Advancements in the Representation of Cloud-Aerosol Microphysics in the GEOS-5 AGCM

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McRAS-AC in GEOS-5

The main features of cloud microphysical properties are simulated by the McRAS-AC (Microphysics of Clouds with Relaxed Arakawa-Schubert and Aerosol-Cloud interaction) scheme implemented in the GEOS-5 AGCM. The version shown uses Fountoukis and Nenes (2005) CCN activation and Barahona and Nenes (2008, 2009) IN activation. Monthly aerosol loading is from GOCART with log-normal size distribution of each species assumed. Other key features of McRAS-AC are level-by-level cloud-scale thermodynamics, and precipitation microphysics from Sud and Lee (2007) based on Seifert and Beheng (2005). One-year model runs with prescribed SST fields are evaluated against satellite data. Fig. 1 shows the microphysical processes of McRAS – AC. Liquid and ice cloud water are double moment (independent number density and mass) prognostic variables, but rain and snow mass fractions are diagnosed.

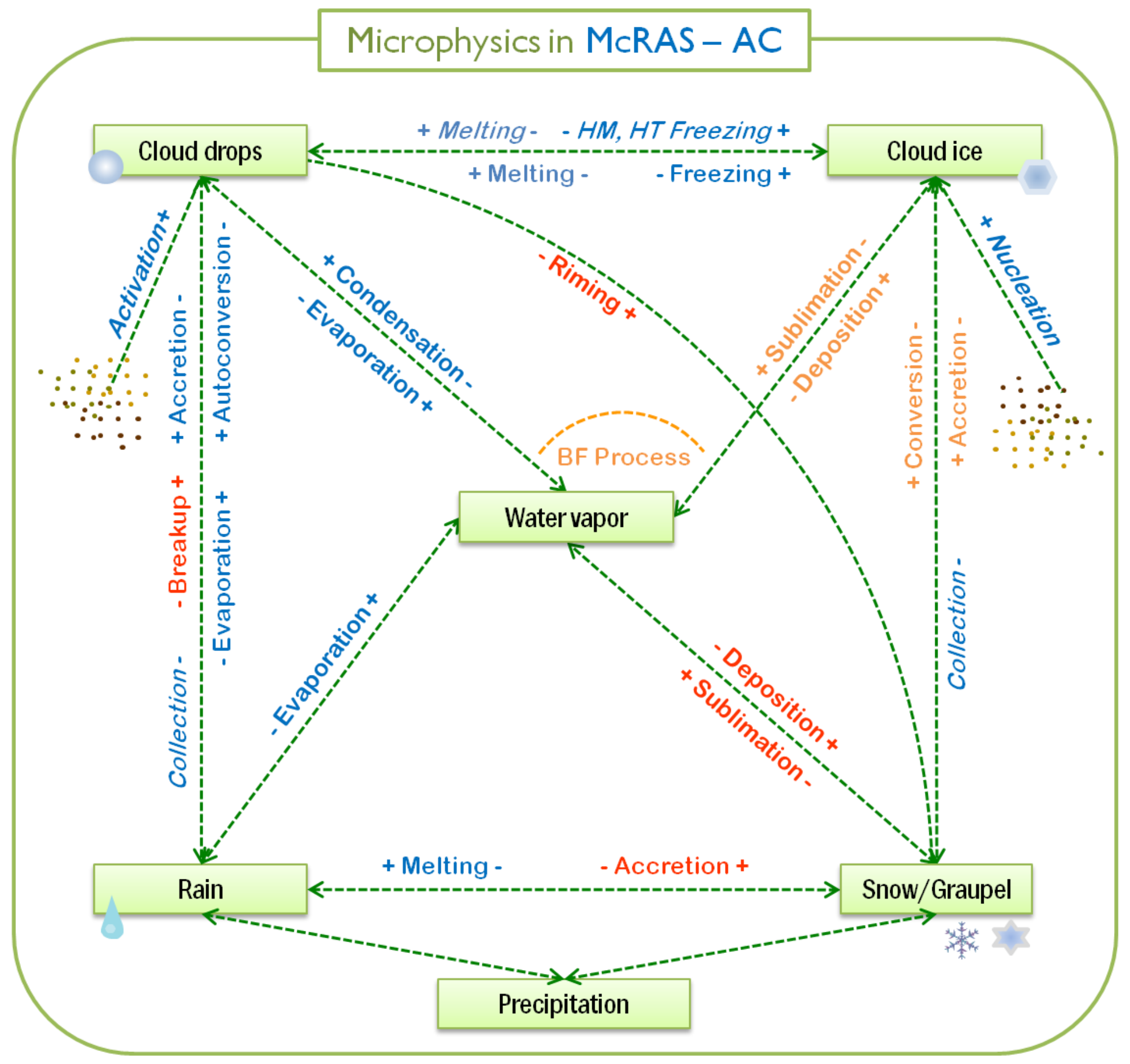


Figure 1. Cloud microphysics in McRAS-AC. (+) sign means sources, while (-) sign sinks. Processes in blue are fully implemented, in orange are only implicitly implemented, while those in red are not yet implemented. Processes in italic involve calculating number densities, while those in roman mixing ratio (mass).

