Ice Supersaturation and its effect on Climate

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Conclusions

1. Observed supersaturation (SSAT) frequency & distribution varies alot.
2. Climate is sensitive to supersaturation. It affects clouds and radiative forcing.
3. Ice fraction & supersaturation looks good with new formulation.
4. Climate is sensitive to the Ice Nucleation (IN) parameterization.
5. Global Aerosol Indirect Effects (AIE) are ~1.5Wm^{-2} in these simulations.
6. SSAT & IN changes increase AOD. Nucleation increases AIE at high latitudes.

Methods: Model & Observation

We use the NCAR Community Atmosphere Model (CAM) version 3.5, a GCM coupled to the Bulk Aerosol Model (BAM) with AEROCOM emissions for 2000 & 1750. CAM has 2-moment cloud microphysics (Morrison & Gettelman, 2008) with droplet nucleation described by Abdul-Razzak & Ghan (2001). Two sets of modifications are introduced. (1) 'SSAT': The model macrophysical closure (Zhang et al 2003) is modified to close only on liquid saturation, and vapor deposition onto ice and liquid conversion to ice (Bergeron process) are included. (2) 'Liu IN': a new ice nucleation (IN) scheme (Liu et al, 2007) is implemented in the model to replaced the fixed IN scheme of Cooper (1986). (1) & (2) are also combined ('SSAT+Liu IN' runs).

Observations: We compare model ice saturation to humidity data from satellites (AIRS) and commerical aircraft (WVSS and MOZAIC). Simulations are also compared to MLS ice waer content observations

Ice Supersaturation

Ice Supersatration is frequent in the upper troposphere observed by satellites (AIRS) and aircraft (WVSS). WVSS-II data is from Tunable Diode Lasers on US based commercial cargo aircraft (Fig 1).

New CAM simulations indicate a similar distribution of supersaturation, peaking near the tropopause in the UTLS.

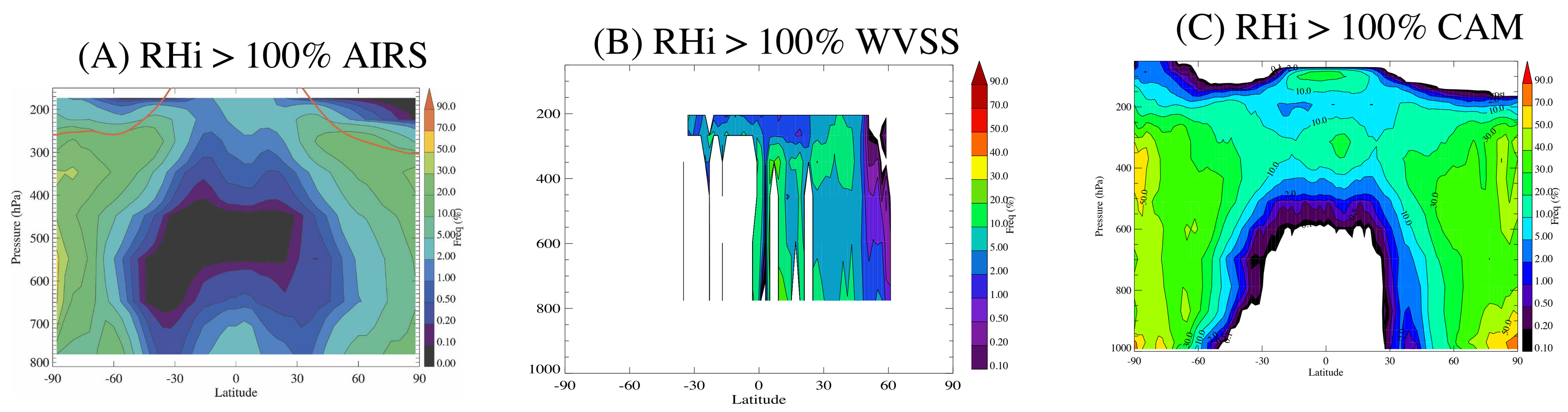

Fig 1: Annual zonal mean supersaturation (RHi > 100%) frequency from (A) AIRS, (B) WVSS & (C) CAM

Ice Supersaturation Climate Effect

Including supersaturation in CAM results in a decrease of cloud fraction, particularly mid and high cloud fraction (Fig 2). Ice water path also decreases (not shown). The result (Fig 3) is a significant global reduction (5 Wm^{-2}) in simulated longwave cloud forcing (LWCF).

