Inclusion of Ammonium Sulfate Aerosols in McRAS-AC: an SCM Evaluation

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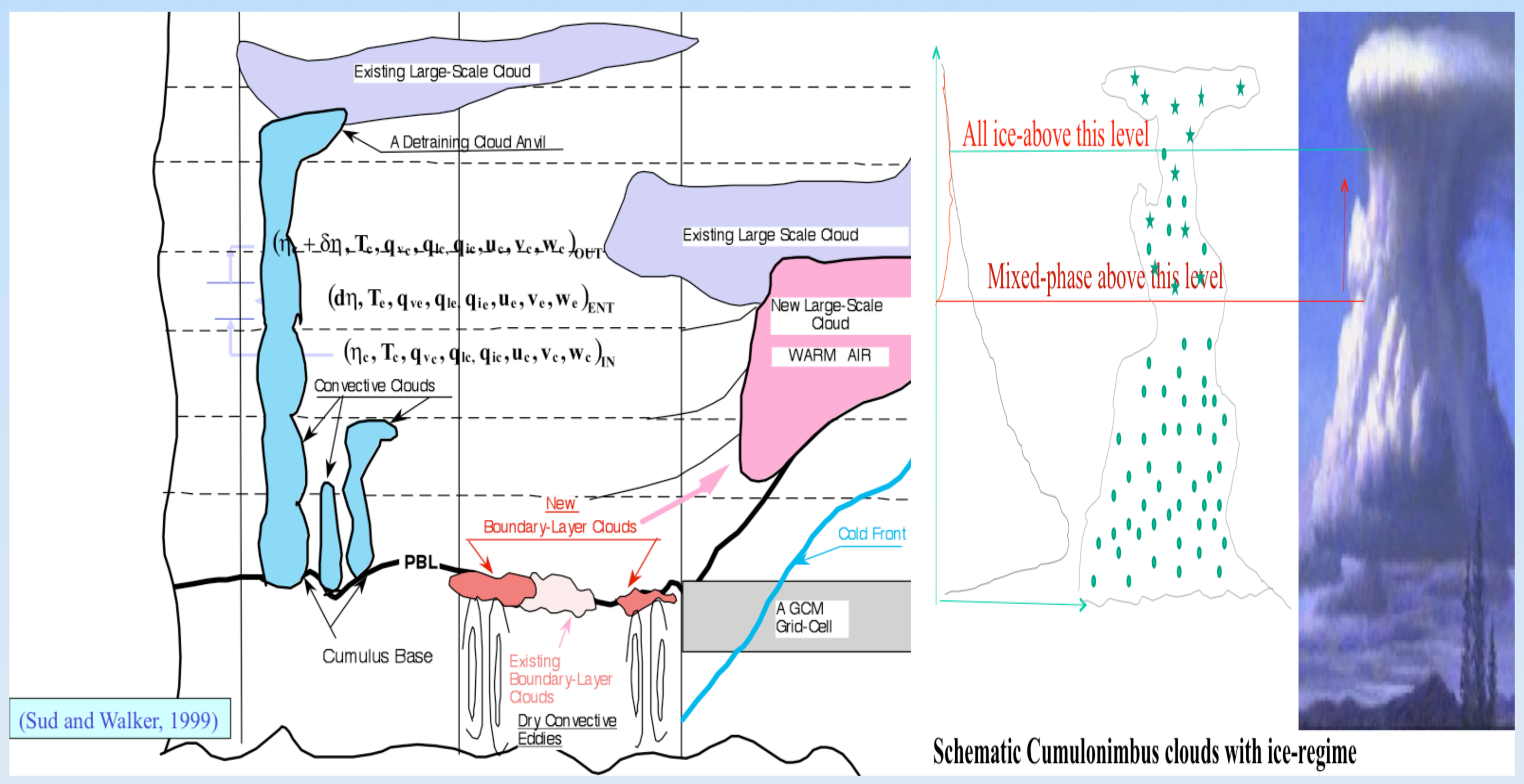
Problem description

Simulated ice-clouds have large biases in present-day climate models, particularly GCMs that include aerosol-cloud interactions for nucleating cloud particles inside the convective towers. Recent cloud-chamber studies have led to the discovery of significant nucleating effects of ammonium sulfate $(NH_4)_2SO_4$ aerosols abundant in the upper atmosphere after all other IN-aerosols have been depleted as CCN.

