Recent Tropical Cyclone Data Assimilation Research at NOAA/AOML Hurricane Research Division and University of Miami/CIMAS

Altuğ Aksoy

University of Miami / CIMAS
NOAA / AOML / Hurricane Research Division

13 April 2023

Introduction

General Overview of Talk

1. What TC-DA Research Do We Do at HRD and UM?
2. Part 1: Data Collection, Hosting, & Testing
3. Part 2: Testing of New Observing Platforms
4. Part 3: Testing of New DA Methodologies
5. Summary / Final Thoughts

Overview Of TC-DA Research At HRD/UM

TC-DA Research at HRD/UM Spans All Phases of The DA Life Cycle

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- Quality Control and Hosting of Datasets

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2. **New Platforms:**
   - Testing of New Observing Platforms for Data Collection and Assimilation
   - Testing of New Procedures of Quality Control and Preprocessing

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	Testing of New Procedures of Quality Control and Preprocessing
③ **New Methods:**	Development of New Data Assimilation Techniques
④ **Operational:**	Implementation of Above Research in Operational Systems

Part 1:
Data Collection, Hosting, & Testing

Data Collection: The Big Picture (In The Air)

In-situ
- Wind, press., temp., moisture

Expendables
- Dropsondes
- AXBT, AXCP, buoy

Remote Sensors
- Tail Doppler Radar (TDR)
- SFMR/HIRAD
- WSRA
- Scatterometer/profiler
- UAS/sUAS

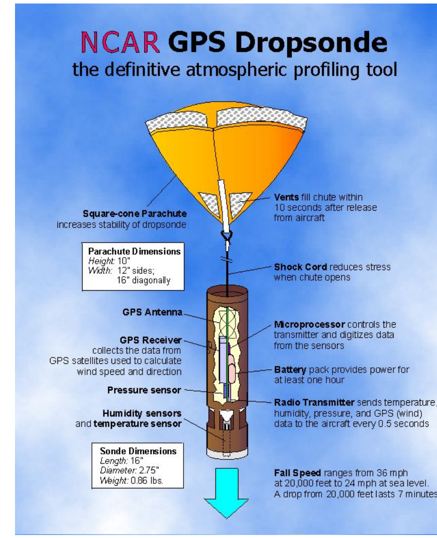
NOAA P-3s

NOAA G-IV

NASA Global Hawk UAS

G-IV Tail Doppler Radar

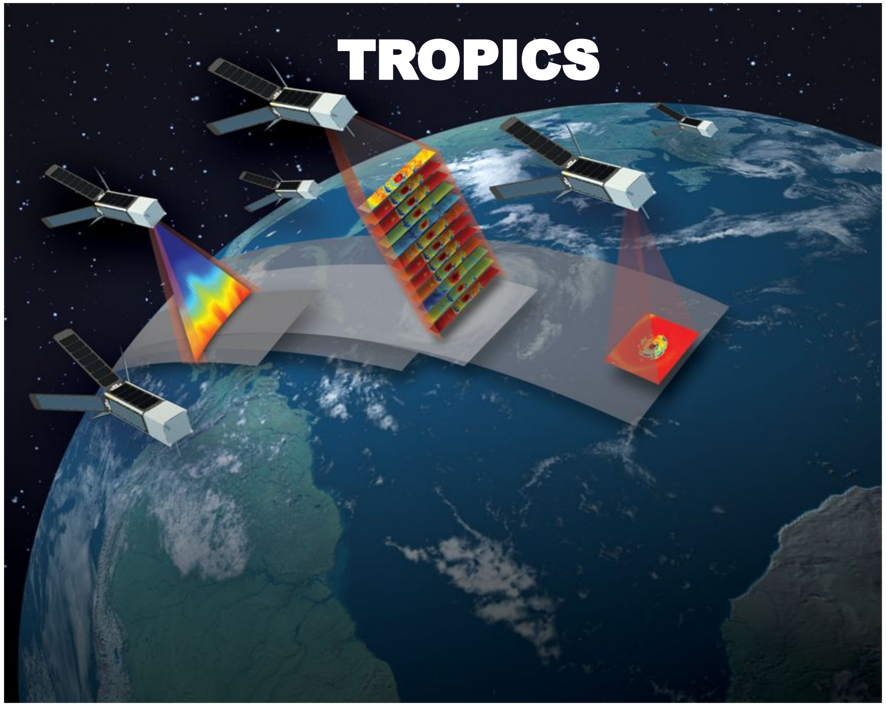
Coyote sUAS



GPS Dropsonde

Doppler Wind Lidar

Data Collection: The Big Picture (In Space)

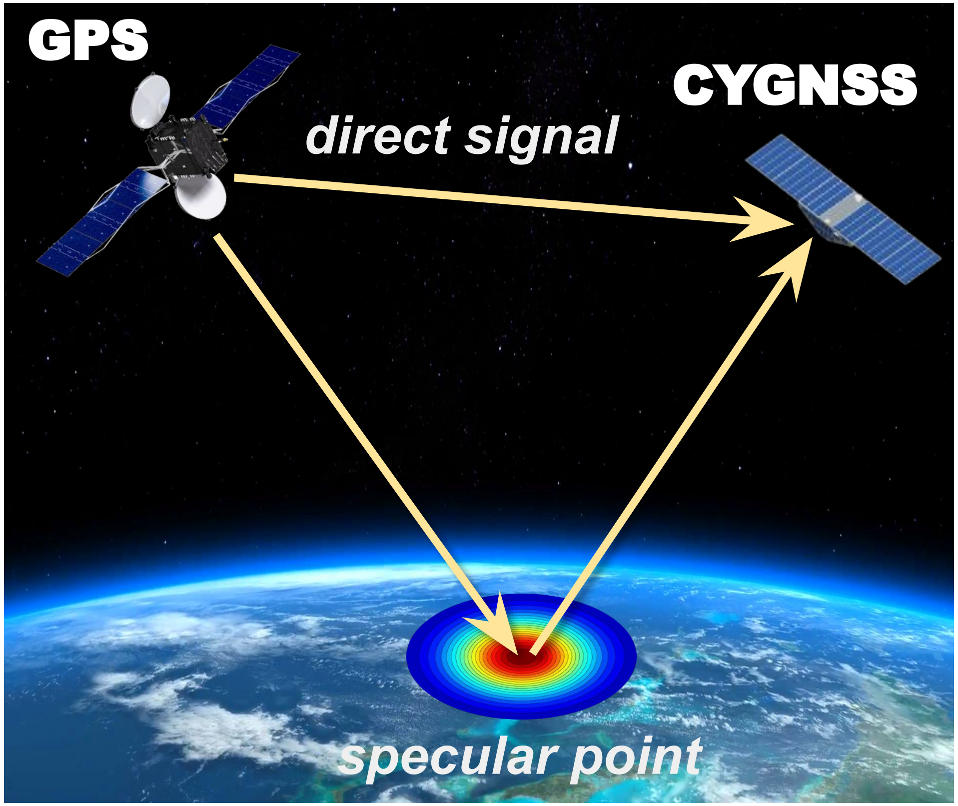


Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS)

Thermodynamics of the Troposphere and Precipitation Structure for Storm Systems

Cyclone Global Navigation Satellite System (CYGNSS)

Surface Wind Speed Retrievals



From Collection To Availability: Data Hosting

Hosting of “Raw” Data Is Still Based on Year/Storm/Particular Mission

From Collection To Availability: Data Hosting

Part 1

Hosting of “Raw” Data Is Still Based on Year/Storm/Particular Mission

https://www.aoml.noaa.gov/2022-hurricane-field-program-data/#ian

+ 20220928U3

− 20220928H1

Wednesday, September 28

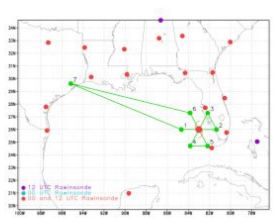
Take Off: 0755Z Harligen	**Aircraft**: NOAA42	**Tasking**: EMC
Landing: 1442Z Harligen	**Mission ID**: 2809A	**Pattern**:Butterfly

Download Data:

SFMR	Dropsonde	Radar	Flight-Level (ASCII)	Flight-Level (NetCDF)

Mission Documents & Plots:

Lead Scientist	Dropsonde	Radar	Flight Director



20220928H1 Proposed Track

+ 20220928U4

+ 20220929U1

+ 20220930U1

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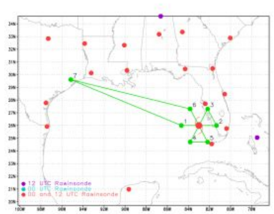

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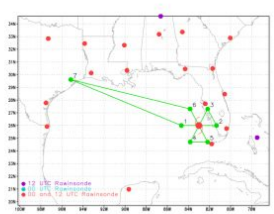

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2 Availability Is Mission-Based

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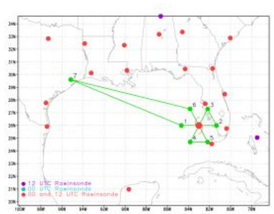

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1 Availability Through AOML/HRD Website

2 Availability Is Mission-Based

3 Availability Is Instrument-Based

From Collection To Availability: Data Formats

Documentation Is Based On Platforms and Info On Ob Errors Is Scarce

From Collection To Availability: Data Formats

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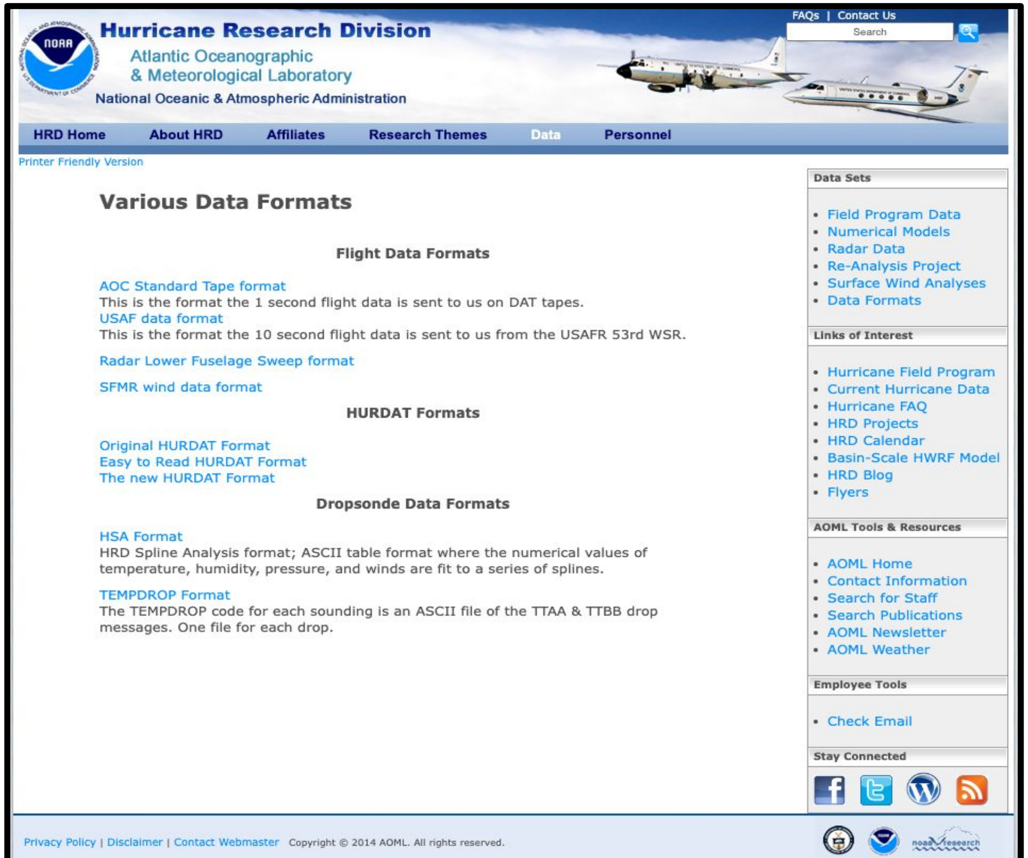

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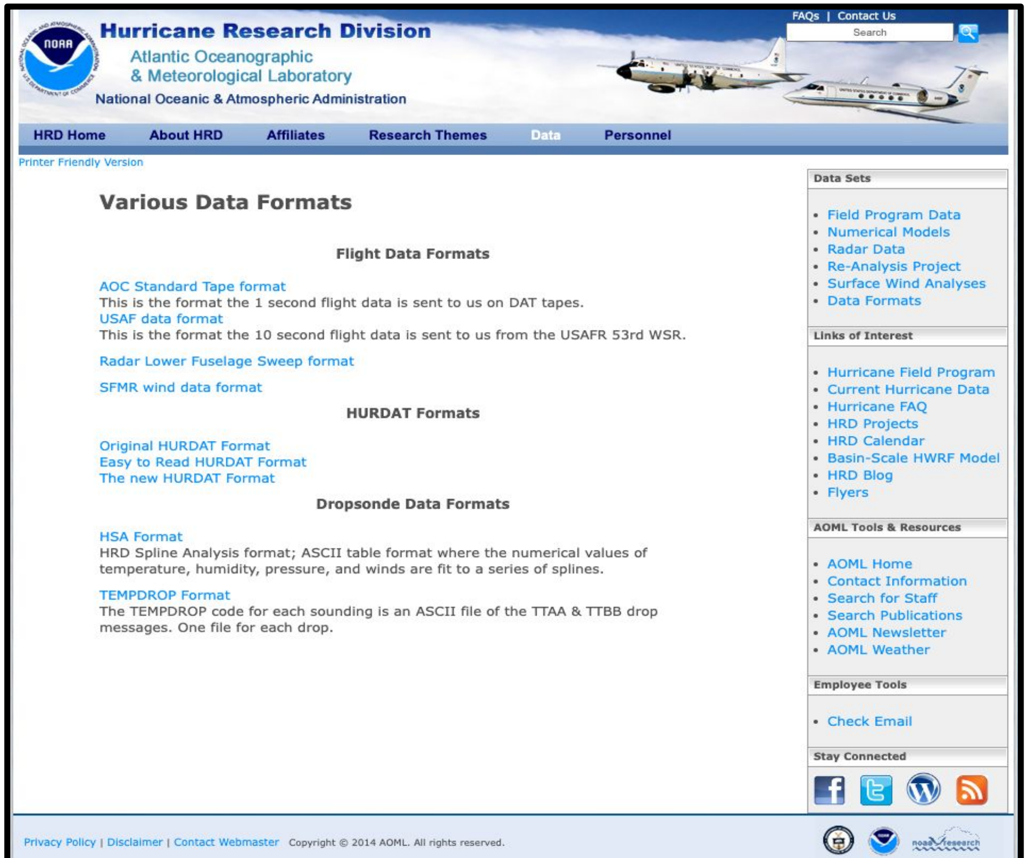

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Printer Friendly Version

Various Data Formats

Flight Data Formats

AOC Standard Tape format
This is the format the 1 second flight data is sent to us on DAT tapes.
USAF data format
This is the format the 10 second flight data is sent to us from the USAFR 53rd WSR.

