Wind Profiling with the Airborne Doppler Aerosol Wind Lidar During the 2022 Convective Processes Experiment

John W. Cooney[1], Kristopher M. Bedka[2], John Marketon[1], Zhaoyan Liu[1], Dave Emmitt[2], Steve Greco[2], Michael Kavaya[1], Sharon Rodier[3], Amin Nehrir[1], and the LaRC DAWN Engineering Team

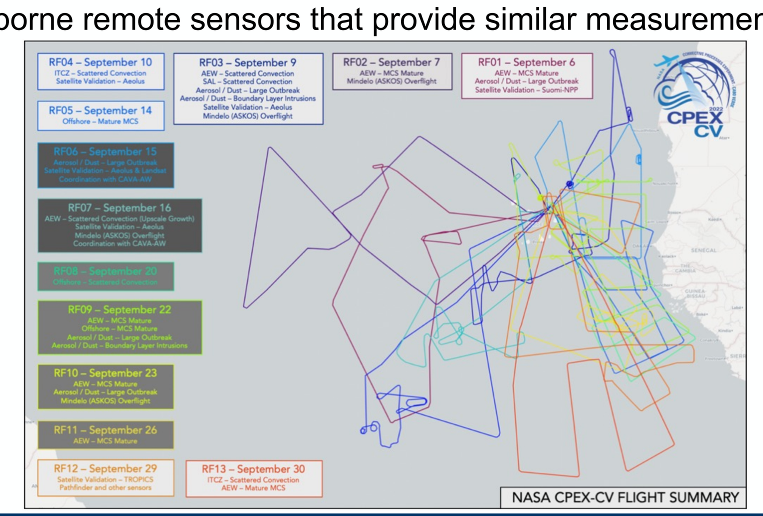
[1]NASA Langley Research Center, [2]Simpson Weather Associates, [3]Analytical Mechanics Associates

Introduction and Objective

NASA Langley Research Center (LaRC) started development of the airborne Doppler Aerosol WiNd (DAWN) lidar system in the late 2000's. DAWN has since flown in 8 NASA flight campaigns, measuring vertical profiles of aerosol backscatter intensity, line of sight (LOS) wind speed, and vector wind speed and direction with high spatial/vertical resolution and precision. In September 2022, DAWN, along with a suite of other instruments, flew aboard the NASA DC-8 during the Convective Processes EXperiment – Cabo Verde (CPEX-CV) field campaign. The overarching CPEX-CV goal was to investigate atmospheric dynamics, marine boundary layer properties, convection, the dust-laden Saharan Air Layer, and their interactions across various spatial scales to improve understanding and predictability of process-level lifecycles in the data-sparse tropical East Atlantic region.