Our Approach

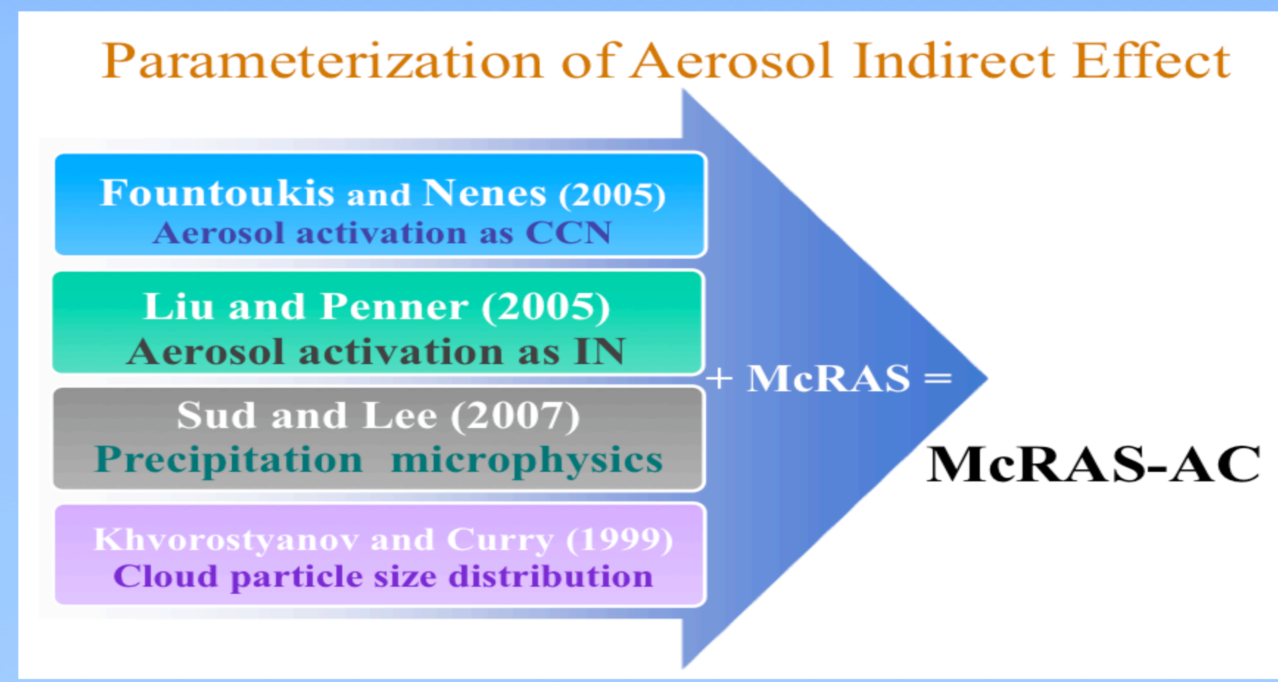
We have included $(NH_4)_2SO_4$ nucleating effects into the cloud physics of McRAS-AC (NASA's microphysical cloud scheme with Relaxed Arakawa Schubert cloud parameterization upgraded with aerosol-cloud interactions physics). An $(NH_4)_2SO_4$ aerosols parameterization is used to evaluate its impact on clouds using a single-column model (SCM) employing SGP and NSA driver data sets. Twin simulations with and without $(NH_4)_2SO_4$ aerosols were produced. The monthly behavior of the simulated clouds was evaluated against the available ground and satellite data to determine the influence of $(NH_4)_2SO_4$ aerosols on cloud particle number densities, size, optical thicknesses, and the resulting long- and short-wave cloud radiative forcings.

