Potential Research Topics for the ARM Science Plan: Characterizing Cirrus Size Distributions and Their Mass Sedimentation Rates

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Inoue (1985), Parol et al. (1991) and others have shown that the retrieved effective emissivity at 12 μm, $\varepsilon_{eff}(12\ \mu m)$, is related to $\varepsilon_{eff}(11\ \mu m)$ as:

$$\varepsilon_{eff}(12\ \mu m) = 1 - [1 - \varepsilon_{eff}(11\ \mu m)]^{\beta_{eff}}$$

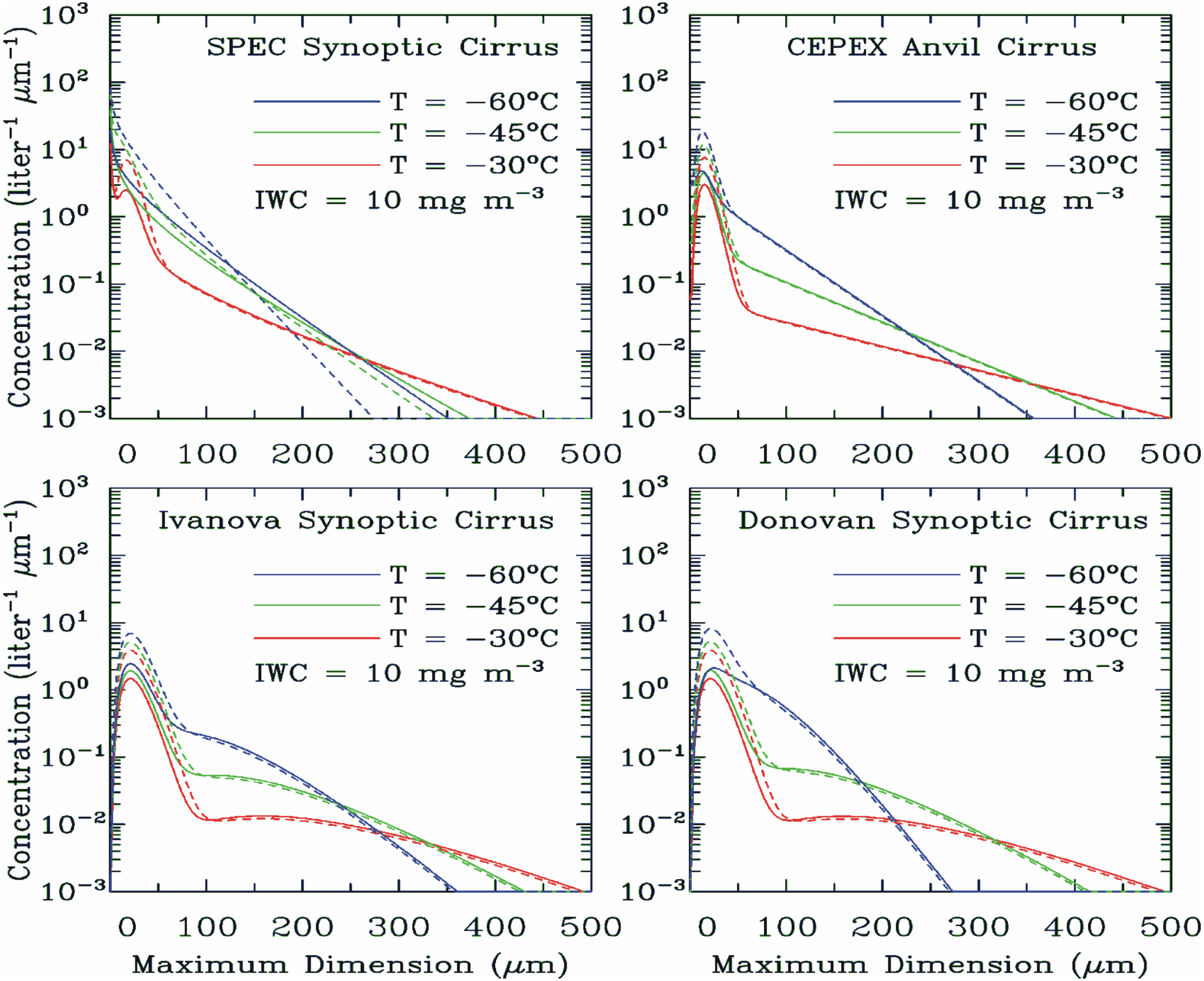
for tropical and mid-latitude cirrus, where

$$\beta_{eff} = Q_{abs,eff(12\ \mu m)}/Q_{abs,eff(11\ \mu m)} \approx 1.08 \pm 0.04$$

