The Impact of Aeolus Satellite and Airborne Doppler Wind Lidar Measured Wind Profiles on Numerical Simulations of Tropical Cyclones and Tropical Convection

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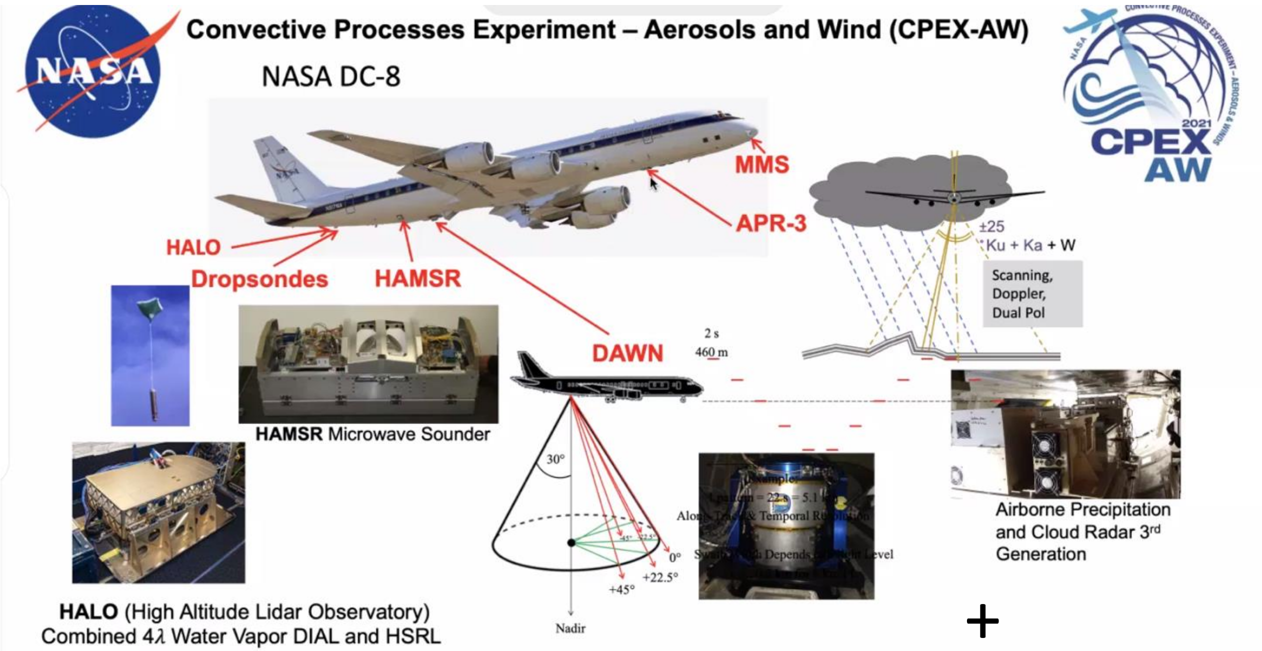
Background and Motivation

- Tropical cyclones and tropical convection are essential components of weather and climate.
- In-situ data are commonly sparse over the tropical ocean.
- Doppler wind lidar (DWL) measurements provide valuable data sources of 3-dimensional winds through the wind profiles.
  - ESA Aeolus Satellite
  - Airborne DWL measurements from recent NOAA and NASA research and operational field campaigns
- What are the impacts of assimilation of DWL wind profiles on numerical simulations of tropical cyclones and tropical convection during recent research and operational field campaigns?
- What implications did we obtain for the observing system and data assimilation?

Data Assimilation during NASA CEPX-AW 2021

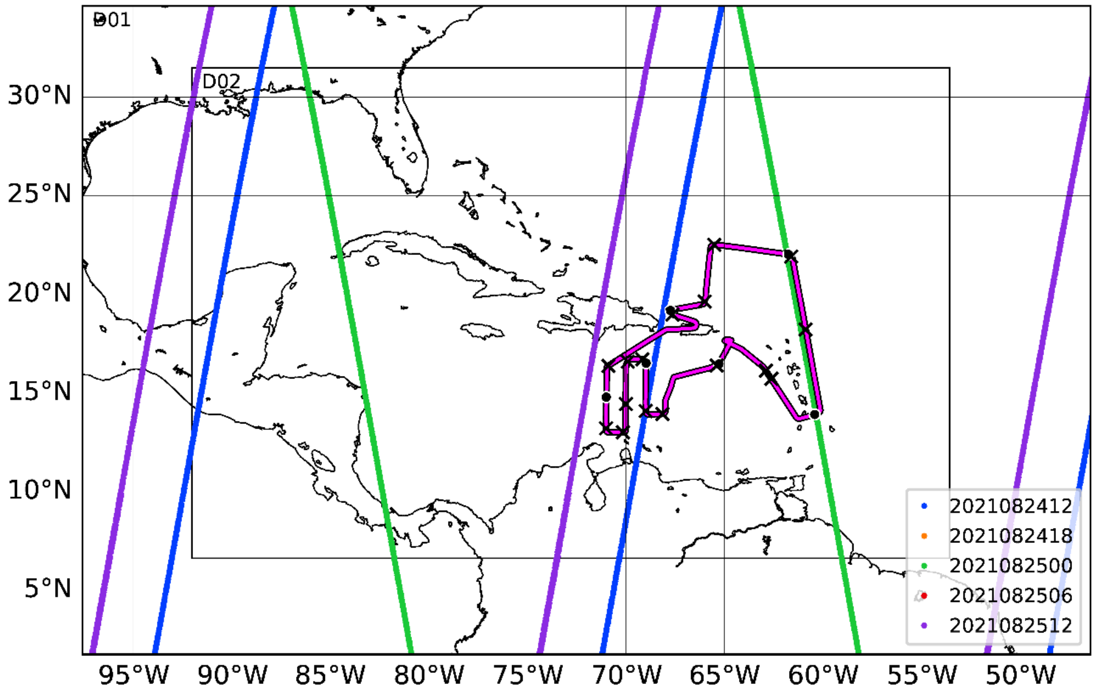
CEPX-AW Field data. (August 2021)



DAWN (Doppler Aerosol WiNd) *lidar* system

+ Aeolus Satellite Data

Aug 24-25, 2022



NCEP GSI-Based 3D Ensemble-Variational Hybrid Data Assimilation (3DEnVAR) for WRF and HWRF

$$J(x) = \frac{1}{2}(x - x^b)^T(\beta_1 B_1 + \beta_2 B_2)^{-1}(x - x^b) + \frac{1}{2}(y^0 - H(x))^T R^{-1}(y^0 - H(x))$$

B_1: Static, pre-generated matrix using NMC method

B_2 : A flow-depend matrix derived from ensemble forecasts

Weighting factors: β_1 and β_2

When β_2 = 0 -- 3DVAR

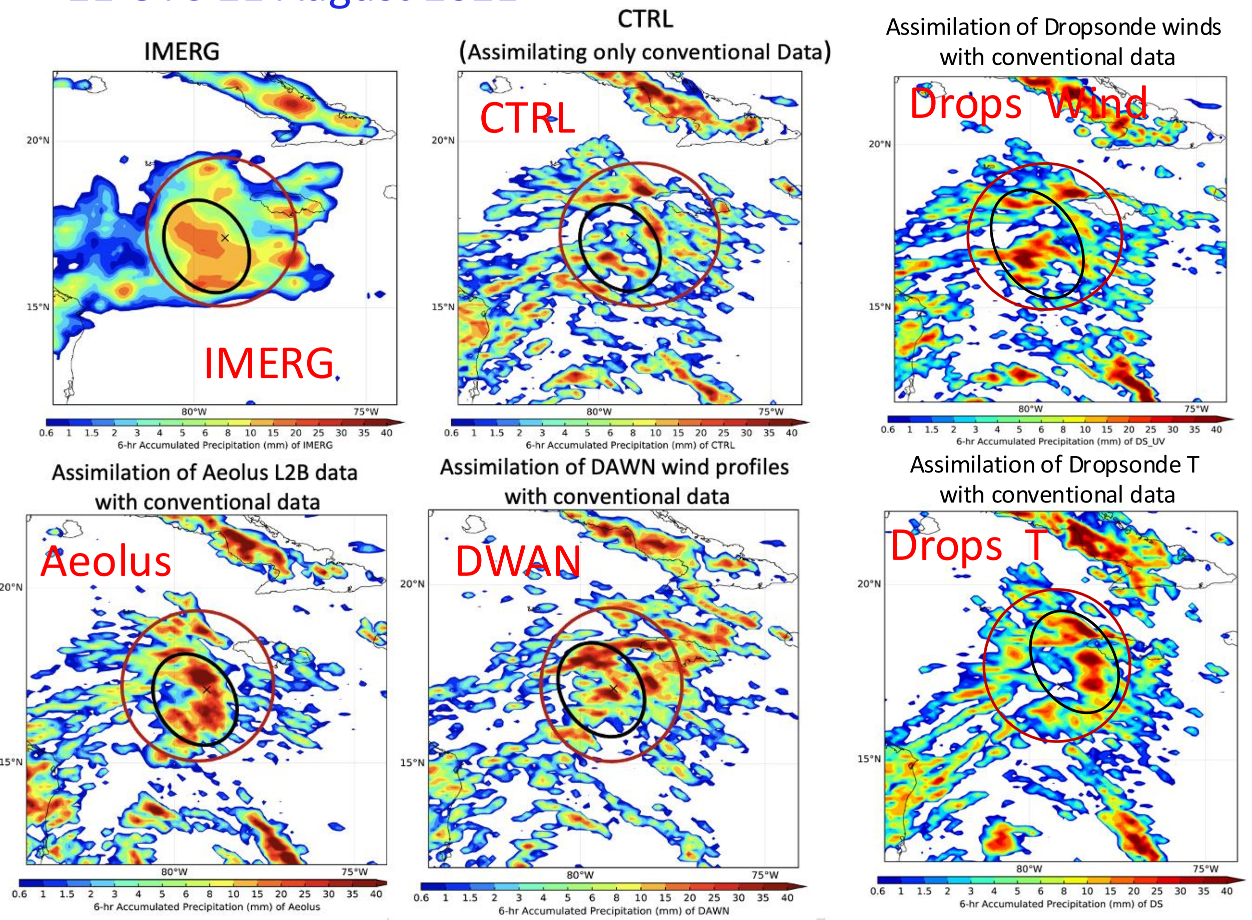
Data Assimilation during NASA CEPX-AW 2021: Data Impact

- Mesoscale community Weather Research and Forecasting (WRF) model at cloud permitting scale (~ 3 km)
- NCEP GSI-based hybrid ensemble-3DVAR (3DEnVAR) data assimilation system

- Control (CTRL) simulation assimilates all routine conventional observations used in operational NWP.
- The impact of field observations and Aeolus satellite data on numerical simulations of tropical convection systems and their environmental conditions are examined.

- For Aeolus data assimilation, L2B (Rayleigh-clear and Mie-cloudy) data are assimilated.