Cloud Optical properties

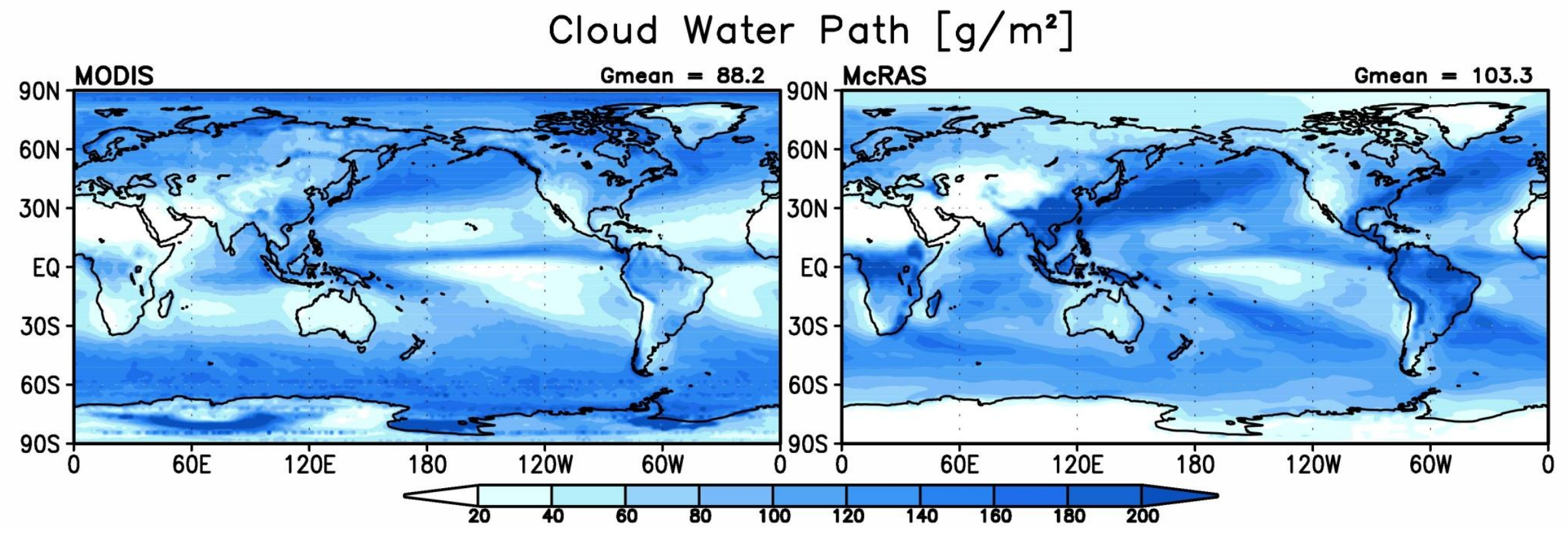
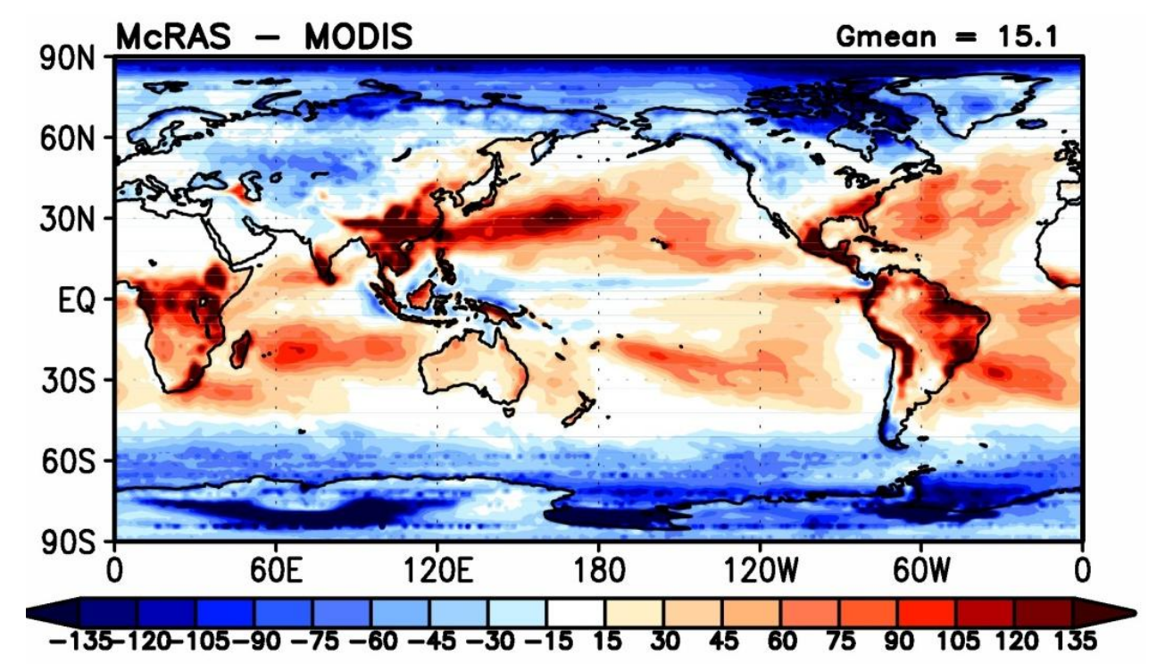


