Supplement for “Using CALIOP to constrain blowing snow emissions of sea salt aerosols over Arctic and Antarctic sea ice”

1 Combining daytime and nighttime CALIOP observations to calculate nighttime-equivalent extinction coefficients

The daytime CALIOP estimates of aerosol extinction coefficients have higher sensitivity threshold than the nighttime estimates due to the noise from solar photons (Winker et al., 2009), making nighttime extinctions more accurate. Over polar regions during summer, however, nighttime CALIOP observations are very limited due to constant solar illumination. In order to examine the seasonal variation in CALIOP aerosol extinction coefficients over polar regions, we calculate nighttime-equivalent CALIOP aerosol extinction coefficients following the approach of Di Pierro et al. (2013). The nighttime-equivalent aerosol extinction is the weighted average of nighttime and adjusted daytime aerosol extinctions. The daytime aerosol extinctions are adjusted with a scaling factor, which takes into account the different sampling frequency of daytime and nighttime observations. The nighttime-equivalent aerosol extinction coefficient (ε_{neq}) is calculated following Eq. (1):

$$\varepsilon_{neq} = (f_n \cdot \varepsilon_n \cdot N_n + f_d \cdot SF \cdot \varepsilon_d' \cdot N_d) / (N_n + N_d), \quad (1)$$

where f is the aerosol detection frequency and the subscripts of d and n correspond to the daytime and nighttime. The ε symbol denotes the observed aerosol extinction coefficient, and $\varepsilon_d' = \varepsilon_d/1.6$, which is scaled to take into the account of higher sensitivity threshold of daytime data (See following and Fig. S1a). SF is a scaling factor taking into account the different detection sensitivities of daytime and nighttime retrievals. N is the number of CALIOP samplings.

In the absence of daytime data, we have

$$\varepsilon_{neq} = f_n \cdot \varepsilon_n \quad (2)$$

as we assign undetected aerosol layers (or clear air) an extinction coefficient value of 0.0 km^{-1}.

The scaling factor, SF, is defined as $SF = f_n/f_d$ based on the relationship between SF and backscatter coefficient during winter months (November-April for the Arctic and May-October for the Antarctic) over the 62-70° N/S latitude band following Di Pierro et al. (2013).

Figure S1c shows that both daytime and nighttime aerosol detection frequency decrease with height during Arctic (62-70°N) winter (October-April 2007-2009), with the daytime detection frequency being 1.5-8 times lower than the nighttime detection frequency. The average daytime aerosol backscatter coefficients are ~60% higher than the nighttime ones, as the daytime profiles have a higher sensitivity threshold and do not detect faint aerosol layers with lower aerosol extinctions. Scaling the daytime aerosol backscatter coefficients by 0.6 ($\beta'_d=\beta_d/1.6$) we get a daytime backscatter vertical profile in good agreement with the nighttime one (Figure S1b). A linear fit between the $f_d\ /f_n$ and mean aerosol backscatter coefficient ($\beta = [\beta_n + \beta'_d]/2$), results in the following relationship between the scaling factor (SF) and β

$$SF = f_n / f_d = 1/[0.123+0.148 \cdot \beta] \quad (3)$$

We combined equations (3) and (1) and get the estimate of nighttime equivalent data for the Arctic as shown in Fig. 3a–b. The monthly nighttime equivalent aerosol extinction coefficients agree with the nighttime one within 10% during winter (September-April). During May and July, the nighttime aerosol extinction is higher than the nighttime-equivalent one, as the nighttime overpass only reach up to 62°N and over 60% of the 60-62°N band is covered by continents and generally has higher aerosol extinction than the central Arctic. The wintertime (November–April) vertical profile of nighttime-equivalent aerosol extinction agrees with the nighttime one within 5% (Fig. S3b).

