



Requirements and Technology Advances for Global Wind Measurement with a Coherent Lidar: A Shrinking Gap

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Customers for Global Winds

Air Force	2007	"Among the 15 missions recommended by the National Research Council Decadal Survey Report on Earth Science and Applications from Space, the measurement of global tropospheric winds would provide the greatest potential benefit to the mission of the United States Air Force. DWL would provide data critical to the DoD's need to characterize and exploit the environment for strategic and operational advantage." Aug. 1, 2007 Letter from Director of Weather to NASA SMD AA (Dr. Alan Stern)
NRC	2007	One of 15 recommended NASA earth science missions. [National Research Council (NRC), "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond," p. 2-14, The National Academies Press, Wash DC, "Decadal Survey" (DS)]
NASA	2007	Highest priority of "Weather" Science Focus Area. [NASA, "Science Plan for NASA's Science Mission Directorate," pp. 60-61]
US/NSTC/ CENR/ IWGEO (now GEO)	2005	Highest priority for improved weather forecasting. High importance to Weather, Disasters, Oceans, Climate, and Human Health Societal Benefit Areas; medium importance to Agriculture and Ecology. [National Science and Technology Council, Committee on Environment and Natural Resources, Interagency Working Group on Earth Observations, "Strategic Plan for the U.S. Integrated Earth Observation System," p. 37]
ESA	1999	"improvement in analyzing global climate, its variability, predictability and change requires measurements of winds throughout the atmosphere." [ESA, "Reports for Mission Selection. The Four Candidate Earth Explorer Core Missions. Atmospheric Dynamics Mission," SP-1233 (4)]
NPOESS (IPO)	1996	Highest priority unaccommodated NPOESS measurement. "Direct tropospheric wind measurements would provide a greater impact on numerical weather prediction than any other new space-based observation." [NPOESS/IPO (Integrated Program Office), "Unaccommodated Environmental Data Records: Technology Status and Promising Technological Areas," pp. 4, 6]
WMO	1996	"Observations of upper winds are essential for operational weather forecasting on all scales and at all latitudes, ..." [WMO, "Guide to Meteorological Instruments and Methods of Observation," 6 th ed., WMO-No. 8, pp. I.12-31, I.13-1]



Early Mission Concept



- 525 km orbit height
- Single pulsed Doppler lidar system covers troposphere
- Continuously rotating telescope/scanner
- Line of sight (LOS) wind profiles from each laser shot
- ~ 20 J pulse energy
- ~ 1.5 m rotating telescope
- Requirement: eyesafe solid state pulsed laser
- 2-micron technology for coherent detection
- 20 mJ/5 Hz demonstrated vs. 20 J/10 Hz required
- Energy deficiency of x1000 (30 dB) !



Ideas, Advances, and Changes

Factor	Notes
2-Micron Laser Technology Advances	Pulse energy, pulse repetition frequency (PRF)
Hybrid Doppler Lidar Concept	Use both coherent and direct detection Doppler lidars to cover the troposphere
Step-Stare Scanning and Shot Accumulation	Permit multiple laser shots to be combined for each LOS wind profile measurement
Lower Orbit Height to 400 km	SNR proportional to inverse range squared
Demonstration Wind Mission Requirements	Relaxed measurement requirements for a demonstration mission



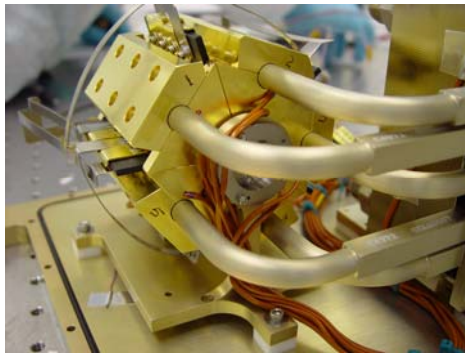
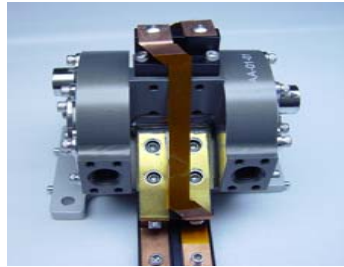
2-Micron Laser Advances at LaRC

