Lidar Measurements of Wind and Cloud around Venus from an Orbiting or Floating/Flying Platform

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Venus Science Priorities for Laboratory Measurements and Instrument Definition Workshop
April 7–8, 2015
Hampton, Virginia

Outline

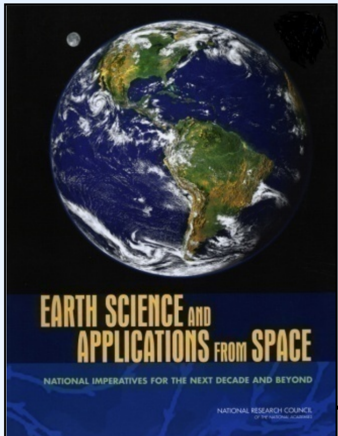
Coherent Doppler Wind Lidar Technology Development at NASA Langley Research Center for Space-based Observations

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

Coherent Doppler Wind Lidar for Venus

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

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

NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES

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Washington, D.C.
www.nap.edu

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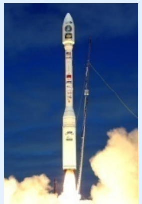
TABLE ES.2 Launch, Orbit, and Instrument Specifications for Missions Recommended to NASA

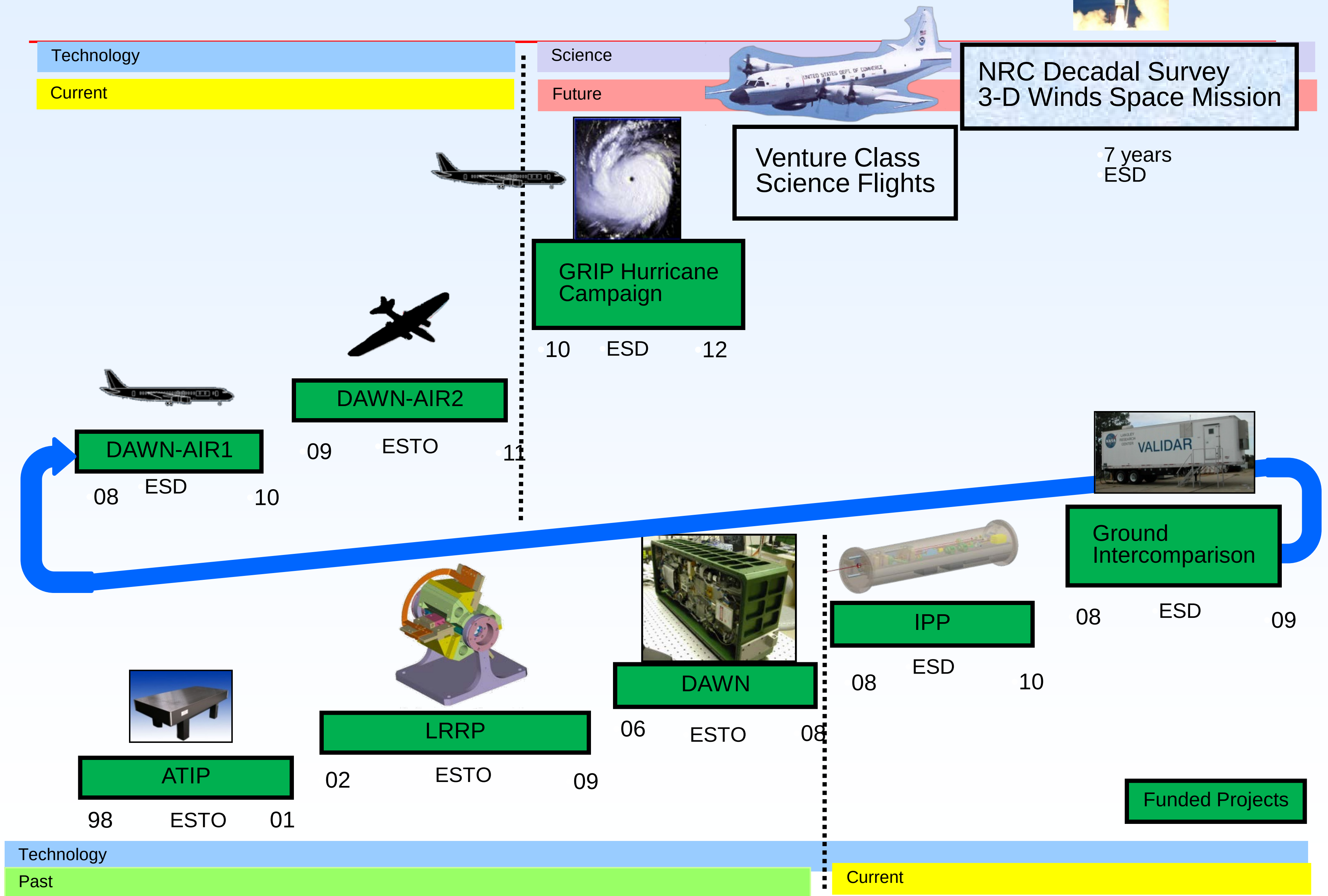
Decadal Survey Mission	Mission Description	Orbit[a]	Instruments	Rough Cost Estimate (FY 06 $million)
2010-2013				
CLARREO (NASA portion)	Solar and Earth radiation; spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally resolved interferometer	200
SMAP	Soil 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 shee… understanding natu… vegetation structure…			
2013-2016				
HyspIRI	Land surface compo… mineral characteriza… ecosystem health			
ASCENDS	Day/night, all-latitud… integrals for climate…			
SWOT	Ocean, lake, and rive… and inland water dy…			
GEO-CAPE	Atmospheric gas col… forecasts; ocean colo… health and climate e…			
ACE	Aerosol and cloud p… water cycle; ocean c… biogeochemistry			
2016-2020				
LIST	Land surface topogr… and water runoff			
PATH	High-frequency, all-w… humidity soundings… and sea-surface tem…			
GRACE-II	High-temporal-resol… tracking large-scale…			
SCLP	Snow accumulation…			
GACM	Ozone and related g… air quality and strato… prediction			
3D-Winds (Demo)	Tropospheric winds… and pollution transp…			