We also derive the nighttime-equivalent scaling factor for the Antarctic in the same manner (Fig. S2), and get:

$$SF = 1/[0.121+0.122 \cdot \beta] \quad (4)$$

The calculated nighttime-equivalent aerosol extinctions in the Antarctic is in close agreement with the nighttime ones in February–November (Fig. S3c). The much higher nighttime aerosol extinction, in December–January, compared to the nighttime-equivalent, is again due to the limited nighttime overpass up to 62°S, and the zonal mean aerosol extinctions decrease toward south pole over the Southern Ocean (Fig. 3). The wintertime (May–October) nighttime equivalent vertical profiles closely agree with the nighttime data (Fig. S3d).

2 Calculating FYI and MYI in MERRA

The multi-year (MYI) sea ice extent in this study is defined as the minimum sea ice extent during summer (September for Arctic and February in Antarctic) in the MERRA fields. In January–September over the Arctic, the MYI sea ice extent is the previous September minimum sea ice extent. We apply the same method for the Antarctic. We calculate the first-year sea ice (FYI) extent by subtracting the MYI extent from the MERRA total sea ice extent. Figure S4 shows the seasonal variations of FYI and MYI sea ice extent over the Arctic and Antarctic.

References

Di Pierro, M., Jaeglé, L., Eloranta, E. W., and Sharma, S.: Spatial and seasonal distribution of Arctic aerosols observed by the CALIOP satellite instrument (2006–2012), Atmos. Chem. Phys., 13, 7075-7095, https://doi.org/10.5194/acp-13-7075-2013, 2013.

Winker, D. M., Vaughan, M. A., Omar, A., Hu, Y., and Powell, J. A.: Overview of the CALIPSO Mission and CALIOP Data Processing Algorithms, J. Atmos. Ocean. Tech., 26, 2310–2323, doi:10.1175/2009JTECHA1281.1, 2009.

