Coherent Doppler Lidar for Wind Measurements on Venus

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Outline

Coherent Doppler Wind Lidar for Venus

1. **Objectives and Approach**
2. **Proposed Lidar Instrument and Performance Simulation for Venus**

Coherent Doppler Wind Lidar Technology Development at NASA Langley Research Center for Space-based Observations

1. **Hardware Development**
2. **Hardware Demonstration**
3. **Measurement Technique Demonstration**
4. **NASA GRIP Hurricane Study Field Campaign on DC-8**

Need for Doppler Wind Measurements on Venus

- Global superrotation is a puzzle
- Keys to understanding the circulation are spatially distributed measurements at the same vertical level to enable estimates of eddy and mean contributions to transport of angular momentum meridionally
- Cloud motions provide only day side winds with high spatial resolution
- Night side cloud tracking measurements refer to a different level
- Hence the true zonal average circulation is not well known

Objectives

- Obtain direct measurement of Venus winds within the upper cloud layer and the overlying aerosol (haze) layer
- Obtain directly measured heights of cloud tops and their optical depths
- Obtain aerosol concentration and distribution within the upper haze layer

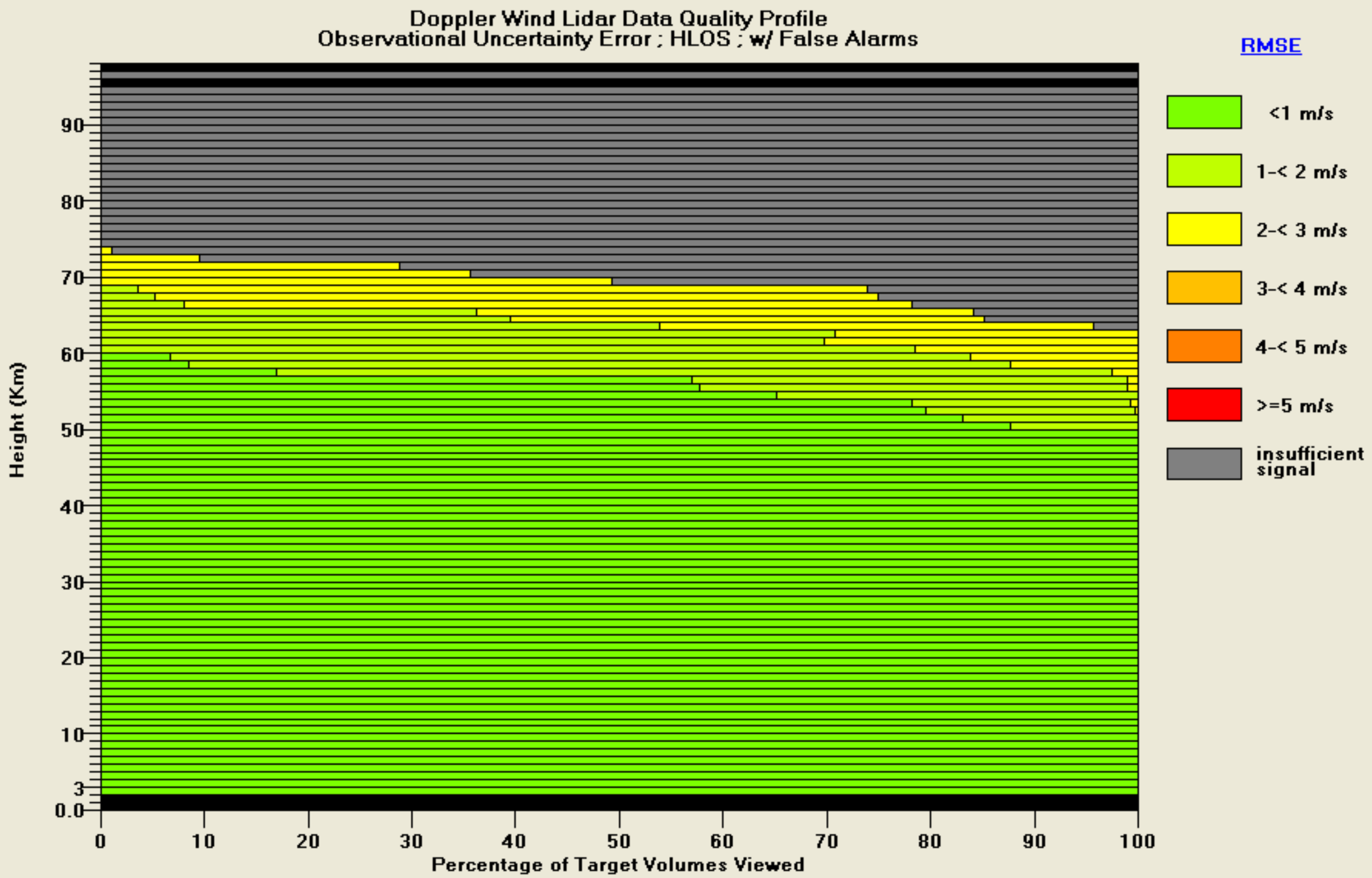
Proposed Approach

- The thick uniform cloud cover (1 micron radius and sub-micron sized haze particles in polar latitudes) should enable good Doppler measurements and provide height resolved results of atmospheric motions
- Use an orbiting Doppler lidar to obtain u,v,w components of the winds (clouds and aerosols permitting).
- Design instrument for 1km vertical resolution and 200 km horizontal spacing of profiles; enable on-orbit changes to integration and sampling strategies.
- Operate full or partial orbits depending upon platform power availability

