Investigation of winds near the ocean surface using airborne Doppler Wind Lidar and dropsondes

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Focus on the lowest 50 meters of atmospheric MBL

- What is the "true" wind at the traditional 10 meter reference height over water, especially for wind speeds >15m/s?
- What do airborne Doppler Wind Lidars(DWL) and dropsondes have to contribute to the calibration of OVWs, especially in conditions of U10>15m/s?
- Two specific issues today:
  - What is the height assignment precision of the HDSS (dropsonde) wind information?
  - How are the DWL wind retrievals below 50m to be used in studies of the Marine Boundary Layer with >15m/s winds?

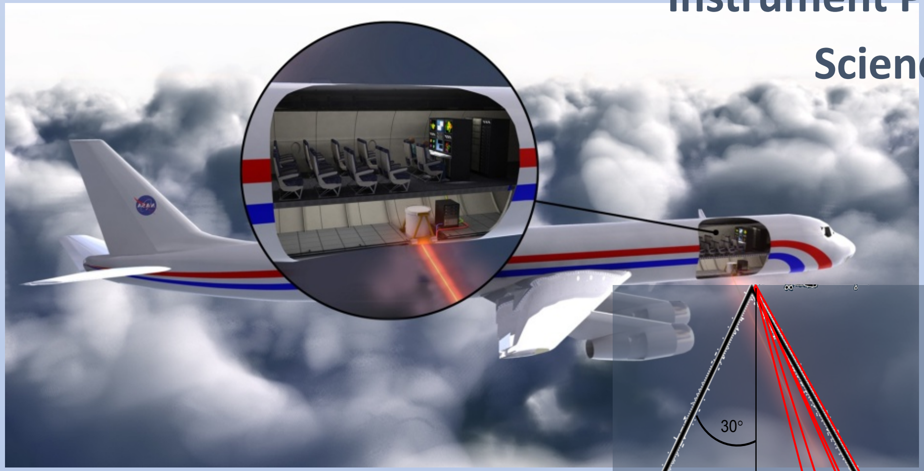
Overview

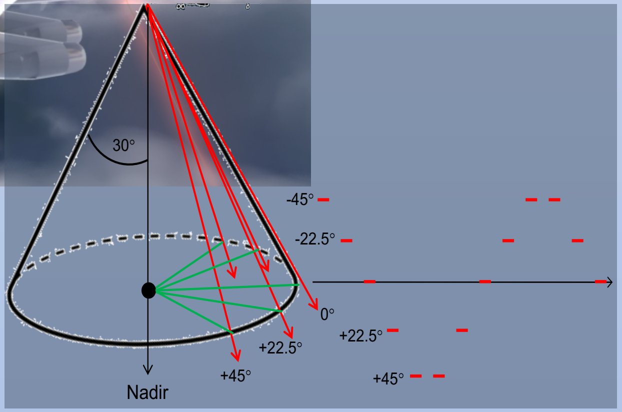
- Lowest 50m of the PBL is just one focus area of a more comprehensive series of multi-agency (NASA, ONR and NOAA) funded investigations of the PBL (mostly over water) using airborne Doppler Wind Lidars, dropsondes and other remote sensing capabilities.
- PolarWinds (NASA DC8) 2015, Iceland: > 80 hours DWL time and ~100 dropsondes.
- CPEX (NASA DC8) 2017, Florida: >100 hours DWL time and ~ 300 dropsondes.
- Hurricane Reconnaissance (NOAA P3) 2015-2018, Florida: > 100 hours DWL time and ~ 100 dropsondes
- Aeolus cal/val preparations(NASA DC8) 2019, California: ~45 DWL hours and 64 dropsondes.

Doppler Aerosol Wind (DAWN) Lidar System

Instrument PI: Michael J. Kavaya, NASA LaRC

Science PI: G. D. Emmitt, SWA





As used in CPEX

Attribute	Value
Airplanes Flown	DC-8 and UC-12B
Solid-State Laser Crystal and Wavelength	Ho:Tm:LuLiF, 2.053 Microns
Laser Architecture	Master Oscillator Power Amplifier (MOPA)
Pumping Source, Wavelength, Duration	100mJ, 10HZ, 180ns
Laser Pulse Energy E, Rate f, FWHM Duration t	15 cm
Telescope Diameter D, Magnification M	15 cm, 20
Light Detection Material, Technique	InGaAs, Coherent, Dual-Balanced
Scanner Diameter, Type, Deflection	15 cm, Step-Stare Rotating Wedge, 30° About Nadir
Eye Safety	Safe at any Range When DAWN Closed Up for Flight
Pointing Knowledge Technique	Dedicated INS/GPS on Lidar; dry land returns
LOS Wind Measurement Precision	< 1 m/s
Maximum LOS, Horizontal Wind	±80 m/s, ±160 m/s
Captured Data Length in Range, Altitude	0 – 16.4 km, 0 – 14.2 km
Vertical Resolution	133 m for 512-Sample Range Gate

Vertical resolution: 66/33m

Single shot horizontal resolution in PBL: <20m

Lowest level of wind retrieval: ~ 16m using SRGs

Full tropospheric profiles using 2 second stares from surface to 12km

DAWN Capabilities

High coherent Doppler lidar sensitivity to aerosol backscatter, enabling excellent vertical resolution, accuracy, and atmospheric coverage

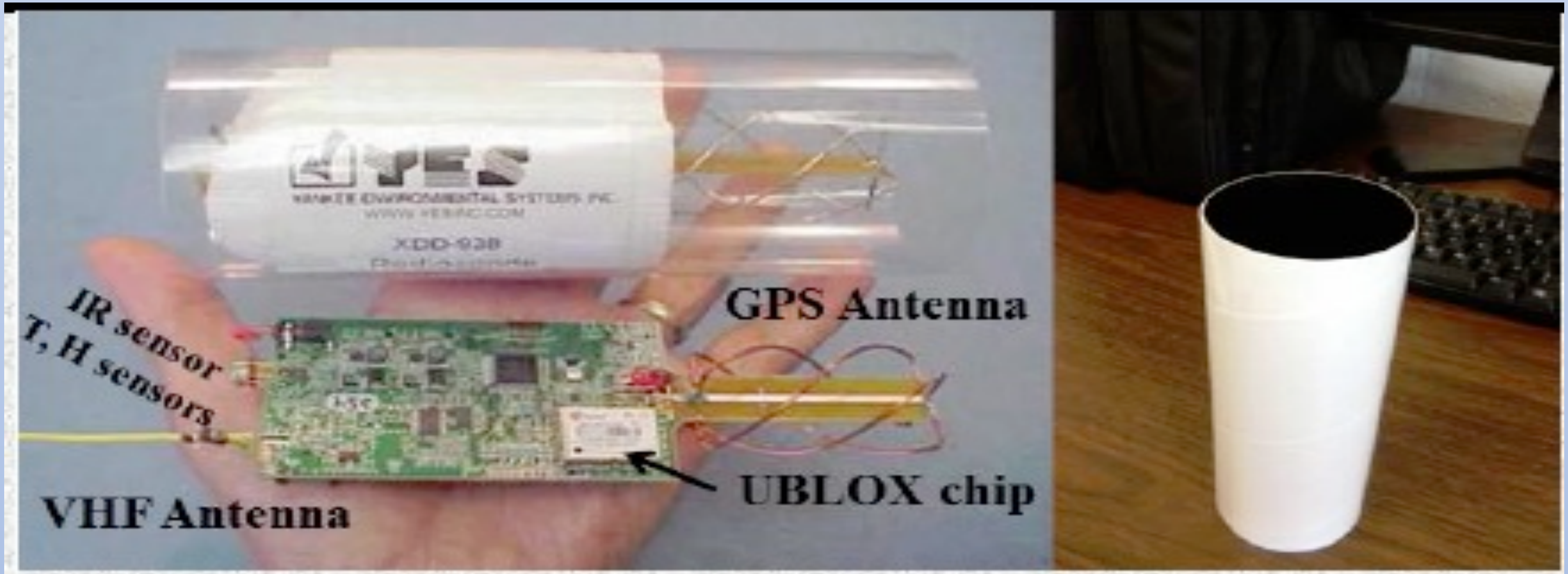
Provides vertical profiles of horizontal wind vectors, LOS range wind and wind turbulence profiles, and relative aerosol backscatter profiles

Optional number of azimuth angles (up to 12) permits trade of wind variability determination vs. horizontal resolution

Optional number of laser shots averaged for each LOS wind profile permits trade of atmospheric coverage vs. horizontal resolution

Data may be processed multiple ways to provide various combinations of vertical and horizontal resolution, atmospheric coverage, and expected accuracy statistics

HDSS dropsonde developed by ONR by YES



XDD (wt 58g, size 17.8x6.6 cm-upper) with printed circuit board, GPS and VHF antenna and sensor location (lower-left). Modified XDD (right) with black/white cardboard cylinder to minimize radiation effects.

