Plans for using DAWN in multi-scale interaction study in the tropics (CPEX 2017)

G. D. Emmitt, S. Greco, M. Kavaya and U. Singh

Working Group on Space-based Lidar Winds

Hampton, Virginia

21-23 March, 2017

Outline

- Prior experience during PolarWinds/ADM Cal/Val (2014 and 2015)
  - DAWN under performed its design in terms of sensitivity
  - Accuracy (<.5m/s) was well within expectations once heading drift was corrected
  - Reliability was > 99.9%
- Post campaign findings
  - Some component damage
  - Non-optimal alignment of….. (Henderson presentation)
  - System found focused near 500m
- Plans for DAWN in CPEX (May/June 2017)
  - Multiscale proposal

Situation

- DAWN has undergone extensive evaluation and adjustments post PolarWinds campaign.
- Based upon analyses by SWA, the PolarWinds performance (sensitivity) was between 20 and 25dB lower than expectations based upon design.
- Evaluation by Beyond Photonics (BP) in 2016 found alignment issues and some component degradation.
- Analysis by BP estimated that ~ 16-17dB of the sensitivity losses could have been due to focus.
- Until recently (2017) there had been no full system performance calibration except for some data taken at LaRC off an atmosphere of unknown backscatter distributions.

DAWN performance summary using DLR MAG1 as reference

Parameter	Units	DLR-MAG1	NASA-DAWN	FOM Ratio	Comments	Full up DAWN	FOM Ratio
Energy/Pulse	J	0.0015	0.1	66.67		0.22	146.67
PRF	Hz	500	5	0.01		10.00	0.02
Pulse length	m	68	27			27.00	
Aperture	m	0.108	0.15	1.93		0.15	1.93
Dwell/LOS	seconds	1	20	0.45	100 shots	20.00	0.63
Pl/LOS range	#	2	6	1.73	Independent obs	6.00	1.73
LOS FOM Ratio				99.61			309.93
			dB	19.98	resource metric		24.91
Sensitivity Comparison on 5/15/15					100 shots		
		10900	10700				
		5000	6500				
		5900	4200	1.97			
			dB	2.95			
Bottom line "missing" dB for DAWN				22.94	3dB uncertainty		
Sensitivity comparison on 5/19/15					20 shots		
		9200	8800				
		4000	7000				
		5200	1800	8.35			
				9.21	"2.22" 100 shot		
Sensitivity comparison 5/13/15					100 shots		
		8600	8500				
		2500	5000				
		6100	3500	3.04			
				4.83			
Sensitivity comparison on 5/23/15					20 shots		
		10000	8700				
		4000	7000				
		6000	1700	12.46			
				10.95	"3.97" 100 shots		

Quantitative comparison between DAWN on the NASA DC-8 and the DLR 2 micron WindTracer flown on the Falcon. Comparisons made on 4 different days in May 2015.

Findings: DAWN appeared to be underperforming by ~23dB due to causes unknown…focus suspected.

Preliminary Findings from March 9, 2017 evaluation of DAWN sensitivity

- DAWN was set up at NASA LaRC DWL test range on March 9, 2017.
- The atmosphere was characterized visually as cloud free, excellent visibility with "clear blue" sky. Later in the evaluation period some high thin cirrus moved in providing returns from > 10 km.
- DAWN recorded useful returns from heights in the vertical direction of 10 -11km and in the horizontal (18 degrees slanted up) of 35 – 45km with 10 second integration. More modest distances (6 km) were sampled with 2 second integration data in the vertical.
- Distinction between clouds and aerosols in the distant (> 6km vertical) field of view is a major focus of ongoing analyses of the data taken and comparisons with the 1.06 µm Mie-backscatter profiles provided by Hampton University.
- Initial evaluation supports a very much improved DAWN instrument with quantification of this improvement still underway.

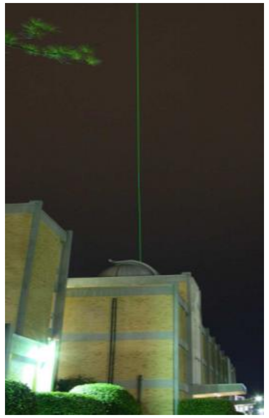
DAWN set up and tests

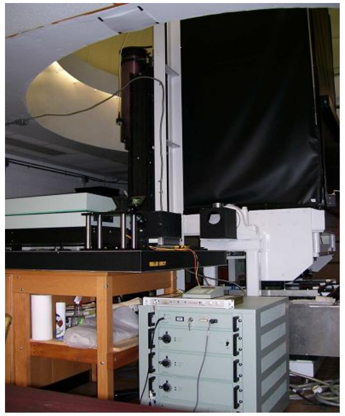
- 100mJ; 10Hz; 15 cm
- Data processing range gate (153m) same as in Polar Winds
- Default 20 shot (2 seconds) integration as in PolarWinds; additional shot integrations used (10,50 and 100)
- Mie-Backscatter (1.06um) from Raman lidar at Hampton University (10km away)
- Focus tests from ~550m – collimated pointed vertical
- Slant range tests performed at 18.5 degrees from horizon pointed north.

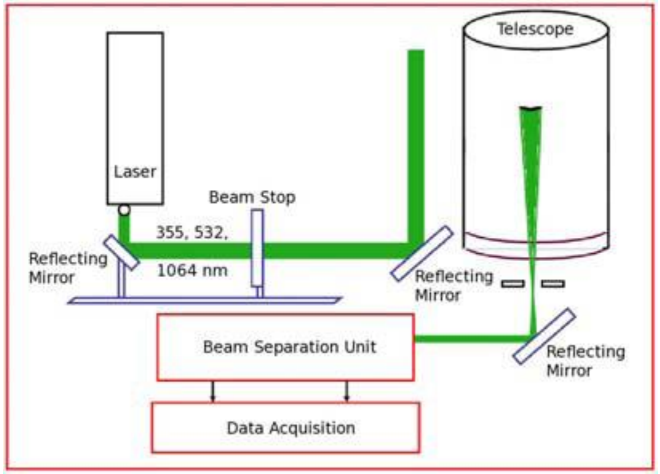
DAWN test site
At NASA LaRC

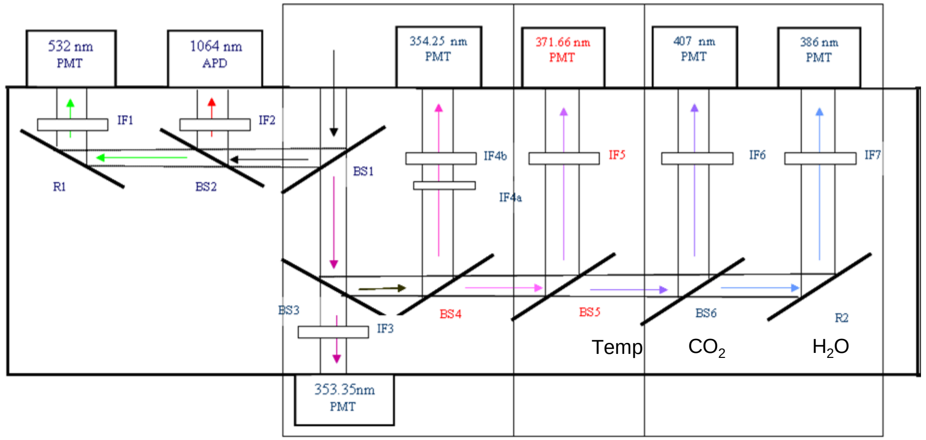
Relative locations
of DAWN Test Site
and Hampton University
Mie-Raman Lidar

Hampton University Mie-Raman Lidar







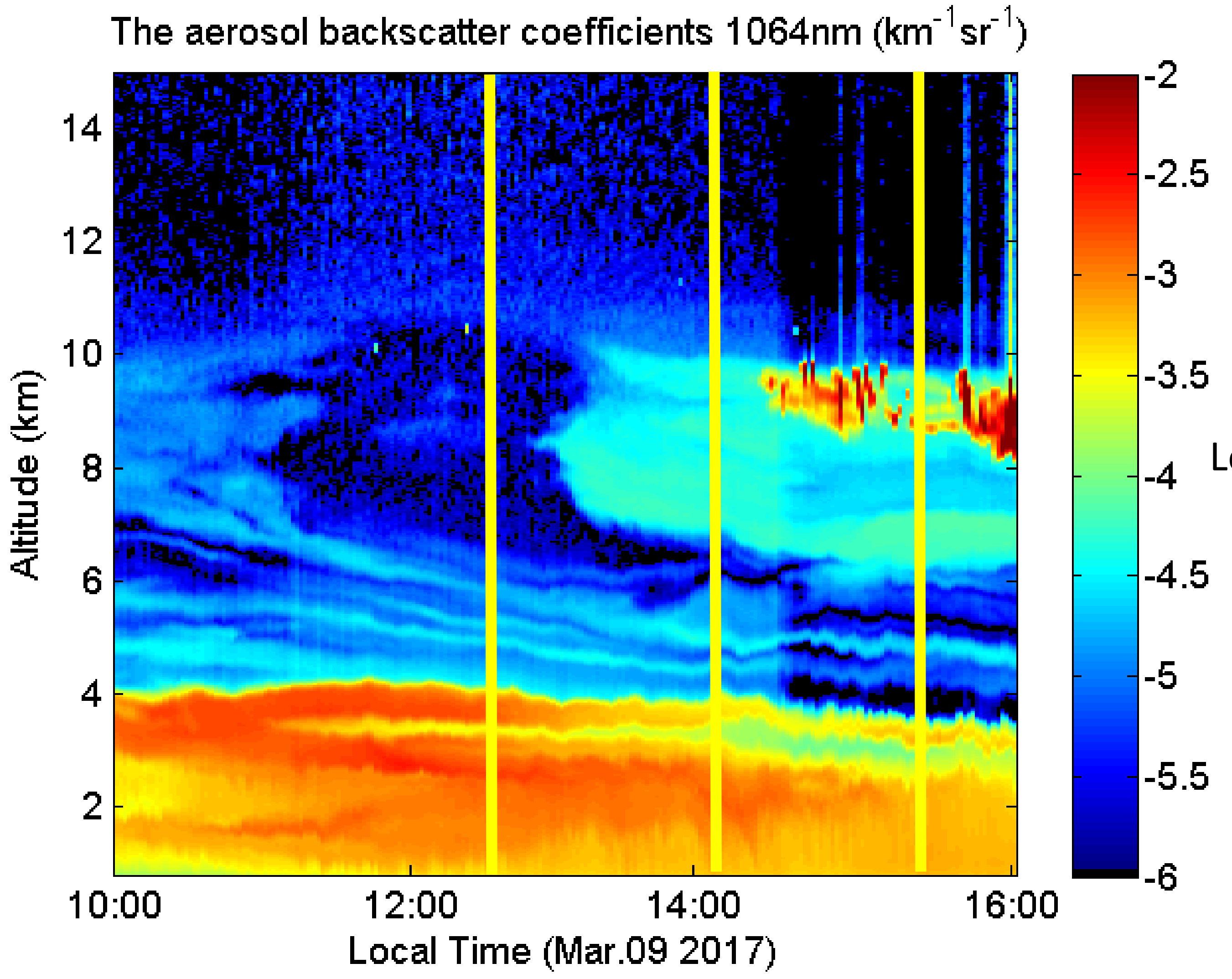


HU lidar is located on the Hampton University Campus (37.02° N, 76.34° W).