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	✓

3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	650

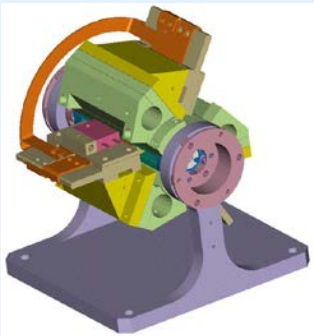
Roadmap to 3-D Winds Space Mission



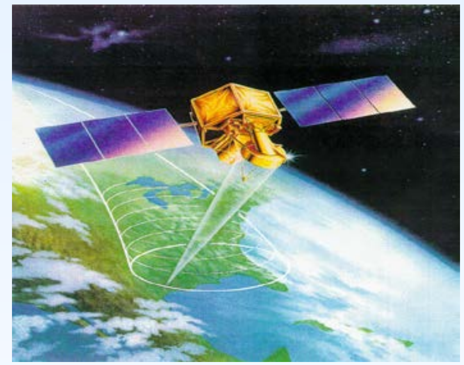


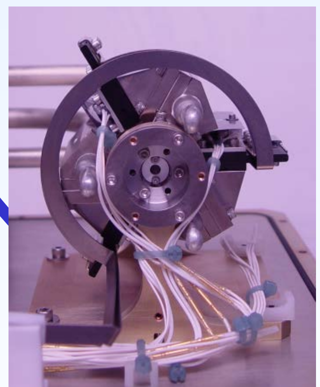
Technology Maturation Example

A fully conductively cooled 2-micron solid-state pulsed laser has been demonstrated to enable space-borne 3-D Wind measurements



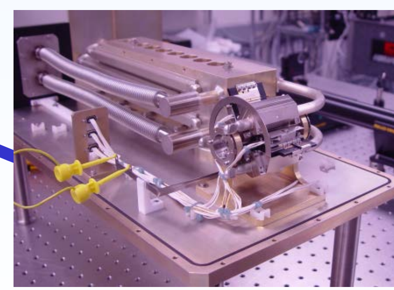
Analysis & Design





Fabrication

Quantum Mechanical Modeling



System Integration

Space Qualifiable Design

Testing and Model Verification

Mobile Ground based High Energy Wind Lidar Transceiver – LRRP/DAWN Funded

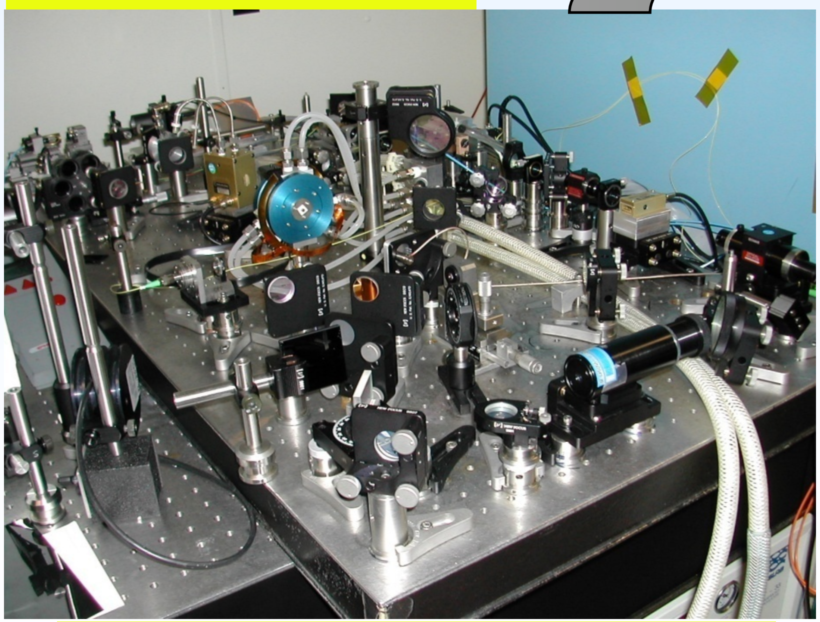
Transceiver (Transmitter + Receiver)
Without telescope or scanner

