Coherent lidar wind measurement activities at NASA Langley

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Working Group on Space-Based Lidar Winds
Boulder, CO USA

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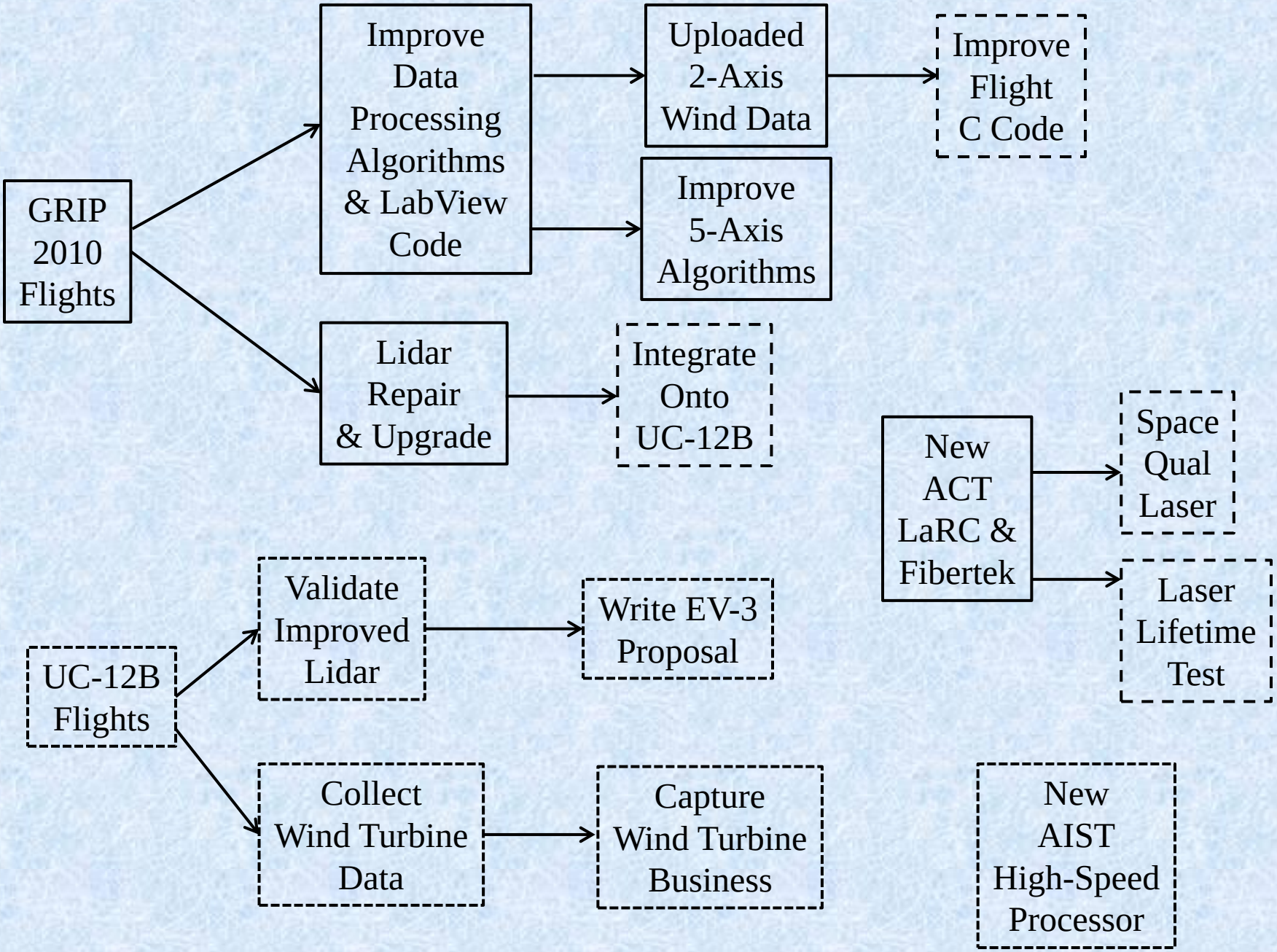
- NASA SMD ESD GRIP Funding
- NASA Langley B&P Funding
- NASA SMD ESTO ACT Funding
- NASA SMD ESTO AIST Funding

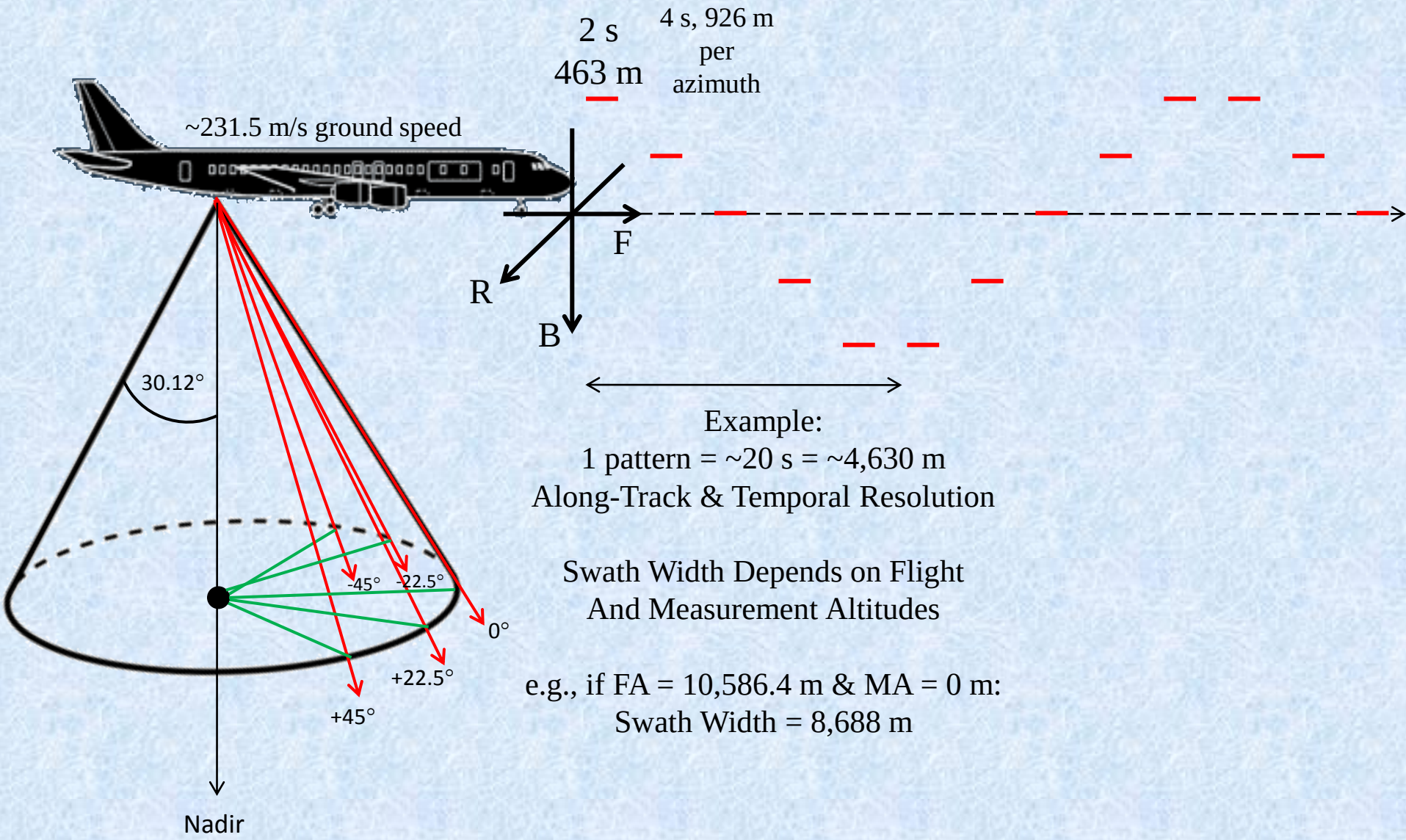
Activities: Past, Present, and Future



Past

Nominal Scan Pattern: DAWN During GRIP Campaign

5 different azimuth angles from -45 to + 45°
2 sec shot integration; 2 sec scanner turn time



Example:
1 pattern = ~20 s = ~4,630 m
Along-Track & Temporal Resolution

Swath Width Depends on Flight
And Measurement Altitudes

e.g., if FA = 10,586.4 m & MA = 0 m:
Swath Width = 8,688 m

GRIP DC-8 and DAWN Wind Lidar: By the Numbers

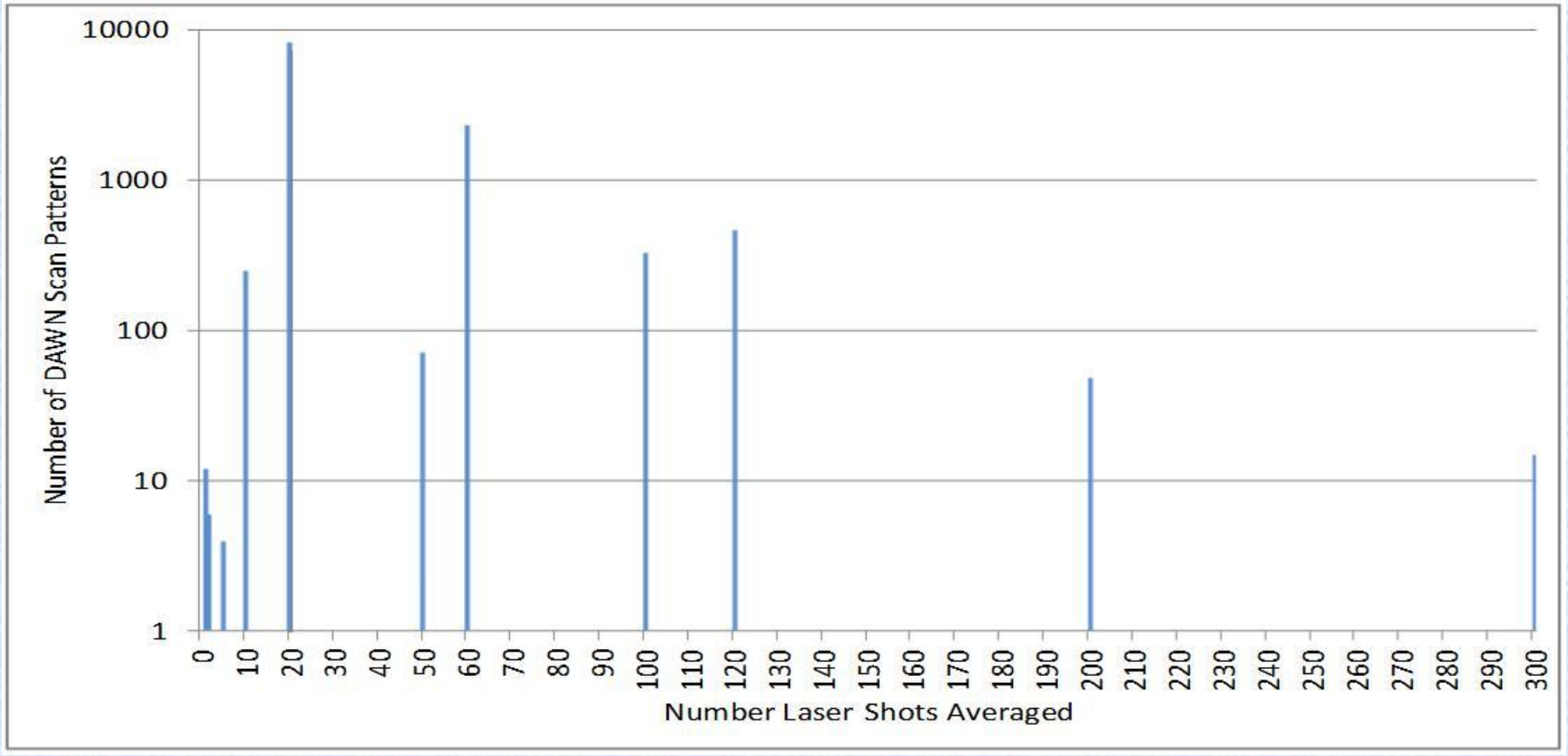
	All Flights	Science Flights
Dates	8/5 - 9/25/10	8/17 - 9/22/10
Flights	25	15
DAWN Scan Patterns*	13,062	11,685
DAWN Laser Shots	2,243,620	2,058,520
DAWN Emitted Photons**	$5.8\ 10^{24}$	$5.3\ 10^{24}$

	Total	Fraction
DC-8 Flight Minutes	6712	5987 (89%) DAWN Collecting Data
DAWN Data Minutes	5987	4634 (95%) Uploaded to GRIP Web Site

*scan pattern yields horizontal wind vertical profile; ~1 dropsonde
**assuming 250 mJ pulses

Lidar Scan Patterns vs. Number Laser Shots Averaged

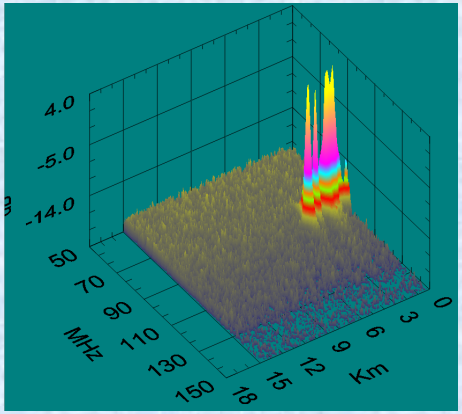
Measurement Time & Horizontal Range Resolution