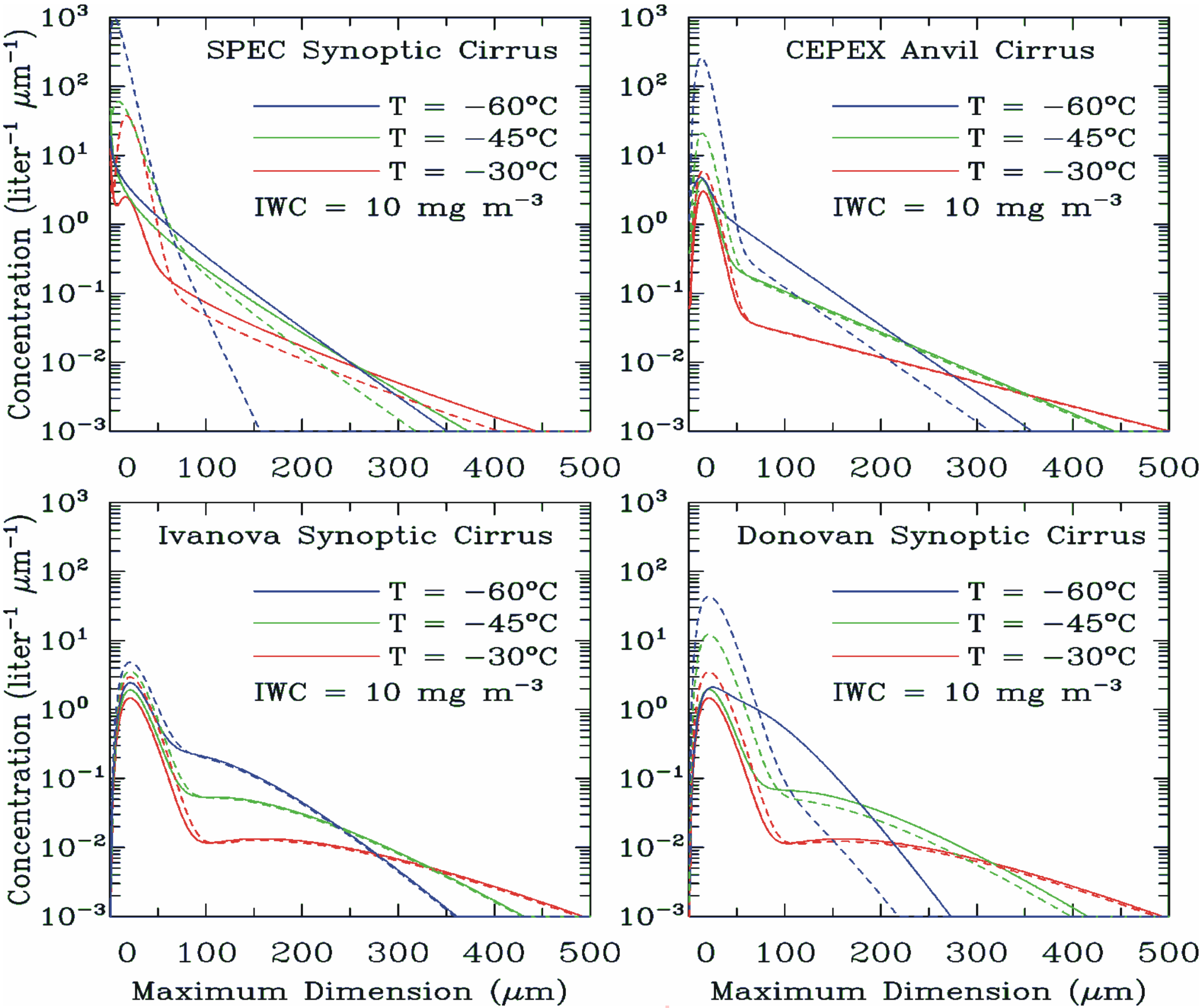
$$Q_{abs,eff} = Q_{abs}\,(1 - \omega_o\, g)/(1 - \omega_o)$$

When g => 1, all scattering is completely forward scattering and radiation is not redistributed.

