Aeolus Level 1 data processing and instrument calibration

Oliver Reitebuch (DLR) and Alain Dabas (Météo France)
Uwe Marksteiner, Marc Rompel, Markus Meringer, Karsten Schmidt, Dorit Huber, Ines Nikolaus, Jon Marshall, Frank de Bruin, Thomas Kanitz, Anne-Grete Straume

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Outline of the talk

- How are winds measured by ALADIN and are retrieved up to Level 1?
- Why is a calibration needed for ALADIN and how is it performed?
- Why are ground-returns important for bias correction of ALADIN winds?
Rayleigh wind sensitivity 0.3% / m/s
=> Determine signal intensity with an accuracy in the order of 0.05% to 0.5%
=> offset corrections and calibration

Mie wind sensitivity 18 m/s per pixel
+ Mie fringe width 30 m/s
=> Determine centroid of a signal, which is 30 m/s broad (FWHM) with an accuracy of 1/100 to 1/20 of a pixel width => high SNR and QC

Doppler -Equation: \[ \Delta f = 2f_0 \frac{V_{\text{LOS}}}{c} \]
1 m/s ⇔ 5.64 MHz ⇔ 2.37 fm
354.8 nm ⇔ 844.955 THz
1 pm ⇔ 422 m/s

Response:

\[ R_{\text{Ray}} = \frac{I_A - I_B}{I_A + I_B} \]
\[ R_{\text{Mie}} = x_{\text{centroid}} \]

Fig.: Reitebuch (2012): Wind Lidar for Atmospheric Research, in Springer Series
Main processing steps for wind retrieval up to Level 1

**L1B Wind Mode Data**
- all instrument related corrections and calibrations
- both Mie and Rayleigh winds
- no atmospheric corrections, e.g. temperature, pressure, aerosol cross-talk to Rayleigh => L2B product
- no scene classification or grouping => L2B product

**L1B Data Product**
- geolocation, pointing, instrument data
- signal amplitudes, signal-to-noise ratio
- scattering Ratio \( \frac{\beta_{mol} + \beta_{aer}}{\beta_{mol}} \)
- Mie and Rayleigh wind
- error quantifiers and quality flags in Product Confidence Data PCD
- ground-return signal and speed

AOCS: Attitude+Orbit Control System
DEM: Digital Elevation Model
ALADIN instrument modes and processors

**ALADIN instrument modes**

- Dark Current Calibration DCC
- Instrument Defocus Characterisation IDC
- Instrument Auto Test IAT
- Laser Beam Monitoring LBM
- Instrument Spectral Registration ISR
- Instrument Response Calibration IRC
- Wind Velocity Measurement WVM
- Dark Current in Memory Zone DCMZ

**Wind Velocity Measurement WVM**
- off-nadir pointing with 35°
- fixed laser frequency

**Instrument Response Calibration IRC**
- nadir pointing
- laser frequency ramp

**Calibration Processors**
- L1B Wind Retrieval
- L2B Wind Retrieval
- L2A Aerosol Retrieval

**internal laser reference signal**

**internal + atmospheric signal**
Why are calibrations needed for ALADIN?

Rayleigh spots

Measure \( R \) for \( v_{\text{LOS}} = 0 \) m/s (nadir pointing) and vary \( \Delta f \) by changing laser frequency (IRC)

\[
R = \frac{I_A - I_B}{I_A + I_B}
\]

Instrument Response \( R \)

\( R : \hat{x}_0 \) centroid pixel

Rayleigh-Brillouin \( I(f) = f(T, p, h) \) with \( T \) and \( p \) from NWP model

Level 1 and Level 2 Mie

Doppler frequency \( \Delta f \) and LOS wind \( v_{\text{LOS}} \)

\[
\Delta f = 2 \cdot f_0 \cdot \frac{v_{\text{LOS}}}{c}
\]

Level 2 Rayleigh

Compute \( R(\Delta f) \)

Instrument function \( T(f) \) from ISR for Rayleigh

Level 1 and Level 2 Mie
Rayleigh-Brillouin correction (AUX_RBC) and Instrument radiometric calibration (AUX_CAL) files are computed by the calibration suite processors. Temperature and pressure profiles (AUX_MET) are provided by ECMWF. Both require a careful spectral characterisation of the Rayleigh spectrometer.
Instrument Spectral Registration (ISR instrument mode)

Laser frequency scanned across a full Free Spectral Range FSR with $\Delta f = 25 MHz$
only internal path recorded, no atmospheric signal

**Problem:**

The étendue (optical properties) of the beam in the internal and atmospheric paths are different!