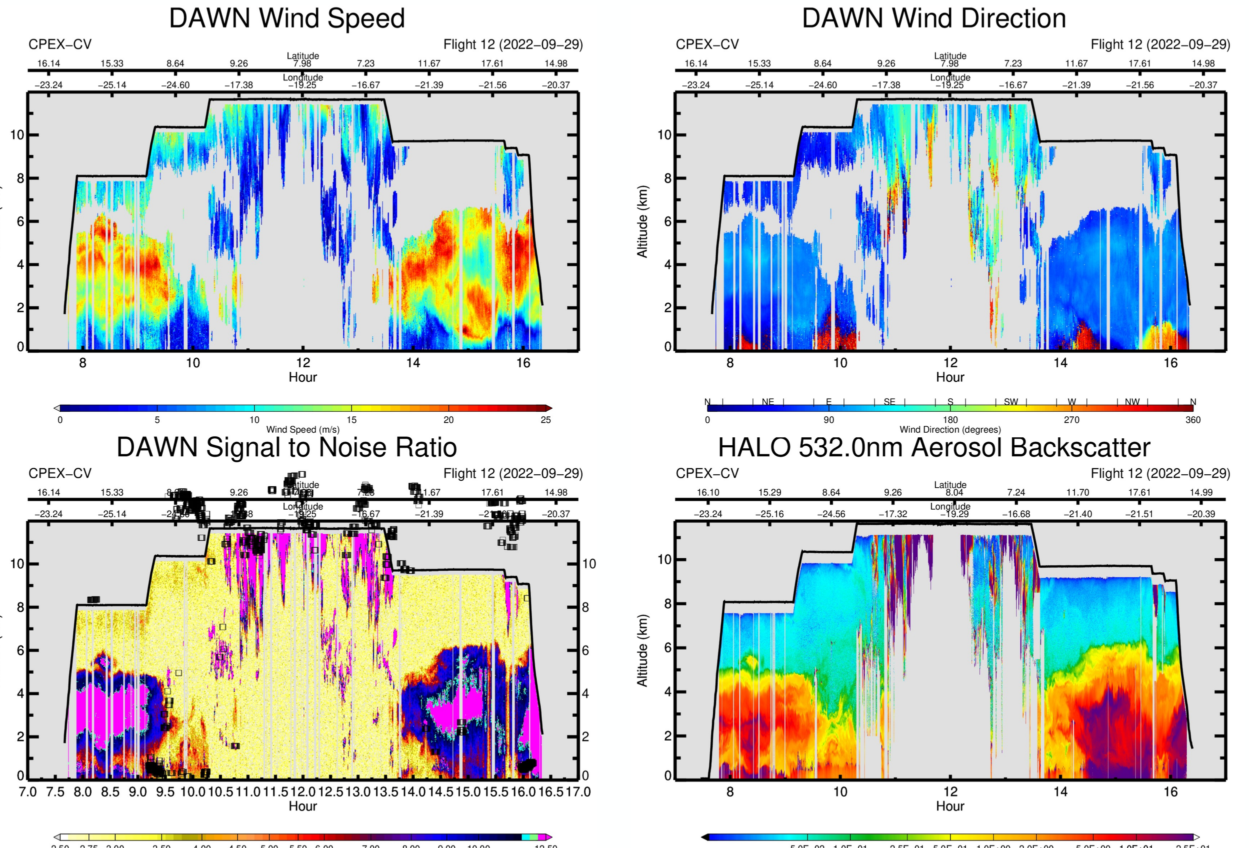
Specific CPEX-CV science goals include:

1. Improve understanding of the interactions between large-scale environmental forcings (e.g., African easterly waves, ITCZ, Saharan Air Layer, mid-level African easterly jet) and the lifecycle and properties of convective cloud systems, including tropical cyclone precursors, in the tropical East Atlantic region.
2. Observe how local kinematic (wind) and thermodynamic conditions, including the vertical structure and variability of the marine boundary layer, relate to the initiation and lifecycle of convective cloud systems and their processes (e.g., cold pools).
3. Investigate how dynamical and convective processes affect size dependent Saharan dust vertical structure, long-range Saharan dust transport, and boundary layer exchange pathways.
4. Assess the impact of CPEX-CV observations of atmospheric winds, thermodynamics, clouds, and aerosols on prediction of tropical Atlantic weather systems, and validate and interpret spaceborne remote sensors that provide similar measurements.



DAWN Instrument Summary

DAWN is a coherent-detection Doppler wind lidar that generates pulses at 10 Hz with 80-100 mJ energy at ~2 um wavelength. The backscatter return from aerosols is measured to derive Doppler shift relative to the transmitted pulse frequency. Pulses are sent through a wedge scanner that redirects them 30° off nadir into the atmosphere. The wedge rotates across a selected number of LOS, usually 2 or 5, in angles ranging from +/- 45° in azimuth from the aircraft heading. LOS wind speed data from multiple LOS are combined to derive a wind vector. Typical DAWN operation was 5 LOS x 20 pulses/LOS, yielding 4-5 km spacing between profiles. DAWN profile data were sampled to a 30 m vertical resolution. Vertical integration up to 1 km depth to derive winds with weak aerosol returns.