Compact

Higher Energy

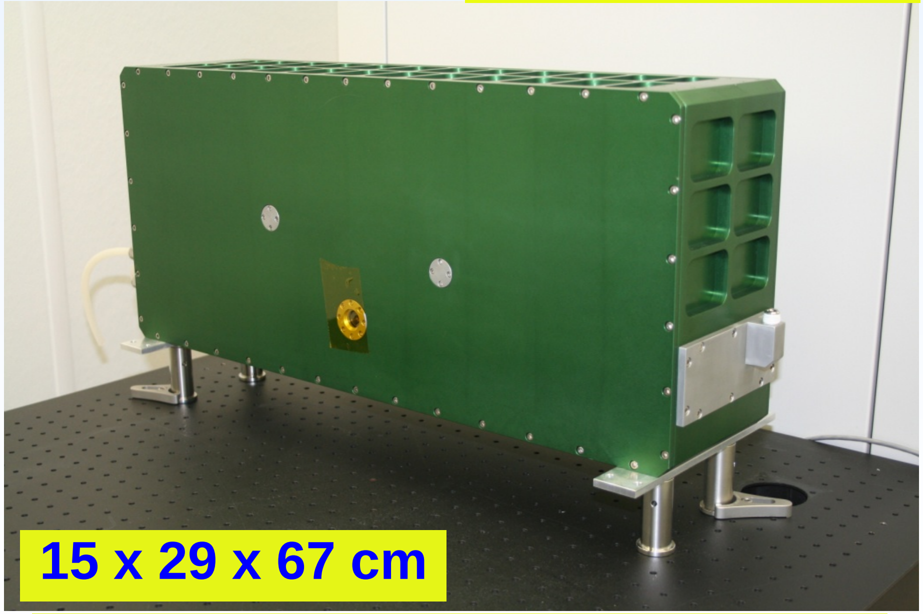
Robust

Table-Top
90 mJ/pulse
5 pulses/sec.
3’x4’ Optical Table



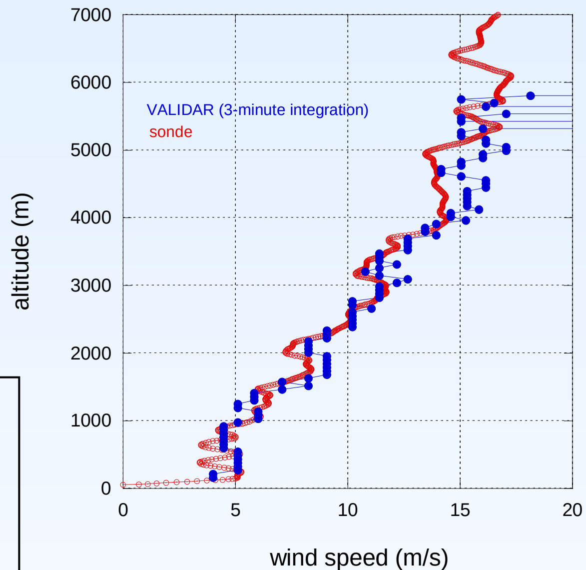
Previous implementation
Table-Top, 90 mJ per pulse

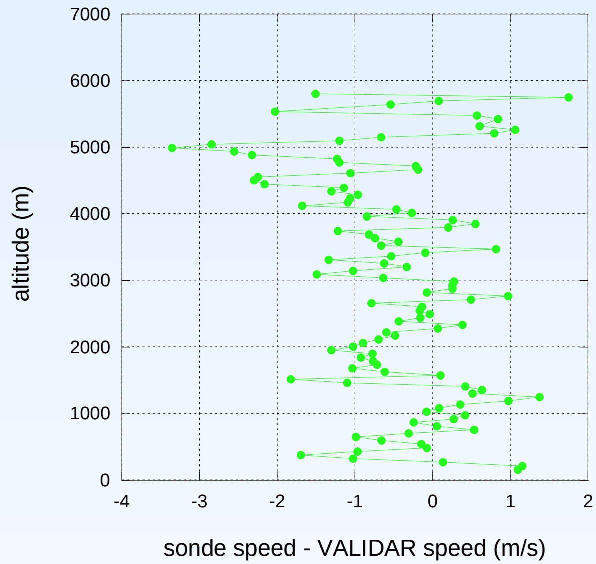
250 mJ/pulse
10 pulses/sec.
5.9” x 11.6” x 26.5”
75 lbs.; 34 kg