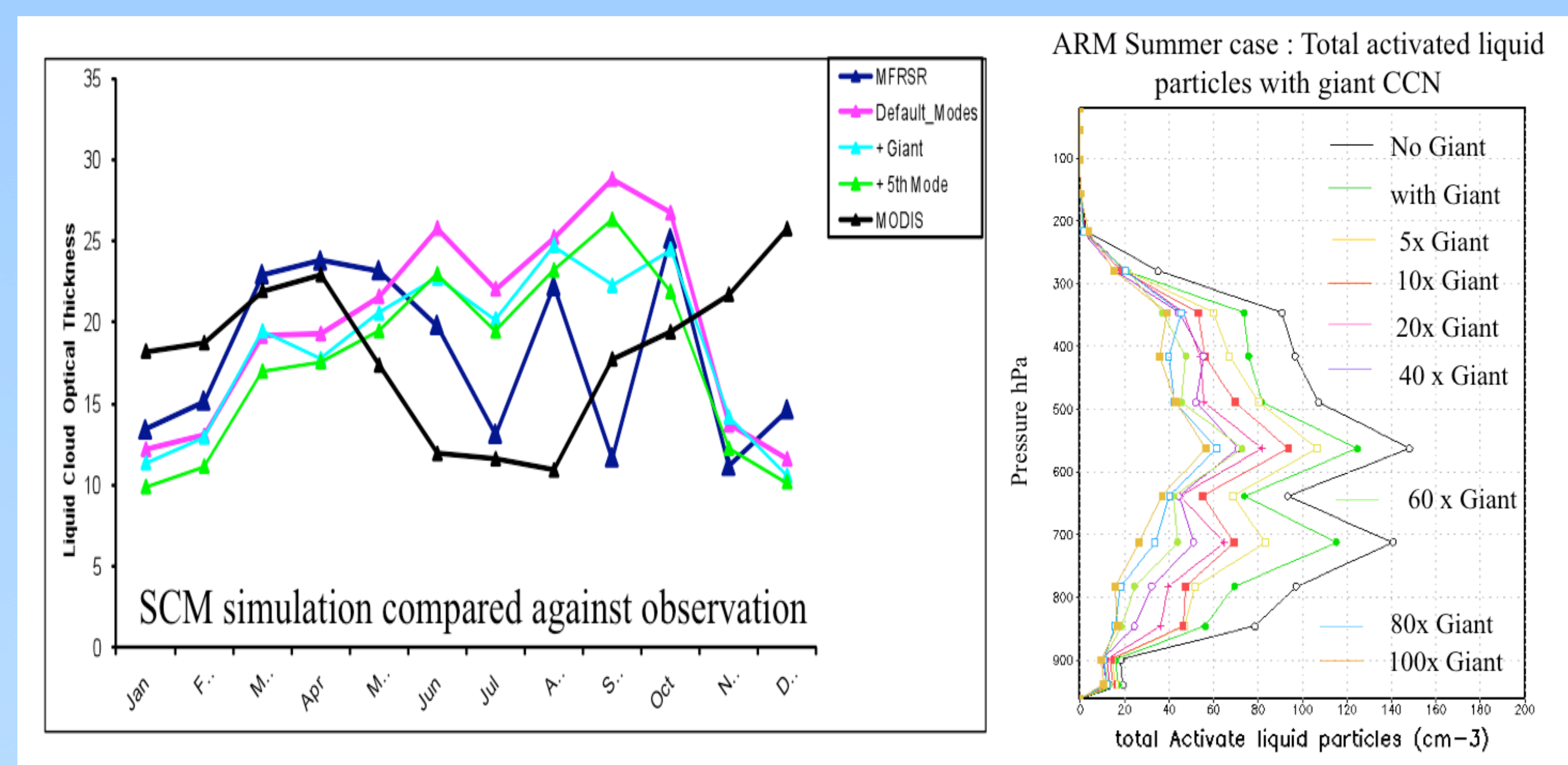


Above Left: *Schematic showing the three cloud type of McRAS-AC namely convective, boundary-layer, and stratiform; right panel shows the three resolved regimes of cloud water: liquid, mixed-phase and ice. We parameterize all of them; mixed-phase and ice clouds nucleated by aerosols and interacting with precipitation microphysics are drawn from the McRAS module at the top of the center column. Barahona and Nenes (2009) is implemented and tested with and without ammonium sulfate aerosols for Simulated IN/IPNC.*

