



DAWN Coherent Wind Profiling Lidar Flights on NASA's DC-8 during GRIP

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AITT-07 "DAWN-AIR1"

GRIP

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Airplane Change & Rephasing

NASA LaRC Director Office, Steve Jurczyk, *\$ Augmentation*

NASA LaRC Engineering Directorate, Jill Marlowe, John Costulis, *\$Augmentation*

NASA LaRC Chief Engineer, Clayton Turner, *1 FTE*

NASA LaRC Science Directorate

Garnett Hutchinson, Stacey Lee, and Keith Murray



Project Personnel (DAWN, DAWN-AIR1, DAWN-AIR2, & GRIP)

*operated DAWN on GRIP flights



Dr. Michael J. Kavaya*	PI, LaRC	Overall project coordination including cost and schedule control and reporting. Lead, coherent lidar & data processing
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Garfield A. Creary*	LaRC	Project Manager
Dr. G. David Emmitt	Co-I, SWA Pres.	Science planning, data analysis, lidar attitude knowledge
Dr. Grady J. Koch*	Co-I, LaRC	Lead, lidar system overview, lidar receiver design, lidar remote sensing
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Dr. Jirong Yu*	Co-I, LaRC	Lead, pulsed laser design, lidar remote sensing
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Dr. Joel F. Campbell	LaRC	Data processing
Dr. Songsheng Chen	LaRC	Laser alignment
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Mark L. Jones	LaRC	INS/GPS software
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Anna M. Noe	LaRC	Aircraft accommodation
Don P. Oliver	LaRC	Aircraft accommodation
Karl D. Reithmaier	SSAI	Mechanical design
Geoffrey K. Rose	LaRC	Mechanical engineering
Teh-Hwa Wong	SSAI	Mechanical engineering
William A. Wood	LaRC	Software



Past Work: 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:

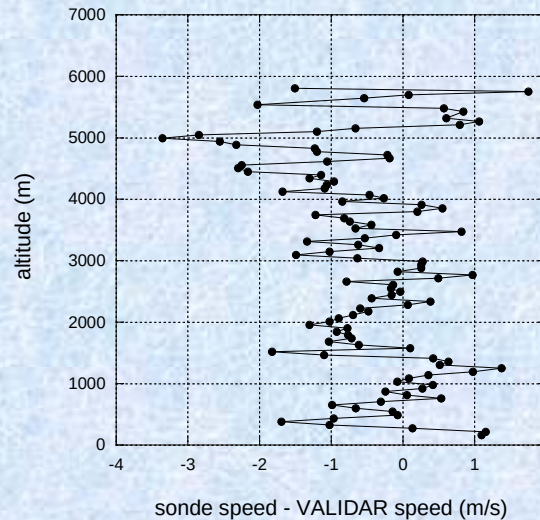
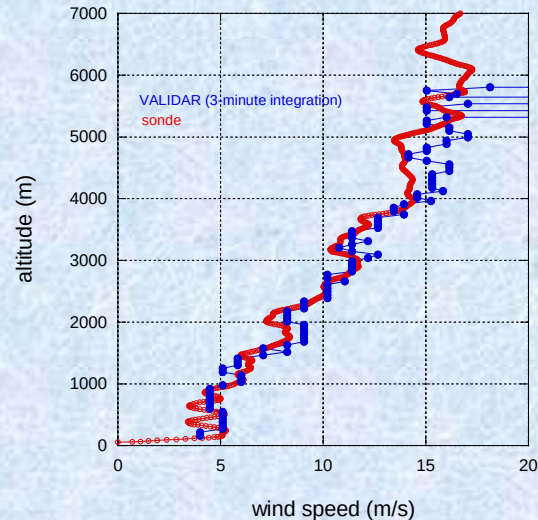
- LaRC has previously demonstrated a world record 1200 mJ of pulse energy at 2 Hz (12/05)
- LaRC has demonstrated fully conductively cooled oscillator/amplifier to 400 mJ, 5 Hz (08/07)
- Simulations of the Decadal Survey winds space mission with a hybrid lidar indicate a coherent lidar requirement of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



Past Work: Excellent Ground-Based Wind Performance by DAWN at Howard University, Beltsville, MD; U. Singh, PI

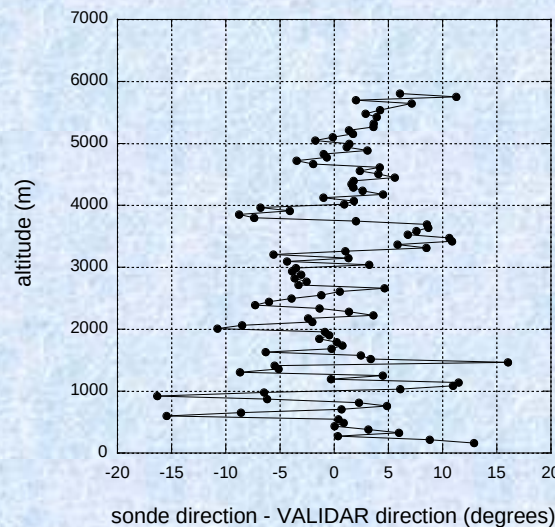
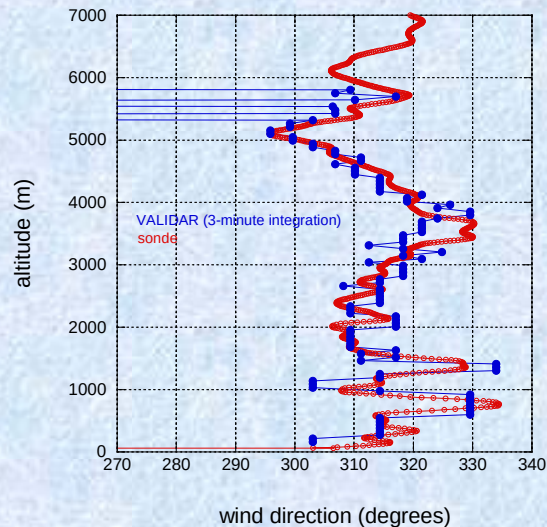


