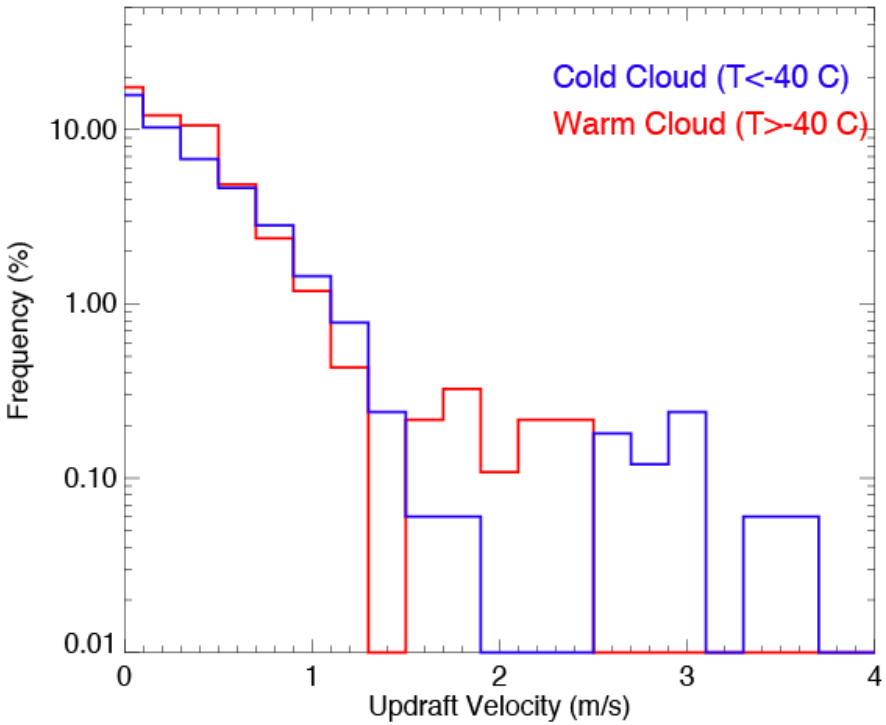
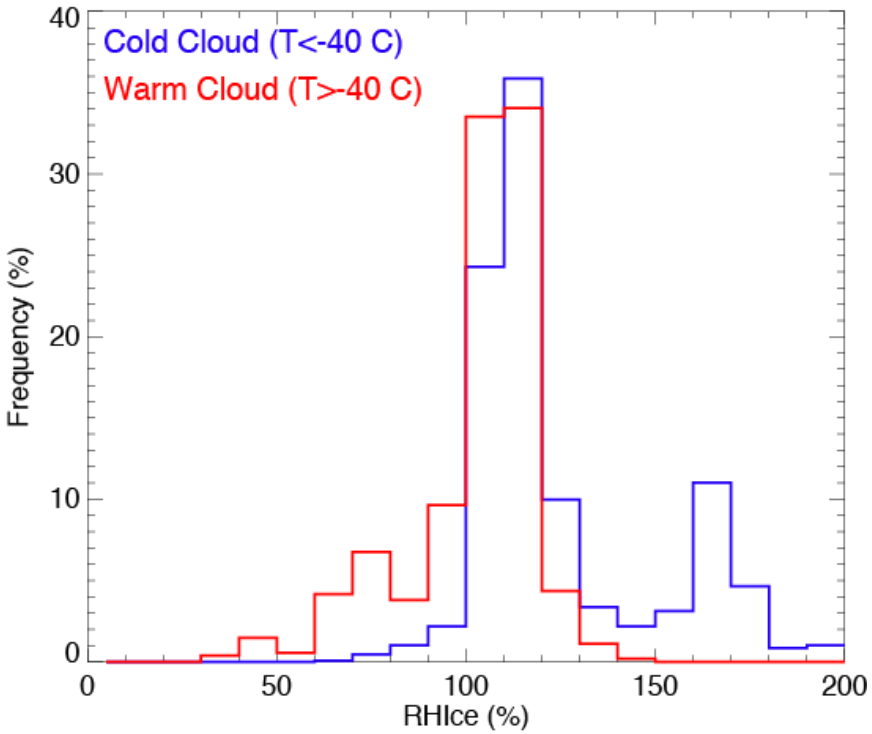
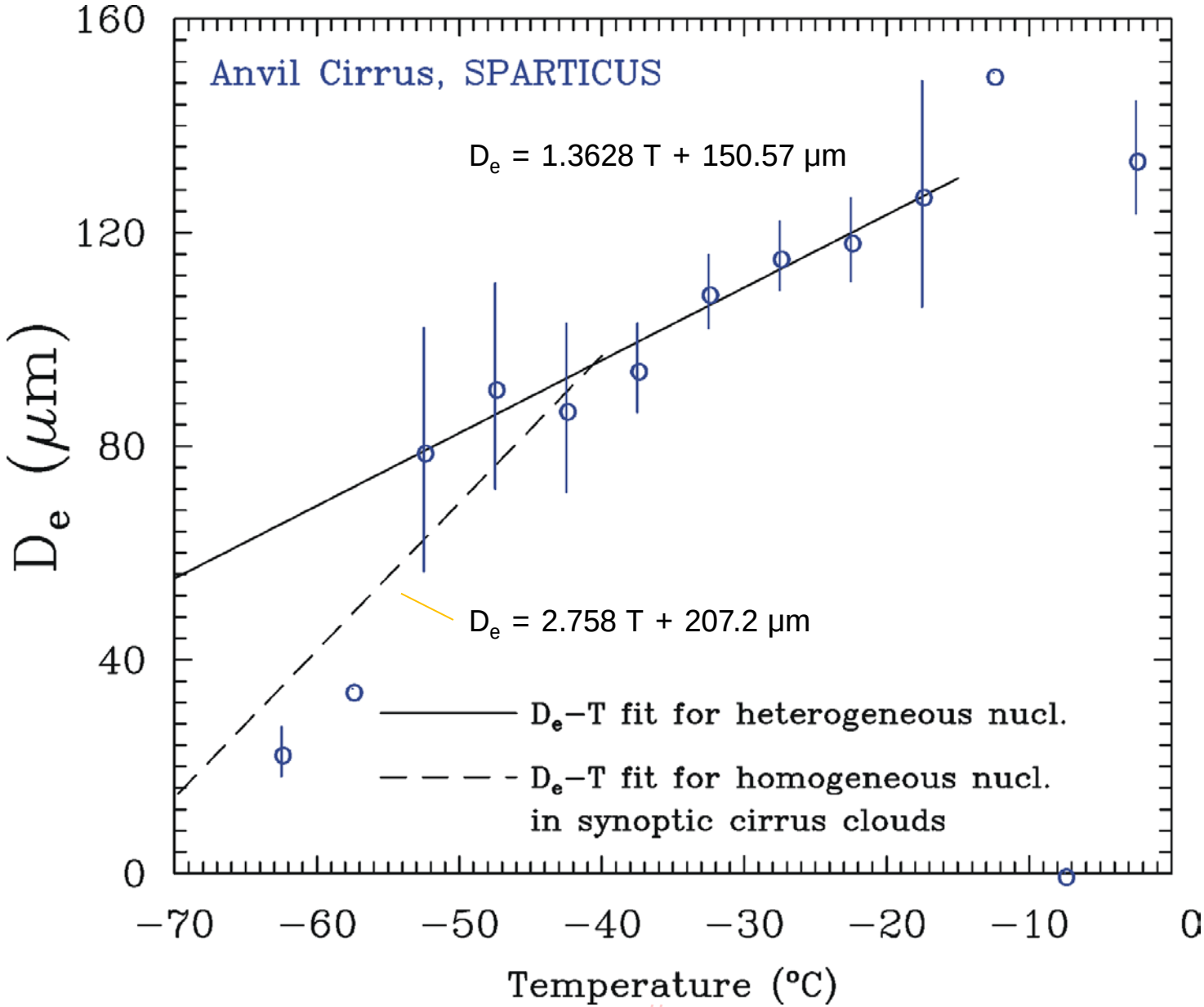