Initial Considerations

- Build upon the NASA funded Mars Lidar Simulation Model (MLSM) developed by Simpson Weather Associates.
- Modify as needed to represent Venus conditions; preference is to use a community Venus weather model.
- Assume similarities in cloud reflectance at 2 μm and spherical particles in the haze layer.

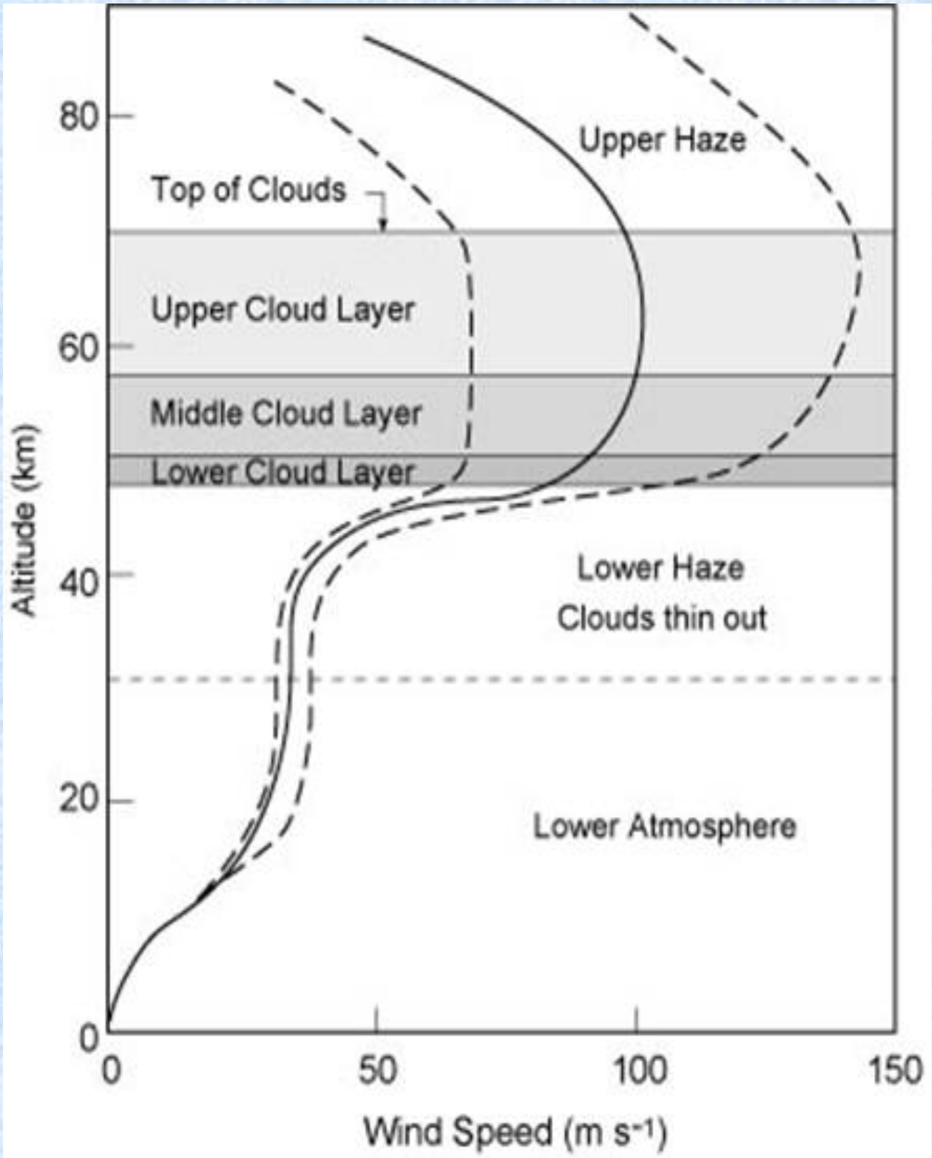
Doppler Wind Lidar Profile Simulation on Mars (Example)



RUN: MCD Ls=0 deg 2001Z (2 hr sim.) Global
ALTITUDE: 400 Km ORBIT INC: 98 deg
TARGET ATM.: median Backscatter, R= 0.30, constant Q
ELEVATED DUST: user defined R = 0.00 um

DETECTION: DWL SCAN: 4 pt. Step/Stare
WAVELENGTH: 2.053472 um NADIR: 45. deg
ENERGY: 0.25 J APERTURE: 0.5 m PLT PWR: 63 W
PRF: 10. Hz ACCUM. TIME: 25 s BETA THR.: 50.%