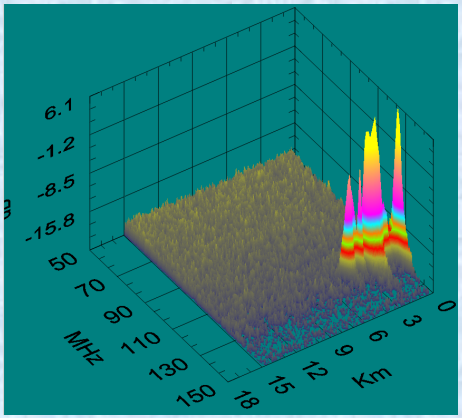
Shots Averaged	Scan Pattern Time	If V_{DC8} = 450 knots = 231.5 m/s
20	20 s	4.6 km
60	40 s	9.3 km
120	70 s	16.2 km

August 24, 2010; Data Folder 143213; Scan Pattern 1
60 laser shots averaged
Periodograms shifted to remove laser jitter before averaging

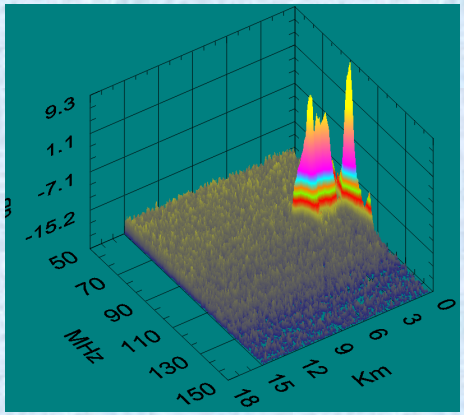
-45 Azimuth 1

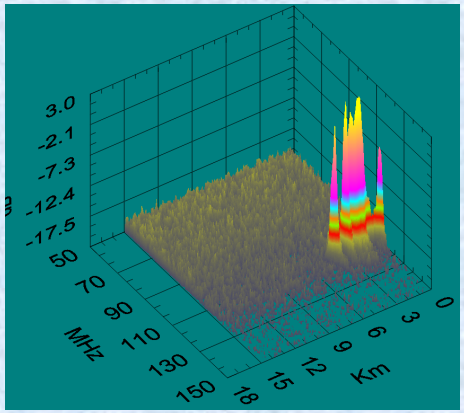


0 Azimuth 3

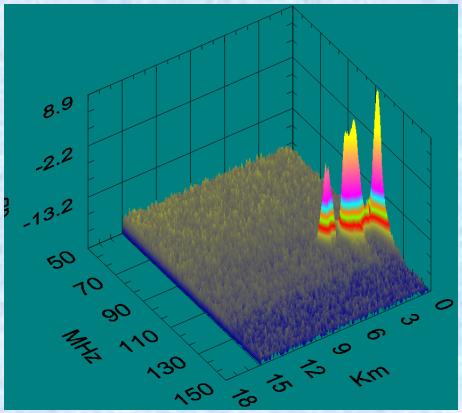


45 Azimuth 5





-22.5 Azimuth 2



22.5 Azimuth 4

$$f_{SIGDET} = \left|\left[\left(f_{SEED} + f_{JITTER}\right) + f_{AIRCRAFTLOS} + f_{WINDLOS}\right] - f_{SEED}\right|$$

$$= \left|f_{JITTER} + f_{AIRCRAFTLOS} + f_{WINDLOS}\right| = f_{JITTER} + f_{AIRCRAFTLOS} + f_{WINDLOS} \approx f_{AIRCRAFTLOS} + f_{WINDLOS} \approx f_{AIRCRAFTLOS}$$

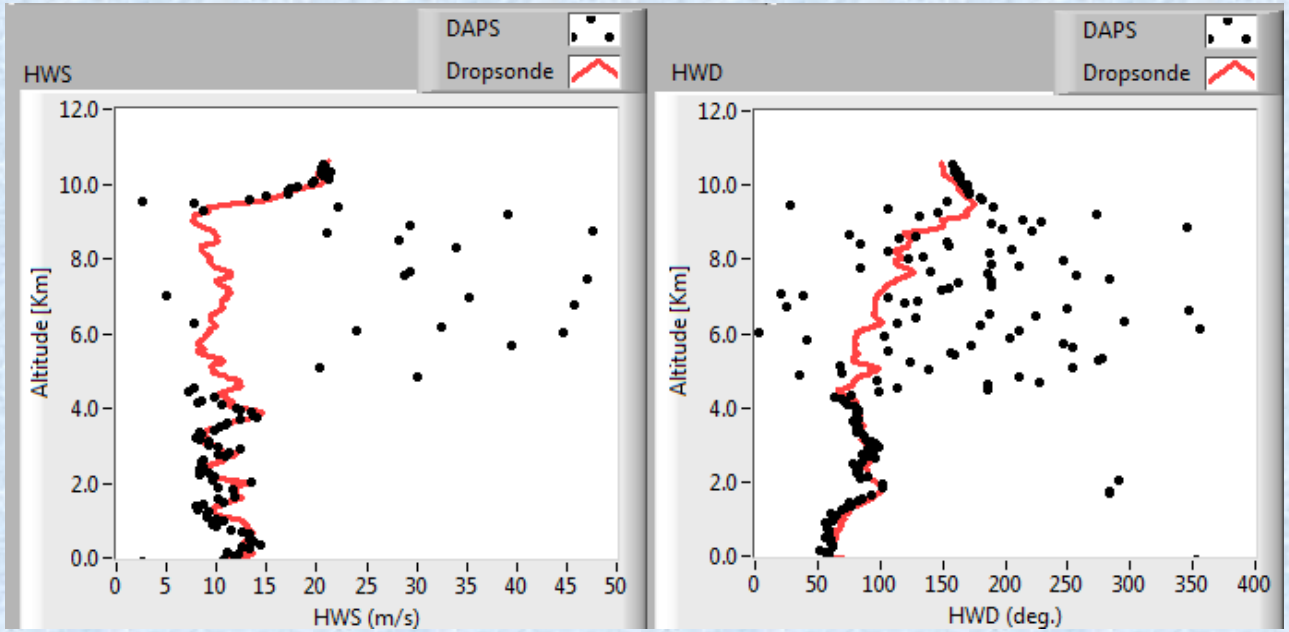
Zero drift angle predicted $f_{AIRCRAFTLOS}$ for 231.5 m/s are: 80, 105, 113, 105, 80 MHz

Example: Comparison DAWN to Dropsonde

9/1/10, data folder 161736, 20 shots averaged, 5.1 km resolution, Earl

Dropsonde Time		Time Since Last Dropsonde (min)	Dropsonde File Names			FOLDER NUMBER FIRST	SECOND	DROP TIME SCAN NUMBER	N
172015	12.6	12.6	D20100901_172015_PQC.eol			20100901	161736	120	20

12 km



N = number shots averaged

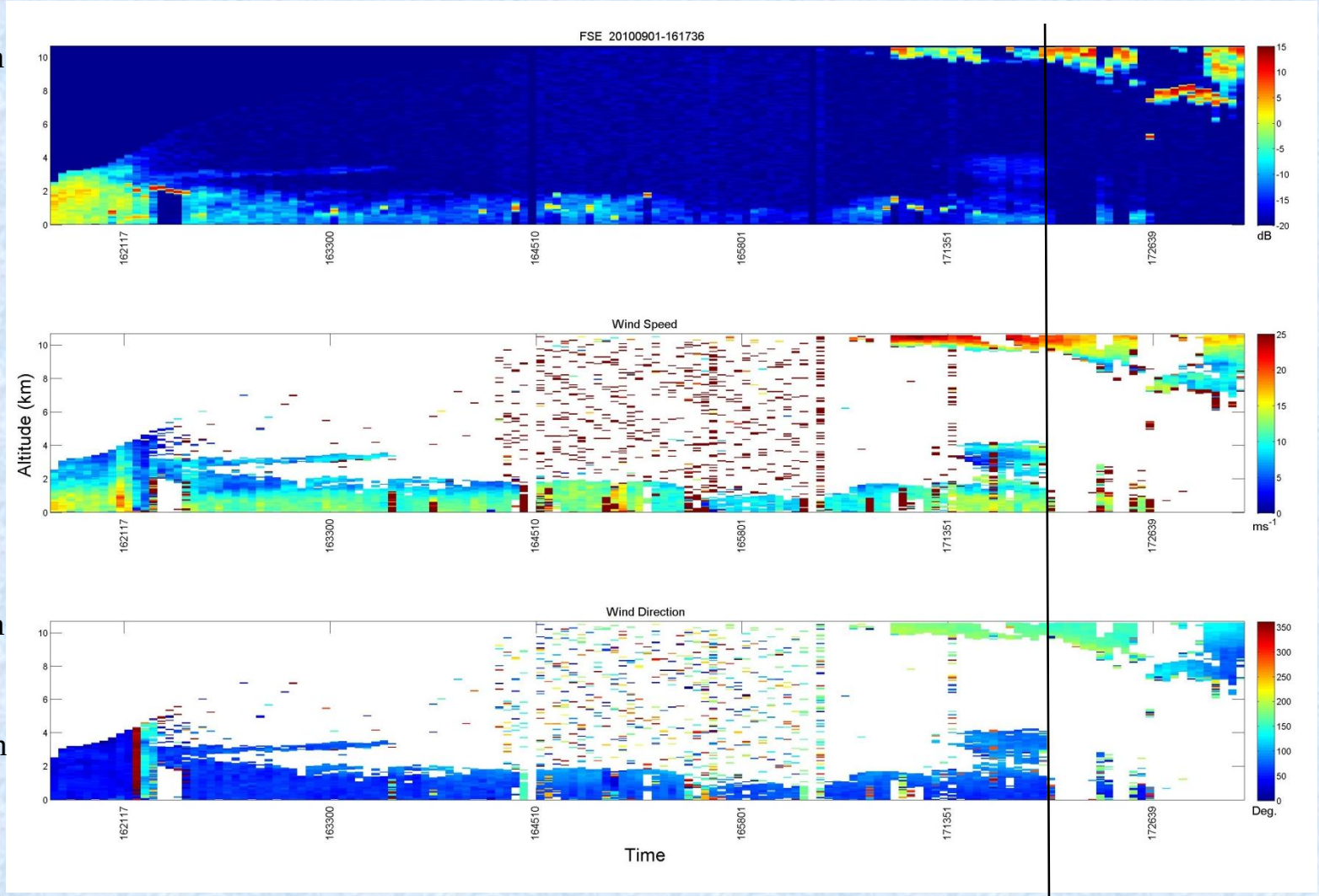
Agreement near the DC-8 and 0 – 4 km altitude

Example: Vertical Slice, ~ 75 Minutes Duration, 20 Shots Averaged, ~5.1 km Resolution, Taking off from Ft. Lauderdale, Earl

9/1/10, data folder 161736

10 km

Energy



10 km

Speed

25 m/s

10 km

Direction

Region of relatively high aerosol backscatter

~ 17:20:15 dropsonde launch time of previous slide

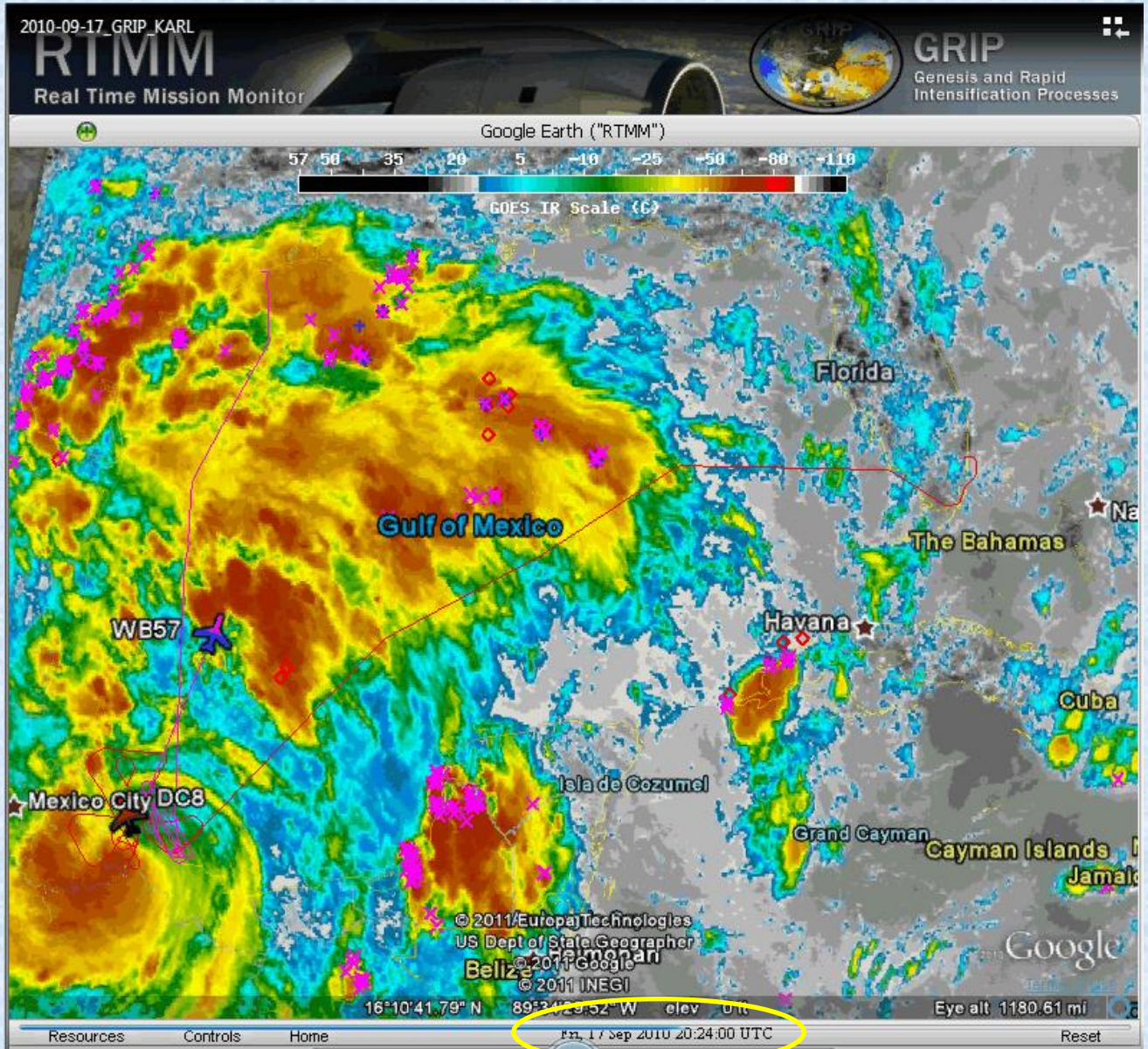
This is the uploaded data type
FSE = Frequency-domain signal energy estimate

