Airborne Doppler Wind Lidar Atmospheric Boundary Layer Research

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WORKSHOP ON THE FUTURE OF ATMOSPHERIC BOUNDARY LAYER OBSERVATIONS

10_25_2017

Outline

- Brief history of Airborne Doppler Wind Lidars (ADWL)
- The ADWL technologies used (CIRPAS, ONR, NASA/LaRC and ARL)
- ADWL Projects over last 10 years
  - TODWL (MAG1A) in KDMF research, complex terrain and C-17 WTVs
  - P3DWL (WTX) in TPARC (2008)
  - DAWN in Arctic PolarWinds and ADM Cal/Val
  - TODWL in C-17 WTVs research
  - P3DWL on NOAA's N42 for hurricane and SAL research
- Plans for 2017 and 2018
  - Finish 2017 hurricane season
  - Late summer 2018 Cal/Val underflights of ESA's Aeolis wind mission.

Space-based concepts

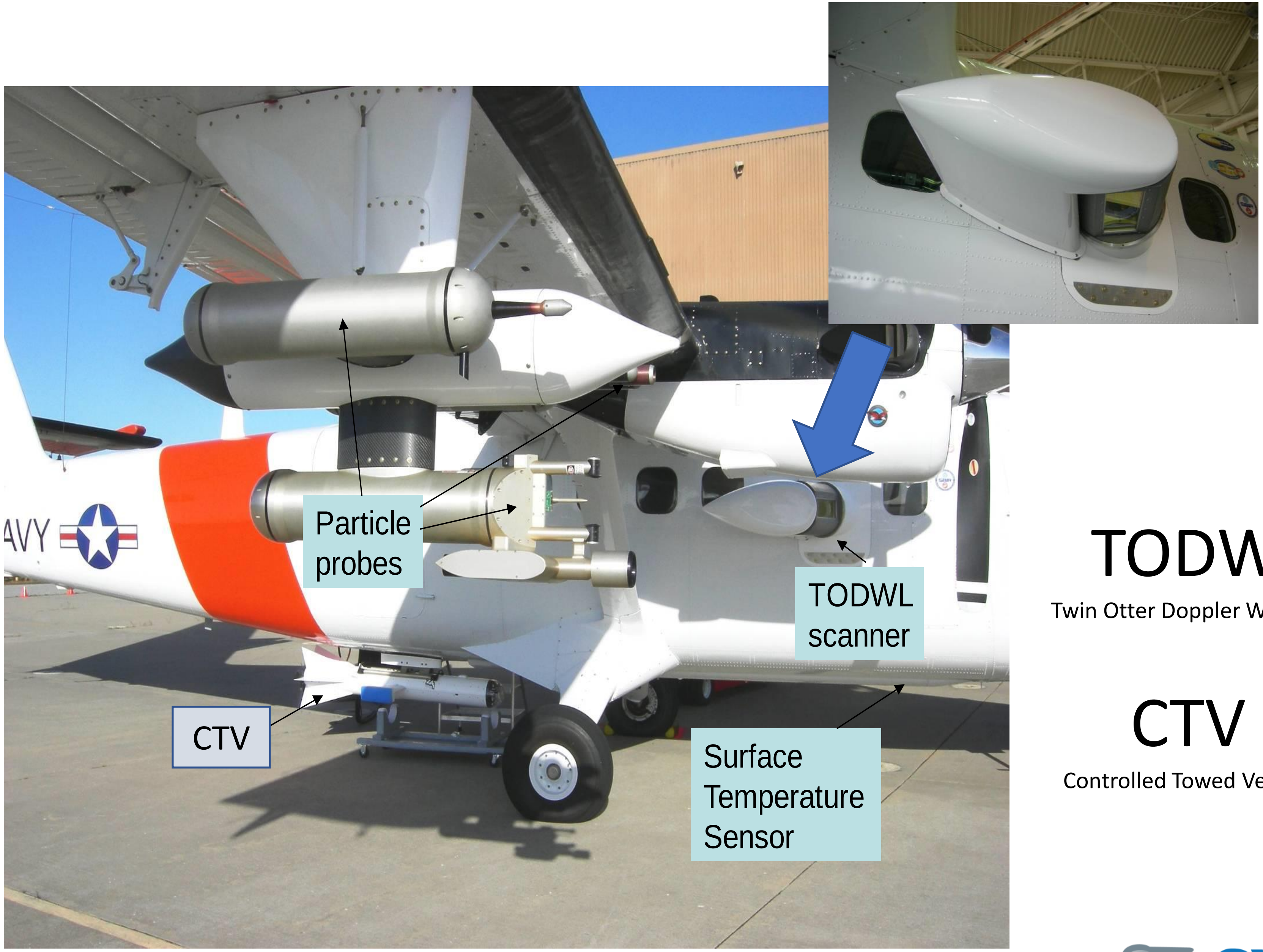
- **Windsat** (AF and NOAA)
- **LAWS** (Laser Atmospheric Wind Sounder)
- **SPARCLE** (Space Readiness Coherent Lidar Experiment)
- **JEM-CDL** (Japanese Coherent Doppler Lidar)
- **GTWS** (Global Tropospheric Wind Sounder)
- **ADM** (Atmospheric Dynamics Mission)
- **GWOS** (Global Wind Observing Sounder-Hybrid)
- **NWOS** (NPOESS Wind Observing Sounder-Hybrid)

Brief history of airborne lidars

- Ron Schwiesow, NOAA, 1976
  - Bi-static, CO_2 on light aircraft observing waterspouts
- Convair 990, NASA, 1984
  - CCOPE, CO_2, two wedge scanner, side looking, severe storm gust fronts, cloud top divergence, valley flows
- DC8, NASA and NOAA, 1985 – 1990s
  - MACAWS , CO_2 hurricane overflight
- Falcon, DLR, 1994 - present
  - CO_2 , ADOLAR, WIND
  - 2 um ,HRDL (NOAA)
  - 2 um
- B757/DC8, NASA, 2001
  - 2 um, ACLAIM, non-scanning, turbulence and vertical velocities
- Twin Otter, ONR, 2002 - present
  - 2 um, TODWL , MBL, complex terrain
- Navy P3, ONR, 2008 - present
  - 1.6 um, typhoon research
- NASA/LaRC (2010 – present)
  - DAWN at 2 um on DC8 and UC-12B
- Ball Aerospace (2012)
  - .355 um, demo on WB57
- NASA/GSFC (2013 – present)
  - TwiLight at .355 um demos on ER2 and Global Hawk

Data Utility

- Primary use of airborne DWL data has been diagnostic
  - Severe storm research
  - Flow in complex terrain
  - Organized Large Eddies (OLEs)
  - Marine Boundary Layer jets
  - Evaluation of mesoscale models
- Less has been done, however, with airborne DWL data to test impact on NWP



