Longwave Aerosol Direct and Indirect Radiative Effects at the NSA Site

D. Lubin
Scripps Institution of Oceanography
La Jolla, California

A. Vogelmann
Brookhaven National Laboratory
Upton, New York

Aerosol IR Direct Effects

Aerosols with large particles, such as dust or sea salt, can exert significant amounts of direct infrared (IR) forcing at the surface. For example, recent observations from Aerosol Characterization Experiment (ACE)-Asia indicate that the aerosol IR forcing at the surface can be a few Wm^{-2} up to almost 10 Wm^{-2} (Vogelmann et al. 2003, Markowicz et al. 2003). Further investigation indicates that the IR forcing pattern tends to correlate with the surface concentrations of submicron Ca^{++}, which may serve as a dust indicator. Climate Monitoring and Diagnostics Laboratory (CMDL) observations of aerosol concentrations at Barrow indicate that submicron Ca^{++} as well as Cl^{-} concentrations can be large. This suggests that it may be possible that dust and sea salt exact a significant IR forcing at the North Slope of Alaska (NSA) site.

We investigated this possibility using atmospheric emitted radiance interferometer (AERI) observations and Line-by-Line Radiative Transfer Model (LBLRTM) calculations. We culled the aerosol observations for high and low concentrations of submicron Ca^{++} and Cl^{-}, and selected periods when the active remote sensing cloud layer (ARSCL) indicated clear-skies. LBLRTM calculations for an arctic winter atmosphere indicate that the 10-μm window is most sensitive to the estimated uncertainties in the temperature profile, with a secondary uncertainty for the water vapor profile (due to the dry arctic atmosphere). Typical uncertainties in the ozone profiles for the NSA will prevent detecting an aerosol IR signal in the 9.6-μm ozone band. However, spectra from the 3-μm window are far less sensitive to any of these uncertainties, and this region can serve as an excellent detector of aerosol effects at nighttime (when the solar effects in the window are absent).

We derived the aerosol radiance effect for the AERI channels, by subtracting a clear-sky spectra modeled using LBLRTM. Profile inputs for the calculations were obtained from the sonde profiles scaled by the column water vapor content measured by the microwave radiometer (MWR). Ozone profiles were obtained from climatology. We find that aerosol radiance effect for the high Ca^{++} and Cl^{-} concentrations were very similar to those for the low concentrations cases. Thus, we deduce that aerosols at the NSA do not exert a significant IR influence at the surface.

Aerosol IR Indirect Effects

In contrast to the direct effect, the indirect effect on cloud radiative properties proved to be detectable in AERI channel 1 data. We first used the ARSCL data to identify single-layer clouds under which AERI spectra were measured, with bases and geometric thicknesses under 1000 m. It was necessary to identify these potentially optically thin cases because, at optical thickness above 10, a cloud radiates as a blackbody in the longwave and will display no sensitivity in spectral emitted radiance to microphysical properties. Further sorting on the AERI spectra was done on CMDL aerosol concentrations measured at Barrow. To search for the indirect effect, we isolated those AERI spectra measured under the top and bottom 20th percentiles in aerosol number concentration observed in each calendar year (typically larger than 200 cm^{-3}, and smaller than 40 cm^{-3}, respectively). The assumption here is that CMDL-measured condensation nucleus (CN) correlates with cloud condensation nuclei (CCN) in low-level stratus. From the years 1999-2001, we identified several hundred useful cases in which AERI spectra were obtained under low, geometrically thin clouds, in the presence of these low and high aerosol CN concentrations.

Theoretical radiative transfer considerations (Lubin 2004) indicate that under optically thin cloud the overall slope of the spectral brightness temperature between 800 – 1000 cm^{-1} varies with effective particle radius r_{eff}, for a fixed liquid water content. At smaller r_{eff}, the AERI-measured brightness temperature decreases more rapidly with increasing wavenumber (Figure 1). If aerosols are modifying the clouds toward a smaller effective radius, the slope of the AERI-measured brightness temperature will become more negative. Thus, for a statistically significant sample of optically thin clouds having a finite range in liquid water content, we would expect to identify two different distributions in the brightness temperature slope corresponding to the lowest and highest aerosol CN concentrations.