sonde on February 24, 2009 at 17:59 local



Wind Speed

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

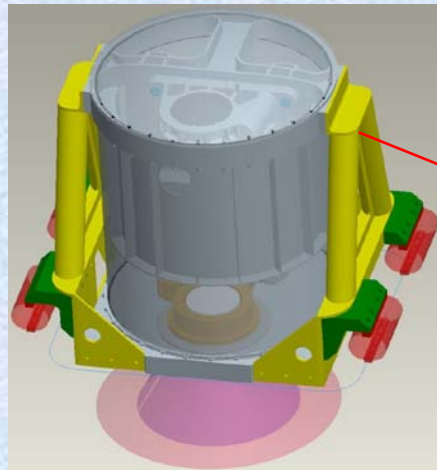
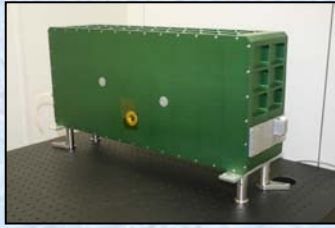


Wind Direction

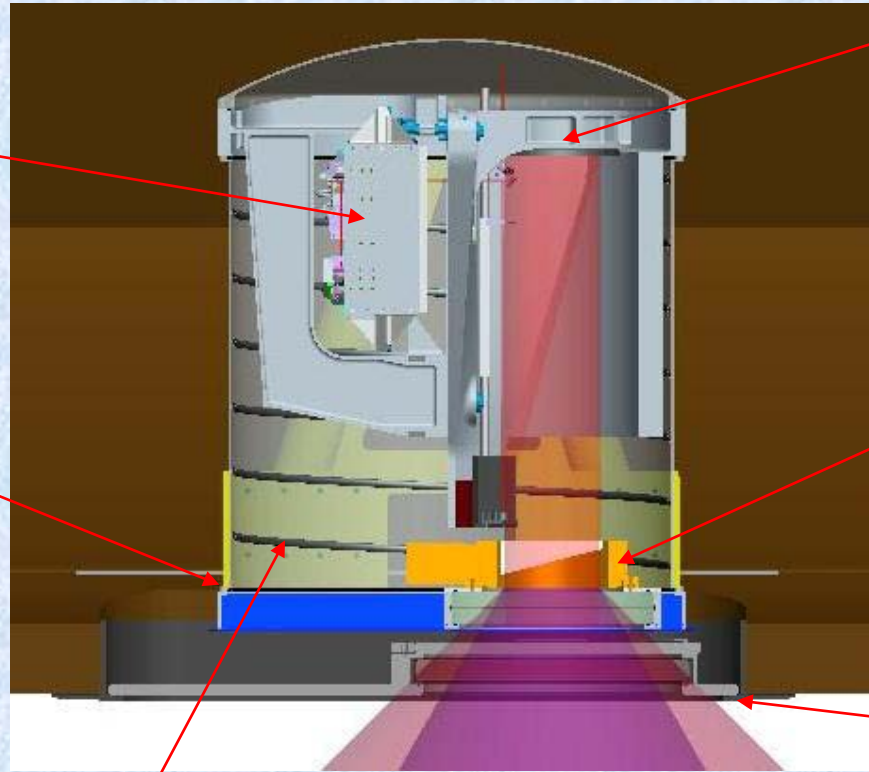
- root-mean-square of difference between two sensors for all points shown = **5.78 deg**



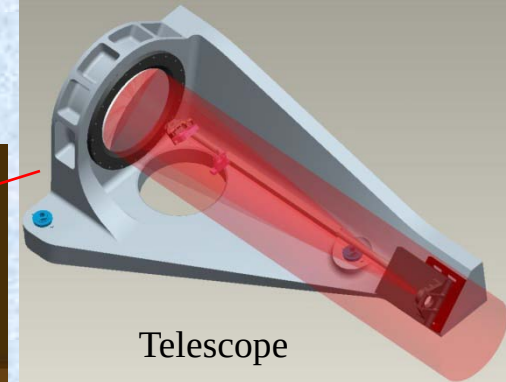
DAWN Lidar System Development for the DC-8



29" x 36" x <37" Tall
Sealed Enclosure &
Integrated Lidar Structure



3/8" Cooling Tube

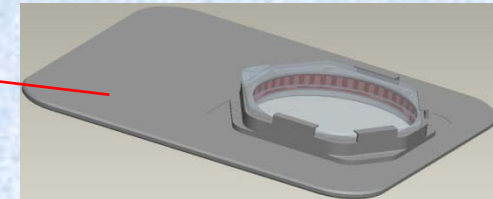


Telescope



Newport Scanner
(RV240CC-F)

