Validation and Calibration of ADM-Aeolus using Doppler lidars

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Ocean Remote Sensing Institute (ORSI), Ocean University of China (OUC), Qingdao,
1. Overview of ORSI’s lidar activities
   Motivation & Applications
2. Available instruments for CAL/VAL
   Ground based direct detect & coherent Doppler wind lidar, HSRL, Raman depolarization lidar
3. Field experiments related to ADM-Aeolus Cal/Val
   Lidar campaigns in Qingdao, Beijing, East China Sea, Tibetan Plateau, etc.
Ocean Remote Sensing Institute, ORSI

Satellite Remote Sensing
- SST, SSW, 3Sea Wave, Current, Ocean Color, Oil Spill, etc.

Lidar and Ocean Optics
- Wind, Temperature, Cloud, Aerosol, Ocean Optics, etc.

Marine Geographical Information System
- Satellite Remote sensing, Virtual Reality of Oceanography, etc.

ORSI 23 Faculties, ~100 Master & Ph.D students

Lidar 7 Faculties, ~20 Master & Ph.D students
Lidar research at ORSI

- Direct-detection Doppler lidar / High spectral resolution lidar
  wind, temperature and aerosol in boundary layer and troposphere
- Coherent Doppler lidar
  wind in boundary layer
- Raman lidar and Polarization lidar
  water vapor, cirrus and aerosol
- Ocean Lidars
  ocean optics, chlorophyll and oil leakage
- Lidar technology
  Laser seed injection and frequency stabilization, spectrometer, retrieval algorithm, digital signal processor, etc.
Recent atmospheric lidar campaigns

- 2005~2006: radiosonde validation
- 2006 International Sailing Games: wind profiler
- 2007 International Sailing Games: wind profiler, buoys
- 2007 Ground anemometer validation campaign
- 2008 Olympics: operational sea surface wind monitoring
- 2008 Spacecraft landing area: wind profile monitoring
- 2009 Storm observation: lidar, radars
- 2010 WMO radiosonde validation campaign at Yangjiang
- 2010 Sea surface wind observations for Asia Game
- 2011-2012 CMA Lidar and radiosonde campaign in Beijing
- 2013 Atmospheric lidar observation in Indian Ocean
- 2013-2017 CMA the 3rd Tibetan Plateau atmosphere scientific campaign
Direct Detect Doppler Wind Lidar / HSRL

- Atomic absorption using iodine vapor
- Fabry-Perot interferometer
- Fezeau interferometer

Atmospheric Molecules

Aerosol particles

ALADIN & A2D

Fabric-Perot etalon

Atomic filter

Fezeau interferometer

 Courtesy of O. Reitebuch
Principle of wind measurements

Measured signal:

\[ N_M(r, v) = k_M \frac{A}{r^2} \Delta r [T_a(v) \beta_a(r) + T_m(v) \beta_m(r)] T^2(r) \]

\[ N_R(r, v) = k_R \frac{A}{r^2} \Delta r [\beta_a(r) + \beta_m(r)] T^2(r) \]

\[
\Delta T = M_W \Delta V_{LOS} = \Delta V_{DOP} \Delta T = \Delta V_{DOP} (\Delta T) \\
M_W = \frac{N_M}{N_R} \\
R_w = \frac{N_M}{N_R} \\
S = \frac{dR_F}{dV_{LOS}} \\
V_{LOS} = \frac{R_F}{S} = \frac{R_F}{S}
\]
Wind measurement sensitivity calibration

1. Tune the frequency of transmitting laser to 3 points along one slope of iodine line
2. Fit received signal of 3 frequency to obtain wind sensitivity
Data product: Wind Profile

Wind Profile comparison results between Wind Lidar (8:45) and Radiosonde (8:00) on May 7, 2006

Wind Profile comparison results between Wind Lidar (20:20) and Radiosonde (20:00) on October 19, 2007
Data Product: SSW & 4-D VAR

Sea Surface Wind in Olympic Sailing Event
HRSL method for Aerosol

\[ N_1(z) = k_1 \left( \frac{\Delta z}{z^2} \right)(\beta_a(z) + \beta_R(z)) \exp \left\{ -2 \int_0^z [\alpha_a(z') + \alpha_R(z')]dz' \right\} \]

\[ N_2(z) = k_2 \left( \frac{\Delta z}{z^2} \right)f_R\beta_R(z) \exp \left\{ -2 \int_0^z [\alpha_a(z') + \alpha_R(z')]dz' \right\} \]

Receiver transmittance

aerosol & molecular
Data Product: Aerosol Extinction Profile

Fine
2005-10-21

Cirrus
2005-10-22

floating dust
2005-11-07

Aeolus Science & Cal/Val WS, Frascati
Ground-based incoherent Doppler wind lidar using iodine absorption lines

First Doppler lidar in China, 1998-2000

Troposphere wind profiles & 3D wind field
Doppler Lidar measuring sea surface wind

- Development started in 2005.
- 2008 Olympics wind observations

Wind profile and 3D wind field with resolution of 100m; update rate at 10 minutes

Shipborne Doppler wind lidar

- **New transceiver telescope** is designed for long term alignment stability.
- The 10 times **higher peak power DPSS laser** to get better SNR for wind measurement in the troposphere.
- **Very compact Doppler frequency discriminator** and frequency stabilizer and are developed to fit in a 4U 19“ cabinet rack.
- **New scanner** is designed for precise beam pointing and direction compensation due to the ship rolling.
# Doppler wind lidar / HSRL performances