New Packaging
Compact, Robust, 250 mJ per pulse

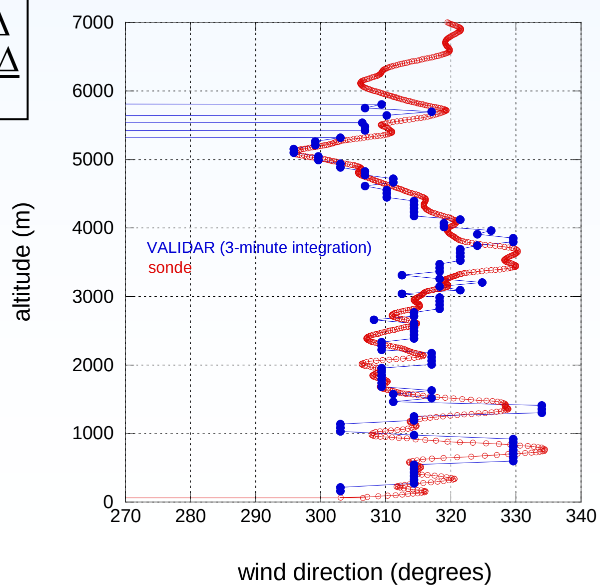
Comparison of Coherent Lidar and Sonde

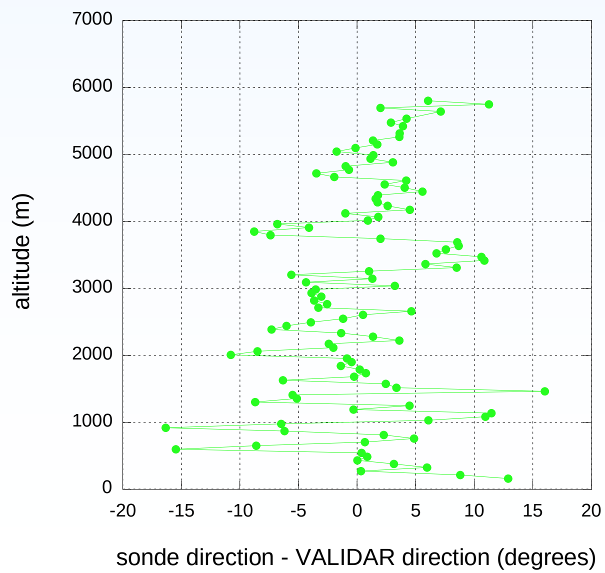




<u>1.06 m/s</u> Root-mean-square of the difference between the two sensors for all points shown

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





<u>5.78º</u> Root-mean-square of the difference between the two sensors for all points shown

GRIP DC-8 Payload

Dropsondes
(Vertical Profiles of Temp, Press, Humidity and Winds)

CAPS, CVI, PIP
(Cloud Particle Size distributions, Precip Rate, Rain & Ice water content)

LASE
Lidar Atmospheric Sensing Experiment (H2Ov, Aerosol profiles and Cloud distributions)

DAWN
Doppler Aerosol Wind Lidar (Vertical Profiles of Vectored Horizontal Winds)

APR-2
Airborne Precipitation Radar Dual Frequency (Vertical Structure Rain Reflectivity and Cross Winds)

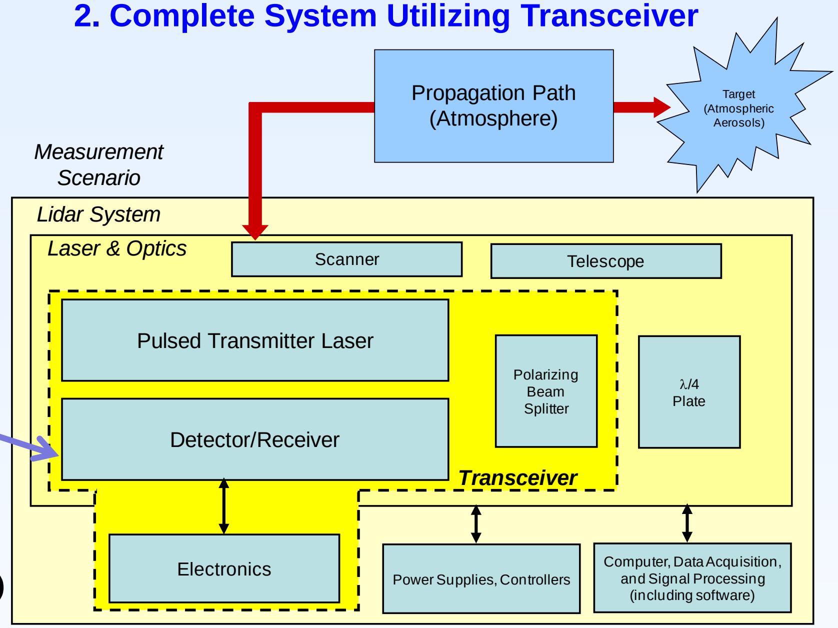
MMS
Meteorological Measurement System (Insitu Press, Temp, 3D Winds and Turbulence)

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)

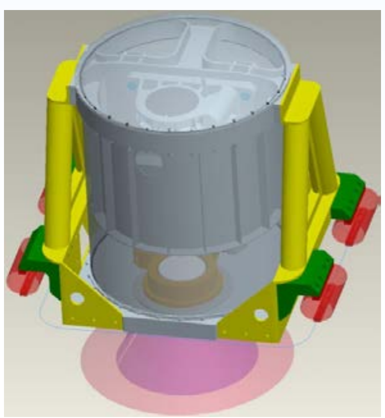
2. Complete System Utilizing Transceiver



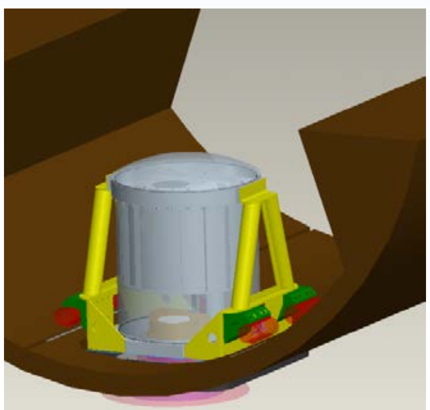
3. Ground-based Wind Measurement Performance

