Airborne Doppler Wind Lidar Investigations of the PBL as Part of Planning for a Space based DWL

G. D. Emmitt
Simpson Weather Associates
&
M. J. Kavaya
NASA/LaRC

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Greenbelt, MD

Airborne PBL investigations using three airborne DWLs

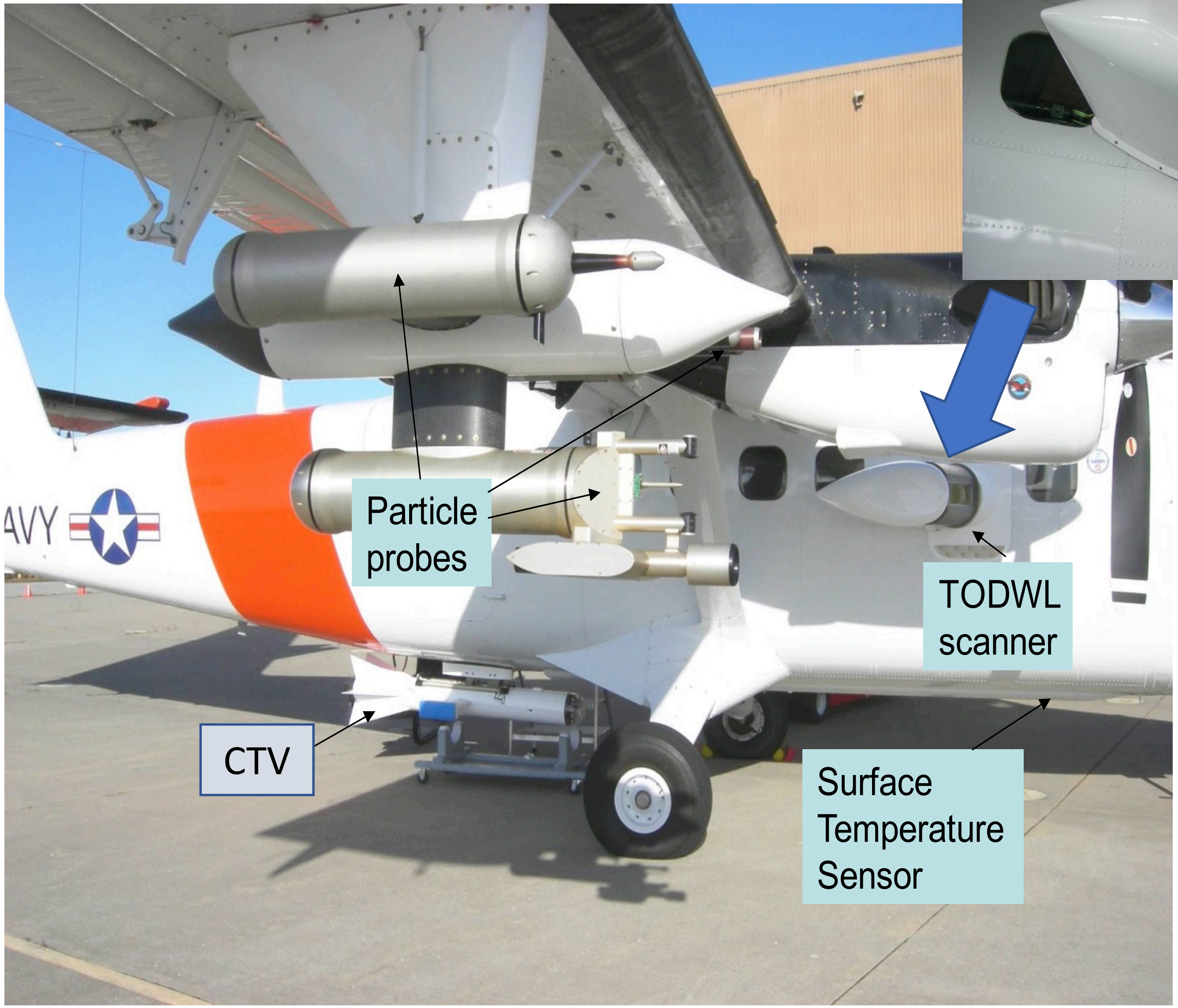
- TODWL (Navy) 2001- present
  - Wind Lidar
  - Temperature and moisture sensors for profiles
  - Turbulent flux probes
  - Particle probes
- P3DWL (Navy and NOAA) 2014 - present
  - Wind profiles near/in convective clouds
  - Hydrometeor fall speeds
- DAWN (NASA) 2014 - present
  - Full tropospheric profiles from 30,000’
  - High resolution of PBL winds (35m vertical)

PBL structure and dynamics mapped by ADWL

- Vector wind profiles within and above the PBL
  - Nadir 12 point step and stare VAD (standard scanning mode)
    - 50 meter vertical and 1 -2km horizontal
  - Shallow angle forward sector scan
    - 1-5 m vertical resolution; 750 m horizontal repeat
- Aerosol gradients
  - Deduced from lidar SNR
  - Top of PBL defined by aerosols(?)
  - Mixing across boundary
- Turbulence within PBL on two scales
  - Spectral broadening
    - single shot product: scale ~ 5 – 25m
  - Shot-to-shot variability
    - Sampling varies depending upon platform speed and lidar PRF
- Organized structures within the PBL
  - Organized Large Eddies
  - Low Level Jets
- PBL capping cloud winds
  - Shear within clouds optical permitting

Airborne Doppler Wind Lidar Data Utility

- Primary use of the three agency's airborne DWL data has been diagnostic
  - Severe storm research
  - Flow in complex terrain
  - Organized Large Eddies (OLEs)
  - Marine Boundary Layer jets
  - Evaluation of mesoscale NWP models
  - **Providing over-sampling for evaluation of space-based DWL concepts**
    - **Special interest in sampling in vicinity of clouds**
    - **Input to "library" of flux parameterizations based upon Satellite observations**
- Additional uses
  - Wing tip vortices within a turbulent PBL
  - Precision Air Drops: winds in complex terrain
  - Data assimilation into NWP models for NOAA
  - Data assimilation into WRF Model for DAS research



TODWL

Twin Otter Doppler Wind Lidar

CTV

Controlled Towed Vehicle

P3DWL for TPARC/TCS-08 and NOAA HFIP

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

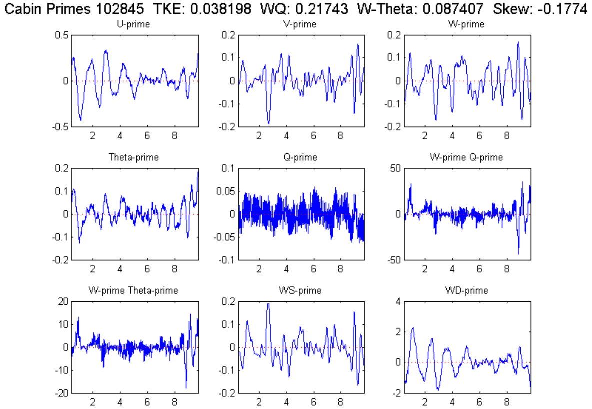
TODWL and P3DWL data description

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 precision	< 10 cm/s	< 5cm/s for stationary groundbased operations
Maximum range	6 -20 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	500 Hz	Integration of several shots is typical to improve range performance

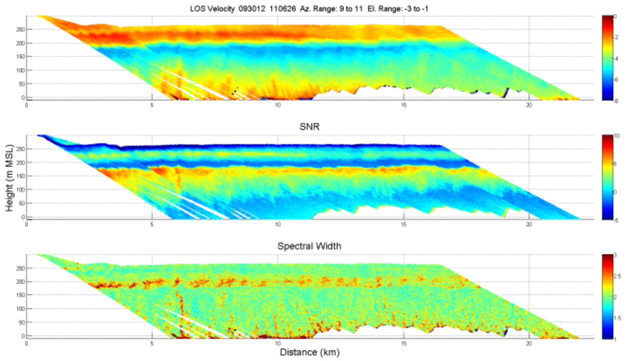
PBL structure prospecting with DWL

- 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 (Twin Otter).
- No-cloud case
  - Aircraft flies just above PBL (defined by t/q profile by Twin Otter) with DWL pointed at a 5-10 km intercept with ocean surface
- Cloud case
  - Aircraft flies just below(in?) cloud bases

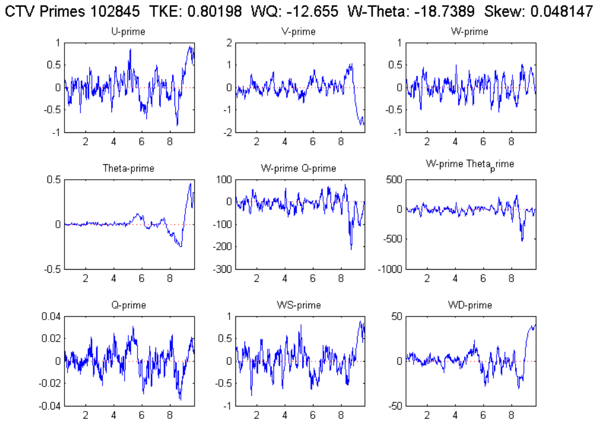
CIRPAS Twin Otter with CTV below



Twin Otter Probe Data



TODWL Time/height Cross sections



Towed Vehicle Flux Data

SWA

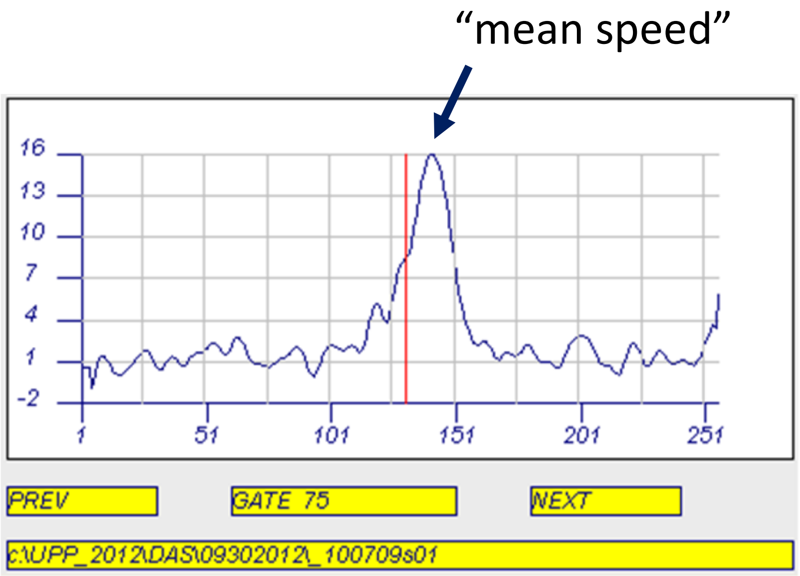
September 2018 investigations near Monterey, CA

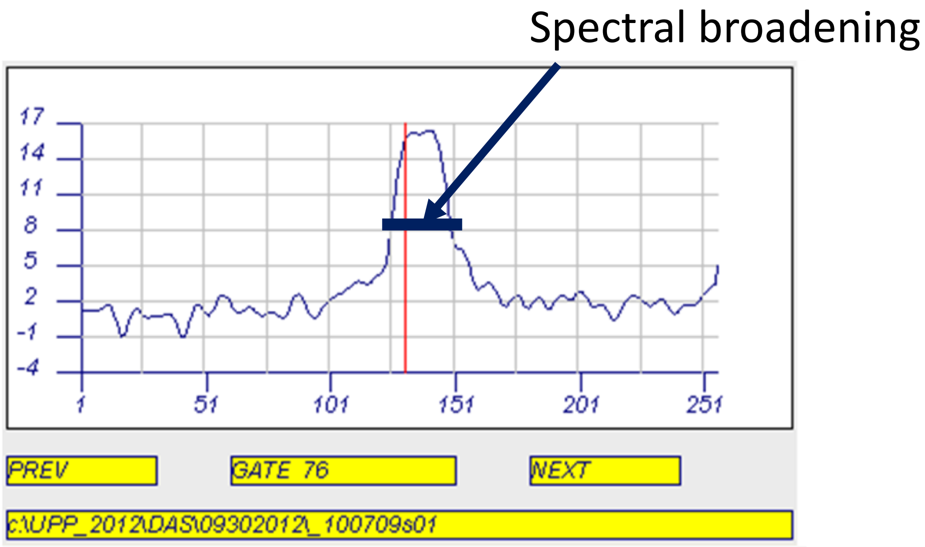
- Extended prior investigations (2001-2012)of LLJs and OLEs in the MBL.
- Investigated and characterize the presence of rolls (OLEs) at the boundaries of stratocumulus topped MBLs as well as cloud free PBLs. Generate PDFs for roll "energetics" as function of winds, PBL depth and stability profile.
- Continued study the potential impact on the development and implementation of the Eddy Diffusivity Mass Flux parametrization for NWP models.

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.