Example: Vertical Slice, ~ 163 Minutes Duration, 100 Shots Averaged, ~14.4 km Resolution, Karl, No Visible Eye

9/17/10, data folder 174448

End of next slide data,

repeated flight legs shown

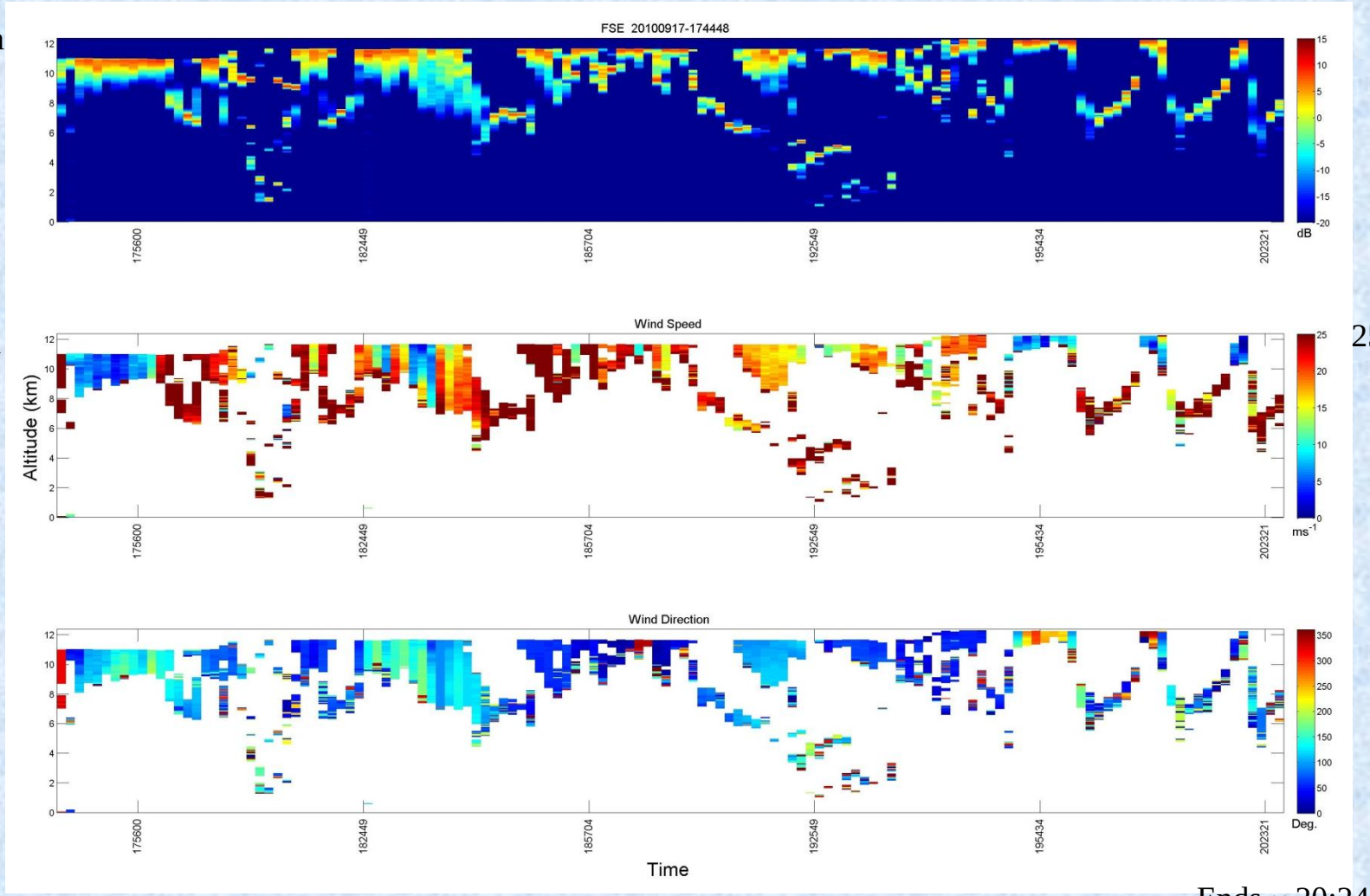


Example: Vertical Slice, ~ 163 Minutes Duration, 100 Shots Averaged, ~14.4 km Resolution, Karl, No Visible Eye

9/17/10, data folder 174448

12 km

Energy



12 km

Speed

25 m/s

12 km

Direction

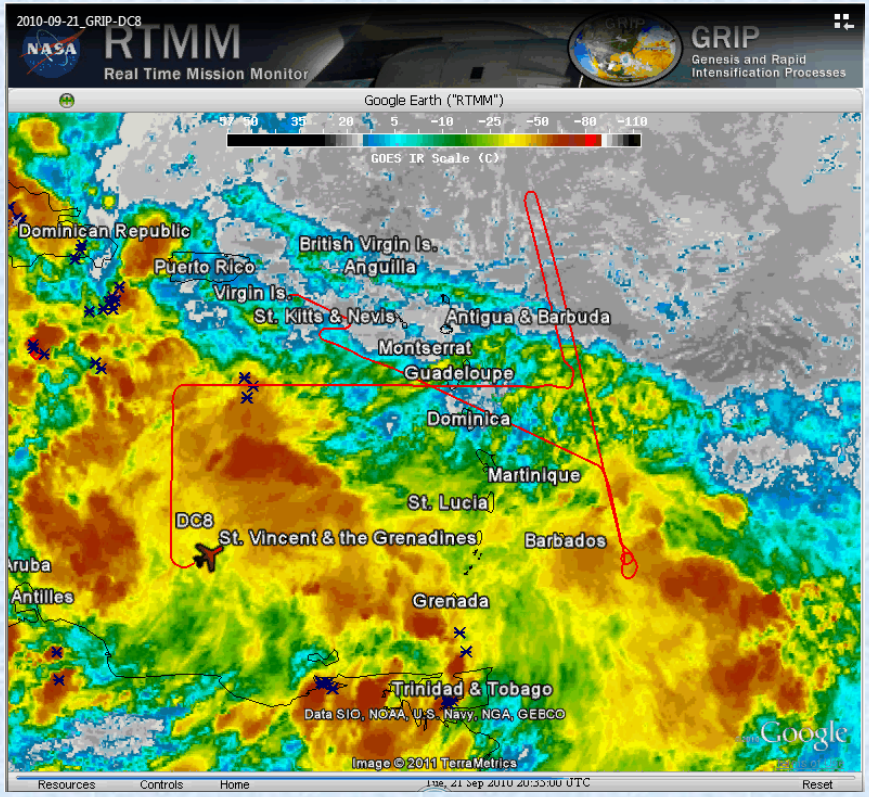
Ends ~ 20:24:00

Note: ascending and descending clouds; lots of repeated flight legs

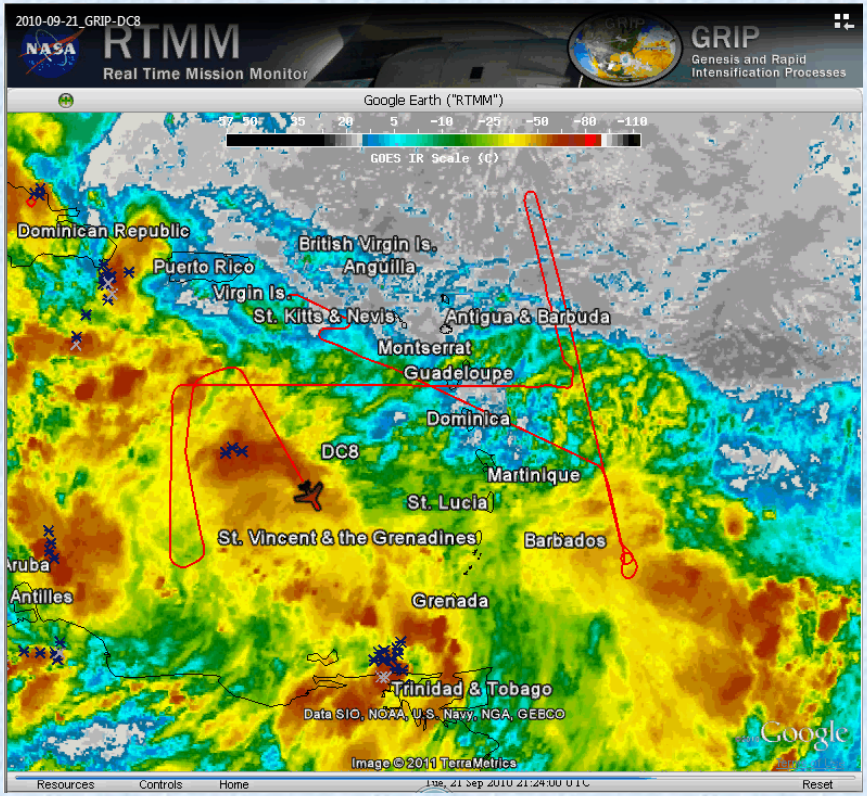
Example: Vertical Slice, ~ 202 Minutes Duration, 60 Shots Averaged, ~9.7 km Resolution, PG146, AL95, No Visible Eye

9/21/10, data folder 192329

Complete Circle of Wind Direction (see next slide)



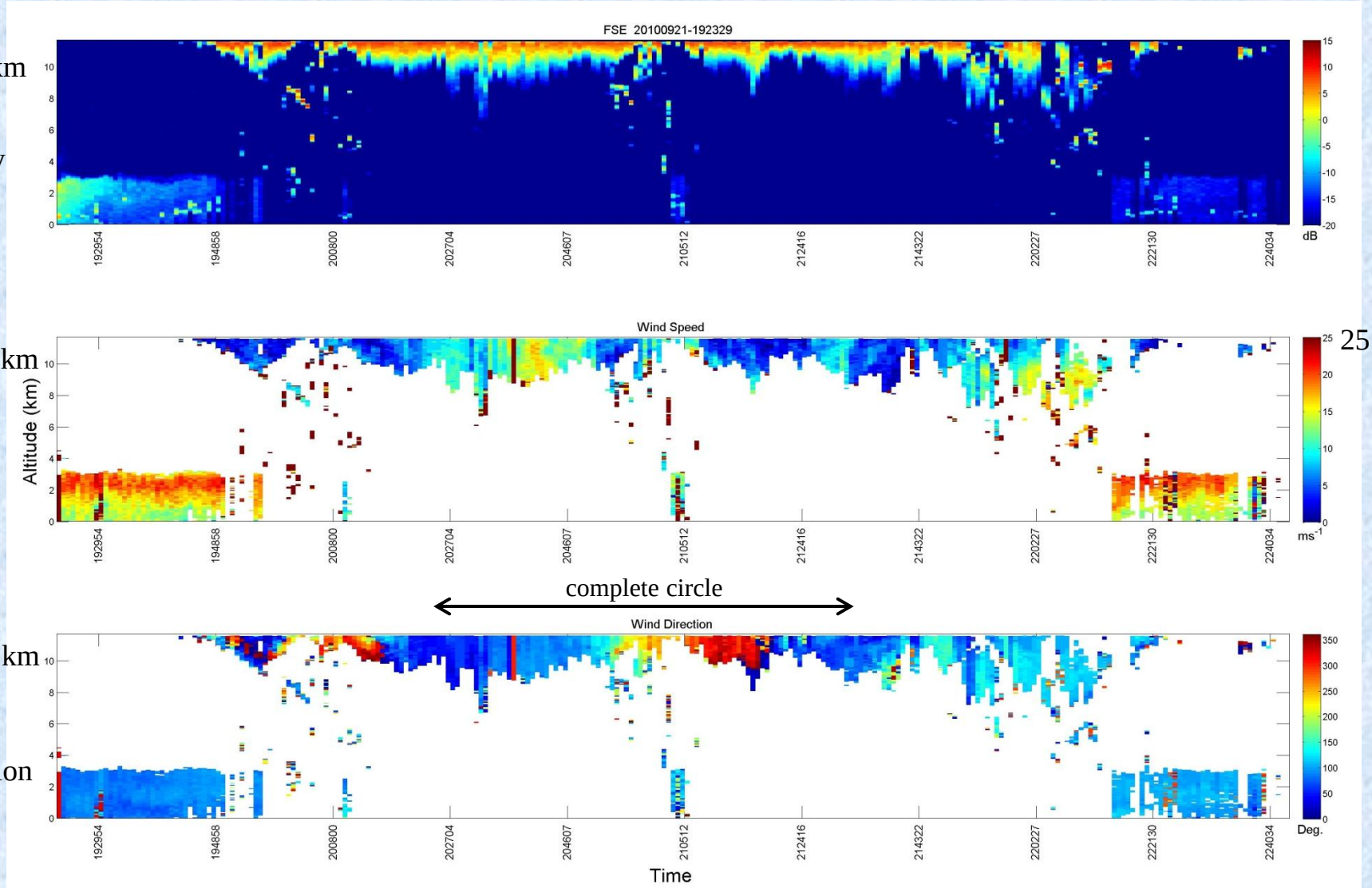
20:35:00, ~Begin



21:24:00, ~End

Example: Vertical Slice, ~ 202 Minutes Duration, 60 Shots Averaged, ~9.7 km Resolution, PG146, AL95, No Visible Eye