RHi in cold anvils correspond mostly to heterogeneous nucleation conditions, with secondary peak corresponding to homogeneous nucleation conditions. This is consistent with the hypothesis that the ice was produced heterogeneously within the convective column with supersaturations increasing with height until the RHi threshold for homogeneous nucleation was reached when T < -55° C.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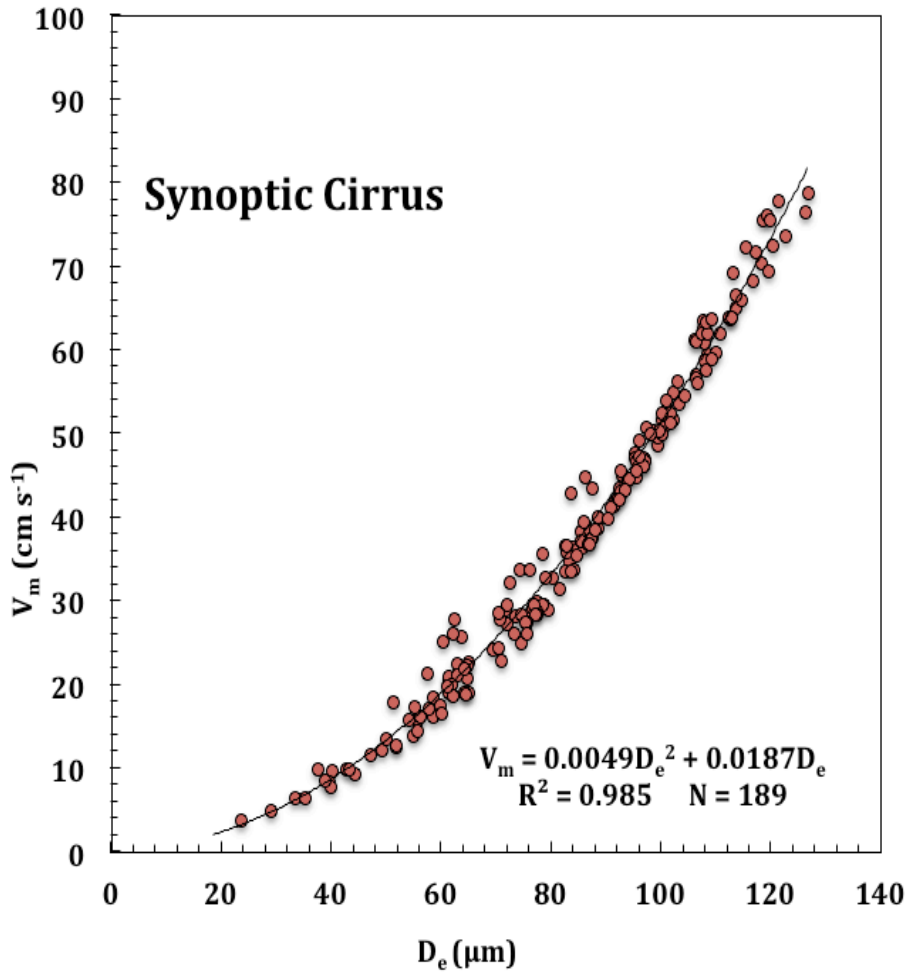
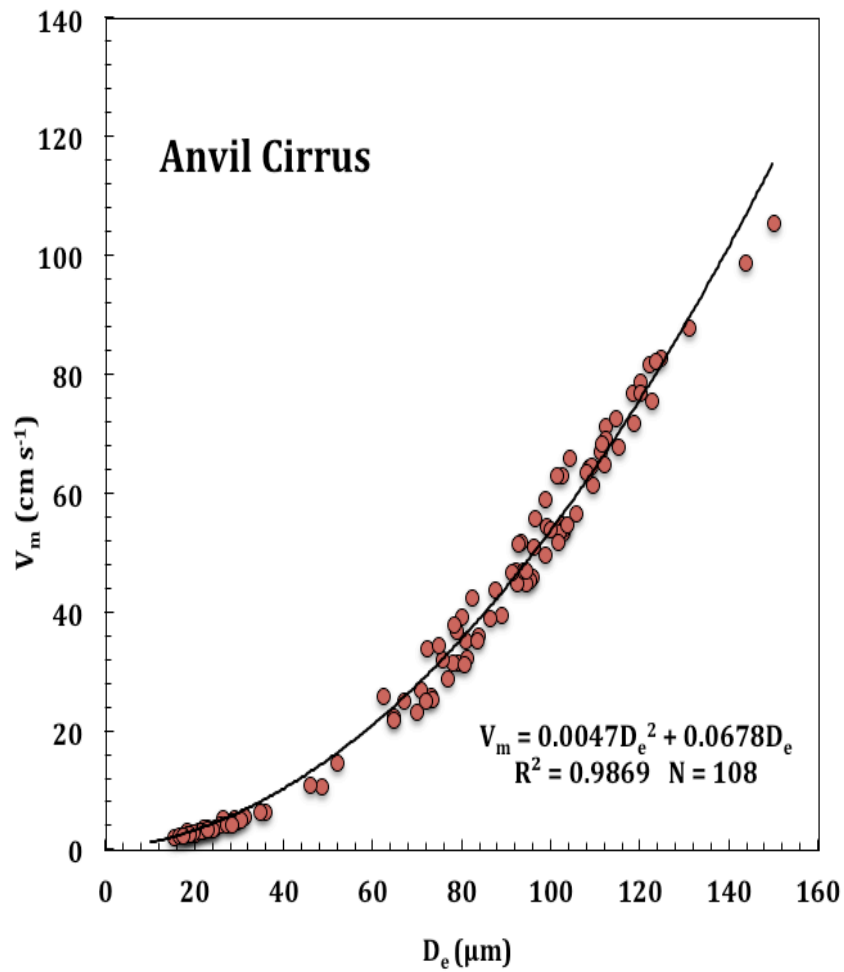
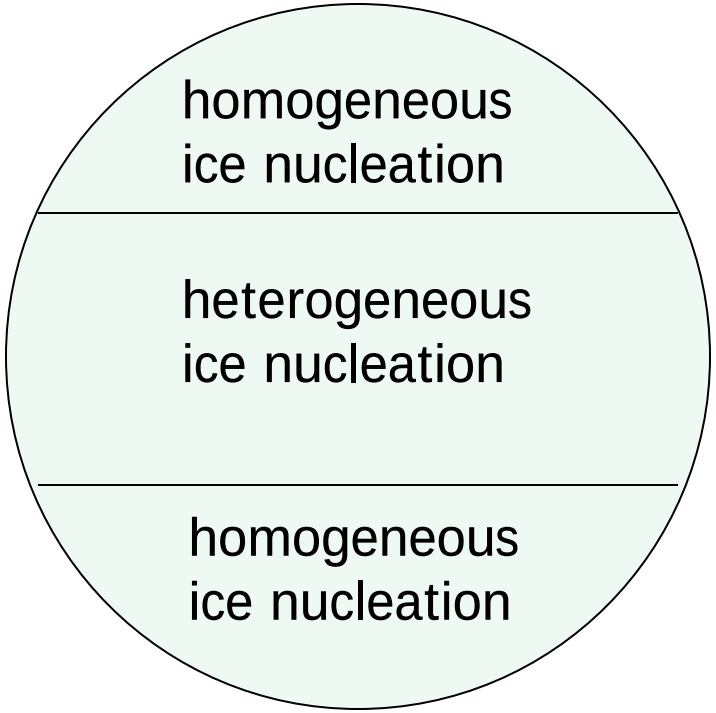
Mass weighted ice fall speed predicted from D_e in GCM runs