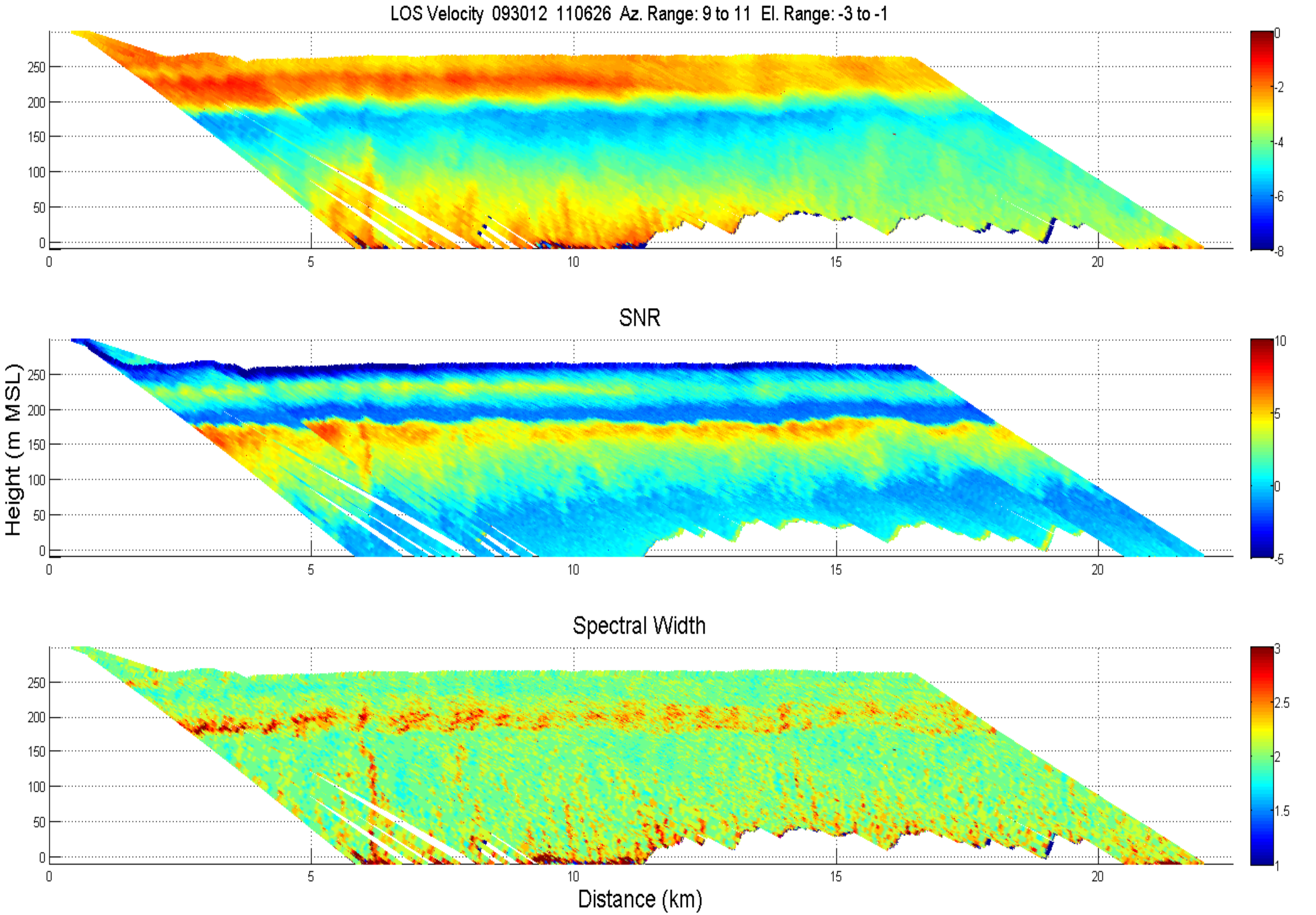




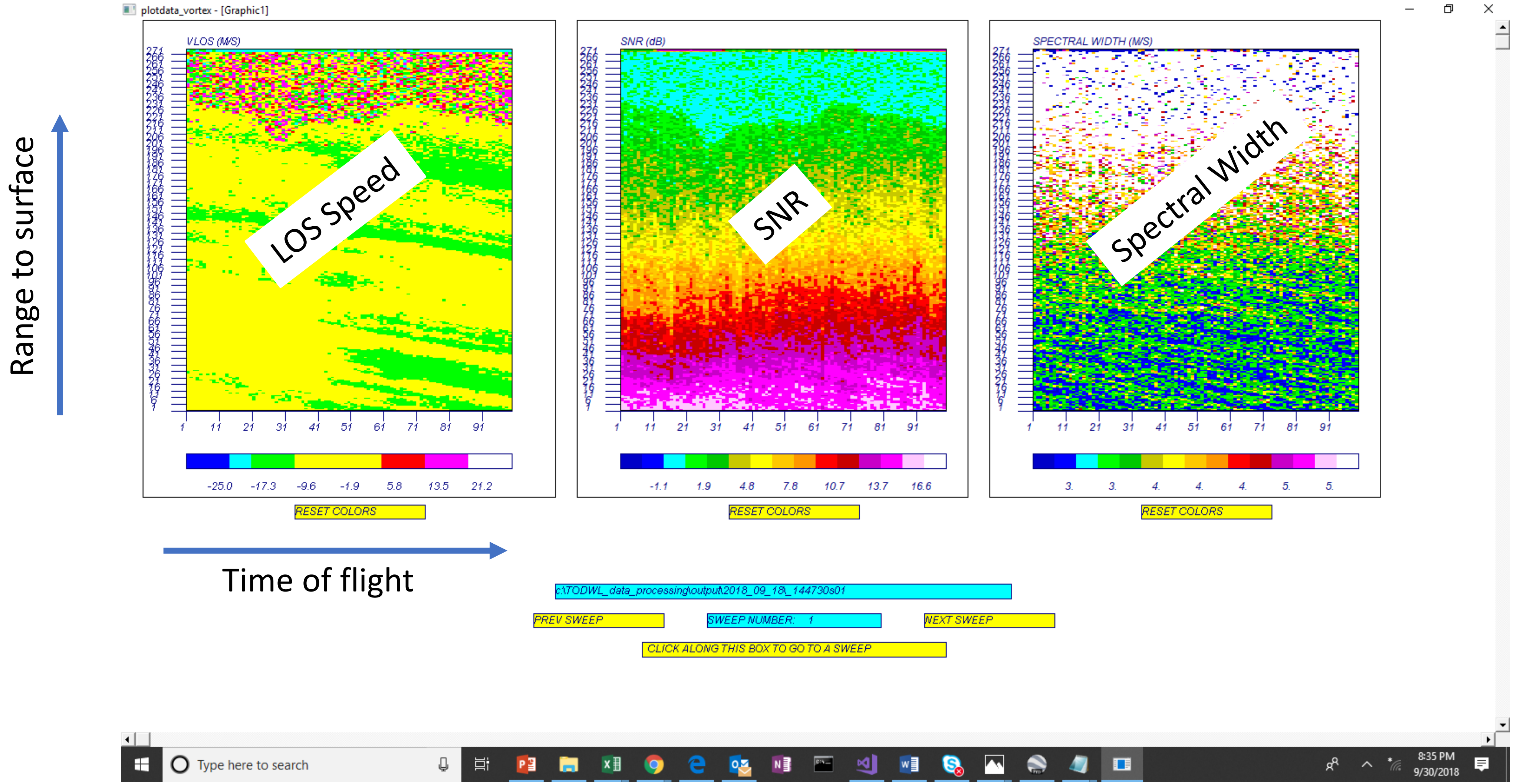
Horizontal Motion

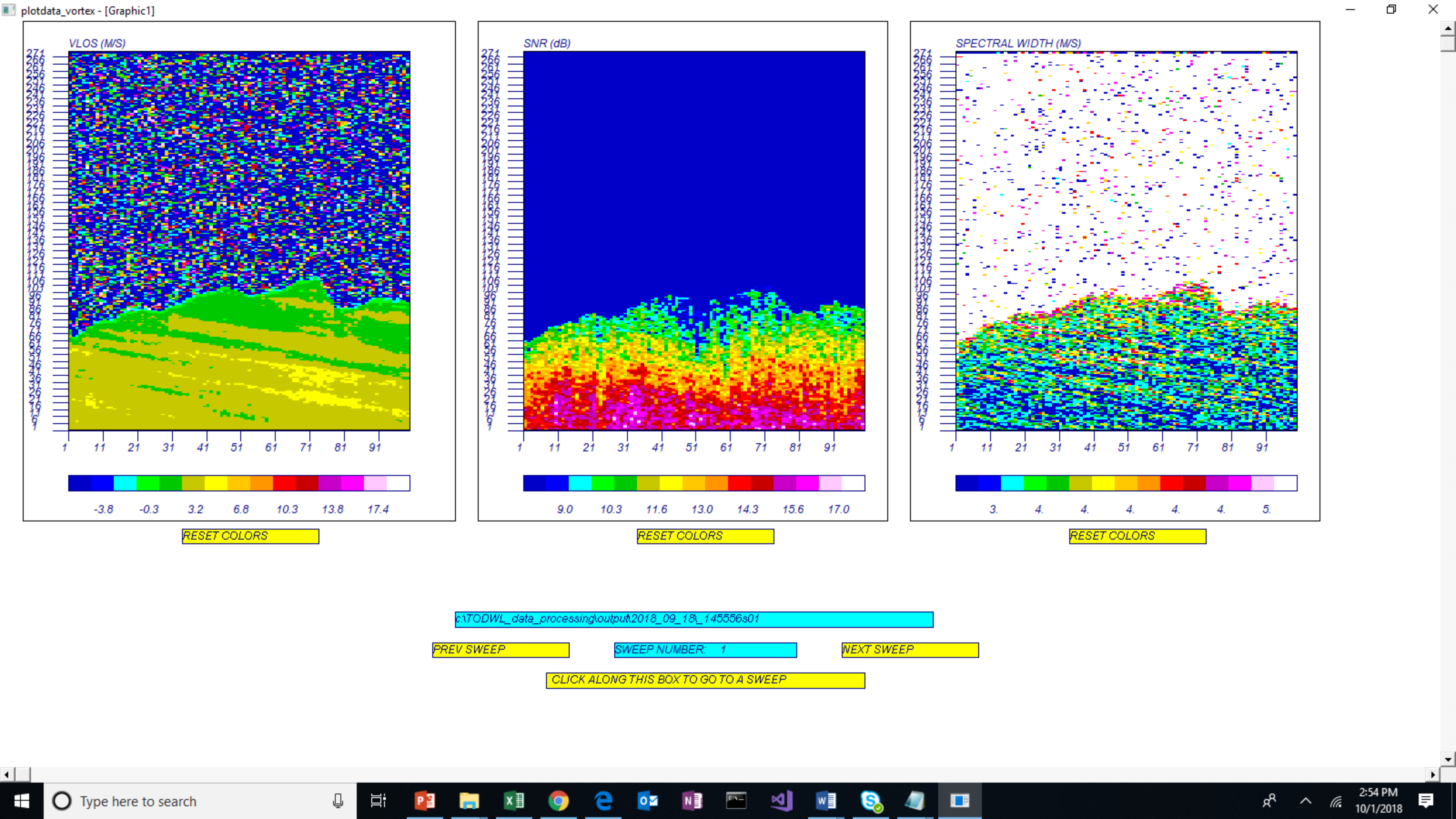
Aerosol backscatter

Turbulence

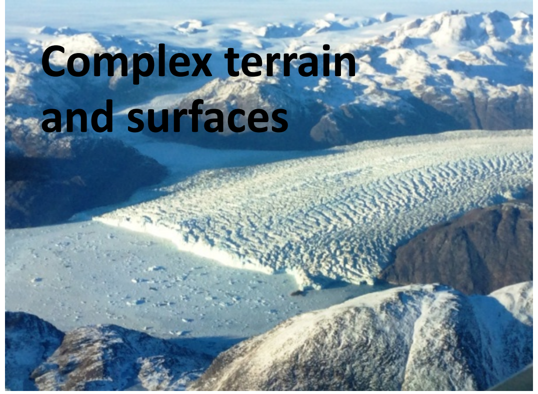


9/18/18
PBL winds at 125m = 15 kts

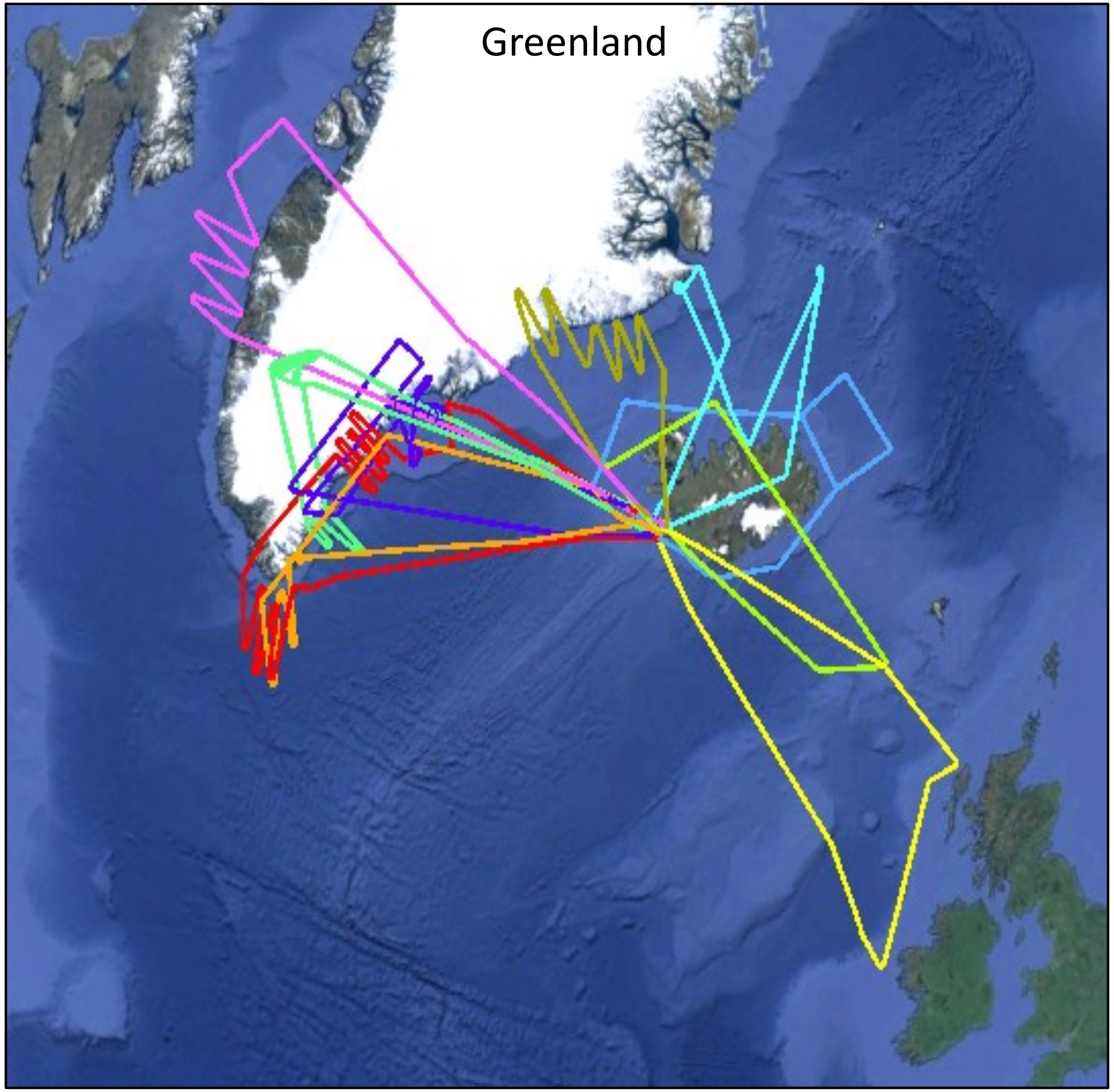



plotdata_vortex - [Graphic1]
VLOS (M/S)
SNR (dB)
SPECTRAL WIDTH (M/S)
1 11 21 31 41 51 61 71 81 91
-3.8 -0.3 3.2 6.8 10.3 13.8 17.4
9.0 10.3 11.6 13.0 14.3 15.6 17.0
3. 4. 4. 4. 4. 4. 5.
RESET COLORS
RESET COLORS
RESET COLORS
c:\TODWL_data_processing\output\2018_09_18_145556s01
PREV SWEEP
SWEEP NUMBER: 1
NEXT SWEEP
CLICK ALONG THIS BOX TO GO TO A SWEEP
Type here to search
2:54 PM
10/1/2018

ADM/PolarWinds Campaign I November 2014



PolarWinds Campaign II Flight Tracks



DuVivier, A.K., Cassano, J.J., Greco, S. and Emmitt, G.D., 2017: A Case Study of Observed and Modeled Barrier Flow in the Denmark Strait in May 2015. *Monthly Weather Review*, *145*(6), pp.2385-2404

Greco, S. , G.D. Emmitt , J. Cassano , K. Hines , and M. Kavaya, 2018: PolarWinds: Airborne Doppler Wind Lidar missions in the Arctic for atmospheric observations and numerical model, submitted for publication to MWR.

