Ground-based Rayleigh-Mie Doppler wind lidar: design, observations and proposal for Aeolus CAL/VAL.

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Ground-based Rayleigh-Mie Doppler lidar

• Measurement of horizontal wind components between 5 and 50 km altitude with accuracy better than 1 m/s up to 30 km

• Demonstration of the method in 1989, quasi-regular observations at OHP during 1993-1996, sporadic observations since then

• Two lidar systems deployed at Haute-Provence observatory (Southern France, 44°N) and Maïdo observatory (Reunion island, 21°S)

• Doppler shift of the backscattered light is detected using a double-edge Fabry-Perot interferometer (direct detection)

• Method exploited by the ALADIN onboard ADM (Rayleigh channel)

• Night-time (twilight) cloud-free or thin cirrus conditions required
Rayleigh-Mie Doppler lidar


\[ \Delta \lambda(z) = 2\lambda_0 \sin \theta \frac{v_h(z)}{c}, \]

1 m/s wind speed \[\leftrightarrow\] 2 fm Doppler shift

\( \lambda_0 \) – emitted wavelength (532 nm)
\( \theta \) – line-of-sight angle from zenith
\( v_h \) – horizontal wind speed

Response to Doppler shift

\[ R(z) = \frac{N_A(z) - N_B(z)}{N_A(z) + N_B(z)}, \]

\( N_A \) and \( N_B \) are the number of photons transmitted through the bandpasses A and B

FPI bandpasses are spectrally tuned symmetrically on both sides of the Rayleigh-Mie backscattered line by air pressure adjustment

Laser beam is alternatively steered toward the west and the north for measuring zonal and meridional wind components.

Vertical pointing is used to obtain zero Doppler shift reference (assuming negligible vertical wind)
Rayleigh-Mie Doppler lidar
Haute-Provence observatory (OHP)

44°N, 6°E, 650m amsl

- **Laser**:
  - Spectra-Physics Nd:YAG laser
  - Q-switched, injection-seeded
  - Emission wavelength: 532 nm
  - Emission line FWHM: 0.14 pm
  - Power: 800 mJ/pulse, 24 W mean
  - Repetition rate: 30 Hz

- **Telescopes**:
  - 3 telescope assemblies with 4 receiving mirrors (Ø=500mm), total area of each: 0.78 m²
  - Direction of view: East, North and vertical
  - Angle from zenith for inclined pointings: 40°

- **Detection**:
  - 4 photomultipliers + electronic obturation:
    - High gain channels (90 % → 10 - 45 km),
    - Low gain channels (10% → 5 - 13 km).

- **Acquisition**:
  - LICEL transient recorder, 16384 bins
  - Maximum vertical resolution: 5.3 m
Rayleigh-Mie Doppler lidar
Maïdo observatory, Reunion island
21°S, 55°E, 2158 m amsl

- **Laser**:  
  - Spectra-Physics Nd:YAG laser  
  - Q-switched, injection-seeded  
  - Emission wavelength: 532 nm  
  - Emission line FWHM: 0.14 pm  
  - Power: 800 mJ/pulse, 24 W mean  
  - Repetition rate: 30 Hz

- **Telescopes**:  
  - 1 telescope with rotating mirror, collective area 0.3 m²  
  - Direction of view: West, South and vertical (to be installed)  
  - Angle from zenith for inclined pointings: 41°

- **Detection**:  
  4 photomultipliers + electronic obturation:  
  - High gain channels (90% → 10 - 45 km),  
  - Low gain channels (10% → 5 - 13 km).

