Eureka starphotometer

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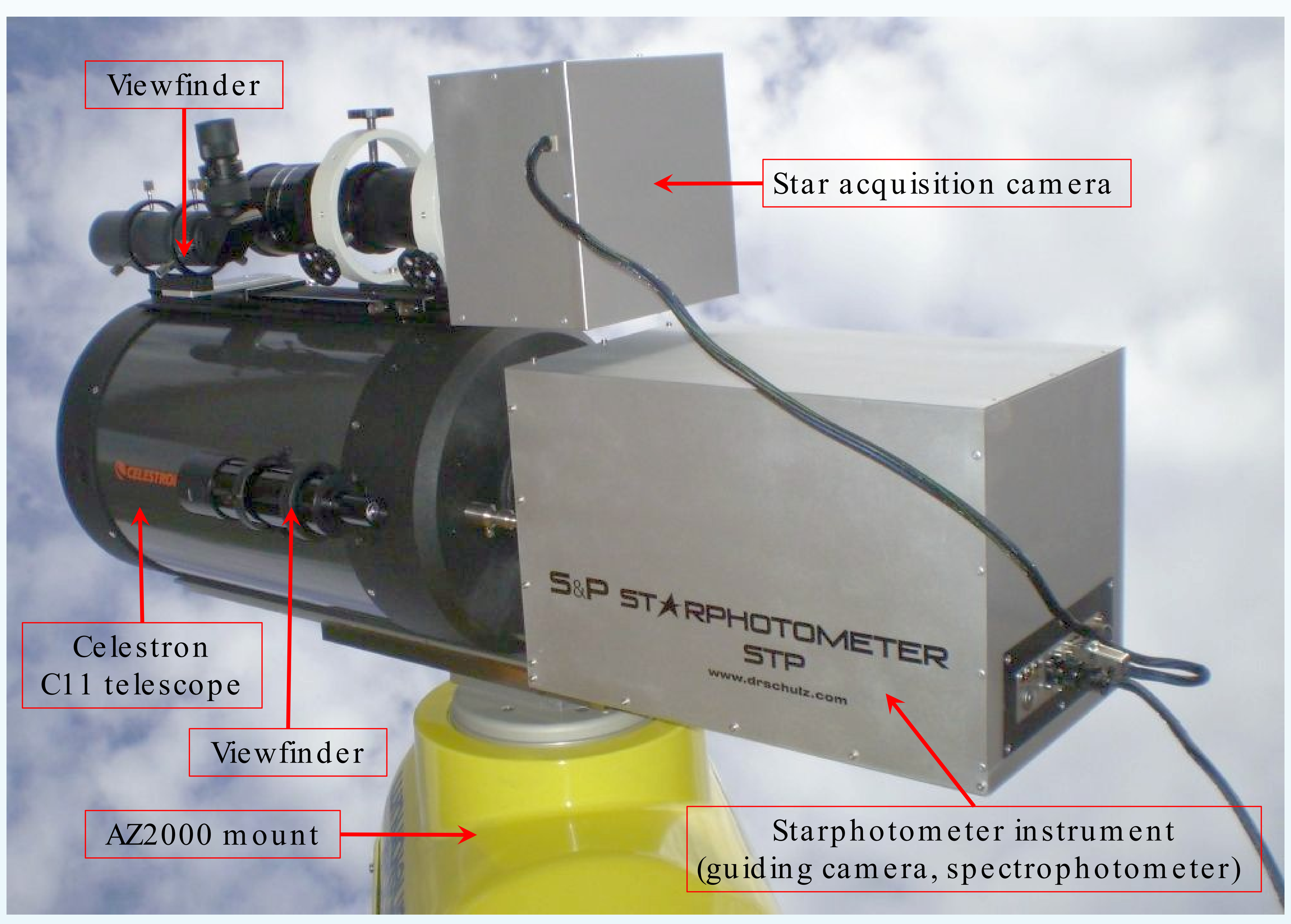
Introduction

A starphotometer is a passive remote sensing instrument that permits the retrieval of atmosphere spectral optical depth (OD) from measurements of attenuated starlight. It enables the monitoring of the abundance and (to a degree) the nature of transparent atmospheric particles (like aerosols and optically thin clouds) and trace gas content (like ozone, molecular oxygen and water vapor). Its very small field of view makes it, arguably, the only photometer able to perform aerosol and gas measurements through thin ice clouds. For cloud-free observations it represents a nighttime complement to the more familiar sunphotometer and an alternative to the duty-cycle (moonlight) limited moonphotometer. On the other hand, an important shortcoming of starphotometry is the increased signal-noise associated with star scintillation effects.