- 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

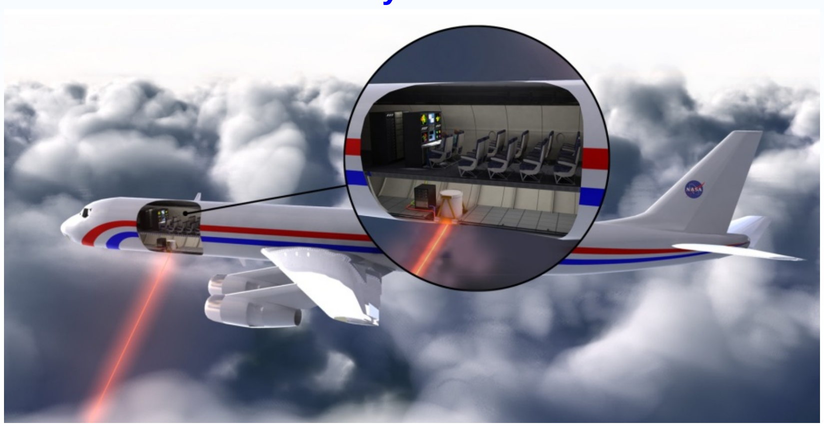
4. Enclosure for All Lidar Optics
Robust Aircraft Design



5. Optics in DC-8

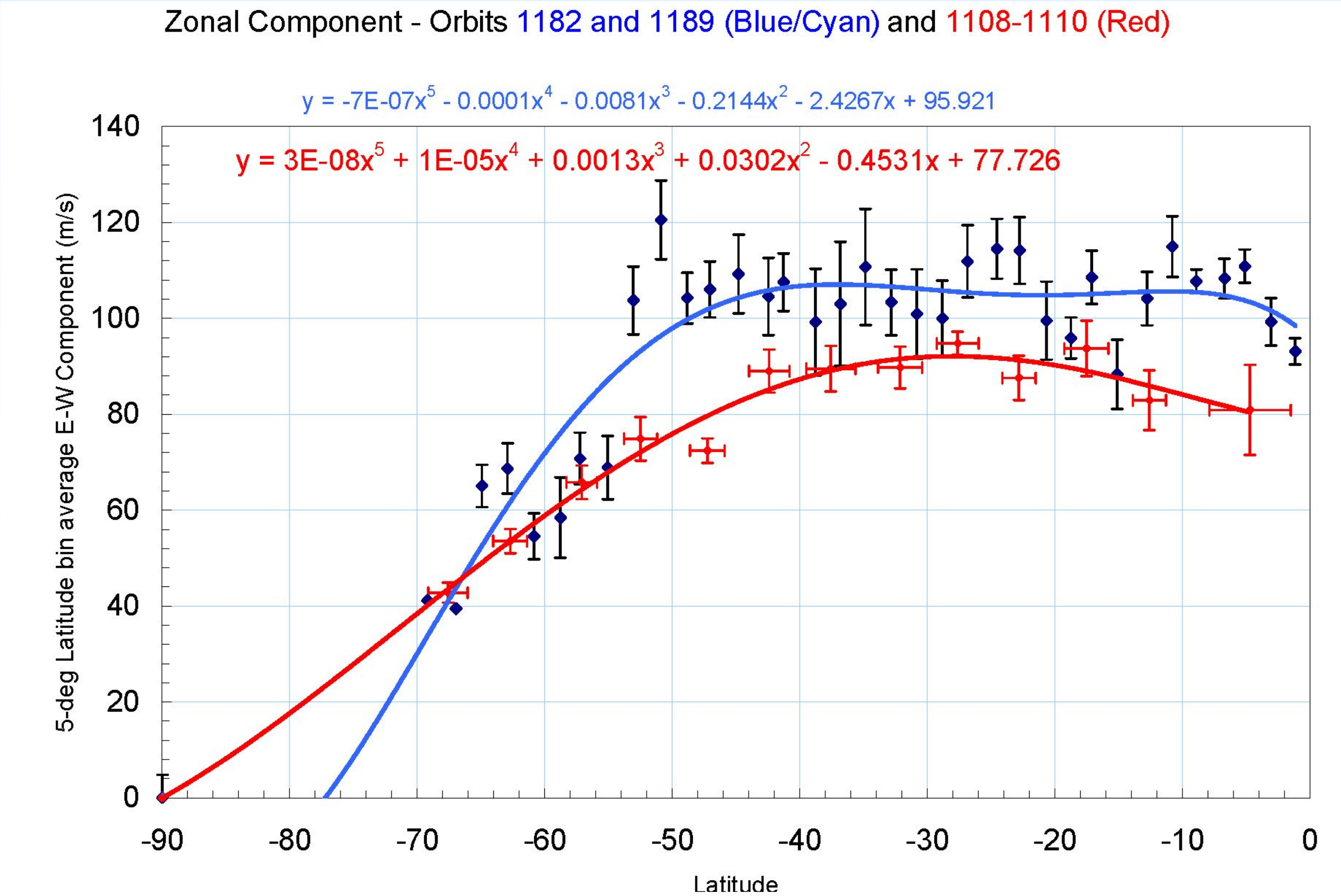


6. Lidar System in DC-8



Need for Doppler Wind Measurements on Venus

- Global super-rotation 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


Zonal Component - Orbits 1182 and 1189 (Blue/Cyan) and 1108-1110 (Red)
y = -7E-07x5 - 0.0001x4 - 0.0081x3 - 0.2144x2 - 2.4267x + 95.921
y = 3E-08x5 + 1E-05x4 + 0.0013x3 + 0.0302x2 - 0.4531x + 77.726
5-deg Latitude bin average E-W Component (m/s)
Latitude
140
120
100
80
60
40
20
0
-90
-80
-70
-60
-50
-40
-30
-20
-10
0