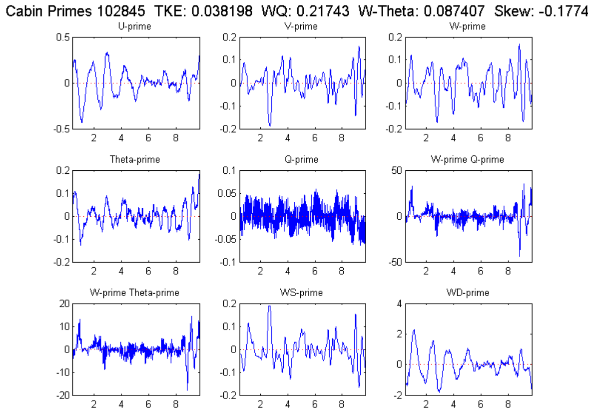
TODWL

Twin Otter Doppler Wind Lidar

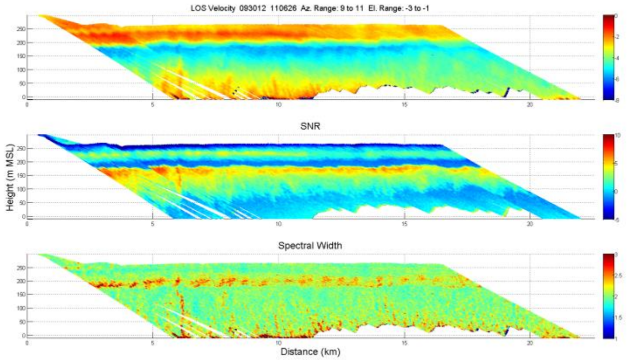
CTV

Controlled Towed Vehicle

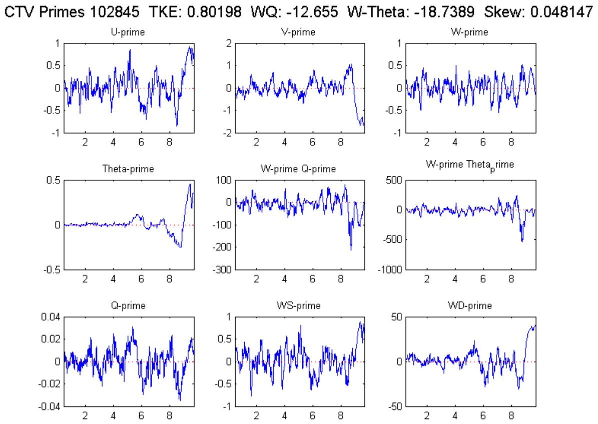
CIRPAS Twin Otter with CTV below



Twin Otter
Probe Data



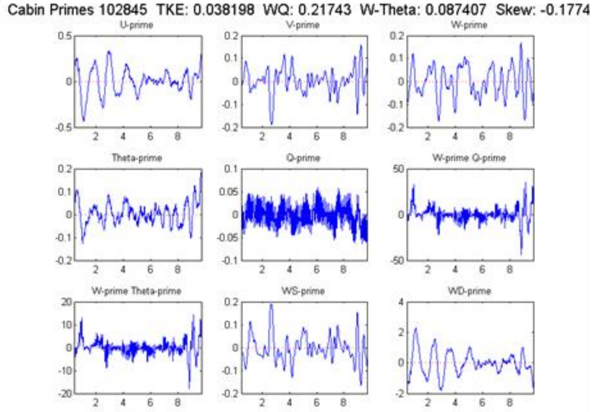
TODWL
Time/height
Cross sections



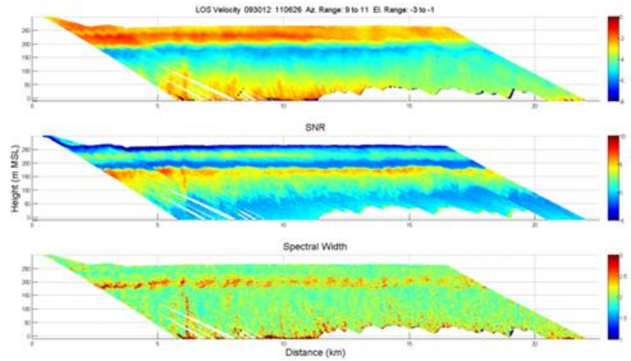
Towed Vehicle
Flux Data

SWA

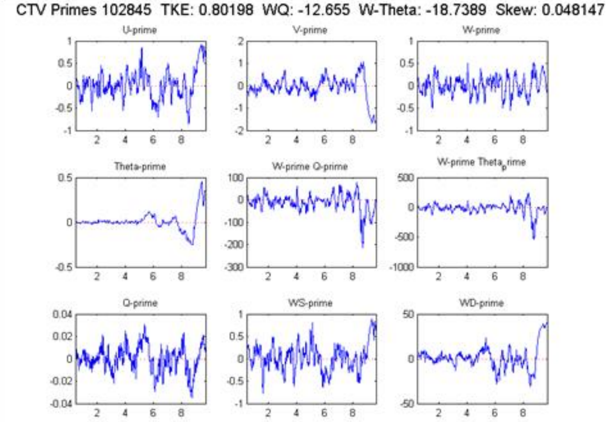
CIRPAS Twin Otter with CTV below



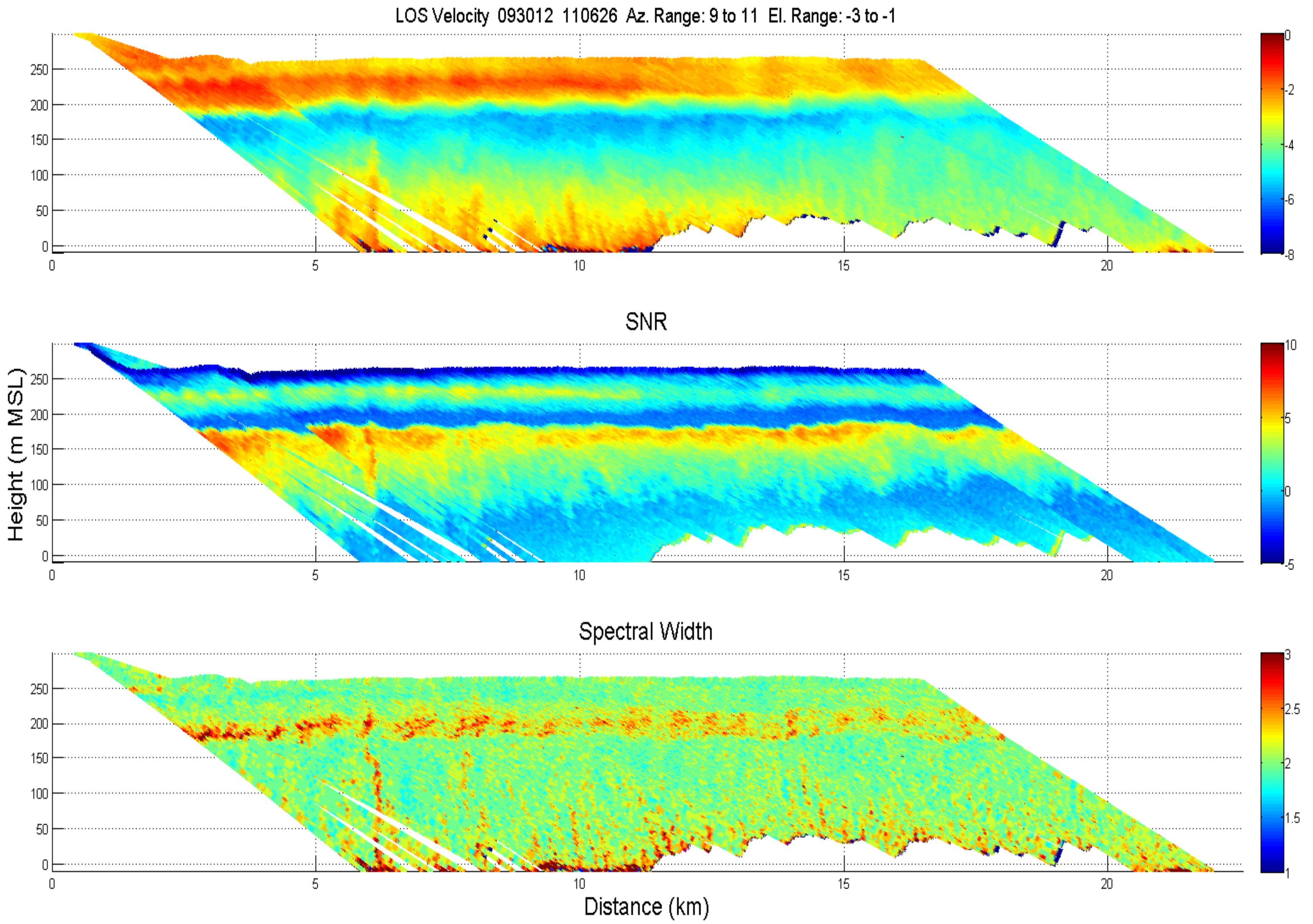
Twin Otter Probe Data



TODWL Time/height Cross sections



Towed Vehicle Flux Data

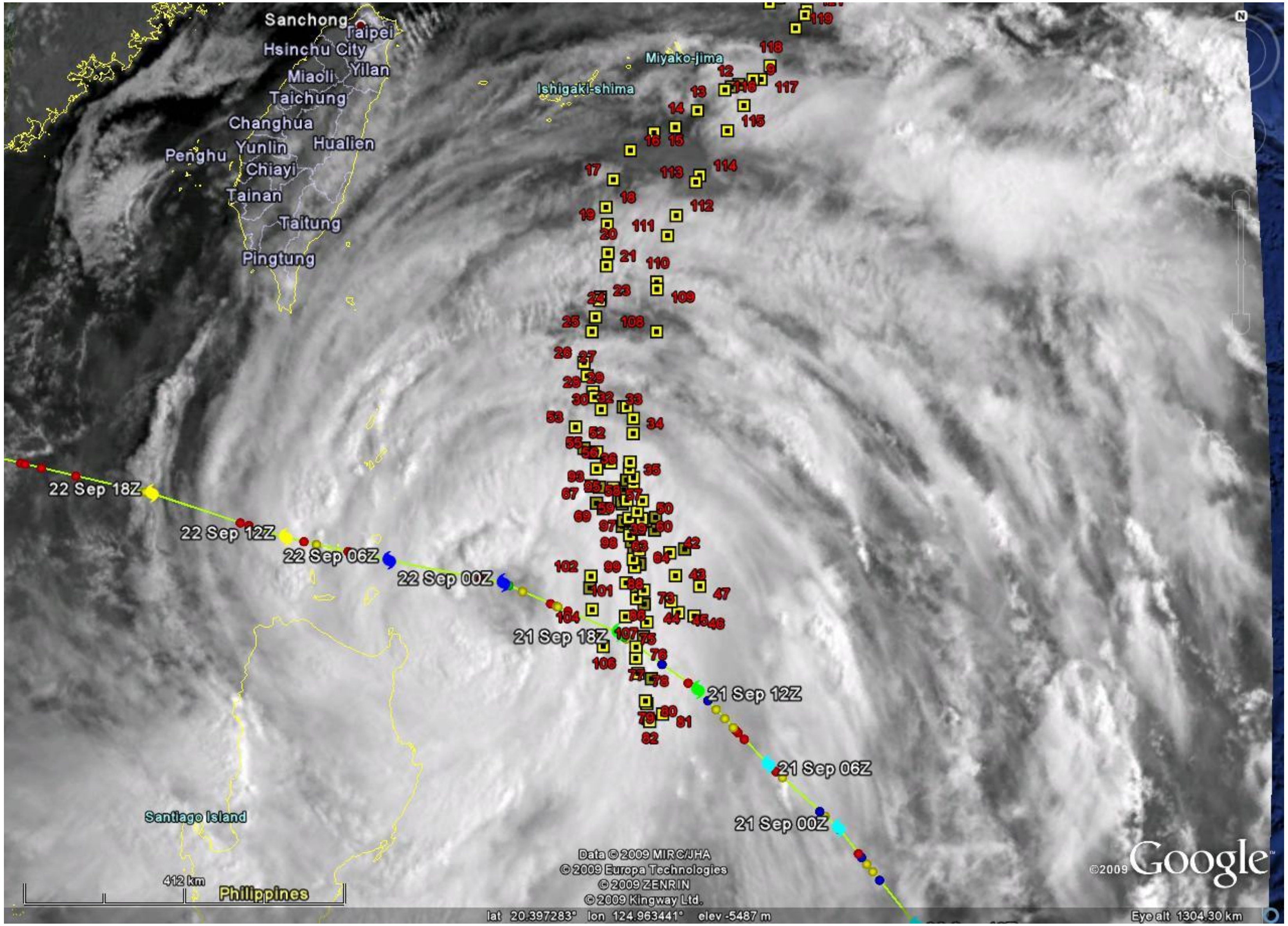


LOS Velocity 093012 110626 Az. Range: 9 to 11 El. Range: -3 to -1
SNR
Spectral Width
Height (m MSL)
Distance (km)

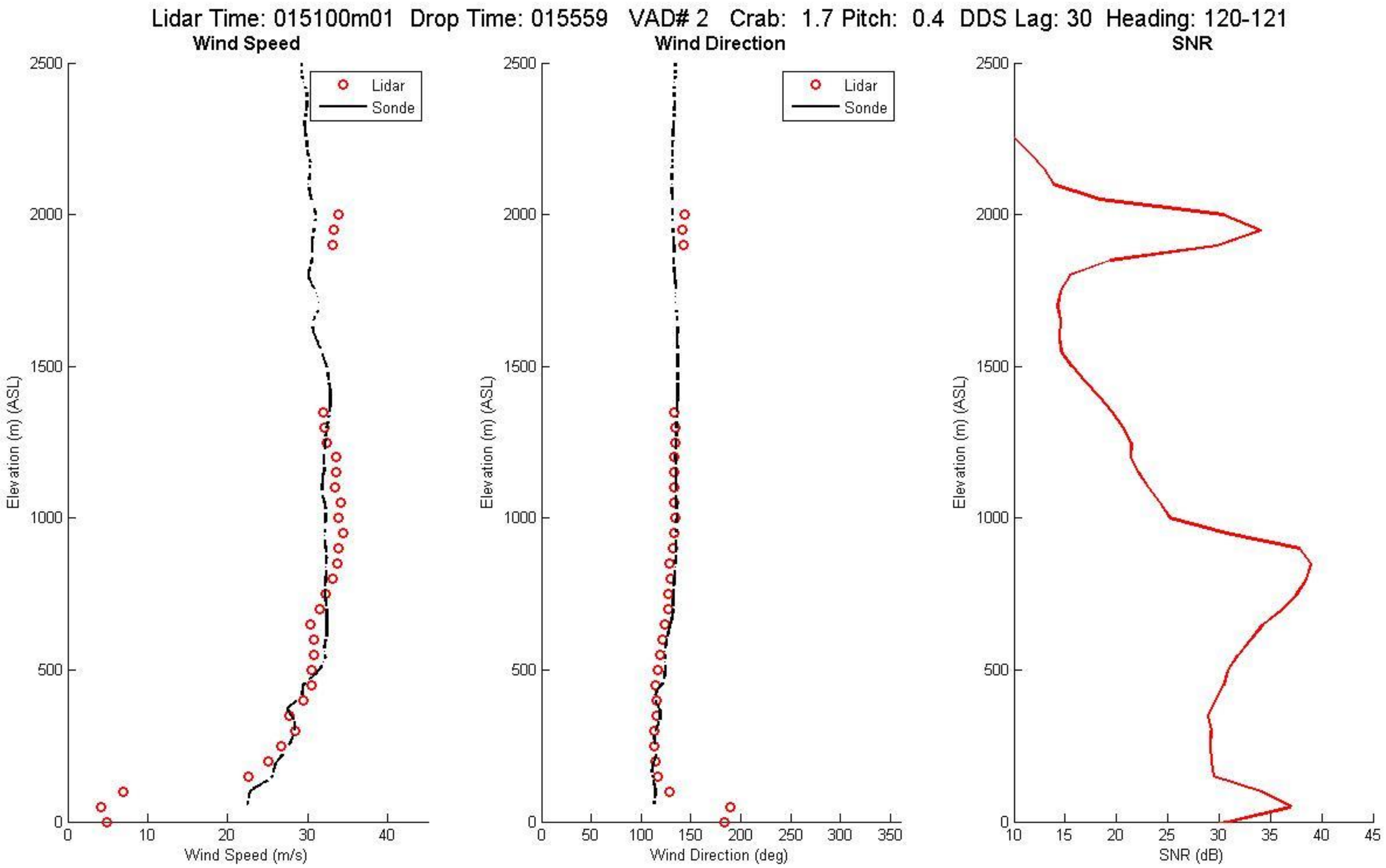
P3DWL for TPARC/TCS-08

1.6 um coherent WTX (ARL/LMCT)
10 cm bi-axis scanner (NASA)
P3 and other parts (NRL)
Analyses software (SWA/CIRPAS)

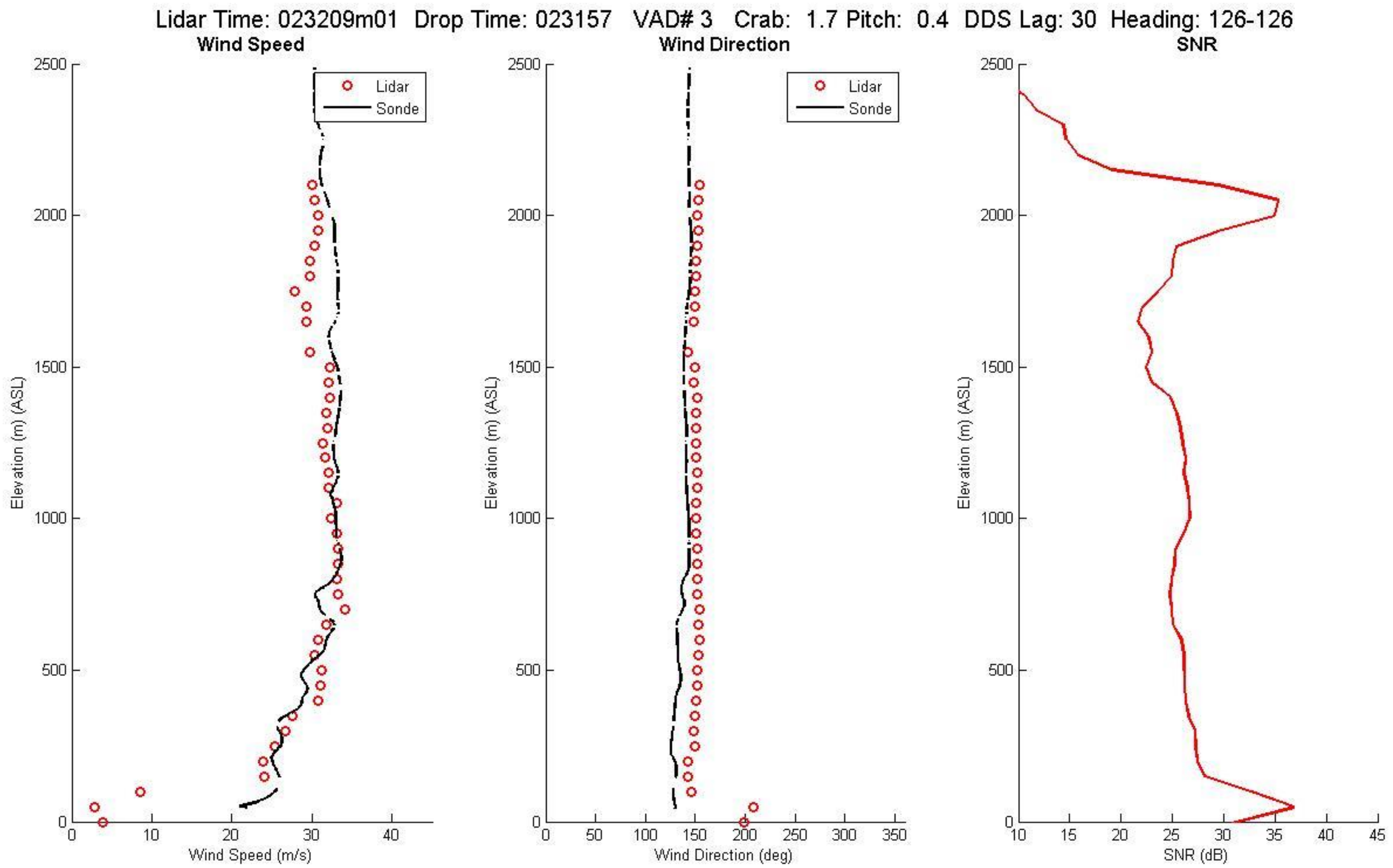
Typhoon Hagupit (0200GMT , September 22, 2008,)



Multi layer clouds (0151 9/22)



Deep aerosol layer capped with thin stratus (0232 9/22)

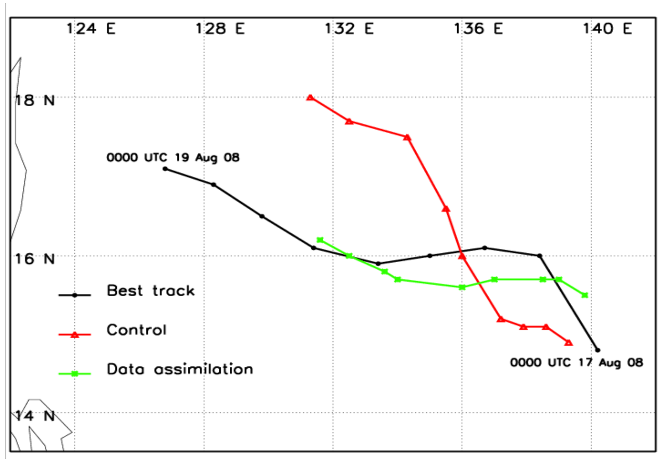


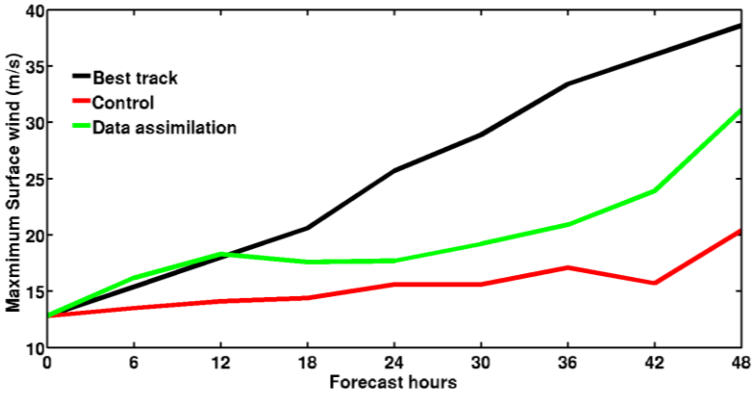
Impact of Airborne Doppler Wind Lidar Profiles on Numerical Simulation of Tropical cyclones: First snapshot with Typhoon Nuri (2008)

Zhaoxia Pu and Lei Zhang, ***Department of Atmospheric Sciences, University of Utah***
G. David Emmitt, ***Simpson Weather Associates, Inc.***

Model: Mesoscale community Weather Research and Forecasting (WRF) model
Data: Doppler wind Lidar (DWL) profiles during T-PARC for the period of 0000UTC –0200 UTC 17 August 2008
Forecast Period: 48-h forecast from 0000UTC 17 August 2008 to 0000UTC 19 August 2008
Control: without DWL data assimilated into the WRF model.
Data Assimilation: With DWL data assimilated into the WRF model

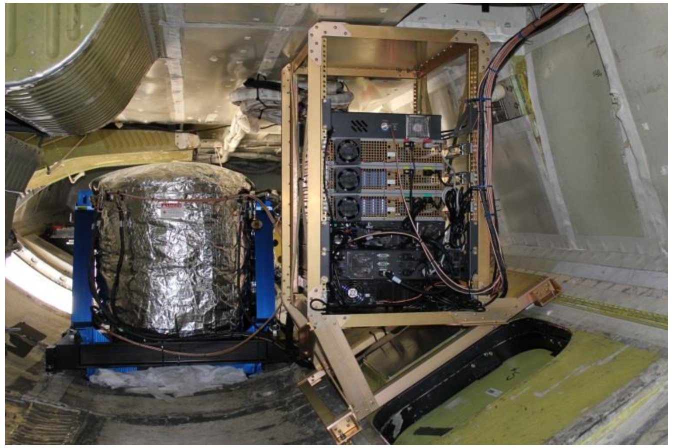
Data impact: Control vs. Data assimilation

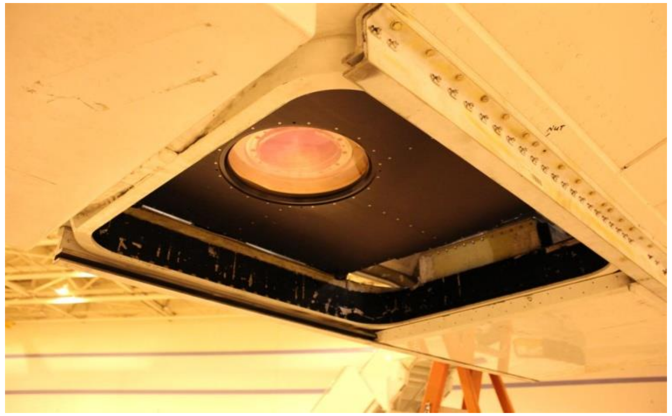




- **Assimilation of DWL profiles eliminated the northern bias of the simulated storm track .**

