Development of a Space-qualifiable, Conductively-cooled 2-micron Coherent Lidar Transmitter for Global Wind Measurements

Upendra N. Singh, Mulugeta Petros, Jirong Yu, and Michael J. Kavaya
NASA Langley Research Center, Hampton, Virginia 23681 USA

Timothy Shuman and Floyd Hovis
Fibertek, Inc, Herndon, Virginia, USA
(757).864.1570
Upendra.N.Singh@nasa.gov

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Working Group on Space-based Lidar Winds
Boulder, Colorado
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Outline

- Background and motivation
- Technology Development
  - Compact 2µm wind lidar transceiver
  - Conductive cooled 2µm Oscillator/Amplifier development
- Ground and Airborne campaigns
- Fully Conductively-cooled Risk Reduction Laser
- Conclusions
Motivation for 2µm Laser/Lidar Development
NRC Recommended “3-D Winds” Mission

“Knowledge derived from global tropospheric wind measurement is an important constituent of our overall understanding of climate behavior.[1]”

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Global Winds

<table>
<thead>
<tr>
<th>9 Societal Benefits</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme Weather Warnings</td>
<td>✓</td>
</tr>
<tr>
<td>Human Health</td>
<td>✓</td>
</tr>
<tr>
<td>Earthquake Early Warning</td>
<td></td>
</tr>
<tr>
<td>Improved Weather Prediction</td>
<td>✓ #1</td>
</tr>
<tr>
<td>Sea-Level Rise</td>
<td></td>
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<tr>
<td>Climate Prediction</td>
<td></td>
</tr>
<tr>
<td>Freshwater Availability</td>
<td></td>
</tr>
<tr>
<td>Ecosystem Services</td>
<td></td>
</tr>
<tr>
<td>Air Quality</td>
<td>✓</td>
</tr>
</tbody>
</table>

Early Mission Concept for Earth Winds
Laser Atmospheric Wind Sounder (LAWS)

- 525 km orbit height
- Single, pulsed coherent Doppler lidar system covers troposphere
- Continuously rotating telescope/scanner
- Line of sight (LOS) wind profiles from each laser shot
- ~ 20 J pulse energy
- ~ 1.5 m rotating telescope

• Required: eye-safe laser
Space-Based Doppler Wind Lidar

2-µm Coherent Doppler Lidar

1 µm laser
Diode Pump Technology
Inj. Seeding Technology
High Energy Technology
Conductive Cooling Techn.
Compact Packaging
Doppler Lidar Ground Demo.

0.355-µm Direct Detection Doppler Lidar

Global Winds Approach Using Hybrid Doppler Lidar

NASA

Autonomous Oper. Technol.
Space Qualif.
Lifetime Validation
Pre-Launch Validation
Hybrid Demonstration
Hybrid Operational

1-µm laser
Diode Pump Technology
Inj. Seeding Technology
Conductive Cooling Techn.
High Energy Technology
Compact Packaging
Doppler Lidar Ground Demo.

Hybrid Aircraft Operation
UAV Operation
## Basic Performance Goals for 2µm Doppler Lidar

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Wavelength</td>
<td>2.053 -µm</td>
</tr>
<tr>
<td>Laser Pulse Energy</td>
<td>250 mJ</td>
</tr>
<tr>
<td>Repetition Rate</td>
<td>10 Hz</td>
</tr>
<tr>
<td>Pulse Width</td>
<td>&gt;150 ns</td>
</tr>
<tr>
<td>Beam Quality</td>
<td>$M^2 &lt; 1.2$</td>
</tr>
<tr>
<td>Pulse Spectrum</td>
<td>Single frequency (seeded)</td>
</tr>
<tr>
<td>Cooling</td>
<td>Conductively cooled via heat pipes</td>
</tr>
<tr>
<td>Laser Size</td>
<td>23.9” x 14” x 7.7” (L x W x H)</td>
</tr>
<tr>
<td></td>
<td>Including heat pipes and condenser</td>
</tr>
</tbody>
</table>
Pulsed Laser Development

2 Lasers, 4 Techniques, 6 Priority Measurements

1 MICRON

- Key Technologies in Common
  - Laser Diodes
  - Laser Induced Damage
  - Frequency Control
  - Electrical Efficiency
  - Heat Removal
  - Ruggedness
  - Lifetime
  - Contamination Tolerance