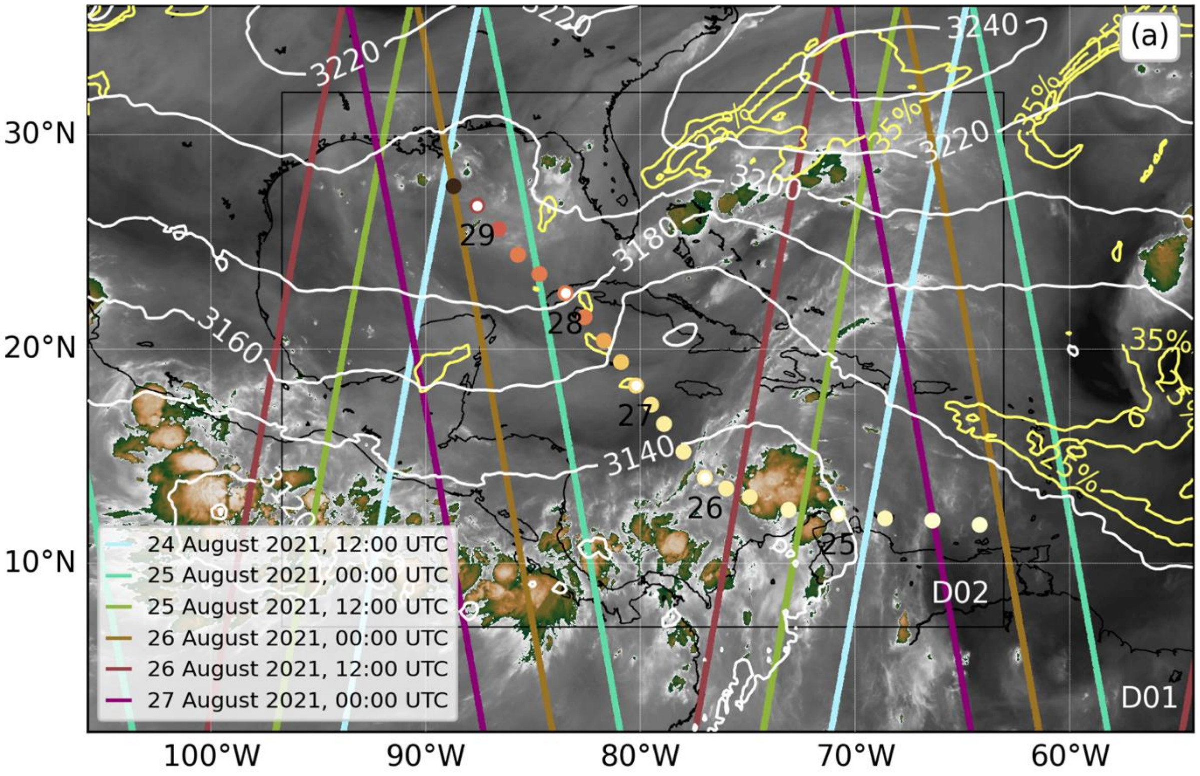
21 UTC 21 August 2021



- *6-hr accumulated precipitations of different experiments with a 10 X 10 degree box centered at the location of AEW (indicated by black cross).*
- Compared with CTRL, assimilation of Aeolus L2B data, DAWN wind profiles, and dropsonde data helps the model to reproduce more organized convection in the critical regions associated with AEW.

Assimilation of Aeolus Horizontal LOS -- Hurricane Ida

Ida's track - Aeolus LOS obs.



Feng and Pu (2023)

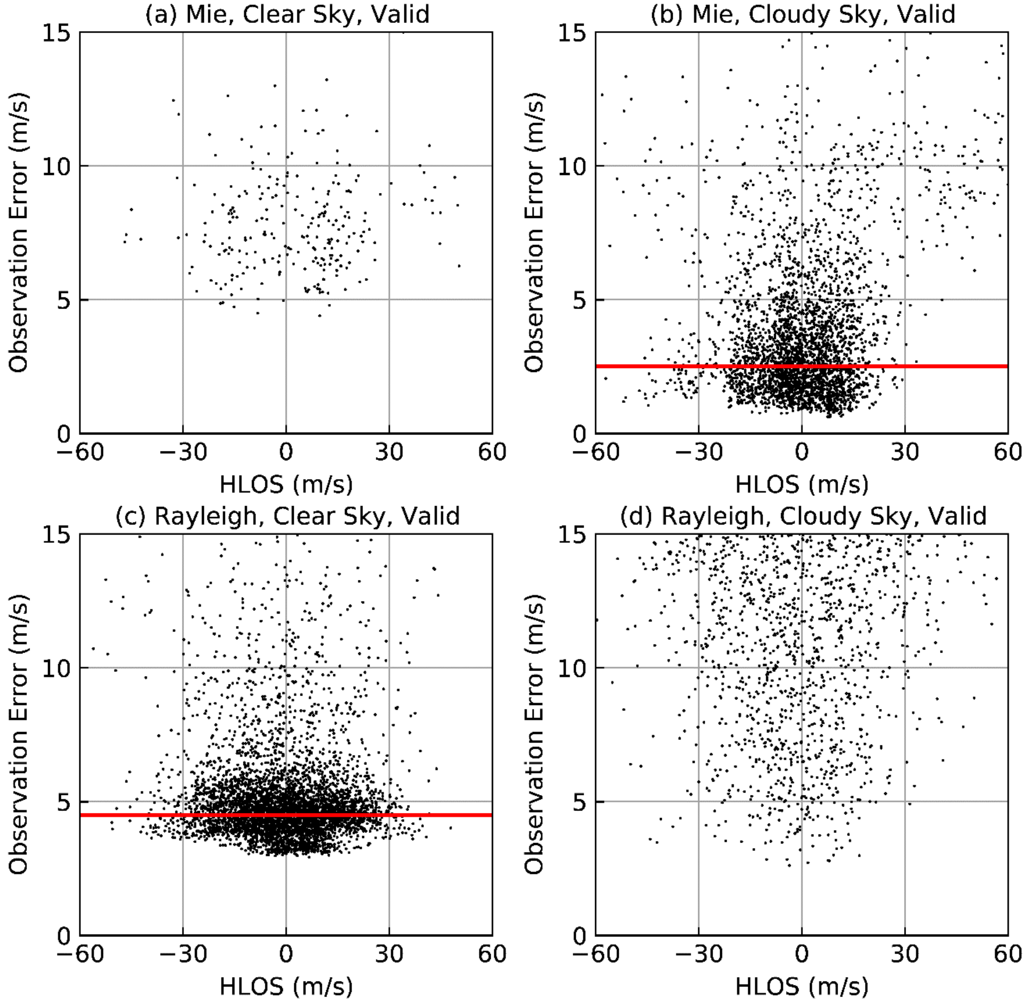
List of Experiments

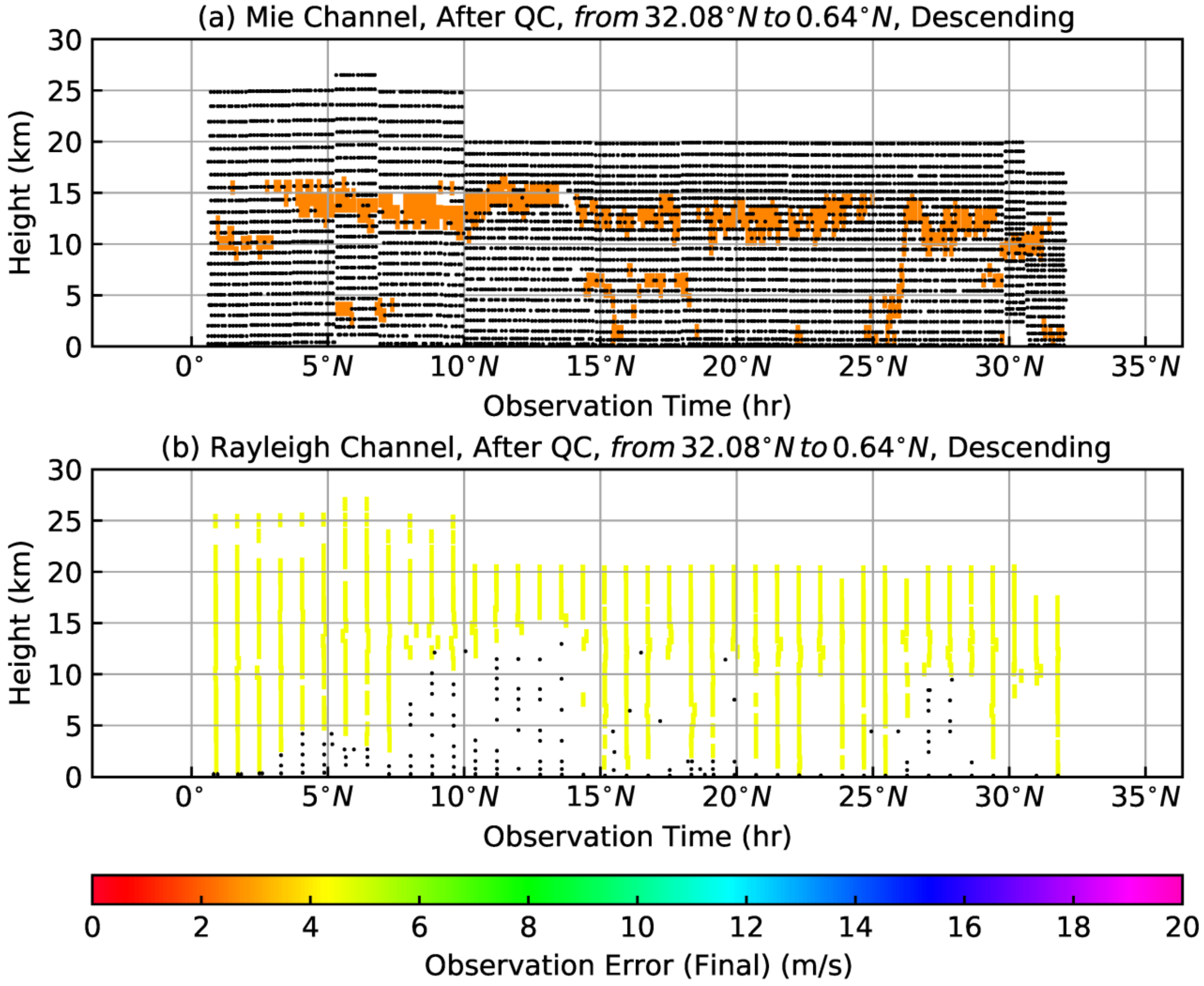
Table 3. List of experiment configurations.

Experiment	Case	Initial time	Cycling DA period	Horizontal scale (km)	Vertical scale (grid units)	DA observation	Forecast
2406	Ida	24 August 2021, 06:00 UTC	From 24 August 2021, 12:00 UTC, to 26 August 2021, 06:00 UTC (3DEnVAR)	110	3	NCEP GDAS data	48 h forecasts initialized from DA cycles 5–8
2406_L2B	Ida	24 August 2021, 06:00 UTC	From 24 August 2021, 12:00 UTC, to 26 August 2021, 06:00 UTC (3DEnVAR)	110	3	NCEP GDAS data, Aeolus L2B HLOS winds	48 h forecasts initialized from DA cycles 5–8
2412	Ida	24 August 2021, 12:00 UTC	From 24 August 2021, 18:00 UTC, to 26 August 2021, 12:00 UTC (3DEnVAR)	110	3	NCEP GDAS data	48 h forecasts initialized from DA cycles 5–8
2412_L2B	Ida	24 August 2021, 12:00 UTC	From 24 August 2021, 18:00 UTC, to 26 August 2021, 12:00 UTC (3DEnVAR)	110	3	NCEP GDAS data, Aeolus L2B HLOS winds	48 h forecasts initialized from DA cycles 5–8
2418	Ida	24 August 2021, 18:00 UTC	From 25 August 2021, 00:00 UTC, to 26 August 2021, 18:00 UTC (3DEnVAR)	110	3	NCEP GDAS data	48 h forecasts initialized from DA cycles 5–8
2418_L2B	Ida	24 August 2021, 18:00 UTC	From 25 August 2021, 00:00 UTC, to 26 August 2021, 18:00 UTC (3DEnVAR)	110	3	NCEP GDAS data, Aeolus L2B HLOS winds	48 h forecasts initialized from DA cycles 5–8
2500	Ida	25 August 2021, 00:00 UTC	From 25 August 2021, 06:00 UTC, to 27 August 2021, 00:00 UTC (3DEnVAR)	110	3	NCEP GDAS data	48 h forecasts initialized from DA cycles 5–8
2500_L2B	Ida	25 August 2021, 00:00 UTC	From 25 August 2021, 06:00 UTC, to 27 August 2021, 00:00 UTC (3DEnVAR)	110	3	NCEP GDAS data, Aeolus L2B HLOS winds	48 h forecasts initialized from DA cycles 5–8
2500_L2B_H1	Ida	25 August 2021, 00:00 UTC	From 25 August 2021, 06:00 UTC, to 27 August 2021, 00:00 UTC (3DEnVAR)	55	3	NCEP GDAS data, Aeolus L2B HLOS winds	48 h forecasts initialized from DA cycles 5–8
2500_L2B_H2	Ida	25 August 2021, 00:00 UTC	From 25 August 2021, 06:00 UTC, to 27 August 2021, 00:00 UTC (3DEnVAR)	220	3	NCEP GDAS data, Aeolus L2B HLOS winds	48 h forecasts initialized from DA cycles 5–8
2500_L2B_V1	Ida	25 August 2021, 00:00 UTC	From 25 August 2021, 06:00 UTC, to 27 August 2021, 00:00 UTC (3DEnVAR)	110	1.5	NCEP GDAS data, Aeolus L2B HLOS winds	48 h forecasts initialized from DA cycles 5–8
2500_L2B_V2	Ida	25 August 2021, 00:00 UTC	From 25 August 2021, 06:00 UTC, to 27 August 2021, 00:00 UTC (3DEnVAR)	110	6	NCEP GDAS data, Aeolus L2B HLOS winds	48 h forecasts initialized from DA cycles 5–8
1918	MCS	19 August 2021, 18:00 UTC	From 20 August 2021, 00:00 UTC, to 21 August 2021, 00:00 UTC (3DVAR)	/	/	NCEP GDAS data	30 h forecasts initialized from DA cycle 5
1918_L2B	MCS	19 August 2021, 18:00 UTC	From 20 August 2021, 00:00 UTC, to 21 August 2021, 00:00 UTC (3DVAR)	/	/	NCEP GDAS data, Aeolus L2B HLOS winds	30 h forecasts initialized from DA cycle 5

A slash (/) indicates that the horizontal and vertical localization scales are not needed.