Radar Lower Fuselage Sweep format

SFMR wind data format

HURDAT Formats

Original HURDAT Format
Easy to Read HURDAT Format
The new HURDAT Format

Dropsonde Data Formats

HSA Format
HRD Spline Analysis format; ASCII table format where the numerical values of temperature, humidity, pressure, and winds are fit to a series of splines.

TEMPDROP Format
The TEMPDROP code for each sounding is an ASCII file of the TTAA & TTBB drop messages. One file for each drop.

Data Sets

- Field Program Data
- Numerical Models
- Radar Data
- Re-Analysis Project
- Surface Wind Analyses
- Data Formats

Links of Interest

- Hurricane Field Program
- Current Hurricane Data
- Hurricane FAQ
- HRD Projects
- HRD Calendar
- Basin-Scale HWRF Model
- HRD Blog
- Flyers

AOML Tools & Resources

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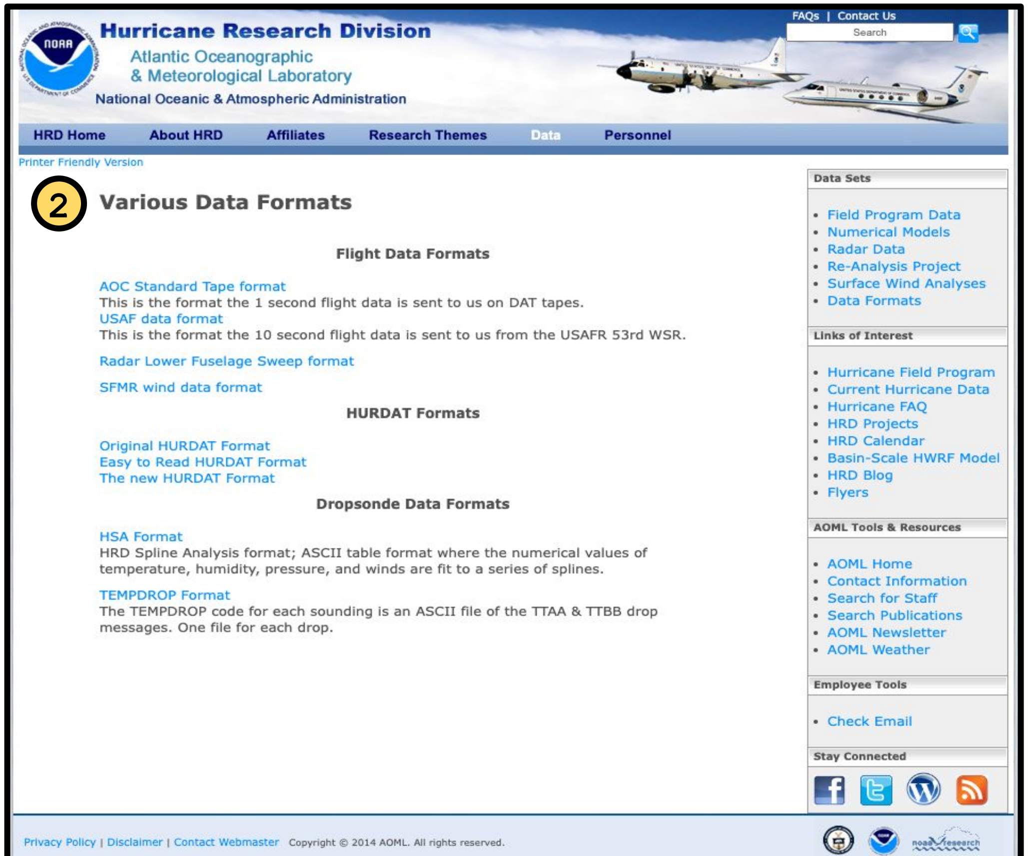

1 Availability Through AOML/HRD Website

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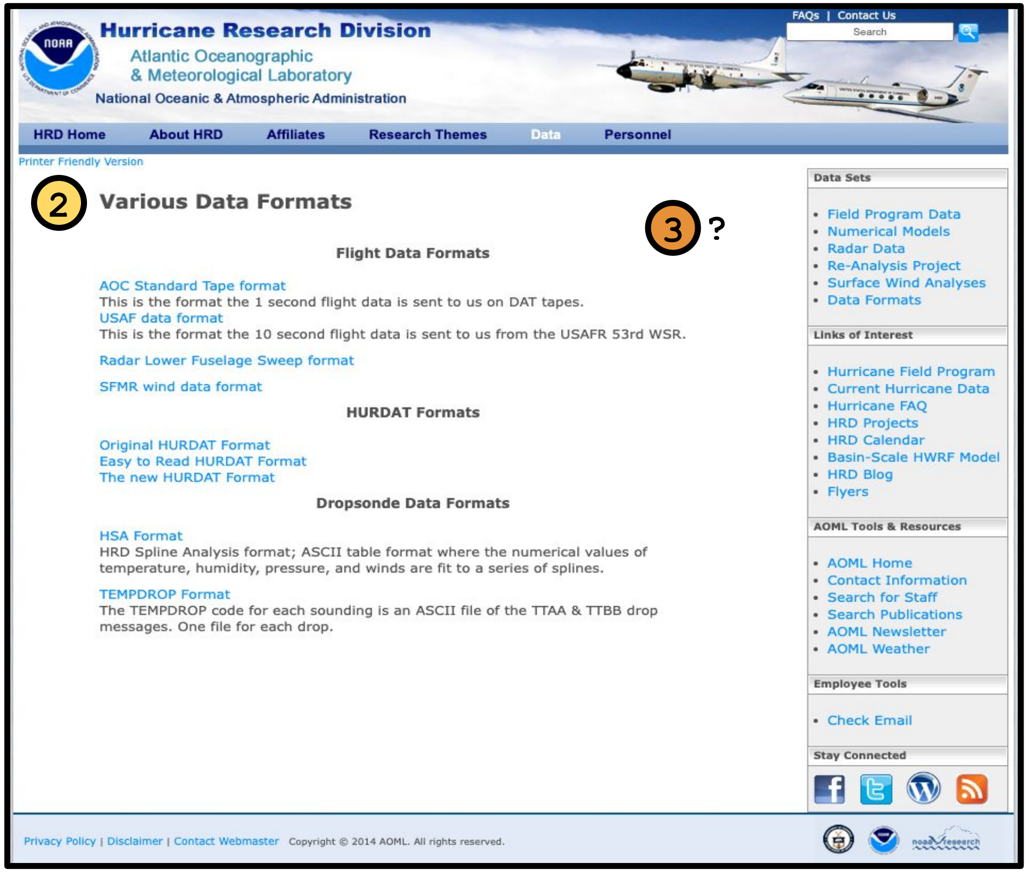

1 Availability Through AOML/HRD Website

2 Availability Is Platform-Based

3 No Straightforward Information On Observation Errors

HRDOBS: A Comprehensive TC Dataset For DA

A Comprehensive Dataset For Data Assimilation And Science Applications

(K. Sellwood and A. Aksoy)

- Uses A common observation-processing environment to apply quality control, estimate errors, and convert to standard observation types and scientific units
- Collects observations for all tropical cyclones for which a TC-Vitals file exists
- Centered on 6-h synoptic times (e.g., 00Z, 06Z,12Z,18Z) within +/- 3 h of syn. time
- Contains observations within 20 geographical degrees of the TC-Vitals center
- HDF-5 file format with all platforms/data contained in a single file
- Contains metadata: Storm position & motion, available platforms & instruments
- Supplemental info file with observation counts for each platform
- Currently available for years 2014-2020 with the full dataset to go back to year 2010
- Will be hosted with a DOI following general data hosting standards

HRDOBS: A Comprehensive TC Dataset For DA

A Comprehensive Dataset For Data Assimilation And Science Applications

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INSTRUMENT	AVAILABLE OBSERVATIONS
DROPSONDE	U V wind, Temperature, Specific Humidity every 5 mb
FLIGHT-LEVEL	U V wind, Temperature, Specific Humidity, Pressure
SFMR	Surface Wind Speed, Rain Rate, RR dependent wind error
TDR	Radial Wind Speed Superobs
SUAS	U V wind, Temperature, Specific Humidity, Pressure
DWL	U V wind profiles
BEST TRACK	Center lat/lon, Vmax, Pmin, RMW
HIGH RESOLUTION TRACK	Center lat/lon
VORTEX MESSAGE	Center lat/lon, Observed Vmax (spd and dir) and Pmin

HRDOBS: A Comprehensive TC Dataset For DA

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(K. Sellwood and A. Aksoy)

Sample Supplemental Info File That Contains Number of Observations From Each Observing Platform

```
STORMNAME: BARRY                 STORMNUMBER: 02L
CENTER LAT: 27.8                 CENTER LON: -89.0
DATE VALID: 20190711             TIME VALID: 1800UTC
TIMEWINDOW: 1500Z TO 2100Z
-----------------------------------------------------------------------
PLATFORM                             #OBS                  #OBS
                                 RAW DATA              FINAL QC
-----------------------------------------------------------------------
NOAA 42 Dropsonde                    5310                  4995
NOAA 43 Dropsonde                       0                     0
NOAA 49 Dropsonde                       0                     0
USAF Dropsonde                          0                     0
GHAWK Dropsonde                         0                     0
NOAA 42 Flight-Level                 1408                  1408
NOAA 42 SFMR                         1408                  1408
NOAA 43 Flight-Level                    0                     0
NOAA 43 SFMR                            0                     0
USAF Flight-Level                    1008                   994
NOAA 49 Flight-Level                    0                     0
NOAA 49 SFMR                            0                     0
USAF SFMR                            1008                   994
NOAA 42 TDR                         45252                 45252
NOAA 43 TDR                             0                     0
NOAA 49 TDR                             0                     0
Coyote                                  0                     0
DWL                                     0                     0
Vortex Message                          0                     0
Best Track                             35                    35
Hi-Res Track                         2215                  2215
TOTAL                               57644                 57301
```

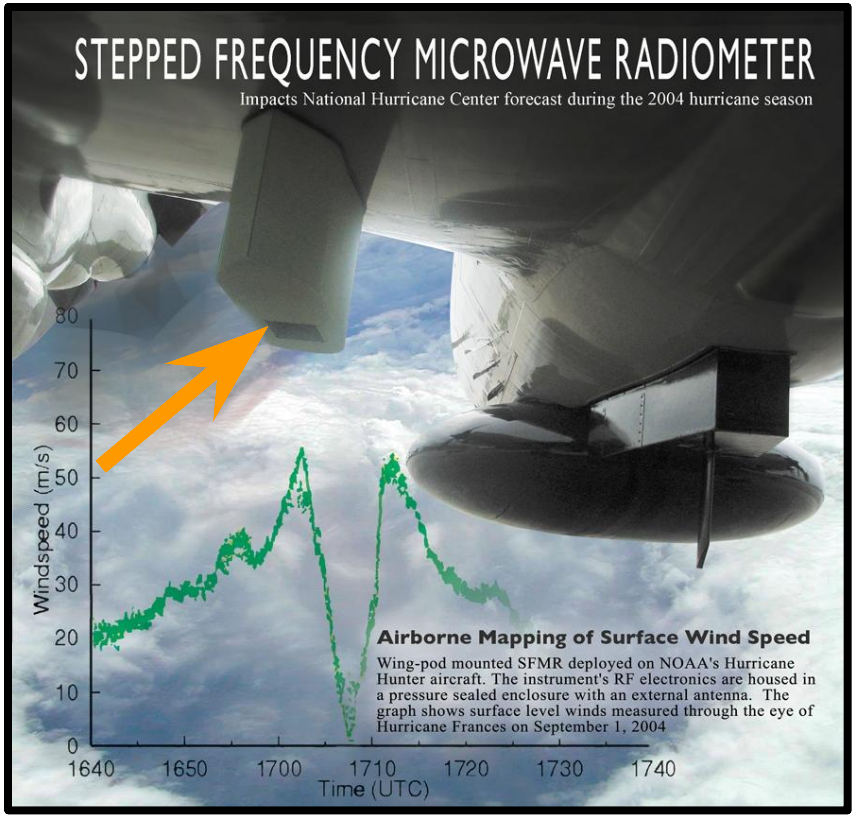
SFMR High-Wind/Rain Errors: Further Analysis

