Towards an assessment of Aeolus' Mie radiometric performance

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Motivation

The intensity of the return signal acquired by Aeolus depends on numerous factors such as the output laser energy, the state of the atmosphere along the line of sight, the characteristics of the target, the optical elements of the instrument and the alignment of laser beam and telescope. Already at an early stage of the mission, it was found that a significant part of the **atmospheric backscatter signal** was **missing on the Rayleigh channel** (about a factor of 2.0 - 2.5).

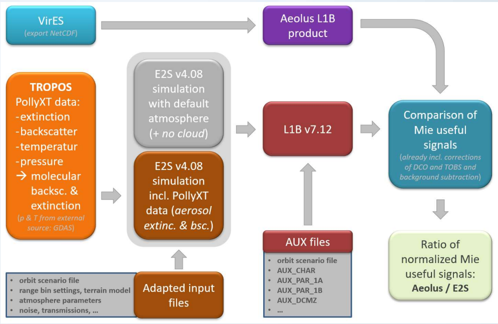
Whereas the properties of the transmission and reception path of the Rayleigh channel can be simulated to a reasonable extent by the Aeolus **End-To-End Simulator** (E2S), it is much more **difficult to align the simulation to the actual characteristics of the Mie channel**, in particular to the transmission function of the Fizeau spectrometer.

Parameter	Simulation (E2S)	Aeolus
range (r^2) to lowest bin	depending on location	depending on location (*ratio ≈1.0*)
pulse energy	set as measured for Aeolus	varying with time (*ratio ≈1.0*)
laser energy correction factor	C1*C2 (FM-B)	reported > emitted (ratio=0.9409 in favour of Aeolus)
transmissionTransmitterChain	0.704	***to be determined by investigations on the Mie radiometric performance***
transmissionReceiverChain	0.289	
Fizeau peak transmission (FSR, …)	0.315	
Mie radiometric gain	0.684 LSB/e^-	*assumed to be as pre-launch* (*ratio ≈1.0*)
ACCD quantum efficiency	0.85	*assumed to be as pre-launch* (*ratio ≈1.0*)
TOBS correction	set as measured for Aeolus	old: TOBS / new: EMSR (minor influence for this analysis)
geometrical factor	0.6366 (*square in circle*)	0.6366

Elevated, optically thick, vertically extended and preferably homogeneous aerosol layers are considered as the most suitable target. With the Raman lidars sensing a drifting aerosol layer from a fixed location and Aeolus as a mobile instrument sampling a quasi-fixed layer, optimization is needed concerning the match of geolocation between the ground-based and space-borne measurements.

Setup of processing chain

As a first attempt to **assess the radiometric performance** of Aeolus' Mie channel, we are trying to derive a ratio between simulated and actual Aeolus signals. Therefore, we compare useful signals obtained with the **E2S** against measurements made with **Aeolus** in aerosol-laden atmospheric scenes. In this context, the backscatter and extinction measurements of portable **ground-based Raman lidar systems from PollyNET** as well as temperature and pressure information from external sources represent essential inputs for the simulation.



Various E2S simulations have been performed to investigate and also verify the sensitivity of the Mie useful signals with respect to input parameters such as noise, extinction, pressure, temperature, $\beta_{aer,co\text{-}polar}$ vs. $\beta_{aer,total}$, tripod obscuration and laser energy.

Inserting external atmospheric data into the E2S

The **E2S** has **no** option to insert **information about depolarization**, but can only use total aerosol backscatter. However, **aerosol does polarize**. In reality this leads to **less signal being backscattered** from aerosol towards Aeolus than is simulated in the E2S. At the same time the signal loss by **extinction remains the same**. Therefore, **Aeolus-like co-polar backscatter** coefficients need to be computed. This is achieved via a conversion of linear depolarization and total backscatter, which can both be provided by ground based instruments such as PollyXT.

$$\delta_{circ} = \frac{2\delta_{lin}}{1-\delta_{lin}} \qquad \beta_{co} = \frac{\beta_{tot}}{(\delta_{circ}+1)}$$

