Wind Measurements from a High Energy, Pulsed, 2-Micron,Coherent-Detection Doppler Lidar and Intercomparison with other sensors deployed during Field Campaign

Upendra N. Singh, Grady J. Koch, Michael J. Kavaya, Jirong Yu and Jeffrey Y. Beyon
NASA Langley Research Center, Hampton, Virginia 23681 USA

Belay Demoz
Howard University, Beltsville, MD USA

Acknowledgements: The authors appreciate the support of Dr. Ramesh K. Kakar, George J. Komar, and Janice L. Buckner of NASA HQ.

European Geophysical Union Conference, May 2- September 7, 2010, Vienna, Austria

Outline

- Background, Motivation and Roadmap
- Field test of newly developed 2-μm lidar transceiver
- Compare 2-μm lidar results with other sensors:
    - Balloon sondes
    - Direct detection wind lidar
    - Leosphere coherent Doppler lidar
    - Radar profiler
    - Aircraft Communications, Addressing and Reporting System

- Demonstrate hybrid wind lidar concept.
- Current and Future activities towards NASA 3-D Mission

Motivation for 2-Micron Laser/Lidar Development

➢ NRC Recommended “3-D Winds” Mission

NRC Decadal Survey

EARTH SCIENCE AND APPLICATIONS FROM SPACE

NATIONAL IMPERATIVES FOR THE NEXT DECADE AND BEYOND

Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future

Space Studies Board

Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

2007

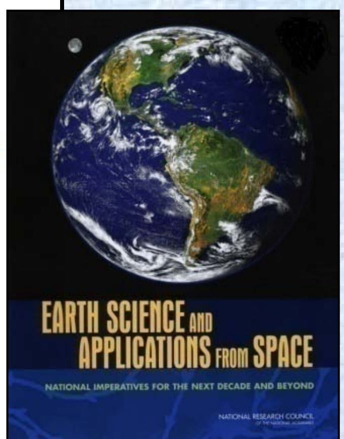
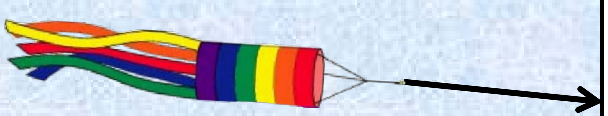
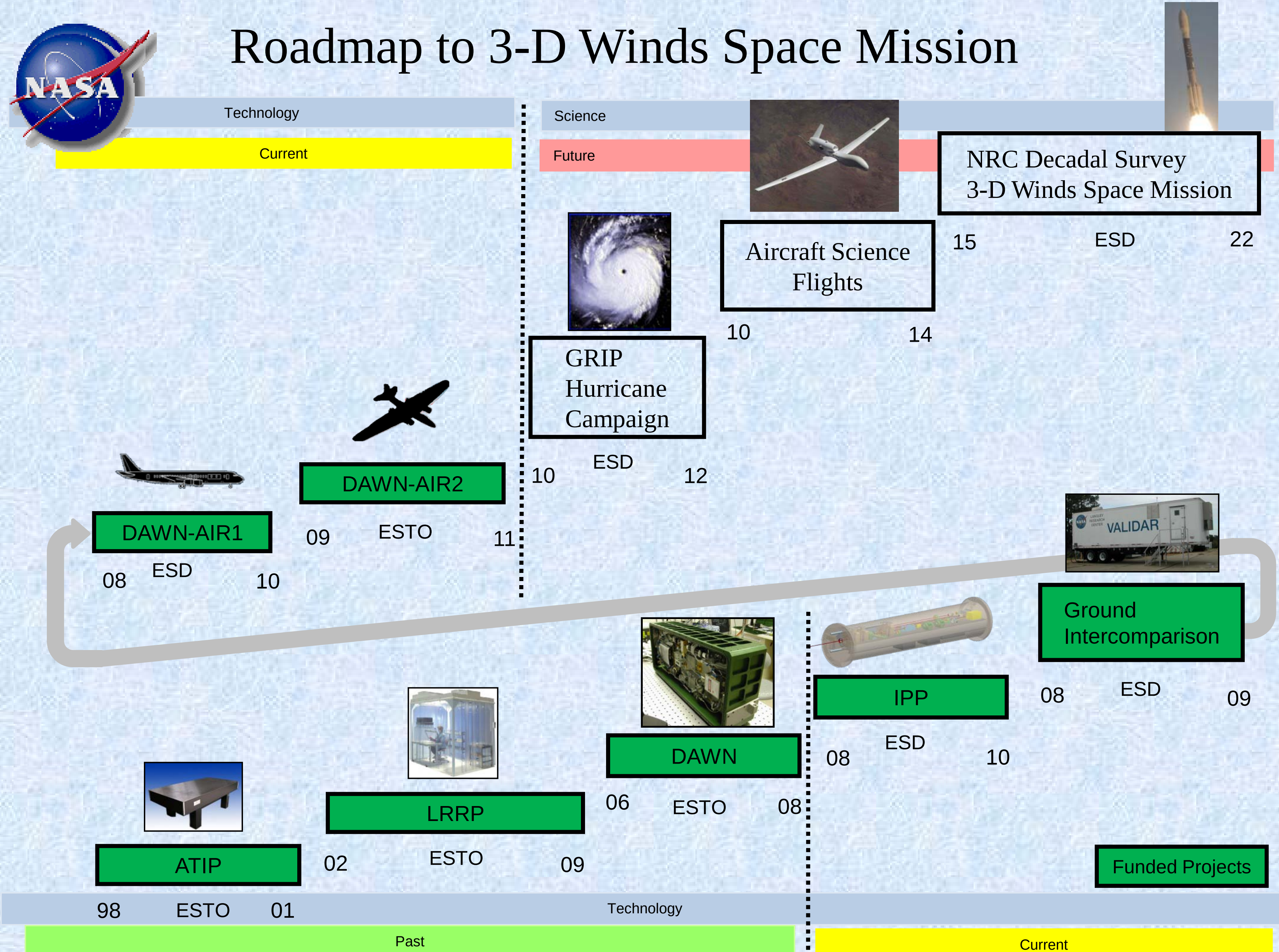


TABLE ES.2 Launch, Orbit, and Instrument Specifications for Missions Recommended to NASA

Decadal Survey Mission	Mission Description	Orbit[a]	Instruments	Rough Cost Estimate (FY 06 $million)
2010-2013				
CLARREO (NASA portion)	Solar and Earth radiation; spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally resolved interferometer	200
SMAP				
ICESat-II				
DESDynI				
2013-2016				
HyspIRI				
ASCENDS				
SWOT				
GEO-CAPE				
ACE				
2016-2020				
LIST				
PATH				
GRACE-II				
SCLP	Snow accumulation for freshwater availability	LEO, SSO	Ku- and X-band radars K- and Ka-band radiometers	500
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	600
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	650

