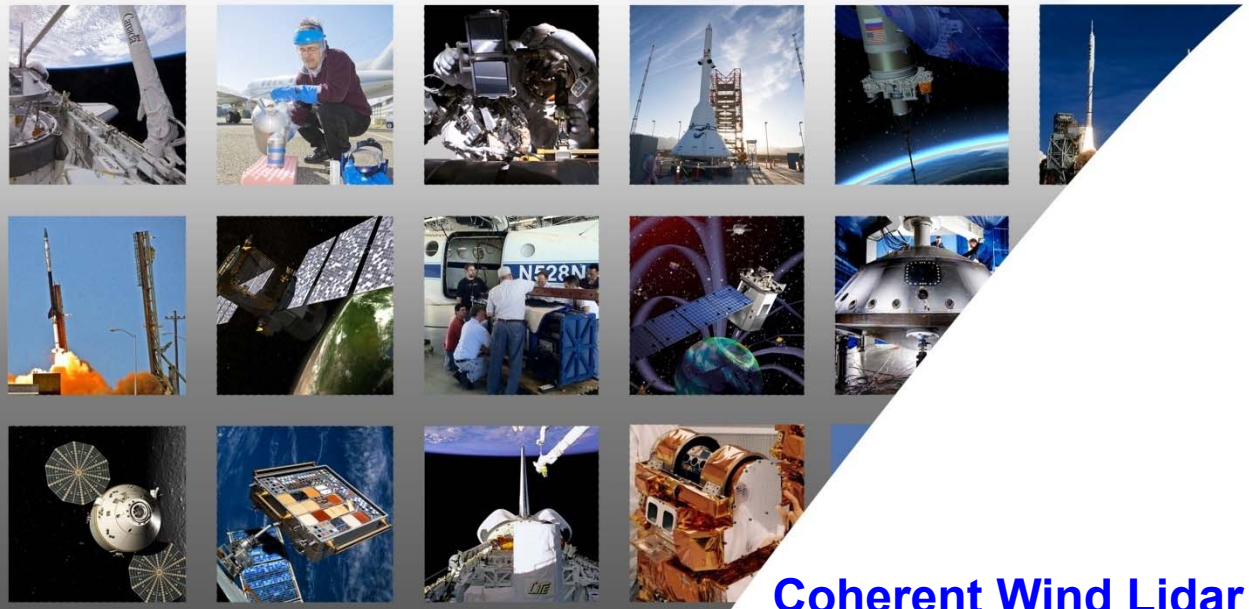


National Aeronautics and Space Administration

NASA

Coherent Wind Lidar Activities and Vision at NASA Langley Research Center

Upendra N. Singh

NASA Langley Research Center, Hampton, Virginia 23681

*Langley Research Center (**M. Kavaya, J. Yu, J. Marketon, Z. Liu**)*

*Beyond Photonics (**S. Henderson, C. Hale**)*

*Fibertek (**F. Hovis**)*

*Simpson Weather Associates (**D. Emmitt, S. Greco**)*

Working Group on Space-Based Lidar Winds
Hampton, VA
21-23 March 2017

Engineering Directorate Concept-to-Flight

www.nasa.gov
http://engineering.larc.nasa.gov/

Outline

- NASA Polar Winds Campaign
- Doppler Aerosol Wind (DAWN) Improvements
- Airborne Convective Processes Experiment Campaign (CPEX)
- 3D Winds Space Pathfinder Project
- SBIR and Industrial Partnership for Space
- International Collaboration for 3-D Space-based Winds

NASA's Polar Winds Campaign and ESA's ADM Cal/Val

- Two airborne Doppler Wind Lidar campaigns:
  - Campaign 1 November 2014 on UC-12B based Kangerlussuaq, Greenland
  - Campaign 2 May 2015 on DC-8 based

  Keflavik, Iceland
- Purpose was to conduct basic polar science investigations and <u>demonstrate technology readiness for ADM Cal/Val</u>

PolarWinds Science and Instrument Team

- G. D. Emmitt (Simpson Weather Associates) , Principal Investigator
- M. Kavaya (NASA/LaRC), Technology Lead
- G. Koch (NASA/LaRC), Instrument Chief Engineer
- U. Singh (NASA/LaRC), Technology and Mission Advisor
- S. Greco (Simpson Weather Associates)
- K.Godwin (Simpson Weather Associates)
- D. Bromwich (Ohio State University)
- K. Hines (Ohio State University)
- J. Cassano (Colorado University)
- R. Foster (University of Washington)
- M. Shapiro (NCAR)
- D. Winker (NASA/LaRC)

2 Polar Winds Campaigns

Polar Winds - Greenland

- Oct-Nov 2014
- Kangerlussuaq, Greenland
- NASA UC-12B: DAWN wind lidar

Polar Winds - Iceland

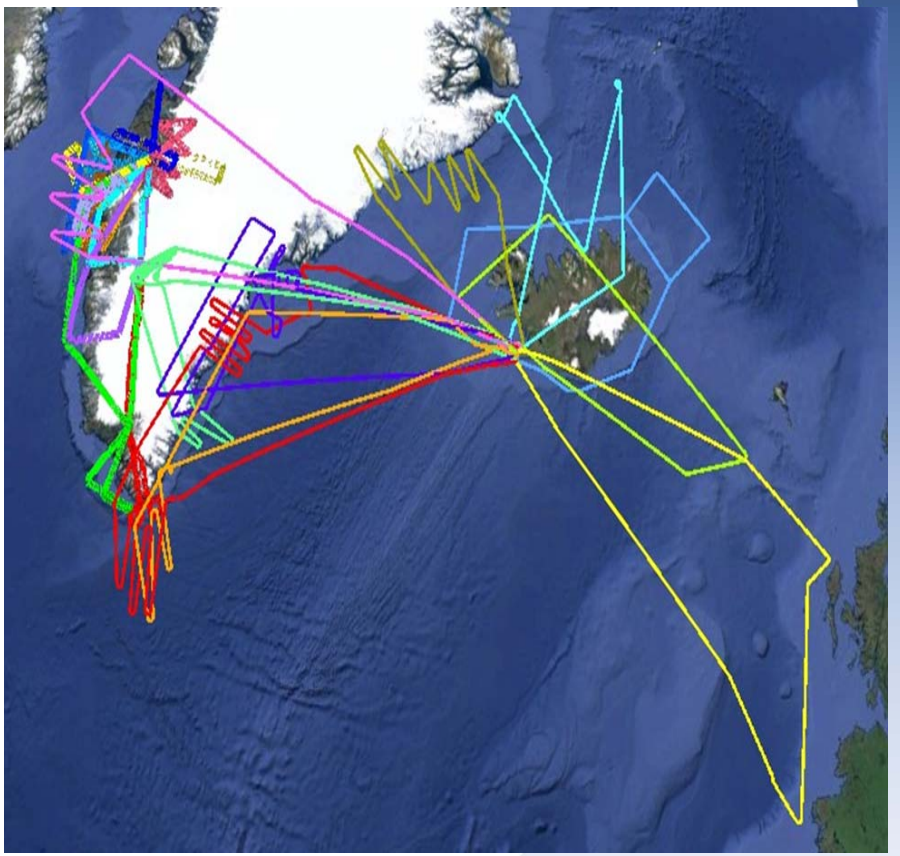
- May 2015
- Keflavik, Iceland
- NASA DC-8: DAWN wind lidar, TWiLiTE wind lidar, dropsondes
- DLR Falcon: ADM-Aeolus simulator, coherent wind lidar

Science Goals

- Low-level Arctic wind circulations
- Simulate underflights of ADM-Aeolus for future Cal/Val