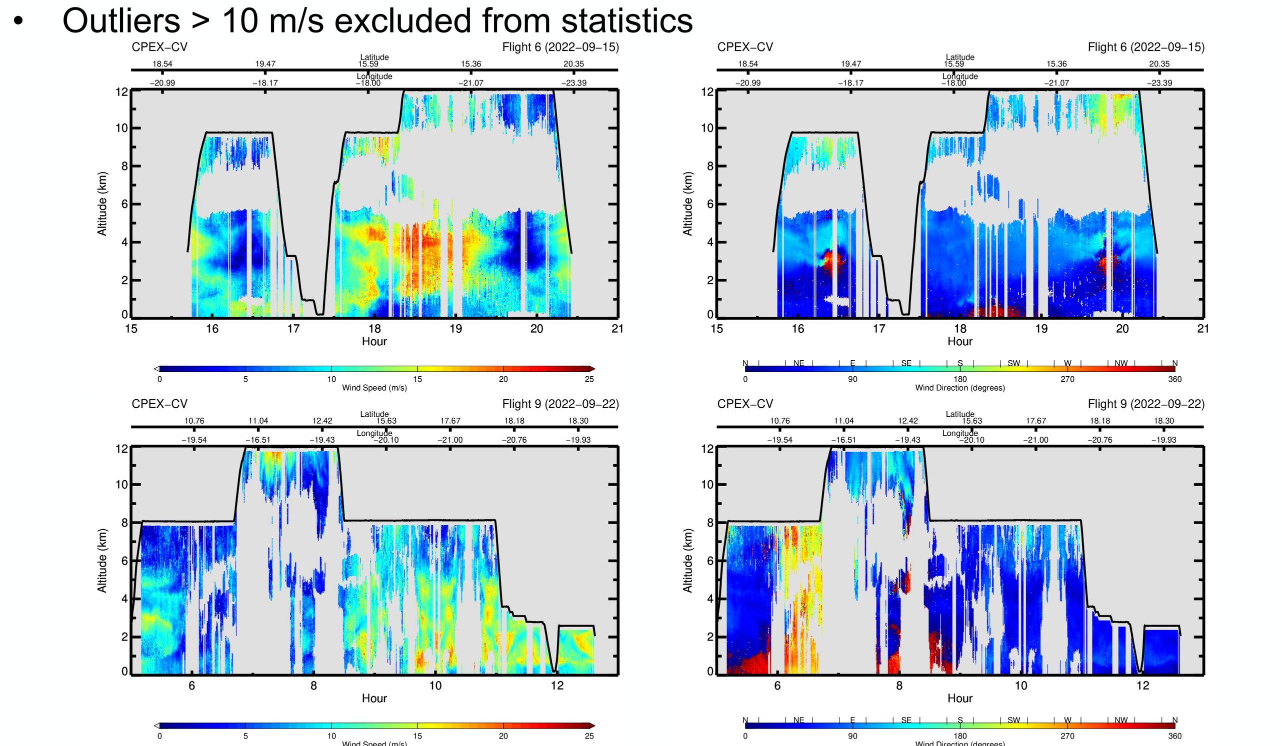


Example DAWN products showing wind speed/direction, signal-to-noise ratio, and High Altitude Lidar Observatory (HALO) 532 nm aerosol backscatter for the 12th CPEX-CV flight. Square boxes on SNR plot show GOES AMVs.

Data and Methods

DAWN quality-controlled U/V-component winds across 13 flights

- Vector Wind Difference = $\sqrt{(u_{wind} - u_{DAWN})^2 + (v_{wind} - v_{DAWN})^2}$
- Outliers > 10 m/s excluded from statistics



DAWN wind speed (left) and wind direction (right) curtain plot for the 6th and 9th CPEX-CV flight.

AVAPS RD-41 dropsondes, used to validate DAWN profiles within ± 2.5 mins of sonde release

- DAWN profiles were co-located with 347 dropsondes and 32,117 vertical levels during CPEX-CV

GOES-16 atmospheric motion vectors derived from infrared (IR), water vapor (WV), visible (VIS), and shortwave IR (SWIR) channels

EUMETSAT METOP Advanced Scatterometer (ASCAT) ocean surface wind speed and direction within ± 1 hour from DAWN profile