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

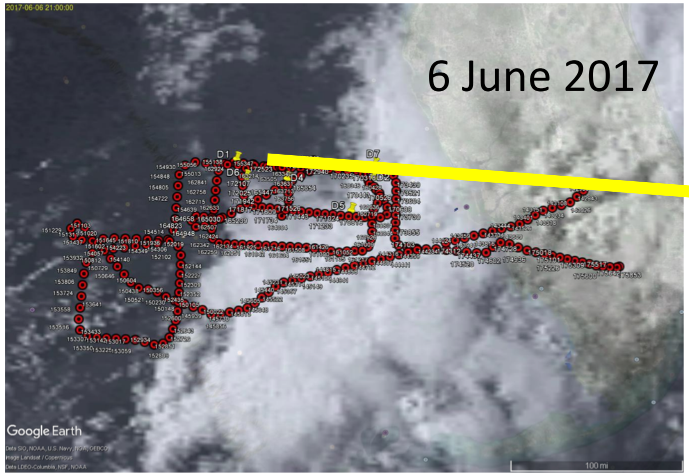
2. Obtain a comprehensive set observations, especially from DAWN, in the vicinity of scattered and organized deep convection in all phases of the convective life cycle

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

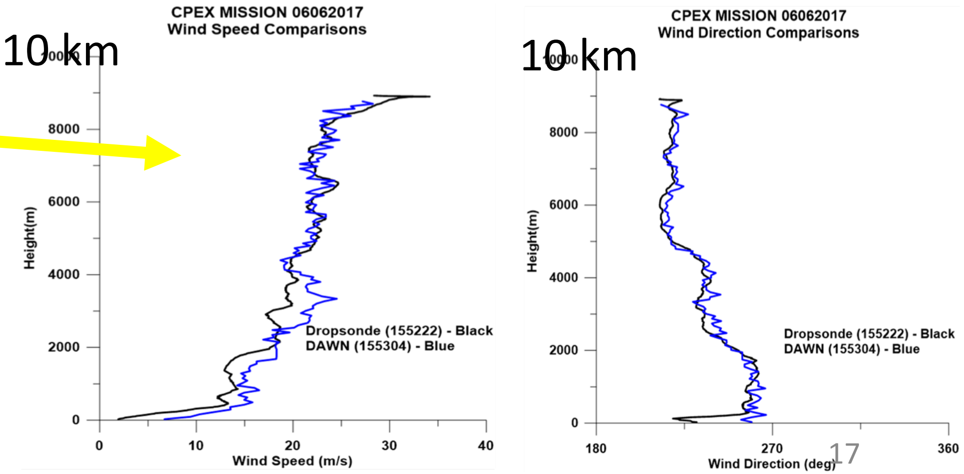
LaRC DAWN on NASA DC8

- 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)

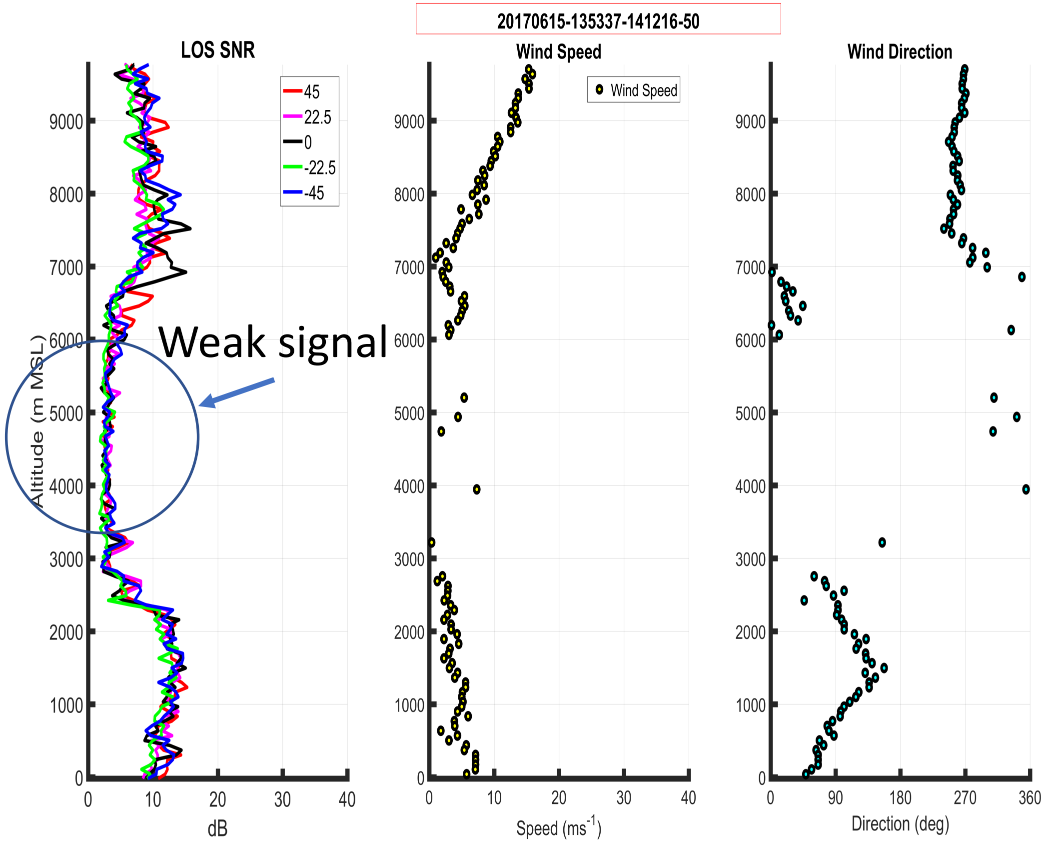


Each red circle is a DAWN sounding location

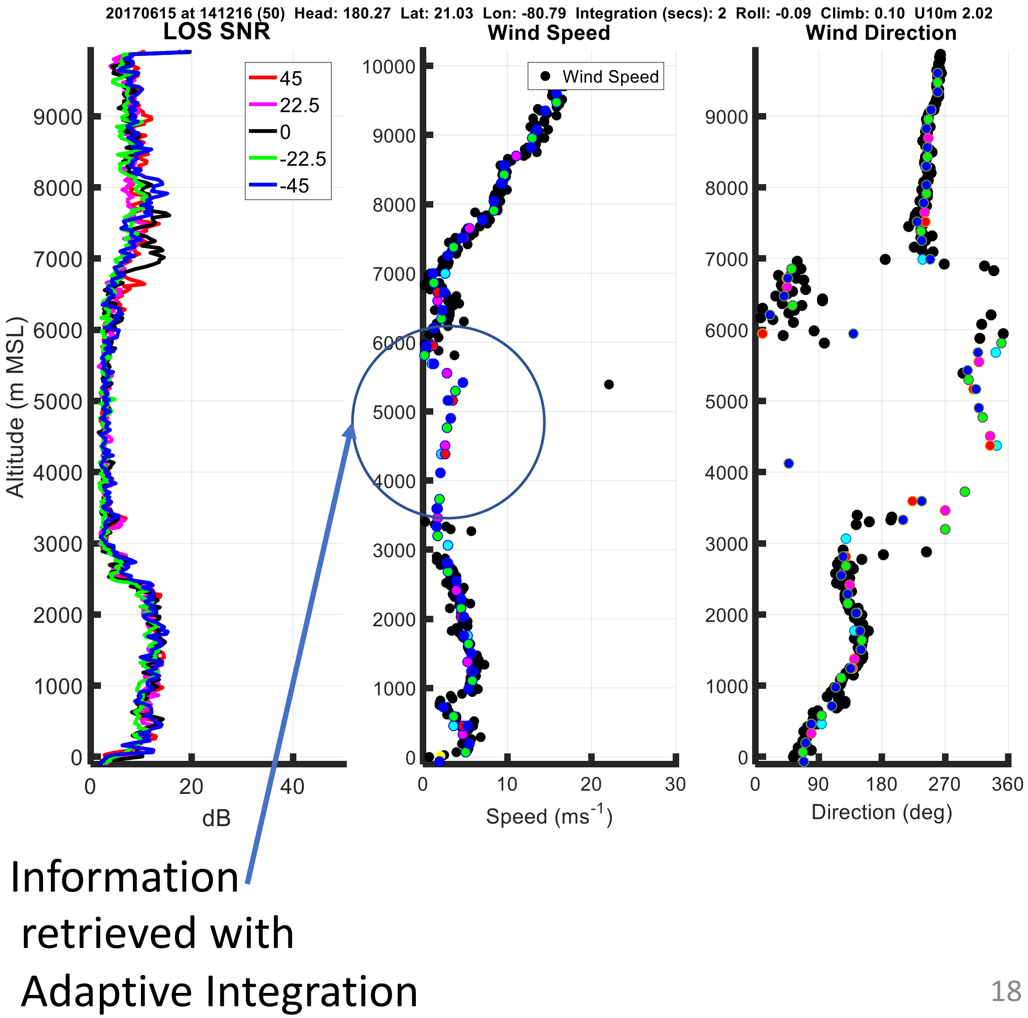
DAWN (blue) vs Dropsonde (black)



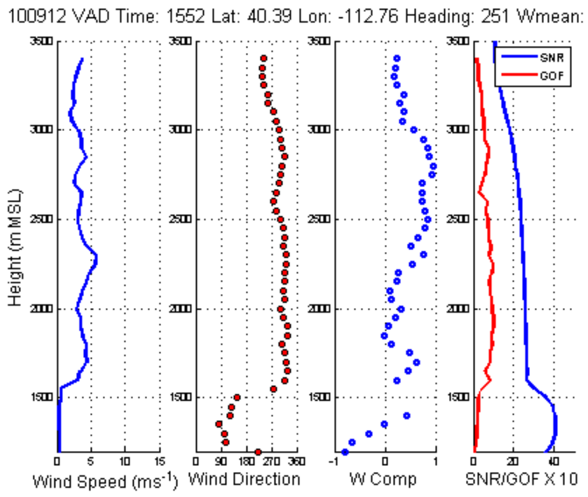
Quicklook (V1)



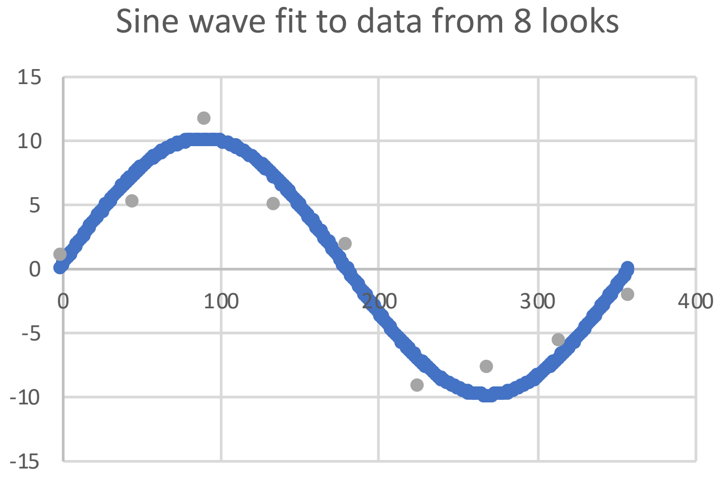
V3 processed profile



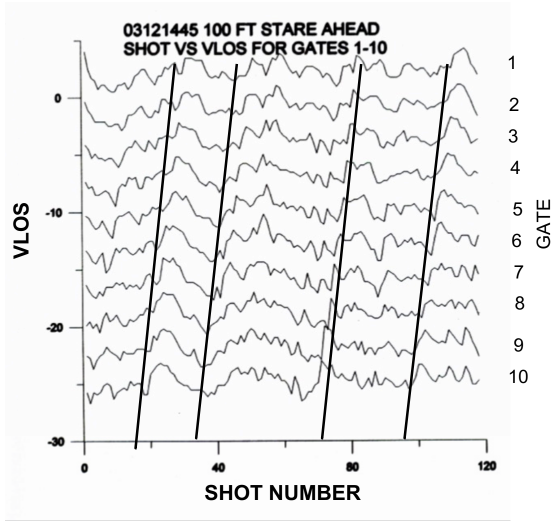
Multi-scale Wind Variability Using DAWN in CPEX