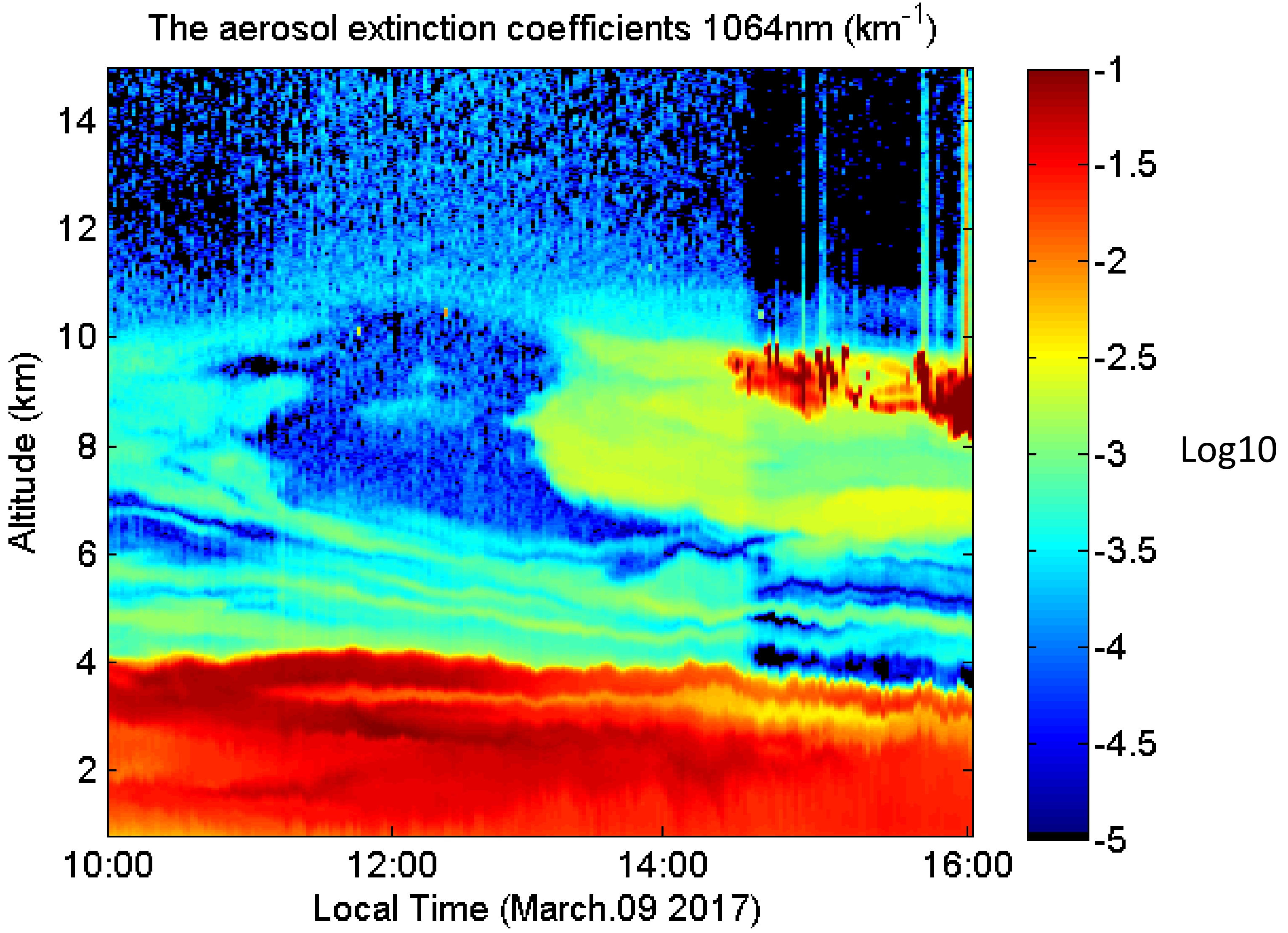
Receiver: 48" Cassegrainian telescope	
Type	Non-coaxial
Diameter (in)	48
Focal Length (mm)	480
Field of View (mrad)	1-4
Detectors	Hamamatsu R7400U-02 PMT
	Perkin & Elmer C30956E-TC APD

Laser: Continuum Powerlite 8020 Nd:YAG	
Wavelength (nm)	1064, 532, 355,
Repetition Rate	20 Hz
Energy (mJ; reported)	1064 nm: 1200
	532 nm: 550
	355 nm: 300
Beam Divergence	0.5 mrad
Linewidth (cm^{-1})	1

Data Acquisition: LICEL Optical Transient Recorder TR20-160	
Analog Acquisition	12 bit A/D Resolution
	20 MHz Sampling rate
Photon Counting Acquisition	250 MHz Maximum Counting Rate
Typical Minimum Height Resolution	15 m



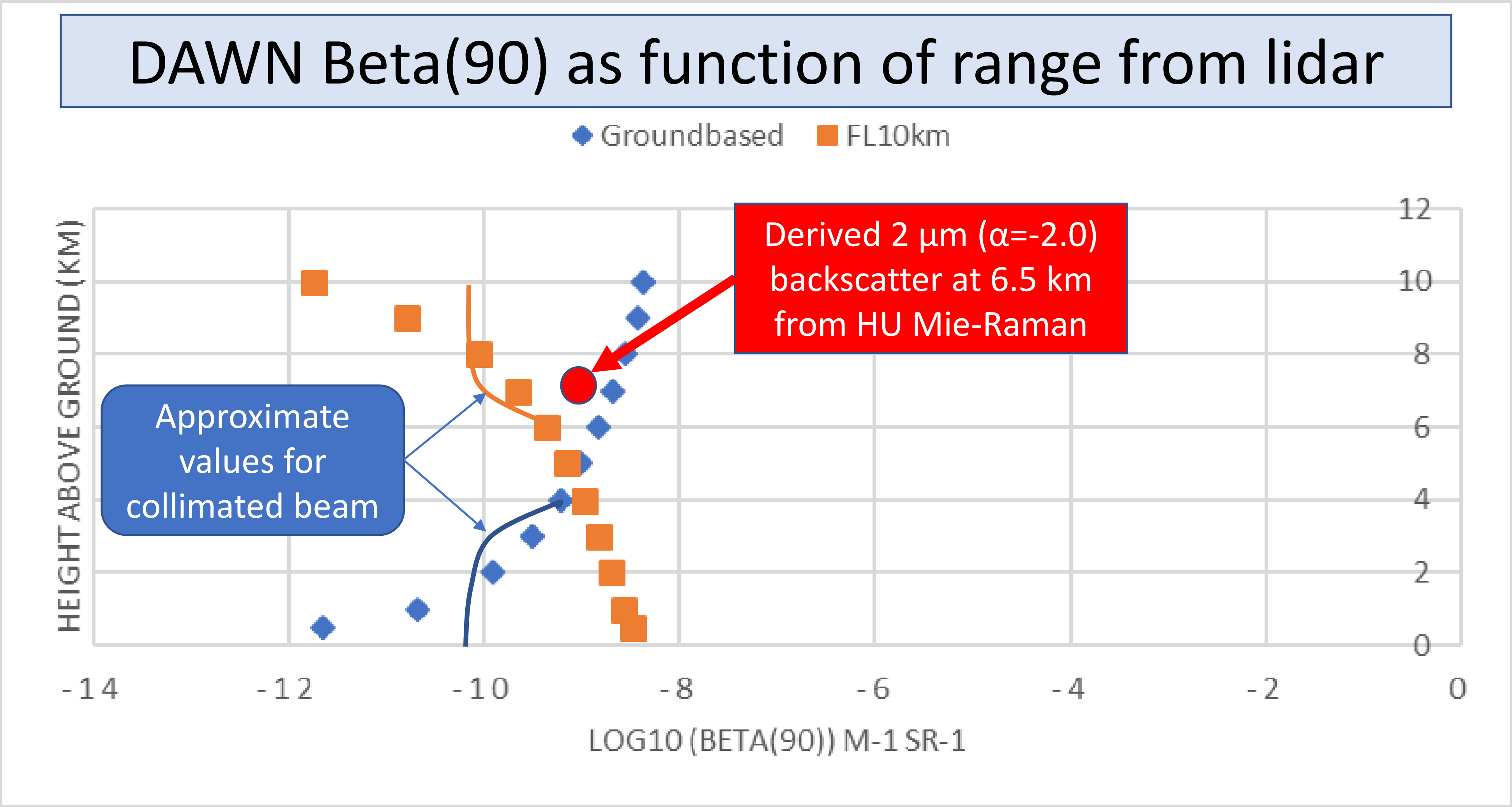
Provided by
Hampton University
Mie-Raman Lidar



Provided by
Hampton University
Mie-Raman Lidar

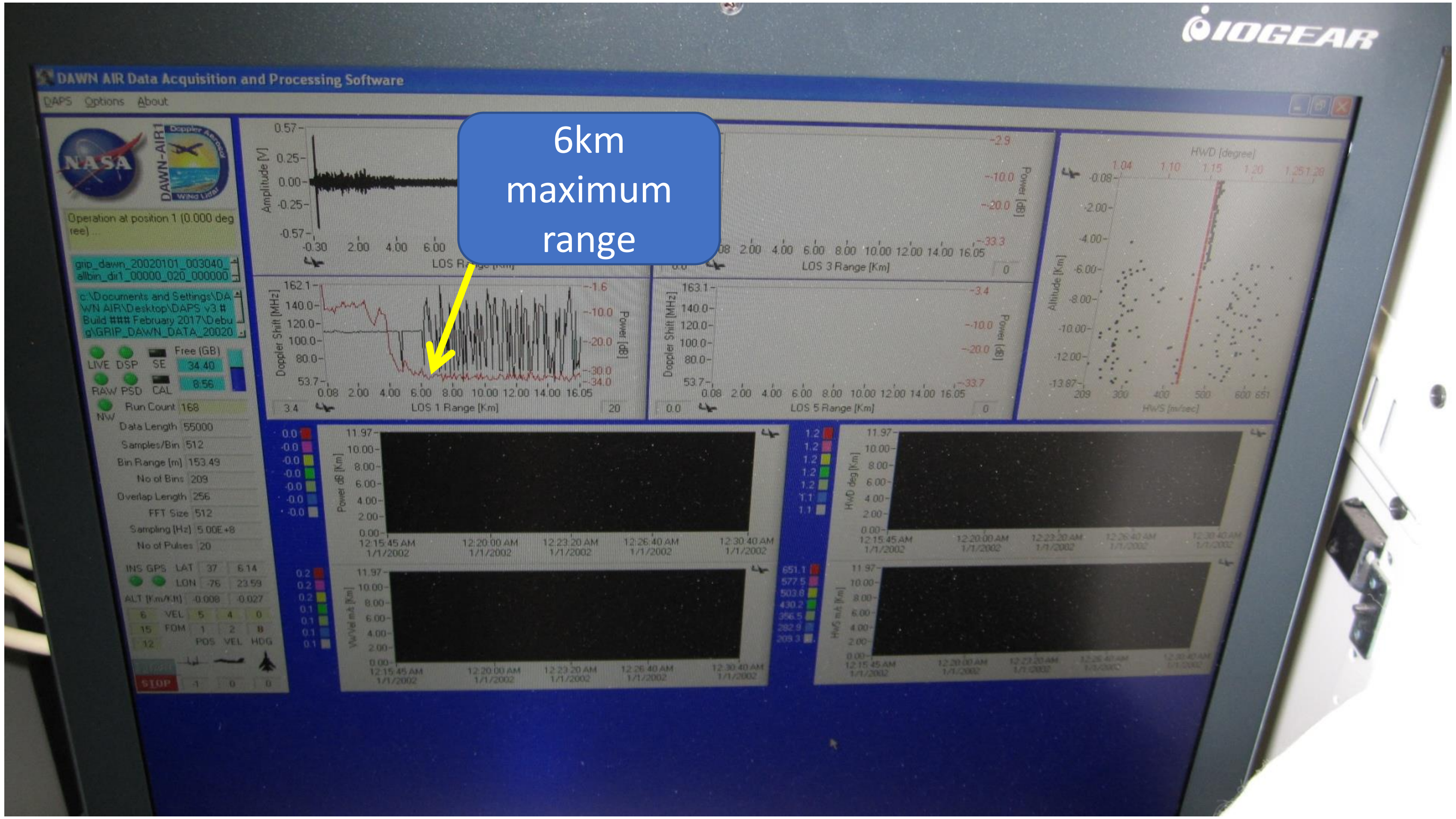
Wavelength Conversion of Backscatter at 1.06um

CALIOP Aerosol Type	Beta(2.05)/ Beta(1.06)	Angstrom Coefficient
Fine Dust	.138	-3.13
Fine Polluted Dust	.174	-2.77
Fine Clean Marine	.234	-2.30
Fine Clean Continental	.259	-2.15
Coarse Clean Continental	.461	-1.23
Fine Polluted Continental	.230	-2.33
Coarse Polluted Continental	1.32	+.43