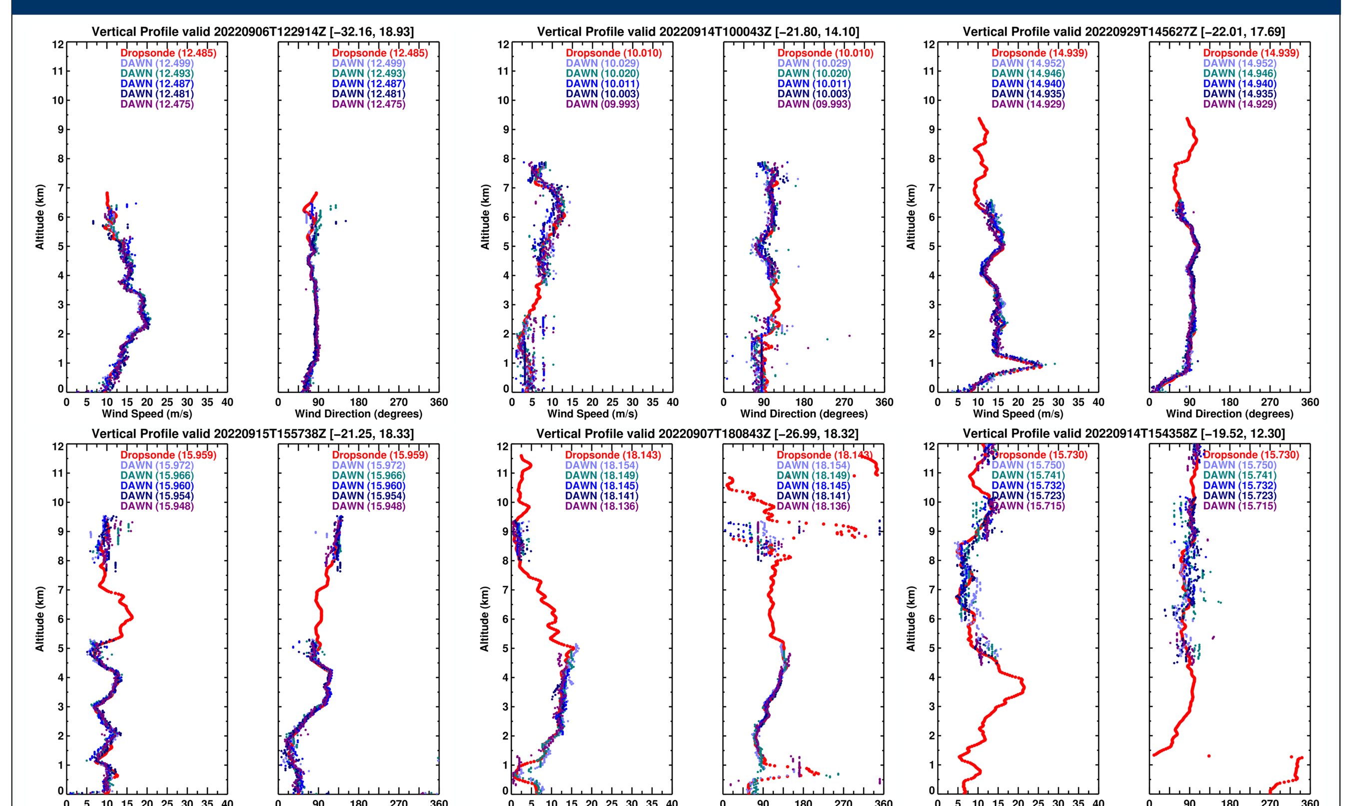
NOAA GFS and NASA GMAO GEOS-5 wind initial analyses, and GMAO MERRA-2 reanalysis, interpolated in time to DAWN profiles

- DAWN data are averaged to model grids for comparison

GFS and GEOS-5 wind forecasts

- GFS forecast times (120, 72, 48, 24, and 12 hours) are interpolated to DAWN profiles. DAWN profiles are averaged to the GFS grid
- GEOS-5 forecast times (132, 72, 48, 24, and 12 hours) provided by Peter Colarco