Figure 3. Annual mean total (=liquid+ice) cloud water path from MODIS Terra (Feb. 2000 to Jan. 2011), GEOS-5, and their difference.



Total (=liquid+ice) water paths (TWP) are compared in Fig. 3. McRAS in GEOS-5 simulates TWP well, with maxima located over ITCZ and the storm tracks. In the difference map, overestimates occur in polluted regions and underestimates in polar regions.

Cloud droplet concentrations are higher over polluted land area, while ice particle concentrations over polar regions (Fig. 4). Land/sea contrast of r_{eff} is clearly shown in Fig. 5. Mean liquid r_{eff} is smaller than MODIS (15.4μm), while ice r_{eff} larger than MODIS (28.6μm). Proper comparison, however, requires use of COSP's MODIS simulator in GEOS-5 (under study).

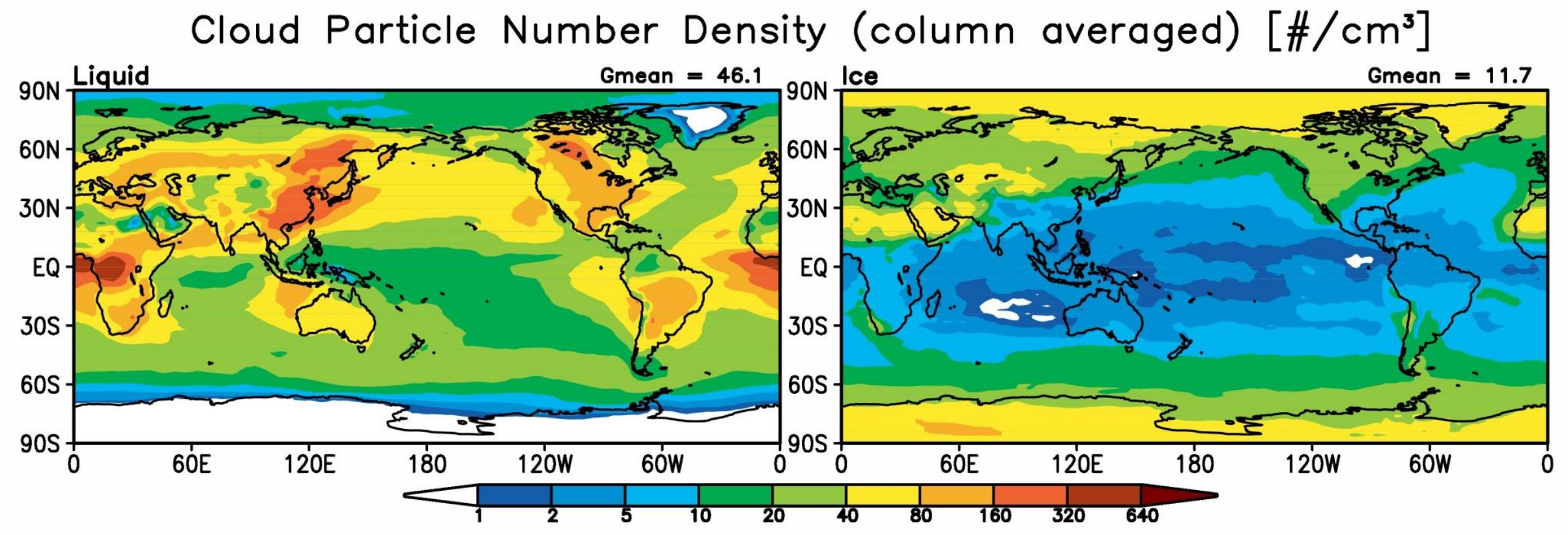


Figure 4. Column averaged (weighted by layer cloud fraction) annual mean particle number density (cm^{-3}) from GEOS-5.