Aeolus Data Assimilation during NASA CEPX-AW 2021: Observation Errors & QC





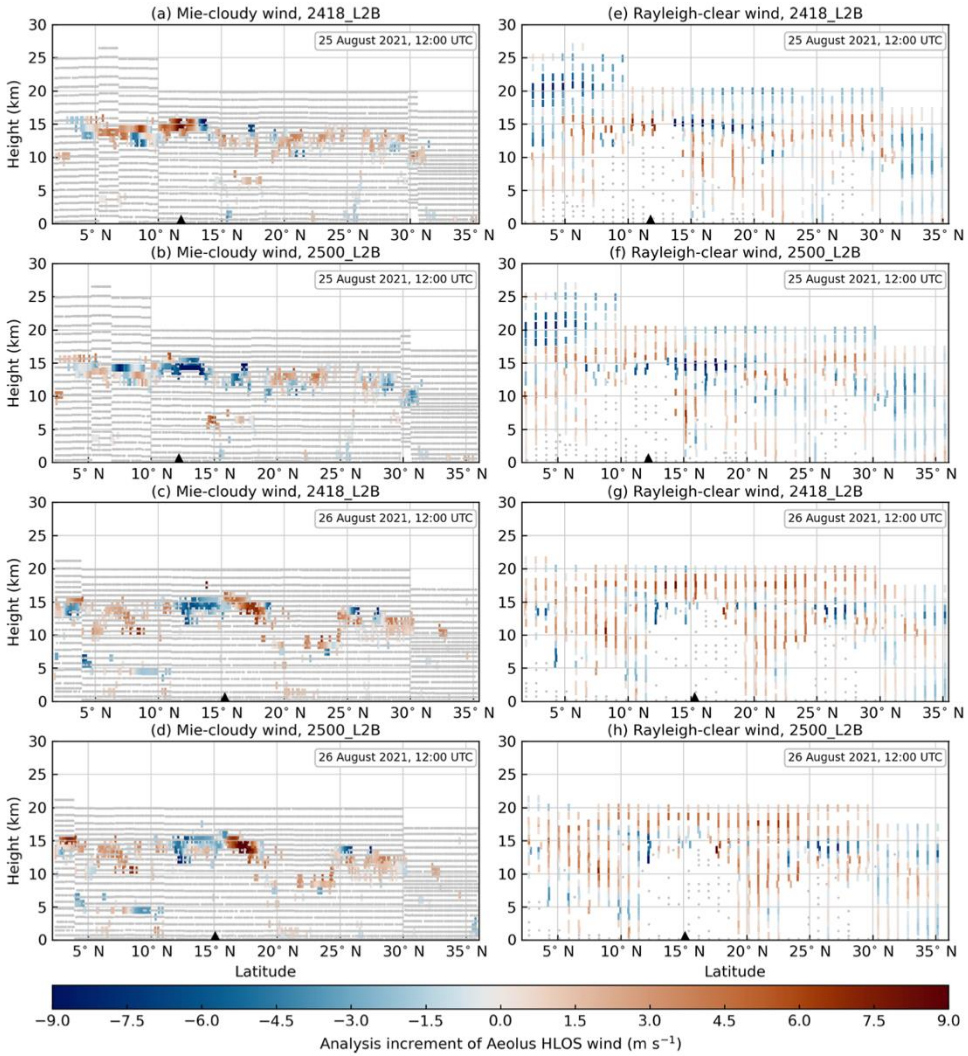
The observation errors in Mie Cloudy (Rayleigh Clear) are set to 2.5 m/s (4.5 m/s).