Retrieved PSD having mean and maximum small crystal concentrations

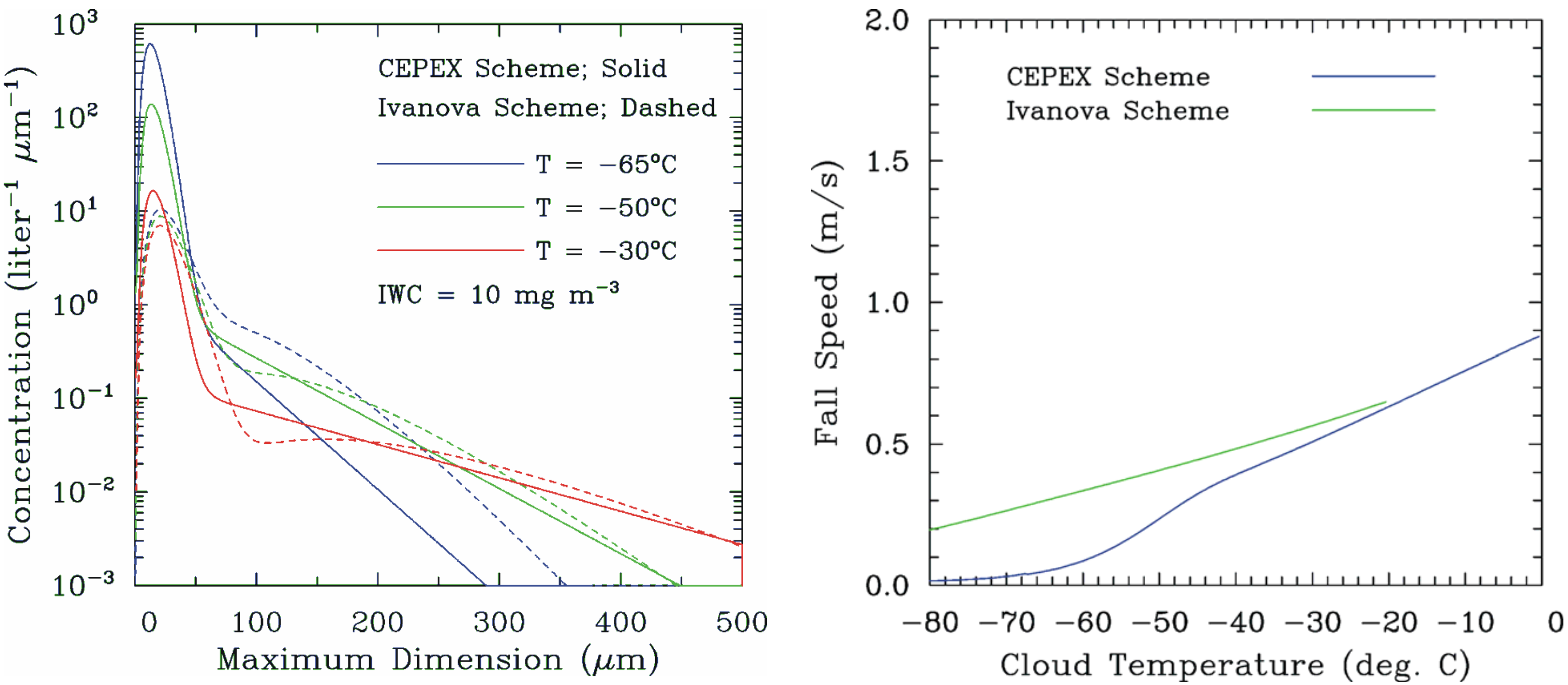


Comparison of original PSD scheme (dashed) with retrieved PSD (solid)



