How Aeolus Cal/Val helps to define validation protocols for space-borne aerosol profiling in the context of the EarthCARE mission

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History of spaceborne lidars

**LITE**
- Lidar
- In-space Technology Experiment
- On Space Shuttle Discovery
- September 1994
- (aka: Laser Altimetry Mission)
- Instrument: Geoscience Laser Altimeter System (GLAS) - sole instrument (532+1064 nm)
- Jan 2003 – Feb 2010

**ICESat**
- Ice, Cloud, and Land Elevation Satellite

**CALIPSO**
- Measures since 7 June 2006
- Elastic polarization lidar at 532 nm and 1064 nm
- Part of the A-Train

**AEOLUS**
- Atmospheric Explorer for Observations with Lidar in Ultraviolet from Space
- Doppler lidar @ 355 nm pointing 35° off nadir
- Launched Jan 2015, duration 6 months
- Launched Aug 2018
- Launch in Autumn 2023?

**EarthCARE**
- Lidar+cloud radar+imager+broad band radiometer onboard one satellite
EarthCARE: Linking Clouds, Aerosol and Radiation

Science: Impact of Clouds and Aerosols on Radiation
Observations:
• Cloud profiles (ice, liquid, mixed), cloud coverage, precipitation
• Aerosol profiles
• Broad-band Solar & Thermal Radiation

Satellite and Payload
• Sun-sync. orbit at 393 km, 14:00 hours descending node
• UV Lidar with high spectral resolution receiver
• W-band Cloud Radar with Doppler (contribution JAXA)
• Imager and Broad-Band Radiometer
• Launch 2023
EarthCARE: Instrumentation

Cloud Profiling Radar (CPR) - JAXA
94 GHz Doppler, 2.5 m dish (folded in photograph)
Level 1: Reflectivity and Doppler profiles

Atmospheric Lidar (ATLID)
High-Spectral Resolution Lidar (HSRL), $\lambda=355\text{nm}$
Two redundant transmit telescopes & 60 cm receive tel.
3 receive channels: molecular, particular, depolarization
Level 1: attenuated backscatter profiles

Multi-Spectral Imager (MSI)
pushbroom, 4 solar + 3 TIR channels
Level 1: TOA radiances and brightness temperatures

Broad-Band Radiometer (BBR)
2 Channels: Solar + Thermal; 3 fixed FoV
Level 2: TOA solar and thermal radiances & fluxes

Photos courtesy Airbus
EarthCARE Cal/Val map

PLUS
• Airborne
• Ship-borne
• Satellite based
• Model

Huge validation effort...
→ Coordination
EarthCARE Cal/Val preparation

• AO (Announcement of Opportunity) call in 2017
• ESA EarthCARE validation workshops in 2018 and 2021, each with ~250 participants

> 30 AO proposals (Cal/Val teams)  
→ adequate validation  
if full funding is achieved

Clear need for common protocols for cloud and aerosol profile validation

https://earthcare-val.esa.int

Involvement in EarthCARE Cal/Val is still possible → rob.koopman@esa.int
Some examples which have been discussed

• Wavelength conversion to 355 nm (or utilisation of correlative instruments with different wavelength)
• Orbital-suborbital attenuated backscatter – L1 validation
• 355 nm depolarization validation
• How to handle/mitigate daytime capabilities/limitations of ground-based lidars (especially RAMAN)
• Scene classification
• Statistical methods
There is a clear need for common practise based on the lessons learned from previous missions

- Enhance maturity of intercomparisons (more quantitative vs presently rather qualitative)
- Enhance thoroughness of statistical intercomparison methods (dealing with sparse data, and with risks of bias)
- Guidance and knowledge transfer
- Obtain broader assessment of EarthCARE validation gaps by engaging Aeolus, CloudSat, CALIPSO, AtmOS communities
Aeolus Cal/Val

Lessons learned for common protocols for best practice
Aeolus – the first wind lidar in space