August 25, 2021

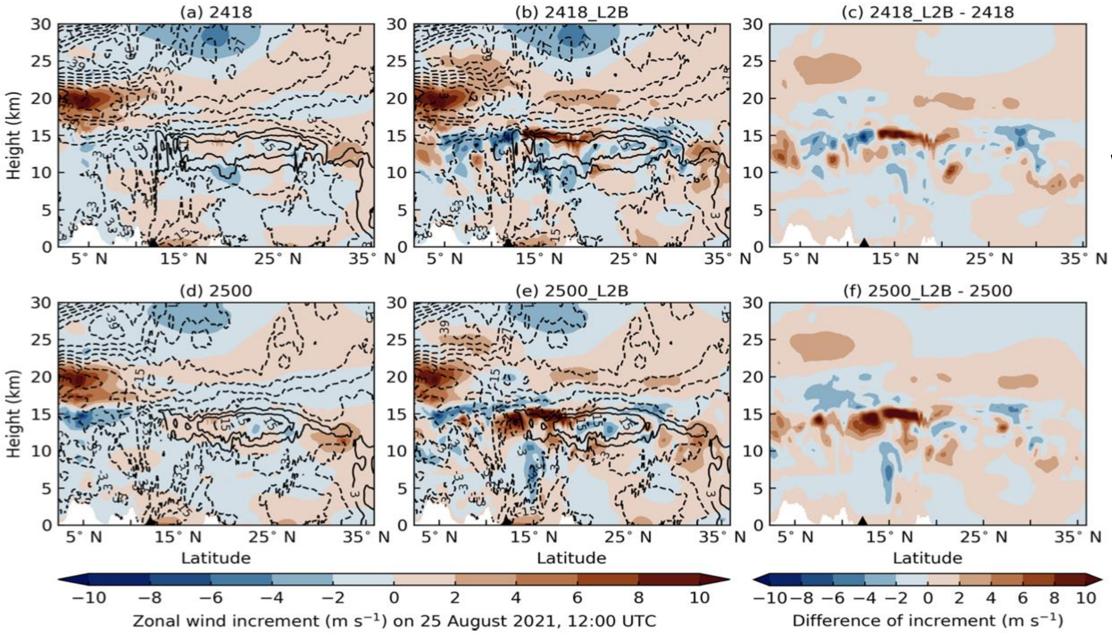
Feng and Pu, 2023

Analysis Increments

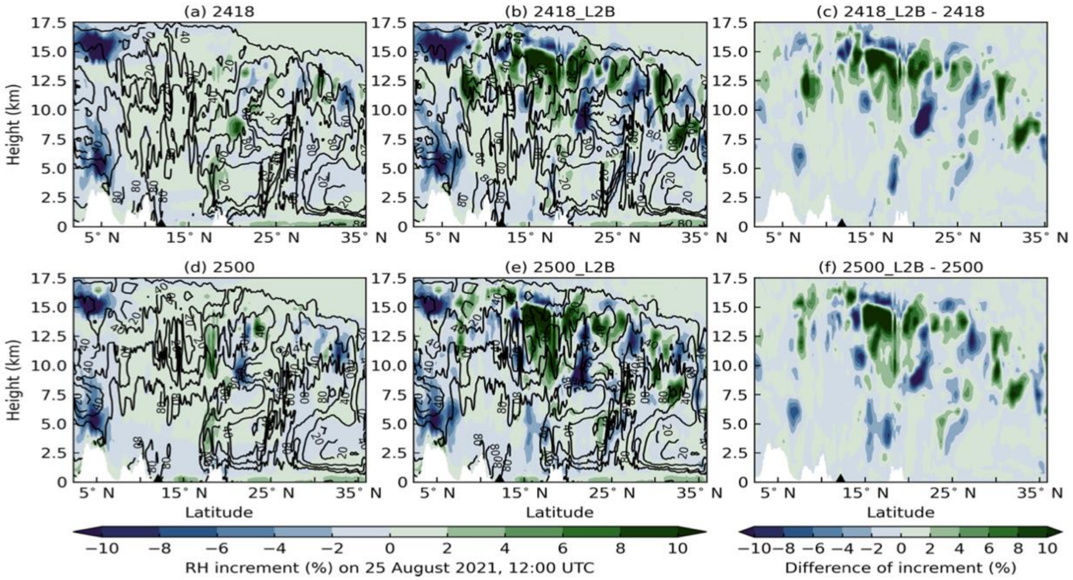
LOS



Winds

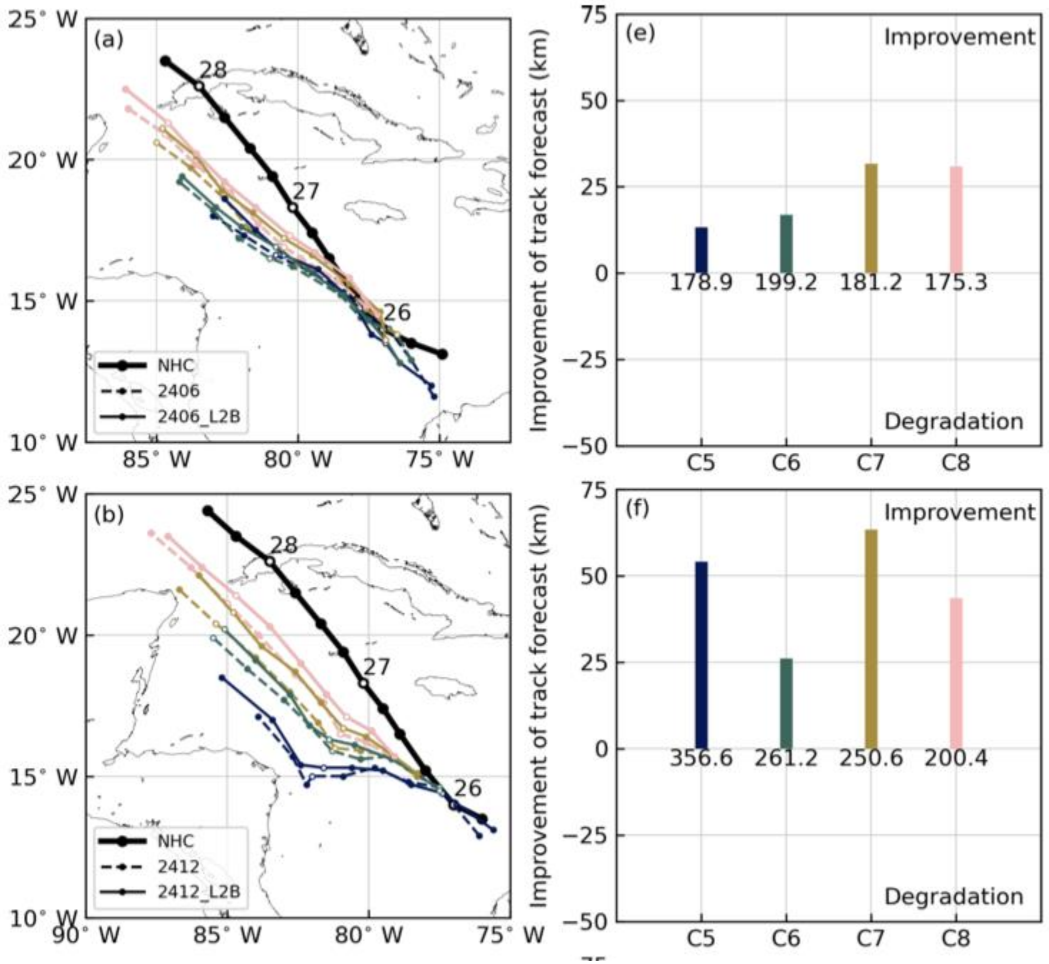


RH

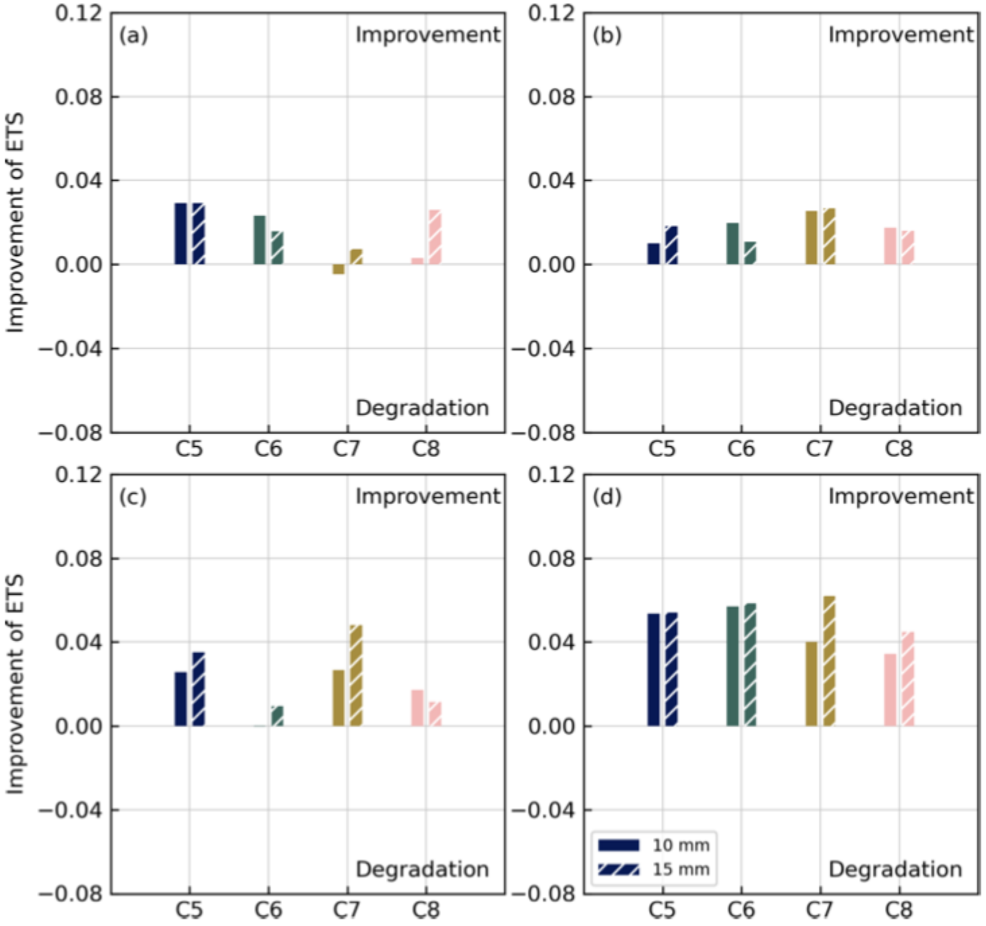


Forecast Improvements

Track

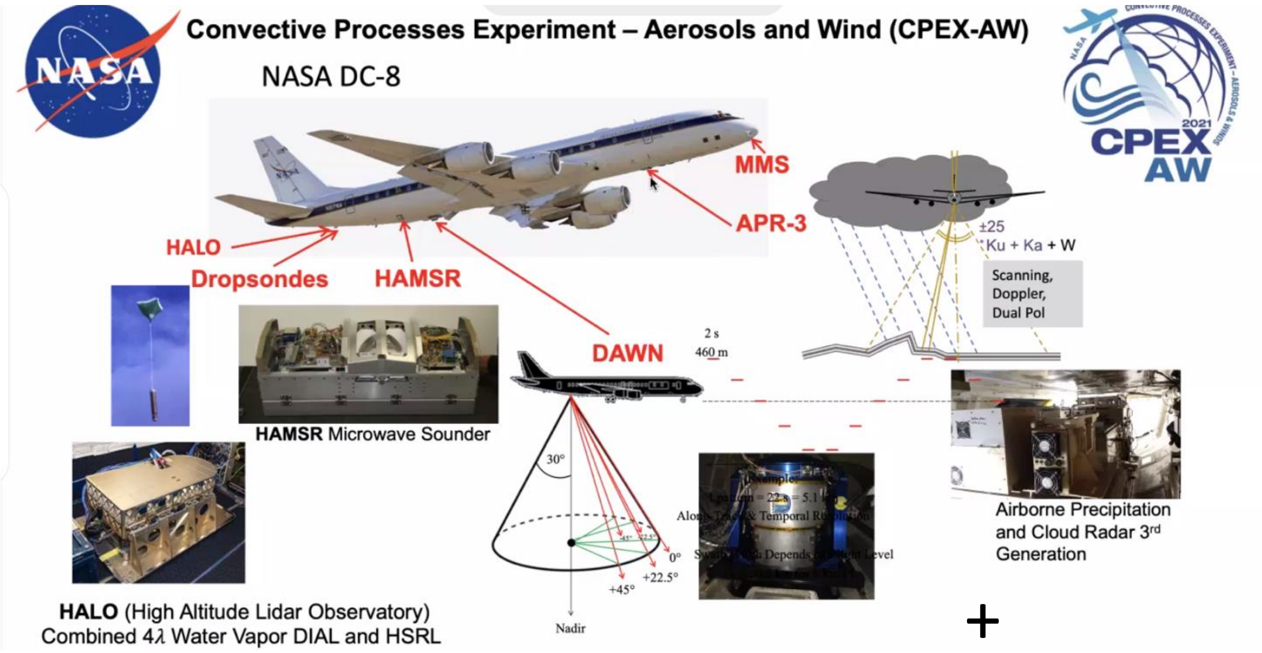


Precipitation



Data Assimilation during NASA CEPX-AW (2021) and CPEX-CV (2022)

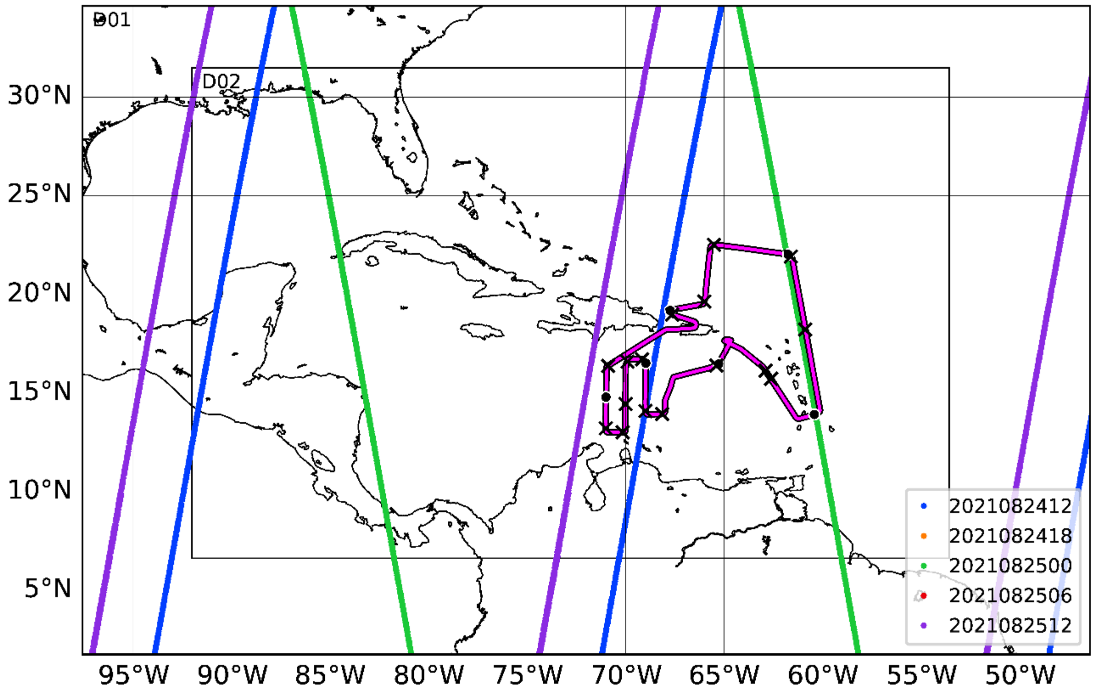
CEPX-AW Field data. (August 2021)



DAWN (Doppler Aerosol WiNd) *lidar* system

+ Aeolus Satellite Data

Aug 24-25, 2022



NCEP GSI-Based 3D Ensemble-Variational Hybrid Data Assimilation (3DEnVAR) for WRF and HWRF

$$J(x) = \frac{1}{2}(x - x^b)^T(\beta_1 B_1 + \beta_2 B_2)^{-1}(x - x^b) + \frac{1}{2}(y^0 - H(x))^T R^{-1}(y^0 - H(x))$$

B_1: Static, pre-generated matrix using NMC method

B_2 : A flow-depend matrix derived from ensemble forecasts

Weighting factors: β_1 and β_2

When $\beta_2 = 0$ -- 3DVAR

Three CPEX-CV（2022） and Two CPEX-AW AEW （2021） Cases

Campaign	AEW Number	Mission Number	Mission Date	Mission Time	Mission Target
CPEX-AW	AEW02	RF01	20 August 2021	19:30 - 24:30	Scattered convections
	AEW03	RF02	21 August 2021	21:00 - 26:30	Scattered convections
CPEX-CV	AEW03	RF01	06 September 2022	10:59 - 18:25	Mature MCS
		RF02	07 September 2022	11:50 - 18:59	Mature MCS
	AEW06	RF07	16 September 2022	13:02 - 20:56	Scattered convections (upscale growth)

[a] the mission time over 24 UTC is on the next day of the mission date.

Flight Tracks, Tracks of AEWs, GOES-16 Ch10 BTs During CPEX-CV

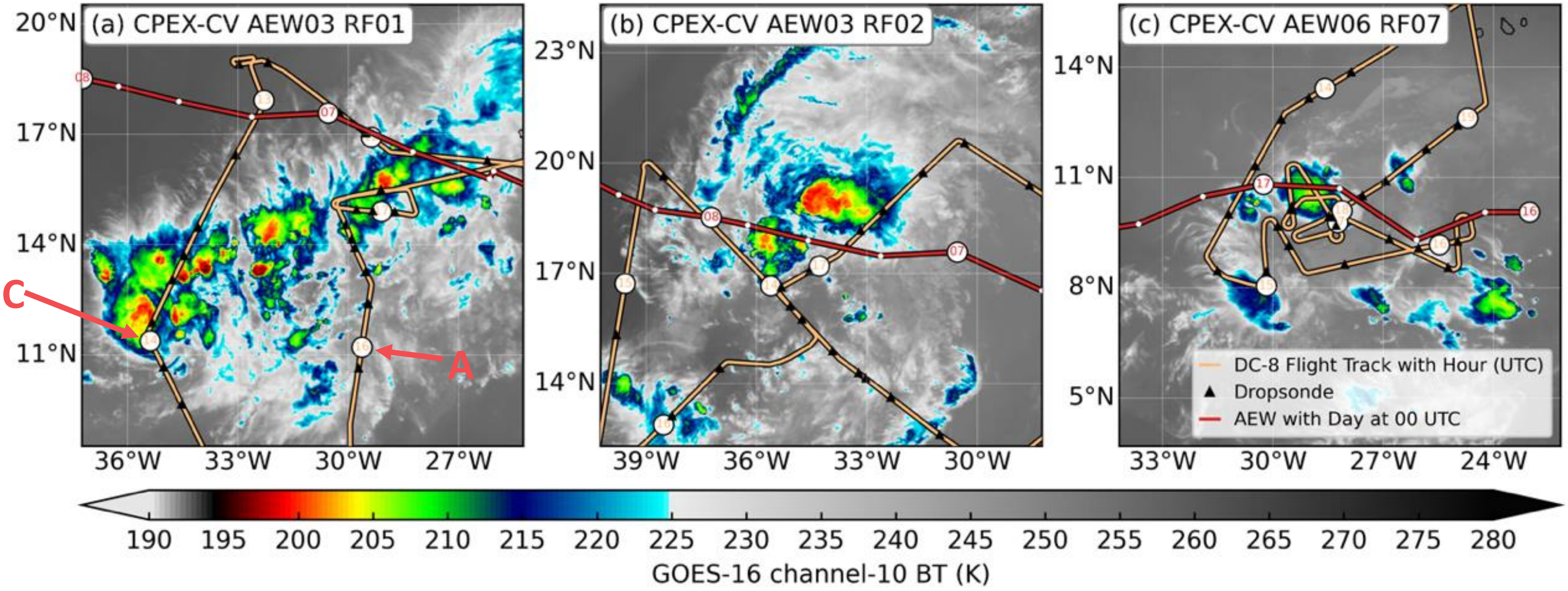


Figure 1. The NASA DC-8 aircraft flight tracks (orange lines) with hours (UTC), the track of AEWs (red lines) with the days (UTC), the locations of the dropsondes (triangles), and the GOES-16 channel 10 brightness temperatures (color shaded) at 18 UTC of the mission day in three NASA DC-8 airborne missions during CPEX-CV.