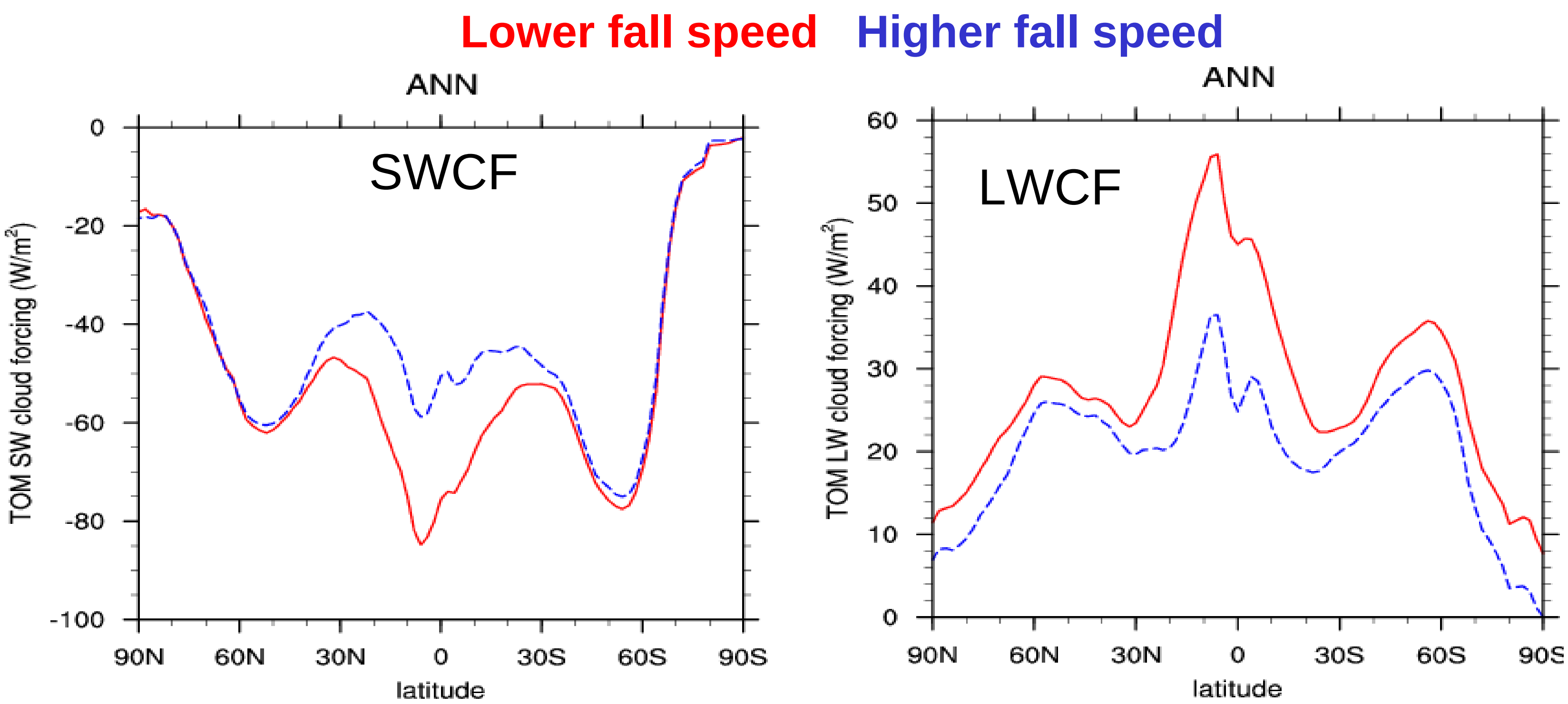
PSD Impact on Mass-weighted Fall Speeds

(from Mitchell et al. 2008, GRL)



PSD Impact on Mass-weighted Fall Speeds (cont.)

(from Mitchell et al. 2008, GRL)



Sanderson et al. (2008, Clim. Dyn.) found climate sensitivity was most influenced by the entrainment coefficient and the ice fall speed.

Geoengineering of the Upper Troposphere: Is It Worth Exploring the Possibility?

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Photo courtesy of Paul Lawson/J.H. Bain

Sanderson et al. 2008, Climate Dynamics:

- **Climate sensitivity depends mostly on the entrainment coefficient and ice fall speed. Considering the reasons why, it is apparent that climate sensitivity is most dependent on the water vapor and cirrus coverage in the upper troposphere.**

Mitchell et al. 2008, Geophys. Res. Letters:

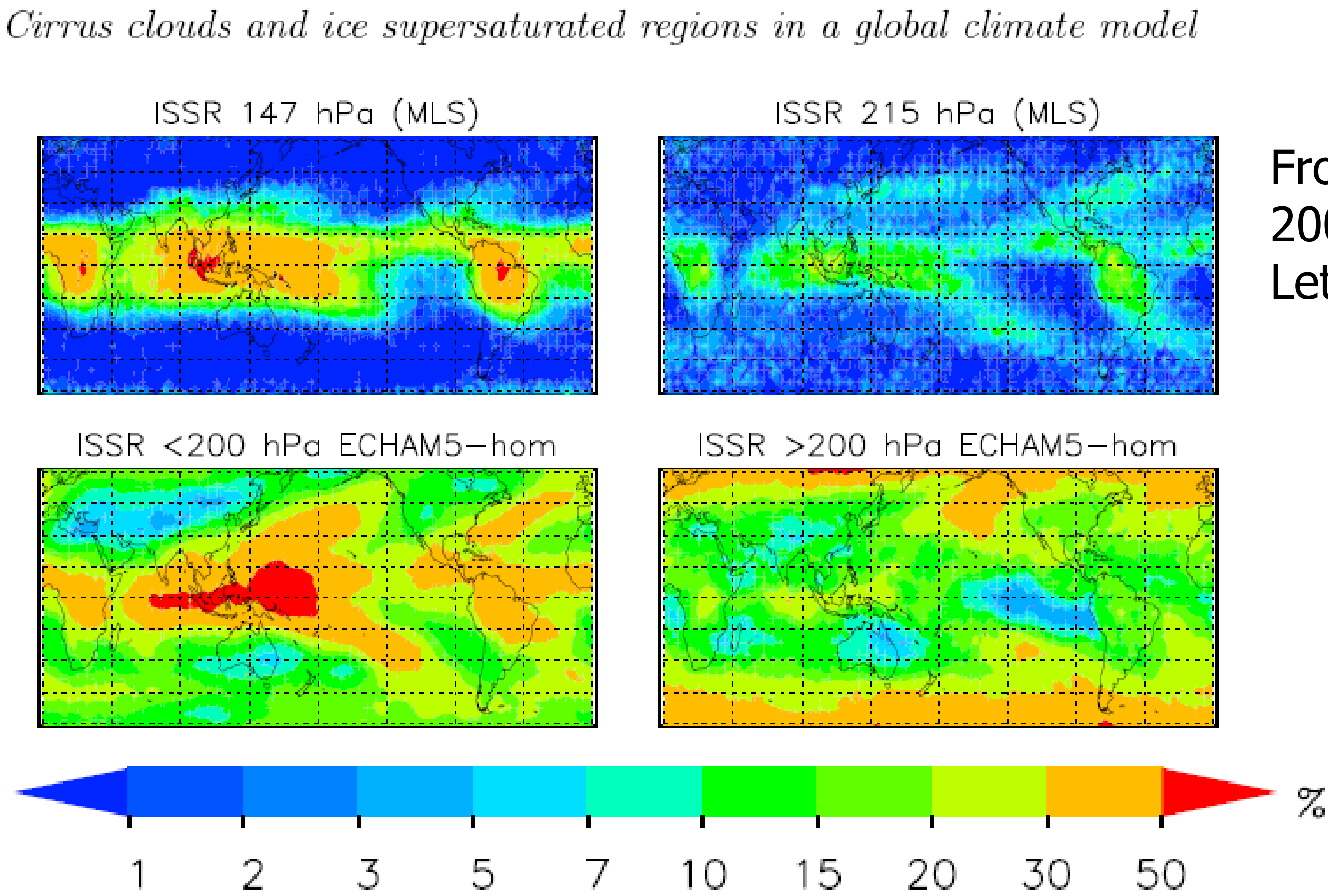
- **CAM3 climatology sensitive to the concentration of small ice crystals through their impact on the ice fall speed. OLR affected mostly by changes in cirrus coverage (as opposed to IWP).**