What we found

Our results show that inclusion of $(NH_4)_2SO_4$ in the SCM mitigates some major biases in the simulated ice clouds while preserving the reasonableness of liquid clouds in McRAS-AC simulations. The results make a strong case for including $(NH_4)_2SO_4$ aerosols not only in McRAS-AC, but in all interactive aerosol-cloud schemes.

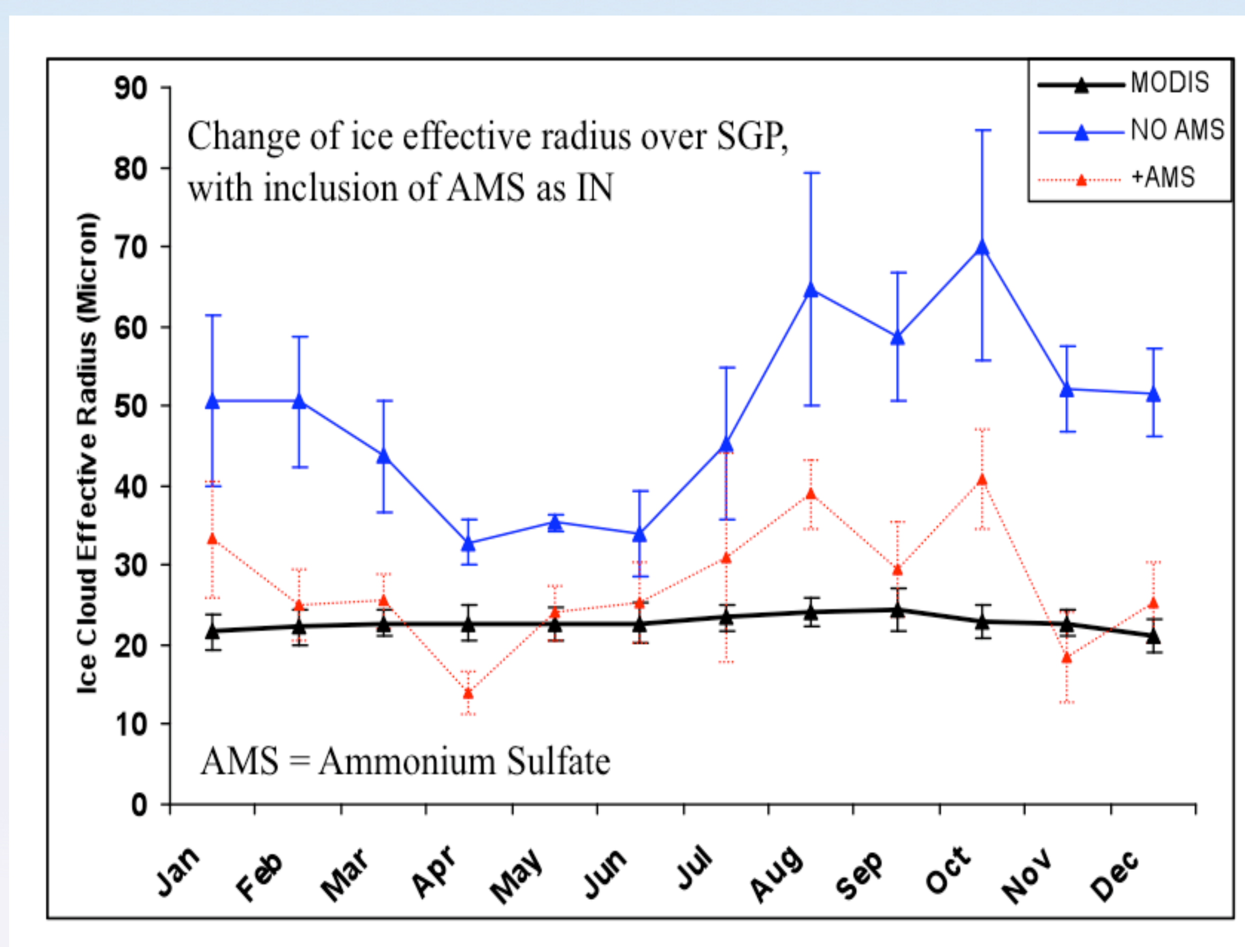




