The Wind Lidar Mission ADM-Aeolus

Recent Science Activities and Status of Instrument Development

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ADM-Aeolus with single payload
Atmospheric LAser Doppler INstrument
ALADIN

- Observations of Line-of-Sight LOS wind profiles in troposphere to lower stratosphere up to 30 km with vertical resolution from 250 m - 2 km horizontally averaged over 50 km every 200 km
- Vertical sampling with 25 range gates can be varied up to 8 times during one orbit
- High requirement on random error of HLOS
  - <1 m/s (z=0-2 km, for Δz=0.5 km)
  - <2 m/s (z=2-16 km, for Δz=1 km), unknown bias <0.4 m/s and linearity error <0.7% of actual wind speed; HLOS: projection on horizontal of LOS => LOS accuracy = 0.6*HLOS
- Operating @ 355 nm with spectrometers for molecular Rayleigh and aerosol/cloud Mie backscatter
- First wind lidar and first High Spectral Resolution Lidar HSRL in space to obtain aerosol/cloud optical properties (backscatter and extinction coefficients)
ADM-Aeolus Coverage and Data Availability

- **3200 wind profiles per day**: about factor 3 more than radiosondes
- **3 hour data availability** after observation (NRT-Service) => 1 data-downlink per orbit;
  30 minutes data availability for parts of orbit (QRT-Service with late start of downlink)
- **launch date late 2009** (consolidated launch date prediction in some months expected)
- **mission lifetime 39 months**: observations from 2010-2012

Overview paper about ADM-Aeolus

and soon ADM-Aeolus Science Report
(ESA publication SP-1311)

and soon TELLUS special edition about
ADM-Aeolus workshop 2006

50 km observations during 6 hour period
Mass and Power Budgets
mass: 1100 kg dry +116-266 kg fuel
power: 1.4 kW avg. (solar array 2.4 kW peak)
mass instrument: 470 kg
power instrument: avg. 840 W (laser 510 W)
Volume: 4.3 m x 2.0 m x 1.9 m

Doppler Lidar Instrument ALADIN
Nd:YAG laser in burst mode operation
(120 mJ @ 355 nm, 100 Hz)
1.5 m Cassegrain telescope
Dual-Channel-Receiver with ACCD detector
(Accumulation Charge Coupled Device)

Orbit
polar, sun-synchronous, dawn-dusk (6 pm LTAN),
97° inclination; height 410 km (395-425 km),
7 days orbit repeat cycle (109 orbits);
92.5 min orbit duration

Pointing and Orbit Control
GPS, Star-Tracker, Inertial Measurement Unit,
Yaw steering to compensate for earth rotation

Launcher
Rockot (Russia), Dnepr (Russia) or Vega (ESA):
tbd in 2008
## Comparison of Power-Aperture Products of Space Lidars

<table>
<thead>
<tr>
<th>Lidar</th>
<th>Lidar altitude</th>
<th>Pulse energy</th>
<th>Pulse rep. rate</th>
<th>Mirror diameter</th>
<th>Power-aperture product</th>
</tr>
</thead>
<tbody>
<tr>
<td>LITE (532 nm)</td>
<td>250 km</td>
<td>560 mJ</td>
<td>10 Hz</td>
<td>1.0 m</td>
<td>$7.0 \times 10^{-11}$ W</td>
</tr>
<tr>
<td>GLAS (532 nm)</td>
<td>600 km</td>
<td>35 mJ</td>
<td>40 Hz</td>
<td>0.9 m</td>
<td>$0.25 \times 10^{-11}$ W</td>
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<tr>
<td>CALIOP (532 nm)</td>
<td>700 km</td>
<td>110 mJ</td>
<td>20 Hz</td>
<td>1.0 m</td>
<td>$0.35 \times 10^{-11}$ W</td>
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<tr>
<td>ALADIN (355 nm)</td>
<td>410 km</td>
<td>150 mJ</td>
<td>100 Hz</td>
<td>1.5 m</td>
<td>$15.8 \times 10^{-11}$ W</td>
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<tr>
<td>ATLID (355 nm)</td>
<td>450 km</td>
<td>20 mJ</td>
<td>100 Hz</td>
<td>0.6 m</td>
<td>$0.28 \times 10^{-11}$ W</td>
</tr>
</tbody>
</table>

adapted from A. Ansmann 2006

Factor 45

Factor 56
Ground Segment - Svalbard Satellite Reception Station

Data-downlink with 5 Mbit/s with X-Band to 2.4 m antenna to Svalbard, Norway (78°15'N)
# ADM-Aeolus Data Products