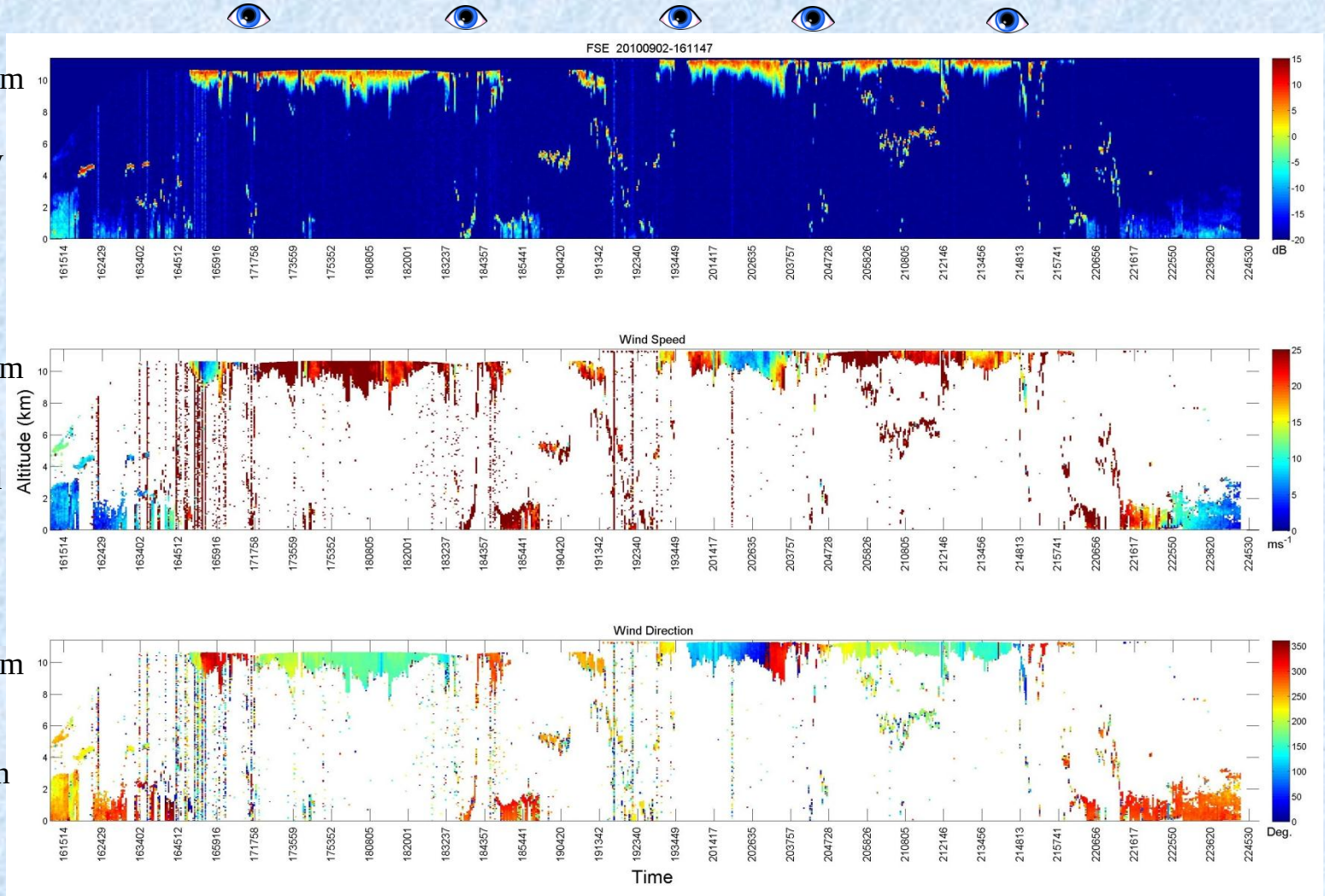
9/21/10, data folder 192329



Note: complete direction sweep centered ~ 21:00:00; wind measurement extends below obvious FSE; BL to cloud deck transitions

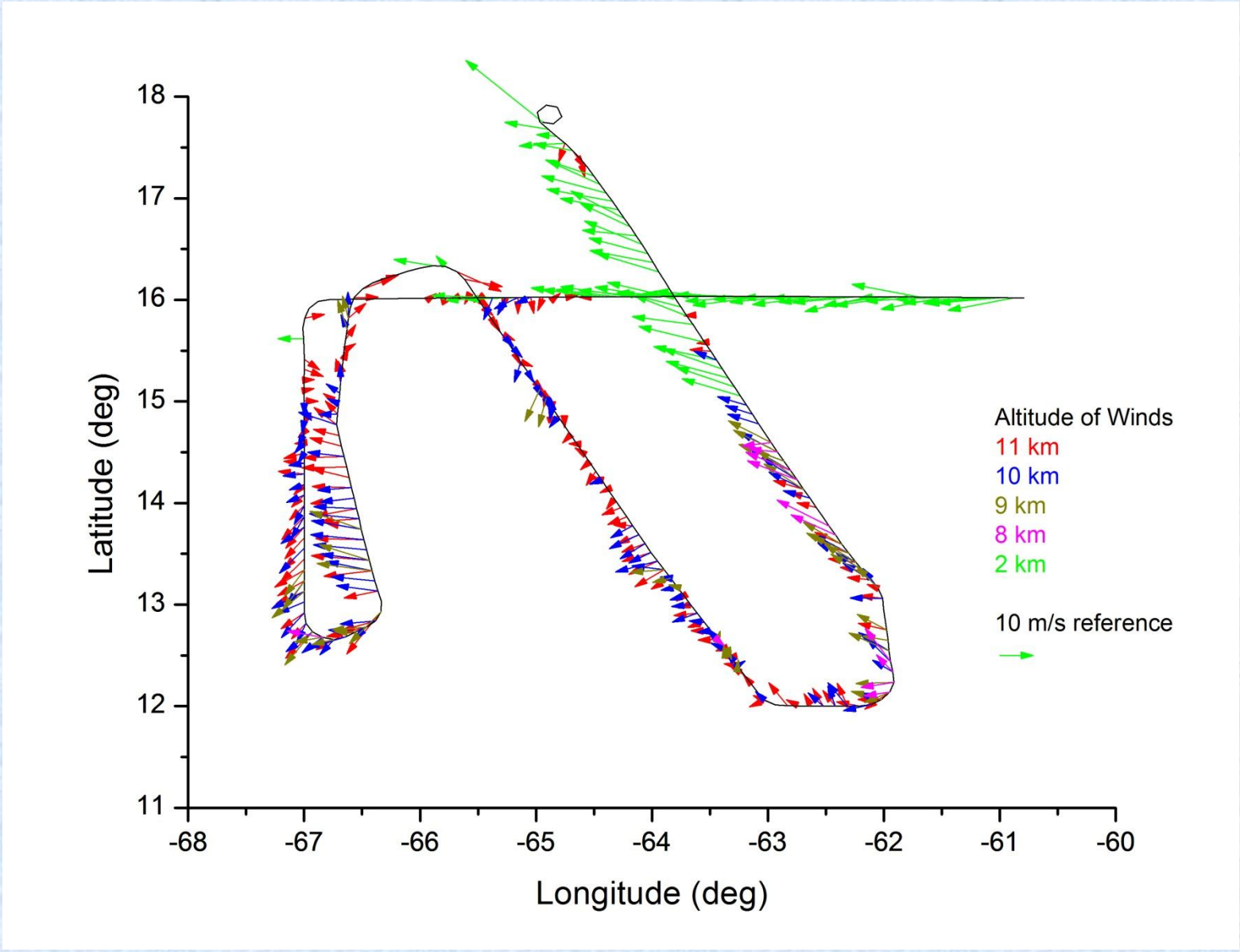
Example: Vertical Slice, ~ 396 Minutes Duration, 20 Shots Averaged, ~5.1 km Resolution, Earl, Visible Eye

9/2/10, data folder 161147



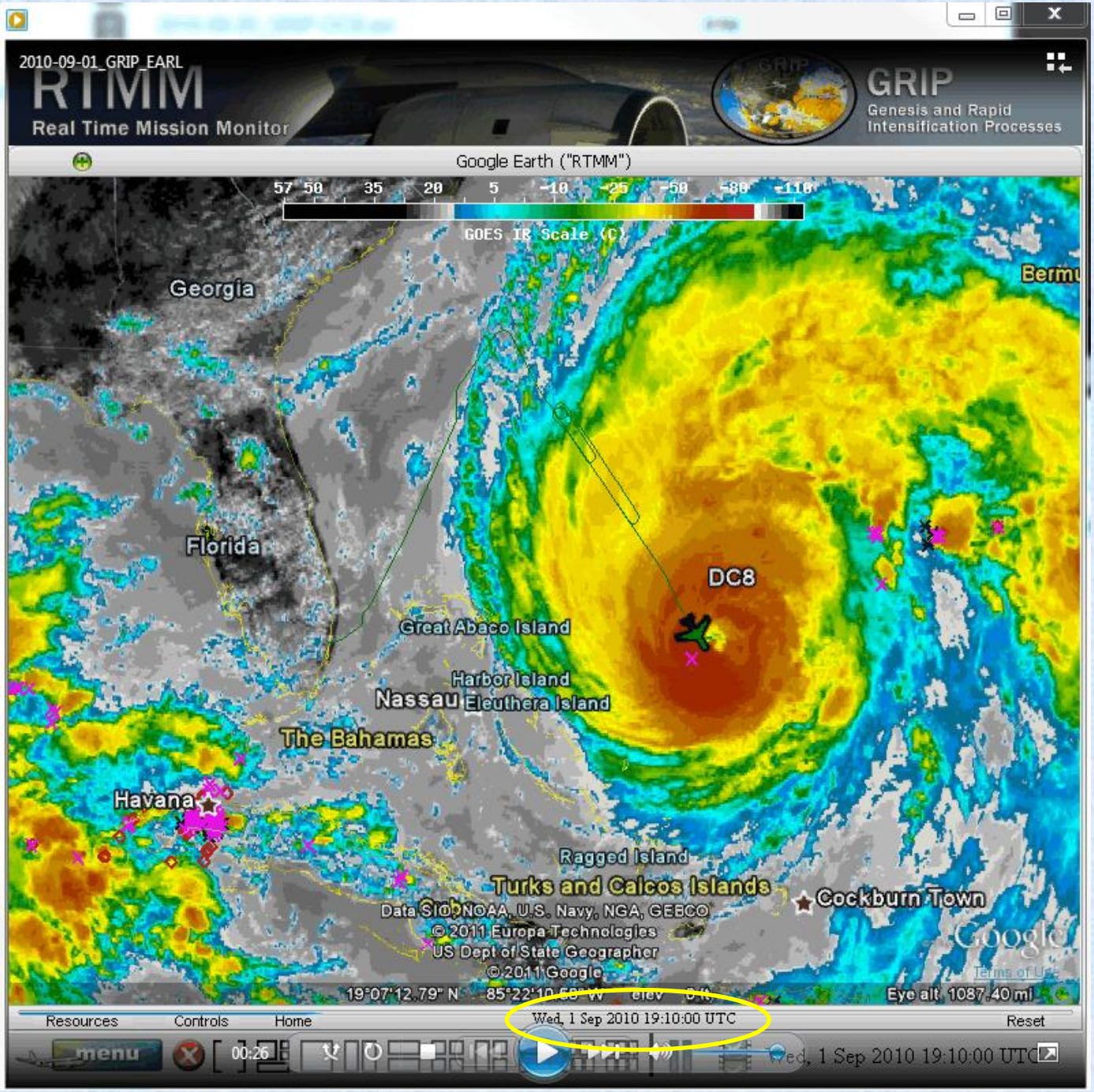
Note: eye clearly seen in lidar data; some eye sidewall winds, MBL & cloud layers at 5 km; 791 scan patterns

Example: Comparison of 5 Constant-Altitude Slices
9/21/10, data folder 192329, 60 shots averaged, ~202 minutes duration,
~ 285 horizontal wind profile attempts



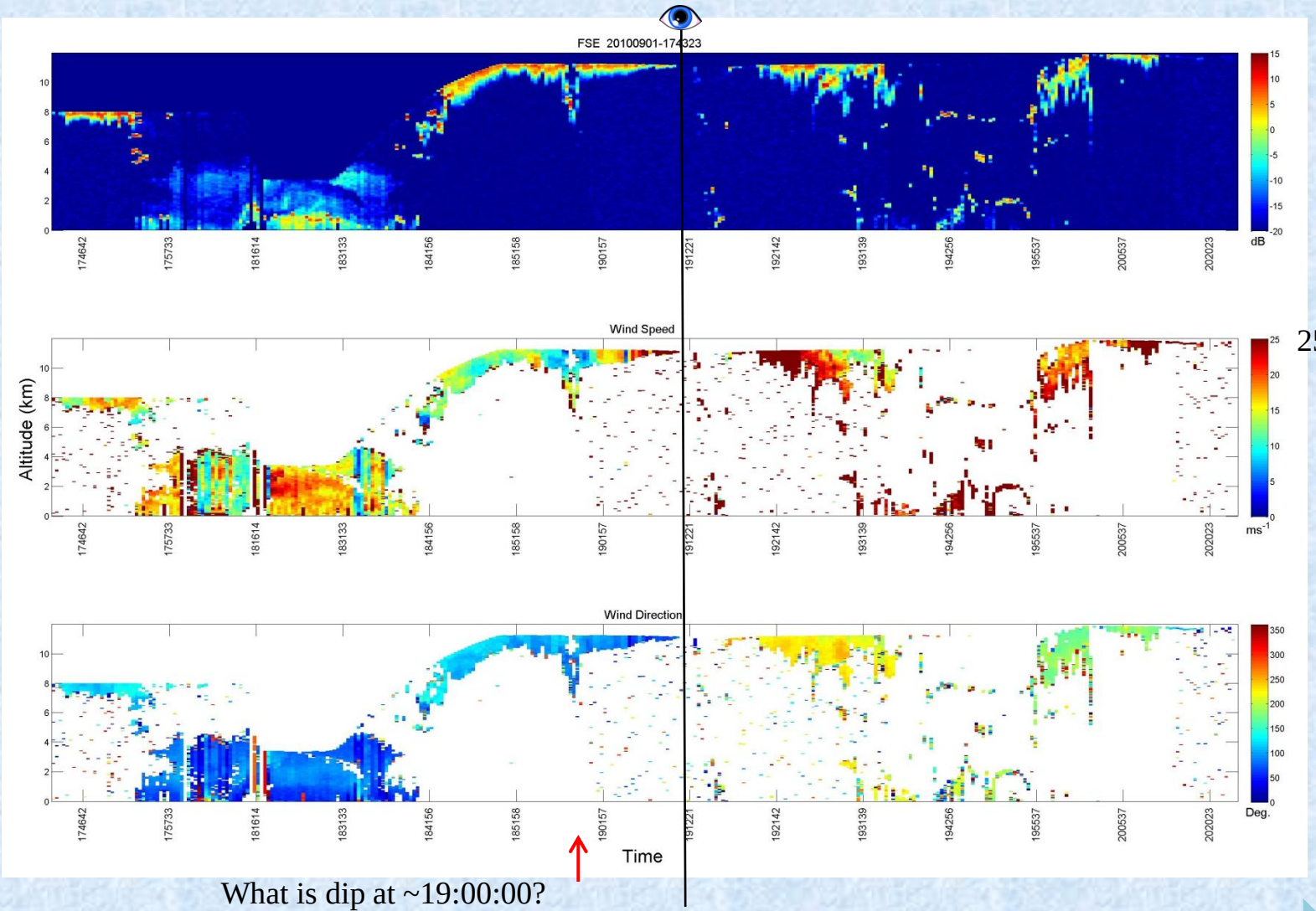
Example:
Crossing Hurricane Earl Eye

9/1/10
Eye crossing of Earl at ~19:12:00 Zulu



Example: Crossing Hurricane Earl Eye
9/1/10 Eye Crossing of Earl at ~19:12:00 Zulu