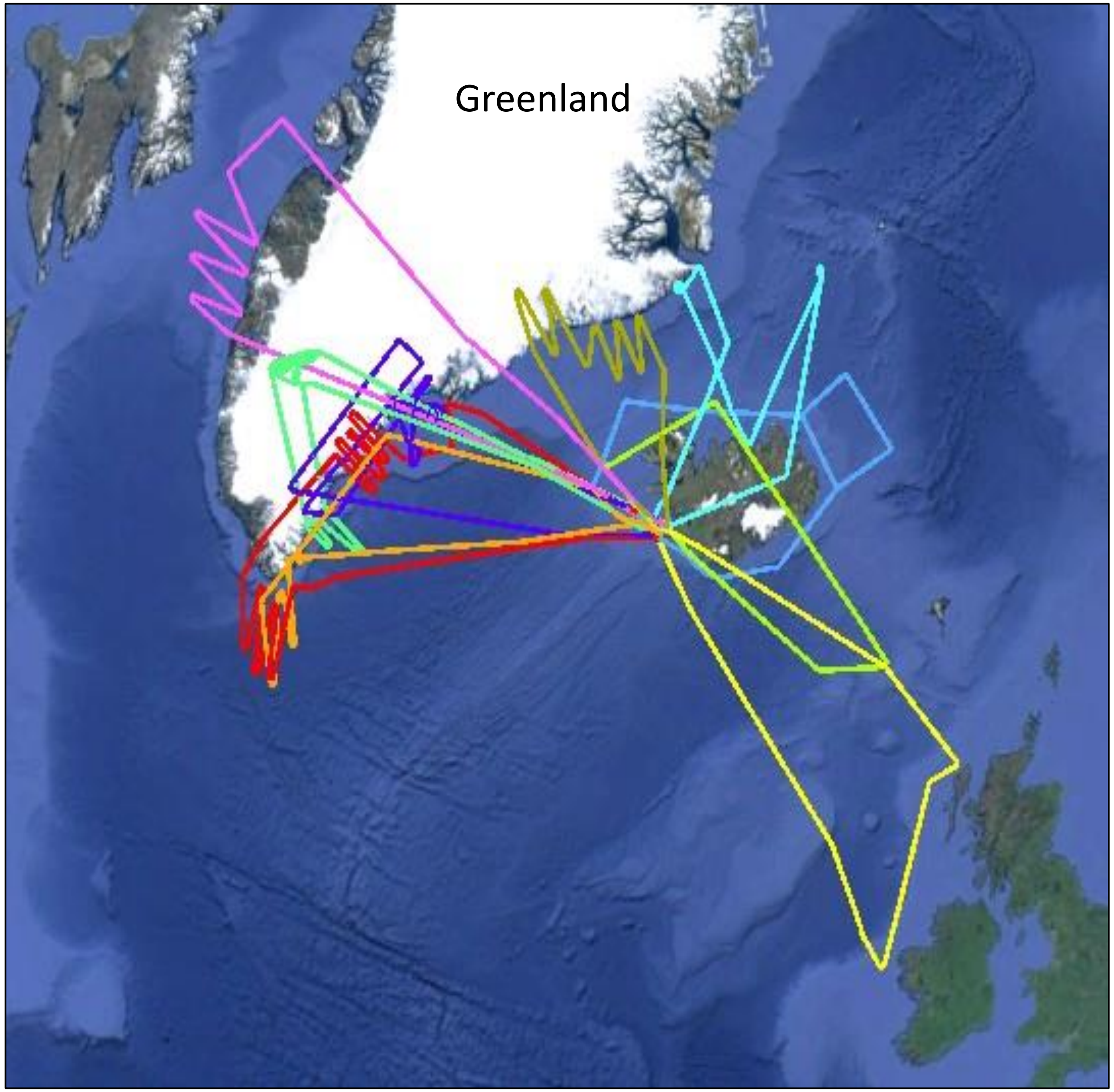
- **Assimilation of DWL profiles resulted in a stronger storm that is more close to the observed intensity of the storm.**





DAWN Integration on DC-8, 2010

L-R: Bo Trieu, Grady Koch, Paul Petzar, Jay Yu, Jeffrey Beyon



PolarWinds Campaign II Flight Tracks

Mission Summary for Campaign II

(51 hours not including ferry hours)

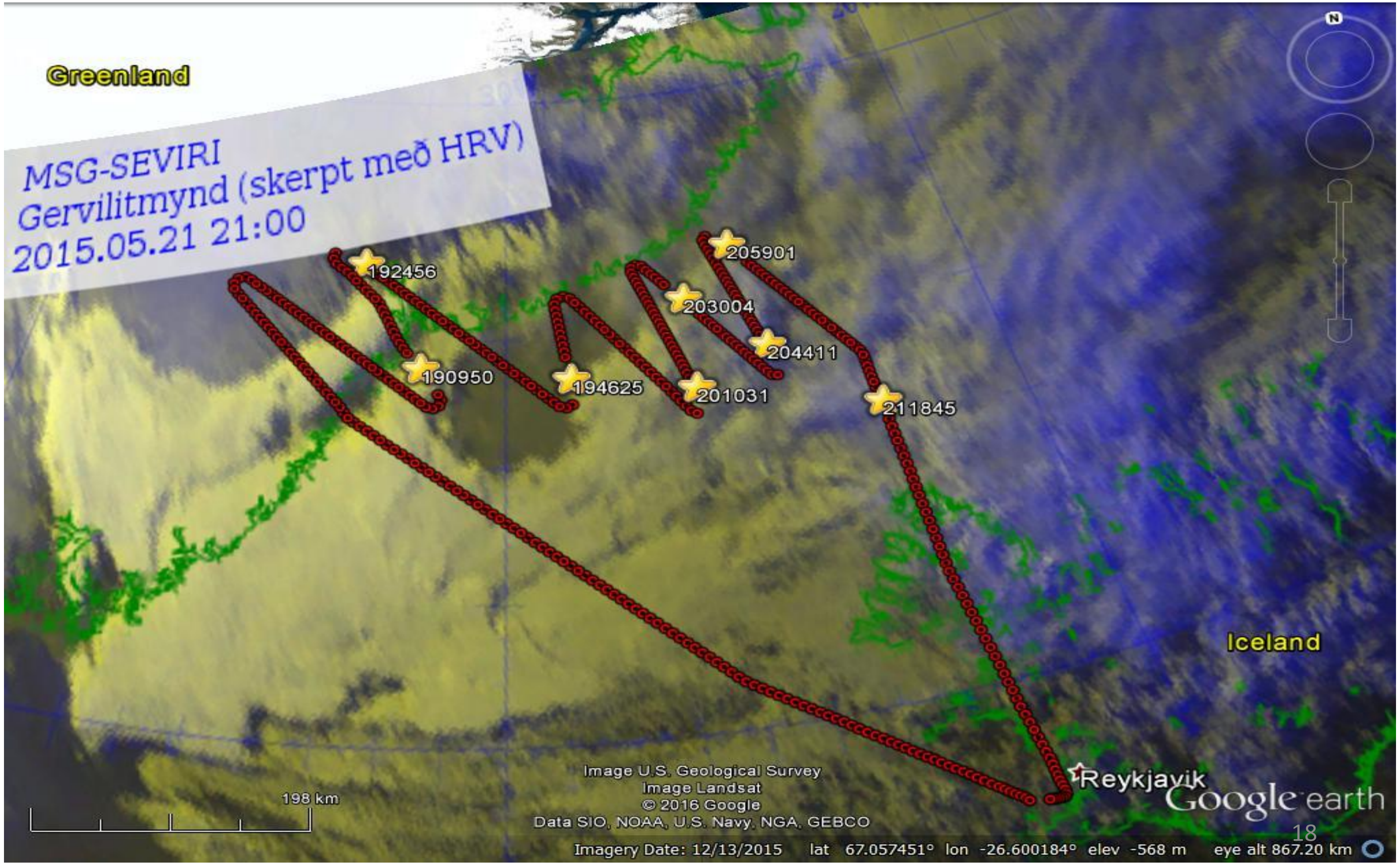
Date	Mission	DC-8	Falcon	Drops	DAWN	TWiLiTE
5/11	Iceland flow splitting with NE BL winds	x		3/5	x	x
5/13	TDS underflight(DLR/NASA) and Greenland CIZ (NASA)	x	x	5/6	x	x
5/15	Upper level jet between Iceland and Scotland	x	x	10/12	x	x
5/16	ADM cal/val over Greenland ice cap; CIZ and Kat-winds	x	x	8/10	x	x
5/17	CALIPSO, MODIS, ASCAT underflights; CIZ;Tip jet	x		8/9	x	x
5/19	Upper level jet over southern Greenland; Tip jet	x	x	7/8	x	x
5/21	Barrier jet	x		7/11	x	x
5/23	Katabatic flows off Greenland east coast; ADM cal/val CIZ	x	x	15/19	x	
5/24	Baffin Strait ice edge west coast of Greenland; rolls	x		11/12	x	
5/25	Upper level jet south of Iceland	x	x	5/6	x	x

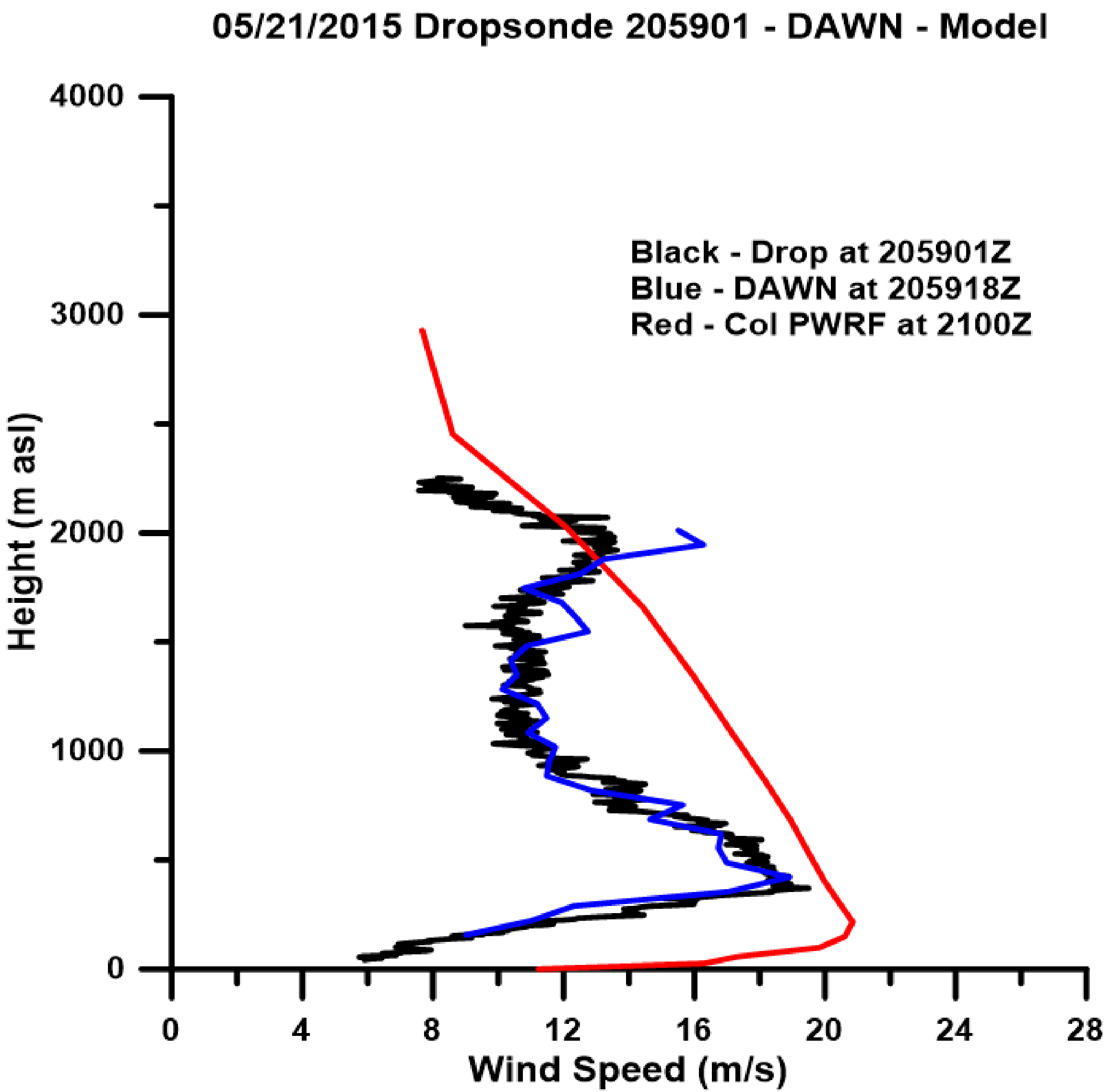
CIZ (Coastal Ice Zone); Kat (Katabatic); BL (Boundary Layer)
Dropsonde numbers indicate good/total dropped

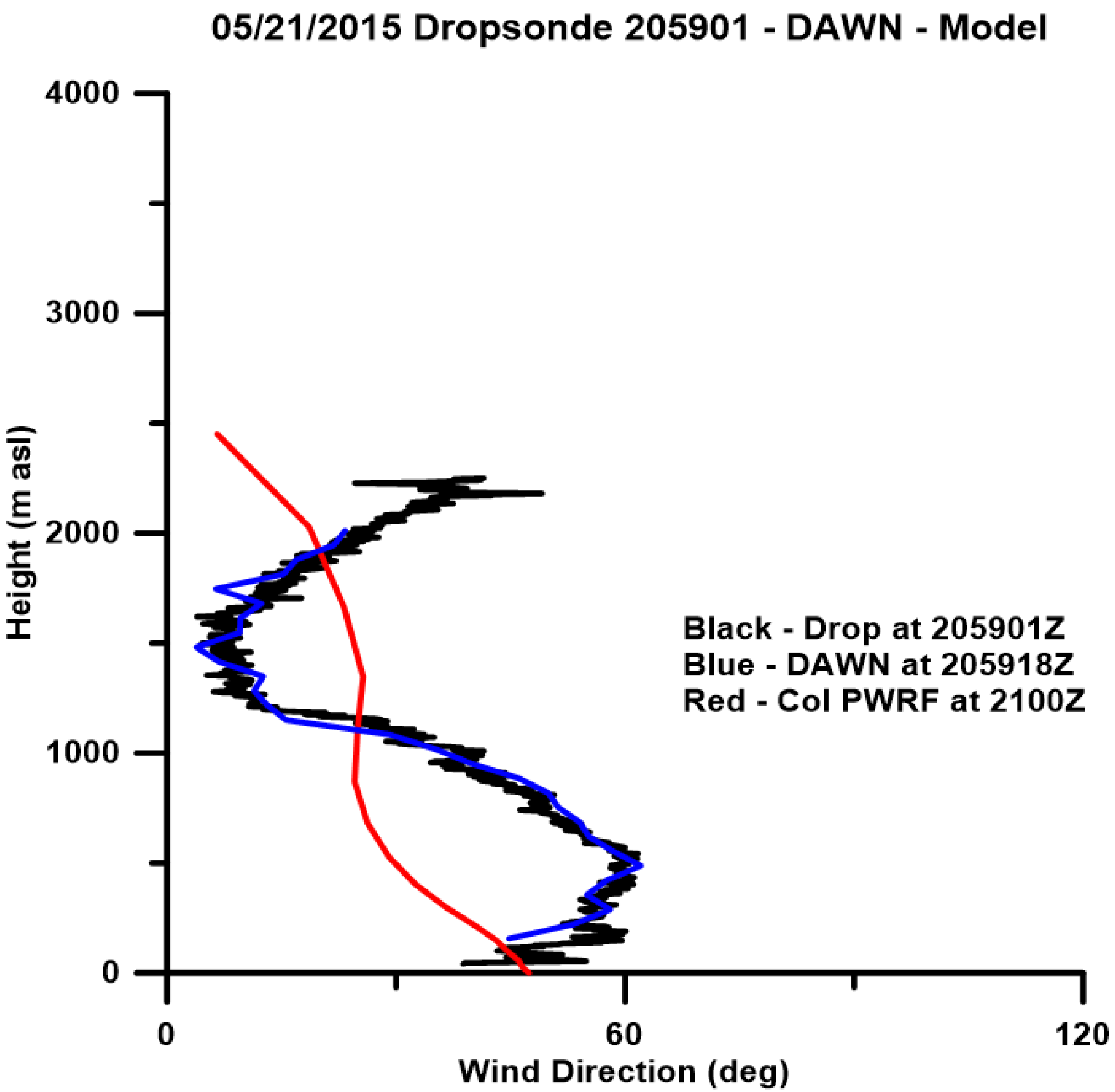
Greenland East Coast Barrier Wind Case

Red circles:
DAWN profiles

Yellow stars:
Dropsondes







Col PWRF: University of Colorado Boulder’s Polar Weather Research Forecast model

CPEX 2017: A Field Experiment to study Convective Processes in the Tropics

25 May – 24 June 2017

DC-8 based in Fort Lauderdale, Florida

DAWN, APR-2, HAMSR, MTHP, Dropsondes, MASC

CPEX Science Objectives

1. Improve understanding of convective processes including cloud dynamics, downdrafts, cold pools and thermodynamics during initiation, growth, and dissipation

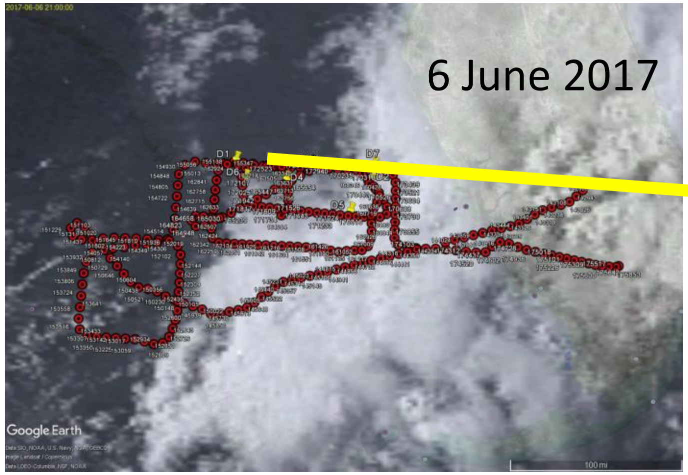
2. Obtain a comprehensive set observations, especially from DAWN, in the vicinity of scattered and organized deep convection in all phases of the convective life cycle

