

## Research Highlight

Atmospheric aerosol particles can indirectly influence the Earth's radiative balance through their interactions with clouds and precipitation. These complex interactions, which are modulated by aerosol properties and local meteorology, represent a key uncertainty in global climate models. Field measurement studies of aerosol-cloud-precipitation interactions are therefore of critical importance, particularly in the Arctic, which has shown enhanced sensitivity to climate change. Accordingly, the DOE Indirect and Semi-Direct Aerosol Campaign (ISDAC) was conducted in Alaska in April 2008 to improve process-based understanding of aerosol indirect effects.

In the present study, aircraft measurements obtained during ISDAC are used to investigate the factors influencing the microphysics and radiative properties of low-level, liquid-dominated Arctic clouds. Analysis was based on vertical profiles through cloud, as well as horizontal flight legs below cloud for the characterization of aerosol. Two distinct aerosol-cloud regimes were identified from the data. More polluted cases, with higher aerosol particle number concentrations below cloud ( $N_a > 500 \text{ cm}^{-3}$ ), were correlated with warmer, geometrically thicker clouds, with higher droplet number concentrations ( $N_d$ ) and liquid water paths ( $LWP$ ) relative to cleaner cases with  $N_a < 250 \text{ cm}^{-3}$  below cloud. These differences are illustrated in Figure 1 for representative cases in each of the aerosol-cloud regimes. On account of their larger geometric thicknesses and higher  $N_d$ , the clouds in polluted cases also had higher optical depths ( $\tau$ ) and albedo ( $A$ ), and hence attenuate and reflect solar radiation more effectively than the thinner clouds in clean cases.

Despite the differences noted above, the average cloud droplet sizes—considered in terms of the mean effective radii ( $r_{\text{eff}}$ )—were similar for both aerosol-cloud regimes, on account of the enhanced  $LWP$  in polluted cases (Figure 2). This enhancement can be explained by both meteorological (temperature, inversion height) and microphysical factors. With regard to the latter, the enhanced  $N_a$  in polluted cases provides more potential cloud-condensation nuclei (CCN); for a given cloud  $LWP$ , this allows for the formation of more droplets of smaller size (first aerosol indirect effect). Vertical profiles of  $r_{\text{eff}}$  in cloud indicated that droplets were smaller than the critical size for drizzle formation; hence, the enhanced CCN and droplet formation in polluted cases likely limit droplet growth, suppressing the formation of precipitation (second aerosol indirect effect). Profiles through cloud in clean cases also showed  $r_{\text{eff}}$  values below the drizzle size threshold; however, given the significantly lower  $N_a$  for these cases, it is likely that larger droplets formed and precipitated out, depleting cloud liquid water. As well, light ice-phase precipitation was often observed in clean cases, providing an additional mechanism for liquid water depletion, consistent with the lower  $LWP$  observed for these cases.

Adiabatic cloud parcel model simulations were used to assess the role of aerosol physicochemical properties in the observed differences between the aerosol-cloud regimes. Characterization of aerosol particles below-cloud indicated that the accumulation mode diameter of particles was larger for polluted cases and that the composition was dominated by biomass burning particles, often internally mixed with organics and sulfate. In clean cases, organics were the main chemical component and were mixed to varying extents with sulfate and biomass burning products. The model results showed that the peak water vapour supersaturation attained in cloud was higher for clean cases, resulting in the activation of almost all particles. For polluted cases, on the other hand, the simulation results indicated a lower peak supersaturation in cloud due to the competition for water vapour among the more numerous particles, resulting in the preferential activation of larger and/or more

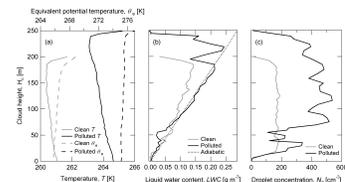


Figure 1. (a) Absolute and equivalent potential temperature, (b) liquid water content, and (c) droplet number concentration from vertical profiles through cloud for a clean case on April 27, 2008 and a polluted case on April 19, 2008. The adiabatic liquid water content is shown for reference in (b).

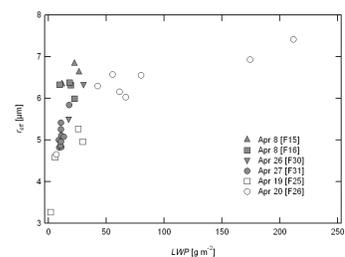


Figure 2. Mean cloud droplet effective radius as a function of liquid water path for all profiles through liquid-dominated cloud in clean (grey markers) and polluted (white markers) aerosol conditions. Flight dates [flight numbers] are indicated for each case.

hygroscopic particles. These differences in activation and the initial sizes of cloud droplets may have ramifications for the observed  $r_{\text{eff}}$ , though it is difficult to separate their contribution from the other microphysical and meteorological factors considered above.

In summary, aircraft measurements obtained during ISDAC and related parcel model simulations have been used to illustrate the complex relationships among aerosols, cloud microphysics, cloud radiative properties, and meteorology in liquid-dominated Arctic clouds. Additional studies are required to disentangle the relative contributions of these factors, in order to better understand, describe, and predict aerosol indirect effects in the Arctic.

### Reference(s)

Earle ME, PS Liu, JW Strapp, A Zelenyuk, D Imre, GM McFarquhar, NC Shantz, and WR Leaitch. 2011. "Factors influencing the microphysics and radiative properties of liquid-dominated Arctic clouds: insight from observations of aerosol and clouds during ISDAC." *Journal of Geophysical Research – Atmospheres*, , doi:10.1029/2011JD015727. ACCEPTED.

### Contributors

Michael Earle, *Environment Canada*; Peter Liu, *Environment Canada*

### Working Group(s)

Cloud-Aerosol-Precipitation Interactions