Investigation of the EPS-Aeolus performance with end-to-end simulations

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EPS-AEOLUS

Based on the success of the first wind lidar in space, the Earth Explorer mission Aeolus by the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and ESA are jointly developing the follow-on mission **EPS-Aeolus** planned to be launched in 2034. With substantial improvements in instrument design – such as a bi-static optical design, a more powerful laser, and an enhanced detector technology – EPS-Aeolus aims to achieve a higher vertical and horizontal resolution, to extend the wind measurement coverage into the stratosphere, and deliver more accurate wind measurements with smaller random error as achieved for Aeolus.

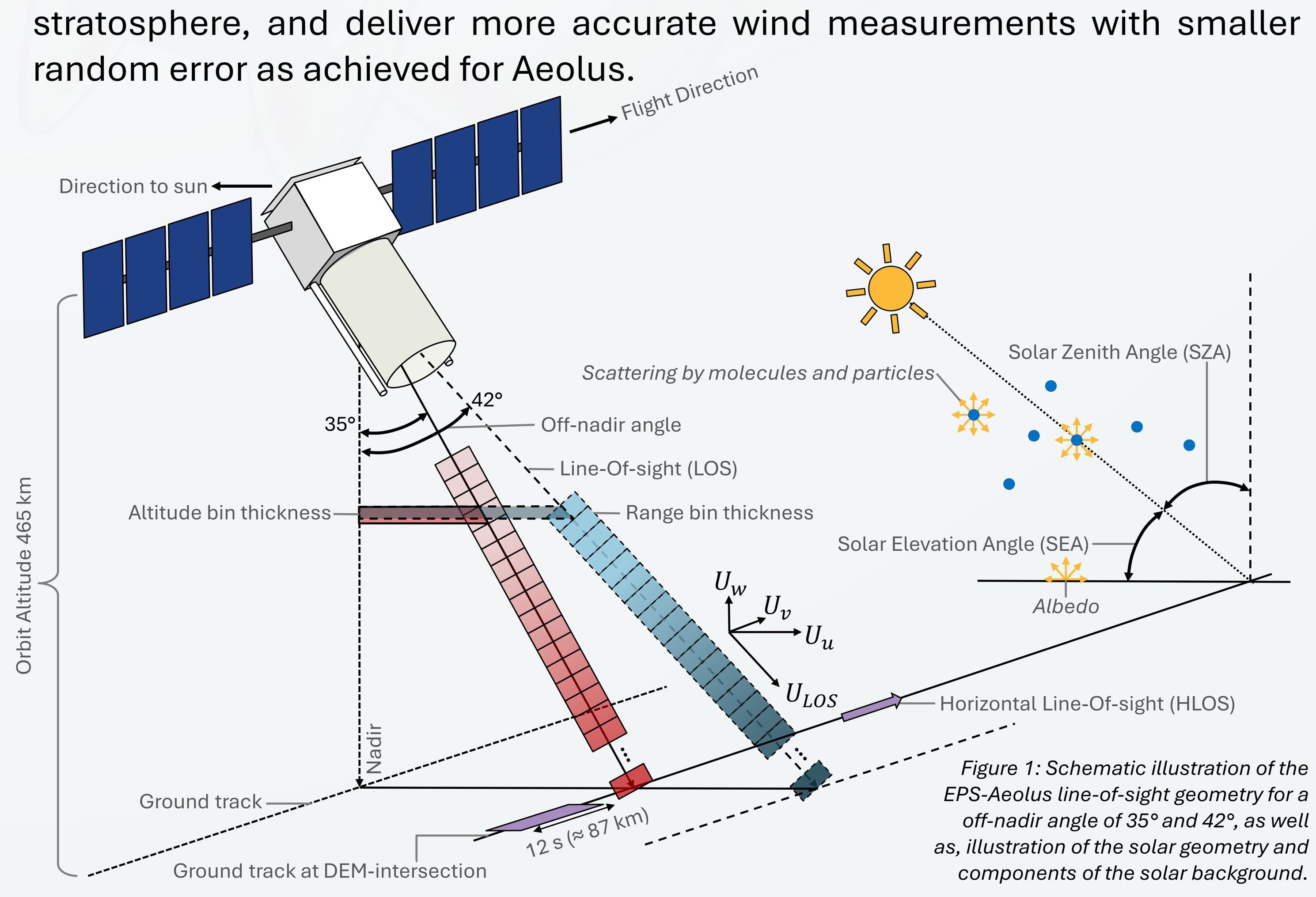

Figure 1: Schematic illustration of the EPS-Aeolus line-of-sight geometry for a off-nadir angle of 35° and 42°, as well as, illustration of the solar geometry and components of the solar background.

INFLUENCE OF THE SOLAR BACKGROUND ON THE RAYLEIGH WIND RANDOM ERROR