Question: Given their top-ranking influence on climate sensitivity, can upper troposphere cirrus clouds and water vapor be modified to reduce the rate of global warming?

Answer: Don't know, but possibly by introducing efficient ice nuclei where the cirrus cloud greenhouse effect is strongest and ice supersaturation is highest ($T < -40\ ^oC$).

Background:

- Homogeneous nucleation often dominates for T < -40 °C with ice saturation ~ 40%
- MLS satellite measurements indicate large portions of the clear-sky upper troposphere are supersaturated wrt ice (see figure)

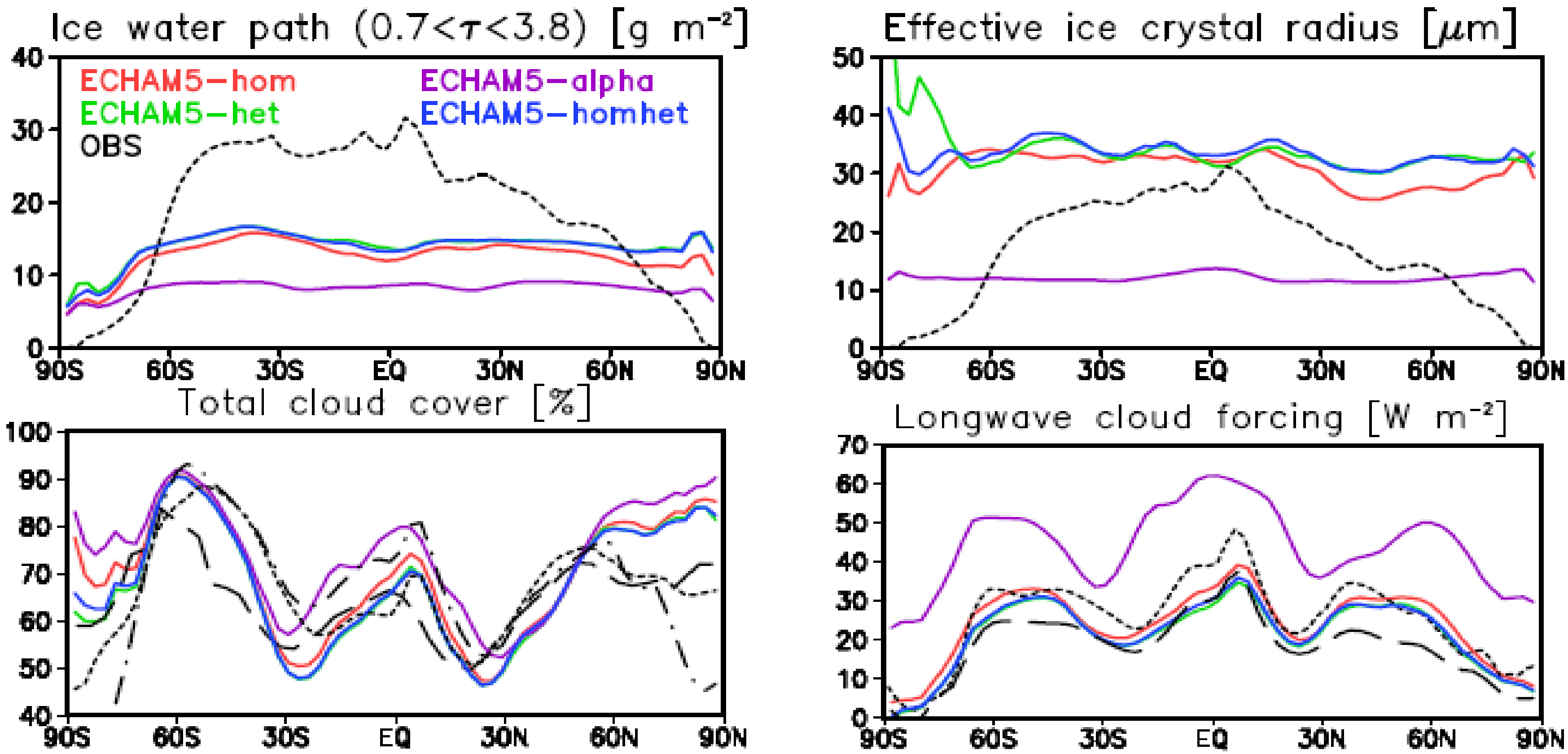


From Lohmann et al. 2008, Environ. Res. Letters

Background (cont.):