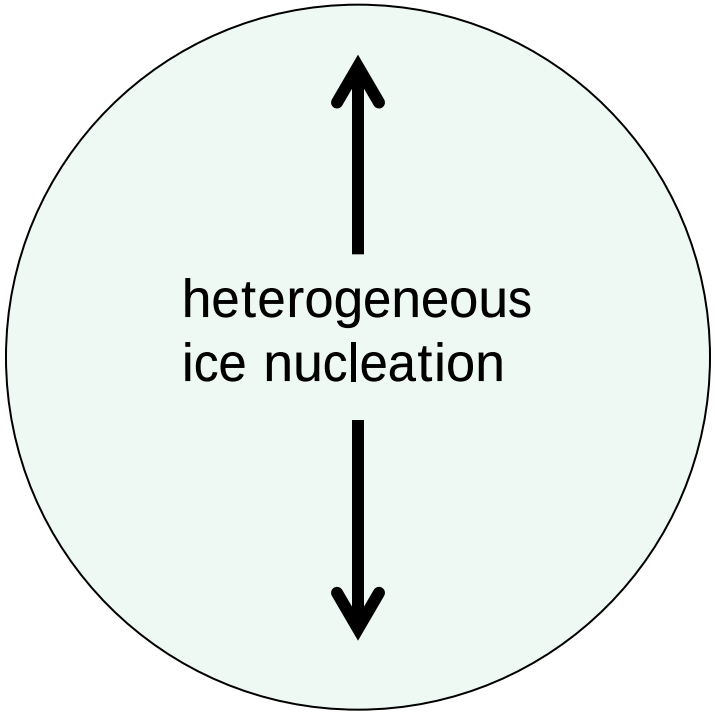


Experimental Design: Ice Nucleation Zones

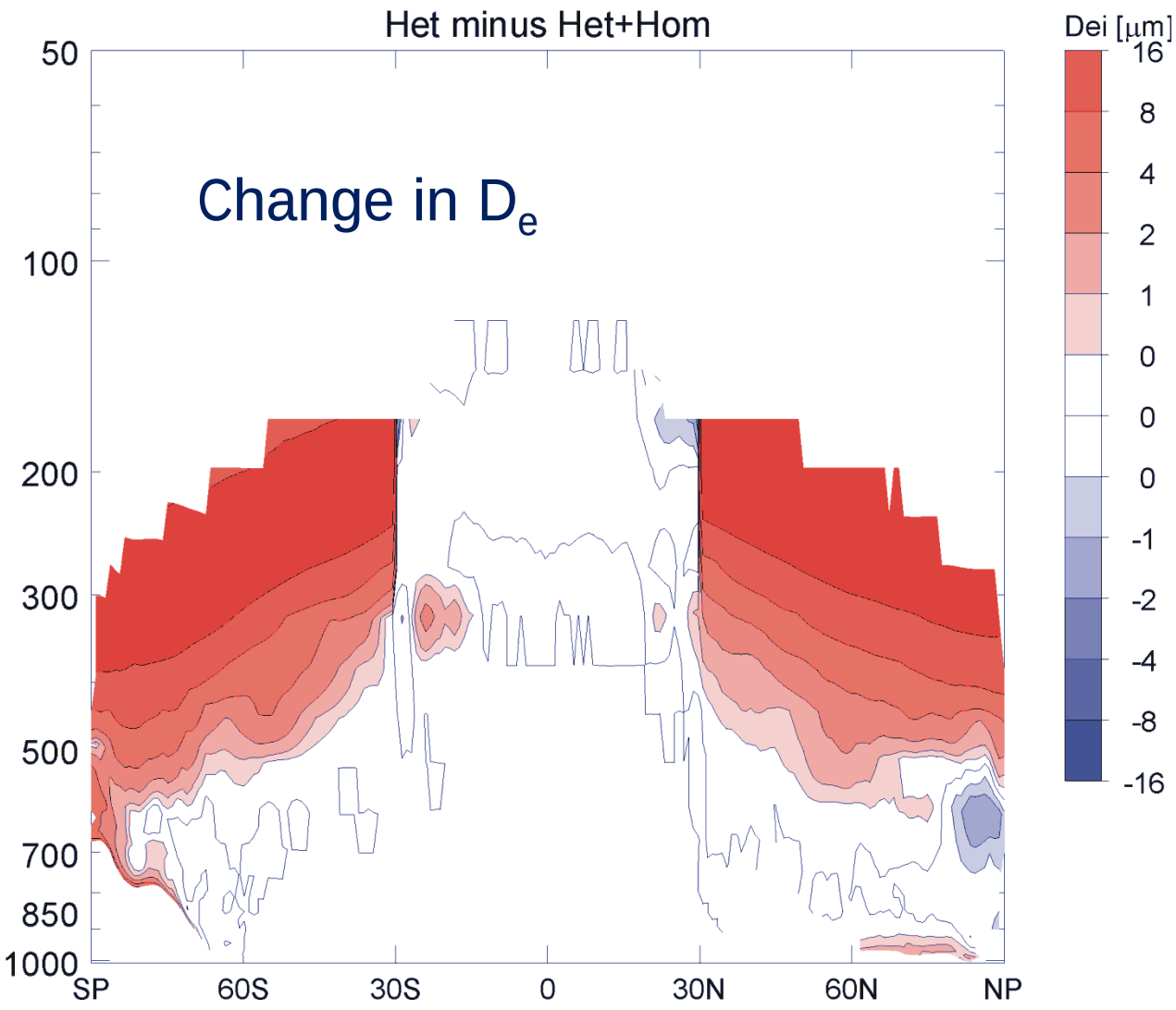
Results from Cziczo et al. (Science 2013) and our results indicate heterogeneous nucleation dominates in anvil cirrus. Therefore, for the observation based simulation, heterogeneous nucleation was assumed in the ± 30° latitude zone and homogeneous nucleation was assumed outside this zone.



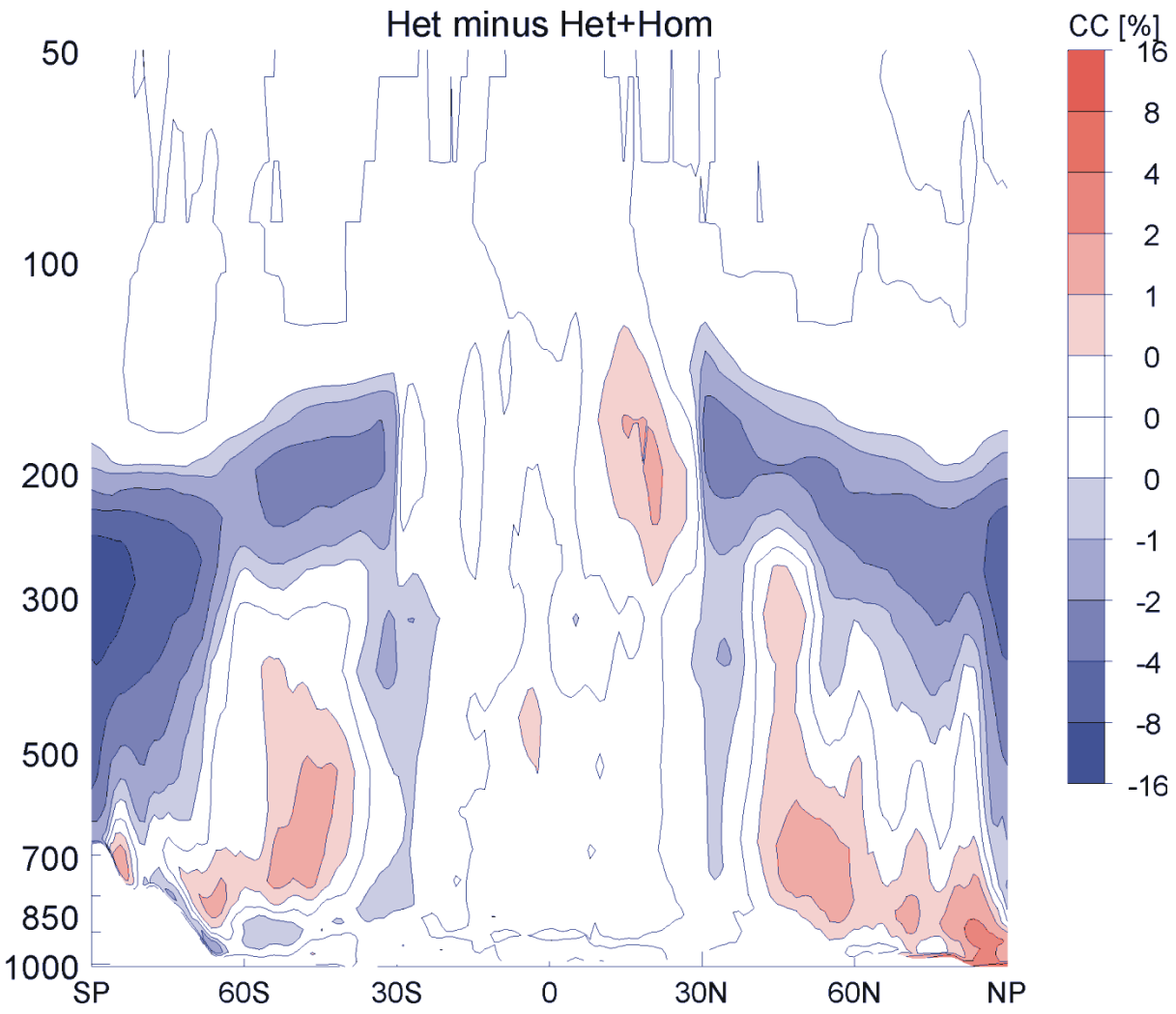
verses



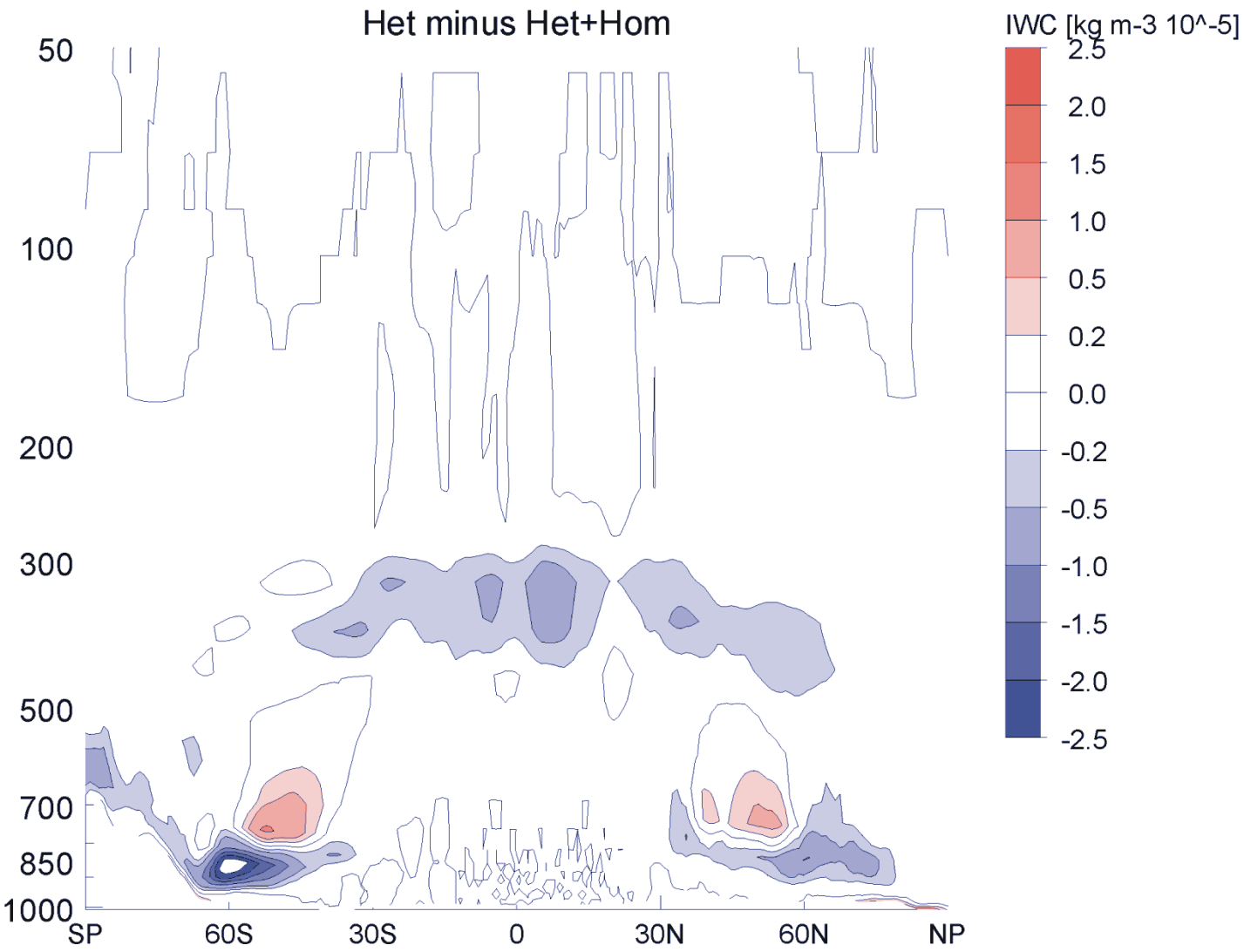
CAM5 Results: Heterogeneous – (Homo- & heterogeneous)