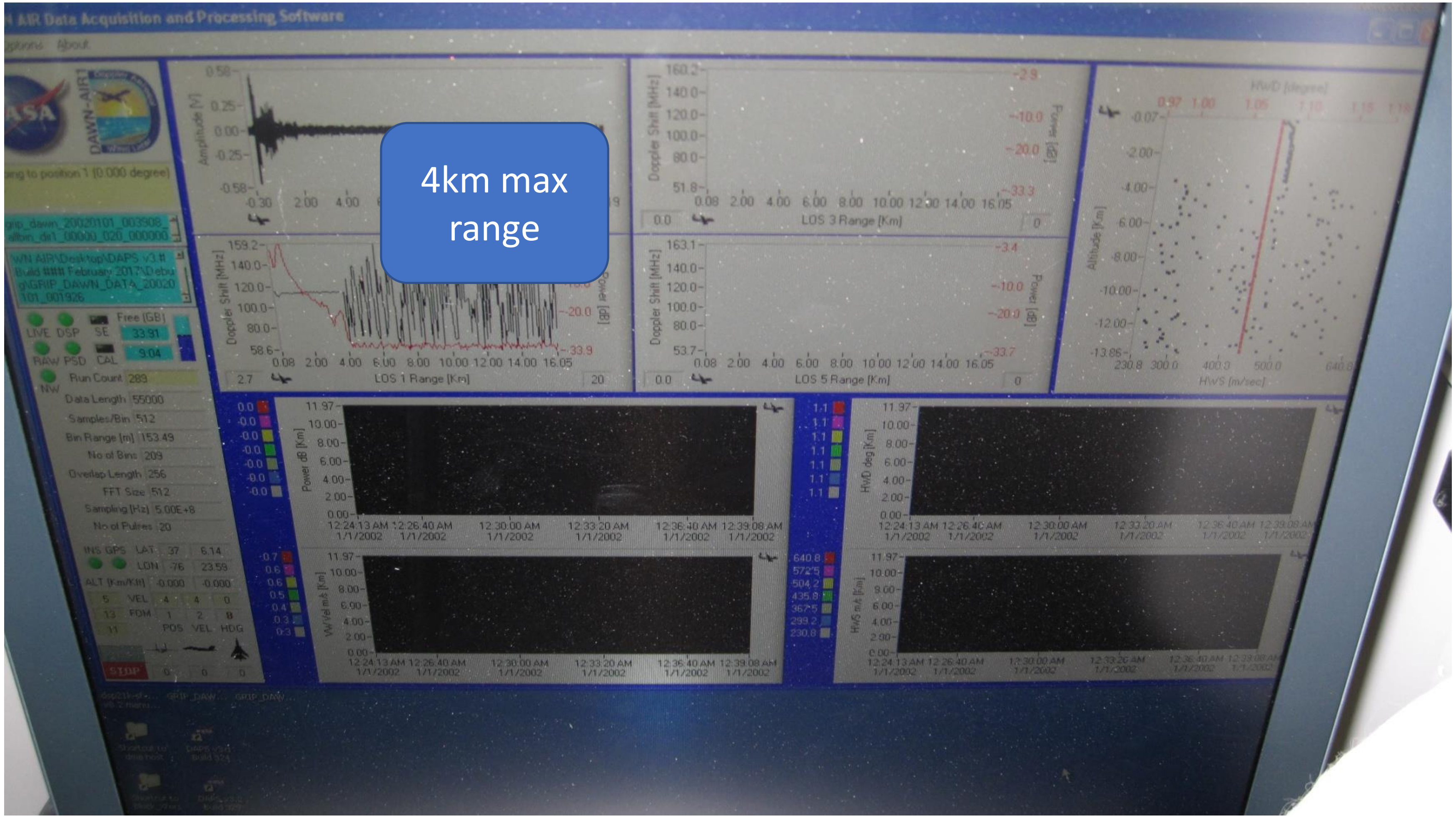
Notes: Total optical throughput efficiency of .044 assumed (down 5 dB from "ideal")
All DAWN calculations done for 2 second integrations

Sky Conditions at 12:30



12:38

Shot Integration: 20 (2 seconds)
Range gate: 153m
Collimated
Vertical Pointing



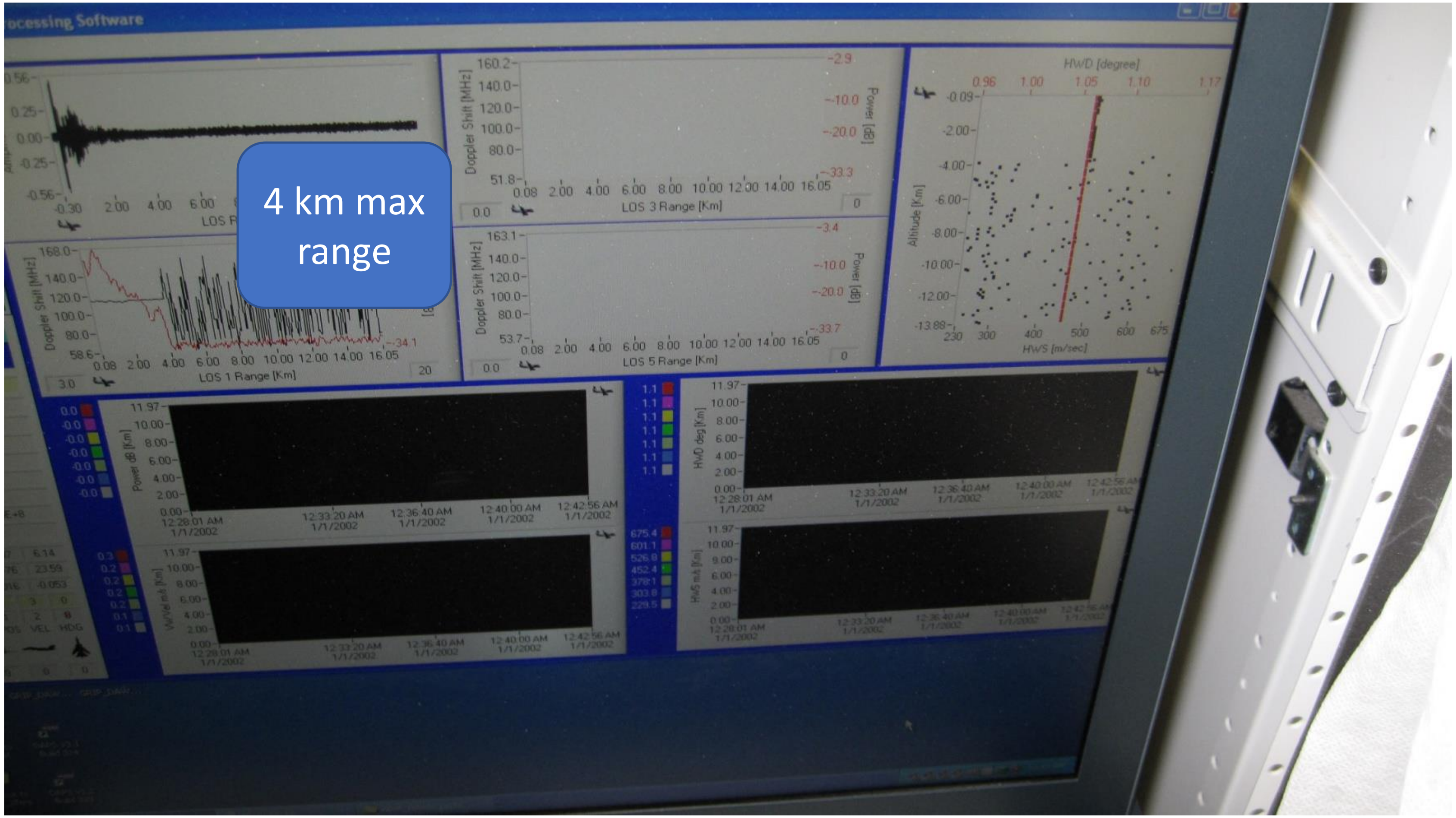
Shot Integration: 20 (2 seconds)

Range gate: 153m

Focused: ~550m

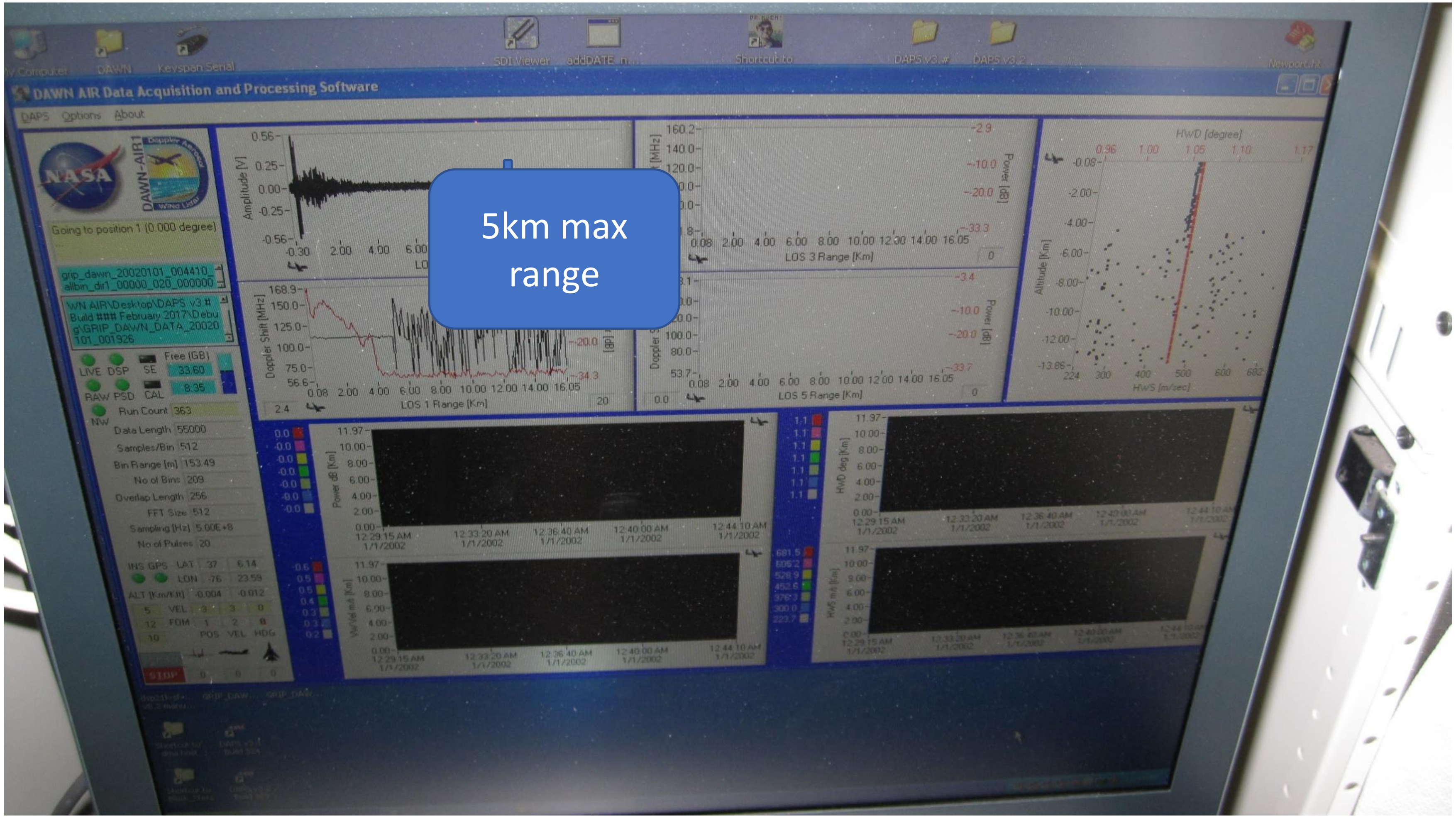
Vertical Pointing

12:39



Shot Integration: 20 (2 seconds)
Range gate: 153m
Focused: ~750m
Vertical Pointing