The Eureka starphotometer (serial SPST09) was installed in November 2010. It is the last in a series of nine instruments built by the German company Dr. Schulz & Partner GmbH, which has now ceased operations. It is based on the Ocean Optics QE65000 spectrometer using a Hamamatsu S7031-1006 CCD sensor. It provides 1000 measurement channels (covering the 400-1080 nm spectral range) from which 20 are operationally employed: 401.8, 421.9, 445.2, 466.0, 498.7, 520.2, 551.9, 576.6, 604.9, 643.2, 674.4, 747.4, 762.8, 778.2, 861.7, 878.4, 935.9, 936.7, 995.2 and 1019.8 nm. This instrument is attached to an 11 inch diameter (279.4 mm) Celestron C11 Schmidt-Cassegrain telescope, with a 98 mm diameter secondary mirror. A ruggedized alt-azimuth mount built by 10Micron is employed for star pointing. The entire system is contained inside a ruggedized dome built by Baader Planetarium GmbH.

Channels [7,9,10,11] enable the retrieval of ozone absorption OD, channel 8 is for O_2-O_2 absorption OD, channel 13 is for the molecular oxygen OD, while 17-18 are reserved for water vapor. The remaining largely absorption free channels provide the spectral OD for particle OD analyses.



Retrieval methods

Symbol glossary

- F = Measured star signal (counts/second)
- $S = -2.5 \log_{10} F$ = Measured star magnitude
- M_0 = Extra-terrestrial catalog star magnitude
- C = Calibration constant (Langley method)
- $x = 1.086\, m$ (m = air mass)
- τ = Optical depth

One-Star Methods (OSM)

Absolute OSM: optical depth retrieved for each sample

$$\tau = \frac{S - M_0 + C}{x}$$

Δ OSM: finite difference, same star, different times

$$\tau = \frac{\Delta S}{\Delta x}$$

Two-Star Methods (TSM)

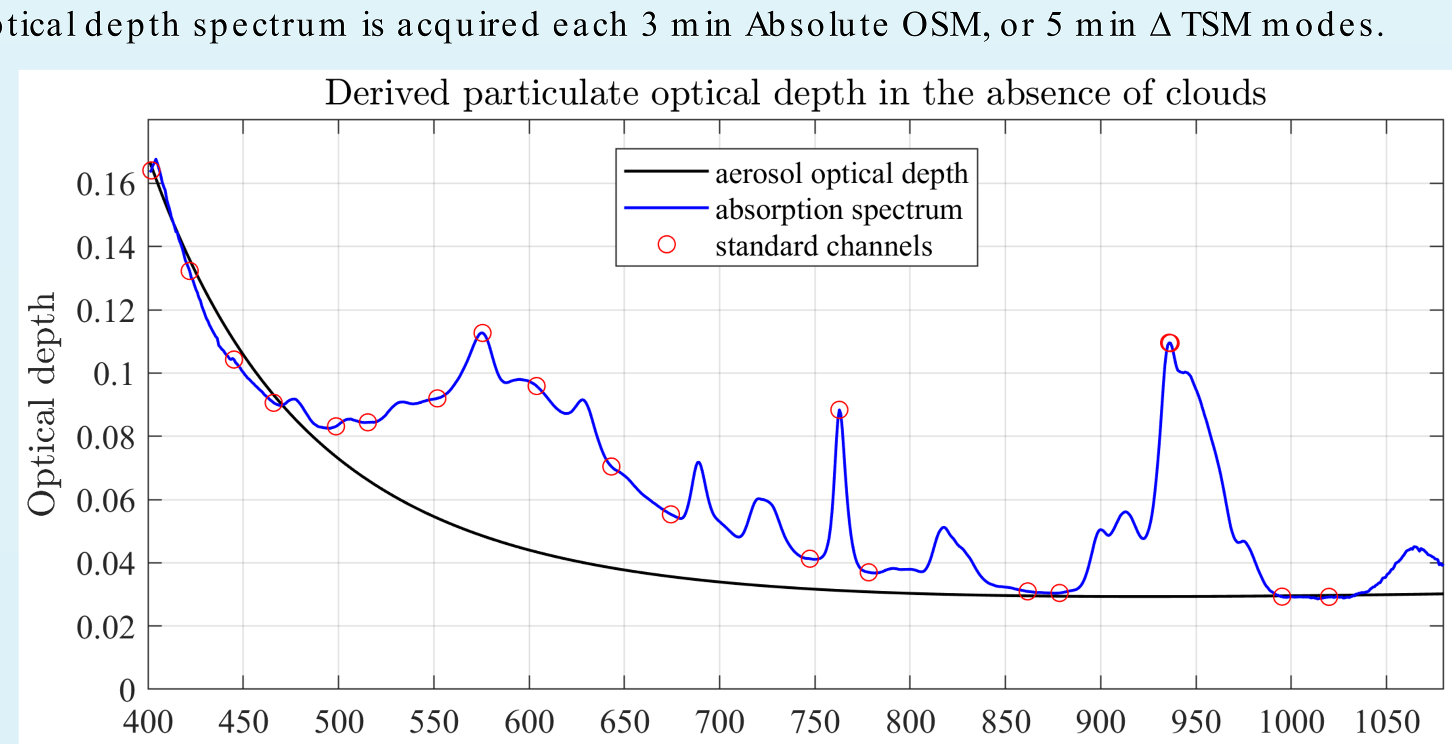
Δ TSM: finite difference, quasi-simultaneous acquisition times (consecutive samples)