Target Region for VenWinds



VenWinds Instrument

Wavelength (μm)	2.0	
Energy per pulse (mJ)	1	
Pulse length (nsec)	180	
PRF (Hz)	500	
Optical output (watts)	.5	
Wallplug power (watts)	10	Includes cooling but not data collection/ transmission
Telescope diameter (cm)	10	
Scanner (step stare 4 azimuth angles plus 1 nadir)		Other beam director options can be considered
Nadir scanning angle (degrees)	20	Can be varied.
Dwell time (seconds)	10	This would result in 5000 samples being integrated for one LOS wind component.
Sample volume diameter (m)	.1	
Sample volume length; range gate (m)	1100	The number of pulse lengths in this volume
Beta50 (msr-1)	6.4*10-7	Backscatter for Venus clouds ~ 1.0*10-5
Weight (kg)	15 -50	Depends upon effort to light weight current technology
Dimensions (l x w x h)	TBD	

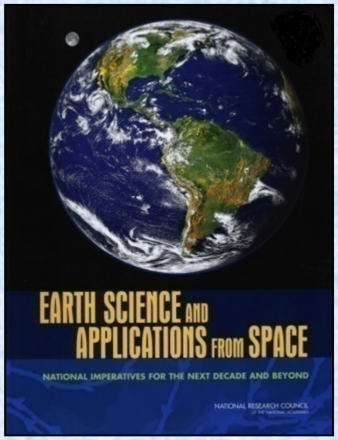
VenWinds Data

Height resolution(m) (average wind in layer)	1000	
Horizontal spacing between wind profiles (u,v,w) (km)	200	This can be changed to be as small as 25km with no sacrifice on accuracy, just sensitivity.
LOS velocity precision (m/s)	< 1	
Maximum horizontal wind (m/s)	200	
Aerosol profiles (m) (layer average during scan)	1000	Each LOS observation yields a wind speed, turbulence estimate (TKE) and signal intensity
Number of profiles per orbit	100 - 1000	Varies with integration time
Vertical coverage	TBD	Minimum of cloud top speeds and heights
Range resolution to cloud top (m)	~ 100 meters	

Summary

- NASA Langley Research Center is the world leader in developing pulsed 2-micron coherent Doppler/DIAL/backscatter lidar for space remote sensing of Earth's atmosphere and have successfully developed and matured the DWL technologies and techniques
- These technologies can be customized and matured for Venus through leveraging the knowledge and knowhow acquired by the LaRC team in last two decades
- Simpson Weather Associates and NASA LaRC have jointly developed a Mars Lidar Simulation Model to test DWL concepts for a Mars mission and it can be used for Venus wind simulation
- Based upon general available information regarding the atmosphere of Venus, a small Doppler Wind Lidar (DWL) could provide wind, cloud and aerosol information from an orbit of several 100 kms above the surface of Venus.
- Issues of power, weight, volume need to be addressed to identify the tall poles in this proposed instrument.