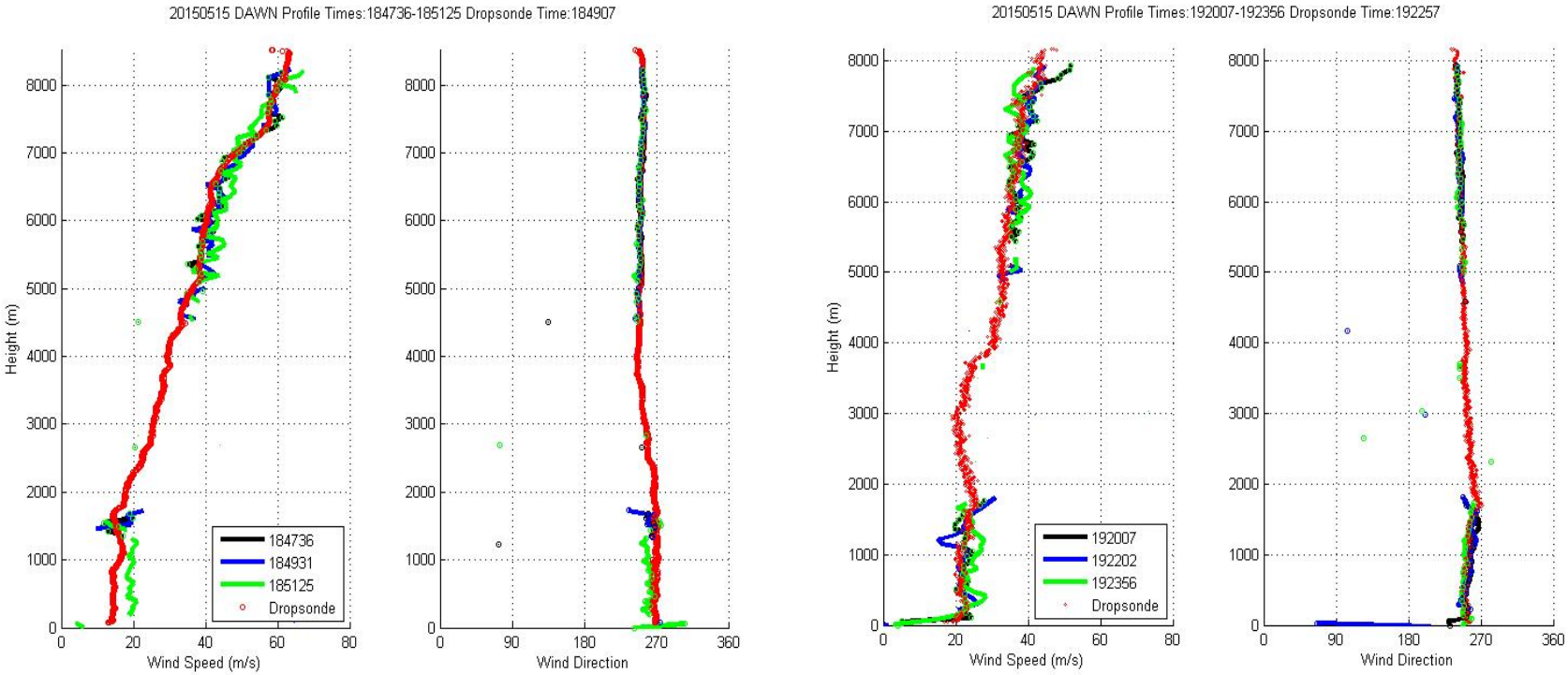
Wind Circulations Studied

- The Greenland Tip Jet
- Barrier Winds off the east coast of Greenland
- Katabatic flows along the Greenland coastline
- Boundary layer rolls and OLES over the water
- Flow over transitional ice and water zones
- Flow over the Greenland Ice Cap



Three Consecutive DAWN Wind Profiles Compared to Dropsondes

18:47:36-18:51:25 vs. 18:49:07 | 2015 May 15 | **19:20:07-19:23:56 vs. 19:22:57**

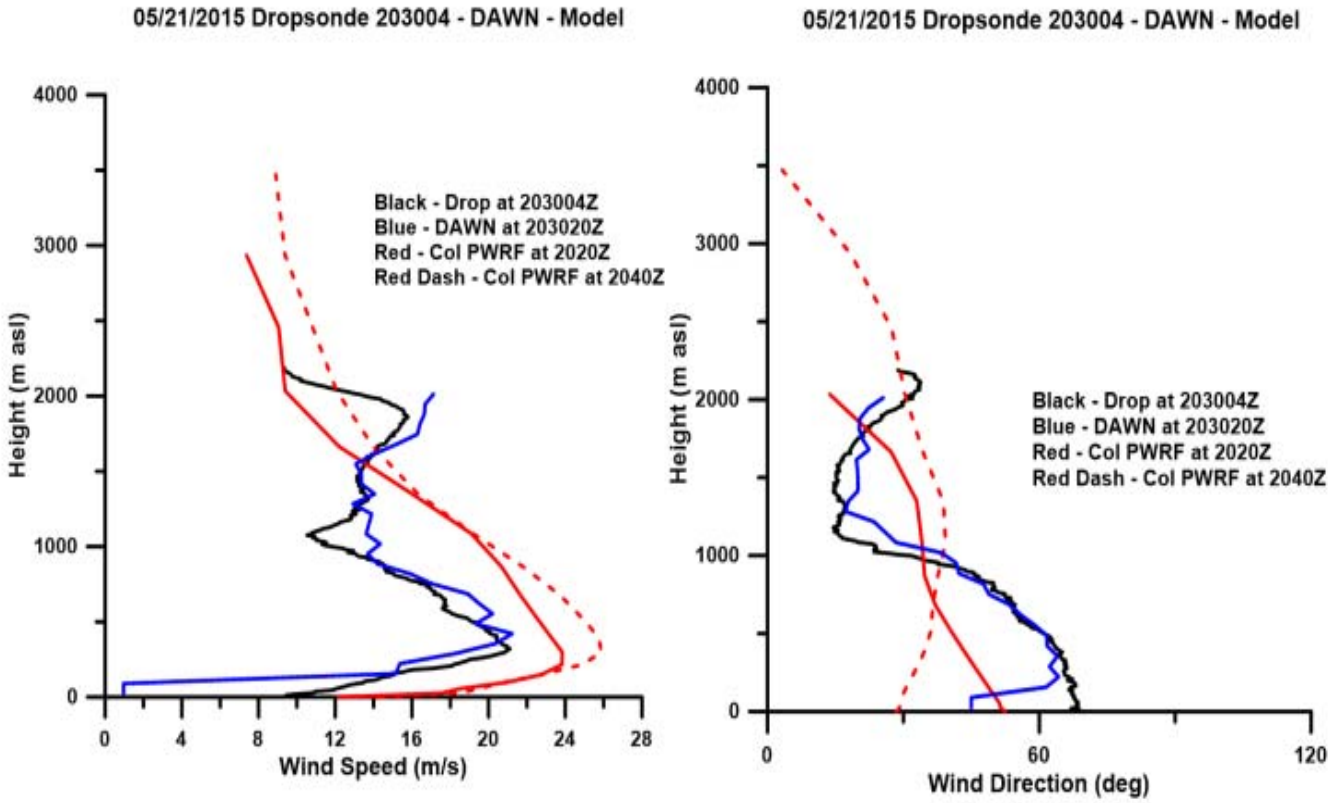


Red circles: Dropsondes from NASA/DC-8

Black, blue, and green: 3 consecutive DAWN profiles within 2 minutes of dropsonde release

(Note many DAWN points are obscured by the red dropsonde line)

DAWN Profiles vs. Dropsonde Profiles vs. Polar WRF Model Forecast



A comparison of wind speed and direction profiles measured by DAWN (blue) and co-located and near instantaneous dropsondes (black) as well as two Polar WRF model forecasts (red) around the same time (2010Z) on May 21, 2015 during Polar Winds Campaign 2 near the east coast of Greenland (from Emmitt, 2017)

Summary of Major Results and Plans

- More than 80 hours of DAWN research flights in 2014 and 2015 in the Arctic region near Greenland and Iceland. Most hours were related to PolarWinds science objectives. Six missions flown together with DLR Falcon. NASA provided ESA the requested dropsonde and wind profiling support. DAWN in final round of processing.
- DAWN/dropsonde comparisons demonstrated close agreement.
- While DAWN performed less than ideally due to misalignments, the DAWN profiles have provided quality data for numerical model (e.g. Polar WRF) validation. Since Campaign II, DAWN's performance has been improved by a factor ~ 24x by Beyond Photonics.
- All PolarWinds and ADM Cal/Val objectives were met.
- Level 0 – 3 data and documentation are to be archived at the LaRC DAAC (ASDC).
- More than 10 conference/workshop presentations. Two papers are being prepared for publication, one was accepted in Monthly Weather Review. Three papers were presented at the 2017 AMS Annual Meeting.
- DAWN, with its precision and recently restored sensitivity, represents the most capable coherent airborne DWL available for atmospheric research. NASA ESD has recently selected it to participate in its forthcoming Convective Processes Experiment (CPEX) Campaign