Category	Advancement	Current Space Requirement
Pulse Energy	0.02 J to 1.2 J (x60)	0.25 J
Pulse Repetition Frequency	1 Hz to 10 Hz	5 Hz
Wallplug Electrical Efficiency	Invented Ho:Tm:LuLiF (+20% improvement)	~ 1.4%
Host Crystal	YAG to YLF to LuLiF	LuLiF
Components	Oscillator, Preamplifier, Amplifiers	Oscillator & 1 Amplifier
Mode	Normal to Q-Switched to Injection Seeded	Injection Seeded
Beam Quality	1.1 x Diffraction Limit	1.1 x Diffraction Limit
Pulse Spectrum	~ 2.5 MHz FWHM	~ 2.5 MHz FWHM
Cooling Method	All Liquid to Half Conductive, Half Liquid to All Conductively Cooled	All Conductively Cooled
Pump Diode Array Package	C to A to AA to G	G package

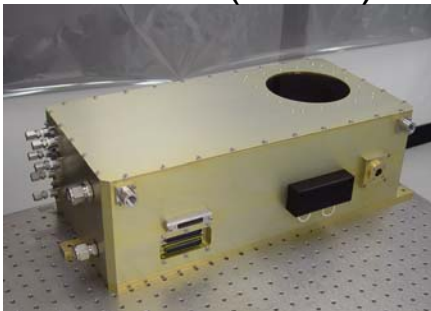


2-Micron Laser Advances at LaRC

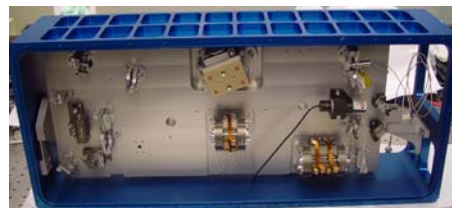
Oscillator
&
Amplifier
Designs



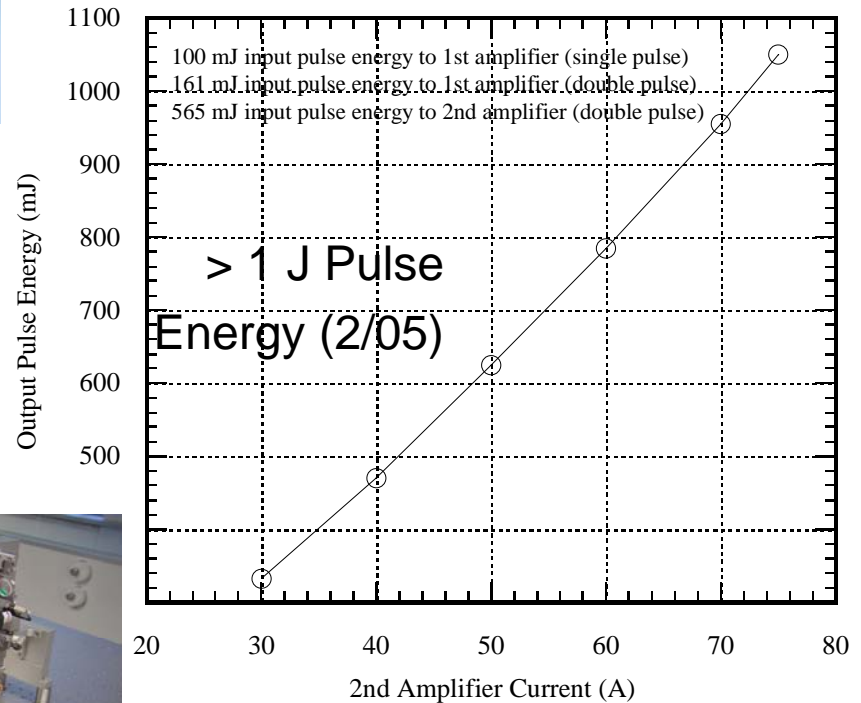
Fully conductively
cooled (11/03)



