Revisiting Estimates of Longwave Aerosol Indirect Effects in Thin, Liquid-Containing Arctic Clouds

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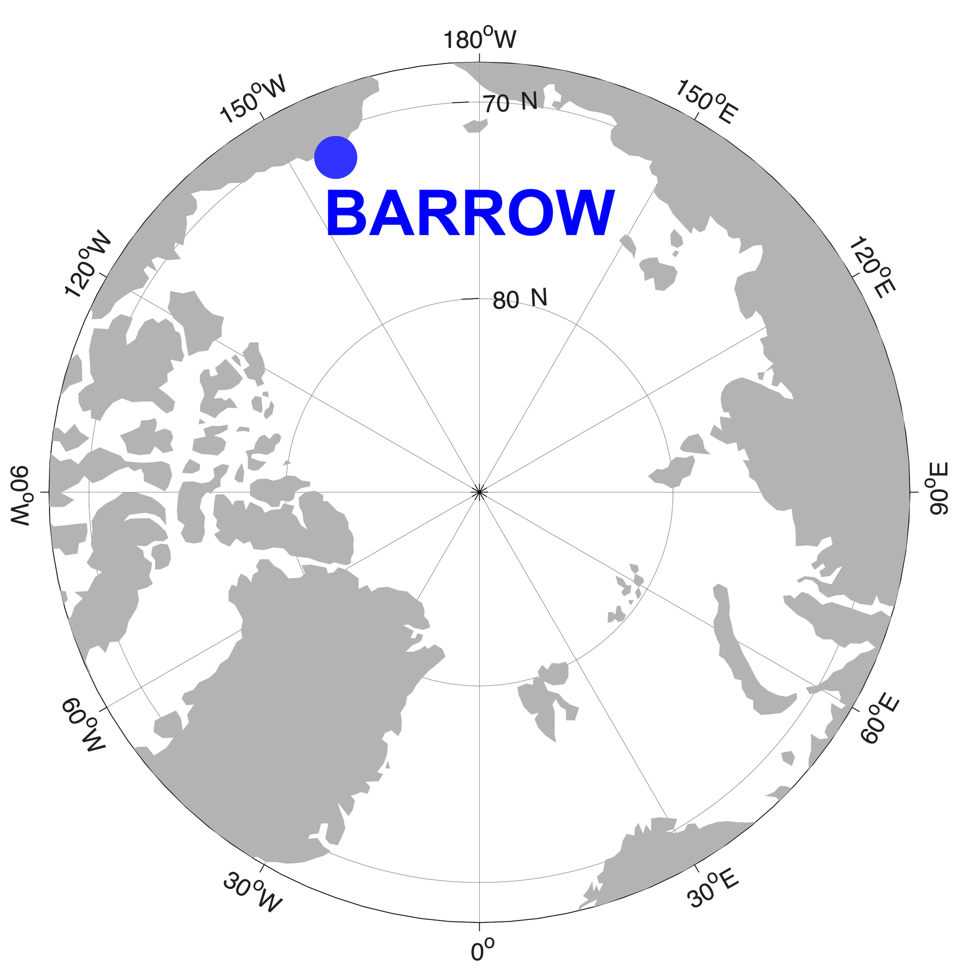
Introduction

Of the uncertainties surrounding our understanding of global climate, one of the largest involves the relationships between aerosols and clouds along with the resulting impacts on atmospheric radiation and precipitation. Due to very limited profiling of aerosol properties, traditionally aerosol-cloud interactions are evaluated using surface aerosol measurements as a proxy for aerosol at cloud height. At low- and mid-latitudes, clouds often form atop a well-mixed atmospheric boundary layer, meaning that the use of surface-based aerosol measurements is not necessarily unreasonable. At high latitudes, however, the atmosphere is often very stable. This stability limits vertical mixing of aerosols, meaning aerosol properties (e.g. number, hygroscopicity, scattering, size) observed at the Earth's surface may be very different from those at cloud height. This limitation makes it challenging to interpret previous efforts to understand the impacts of aerosols on liquid-containing Arctic clouds (e.g. Lubin and Vogelmann, 2006).

In this work, we first use a variety of measurements from high-latitude measurement campaigns that included some form of aerosol profiling to demonstrate the relationship between surface and elevated aerosol properties under different stability regimes. Then, using surface-based remote sensors we derive and validate estimates for atmospheric mixing state. This mixing state product is subsequently used to provide revised estimates on the influence of aerosol effects in thin, liquid-containing Arctic stratiform clouds using only cases in which the lower atmosphere is well mixed.