Doppler Aerosol Winds (DAWN) Improvements

Dawn Improvements

- DAWN has been underperforming by many dB in aerosol sensitivity
- Due to the high pulse energy, good science was still obtained

- DAWN was sent to Beyond Photonics, Boulder, CO in FY16
  - Replaced malfunctioning fiber network
  - Improved transmit & BPLO beam size, curvature, and alignment
  - Improved transmit/BPLO match to each other, and to telescope
  - Investigated telescope losses
  - ➢ See also Sammy Henderson presentation this meeting

- After return to LaRC
  - Reviewed BP changes
  - Practiced & repeated BP coherent lidar testing techniques
  - Modified laser/optics enclosure to permit alignment after complete assembly
  - Modified enclosure to permit BP lidar system efficiency test after complete assembly
  - Improved noise floor “flatness”
  - Analysis showed inadequate cross-country bump isolation in trailer; improved isolation

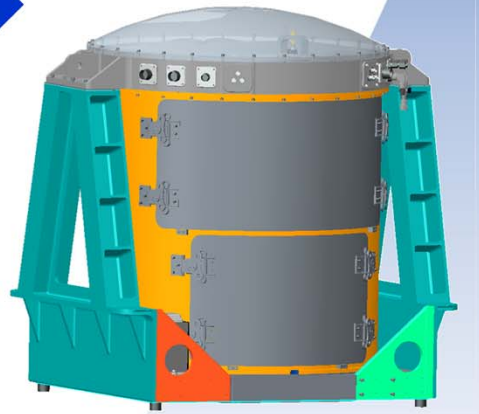
Improvement of Post-Assembly Access to DAWN Laser & Optics