DC8 Port/Window/Shutter



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



DAWN Transport and Atmospheric Access Trailer with Clean Room Capability





DAWN Optics Mounted in DC-8 Cargo Level





Three DAWN Cabin Stations with 2 or 3 Operators



1. Laser Control (L)
2. Data Processing (R)



3. Laser Chillers (3)





DAWN Laser & Lidar Specifications



Pulsed Laser

Ho:Tm:LuLF, 2.05 microns

2.8 m folded resonator

~250 mJ pulse energy

10 Hz pulse rate

180 ns pulse duration

Master Oscillator Power Amplifier

Laser Diode Array side pumped, 792 nm

~Transform limited pulse spectrum

~Diffraction limited pulse spatial quality

Designed and built at LaRC

Lidar System

15-cm diameter off-axis telescope

Dual balanced heterodyne detection

InGaAs optical detectors

Integrated INS/GPS

Lidar System in DC-8

Optics can in cargo level

Centered nadir port 7

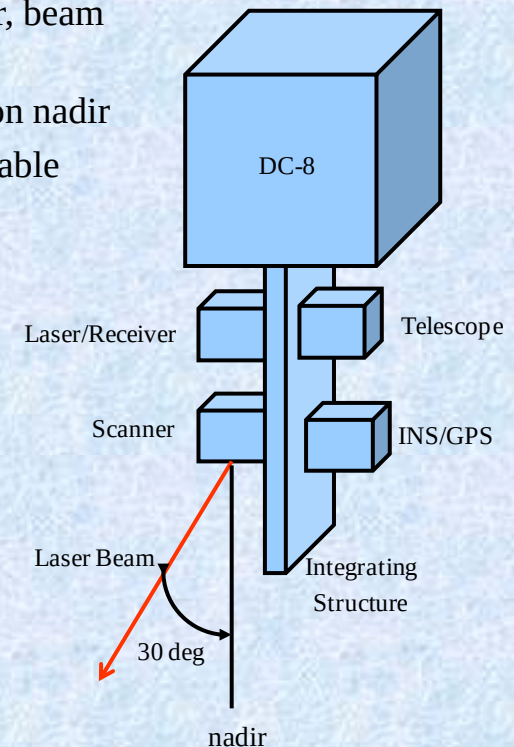
One electronics rack in cargo level

Two electronics racks in passenger level

Refractive optical wedge scanner, beam deflection 30.12 deg

Conical field of regard centered on nadir

All azimuth angles programmable



DAWN Mechanical Assembly for Optical Alignment, and Pointing Control & Knowledge



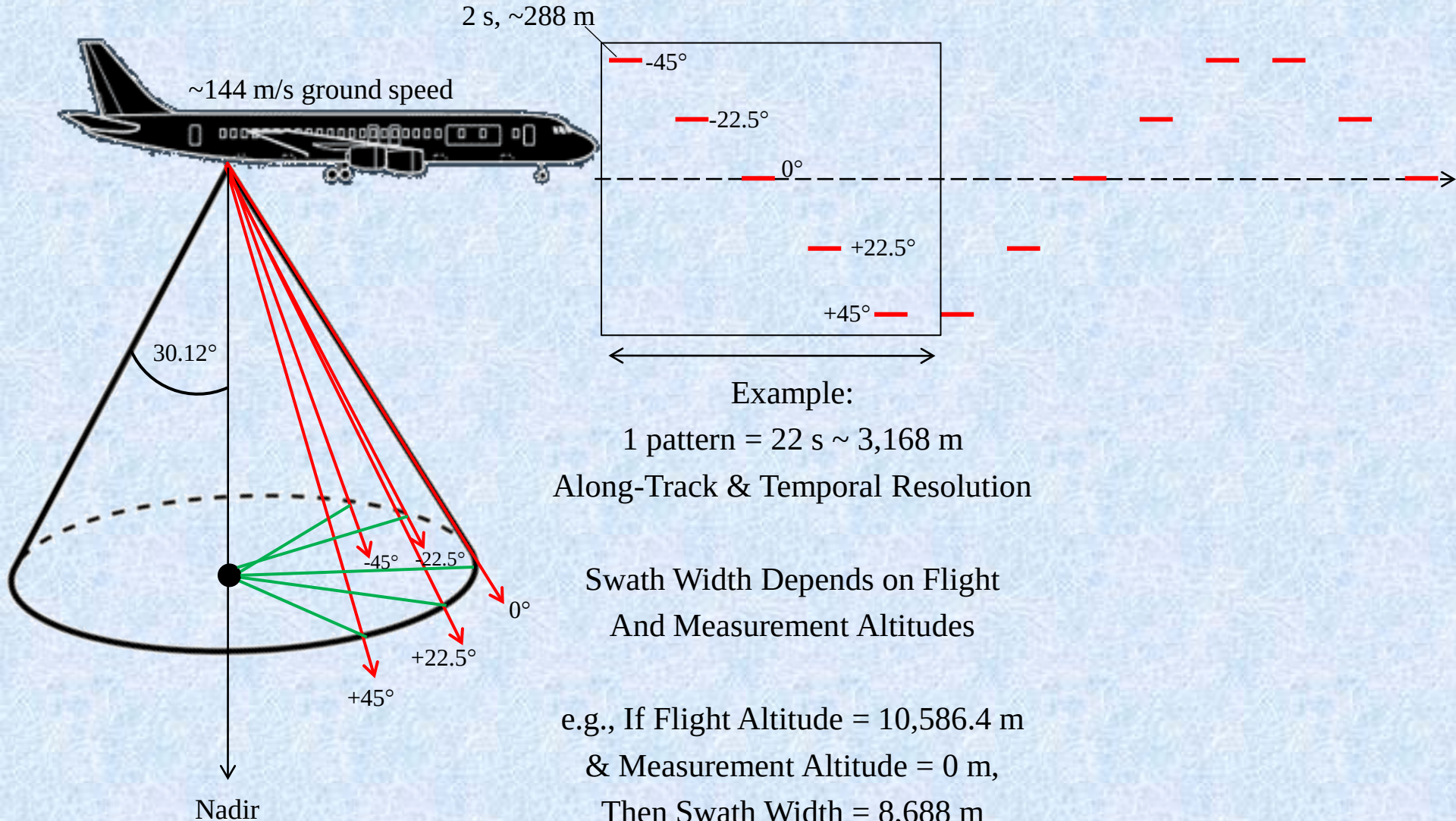
Nominal Scan Pattern: DAWN During GRIP Campaign



Left to right scan pattern followed by right to left scan pattern, etc.