Part 1

H. Hollbach (FSU, NGI, AOML/HRD)

Stepped Frequency Microwave Radiometer (SFMR)

- Installed underneath the NOAA P-3 and Air Force Reserves' C-130 Hurricane Hunter aircraft
- Downward-looking infrared radiometer passively reads the microwave radiation coming from the ocean surface
- Estimates of the ocean surface brightness temperature are made at six frequencies between 4.6 and 7.2 GHz
- Regression relationships are then used to make estimates of the surface wind speed and rain rate

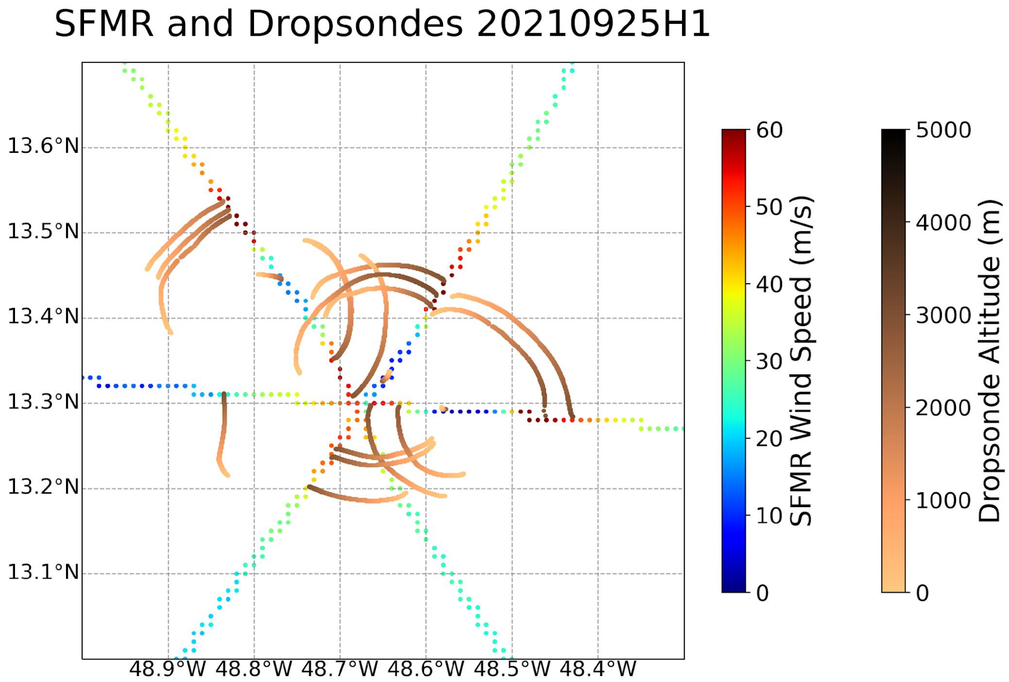


SFMR High-Wind/Rain Errors: Further Analysis

H. Hollbach (FSU, NGI, AOML/HRD)

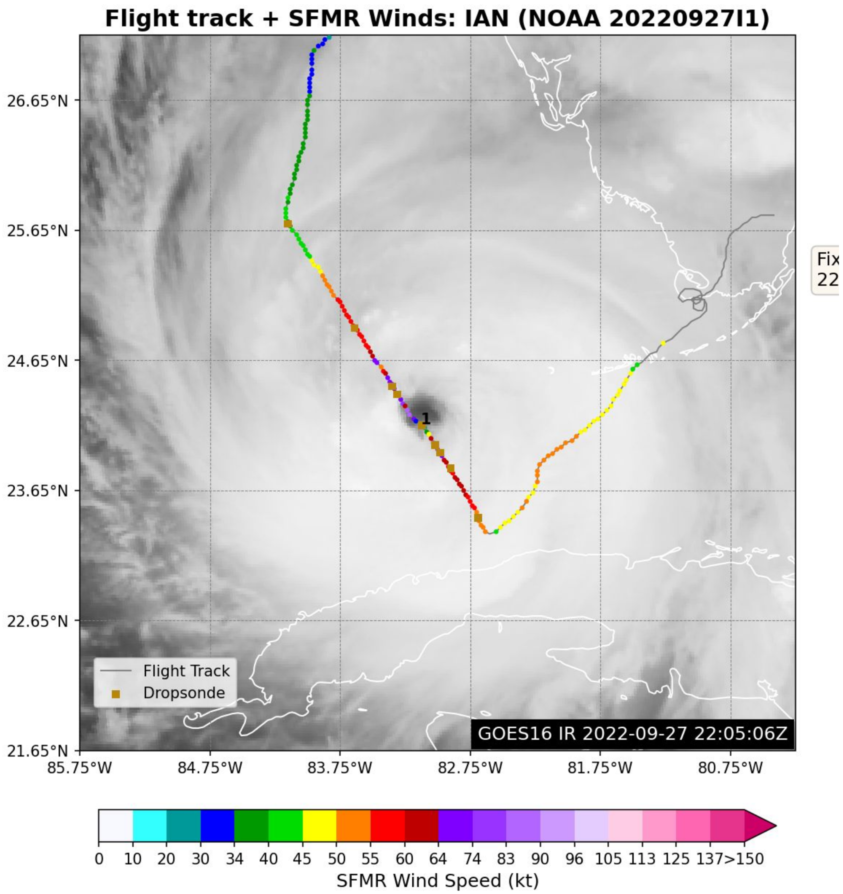
Stepped Frequency Microwave Radiometer (SFMR): Problems Identified

- Colocations with dropsondes in high winds are challenging
- Primary option for independent rain rate source is TDR, which does not have a calibrated reflectivity archive
  - Previous TDR Z-R relationship may not be reliable
- Coincident IWRAP data show misalignment of near-surface wind speed peak compared to SFMR in high winds and high rain

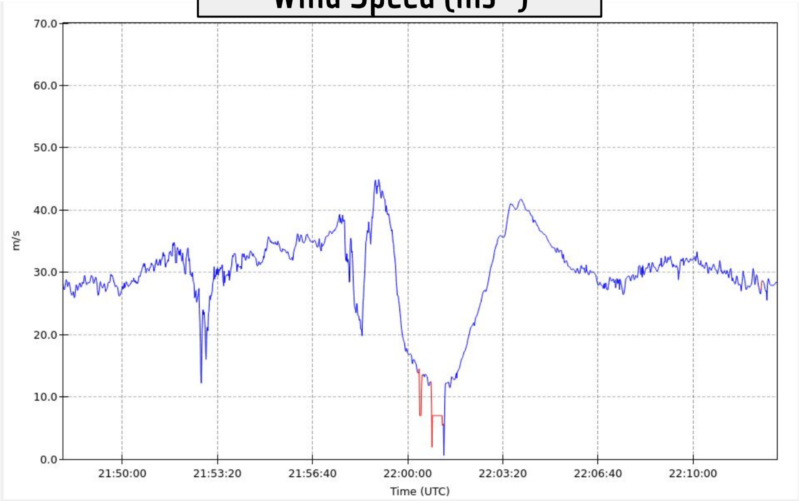


SFMR High-Wind/Rain Errors: Example in Hurricane Ian

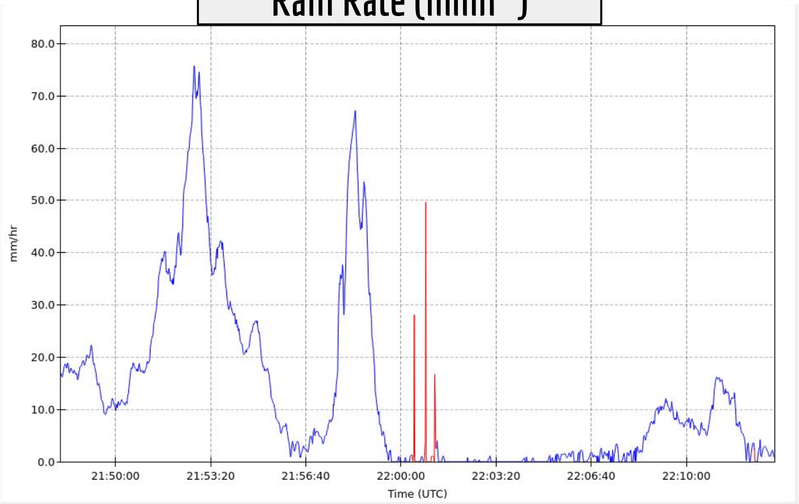
H. Hollbach (FSU, NGI, AOML/HRD)



Wind Speed (ms^{-1})



Rain Rate (mmh^{-1})



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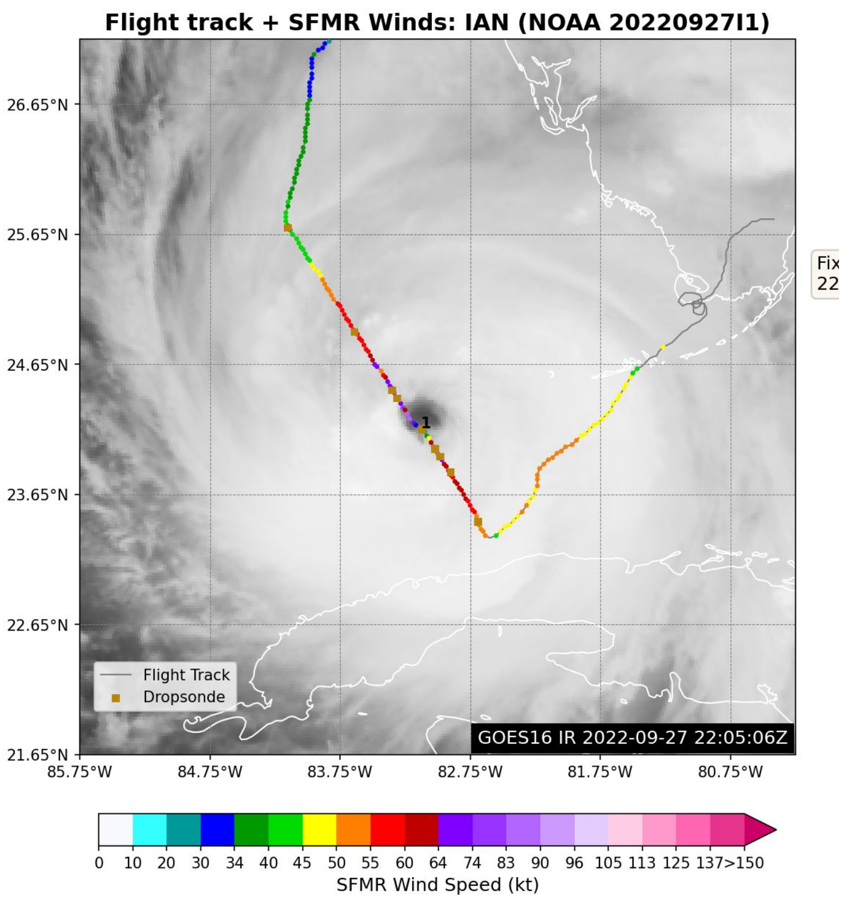
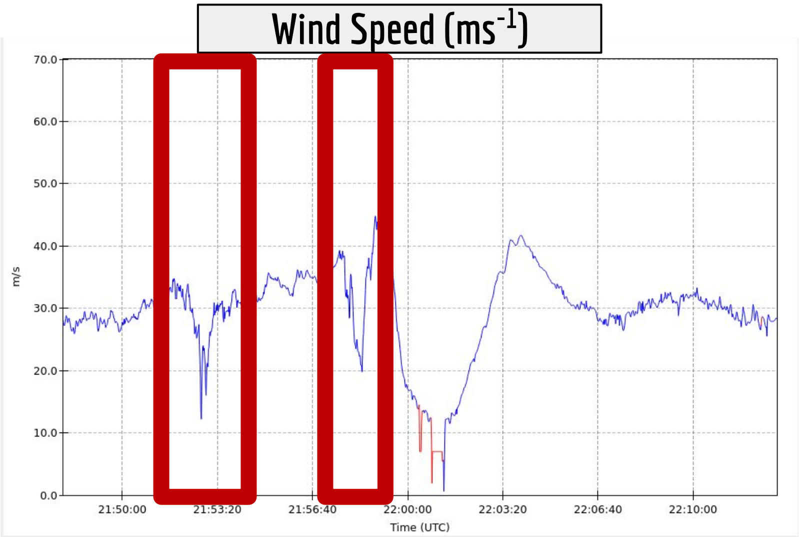
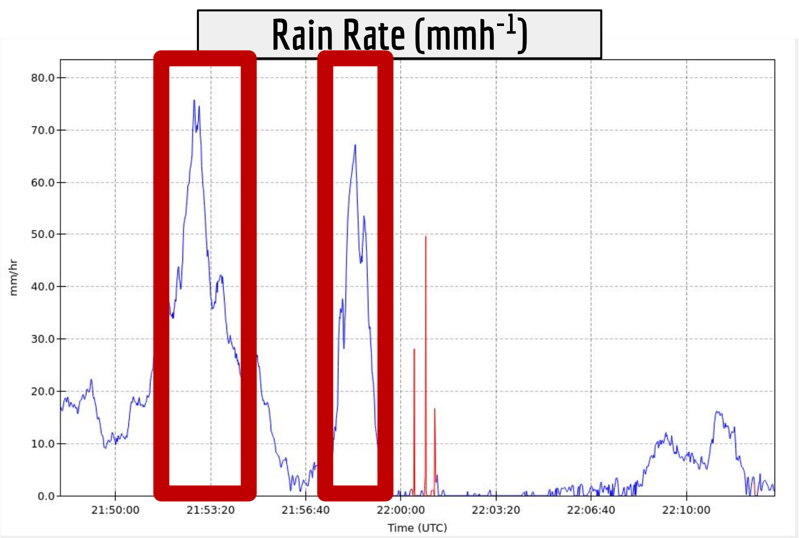