One constraint for the reduction of the wind random error is the effect of the **solar background radiation**. The solar background refers to solar radiation reflected from molecules, clouds, aerosols, or the Earth's surface which is able to enter the telescope and contributes to the noise of the lidar measurements (see Figure 1). The solar background reduces the signal-to-noise ratio (SNR) and causes less accurate measurements especially during daylight conditions along the orbit and over bright surfaces.
The E2S is currently upgraded for the simulation of solar background variations along the orbit.

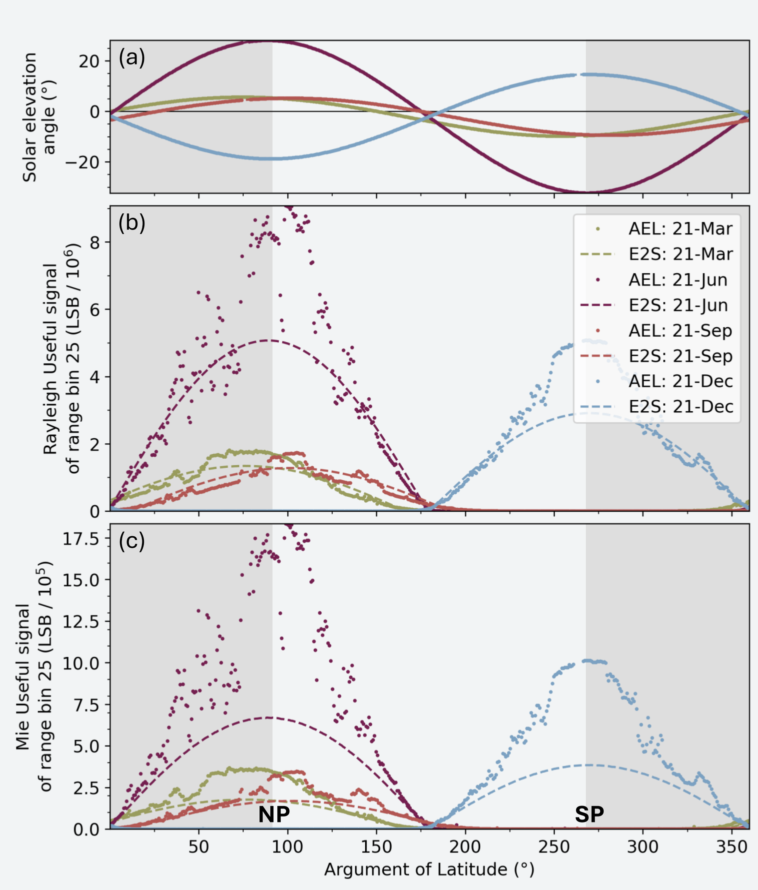

Figure 2: Rayleigh and Mie useful signals of the in-orbit Aeolus solar background observations (dots) and respective simulations (dashed lines) with FOV = 18 µrad in (b) and (c), (a) shows the corresponding Solar Elevation Angle. All are based on four different full orbits around vernal equinox, summer solstice, autumnal equinox and winter solstice. NP and SP mark the North Pole and South Pole.