5 different azimuth angles from -45° to $+45^\circ$

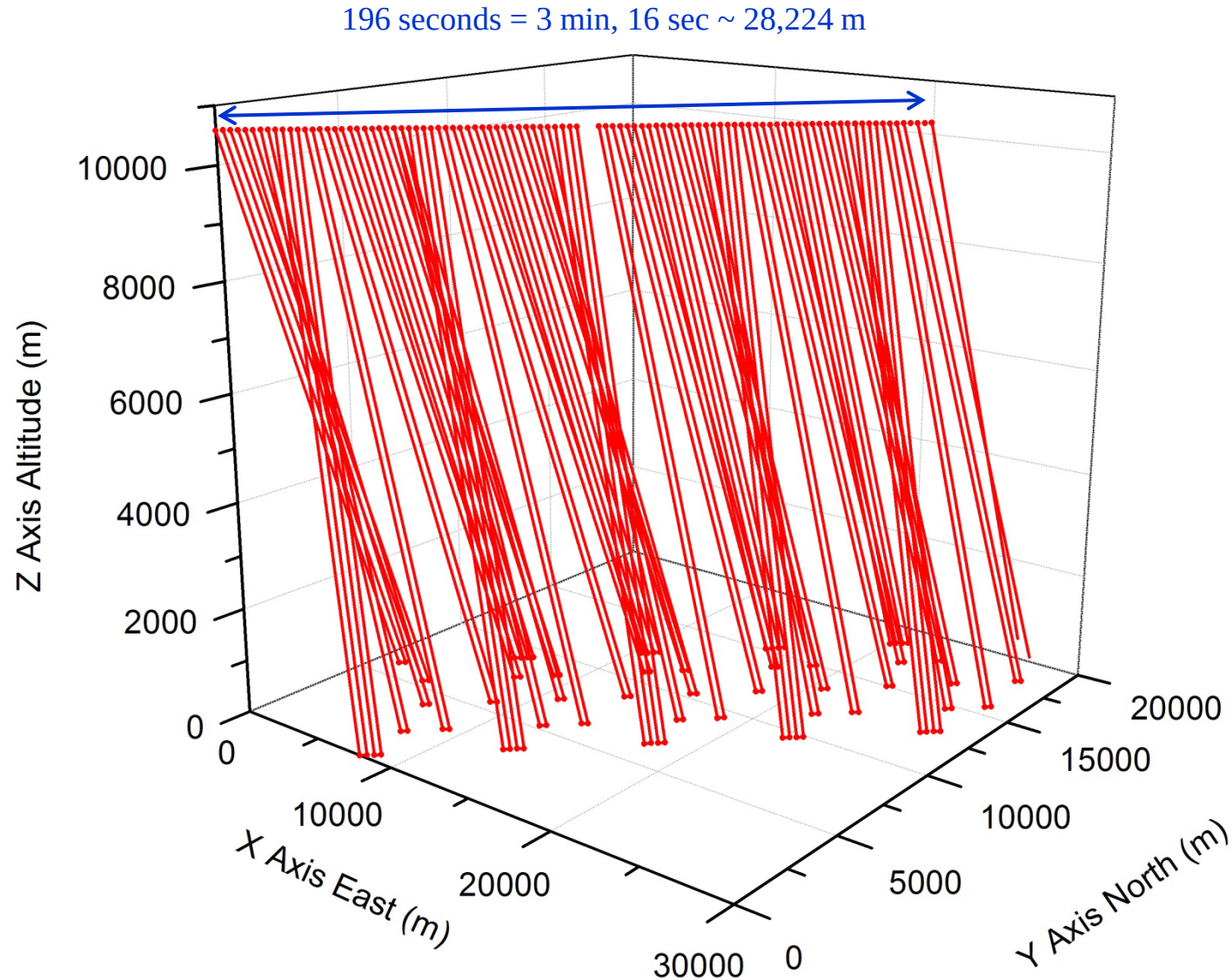
2 sec (20 shot) integration; 2 sec scanner turn time