Engineered Packaging



One-Joule Pulse Output Result



- Also:
- Crystal material and doping
 - Temperature control
 - New LDA packages
 - 1 J w/o preamplifier (12/05)
 - Pulse spectrum
 - Beam quality
 - Efficiency

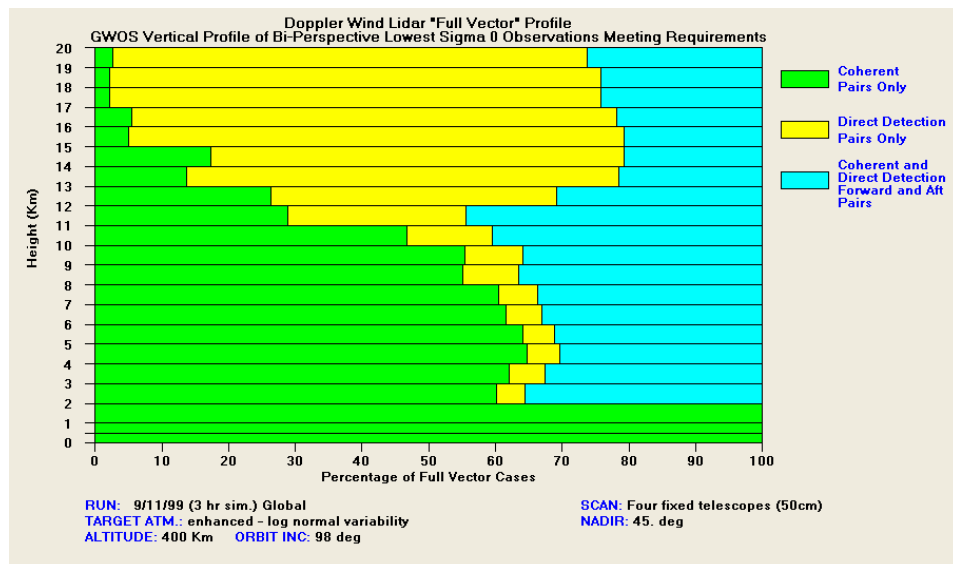
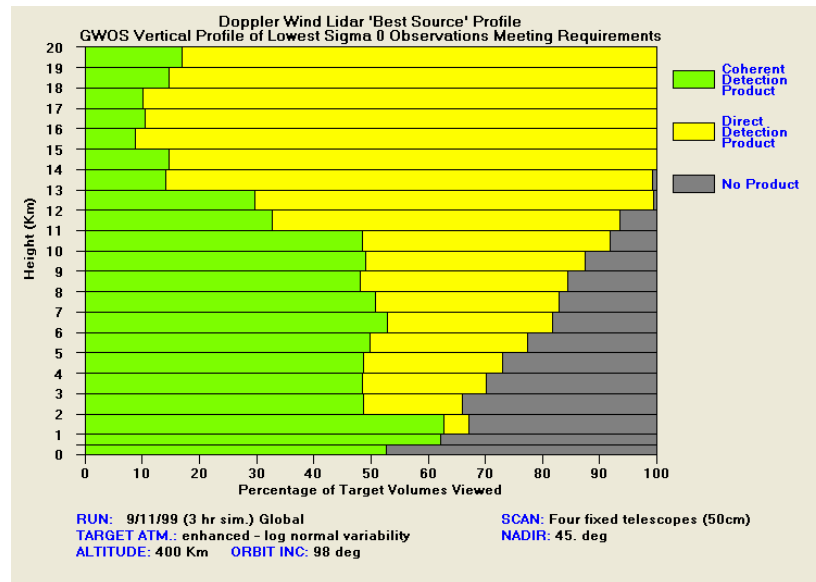


Hybrid Doppler Lidar Concept

Complementary Lidars Together Lower Total Mass, Power, Cost, Risk

Green represents percentage of sampled volumes when coherent subsystem provides the most accurate LOS measurement; **Yellow** is for direct detection; **Gray** is when neither system provides an observation that meets data requirements