<table>
<thead>
<tr>
<th>Product</th>
<th>Contents</th>
<th>Processor developer and location</th>
<th>Size in MByte/orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 0</td>
<td>Time ordered source packets with ALADIN measurement &amp; housekeeping data</td>
<td>MDA (Canada) Tromsø (Norway)</td>
<td>47</td>
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<tr>
<td>Level 1b</td>
<td>Ge-located, calibrated observational data</td>
<td>MDA (Canada) Tromsø (Norway)</td>
<td>10-15 (BUFR) + 22 (EE XML Format)</td>
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<tr>
<td></td>
<td>- preliminary HLOS velocity profiles (standard atmosphere used in Rayleigh processing)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>- viewing geometry &amp; scene geo-location data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 2a</td>
<td>Supplementary product</td>
<td>DLR-IMF</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>- Cloud profiles, coverage, cloud top heights</td>
<td>Tromsø (Norway)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Aerosol extinction and backscatter profiles, ground reflectance, optical depth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 2b</td>
<td>Consolidated HLOS wind observations</td>
<td>ECMWF Reading</td>
<td>18</td>
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<tr>
<td></td>
<td>Consolidated HLOS wind profiles; temperature T and pressure p (Rayleigh-Brillouin correction applied with ECMWF model T and p)</td>
<td>ECMWF Reading</td>
<td>18</td>
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<tr>
<td>Level 2c</td>
<td>Aeolus assisted wind vector product</td>
<td>ECMWF Reading</td>
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<td>Vertical wind profiles (u and v component); NWP model output after assimilation of Aeolus wind</td>
<td>ECMWF Reading</td>
<td>22</td>
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## Ongoing ADM-Aeolus Scientific Studies

<table>
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<th>Title</th>
<th>Team</th>
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<tr>
<td>Consolidation of ADM-Aeolus Ground Processing including L2A Products</td>
<td>DLR Germany</td>
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<td>Météo-France, KNMI, IPSL, PSol</td>
</tr>
<tr>
<td>Development and Production of Aeolus Wind Data Products</td>
<td>ECMWF UK</td>
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<tr>
<td></td>
<td>Météo-France, KNMI, IPSL, DLR</td>
</tr>
<tr>
<td>ADM-Aeolus Campaigns</td>
<td>DLR Germany</td>
</tr>
<tr>
<td></td>
<td>Météo-France, KNMI, IPSL, DWD, MIM</td>
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<tr>
<td>Optimisation of spatial and temporal sampling</td>
<td>KNMI Netherlands</td>
</tr>
<tr>
<td>Tropical dynamics and equatorial waves</td>
<td>MISU Sweden</td>
</tr>
<tr>
<td>Rayleigh-Brillouin Scattering Experiment</td>
<td>tbd</td>
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</tbody>
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ESA plans an Announcement of Opportunity AO for ADM-Aeolus scientific use of data for late 2008 in addition to the AO for Cal/Val
Announcement of Opportunity AO issued by ESA for Cal/Val on October 1, 2007
- Open to PI worldwide in order to get access to ADM-Aeolus data; but no funds provided by ESA (BYOF)
- AO was open until December 15, 2007
- 15 proposals received with PI´s from Canada, China, France, Germany, Japan, Netherlands, Norway, and USA
- Review by ESA and external experts until end March 2008
- Notification of PI´s until end March 2008
- ESA plans to organize an AO user workshop in late 2008
**Atmospheric LASer Doppler INstrument (ALADIN)**