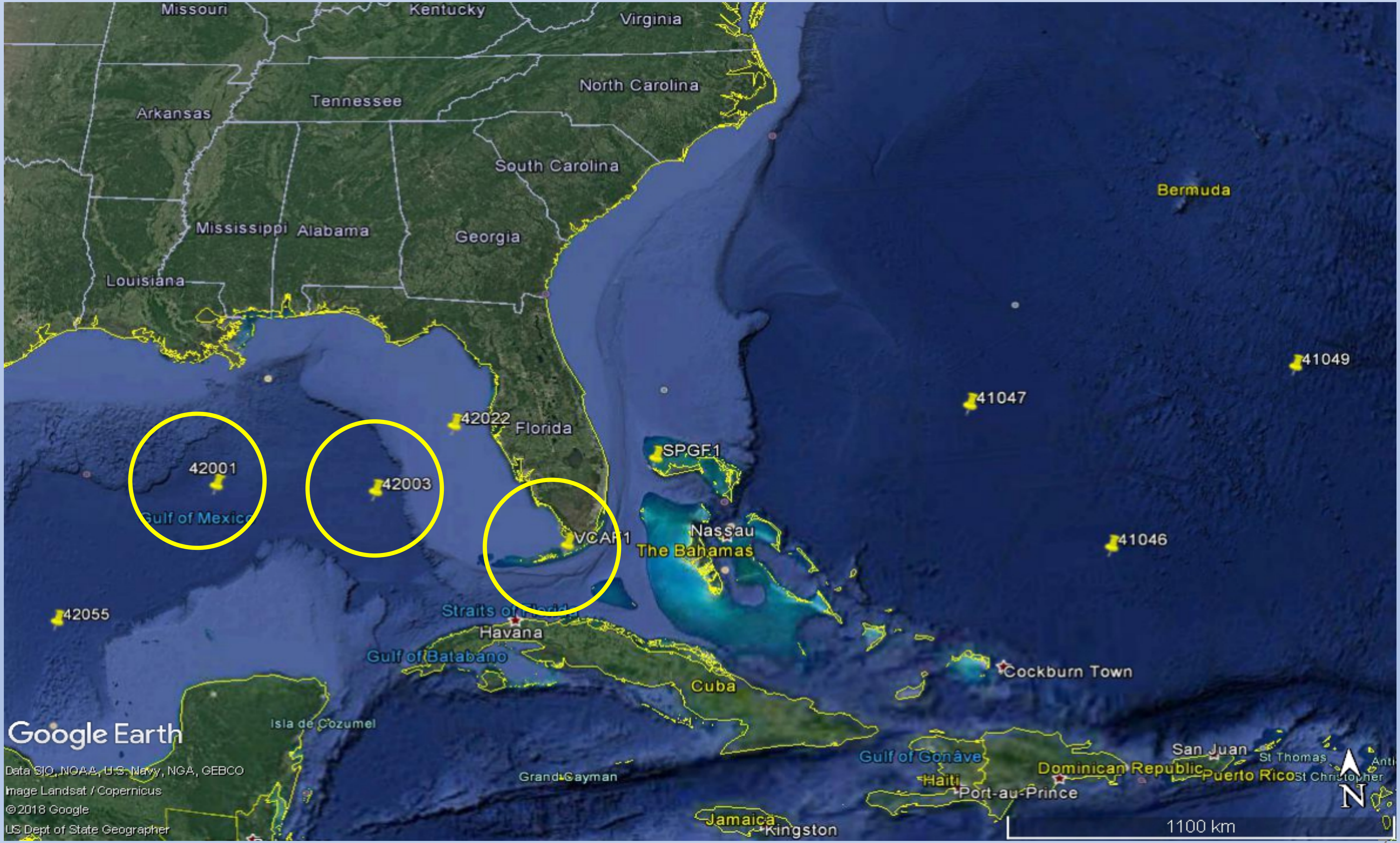
HDSS and XDD Overview

The HDSS (High Definition Sounding System) and eXpendable Digital Dropsonde (XDD)developed by Yankee Environmental Systems through ONR (Black et al., (2107) was used. Before CPEX this dropsonde system had been deployed over the past seven years including :

-Test deployments on the Twin Otter (2011), DC-8 (2013) and WB57 (2013)

The HDSS was selected for three primary advantages over prior dropsonde technologies:

- high fall speeds (~30m/s – 18m/s) reduces horizontal drift distances which is highly desirable in the proximity of organized convection
- surface temperature sensor was seen as particularly important near and under deep convection generating cold pools
- >12 simultaneous sonde tracking capability enables rapid deployment in areas which the science team identified as meeting mission priority.



Missouri
Kentucky
Virginia
North Carolina
Tennessee
Arkansas
South Carolina
Bermuda
Mississippi
Alabama
Georgia
Louisiana
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41047
42022
Florida
SPGF1
42001
42003
Gulf of Mexico
VCAF1
Nassau
The Bahamas
41046
42055
Havana
Gulf of Batabano
Cockburn Town
Cuba
Google Earth
Isla de Cozumel
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
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US Dept of State Geographer
Gulf of Gonâve
San Juan
St Thomas
Dominican Republic
Puerto Rico
Haiti
Port-au-Prince
Grand Cayman
Jamaica
Kingston
1100 km
N

Near Surface Wind Comparisons Near Buoys (CPEX)

CPEX Mission	DAWN(~50m)	Buoy (id #)	Dropsonde(~20m)
May 27, 2017	4.3/110	3.8/121 (42001)	5.0/124
June 1, 2017	2.8/183	3.6/146 (42003)	NA
June 16, 2017	3.2/192	3.7/162 (VCAF1)	3.9/180
June 20, 2017	13.5/161	10.9/157 (42001)	13.2/160
June 20, 2017	12.6/162	11.7/352 (42395)	9.7/ 10
June 21, 2017	12.1/185	9.3/171 (42001)	11.6/173
June 21, 2017	10.5/192	9.0/167 (42001)	11.6/168

Dropsonde has high speed bias and clockwise directional bias

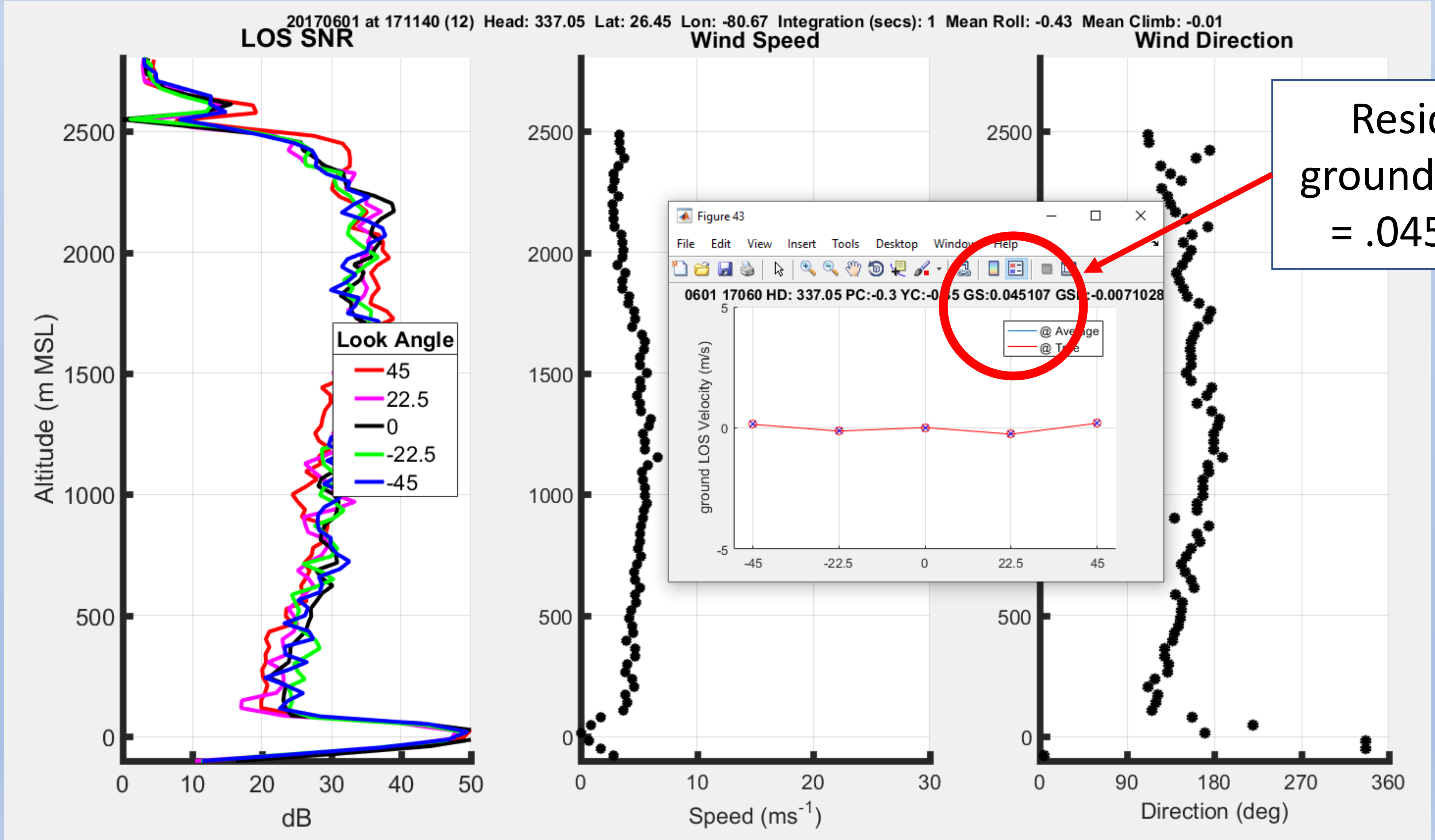
Evaluation of the HDSS data below 50m in MBL

- On-going at both YES and SWA with funding from NASA and ONR.
- The nominal fall speed of the HDSS in the last second before “splash down” is ~18m/s.
- The sonde broadcasts a data packet once per second that contains 2 and 4 Hz information.
- The computed geopotential height is trusted over the GPS report height near the ocean surface.
- Recent questions raised by the OVWs and NWP communities have initiated an investigation into the last second of data transmission
- **Current finding: the height assignments for HDSS GPS winds is off by 1.53 seconds or ~28 meters. Thus the U10 winds are biased high…still looking for truth for comparisons.**

DAWN/Drop Comparison setup

- Ground return calibration for DAWN while over Florida peninsula
  - Straight and level between 3 and 4 km AGL
  - Perform calibration flight segment before and after an over-water mission clouds and ATC permitting.
- 162 (out of 325) CPEX dropsondes over 16 flights were used in the comparisons (~15,000 height segments of ~ 66 meter DWL vertical resolution)

Example of attitude calibration for DAWN during CPEX

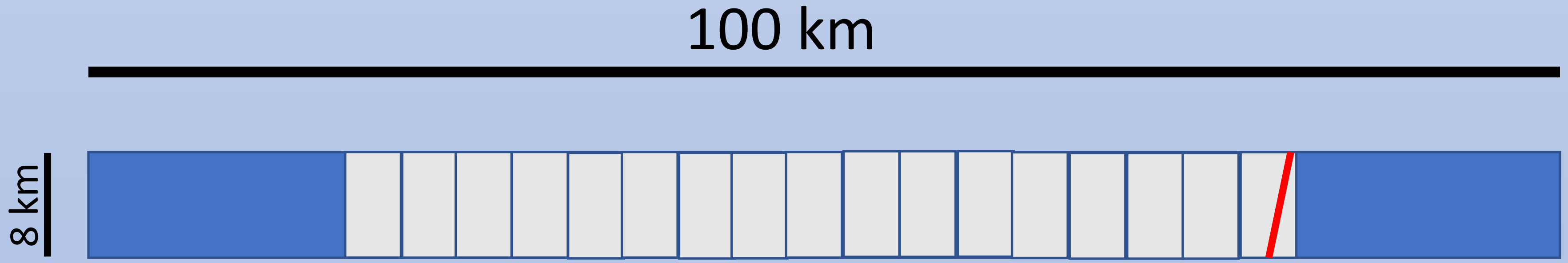


Residual ground speed = .045 m/s

Example ground return calibrations with residual ground speed (Nominal DC-8 groundspeed during calibration is 175m/s)

Date	Yaw Correction	Pitch Correction	Ground Speed(m/s)	GOF
May 27	-0.30	-0.30	0.037	-0.059
May 29	-0.30	-0.30	0.199	0.025
June 1	-0.35	-0.30	0.045	-0.007
June 15	-0.45	-0.20	0.037	0.038
June 23	+0.05	-0.60	0.023	-0.018
June 24	-0.15	-0.55	0.101	0.037