$$\tau = \frac{\Delta S - \Delta M_0}{\Delta x}$$

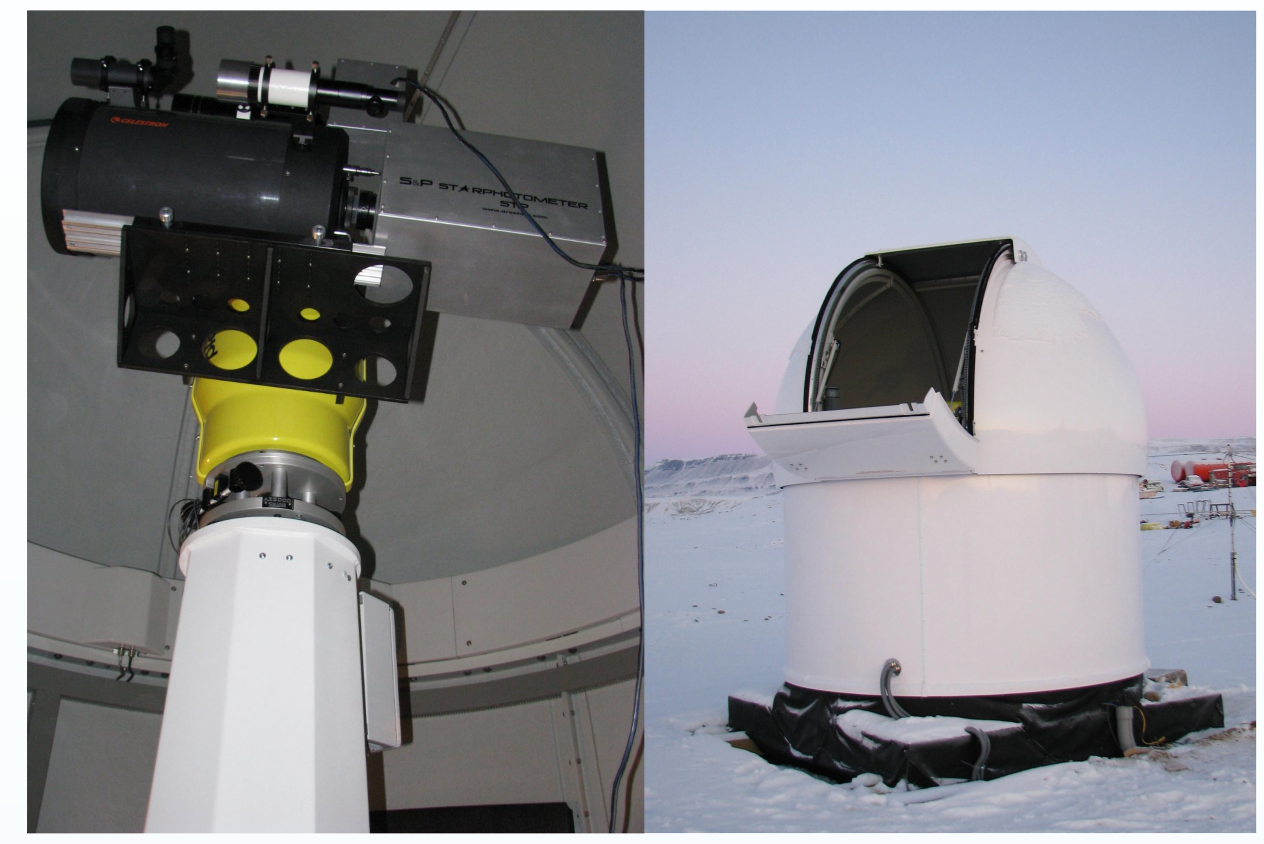
ΔΔ TSM: double finite difference, two stars, different x, different times