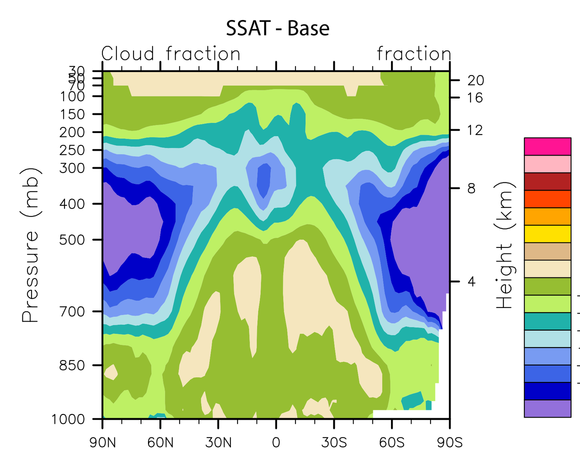

Fig 2: Annual CAM ΔCloud fraction between supersaturation run (SSAT) & base model

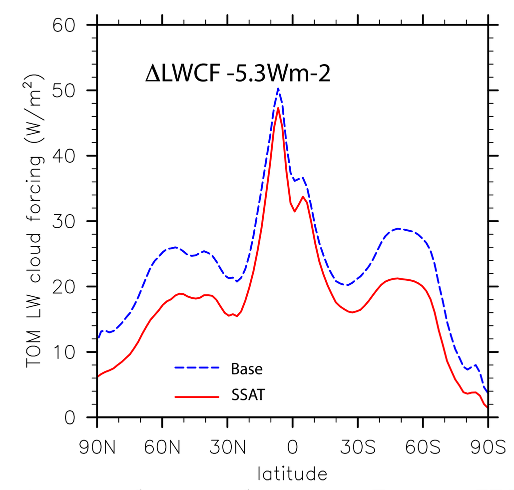

Fig 3: Annual zonal mean Long Wave Cloud Forcing (LWCF) for SSAT & base runs.

Ice Microphysics & Nucleation

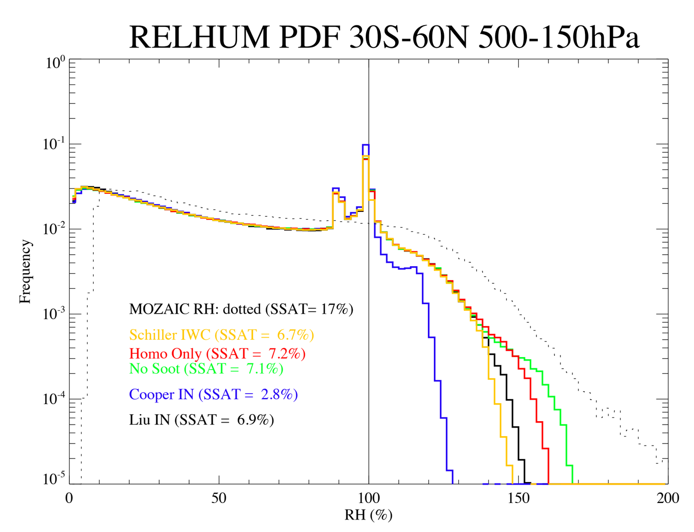

Fig 4: RH PDF from CAM simulations (solid lines) & MOZAIC data (dotted).

Probability distributions of RH from CAM compare well to observations. Reduction of ice nucleation (Liu IN, Liu IN without soot, Liu IN & homogenous nucleation only) creates more supersaturation than the Cooper IN formulation (Fig 4).

The simulation of ice fraction (Fig 5) is improved in the new formulations, relative to observations (Field et al 2005). Little ice exists for T< -35°C.

Simulated Ice Water Contents (IWC) are similar to MLS satellite observations (Fig 6). Model fields include precipitation (snow) for comparison. Altitudes are slightly different, but patterns at ~220hPa are similar.

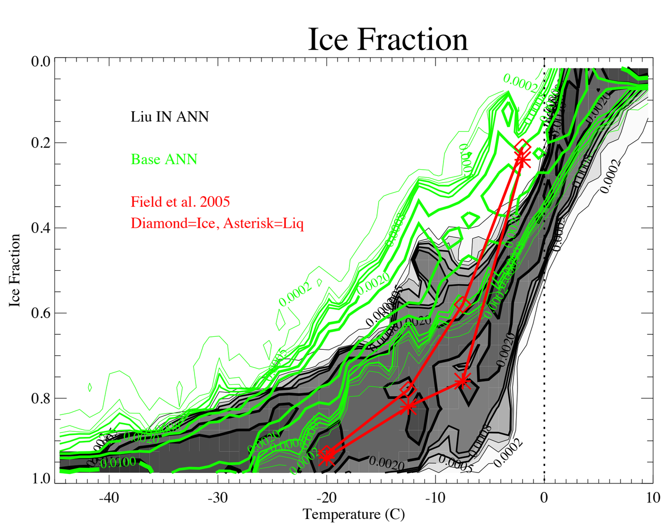

Fig5: CAM Ice Fraction for base (green) and new (black & shading) runs. Red indicates in-situ observations.