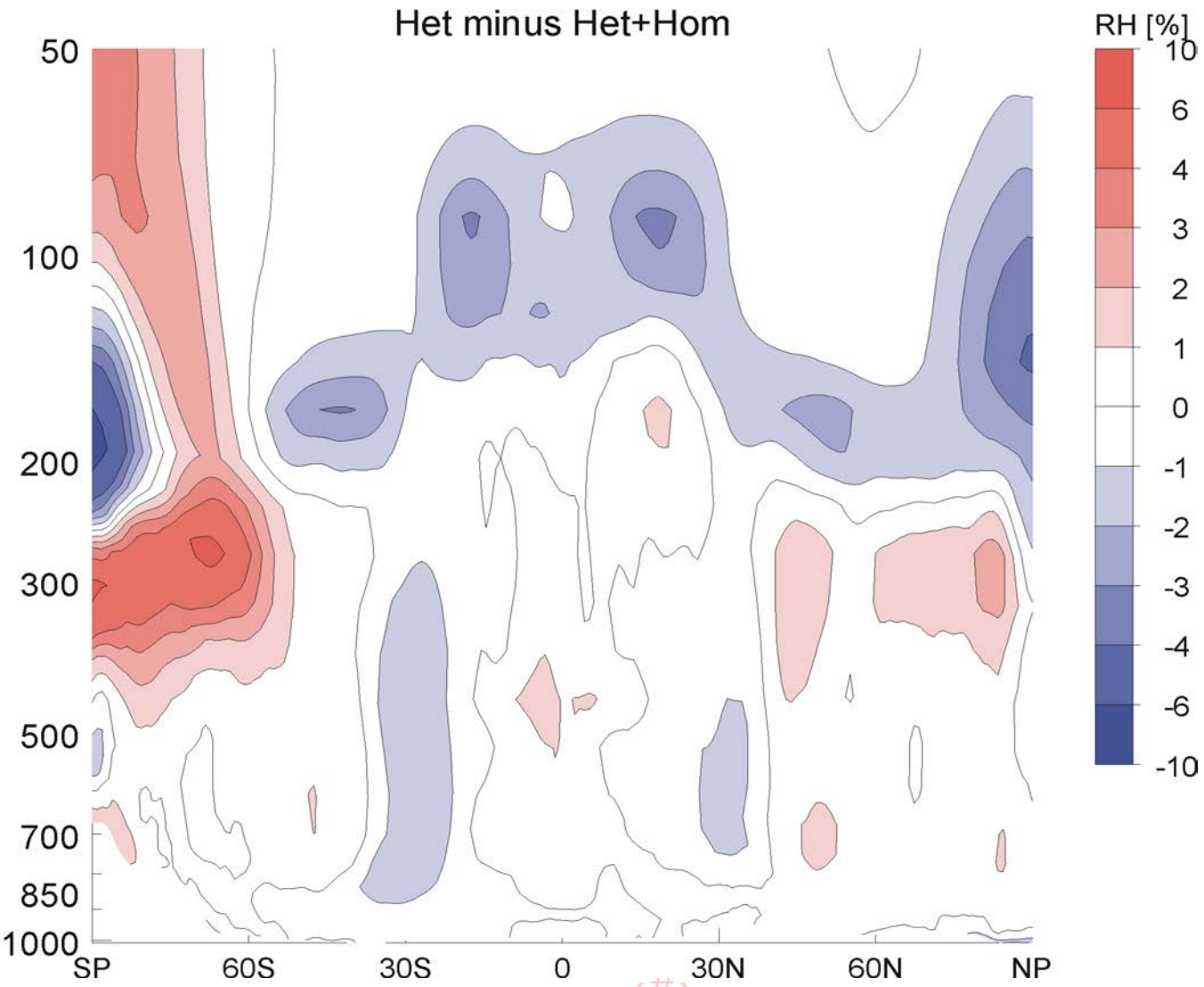
Change in Cloud Cover



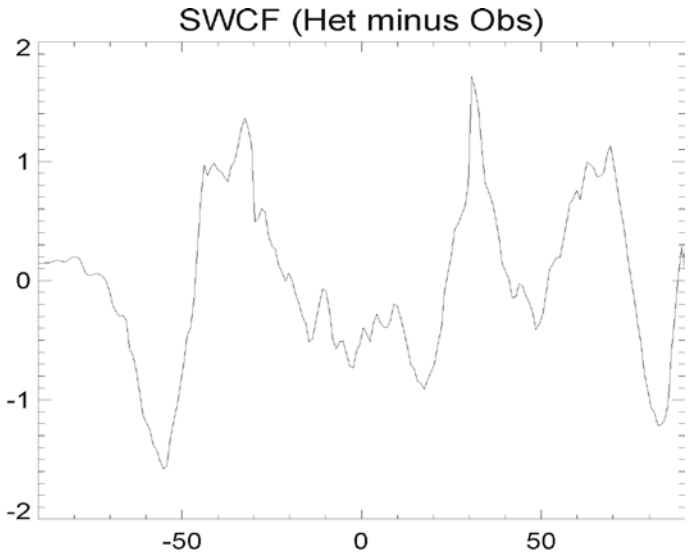
Change in Cloud IWC

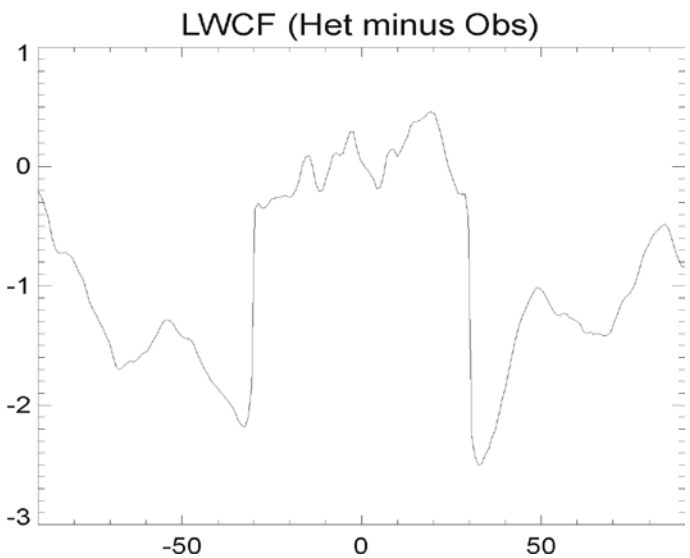


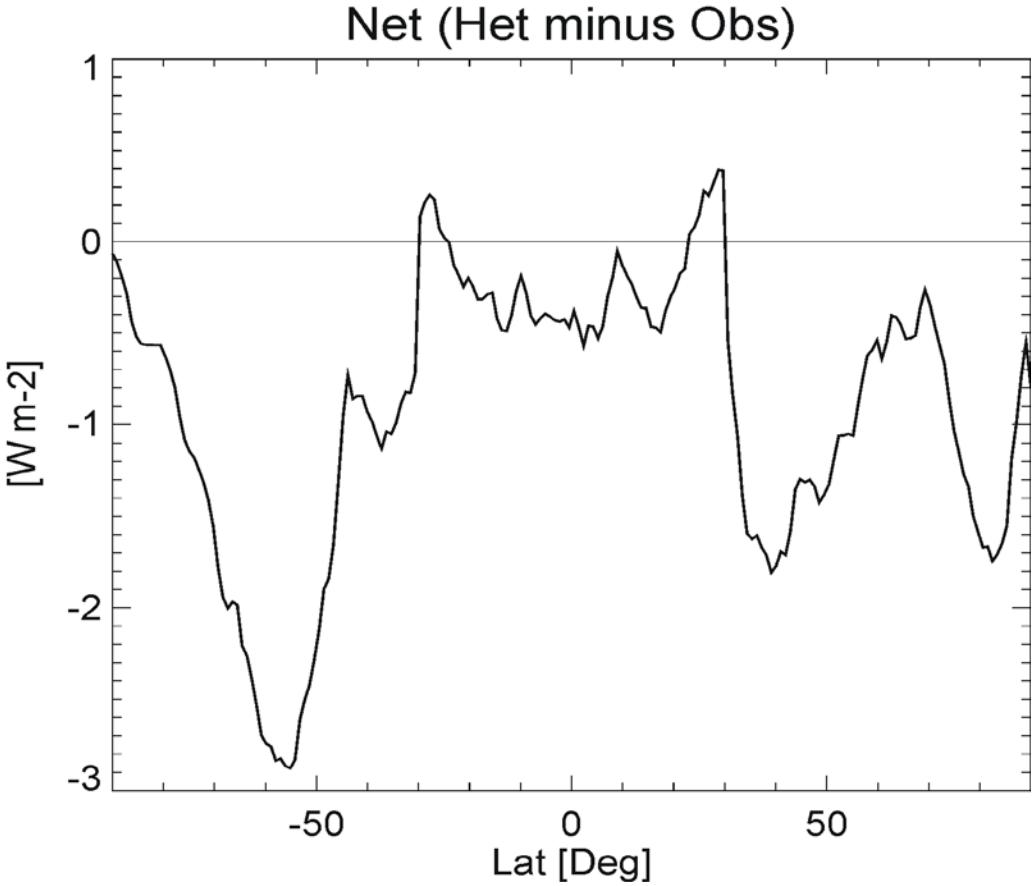
Change in Relative Humidity



Cloud Net Radiative Forcing Differences; zonal means

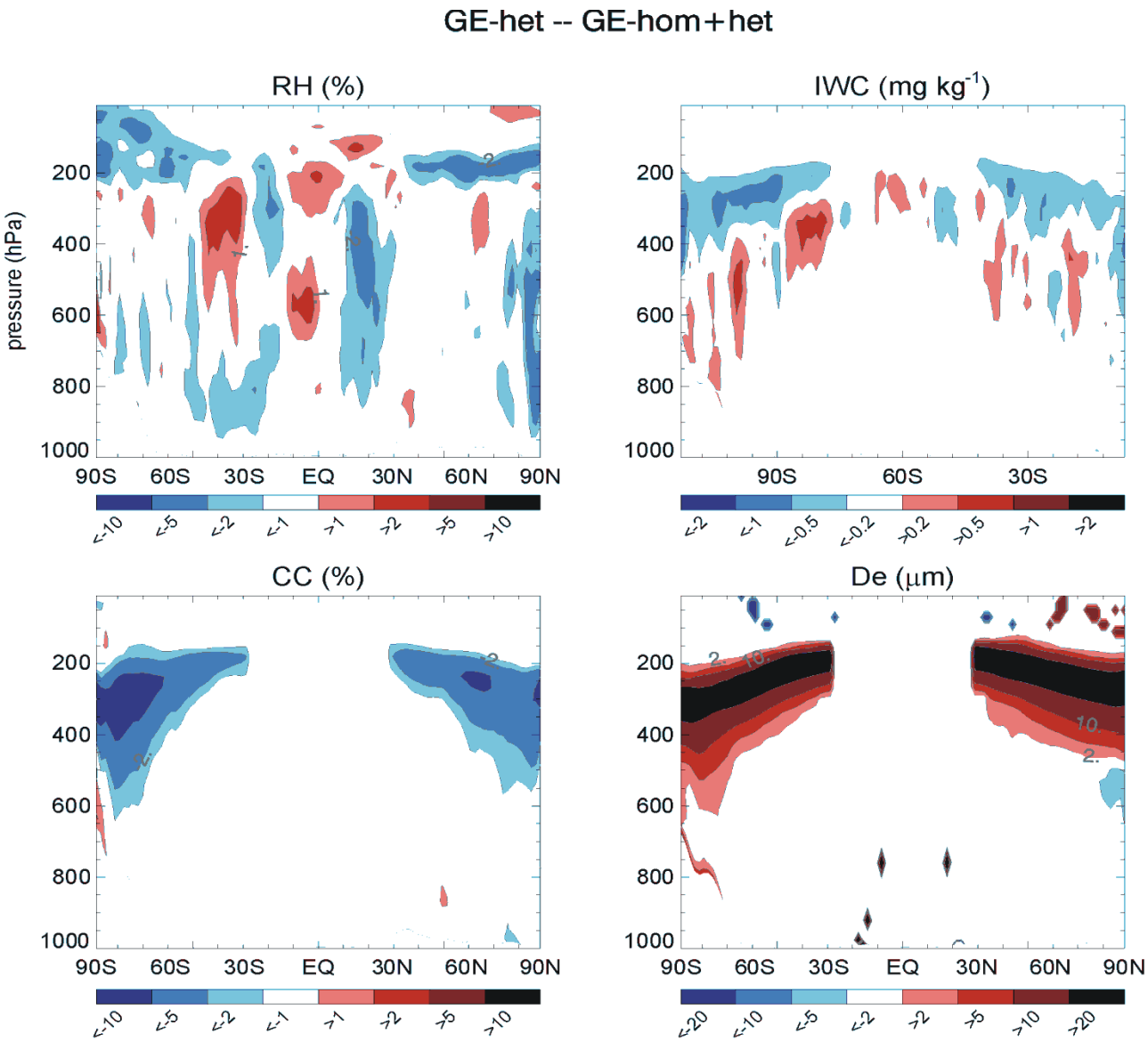




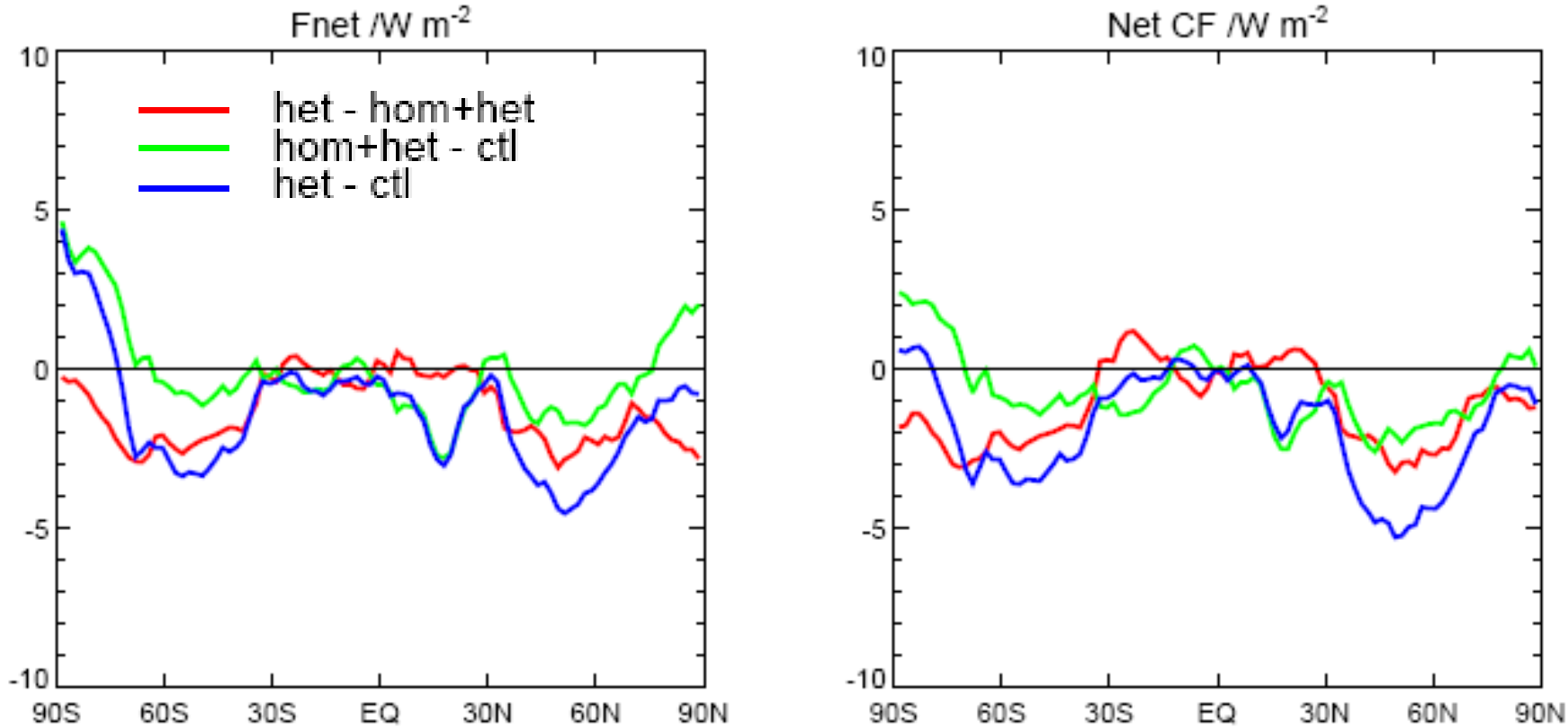