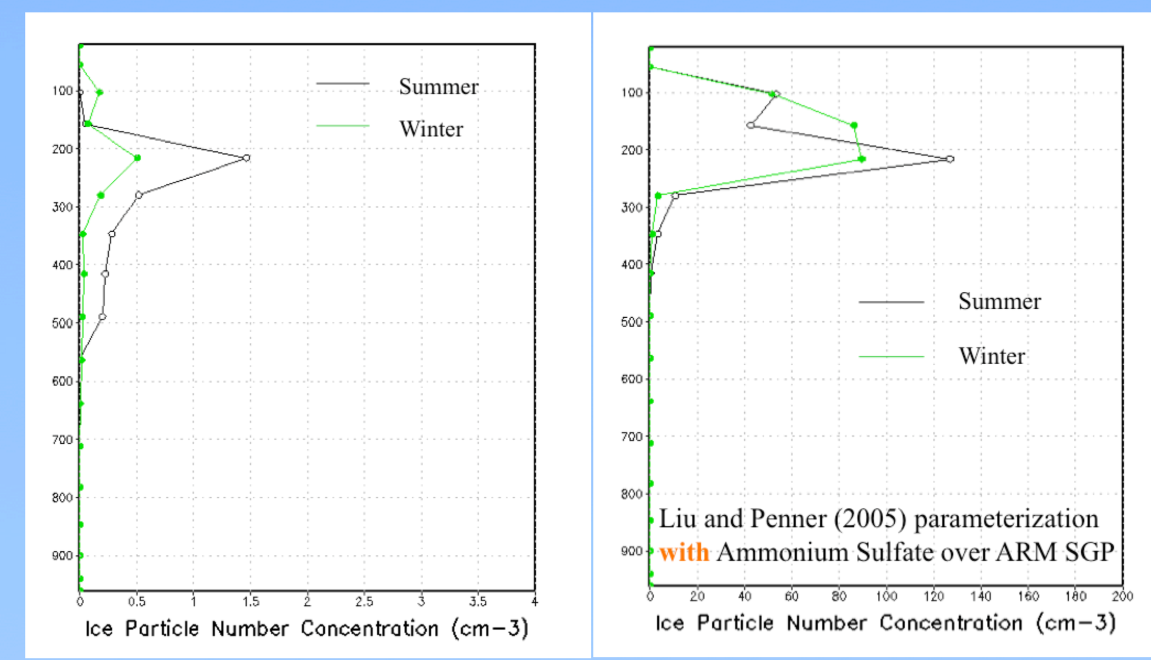
Left: *Optical Thickness of Water Clouds for: 1) Baseline Simulation 2) with 2% Giant CCN, 3) with condensation on existing cloud drops versus MODIS retrievals/ MFRSR data. Note large differences between observational estimates.* ***Right:*** *Sensitivity of activated droplet number to giant CCN mass fraction.*