Nominal Scan Pattern: DAWN During GRIP Campaign

~ 9 scan patterns shown

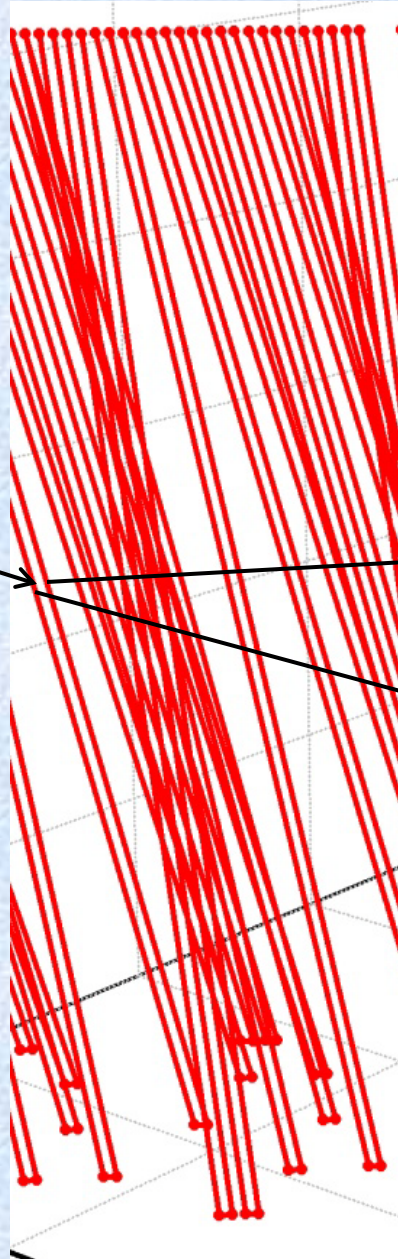




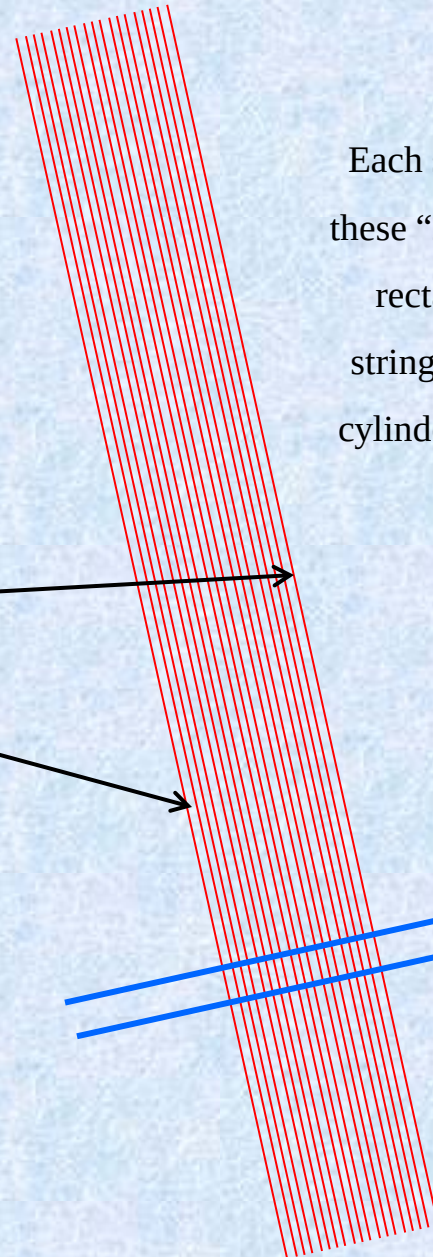
Harp Strings of Illuminated Air



Each pair of lines
drawn represents
shot accumulation
consisting of 2 sec
and 20 laser shots



Each scan pattern has 5 of
these “20 string harps” tilted
rectangles. Each “harp
string” is approximately a
cylinder of 20 cm diameter.



Example of range
gate length, 153.5
m in range, 133 m
in height



DAWN Data Products

All vs. Along-Track Dimension



Near Term Data

1. 5 LOS wind profiles vs. altitude
2. 5 LOS relative aerosol backscatter profiles vs. altitude
3. Profile of u , v , and w vs. altitude (MAIN PRODUCT)

Farther Term

4. Wind turbulence profiles vs. altitude
5. Correlations of wind, wind turbulence, and aerosol backscatter
6. Assimilation of wind data into NWP models (NOAA)
7. Study of near ocean surface velocities (wind, spray, wave, current)
8. Multiple profiles of u , v , and w vs. altitude for investigating wind spatial variability (3 out of 5)

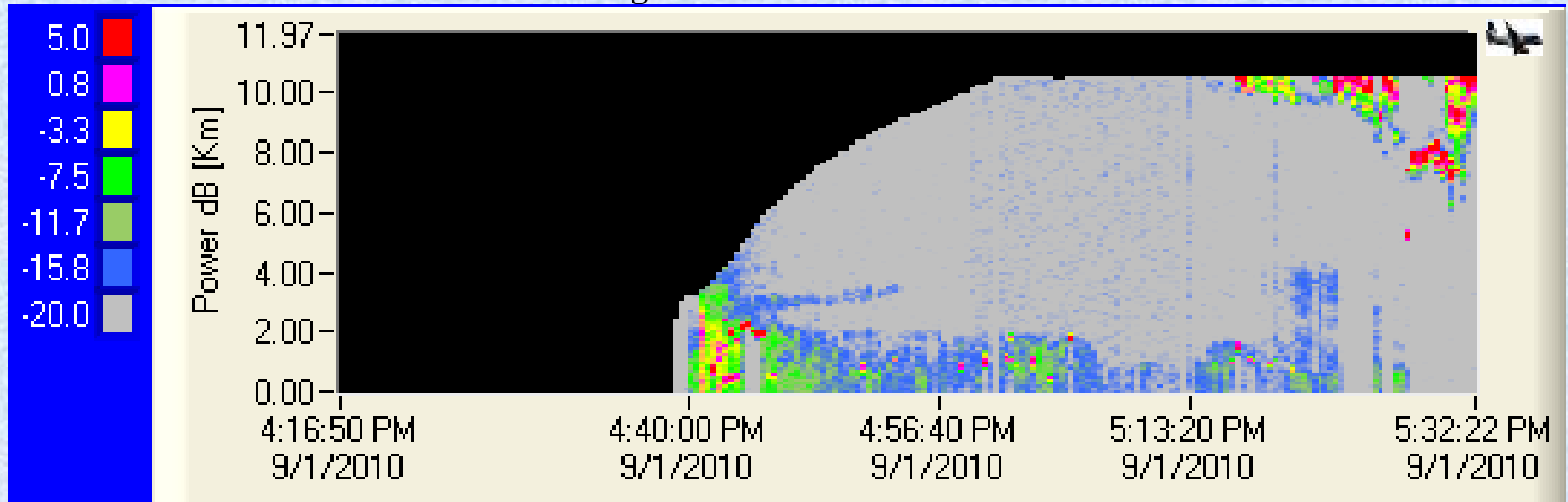
GRIP Science Team

9. Fusion of wind data with other GRIP or non-GRIP data for hurricane research (GRIP science team)



DAWN Vertical Coverage During GRIP

Signal Power of 0 deg. Azimuth Angle
Strong Function of Cloudiness



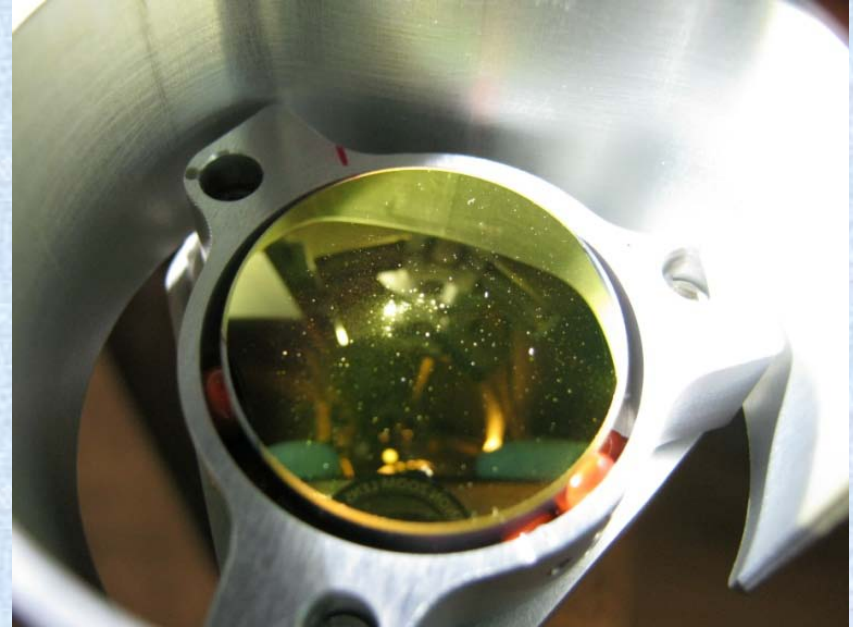
- DC-8 taking off from Fort Lauderdale to fly into Earl
- Signal return affected by aerosol backscatter, atmospheric extinction, and $1/R^2$ (DC-8 altitude)
- Solid gray not measured
- Note almost complete profiles from 5:00 – 5:13 pm Zulu!
- Integration is 20 shots or 2 sec.; more integration would measure more gray
- Probably measure entire profiles next time