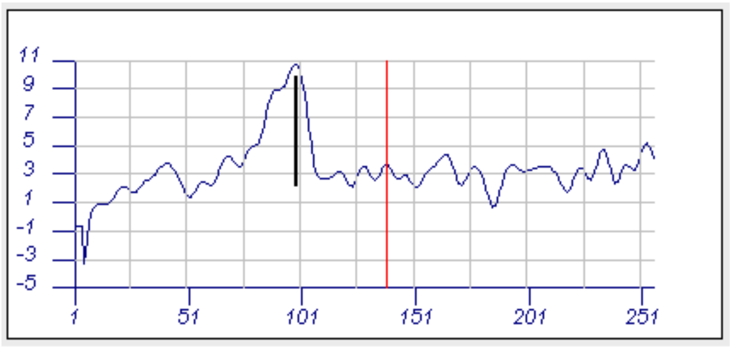
3km – 200km



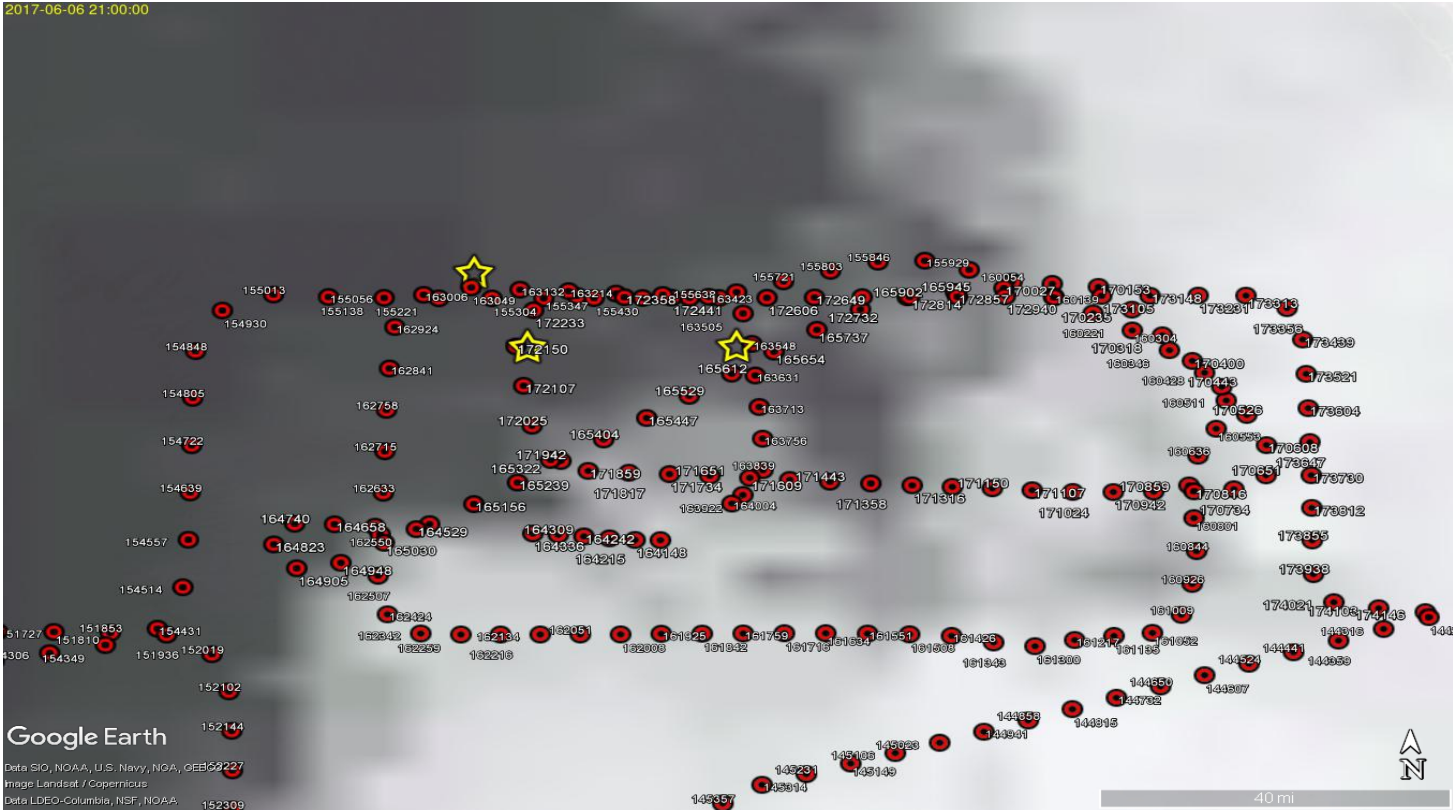
500 – 3000m

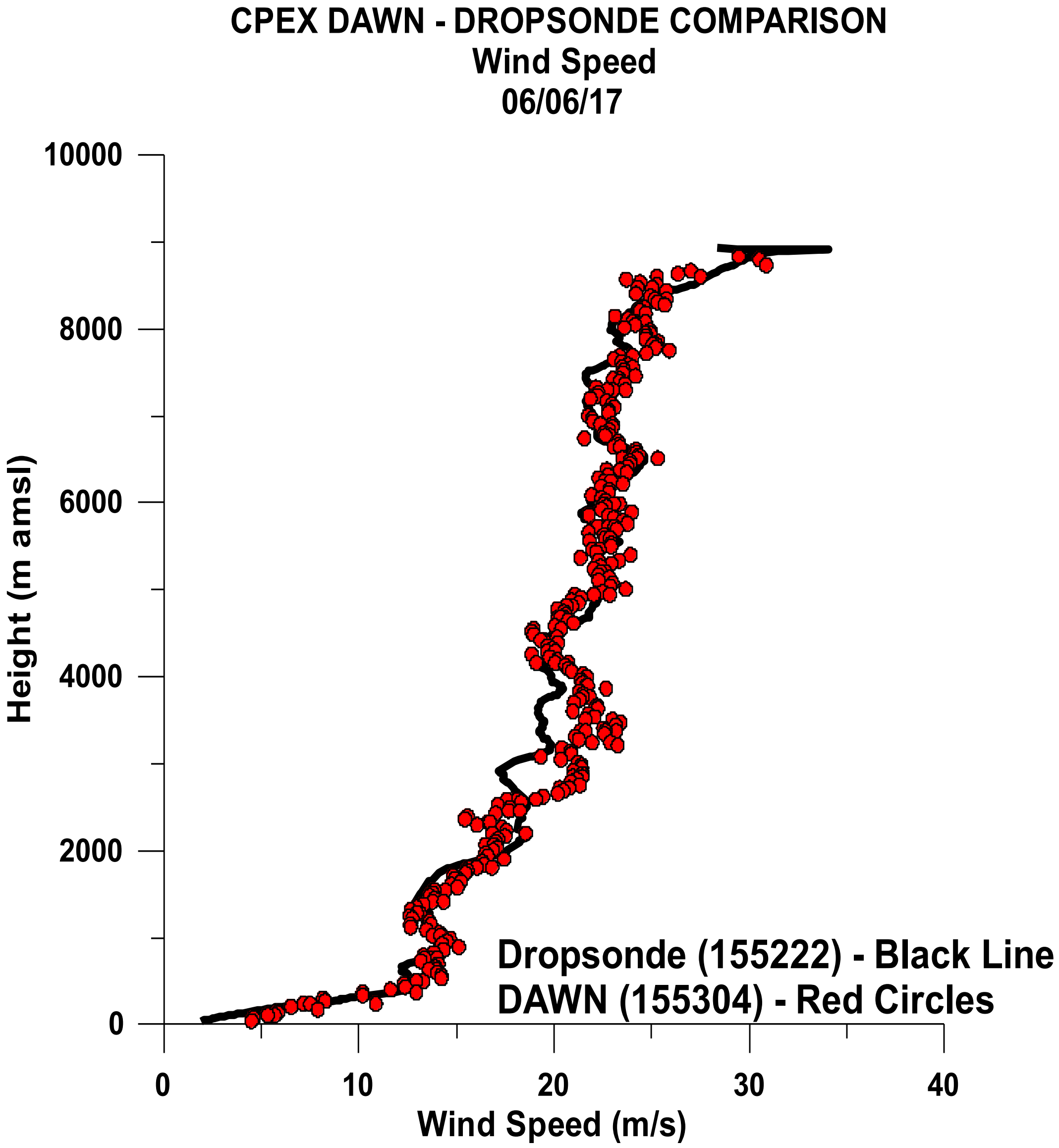


50 – 400m

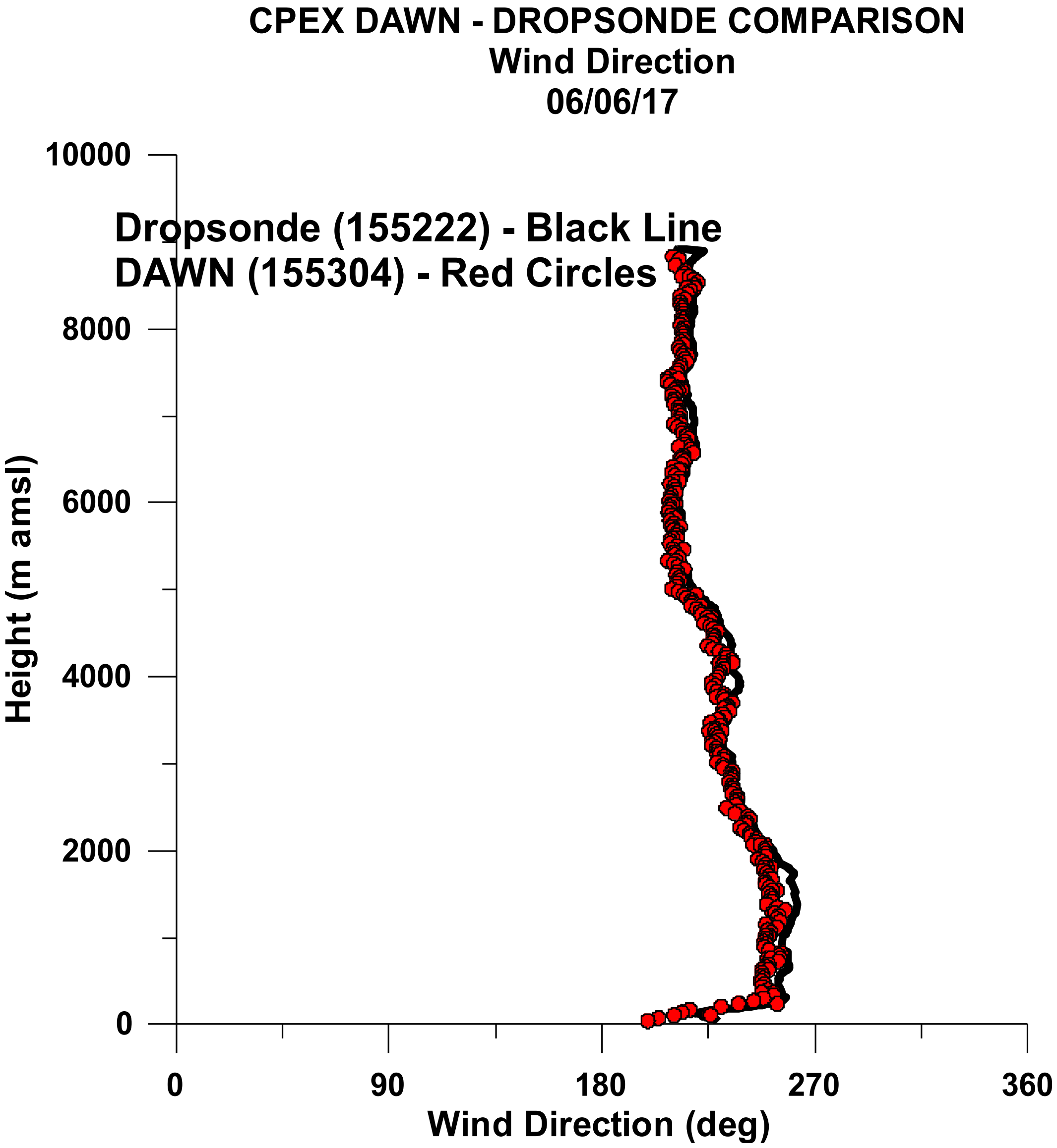


< 100m

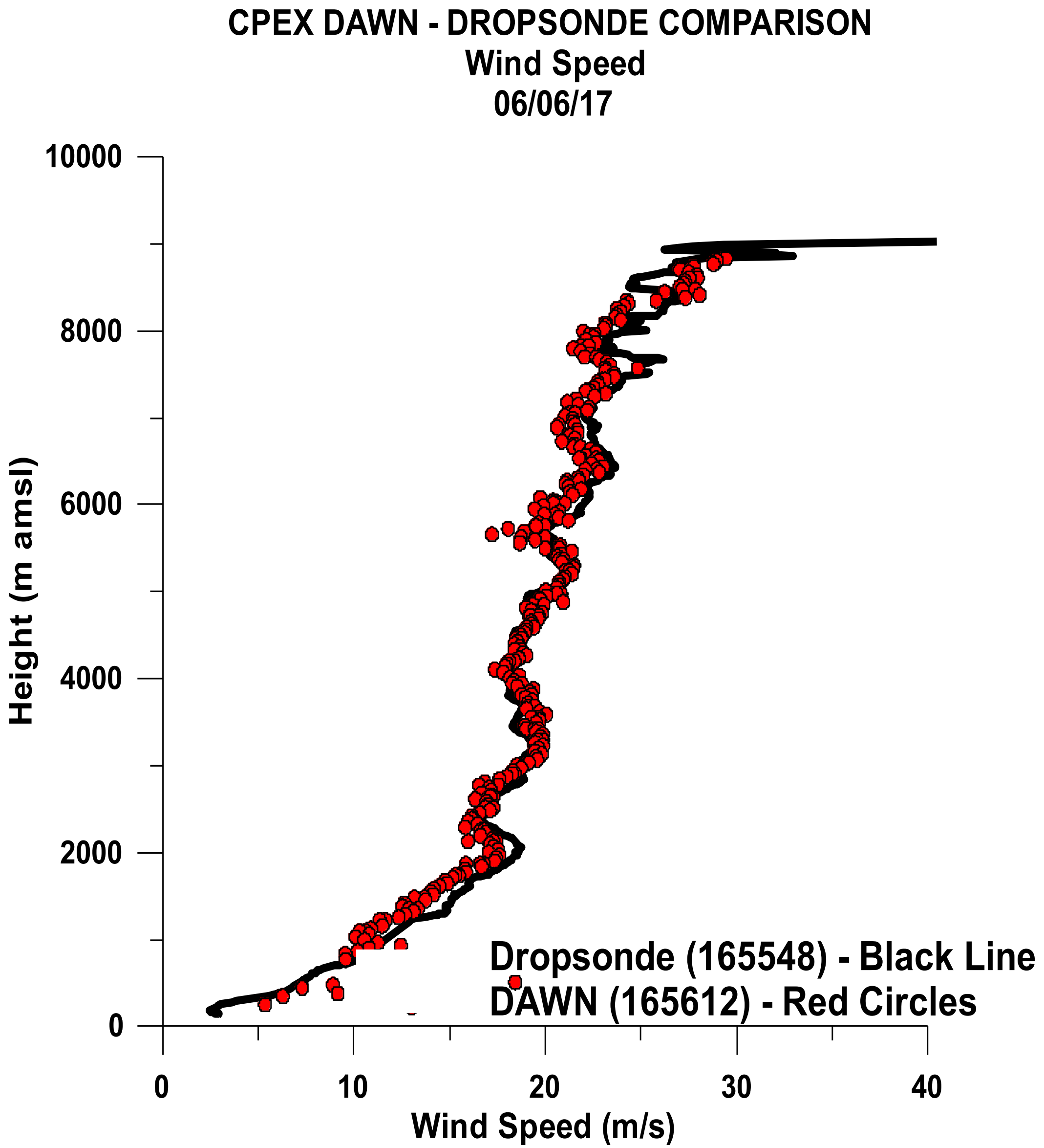

2017-06-06 21:00:00
Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Data LDEO-Columbia, NSF, NOAA
40 mi
N