3. Improve model representation of convective and boundary layer processes over the tropical oceans using a cloud-resolving, fully coupled atmosphere-ocean model

4. **Improve model assimilation of the wind, temperature and humidity profiles** from the wind lidar and dropsondes into numerical weather prediction models

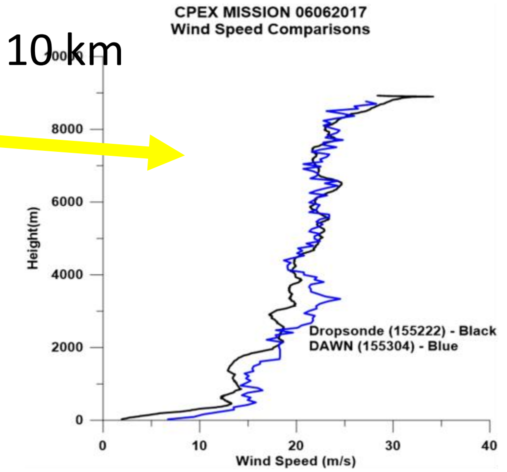
LaRC DAWN on NASA DC8

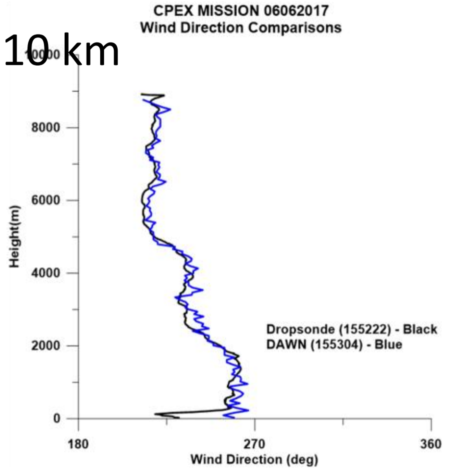
- DAWN is NASA’s most capable airborne wind-profiling lidar
- Previously participated in NASA GRIP (2010) and Polar Winds (2014-15) airborne campaigns
- Laser pulses at 2-micron wavelength and 10 Hz are eyesafe at any range; daytime observations not compromised by solar background
- Data may be post flight processed multiple times with various number of shots accumulated (horizontal resolutions), vertical resolutions, and wind search bandwidths for maximum information extraction
- CPEX science flights indicate excellent vertical coverage and agreement with dropsonde winds (e.g. from 9.5km in plots below)

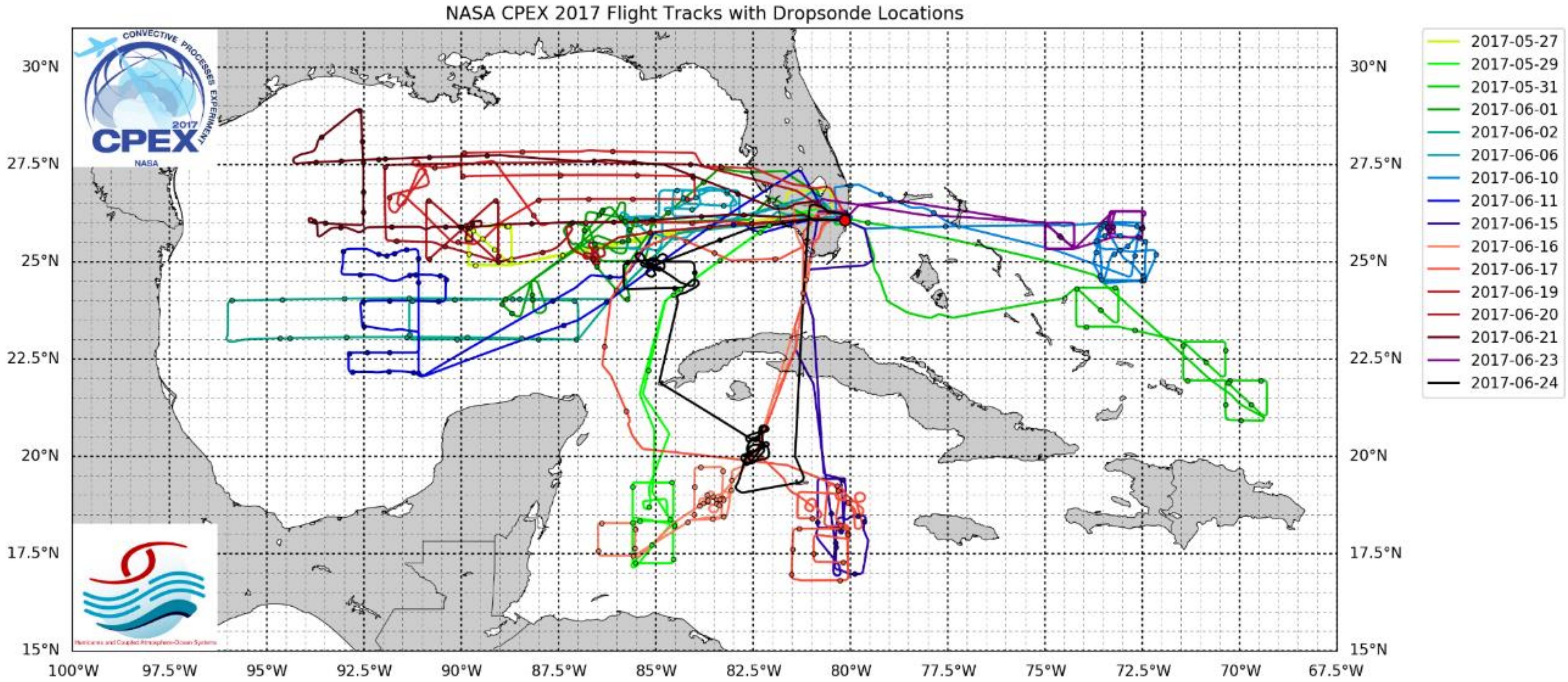


Each red circle is a DAWN sounding location

DAWN (blue) vs Dropsonde (black)






NASA CPEX 2017 Flight Tracks with Dropsonde Locations
CONVECTIVE PROCESSES EXPERIMENT
2017
CPEX
NASA
30°N
27.5°N
25°N
22.5°N
20°N
17.5°N
15°N
100°W
97.5°W
95°W
92.5°W
90°W
87.5°W
85°W
82.5°W
80°W
77.5°W
75°W
72.5°W
70°W
67.5°W
2017-05-27
2017-05-29
2017-05-31
2017-06-01
2017-06-02
2017-06-06
2017-06-10
2017-06-11
2017-06-15
2017-06-16
2017-06-17
2017-06-19
2017-06-20
2017-06-21
2017-06-23
2017-06-24

Multi-scale Wind Variability Using DAWN in CPEX

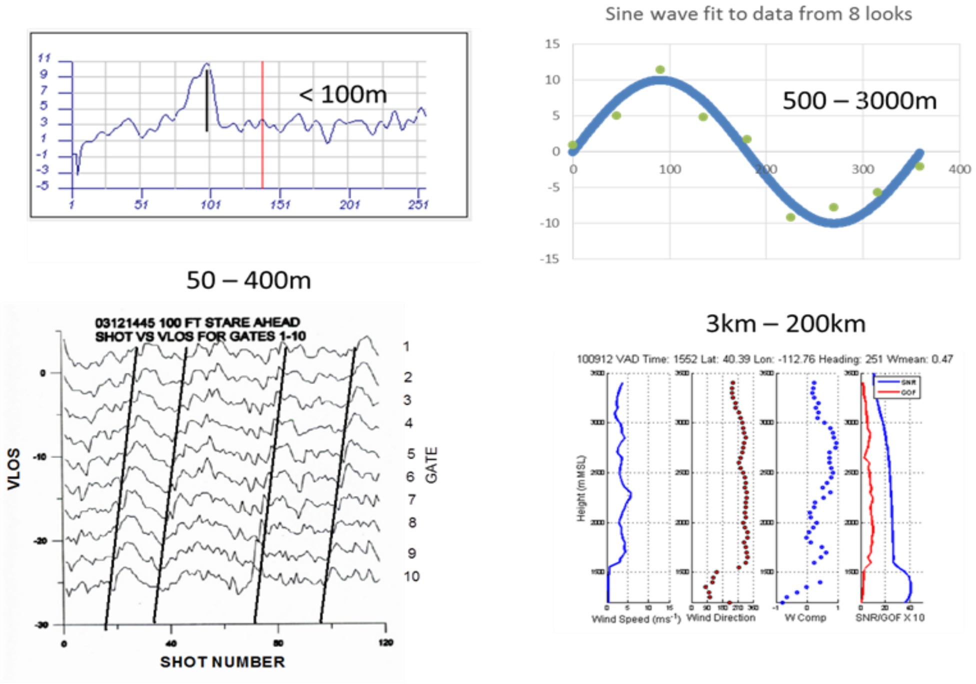
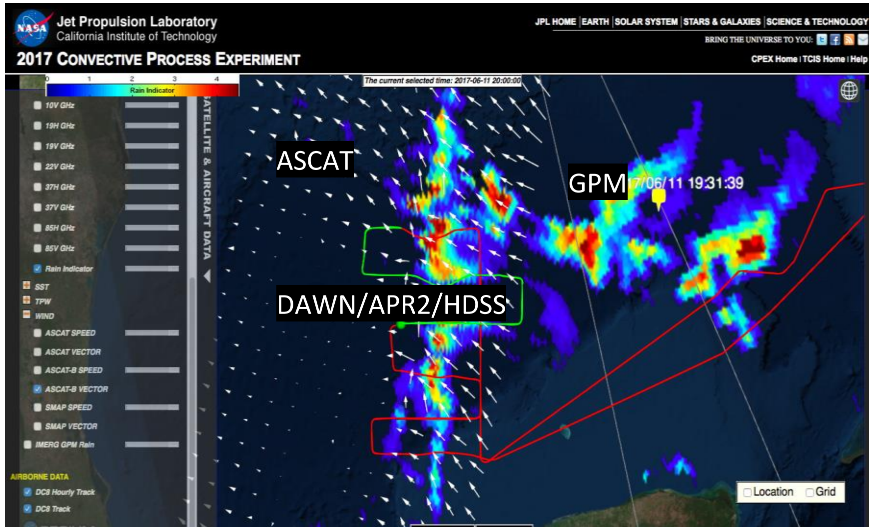
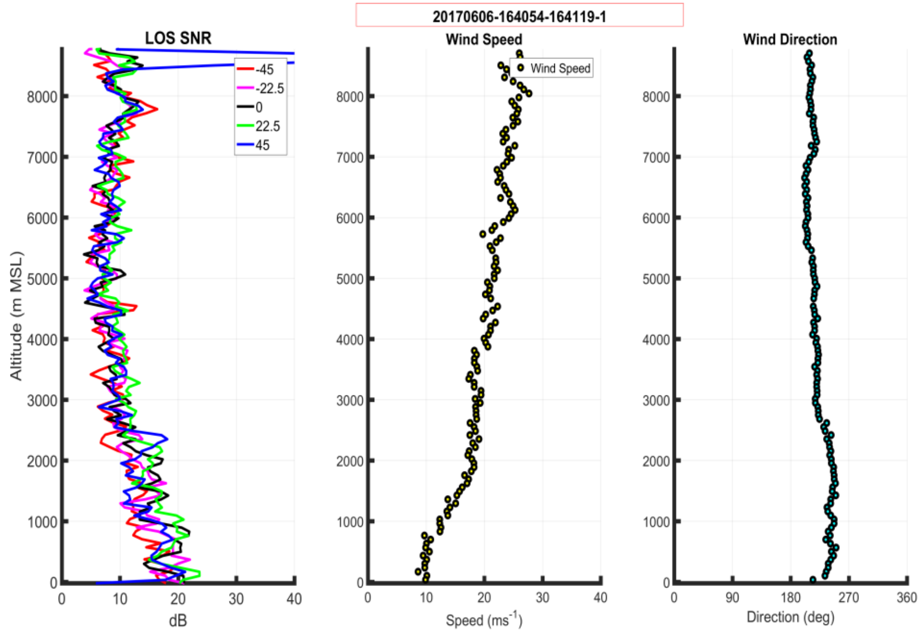
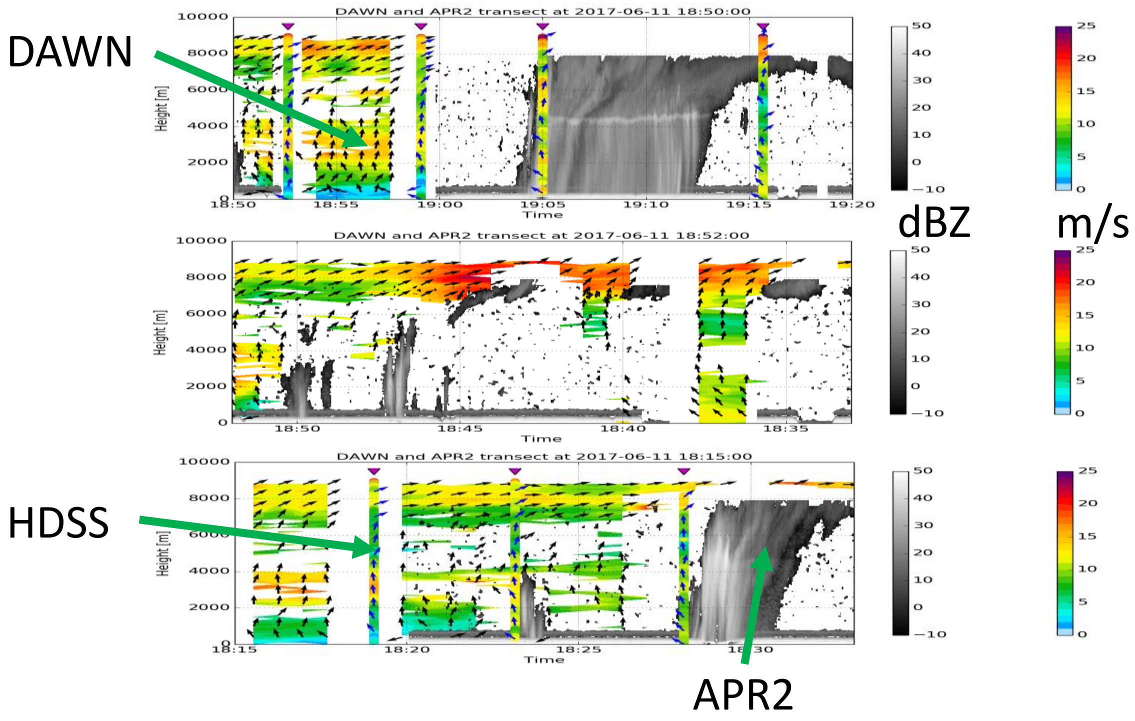


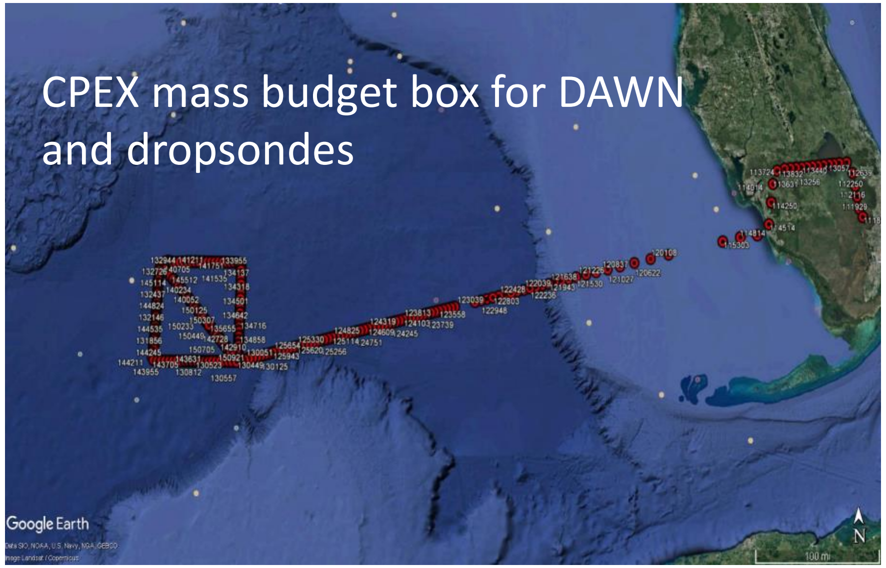
Illustration of the four scales of atmospheric dynamics observed with DAWN as explained in the text.