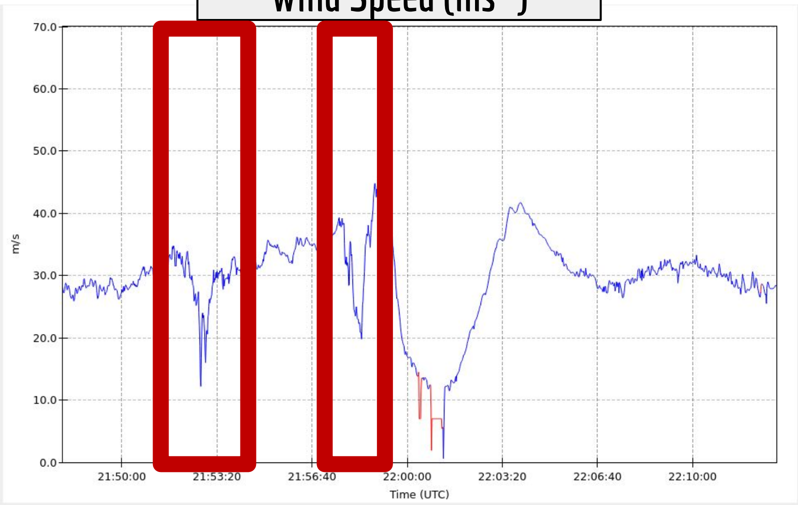




SFMR High-Wind/Rain Errors: Implications

H. Hollbach (FSU, NGI, AOML/HRD)

Wind Speed (ms^{-1})



- SFMR radiative transfer equations may not be accounting for rain correctly when larger drops are present
- Uncertainty in magnitude and location of peak wind speed
- Additional uncertainty for intensity estimation
- Potential mismatches between NHC Best Track intensity and DA analyses that incorporate more than just SFMR data

Part 2:
Testing Of New Observing Platforms

Example: Assimilation of sUAS Observations

AOML/HRD and UM/CIMAS Are Involved In The Testing of Several sUAS Platforms

Example: Assimilation of sUAS Observations

AOML/HRD and UM/CIMAS Are Involved In The Testing of Several sUAS Platforms

1

AREA-I Altius 600

Endurance: 4+ Hours Demonstrated

Range: 276 mi / 440 km

Weight: 20-27 lbs (3-7lb Payload)

Launch Platforms: Dropsonde chute

Example: Assimilation of sUAS Observations

Part 2

AOML/HRD and UM/CIMAS Are Involved In The Testing of Several sUAS Platforms

1

AREA-I Altius 600

Endurance: 4+ Hours Demonstrated

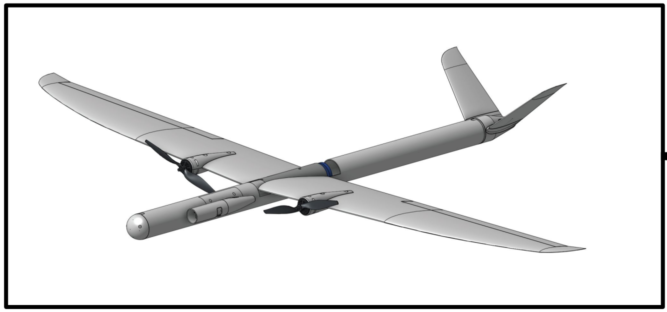
Range: 276 mi / 440 km

Weight: 20-27 lbs (3-7lb Payload)

Launch Platforms: Dropsonde chute

2

Blackswift S0



Endurance: 90 minutes

Range: Up to 15,000 ft AGL

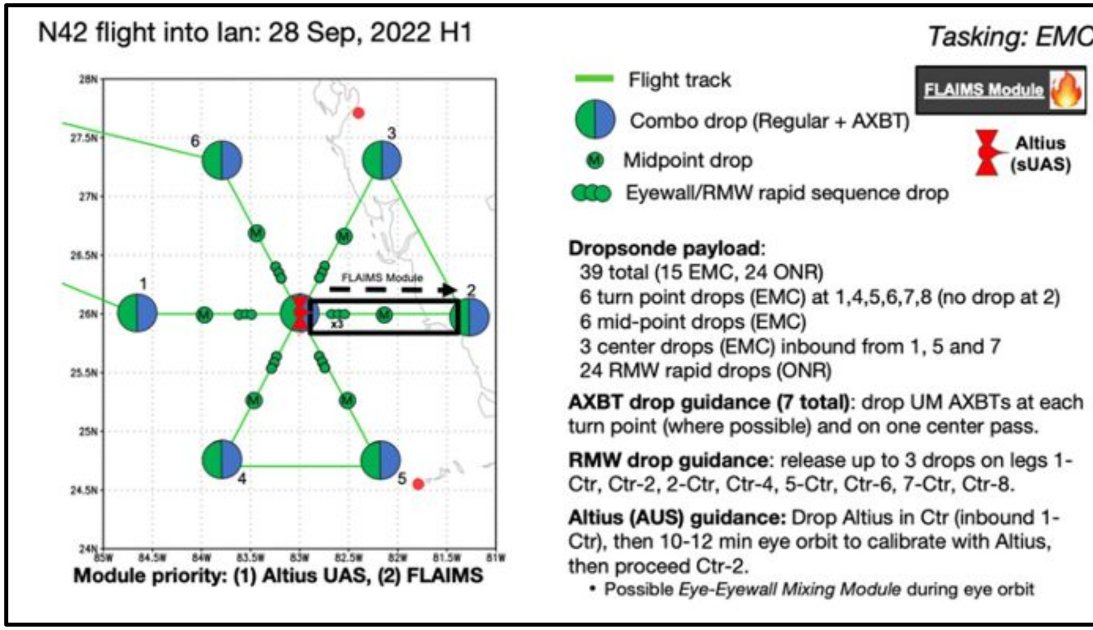
Weight: 3.5 lbs

Launch Platforms: Dropsonde chute

Altius sUAS DA: Case & Data

(K. Sellwood, D. Wu, A. Aksoy, J. Sippel)

Hurricane Ian (2022)
Mission Plan



Altius sUAS DA: Case & Data

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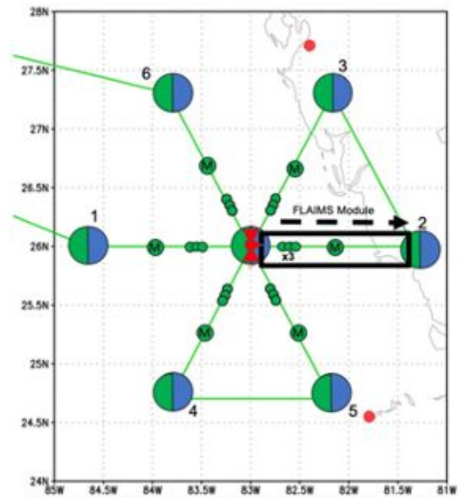
Hurricane Ian (2022) Mission Plan

N42 flight into Ian: 28 Sep, 2022 H1

Tasking: EMC



Module priority: (1) Altius UAS, (2) FLAIMS

- Flight track
- Combo drop (Regular + AXBT)
- Midpoint drop
- Eyewall/RMW rapid sequence drop

FLAIMS Module

Altius (sUAS)

Dropsonde payload:

39 total (15 EMC, 24 ONR)
6 turn point drops (EMC) at 1,4,5,6,7,8 (no drop at 2)
6 mid-point drops (EMC)
3 center drops (EMC) inbound from 1, 5 and 7
24 RMW rapid drops (ONR)

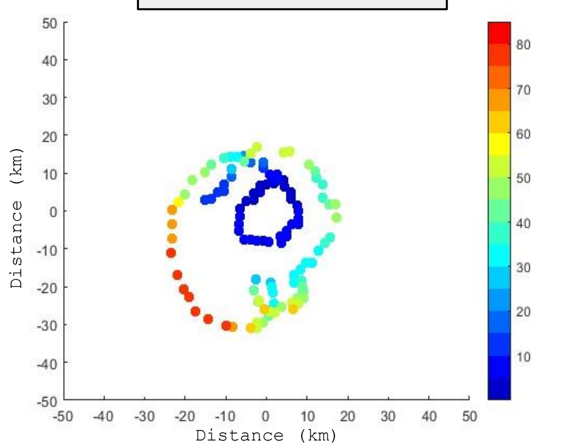
AXBT drop guidance (7 total): drop UM AXBTs at each turn point (where possible) and on one center pass.

RMW drop guidance: release up to 3 drops on legs 1-Ctr, Ctr-2, 2-Ctr, Ctr-4, 5-Ctr, Ctr-6, 7-Ctr, Ctr-8.

Altius (AUS) guidance: Drop Altius in Ctr (inbound 1-Ctr), then 10-12 min eye orbit to calibrate with Altius, then proceed Ctr-2.

- Possible *Eye-Eyewall Mixing Module* during eye orbit

Wind Speed (ms^{-1})



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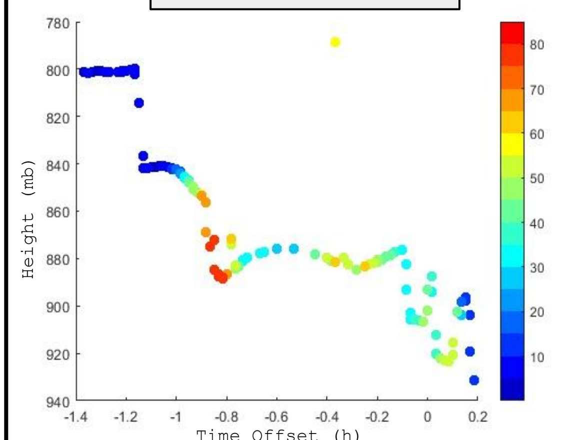
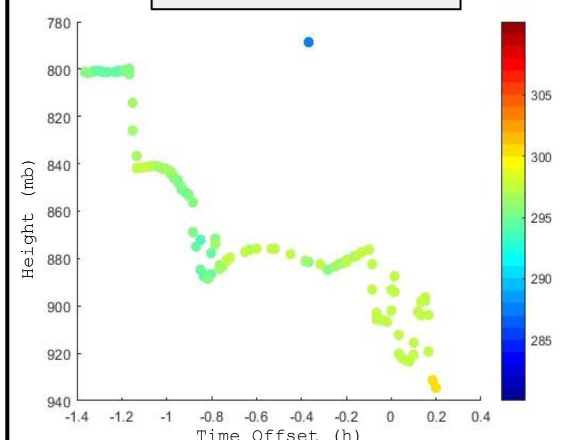
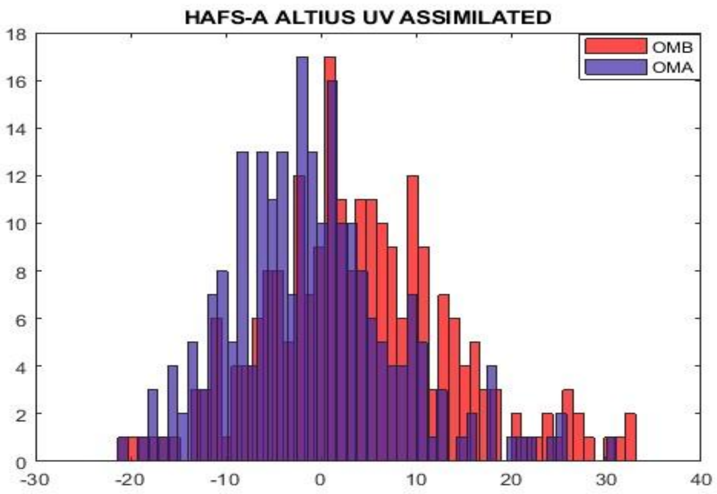


Temperature (K)



Altius sUAS DA: OMA/OMB Stats (UV)

(K. Sellwood, D. Wu, A. Aksoy, J. Sippel)



HAFS-A ALTIUS UV	ACCEPTED OMB	OMA	REJECTED OMB	OMA
#OBS	234	234	4	4
RMS ERROR	10.96	8.85	72.36	71.21
ABS ERROR	8.42	6.82	62.79	61.92
BIAS	4.16	-0.94	44.76	43.01