Decadal Survey 3D-Winds Mission



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

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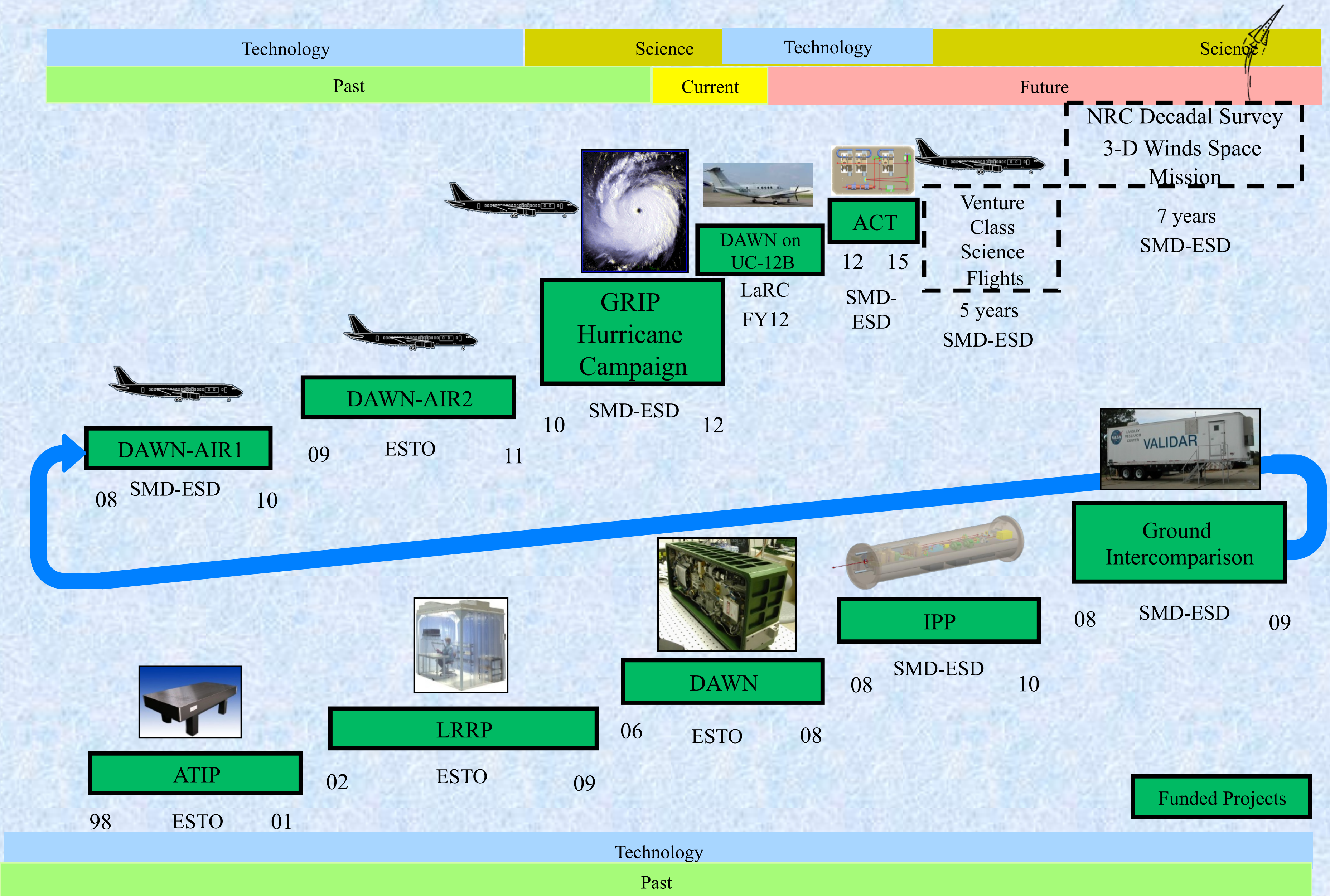
TABLE ES.2 Launch, Orbit, and Instrument Specifications for Missions Recommended to NASA

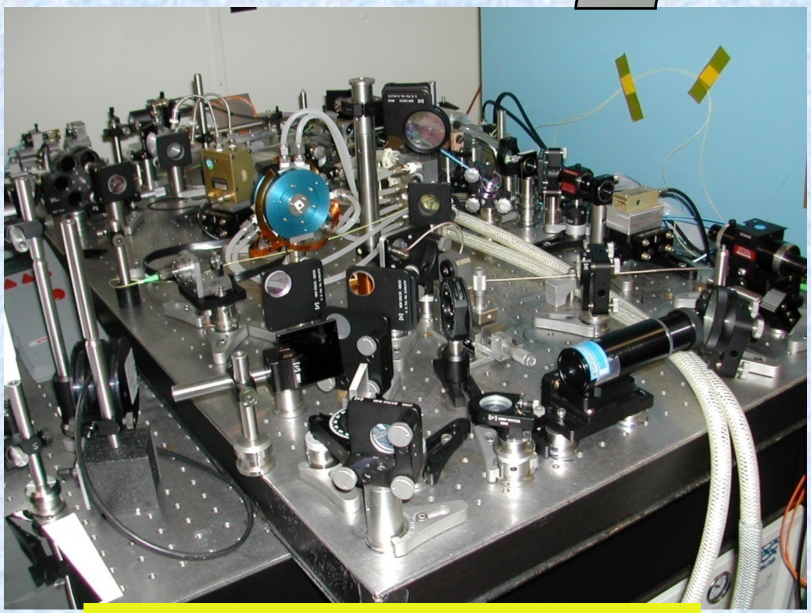
Decadal Survey Mission	Mission Description	Orbit[a]	Instruments	Rough Cost Estimate (FY 06 $million)
2010-2013				
CLARREO (NASA portion)	Solar and Earth radiation; spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally resolved interferometer	200
SMAP	Soil moisture and freeze-thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	300
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter	300
DESDynI	Surface and ice sheet deforma… understanding natural hazards… vegetation structure for ecosy…			
2013-2016				
HyspIRI	Land surface composition for … mineral characterization; vege… ecosystem health			
ASCENDS	Day/night, all-latitude, all-seas… integrals for climate emissions			
SWOT	Ocean, lake, and river water le… and inland water dynamics			
GEO-CAPE	Atmospheric gas columns for … forecasts; ocean color for coast… health and climate emissions			
ACE	Aerosol and cloud profiles for … water cycle; ocean color for op… biogeochemistry			
2016-2020				
LIST	Land surface topography for l… and water runoff			
PATH	High-frequency, all-weather te… humidity soundings for weath… and sea-surface temperature[b]			
GRACE-II	High-temporal-resolution grav… tracking large-scale water mo…			
SCLP	Snow accumulation for freshw…			
GACM	Ozone and related gases for i… air quality and stratospheric o… prediction			
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	650

Winds & Decadal Survey's 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 at NASA Langley