Datasets Used



ARM CLIMATE RESEARCH FACILITY

A variety of long-term (here 2000-2003) datasets from the DOE Atmospheric Radiation Measurement (ARM) North Slope of Alaska site (in Barrow, AK) are used to derive revised AIE estimates for single-layer Arctic clouds. Datasets used are outlined in the lists below. The availability of long-term datasets, as collected through the ARM program, is critical for evaluations of AIE. This is because a relatively large number of cases must be available to result in statistically significant results. We are currently working to expand this evaluation beyond the 2000-2003 time period, using measurements from 2004-2014.

To derive lower atmospheric mixing:

- Millimeter Cloud Radar (MMCR) reflectivity and Doppler velocity
- Wind Profiler derived horizontal wind speed. If the wind profiler is not available, interpolated radiosonde measurements are used
- Ceilometer/MPL backscatter to derive cloud boundary (base)

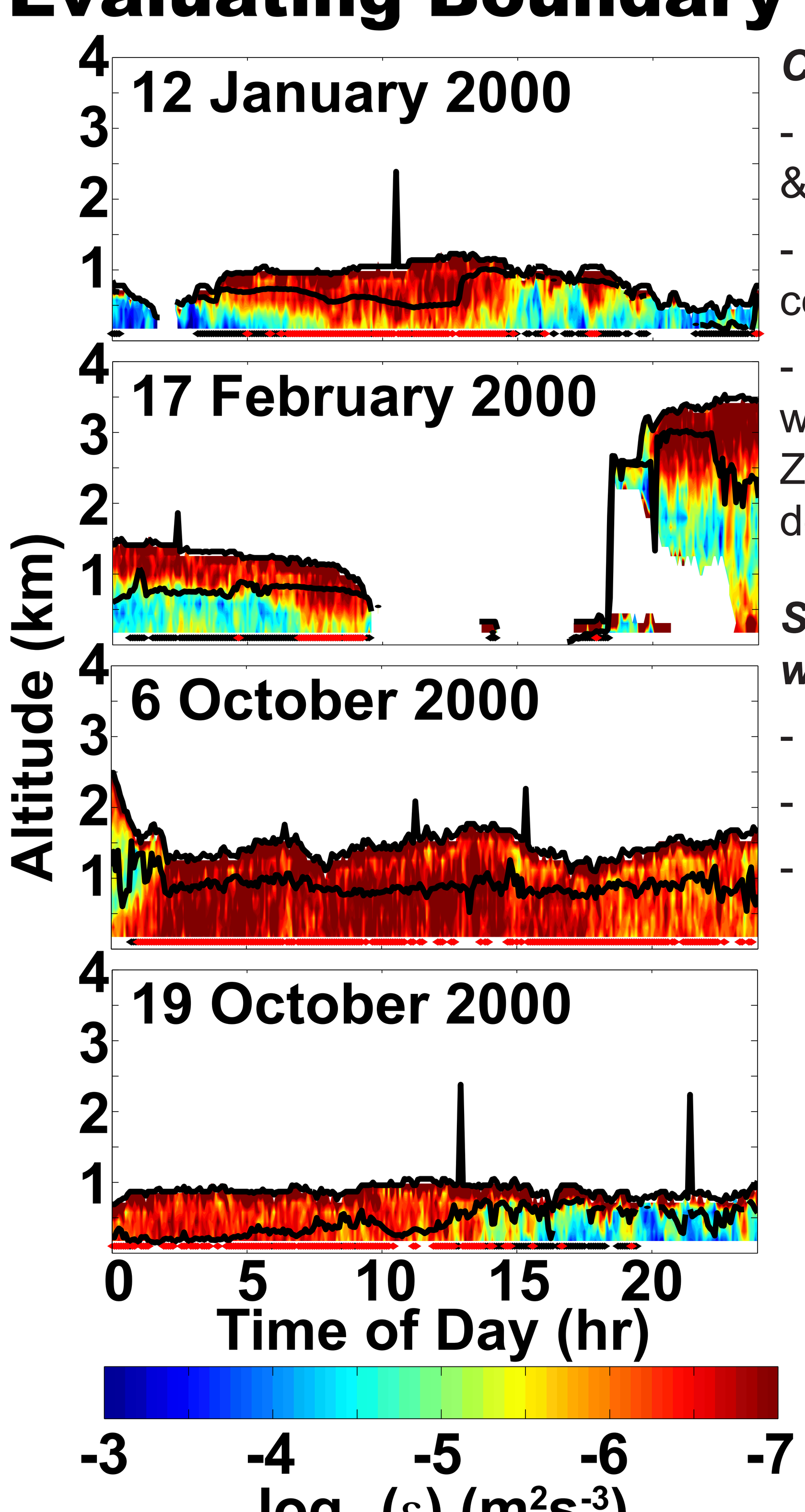
For more information, please see:
Shupe et al. [2012, AMT]

