Aeolus M1 Bias Correction using Ground Correction Velocities

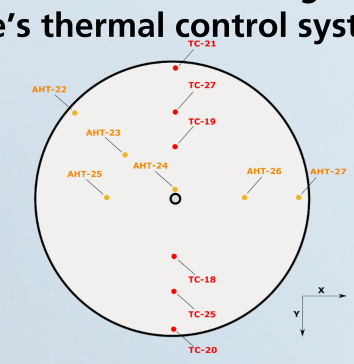
Fabian Weiler[1], Michael Rennie[2] and Oliver Reitebuch[1]

[1] German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V., DLR), Institute of Atmospheric Physics, Oberpfaffenhofen 82234, Germany

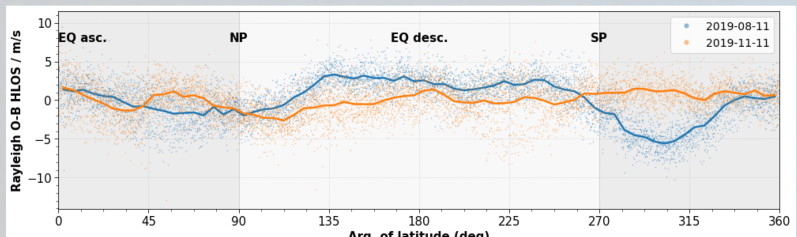
[2] European Centre for Medium-Range Weather Forecasts (ECMWF), Shinfield Park, Reading RG2 9AX, United Kingdom

Introduction

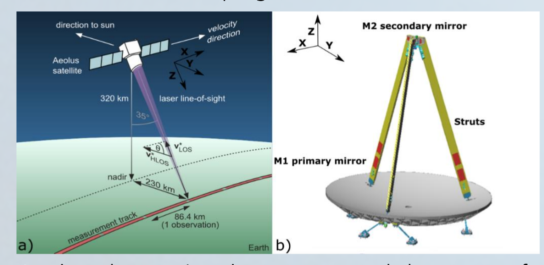
- Comparison between **Aeolus Rayleigh** and NWP (ECMWF) winds showed **large scene-dependent biases of up to 8 m/s depending** on the **orbit phase** which were not expected before launch
- Strong **correlation of the wind bias** with small **temperature fluctuations** of 0.3°C across the **primary mirror** (M1) of the instrument's telescope
- **Temperature fluctuations** related to top-of-atmosphere **reflected shortwave and outgoing longwave radiation** of the Earth and the response of the **telescope's thermal control system**
- Aeolus telescope:
  - 1.5 m and 46 mm diameter primary and secondary mirror
  - Active thermal control loop to keep temperature of primary mirror at a fixed set point; struts and M2 also thermally controlled
  - Several temperature sensors located on the back side of the primary mirror
  - Temperature sensor information available in the Aeolus housekeeping data products



A schematic illustration of the Aeolus M1 mirror. The red and orange dots indicate the positions of the thermal control (TC) and accurate housekeeping (AHT) thermistors..



Rayleigh clear wind bias (E(O-B)) as a function of the argument of latitude on 11 August (blue) and 11 November (orange) 2019. The blue and the orange lines show the E(O – B) values as binned averages using a bin size of 5° for the argument of latitude.