Experiment Design

Conventional data (CONV)

Experiment	PREPBUFR	DAWN	HALO	Dropsonde
CONV	✓	×	×	×
DAWN	✓	✓	×	×
HALO	✓	×	✓	×
DS	✓	×	×	✓
DAWN_HALO	✓	✓	✓	×
DAWN_DS	✓	✓	×	✓
HALO_DS	✓	×	✓	✓
DAWN_HALO_DS	✓	✓	✓	✓

[a]✓ indicate the observations are assimilated; × indicate the observations are not assimilated.

- WRF model
- GSI 3DEnVar data assimilation system

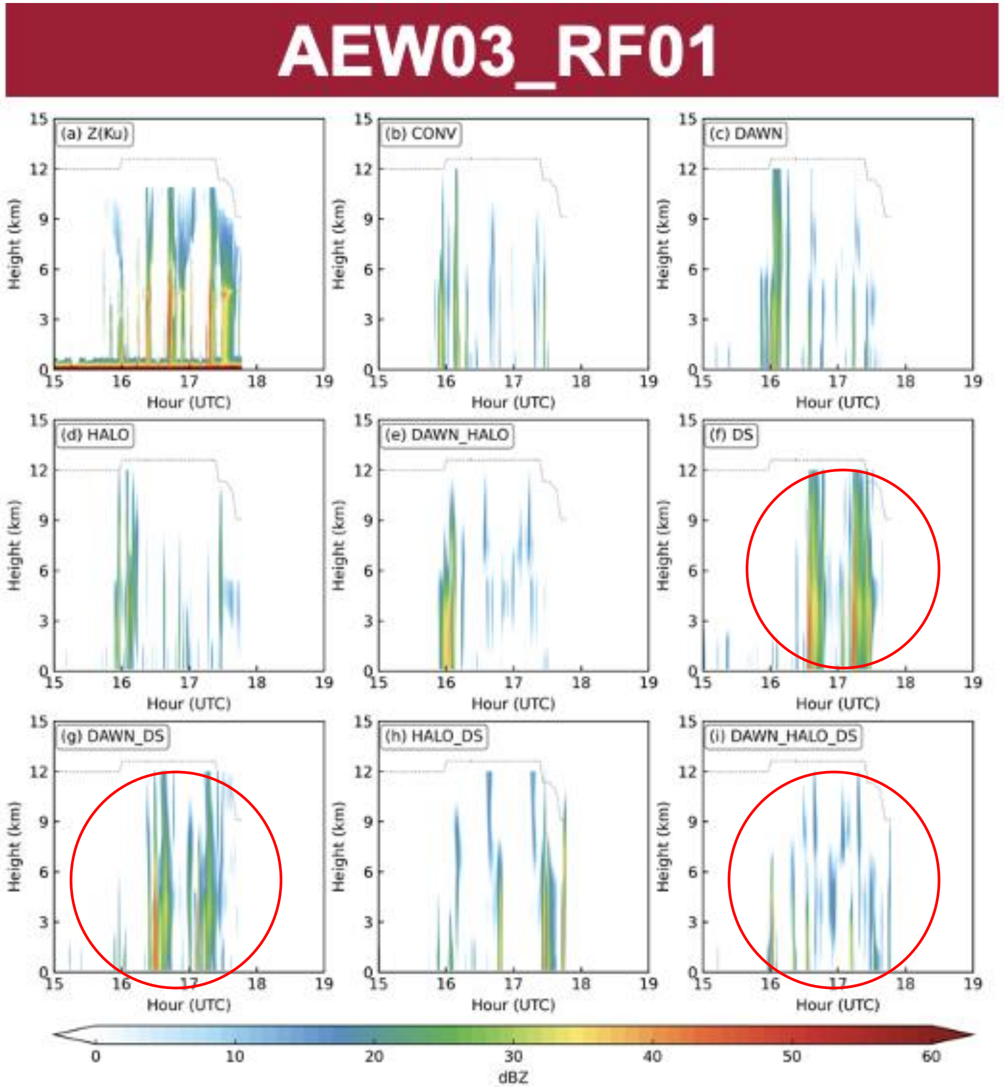
$$J(x) = \frac{1}{2}(x - x^b)^T(\beta_1 B_1 + \beta_2 B_2)^{-1}(x - x^b) + \frac{1}{2}(y^o - Hx)^T R^{-1}(y^o - Hx)$$

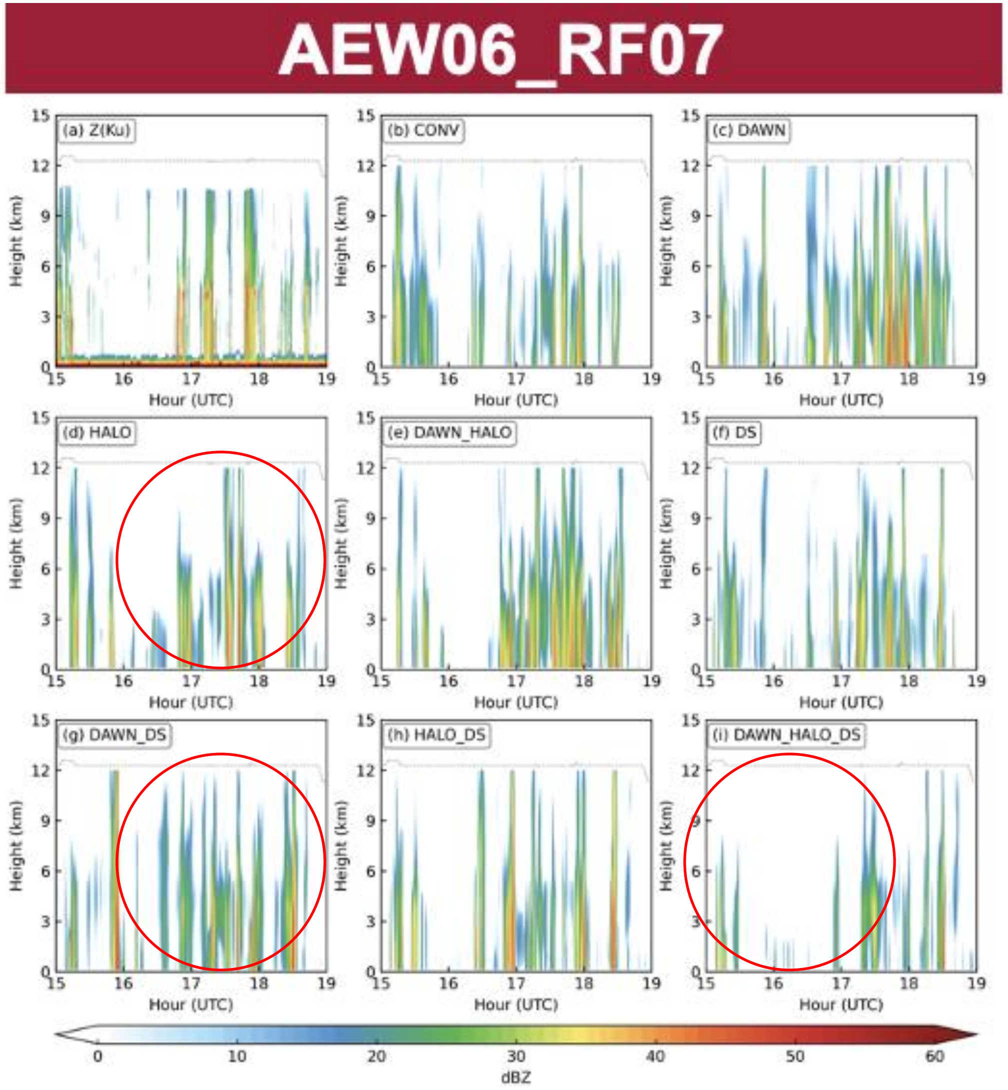
B_1: Static background error covariance
B_2 : Ensemble background error covariance

Weighting factors: β_1 and β_2

The WRF ARW model and the **NCEP GSI-based 3DEnVAR hybrid DA system** are used.

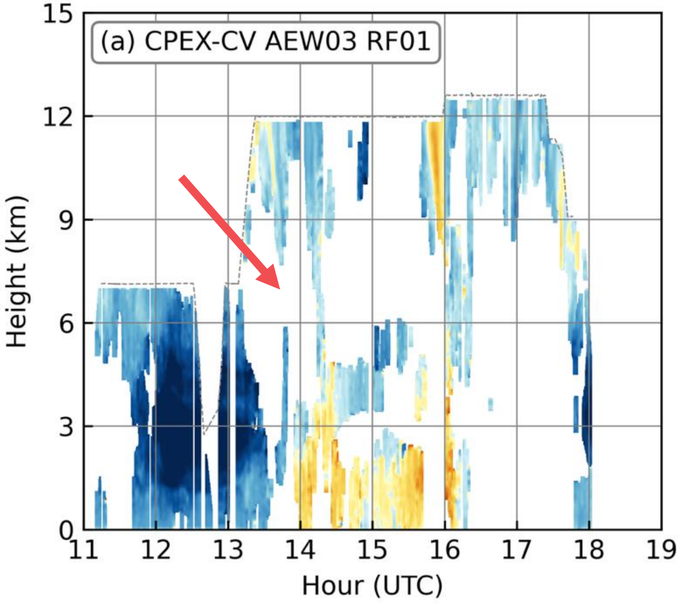
Radar Reflectivity from APR-3 Ku Band vs. WRF Simulations