DAWN
wind profile
from 30000'
around CPEX
mass budget
box

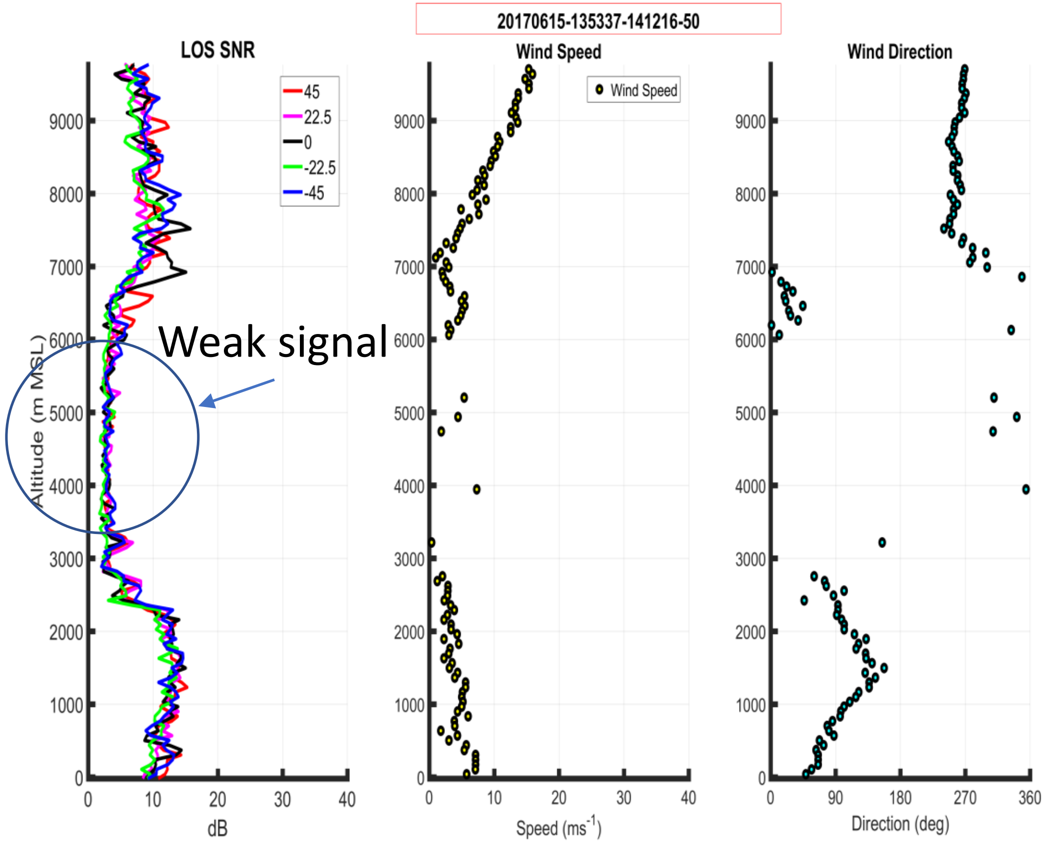


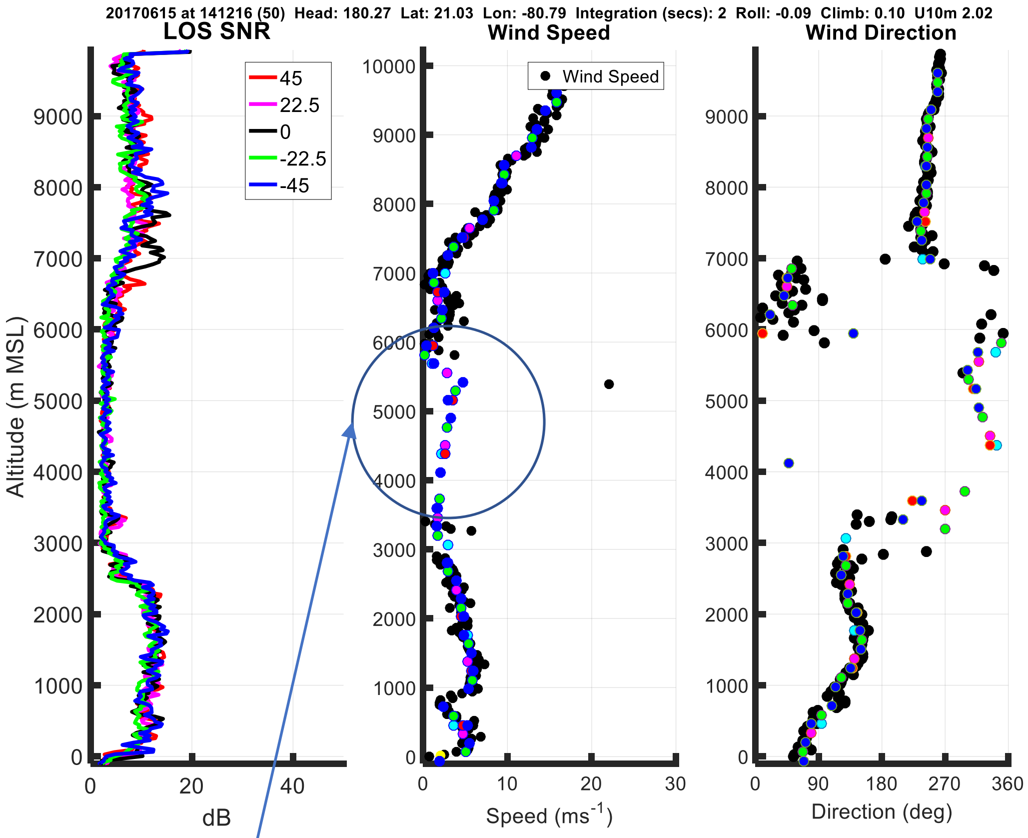




Quicklook (V1)

V3 processed profile





Information retrieved with Adaptive Integration

Investigating the impacts of LLJs and OLEs on ABL exchanges and transports using an airborne Doppler wind lidar

G. D. Emmitt & S. Greco, SWA

R. Foster, APL UWash

K. Godwin, KSG, LLC

Objectives

- Extend prior investigations (2001-2008)of LLJs and OLEs in the MBL and PBLs.
- Investigate and characterize the presence of rolls (OLEs) at the boundaries of stratocumulus topped MBLs.
- Study the potential impact on the development and implementation of the EDMF into forecast models.

TODWL data description

Attribute	Performance Metric	Comments
LOS resolution (applies to vertical profiles of 3D winds as well)	50 m	Range resolution to hard targets (ground or dense cloud) can be better than 10 meters.
U,V,W resolution	< 10 cm/s	< 5cm/s for stationary groundbased operations
Maximum range	6 -30 km	Very dependent upon aerosols
Time to complete full step stare conical scan for wind profiles	~ 20 sec	12 point step stare with .5 -2 second dwells
Sampling frequency	100 Hz	Integration of several shots is typical to improve range performance

Structure prospecting with DWL

- Feature prospecting uses a very shallow angle below the horizon (~ -1 -3 degrees for a 300m flight altitude).
  - Results in ~ 2 m vertical resolution and 50 m horizontal resolution with ~10 meter sliding sample.
  - It takes ~ 40 seconds to profile 100 meters below the aircraft.

Summary of segment statistics

Flight Segment	TODWL Altitude	CTV Altitude	Heading	TKE	Sensible Heat (W)	Latent Heat (W)	Skewness
1007	284	60	94	.19	8.55	3.43	-.40
				1.92	-1.28	15.15	.90
1028	292	25	98	.04	.22	.09	-.18
				.80	-12.6	-18.7	.05
1106	286	75	294	.05	3.02	1.21	-.51
				1.1	-3.36	-1.19	-.17
1111	290	75	293	.24	1.98	.80	-.37
				.29	-.74	.55	.22
1121	288	climbing	98	.14	-1.11	-.44	.90

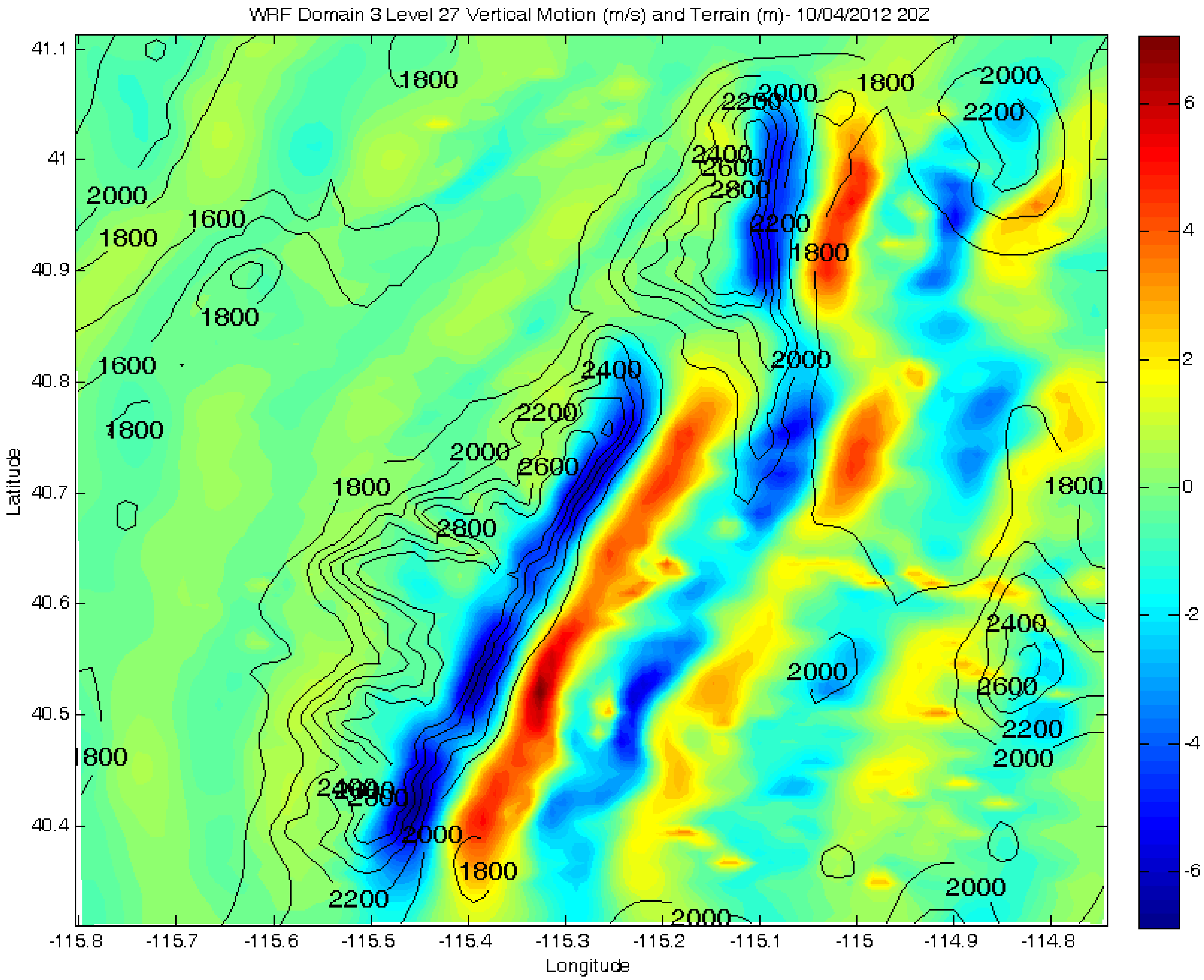
Weather Research Forecast (WRF) Model

- Three or four nested grid configuration

- Grid 1 with 9 km res.(540 km x 540 km domain)
- Grid 2 with 3 km res. (210 km x 210 km domain)
- Grid 3 with 1 km res. Up to 90 km x 90 km domain
- Grid 4 with 333 m res. over 35 km x 35 km domain

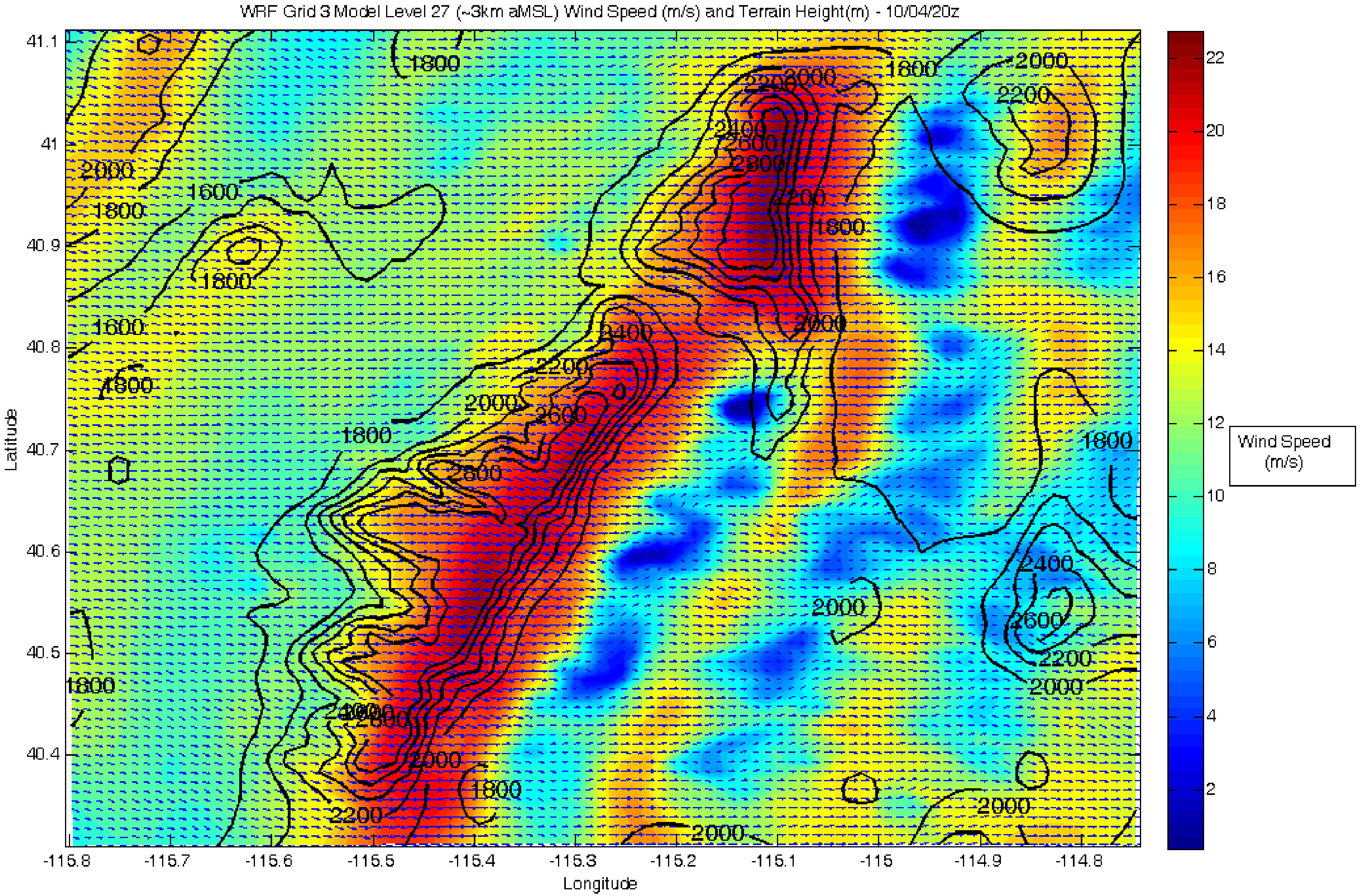
- 42 terrain-following vertical levels
- 200mb Model top
- NAM Analysis used as boundary conditions