DAWN Validation With AVAPS Dropsondes

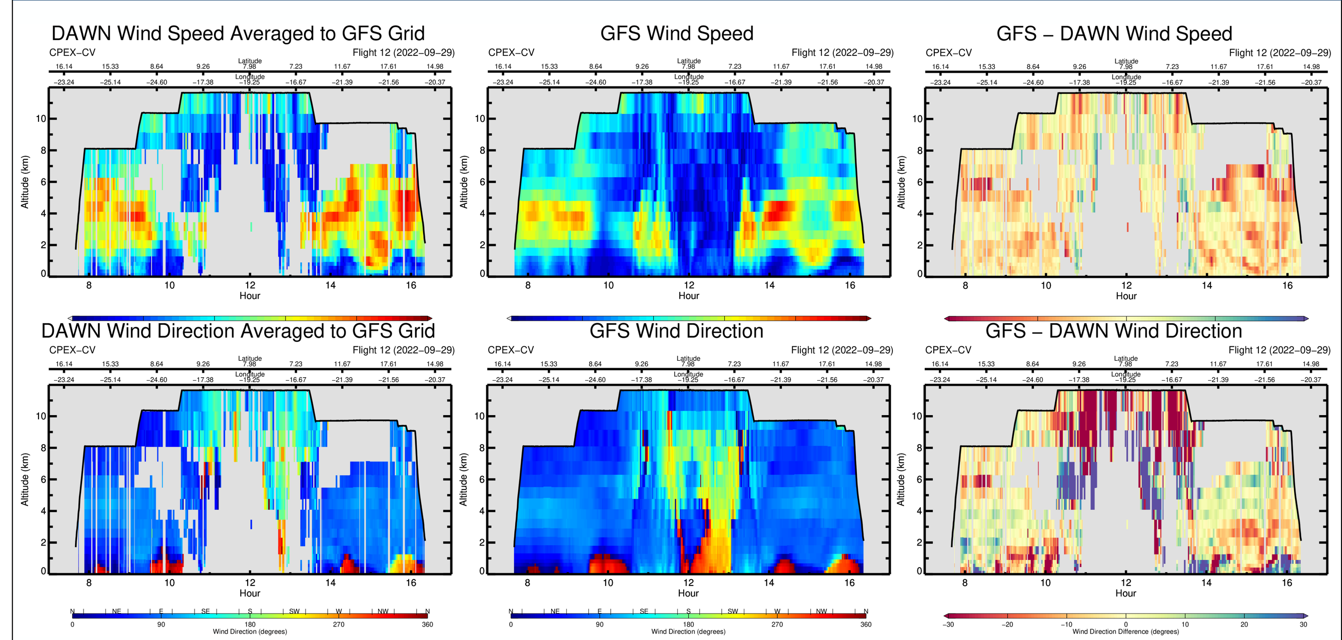


Six examples of DAWN and dropsonde vertical profiles for wind speed and direction during CPEX-CV. The 5 nearest DAWN profiles (colored dots) per sonde (red) are shown.

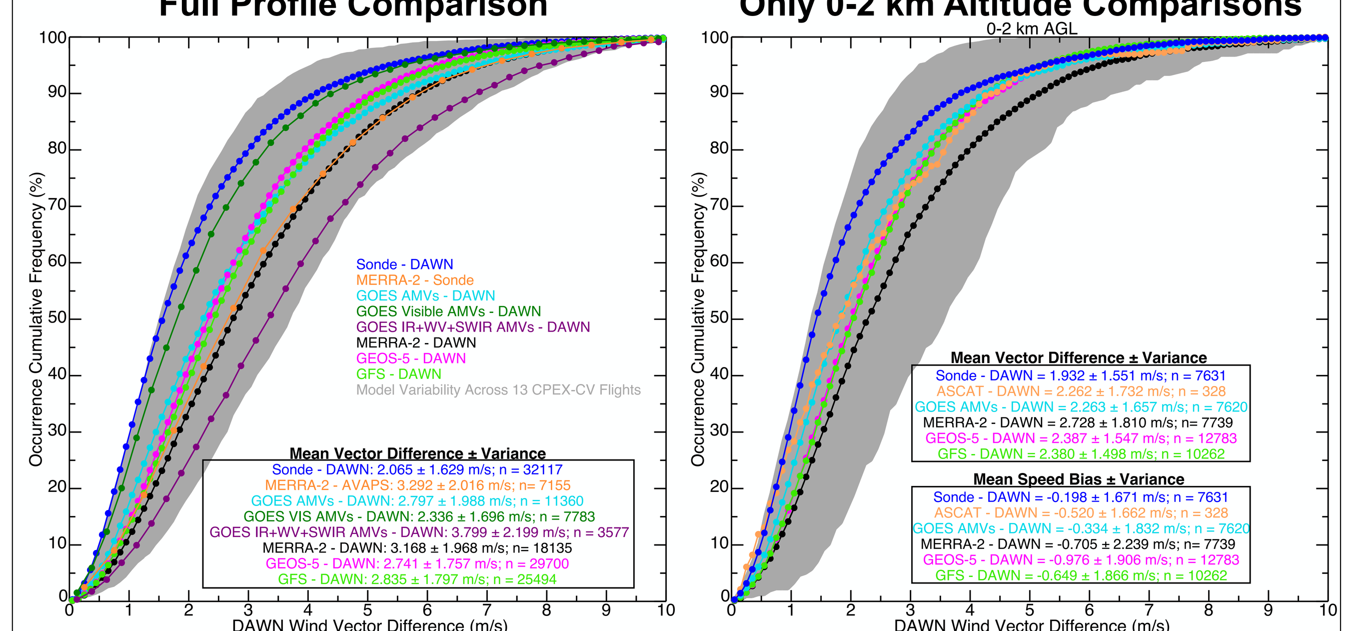
	0-5 m/s (N=8310)	5-10 m/s (N=13244)	10-15 m/s (N=7302)	15-20 m/s (N=3026)	20+ m/s (N=235)	All (N=32117)
Speed (m/s)	-0.78 ± 1.70	-0.08 ± 1.78	0.02 ± 1.79	0.05 ± 1.43	0.49 ± 1.35	-0.22 ± 1.79
Direction (°)	1.64 ± 43.99	0.03 ± 19.48	-0.62 ± 8.97	-0.46 ± 4.71	0.62 ± 4.02	0.26 ± 26.04