GWOS with enhanced aerosol mode



When two perspectives are possible

Green: both perspectives from coherent system

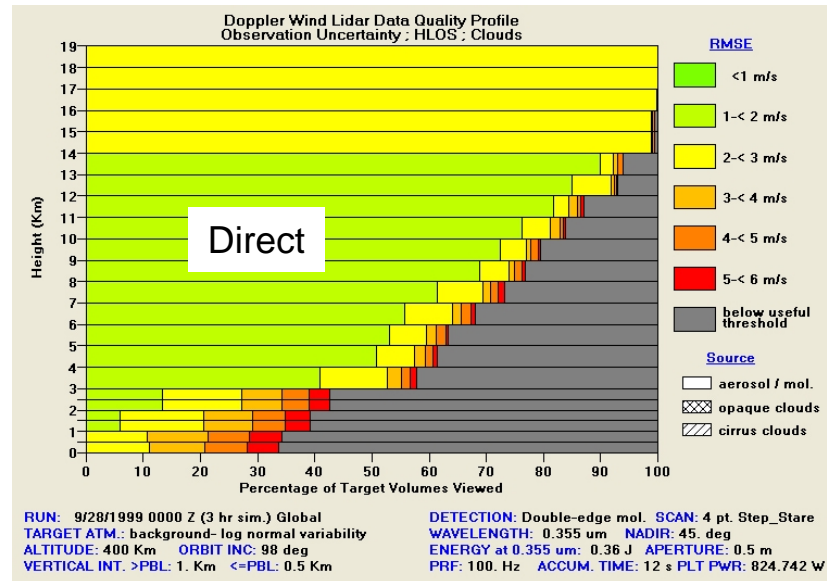
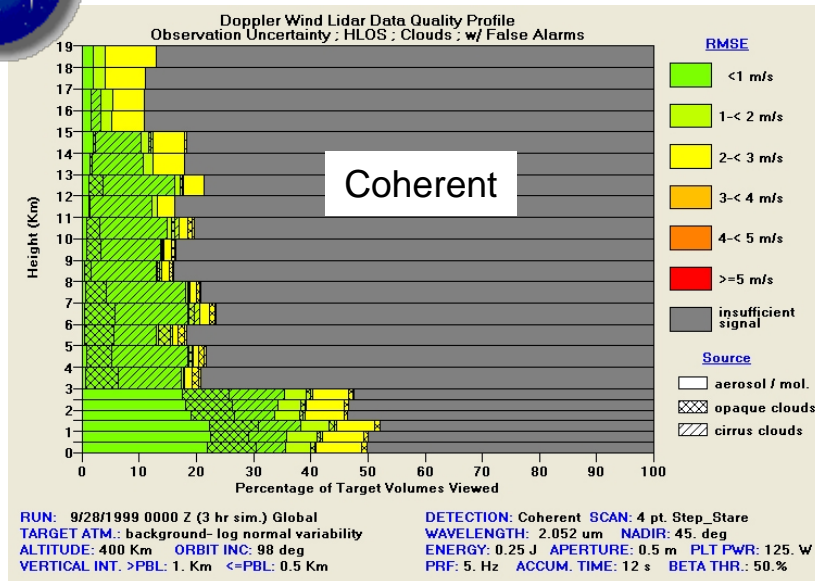
Yellow: both perspectives from direct molecular