DAWN vs dropsonde sampling comparisons



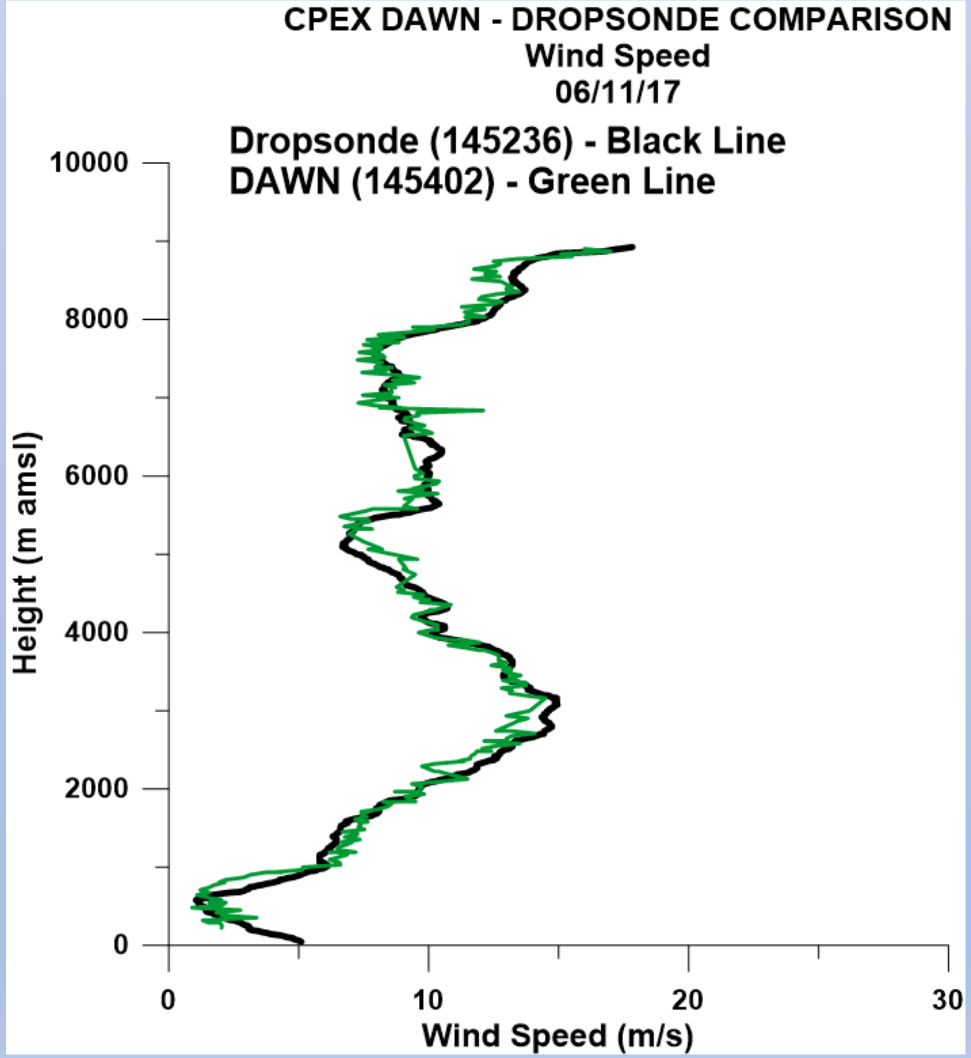
Dropsonde: 30 -20m/s fall speeds
Time in flight: 8000 m in ~5.3 minutes
DC-8 ground distance: ~ 65 km
Horizontal drift (10m/s wind): 3.2 km

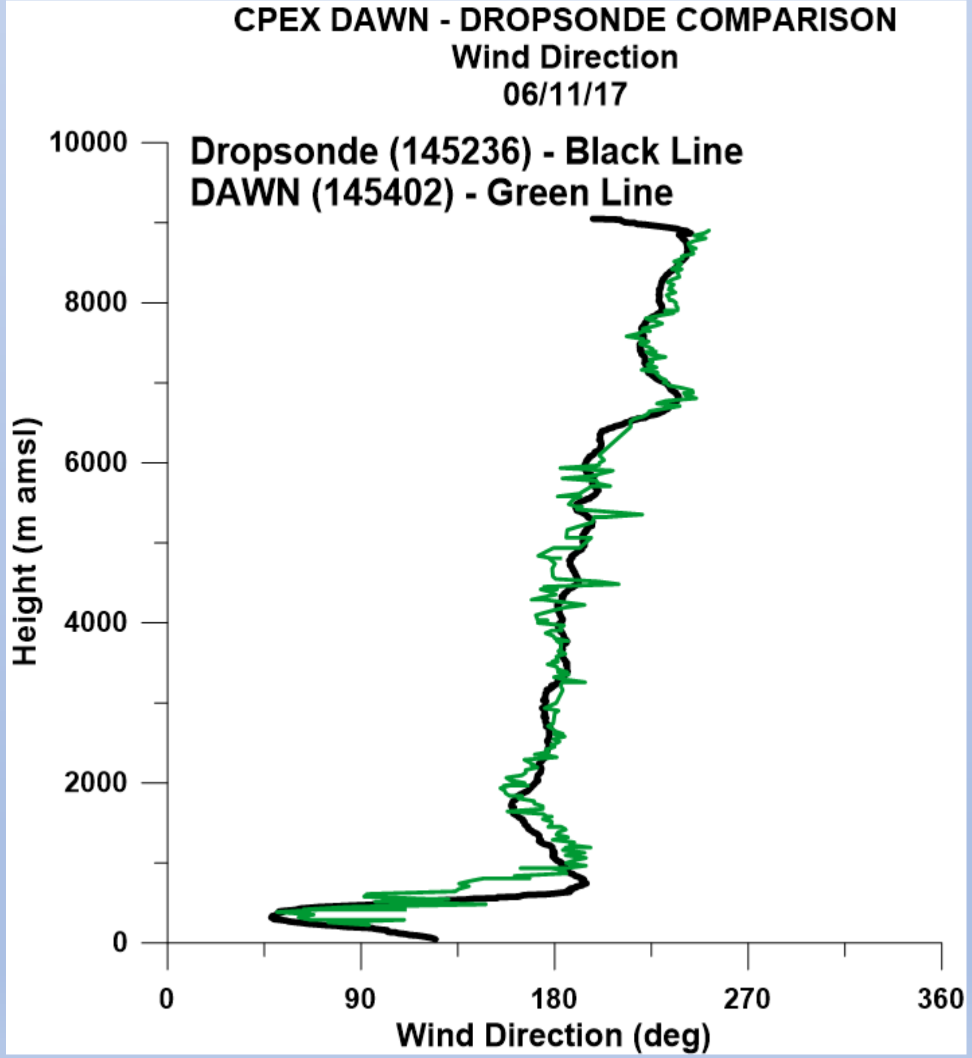
DAWN: ~10 seconds sampling +9 seconds overhead per sounding (3.8km)

Co-located ~ within 5 km

Coincident ~ 5 minutes

Example DAWN-Dropsonde comparison during CPEX 2017





DAWN-Dropsonde comparisons from CPEX 2017
Wind Speed (m/s)

	Number 37m seg	MEAN Z DIFF (m)	BIAS (m/s)	MEAN ABS (ΔWS)	ΔWS RMSD
ALL	15517	3.08	0.09	1.13	1.55
2 LOOK	6921	3.26	0.05	1.28	1.72
5 LOOK	8596	2.93	0.13	1.01	1.39

Differences by wind speed interval (m/s)

Wind Speed Interval	Number 37m seg	MEAN Z DIFF (m)	BIAS (m/s)	MEAN ABS(ΔWS)	ΔWS RMSD
0-5 m/s	3193	3.05	-0.36	1.00	1.38
5-10 m/s	5999	3.00	0.10	1.11	1.47
10-15 m/s	3717	3.09	0.27	1.17	1.57
>15 m/s	2608	3.26	0.40	1.26	1.83

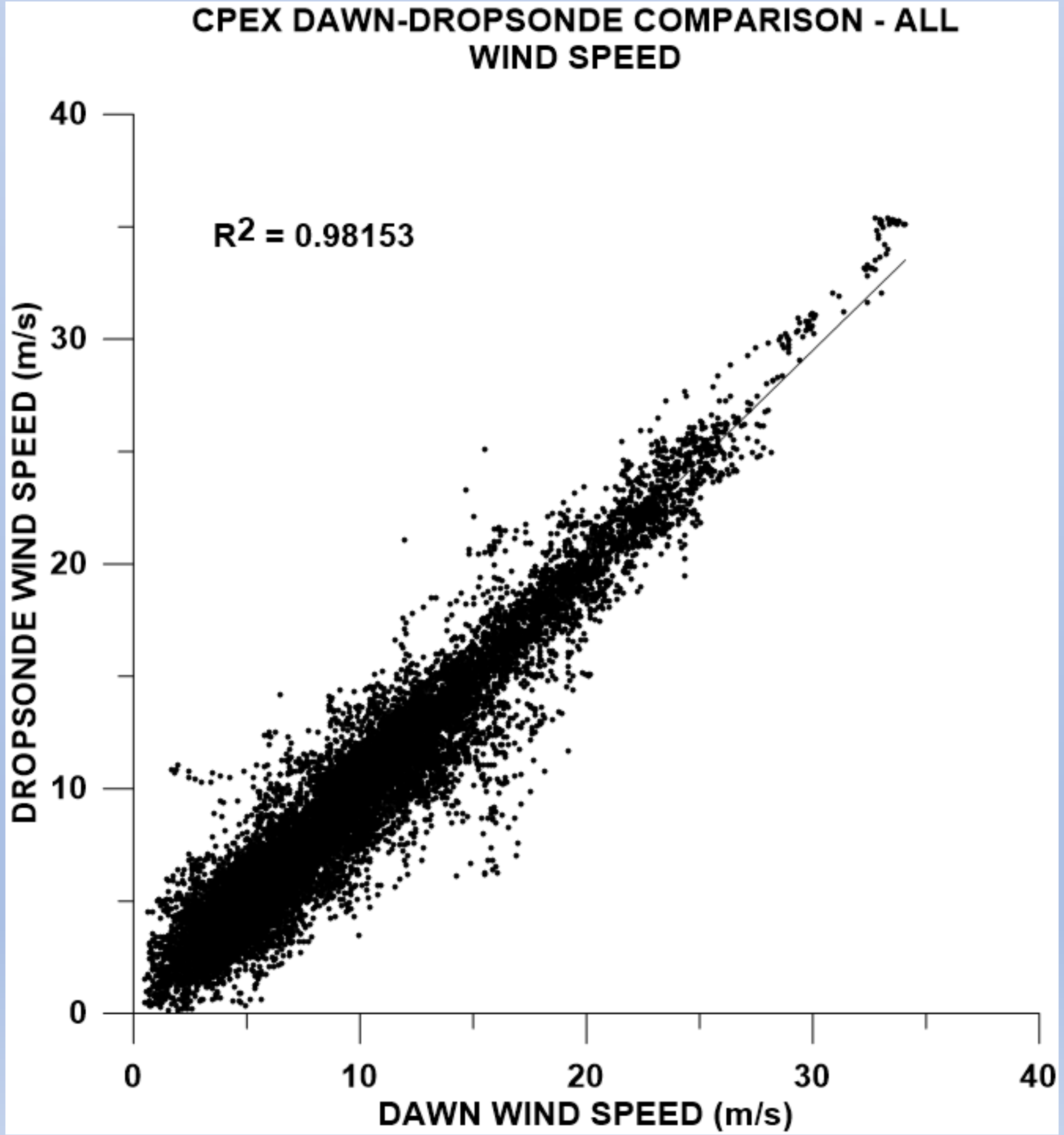
Wind Speed Interval	Number 37m seg	MEAN Z DIFF (m)	BIAS (deg)	MEAN ABS(ΔWD)	ΔWD RMSD
0-5 m/s	3193	3.05	4.34	23.40	37.4
5-10 m/s	5999	3.00	0.43	10.08	16.1
10-15 m/s	3717	3.09	-0.99	6.48	9.30
>15 m/s	2608	3.26	-1.22	5.48	10.13