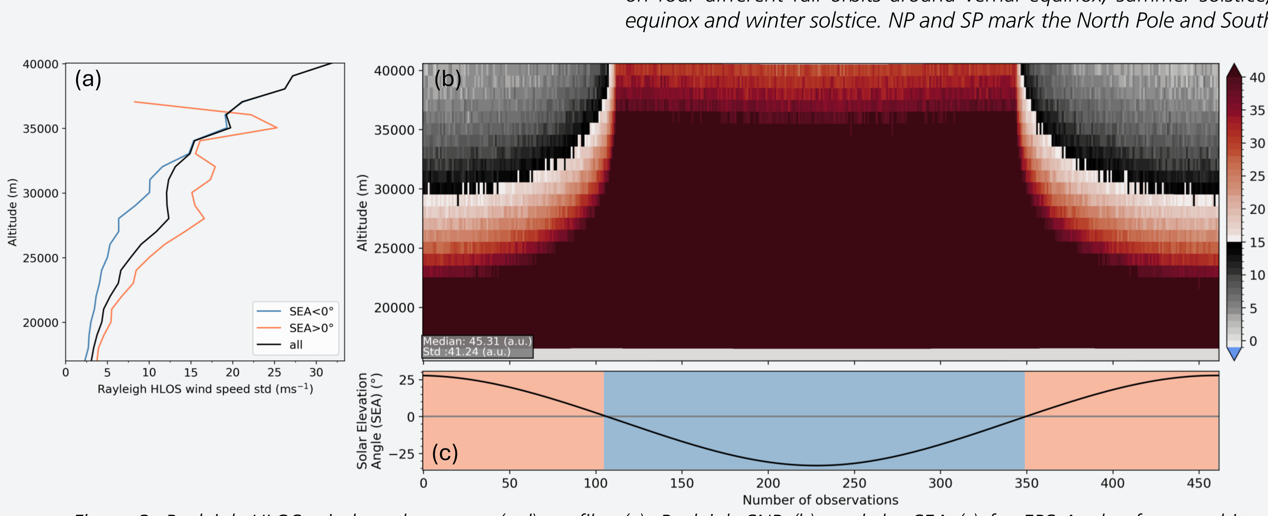

Figure 3: Rayleigh HLOS wind random error (std) profiles (a), Rayleigh SNR (b), and the SEA (c) for EPS-Aeolus for an orbit at summer solstice (21st June, maximum solar background) with range bin thickness of 1000 m, P/N=20/30, an off-nadir angle of 35°, a solar background integration time of 625 µs, FOV=55 µrad and IF=0.5 nm (for Aeolus it was 18 µrad and 1 nm, respectively). Observations with SNR < 15 are set to invalid in the L1B processing of the Rayleigh HLOS wind.

- The E2S is capable of reproducing the development and magnitude of the solar background signal along an orbit when the Solar Elevation Angle (SEA) is smaller 10°. The amplitude and variability of the background are strongly influenced by cloud cover. However, the maximum solar background, especially over the poles where the ice and snow albedo is enhanced in the UV, is not yet sufficiently represented in E2S and will be addressed in future updates.
- The amount of solar background sampled depends i.a. on the Field-of View (FOV) and Interference-Filter Width (IFW) of EPS-Aeolus. The random error will be increased and the data coverage reduced for Rayleigh winds depending on the solar elevation angle and the atmospheric and ground albedo.

EPS-AEOLUS END-TO-END-SIMULATIONS

The **End-to-End Simulator** (E2S) developed for the Aeolus mission is aligned with the specifications of EPS-Aeolus to access the **performance of EPS-Aeolus**.
The E2S generates raw data as downlinked by the Aeolus satellite based on the input of a user-specified atmosphere, an albedo model and Digital Elevation Model (DEM), orbit and pointing information. By using the Aeolus Level 1B (L1B) processor, the raw data is processed to a L1B product which contains Rayleigh and Mie signals and Horizontal Line-Of-Sight (HLOS) winds.