- Direct-Detection Doppler Lidar at 355 nm with 2 spectrometers to analyse backscatter signal from molecules (Rayleigh) and aerosol/clouds (Mie)
- Double edge technique for spectrally broad molecular return, e.g. NASA GLOW instrument (Gentry et al. 2000), but sequential implementation
- Fizeau spectrometer for spectrally small aerosol/cloud return
- Uses Accumulation CCD as detector => high quantum efficiency >0.8 and quasi-photon counting mode
- ALADIN is a High-Spectral Resolution Lidar HSRL with 3 channels: 2 for molecular signal, 1 for aerosol/cloud signal => retrieval of profiles of aerosol/cloud optical properties possible
**Transmitter laser assembly:**
Reference Laser Head with stabilized tunable MISER lasers seeding the Power Laser Head with low power oscillator, two amplifiers and tripling stage, two redundant laser assemblies in ALADIN

**Telescope:**
1.5 m diameter, Cassegrain, SiC lightweight structure, afocal, thermally focused

**Transmit/receive optics:**
polarizer as T/R switch, Laser Chopper mechanism, 1 focus as field stop, interference filter and prism for broad-band rejection of solar background

**Mie receiver:**
Fizeau interferometer, thermally stable, fringe imaged on single accumulation CCD

**Rayleigh receiver:**
Double edge Fabry-Perot interferometer, sequentially illuminated, temperature tunable Outputs focused on single accumulation CCD
Aeolus Structure Model Acoustic and Shaker Test 2005
ALADIN OSTM and Laser Radiator 2005

Optical Structure Thermal Model (OSTM), Power Laser Head (PLH), Reference Laser Head (RLH), Optical Bench Assembly (OBA)
Satellite bus during integration at Astrium, Germany and was finalised at Astrium Stevenage, UK

Mechanical and electrical integration is complete, including AOCS, CESS, GPS, IMU

Intermediate On-Board Software Version delivered in December 2007
1.5 m afocal Cassegrain SiC Telescope at Astrium Toulouse, France
mass 75 kg, thermal refocusing, total wavefront error is below 300 nm,
magnification 41.67, secondary mirror Ø 46 mm
Transmit-Receive Optic

Transmit-Receive Optics from Kayser-Threde, Germany
including transmit-path optic, calibration path optic, receive path optic with background filter (equivalent bandwidth 1nm, T=0.8), Laser Chopper Mechanism, Field Stop and polarizing optics
Optical Receiver - Mie and Rayleigh Spectrometer

Mie and Rayleigh-Spectrometer from Contraves (Switzerland), now Oerlikon Space
Integration of the Optical Bench Assembly (OBA) at Astrium-Toulouse finalized.

Optical, electrical and performance characterisation will be performed.
Detector Unit with Accumulation CCD from e2V (UK)

ACCD Image Zone is 16*16 pixels; memory zone has 25 rows => thus 25 range gates
quantum efficiency 0.85, quasi-photon counting due to low read-out noise
because of on-chip accumulation of charges
ACCD cooled to -30°C via thermo-electric coolers
Power Laser Head from Galileo Avionica, Italy
1 Engineering Qualification Model built; 1 Flight Model built, a total of 3 Flight Models will be built
480 x 350 x 180 mm, 27 kg
total laser mass including electronics is 51.5 kg (without harness)

Reference Laser Head from TESAT, Germany
3 Flight Models built, tested and delivered
150 mm length, 2.1 kg
Laser Transmitter - Optical Layout and Specifications

**Specifications**
- 120 mJ at 355 nm with 100 Hz, 30 ns pulse length
- burst mode operation (5 s warm-up, 7 s on, 12 s off for power amplifiers, not master oscillator)
- 4 MHz (UV) rms frequency jitter
- tunability over 11 GHz for calibration
- output beam: Ø 7.5 mm with 400 µrad
- conductively cooled via a cold plate

**Laser Diodes**
- Flight models from Quantel Laser Diodes all manufactured (108 stacks total, 48 stacks needed), tested and qualified (6 month test):
  - Life-testing of diodes continuous up to 2 years