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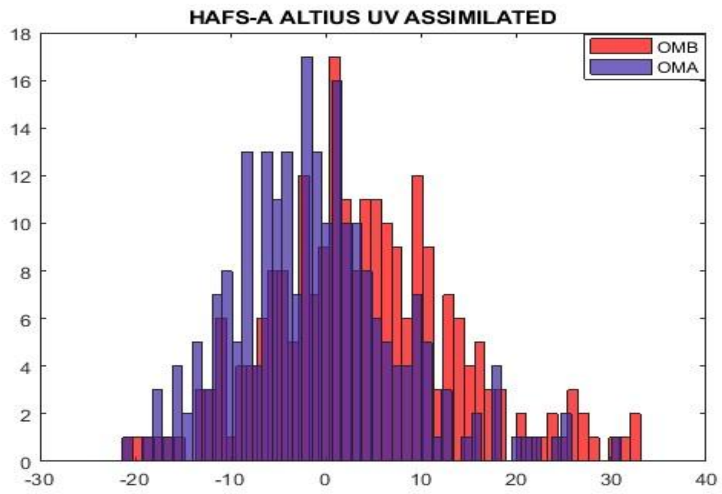

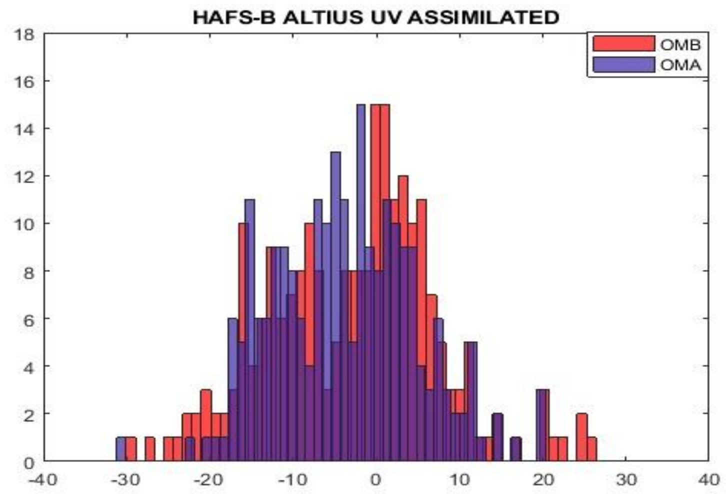

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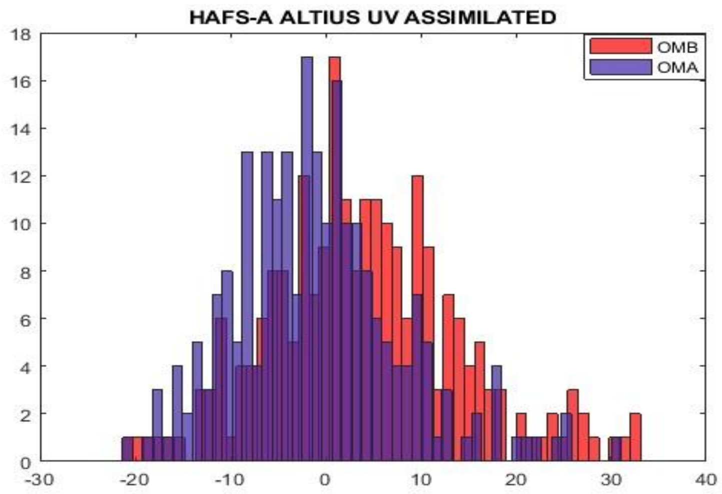
#OBS	234	234	4	4
RMS ERROR	10.96	8.85	72.36	71.21
ABS ERROR	8.42	6.82	62.79	61.92
BIAS	4.16	-0.94	44.76	43.01

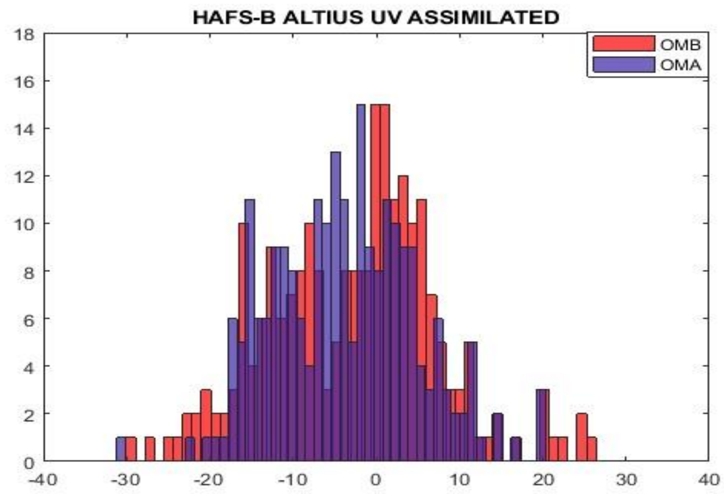
HAFS-B ALTIUS UV	ACCEPTED OMB	OMA	REJECTED OMB	OMA
#OBS	228	228	4	4
RMS ERROR	10.53	9.43	68.19	68.85
ABS ERROR	8.19	7.60	58.84	59.65
BIAS	-2.67	-3.79	39.54	39.96

Altius sUAS DA: OMA/OMB Stats (UV)

Part 2

(K. Sellwood, D. Wu, A. Aksoy, J. Sippel)



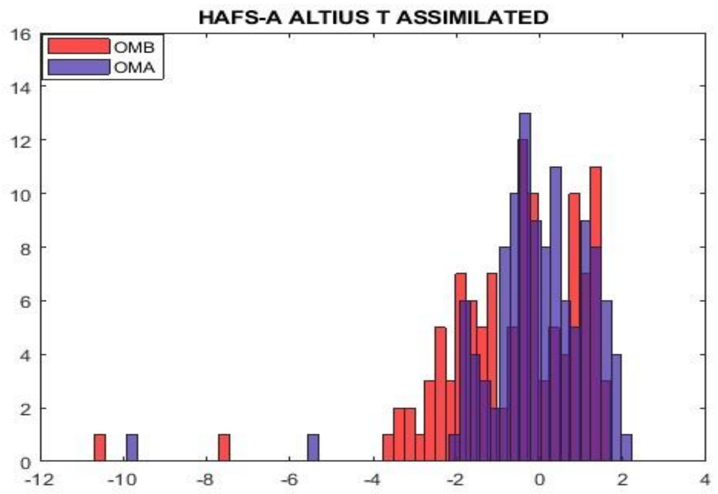


HAFS-A ALTIUS UV	ACCEPTED OMB	OMA	REJECTED OMB	OMA
#OBS	234	234	4	4
RMS ERROR	10.96	8.85	72.36	71.21
ABS ERROR	8.42	6.82	62.79	61.92
BIAS	4.16	-0.94	44.76	43.01

HAFS-B ALTIUS UV	ACCEPTED OMB	OMA	REJECTED OMB	OMA
#OBS	228	228	4	4
RMS ERROR	10.53	9.43	68.19	68.85
ABS ERROR	8.19	7.60	58.84	59.65
BIAS	-2.67	-3.79	39.54	39.96

Altius sUAS DA: OMA/OMB Stats (T)

(K. Sellwood, D. Wu, A. Aksoy, J. Sippel)



HAFS-A ALTIUS T	ACCEPTED OMB	OMA	REJECTED OMB	OMA
#OBS	116	116	0	0
RMS ERROR	1.88	1.45	n/a	n/a
ABS ERROR	1.33	0.95	n/a	n/a
BIAS	-0.63	-0.04	n/a	n/a

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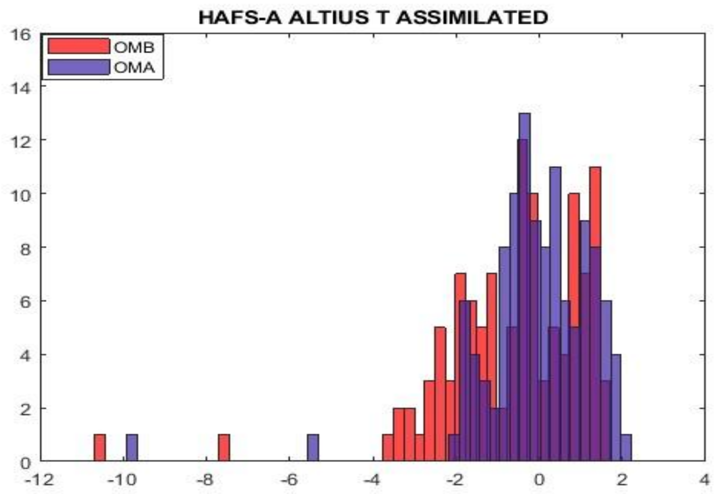

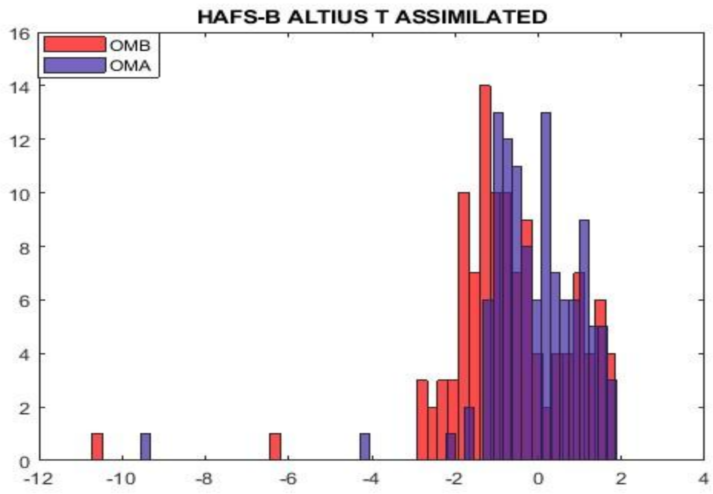

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HAFS-B ALTIUS T	ACCEPTED OMB	OMA	REJECTED OMB	OMA
#OBS	115	115	0	0
RMS ERROR	1.74	1.32	n/a	n/a
ABS ERROR	1.23	0.88	n/a	n/a
BIAS	-0.71	-0.11	n/a	n/a

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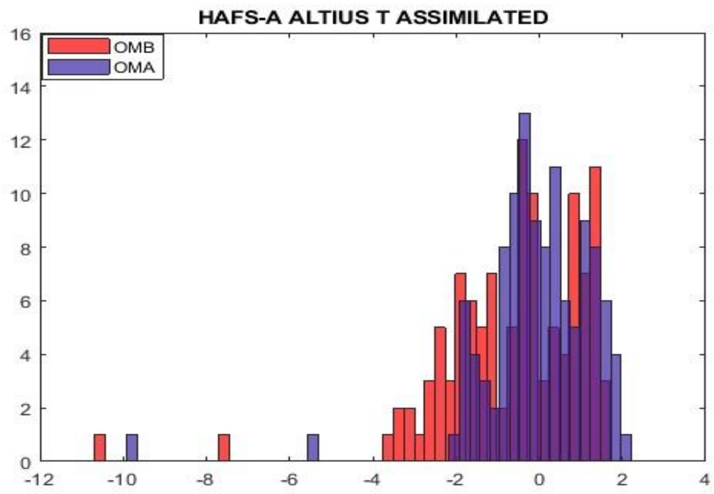

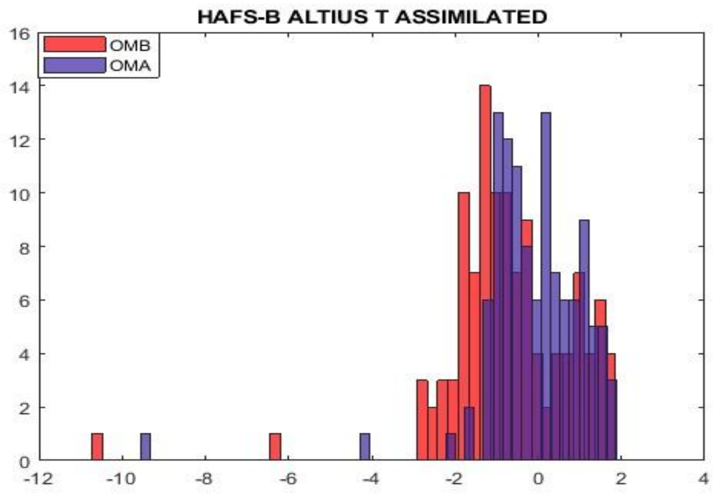

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Altius sUAS DA: Forecast Error Comparison

(K. Sellwood, D. Wu, A. Aksoy, J. Sippel)

MEAN ERROR	TRACK	VMAX	PMIN
HAFS-A CONTROL	160.39	6.26	7.75
HAFS-A ALTIUS	158.94	6.71	7.67
HAFS-B CONTROL	144.73	5.58	8.17
HAFS-B ALTIUS	151.40	5.94	8.5