$$\tau = \frac{\Delta\Delta S}{\Delta\Delta x}$$

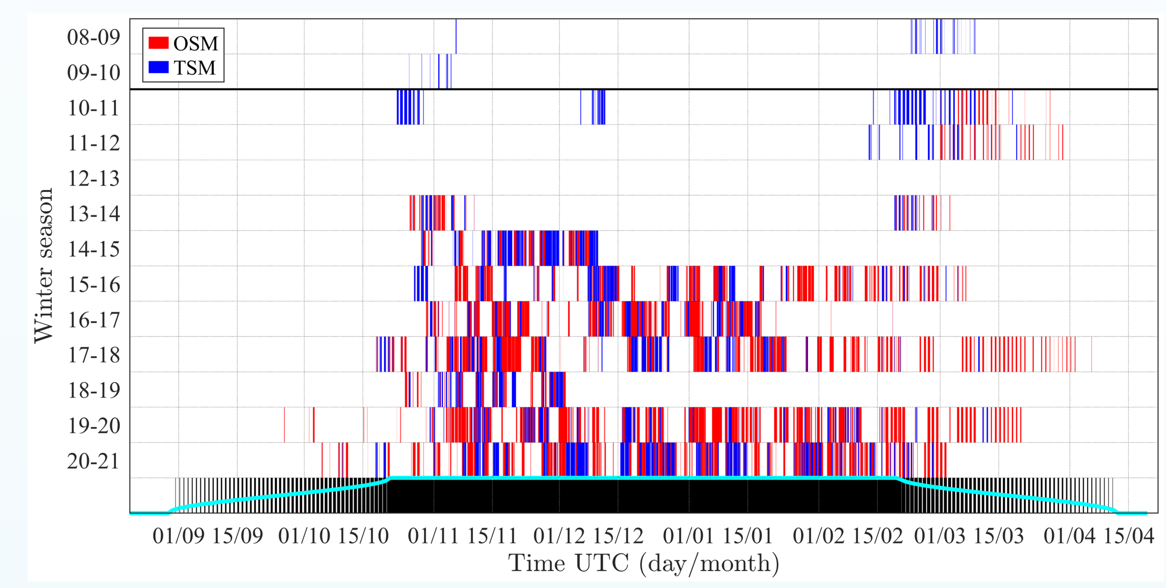
One optical depth spectrum is acquired each 3 min Absolute OSM, or 5 min Δ TSM modes.



MMCR (cloud radar) and CRL (Candac Raman Lidar) quick-look profiles synchronized with moon- & star-photometric ODs are available at: starphotometry.espaceweb.usherbrooke.ca/eureka/