Global Winds 9 Societal Benefits	
Extreme Weather Warnings	✓
Human Health	✓
Earthquake Early Warning	
Improved Weather Prediction	**✓#1**
Sea-Level Rise	
Climate Prediction	
Freshwater Availability	
Ecosystem Services	
Air Quality	✓




Roadmap to 3-D Winds Space Mission
Technology
Current
Science
Future
NRC Decadal Survey
3-D Winds Space Mission
15
ESD
22
Aircraft Science Flights
10
14
GRIP Hurricane Campaign
10
ESD
12
DAWN-AIR2
09
ESTO
11
DAWN-AIR1
08
ESD
10
VALIDAR
Ground Intercomparison
08
ESD
09
IPP
08
ESD
10
DAWN
06
ESTO
08
LRRP
02
ESTO
09
ATIP
98
ESTO
01
Funded Projects
Technology
Past
Current

Ground-Based Hybrid Wind Lidar Demo Winter 2009

- The LaRC mobile lidar is deployed as part of NASA HQ funded (ROSES-2007, Wind Lidar Science Proposal entitled "Intercomparison of Multiple Lidars for Wind Measurements (PI: Upendra Singh)
- Utilized NASA LaRC Compact DAWN Lidar Transceiver for 2-micron lidar
- Site at Howard University Research Campus in Beltsville, Maryland

2-μm Lidar Parameters

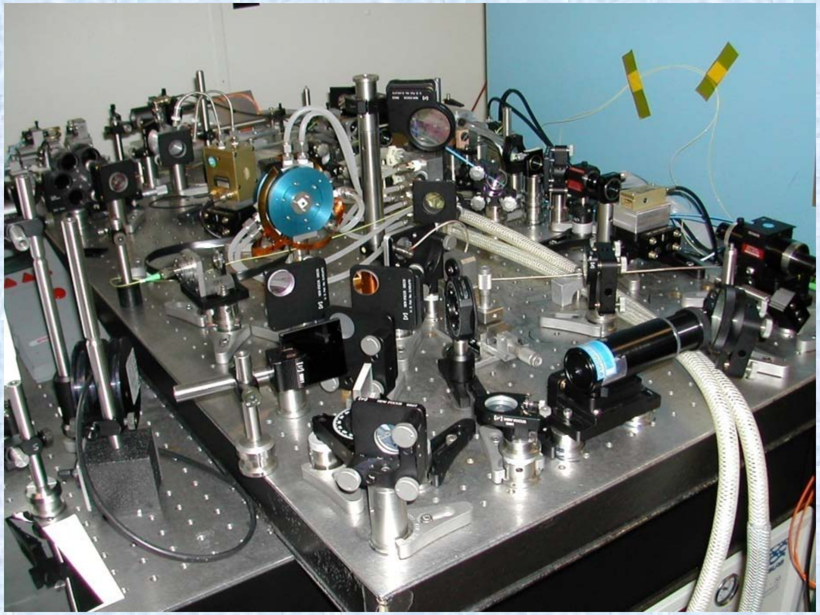
- Pulse energy = 250 mJ
- Pulse repetition rate = 5 Hz (upgrade soon to 10 Hz)
- Pulsewidth = 140 ns
- Telescope aperture = 15 cm
- Wavelength = 2053 nm (Ho:Tm:LuLiF)
- Data acquisition : 500 Ms/s, 8 bits, real-time processing
- Scan pattern: zenith view interleaved with 45-degree elevation cone
- Operations: run continuously up to 84 hours, unattended for long periods

DAWN Transceiver

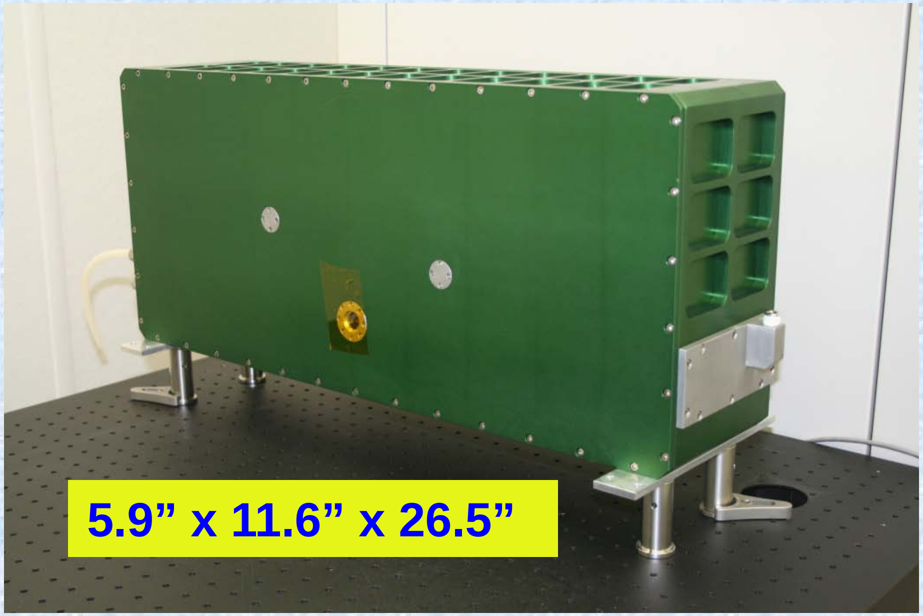
- Smaller
- More energy
- More robust

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

DAWN Transceiver (Transmitter + Receiver)
250 mJ/pulse, 5 pulses/sec.
5.9" x 11.6" x 26.5", 75 lbs.; 15 x 29 x 67 cm, 34 kg
(no telescope or scanner)



Previous implementation
90 mJ per pulse



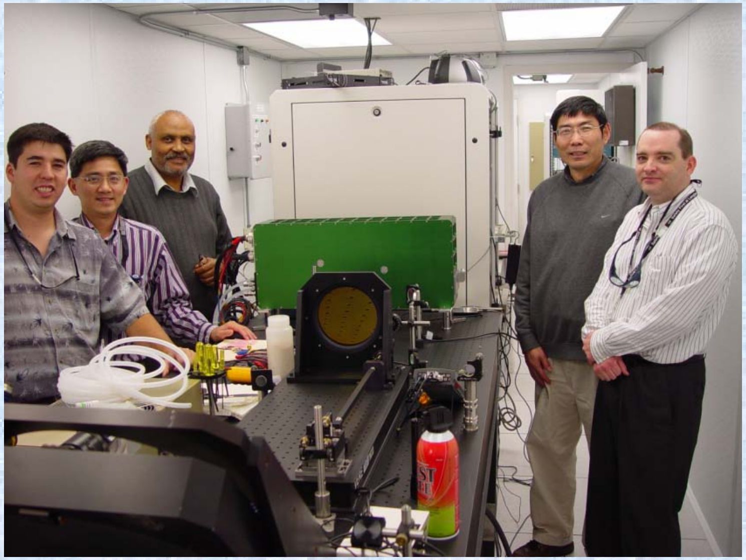
Completed DAWN package
Small, Robust, 250 mJ per pulse