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

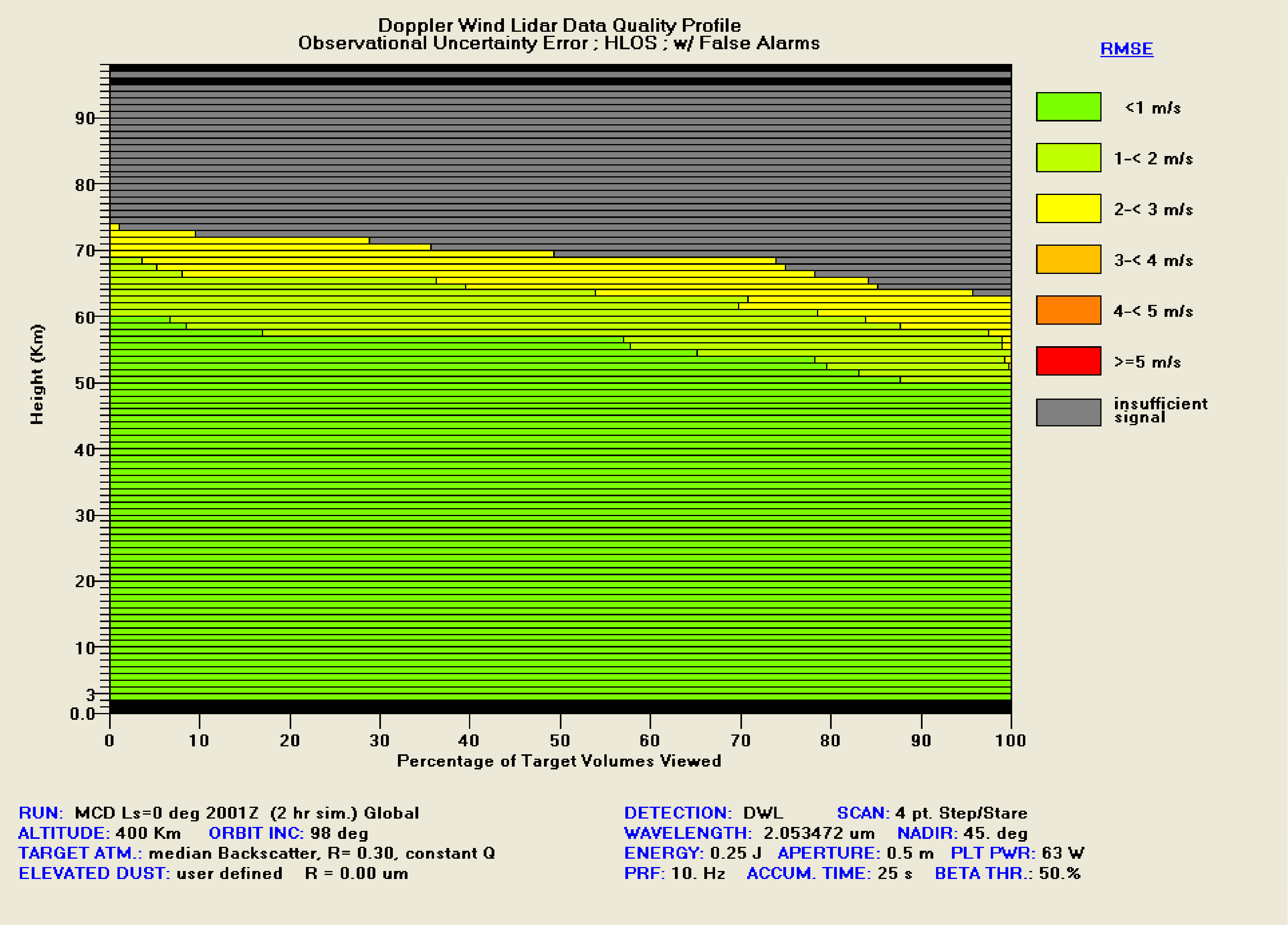
Proposed Approach

- 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

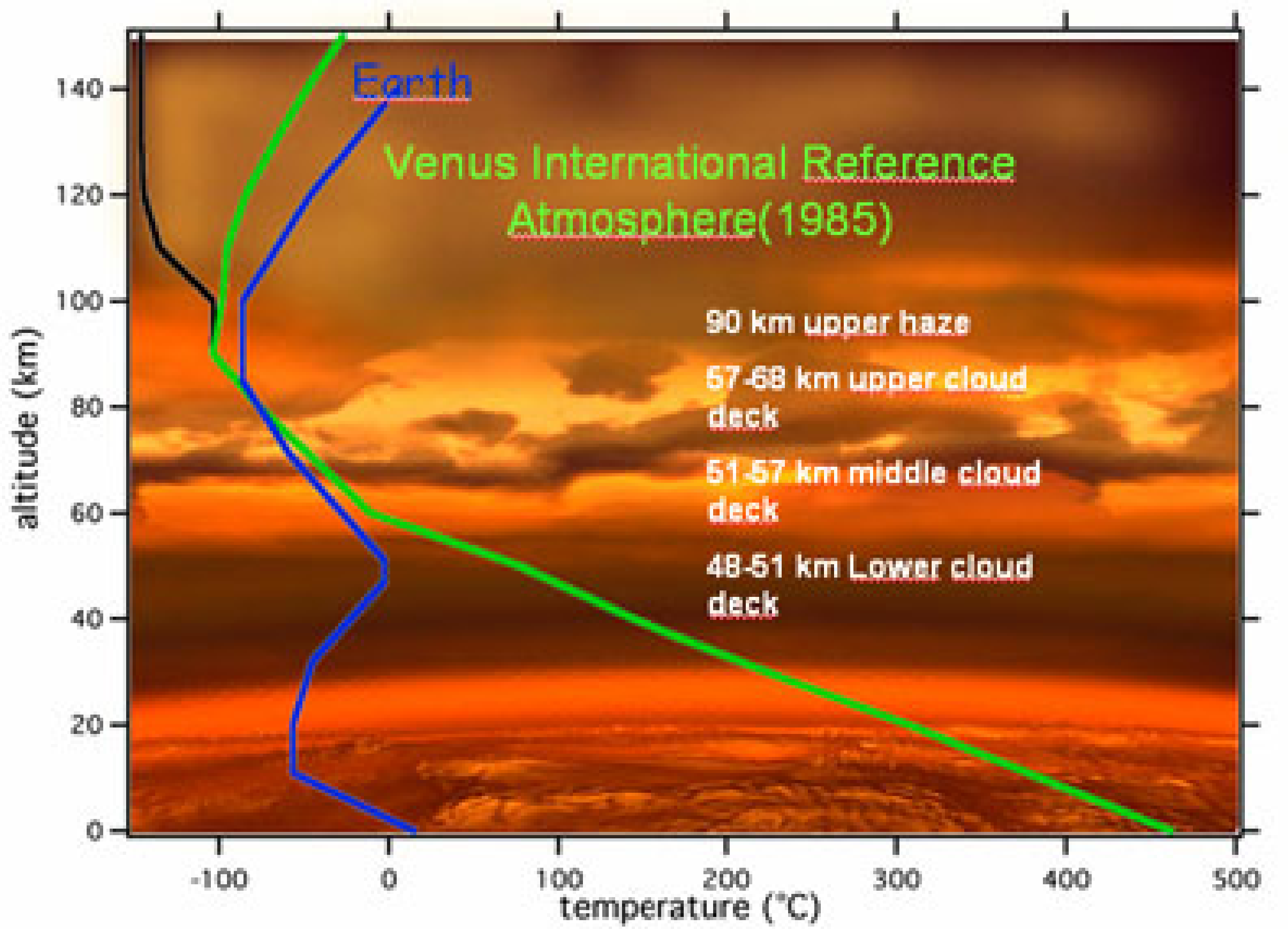