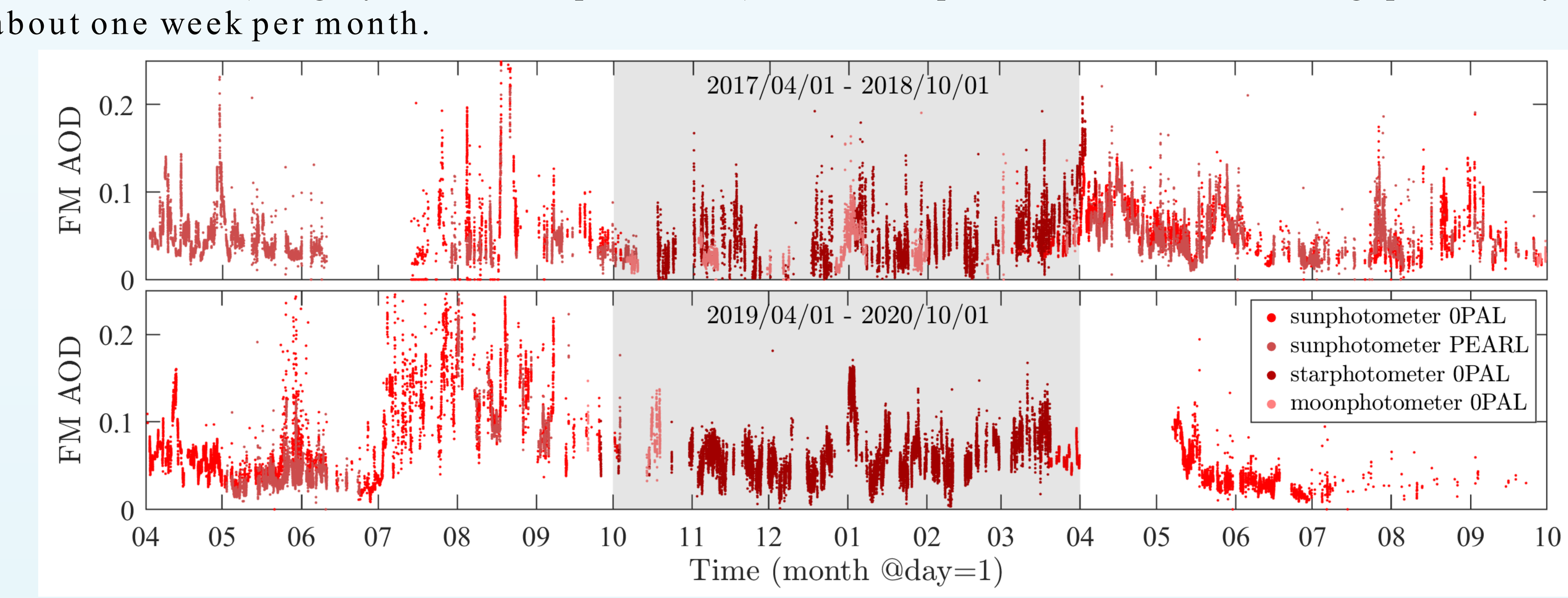
Mounted starphotomer inside the Baader dome (above left) and outside view of the dome (above right).



Duty-cycle of starphotometer measurements over the years. Gaps are largely attributable to hardware repairs and maintenance. OSM (One-Star Measurement) and TSM (Two Star measurement) times are represented by red and blue colours respectively. The thickness of the bottom black vertical lines represents the darkness duration on any given day.