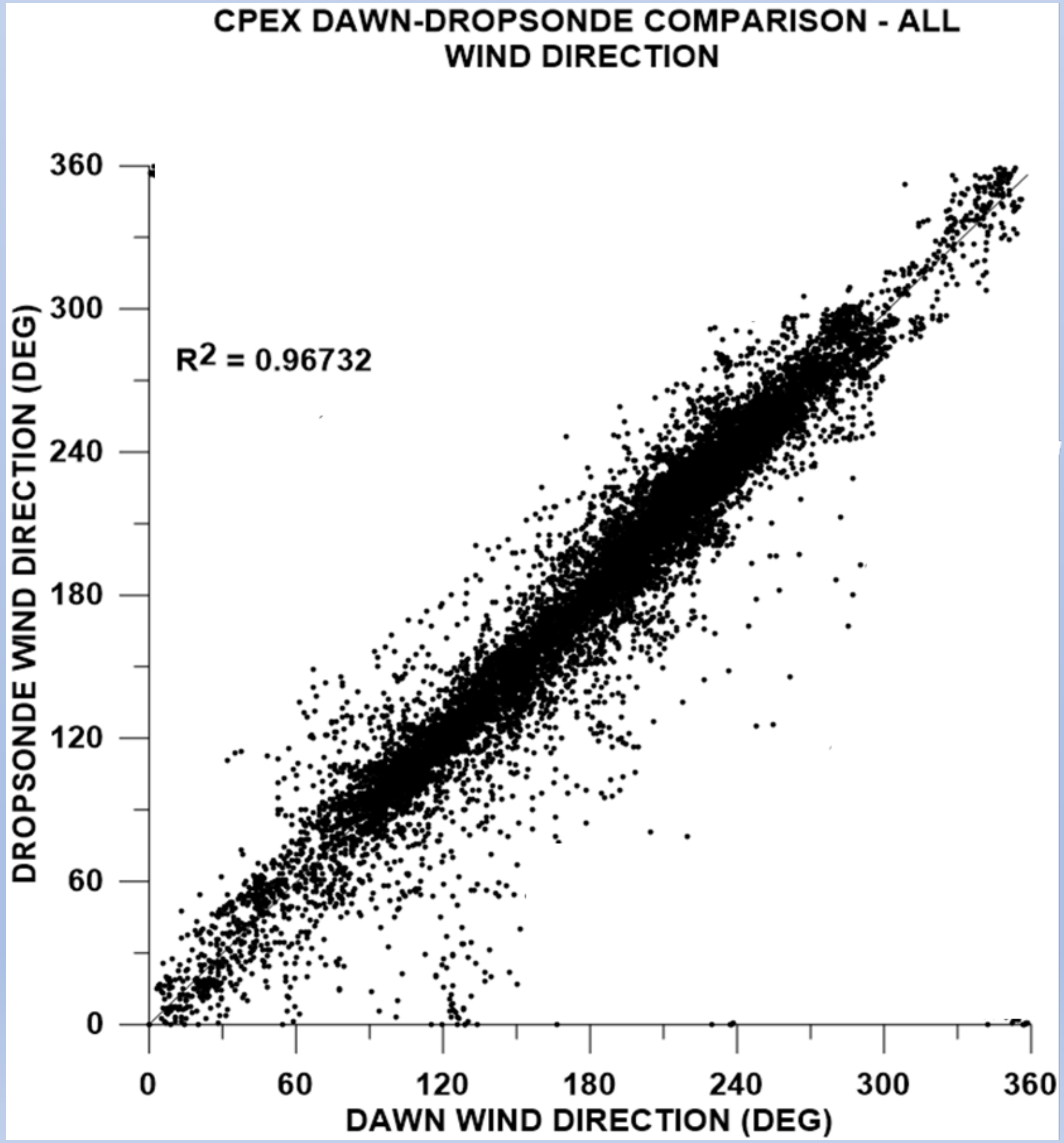
Differences by height interval (km)

Height Interval	Number 37m seg	MEAN Z DIFF (m)	BIAS (m/s)	MEAN ABS(ΔWS)	ΔWS RMSD
0-3 km	4935	2.52	-0.02	0.95	1.26
3-6 km	2079	2.91	0.26	1.20	1.62
6-9 km	5774	3.32	0.27	1.14	1.58
9-12 km	2732	3.70	-0.20	1.38	1.84

Height Interval	Number 37m seg	MEAN Z DIFF (m)	BIAS (deg)	MEAN ABS(ΔWD)	ΔWD RMSD
0-3 km	4935	2.52	1.62	9.79	17.5
3-6 km	2079	2.91	0.78	10.10	18.4
6-9 km	5774	3.32	0.31	14.25	26.4
9-12 km	2732	3.70	-0.68	8.09	11.88

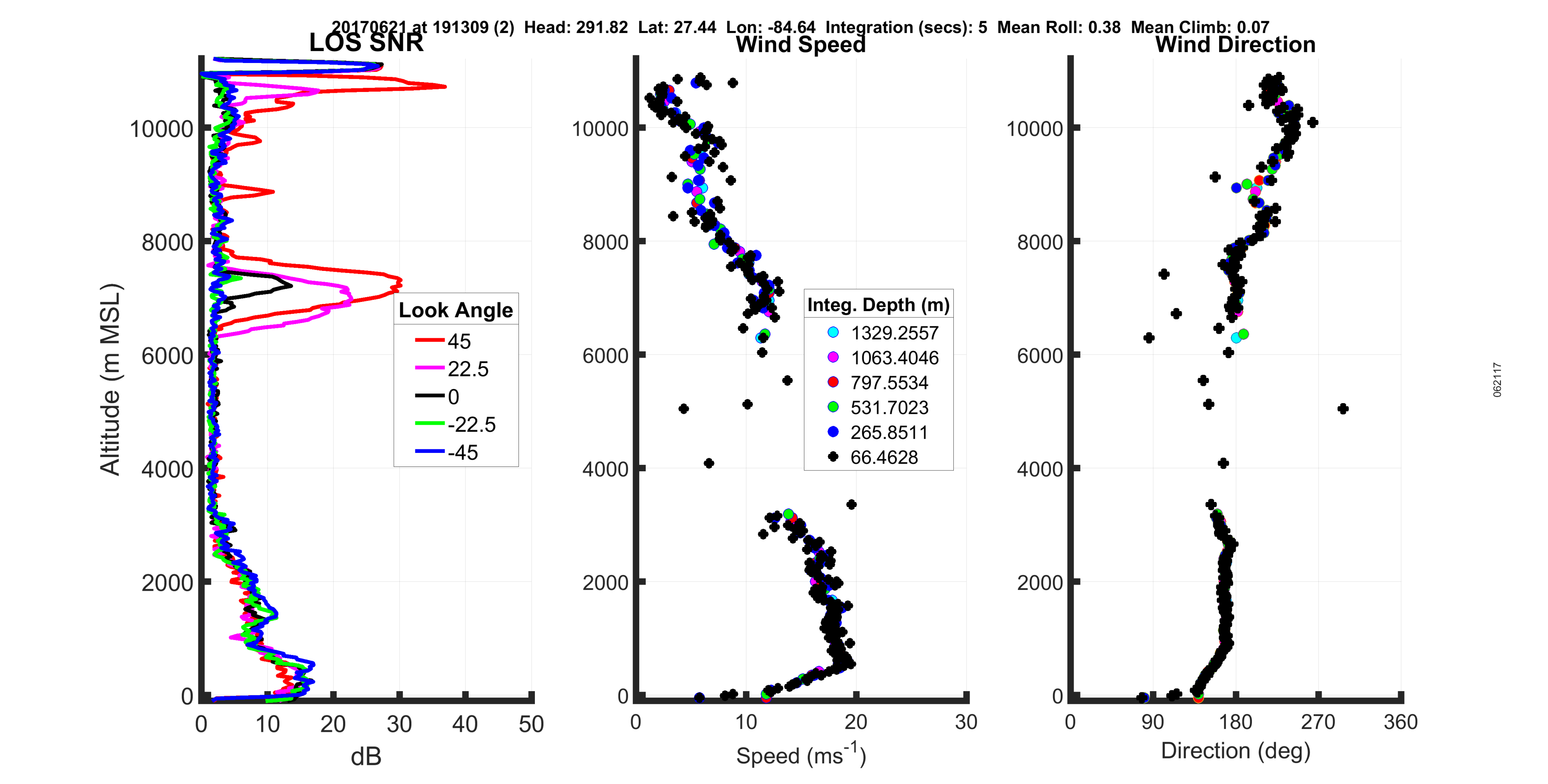
All DAWN – Dropsonde Comparisons from 2017 CPEX
(162 ~ co-located, coincident DAWN and Dropsonde Profiles)