Wind retrieval precision generally improved as wind speeds increased. DAWN compared favorably with dropsondes with a bias < 0.25 m/s and RMS < 1.8 m/s

Validating NASA and NOAA Models and Satellite Winds



Comparisons between DAWN and NOAA NCEP GFS model data along DC-8 flight track for the 12th CPEX-CV flight.



Wind lidar observations from CPEX-CV as a validation reference to quantify wind analyses and satellite observation uncertainty throughout the full column beneath the aircraft, and within the 0-2 km AGL layer.

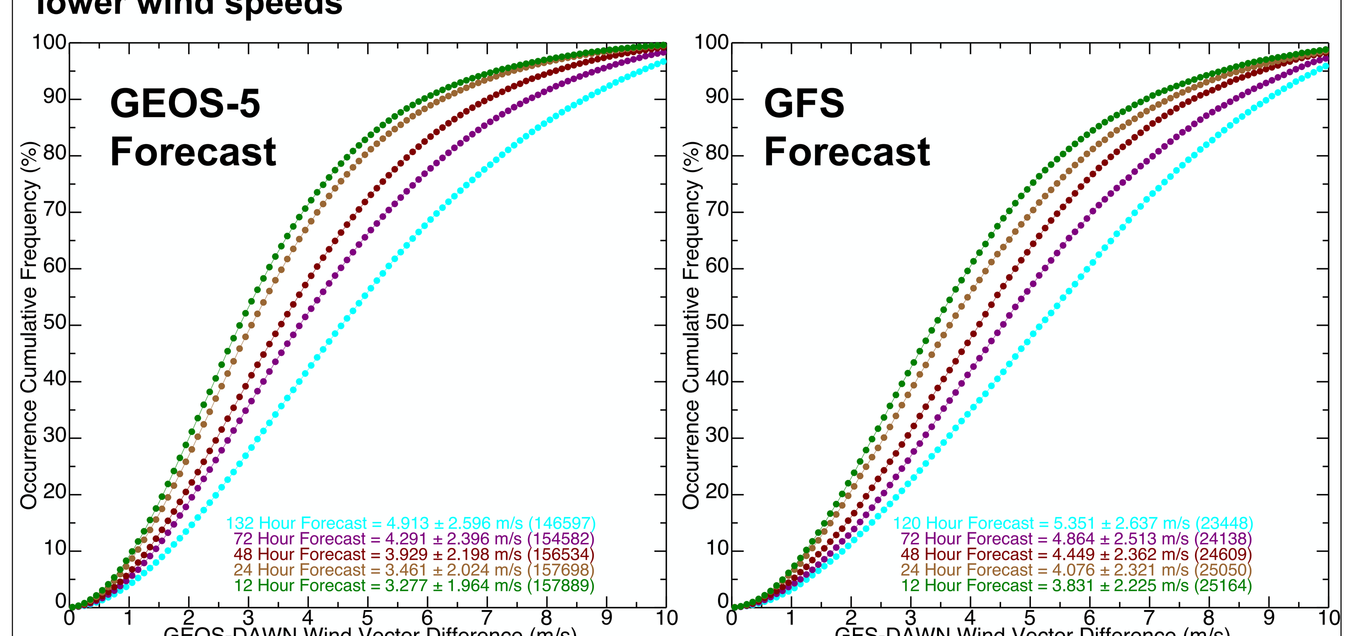
Given the good agreement between DAWN and dropsondes, DAWN is considered a worthy reference dataset