WRF Domain 3 Level 27 Vertical Motion and Terrain

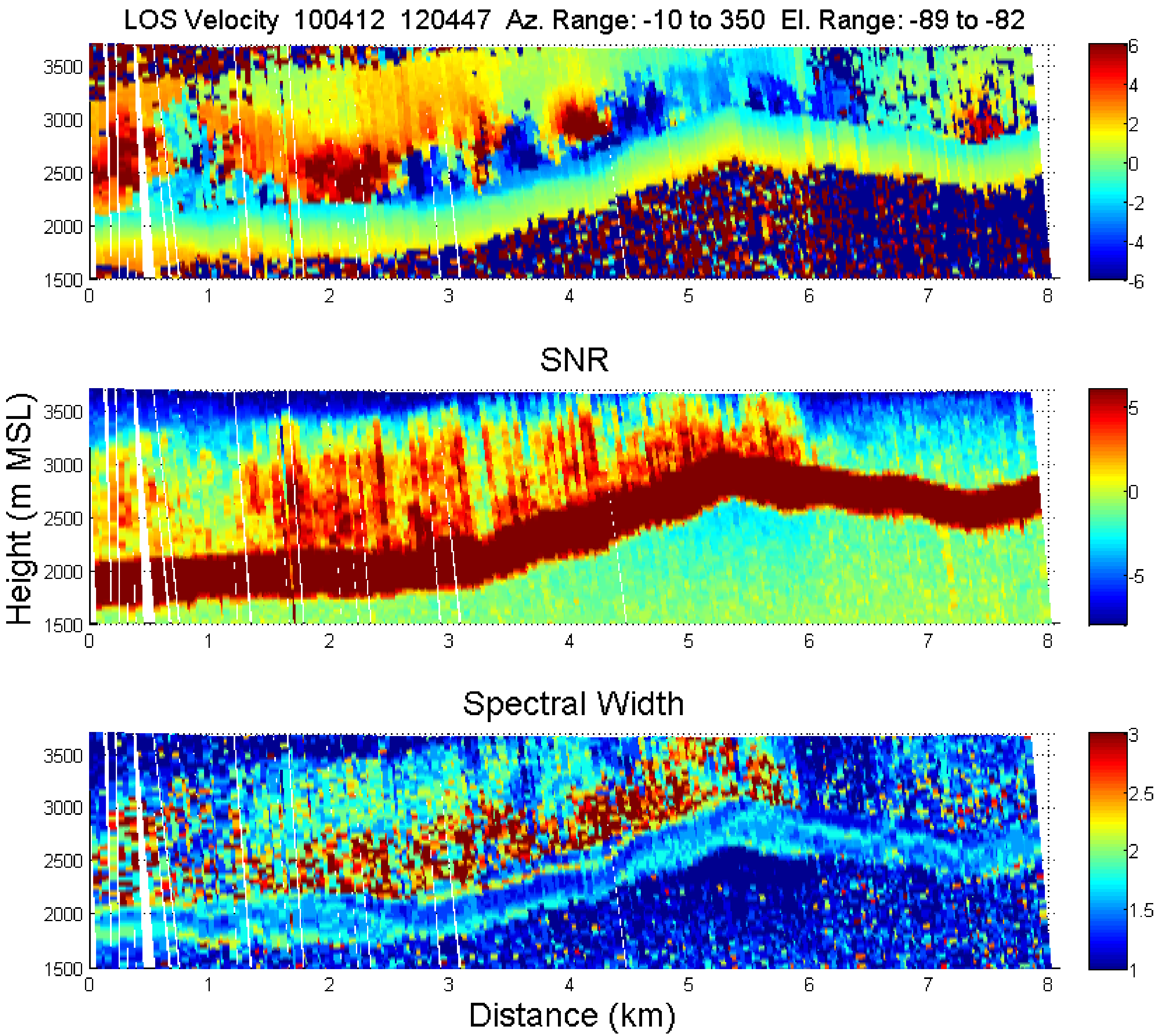


W (m/s)

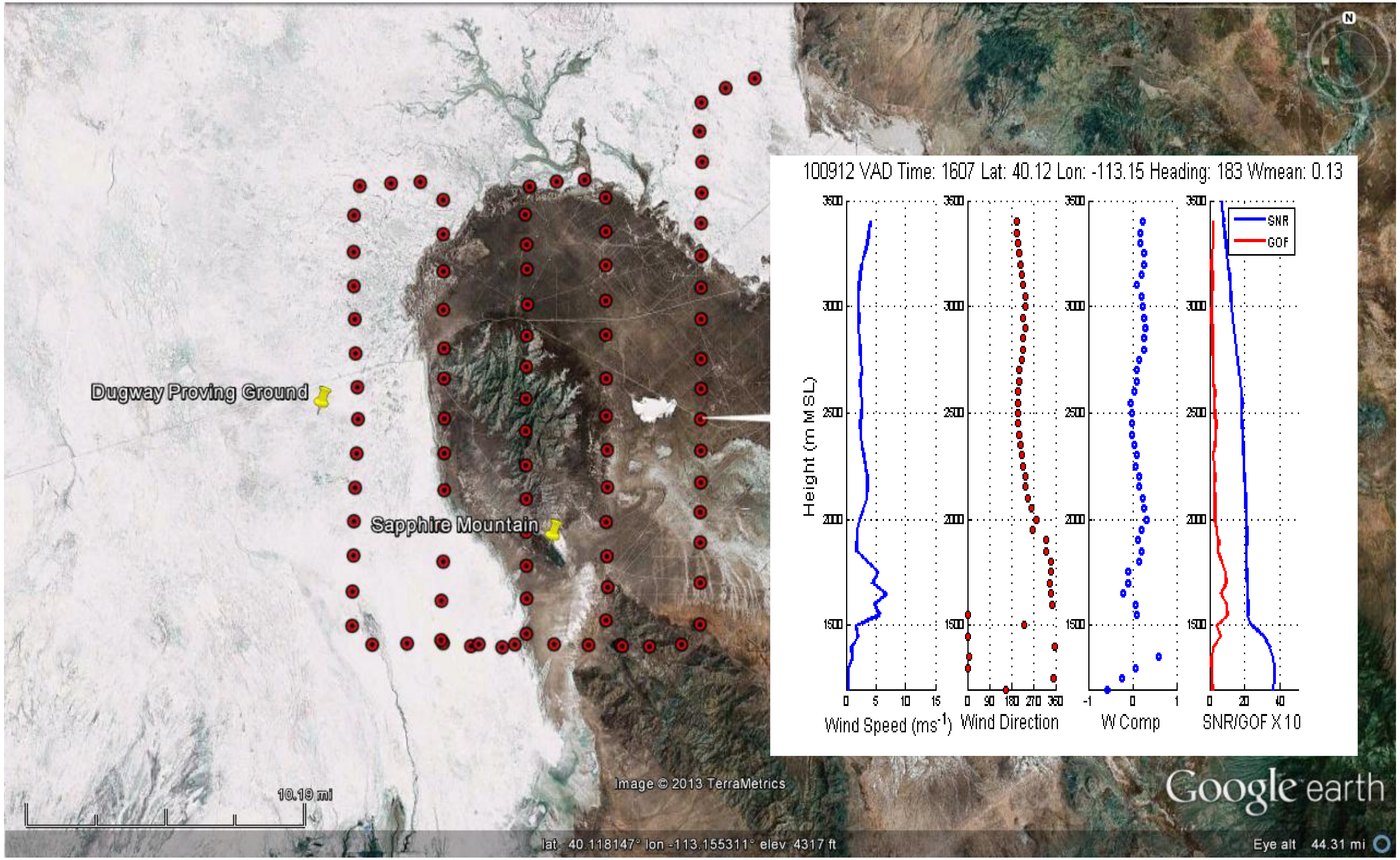
WRF Domain 3 Level 27 Wind Speed and Terrain



N41.9°
N41.7°
N41.5°
N41.3°
N41.1°
N40.9°
Elko
W115.75°
W115.25°
N40.7°
W114.75°
N40.5°
N40.3°
© 2013 Google
Image Landsat
Google earth

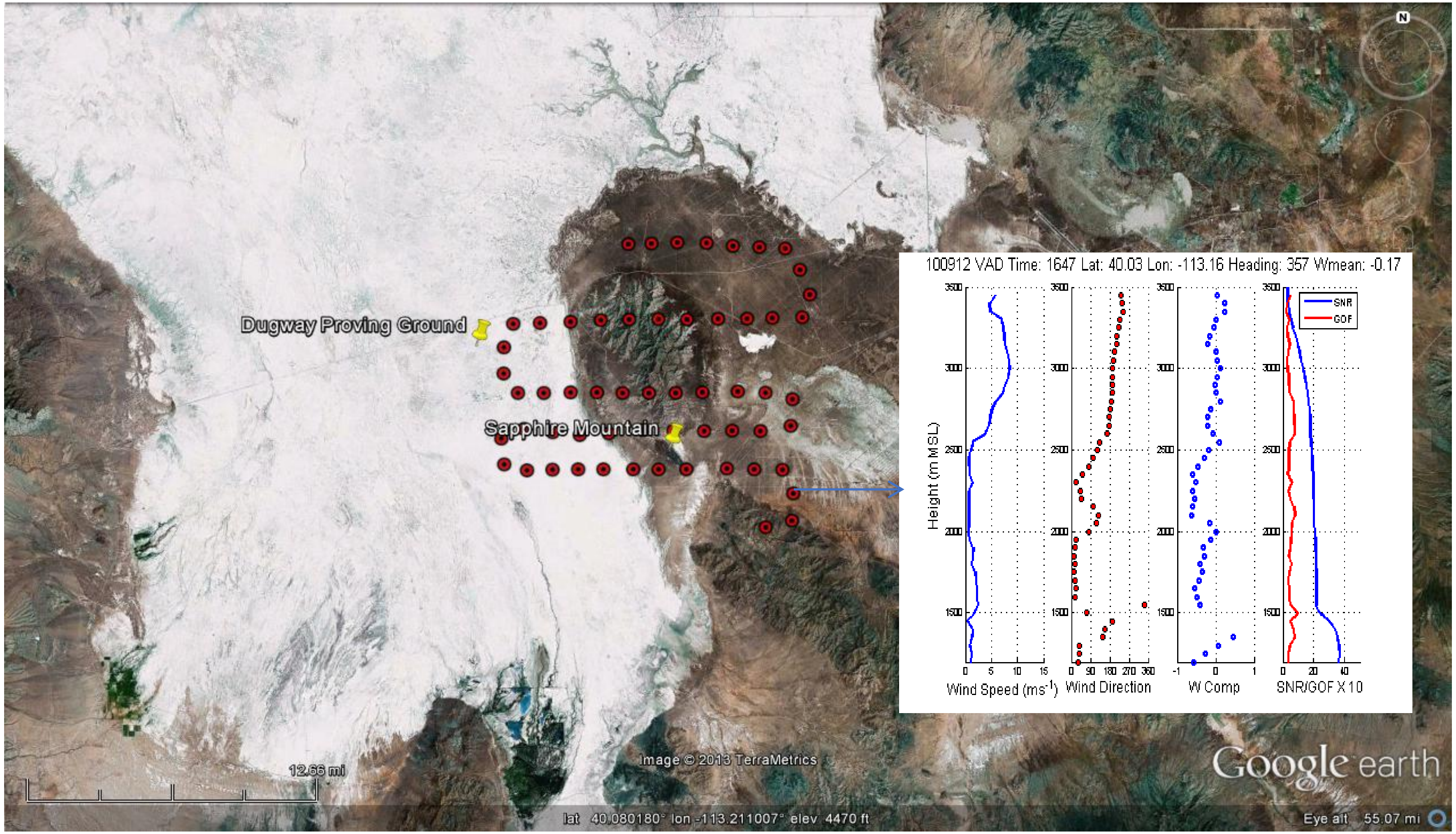

LOS Velocity 100412 120447 Az. Range: -10 to 350 El. Range: -89 to -82
SNR
Spectral Width
Height (m MSL)
Distance (km)
3500
3000
2500
2000
1500
0
1
2
3
4
5
6
7
8
6
4
2
0
-2
-4
-6
5
0
-5
3
2.5
2
1.5
1

MATERHORN 2012 TODWL N-S Legs on October 9, 2012
1601 - 1641



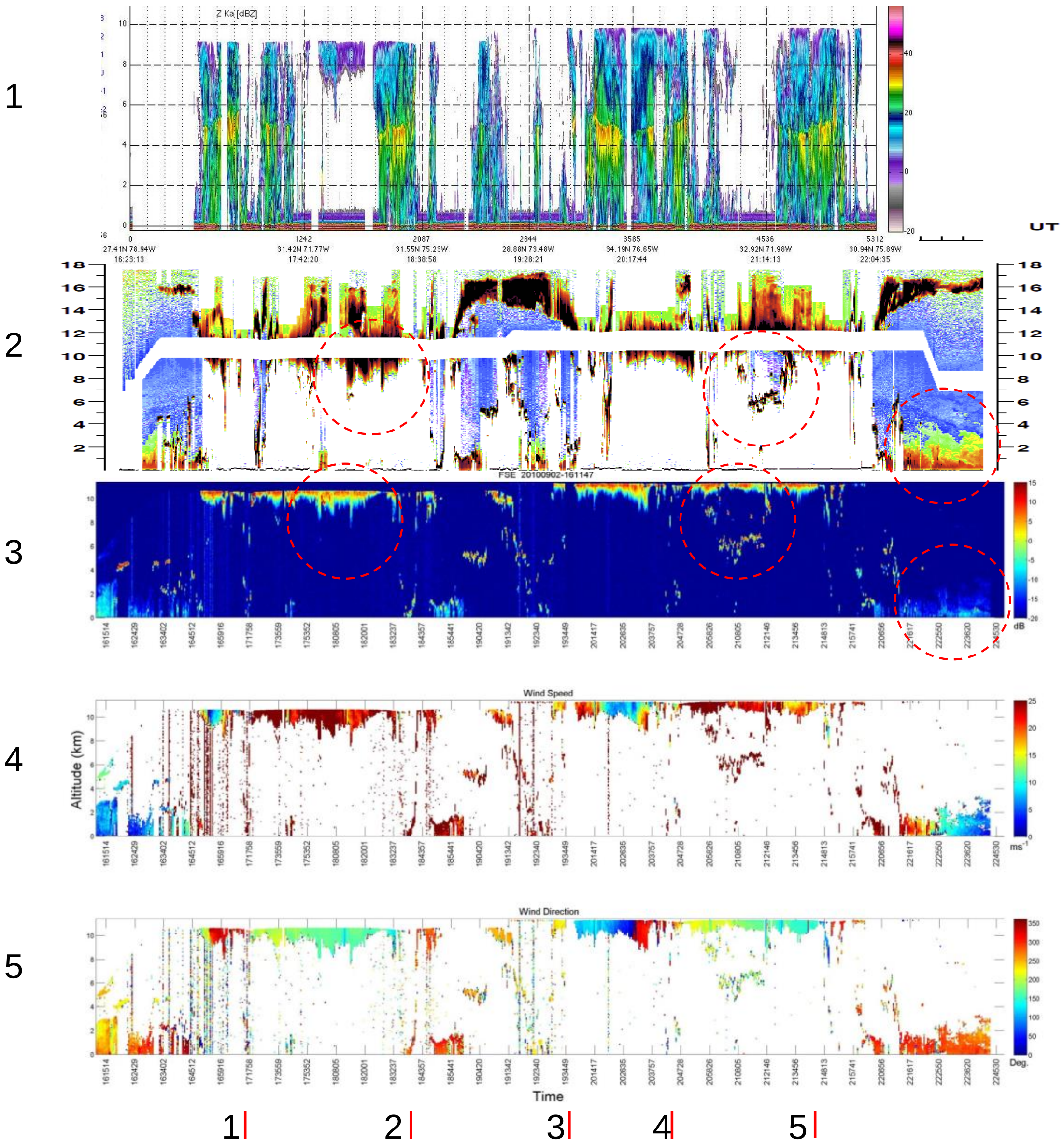
*** - Provided by Simpson Weather Associates, NRL, ONR, ARL and ARO**

MATERHORN 2012 TODWL E-W Legs on October 9, 2012
1646 - 1711



*** - Provided by Simpson Weather Associates, NRL, ONR, ARL and ARO**

DAWN vs. LASE vs. APR-2 in Hurricane Earl



Top to bottom panels: 1) APR-2 radar reflectivity data, 2) LASE aerosol data looking both up and down; 3) DAWN SNR; 4) DAWN horizontal wind speed, and 5) DAWN horizontal wind direction