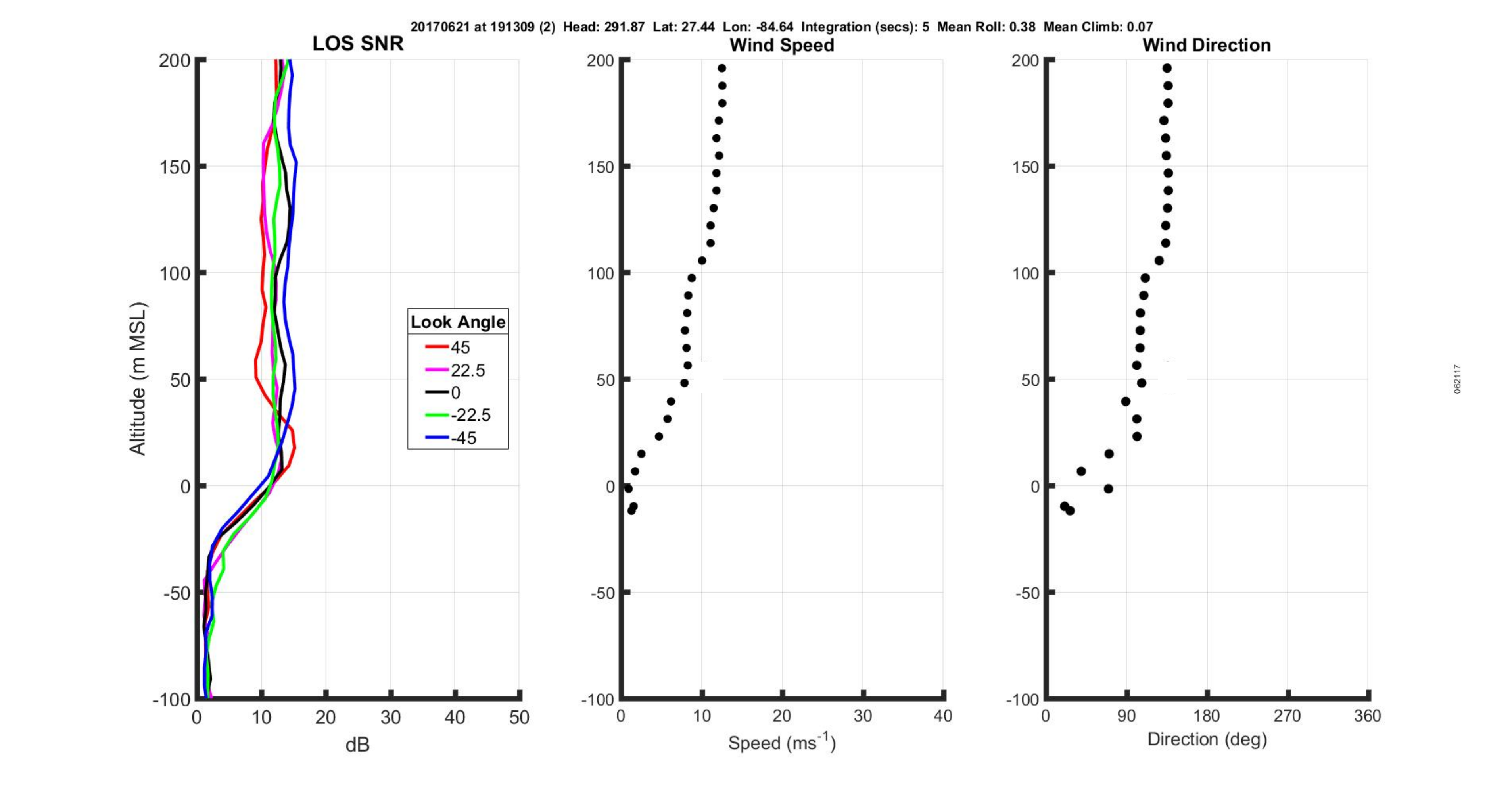


Focus on the lowest 50m with airborne DWL

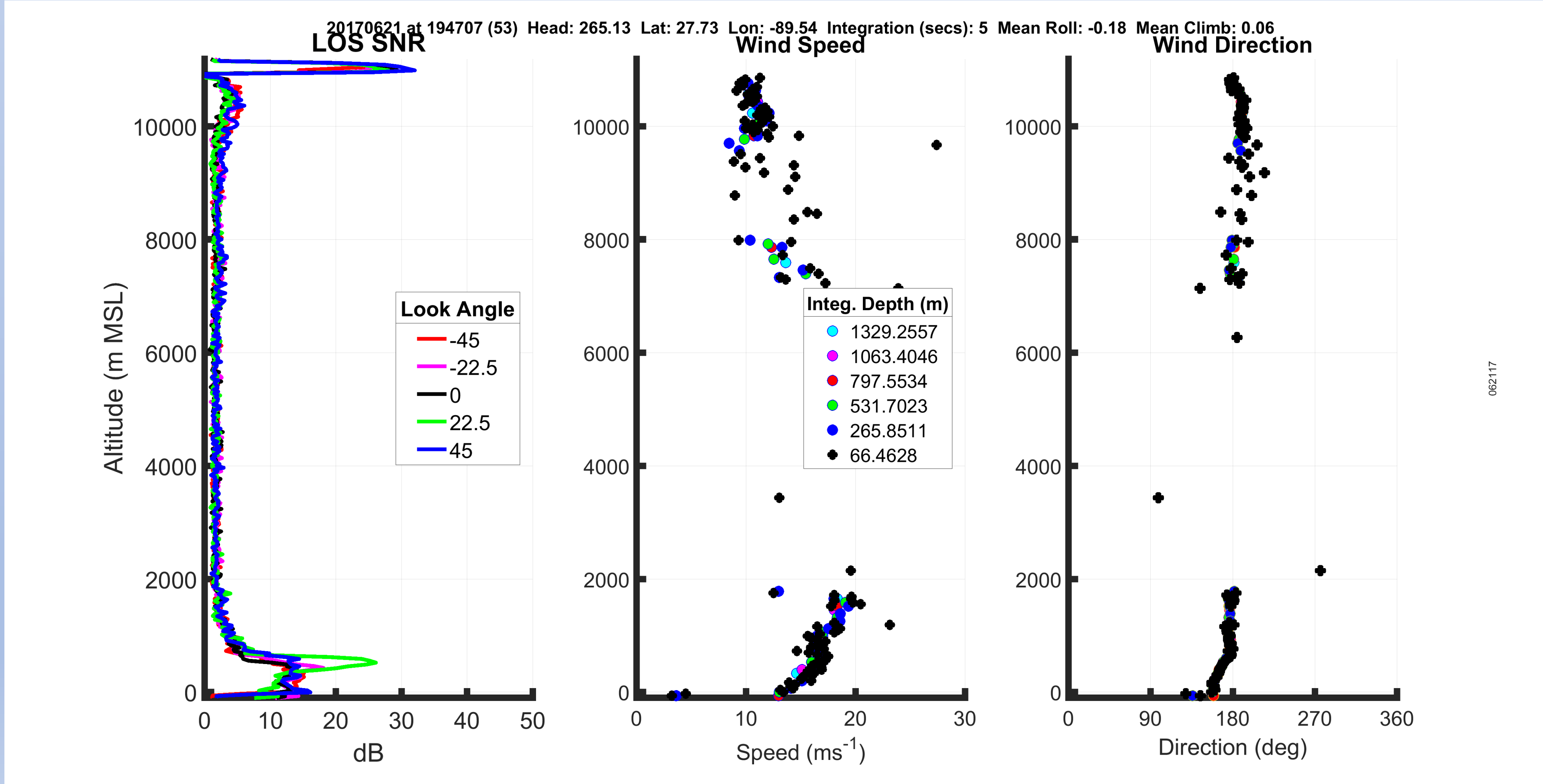
Example 1 from DAWN during CPEX



Focus on lowest 200m using sliding gates

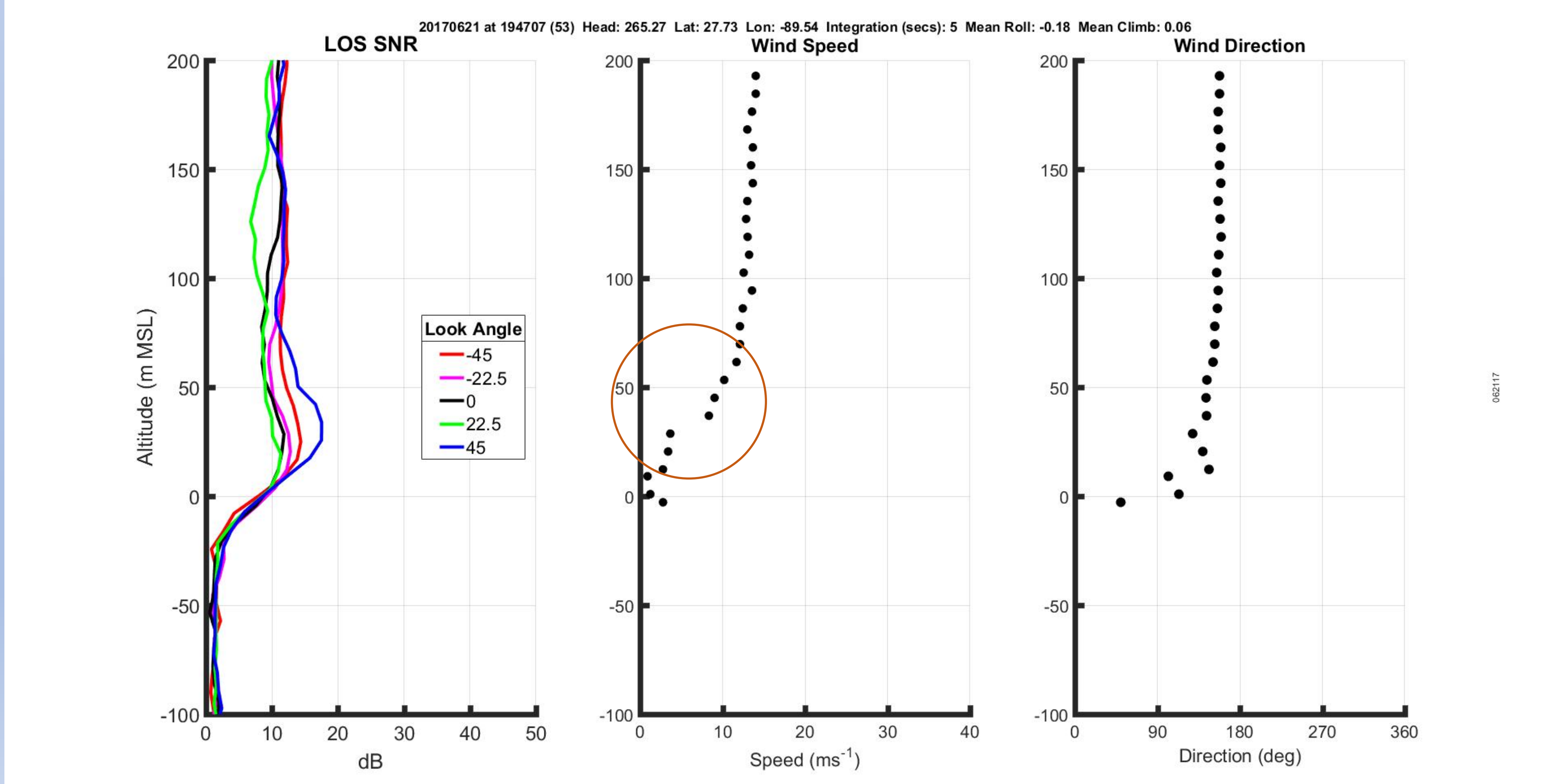


Example 2

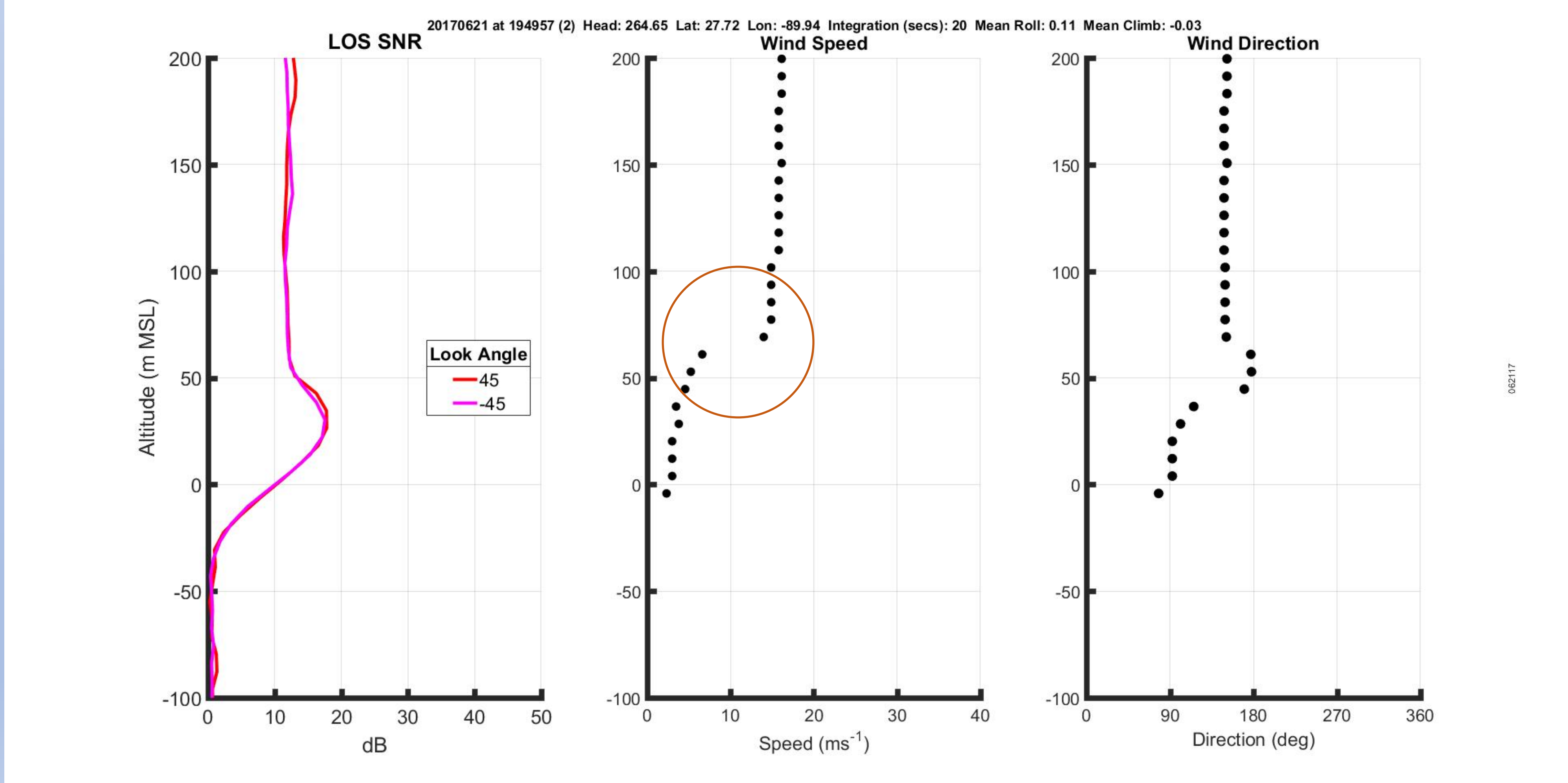


20170621 at 194707 (53) Head: 265.13 Lat: 27.73 Lon: -89.54 Integration (secs): 5 Mean Roll: -0.18 Mean Climb: 0.06
LOS SNR
Wind Speed
Wind Direction
Altitude (m MSL)
Look Angle
-45
-22.5
0
22.5
45
dB
Integ. Depth (m)
1329.2557
1063.4046
797.5534
531.7023
265.8511
66.4628
Speed (ms^{-1})
Direction (deg)
062117