Why Entire Profiles Next Time



- Post-GRIP: Discovered burn on telescope secondary mirror likely entire GRIP ~ 10 dB loss. Already fixed 4/28/11.
- Post-GRIP: Discovered slight laser misalignment, at altitude had to cool laser to keep it working. This cooling misaligned the receiver ~ 3 dB loss for most of GRIP. Already fixed.
- Planned 250 mJ, 10 Hz laser but actually 200 mJ, 10 Hz. Already fixed.
- So we effectively flew a $200/10/2 = \underline{10 \text{ mJ, } 10 \text{ Hz}}$ laser
- Next time will be 250 mJ, 10 Hz





DAWN Horizontal Coverage During GRIP



Science Flight	DC-8 Flight Minutes	DAWN Data Minutes	DAWN to DC-8 Fraction
8/17 Zulu	281.2	176.0	0.63
8/24	437.4	368.9	0.84
8/29-30	502.8	427.4	0.85
8/30	399.9	380.6	0.95
9/1-2	478.1	469.15	0.98
9/2	466.5	444.3	0.95
9/6-7	441.2	407.6	0.92
9/7-8	420.8	395.5	0.94
9/12-13	500.4	463.6	0.93
9/13-14	500.6	421.8	0.84
9/14-15	410.8	334.8	0.82
9/16-17	486.4	475.5	0.98
9/17	485.8	422.3	0.87
9/21	443.9	399.6	0.90
9/22	456.2	400.1	0.88
Total	6711.9	5987.1	0.89

DAWN fractions would be slightly higher than shown for DC-8 port shutter open times; and even higher for times spent at science targets

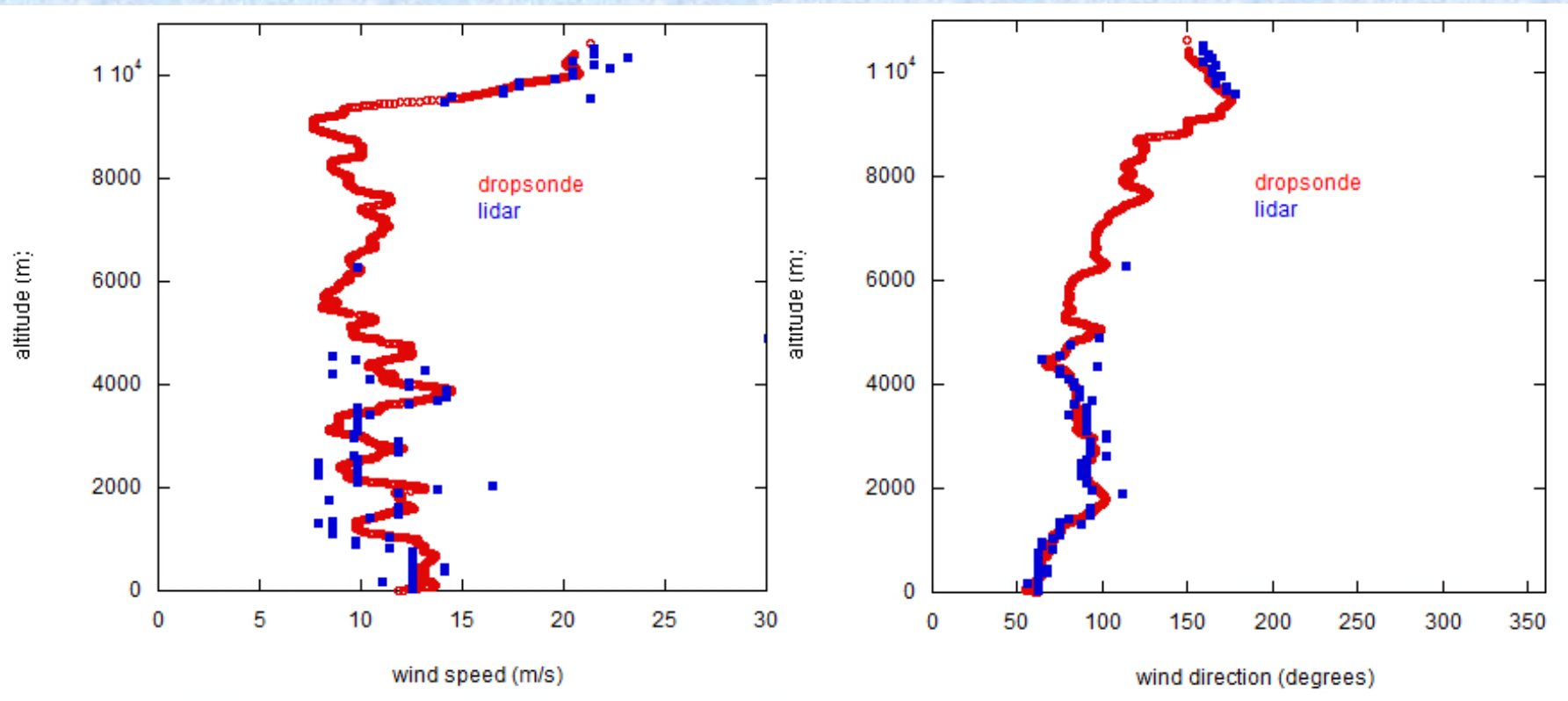
Very roughly: 0.367 min/DAWN scan ... total 16,000 scans ... vs. 328 dropsondes