DAWN Transceiver vs. Commercial Doppler Lidar

Commercial Doppler Lidar

2 microns, 2 mJ, 500 Hz, 10 cm telescope
111 x 85 x 102 H inches, > $1 M

LaRC DAWN



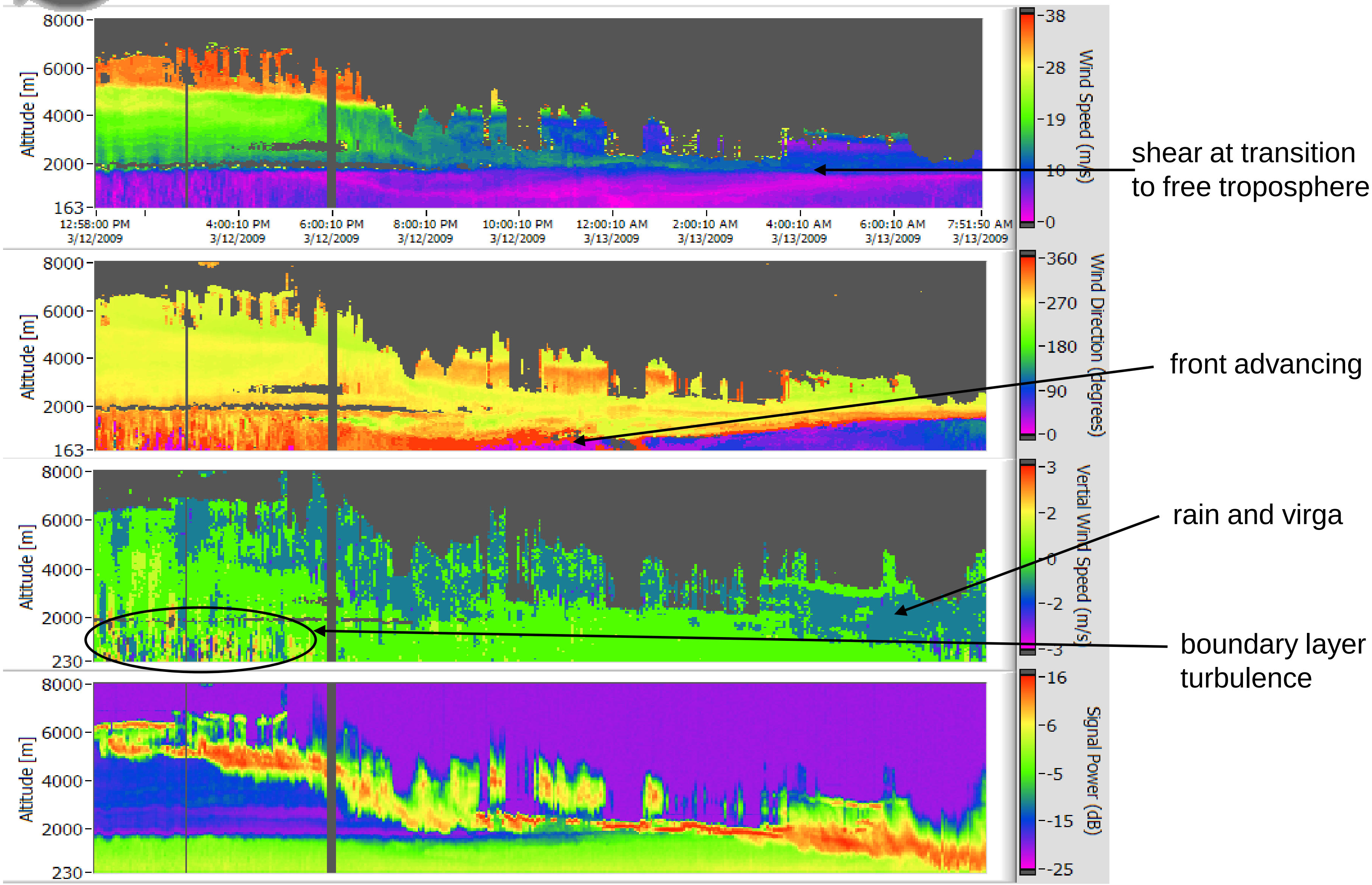
2 microns, 250 mJ, 5 Hz, 15 cm telescope
Transceiver: 6 x 12 x 27 inches, 75 lbs

DAWN vs. COTS Unit

Wind figure of merit = E x √PRF x D^2
Energy gain = x125
Energy-PRF gain = x13
Energy-PRF-diameter gain = x26
Either x26 in aerosol backscatter sensitivity or x5 in range