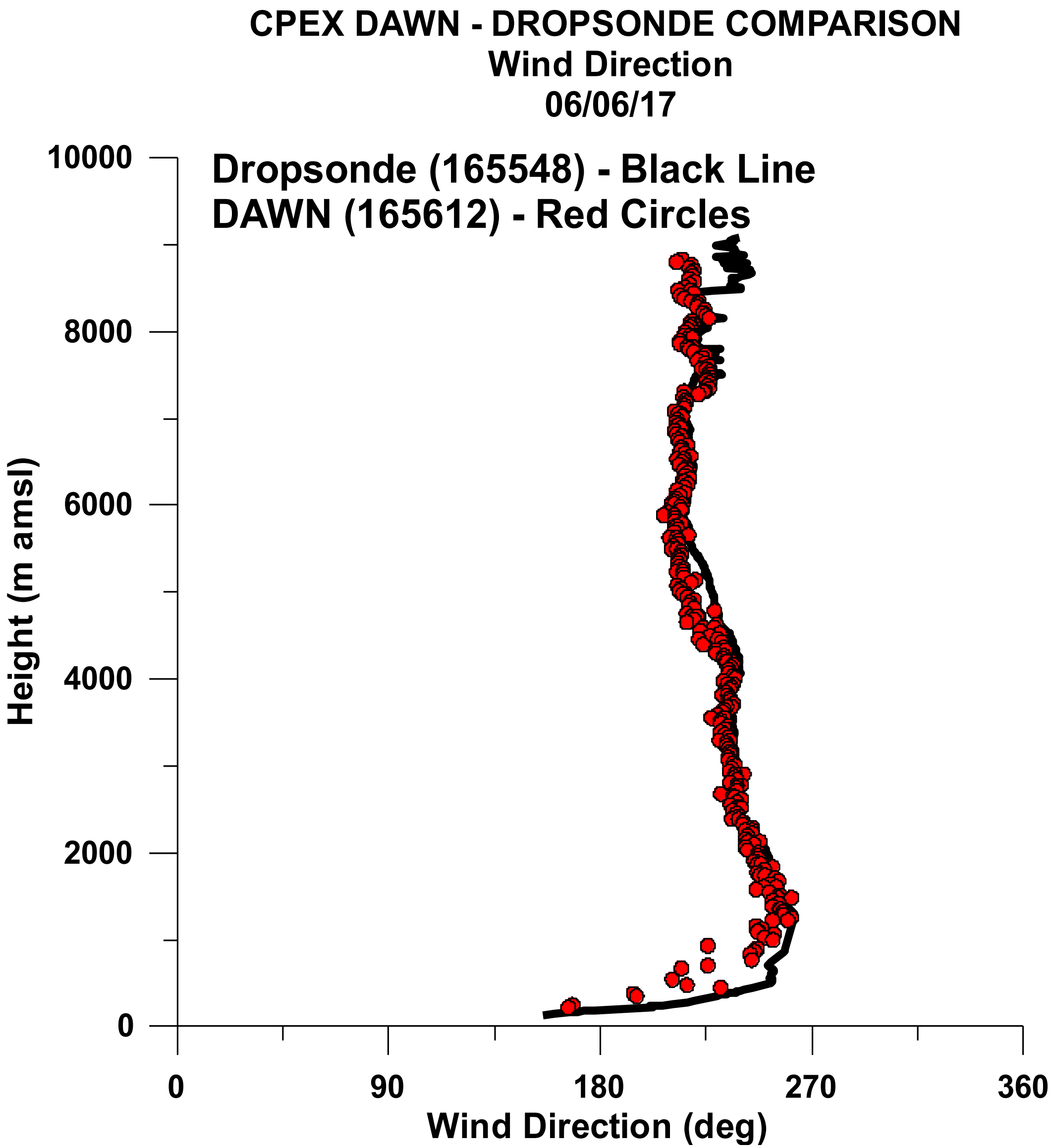


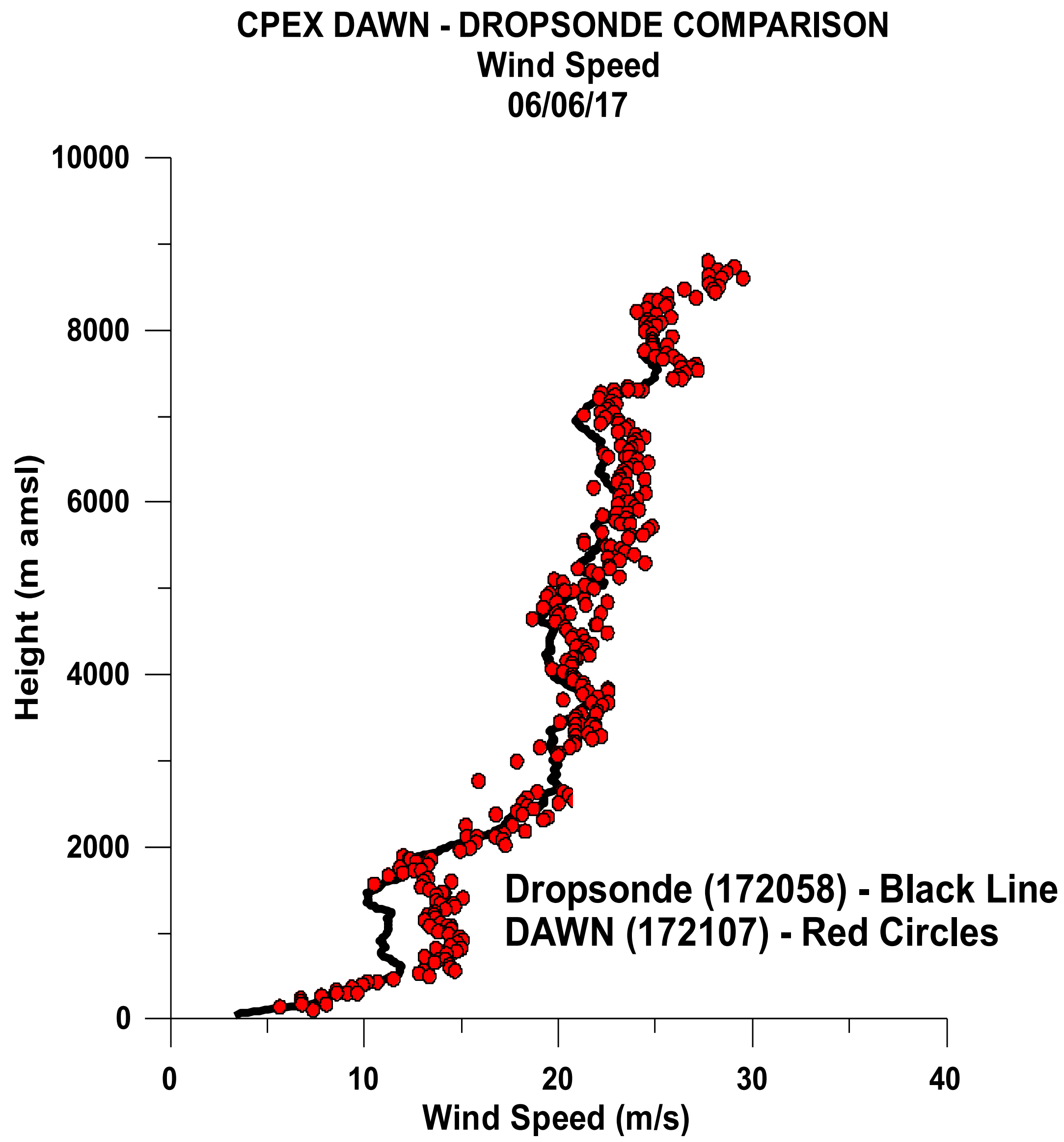
CPEX DAWN - DROPSONDE COMPARISON
Wind Speed
06/06/17
Height (m amsl)
Wind Speed (m/s)
0
2000
4000
6000
8000
10000
0
10
20
30
40
Dropsonde (155222) - Black Line
DAWN (155304) - Red Circles

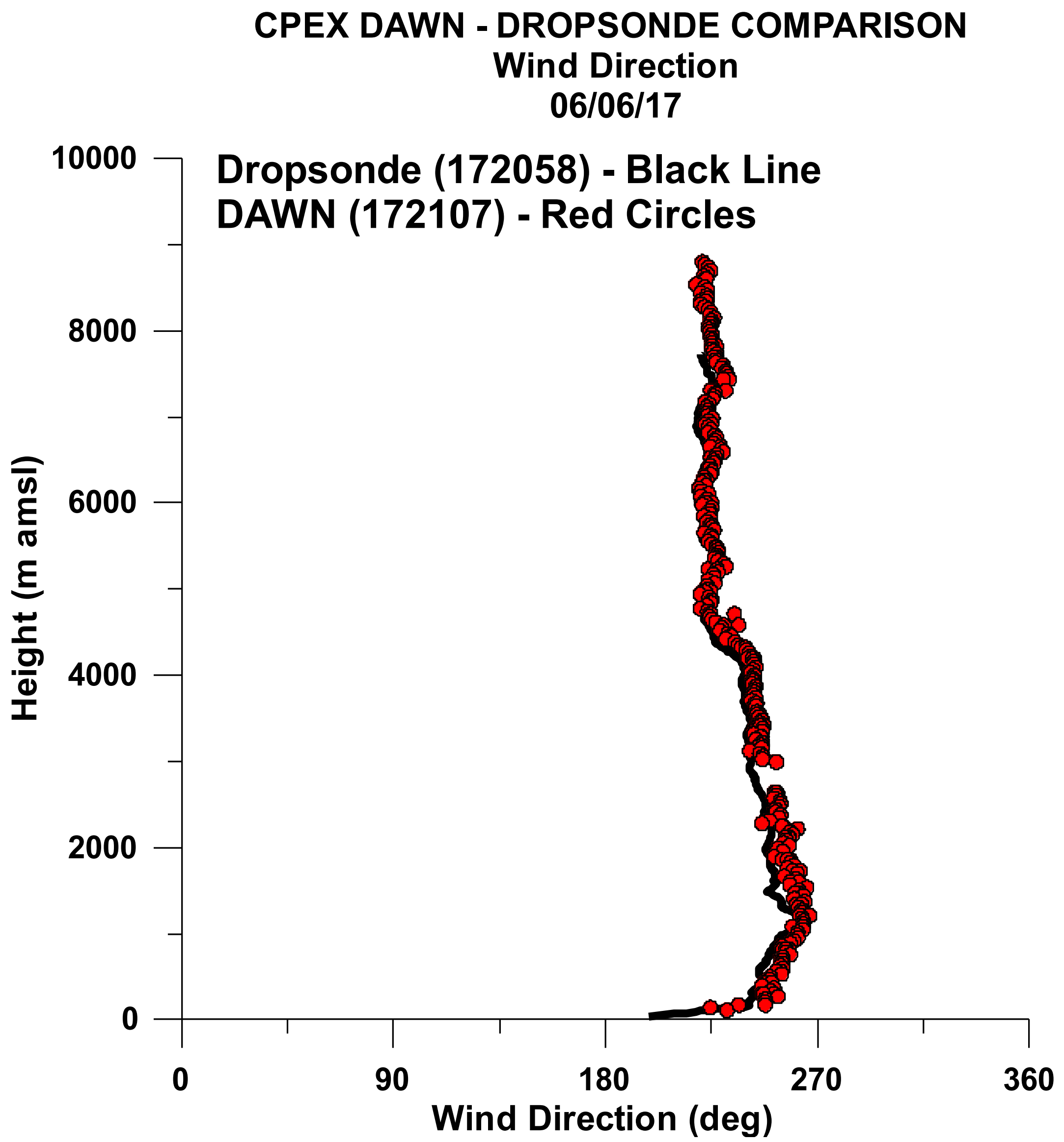


CPEX DAWN - DROPSONDE COMPARISON
Wind Direction
06/06/17
Height (m amsl)
Wind Direction (deg)
0
2000
4000
6000
8000
10000
0
90
180
270
360
Dropsonde (155222) - Black Line
DAWN (155304) - Red Circles


CPEX DAWN - DROPSONDE COMPARISON
Wind Speed
06/06/17
Height (m amsl)
10000
8000
6000
4000
2000
0
0
10
20
30
40
Wind Speed (m/s)
Dropsonde (165548) - Black Line
DAWN (165612) - Red Circles


CPEX DAWN - DROPSONDE COMPARISON
Wind Direction
06/06/17
Dropsonde (165548) - Black Line
DAWN (165612) - Red Circles
Height (m amsl)
10000
8000
6000
4000
2000
0
0
90
180
270
360
Wind Direction (deg)