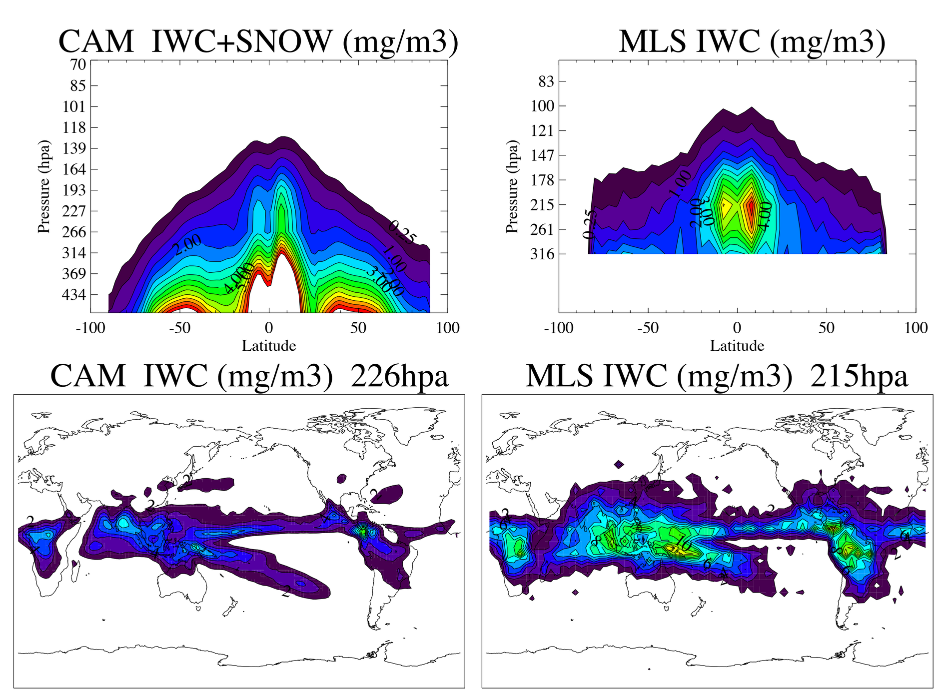

Fig 6: CAM (left) and MLS (right) ice water contents for annual zonal mean (top) and at ~220hPa (bottom). CAM data includes snow.

Ice Nucleation (IN) Climate Effect

A change in the nucleation also changes clouds and radiative forcing. Fig 7 shows an increase in clouds when fixed IN are used (clouds decrease with new IN formulation). This decrease in clouds is associated with a significant (5.5Wm^{-2}) decrease in Long Wave Cloud Forcing (LWCF).

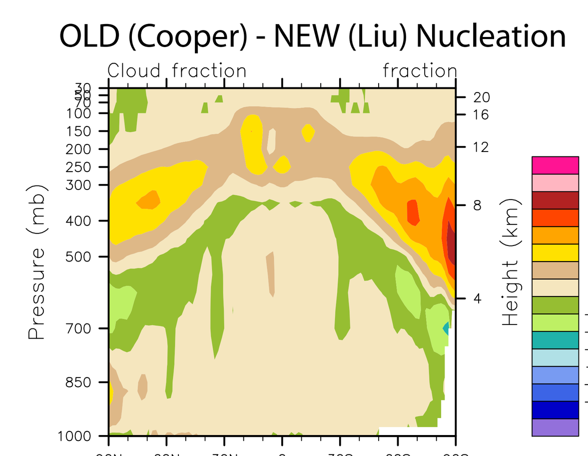

Fig 7: Cloud fraction change for runs with (NEW) & without (OLD) Liu ice nucleation. (OLD = SSAT, NEW=SSAT+Liu IN)