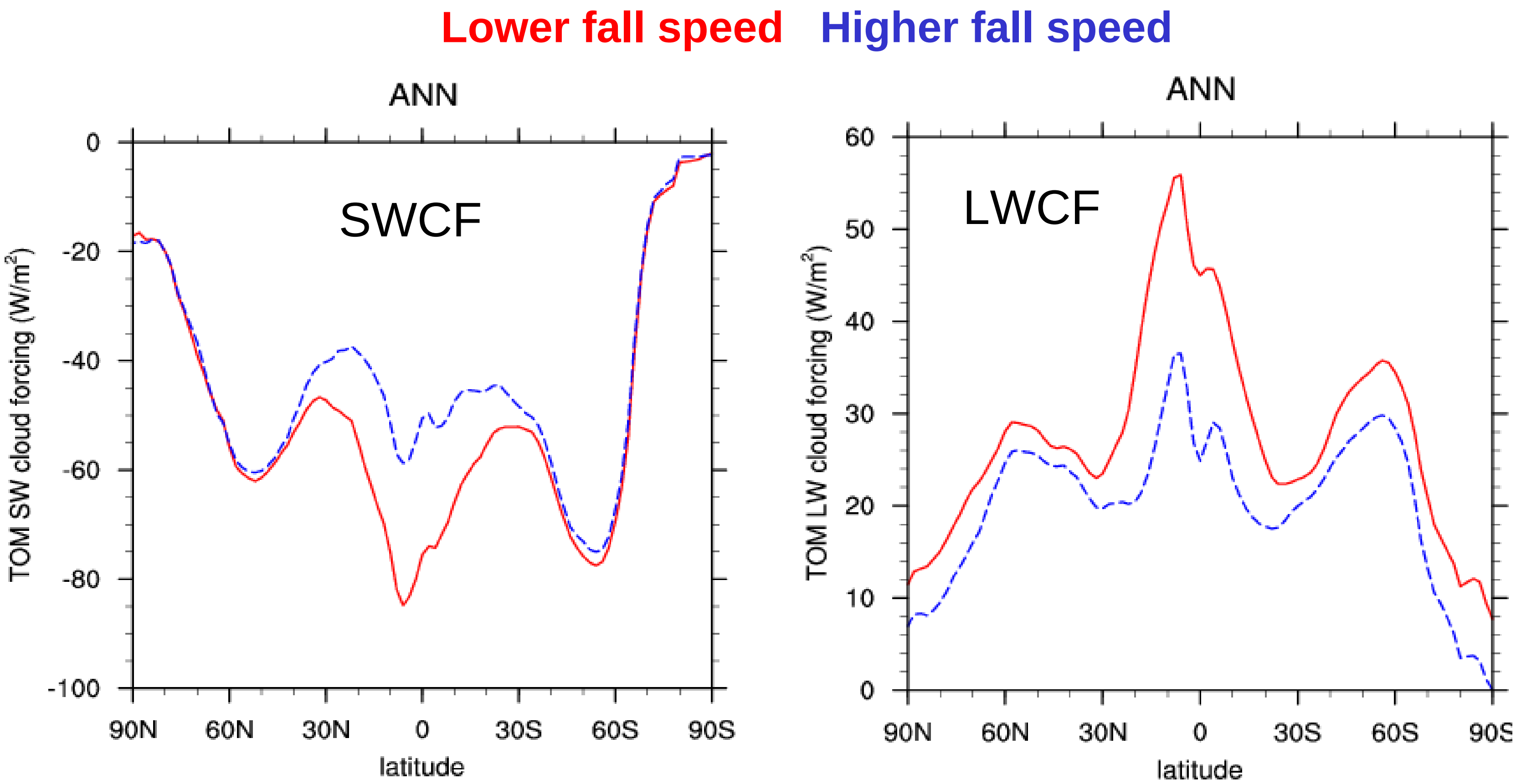
- For such conditions, more efficient heterogeneous ice nuclei outcompete the natural homogeneous ice nuclei and form larger ice crystals having higher fall speeds.
- This leads to reduced cirrus coverage and greater OLR in GCM experiments