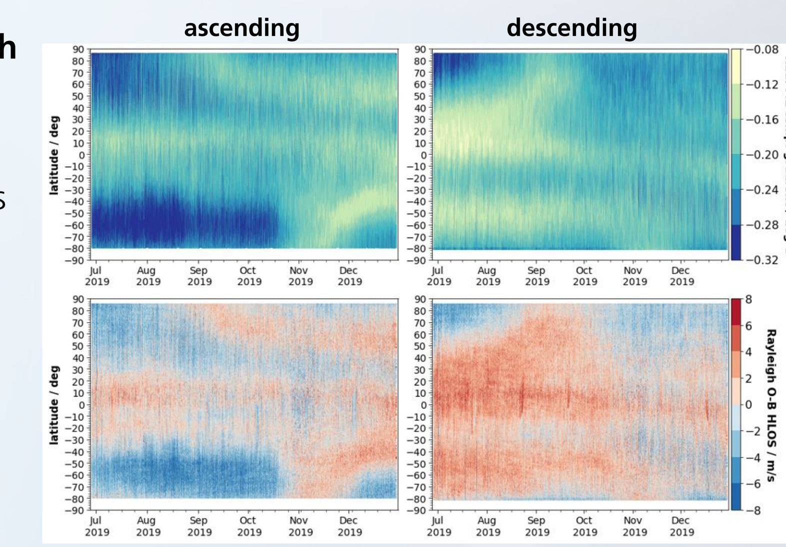


Aeolus observational geometry and the setup of the telescope with the M1 primary and M2 secondary mirrors and the mounting struts.

Telescope Induced Wind Bias

- Strong **linear correlation** between the **radial M1 temperature gradients** and **the Rayleigh clear wind bias**
- Mechanism: Temperature variations affect the shape of the primary mirror → change of focus and beam tilt → change of the angle-of-incidence of the light onto spectrometers → apparent frequency shift → wind bias
- **Sensitivity** of the **Mie channel** towards M1 temperature fluctuations is ~**10 times less** compared to the Rayleigh channel
- Bias correction:

$$\textbf{Bias} = f(M1_{temps}(t))$$



Hovmöller diagrams of the radial temperature gradient (top) and the Rayleigh clear E(O – B) HLOS values (bottom) from 28 June to 31 December 2019 split up into ascending and descending orbit phases.

O – B statistics:
- Model background (B) based on ECMWF equivalent HLOS winds
- Available for each Aeolus wind observation (O)
- Based on 6h forecasts from the operational ECMWF model $T_{CO}1279$

ZWC winds:
- L1B Zero Wind Correction (ZWC) velocities
- Obtained from non-moving surface returns (zero-wind speed reference)
- Limited coverage (high albedo regions)

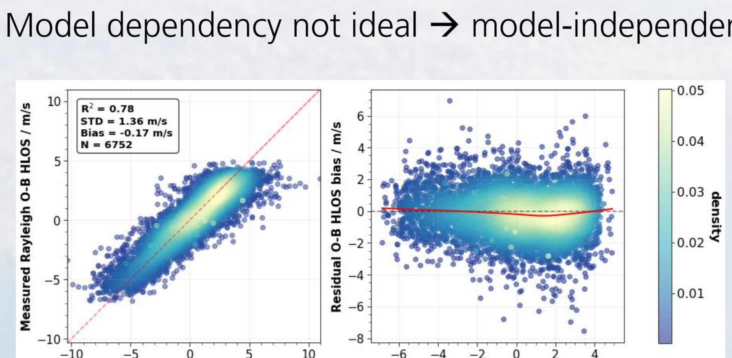
Weiler, F., Rennie, M., Kanitz, T., Isaksen, L., Checa, E., de Kloe, J., Okunde, N., and Reitebuch, O.: Correction of wind bias for the lidar on board Aeolus using telescope temperatures, Atmos. Meas. Tech., 14, 7167–7185, https://doi.org/10.5194/amt-14-7167-2021, 2021.

Operational Bias Correction

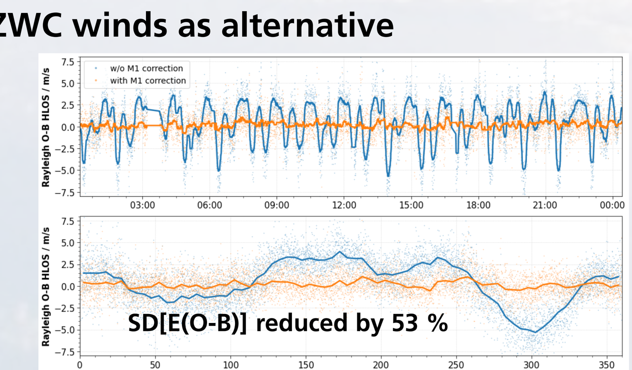
- **Multiple linear regression (MLR)** approach with all available M1 temperature sensors as independent variables and the L2B O-B values as dependent variables:

$$\mathbf{E(O-B)} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1}\cdot \mathbf{AHT22} + \boldsymbol{\beta_2}\cdot \mathbf{AHT23} + \cdots + \boldsymbol{\beta_{15}}\cdot \mathbf{TC32} + \boldsymbol{\varepsilon}$$