Example: September 1, 2010

Lidar scan number 120 of data folder 16:17:36

17:20:11 – 17:20:31; 2-axis



Latitude = 29.95 N

Longitude = 75.75 W

GPS Altitude = 10,611 m

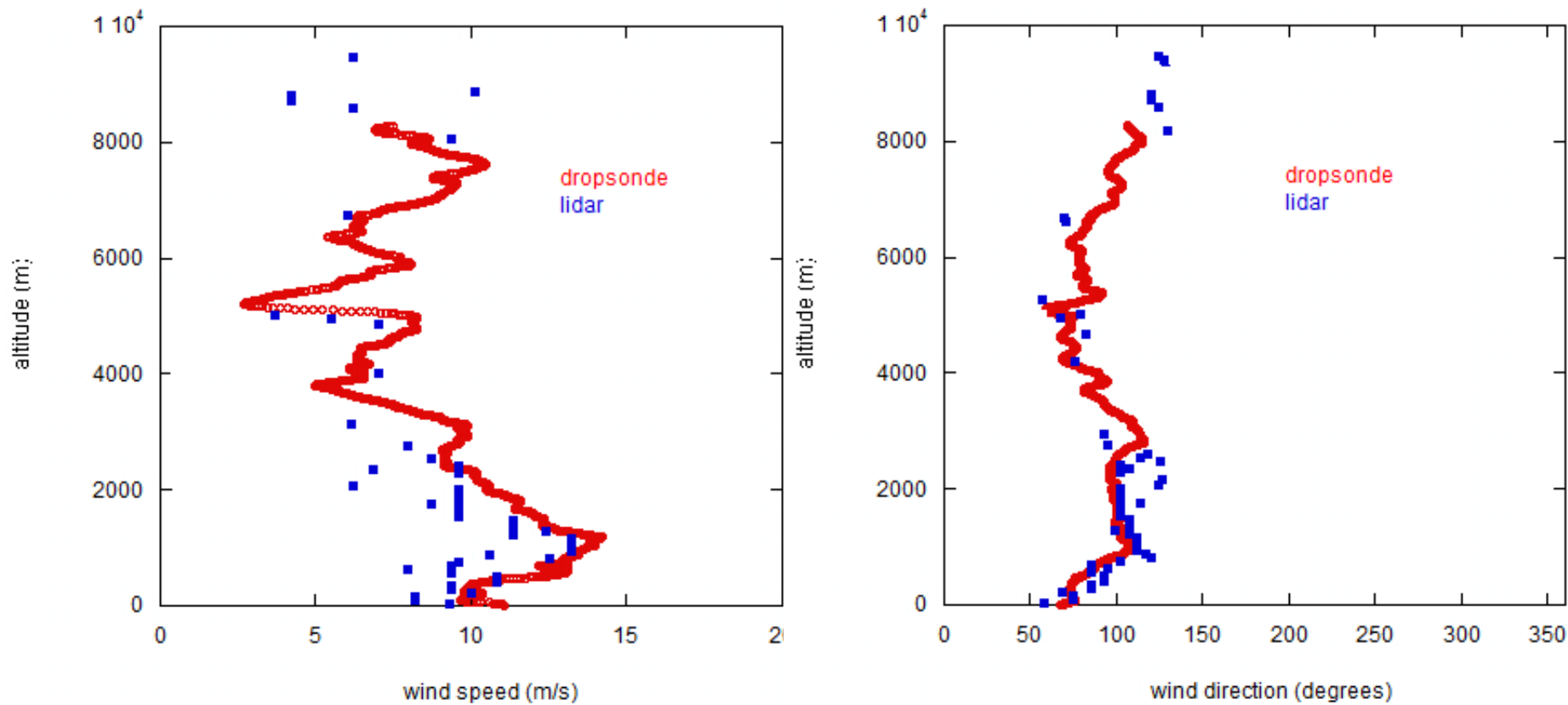
Over Atlantic Ocean

Ground Speed = 224.6 m/s

True Heading = 146 degrees



Example: September 7, 2010
Lidar scan number 74 of data folder 18:30:23
19:24:14 – 19:24:34; 2-axis