Remove inner half cylinder

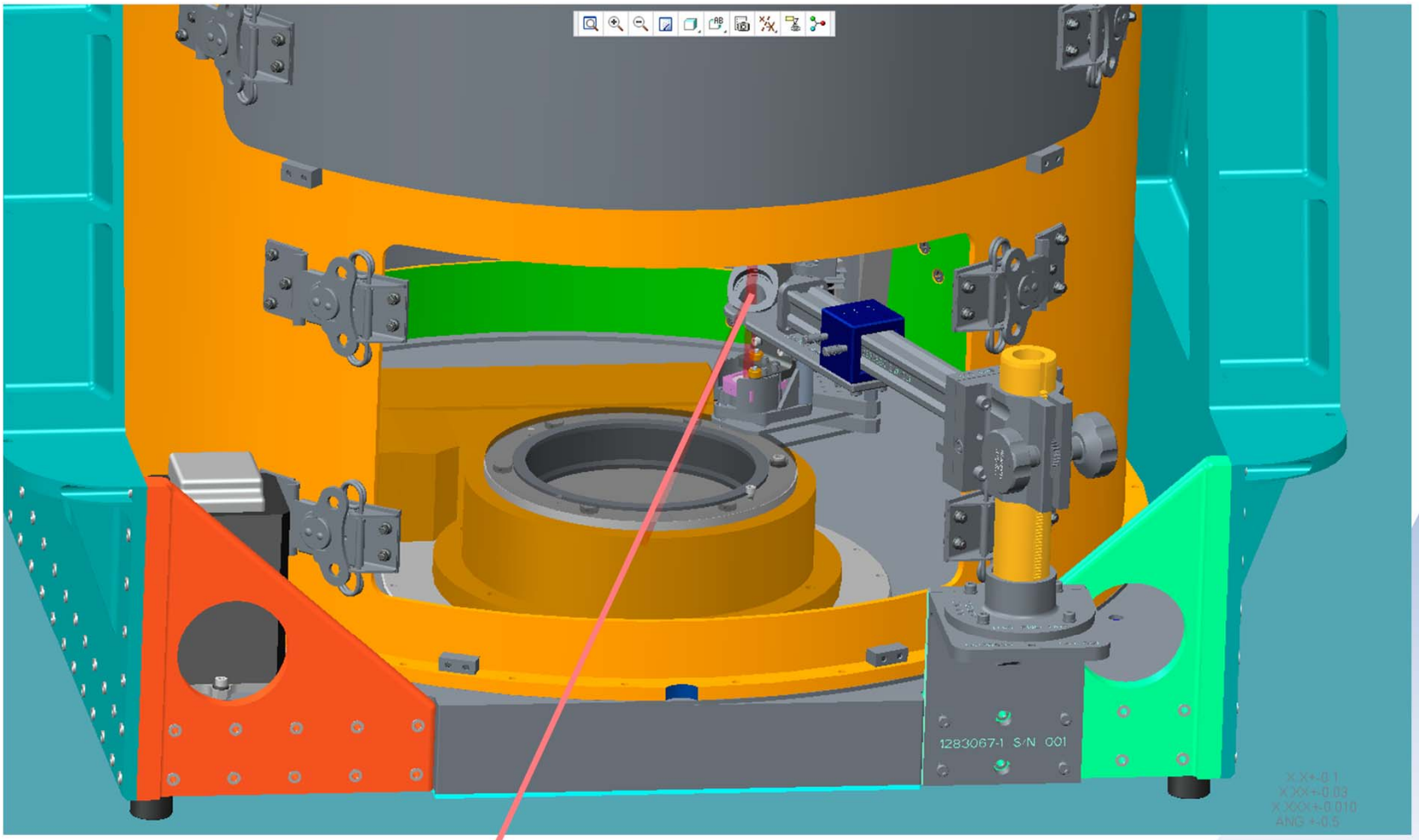
Add new stiffeners to compensate

Add alignment access holes for

laser, receiver, and telescope

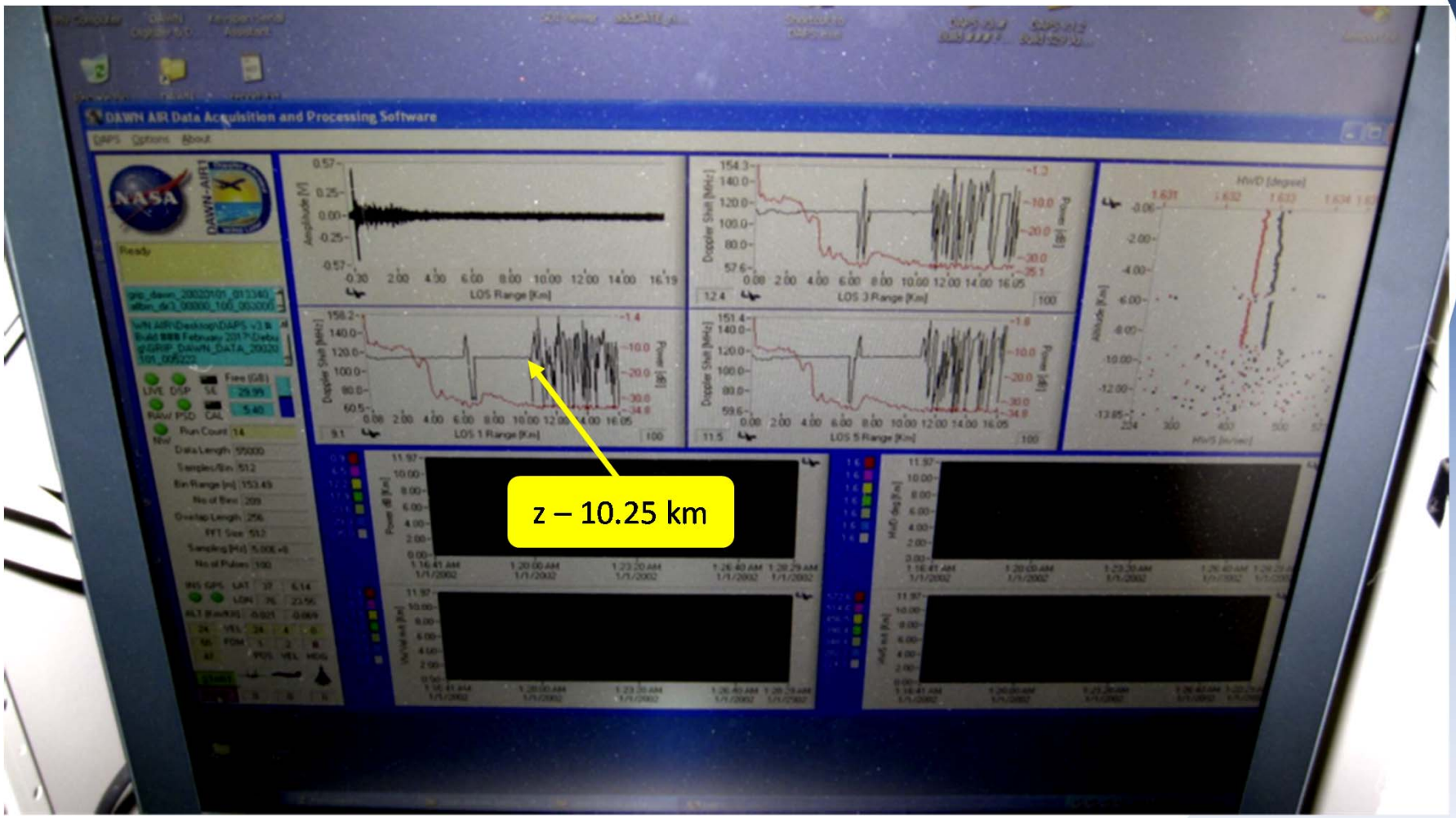


Add Small Beam Redirection for Lidar System Efficiency Measurement



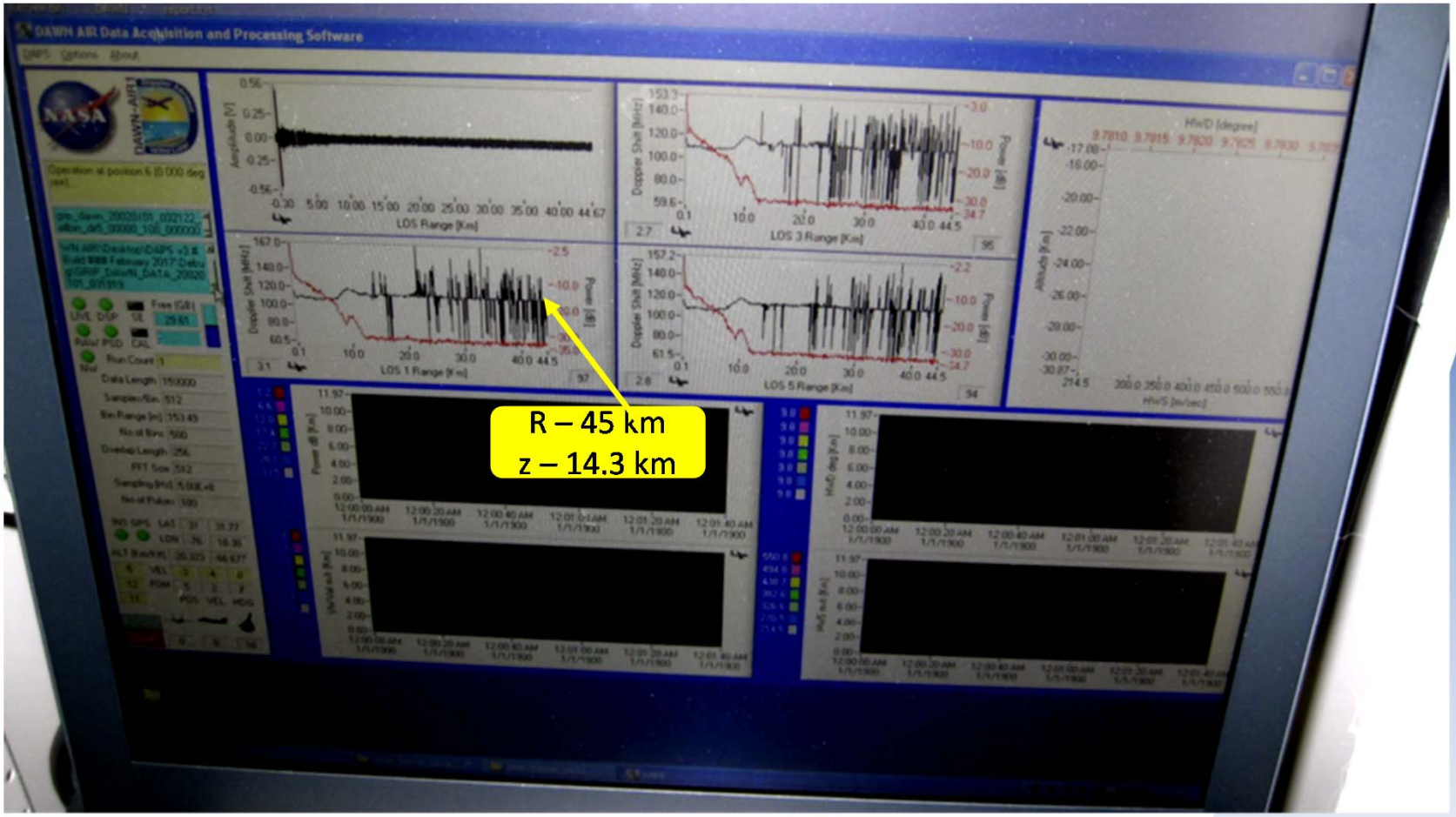
Aim small beam out of cylinder to direct to calibration target

3-10-17 Test of Improved DAWN



At LaRC, 2:15 pm, collimated, ~vertical, 153 m range gate, 100 shots = 10 seconds

3-10-17 Test of Improved DAWN



At LaRC, 3:24 pm, collimated, 18.5 degrees above horizon, 153 m range gate, 100 shots = 10 seconds

Airborne Convective Processes Experiment Campaign (CPEX)

CPEX Campaign

- NASA AO, Dr. Ramesh K. Kakar (see also Ramesh's presentation this meeting)
- Convective Processes Experiment
- May 25 – June 25, 2017
- DC-8 based in Fort Lauderdale, CA USA
- Science team co-leads: Dr. Shuyi Chen/U. Miami; Dr. Ed Zipster/U. Utah
- Instruments
  - DAWN (Doppler Aerosol WiNd lidar) – horizontal vector wind profiles
  - APR-2 (Airborne Precipitation Radar) – reflectivity, depolarization, wind/hydrometeor velocity
  - HAMSR (High Altitude MMIC Sounding Radiometer) – T & H_2O vapor & liquid profiles
  - MTHP (Microwave Temperature and Humidity Profiler) – T, RH
  - Yankee Environmental Dropsondes – P, T, RH, wind, SST
  - MASC (Microwave Atmospheric Sounder)

Acknowledgments
Preparing DAWN for CPEX

DAWN Team

Bruce Barnes
Songsheng Chen
Zhaoyan Liu
John Marketon
Anna Noe
Larry Petway
Diego Pierrottet
Ruben Remus
Aboubakar Traore
Jirong Yu

Engineering Support

Warren Davis
Bill Luck
Ed Nemie
Thuan Nguyen
Gugu Rutherford
Elaine Seasly

Fabrication Support

Mark Simonton

Advocacy

David Emmitt
Upendra Singh

DAWN Heritage

Grady Koch

Sponsors

Ramesh Kakar
Jack Kaye

Management Support

David Young
JD Reeves

Ed Healy
Drew Hope
Dan Baize
Glenn Hines
Tinesha Blackmore

3D Winds Space Pathfinder (WIND-SP)