9/1/10, data folder 174323



25 m/s

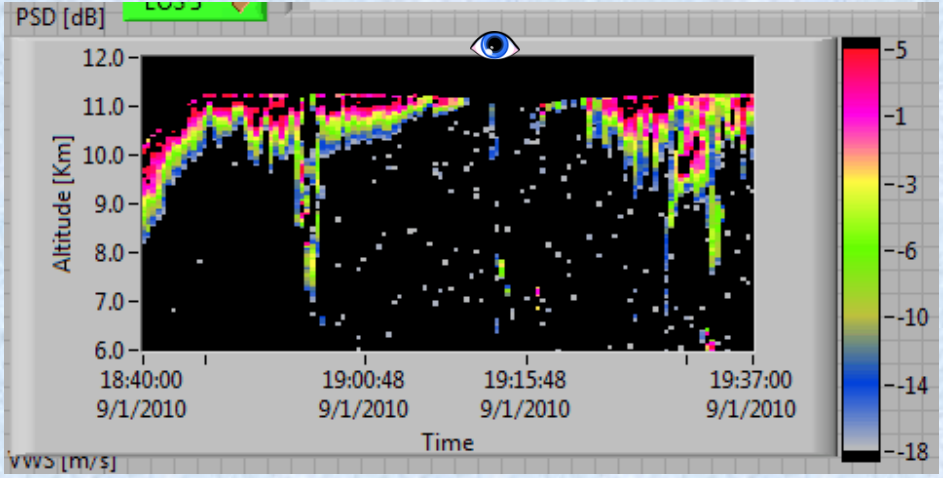
What is dip at ~19:00:00?

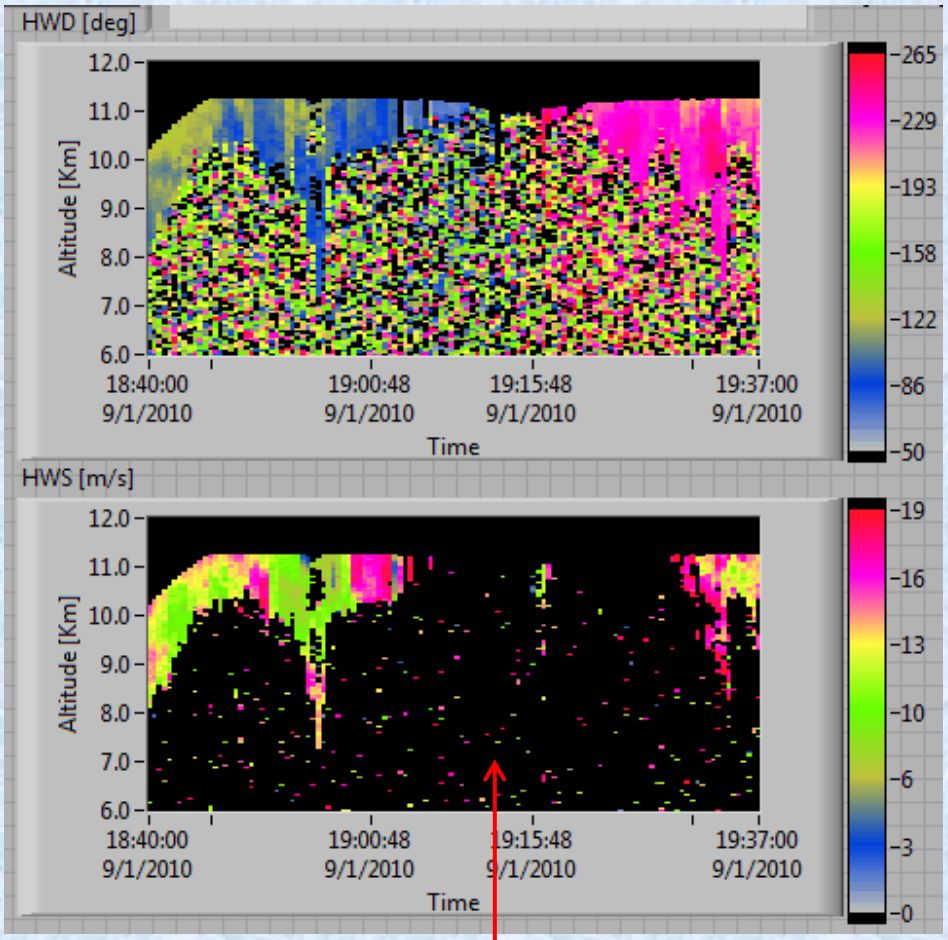
~19:12:00 Zulu

Energy

Direction

Speed





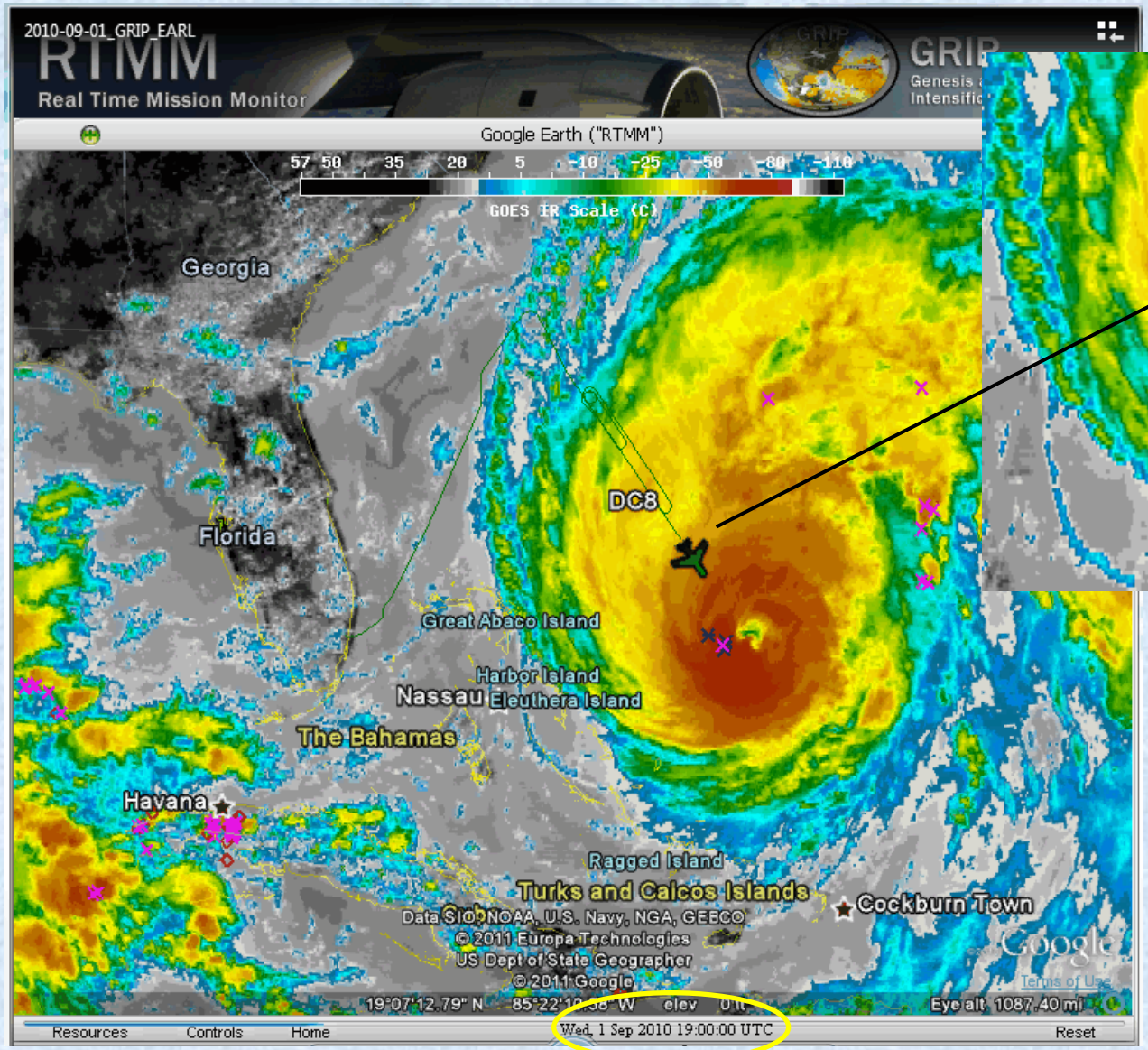
9/1/10 Eye Crossing

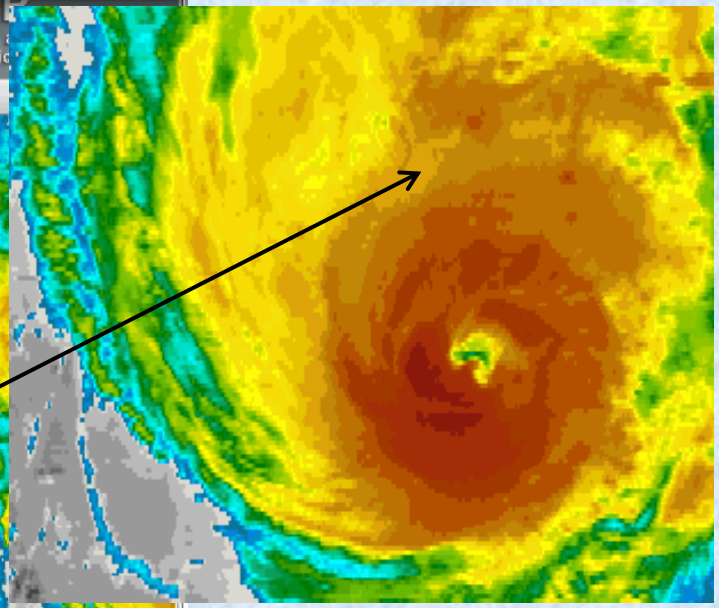
Zoom in Altitude,
Zoom in Color Bars

- ~ 150 deg wind direction change across eye
- Slower wind magnitude at dip
- Higher wind magnitude down low in dip

9/1/10 Eye Crossing

What is Dip at ~ 19:00:00?