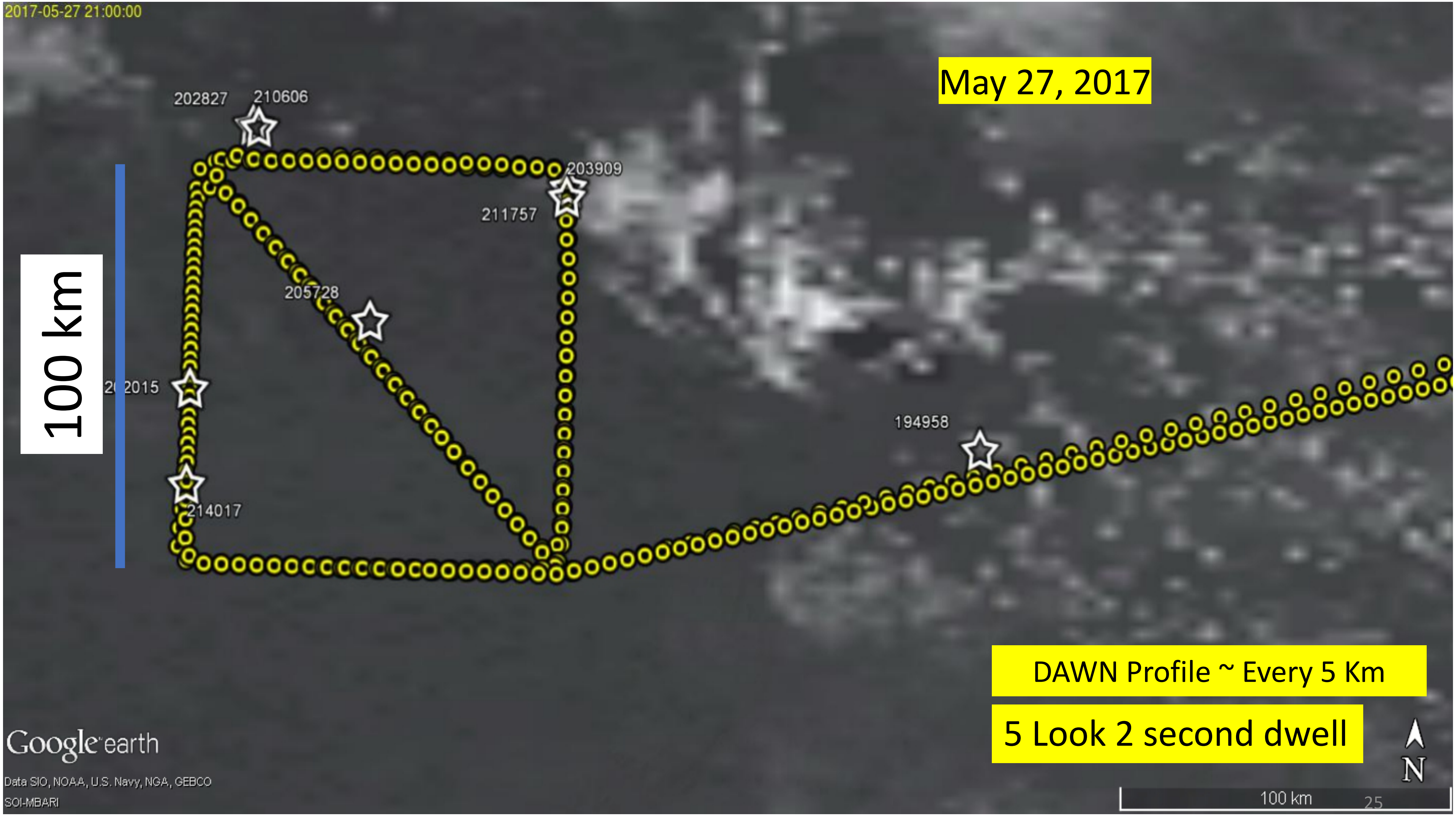

CPEX DAWN - DROPSONDE COMPARISON
Wind Speed
06/06/17
Height (m amsl)
0
2000
4000
6000
8000
10000
0
10
20
30
40
Wind Speed (m/s)
Dropsonde (172058) - Black Line
DAWN (172107) - Red Circles


CPEX DAWN - DROPSONDE COMPARISON
Wind Direction
06/06/17
Dropsonde (172058) - Black Line
DAWN (172107) - Red Circles
Height (m amsl)
0
2000
4000
6000
8000
10000
0
90
180
270
360
Wind Direction (deg)

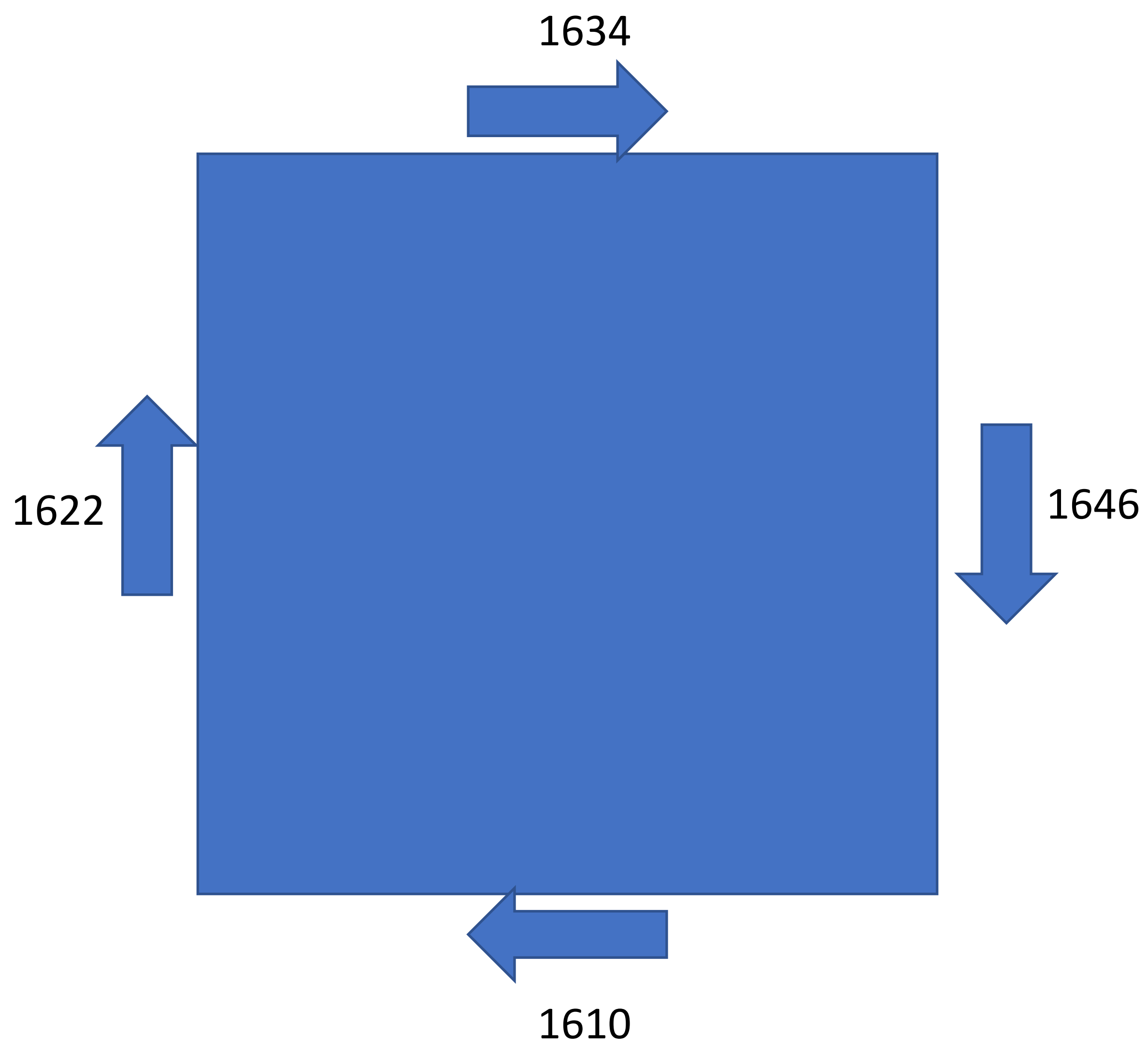
CPEX Mass Budget Science

- Objective
  - Compute mass budgets and divergence for 100 km x 100 km x 6-10 km volumes containing various degrees of cloud coverage to help us describe the dynamics of the atmosphere over the tropical ocean
- CPEX Boxes
  - **Over 20 ~ 100 km x 100 km boxes were flown during CPEX 2017 which included:**

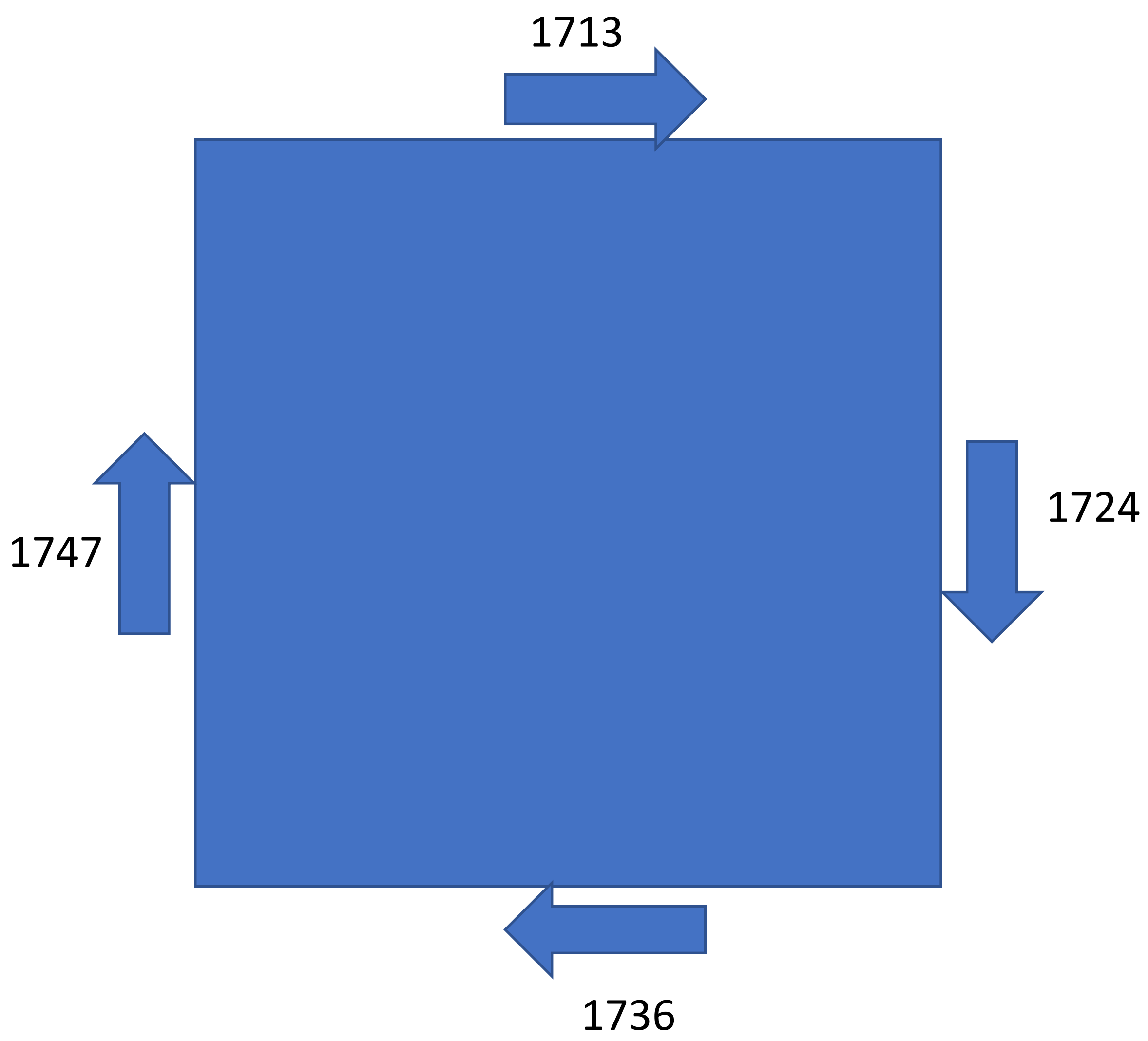
    1) Undisturbed conditions
    2) Disorganized or scattered/broken convection
    3) Decaying convection
    4) Organized (line/area) convective system


2017-05-27 21:00:00
May 27, 2017
202827
210606
203909
211757
205728
100 km
194958
214017
DAWN Profile ~ Every 5 Km
5 Look 2 second dwell
Google earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
SOI-MBARI
N
100 km