To derive cloud microphysics and emissivity:

- Rawinsonde Temperature and water vapor profiles
- AERI surface radiation
- Ceilometer/MPL derived cloud boundaries
- MMCR reflectivity, doppler velocity
- Microwave Radiometer derived LWP
- Spectrometer derived O_3 profile
- ECMWF Analysis for T, RH profiles

For more information, please see:
Garrett and Zhao [2013, AMT]

Evaluating Boundary Layer Mixing



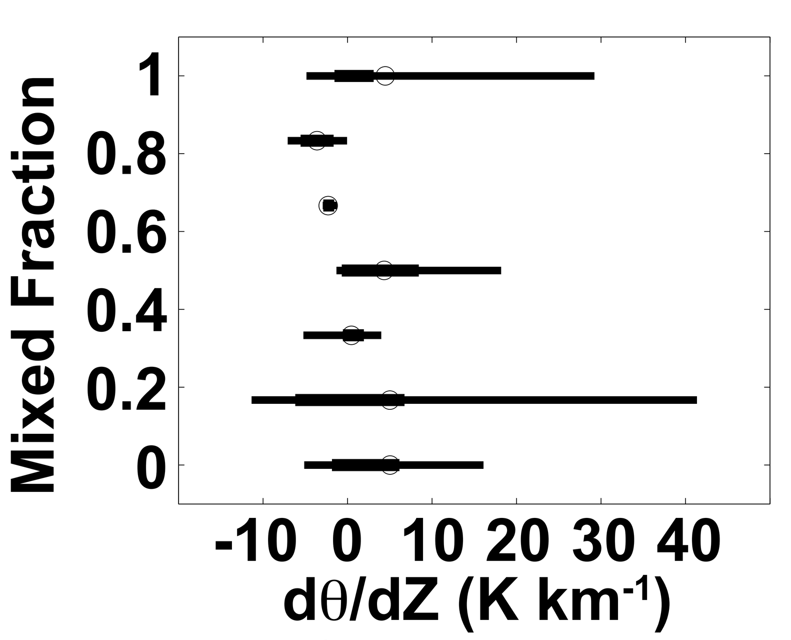
Turbulent dissipation rates as calculated for four cases. Red diamonds (bottom) indicate well-mixed time periods.

Cases of Interest:

- Cloud top height, from MMCR <1500 m & >135 m
- Cloud thickness, from MMCR and lidar/-ceilometer < 700 m & > 135 m
- Cloud determined to contain liquid water by AERI retrieval (see Garret and Zhao [2013, AMT] for details on phase determination