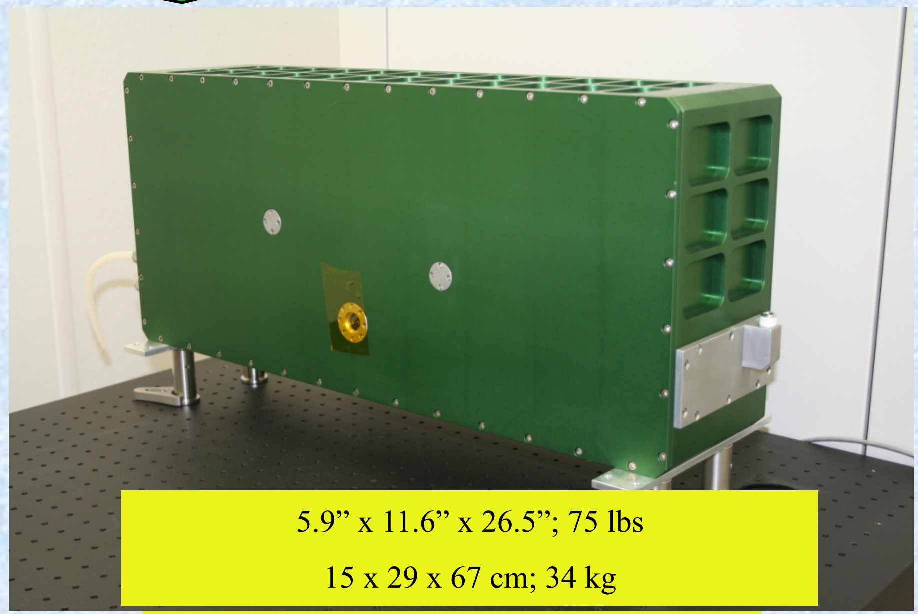


Lidar Transceiver (Transmitter + Receiver) Development at LaRC



Previous implementation

90 mJ per pulse



5.9" x 11.6" x 26.5"; 75 lbs

15 x 29 x 67 cm; 34 kg

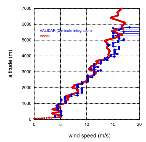
Completed DAWN package

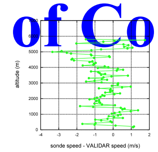
Small, Robust, 250 mJ per pulse, 10 Hz

Also, separately:

- LaRC has previously demonstrated a world record 1200 mJ of pulse energy at 2 Hz (12/05)
- LaRC has demonstrated fully conductively cooled oscillator/amplifier to 400 mJ, 5 Hz (08/07)
- Simulations of the Decadal Survey winds space mission with a hybrid lidar indicate a coherent lidar requirement of 250 mJ pulse energy at 5 Hz

Comparison of Coherent Lidar and Sonde

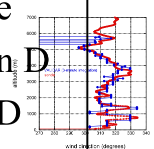


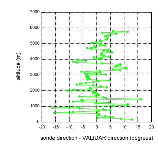


- Root-mean-square of difference between two sensors for all points shown = **1.06 m/s**

Error Tree

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



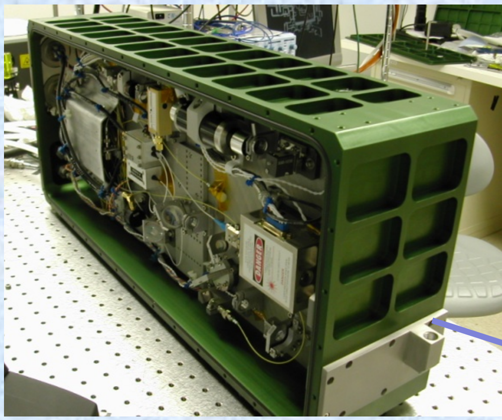


- Root-mean-square of difference between two sensors for all points shown = **5.78 deg**

Genesis and Rapid Intensification Process (GRIP) Campaign

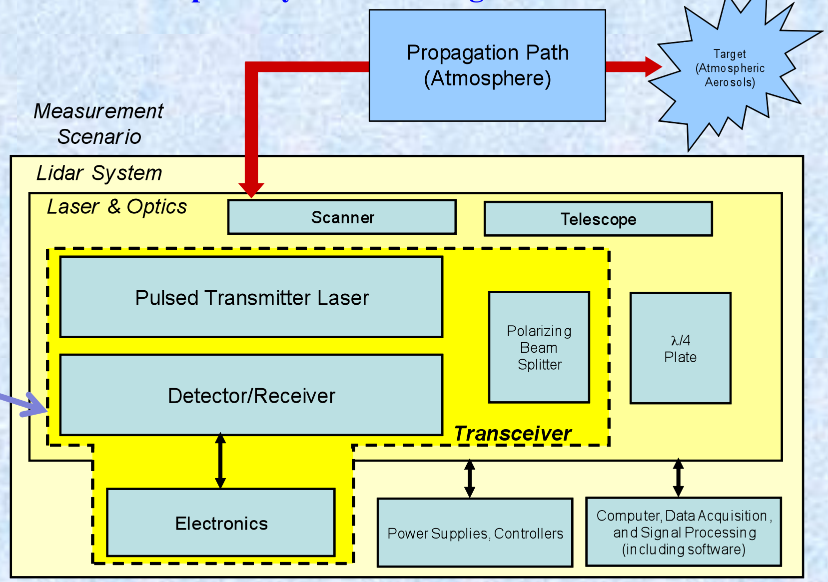
Coherent Pulsed Doppler Wind Profiling Lidar System