Lowest 200m under white cap conditions

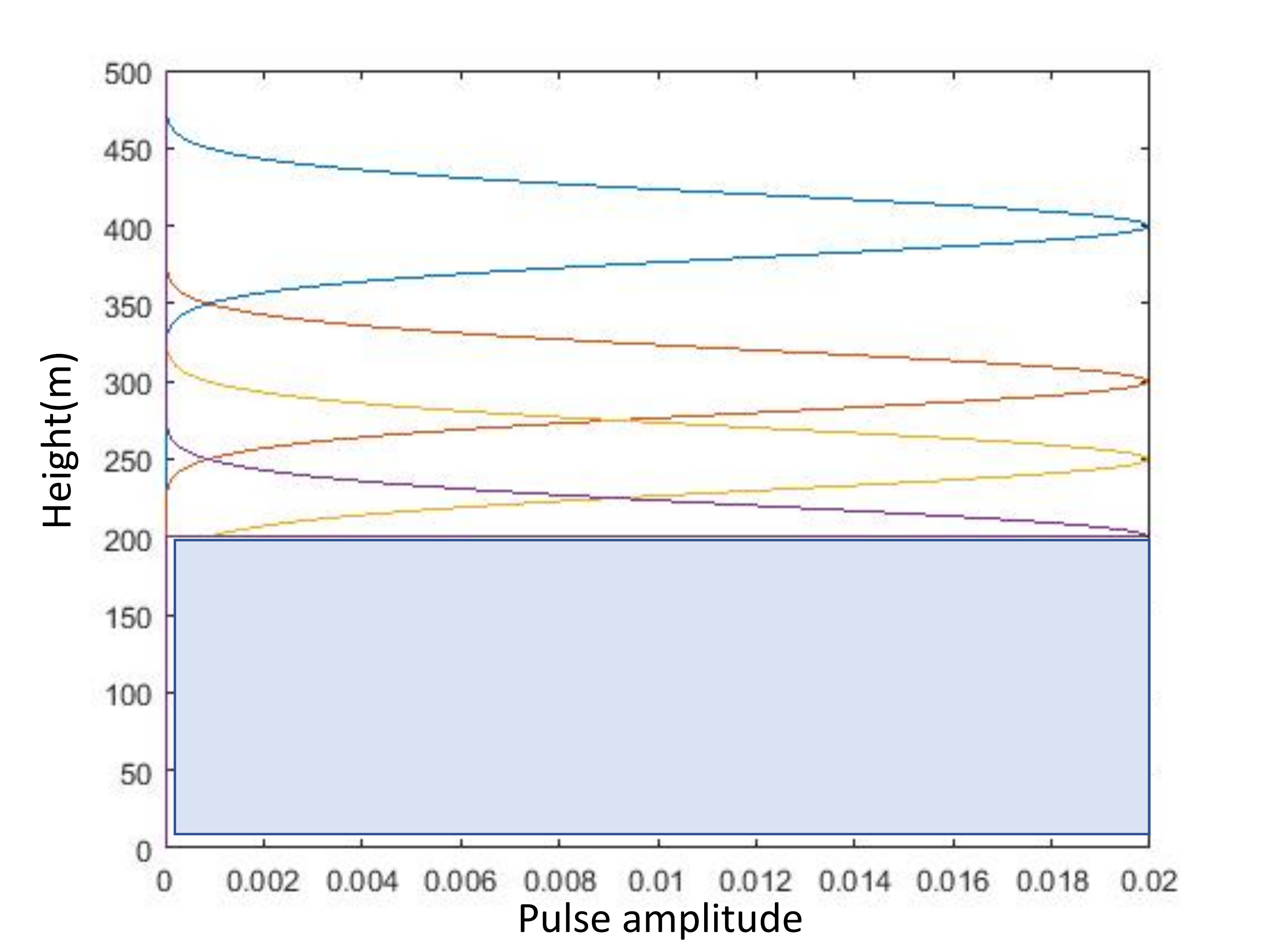


High wind conditions

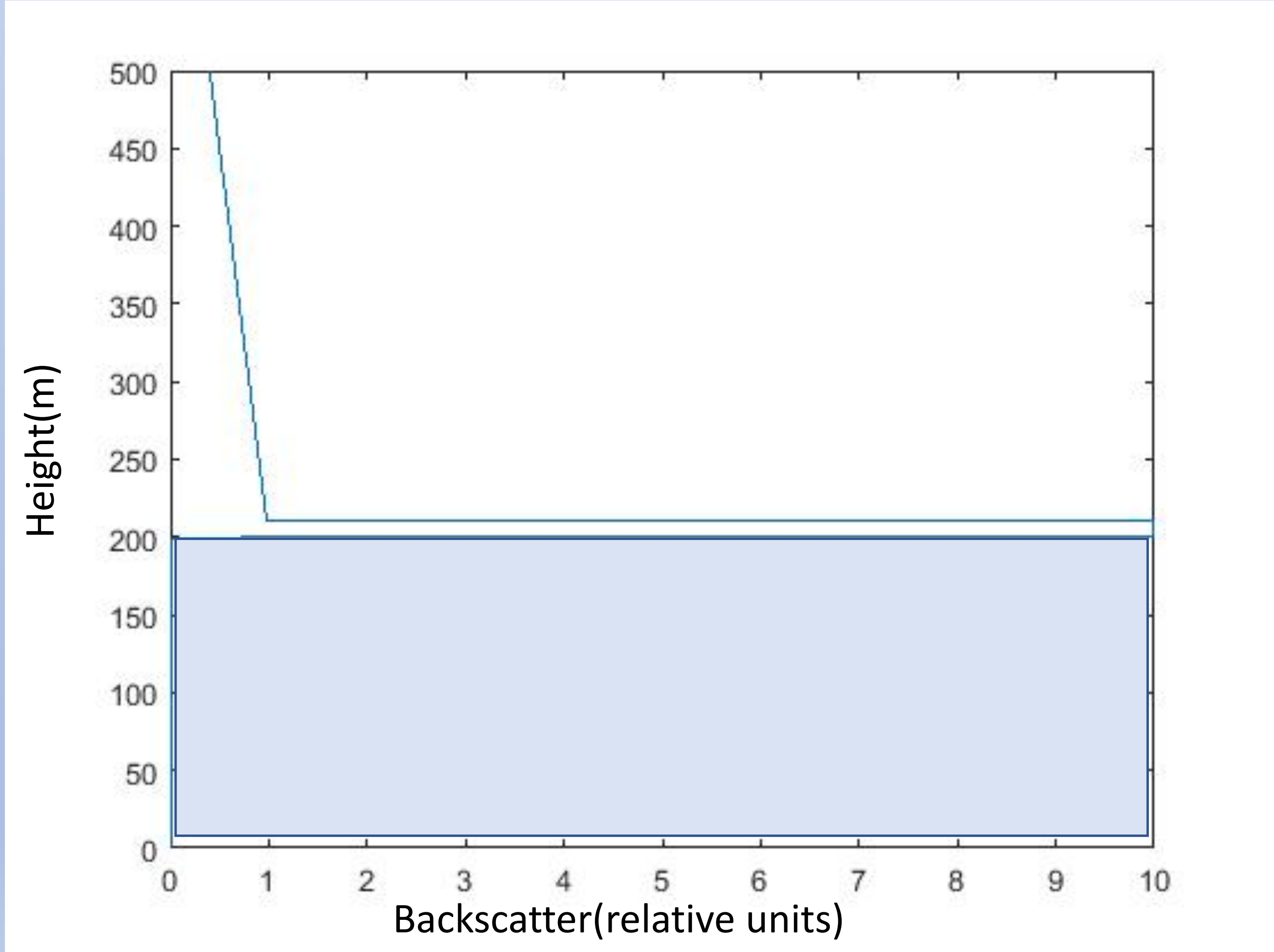


Simulations of Airborne DWL measurements within the lowest 50ms over water

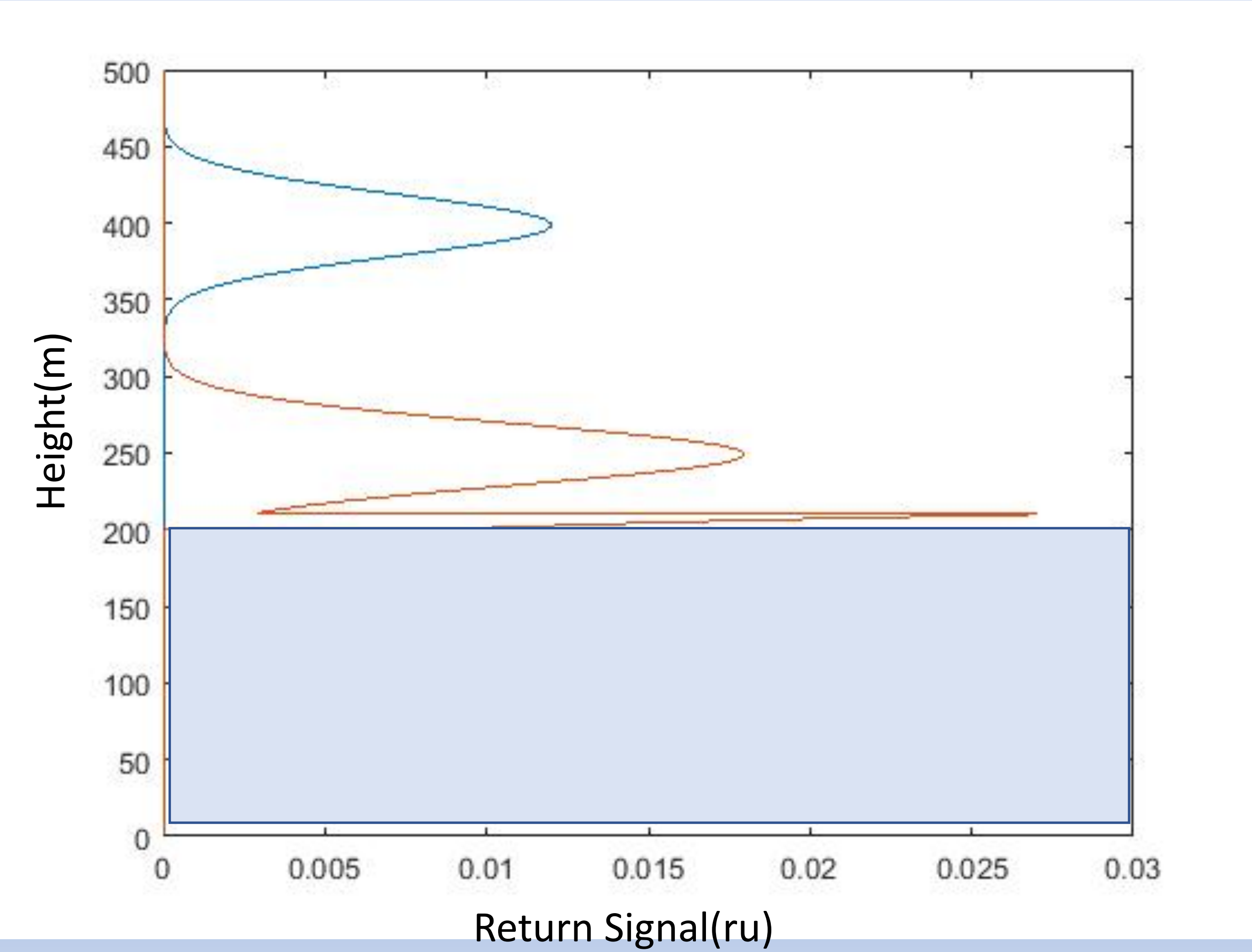
DWL pulse for 4 positions relative to ocean surface



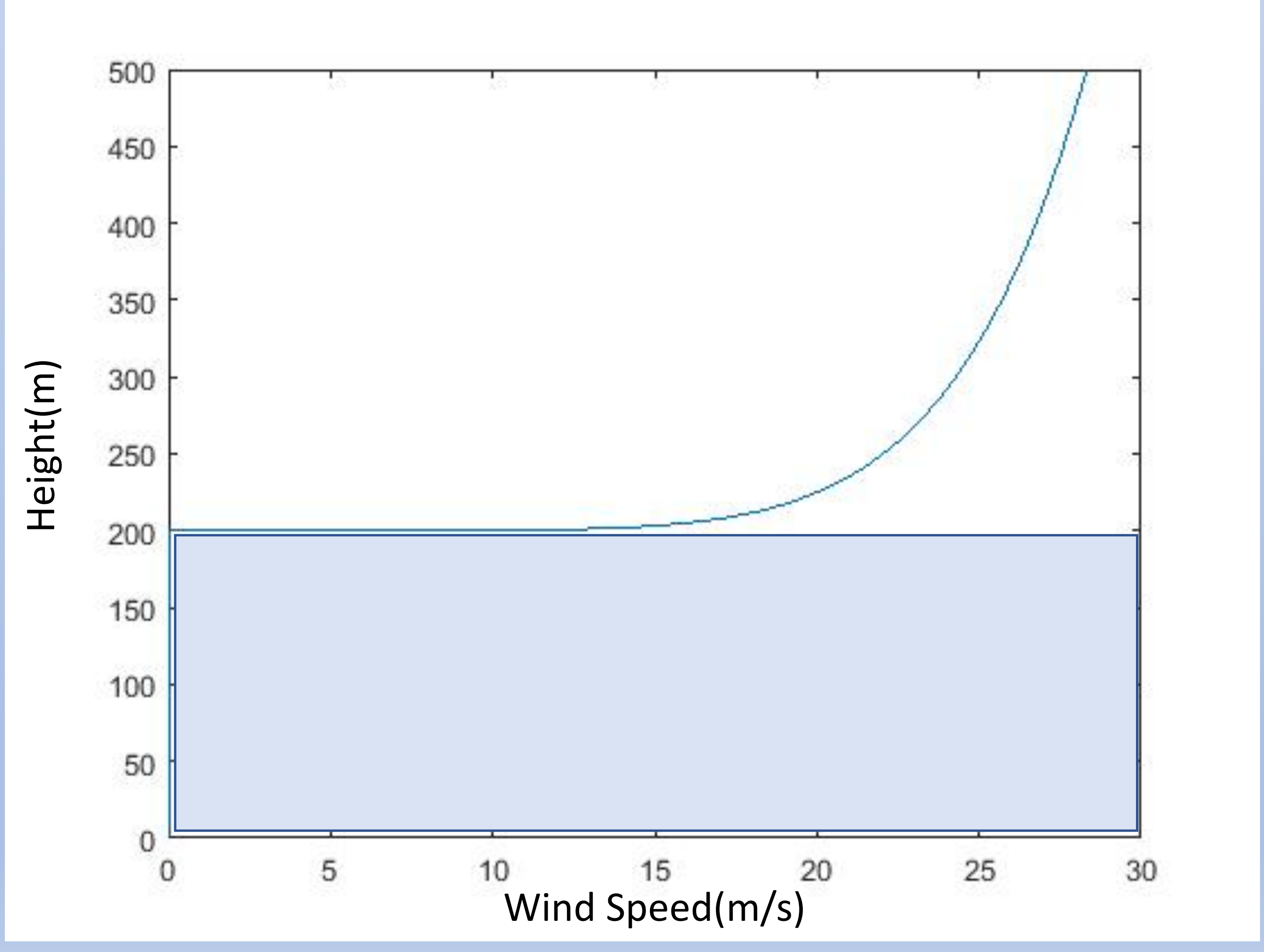
Backscatter: white caps with spray below 10m



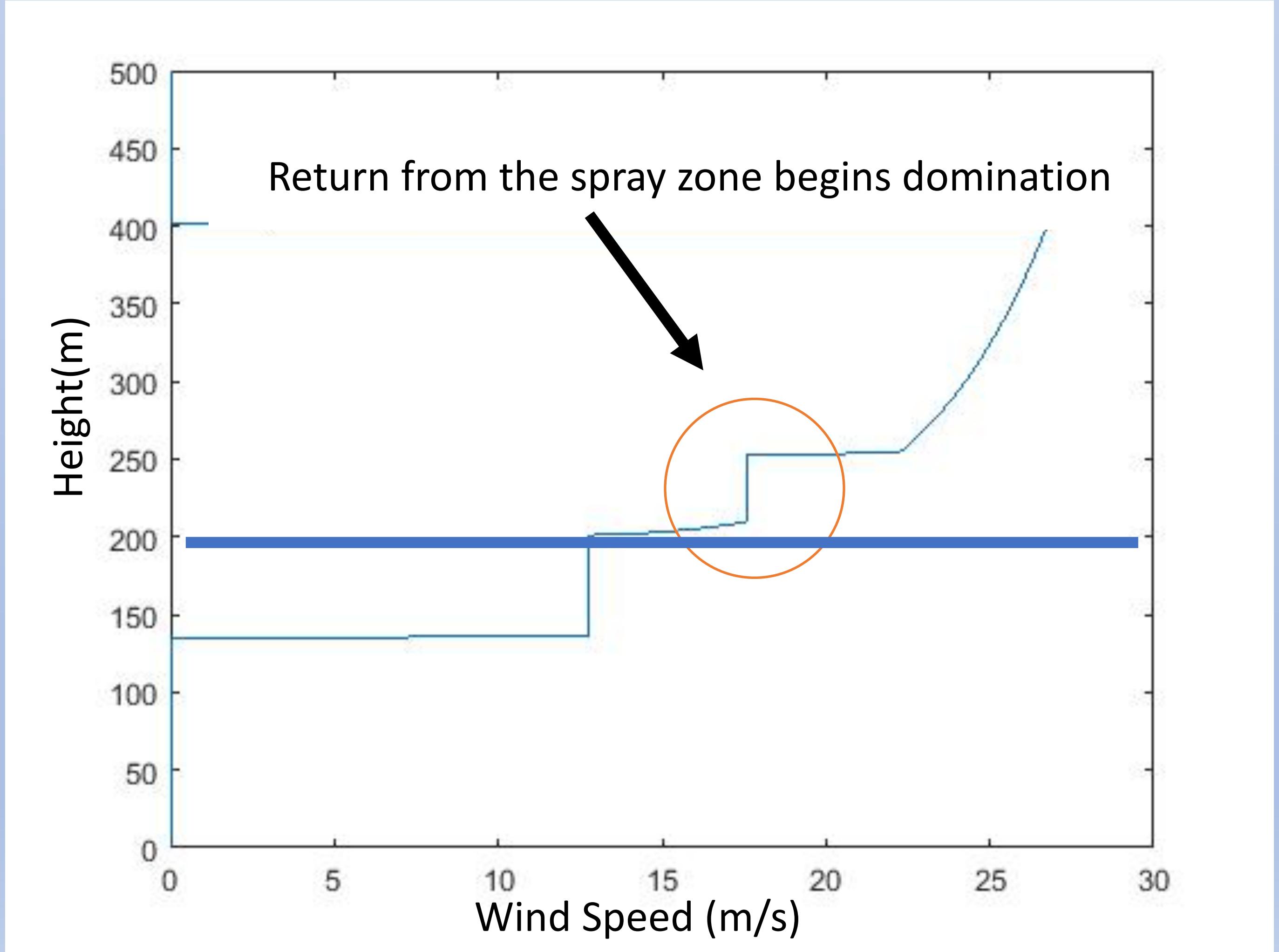
Return signal within range gate



Wind profile using .14 coefficient in power law



Wind speed per DWL in lowest 50m



Summary

- HDSS sondes may be reporting winds between 20 and 30 meters as much nearer the surface. The average event time error is 1.53 seconds which translates to ~28m with fall speeds of 18m/s.
- The airborne Doppler Wind Lidar (NASA's DAWN) makes retrievals down to the surface using sliding variable and adaptable gates on the raw digitized return. <u>**However**</u>:
  - Below 50 meters above the water surface the retrievals are heavily dependent upon the backscatter structures.
  - At low wind speeds the near surface (< 10m) values are reported at heights below the surface (can be adjusted after the processing)
  - At high winds speeds with whitecaps and water/salt sprays, <u>**the speed of the spray is reported starting at gate altitudes around 50m**</u>.
- Recent investigations of high wind situations has revealed a possible method for retrieving <u>**winds at and below 10ms with an airborne DWL**</u>.