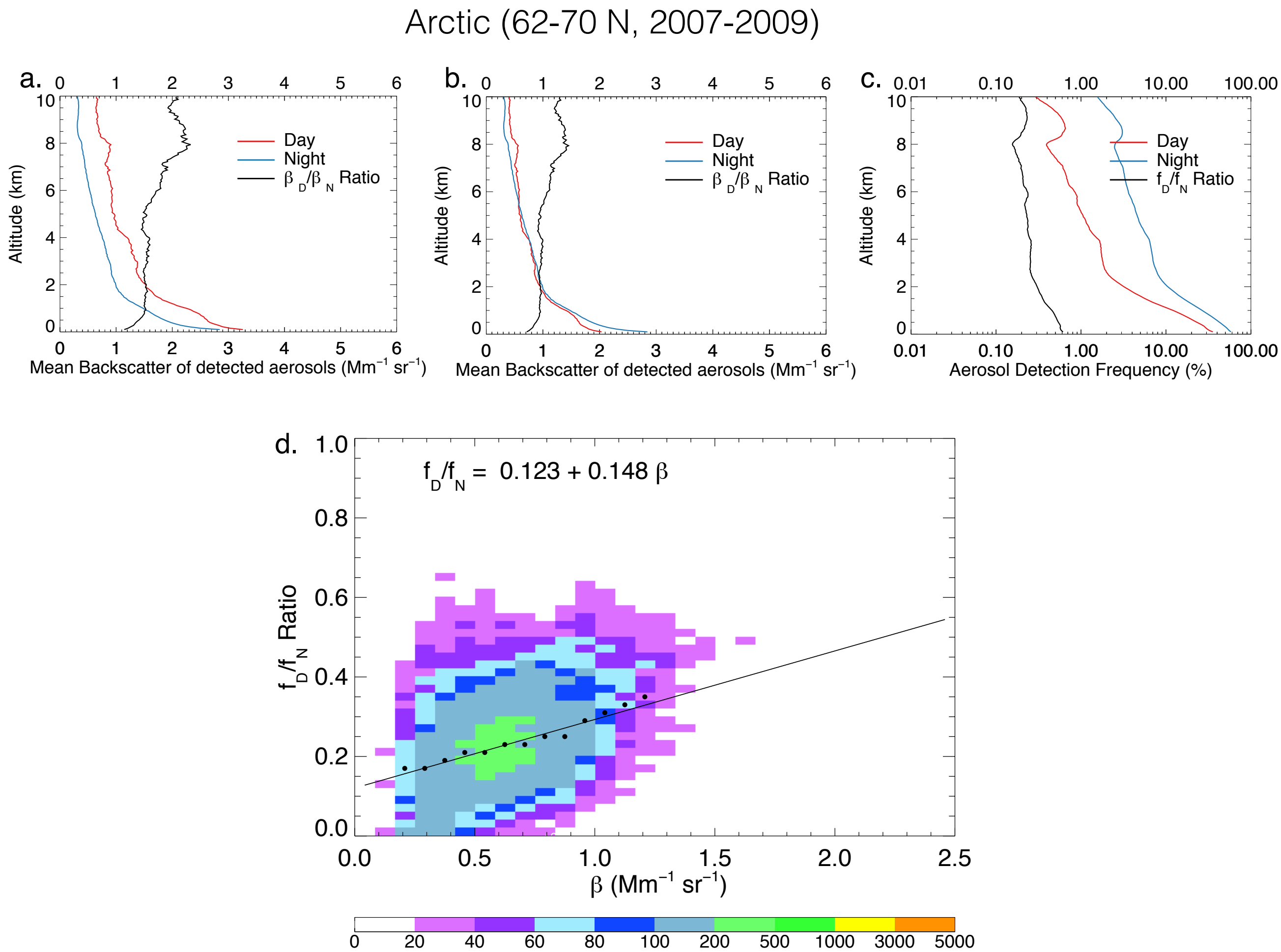

Figure S1: Vertical profiles of backscatter coefficients for detected aerosol layers (a-b) and aerosol detection frequency (c) in November-April 2007-2009 at 62°-70°N. The daytime backscatter coefficients shown in (b) are scaled ($\beta'_d=\beta_d/1.6$). Daytime profiles are shown in red lines, and nighttime profiles are shown in blue lines. The black lines in a-b indicate the ratios of daytime-to-nighttime backscatter coefficients. The black line in (c) shows the ratios of daytime-to-nighttime aerosol detection frequency (f_D/f_N). Shown in (d) is the scatterplot of f_D/f_N ratio as a function of the mean backscatter coefficients. The colors represent the number of points in each bin. Black circles are the median f_D/f_N ratio for the corresponding mean backscatter coefficient. The black line is the linear fit of the black circles.