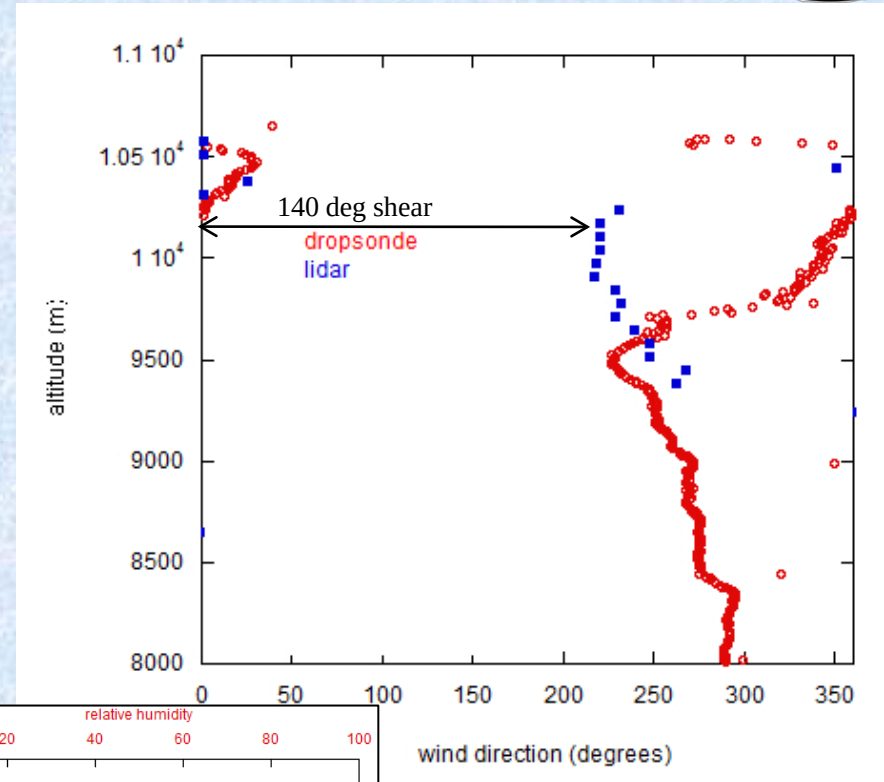
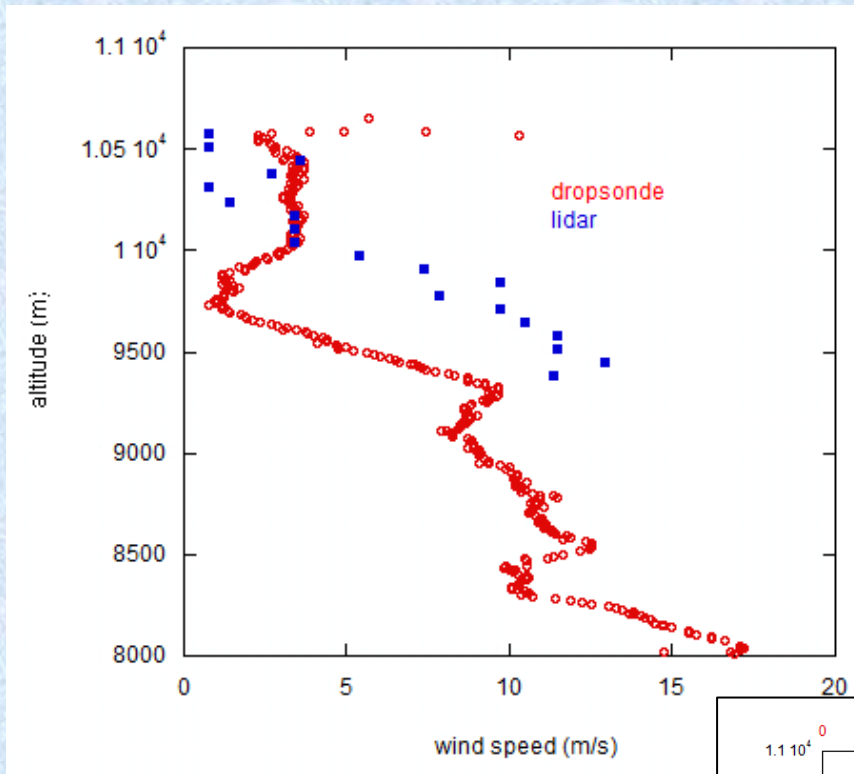
Latitude = 20.418 N
Longitude = 65.7 W
GPS Altitude = 9,673 m
Over Atlantic Ocean
Ground Speed = 218 m/s
True Heading = 88.7 degrees



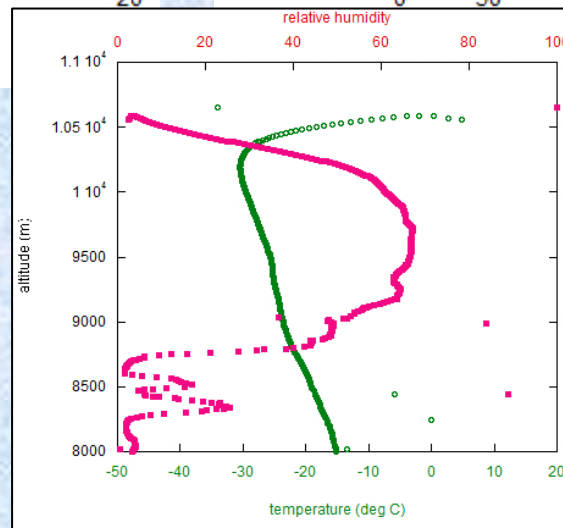
Example: September 2, 2010

Lidar scan number 99 of data folder 16:11:47

16:55:14 – 16:55:33; 2-axis



Latitude = 31.34 N
Longitude = 77.74 W
GPS Altitude = 10,650 m
Over Atlantic Ocean
Ground Speed = 240.5 m/s
True Heading = 76.5 degrees



T and RH, not quality controlled



Data Processing Status



3 Parallel Efforts:

1. LaRC: use only azimuths -45 and +45 deg and assume $w = 0$ (furthest along)
2. LaRC: use all 5 azimuths and solve for w
3. SWA/Emmitt: use all 5 azimuths and assume $w = 0$



Data Processing Enhancements Desired for GRIP Science Team Use



1. Implement noise whitening using actual recorded “laser off” data
2. Implement periodogram zero padding for better multiple shot frequency registration
3. Depending on dropsonde trajectory, combine different altitude regions of several scans for best collocation with dropsonde
4. Implement summation of several successive scan patterns for better vertical coverage
5. Develop combined display with different horizontal resolutions at different altitudes
6. Monitor DC-8 roll and pitch for possible effect on equal altitude combining of different azimuth directions



Conclusions



- Project team worked exceptionally hard to field DAWN in time for GRIP
- DAWN shipped to Palmdale 3 weeks after broken laser rod
- SMD, ESTO, and LaRC provided resources needed to complete job
- DAWN had only one 3-hr shakedown flight before embarking on a science field campaign
- Several encountered problems were triaged to maximize recorded data quantity and quality
- DAWN took data over 90% of science flight time
- Two sources of unexpected SNR loss reduced effective size of DAWN lidar by 13 dB
- Examples of DAWN vs. dropsonde wind data show fundamental correct operation of DAWN
- The instrument problems have already been repaired