1. World's Most Capable Transceiver Packaged, Compact, Robust



- 0.25 J pulse energy, 10 Hz PRF
- 15 cm receiver optical diameter, 34 kg (75 lbs.)
- 15.2 x 29.5 x 67.3 cm (6 x 11.6 x 26.5 inches)

2. Complete System Utilizing Transceiver



3. Ground-based Wind Measurement Performance

RMS wind difference from balloon sonde, 0 – 6 km altitude, = 1.1 m/s and 5.8°

No alignment needed after interstate travel in trailer

Overnight unattended operation

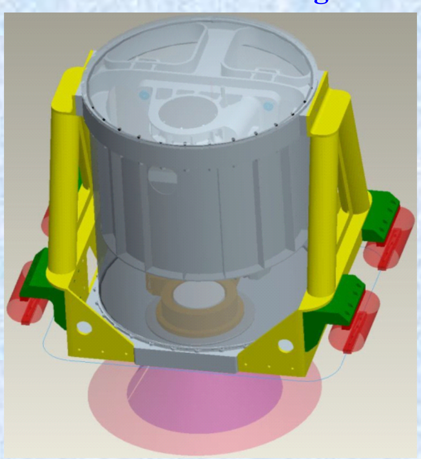
Vertical winds to 11 km altitude

Horizontal vector winds to 7 km altitude

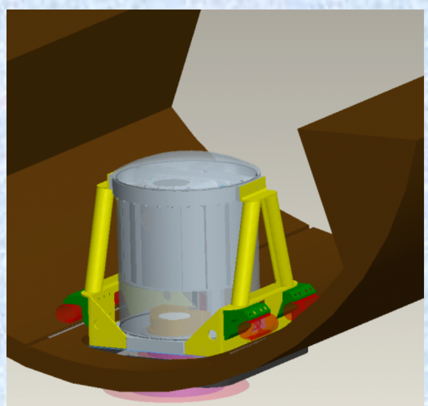
Data processing choice of multiple values of vertical and horizontal resolution

Same technology as anticipated space mission

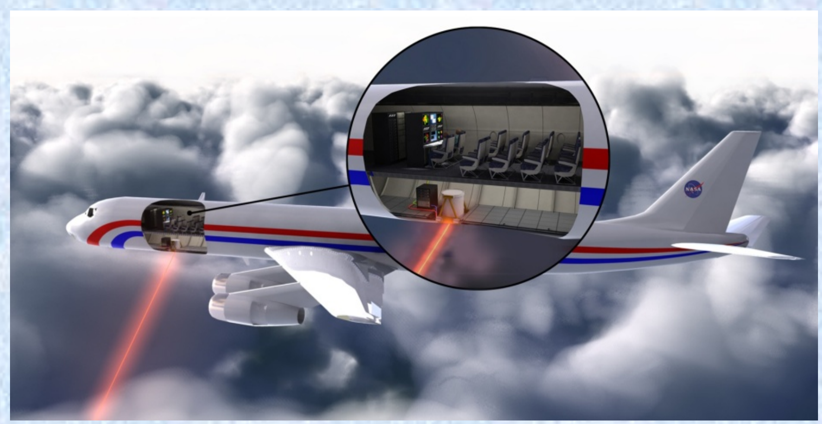
4. Enclosure for All Lidar Optics Robust Aircraft Design



