The dependence of ice microphysics on aerosol concentration in arctic mixed-phase stratus clouds during ISDAC and M-PACE

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1. Motivation

Aerosols indirectly affect mixed-phase cloud microphysics through 3 mechanisms:

- ***glaciation indirect effect*** **– increases in ice nuclei (IN) → increases in ice crystal concentration (N_{ice})**
- ***riming indirect effect*** **– increases in cloud condensation nuclei (CCN) → decreases in liquid drop size → inhibits riming, decreasing ice water content (IWC)**
- ***cold 2nd indirect effect*** **– increases in CCN → increases in liquid concentration N_{liq}→ decreases in liquid drop size, inhibits ice crystal formation & decreases N_{ice}**

Examined effects for single-layer stratus (8, 18 & 26 Apr. 2008) sampled during Indirect and Semi-Direct Aerosol Campaign (ISDAC); comparison with Oct. 2004 Mixed-Phase Arctic Cloud Experiment (M-PACE) gives more insight.

2. Method for Determining Cloud-Aerosol Relationships for ISDAC

Relationship between in cloud & out of cloud aerosol properties determined for ramped profiles flown by National Research Council of Canada Convair-580 during ISDAC following Fig. 1.

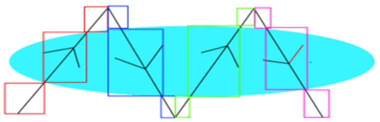

Fig. 1.Teal ellipse denotes cloud, black line flight track. Average below/above cloud interval denoted by colored box matching in cloud interval denoted by same color.

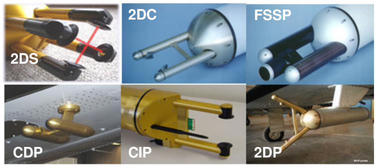

Fig. 2. Probes used to measure $N_{liq}(D)$ & $N_{ice}(D)$ during ISDAC.

Comparing SDs & mass closure tests gives best liquid & ice SDs ($N_{liq}(D)$, $N_{ice}(D)$), & IWC.

- **Cloud Droplet Probe (CDP) for liquid SDs & liquid water content (LWC) for D < 50 µm;**
- **2D Stereo Probe (2DS): 50 < D < 300 µm, 2D Cloud Probe (2DC): 300 < D < 800 µm, & 2D Precipitation Probe (2DP): D > 800 µm**
- **Aerosol (N_{PCASP}) from Passive Cavity Aerosol Spectrometer (PCASP); IN from Continuous Flow Diffusion Chamber (CFDC)**
- **Images from Cloud Particle Imager (CPI) provide size-habit distributions needed for optimum m-D relations to give IWC**

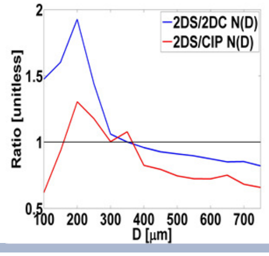

Fig 3: 2DS $N_{ice}(D)$/ 2DC or CIP $N_{ice}(D)$ for ISDAC ice cases. Large variation for D < 300 µm consistent with measurement uncertainties.

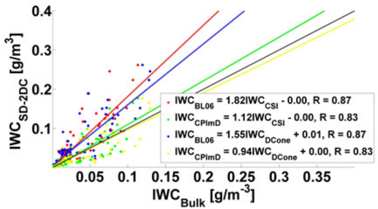

Fig 4. IWC from m-D relations applied to SDs separated by CPI habit more consistent with bulk IWC from Nevzorov or CSI probe than that derived from SDs using Baker and Lawson [2006] technique. Each point 30 s average.

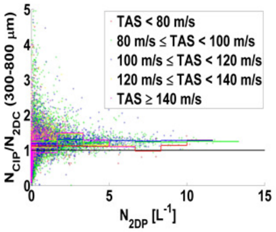

Fig 5. CIP N_{ice}/ 2DC N_{ice} for 300 < D < 800 µm vs. 2DP N_{ice} sorted by air speed. 30 s averages. 2DC & CIP agree well in this size range.