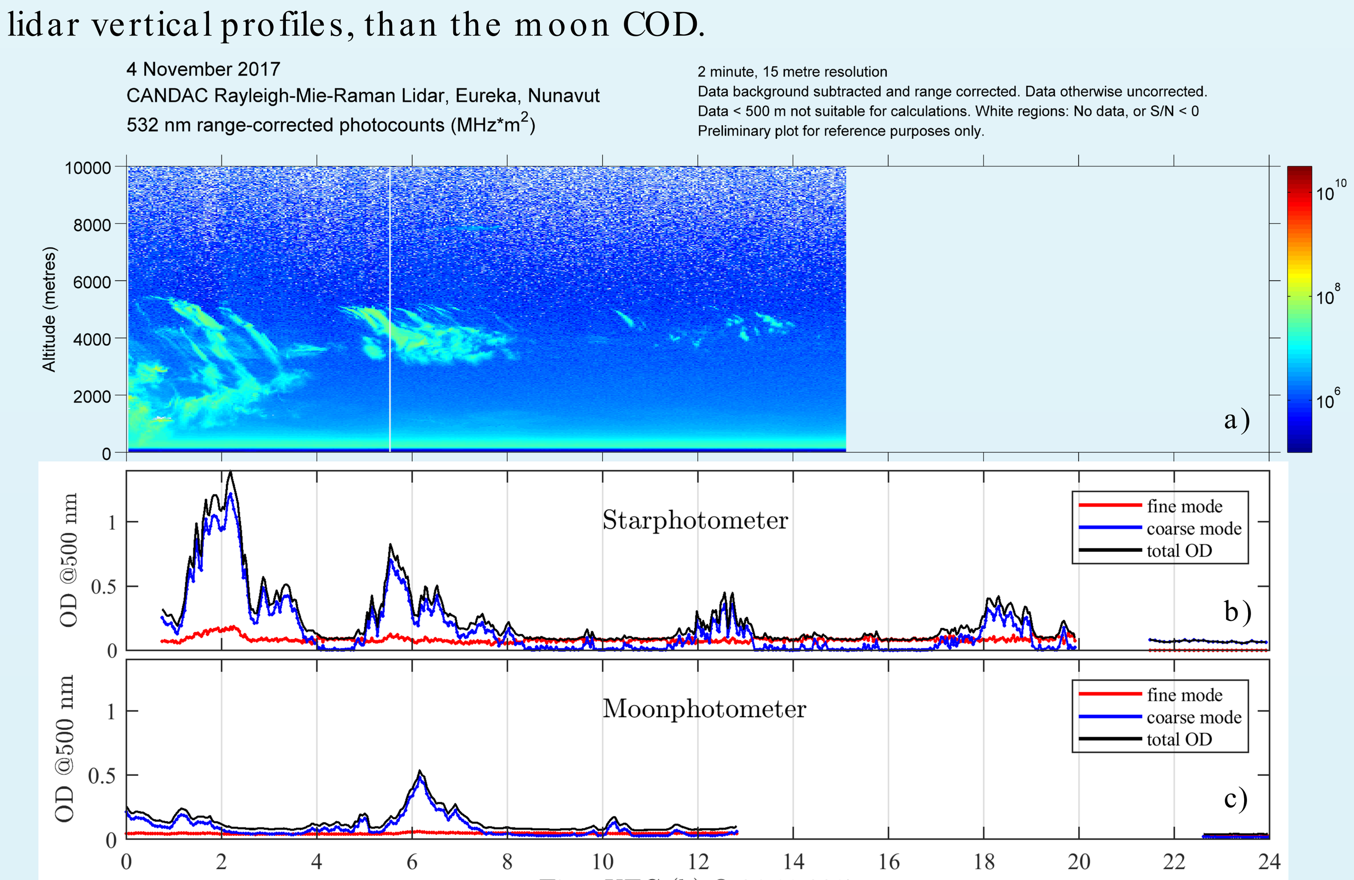
Research

A primary research focus is the climatology of aerosol seasonal variations. In Eureka, the starphotometer provides data during the six month Polar-winter gap in the sunphotometer measurements (the gray area in the plot below). The moonphotometer also fills this gap, but only for about one week per month.



Temporal plot of fine mode aerosol optical depth (FM AOD) at 500 nm, provided by AERONET/AEROCAN Polar-summer retrievals at 0PAL and PEARL with starphotometer and AERONET/AEROCAN (0PAL) moonphotometer retrievals, bridging the Polar-winter gap (the lunar-phase dependent moonphotometer retrievals being restricted to about one week per month). Cloud screening is provided by the (spectral) cloud screening capability of the SDA (Spectral Deconvolution Algorithm): however, to reduce the impact of large optical depth clouds on retrieval accuracy we restrict the FM AOD retrievals to those with the coarse mode (CM) AOD < 0.3. The FM and CM AOD are a product of the SDA.

Another focus is the interaction of aerosols and clouds and attendant cloud formation processes. The very small field of view renders starphotometer measurements less sensitive than their sun and moon analogues to optical depth errors induced by the forward scattering effects of cloud particles and thus more capable of quantifying both aerosol and cloud optical depth contributions. This is particularly advantageous when attempting to characterize the complexity of ice clouds formation during the polar night. The case below emphasizes the better correlation between starphotometer cloud OD (COD) with lidar vertical profiles, than the moon COD.



Above (top to bottom graphs) (a) Candac Raman Lidar (CRL) range-corrected vertical profile of photon counts (indicator of particulate backscatter), (b) fine (sub-µm), coarse (super-µm) and total AODs derived from starphotometry AOD spectra (SDA method), (c) SDA applied to AERONET moonphotometer data.

References

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