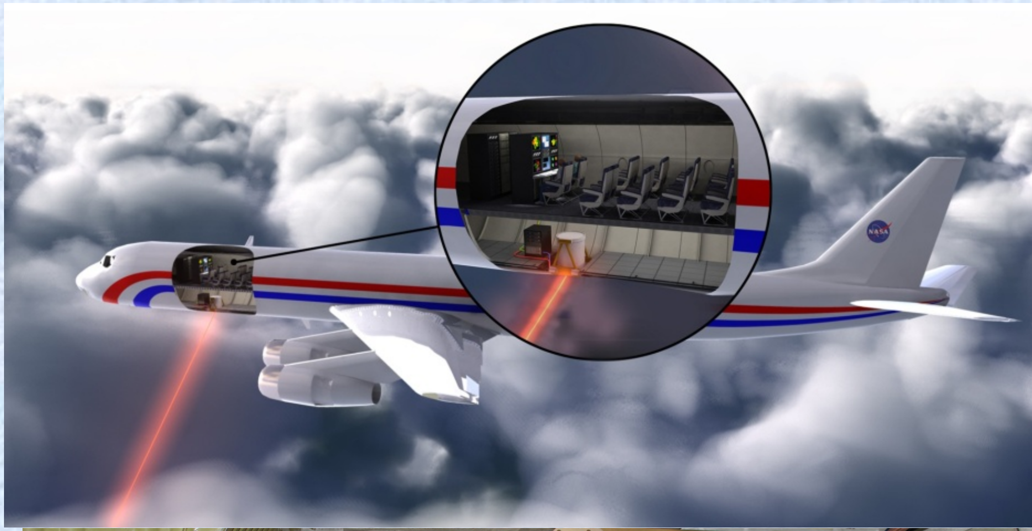
5. Optics in DC-8

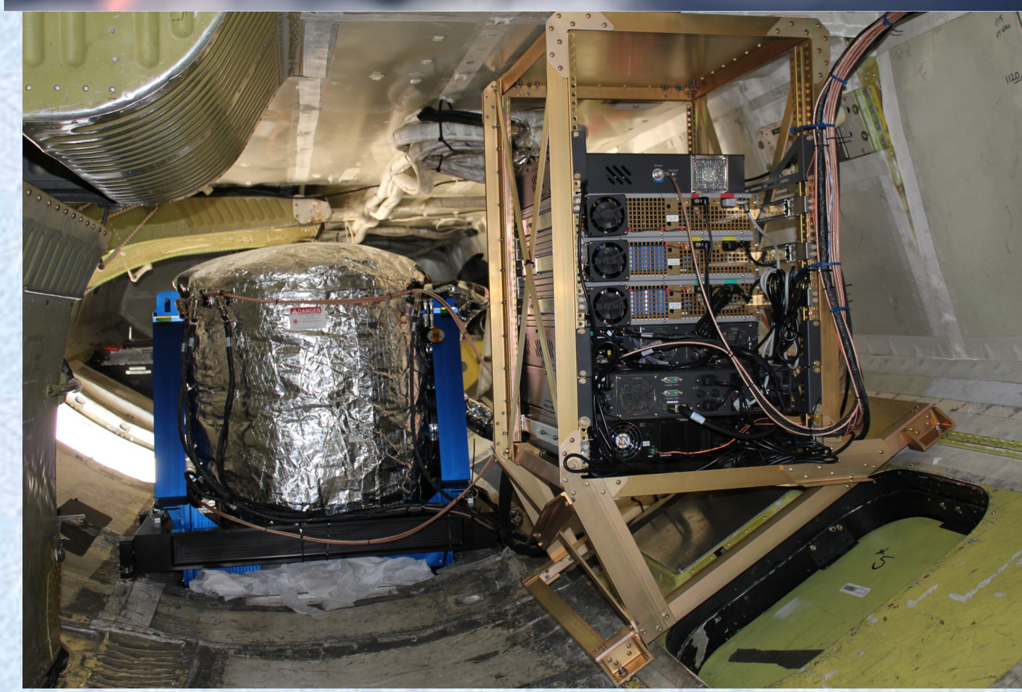


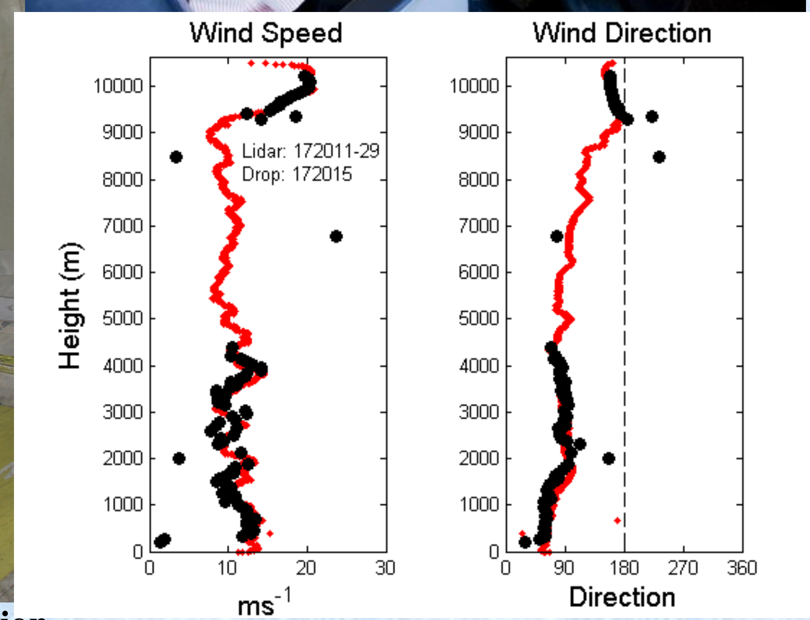
6. Lidar System in DC-8



NASA Langley DC-8 Wind Lidar During GRIP (2010)