12:42



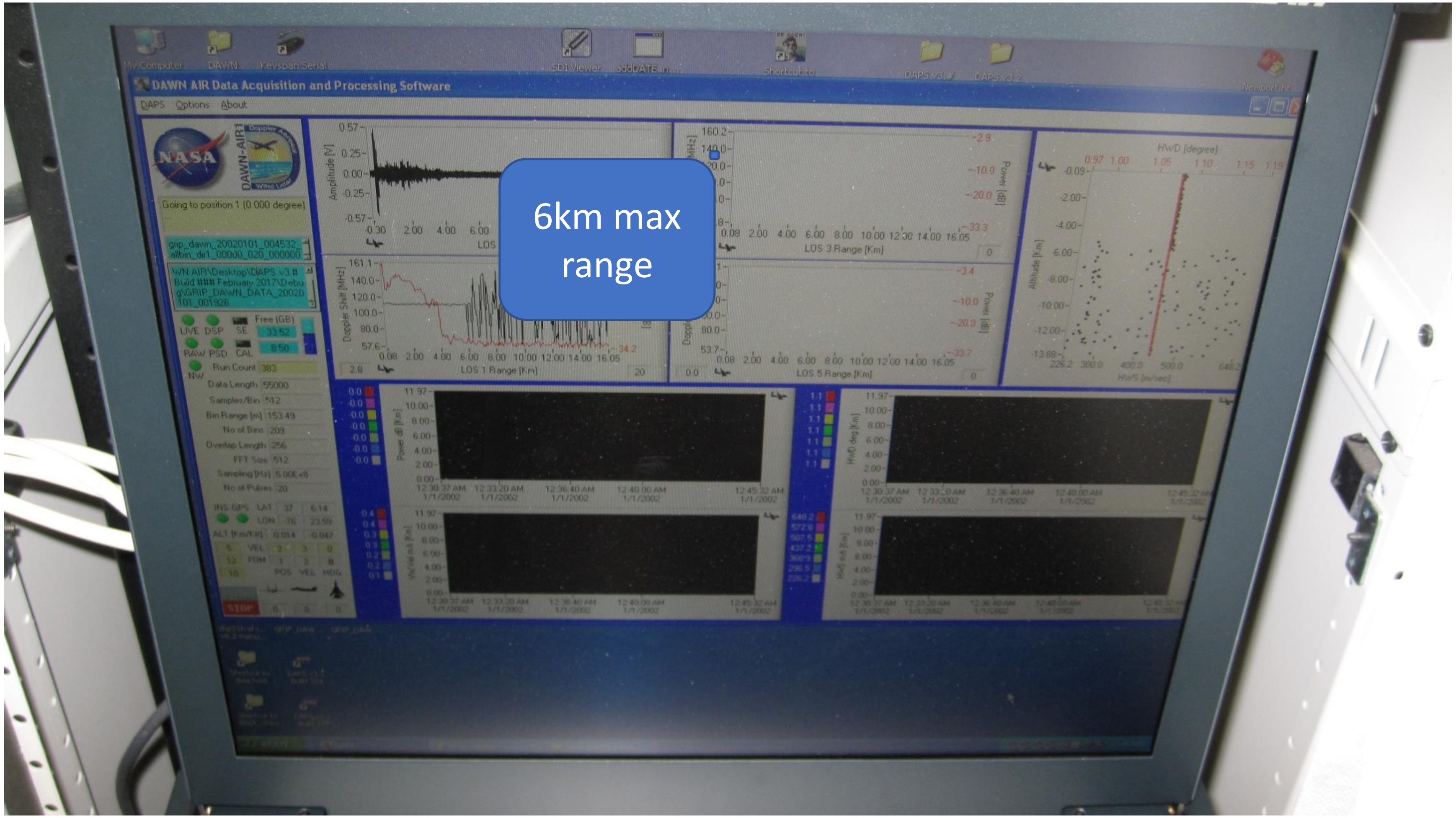
Shot Integration: 20 (2 seconds)

12:43

Range gate: 153m

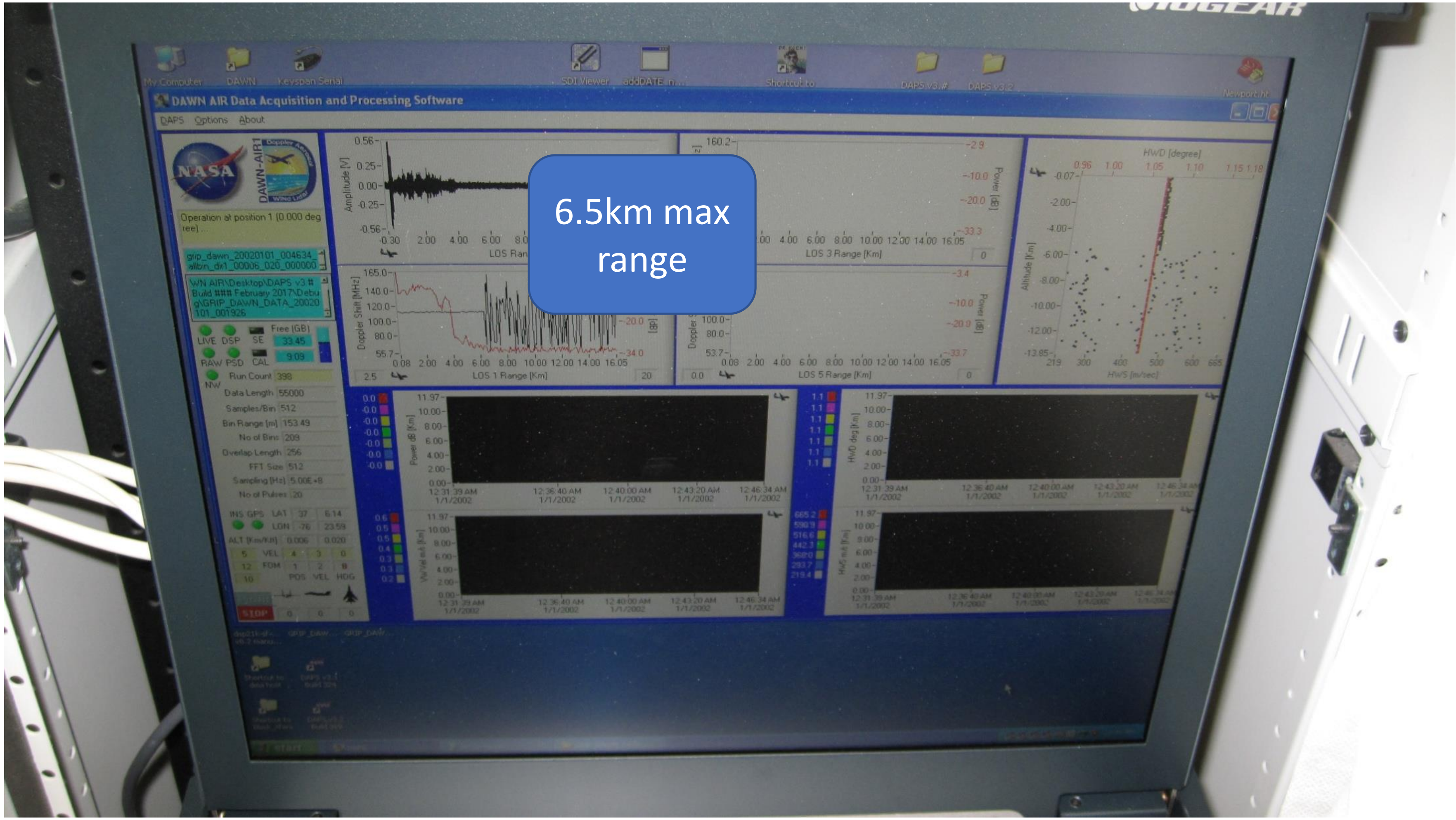
Focused: ~1000m (est)

Vertical Pointing



Shot Integration: 20 (2 seconds)
Range gate: 153m
Focused: ~1250m
Vertical Pointing

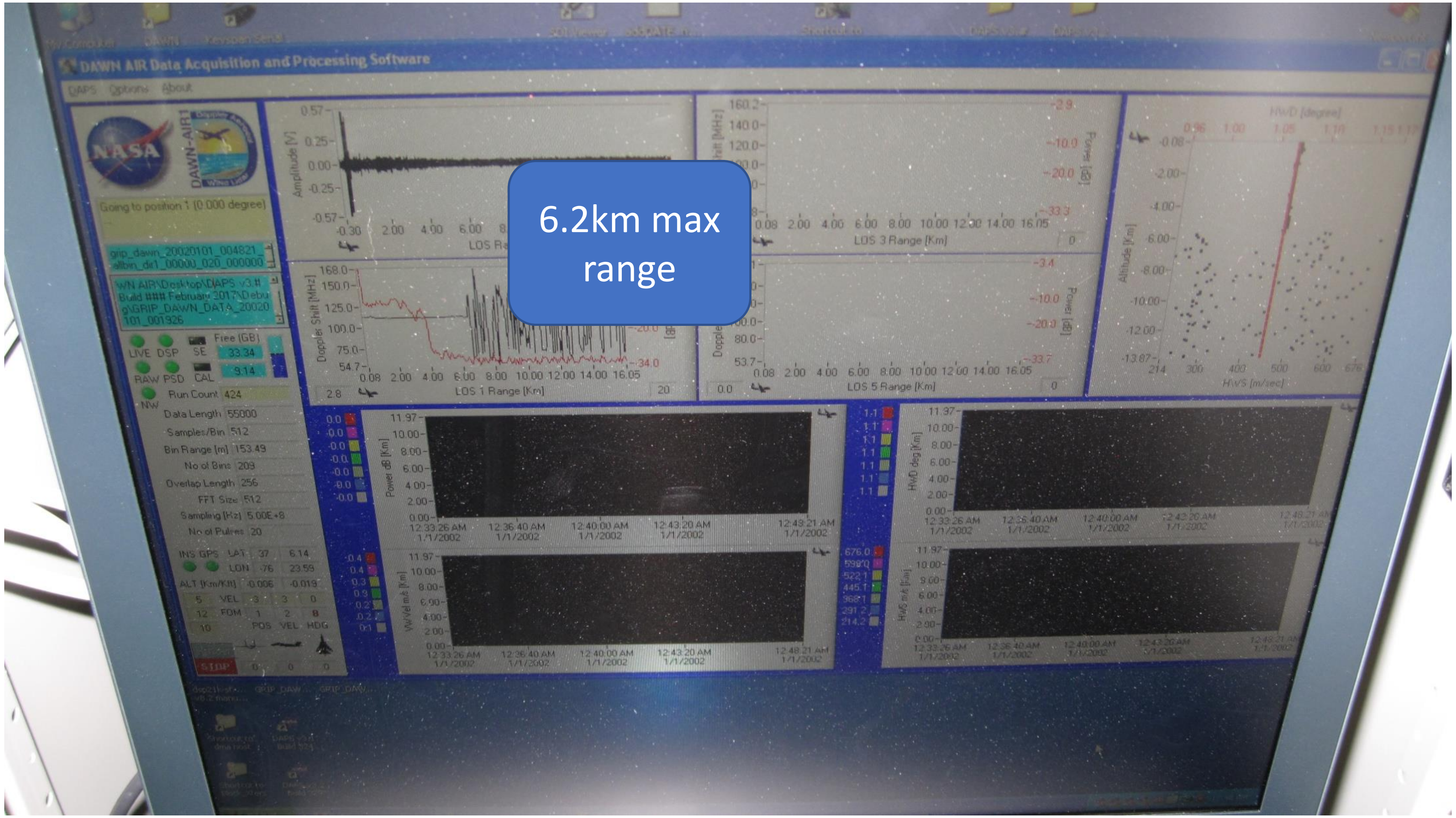
12:44



6.5km max range

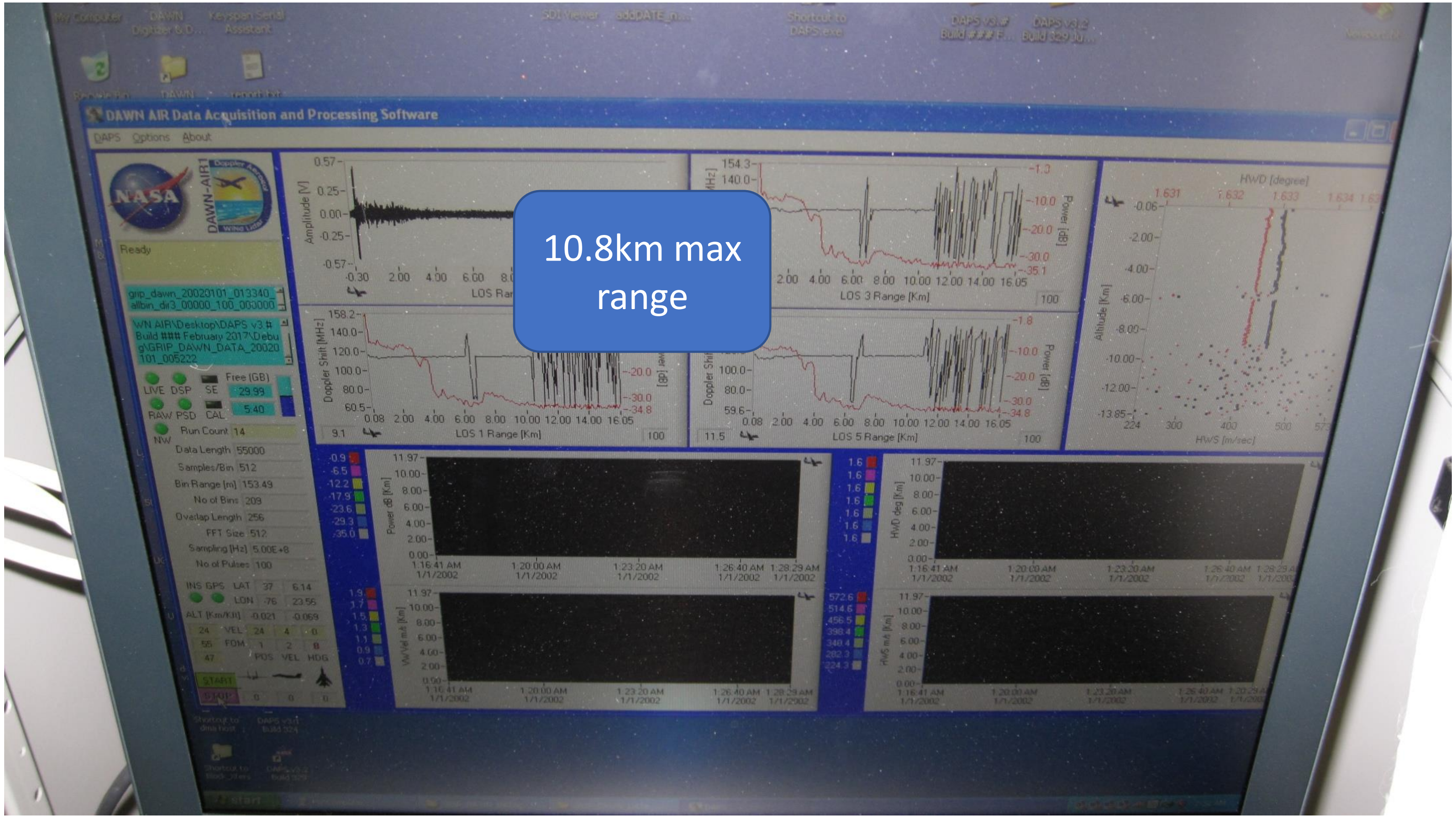
12:46

Shot Integration: 20 (2 seconds)
Range gate: 153m
Focused: ~2000m
Vertical Pointing