Figure 2 shows that this is indeed what we observe in our AERI cloud data sample described above. The data for Figure 2 pertain to surface temperatures warmer than 270 K, in which cases we expect mainly liquid water in cloud. Even if we consider all ARSCL-identified clouds with bases below 2000 m and any geometric thickness, there is a tendency for the low-CN cases to exhibit flatter 800-1000 cm^{-1} brightness temperature slopes. The contrasts in the slope distributions for the low-CN cases (A) and high-CN cases (B) become more apparent as we restrict the cloud bases to lower altitudes and geometric thickness to < 1000 m. The peaks in these distributions around zero most likely result from optically thicker clouds radiating as blackbodies, and our ongoing analysis involves identifying these cases using additional NSA measurements for shortwave optical depth [e.g., pyranometer or multi-filter rotating shadowband radiometer (MFRSR)] or microwave measurements of cloud liquid water content.

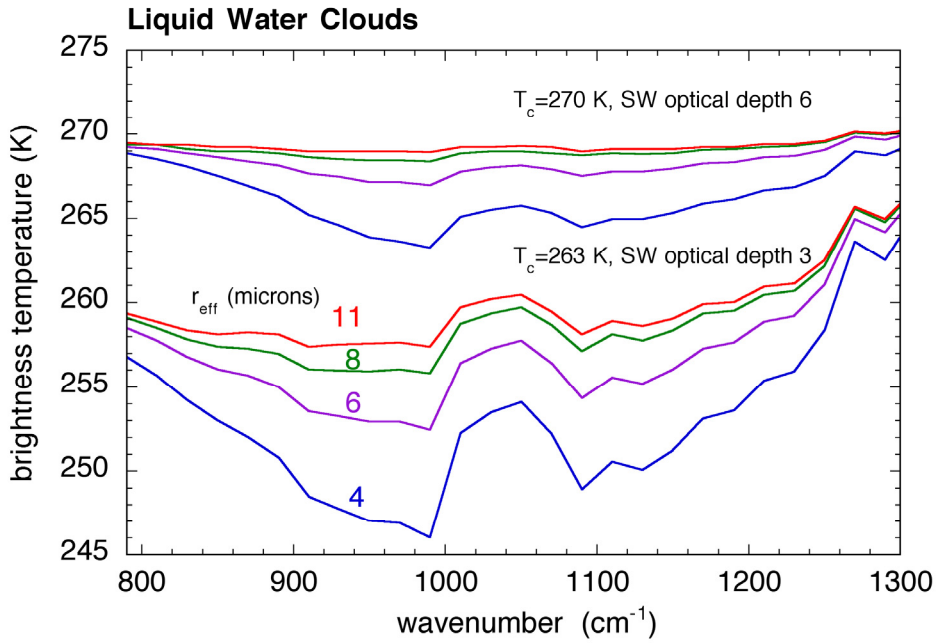
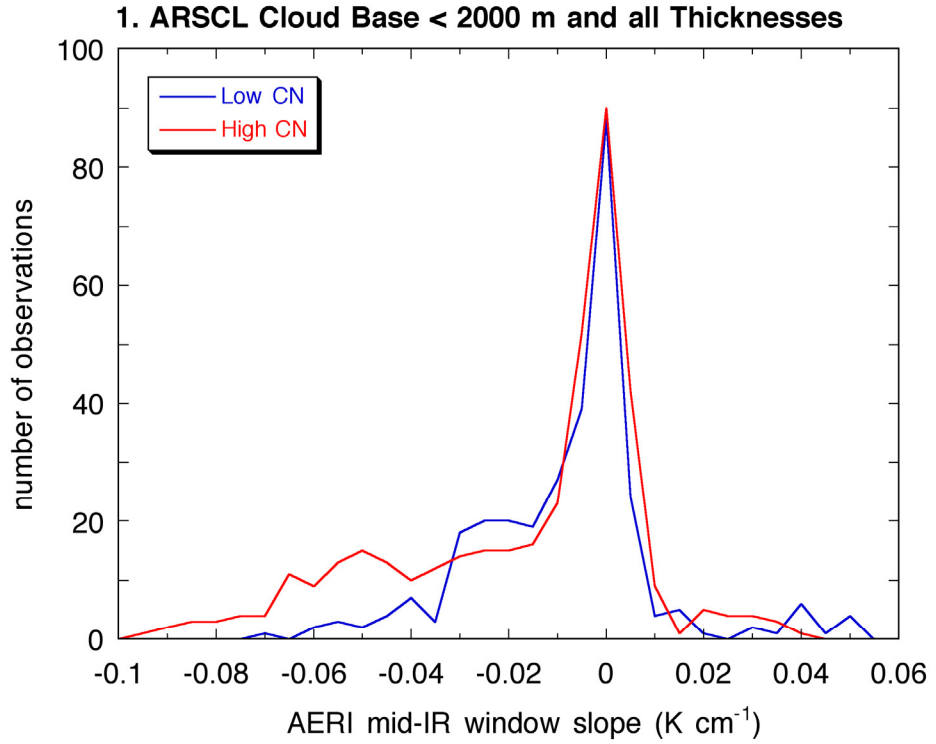


Figure 1. Radiative transfer simulation of the spectral brightness temperature that would by measured by the AERI under liquid water clouds of fixed (conservative scattering) optical depth but varying effective droplet radius.