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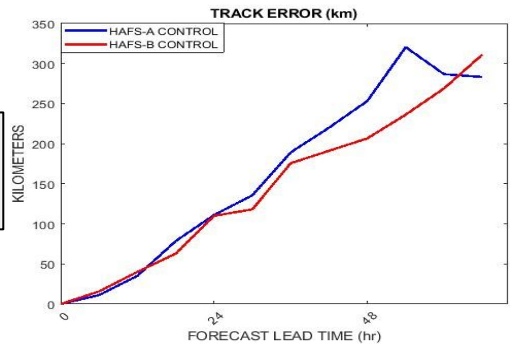
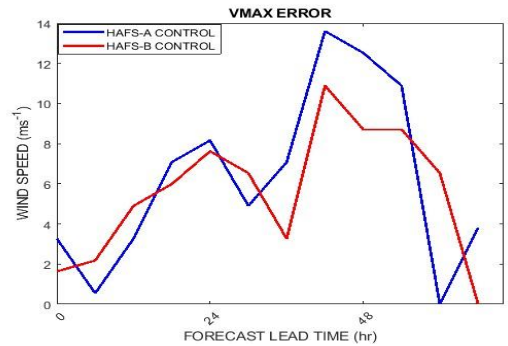
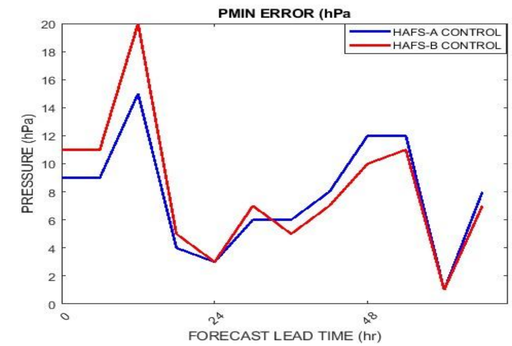
Control
HAFS-A vs. HAFS-B







Altius sUAS DA: Forecast Error Comparison

Part 2

(K. Sellwood, D. Wu, A. Aksoy, J. Sippel)

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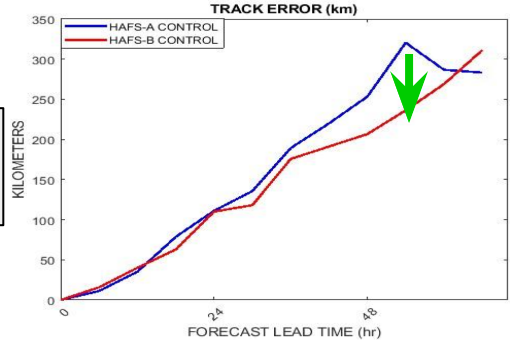

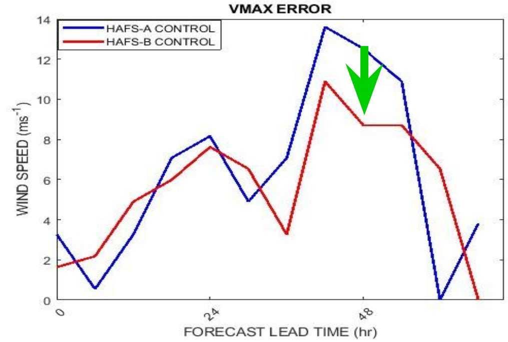

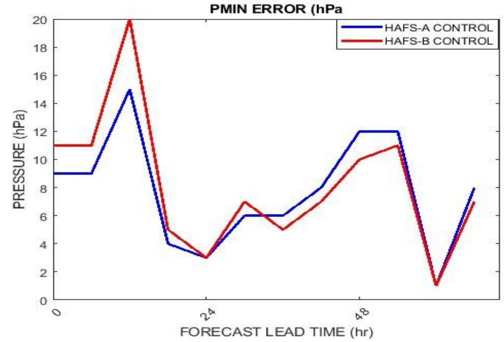

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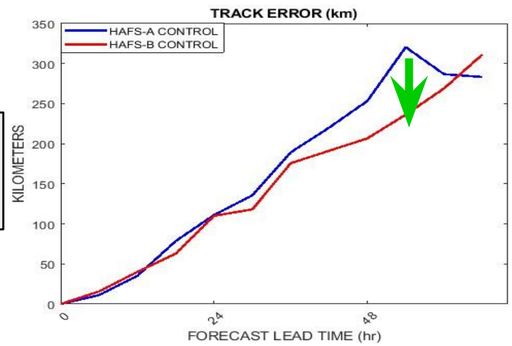
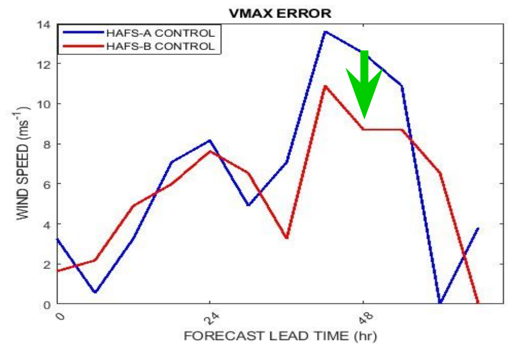
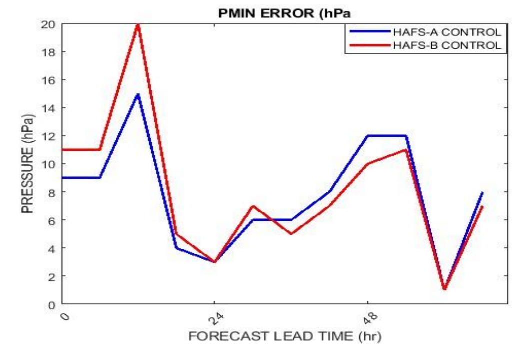
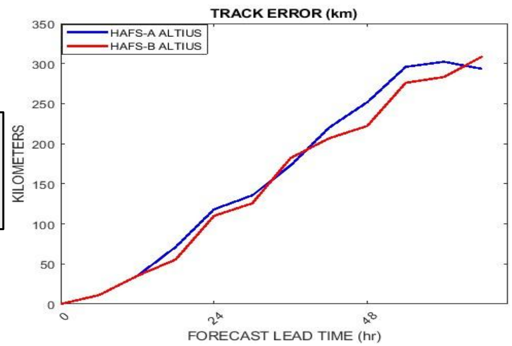
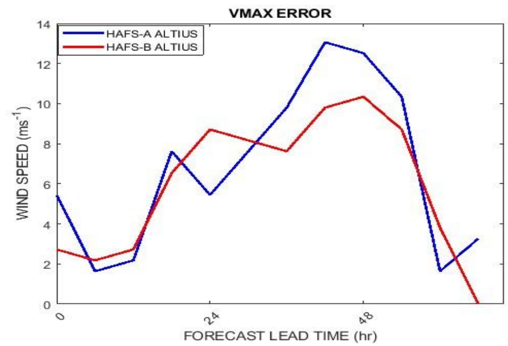


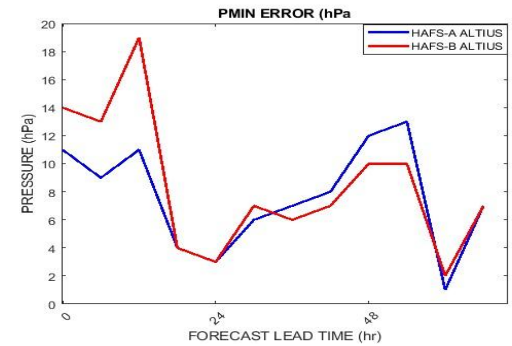




Control+Altius
HAFS-A vs. HAFS-B







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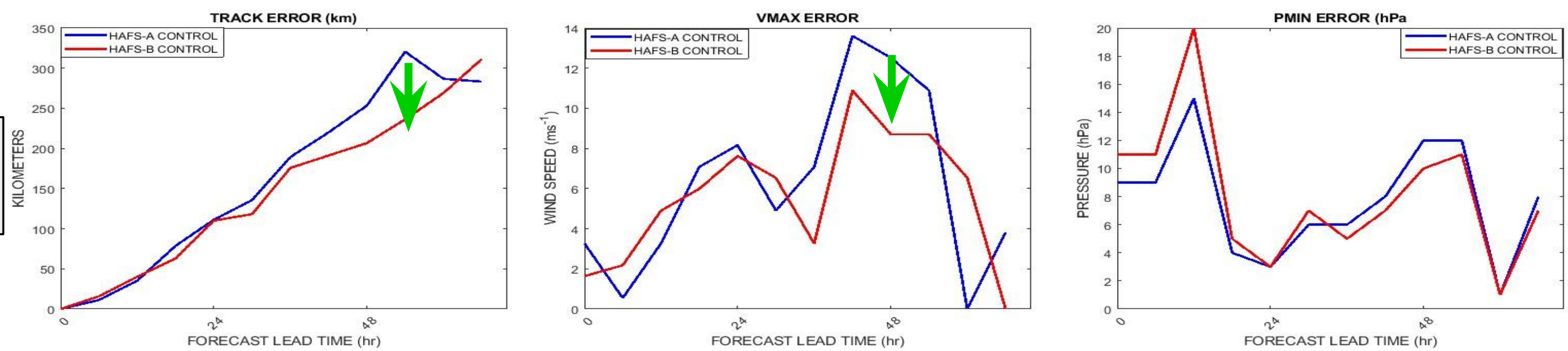

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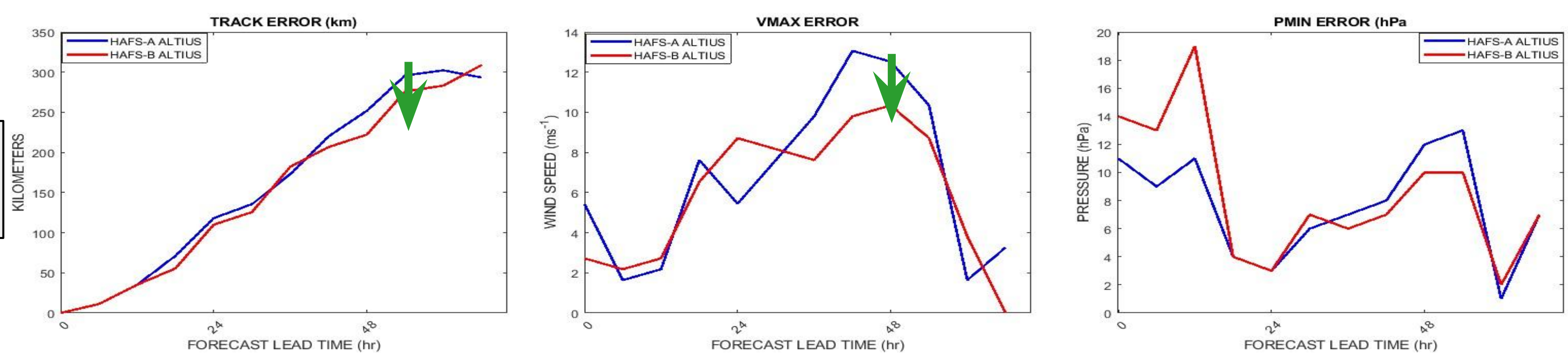

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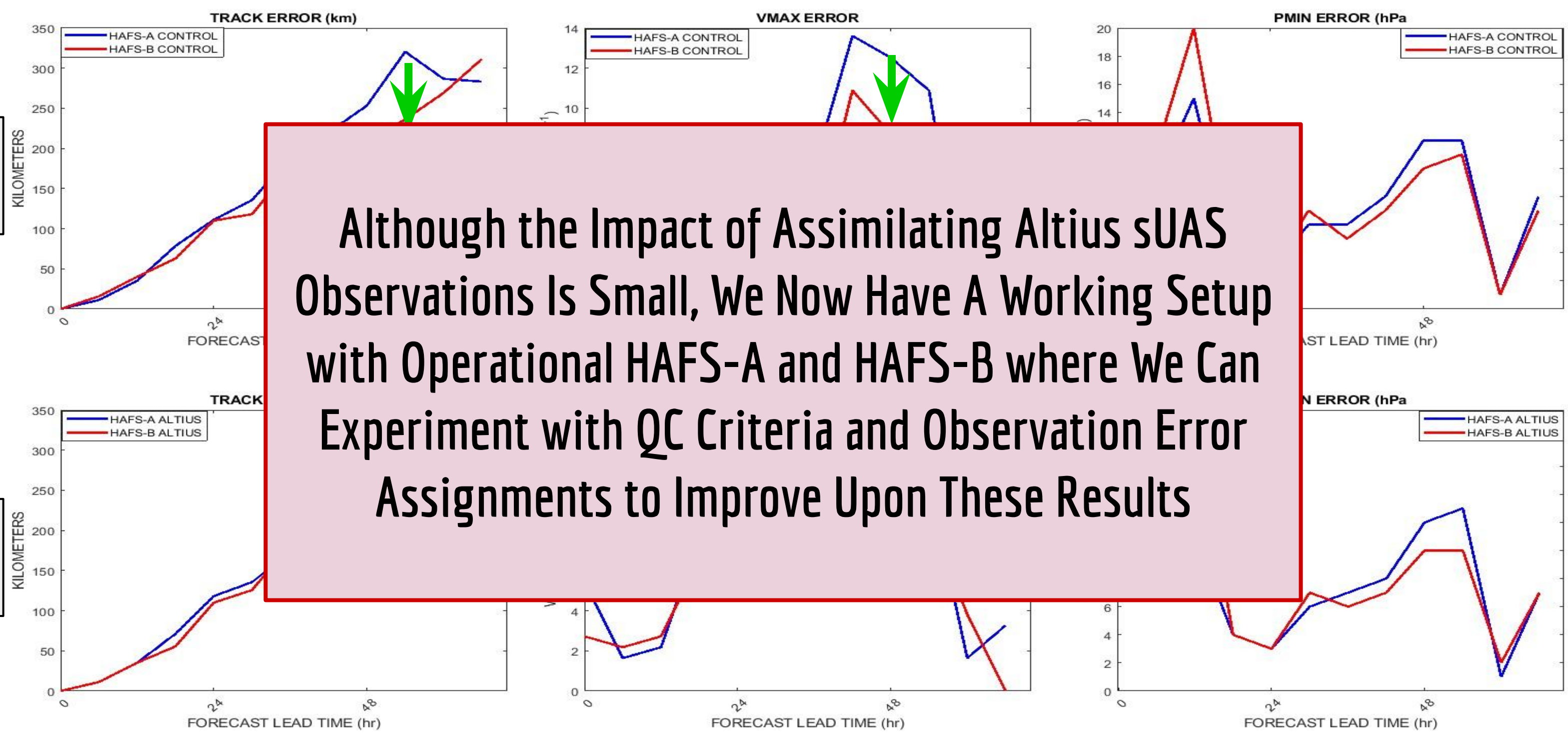

Although the Impact of Assimilating Altius sUAS Observations Is Small, We Now Have A Working Setup with Operational HAFS-A and HAFS-B where We Can Experiment with QC Criteria and Observation Error Assignments to Improve Upon These Results

Part 3:
Testing Of New DA Methodologies

Online Quality Control: Introduction

During The DA Process, We Are Typically Presented An Observation's Difference From The Model Background:
The Decision We Need to Make Is: Is $OMB = \Delta y = y^b - y^o$ Too Big?