12:47

Shot Integration: 20 (2 seconds)
Range gate: 153m
Focused: collimated
Vertical Pointing



Shot Integration: 100 (10 seconds)

Range gate: 153m

Focused: collimated

Vertical Pointing

2:15

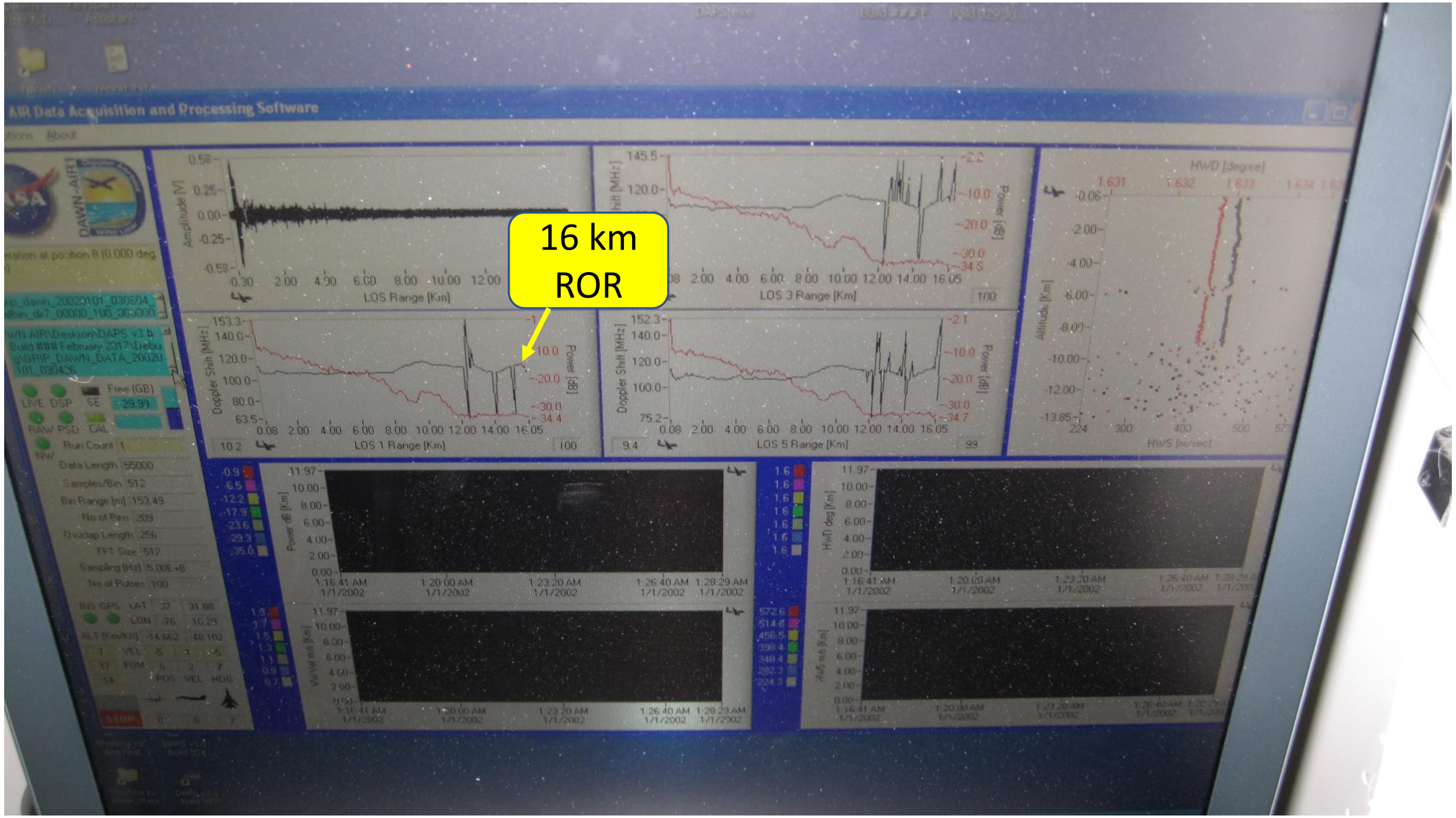
Sky Conditions at 2:25

Looking due North

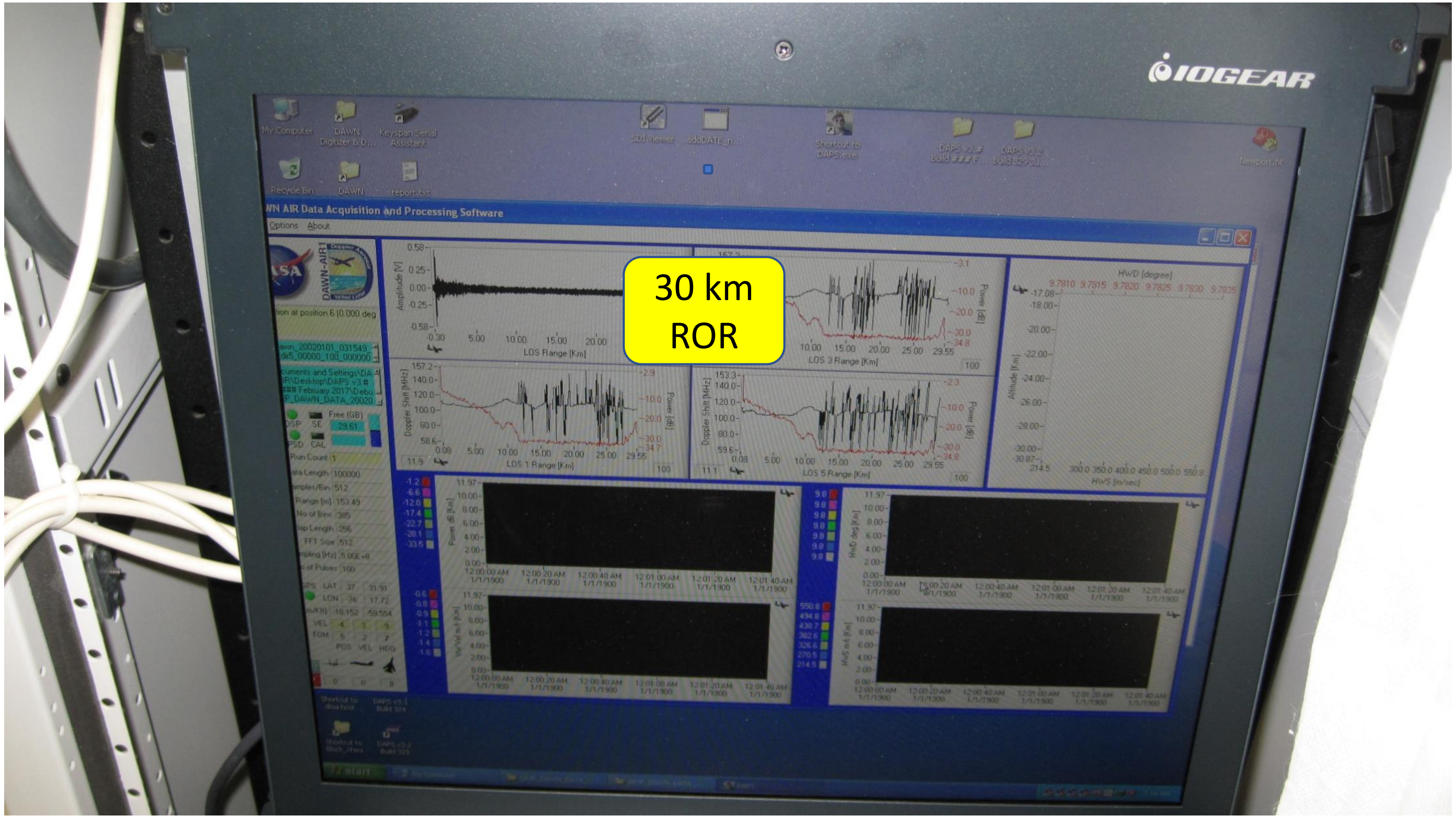
Slant path observations

- 18.5 degrees up from horizon (sin(18.5) = .317)
- Pointed North

Range (km)	**Height above ground (km)**
16	5.08
30	9.51
45	14.26

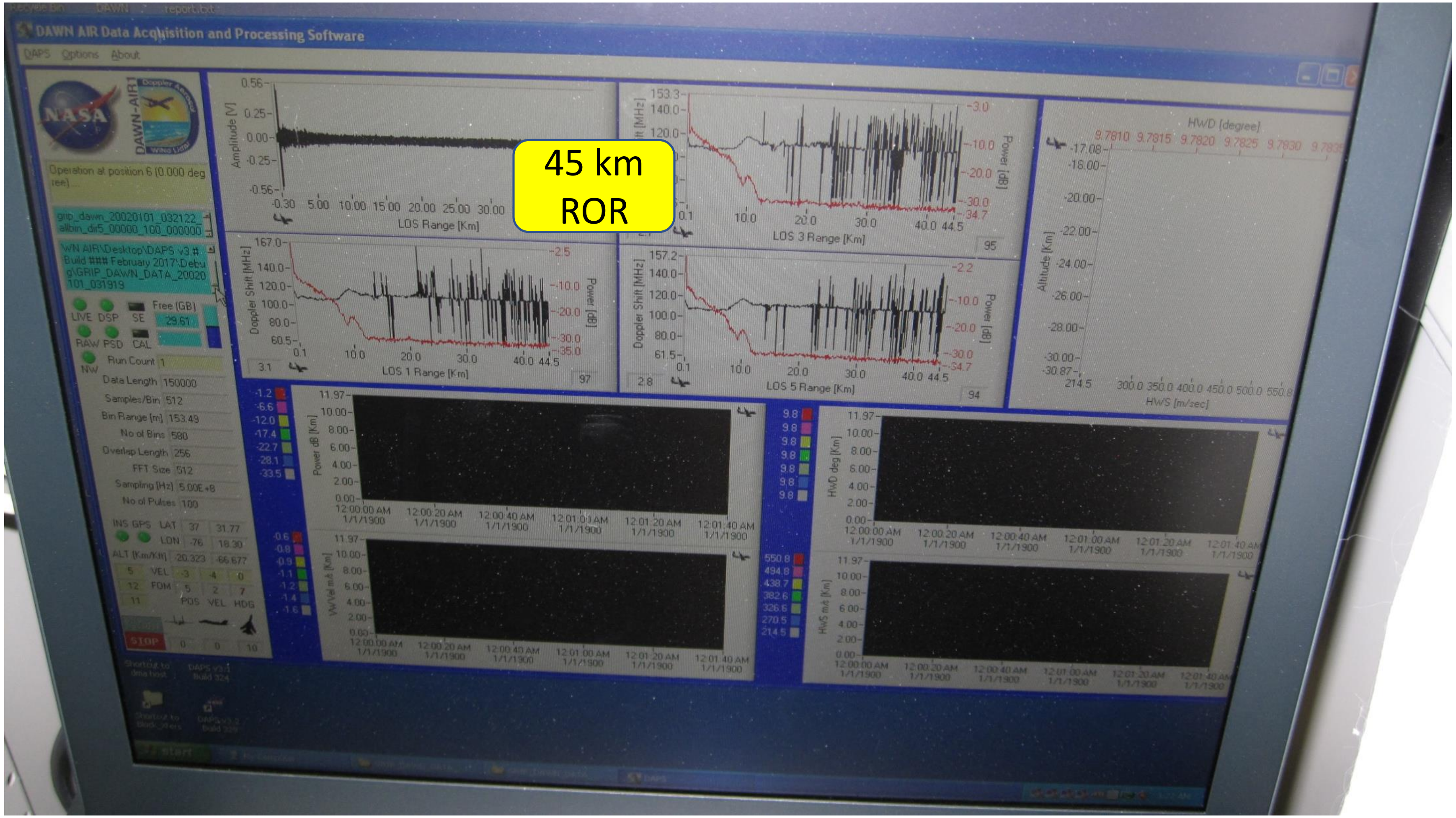


Shot Integration: 100 (10 seconds) 3:05
Range gate: 153m
Focused: collimated
Pointing: 18.5 degrees above horizon