GCM study by Lohmann et al. in Environ. Res. Letters, 2008

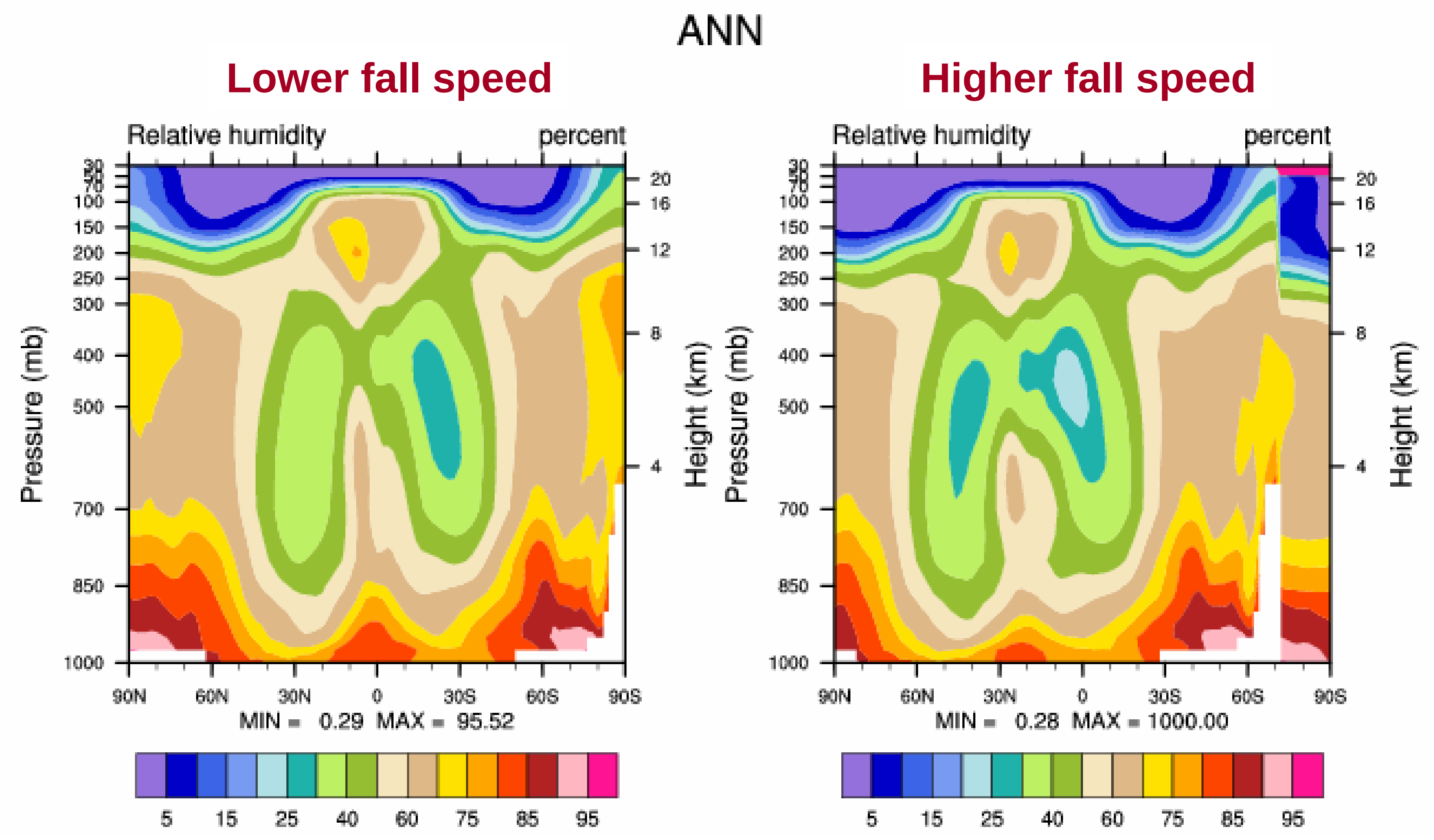


Background (cont.):

Similar results were found in GCM (CAM3) study by Mitchell et al. 2008, GRL. As fall speeds increase, net cooling occurs where global warming effects are greater (mid-latitudes & polar regions). Key difference from Lohmann et al. is that fall speed change is greater in the tropics.



Background (cont.):
Unpublished findings from Mitchell et al. (2008) show that increasing the ice fall speed also decreases the RH in the middle and upper troposphere.



Geoengineering idea:

- Introduce very efficient ice nuclei into the upper troposphere where greenhouse effect of cirrus is strongest ($T < \sim 40\ ^{o}C$). Apply over mid-latitude & polar regions or over entire globe.
- Cirrus forming is this treated air mass may have larger ice crystals with greater fall speeds and thus higher ice removal rates.
- Initially cirrus coverage may increase in otherwise clear-sky ice-supersaturated conditions.
- Eventually a new equilibrium will be attained that may be drier due to
    1) Greater ice removal rates
    2) Depletion of water vapor in otherwise clear-sky supersaturated regions through ice sedimentation.
- Outgoing longwave radiation increases due to less cirrus coverage and lower RH in upper troposphere. Shortwave radiation is not affected much. This should lower surface temperatures (Sanderson et al. 2008).

Seeding Material and Delivery Mechanism:

- Several substances have been found that nucleate ice as efficiently as silver iodide, are relatively inexpensive and are non-toxic.

- The delivery mechanism may already exist if seeding substrate can be injected and vaporized in the exhaust of commercial airliner engines. The engines themselves may not need to be exposed to seeding material.