3. Analysis

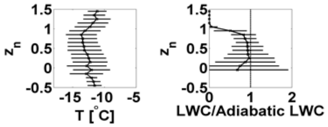

Fig 6. Mean/σ T & LWC /adiabatic LWC vs. normalized altitude z_n for ISDAC cases. Sub-adiabatic LWC at z_n > 0.8 consistent with dry air entrainment from above cloud.

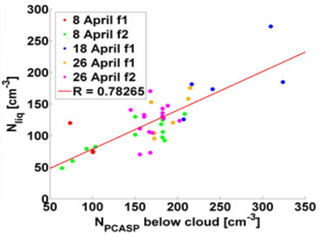

Fig 8. Mean N_{liq} & below cloud N_{PCASP} strongly correlated consistent with nucleation at cloud base. Adiabatic LWC vs. z_n (Fig. 6) → condensation growth in updraft. Correlation with N_{PCASP} above cloud much weaker (0.37).

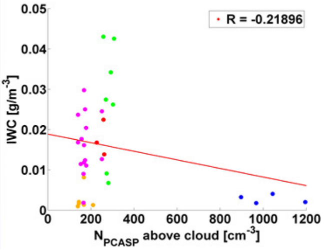

Fig 10. Cloud mean IWC & above cloud N_{PCASP} weakly correlated. Correlation with below cloud N_{PCASP} also weak (-0.32). Thus no evidence of riming indirect effect. Colors as in Fig. 8.

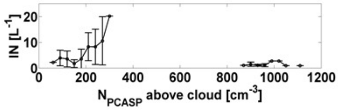

Fig 7. Mean/σ IN vs. N_{PCASP} above cloud. IN sampled ~-25° C at water sub-saturation. IN increase with N_{PCASP} < 400 cm^{-3} suggests deposition nucleation important

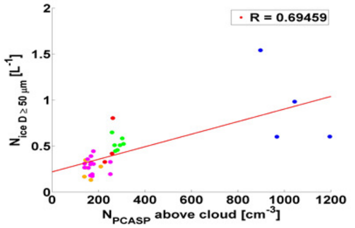

Fig 9. N_{ice}(D > 50 µm) & above cloud N_{PCASP} strongly correlated consistent with glaciation indirect effect, most likely from IN entrained above cloud (see IN vs. N_{PCASP} in Fig. 7). Colors as in Fig. 8. Correlation with N_{PCASP} below cloud much weaker (0.37).

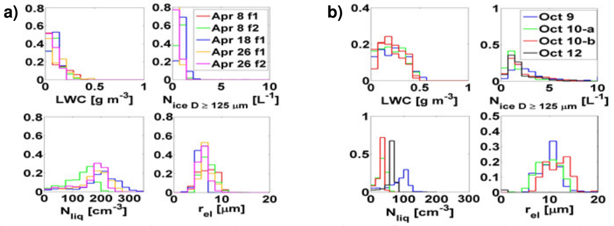

*Fig 11. Normalized frequency histograms of N_{ice}(D > 125 µm), N_{liq}, liquid effective radius (r_{el}), & LWC for ISDAC **(a)** and M-PACE (**b**). M-PACE conditions cleaner than ISDAC conditions. Lower $N_{liq,}$higher $r_{el,}$ & N_{ice}(D > 125 µm) for M-PACE consistent with cold second indirect effect. Higher LWC in M-PACE consistent with more open water in arctic fall than spring.*

4. Conclusions

For ISDAC single-layer stratus:

- **Nucleation of liquid drops occurred at cloud base**
- **Glaciation indirect effect operated through entrainment of IN & dry air above cloud**
- **Riming indirect effect did not play big role**

Differences in ISDAC & M-PACE single-layer stratus consistent with operation of cold second indirect effect & greater surface fluxes during fall

- **Future modelling studies should isolate these effects**

5. Reference

Baker, B. A., and R. P. Lawson, 2006: *J. Appl. Meteor.*, **45**, 1282-1290.

6. Acknowledgements

This work was supported by the Office of Biological and Environmental Research (BER) of the U.S. Department of Energy (DE-FG02-02ER63337, DE-FG02-07ER64378 and DE-FG02-09ER64770) as part of the ASR + AAF program. Data were obtained from the ARM program archive, sponsored by the U.S. DOE, Office of Science, BER, Environmental Sciences Division.

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