3:16

Shot Integration: 100 (10 seconds)
Range gate: 153m
Focused: collimated
Pointing: 18.5 degrees above horizon



Shot Integration: 100 (10 seconds)

Range gate: 153m

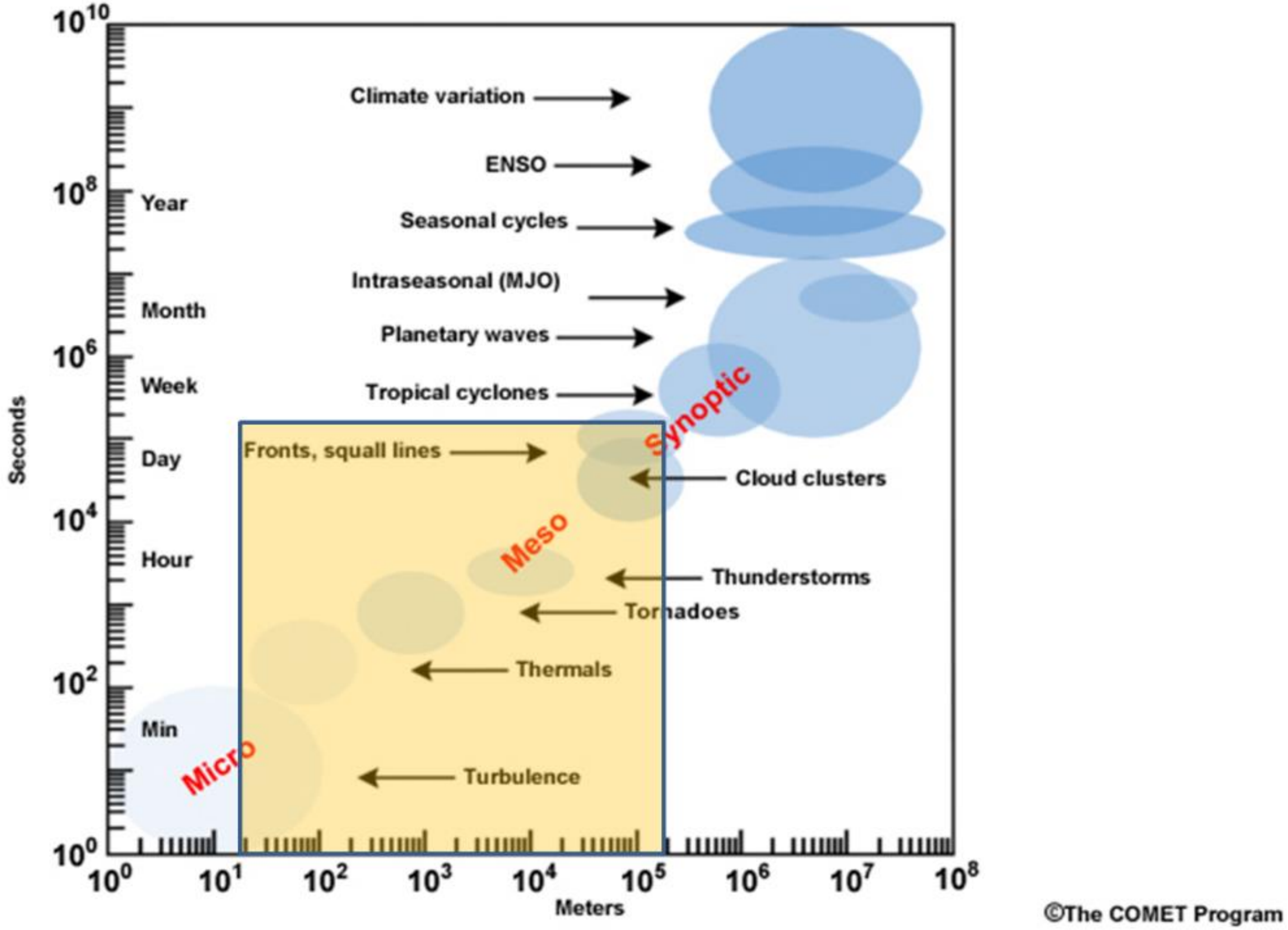
Focused: collimated

Pointing: 18.5 degrees above horizon

3:24

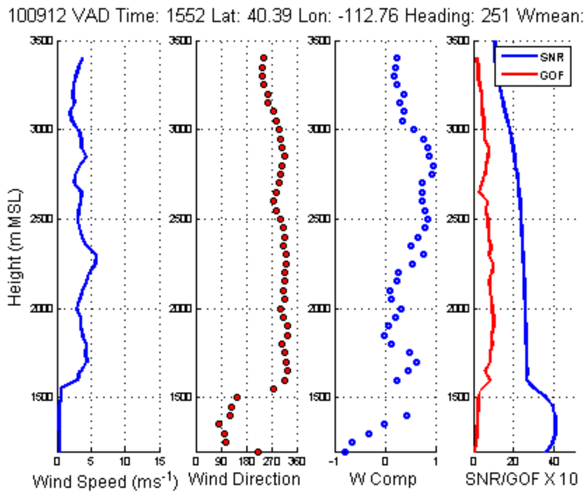
DAWN in CPEX 2017

1. **Document and investigate tropical convective processes, their interactions on multiple scales (10m-100km) and at differing times within their life cycle including initiation, growth, organization and disruption.** A basic set of questions about tropical convection derive from the ageostrophic nature of forcing at tropical latitudes. Given that the mass fields are not the primary driver, our knowledge of the winds on convective scales over the open tropical oceans is a severe constraint on making progress in model based forecasting. CPEX offers an opportunity to use an airborne Doppler Wind Lidar (DAWN) to explore the relationship between measured wind, aerosols, temperature, moisture, sea surface temperature (if Yankee dropsondes are used) and precipitation and observables from space.
2. **Investigate the PBL structure, aerosols and circulations within the lower tropical troposphere under all conditions, including the presence of the SAL or synoptic scale disturbances.** Special focus will be upon studying the existence of boundary layer rolls and the disparity of PBL depths (on horizontal scales of 25m – 200km) as defined by mixing, wind profiles, aerosol concentrations or moisture/density structure. Comparisons with satellite derived PBL heights (e.g. CALIPSO) will be made when possible with regards to orbit and clouds.
3. **Identify the best numerical model data assimilation method (e.g., 4DEnVar vs. 3DEnVar) for DAWN wind profile data.** The high spatial density of the DAWN wind profiles represents a challenge to data assimilation if super-obing and averaging are to be minimized. We will use number of models and data assimilation schemes (see section 4.2.2) to investigate the impact of assimilating the detailed wind profiles from DAWN on numerical simulations.
4. **Simulate post launch ADM Cal/Val support by investigating how ADM will perform in the tropics, particularly during cloudy or non-cloudy conditions.** Having already performed preparatory ADM Cal/Val exercises with DAWN in the Arctic where the emphasis was on cloud free surface returns over ice and within strong tropospheric jets, we will use CPEX as an opportunity to develop baselines for probing the tropical atmosphere which is topped by cirrus and which hosts a wide variety of low level scattered clouds.

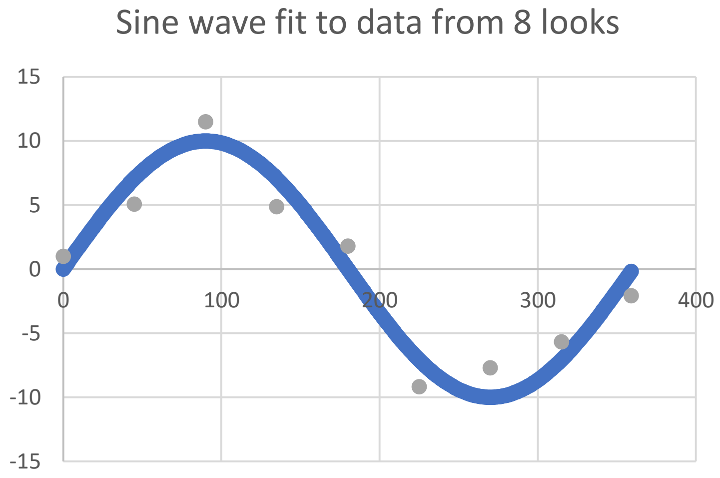


Space and time-scales of dynamical atmospheric processes (The COMET Program).
The orange area denotes the time/space scales that are the focus of this proposal.

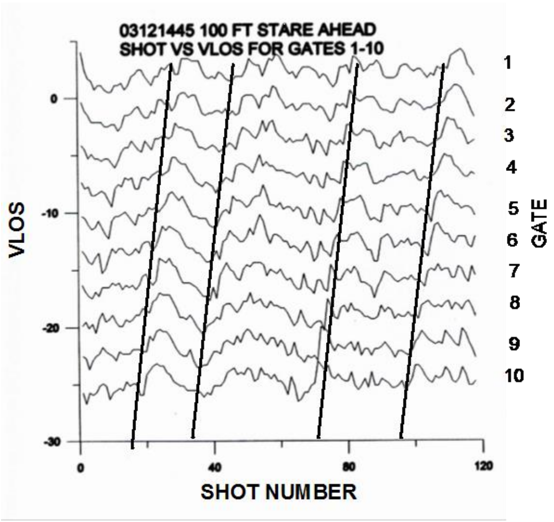
Multi-scale Wind Variability Using DAWN in CPEX



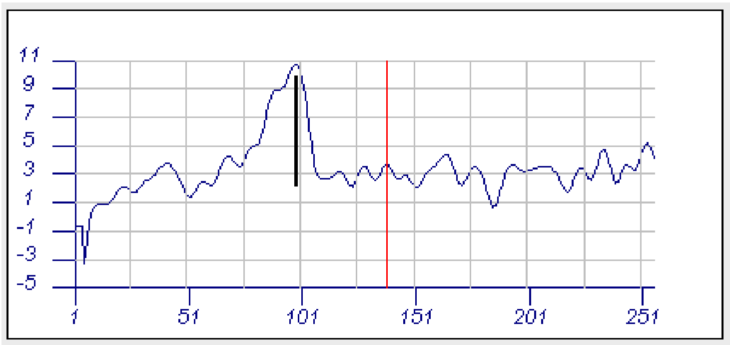
3km – 200km



500 – 3000m



50 – 400m

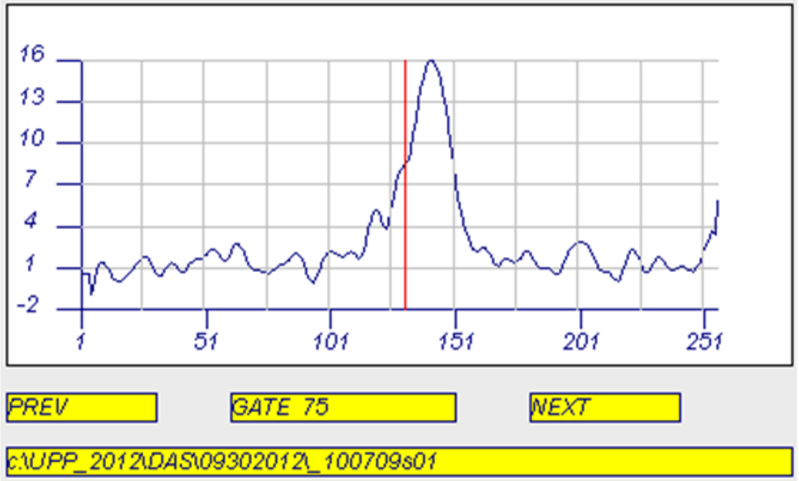


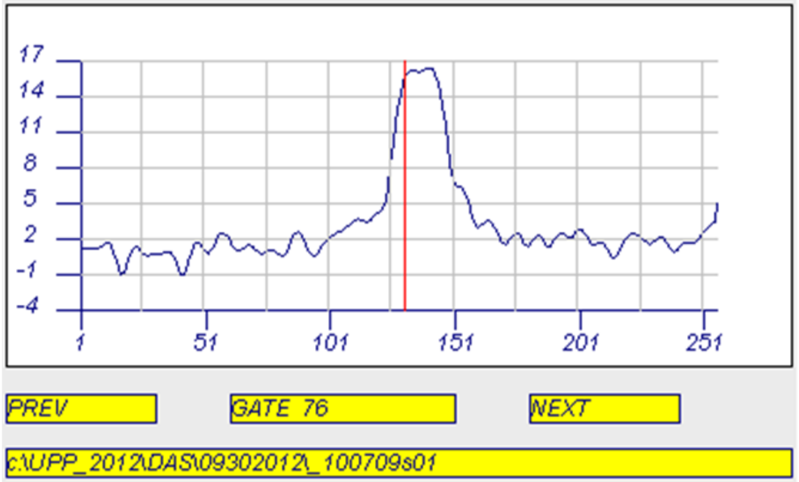
< 100m

Spectral analyses of TODWL data

The TODWL is a 2 micron, eyesafe coherent detection lidar. The returning signal is heterodyned with a local optical oscillator and then digitized (200 MHz). An FFT is used to process the resulting time series with 50m line-of-sight resolution. In homogeneous flows with weak turbulence, a single spectral feature (top panel) is identified as the frequency representation of the radial wind speed.