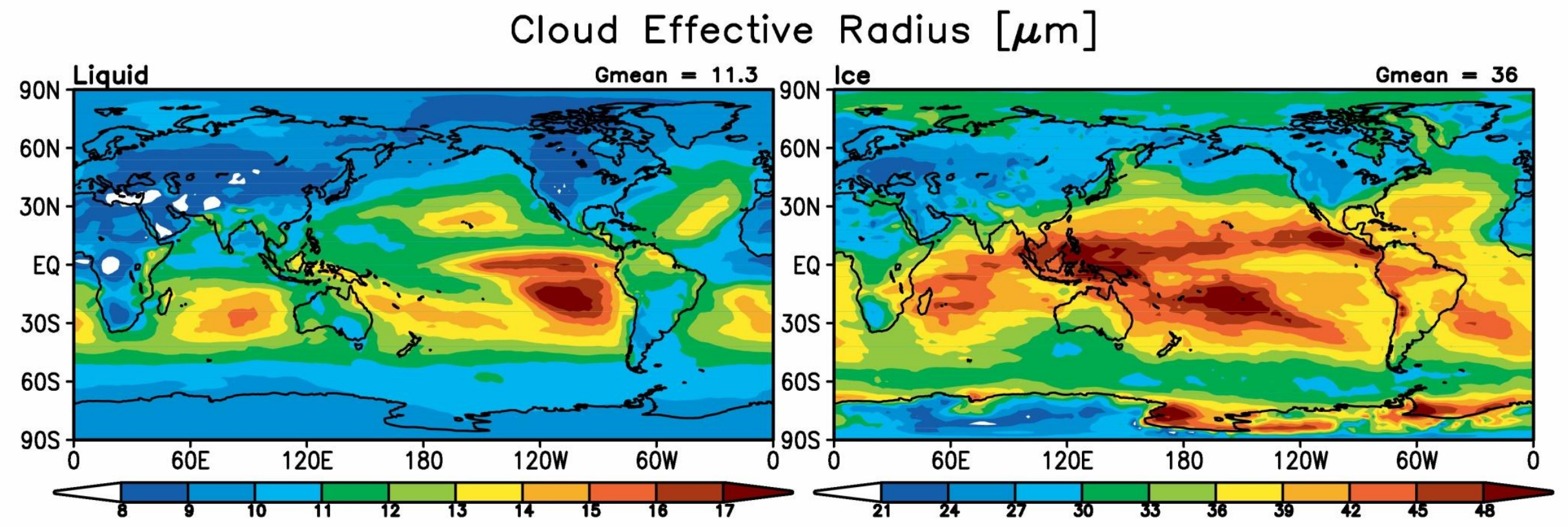


Figure 5. Cloud particle effective radius from GEOS-5 calculated as in Fig. 4.

Sea Salt Sensitivity test

Sea salt (SS) aerosol is a major CCN source over ocean. But global mean of GOCART SS concentration over ocean at 900hPa is only 4 cm^{-3}. With increasing SS, TWP increases, TOA net SW and liquid r_{eff} decrease (Table 1), making disagreement with MODIS r_{eff} worse.

SS	Net SW (Wm^{-2})	TWP (gm^{-2})	R_{eff} (μm)
1	219.0	111.0	12.8
10	215.6	119.1	12.0
25	213.0	127.2	11.3
50	208.8	135.7	10.6

Table 1. Global ocean mean of TOA net SW, TWP, and r_{eff} of cloud drop with increasing SS number concentration