Simulation Experiments for IN Evaluations

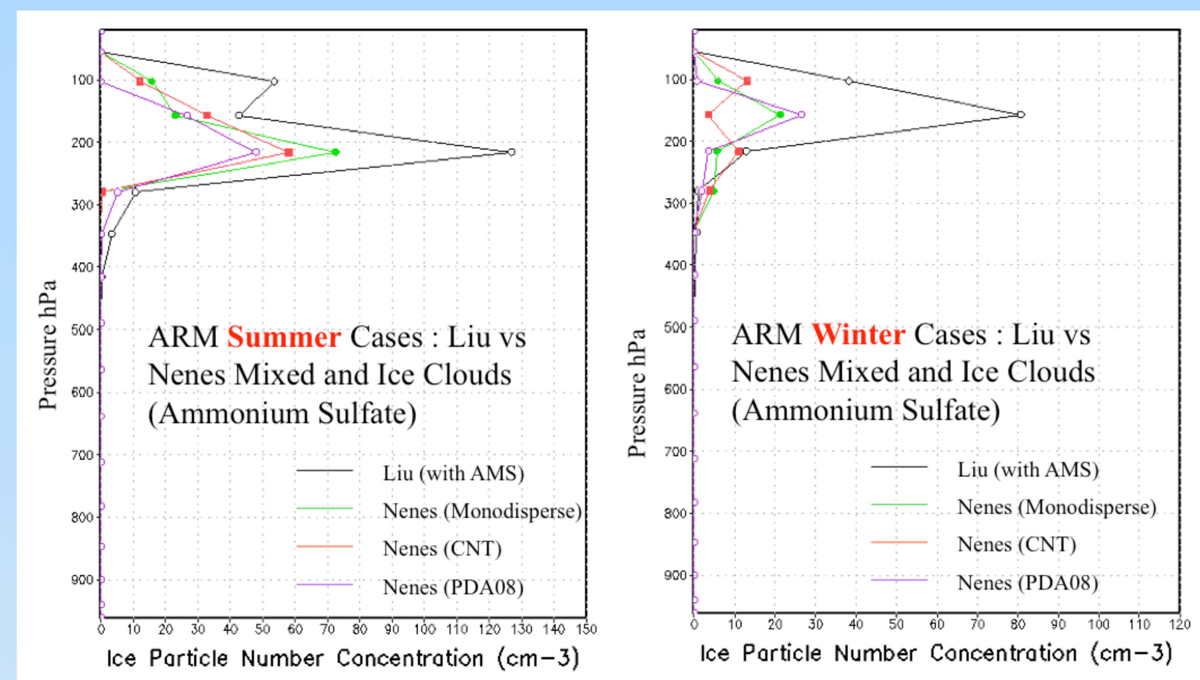
Ice nucleation Simulations	Liu & Penner (2005)	Barahona and Nenes, (ACP 2009) 3-Nucleation Theories		
All simulations are performed with Fountoukis & Nenes (2005) liquid cloud CCN plus mixed-ice phase cloud IN with and without $(NH_4)_2SO_4$.	Immersion, contact, and deposition nucleation for mixed phase clouds. Bergeron-Findeisen process included	**Monodisperse** Freezing by Barahona and Nenes, ACP, 2009).	**Polydisperse** Classical Nucleation Theory (CNT)	**Polydisperse** Using correlation due to Phillips et al, (2008) or PDA08.

