Synchronized starphotometry and lidar measurements in the High Arctic

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The Arctic is generally considered as a very pristine environment due to its remoteness and lack of local pollution. However, trace gases and aerosols from mid-latitude sources (such as volcanic eruptions, natural forest fires and Asian dust storms), can reach the Arctic regions in significant concentrations. Furthermore, winter to early-spring meteorological conditions facilitate the transport of anthropogenic air pollution into the Arctic, resulting in ***Arctic Haze*** - a climatologically important, phenomenon of Arctic aerosol enhancement.

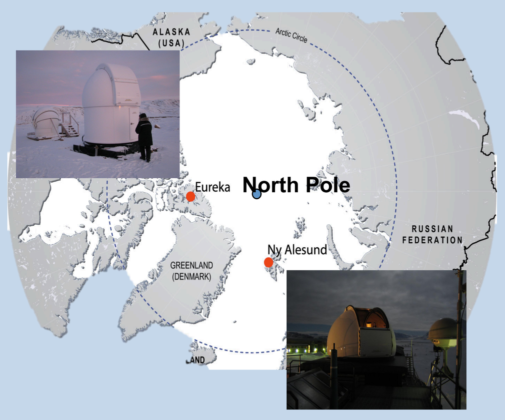


Figure 1: Locations of the two starphotometer measurement sites.

Aerosol optical depth (AOD), is a multi-spectral indicator of the total vertical extinction due to atmospheric aerosols. It is the most important (aerosol) radiative forcing parameter.

Night-time AOD measurements at all latitudes are very scarce; and the data gap is especially critical in the Arctic where polar night winter darkness lasts about 6 months. Starphotometry techniques based on extinction measurements of bright-star radiation help to mitigate the lack of consistent and regular Polar Night measurements.

Two starphotometers (denoted as SP-NYA and SP-PRL respectively) are currently installed in the Arctic region (Figure 1): one at Ny Alesund (Spitsbergen, 78°55''N, 11°55''E) and the second at the PEARL station in Eureka, Nunavut, Canada (79°59'N, 85°56'W).

SP-NYA has been in operation since 1995 and together with sunphotometry has provided day-night (summer to winter) AOD-derived indicators of multiyear aerosol dynamics at Ny-Alesund (Herber et al, 2002). SP-PRL has been in limited operation since 2008.

The optical suite at both stations includes co-located aerosol lidar systems: the CRL (CANDAC Raman Lidar) at Eureka and the KARL (Koldewey Raman Lidar) and MPL (Micropulsed Lidar) at Ny Alesund. During the Polar Winters of 2010-11 and 2011-12 all instruments were run whenever possible with the exception of periods subject to unfavourable weather conditions or operational difficulties. An overview of the acquired data is shown in Figure 4. The 2011-12 dataset for Ny Alesund is currently being processed and is not shown.

Starphotometry

Starphotometry is based on the extinction measurements of bright-star radiation. Two measurement methods are currently used (Figure 2): a two-star method (TSM) and a one-star method (OSM). TSM is a differential method and does not require an absolute calibration. It is however susceptible to horizontal inhomogeneities. OSM, a night-time analogue of sunphotometry, is operationally more robust but requires absolute calibration values, M_{0i}.

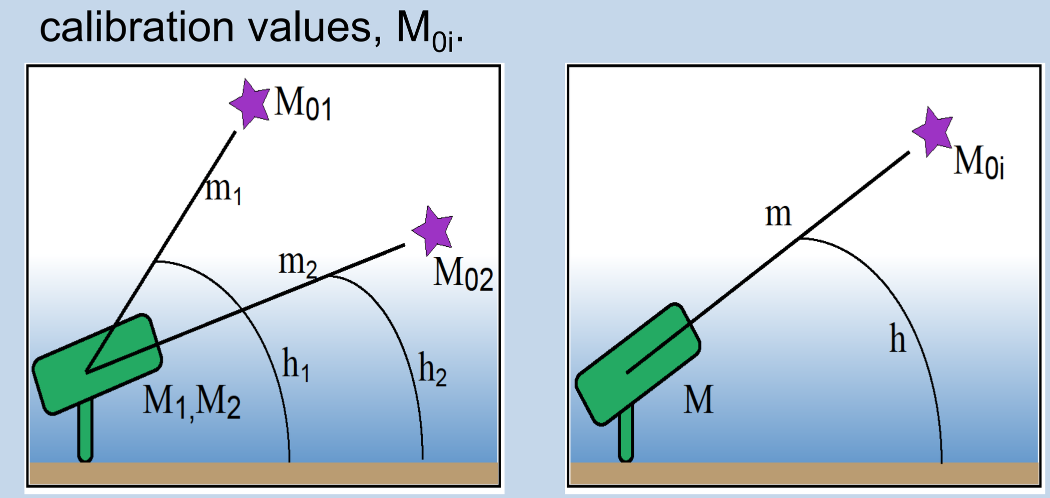


Figure 2. Starphotometry techniques. Left: TSM. Right: OSM. M – measured magnitude; M_0 – extraterrestrial magnitude; m – air mass; h – elevation angle.