The ISR does not characterize the spectral characteristics of the Rayleigh spectrometer for the atmospheric path
A scheme was devised to characterize the impact of the beam étendue.

Based upon the following assumption (convolution)

\[ \tau_{A,B}^\text{atm}(f) = \tau_{A,B}^\text{int} \otimes \Pi_{\Delta,x}(f) \]

The estimation of \( \Delta \) (width) and \( x \) (tilt) uses the Rayleigh Response Calibration RRC)

Nadir pointing mode for 20 minutes preferably over land with high UV albedo, e.g. Antarctica and low cloud coverage with

- Internal reference
- Atmospheric signal
- Ground returns

\[ \Delta^{-1}(1 + 0.5x) \]

\[ \Delta^{-1}(1 - 0.5x) \]

\[ \Pi_{\Delta,x}(f) \]
Why are ground returns important for ALADIN?

Calibration in nadir pointing
- determination of Mie and Rayleigh response coefficients for ground returns

Wind mode
- Determination of initial LOS pointing offsets in commissioning phase
- Continuous correction for harmonic bias
- Determination and monitoring of coefficients for range-dependent bias

Specific challenges for using ground returns with Aeolus
- Coarse range gate resolution of 250-500 m
- ACCD detector principle resulting in range gate overlap of 150 m
- Imperfections in images on detector
  ⇒ distribution of ground return in several range gates
  ⇒ mixture of atmospheric and ground signal in ground-return range gates

Simulation of ground returns over 10 orbits with harmonic bias

Simulation of ground returns over 20 orbits with range dependent bias RDB over Antarctica

Determination of RDB slope using ground
⇒ use in L1/L2 wind retrieval for correction pre-launch slopes:
  Ray: 0.35 m/s / 10 km
  Mie: 0.11 m/s / 10 km

LOS ground speed [m/s]

mean range to ground [km]
Specific characteristics of ALADIN

- beam Diameter ratio from telescope (Ø 1.5 m) to Rayleigh Spectrometer (Ø 20 mm) is factor 75 => magnification of 2.4 µrad by factor of 75 at Rayleigh spectrometer
- small FOV of only 18 µrad
- high sensitivity of spectrometer to incidence angle => wavelength shift => wind speed bias
- compensated within ALADIN for one specific range, but remaining angular misalignment for other ranges => range-dependent bias

\[ \phi = 1.13 \text{ mrad/s} \]
\[ \Delta \Theta = 2.4 \mu \text{rad} \]
\[ \Delta t = 2.13 \text{ ms} \]
\[ \Delta s = 16 \text{ m} \]
\[ \Delta s = 0.8 \text{ m} \]
\[ v = 7.66 \text{ km/s} \]
Aeolus – the first wind lidar in space - first time for retrieval algorithms for spaceborne wind lidars

- **requirement on random error** (precision): 1 m/s (0-2 km) to 2.5 m/s (2-16 km) HLOS => mainly determined by photon (signal+solar background) Poisson noise

  validate random error by colocated observations (ground, airborne, balloon)

- demanding requirements for the **systematic error** bias <0.7 m/s => mainly determined by instrument stability, calibration and bias correction

  strong influence of algorithms for wind retrieval, calibration, and bias characterisation and correction using ground-returns

- Wind products need to be available for NWP users within 3 hours after observation => different to other lidar missions and science-driven missions

  Aeolus benefits from monitoring of Aeolus wind products with NWP models and validation

Fig. ESA / ATG-medialab