- 0.532 micron
  - OPO

- 0.355 micron
  - Surface Mapping, Oceanography

- 1.06 micron
  - Altimetry

2 MICRON

- Key Technologies in Common
- DIAL: Ozone Aerosols/Clouds
- Backscatter Lidar: Aerosols/Clouds
- Atmosphere: Lower Upper
- 2.05 micron
  - Doppler Lidar: Coherent Ocean/River Surface Currents
  - Coherent Winds
  - Noncoherent Winds
  - Direct

- 0.30-0.32 micron
  - Doppler Lidar: Wind

- 2.05 micron
  - Backscatter Lidar: Aerosols/Clouds

Laser Risk Reduction Program (LaRC-GSFC) (NASA HQ Funded Directed Program 2001-2010)
Process to 3-D Winds Space Mission at NASA Langley

<table>
<thead>
<tr>
<th>Technology</th>
<th>Science</th>
<th>Technology</th>
<th>Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Past</td>
<td></td>
<td>Current</td>
<td></td>
</tr>
</tbody>
</table>

- **Past**
  - ATIP: 02, ESTO: 09
  - LRRP: 06, ESTO: 08
  - DAWN-AIR1: 08, SMD-ESD: 10
  - DAWN-AIR2: 10, SMD-ESD: 12

- **Current**
  - GRIP Hurricane Campaign
  - DAWN on UC-12B: LaRC FY12, 12, 15
  - ACT: 12, 15
  - SMD-ESD
  - DAWN: 08, SMD-ESD: 10

- **Future**
  - NRC Decadal Survey
  - 3-D Winds Space Mission
  - ESTO
  - IPP: 08, SMD-ESD: 09
  - Ground Intercomparison: 7 years SMD-ESD

**Timeline**
- 08 SMD-ESD: 09
- 10 SMD-ESD: 11
- 08 SMD-ESD: 12
- 08 SMD-ESD: 09

**Parts**
- DAWN on UC-12B
- GRIP Hurricane Campaign
- ACT
- SMD-ESD
- DAWN
- IPP
- Ground Intercomparison

**Technology**
- ATIP
- LRRP
- DAWN-AIR1
- DAWN-AIR2
A fully conductively cooled 2-micron solid-state pulsed laser has been demonstrated for the first time.

Technology Enables: Measurement of global 3-D Winds
Mobile Ground based High Energy Wind Lidar Transceiver – LRRP/DAWN Funded

Table Top Transceiver
(Transmitter + Receiver)
90 mJ/pulse, 5 pulses/sec.
3’x4’ Optical Table
(no telescope or scanner)

Engineered Transceiver
250 mJ/pulse, 10 pulses/sec.
5.9” x 11.6” x 26.5”, 75 lbs.;
15 x 29 x 67 cm, 34 kg
(no telescope or scanner)
The LaRC mobile lidar is deployed as part of NASA HQ funded Program
Utilized NASA LaRC Compact DAWN Lidar Transceiver for 2-μm lidar
Site at Howard University Research Campus in Beltsville, Maryland
- Root-mean-square of difference between two sensors for all points shown is **1.06 m/s** for wind speed and **5.78 deg.** for wind direction
DC-8 Wind Lidar During GRIP (2010)

- Harden the transmitter for airborne application
- Add telescope and scanner within the enclosure
- Airborne wind measurement during GRIP campaign
LaRC Partnership with Fibertek for Space Qualifiable 2-micron Laser Development for NASA 3-D Wind Mission

- Laser Risk Reduction Program (ESTO) - 2001-’10
  - LaRC has demonstrated fully conductively cooled oscillator/amplifier to 400 mJ, 5 Hz (08/07)

Partnership with Fibertek:

- Innovative Partnership Program (LRRP/ESD/Fibertek)
  - 3-m cavity, 792 nm pumped, conductively cooled 200 mJ, single frequency output at 5 Hz – first generation

- Advanced Component Technology (LaRC/ESTO/Fibertek)
  - Compact, 1.5 meter cavity, 808 nm pumped, fully conductively cooled laser transmitter delivering wind quality 250 mJ 10 Hz output for 3-D Wind mission
Innovative Partnership Program (LRRP/ESD/Fibertek)  
2007-2010  
(PI: Singh, Co-I: Yu, Kavaya LaRC; Co-I: Hovis, Fibertek)

Single frequency 2-micron Laser (200 mJ/5Hz) built and delivered by Fibertek to NASA LaRC

2-micron Risk Reduction Laser Transmitter
Design and Fabrication of a Breadboard, Fully Conductively Cooled, 2-Micron, Pulsed Laser for the 3-D Winds Decadal Survey Mission

PI: Upendra Singh, NASA LaRC

• Design and fabricate a space-qualifiable, fully conductively-cooled, 2-micron pulsed laser breadboard meeting the projected 3-D Winds mission requirements
  • Utilize improvements in key technologies including high-power, long-life space-proven 804 nm pump diodes; derated diode operation, and heat pipe conductive cooling
  • Perform a long-duration life test on the laser system to evaluate mission readiness.