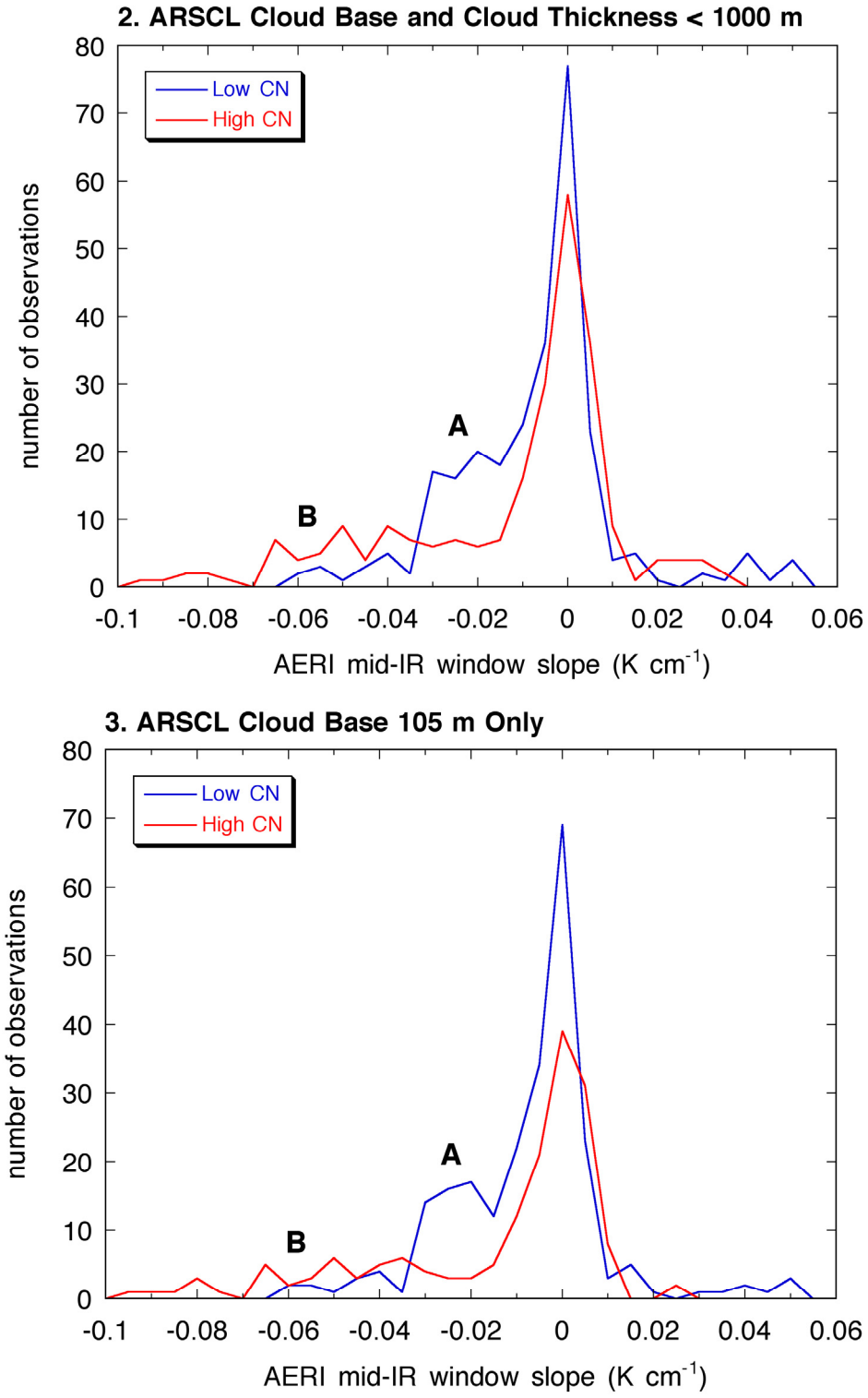


Figure 2. Histograms of the AERI-measured 800-1000 cm-1 brightness temperature slope under single layer clouds identified by the ARSCL, for the lowest and highest 20th percentile in aerosol CN.

References

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