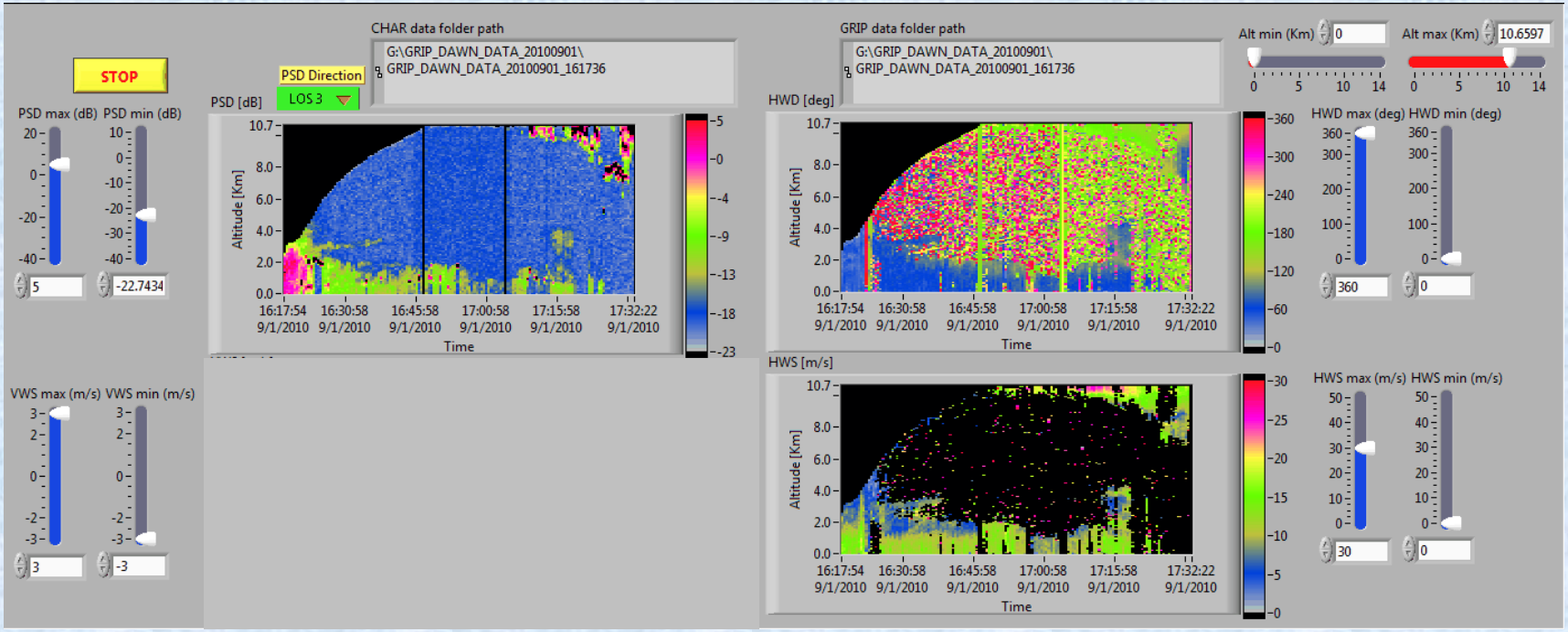




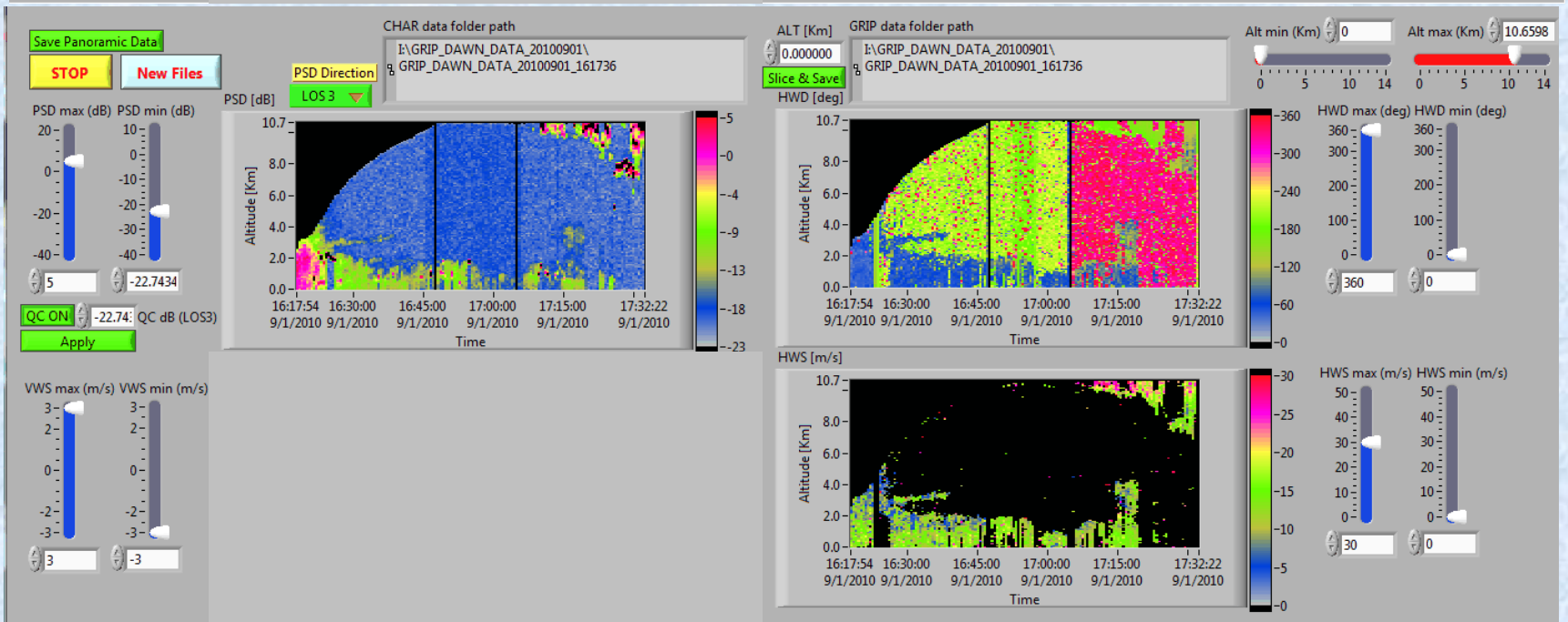
- NOAA: "In an infrared image, cold clouds are high clouds"
- ∴ Warmer region is lower clouds, hence the dip

Comparison: 2-axis vs. 5-axis

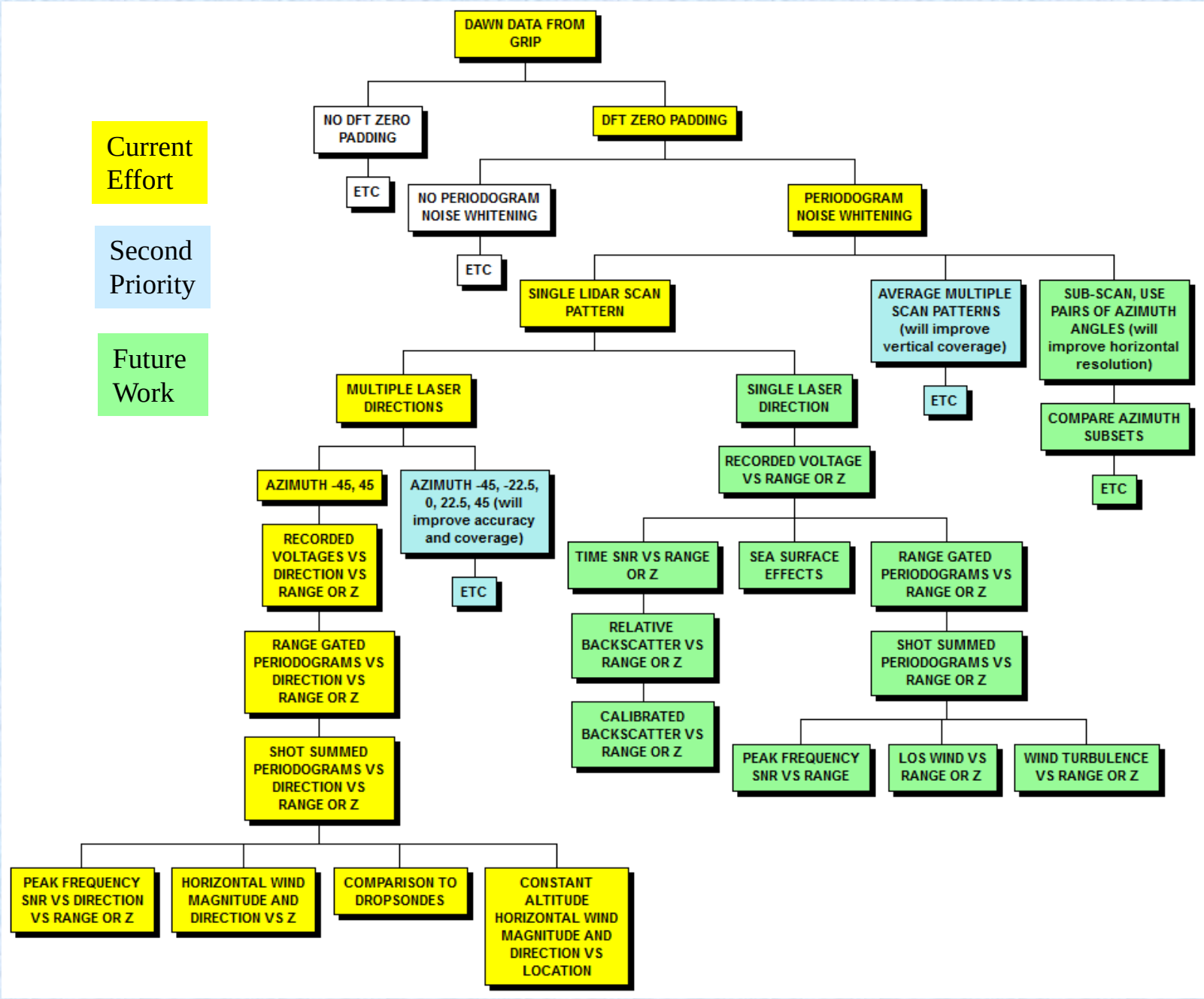
2-axis



5-axis



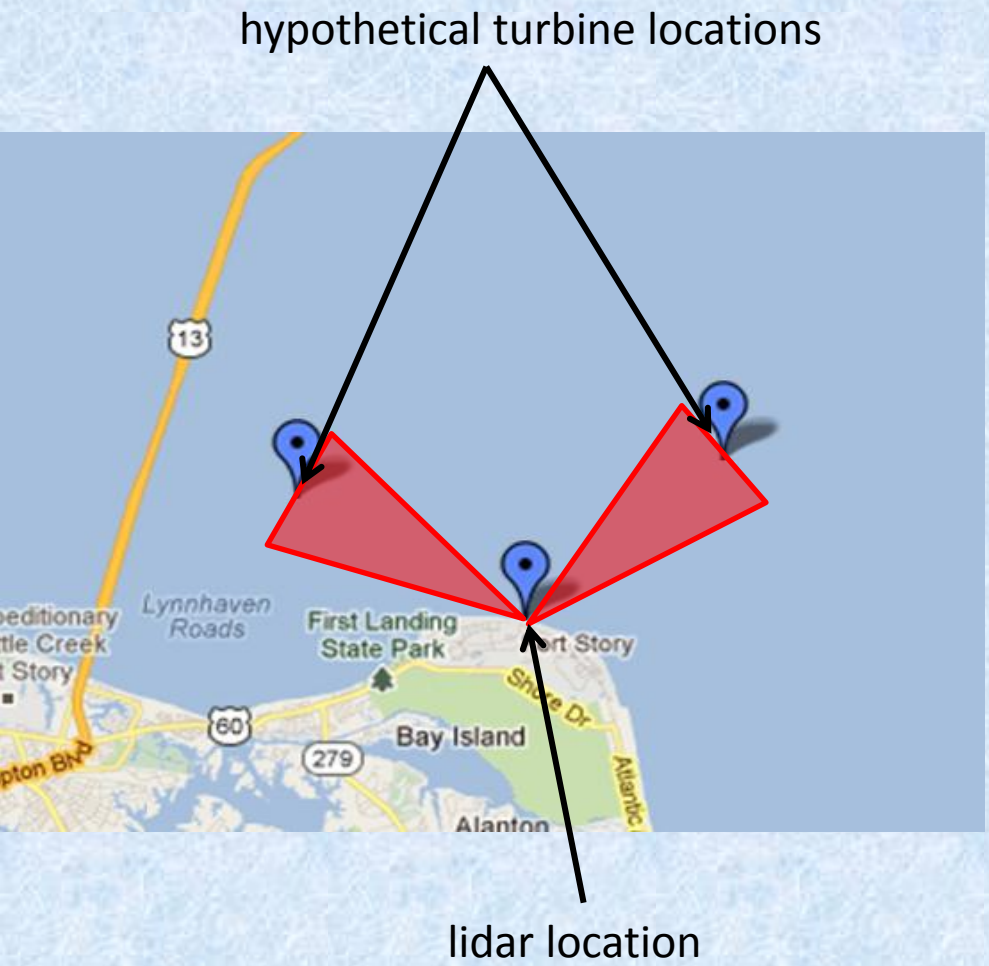
DAWN Data Processing Outline. All Data vs. Along-Track Dimension



Present

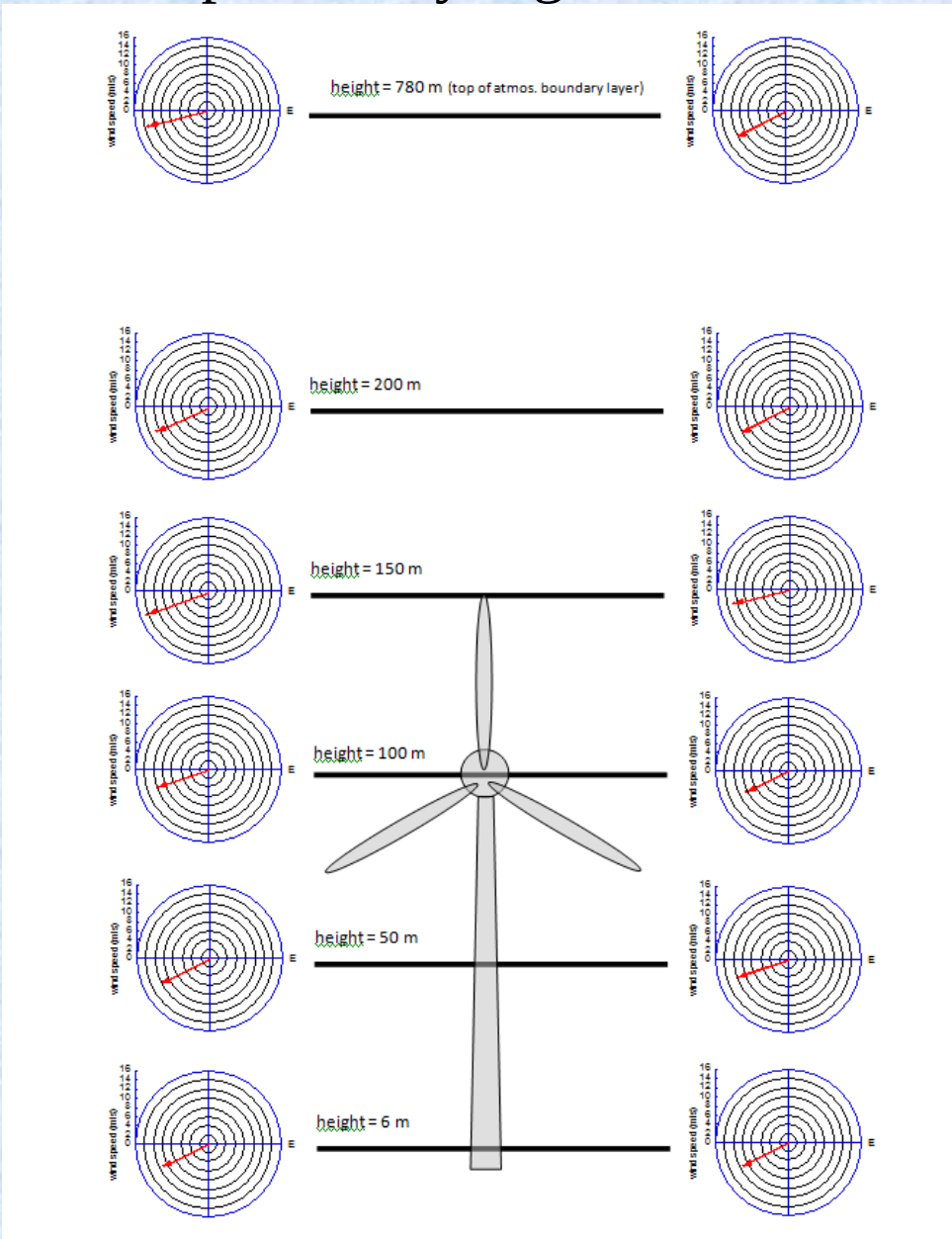
Field Test for Offshore Wind Energy Application

Oct 2011, Fort Story, VA



- in following measurement example lidar is scanned +/- 15 degrees, centered at two different bearings.
- one bearing at 49-degrees is toward a hypothetical turbine in Atlantic Ocean.
- second bearing at 300-degrees is toward a hypothetical turbine in Chesapeake Bay.