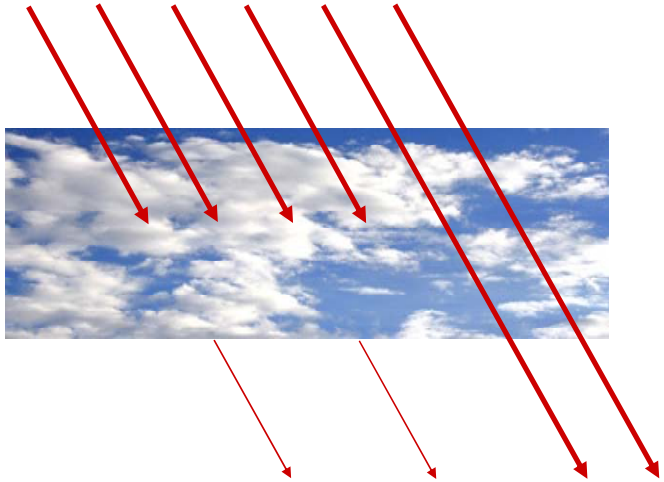
Directed Project from

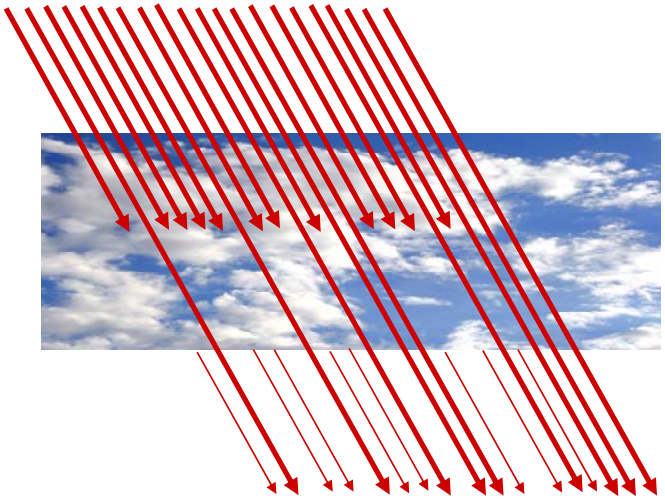
NASA HQ Earth Science Division

3D Winds Space Pathfinder (WIND-SP)

- Winds Space Pathfinder (WIND-SP), **NASA ESD directed program**, to design, develop and demonstrate a next generation coherent detection winds lidar that represents a major step towards the ultimate 3D Winds Space Mission
- A collaborative effort between **Simpson Weather Associates, Beyond Photonics, and NASA LaRC**, which builds on the DAWN airborne DWL heritage to advance an instrument with new **high pulse rate end-pumped 2-micron laser technology** (ESTO ACT leveraged), new transmitter thermal management architecture, new receiver and data retrieval system
- **End pumping greatly improves efficiency**: less heat deposited in crystal, less crystal damage probability, **less heat to remove**, pump better matched to lasing volume, **better beam quality**
- Lower laser pulse energy reduces optics damage risk; NOHD remains at 0 m
- **Higher laser pulse rate recognizes the ubiquity of clouds on earth, more cloud penetration, more winds below clouds, and more cloud winds**
- **Incorporate changes towards space form, fit, and factor when feasible**
- Enable a pathfinder space mission to learn more about aerosol backscatter, off-nadir cloud statistics, coherent lidar technology, and assimilation of winds into the models

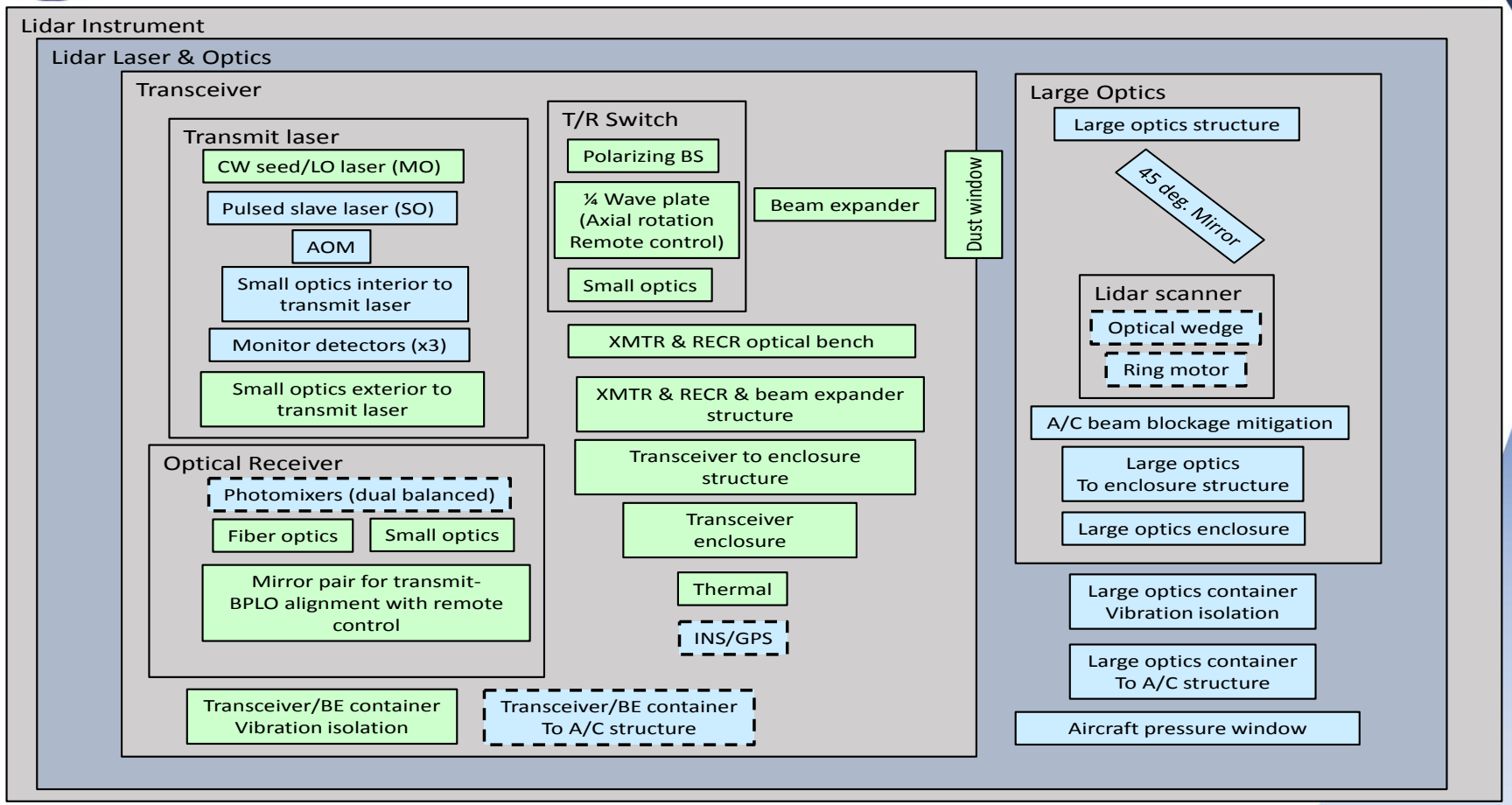
Existing DAWN Versus Proposed DAWN-SP





Existing DAWN Wind Lidar		Proposed DAWN-SP Wind Lidar
250mJ, 5Hz Laser	Laser Pulses	32 mJ, 300Hz
Equal	Aerosol Sensitivity (Lidar Figure of Merit)	Equal
Less	Cloud Wind Measurements	Up to 60x more
Less	Laser Shots Through Cloud Holes	Up to 60x more
Less	Wind Measurements Below Clouds	Up to 60x more
Higher	NWP Assimilation Representativeness Error	Much Lower
Good	Fractional Laser Efficiency	Higher
Good	Laser Beam Quality	Good
Low at 2 microns	Risk of Contamination Optics Damage	~8x lower