For more information on the function of the E2S and simulation results of the E2S for EPS-Aeolus have a look at the companion ***poster No. 51*** *"Upgrading an end-to-end simulator for Aeolus to EPS-Aeolus"!*

Table 1: Overview of parameters used for the EPS-Aeolus end-to-end simulations for this study.

Parameter	Value
(average) Orbit altitude	465 km
Duration	462 x 12 s (= one orbit)
Laser energy	150 mJ
Transmission Transmitter and Receiver (Aeolus)	0.289, 0.704
Range bins	66 x (500 or 1000) m
Atmosphere	U.S. Standard atmosphere, 0 ms^{-1} wind Speed, Median aerosol
Noise	Enabled (reproducible)
Solar Background	None or average
Field-Of-View (FOV)	55 µrad
Interference-Width (IFW)	0.5 nm
Off-nadir angle	35° - 50°

INFLUENCE OF THE OFF-NADIR ANGLE ON THE RAYLEIGH SIGNAL AND WIND RANDOM ERROR

One import parameter for the reduction of the wind random error is the **off-nadir angle**. With a larger off-nadir angle, a larger fraction of the horizontal wind speed component can be observed (see Figure 1). It is currently studied with the E2S, if an increase of the off-nadir angle is beneficial for EPS-Aeolus.