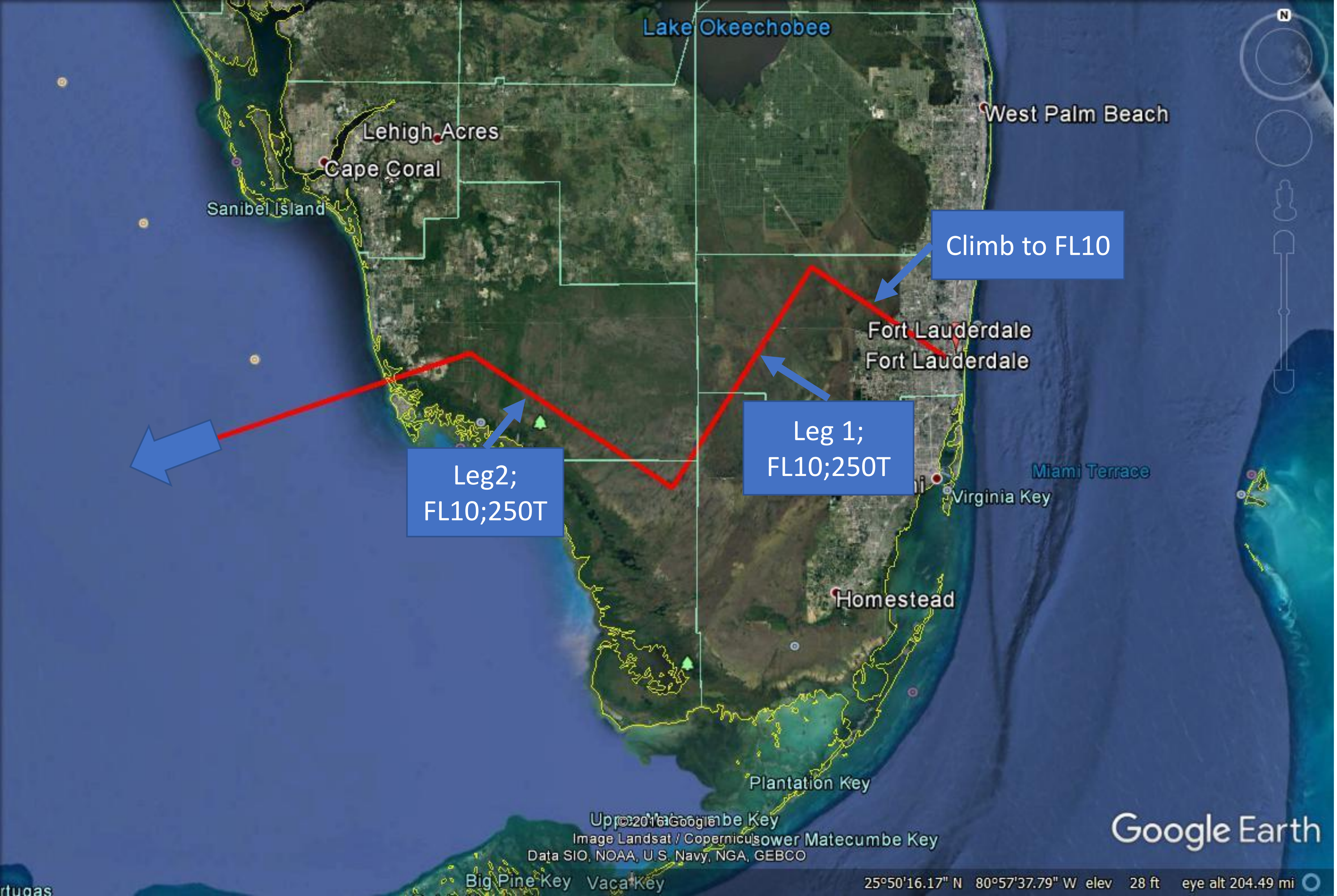
When probing a turbulent and/or highly sheared environment, the spectral feature is broadened. It is this broadening that we use for estimating turbulence on scales of 25 -100 meters with multi-pulse integrations over 50 – 200 meters horizontally.





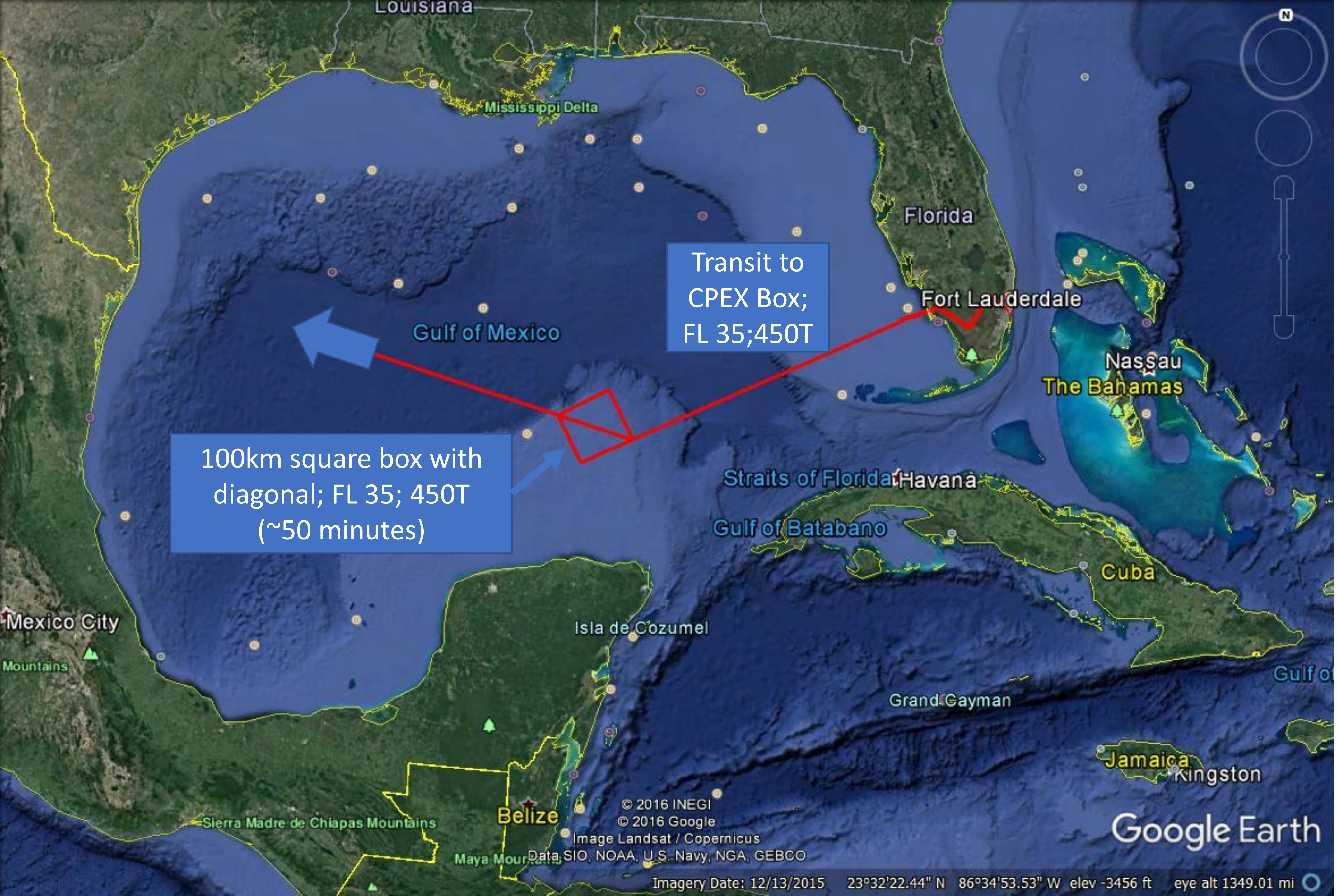
Mass Budget CPEX BOX mission segments

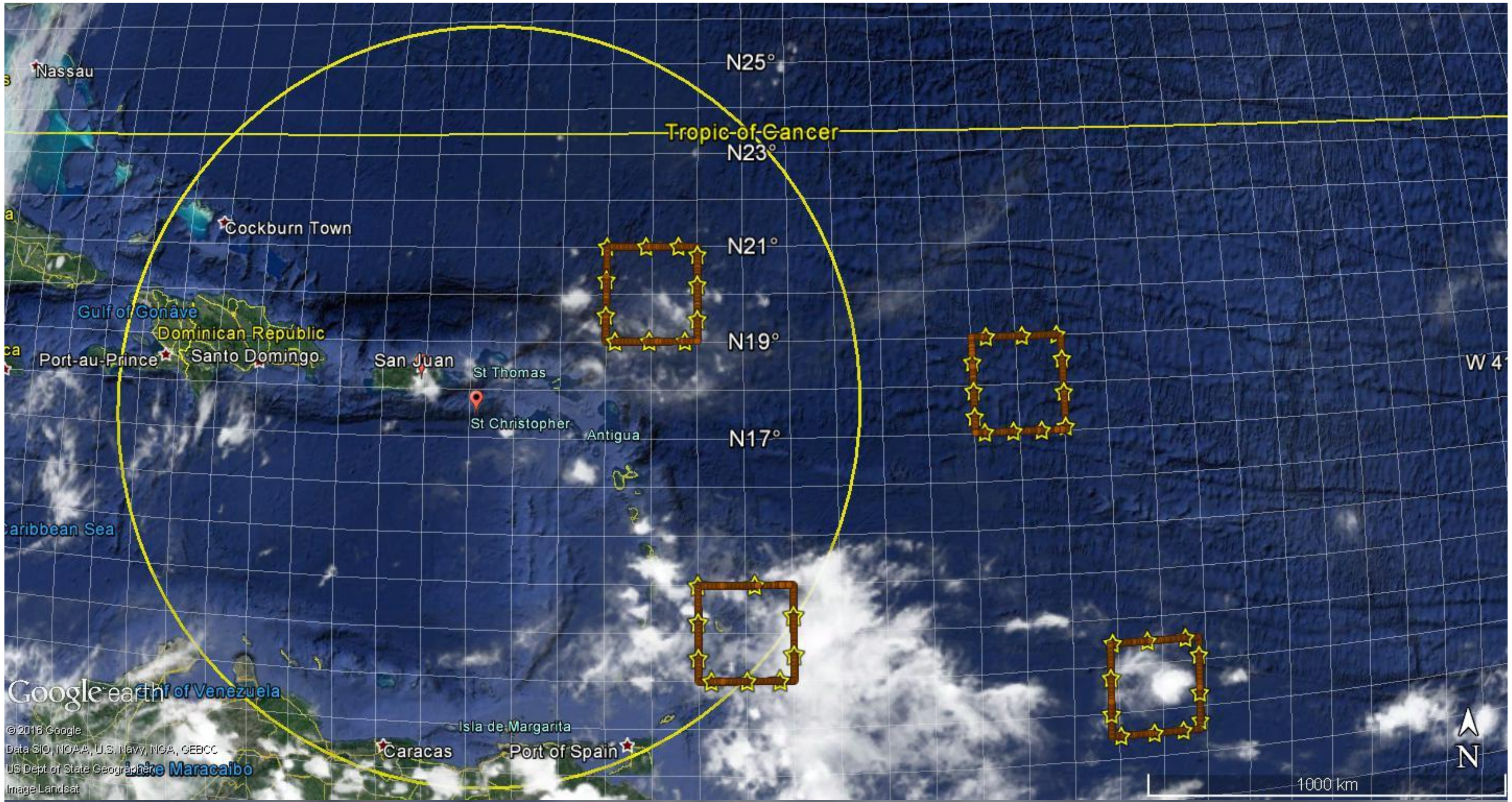
- DAWN velocity calibration legs
  - Two orthogonal legs
  - Over the Everglades or any other land surface
  - Straight and level for 5 minutes (35 – 75 km depending upon speed)
  - At or above FL10
  - At or above 250T
  - At start and end of flight
- CPEX BOX
  - At or above FL10 (clouds and aerosols permitting, fly higher)
  - At or above 400T
  - Corners selected before takeoff based upon model predictions and satellite data (CYGNSS, CALIPSO, GOES, ASCAT, etc.)
  - No change in corner waypoints at any time unless flight safety is an issue.
  - Revisit before returning to base with delta time of 3-4 hours preferred.
  - Continuous monitoring of the CPEX BOX may be considered for one short mission.