Global mean all-sky net radiative forcing, het – obs, = -0.826 W m^{-2}

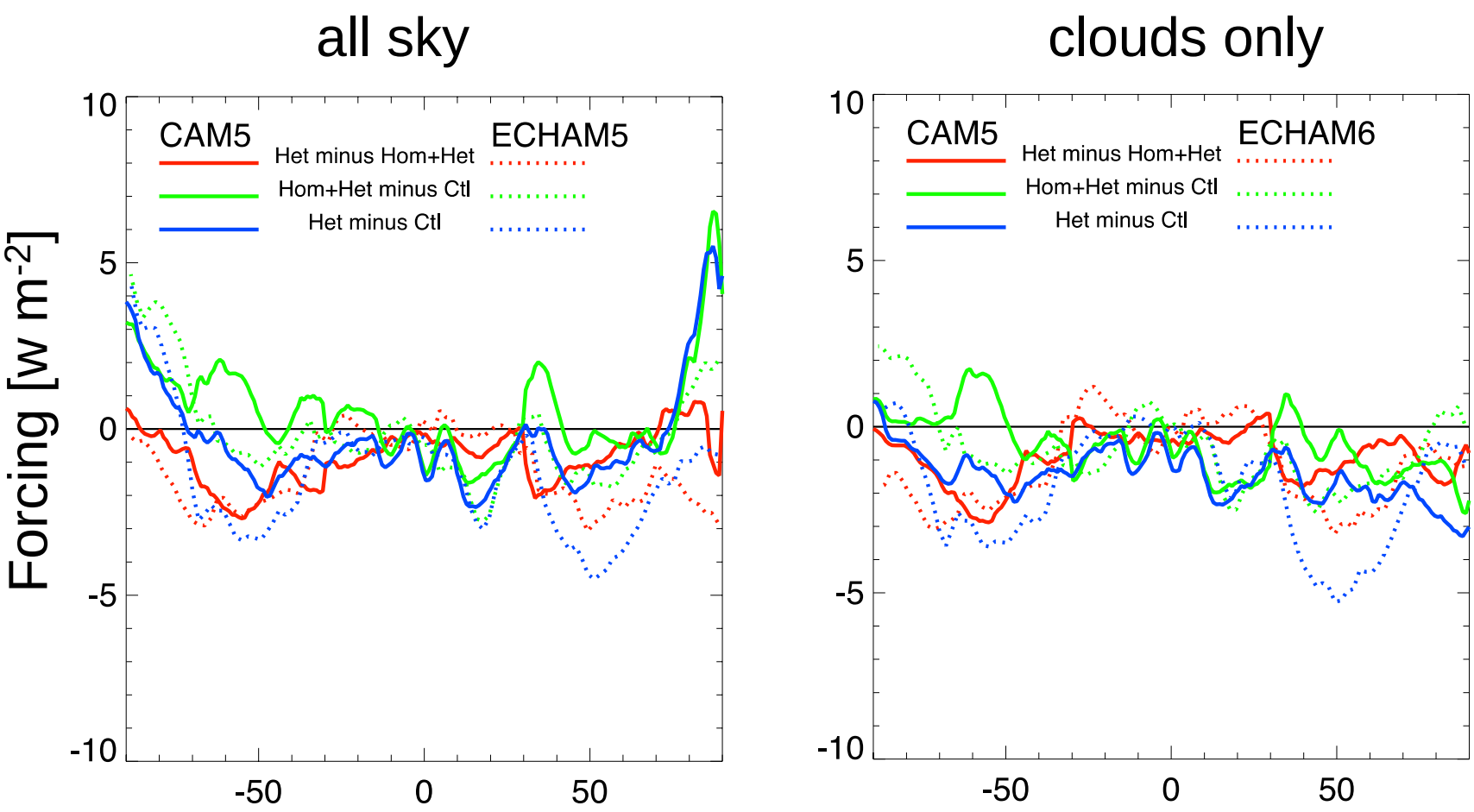
ECHAM6 Results: Heterogeneous – (Homo- & heterogeneous)



Net Radiative Forcing Differences; zonal means



Global mean all-sky net radiative forcing, het – obs, = -0.989 W m^{-2}



Net radiative forcing differences (all sky)
CAM5 -0.825964
ECHAM6 -1.28051
Net radiative forcing differences (clouds)
CAM5 -0.911210
ECHAM6 -1.17228