• Leverage LaRC 2-micron laser development from earlier efforts
  • Utilize Fibertek CALIPSO mission flight laser design and development knowledge
  • Upgrade previous Fibertek two-micron laser design for flight-like laser based on space heritage
  • Utilize space-ready, sealed cylindrical package
  • Perform vacuum test while operating at the output requirements of the 3-D Winds mission

Co-Is/Partners: Jirong Yu, Michael Kavaya, LaRC; Floyd Hovis, Tim Shuman, Fibertek, Inc.

• Complete laser mechanical design update and improved laser thermal modeling 01/13
  • Assemble and test heat pipe cooled module 04/13
  • Fabricate and test ring laser with heat pipe cooled module 12/13
  • Install and test amplifiers 03/14
  • Integrate with canister and test 04/14
  • Vacuum-test laser 10/14
  • Complete acceptance testing 07/15
  • Complete analysis and performance testing 12/15

2-Micron Space Qualifiable Pulsed Laser for 3-D Winds

TRL_{in} = 3   TRL_{out} = 5
ACT Program Summary

• Technical Objective(s)—
  – Deliver a ruggedized 2.053 μm MOPA laser with the following parameters:
    • 250 mJ pulse energy
    • 10 Hz repetition rate
    • Beam quality (M²) < 1.2
    • >100 ns pulse width
    • Conductively cooled via heat pipes
  – Reach Technical Readiness Level (TRL) 5 by surviving a thermal-vac test.

• Period of Performance – 38 months

• Deliverable Items - 2 μm laser meeting the performance requirements after surviving a thermal vac test, monthly technical and financial reports, quarterly and yearly financial reports, thermal vac test definition and results report, oscillator test procedure and results report, final technical report

  – 2 μm laser transmitter meeting the performance requirements and surviving a thermal-vac test

  – Thermal vac test procedure and results report

  – Oscillator and amplifier performance report
Linear Cavity Data

Energy Curves - 11" L-Shaped Cavity - Current - 10 Hz

Now reaching energies expected from a short cavity!
Expect 80 mJ of Q-switched output for 3.6 J of pump energy

Phase II achieved 3X amplification – on track for 240 mJ after amplifier pair
Conductively Cooled Laser Design

Box dims: 19"x11"x7.1" (LxWxH)
ICESat-2: 16"x11"x4.4" (LxWxH)
Mounting feet for illustration only

Housing itself: 19"L x 11"W x 6.1"H
Complete assembly: 23.9"L x 14"W x 7.7"H
### Summary and Conclusion

<table>
<thead>
<tr>
<th>Past</th>
<th>Today</th>
</tr>
</thead>
<tbody>
<tr>
<td>525 km</td>
<td>400 km</td>
</tr>
<tr>
<td>12 cross-track positions</td>
<td>2 cross-track positions</td>
</tr>
<tr>
<td>1 shot measurement</td>
<td>Multiple shot accumulation</td>
</tr>
<tr>
<td>Continuously rotating 1.5 m telescope</td>
<td>4 stationary 0.5 m telescopes</td>
</tr>
<tr>
<td>Single coherent Doppler lidar</td>
<td>Dual-coherent &amp; direct hybrid Doppler lidar</td>
</tr>
<tr>
<td>Gas laser</td>
<td>Solid-state eyesafe laser</td>
</tr>
<tr>
<td>20 mJ 2µm solid state energy</td>
<td>1200 mJ 2-µm solid state energy</td>
</tr>
<tr>
<td>Space required energy = 20 J</td>
<td>Space required energy = 0.25 J</td>
</tr>
<tr>
<td>Energy deficit = 1,000</td>
<td>Energy surplus = 5</td>
</tr>
<tr>
<td>2µm lidar not aircraft validated</td>
<td>2µm lidar is aircraft validated</td>
</tr>
</tbody>
</table>
Questions?