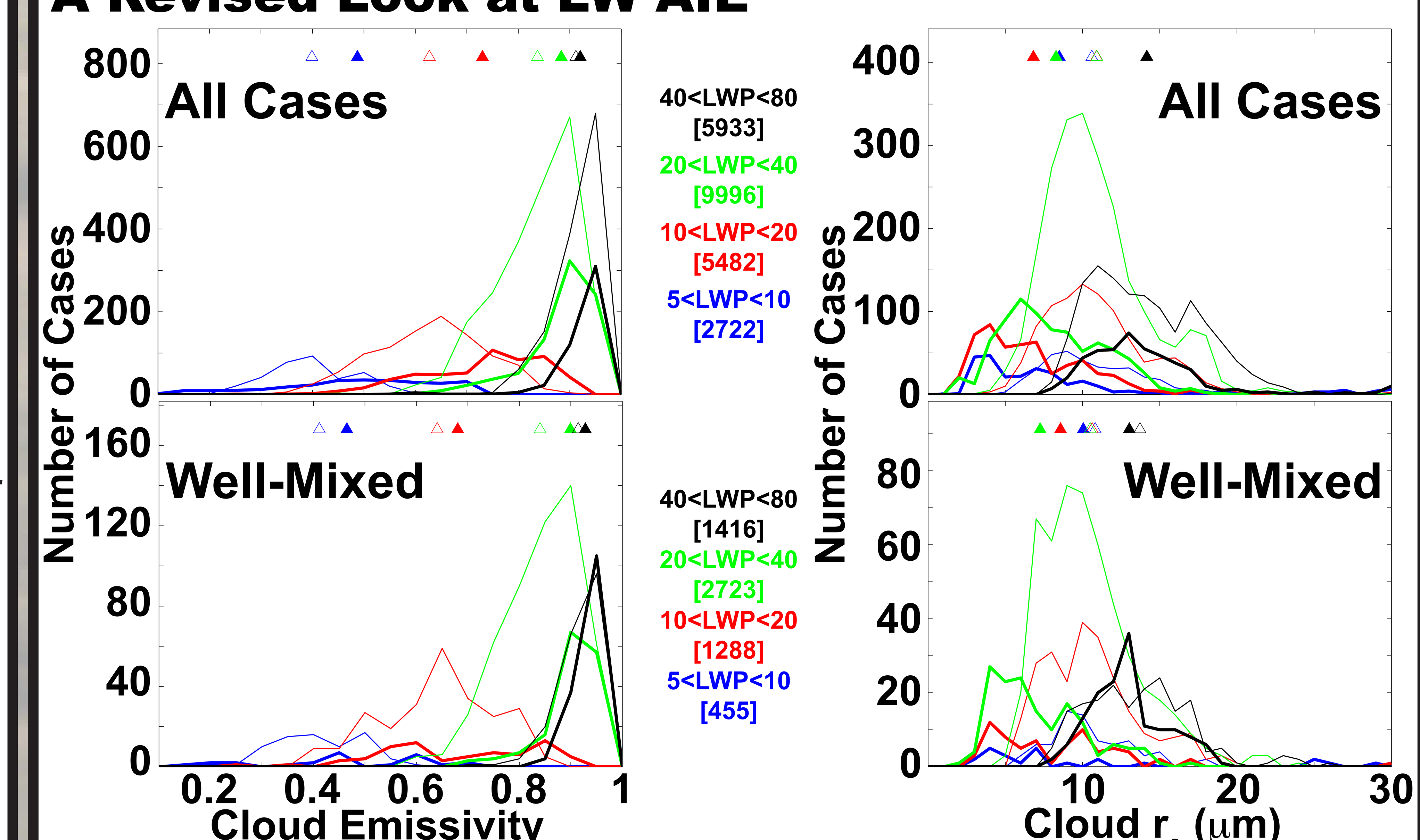
Sub-cloud region is determined to be well mixed based on a combination of:

- Low turbulent dissipation rate variance
- High mean turbulent dissipation rate
- High minimum turbulent dissipation rate



Distributions of radiosonde lapse-rate for liquid cloud cases. Mixed fraction represents the number of points (of 6) determined to be well-mixed.

A Revised Look at LW AIE



Distributions of cloud emissivity (left) and cloud droplet effective radius (r_e, right) for clouds of different liquid water path (LWP) ranges. Thin lines represent clean cases (surface aerosol scattering (s) < 1.6), while thick lines represent polluted cases (s>7.7). Distribution means are indicated by triangles (open are clean, filled are polluted). FIgures are similar to Fig. 2 in Garrett and Zhao (2006 [Nature]). Brackets indicate total numer of 5 min. samples.

Mean r_e, droplet concentration (N) and LWP for all cases and well mixed cases only [in brackets] under polluted (top) and clean (bottom) conditions.

	$\overline{r_e}$ (μm)	$\overline{N}$ (cm^{-3})	$\overline{LWP}$ (g m^{-2})
Polluted	10.3 [10.2]	128.8 [98.2]	25.7 [33.4]
Clean	12.1 [11.3]	65.0 [39.8]	30.7 [28.3]

Next Steps

- Extend study beyond 2000-2003 to improve statistical significance of results
- Thoroughly evaluate radar-derived determination of atmospheric mixing using radiosondes from the last decade of measurements from NSA
- Evaluate the true influence of atmospheric mixing on the use of surface-based aerosol measurements for deriving aerosol indirect effects in thin liquid-containing Arctic clouds
- Use HSRL data to demonstrate the relationship between aerosol loading near the surface and aerosol loading at cloud height under clear conditions

References

Garrett, T.J. and C. Zhao (2013): Ground-based remote sensing of thin clouds in the Arctic, *Atmos. Meas. Tech.*, **6**, 1227-1243, doi: 10.5194/amt-6-1227-2013

Lubin, D. and A.M. Vogelmann (2006): A climatologically significant aerosol longwave indirect effect in the Arctic, *Nature*, **439**, 453-456, doi:10.1038/nature04449.

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ASR Atmospheric System Research