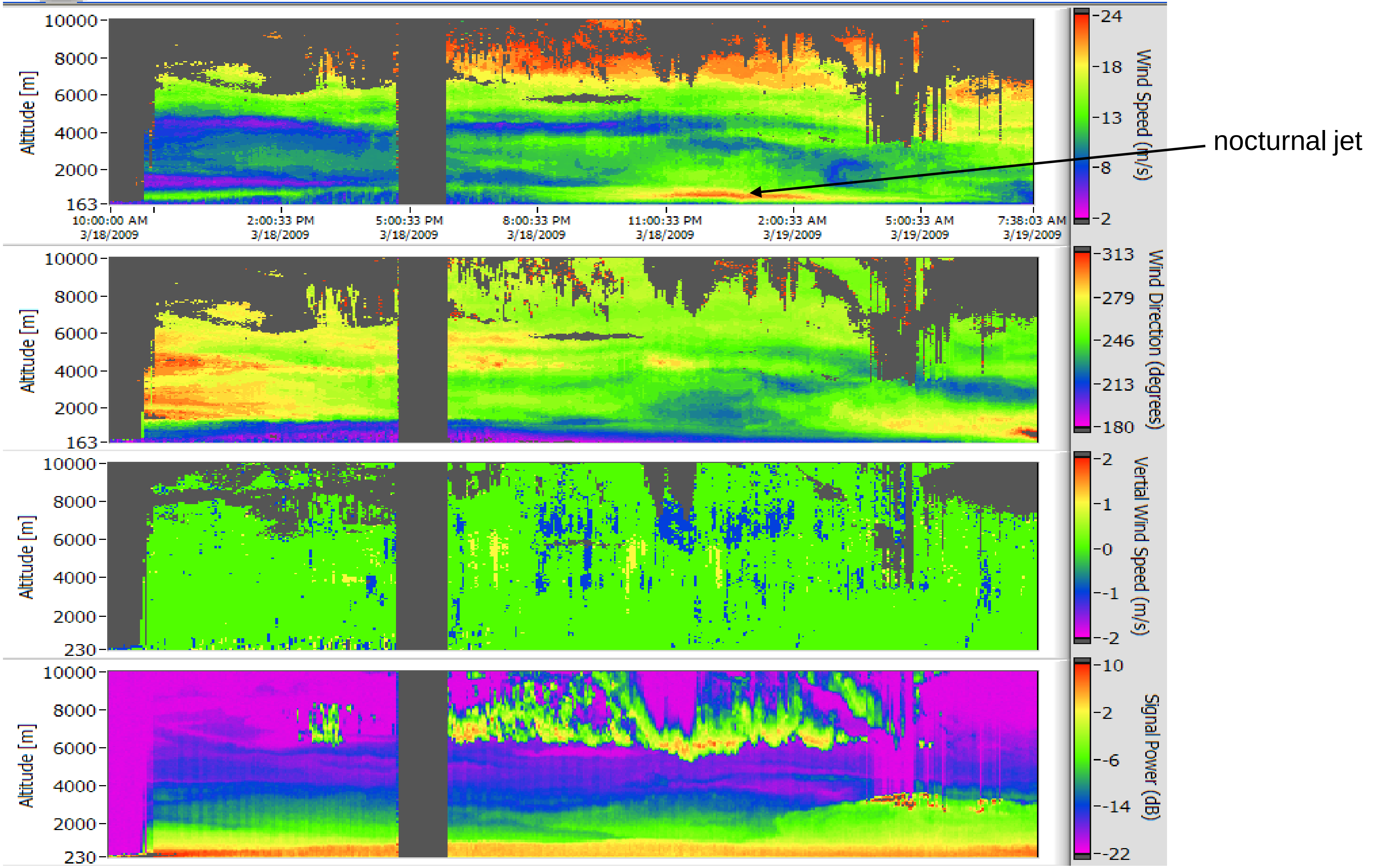
Sample Wind Measurement 1

(3 minutes per scan)



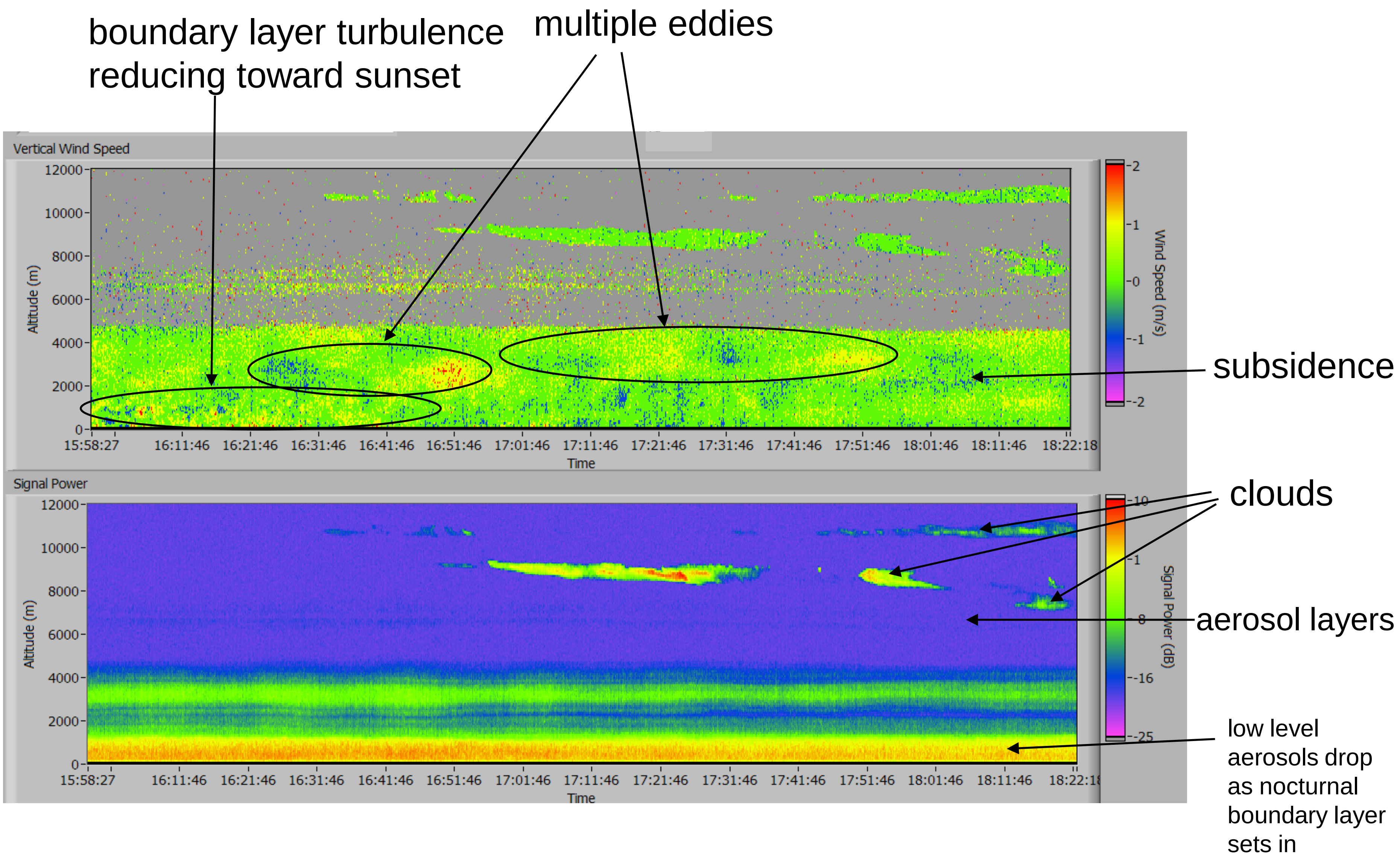
Sample Wind Measurement 2

(3 minutes per scan)