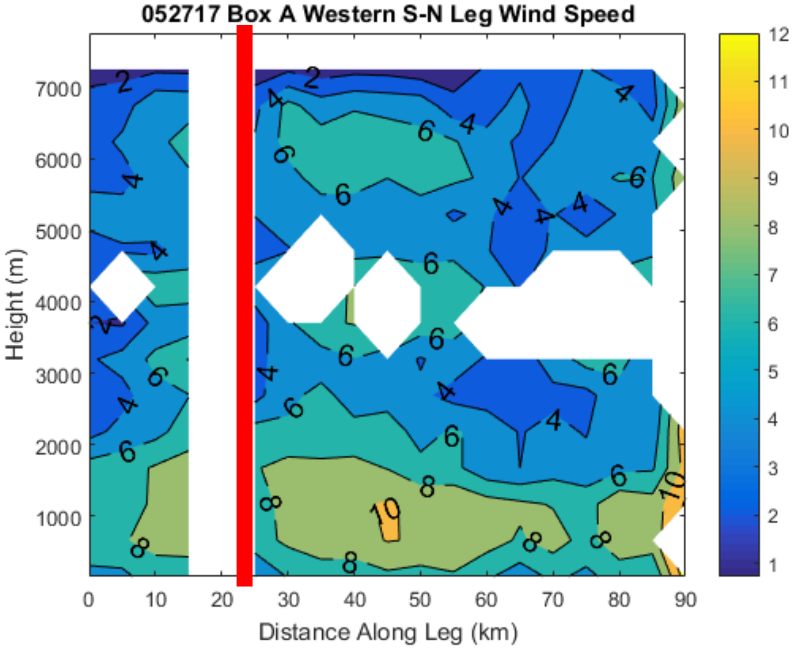
BOX A

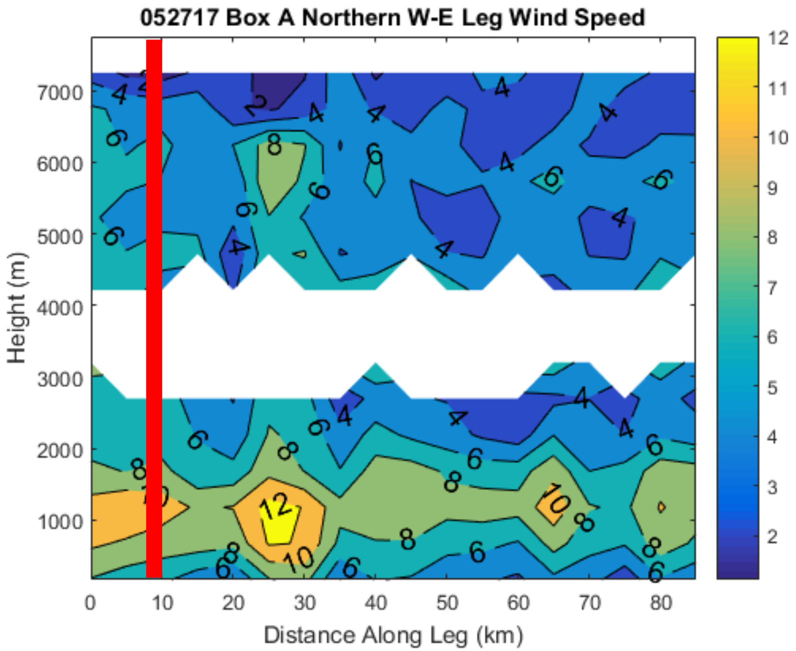


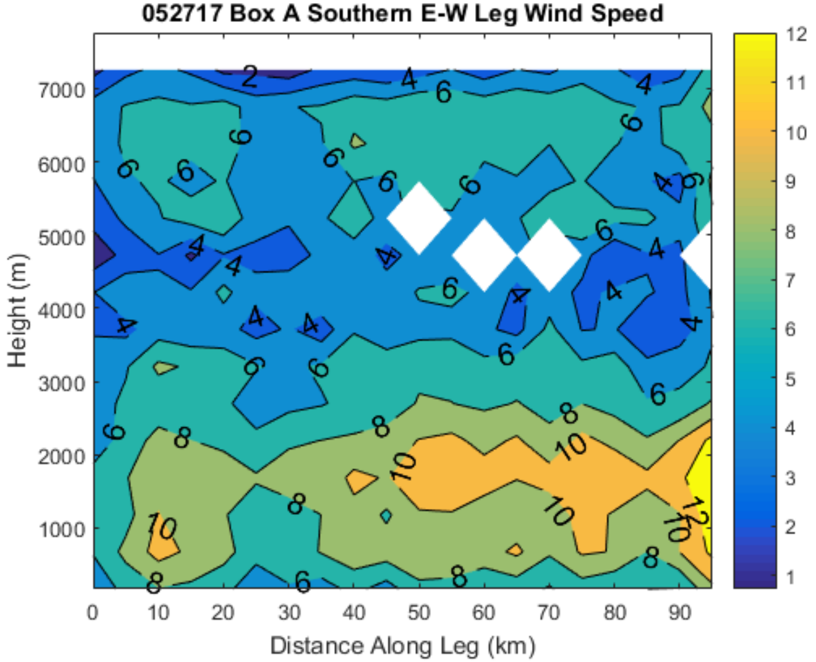
BOX B

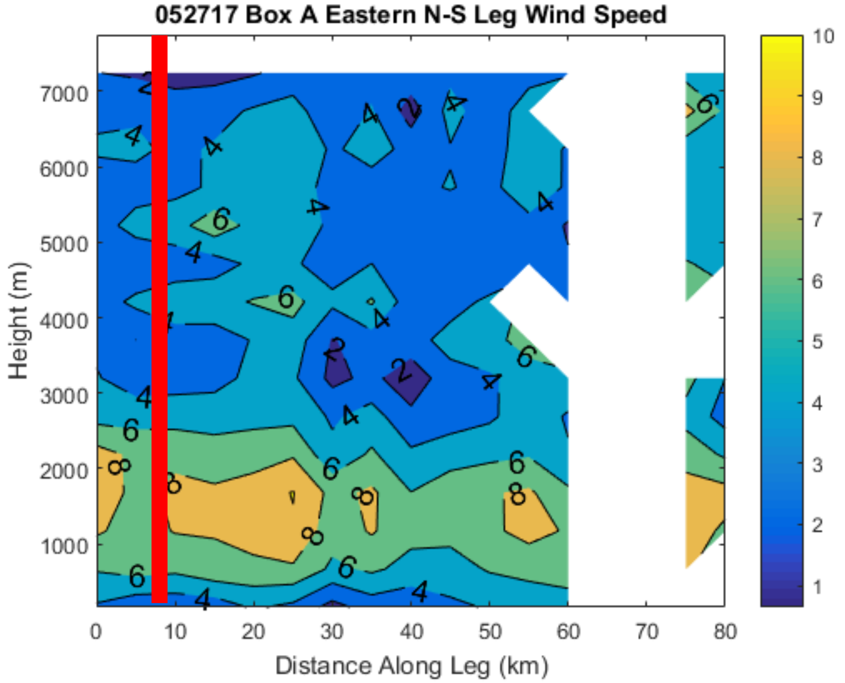


BOX A



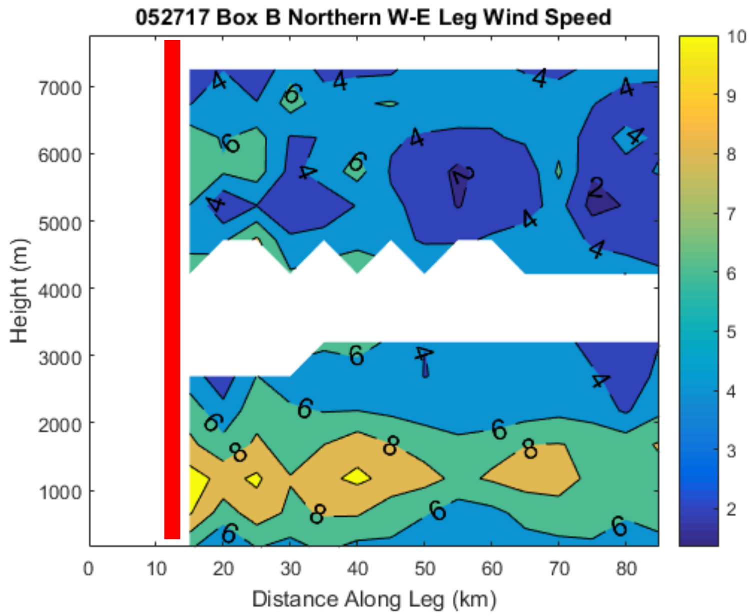


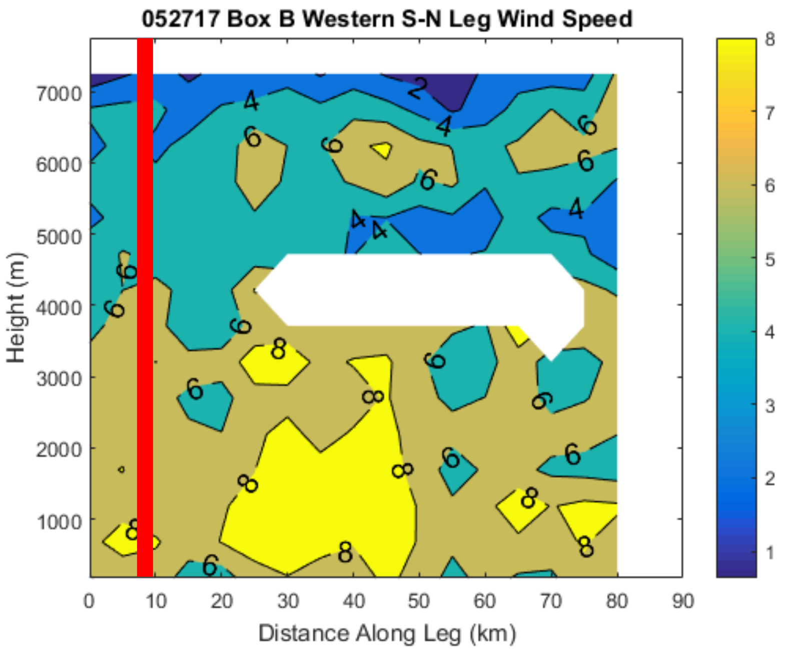


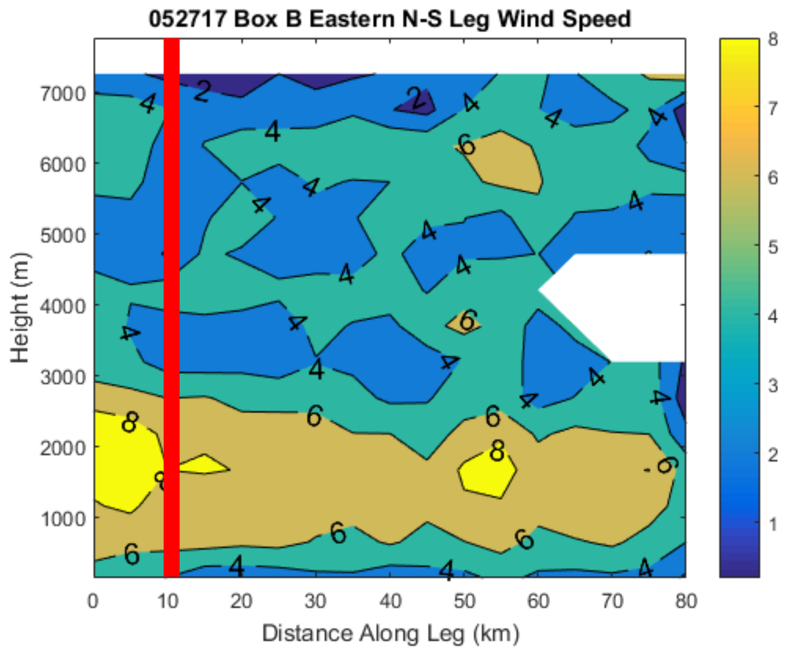


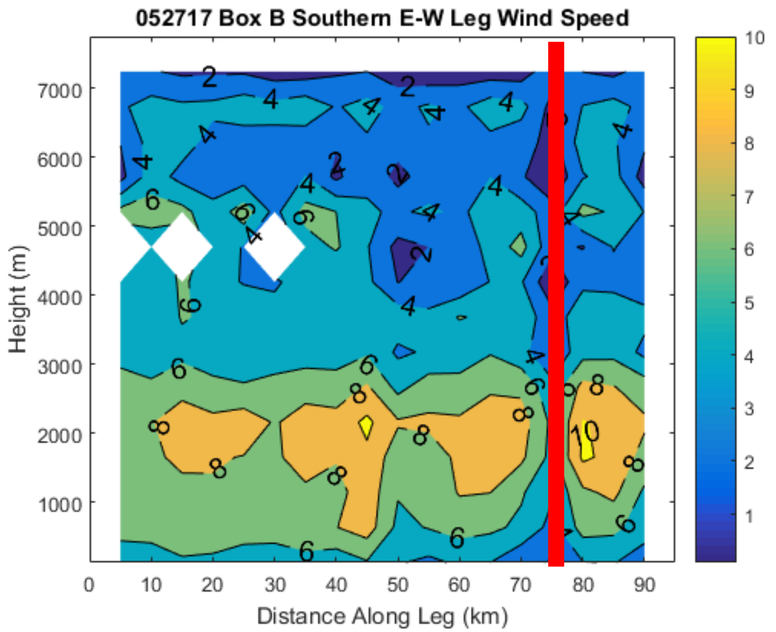
Wind Speed

BOX B



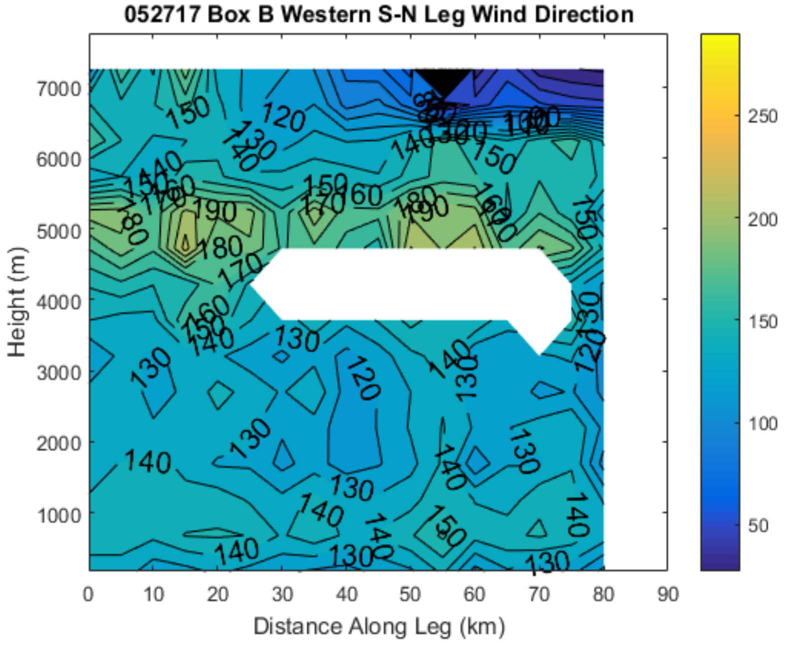


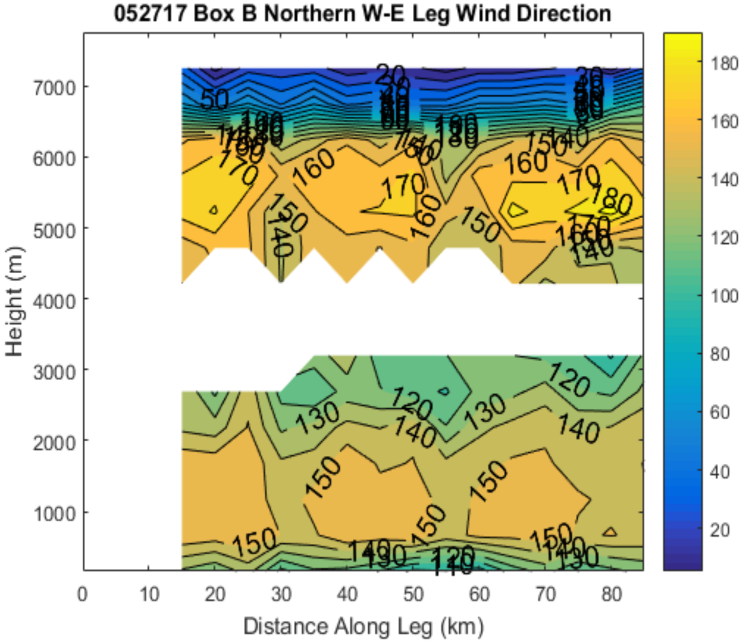


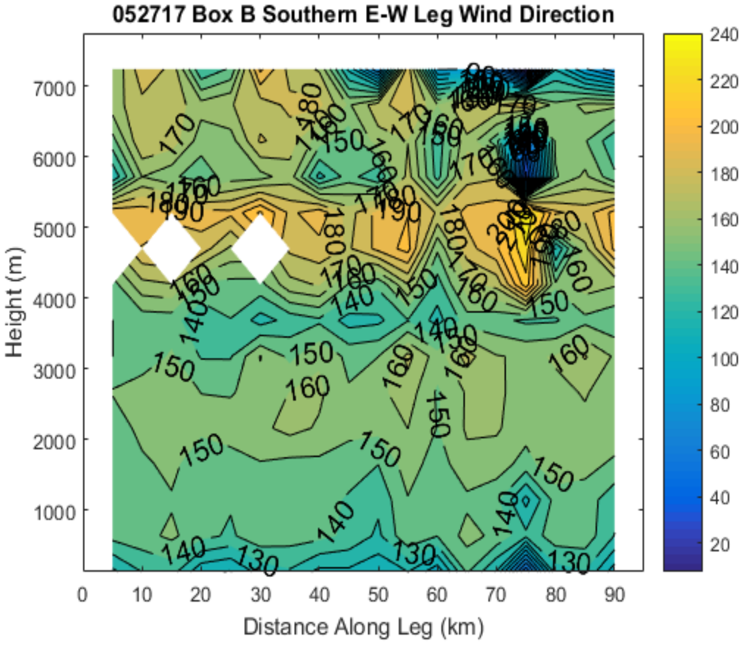


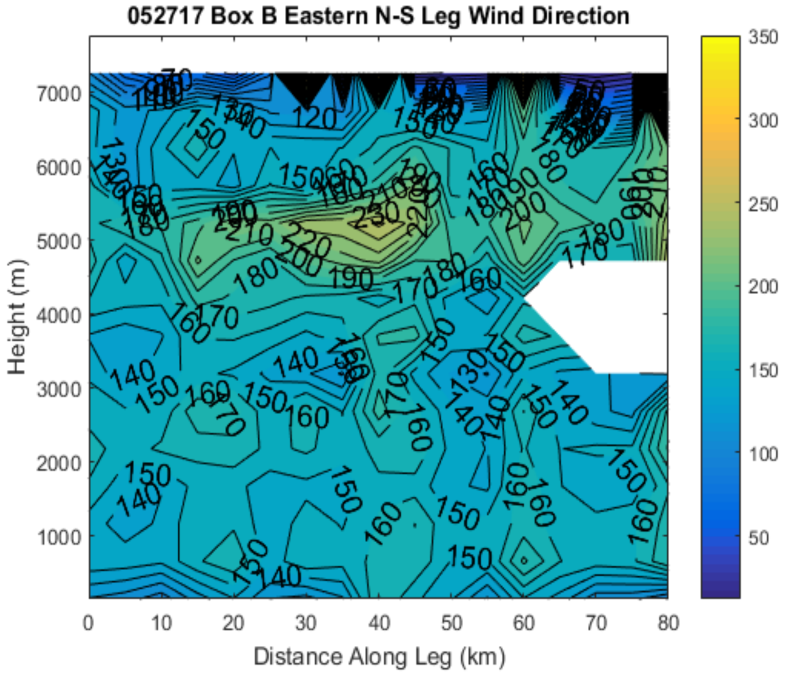
Wind Speed

BOX B

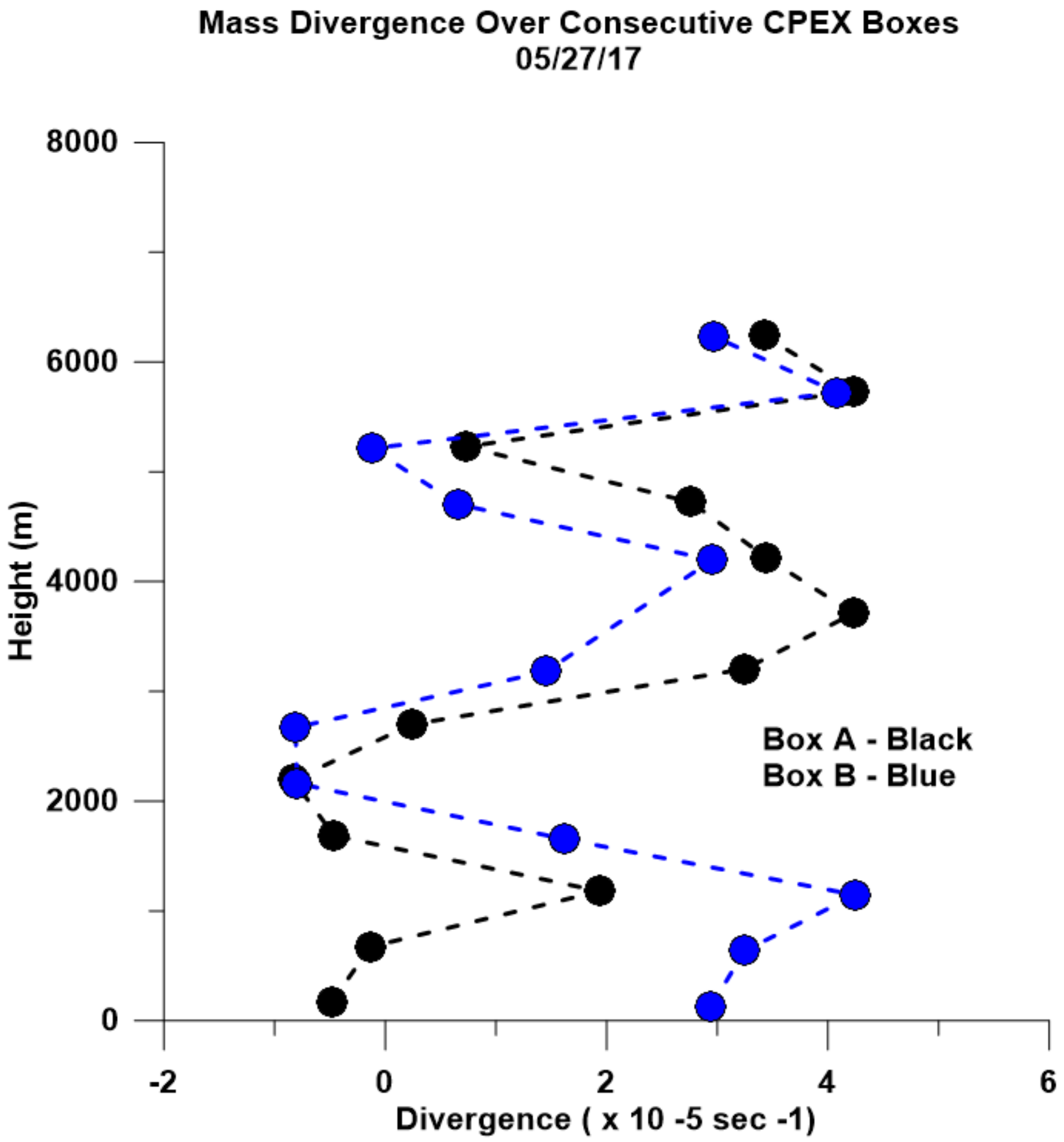


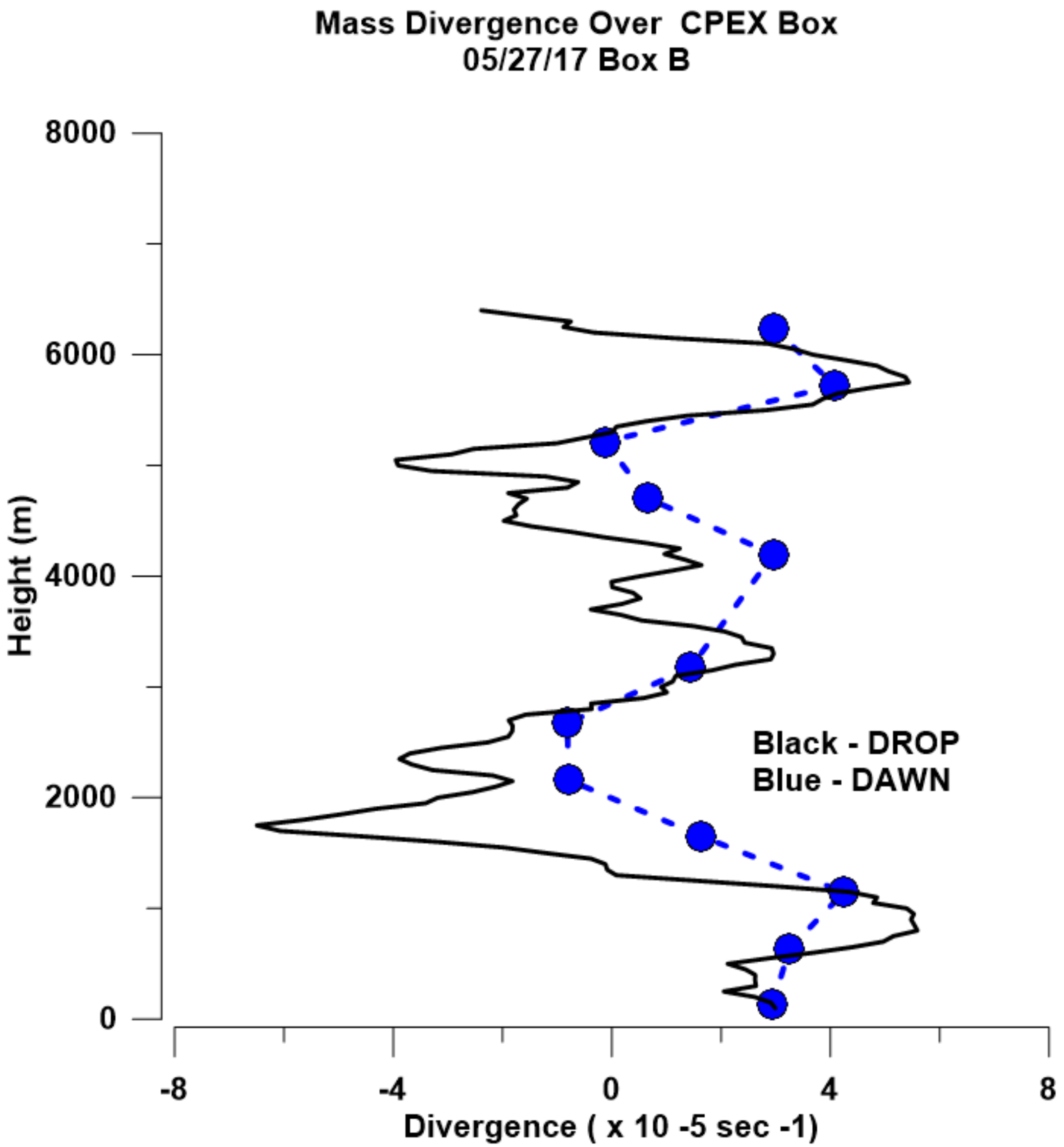






Wind Direction


Mass Divergence Over Consecutive CPEX Boxes
05/27/17
8000
6000
4000
2000
0
Height (m)
-2
0
2
4
6
Divergence (x 10 -5 sec -1)
Box A - Black
Box B - Blue


Mass Divergence Over CPEX Box
05/27/17 Box B
8000
6000
4000
2000
0
Height (m)
-8
-4
0
4
8
Divergence (x 10 -5 sec -1)
Black - DROP
Blue - DAWN

Space-based perspective

WIND-SP (Space Pathfinder)

- Instrument and preliminary mission design funded by NASA through LaRC
- DWL pathfinder concept is a follow-on to White Papers submitted to National Academy of Sciences in 2017 by LaRC and SWA.
- Focus upon atmospheric boundary layer is consistent with National Academy of Sciences Boundary Layer Workshop (10/17) and the Decadal Survey recommendations. Mid and upper troposphere still well represented with a WIND-SP pathfinder mission.
- Mission is being designed to explore various sampling strategies suitable for NASA's lower tropospheric atmospheric processes research (see recent Decadal Survey report) and follow-on operational NWP **in the presence of clouds (>80% of lidar shots have cloud returns globally)**.

Integrating a Doppler Wind Lidar into a network of wind observing systems: capitalizing on synergisms with a high precision, cloud scene penetrating lidar.

Dr. G. D. Emmitt (Simpson Weather Associates), Dr. T. N. Krishnamurti (Florida State University), Dr. M. J. Kavaya and Dr. U. N. Singh (NASA/LaRC)

Executive Summary

……we argue for an initial pathfinder/survey mission that **recognizes the preponderance and impact of clouds and favors high precision/representativeness** over global coverage. The suggestions offered here are, in part, a response to NASA's recent recommendation "It is important to avoid all or nothing strategies for the three dimensional wind vector measurements, as important progress is possible with less than comprehensive observing strategies."

This white paper from NASA LaRC is guided, in part, by decades of discussions/deliberations within the NASA/NOAA funded Working Group on Space-based Lidar Winds and the following three assertions: a) **No single technology** is likely to deliver, at a reasonable cost, full tropospheric/lower stratospheric wind profiles at the horizontal/vertical coverage and precision desired by the communities associated with the Earth System Science Themes; b) **Capitalization on synergisms** between a DWL and existing or promising future wind observing systems is key to optimizing the Nation's investment in enhancing the collection of global wind data for both the research and operational communities; c) It is highly desirable to seek international and/or private sector **partnerships** to achieve the most cost effective DWL space missions. ……