Partner's Division of Responsibility



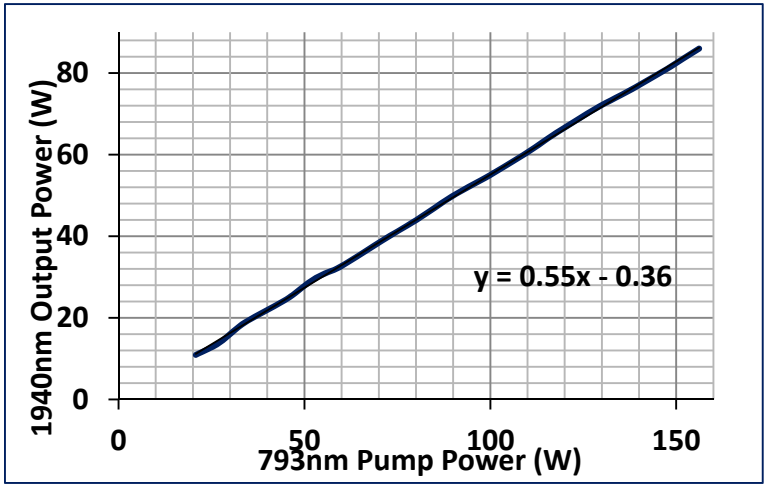
SBIR and Industrial Partnership for Space

Targeted SBIR Investments in Enabling Technologies for Space

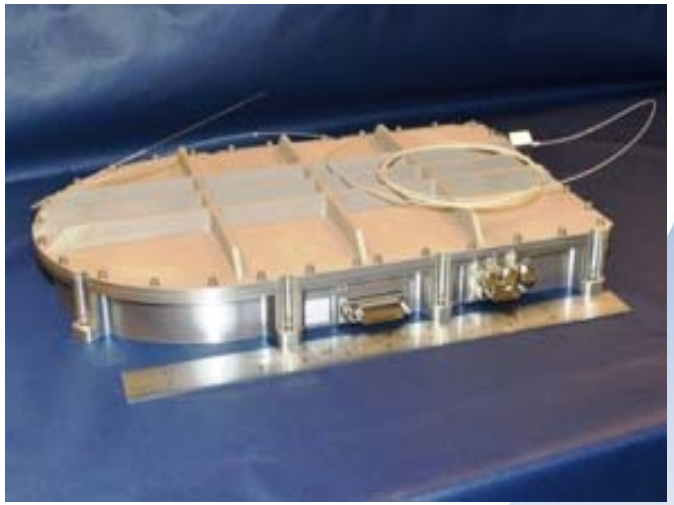
- Targeted SBIR Investments and industrial partnership is critical in advancing and maturing the technologies for space
- Example of some relevant SBIR's being leveraged
  - Fibertek, Inc – High Efficiency 1.94 micron Tm:Fiber Laser (F. Hovis Talk, this mtg – 3/22)
  - Beyond Photonics – Solid-state 2-micron seed/Lo laser (S. Henderson talk, this mtg. – 3/22)
  - AdValue Inc., – High-power 2-micron Fiber seed laser
- Partnership with other NASA Centers and Industry
  - NASA Jet Propulsion Laboratory – Semiconductor 2-micron Seed Laser
  - NASA GSFC and DRS Detectors– High performance MCT detectors for 2-micron

High Efficiency Tm: Fiber Laser

- 2 Stage Tm Fiber laser Design. 793nm pumped
- 86W, Diffraction limited, 55% Optical to Optical efficiency.
- Estimated 20% Electrical to Optical Efficiency (from power into the diode pump laser)
- Polarization Maintaining.
- Will be packaged inside TRL 6, GEVS Tested, Space EDFA Package (25W at 1.57um)
- Thermal Analysis and Structure show good performance and meets margin of safety.
- High Reliability, redundant pump diodes.
- Expect radiation testing will confirm acceptable performance for 3 Year ISS mission



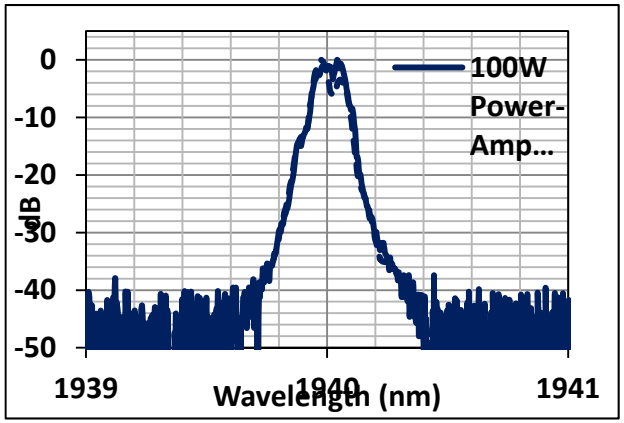
Laser Efficiency 55% Optical to Optical.
Estimate 20% Electrical to Optical
3X better than COTS Tm lasers



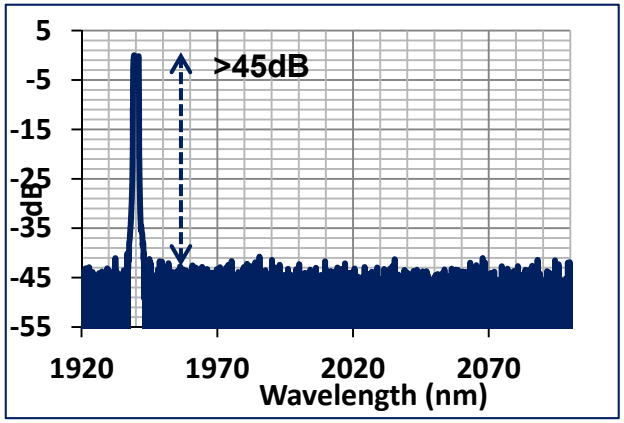
Tm Laser will fit inside Fibertek 25W EDFA TRL6 Tested Space Laser Package
Size: 14″ x 8.5″ x 2.1″. Mass is <8.5 lbs.

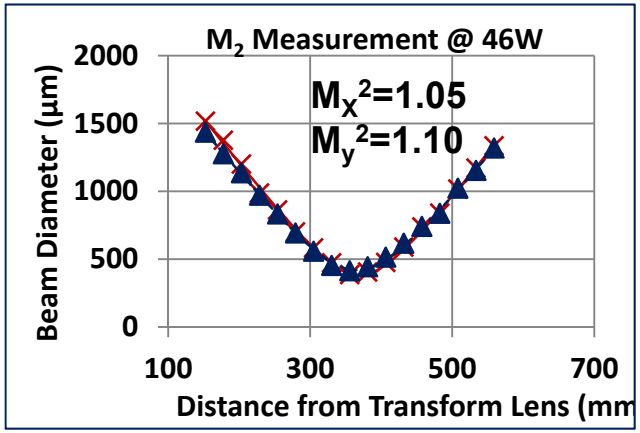
Near Diffraction Limited Beam, Narrow Linewidth

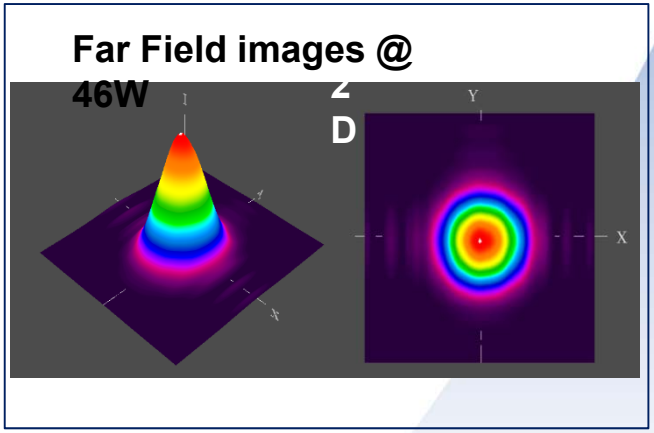
- Diffraction limited beam quality is achieved
- Linewidth < 0.3nm