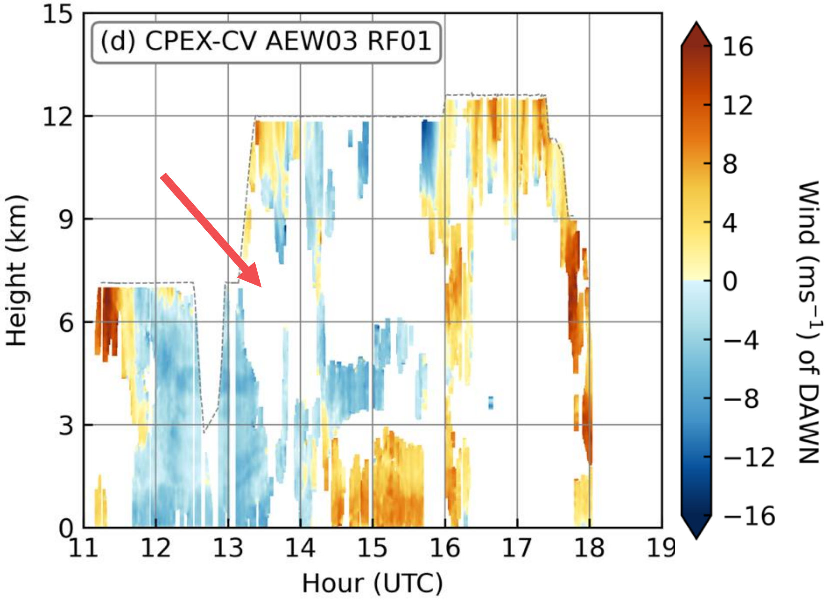


DAWN Winds, HALO Water Vapor of AEW03 in CPEX-CV RF01

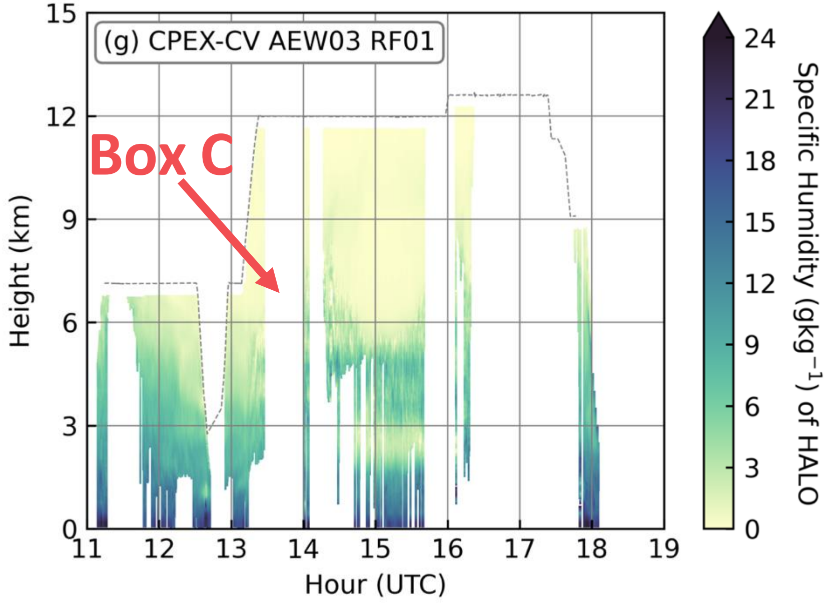
DAWN U Wind



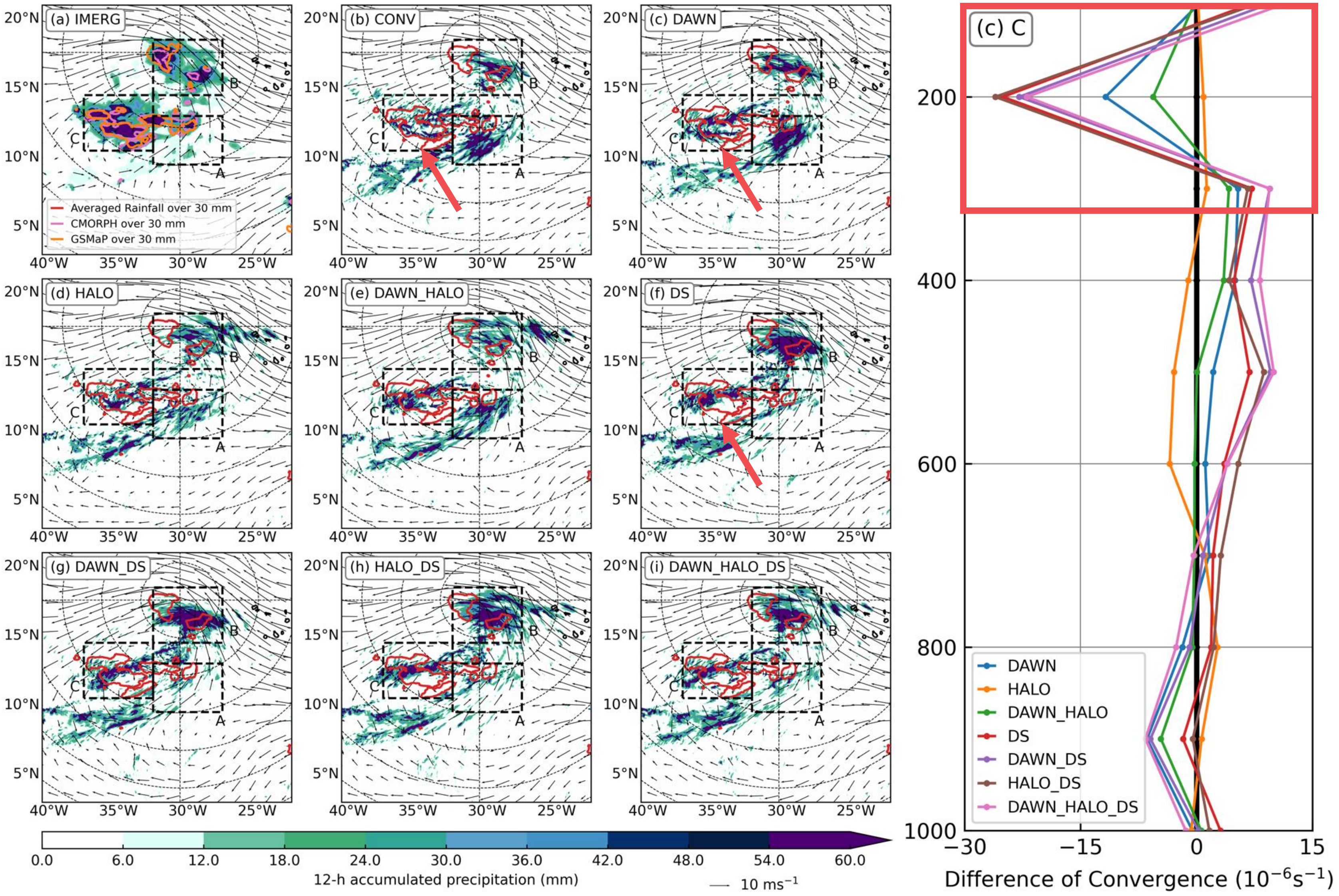
DAWN V Wind



HALO Water Vapor

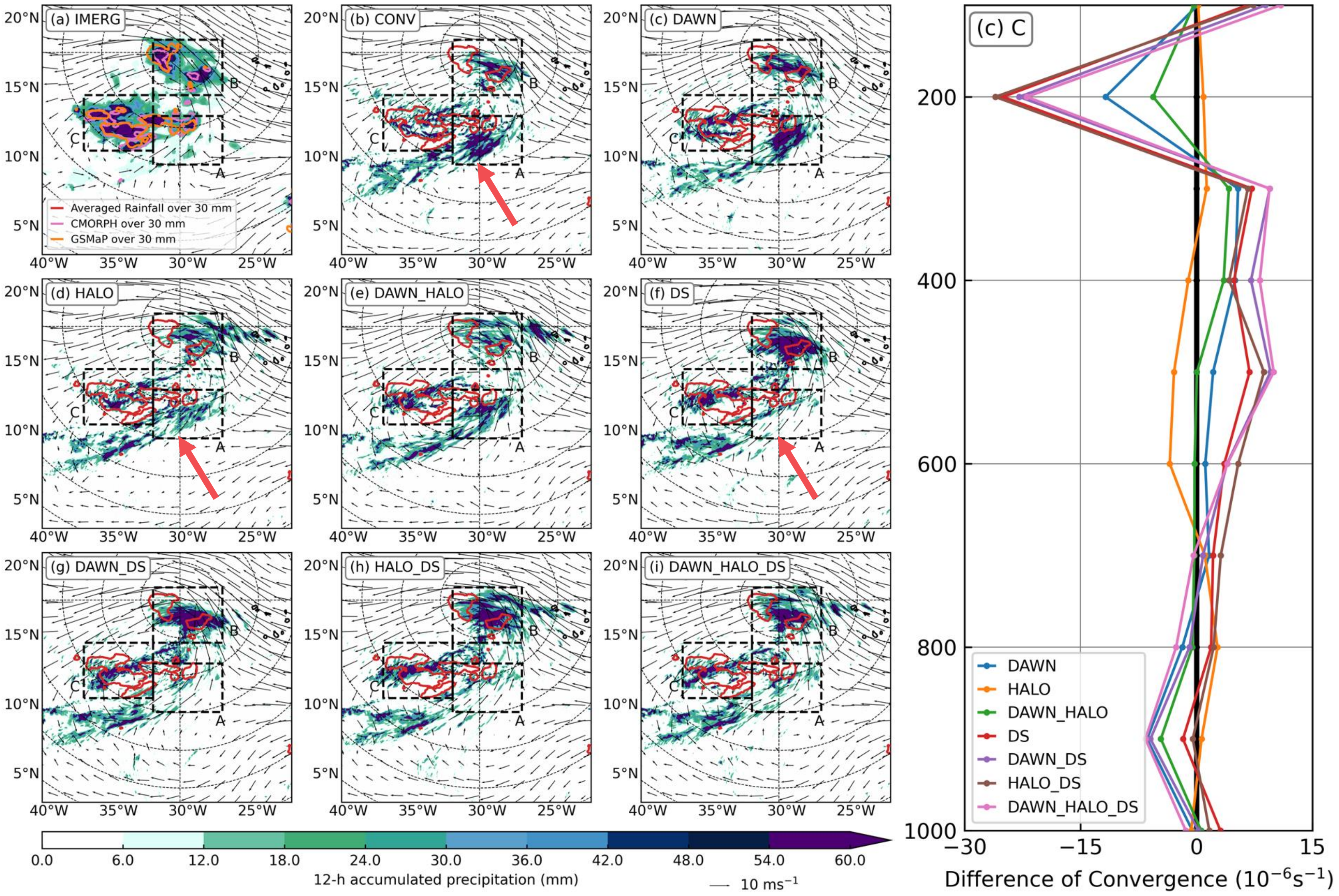


DAWN Winds: Increase Upper-Level Divergence in Box C



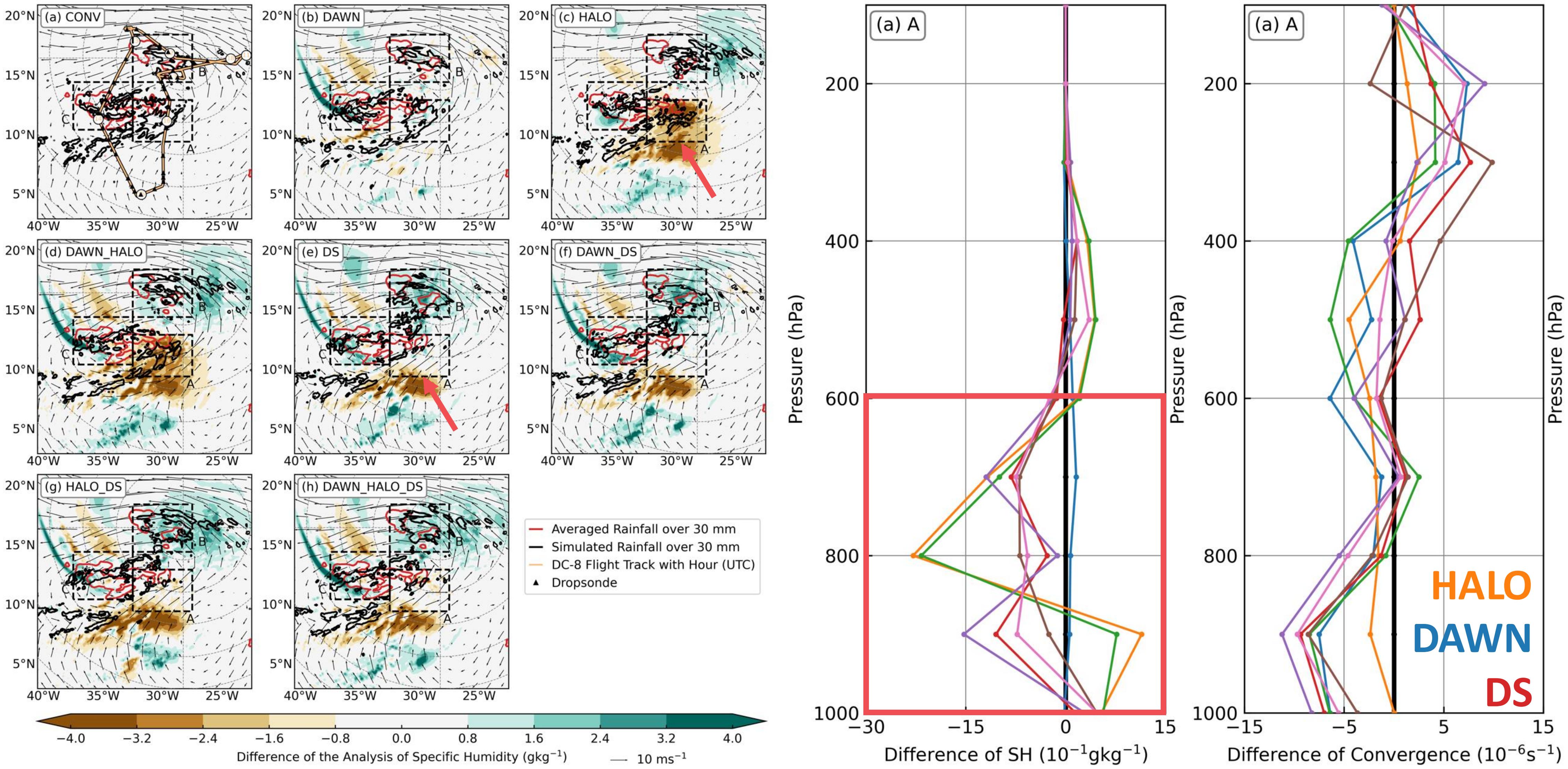
- CPEXCV AEW03 RF01
- CONV: **Box C**
  Scattered convections
- **DAWN**, **DS**: **Box C**
  More organized
  Stronger divergence