- ESA Earth Explorer Mission
- First European lidar in space called Aladin
- **First lidar @ 355 nm** in space
- First HSRL lidar in space
- Profiles of the **west-east wind component**
- Provides also **aerosol & cloud products**
- Intensive validation efforts needed
  → lessons learned for EarthCARE with ATLID
Some examples to be discussed
- Lessons learnt from Aeolus Cal/Val

• Wavelength conversion (or utilisation of correlative instruments with different wavelength)
• Orbital-suborbital attenuated backscatter – L1 validation
• 355 depolarization validation
• How to handle/mitigate daytime capabilities/limitations of ground-based lidars (especially RAMAN)

• Scene classification
• Statistical methods
Cloud contamination and representativeness problem → different for different missions
Cloud screening, scene classification essential

Extreme horizontal variability for both aerosols and clouds
Horizontal aerosol homogeneity within the 100 km circle

100 km for co-location radius is a recommendation and can be modified depending in station and scene.
Some examples to be discussed
-- Lessons learnt from Aeolus cal/Val

• Wavelength conversion (or utilisation of correlative instruments with different wavelength)
• **Orbital-suborbital attenuated backscatter** – L1 validation
• 355 depolarization validation
• How to handle/mitigate daytime capabilities/limitations of ground-based lidars (especially RAMAN)
• Scene classification
• Statistical methods
Different space borne lidars – ground-based lidars

Attenuated backscatter measured from ground and space is not the same
→ Level one comparison is challenging
→ Even though one measures at the same frequency
Example at 355 nm

$$\text{AttBSC}(R) = \frac{(P^\lambda(R) - P_{BG})R^2}{C_{SYS}^\lambda O^\lambda(R)} = [\beta^\lambda_{par}(R) + \beta^\lambda_{mol}(R)] \exp \left\{ -2 \int_0^R \left[ \alpha^\lambda_{par}(r) + \alpha^\lambda_{mol}(r) \right] dr \right\}$$

PollyXT_TROPOS; Leipzig, Germany, 27 March 2020. 1830-1930 UTC

With measured backscatter and extinction profiles from ground one can calculate the attenuated backscatter from space!

- Ground based:
  - Signal maximum ~ ground
- Space borne:
  - Signal maximum (Aeolus) at 7 km

For Level 1 validation, you need Level 2 products from ground

But multiple scattering is not addressed with this simple approach
Underestimation of extinction and optical depth by 25%–35%.

Impact of multiple-scattering effect for CALIPSO

Wandinger et al., 2010

Amiridis et al., ACP, 2013
How to come to a (CEOS) validation protocol for
Aerosol profile
Cloud & precipitation profiles?

• Community consensus on approaches for
  • Data acquisition strategies
  • Data intercomparison methods/strategies (remember examples given)
  • Combining remote sensing and in-situ measurements.

• But, not mandatory: Different approaches can and should co-exist
• But should be unambiguously distinguished when interpreting results
The way forward

• Expert group currently forming
• Use expertise from existing projects (FRN4radar, DIVA, CARDINAL etc.)
• Identify important open issues (where no common practice is available yet).
• For some topics, contributions may lead to the development of scientific code which will be made publicly (like e.g. attenuated backscatter issue).
• Lessons learnt from Aeolus (scene classification, backward trajectories, co-location exercises, Aerosol typing?) → Will be of great interest for EarthCARE
• Contribution from Aeolus community strongly desired

Initial version of the best practice at EarthCARE launch

You are very welcome to contribute in formulation of best practise:
Email to Rob.Koopman@esa.int, Stephanie.Rusli@esa.int, elmarinou@noa.gr, baars@tropos.de
EarthCARE Cal/Val preparation

- Dedicated EarthCARE sessions at Living Planet Symposium May 2022:

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<td>E2.06 EarthCARE ReadyForLaunch</td>
<td>A9.04 Mass Balance of the Cryosphere - Session on Results</td>
<td>C4.02 HAPs – High-Altitude Pseudo Satellites</td>
<td>B8.08 Copernicus Sentinel Expansion Missions - New capabilities for the Copernicus 2.0</td>
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<td>C5.03 Open Source Science, toolboxes and Jupiter technologies in EO</td>
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Poster in A1.09

Defining validation protocols for space-borne aerosol and cloud profile products