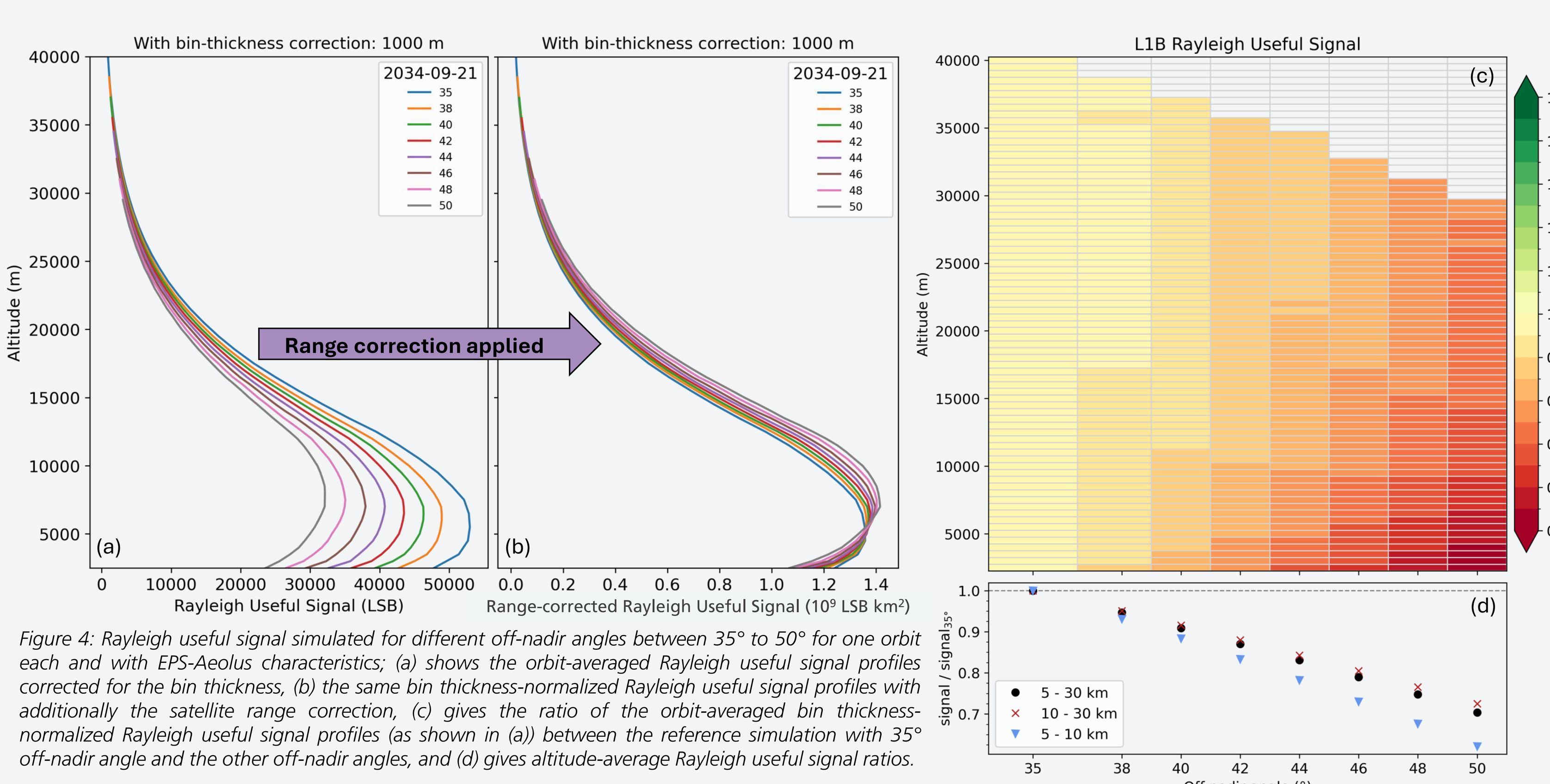

Figure 4: Rayleigh useful signal simulated for different off-nadir angles between 35° to 50° for one orbit each and with EPS-Aeolus characteristics; (a) shows the orbit-averaged Rayleigh useful signal profiles corrected for the bin thickness, (b) the same bin thickness-normalized Rayleigh useful signal profiles with additionally the satellite range correction, (c) gives the ratio of the orbit-averaged bin thickness-normalized Rayleigh useful signal profiles (as shown in (a)) between the reference simulation with 35° off-nadir angle and the other off-nadir angles, and (d) gives altitude-average Rayleigh useful signal ratios.