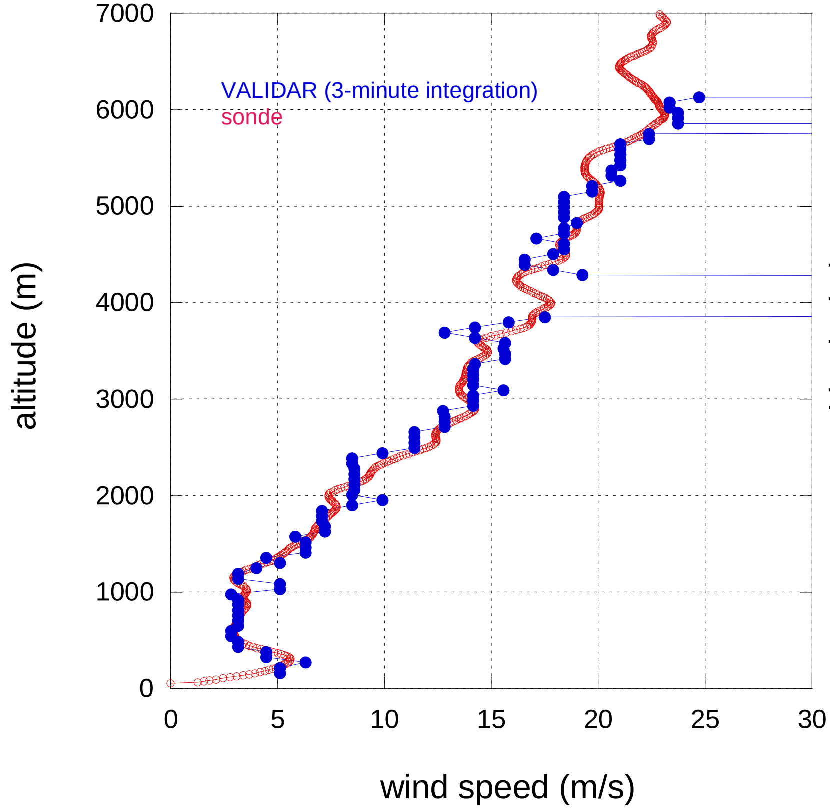


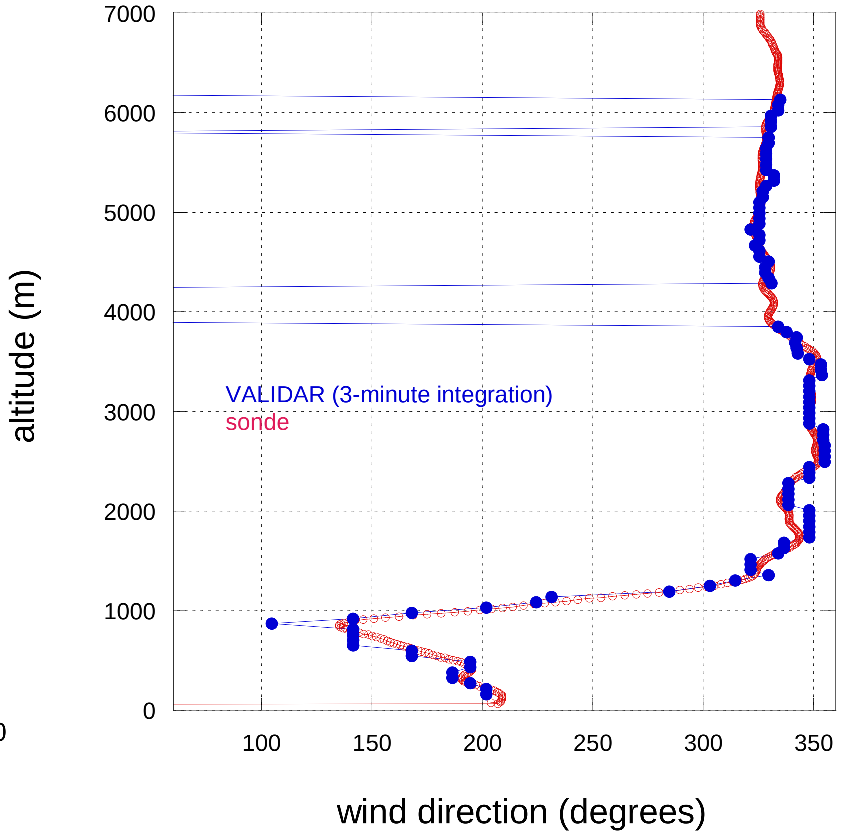
Sample Wind Measurement 3: Vertical Wind

(4 second integration)



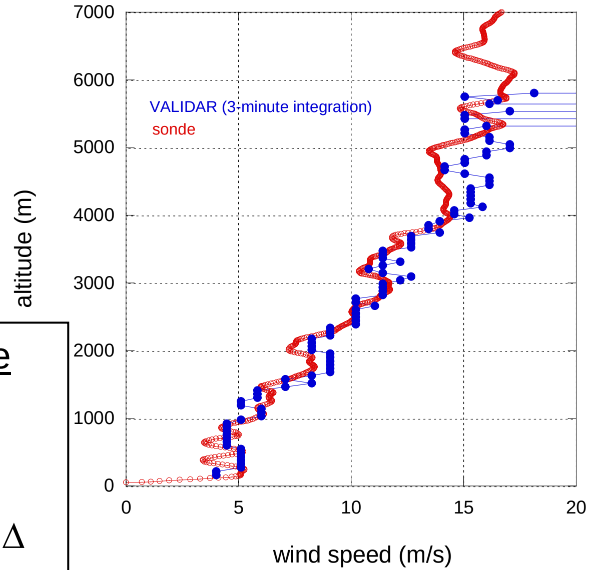
Coherent Lidar and Wind Sonde Comparison

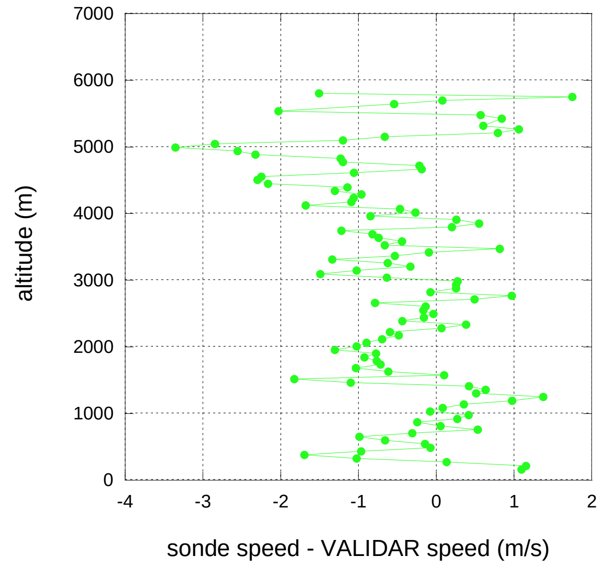




- Data taken March 17, 2009 at 22:03 local (March 18, 2009 2:03 UTC)
- Wind sondes are balloons carrying aloft a GPS receiver—the receiver radios back the balloon's position to determine the horizontal wind vector
- Lidar using 3-minute integration time. Jumps off the scale are due to "bad" points where wind is not being measured from low SNR.