DAWN, HALO: Suppress Spurious Convections in Box A



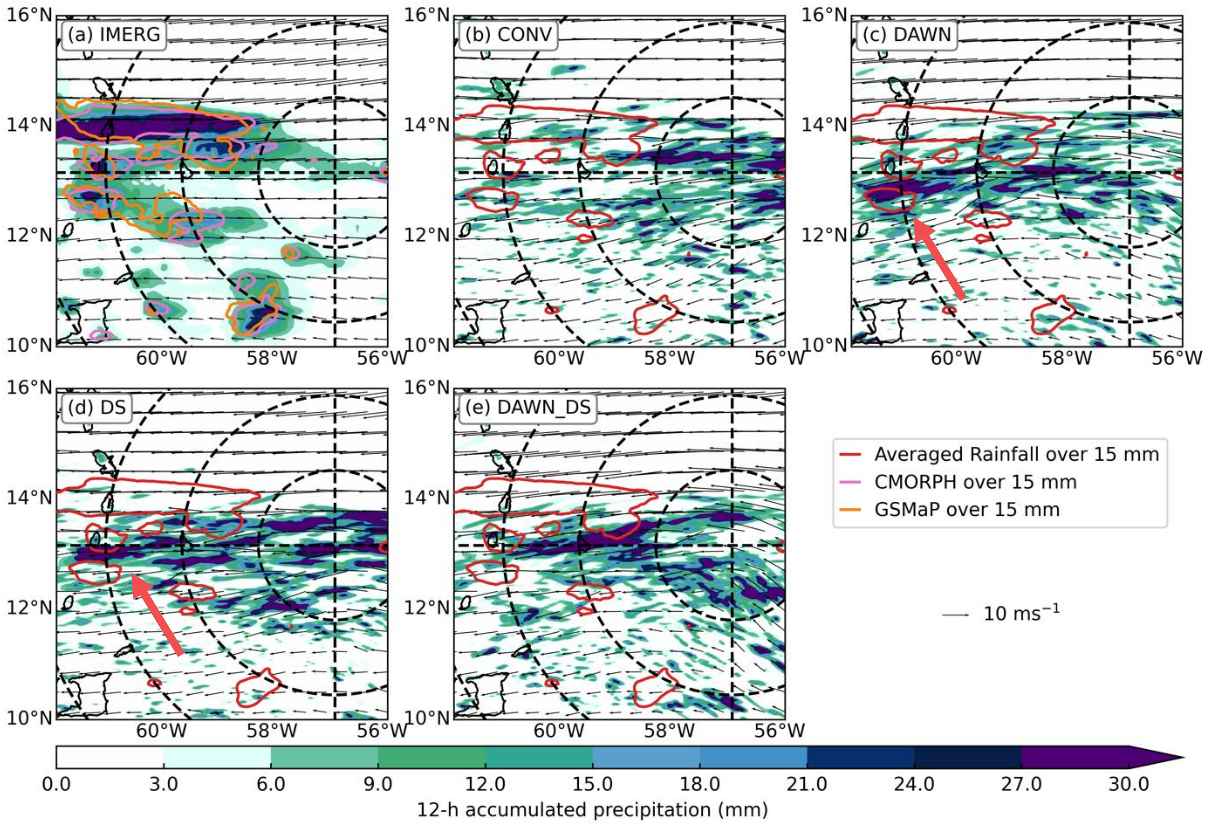
- CPEXCV AEW03 RF01
- CONV: **Box C**
  Scattered convections
- **DAWN**, **DS**: **Box C**
  More organized
  Stronger divergence
- CONV: Box A
  Spurious rainfall
- **HALO**, **DS**: **Box A**
  Weaker precipitations

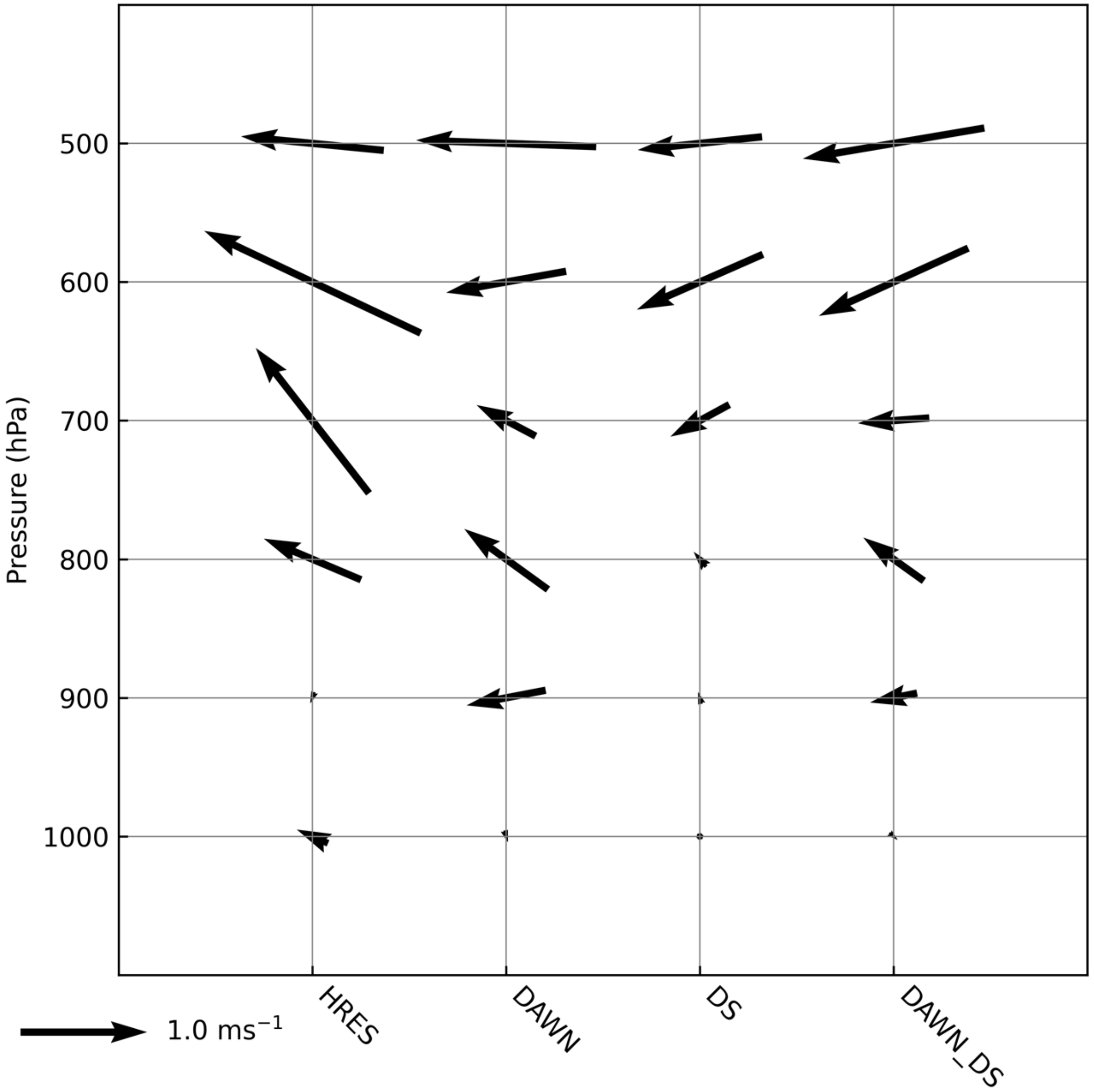
DAWN, HALO: Suppress Spurious Convections in Box A



DAWN Winds: Strengthen the AEJ

- **CPEX-AW AEW03 RF02**
- CONV: Near the center of the AEW03
- DAWN, DS: Stronger AEJ as ECMWF HRES





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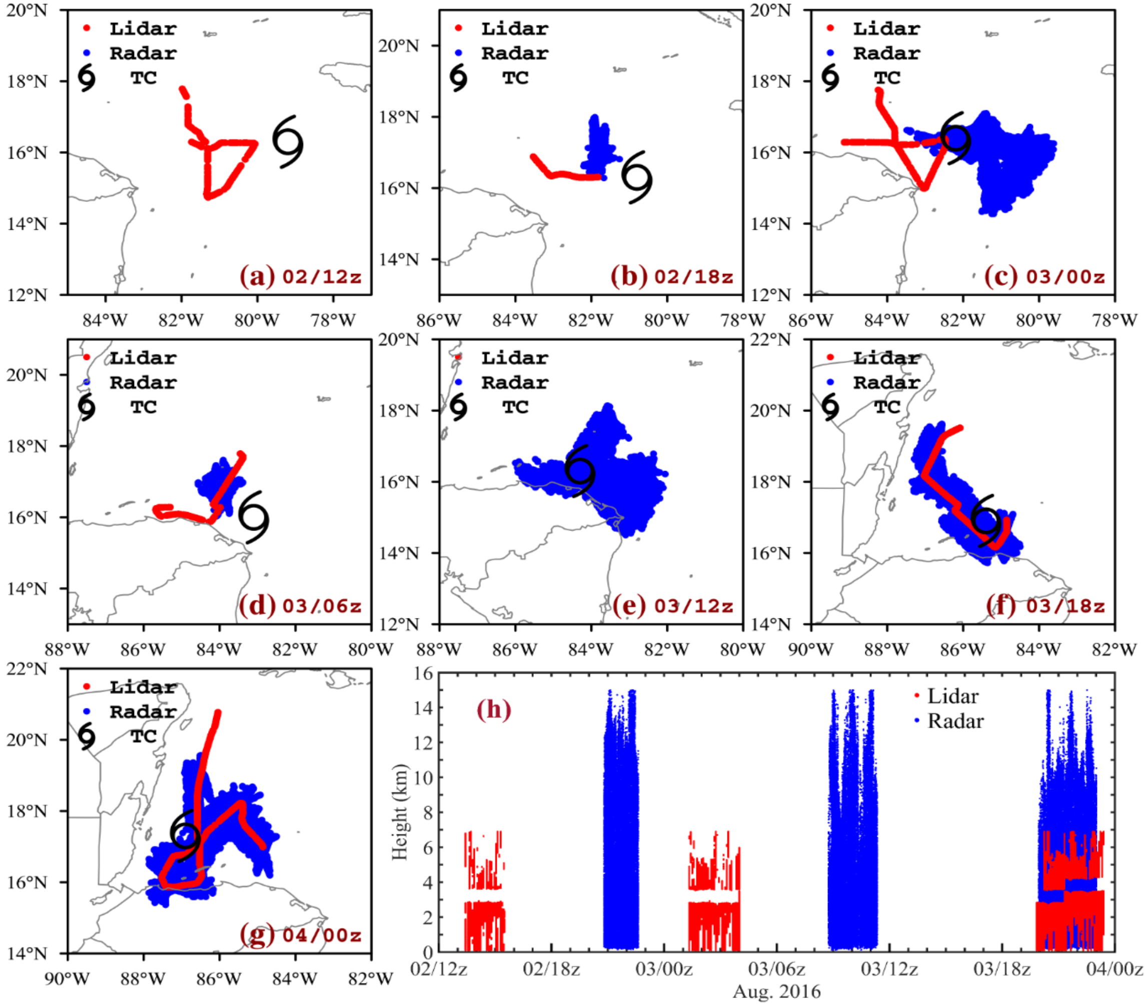
Combined Assimilation of Doppler Wind Lidar (DWL) Wind Profiles and Tail Doppler Radar (TDR) Radial Velocity over a Hurricane Inner Core

TDR: Extends ~14km

DWL: ~7km Vertical extension 25m vertical resolution of wind profiles

Hurricane Earl (2016)

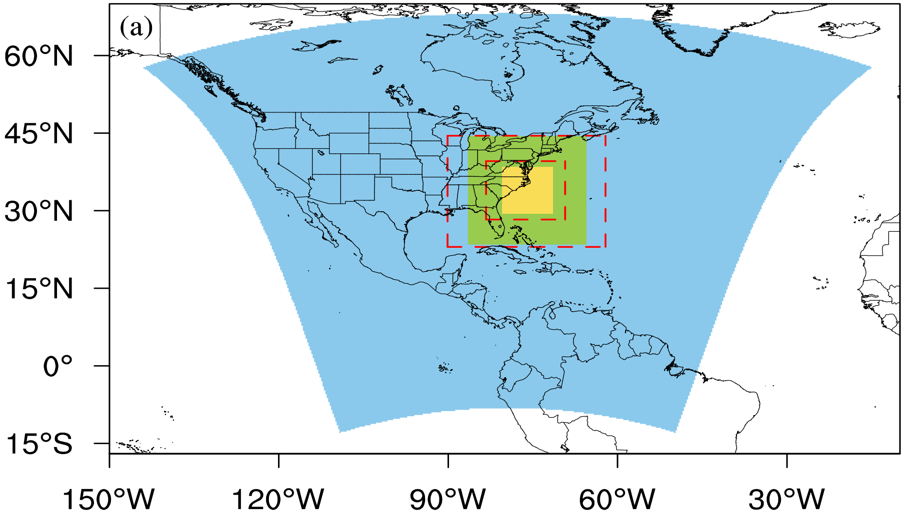


NCEP HWRF model and GSI-based hybrid 3DEnVAR system

- **HWRF Version 4.0**
- **13.5km/4.5km/1.5km resolution**

- **GSI hybrid 3dEnVar data assimilation system**

$$J(x_1', \alpha) = \beta_1 (x_1')^T B_1^{-1} (x_1') + \beta_2 (\alpha)^T A^{-1} (\alpha) + \left(y^{0'} - Hx'\right)^T R^{-1} \left(y^{0'} - Hx'\right) + J_c$$