The 3 NASA and NOAA models agreed quite well with DAWN with mean vector differences between 2.7 and 3.2 m/s

Model performance from the worst and best CPEX-CV flights ranged from 3.5-7.2 m/s for 90% of the observations throughout the full profile, and 2.8-6 m/s in the 0-2 km altitude layer

GOES-16 AMVs offer varying precision, with the best wind estimates coming from visible wavelength cloud tracking

Better dataset agreement with DAWN in the 0-2 AGL layer, mostly attributed to lower wind speeds



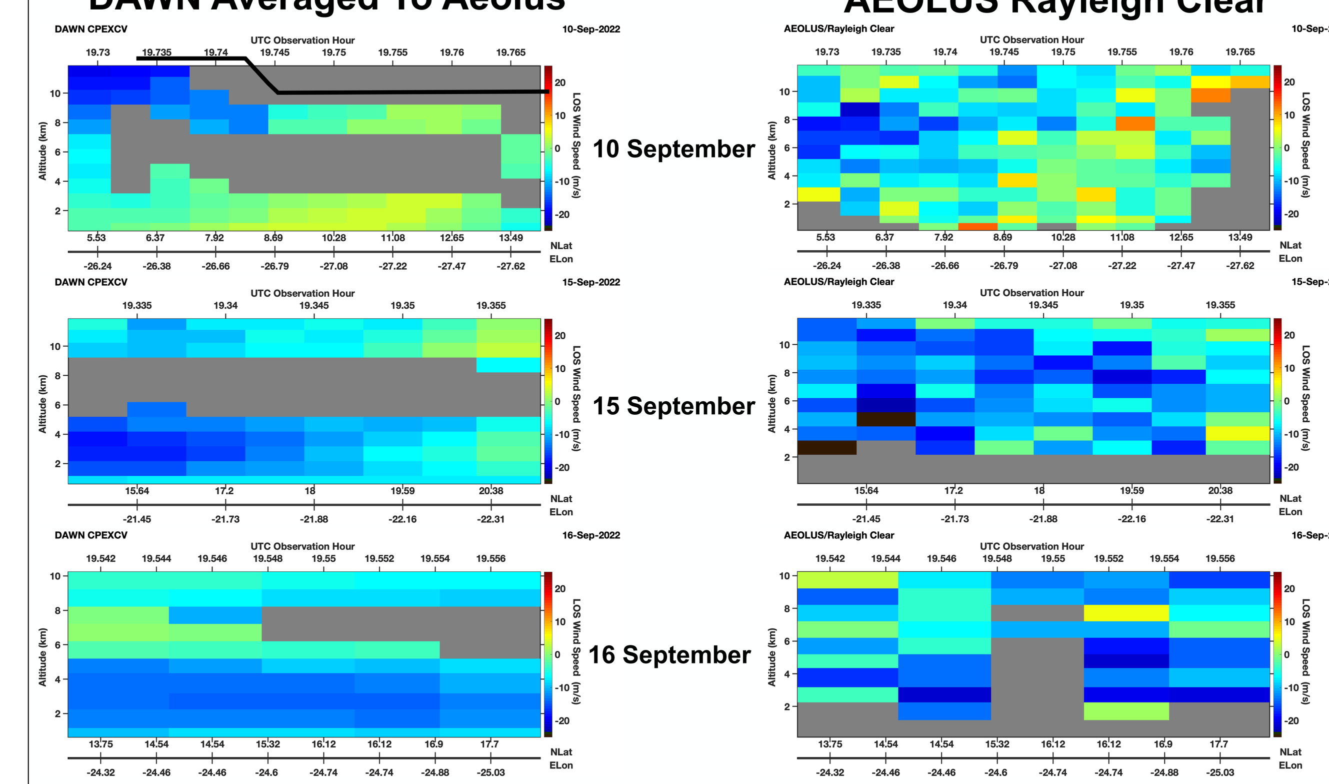
Wind lidar observations from CPEX-CV as a validation reference to quantify GEOS-5 (left) and GFS (right) forecast uncertainty along the 13 CPEX-CV flight tracks.