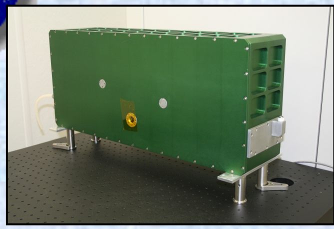




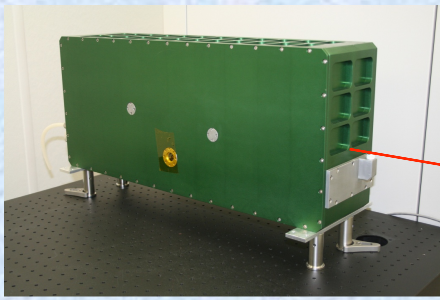


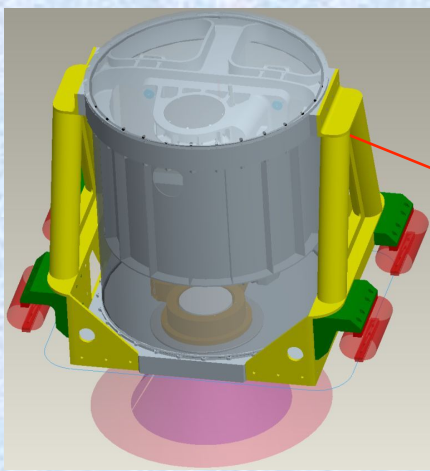
Ho:Tm:LuLiF, 2.05 micron, 250 mJ, 10 Hz, 15 cm, coherent-detection

Genesis and Rapid Intensification Process (GRIP) Campaign



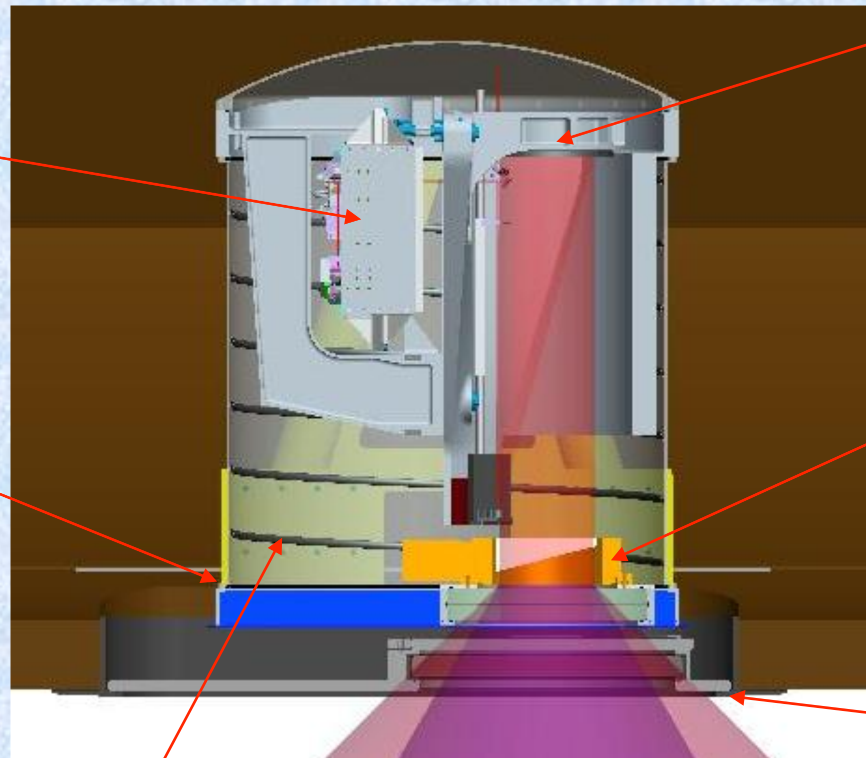
DAWN Lidar System Development for the DC-8



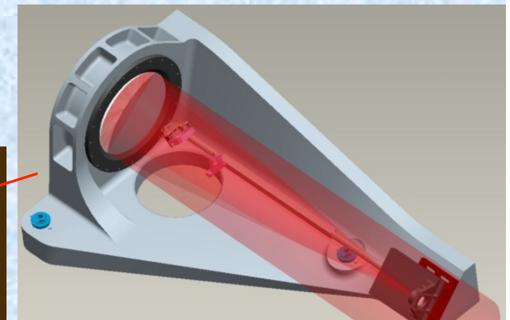


29” x 36” x <37” Tall

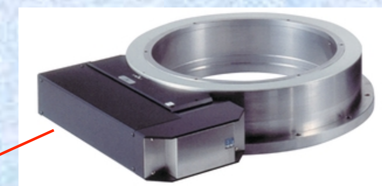
Sealed Enclosure & Integrated Lidar Structure



3/8” Cooling Tube

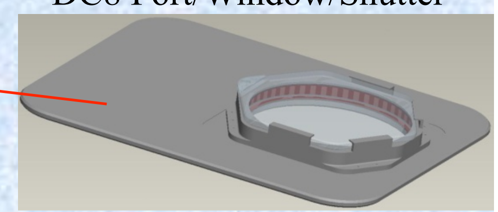


Telescope



Newport Scanner (RV240CC-F)

DC8 Port/Window/Shutter



Electronics, Computer HW & SW, Data Acquisition HW & SW