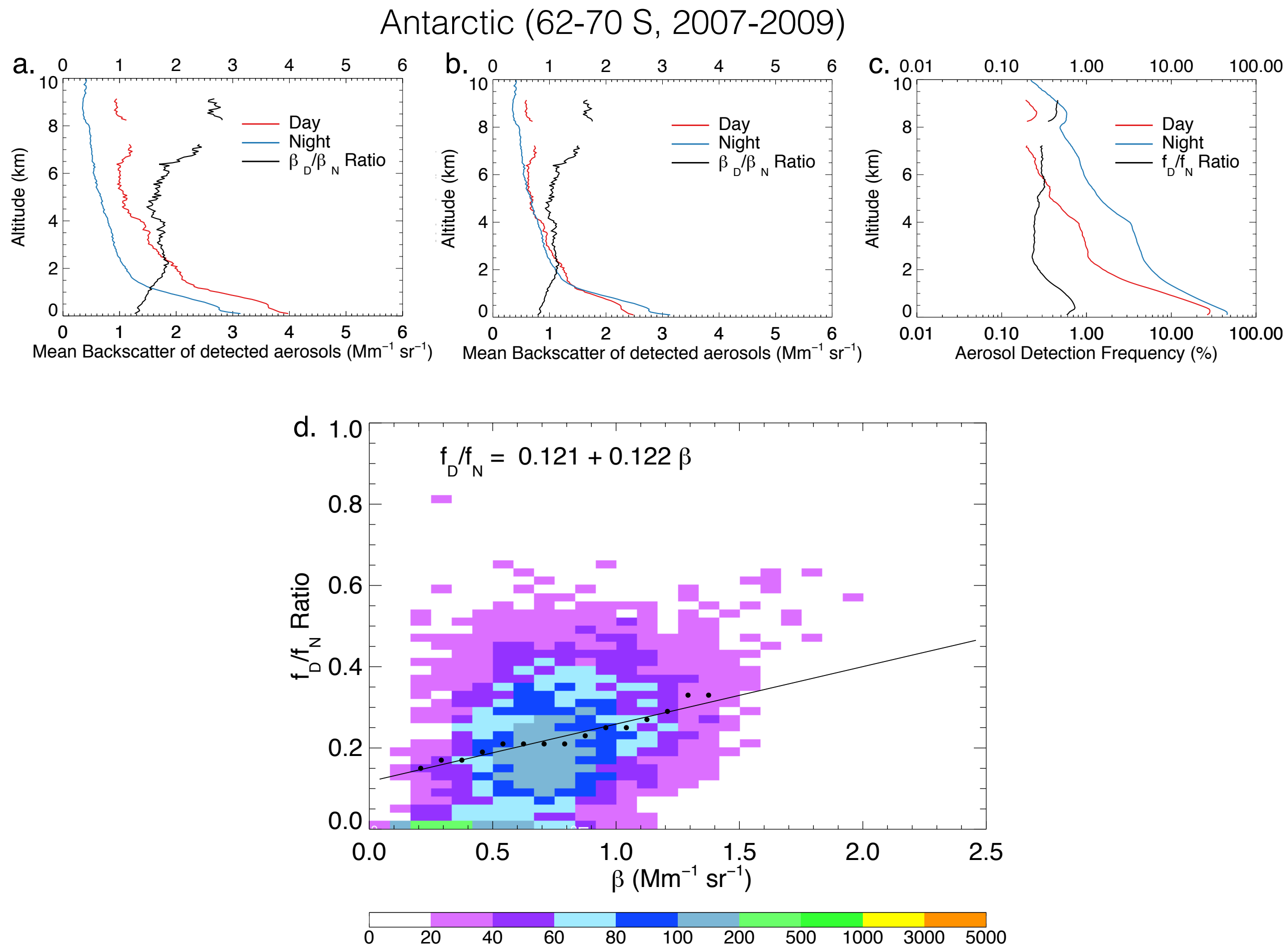

Figure S2: Same as Figure S1, but for May-October 2007-2009 at 62°-70°S.