100W





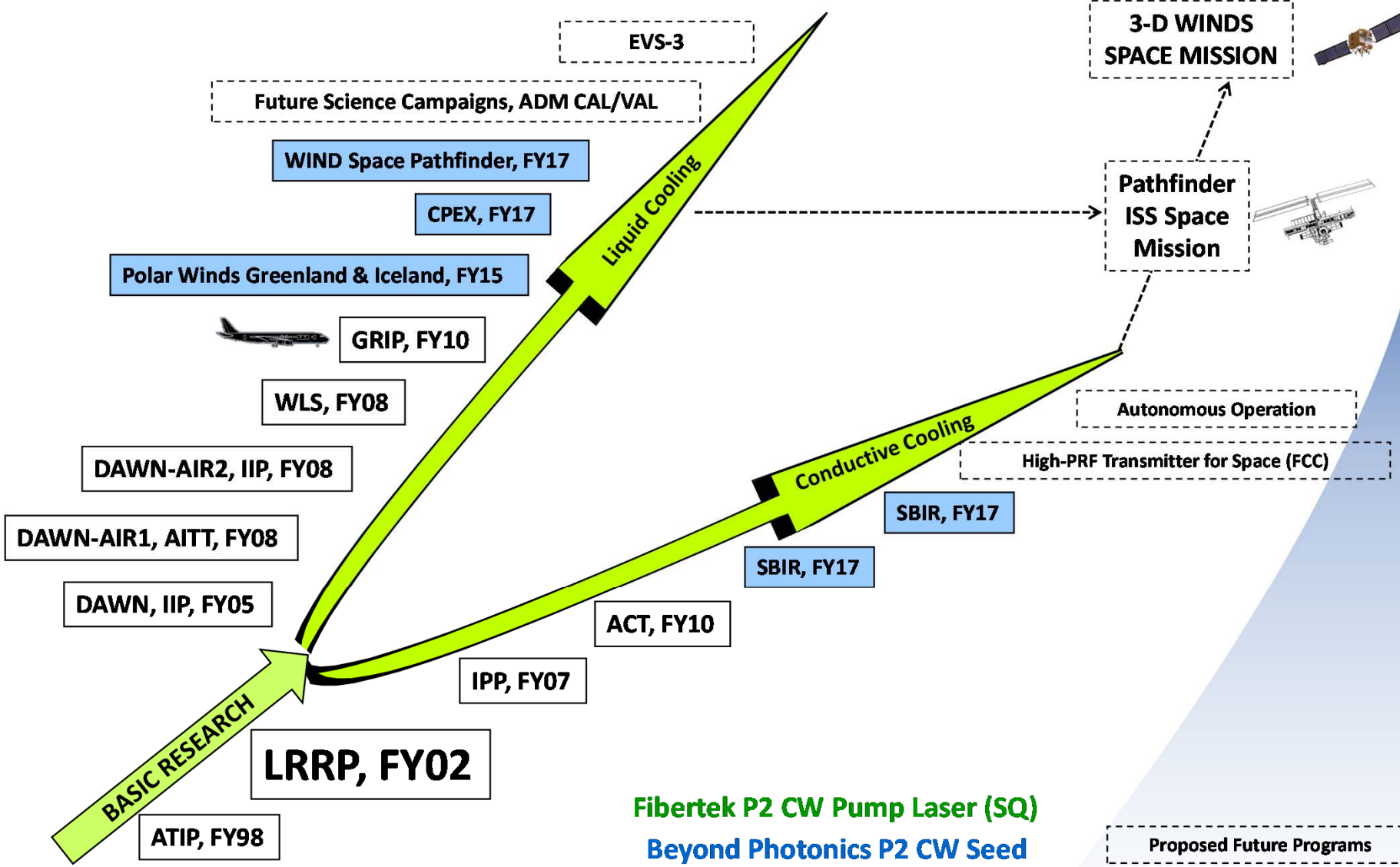


International Collaboration for 3-D Space-based Winds

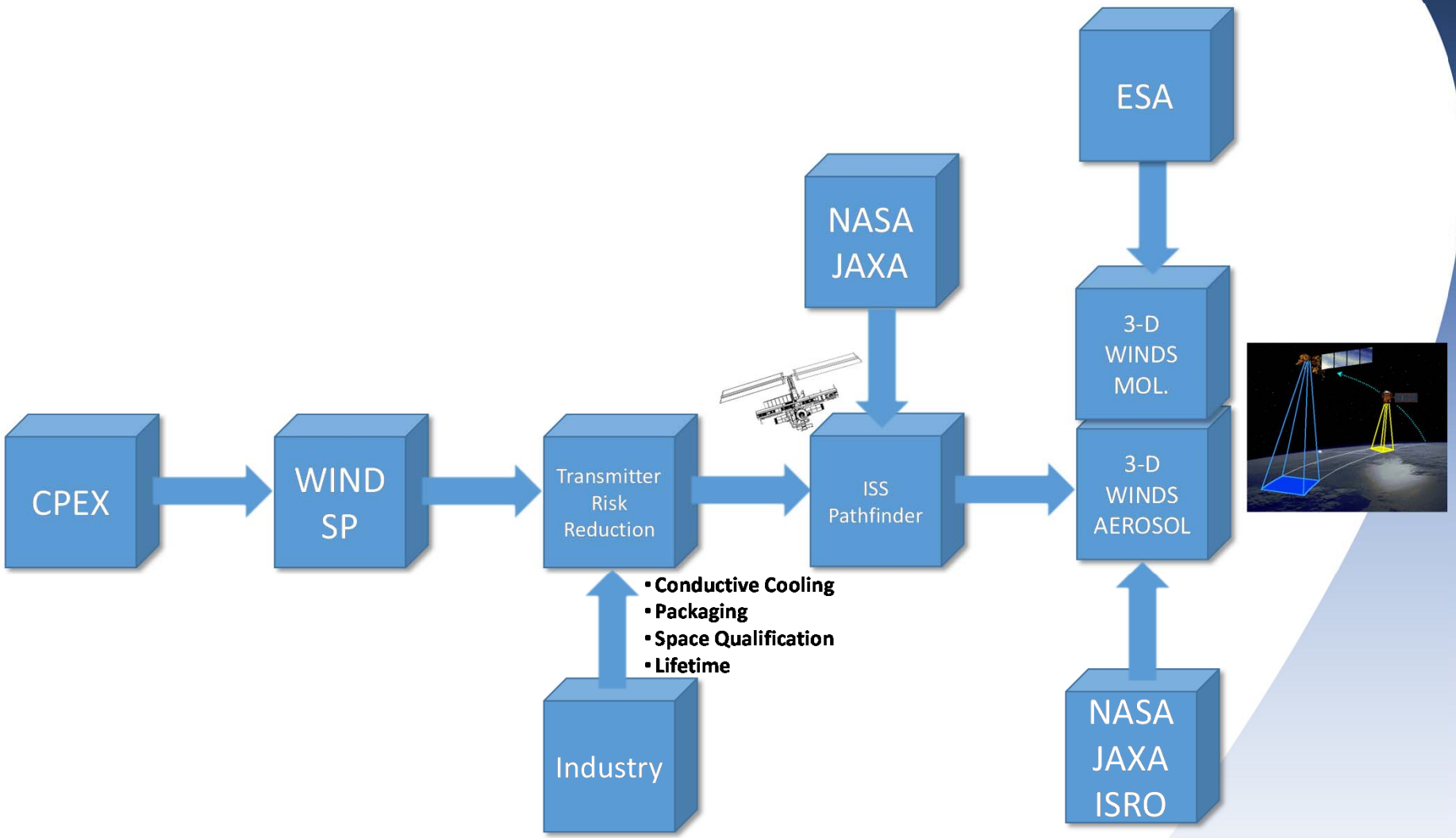
International Partnership

- NASA could benefit by partnering with Japan/JAXA and India/ISRO for a Coherent Doppler Wind Lidar mission
- JAXA, working with agencies such as NICT and NIES, has been developing 2-micron coherent wind lidar for the last 20 years
- JAXA and their industries have indicated a willingness to collaborate with NASA on a 2-micron aerosol DWL mission
- In India, both ISRO and the Ministry of Earth Sciences (MOES) have indicated a desire to work with NASA on a 2-micron coherent DWL mission
- Once matured NASA's 2-micron Coherent Aerosol DWL could possibly fly in formation with ESA's future operational UV Direct molecular DWL satellites for complete troposphere/lower stratosphere wind measurement coverage from space
- The collaboration of NASA, JAXA, ISRO, and ESA will also bring together their respective science communities. The result will be significantly lower cost to NASA and the long-desired and currently lacking global wind measurements