The Eureka SPSTAR starphotometer and its protective dome are shown in Figure 3.

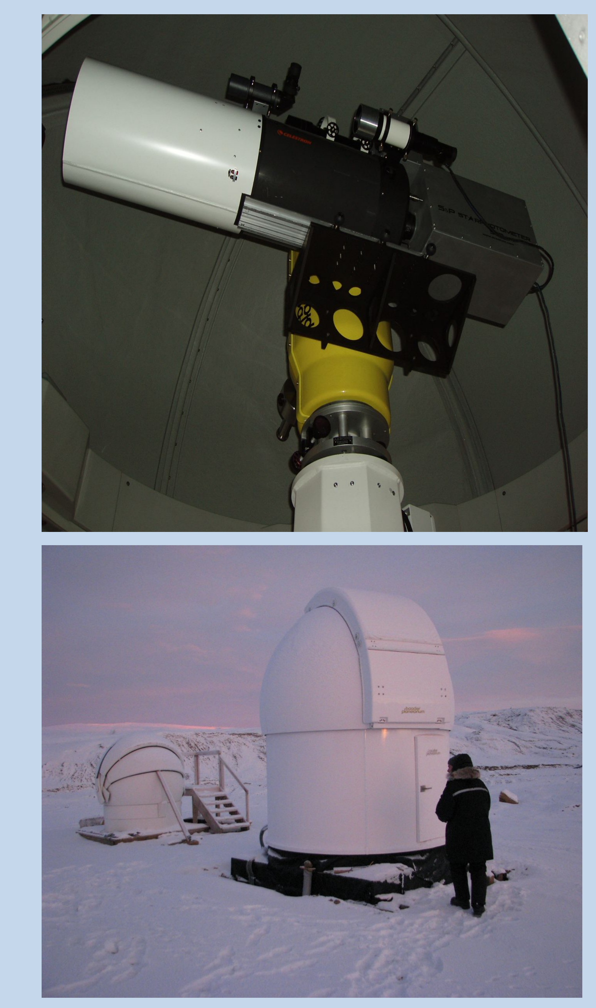


Figure 3. Starphotometer at Eureka. Top: SPSTAR starphotometer on its mount. Bottom: starphotometer protective dome.