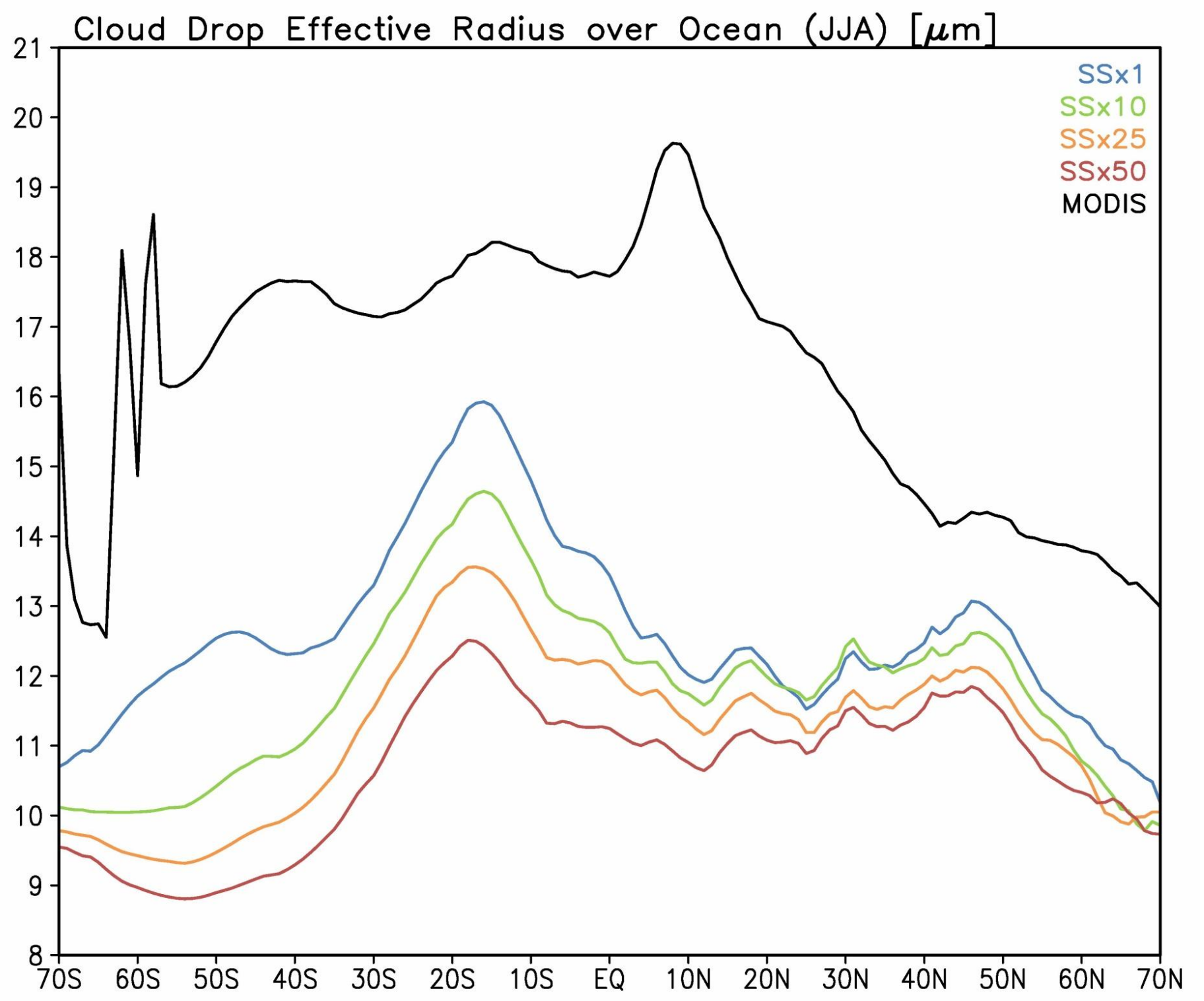


Figure 6. Annual zonal mean of liquid r_{eff} (column averaged by layer cloud fraction). Colored solid lines are experiments with different SS concentrations, black is MODIS Terra.

Cloud water w/o Carbon

Fig. 3 indicates that McRAS generates too thick cloud over central Africa and the Amazon basin, locations of high carbon aerosol loading due to biomass burning. When carbon aerosol is neglected in McRAS, large reductions in TWP occur.