Vortex Relocation

+

Intensity Correction

+

Data Assimilation

6 hourly cycled data assimilation

Data Assimilation Experiments

Experiments	DWL					ADP	TDR		
	u	v	Wind Speed	Horizontal Thinning Distance	Vertical Thinning Distance		Radial Wind	Horizontal Thinning	Gross Error
Control						X			
LUV	X	X				X			
LUVH2V10	X	X		2 km	10 hPa	X			
LUVH5V70	X	X		5 km	70 hPa	X			
LSH5V10			X	5 km	10 hPa	X			
LSH5V50			X	5 km	50 hPa	X			
LSH5V60			X	5 km	60 hPa	X			
LSH5V70			X	5 km	70 hPa	X			
LSH5V80			X	5 km	80 hPa	X			
LSH5V100			X	5 km	100 hPa	X			
LSH2V70			X	2 km	70 hPa	X			
LSH10V70			X	10 km	70 hPa	X			
RH5						X	X	5 km	2.0
RH9						X	X	9 km	2.0
RH20						X	X	20 km	2.0
RH50						X	X	50 km	2.0
LSH5V70 + RH9			X	5 km	70 hPa	X	X	9 km	2.0
LSH5V70 + RH9G10			X	5 km	70 hPa	X	X	9 km	1.0
LSH5V70 + RH9G08			X	5 km	70 hPa	X	X	9 km	0.8
LSH5V70 + RH9G05			X	5 km	70 hPa	X	X	9 km	0.5

CTRL = HWRF operational set-up （2020）

DWL Assimilation

- Wind speeds *vs.* components (u, v)
- Data thinning

Integrated DA with DWL and TDR

- Integrated DA vs. individual DA
- Adjustments in TDR data quality control

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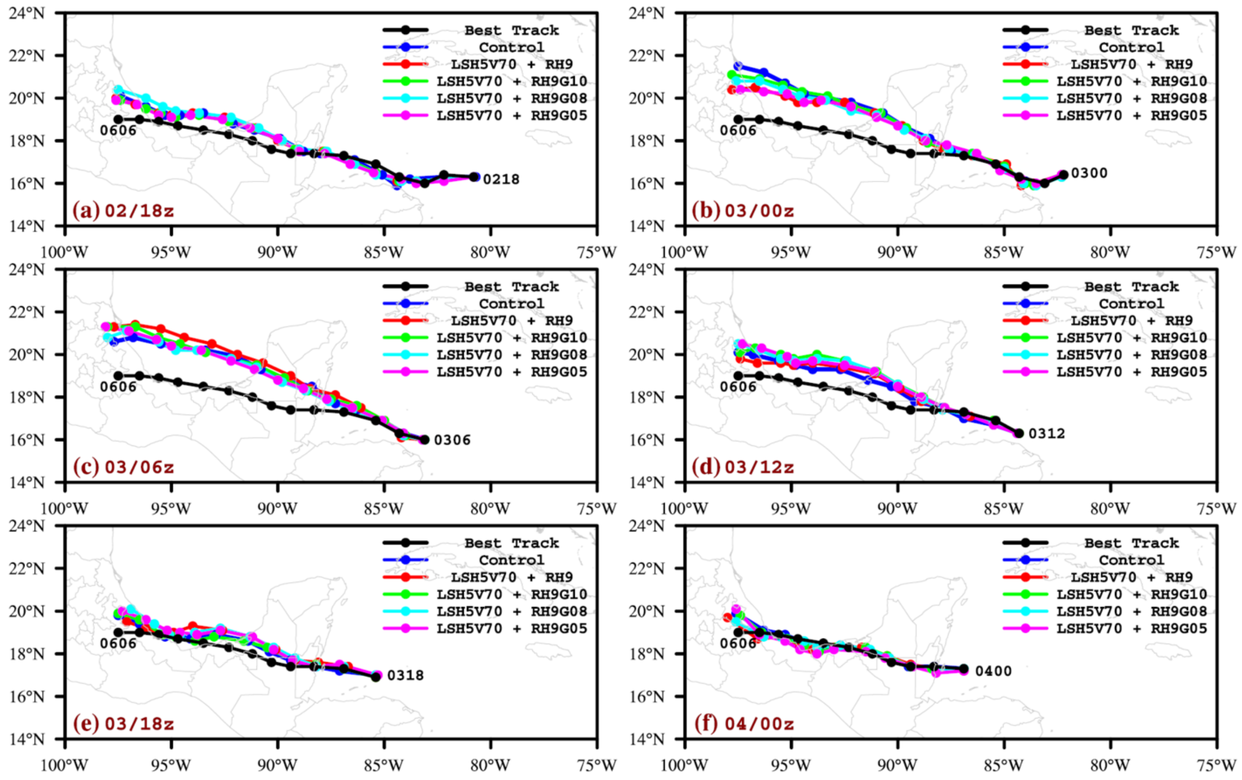
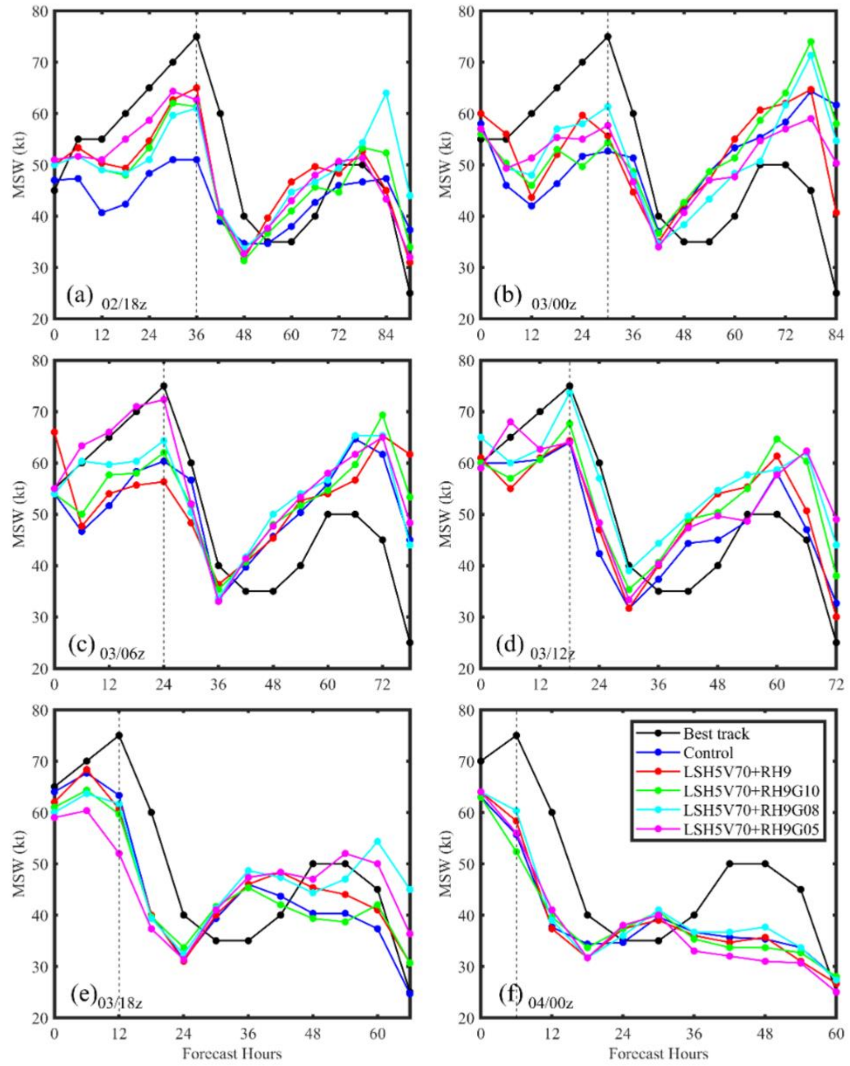
Combined Assimilation: DWL Wind Speeds and TDR Radial Velocity

Track



V_{max}

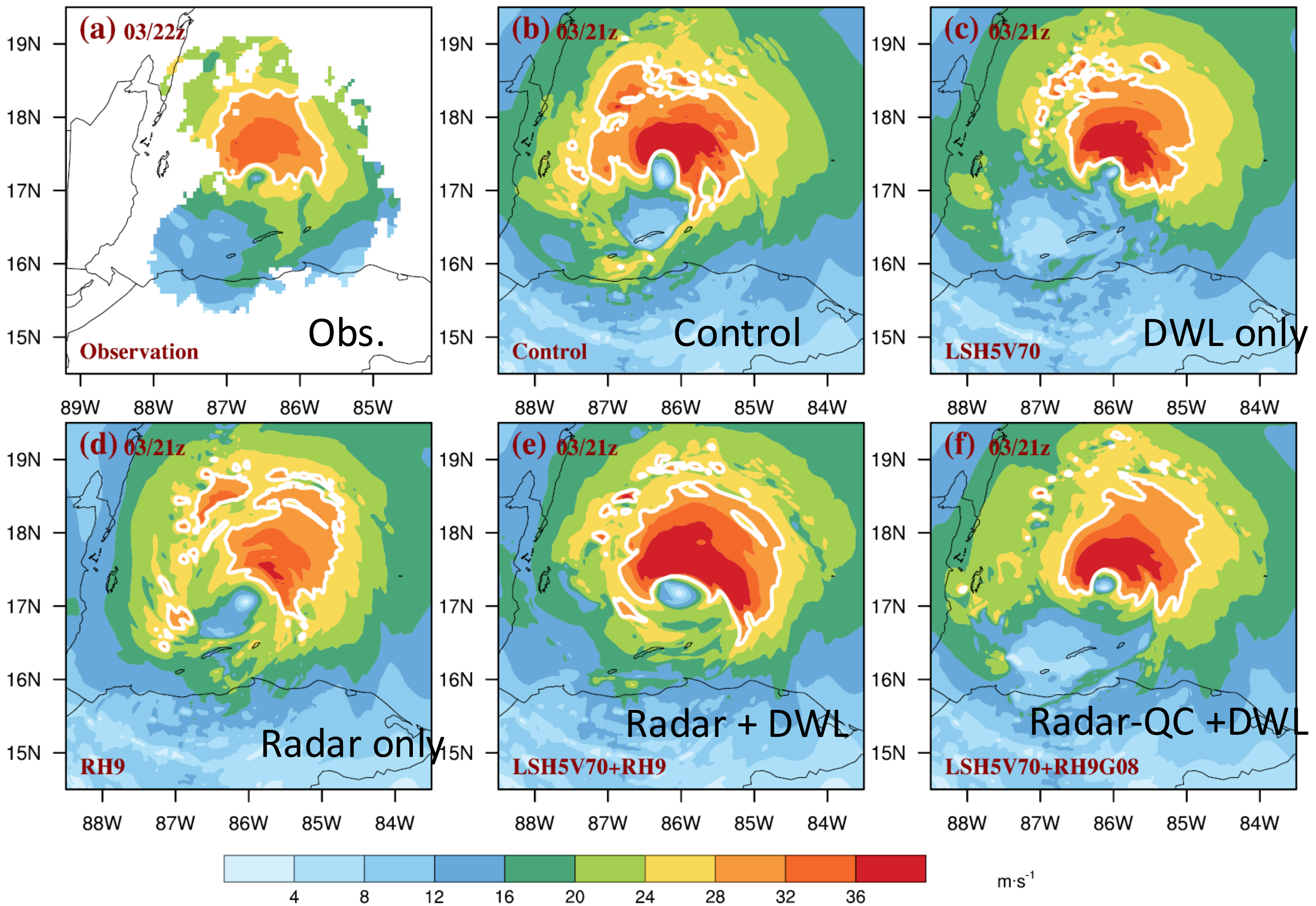


Influence of TDR + DWL

Best track – Black color ; Control. - Blue

Combined Assimilation (Radar +DWL): Influence on Vortex Inner-Core

850 hPa Wind Analysis over the Inner Core at 21 UTC 3 August 2016



Li and Pu (2022)

Summary and Concluding Remarks

- Wind profiles from the Aeolus satellite and airborne Doppler wind lidar (DWL) provide valuable data sources for three-dimensional wind measurements. The assimilation of these wind profiles can have significant positive impacts on numerical simulations of tropical cyclones and tropical convection.

- Three-dimensional wind profiles obtained from space-borne and airborne measurements contribute significantly to the observing system.

- Additionally, attention should be given to developing optimal strategies for integrated data assimilation when combining different types of observations into data assimilation systems.

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