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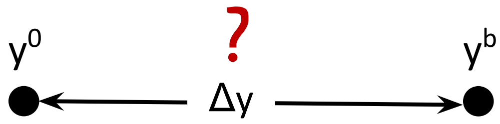

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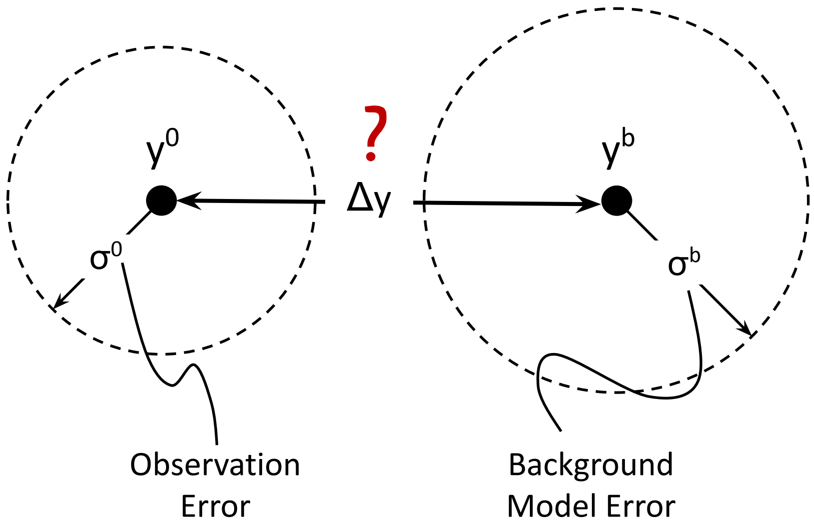

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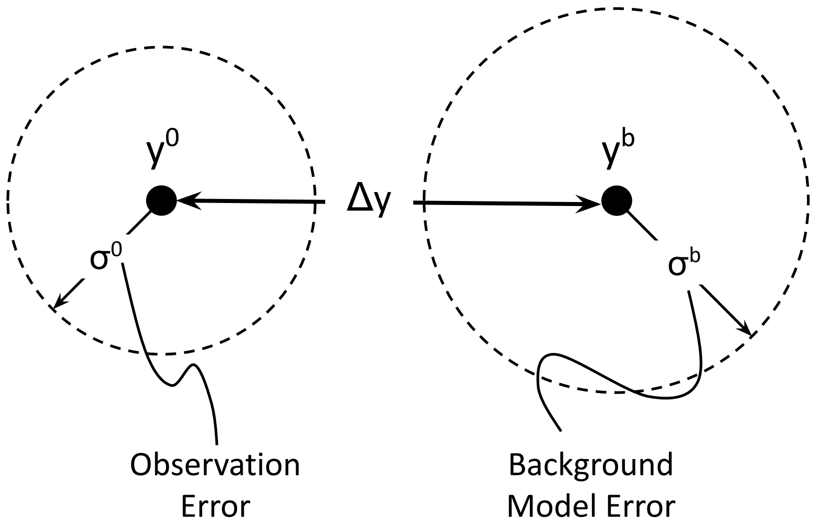

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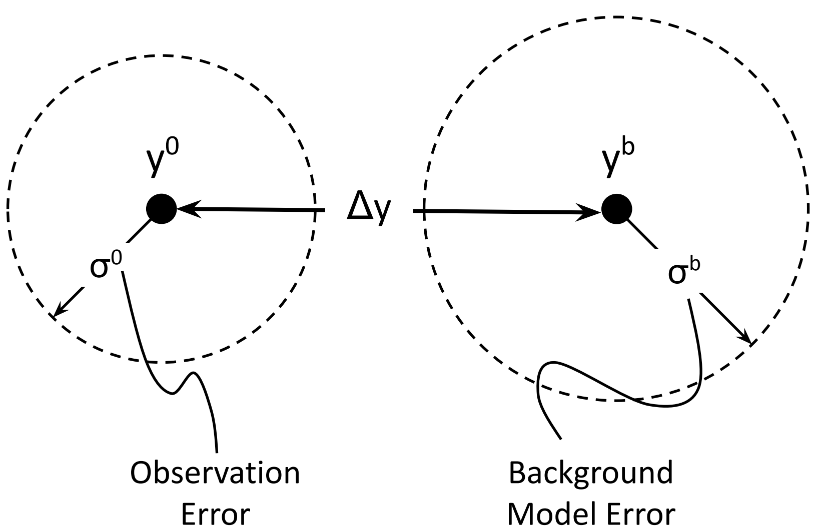

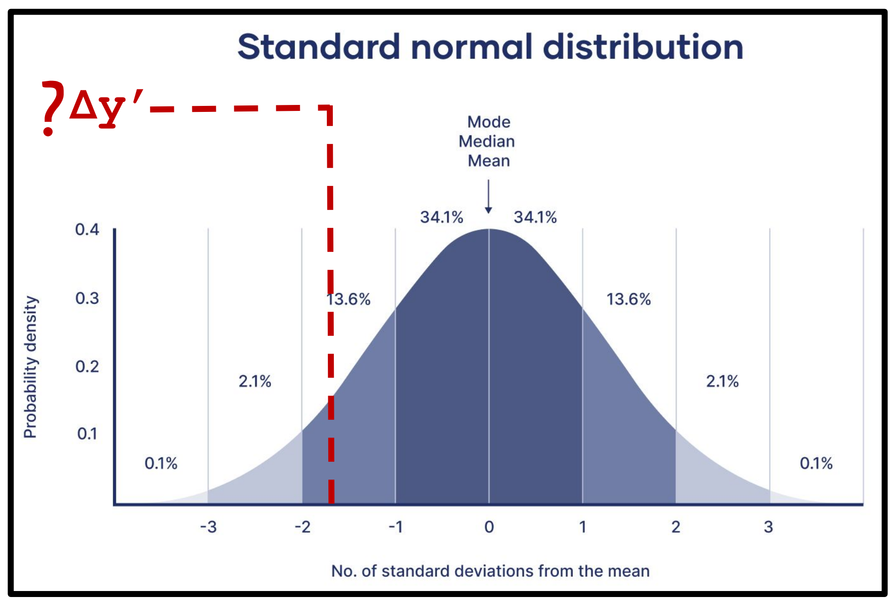

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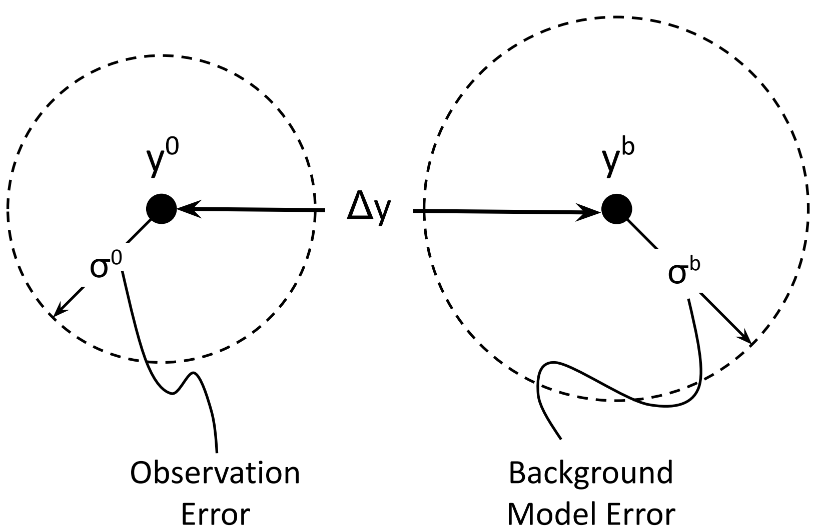

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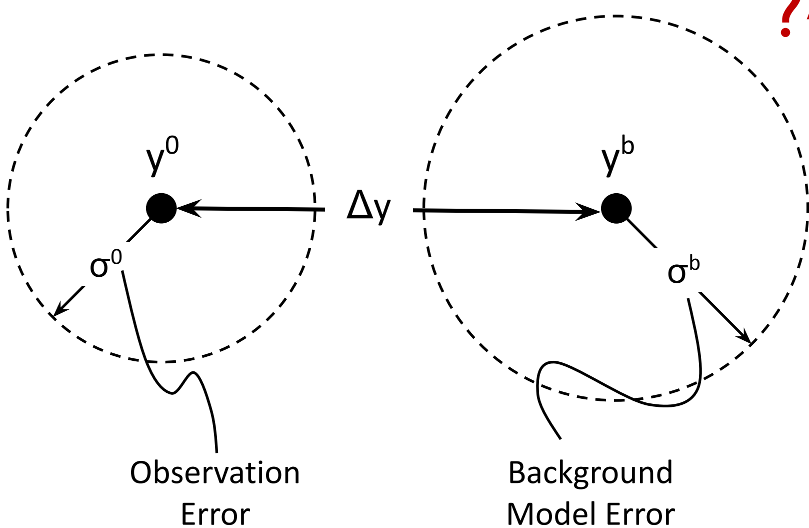

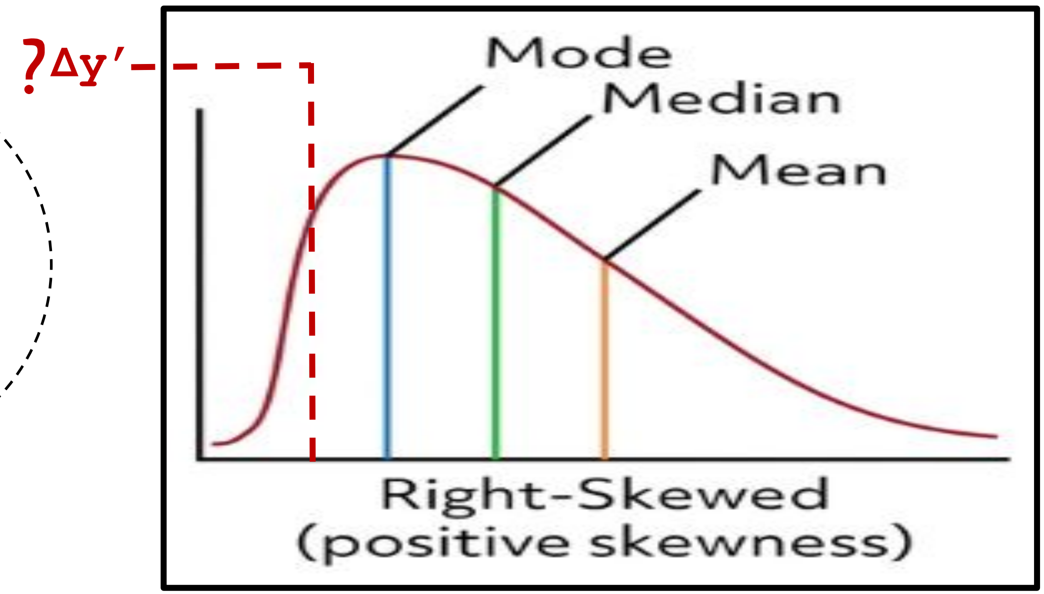

Online Quality Control: A Nonparametric Approach

We Already Established That Best Is To Consider The Normalized OMB For QC:

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Method Used:

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Method Used:

"Interquartile Range"

Q2 = Median of *Entire Dataset*

Q1 = First Quartile = Median of *Lower Half of Dataset*

Q3 = Third Quartile = Median of *Upper Half of Dataset*

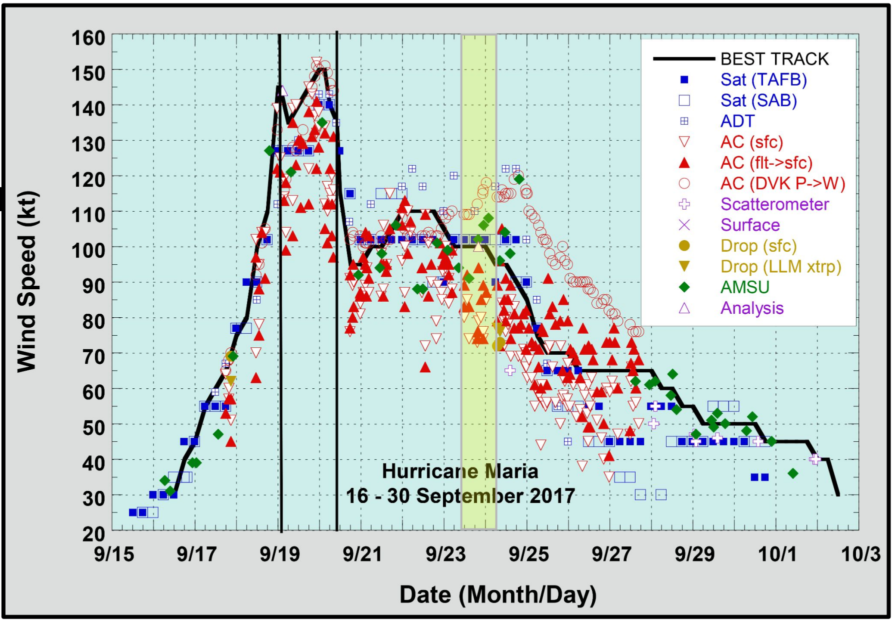
⇒ **Interquartile Range** = IQR = Q3 − Q1

Outliers:

$X < Q1 - 1.5 \times IQR$ or $X > Q3 + 1.5 \times IQR$

Online Quality Control: A Case Study

Hurricane Maria (2017)
1800 UTC 23 September
Centered at 25.98°N / 72.38°W
Category-3 Hurricane
MSLP = 952 hPa
Intensity =100 kt (~51.4 ms^{-1}).