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ground-based</th>
<th>Mobile</th>
<th>Shipborne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detect altitude</td>
<td>1~10 km</td>
<td>0.2~10 km</td>
<td>0.2-15 km</td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>100 m (PBL) 500m (Troposphere)</td>
<td>100 m (PBL) 500m (Troposphere)</td>
<td>50 m (PBL) 100m (Troposphere)</td>
</tr>
<tr>
<td>LOS Accuracy</td>
<td>1 m/s (PBL) 2m/s (Troposphere)</td>
<td>1 m/s (PBL) 2m/s (Troposphere)</td>
<td>1 m/s (PBL) 2m/s (Troposphere)</td>
</tr>
<tr>
<td>PRF</td>
<td>10 Hz</td>
<td>500 Hz</td>
<td>100 Hz</td>
</tr>
<tr>
<td>Averaging time</td>
<td>30 mins (Profile)</td>
<td>15 mins (Profile)</td>
<td>10 mins (Profile)</td>
</tr>
<tr>
<td>Wavelength</td>
<td>532 nm</td>
<td>532 nm</td>
<td>532 nm</td>
</tr>
<tr>
<td>Pulse energy</td>
<td>100mJ</td>
<td>10 mJ</td>
<td>120 mJ</td>
</tr>
</tbody>
</table>

Available sources for ADM/Aeolus Cal/Val
Coherent Doppler Lidar for direct detect DWL Cal/Val

- Boundary layer wind profile measurement with high accuracy of 0.3 m/s.
- Better understanding of the vertical wind under and within clouds.
- Easy to transport for remote area campaign.
- Deployed in the Tibetan Plateau campaign.

S. Wu, et. al. 2012

Wind Profiles

Backscatter

Vertical Wind speed

Aeolus Science & Cal/Val WS, Frascati
Coherent Doppler lidar/CDL for Sea Surface Wind

Dongfanghong II Research vessel

2013 Cruise
April 27th to May 21th

PPI scanning mode of LOS velocity of sea surface wind on May 7th, 2014.

Wind direction change can be seen.

Turbulent wake of the research vessel.
Tibetan Plateau lidar campaign 2013-2017

- The Tibetan Plateau lies at a critical and sensitive junction of four climatic systems: the Westerlies, the East Asian Monsoon, the Siberian cold polar airflow, and the Indian monsoon.
- The 3rd Tibetan Plateau Atmospheric Science Experiment is proposed by China Meteorological Administration (CMA) that is formally to start in 2014. The experiment will carry on for at least 3 years.
- The 2013 lidar campaign is a joint preface experiment organized by OUC/ORSI and CAMS/LAWS (Chinese Academy of Meteorological Sciences/Laboratory of Severe Weather).
Transmitter wavelength: 355nm, 532nm and 1064nm
Receiver channels: 355/374nm, 387nm, 407nm, 532nm ||, 532nm/⊥, 1064nm
Water vapor, Cloud, Aerosol, PBL wind observations in the Tibetan Plateau since 2013.
Locations: Litang (3950 m altitude), Nagqu (4560 m altitude), ...
Multi-wavelength Raman-polarization lidar

- Depolarization ratio
- Extinction coefficient
- Vertical wind
- Vertical water vapor flux
- Water vapor lidar data
- Radiosonde data
- Error bar

Water vapor mixing ratio (g/kg)
Height AGL (km)

$\sigma$, $\alpha$, $H_2O$, Flux
Summary of Cal/Val opportunities

**Instruments & Data products**

A: **Direct-detect technique** but with the different laser wavelength and Doppler frequency discriminator which makes validation effective on the independent technological background. The validation lidars cover most of the data products of ADM-Aeolus such as *LOS wind speed*, *aerosol extinction coefficient* and *backscattering*. Moreover, *aerosol backscattering ratio* and *lidar ratio* can be provided which is essential to calibrate the atmospheric parameter used for aerosol extinction coefficient and wind velocity retrieval in the ADM-Aeolus algorithm.

B: Combined LOS wind velocity, wind profile and 3D wind vectors are the useful tools to validate the ADM-Aeolus measurements.

C: **The mobile Doppler lidar** is a quasi-operational system qualified by the China Meteorological Administration. The quality control and quantity could be credible.

D: **The Coherent Doppler lidar** can validate the direct detect Doppler lidar in PBL. It is practical and efficient to characterize and monitor *sea surface wind vectors*.

E: **Multi-wavelength Raman-polarization lidar** is located at the Qingdao/Tibetan Plateau to study typical *marine / continental aerosol and cloud*.

F: OUC/ORSI is developing a compact **coherent Doppler lidar on UAV** which could be a good option for calibration and validation if sources are available.
Summary of Cal/Val opportunities

Field experiments could be synchronously carried out using ground-based lidars when ADM-Aeolus passes in different sites.

Westerlies

Siberian cold polar airflow

Stainless Plateau

Westerlies

Thanks for listening...

Indian monsoon

East Asian monsoon

Legend:
- Mobile Doppler lidar
- Coherent Doppler lidar
- Multi-wavelength Raman-polarization lidar