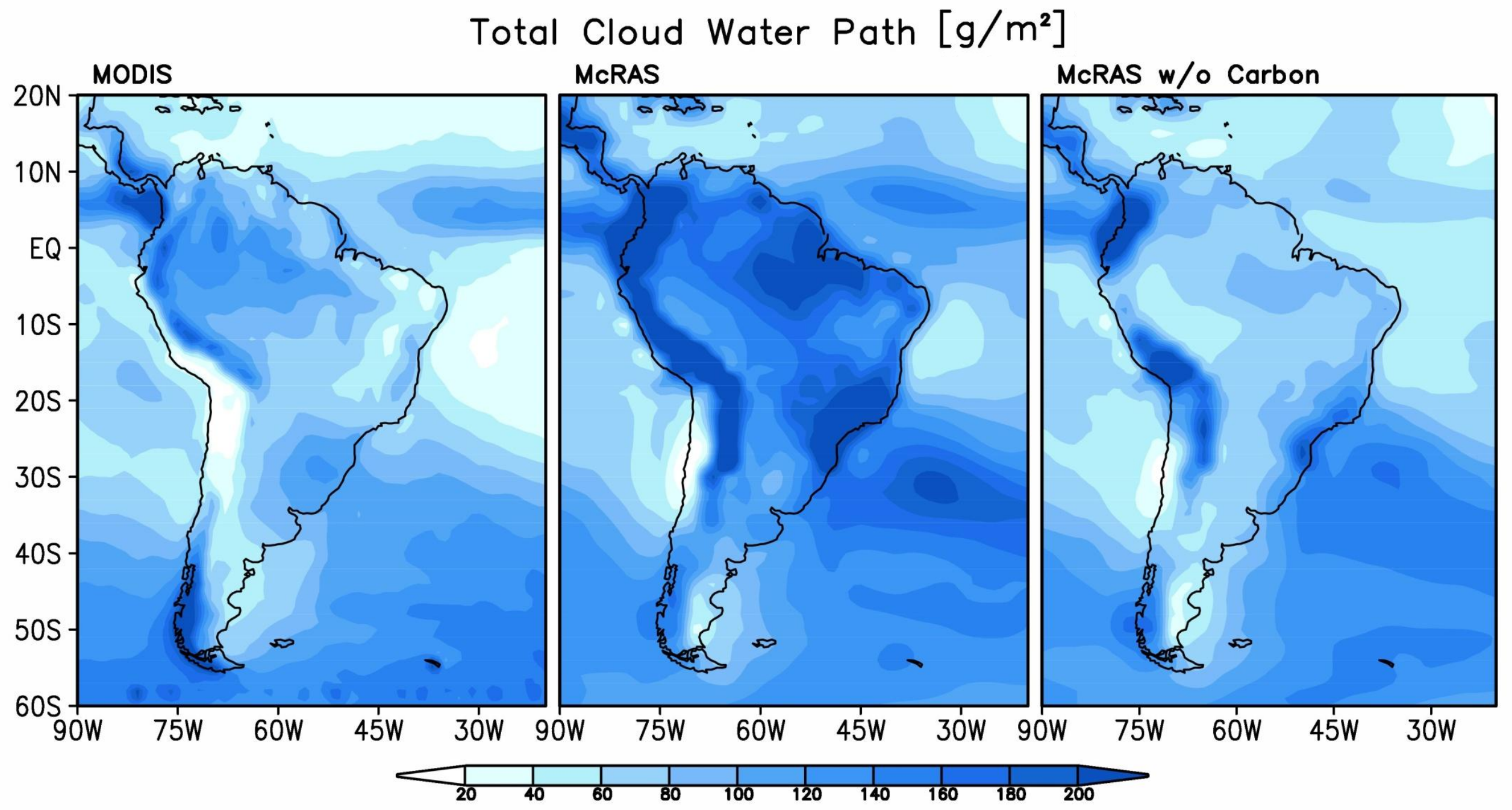


Figure 7. Annual mean TWP over S. America from MODIS Terra, McRAS, and McRAS without carbon (BC and OC).