Comparison of Coherent Lidar and Sonde

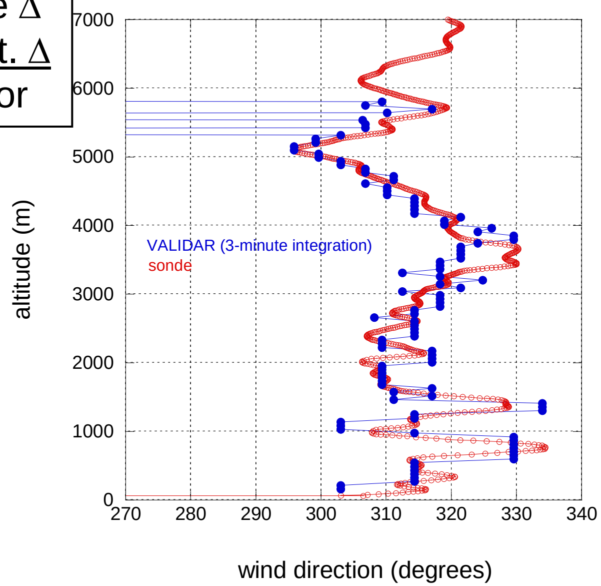


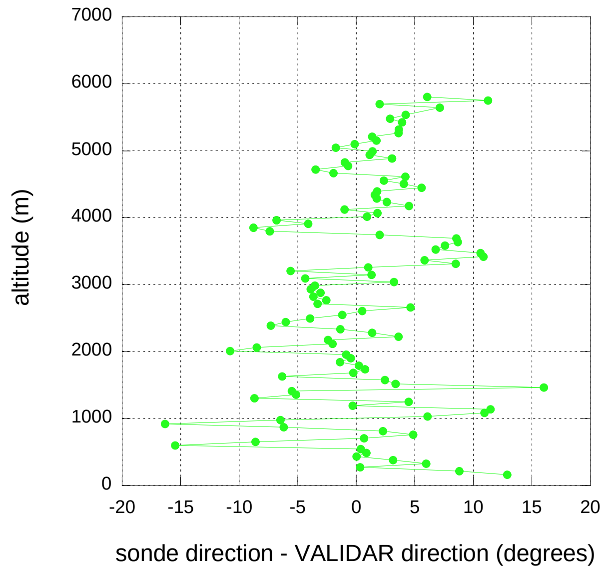


- Root-mean-square of difference between two sensors for all points shown = **<u>1.06 m/s</u>**

Error Tree

Lidar
+Sonde
+Location Δ
+Time Δ
+M Volume Δ
+M Time Int. Δ
=Total Error





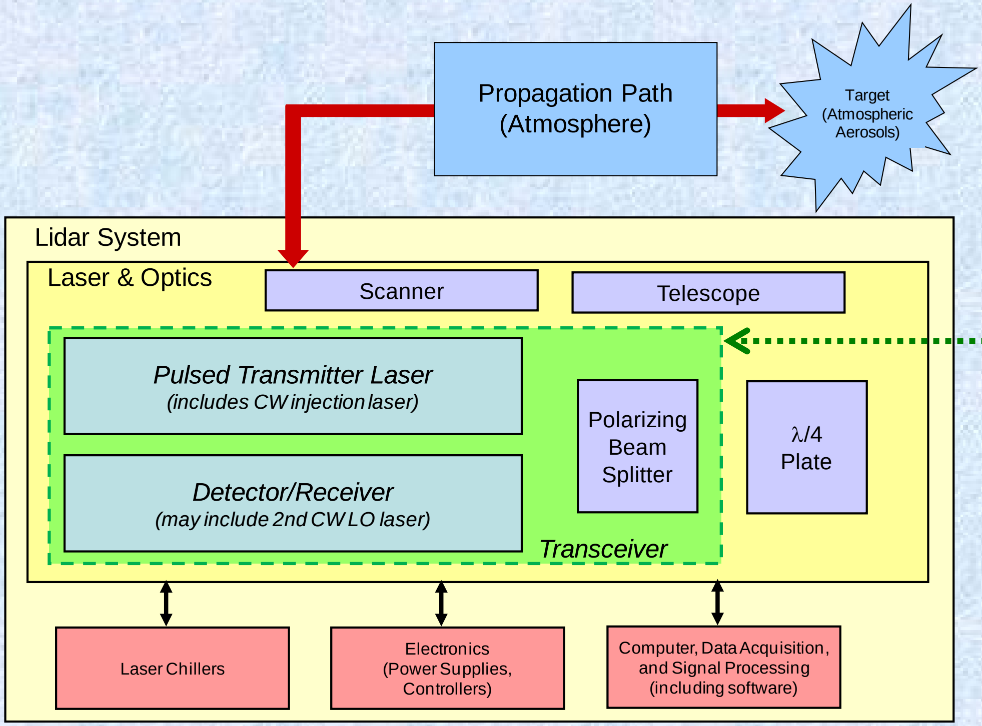
- Root-mean-square of difference between two sensors for all points shown = **<u>5.78 deg</u>**

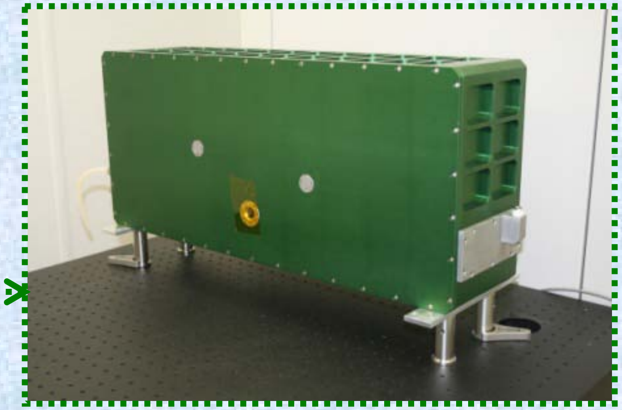
Current Work in Progress

- DAWN-AIR1: Utilize DAWN Transceiver to develop a complete Doppler lidar system for the DC-8 airplane
- No flights included
- DAWN-AIR2: Utilize DAWN-AIR1 hardware and convert to autonomous operation on the DC-8 airplane
- Upgrade hardware to autonomous operation
- Demonstration flights under GRIP Mission