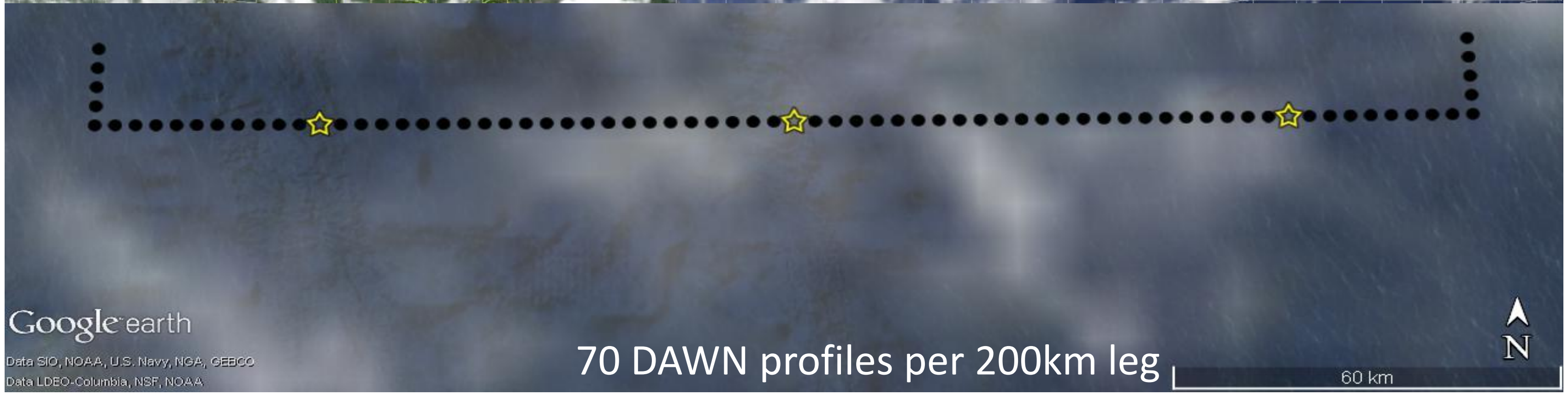


DAWN Calibration Legs: Gulf Experiments

CPEX BOX: Gulf Target on way to target of the day







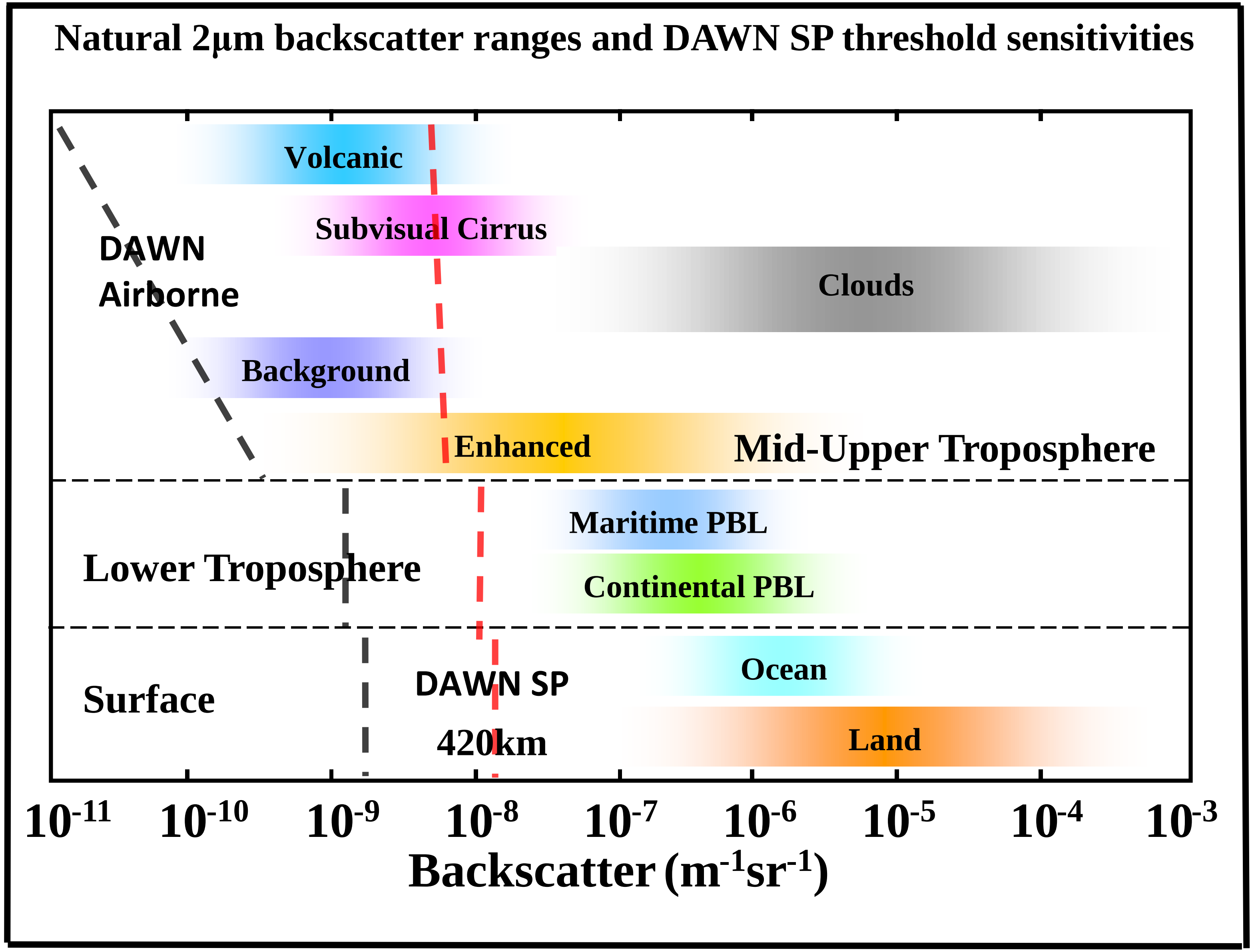
Example boxes
For CPEX if 200km
CPEX Boxes are used

Example DAWN setup for a “CPEX box” experiment

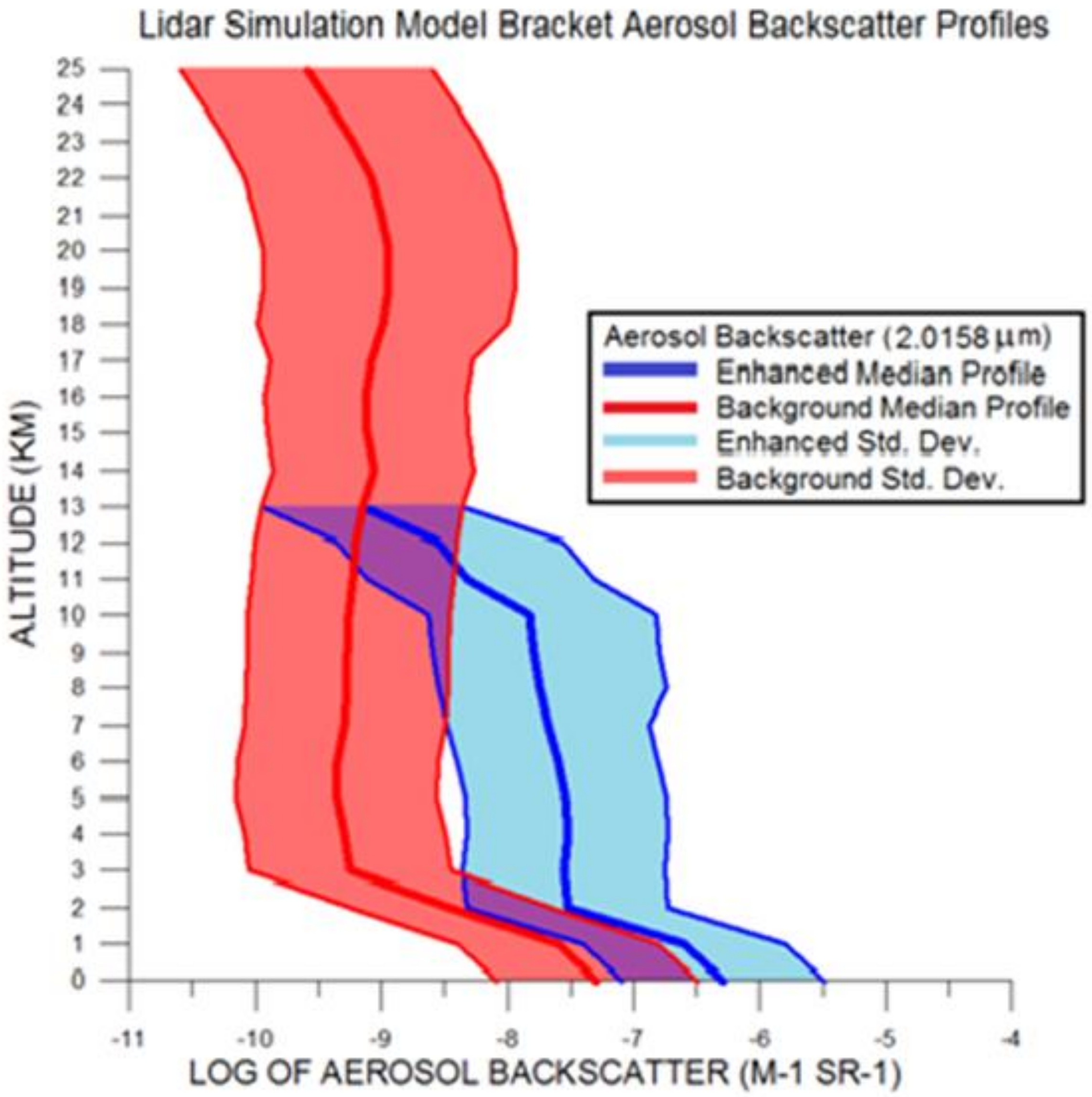
Parameter	Value	Comment
DC-8 altitude (AMSL)	Variable: 3km (10Kft) and 10km (33Kft) most likely.	DC-8 ceiling is ~ 12km (40,000’)
DC-8 ground speed	250 m/s	Can fly slower if desired
DAWN look angles	8 -12 stares w/ equal azimuth intervals	
DAWN nadir angle	30 degrees from nadir	
Dwell time at each stare	1-2 seconds	Dwell at forward stare may be extended to several seconds to prospect for PBL rolls
Shots per second	10	

Summary

- DAWN ready for CPEX with close to design sensitivity
  - ~ 20 dB improvement over PolarWinds
  - Focus at 3 -5 km may be a good option instead of collimated.
- Henderson will discuss DAWN technical findings and modifications.
- CPEX will be an excellent opportunity for DAWN to contribute significantly to the understanding of tropical convection where dynamics play the dominate role in initiation, organization and lifecycle.
- CPEX also offers opportunity to practice ADM Cal/Val underflights.



Natural 2µm backscatter ranges and DAWN SP threshold sensitivities
Volcanic
Subvisual Cirrus
DAWN
Airborne
Clouds
Background
Enhanced
Mid-Upper Troposphere
Maritime PBL
Lower Troposphere
Continental PBL
Ocean
Surface
DAWN SP
420km
Land
10^{-11}
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
Backscatter ($m^{-1}sr^{-1}$)



Lidar Simulation Model Bracket Aerosol Backscatter Profiles
ALTITUDE (KM)
LOG OF AEROSOL BACKSCATTER (M-1 SR-1)
Aerosol Backscatter (2.0158 µm)
Enhanced Median Profile
Background Median Profile
Enhanced Std. Dev.
Background Std. Dev.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
-11 -10 -9 -8 -7 -6 -5 -4