Roadmap to 3-D Coherent Doppler Wind Lidar Mission



Conceptual Roadmap to 3-D Winds Space Mission



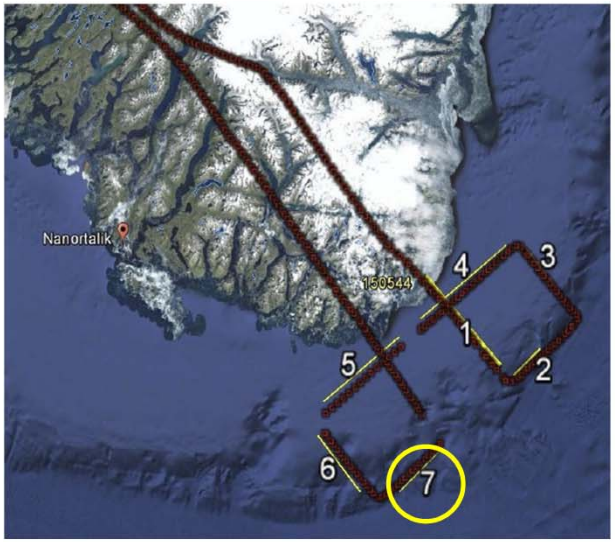
Summary and Conclusions

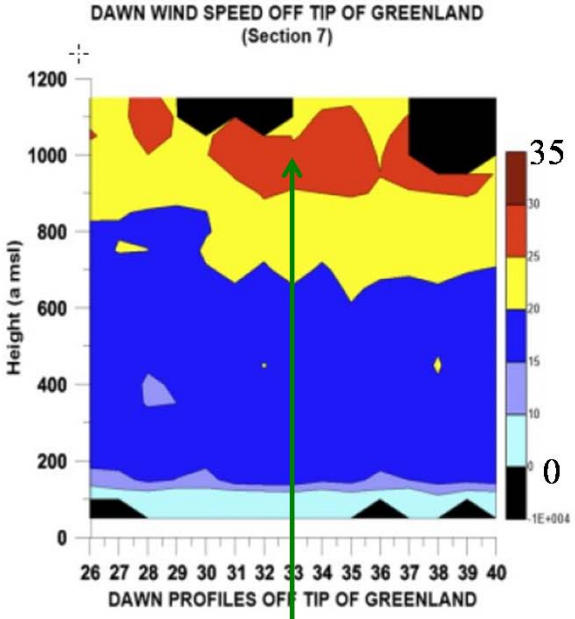
- NASA Langley Research Center has successfully developed Coherent Wind Lidar for ground and airborne measurement of Wind
- The improved DAWN instrument is being readied for Airborne CPEX campaign
- NASA Earth Science Division has recently approved a directed program for NASA Langley to build and field an airborne Doppler lidar system based on a high repetition rate Tm:Fiber pumped Ho:YLF system
- The new laser transmitter operating at 0.04 J and 200 Hz preserves approximately the same aerosol sensitivity as using a 250 mJ, 10 Hz laser, which was shown adequate in mission design studies
- Successful technology development, maturation and risk reduction for space-qualifiable technologies, being currently pursued by NASA Langley with multiple industry, will allow the first pathfinder DWL mission for horizontal wind measurements from the ISS JEM EF
- The current NASA LaRC roadmap with sustained support will lead to an affordable pathfinder and operational wind missions utilizing international collaboration

Questions?

Thanks for your Attention

Wind Speed & Direction Cross-Sections Off Tip of Greenland, 10/31/14





25 – 30 m/s (56 – 67 mph)

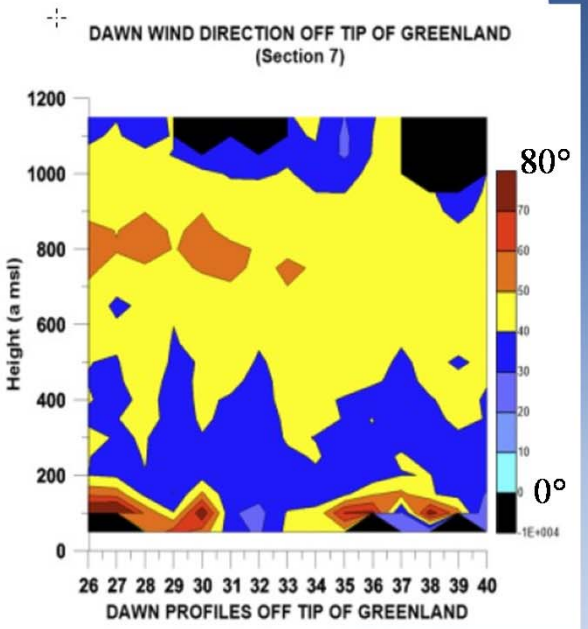
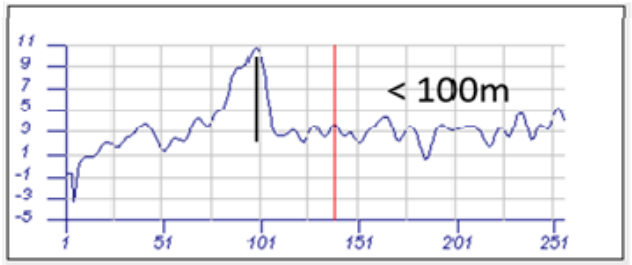
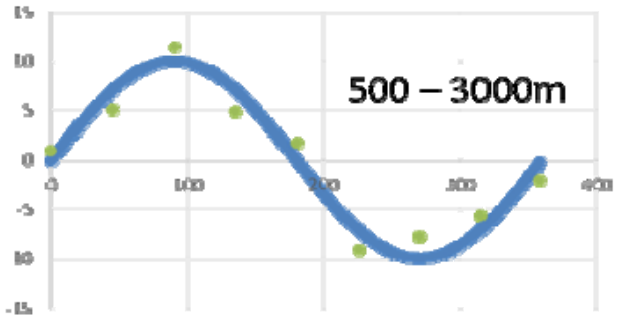


Illustration of the Four Scales of Atmospheric Dynamics Observed with DAWN (From Emmitt, 2017)

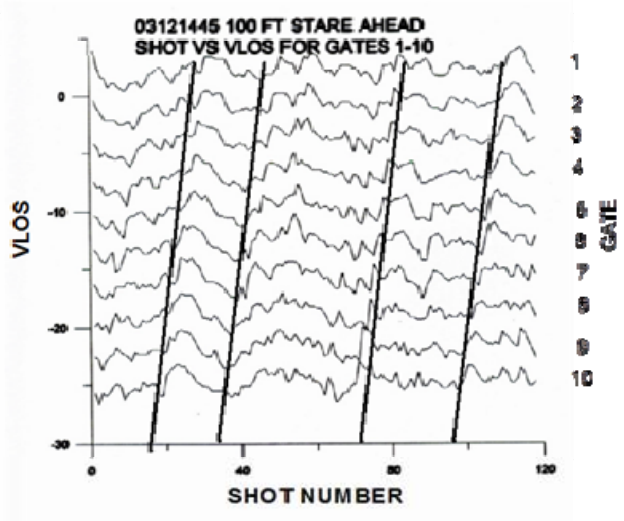
Multi-scale Wind Variability Using DAWN in CPEX



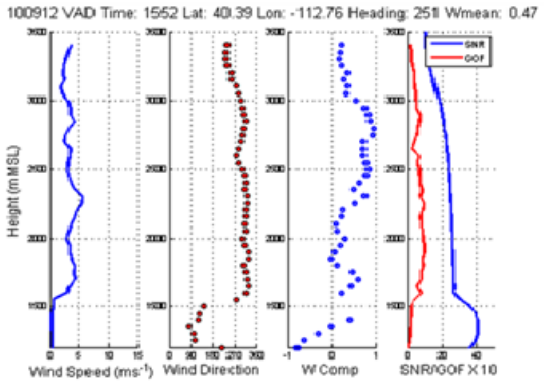
Sine wave fit to data from 8 looks



50 – 400m



3km – 200km



➢ See also Steve Greco presentation this meeting

Install DAWN in DC-8 as it was in 2010 and 2015 With the Improvements