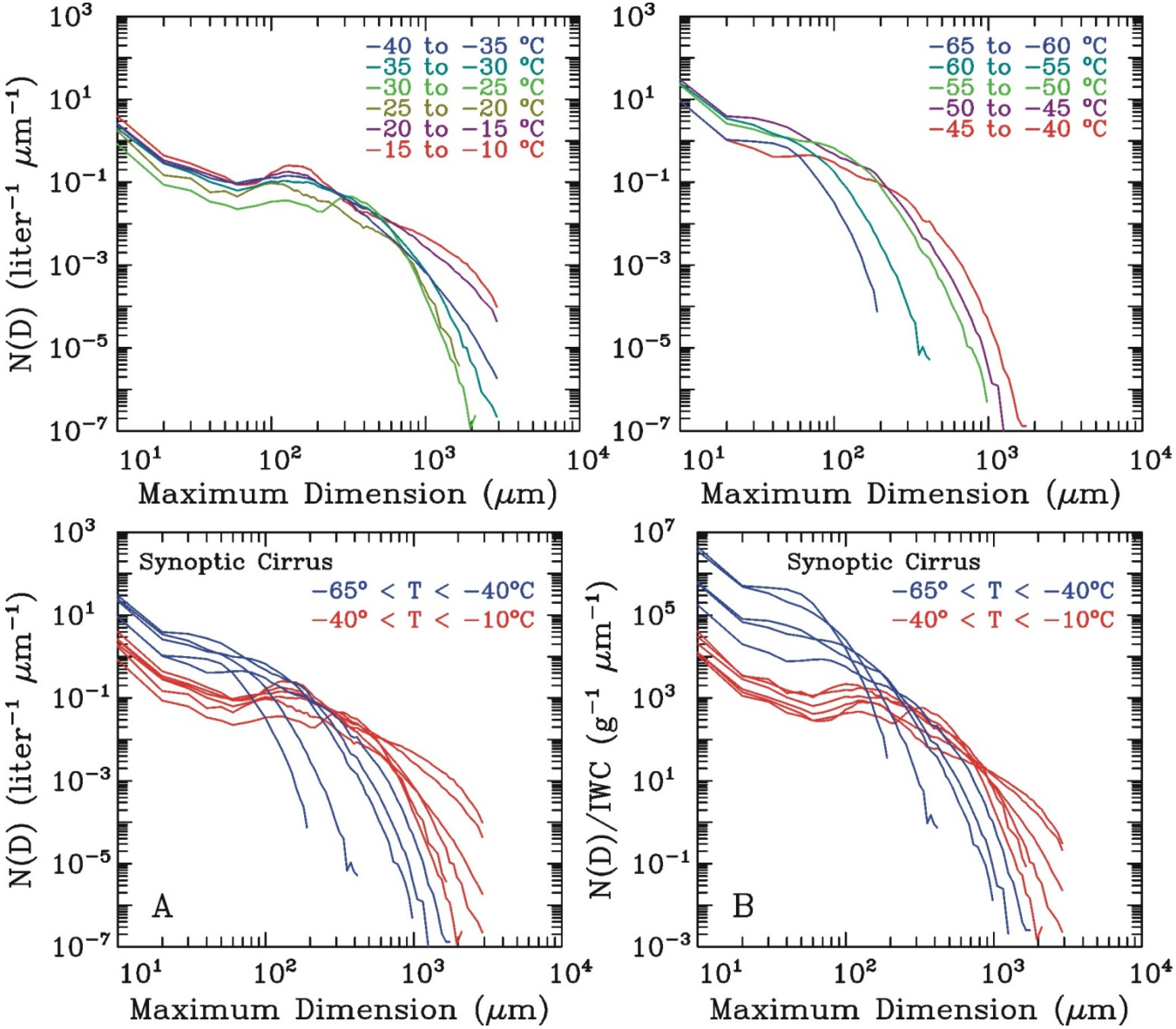
Summary and Conclusions

1. Two GCMs, CAM5 and ECHAM6, were parameterized in terms of D_e and V_m based on SPARTICUS data for conditions representing (1) heterogeneous and (2) homogeneous ice nucleation. Two 5-year GCM simulations were done; with Run 2 assuming heterogeneous nucleation everywhere and Run 1 assuming homogeneous nucleation outside the ± 30° latitude zone.