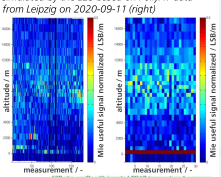
δ_{circ} circular polarization

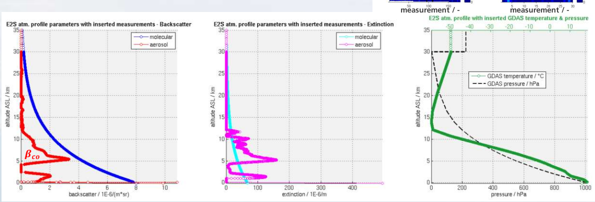
δ_{lin} parallel polarization

β_{co} co-polar backscatter

β_{tot} total backscatter

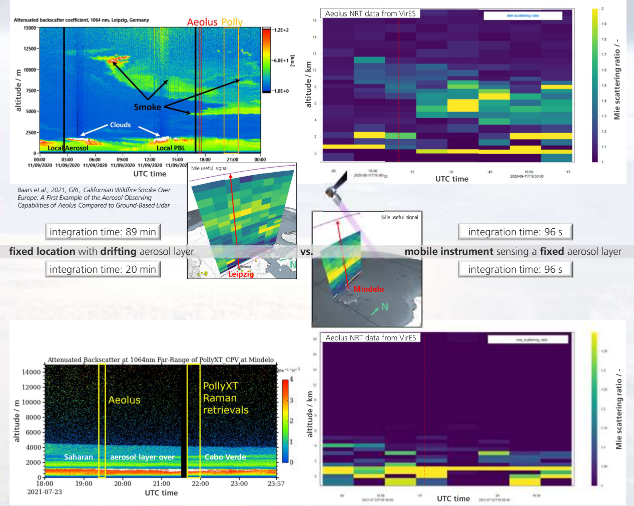
Mie useful signal normalized to range-gate thickness: as measured by Aeolus (left) and as simulated by the E2S based on PollyXT data from Leipzig on 2020-09-11 (right)



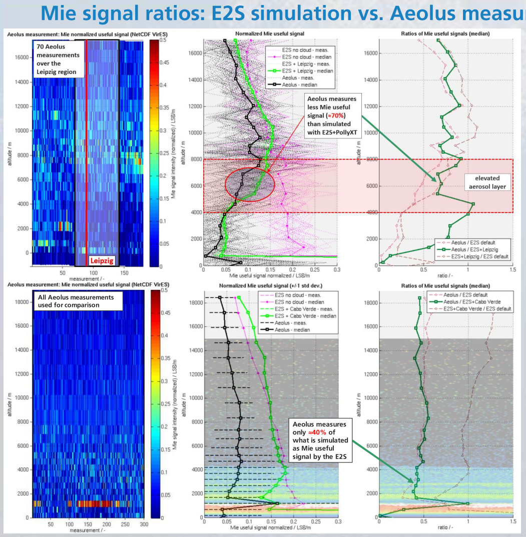


Profiles of atmospheric parameters as used for E2S simulations: merged from E2S defaults and data derived from PollyXT measurements over Leipzig. Pressure and temperature information are provided by the Global Data Assimilation System (GDAS).

Californian wildfire smoke over Leipzig and Saharan aerosol layer



Mie signal ratios: E2S simulation vs. Aeolus measurements



Left:
Aeolus measurements of Mie useful signal normalized to range-gate thickness and centered around Leipzig. Black box indicates comparison region.

Center:
Single measurements and median Mie useful signal from Aeolus and E2S simulations.

Right:
Aeolus/E2S ratios with aerosol layer indicated by red box.

Left:
Aeolus measurements of Mie useful signal normalized to range-gate thickness and centered around Mindelo.

Center:
Median Mie useful signal from Aeolus (black) and noise free E2S simulations incl. PollyXT data (green).

Right:
Normalized signal ratios underlaid with attenuated backscatter data from PollyXT.

Summary and Conclusions

- **Three analyzed cases** of elevated aerosol layers show **different Aeolus-to-E2S Mie signal ratios**:

2018-10-06 United Arabic Emirates:	≈0.9	(*FM-A*)
2020-09-11 Leipzig (*TROPOS*):	≈0.7	(*FM-B*)
2021-07-23 Cabo Verde (*JATAC*):	≈0.4	(*FM-B*)

- The signal ratios themselves show large uncertainties. **Contributors to this uncertainty and the observed signal differences** are the disparities between the conditions of Aeolus measurements, ground based measurements and the simulation such as:
  - location: match of measurements in space & time
  - sampling strategy over heterogeneous aerosol layers
  - potential cloud cover above measurement range
  - E2S input parameters vs. reality: internal and atmospheric path transmission, geometrical factor, detector efficiencies, Rayleigh-to-Mie solar background
  - differences in noise sources (*simulation vs. Aeolus measurement*)
  - assumptions in the derivation of $\beta_{aer,co\text{-}polar}$
  - issues at the real instrument (*e.g. increased laser divergence or clipping*)
- Reducing the number of contributors as well as their magnitude poses the biggest **challenge for a reliable assessment of the Mie radiometric performance**, which might only be achievable via statistical analyses on a larger number of cases.
- The apparent decrease of the signal ratio over time most likely correlates with the general decline of the Rayleigh return signal for Aeolus since launch for FM-A and FM-B, which results in a **time-dependent transmit-receive-chain**.
- Comparisons of Aeolus-E2S-ratios for Mie SNR and scattering ratio might yield better results by excluding the **influence of Rayleigh background**.