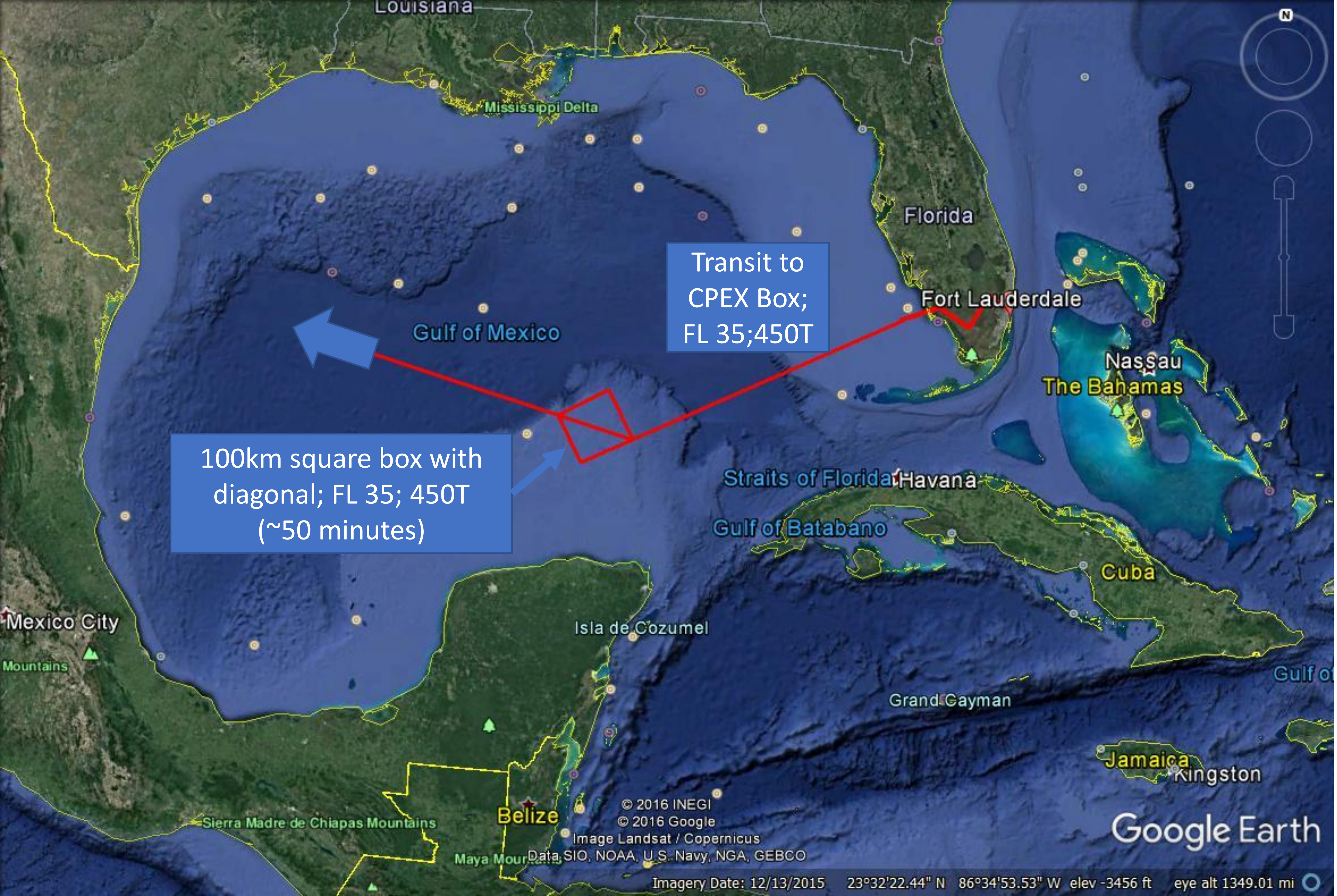
Example of DAWN data taken during GRIP on September 2, 2010 in and near hurricane *Earl*. We also show, for comparison, LASE lidar data and APR-2 radar data, approximately time registered to the DAWN data. The DC-8 repeatedly turned and attempted multiple straight runs over the Earl's eye in the figure. The time axis for panels 2-5 is UTC 16:15:15-22:45:30, which is 396 minutes of data and 791 DAWN scan patterns (horizontal wind profiles). The height axis is 0-10 km for panel 1, 0-18 km for panel 2, and 0-10 km for panels 3-5. In panel 2, the white strip is LASE's lack of data near the DC-8 altitude due to a minimum measurement range. Compare DAWN data only to LASE data that is below the white strip. Panel 3 is a measure of DAWN's signal strength color coded from –20 to 15 dB. Although the DAWN nadir angle is 30° to permit horizontal wind measurements, and LASE points to nadir, panels 2 & 3 agree well in aerosol and cloud structure, and hurricane eye profiles. Dashed circles (L-R) show situations of high clouds only, double cloud layers, and low clouds only. Panel 4 is DAWN's horizontal wind speed color coded from 0-25 m/s. Panel 5 is DAWN's horizontal wind direction color coded from 0-360°. Red tick marks at the bottom indicate approximate eye crossing times. The plot also reveals lidar signal, and therefore, wind measurements from the wall of the eye in the 1st, 2nd, 4th, and 5th eye passes. Panel 5 shows rapid changing of wind direction as we flew over the eye. This is especially evident near red tick-mark 4. We believe the combination of the high DC-8 flight level, high thick clouds, low marine aerosol levels, and an attenuating laser burn on the DAWN telescope secondary mirror led to the frequent lack of DAWN measurements below the clouds. We have implemented several mitigation steps to prevent further burning of the telescope mirror, and these steps worked during our third flight campaign.

Mass Budget CPEX BOX mission segments

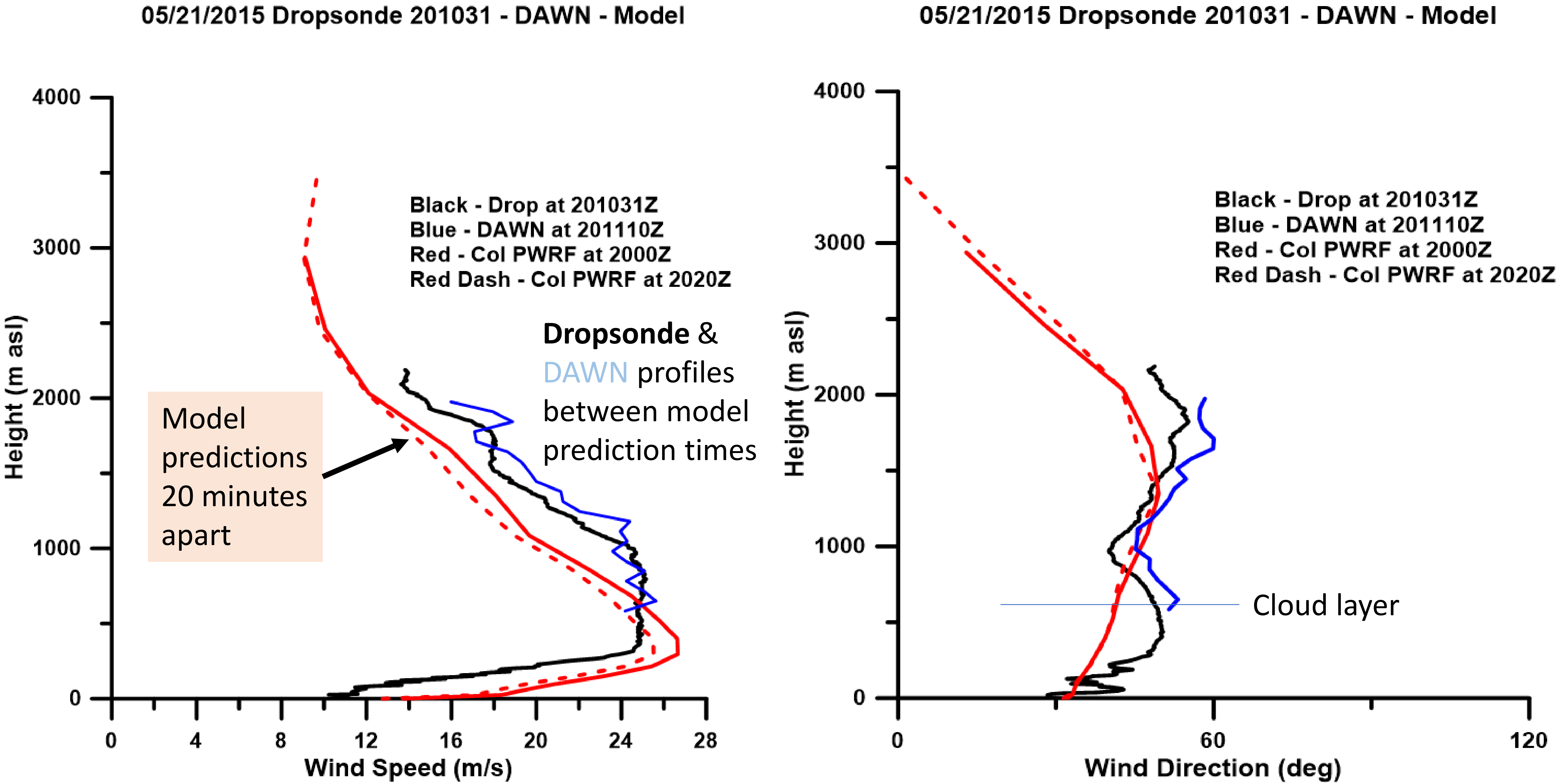
- 12 hours before flight
  - Select CPEX BOX target area after review of models (GFS, WRF, UMCM,..)
    - Looking for 100km x 100km areas in which convection is predicted to grow or decay over a 3 – 6 hour period. Special attention will initially be paid to target areas where there is no convection predicted and/or satellite imagery shows no clouds.
- Preflight
  - Review prior findings and confirm or re-plan CPEX BOX locations
  - See table on next slide showing punch list for CPEX BOX target cases
- Flight
  - Expect a few flights where the same CPEX BOX is flown once on the way to a different target of the day (probably with moist convection with differing organization) and once on the return to base.
  - Once cases 1- 3 are checked off, the need to have no – non-precipitating Cu cases will be satisfied and direct flight to more convective targets more likely.

Mass Budget CPEX BOX mission segments

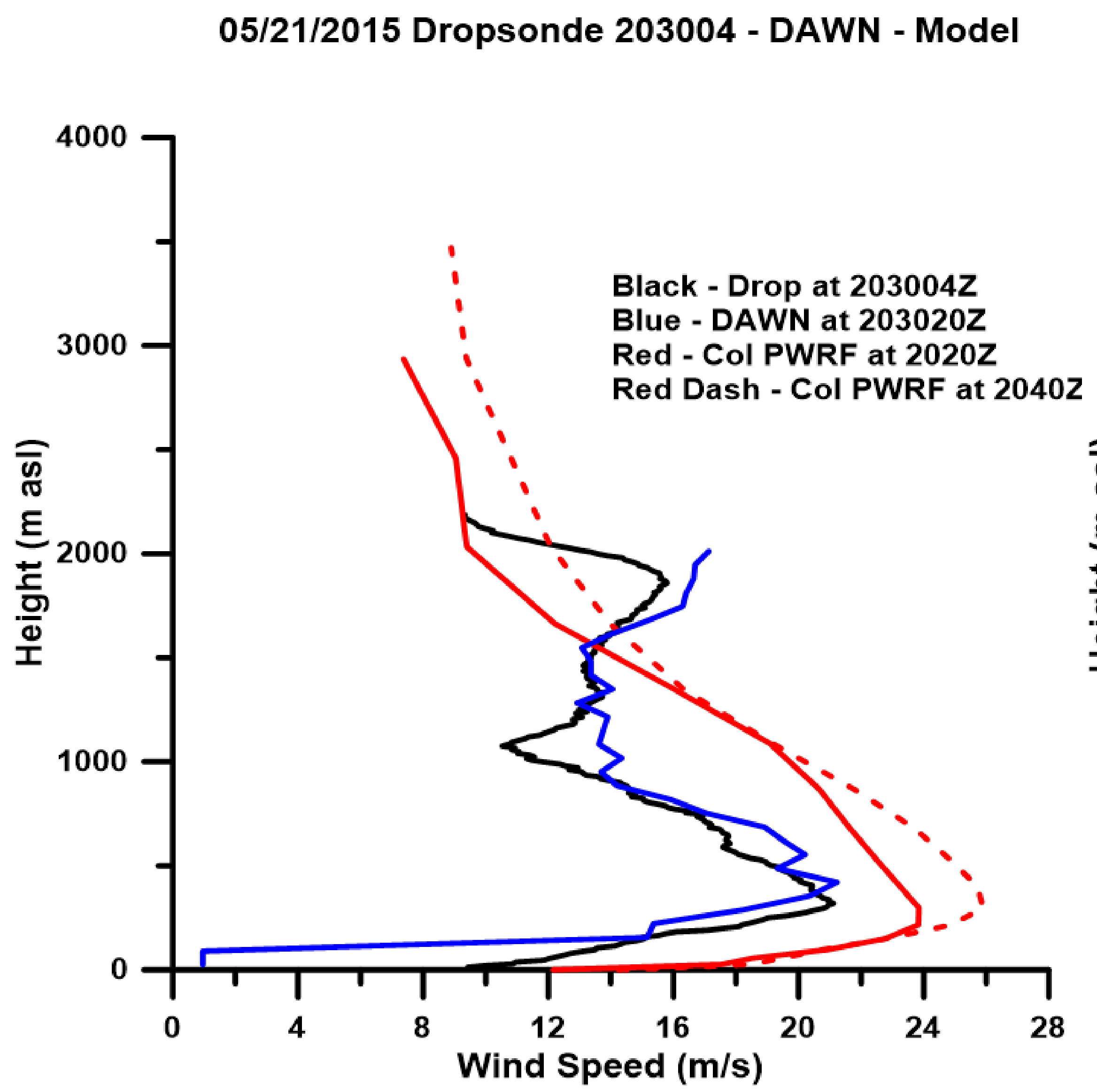
- DAWN velocity calibration legs
  - Two orthogonal legs
  - Over the Everglades or any other land surface
  - Straight and level for 5 minutes (35 – 75 km depending upon speed)
  - At or above FL10
  - At or above 250T
  - At start and end of flight
- CPEX BOX
  - At or above FL10 (clouds and aerosols 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.