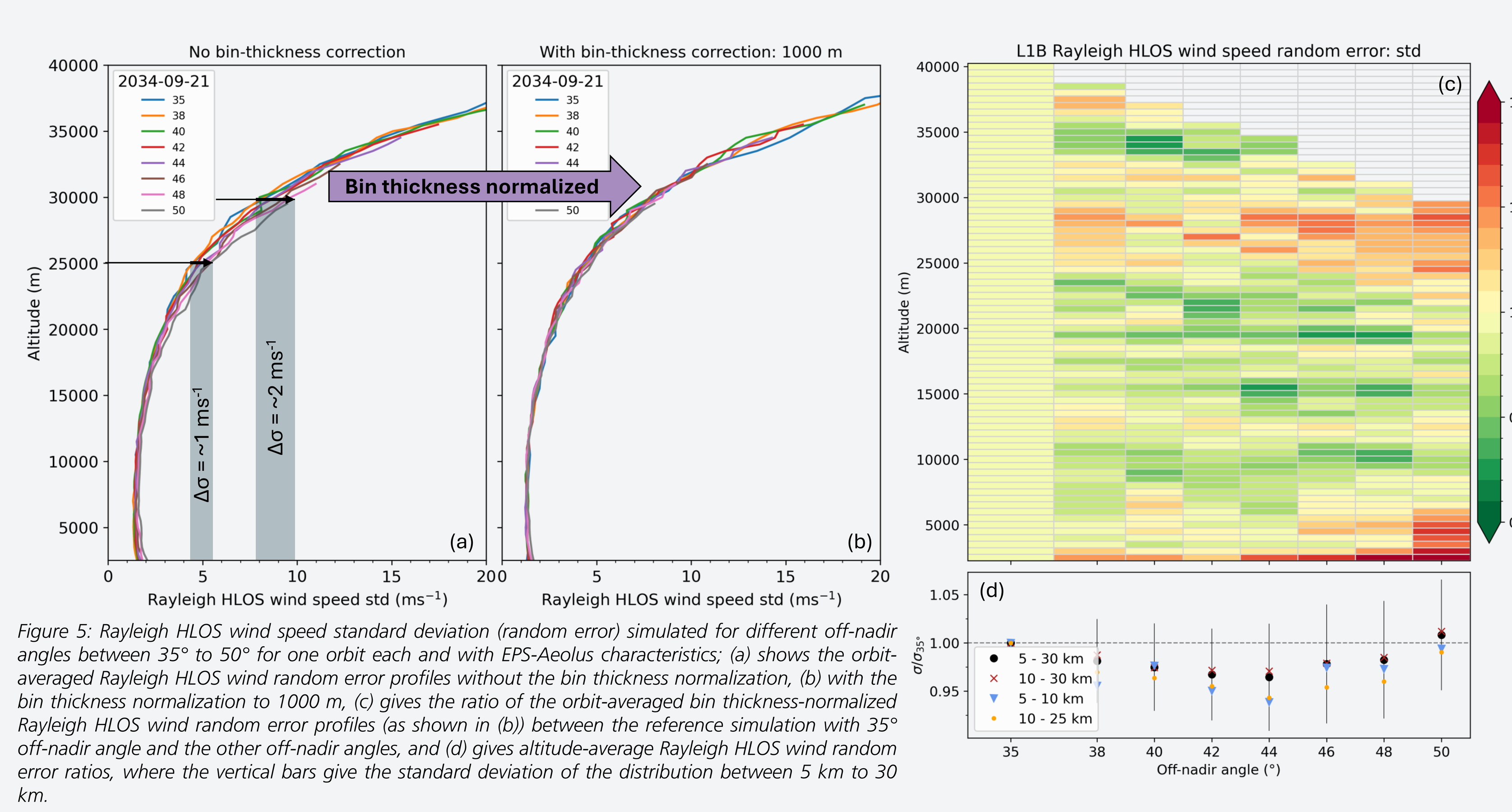

Figure 5: Rayleigh HLOS wind speed standard deviation (random error) simulated for different off-nadir angles between 35° to 50° for one orbit each and with EPS-Aeolus characteristics; (a) shows the orbit-averaged Rayleigh HLOS wind random error profiles without the bin thickness normalization, (b) with the bin thickness normalization to 1000 m, (c) gives the ratio of the orbit-averaged bin thickness-normalized Rayleigh HLOS wind random error profiles (as shown in (b)) between the reference simulation with 35° off-nadir angle and the other off-nadir angles, and (d) gives altitude-average Rayleigh HLOS wind random error ratios, where the vertical bars give the standard deviation of the distribution between 5 km to 30 km.

- Larger off-nadir angles lead to thinner altitude bins, reduce the data coverage with altitude and decrease the absolute Rayleigh Useful Signal, about 2.0% to 2.5% per degree off-nadir angle. This decrease in Rayleigh useful signal will influence the quality of the retrievals of aerosol and cloud optical properties.
- A relative change of Rayleigh useful signal is obtained when the satellite range correction is applied. The relative Rayleigh signal maximum shifts upward in altitude, yielding relatively larger Rayleigh useful signals in the stratosphere for larger off-nadir angles.
- Thinner bins at larger off-nadir angles also increase the Rayleigh HLOS wind random error, thus requiring a bin thickness normalization.
- The **optimum** of the **off-nadir angle** is shallow, altitude-dependent and noise-dependent. The largest improvement of the Rayleigh HLOS wind random error is found around off-nadir angles of **40°-44°**:
  → 3% to 8% improvement of the Rayleigh HLOS wind random error possible at 42°.