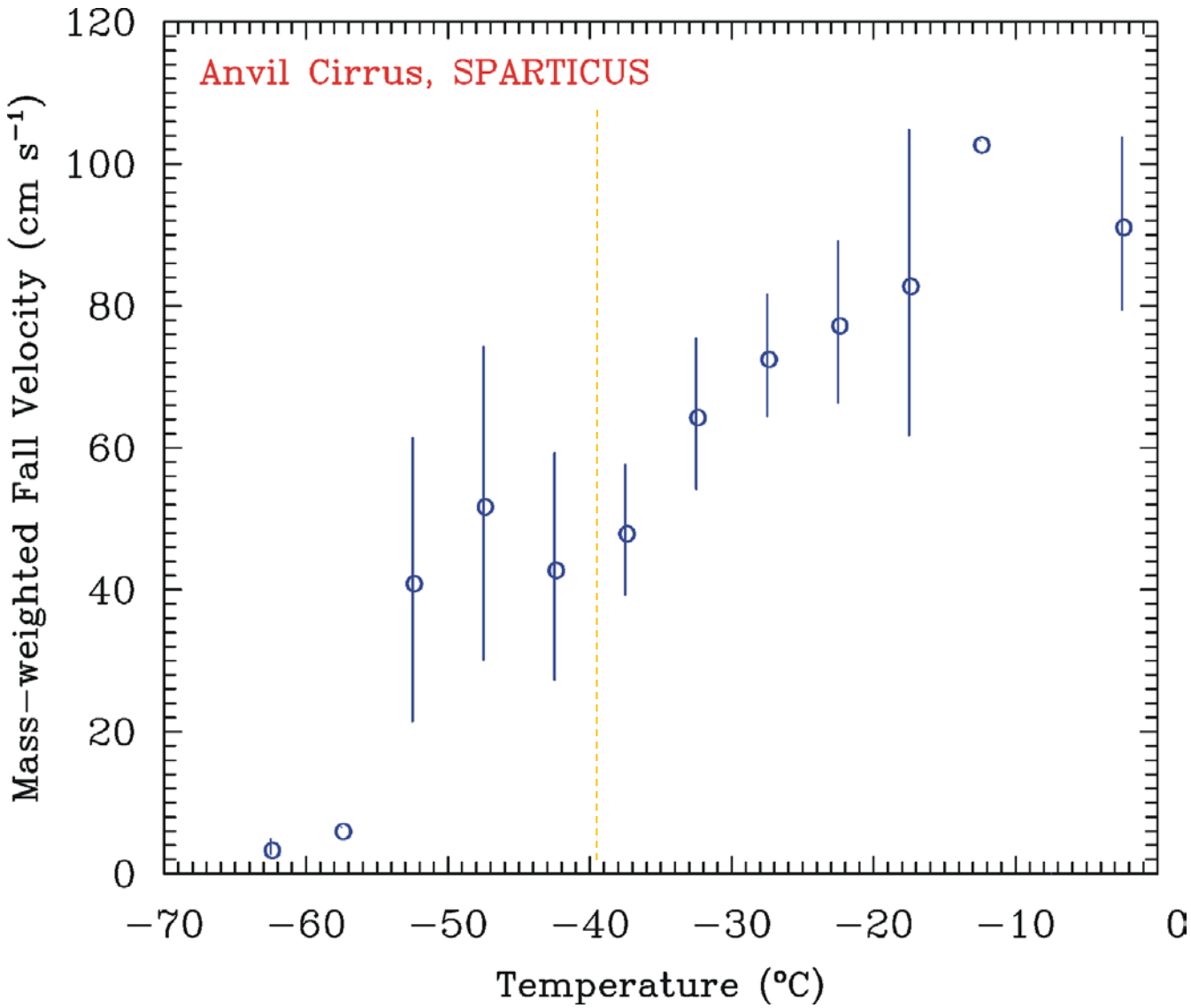
2. Relative to Run 1, Run 2 resulting in a globally averaged net cooling of -0.83 and -0.99 W m^{-2} for CAM5 and ECHAM6, respectively. Cooling on average outside the ± 30° latitude zone was ~ - 2 W m^{-2} for ECHAM6 and more asymmetrical for CAM5; ~ - 1.2 W m^{-2} in the N. hemisphere and ~ 1.7 W m^{-2} in the S. hemisphere.

3. The net cloud radiative forcing from cirrus clouds may depend on atmospheric dust levels.

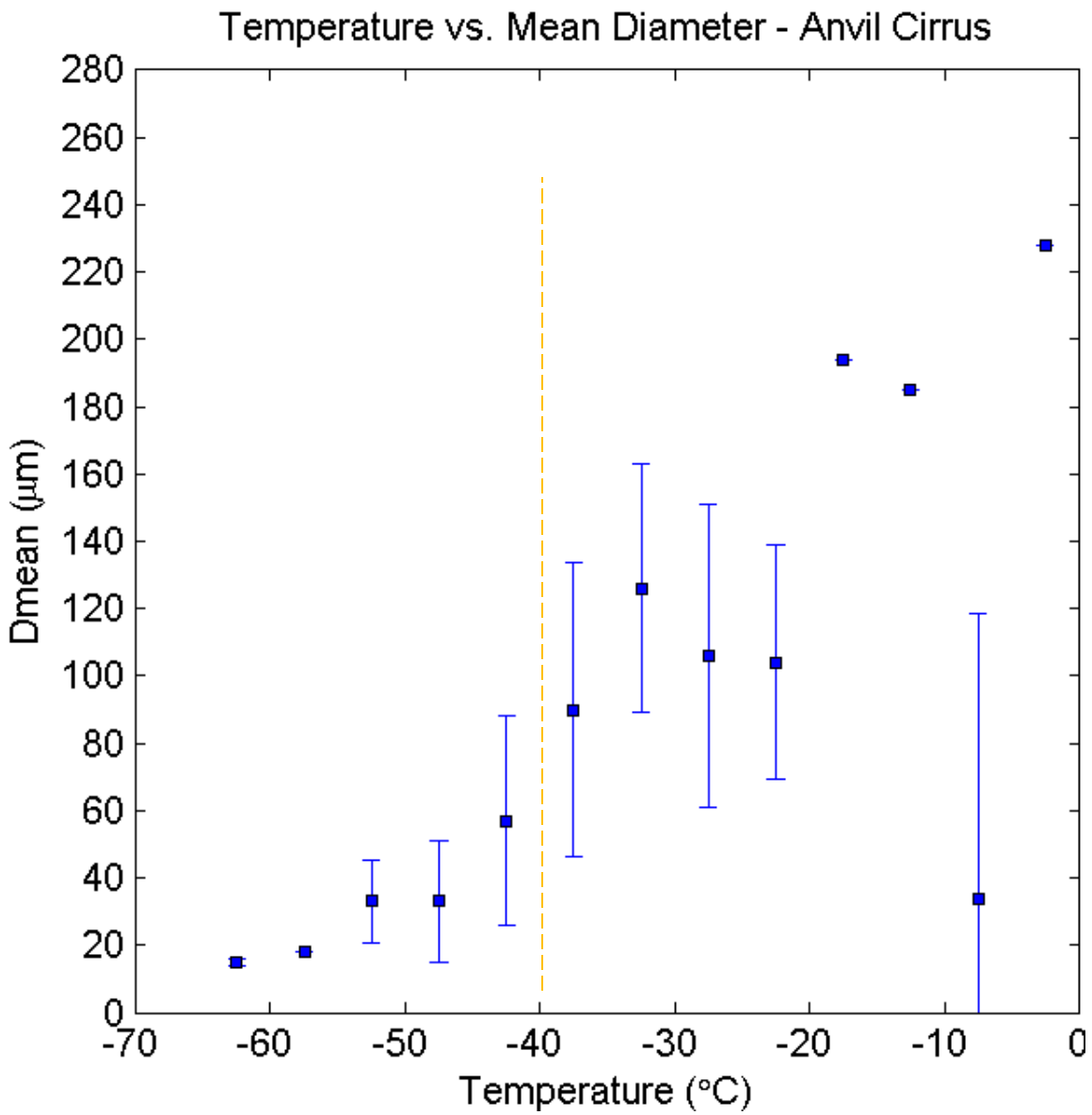
Temperature Dependence of Synoptic SPARTICUS PSD



Temperature dependence of the mass-weighted ice fall-speed for anvil cirrus clouds during SPARTICUS