Blue: one perspective coherent, one perspective direct

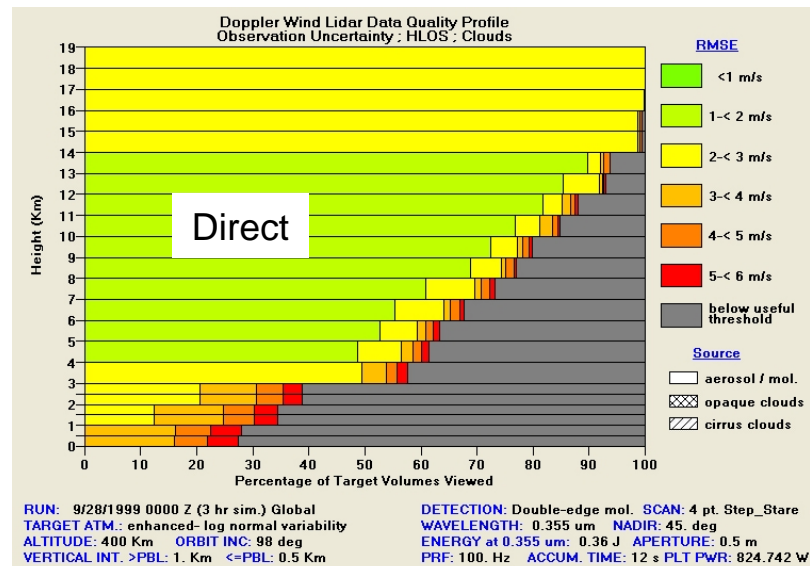
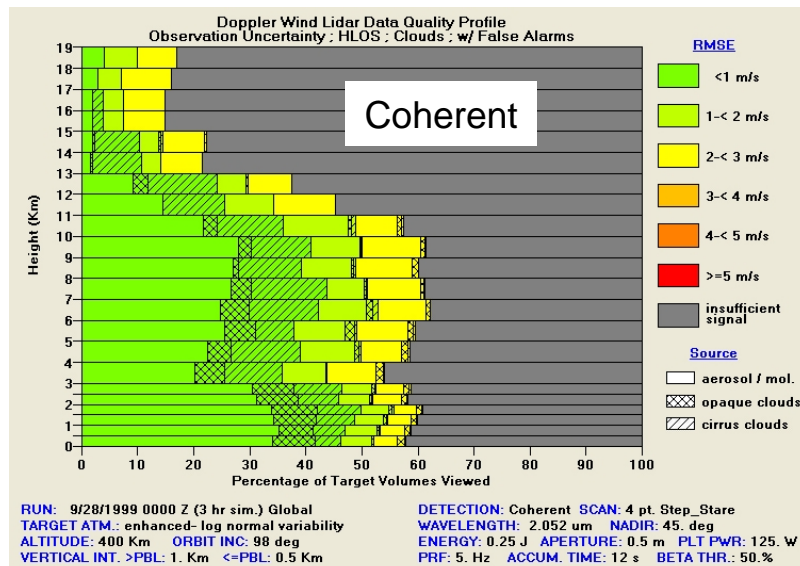


