DAWN in CPEX Campaign and Space
Pathfinder Coherent Wind Lidar Development
at LaRC

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Outline

- **CPEX Campaign**
  - DAWN Instrument
  - DAWN Instrument Improvement
  - DAWN Performance in CPEX

- **Space Pathfinder Coherent Wind Lidar**
  - Objective
  - Technology Advancements
  - Laser Development
  - Transceiver Development
  - Expected Performance

- **Summary**
Doppler Aerosol WiNd (DAWN) Profiling Lidar

DAWN Airborne Instrument:
- Ho:Tm:LuLiF laser, 2.053 µm
- 250 mJ, 10Hz, 180ns, M²=1.1
- 15-cm Telescope, off-axis, afocal
- 30° nadir angle
- Up to 12 azimuth (LOS) angles horizontal wind profile
- Dual-balanced heterodyne detection
- 500 MHz ADC signal sampling
- Computer shot averaging, range gate segmentation for vertical resolution, frequency estimation

Doppler Aerosol WiNd (DAWN) Airborne Science Campaigns

<table>
<thead>
<tr>
<th>Year</th>
<th>Campaign Name</th>
<th>Location</th>
<th>Science Focus</th>
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</thead>
<tbody>
<tr>
<td>2010</td>
<td>Genesis and Rapid Intensification Processes (GRIP)</td>
<td>Fort Lauderdale, FL</td>
<td>Hurricane Research</td>
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<td>2014</td>
<td>Polar Winds – Greenland</td>
<td>Kangerlussuaq, Greenland</td>
<td>Polar Warming Research &amp; ADM Cal/Val Practice</td>
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<tr>
<td>2015</td>
<td>Polar Winds – Iceland</td>
<td>Keflavik, Iceland</td>
<td>Polar Warming Research &amp; ADM Cal/Val Practice</td>
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<td>2017</td>
<td>CPEX</td>
<td>Fort Lauderdale, FL</td>
<td>Convection Research</td>
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<tr>
<td>2018</td>
<td>3 NASA Earth Venture Suborbital Proposals</td>
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Lidar Sensitivity Improvement

- Coherent Lidar S/N is proportional to the Lidar FOM
  \[ F_m \propto \eta_{af} E_t \sqrt{PRF} \Delta t^{0.285} \frac{2}{1+(M^2)^2} \]
- Improved the laser energy by replacing damaged or deteriorated transmitter optics
  - Energy= 100mJ, \( M^2 = 1.04 \), PRF = 10Hz
- Better phase matching in BPLO and pulse beam
  - Matching both the collimated pulse laser and BPLO beam
  - Adjusted BPLO waist size to 2.72mm on secondary
- Optimized the alignment of transmit and BPLO beam
- Replaced fiber coupling network
- Characterized and improved the lidar small beam efficiency
- Optimized telescope far field focusing at 4-5 km range allowing improved performance over range out to \(~10\) km
Pulse Laser Beam and BPLO Alignment

Near Field

Far Field
Lidar Small Beam Efficiency Measurement

* LSE = $\eta_{sys} = \frac{\text{CNR}_{M,PK}}{\text{CNR}_{P,PK}}$

* Measured small beam system efficiency of ≥30%
Convective Processes Experiment (CPEX) aircraft campaign

• Objectives
  • Improve understanding of convective processes
    • including cloud dynamics, downdrafts, cold pools and thermodynamics during initiation, growth, and dissipation
  • Obtain a comprehensive set observations, especially from DAWN
  • Improve model representation of convective and boundary layer processes
  • Improve model assimilation of the wind, temperature and humidity profiles

• North Atlantic Ocean in the summer of 2017, 89 hrs flight time

• Multiple Instruments
  • DAWN (Doppler Aerosol WiNd Lidar) – anchor instrument
  • APR-2 (Precipitation Radar), reflectivity, depolarization, wind/hydrometeor velocity
  • HAMSR, Radiometer, T & H2O vapor & liquid profiles
  • MTHP, (Microwave Temperature and Humidity Profiler) – T, RH
  • Microwave Atmospheric Sounder for Cubesat (MASC)
  • YES Dropsondes – P, T, RH, wind, SST
Base: Fort Lauderdale, FL (KFLL)

- Reliability (availability) was excellent (> 99%)
- Sensitivity improved over PolarWinds by order 10 dB.
Examples of DAWN Performance

The following 4 slides are for soundings within 12 minutes of each other with 5 look angles; 2 second, 1 second and then back to 2 seconds.

Clouds only just above surface
20 shots (2 second integration) 5 Looks
10 shots (1 second integration) 5 looks
Examples of DAWN Performance – cont.

High and Low clouds
10 shots (1 second integration) 5 Looks

No High Clouds
20 shots (2 second integration) 5 looks
DAWN in CPEX Summary

- DAWN operated nearly 100% of the time in spite of high temperature (in cargo bay at startup) and condensation/oil deposits on the window in port 7.
- Greatly improved vertical distribution of sensitivity over previous Polar Winds campaign in Iceland in 2015.
- The CPEX campaign has provided a unique set of more than 5000 DAWN wind profiles and ~ 300 dropsonde wind, temperature and water vapor profiles during all stages of the convective life cycle.
- The DAWN airborne instrument can provide the velocity fields in the vicinity of scattered and organized deep convection.
- CPEX science flights indicate good vertical coverage and good agreement with dropsonde winds.
- The DAWN data have been used to compute mass budgets and divergence for 100 km x 100 km x 8-10 km volumes containing various degrees of cloud coverage ranging from cloud free to broken and scattered convection.
Coherent 2-Micron Wind Lidar Technology Advancement for Space