TOA Radiative Fluxes

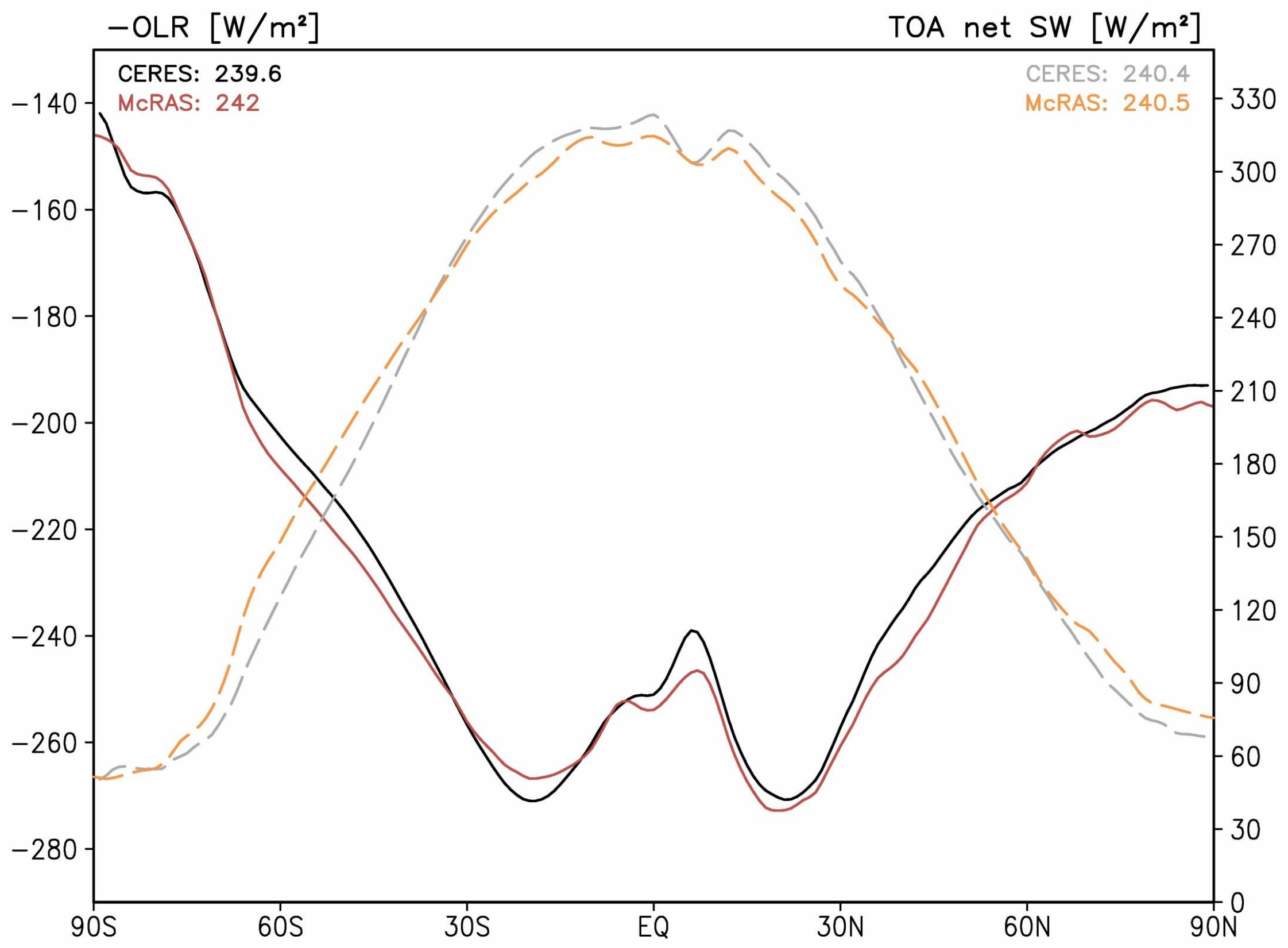


Figure 2. Zonal mean of annual mean net downward SW (dashed) at and -OLR (solid). CERES data (gray and black) and model results (orange and red) are plotted.

The global annual mean of TOA net SW matches quite well CERES , but includes cancellations of warming at high latitude and tropical cooling. TOA fluxes are consistent with cloud water path (Fig. 3). Along the equator, especially over highly polluted areas, very thick clouds are formed that increase the planetary albedo. In high latitudes, cloud water path does not reach the MODIS values. The AGCM OLR is greater than CERES by 2.4 W/m^2. Fig. 8 indicates that model IWC seems to be located lower than CloudSat IWC, though the overall patterns are similar.

Summary

- Aerosol-cloud interaction is well simulated by McRAS-AC in the GEOS-5 GCM; it shows quite reasonable land-ocean contrasts, sensitivity of cloud optical properties to aerosol number concentration.
- Aerosol loading was based on GOCART data; the current simulations clearly show the importance of the aerosol data.
- Bergeron–Findeisen process plays a central role in producing mixed phase clouds; there is large sensitivity to the B-F initiation temperature, suggesting need for further research.

Acknowledgements

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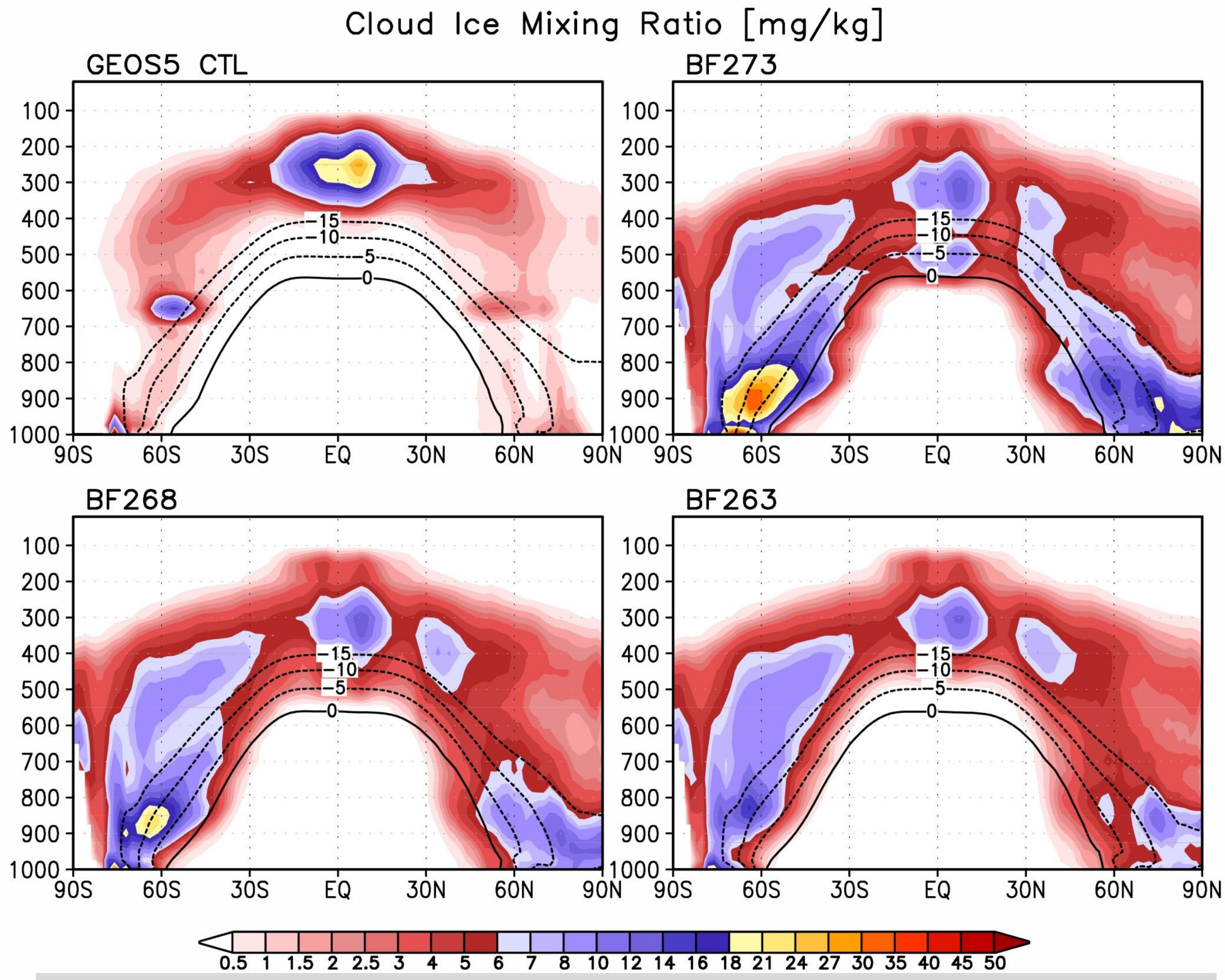
Initiation temperature of Bergeron process