Example Height Profile: Scanning Two Turbine Locations (left Chesapeake Bay, right Atlantic Ocean)



detailed description recently published in Journal of Applied Remote Sensing Vol. 6 (2012)

Design and Fabrication of a Breadboard, Fully Conductively Cooled, 2-Micron, Pulsed Laser for the 3-D Winds Decadal Survey Mission

PI: Dr. Upendra N. Singh, NASA Langley Research Center ($1.2M, 2012-2015)

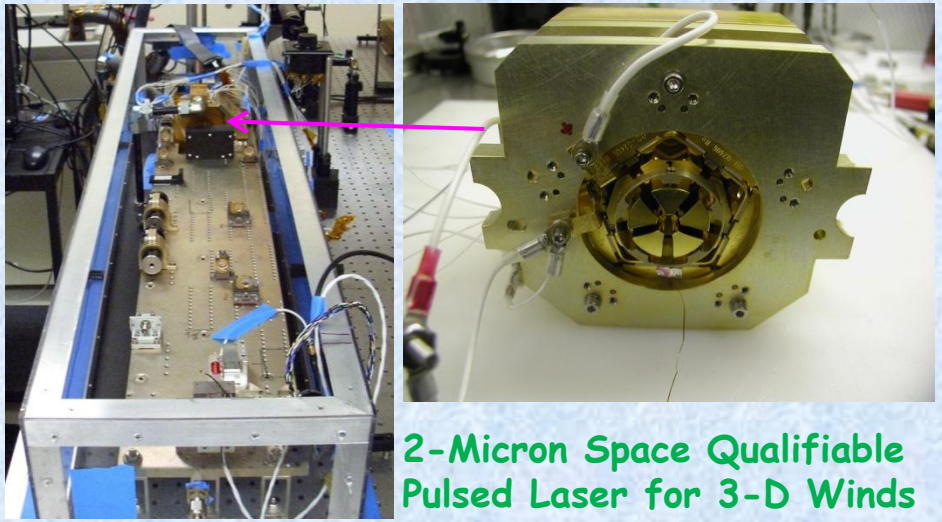
- New ACT
- 5/7/12 – 5/6/15
- Fully conductively cooled
- ISS or FF capable
- 1-meter cavity for less risk
- 808 nm pump LDAs already demonstrated in space
- 250 mJ, 10 Hz better than space mission requirement
- Follow CALIPSO successful model:
  - Fibertek
  - Space qualification at Langley
  - Life testing at Langley

Design and Fabrication of a Breadboard, Fully Conductively Cooled, 2-Micron, Pulsed Laser for the 3-D Winds Decadal Survey Mission

PI: Dr. Upendra N. Singh, NASA Langley Research Center ($1.2M, 2012-2015)

Objective

- Advance the 2-micron pulsed laser technology needed for the NRC Decadal Survey 3-D Winds mission
- Design and Fabricate a space-qualifiable, fully conductively cooled, breadboard laser with parameters matching those needed for the 3-D Winds mission
- Utilize improvements including high-power, long life space proven 804 nm pump diodes; derated diode operation, and heat pipe conductive cooling
- Perform vacuum and lifetime testing of laser



2-Micron Space Qualifiable Pulsed Laser for 3-D Winds

Approach:

- Utilize LaRC knowledge after 2 decades of 2-micron laser development
- Utilize Fibertek knowledge after successful design and development of CALIPSO flight laser
- Leverage parts and materials from ESTO funded LRRP and SMD funded IPP projects
- Upgrade Fibertek laser design for IPP laser
- Utilize space ready cylindrical package of IPP laser
- Perform vacuum and lifetime tests to meet the requirements of the 3-D Winds mission

CoIs: LaRC: Jirong Yu, Michael Kavaya, **Other:** Floyd Hovis, Tim Shuman, Fibertek, Inc.

Key Milestones

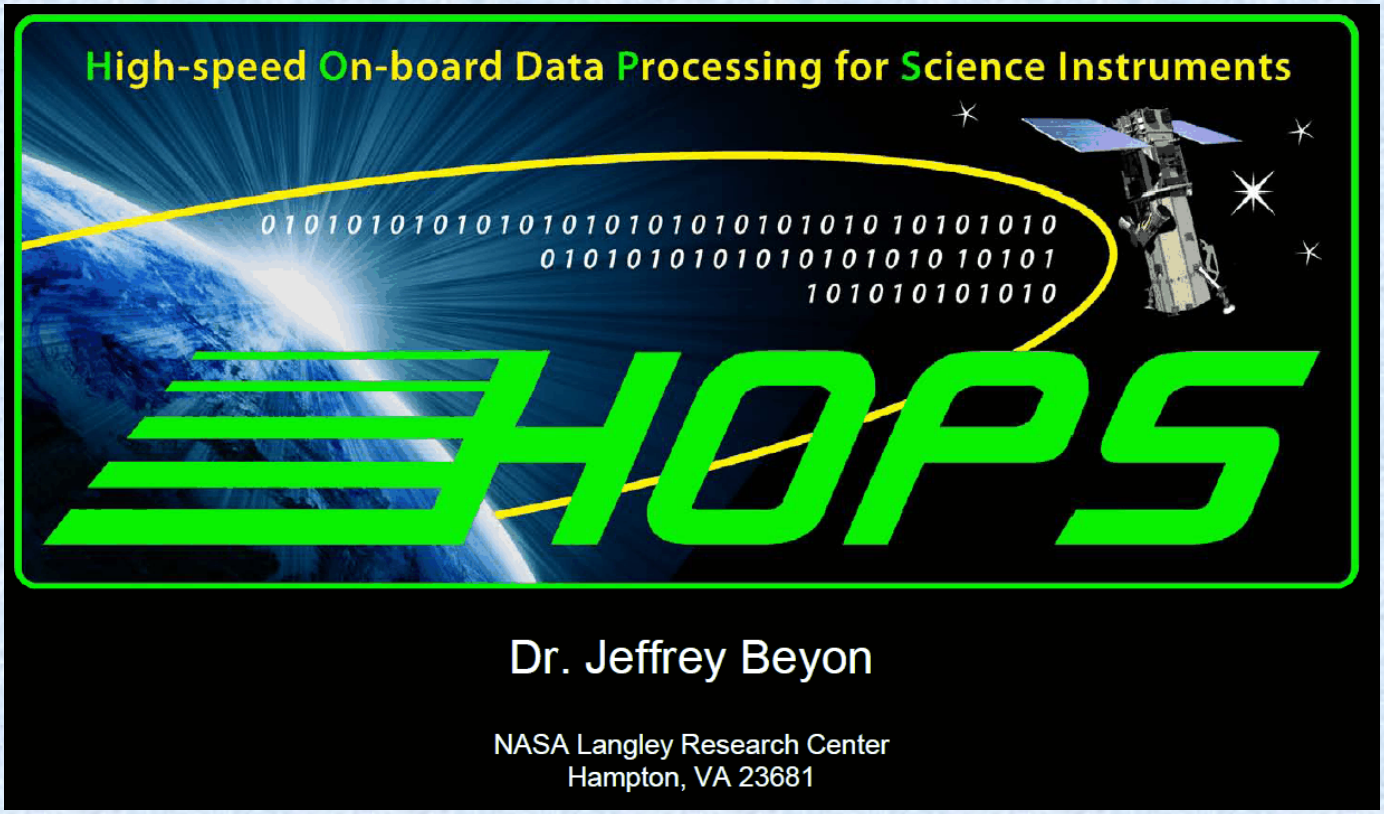
- Complete laser mechanical design update and improved laser thermal modeling — Y1Q3
- Complete assembly & test of heat pipe cooled module — Y1Q4
- Complete fabrication and testing of ring laser with heat pipe cooled module — Y2Q3
- Complete installation & testing of amplifiers — Y2Q4
- Complete integration with canister & testing — Y2Q4
- Complete vacuum test of laser — Y3Q2
- Complete 8 months of life testing — Y3Q4

TRL_{in} = 3 TRL_{out} = 4-5

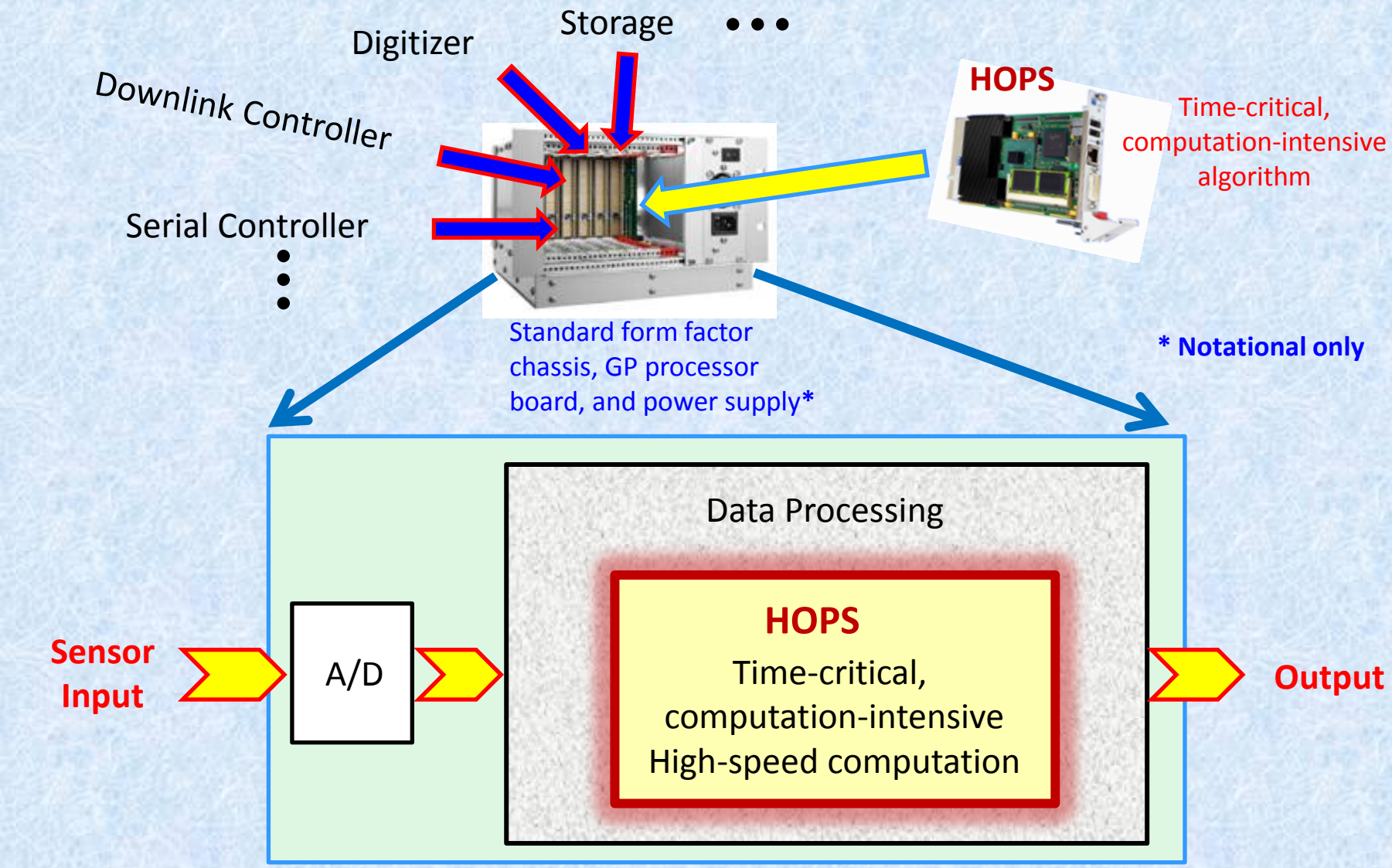
ESTO Earth Science Technology Office

HOPS

- New AIST-11-0007
- 4/1/12 – 3/30/15
- PI = Dr. Jeffrey Beyon
- For ASCENDS, ACE, and 3-D WINDS