- NASA ESTO supported
- 3-year effort, 2017 – 2020
- Deliverables
  - Conceptual design of a space mission and instrument that proves the feasibility of returning wind science from space
  - Operational ground-based coherent detection lidar demonstrator instrument focusing on undemonstrated coherent-detection Doppler wind lidar components required for space
  - Roadmap going forward that shows an understanding of the current design gaps and a logical progression towards a space mission
- Project Team
  - NASA Langley Research Center, Lead – Pulsed transmitter laser, electronics, structure, computer control, data processing
  - Beyond Photonics – CW lasers, optical bench, transceiver enclosure, electronics
  - Simpson Weather Associates, Science Lead – mission concept, lidar parameter trades, advanced processing algorithms
  - Fibertek – Tm fiber pump laser
End-to-End Mission Concept Design

- Several NASA space instrument & mission design studies performed in the past
- Studies baselined coherent lidar laser parameters of DAWN at 250 mJ, 5 or 10 Hz
- Simpson Weather Associates sophisticated space wind lidar performance simulation utilized DAWN laser parameters for mission design & science products
- Coherent wind lidar laser figure of merit (FOM) is linked to aerosol backscatter sensitivity

\[
\frac{1}{\beta_{\text{MINIMUM}}} \propto FOM_{\text{LASER}} \approx \frac{E_{\text{LASER}} \sqrt{PRF_{\text{LASER}} \tau_{\text{LASER}}^{0.285}}}{1 + \left( M_{\text{LASER}}^2 \right)^2}
\]

- backscatter $\beta$, $E$ – energy, pulse repetition frequency (PRF), duration $\tau$, beam quality $M^2$
- New Langley laser baseline and threshold requirements duplicate aerosol backscatter sensitivity of 250 mJ, 10 and 5 Hz, respectively
- Baseline 56 mJ, 200 Hz; threshold 42 mJ, 200 Hz
- Computer simulation new & previous results predict science products of new laser
Optical Block Diagram Highlighting Lidar Technologies to be Advanced

- CW Seed Laser - Fore
- CW Seed Laser - Aft
- CW LO Laser
- Fiber CW Pump Laser
- Pulsed XMTR Laser
- Seed Switch
- "Transceiver"
- Fore/Aft Switch

Symbols:
- Δf
- HET
- DET
- EN
- DET
- RES
- DET
- MON
- T/R

Diagram highlights components and signals in a lidar system, illustrating the flow of CW Seed Laser, Pulsed XMTR, and CW LO Laser, with emphasis on seed switch and transceiver functionality.
Lidar Technologies to be Advanced & Their Space Function

- **Tm Fiber Pump Laser**
  - Advance to space qualifyable

- **2-Micron Pulsed Transmit Laser**
  - New Ho:LuLF, 56 mJ, 200 Hz, end-pumped
  - More wind measurements below, inside, and at top of clouds
  - Lower energy - less chance of optical damage
  - Easier heat removal from laser crystal – less change of fracturing

- **Dual 5 GHz Tunable 2-Micron CW Seed Lasers**
  - Remove orbit velocity & earth rotation Doppler shifts – narrower receiver BW
  - Smaller & higher efficiency
  - Dual GHz frequency offset circuits to tune the seed lasers
  - 5 GHz room temperature optical detectors for feedback loops
  - Single job, fore or aft – no large frequency jumps

- **2-Micron CW Local Oscillator Laser**
  - Smaller & higher frequency
  - Used for frequency offset circuits, outgoing pulse frequency difference optical detector, dual-balanced heterodyne optical detectors

- **Optical Seed Laser Switch**
  - Enables dual seed lasers with no large frequency jumps

- **Optical Fore/Aft Direction Switch**
  - Enables two nonmoving telescopes for fore/aft with single operating lidar system

- **Dual-Balanced Heterodyne Optical Detectors for Atmospheric Signal**
  - High quantum efficiency
  - Room temperature
  - Integrated with optimized bias & preamplifier circuits
  - Fiber coupled – may be placed close to signal conditioning electronics & ADC

- **Transceiver/Optical Bench**
  - Compact
  - Rigid & stable for alignment maintenance
  - Conductively cooled
  - Selected electronics close to components
FiberTek will develop a space qulifiable Tm fiber laser for this project. The specifications for this laser is understood.

The best option is to achieve laser requirements by oscillator only approach. Add an amplifier as necessary.

End pump both sides of the crystal and double pass amplifier configuration is possible, but shall be act very careful
1. Pulse waveform det.
2. Tm Fiber laser output Collimator
3. Resonance det.
4. Pump laser beam shape optics
5. Laser Crystal
6. Q-S
7. PZT
8. Seed Laser fiber collimator
9. Isolator
10. Half wave plate

All mirrors are 0.5 inch dia. Laser cavity size ~42cm x 11cm
Advanced Coherent Wind Lidar Transceiver Preliminary Concept

Transceiver Pressurized Enclosure
23” dia x 10.5” high
Example of Mission Concept Wind Products & Coverage
Background (Low) Aerosol Model

1.4 sec
10 km Cloud Gap

12 sec
80 km Resolution

25 km altitude
Baseline Laser

Threshold Laser
WIND-SP Instrument Summary

- 3 year effort to develop a stand-alone lidar with the technologies and approximate form to fit for a space-based lidar
- This lidar will provide required sensitivity and accuracy for wind profile measurement from space
- Identified the technologies required for WIND-SP Instrument space features
- Team with strong coherent lidar technical skills to develop the required technologies for space lidar
- The project went through conceptual design. Transmitter, transceiver, telescope, electronics and software are been developing to meet the project goal in schedule