Hybrid Doppler Lidar Meets Requirements

GWOS with background aerosol mode



➤ 0.25 J, 5 Hz, 0.5 m GWOS with enhanced aerosol mode 1/0.3 J, 100 Hz, 0.5 m





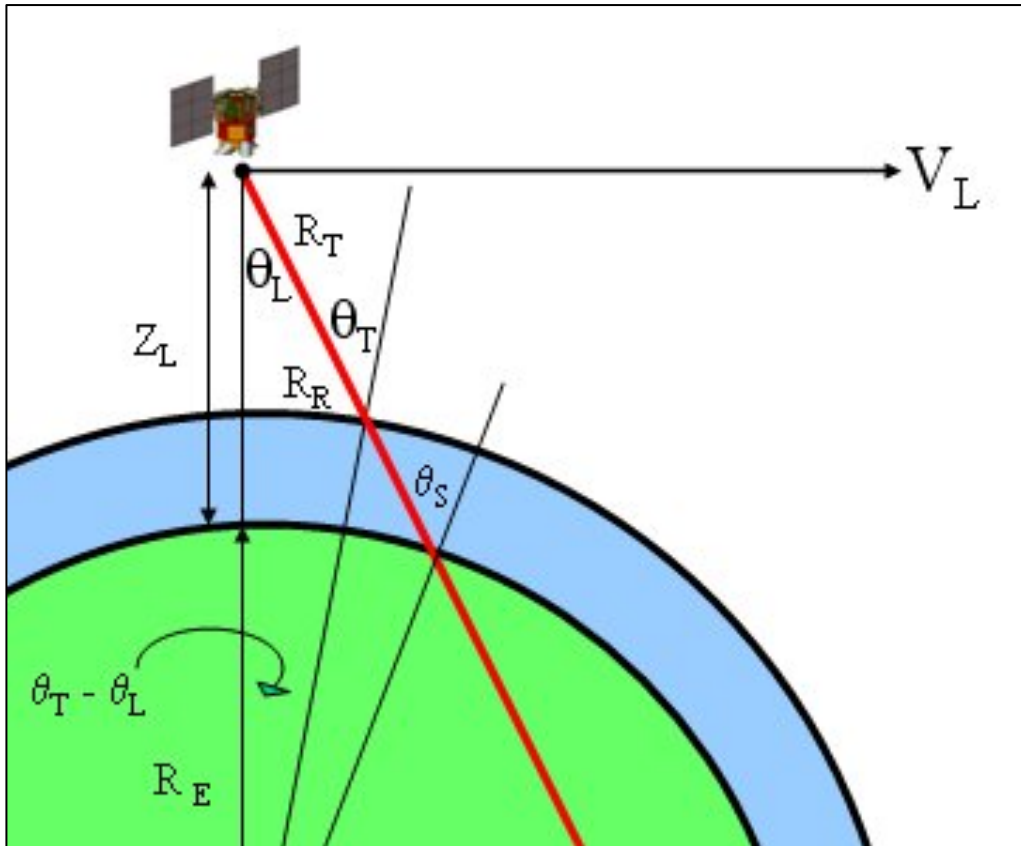
Step-Stare Scanning & Shot Accumulation

GWOS:

- 12 second shot accumulation/azimuth angle
- Ground spot moves forward by 85 km
- Coherent lidar at 5 Hz
- 60 shot attempted accumulation (clouds may block some)
- If 60 successful, lower pulse energy by 87%



Lower Orbit Height



GWOS:

$\theta_L = 45$ degrees

$z_L: 525 \rightarrow 400$ km

$R_T: 776 \rightarrow 585$ km

SNR + 2.5 dB



Demonstration Requirements

	Demo	Threshold	Objective	
Vertical depth of regard (DOR)	0-20	0-20	0-30	km
Vertical resolution:	2	Not Req.	2	km
Tropopause to top of DOR	2	1	0.5	km
Top of BL to tropopause (~12 km)	1	0.5	0.25	km
Surface to top of BL (~2 km)				
Number of collocated LOS wind measurements for horiz ^A wind calculation	2 = pair	2 = pair	2 = pair	-
Horizontal resolution ^A	350	350	100	km
Minimum Number of horizontal ^A wind tracks ^B	2	4	12	-
Velocity error ^C				
Above BL	3	3	2	m/s
In BL	3	2	1	m/s
Minimum wind measurement success rate ^D	50	50	50	%

^A Horizontal winds are not actually calculated; rather two LOS winds with appropriate angle spacing and collocation are measured for an “effective” horizontal wind measurement. The two LOS winds are reported to the user. ^B The 4 cross-track measurements do not have to occur at the same along-track coordinate; staggering is OK. ^C Error = 1 σ LOS wind random error, projected to a horizontal plane; from all lidar, geometry, pointing, atmosphere, signal processing, and sampling effects. The true wind is defined as the linear average, over a 100 x 100 km box centered on the LOS wind location, of the true 3-D wind projected onto the lidar beam direction provided with the data. ^D Scored per vertical layer per LOS measurement.
(corrected errata and clarifications)



Has The Gap Been Narrowed?



pre-1993	2007*
2-micron coherent lidar covers entire troposphere	2-micron and 0.355-micron lidars share the job – hybrid concept
Required pulse energy: 20 J	Required pulse energy: 0.25 J
Demonstrated pulse energy: 0.02 J	Demonstrated pulse energy: 1.2 J
Factor of 1000 deficit ☹️	Factor of 5 margin 😊

Situation has improved by 37 dB!

*2007: also advancements in crystal material, electrical efficiency, cooling method, component count, beam quality, pump laser diodes, and compact packaging



Summary and Conclusions

- Combination of technology advances, hybrid Doppler lidar idea, and demonstration measurement requirements for the first mission has greatly narrowed the distance between demonstrated capability and needed mission performance
- Observing System Simulation Experiments have determined the required measurement performance
- Doppler lidar performance simulations, anchored with experimental results, have determined the required lidar parameters
- NASA's Instrument and Mission Design Teams have accommodated the lidar parameters in a notional mission
- There are numerous customers for the wind data
- The recent NRC Decadal Survey recommended the mission to NASA

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