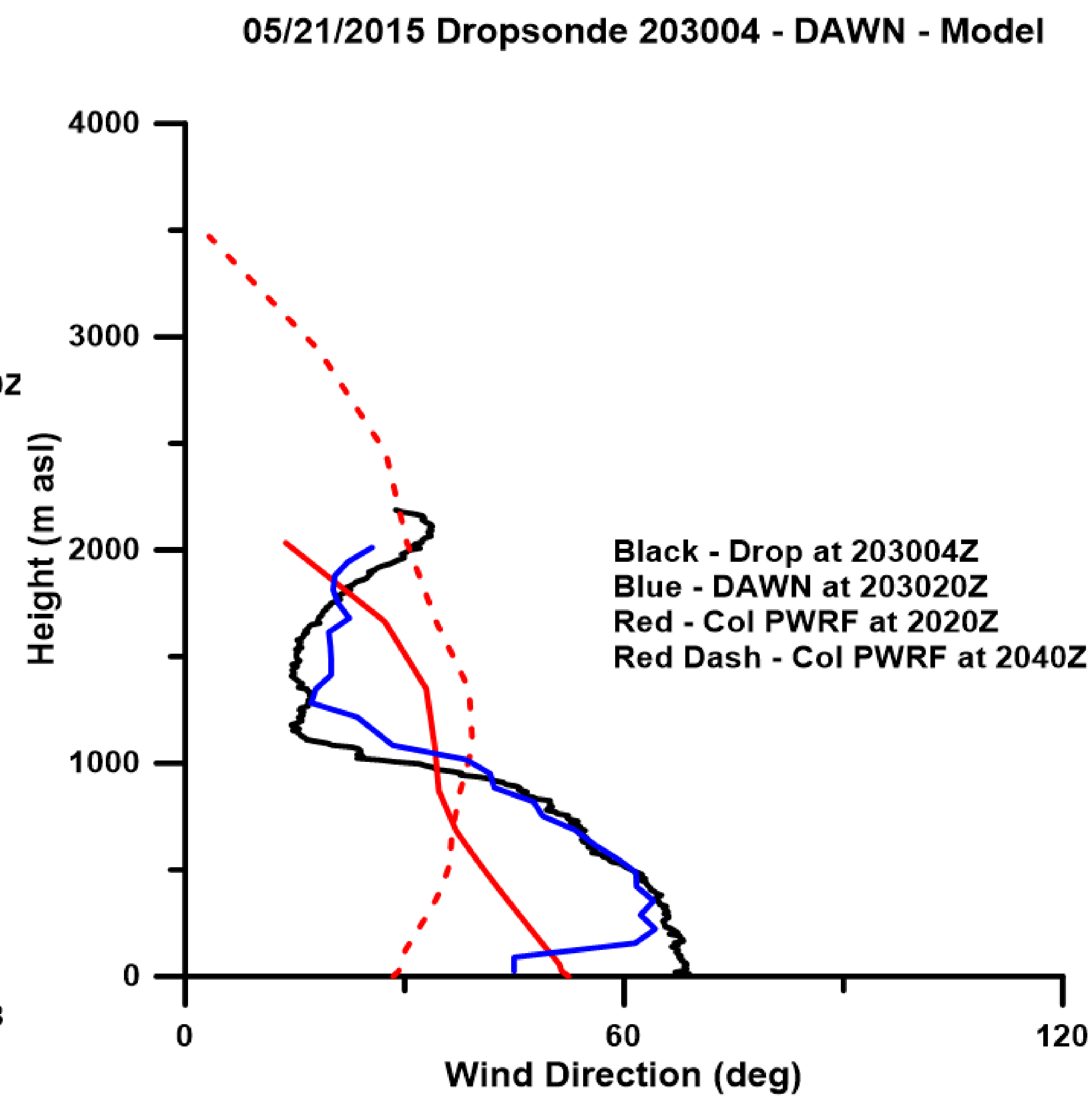


CPEX BOX:
Gulf Target
on way to
target of the day

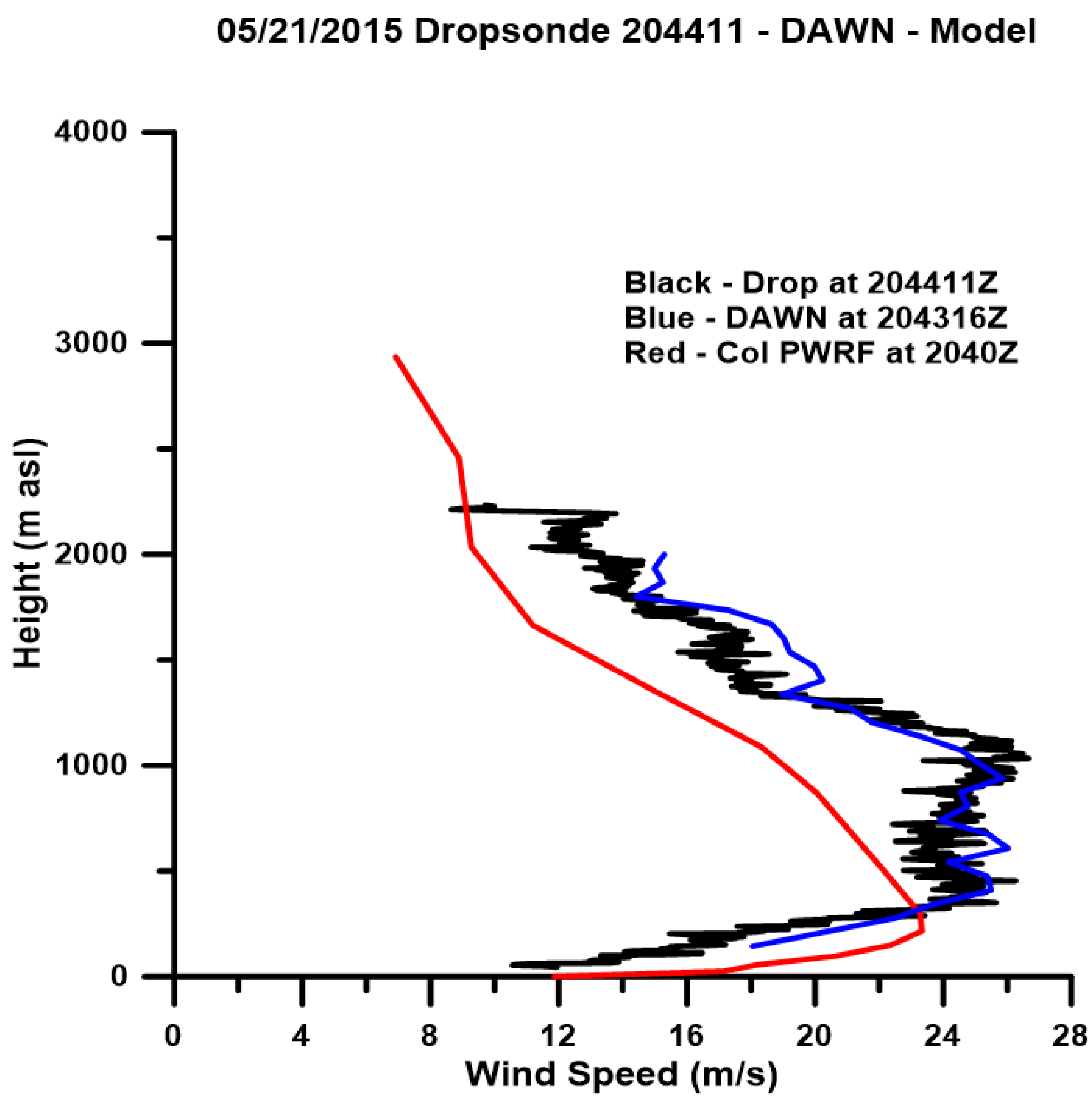


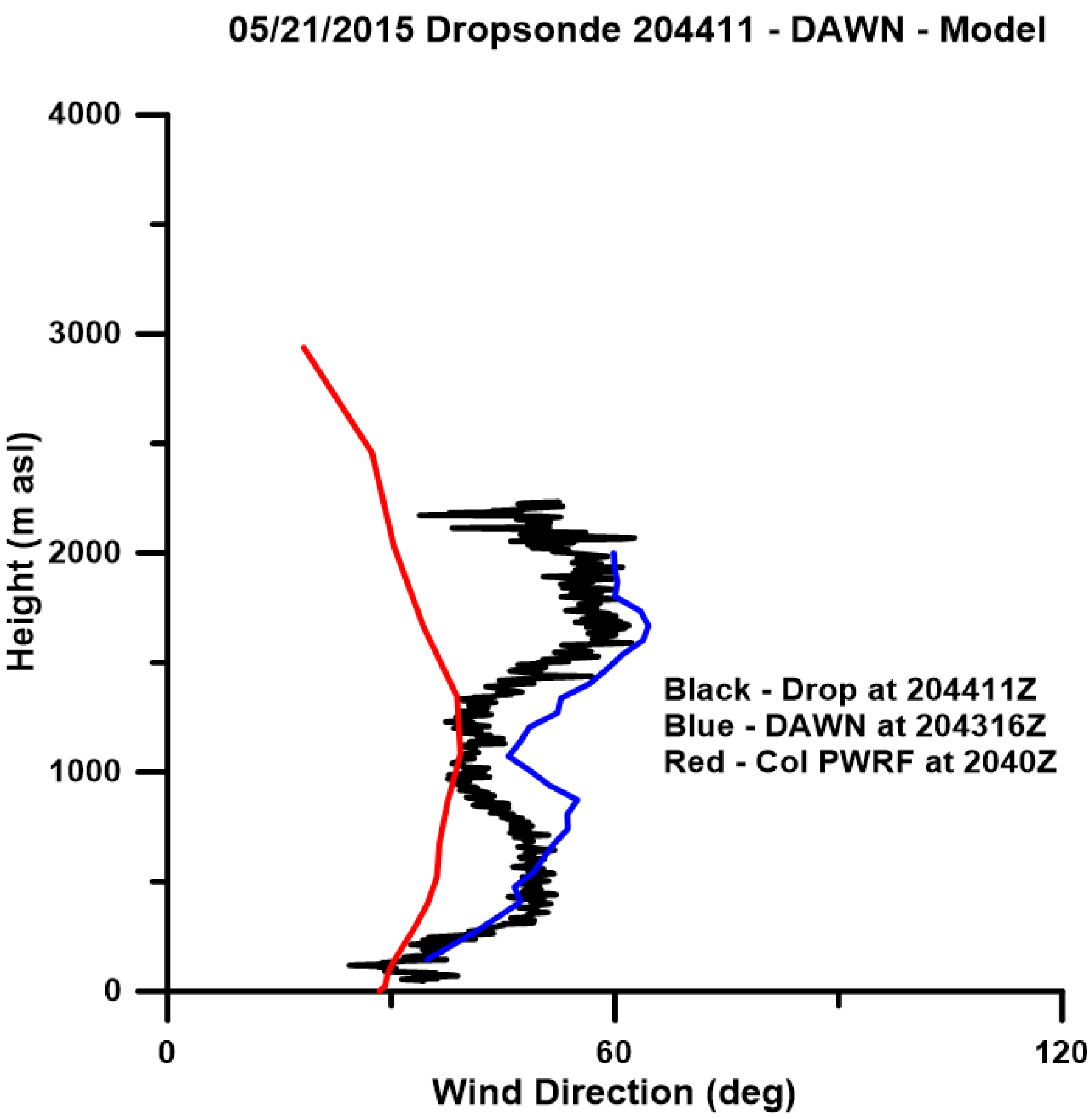
Col PWRF: University of Colorado Boulder's Polar Weather Research Forecast model





Col PWRF: University of Colorado Boulder's Polar Weather Research Forecast model





Col PWRF: University of Colorado Boulder’s Polar Weather Research Forecast model

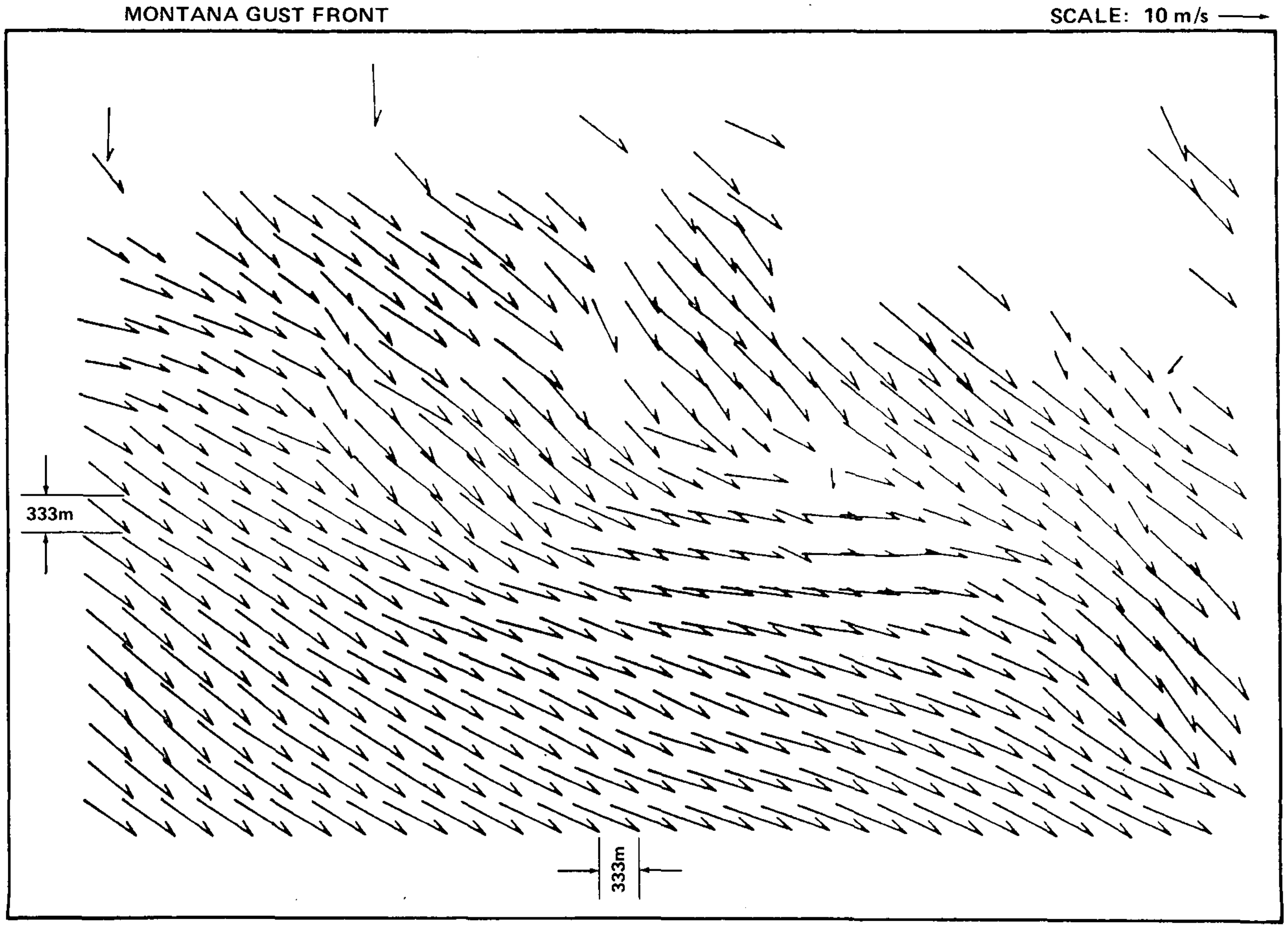
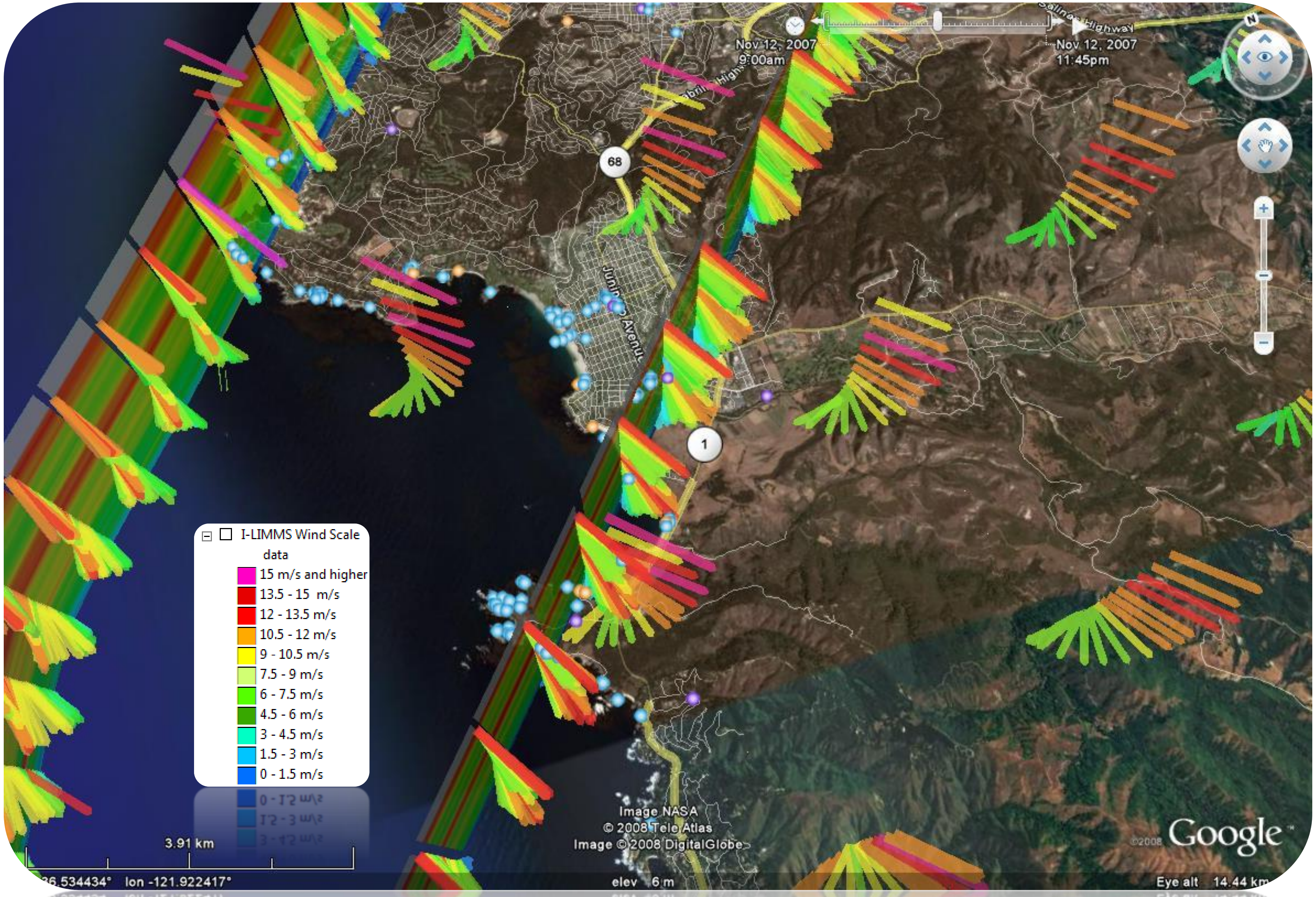


FIG. 10. A post-flight processed ADLS wind field plot. Thunderstorm outflow obtained midway between cloud base and ground during CCOPE (see text). Size of 10 m/s^{-1} arrow is shown; arrows are 333 m apart. The large arrows at right are due to system malfunctions.

Bilbro, et al., 1984

Comparison with 4km MM5



TWOLF
Truck mounted Wind Observing Lidar Facility

Data Products

- **Region of regard**
  - +/- 30 degrees azimuth; +/- 120 degrees elevation
  - Flight level (-200m) to surface
  - Flight level (+200m) to 15km (aerosol and clouds permitting)
  - Forward to 15km (nominal 6-10 in PBL and 1 – 3 above)
- **Resolution**
  - 50 meter overlapped range gates (Gausian pulse ~ 90 m long)
  - 500 Hz rep rate (~ .5 meter along flight track)

Data Products (2)

- 3D wind profiles (u,v,w)
  - 12 point step-stare scan pattern with 20 -30 degree nadir cone (half angle)
  - .5 – 2 second dwells with 1 second transition gaps
  - On P3 a full profile takes ~ 30 seconds (3km)
  - 4 point profiles provide better than 1 km horizontal spacing
  - Special processing required within 200 meters of the surface

Data

Data Products (4)

- Backscatter (attenuated) profiles and aerosol structures
  - Organized Large Eddies
  - Mixed layer heights
  - Aerosol pumping by cloud convection
- Turbulence
  - Within the illuminated volume (~ .1m X 100m)
    - Broadening of spectral features
  - Between shots (~ .5m X 100m)