Both forecast models perform comparably well with GEOS-5 having better accuracy across all forecast hours

Model forecasts generally improved from the largest forecast times to the smallest for each flight

Wind forecast issues were generally due to the timing and location of convection associated with Easterly Waves coming off the coast of Africa

DAWN Comparisons With Aeolus Level 2B Line of Sight Wind



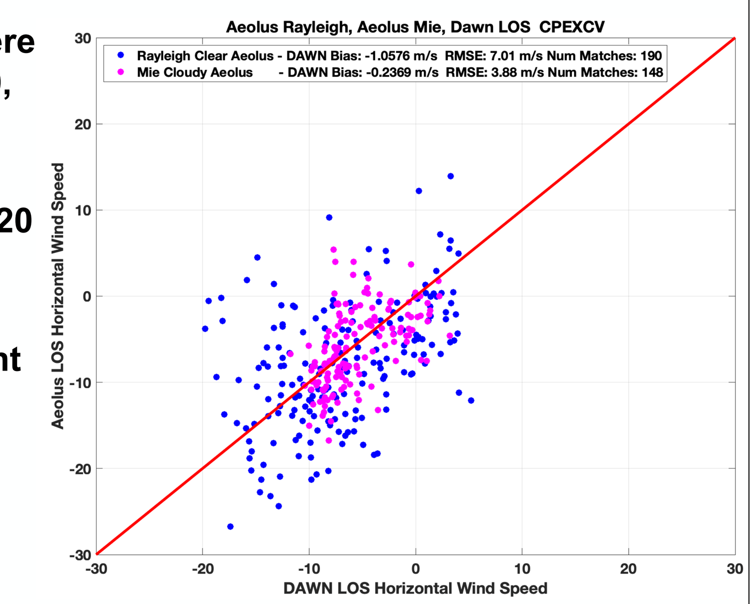
Four DC-8 Aeolus underpasses were executed during CPEX-CV on 9, 10, 15, and 16 September 2022

DAWN LOS wind speeds along Aeolus underpass did not exceed 20 m/s

Dust layers present during all underpasses. A clean layer present in the ~5 to 8 km layer

Rayleigh Clear – DAWN
Bias: -1.06 m/s RMS: 7.01 m/s

Mie Cloudy – DAWN
Bias: -0.24 m/s RMS: 3.88 m/s



Conclusions

- **DAWN showed ~1.8 m/s RMS accuracy when compared with AVAPS Dropsondes**
- **Analysis of a large sample of GOES-16 AMV indicates wind precision ranging from ~2.3-6 m/s relative to DAWN on average with AMVs derived from the visible channel being most precise**
- **NOAA and NASA model initial analyses agreed quite well with DAWN overall**
- **NASA and NOAA forecast models generally performed well but large issues were observed when forecasts mistimed the propagation of convection associated with Easterly Waves**
- **DAWN comparisons with Aeolus found differences comparable to other Aeolus validation sources during this period of the Aeolus lifetime**
- **DAWN data for all 13 research flights have been released for use within the community: https://www-air.larc.nasa.gov/cgi-bin/ArcView/cpex.2022**

Ongoing CPEX Applications of DAWN Data

- **CPEX science team members are using DAWN data from CPEX-CV and CPEX-AW for several investigations**
- Assimilation into cloud-resolving models predicting ITCZ rainfall and tropical cyclone genesis and trajectory
- Convection process studies over Puerto Rico, and oceanic and African coastal convection
- DAWN combined with HALO and HAMSR to study the thermodynamic structure of the Saharan air layer and dust transport
- Investigations of HALO ocean surface wind speed retrieval
- Automated multi-instrument synergy product development