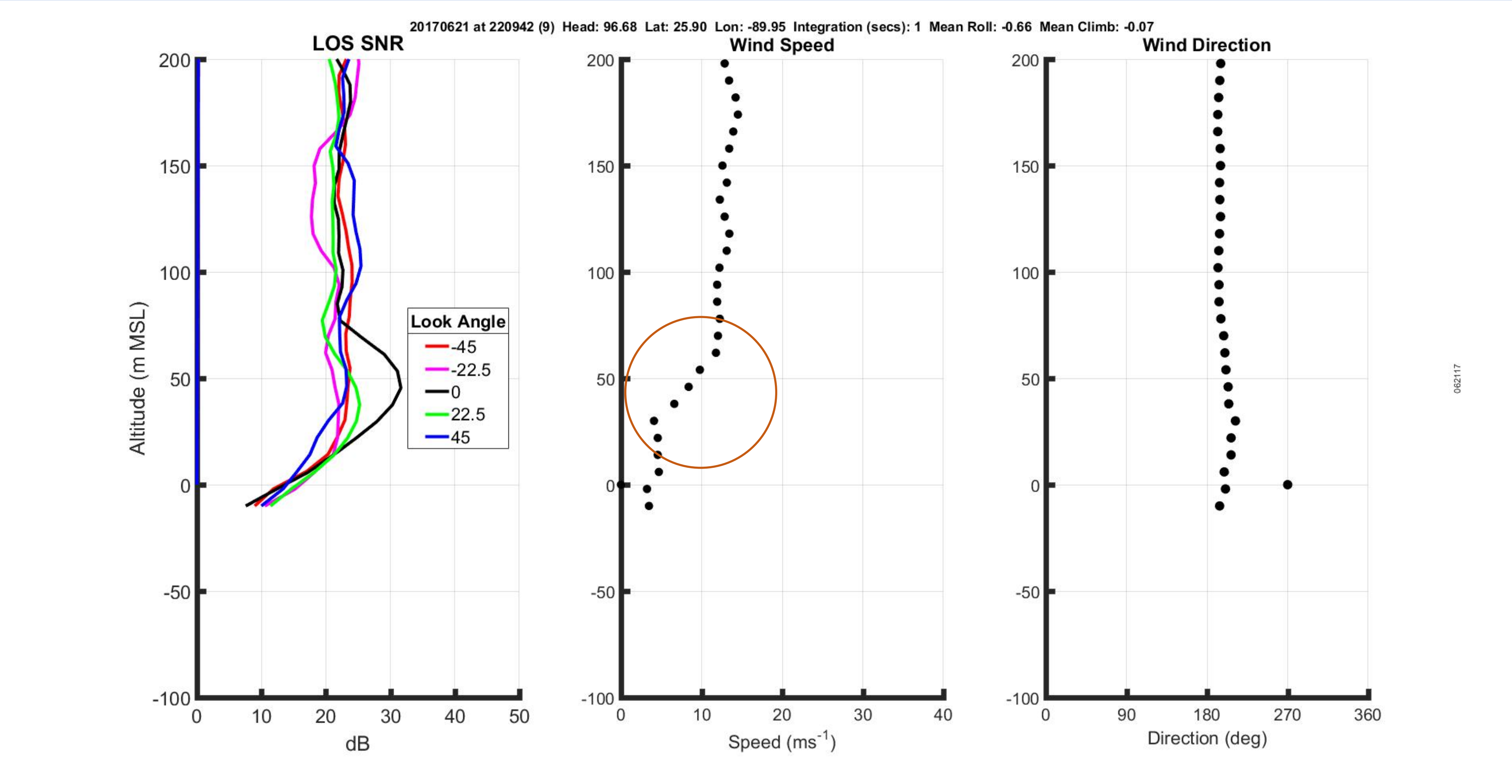
TABLE 2. XDD Sensor Specifications

Parameter	Sensor type/data rate	Accuracy	Resolution
Temperature	Thermistor/2 Hz/1 Hz	.148 degC	0.0168degC
Pressure	MEMS/2–1 Hz	1.5 hPa at 25C	2.5 hPa
Humidity	MEMS/2–1 Hz	1.8% at 25C	0.1%
SST	IR micro-radiometer 9–11 mm/1 Hz	0.2 at 25C	0.0168C

Current cases from CPEX being used to evaluate buoy/drop/DWL 10m winds

Date	Time(GMT)	HDSS(LH)	HDSS(WS)	HDSS(WD)	DAWN(HT)	DAWN(WS)	DAWN(WD)	Buoy WS	Buoy WD
6062017	185611	28.8	15.26	351.7	46.1	15.42	329.6		
6202017	193720	20.4	17.44	149.3	22.5	17.1	151.38		
	194857	9.8	13.19	160.1	24.2	13.15	165.94	10.9	157
	202916	11.9	16.02	164.1	81	18.66	169.25	11.5	162
	204055	15.5	18.11	173.7	52.1	18.9	169		
6212017	190836	10.9	11.67	143.7	26	11.42	136.9		
	194551	5.4	13.04	159.3	5	13.41	156.8		
	200452	16.2	18.9	180.9	62	16.9	188.6		
	200614	19.8	13.67	200.6	50	17.12	186.9	23.1	283
	220904	36	11.7	175	36	5.7	208.8	9.3	171
		72	12.8	179.1	69	8.94	194.1		
		99.8	12.7	178.6	100.7	13.41	200.1		
Other Cases									
6062017	195222	26.6	1.92	231.3	59	3	231.4		
	205548	74	3.2	141.3	63	4.8	166.9		
	212058	28	3.4	193.6	41	6	230.1		
					21	7.28	263.1	4.1	199
6202017	183406	19.8	14.1	17.8				16.8	1
	201923	7.4	9.5	8.5				7.4	6.1
	215235	1.4	11.97	138				0.7	91
6212017	201344	18.7	15.15	251.9	17.3	14.6	254.6		
	205002	16.2	7.5	182.3	32.5	8.4	186.2		
	205518	10.6	15.37	237.8				23.1	283
	211840	10.5	9.66	291.3	36	11.94	309.6	10.3	284
	212800	7.1	12.65	281.4				10.3	284
	213946	8.7	8	272.9	31	7.58	281.5		
	215154	8.6	9	226.8	25	7.9	214.8		
	222005		7.27	181.9	23	6.5	169.4	8.9	166
	223308	25	11.57	167.5	25	10.95	182.58	9.1	167
Wind Speed in m/s									
Height in meters above surface (MSL)									

Another high wind case



Difference sorted by convective conditions

Day	Environment	Number 37m segments	MEAN Z DIFF	BIAS (m/s)	MEAN ABS (ΔWS)	RMSD (m/s)
May 27	GoM Undisturbed	1351(9)	2.77	-.039	0.66	.834
May 29	W Car. Sea Scatt. Convec	1467(13)	2.86	.17	1.04	1.35
May 31	E of Bahamas Scatt. Convec	1637(13)	2.83	0.18	0.93	1.21
June 1	Eastern GoM Org. Convec	590 (13)	3.31	-0.08	1.60	2.12
June 2	GoM Convective	1415 (17)	3.38	0.23	1.24	1.64
June 6	Eastern GoM Undisturbed(W) Convec (E)	893 (6)	3.04	0.18	0.97	1.24
June 10	E of Bahamas Org. Convec	1239 (14)	3.11	0.31	1.26	1.67
June 11	Central GoM Org. Convec/ Inflow	1550 (13)	2.99	-0.01	1.22	1.81
June 15	Caribbean Sea Convective	295 (4)	3.77	0.93	1.78	2.09
June 16	W Car. Sea Convective	991 (12)	3.25	-0.07	1.40	1.95
June 19	GoM Convective/ Pre TS Cindy	513 (8)	3.86	-0.45	1.20	1.60
June 20	Central GoM Convective/ TS Cindy Inflow	1454 (12)	3.30	0.04	1.18	1.62
June 21	Northern GoM Convective/ TS Cindy	1604 (22)	3.00	0.40	1.16	1.54
June 23	E of Bahamas Undisturbed	518 (6)	2.58	0.02	0.89	1.17

DAWN_DROP COMPARISON TABLE CPEX (162 DROPS) – WIND DIRECTION

Day	Environment	Number 37m segments	MEAN Z DIFF	BIAS (deg)	MEAN ABS (ΔWD)	RMSD (deg)
May 27	GoM Undisturbed	1351 (9)	2.77	3.57	10.27	18.0
May 29	W Car. Sea Scatt. Convec	1467 (13)	2.86	2.68	10.37	18.63
May 31	E of Bahamas Scatt. Convec	1637 (13)	2.83	0.57	15.16	29.80
June 1	Eastern GoM Org. Convec	590 (13)	3.31	0.43	6.92	8.41
June 2	GoM Convective	1415 (17)	3.38	-2.02	6.88	10.25
June 6	Eastern GoM Undisturbed(W) Convec (E)	893 (6)	3.04	-2.59	6.14	7.51
June 10	E of Bahamas Org. Convec	1239 (14)	3.11	1.03	16.50	24.0
June 11	Central GoM Org. Convec/ Inflow	1550 (13)	2.99	0.48	8.89	12.69
June 15	Caribbean Sea Convective	295 (4)	3.77	-4.30	11.42	15.76
June 16	W Car. Sea Convective	991 (12)	3.25	-0.17	24.56	40.01
June 19	GoM Convective/ Pre TS Cindy	513 (8)	3.86	-2.84	8.71	12.39
June 20	Central GoM Convective/ TS Cindy Inflow	1454 (12)	3.30	0.28	8.94	19.05
June 21	Northern GoM Convective/ TS Cindy	1604 (22)	3.00	2.23	8.26	13.12
June 23	E of Bahamas Undisturbed	518 (6)	2.58	3.20	15.1	30.7