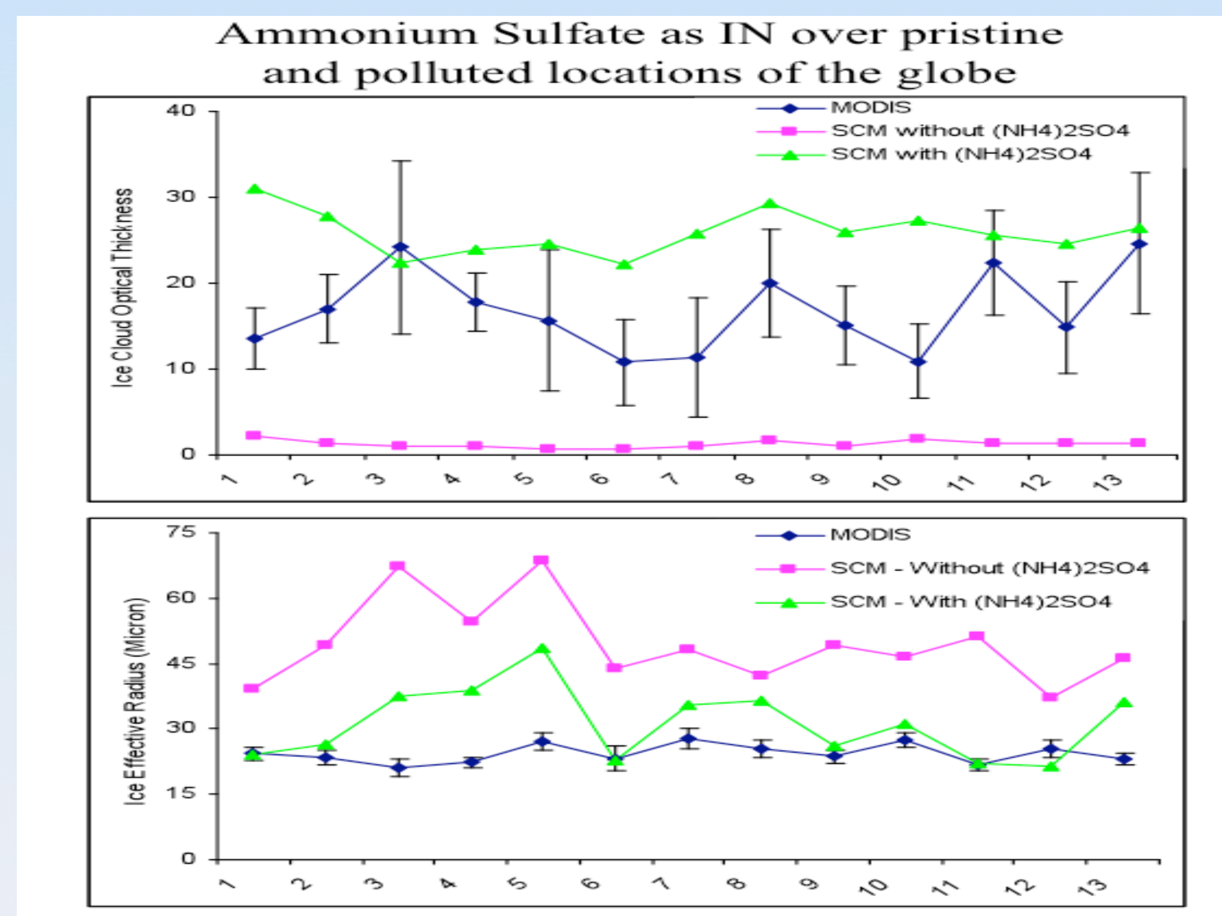


Influence of including $(NH_4)_2SO_4$ on the effective radius of Ice-cloud particles expressed as monthly averages with standard deviation. Ammonium sulfate reduces the effective radius by half corresponding to an almost eight-fold increase in IPNC (ice-particle number concentration) .



Ammonium Sulfate substantially increases the IPNC for both Summer and Winter for Liu and Penner (2005) scheme ***(shown above)*** *as well as Barahona and Nenes (2009) scheme (not shown). A comparison of Liu and Penner (single parameterization) and Barahona and Nenes (3 parameterizations) shows that the former yields more ice cloud particles than the latter scheme(s)* ***(shown below)****. This leads to poor preciptation efficiency and longer-living clouds. Its influence can be properly addressed in a full GCM with interactive thermal and advective feedbacks..*





Influence of Ammonium Sulfate on the optical thickness and effective radius of ice-clouds for 6 pristine and 7 polluted cases (comprising a total of 13 cases). Without Ammonium Sulfate, the optical thickness (effective radius) is way too low (high), whereas with Ammonium Sulfate, the values although still biased, are much better and tunable to get realistic answers through changes in precipitation microphysics (Bhattacharjee et al., 2009).