- **Quality control**: Only valid L2B HLOS winds; Mie/Rayleigh HLOS error thresholds < 8 m/s / 12 m/s; only Mie cloudy and Rayleigh clear
- E(O-B): Horizontally averaged to the L1B observation granularity (~12 seconds) and vertically averaged over all range gates
- Operational software uses **24 hours of past data** (~6500 data points) and is **updated every 12 hours** to correct for global average biases w.r.t the ECMWF model
- Model-based correction justified by **low global average bias of ECMWF** model winds (< 0.2 m/s)
- Averaging of O-B values helps to mitigate issues arising from altitude-varying model errors
- Model dependency not ideal → model-independent **ZWC winds as alternative**



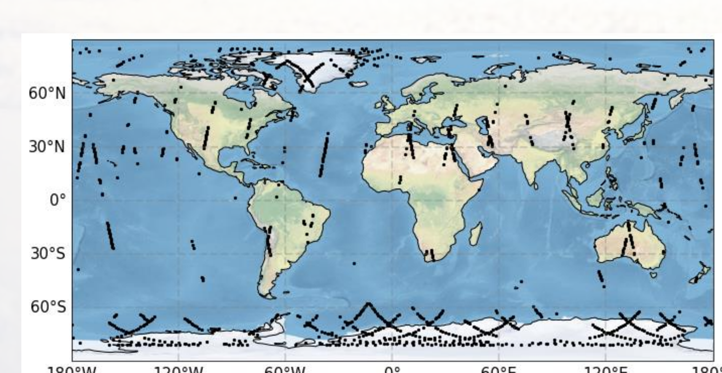
Diagnostic plots for the MLR model with the Rayleigh E(O – B) values (left) and the model residual (right) as a function of the predicted bias. The color coding in both panels indicates the kernel density.



Rayleigh clear E(O – B) HLOS values as a function of time (top) and the argument of latitude (bottom) during 12 August 2019 without and with M1 bias correction.

Ground Correction Velocities

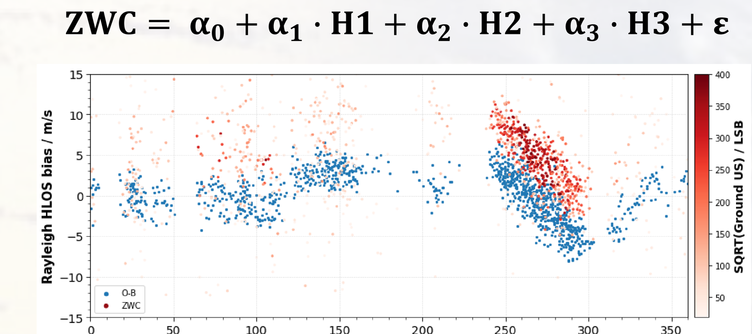
- Obtained from **non-moving ground surface** as zero-wind-speed reference (deviations from zero are considered as systematic errors)
- **L1B processor** uses **a ground detection algorithm** to flag range bins as ground bins; **wind retrieval** is applied to detected ground bins to derive **ZWC winds**
- In contrast to O-B values very **limited coverage**; mainly restricted to **polar regions** with high surface albedo and requires cloud-free observations
- **High noise**; strong dependency on ground useful signal



Geolocation of Rayleigh ZWC winds on 12 August 2019.