**Laser Induced Damage LID**
- All optics qualified for LID; tests up to $10^4$ shots and then extrapolation up to $2-3 \times 10^9$ pulses (39 months)

**Laser Induced Contamination LIC**
- LIC due to outgassing of organic components
- bake-out and purging with air until launch
- 6 month life test of 3rd laser in vacuum planned
Laser Optic Qualification at DLR Stuttgart

ALADIN Power laser head
- more than 70 optical components and about 20-30 unique combinations of substrate and coating
- very compact design => high fluences up to 25 J/cm², most IR optics 5-15 J/cm², most UV optics 2-6 J/cm²
- wavelengths 1064 nm, 532 nm, and 355 nm (UV);
- long pulse lengths of 20-30 ns
- vacuum operation

Laser Induced Damage Threshold LIDT
- LIDT in air with S-on-1 Test with S = 10⁴ shots; tests done with shorter pulse lengths of 3-4 ns => scaling law
- Tests of degradation of LIDT in vacuum => lower LIDT
- Identification of coatings with high vacuum LIDT
- Testing of all coatings used in ALADIN
- Extended LIDT test over Million shots at ESA-ESTEC

Laser Induced Contamination LIC
- LIC due to outgassing of organic components and molecular contamination
- Contaminants accumulate on laser-irradiated optics
- Test campaign in vacuum with 1064 nm and 355 nm, different temperatures and up to 10⁷ shots; on-line monitoring of deposit built-up with fluorescence imaging
- Further tests of LIC at ESA-ESTEC

Microscopic image of damage on laser optic

Photo and material courtesy
Wolfgang Riede, DLR Stuttgart
Laser Transmitter - Flight Model 1

Power Laser Head PLH upper optical bench (without lower optical bench mounted) with Master Oscillator, Pre-Amplifier and Power Amplifier
Laser Transmitter - Flight Model 1

Power Laser Head Lower Optical Bench with Isolators and Higher Harmonic Generation Section (LBO crystals)
Thermal-Vacuum Test of FM1 laser

Flight Model FM1 Laser entering Thermal-Vacuum Test at Galileo Avionica Florence in January 2008

6 month life-testing in vacuum of laser FM3 is planned
Atmospheric Dynamics Mission ADM-Aeolus
Summary and Conclusions

- Satellite bus mechanical and electrical integration completed
- Optical receiver manufactured and integrated including telescope, spectrometers, and ACCD detectors
- Laser Transmitter Flight Model 1 manufactured and thermal-vacuum testing ongoing
- All laser diodes manufactured and qualified
- ESA call for cal/val proposals closed and proposals under review
- Next major milestone will be the thermal-vacuum test of the laser => consolidated launch date in some months expected
- ESA call for science use of ADM-Aeolus data planned for late 2008
ADM-Aeolus
Considerations for Operational Follow-on Missions

- Objective of ADM-Aeolus follow-on missions is to achieve denser horizontal coverage and/or sensing of 2 wind components by 2 to 3 operational satellites in space (PIEW study from KNMI)
- EUMETSAT SWG/AEG have recognized potential of wind lidar within post-EPS
- Temporal gap between end of ADM-Aeolus (around 2012) and post-EPS (after 2018)
- Recommendation of ADM-Aeolus Mission Advisory Group during its October 2007 meeting: "We urge these two agencies to explore the possibility of collaborating also toward developing their joint observing capabilities to include the critical missing vertically resolved wind observations."
- November 2007: Kick-off for (small) study on ADM-Follow-on Missions with focus on new laser concepts by Astrium Germany funded by DLR
LIDAR Instruments for Earth Observation Missions

- **ADM-Aeolus/ALADIN**
  - ESA, launch 2009/10
  - wind profiles, aerosol, clouds

- **EarthCARE/ATLID**
  - ESA, launch 2013
  - aerosol and clouds

- **Calipso/CALIOP**
  - NASA, launch 2006
  - aerosol and clouds

- **IceSAT/GLAS**
  - NASA, launch 2003
  - elevation, aerosol and clouds

- **A-SCOPE for CO₂**
  - Future Lidar Instruments, e.g.