Data summary

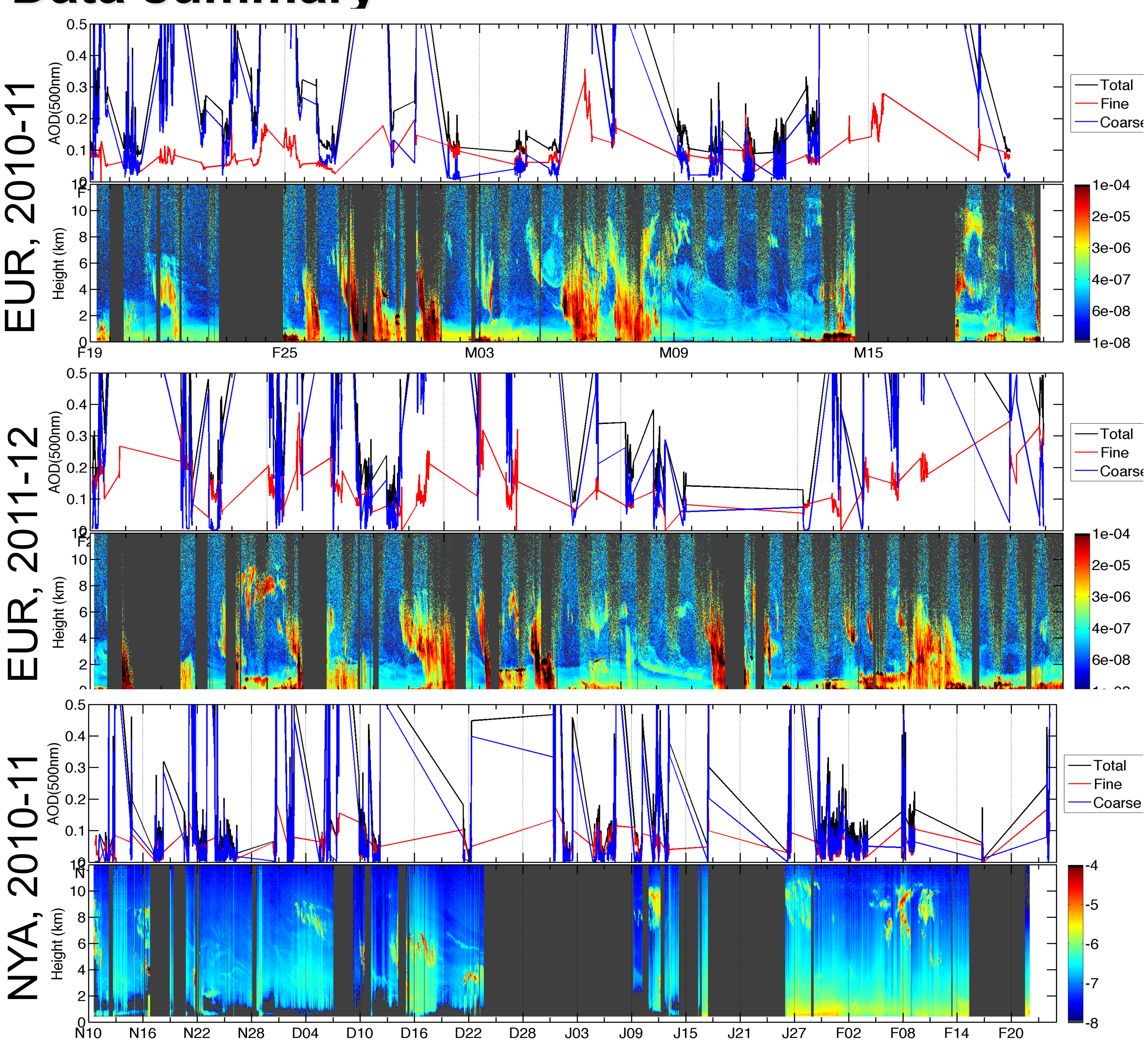
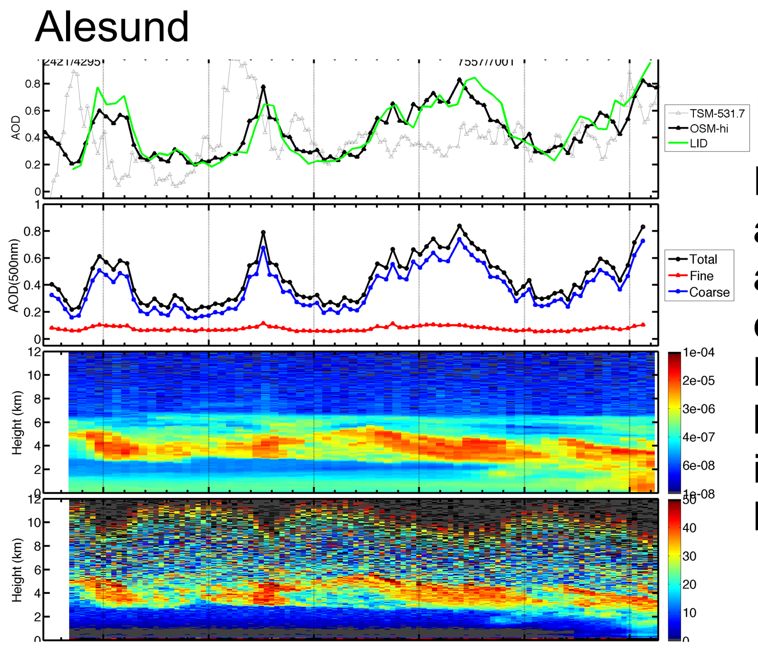


Figure 4. Acquired starphotometer and lidar data. In each plot, the top panel shows the total, fine (sub-micron) and coarse (super-micron) AODs at 500nm from spectral deconvolution algorithm (SDA) of O'Neill et al, 2003, the bottom panel is 532nm backscatter cross-section for CRL or 532nm backscatter coefficient for KARL (/m/sr).