Possible Path Forwards:

1) Perform GCM experiments to test idea and evaluate climate impact

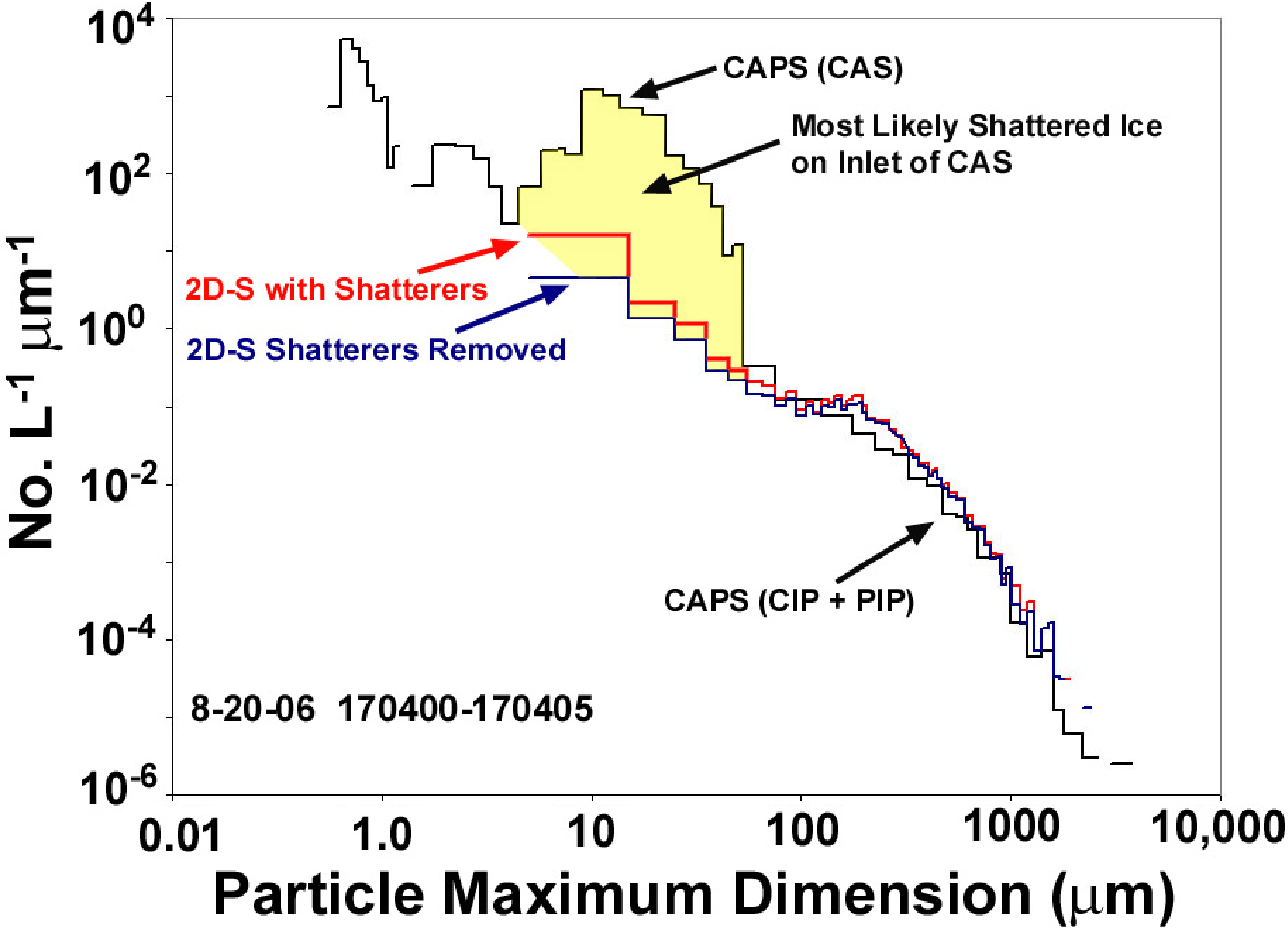
2) Design field campaign to test idea and to help evaluate climate impact

3) Consult with aeronautical engineers on feasibility aspects and with FAA on cost sharing aspects

4) Operational phase

Closing Comments

- GCM experiments on stratospheric aerosol geoengineering show the Earth's climate returning to global warming equilibrium within ~7 years after geoengineering ends. Geoengineering may buy time for transitioning to "green" technologies, but it is not a solution to global warming.
- Ocean acidification would still occur using this approach.
- Geoengineering carries the risk of changing climate in unforeseen ways. If negative side-effects occurred in this approach, the process could be terminated and conditions could return to normal relatively rapidly (as compared to oceanic timescales).
- Since LW and not SW radiation is affected, plants and precipitation amounts may not be affected.
- Relative to other geoengineering schemes, this appears much less expensive and arguably effective, targeting a natural mechanism that appears to have the strongest impact on surface temperatures.



CAPS (CAS)
Most Likely Shattered Ice
on Inlet of CAS
2D-S with Shatterers
2D-S Shatterers Removed
CAPS (CIP + PIP)
8-20-06 170400-170405
No. L-1 µm-1
Particle Maximum Dimension (µm)
10^4
10^2
10^0
10^-2
10^-4
10^-6
0.01
1.0
10
100
1000
10,000