DAWN-AIR1 Approach

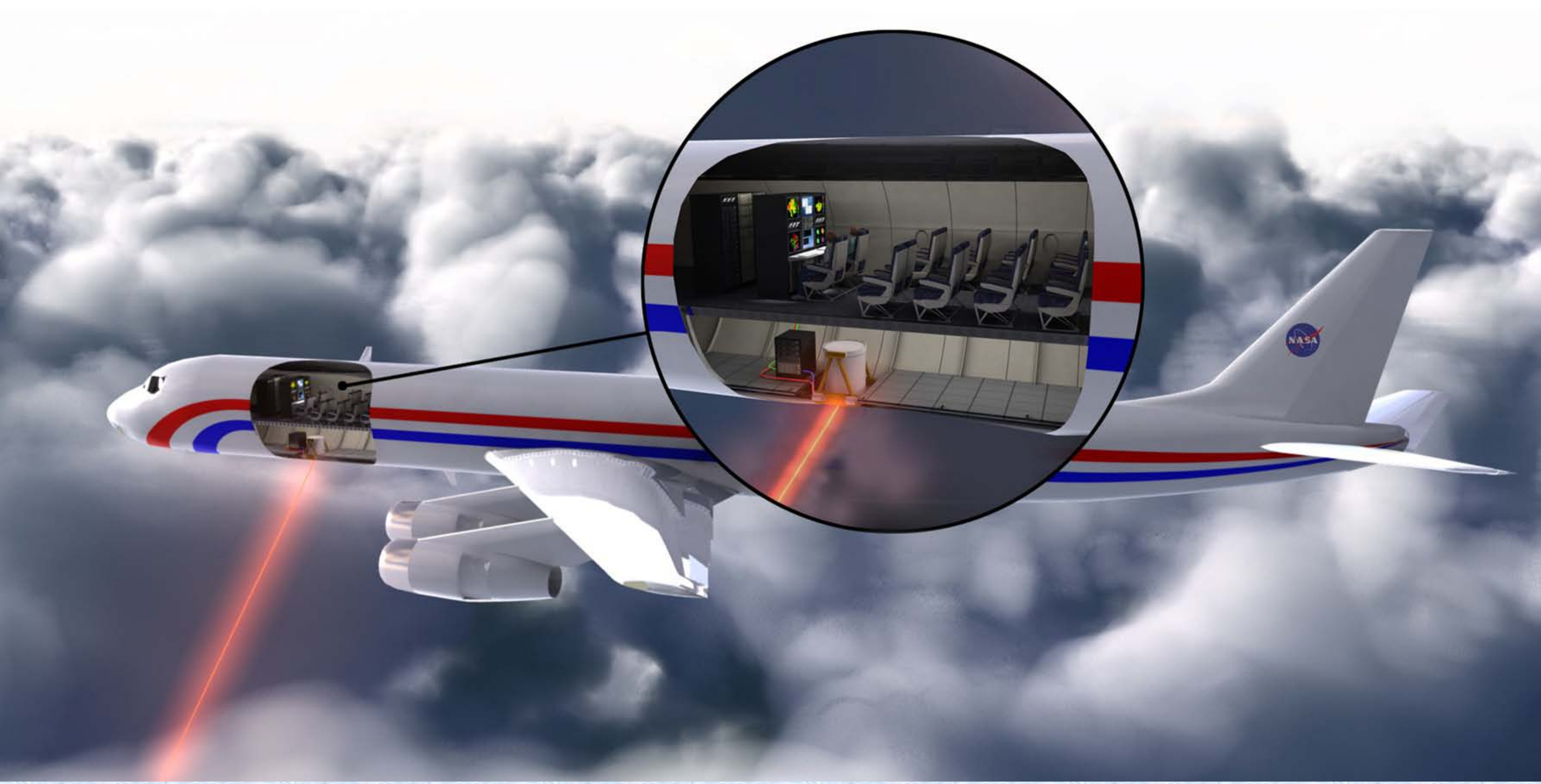
1. Add telescope and scanner to DAWN
2. Ruggedize electronics for DC-8





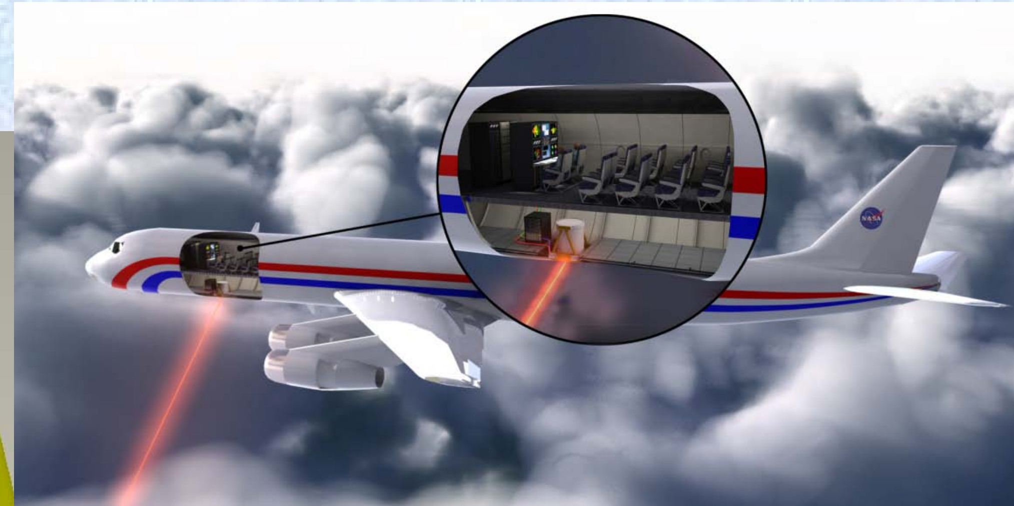
DAWN Transceiver (Transmitter + Receiver)
250 mJ/pulse, 10 pulses/sec.
5.9” x 11.6” x 26.5”, 75 lbs.; 15 x 29 x 67 cm, 34 kg
(no telescope or scanner)

