NOAA Satellite Doppler Wind Activities: A Status Report

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Overview of recent and current activities

- NOAA currently has no “official” program directed at global wind measurements (may change after new planning cycle)

- However, many activities that directly relate to satellite wind measurements exist within, or are supported by NOAA and NPOESS resources

- Range of activities include:
  - Mission planning and design
  - Technology development
  - Impact assessment (OSSEs)
  - Research applications of Doppler lidars
Working Group on Space-Based Lidar Winds

Wind—The Final Frontier

Below is an Acrobat version of a paper entitled
Winds and NPOESS Integrated Program Office

- National Polar Orbiting Environmental Satellite System is the next generation polar orbiting environmental satellite in the US
- Multi-agency program (NOAA, NASA, United States Department of Defense) to measure important environmental parameters associated with missions of the contributing agencies
- NPOESS defines environmental data records (EDR) that specify parameters to be measured by NPOESS instruments
- Winds are the highest priority unaccommodated EDR for NPOESS
- NPOESS supported Mission Development Team to investigate a prospective NPOESS mission
- NPOESS has been re-scoped and delayed due to cost and schedule overruns
Mission Development Team NPOESS Instrument Concept

• Dual Technology (Hybrid) approach.
  - Coherent detection sub-system to provide wind data at cloud tops and within optically thin clouds; in the boundary layer below clear regions and broken cloud decks, aerosols permitting. Primary vertical coverage: boundary layer and cloudy regions up to 20 km
  - Direct detection sub-system to provide wind profiles above the boundary layer in cloud free (or thin cloud) regions, including the important tropopause region, using the return from molecules in the atmosphere. Primary vertical coverage: clear regions from 3 km to 20 km

• Step-scan coverage to provide both components of the horizontal wind at 1 km intervals above the boundary layer and .25-.5 km within the boundary layer.

• Estimated power requirement~350 - 400 watts: the coherent sub-system would be on continuously (~80 watts) and the direct subsystem would operate on a 10% duty cycle (~250 watts average; 850 peak).
DWL Sampling Concept

Built around need for bi-perspective looks at the same scattering volume

- Measure vertical stack of Target Sample Volumes (TSVs)
- Average shots within TSV
- Fore and aft perspectives resolve horizontal wind vectors
- 2 ground tracks
Adaptive targeting with emphasis on US meteorology

(Blue is coherent coverage
Red is both coherent and direct)

Example of targeting a hurricane as it approaches the Gulf coast.
(blue segments: forward looks;
Red segments: aft looks; Blue plus red
Provide full horizontal wind vector)

Baseline Mission Specifies Adaptive Targeting

Examples

Add 100% duty cycle lidar
Add 10% duty cycle lidar
Add cloud winds
Conventional data

Adaptive Targeting Experiments

Better

ANOmalY corRELATION

Model: GEOS-2 Recon.
Verification: ECMWF Nature Run

Control: Conventional Data + Perfect TOVS
CTW: Control + Cloud Tracked Winds
1 m/s Wind: Control + Doppler Wind Lidar (RMSE = 1 m/s)
Adaptive Targeting: Control + Adaptive Targeting of DWL Observations (~10% duty cycle)

Adaptive Targeting with emphasis on US meteorology

(Blue is coherent coverage
Red is both coherent and direct)
NOAA and NASA studied potential impact on Hurricane Forecasting (Example Ivan)

Current data

Lidar Improved Track Prediction

Lidar Improved Intensity Prediction

Divergence Profile

Lidar provides the critical divergence profile

Based upon QuickOSSEs done at GSFC by R. Atlas
NPOESS 3D wind profiler system (dual DWL technologies)
NOAA/FSL Regional OSSE

- NOAA/FSL ran regional coverage OSSE showing impact of direct detection lidar on US forecasts
- Despite dense observation network, lidar data showed positive impact on both wind and temperature predictions
- Impact from both better boundary characterization and assimilation of wind observations over US
UNH Fringe Imaging Demonstration

- Demonstration direct detection technology
- Evaluate performance
- Get experience with measurements