- **High** degree of **correlation** between **O-B and ZWC values** indicating the same M1-dependent bias features
- ZWC cover a broad range of bias values which is a prerequisite for a proper fit
- **Global offset** (~ 4 m/s) between O-B and ZWC values due to different calibration schemes (different calibration intercept values between AUX_RBC_2B and AUX_IRC_1B)
- Due to the higher noise and the lower sample size (~1200 data points) a **downsized weighted MLR approach** is used; M1 temperature clusters (H1-H3) as predictors; ground useful signal as weights:

$$\mathbf{ZWC} = \boldsymbol{\alpha_0} + \boldsymbol{\alpha_1}\cdot \mathbf{H1} + \boldsymbol{\alpha_2}\cdot \mathbf{H2} + \boldsymbol{\alpha_3}\cdot \mathbf{H3} + \boldsymbol{\varepsilon}$$



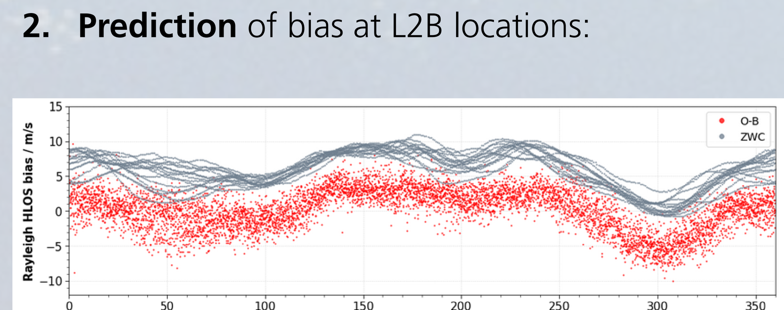
Rayleigh clear E(O – B) HLOS values as a function of time (blue) and Rayleigh ZWC winds (red) as a function of the argument of latitude during 12 August 2019 (16 orbits). The square-root of the ZWC ground useful signal is shown as color-coded information.

Bias Correction based on Ground Correction Velocities

1. **Regression** of M1 temperatures against ZWC:

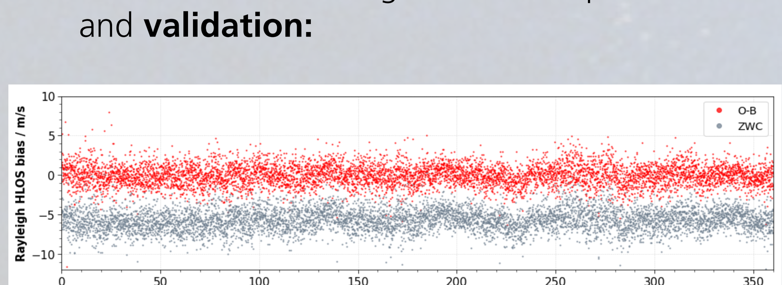
$$\mathbf{ZWC} = \boldsymbol{\alpha_0} + \boldsymbol{\alpha_1}\cdot \mathbf{H1} + \boldsymbol{\alpha_2}\cdot \mathbf{H2} + \boldsymbol{\alpha_3}\cdot \mathbf{H3} + \boldsymbol{\varepsilon}$$

2. **Prediction** of bias at L2B locations:



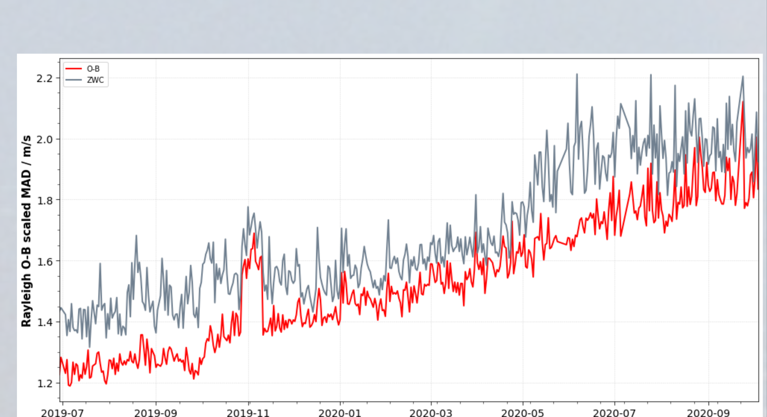
Measured (red) and predicted (grey) Rayleigh clear E(O – B) HLOS values (red) as a function of the argument of latitude on 12 August 2019. The prediction is based on ZWC winds.