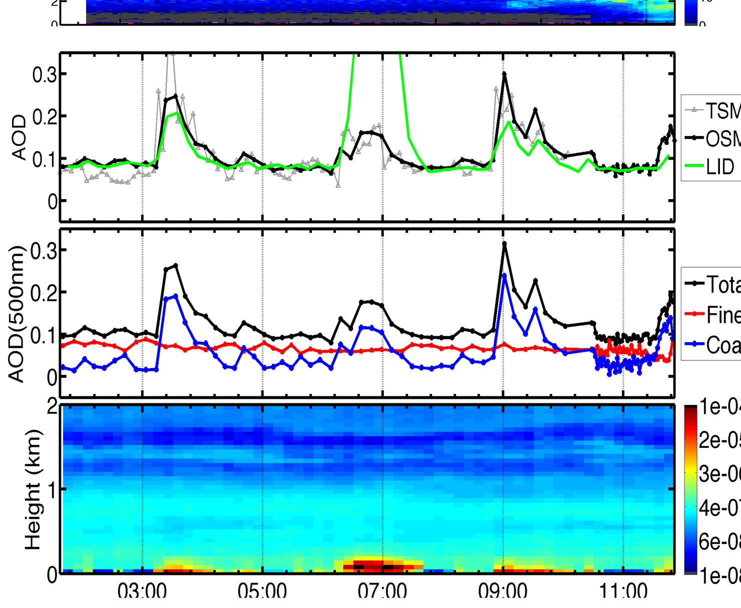
Event examples

Figure 5 shows several examples of the different events observed at Eureka and Ny Alesund



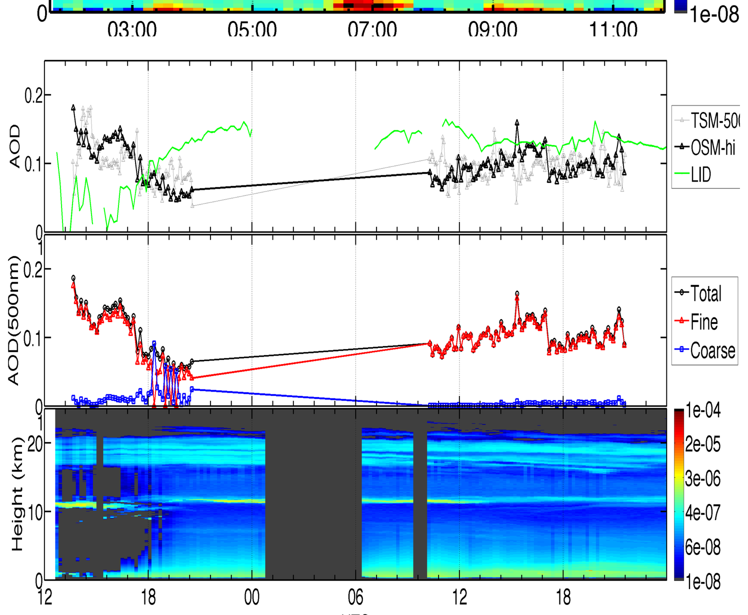
Cloud event (EUR, Feb 21, 2011)

Features: significant variations in AOD between 0.2 and 0.8 in the 11.5-hour measurement period; TSM and OSM differences due to horizontal inhomogeneity; coarse (super micron) mode dominance; high backscatter features in the 3-5 km altitude range; high linear depolarization values (~40%) particles of irregular shape – ice crystals; excellent correlation between CRL AOD and OSM-hi AOD.



Ice crystals event (EUR, Mar 10, 2011)

Features: AOD enhancements around 3:25, 6:35 and 9:00, correlated with lidar (CRL) detected features in the lowest 250m; the integrated lidar signal is dominated by the low-altitude features (for the vertical profile at 7:00, the first 250m contribute more than 80% to the total integrated value); starphotometer reacts to the same very low altitude phenomena observed by the lidar (lidar data can possibly be affected by the overlap correction errors)



PSC event (NYA, Jan 5-6, 2012)

Features: the figure at left shows a polar stratospheric cloud (PSC) between ~ 17 and 20 km, detected by the KARL lidar at Ny Alesund and by CALIOP. The PSC also displayed noisy but low depolarization ratio in the CALIOP profiles (suggestive of the type Ib super-cooled droplets that were the most abundant form of type I PSCs found by Pitts et al. 2011). This feature was also observed by the startphotometer as apparent fine mode event. While this hasn't been validated, it suggests that the PSC was in an aerosol phase rather than type Ib droplets. We are still investigating this.

Figure 5. Starphotometry-lidar, time-syncronous observations at Eureka and Ny Alesund for various dates. From top to bottom (for each of the three observation dates): starphotometry AODs at 532nm (green : lidar optical depth, black - OSM-hi), total, fine and coarse mode AODs at 500 nm, 532nm backscatter cross-section (m^{-1}-sr), 532nm linear depolarization ratio (unitless), when available. The top plot also shows the TSM AOD in grey.

Conclusions:

Starphotometry is a relatively new technology involving weak-signal problems that are considerably more complex (and costly) than those encountered with daytime sunphotometry (problems that can only be exacerbated in the extreme conditions of the Arctic). Our use of lidar / sunphotometry synergism (along with other auxiliary information such as radar profiles and trajectory modelling) is enabling the assemblage of evidence for physically coherent events whose process-level understanding will inevitably generate greater confidence levels in starphotometer retrievals and critical statistics such as multi-year climatologies. Such an assemblage is non trivial in a low AOD (low signal to nosie) environment such as the Arctic.

Acknowledgements

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