Initial Considerations

- 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.

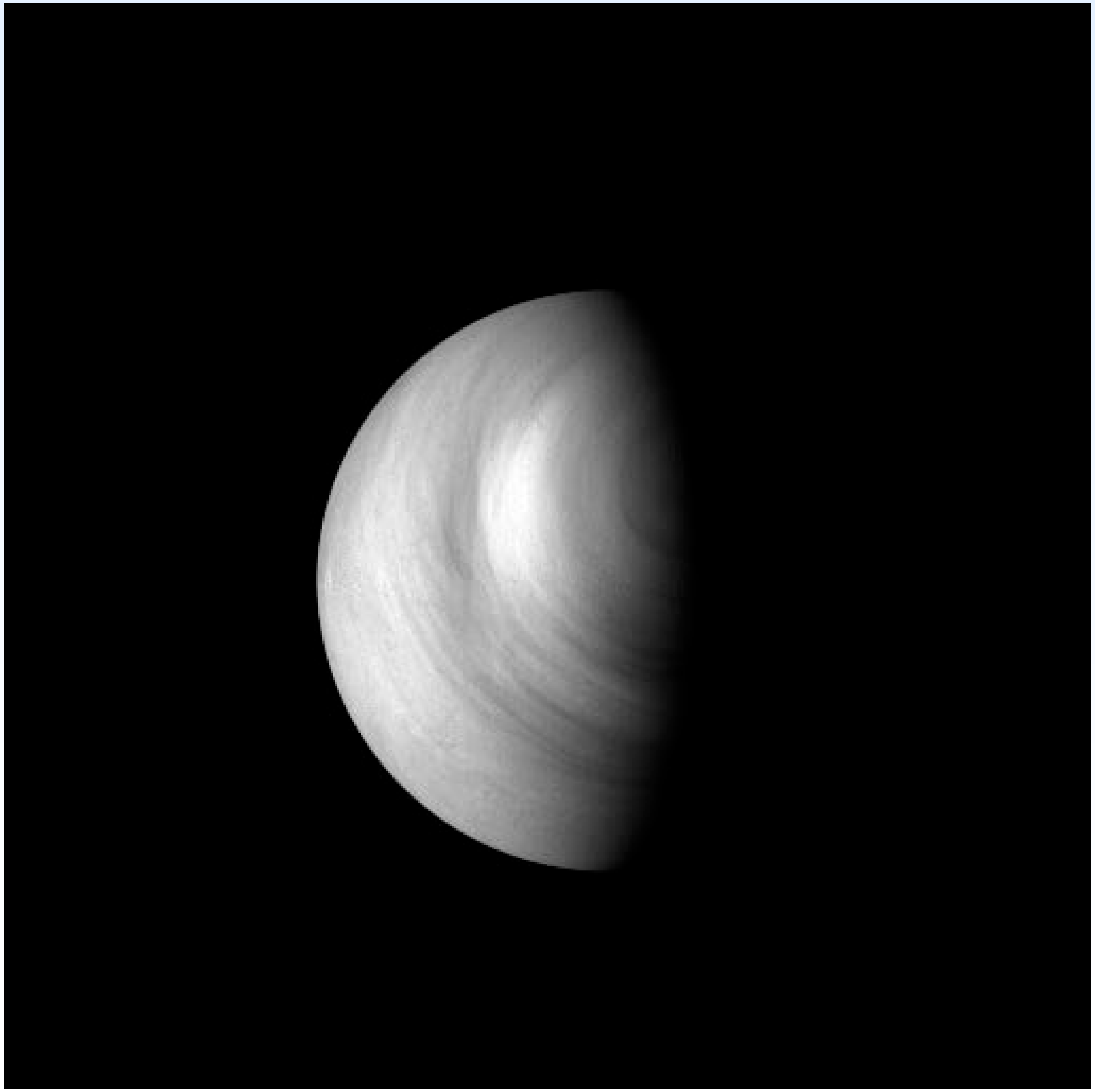
Doppler Wind Lidar Profile Simulation on Mars (Example)