Diagram:
- Atmosphere
- Scattering
- Telescope
- Laser Beam Expander
- Received Signal
- Aerosol Etalon Output
- Molecular Etalon Output
- Direct Detection System
- CLIO
- CCD
Recycle Schematic Diagram

Light in from Telescope or other Etalon

CLIO Cones

Fiber Recycle

Reflections

Light out to Next Element and Return from Etalon or Mirror

Actual Recycler
GroundWinds New Hampshire and Hawaii

<table>
<thead>
<tr>
<th>GroundWinds NH</th>
<th>GroundWinds HI</th>
</tr>
</thead>
<tbody>
<tr>
<td>532 nm</td>
<td>355 nm</td>
</tr>
<tr>
<td>3.5 Watts @ 10 Hz -Single Frequency</td>
<td>3.0 Watts @ 10 Hz-Single Frequency</td>
</tr>
<tr>
<td>High Resolution Molecular and Aerosol Channels</td>
<td>High Resolution Molecular Channel</td>
</tr>
<tr>
<td>50 cm Cassegrain-Schmidt</td>
<td>50 cm Cassegrain -Schmidt</td>
</tr>
</tbody>
</table>
GroundWinds NH

Molecular (Top) and Aerosol (Bottom)
Wind Data Maps

Aerosol to Total Scattering Ratio
NH Wind profile Samples

Winds above North Conway

Lidar Component, AZ = -7. Wind m/s
Archive: 20020629065408_FirstWind

Lidar Component, AZ = -7. Wind m/s
Archive: 20020629065408_FirstWind

Lidar Component, AZ = -7. Wind m/s
Archive: 20020629065408_FirstWind
Next Step: Balloon Mission

- Validate instrument system models for a downward looking platform in a near space environment
- Demonstrate Multi-Order Photon Recycled Fringe Imaging from a high altitude (30 km) balloon
- Demonstrate technology under as many atmospheric conditions as possible; i.e. high and low clouds, high and low winds, variable boundary layer aerosol conditions, day and nighttime
NOAA Ship-based Doppler Lidar Measurements

- Apply motion-corrected, ship-based NOAA Doppler lidars to characterize small-scale wind and aerosol structure over the ocean
- Five marine campaigns spanning tropics, cold ocean, near-shore, inland bays
- Use data to evaluate impact of horizontal and vertical variability on marine boundary layer measurements
- Assess use of shipbased measurements for space wind lidar calibration and validations (ADM?)
Recent shipboard measurements: September 2006

Conical Scans
Lidar operated 24 hours per day for 45 days in the Gulf of Mexico

Vertical Stares
Typical Winds Summary

Large distribution of winds over the experiment period does not convey the commonly observed layering/stratification.
Scaling ground-based and airborne measurements

- Current predictions of space-based lidar performance mainly rely on models (no actual space-based wind measurement data).
- Models must assume values for key parameters such as laser beam quality, laser pulse stability, receiver efficiency, detector noise characteristics, and backscatter.
- Using data from current systems tells us how well we are doing now.
- Scaling question: How would existing systems do if they were looking at the same backscatter from space, but with pulse energy, range, range gate length, receiver aperture, and pulses accumulated scaled to match a space-based system.
- Or, vice versa: If the specifications for a proposed space-based system were scaled to measure from the ground, what performance should it see?
- Effectively, we are scaling everything but the system efficiency.
## Scaling NOAA High Resolution Doppler lidar results to Space

How would a lidar with this performance operate in an NPOESS orbit?