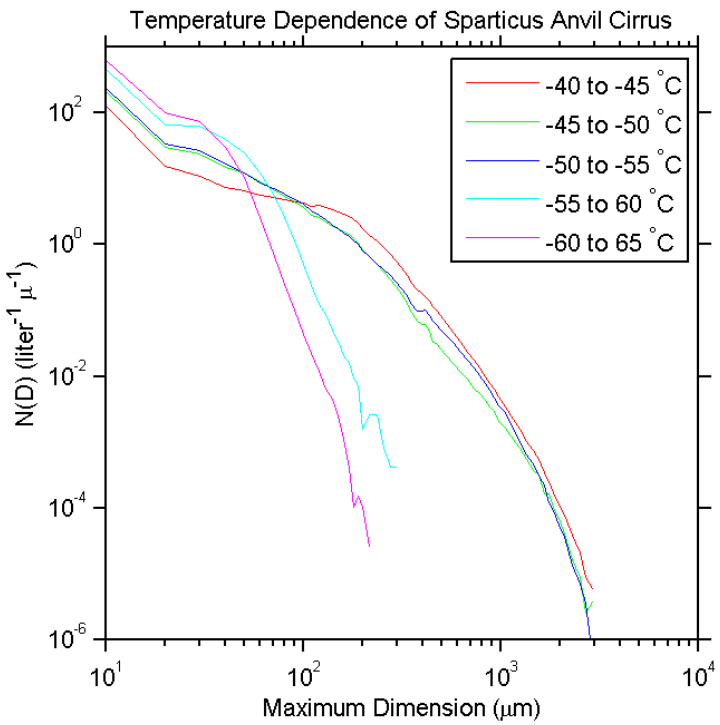


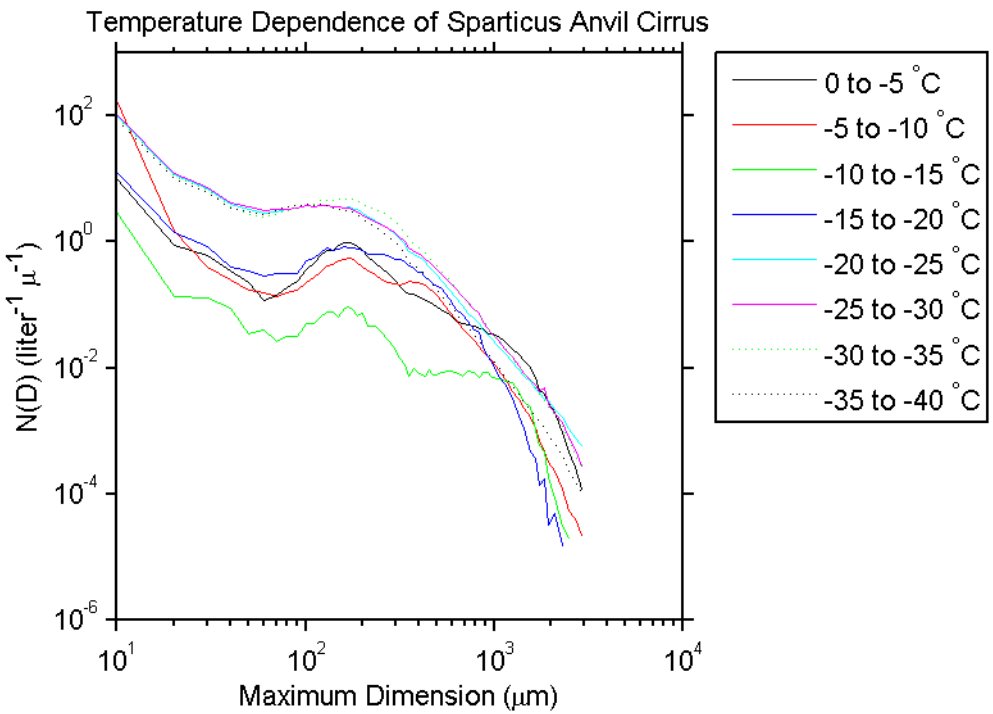
Temperature dependence of ice particle size



Microphysical Evaluation of Nucleation Processes for Anvil Cirrus:

Temperature dependence of PSD shape





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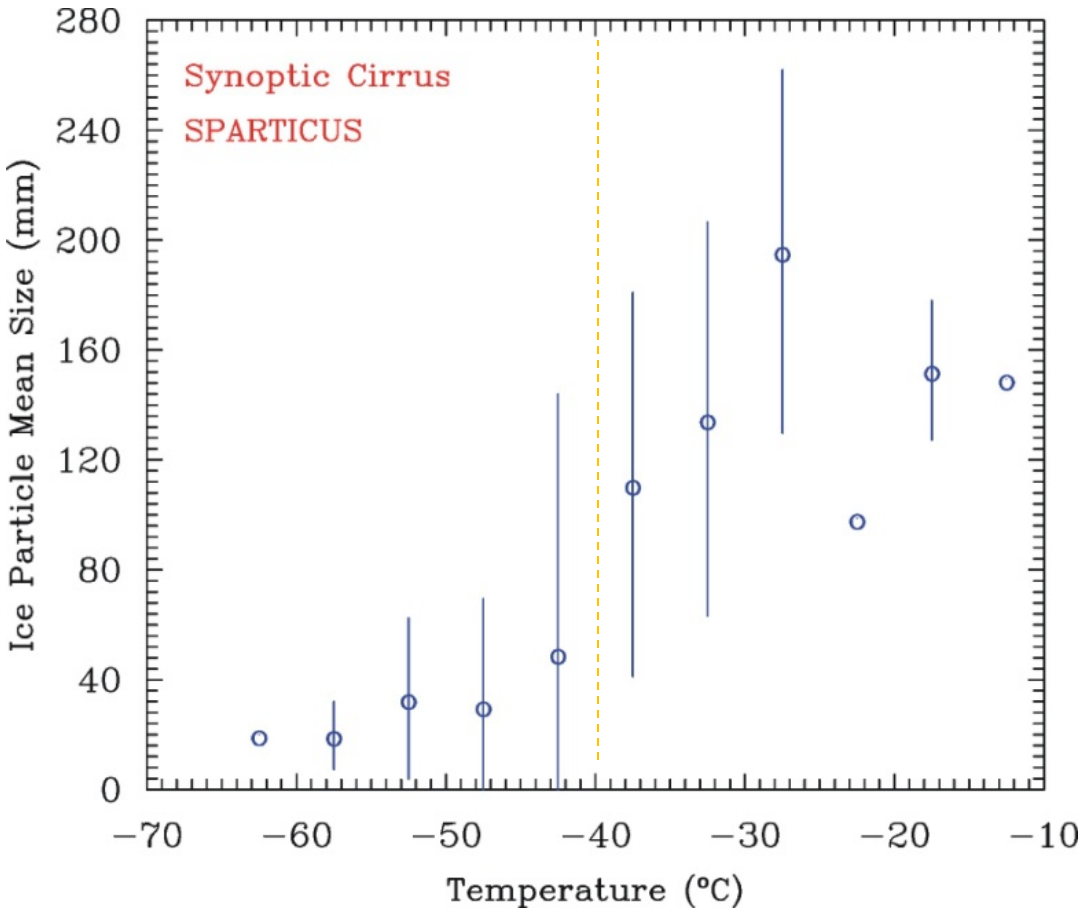
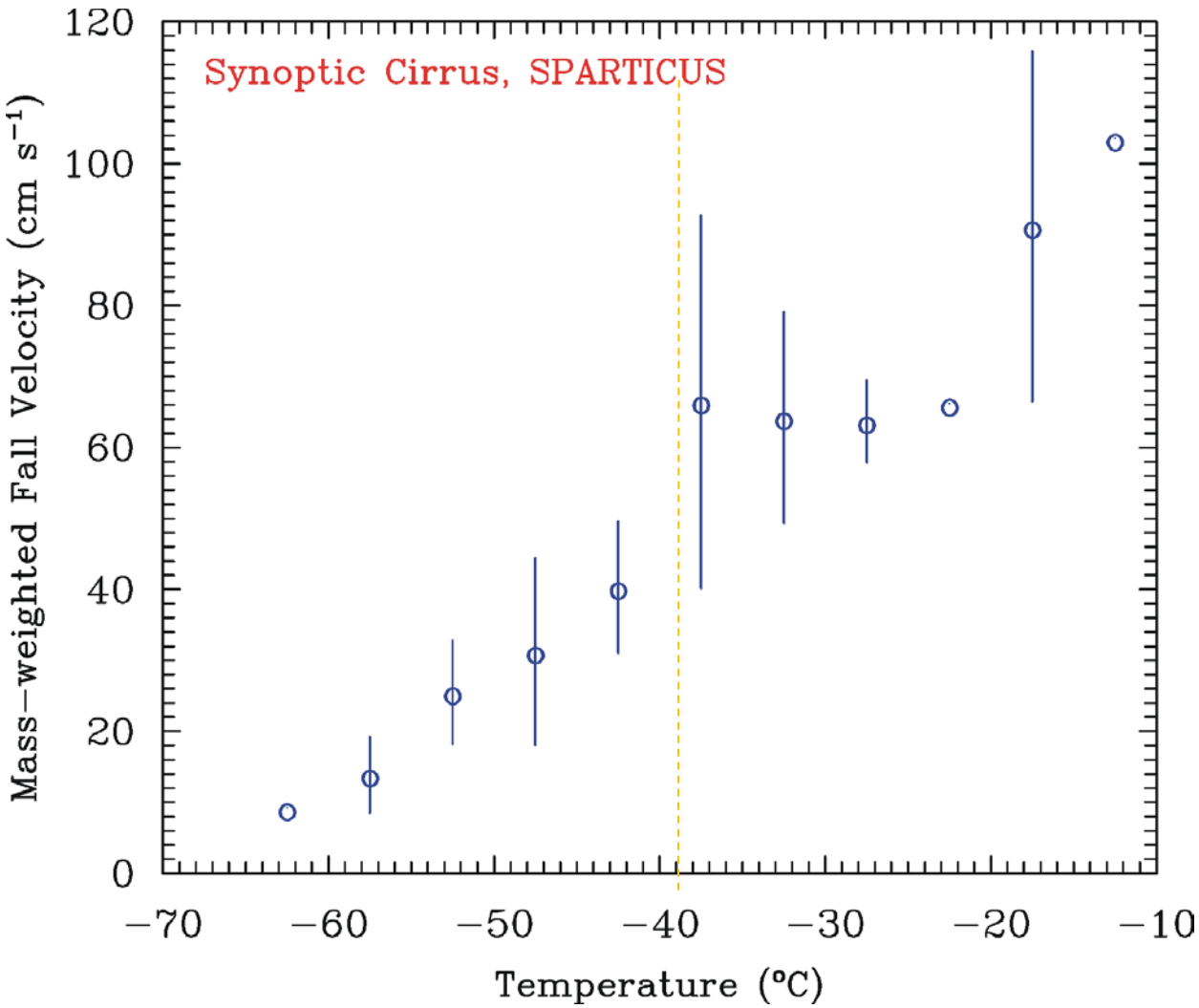
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