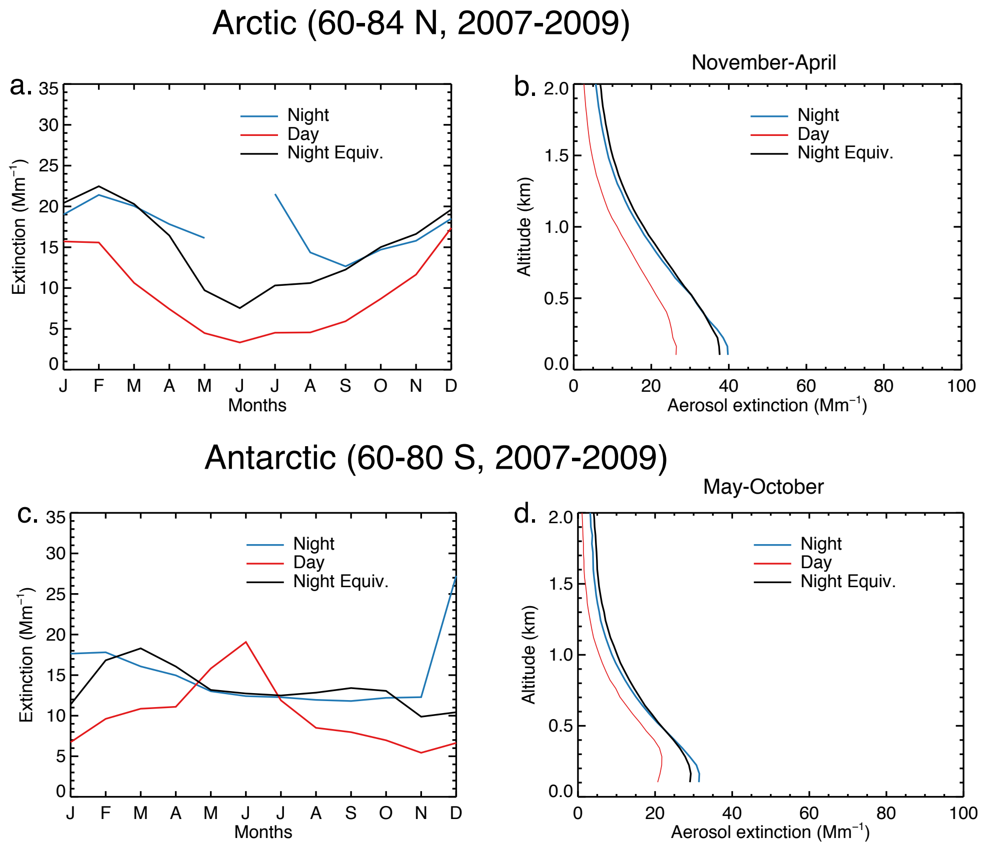

Figure S3: Comparison of seasonal variations of daytime, nighttime and nighttime-equivalent extinction coefficients over the (a) Arctic and (c) Antarctic. Also shown are the vertical profiles of daytime, nighttime and nighttime-equivalent extinction coefficients in the (b) Arctic winter (November–April) and (d) Antarctic winter (May–October).

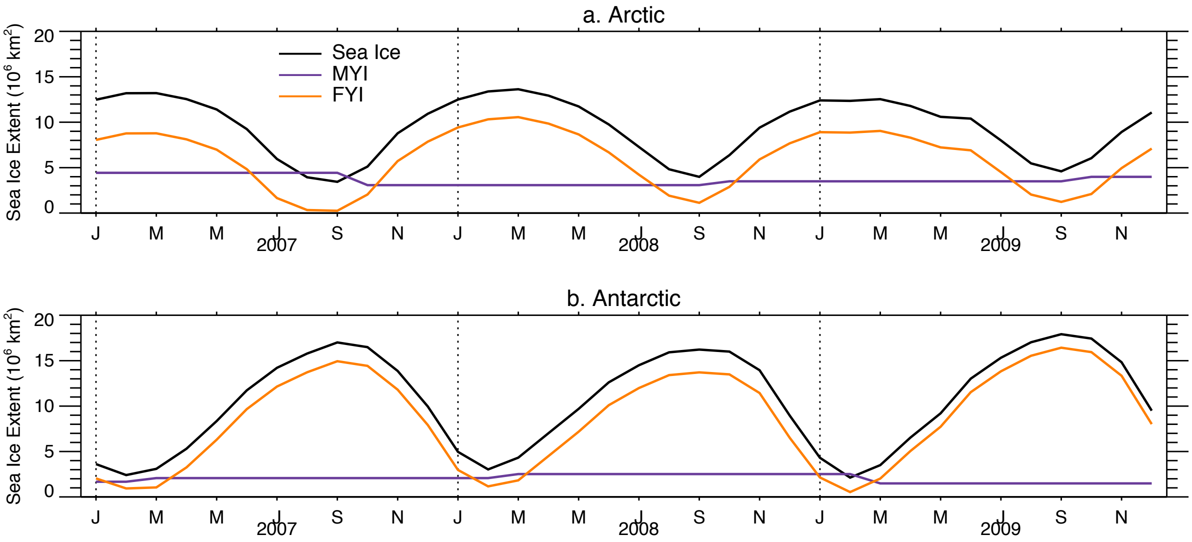

Figure S4: Seasonal variation of monthly sea ice extent (10^6 km^2) of total sea ice (black lines), first-year sea ice (FYI, orange lines) and multi-year sea ice (MYI, purple lines) over the (a) Arctic and (b) Antarctic.