Integration of HOPS into Science Projects



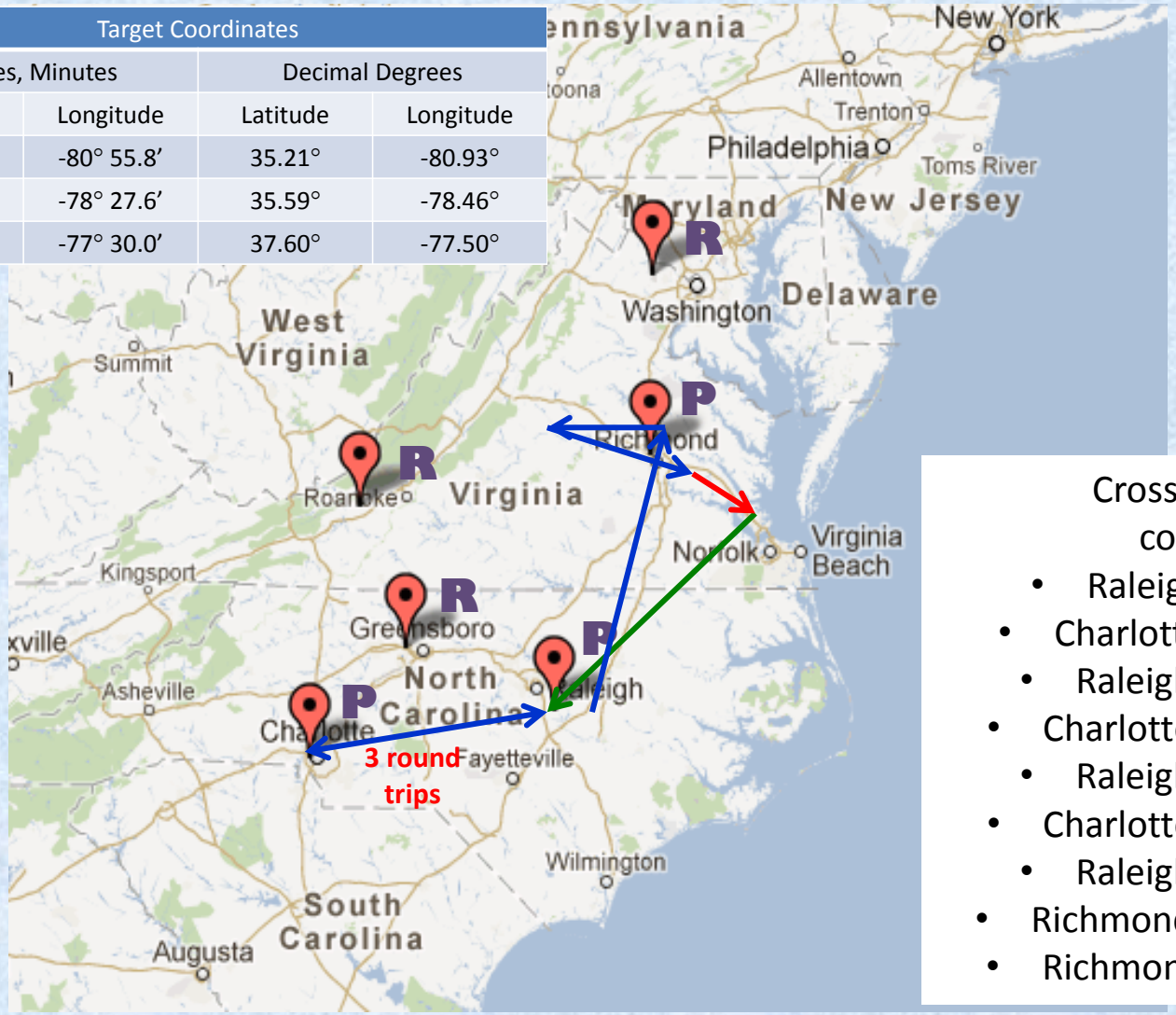
Future

UC-12B

- 28,000 ft (8.5 km)
- 920 mi
- 6.2 hours
- 298 mph (259 knots)
- 2,500 lb. = f(fuel)
- 4200 W
- Pressurized
- $1950/hour + fuel, labor

FY13 Plan
Flight Paths for Week 2

Nearest City	Target Coordinates			
	Degrees, Minutes		Decimal Degrees	
	Latitude	Longitude	Latitude	Longitude
Charlotte	35° 12.6’	-80° 55.8’	35.21°	-80.93°
Raleigh	35° 35.4’	-78° 27.6’	35.59°	-78.46°
Richmond	37° 36.0’	-77° 30.0’	37.60°	-77.50°



Cross three target coordinates at:

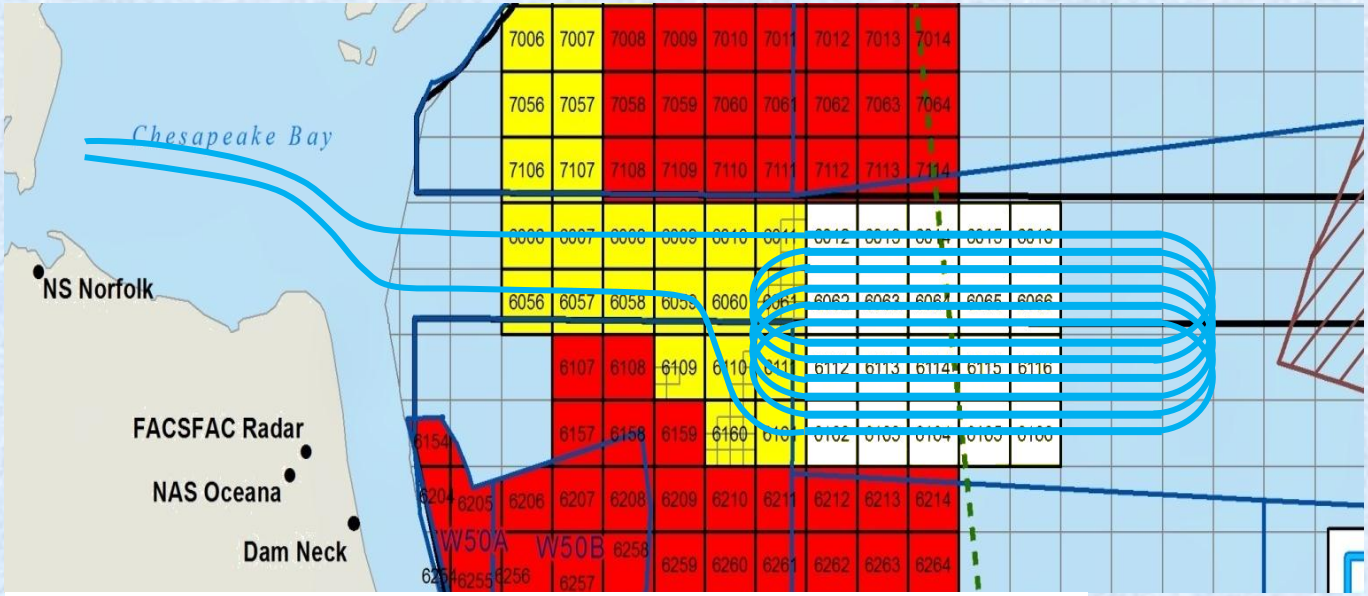
- Raleigh1 - 5,000 ft
- Charlotte1 - 5,000 ft
- Raleigh2 -10,000 ft
- Charlotte2 -10,000 ft
- Raleigh3 -15,000 ft
- Charlotte3 -15,000 ft
- Raleigh4 -15,000 ft
- Richmond1 -15,000 ft
- Richmond2 - 5,000 ft

R – Rawinsondes, 8 am & 8 pm

P – 915 MHz wind profiler radar

FY13 Plan
Test Procedures for Research Flights for wind energy (week 3)

- Aircraft flight altitude of 10,000 feet over the target area (white blocks in diagram below)
- Flight track (blue line below) in a racetrack pattern to overfly wind energy sites (white blocks) off Virginia Beach as diagramed below
- Desire 12 straight transits through wind energy area. Transits are offset from each other by ~0.75 miles
- Radius of turning loop is at pilot's discretion
- Sequence of offset transits is at pilot's discretion
- Require weather of minimal cloud cover between aircraft and ocean surface
- Transits to start at 2:30 PM

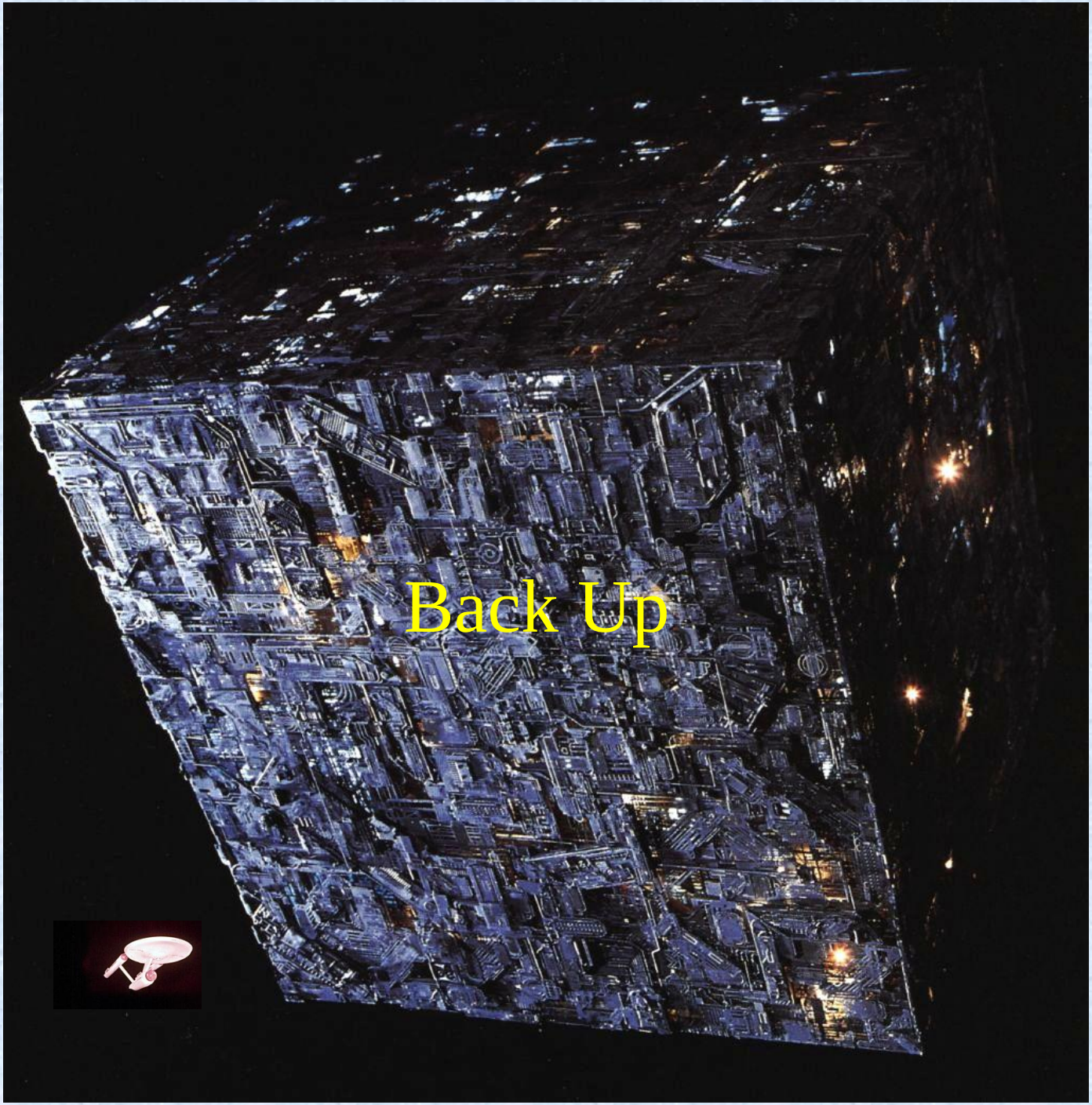


- area of interest is the white blocks; red blocks are restricted flight areas.
- each block is ~3-miles square.
- example flight track of blue line is a total distance of ~450 miles.

- Earth Venture 3 Proposal
- 5 years of aircraft flights
- PI = Prof. Krishnamurti, FSU

Conclusions

- We are thankful to be busy at Langley
- We continue to try to enable the space wind mission & bring in business to Langley
- We appreciate the support and funding received


Back Up

Pulsed, Coherent-Detection, 2-Micron, Doppler Aerosol Horizontal WiNd (DAWN) Profiling Lidar during GRIP

Pulsed Laser

Ho:Tm:LuLF, 2.05 microns
3.1 m folded ring resonator, FSR = 967 MHz
~250 mJ pulse energy
10 Hz pulse rate
200-220 ns pulse duration
Master Oscillator Power Amplifier
Laser Diode Array side pumped, 792 nm, 1 ms
~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 signal optical detectors (2)
InGaAs monitor optical detector (1)
Zero motion heterodyne frequency = 0 Hz
10-bit ADC
INS/GPS integrated to lidar

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° = nadir angle
Conical field of regard centered on nadir
All azimuth angles programmable

Data Acquisition & Processing

5 azimuth angles (-45°, -22.5°, 0°, 22.5°, 45°), all forward
500 Msamples/second ADC
Per sample 2 ns, 0.3 m, 0.26 m height
55,000 samples/shot, 512 samples pre-shot
Maximum 54,488 samples,109 microseconds, 16.335 km range
Nominal range gate 512 samples, 1 microsecond, 154 m, 133 m height
Range gate overlap 256 samples, 50%
N-shot, freq-aligned, averaged periodograms
Periodogram maximum 250 MHz
Periodogram maximum ±128 m/s LOS, ±256 m/s = ±572 mph horiz.
Periodogram information resolution 0.98 MHz, 1.0 m/s
Nominal range gate samples after zero padding 2048
Periodogram resolution for frequency alignment 0.24 MHz, 0.25 m/s

Pre Data Collection Selectable
Post Data Collection Selectable