<table>
<thead>
<tr>
<th>Coherent system Parameter</th>
<th>HRDL</th>
<th>Space system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength (microns)</td>
<td>2.012</td>
<td>2.05</td>
</tr>
<tr>
<td>Energy/pulse (mJ)</td>
<td>1.5</td>
<td>250</td>
</tr>
<tr>
<td>PRF (Hz)</td>
<td>200</td>
<td>10</td>
</tr>
<tr>
<td>Pulse Length (ns)</td>
<td>200</td>
<td>500</td>
</tr>
<tr>
<td>System Eff</td>
<td>.14</td>
<td>.14</td>
</tr>
<tr>
<td>Collector Diam (cm)</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Focus (km)</td>
<td>2.5</td>
<td>Collimated</td>
</tr>
<tr>
<td>Range (km)</td>
<td>2</td>
<td>958</td>
</tr>
<tr>
<td>Range gate (m,samp)</td>
<td>30,10</td>
<td>500,166</td>
</tr>
<tr>
<td>Pulses averaged</td>
<td>100</td>
<td>120</td>
</tr>
<tr>
<td>Scaling factor</td>
<td>1</td>
<td>-22.2 dB</td>
</tr>
<tr>
<td>CNR</td>
<td>-11 dB</td>
<td>-33 dB</td>
</tr>
<tr>
<td># photons/estimate</td>
<td>~80</td>
<td>~19</td>
</tr>
<tr>
<td>Degeneracy</td>
<td>0.32</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Models compute -28 dB
Scaling Edge Technique to Space (B. Gentry)
GLOW LOS Error
\[ \Delta z = 0.5 \text{ km}; \ t = 1 \text{ min} \]
Scaling GLOW to 400 km at z=10km

<table>
<thead>
<tr>
<th></th>
<th>Ground</th>
<th>Space</th>
<th>Scaling factor parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration Time (s)</td>
<td>60</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Dz/cosq (km)</td>
<td>0.707</td>
<td>1.41</td>
<td>0.5</td>
</tr>
<tr>
<td>Laser Power J/s</td>
<td>1.25 W (50 Hz, 0.025 J)</td>
<td>30W (100 Hz, 0.3 J)</td>
<td>0.0417</td>
</tr>
<tr>
<td>Telescope area (m²)</td>
<td>0.116</td>
<td>0.75</td>
<td>0.155</td>
</tr>
<tr>
<td>Atmospheric transmission</td>
<td>0.2</td>
<td>0.95</td>
<td>0.21</td>
</tr>
<tr>
<td>Detector quantum efficiency</td>
<td>0.22</td>
<td>0.3</td>
<td>0.73</td>
</tr>
<tr>
<td>Optics transmission</td>
<td>0.06</td>
<td>0.30</td>
<td>0.2</td>
</tr>
<tr>
<td>Range to Target Volume (km)</td>
<td>14.14</td>
<td>551.6</td>
<td>1522</td>
</tr>
</tbody>
</table>

Scale factor product = 0.9
Edge Signals from 400 km

A = 0.75 m²
E= 300 mJ at 100 pps
T= 10 sec
ΔR= 1.414 km
Z= 400 km
θ = 45 deg
U.S. National Academy of Sciences Decadal Study: Earth Science and Applications from Space

• Charge:
  - Recommend a prioritized list of measurements and identify potential new space-based capabilities and supporting activities within NASA, NOAA and USGS to support national needs for research and monitoring of the dynamic Earth system during the decade 2005-2015.
  - Identify important directions that should influence planning for the decade beyond 2015.
• First draft will come out this fall
• Winds are likely to be a recommended high priority mission

http://qp.nas.edu/decadalsurvey
NOAA activities being proposed for the next 1-3 years

• Hybrid DWL Conceptual Design
  - The Instrument Synthesis & Analysis Laboratory (ISAL) effort at GSFC to provide a preliminary instrument reference design for the hybrid DWL (just completed)
  - An Integrated Mission Design Center (IMDC) effort at GSFC to provide a preliminary DWL mission reference design, including cost estimates

• Tropospheric Wind Demonstration & Validation
  - Continue airborne and ship-based studies for assimilation studies and impact
  - Continue scaling and validation, including multi-technology validation campaign
  - Develop and implement a hybrid Lidar Airborne Demonstrator
  - Collaborate with ESA and European forecast centers on wind lidar activities where appropriate
Proposed NOAA Activities II

Scientific Evaluation and Implementation of future mission

- OSSE Mission Implementation Studies
- OSSE Assessment of Follow-on Missions - Mission Design and Impact on Climate, Air Quality, and Other Non-Weather Areas - NESDIS/OSD FY06 funds will be used (ESRL)
- Support for the Lidar Working Group

International collaborations: potential NOAA-funded activities in support of ADM:

- Validation and assessment using NOAA instruments
- Collaboration on use of ADM data for assimilation and application in forecast models (medium range and regional)
- Joint planning for follow-on missions

Thanks for your attention!