- **Acquisition**:  
  - LICEL transient recorder, 8192 bins  
  - Maximum vertical resolution: 11 m
Scientific applications of DWL observations

Wind climatology for OHP

Seasonal variation of monthly averaged zonal (a) and meridional (b) winds over OHP (1994-1997) (Souprayen et al., 1999)

Wind small-scale fluctuations

Zonal (a) and meridional (b) wind components measured by the Doppler lidar at OHP, 03.09.1997 (Hertzog et al., 2001)

Gravity waves activity

Kinetic energy of GW at 13-20 km altitude range above OHP (Hertzog et al., 2000)

Gravity waves spectrum

GW frequency spectrum at 13-16 km from a single night of measurements, OHP 14.02.1996 (Hertzog et al., 2000)
Uncertainty of the wind measurement for different temporal and vertical resolutions

<table>
<thead>
<tr>
<th>Altitude</th>
<th>5 min/115 m</th>
<th>1 h/115 m</th>
<th>10 min/345 m</th>
<th>7 h/345 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 km</td>
<td>2.7</td>
<td>0.8</td>
<td>1.1</td>
<td>0.2</td>
</tr>
<tr>
<td>16 km</td>
<td>4.1</td>
<td>-</td>
<td>1.7</td>
<td>0.3</td>
</tr>
<tr>
<td>20 km</td>
<td>6.8</td>
<td>2.0</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>25 km</td>
<td>12.2</td>
<td>3.5</td>
<td>-</td>
<td>0.8</td>
</tr>
<tr>
<td>30 km</td>
<td>-</td>
<td>6.0</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(Oppenheim et al., 2001)

**OHP Doppler lidar**: comparison with GPS radiosondes and ECMWF

(Soprayen et al., 1999)
Maïdo Doppler lidar:
comparison with GPS radiosondes and ECMWF (June 2014)

Radiosondes are launched daily from Gillot airport on Reunion island (~30 km away from Maïdo) at 12 UTC (15 LT)

Air distance between RS and DWL profiles up to 60 km

Time lag between RS and DWL profiles = 6-15 h
Validation strategy for ADM-Aeolus

Pre CAL/VAL phase
development of spatial and temporal collocation criteria
- temporal variability of wind on a scale of several hours inferred from ground-based Doppler lidar and radiosondes
- spatial variability of wind inferred from a radiosounding network and reanalysis data sets

CAL/VAL phase
• 3-month measurement campaigns at OHP and Maïdo 1-2 months after the start of nominal Aeolus operation
• > 2 nights of lidar soundings per week at both stations
• QC dataset for validation available 2 months after campaigns
• Complimentary radiosondes
• Aerosol observations using dedicated lidars at both stations

Long-term validation
• Stability of measurements
• Potential for studying atmospheric waves
Validation strategy for ADM-Aeolus

Spatial collocation quality
(depending on the actual Aeolus orbits’ location)
4 medium-distance (100-150 km away) overpasses a week
or
2 close-distance (<50 km) and 2 remote (>200 km) overpasses a week

Temporal collocation and lidar limitations
- ADM overpasses at 06h20 and 17h50 local solar time
- Depending on the Aeolus launch date the sky background during CAL/VAL campaign may be more or less favorable for the ground-based lidars
- Useful measurements are limited to the height range where lidar signal exceeds the sky background by a factor of 2

Expected performance of the ground-based DWL:
error (m/s) for 1 h integration time and 1 km vertical resolution

<table>
<thead>
<tr>
<th>Altitude (km)</th>
<th>Nighttime</th>
<th>Daytime (June-July)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>15</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>20</td>
<td>1.5</td>
<td>1.8</td>
</tr>
<tr>
<td>25</td>
<td>2.8</td>
<td>-</td>
</tr>
<tr>
<td>30</td>
<td>5.0</td>
<td>-</td>
</tr>
</tbody>
</table>
Summary

• Two direct-detection Rayleigh-Mie Doppler wind lidars are deployed at mid-latitude (OHP) and tropical (Maido) sites.

• The system is shown capable of wind measurements between 5 and 50 km with accuracy better than 1 m/s up to 30 km.

• Measurements are used for studying mesoscale wind fluctuations and inertia-gravity waves in the mid-stratosphere as well as for constructing wind climatology up to 50 km altitude

• Ground-based DWL shares the measurement principle with ALADIN Rayleigh channel.

• The proposed program for ADM-Aeolus validation includes pre-CAL/VAL phase and 3-month dedicated validation campaigns

• Longer-term perspective: evaluation of Aeolus capabilities in observing gravity waves


A. Garnier et al., 1990: US licence no. 542 961.