General PBL relevant attributes of the WIND-SP instrument for an ISS or free flyer mission concept

- High aerosol backscatter threshold sensitivity (Beta50% ~ 2.0 E-9 m/sr)
- High “inherent” single shot LOS velocity precision (~ 1-2m/s)
- Very low bias in velocity measurements (<<.5m/s)
- Direct measure of turbulence within illuminated volume
- High vertical potential resolution (~50m) in PBL and clouds
- High horizontal sampling interval (~35m) from ocean/land and clouds.
- Coherent DWL technique suitable for probing partly cloudy scenes
- No solar background degradation of signals (equal day/night data quality)
- Well suited to post collection “sliding range gate and adaptive sample integration” to maximize science data product utility in high gradient cases
- Spectral based frequency estimation in software provides inherent high photon/electrical efficiency and derivation of other spectral moments

Science experiments for space-based coherent DWL

- Potential set of science experiments/objectives
  - Investigate inter-hemispherical transports via LLJs and within tropical convergence zones (ITCZ); How prevalent and energetic are LLJs over the oceans?
  - Develop improved parameterization schemes for PBL depths and growth rates for use in global weather and climate models…especially marine BLs.
  - Investigate the role of vertical shear of the horizontal wind in regions of deep convection and in tropical cyclone maintenance and suppression.
  - Investigate dynamic impacts such as speed and directional shear on the global trans-oceanic transport of pollution.

PBL science data products

- Primary data products
  - Vertical profiles of the horizontal wind vector (surface reflectance, clouds and aerosols permitting)
  - Vertical profiles of the turbulence and variability of the winds within reference sampling volumes (derived from 12 and 1.4 second integrations)
  - LOS wind components for use in 3 and 4DVAR data assimilations for NWP
  - SNR as a function of range and height used to suggest PBL height
- Secondary data products
  - Derived aerosol attenuated backscatter
  - 10m wind estimates using power and log models
  - Surface reflectance “climatology” for 2um
  - Cloud backscatter and shot scale structures (compare to CALIPSO, LITE, CATS, AEOLUS, GLAS)

Summary

- Coherent detection DWL is ideal for PBL investigations from both airborne and space-based platforms
- Processing of coherent DWL data is done in the spectral domain and thus:
  - High “inherent” single shot LOS velocity precision (~ 1-2m/s)(backscatter permitting)
  - Very low bias in velocity measurements (<<.5m/s)
  - Direct measure of turbulence within illuminated volume
  - High vertical potential resolution (~50m) in BL and clouds (adjustable after downlink)
  - High horizontal sampling interval (~.1- 35m) from ocean/land and clouds.
  - DWL technique well suited for probing partly cloudy scenes
  - No solar background degradation of signals (equal day/night data quality)