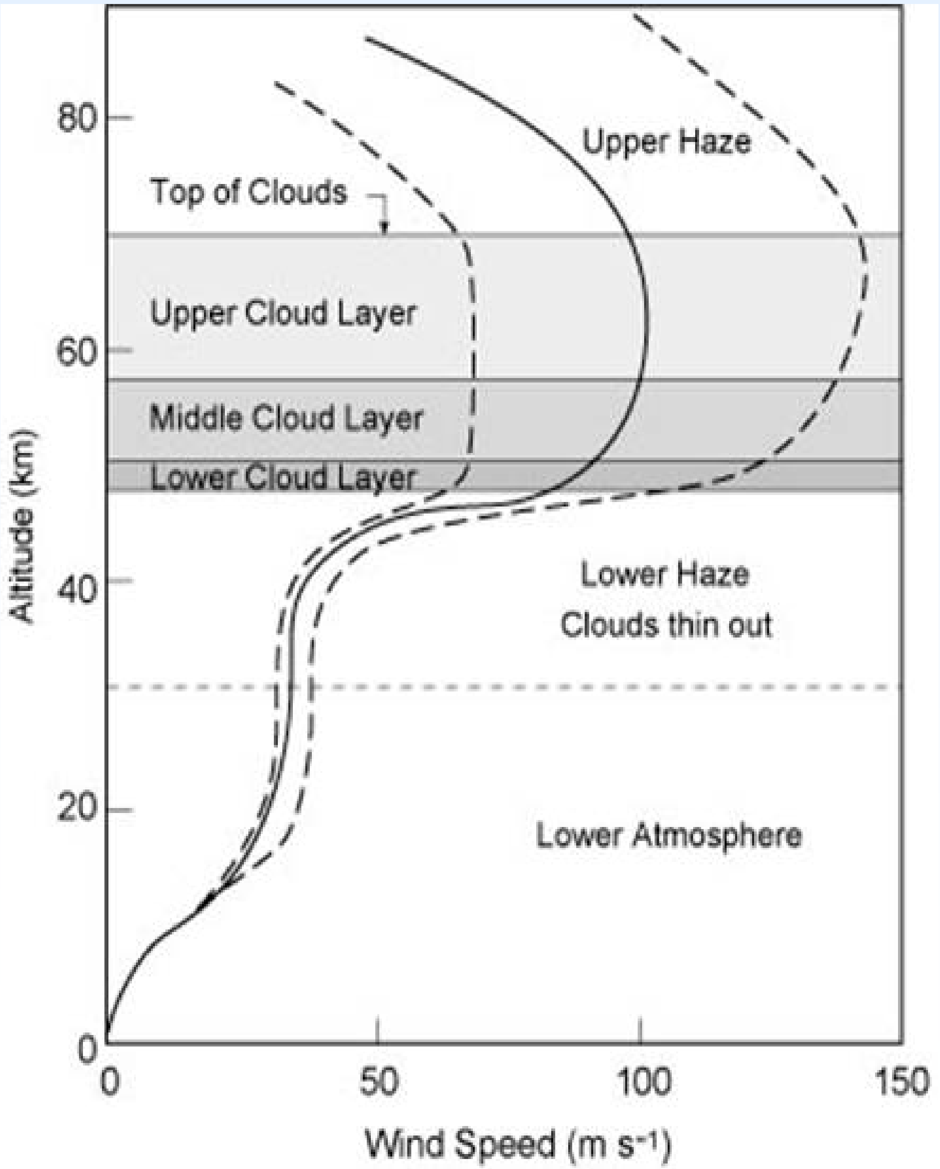
Venus International Reference Atmosphere



Venus Cloud Layers



Target Region for VenWinds



VenWinds Instrument

Wavelength (μm)	2.0	
Energy per pulse (J)	0.001	
Pulse length (nsec)	180	
PRF (Hz)	500	
Optical output (watts)	0.5	
Wallplug power (watts)	10	Includes cooling but not data collection/transmission
Telescope diameter (m)	0.1	
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)	0.1	
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 on effort to reduce weight of 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
Cloud top range resolution (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.