3. **Bias correction** using ZWC-based predictions and **validation:**



M1 bias corrected Rayleigh clear E(O – B) HLOS winds using the O-B- (red) and ZWC-based (grey) methods (red) as a function of the argument of latitude on 12 August 2019.

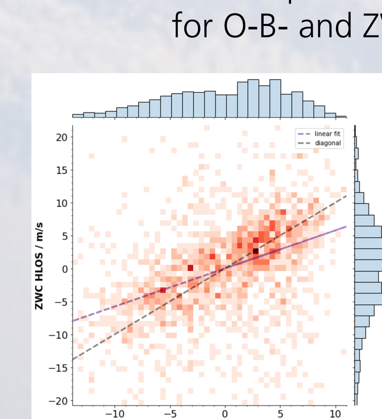
- Comparable performance between O-B and ZWC for the complete time period
- Validation of ZWC approach against O-B values will naturally always favor O-B based correction
- ZWC approach on average ~11% worse than O-B approach
- Performance of ZWC approach instable over time
- Larger differences when the M1 influence on the bias is strong (May-September)



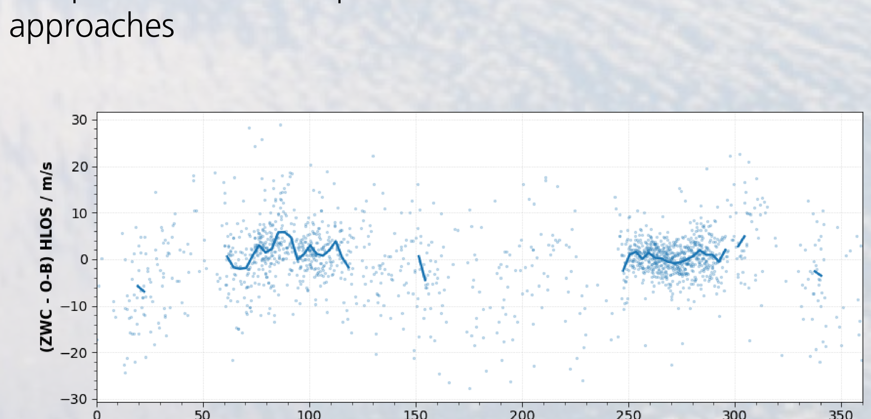
Scaled MAD (median absolute deviation) of the Rayleigh O-B bias after the O-B (red) and the ZWC M1 bias correction (grey) for the period from 28 June 2019 to 28 September 2020.

Remaining Issues and Outlook

- **Systematic difference** between **ZWC and O-B values**:
  - Varies with the orbit phase
  - M1 temperature variations depend on the orbit phase → different M1 fit coefficients for O-B- and ZWC-based approaches



Joint distribution of Rayleigh ZWC and O-B values on 06 June 2020



Difference between Rayleigh ZWC and O-B HLOS values as a function of the argument of latitude on 06 June 2020

- First analysis showed that the difference between ZWC and O-B values is related to the **atmospheric signal contamination** of the Rayleigh ground bins; contamination of narrow bandwidth ground return signal with broad bandwidth molecular atmospheric signal
- **Atmospheric signal contamination depends** on the **surface albedo** (→ground useful signal) and the **thickness of the atmospheric column** in the ground bins
- **Mitigation** approaches for future analysis:
  - Smart filtering depending on ground useful signal and thickness of the atmospheric column
  - Correction of Rayleigh ZWC winds for atmospheric signal contamination