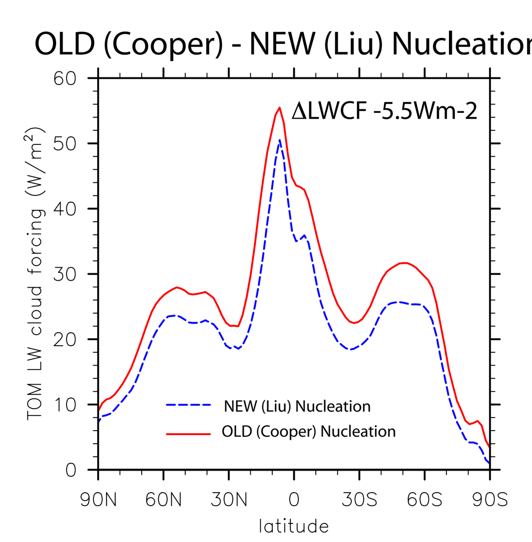

Fig 8: Long Wave Cloud Forcing (LWCF) for OLD and NEW ice nucleation runs. (OLD = SSAT, NEW=SSAT+Liu IN)

Ice Indirect Effects

We conducted prognostic aerosol runs with pre-industrial (1750) & present day (2000) emissions (from the AEROCOM database). Pairs of simulations are compared to look at the Aerosol Indirect Effect (AIE), the residual of:

$$AIE = \Delta TOA - \Delta DE$$

ΔTOA is top of atmosphere change & ΔDE is the change in aerosol Direct Effect. AIE includes changes to liquid & ice clouds in the LW and SW. Base AIE = -1.5 Wm^{-2}.

Fig 9 shows the change in Soot & Sufate number in NH mid-latitudes between 2000 and 1750. Changes at high altitudes are significant.

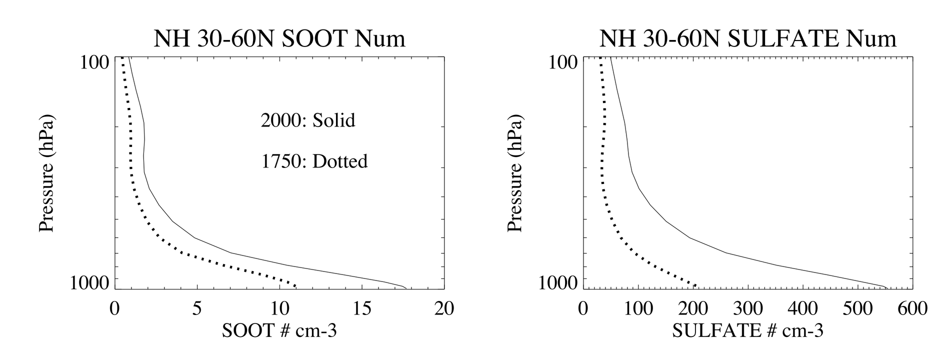

Fig 9: NH zonal average soot (left) & sulfate (right) number concentrations with emissions for 2000 (solid) and 1750 (dotted).

Fig 10 shows results of 3 pairs of runs: Base (black), Supersaturation (SSAT-blue) & supersaturation with Liu ice nucleation (SSAT+ Liu IN red). SSAT and SSAT+ Liu IN increase ΔAOD. Liu IN tends to increase AIE (both runs have SSAT modifications), while SSAT alone reduces AIE.

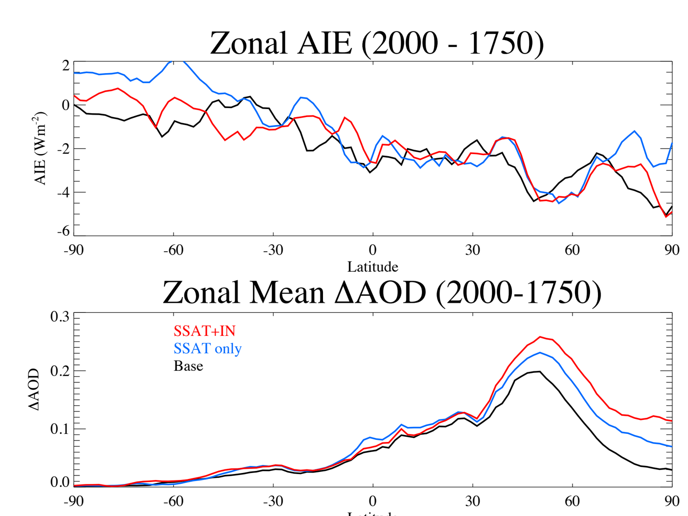

Fig 10: Top: Zonal mean Aerosol Indirect Effect (AIE). Bottom: Aerosol Optical Depth change (ΔAOD) for 3 pairs of runs estimated using AEROCOM emissions (Fig 9).

References

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