CloudSat IWC, non-precipitating Waliser et al. (2009)

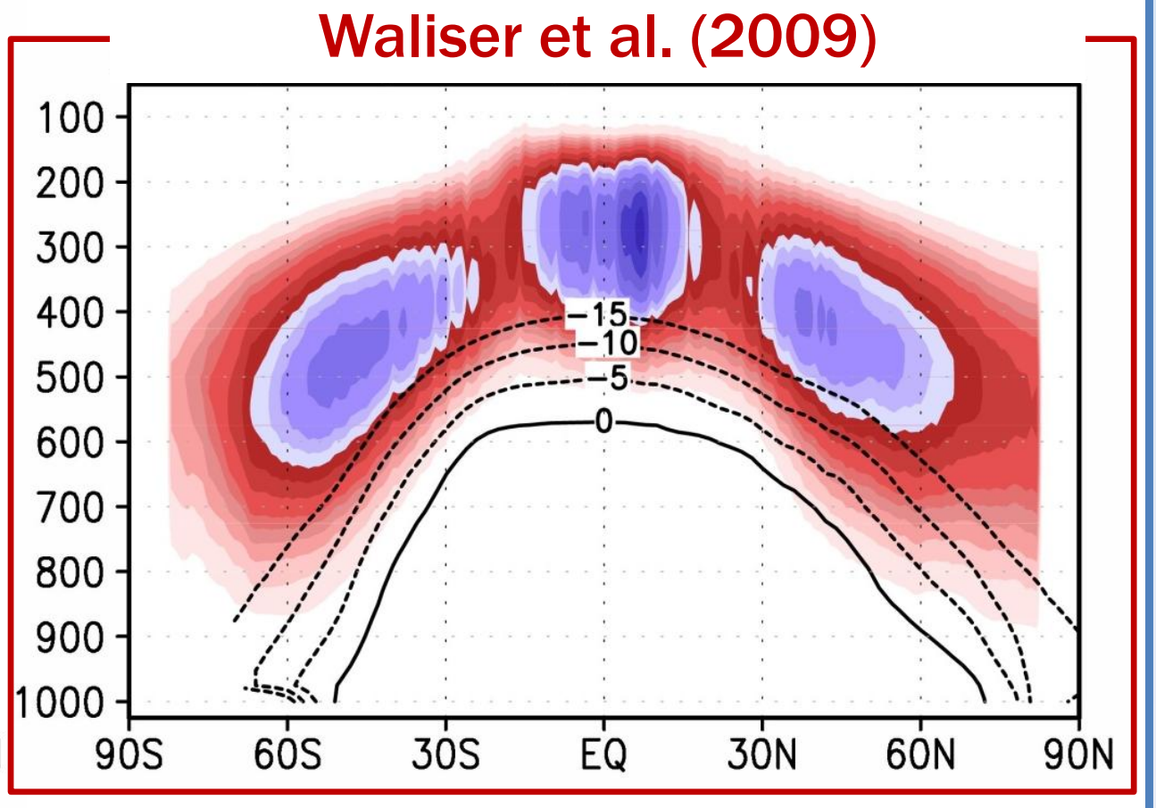


Figure 8. Zonal-height plot of IWC (mg/kg) annual mean. GEOS-5 control uses T-dependent ice/liquid fraction, while the three McRAS simulations incorporate the Bergeron-Findeisen (B-F) process per Rotstayn (2000).

Simulation of the B-F process makes for better zonal – height profiles of IWC, but it causes too little (too much) liquid (ice) in the mixed phase; so it needs to be tempered. This can be achieved by modifying temperature for the onset B-F process (figures show results for T=273, 268, and 263 K)