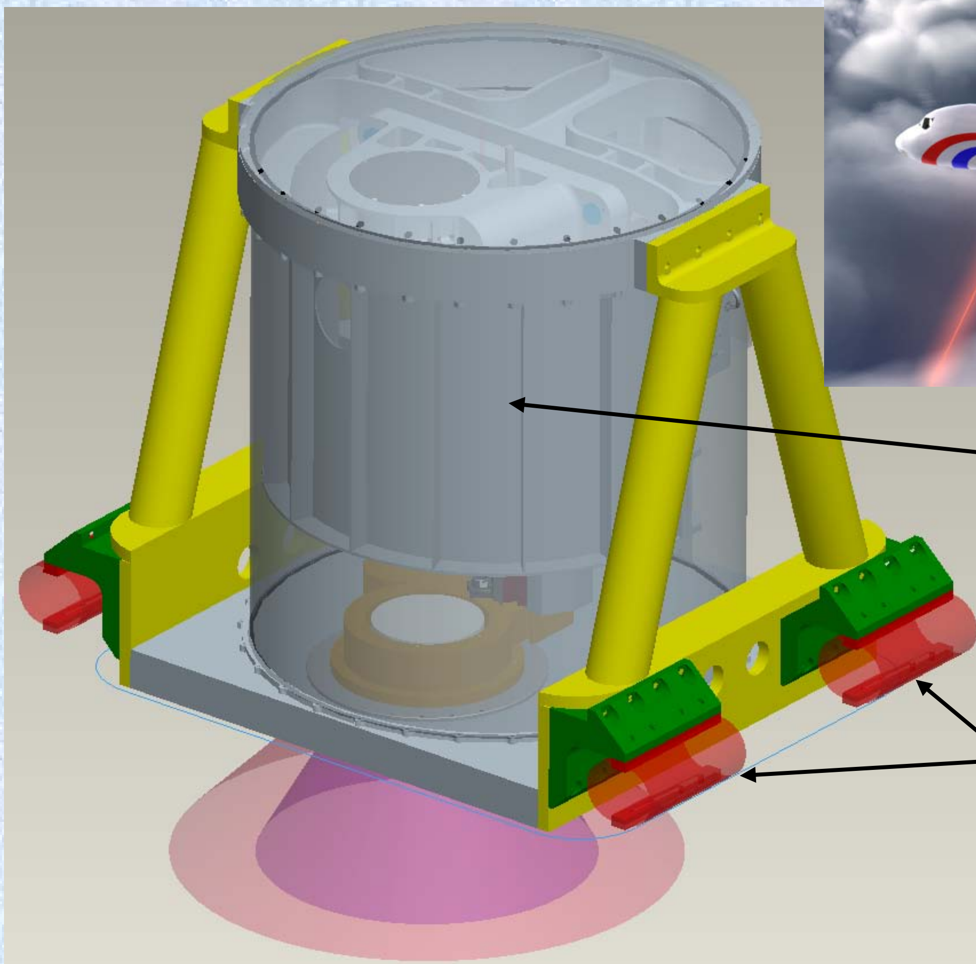
DAWN-AIR 1
Artist Concept



- 30 deg nadir angle
- Any azimuth angle

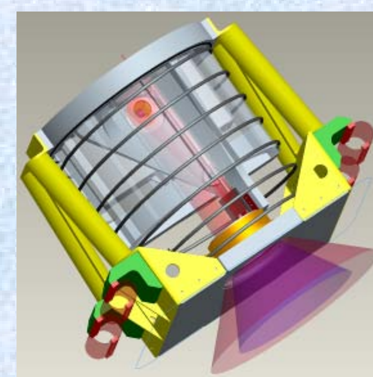
DAWN-AIR1





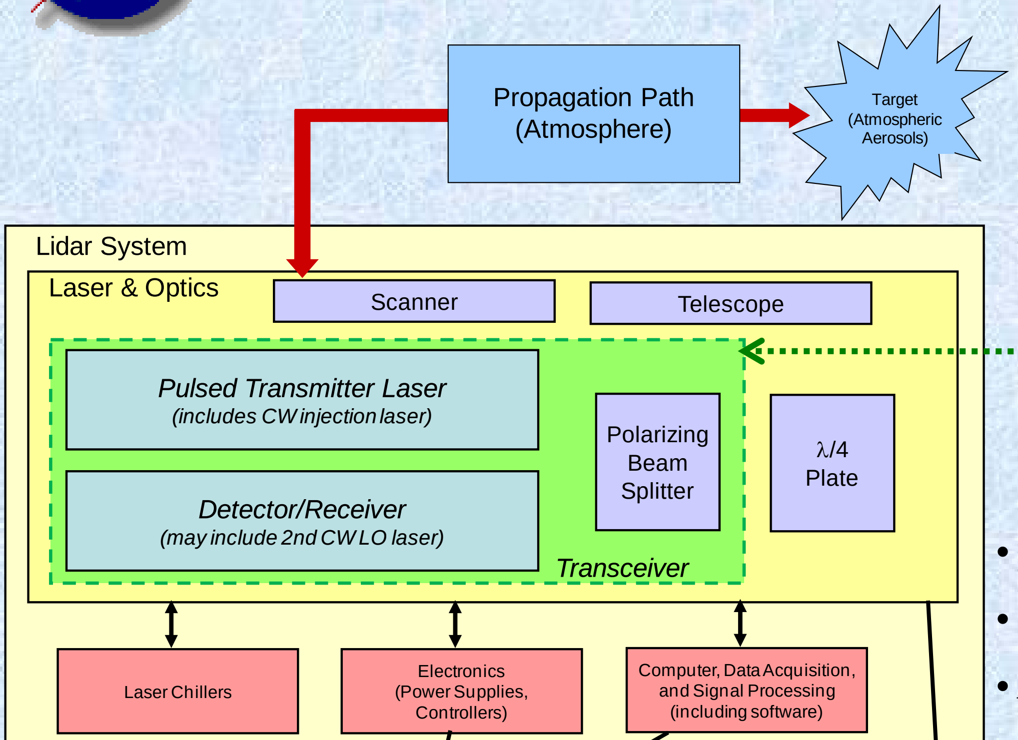
Lidar Sealed Enclosure
Contains:
DAWN Transceiver
Telescope
Scanner & Wedge

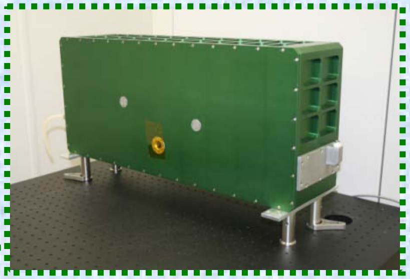
Vibration Isolation



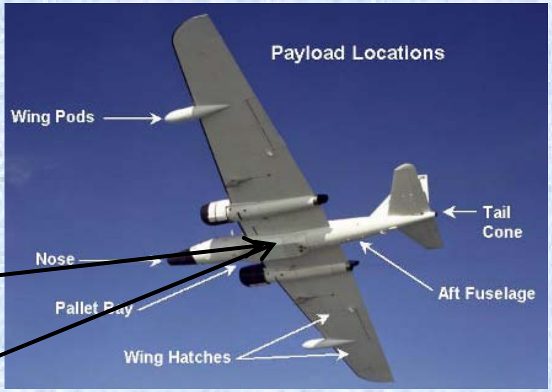
As shown with both the 30deg and 45deg cone

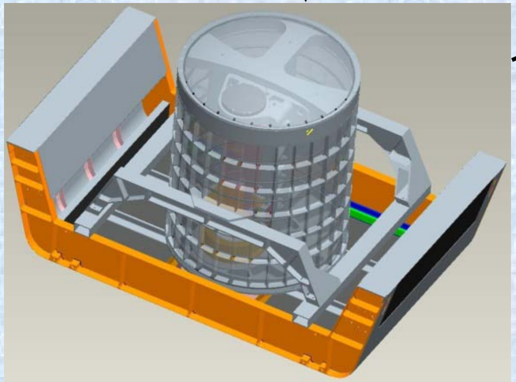
DAWN-AIR2 Approach





- 2 3-ft pallets
- 45 deg nadir angle
- Any azimuth angle





Conclusions

- A newly developed 2-micron lidar wind transceiver was deployed during a ground-based wind lidar comparison of Coherent and direct detection wind measurement campaign
- Coherent detection measurements intercomparison with ballon sonde shows an excellent agreement (RMS difference of 1.06 m/sec and 5.78 degrees in wind speed and direction, respectively) up to 6 km of altitude with 3-minute averaging
- Intercomparison with other sensors on the site are underway
- DAWN transceiver are being packaged for two aircraft campaign on a DC-8, one of them being autonomous