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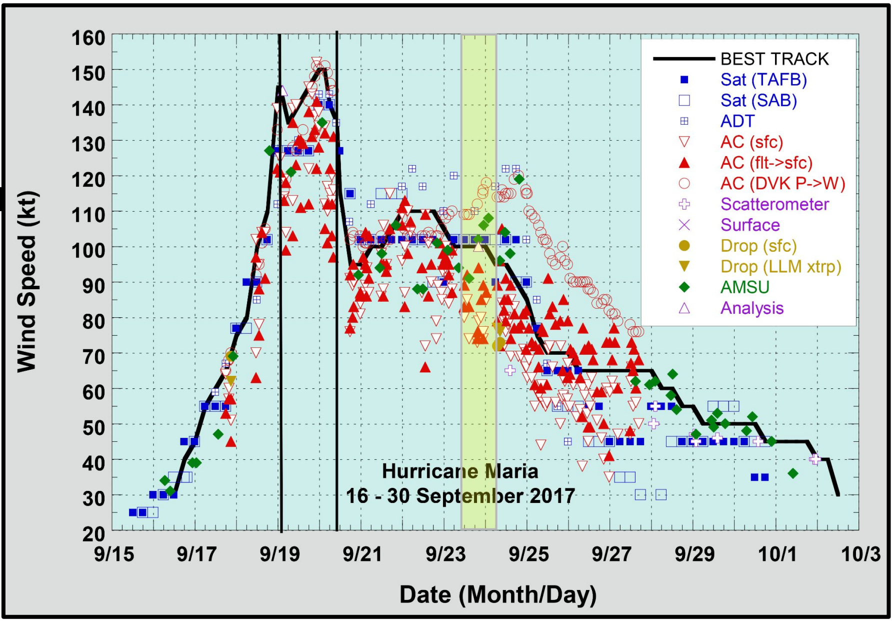
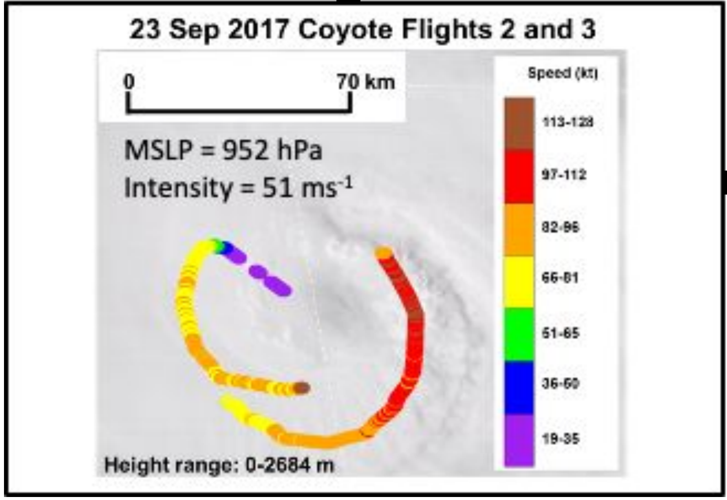
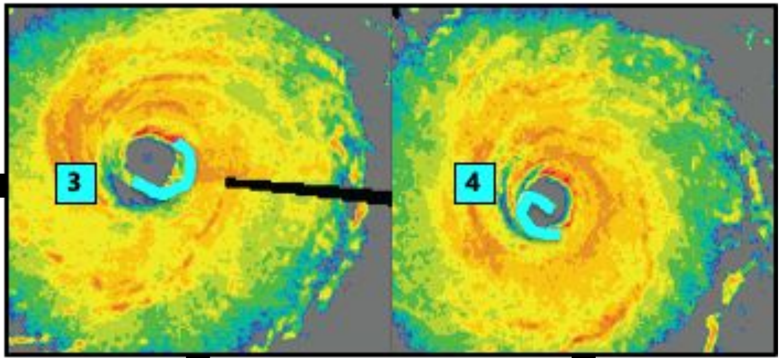


Two Coyote sUAS Flights

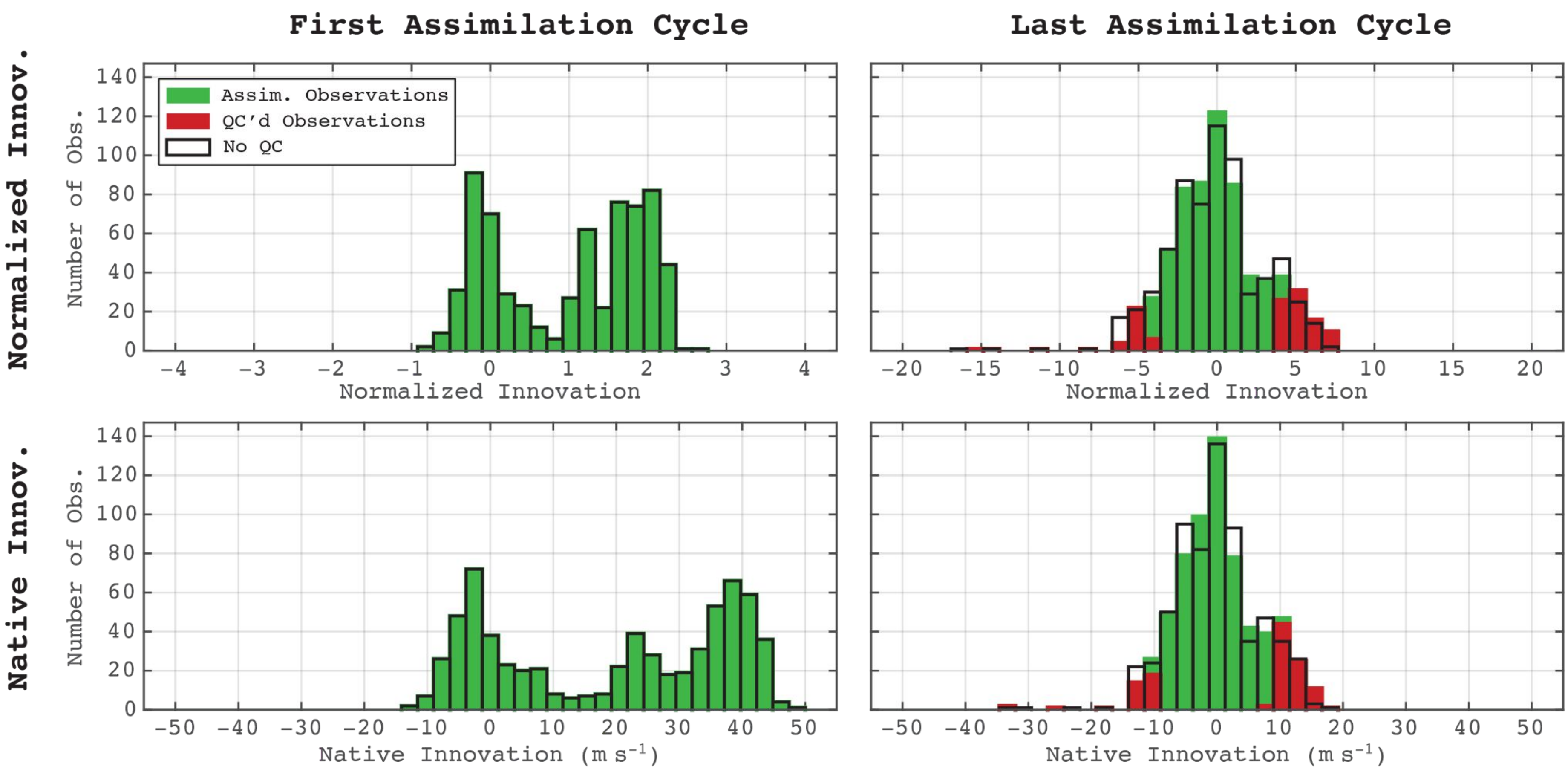




32-minute Mission
Max. Wind Speed 67 ms^{-1}

32-minute Mission
Max. Wind Speed 57 ms^{-1}

Online Quality Control: What Was Filtered Out?



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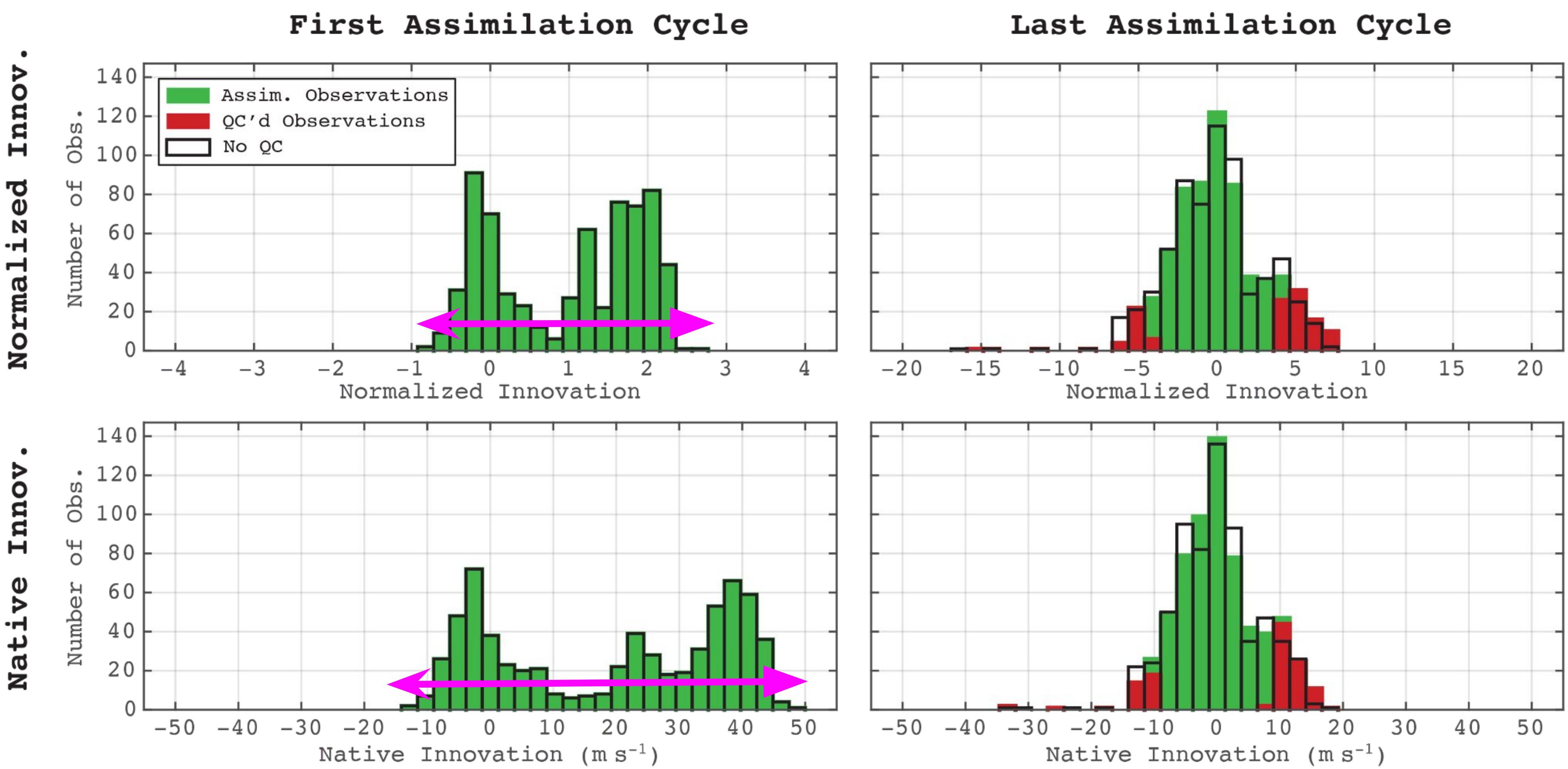

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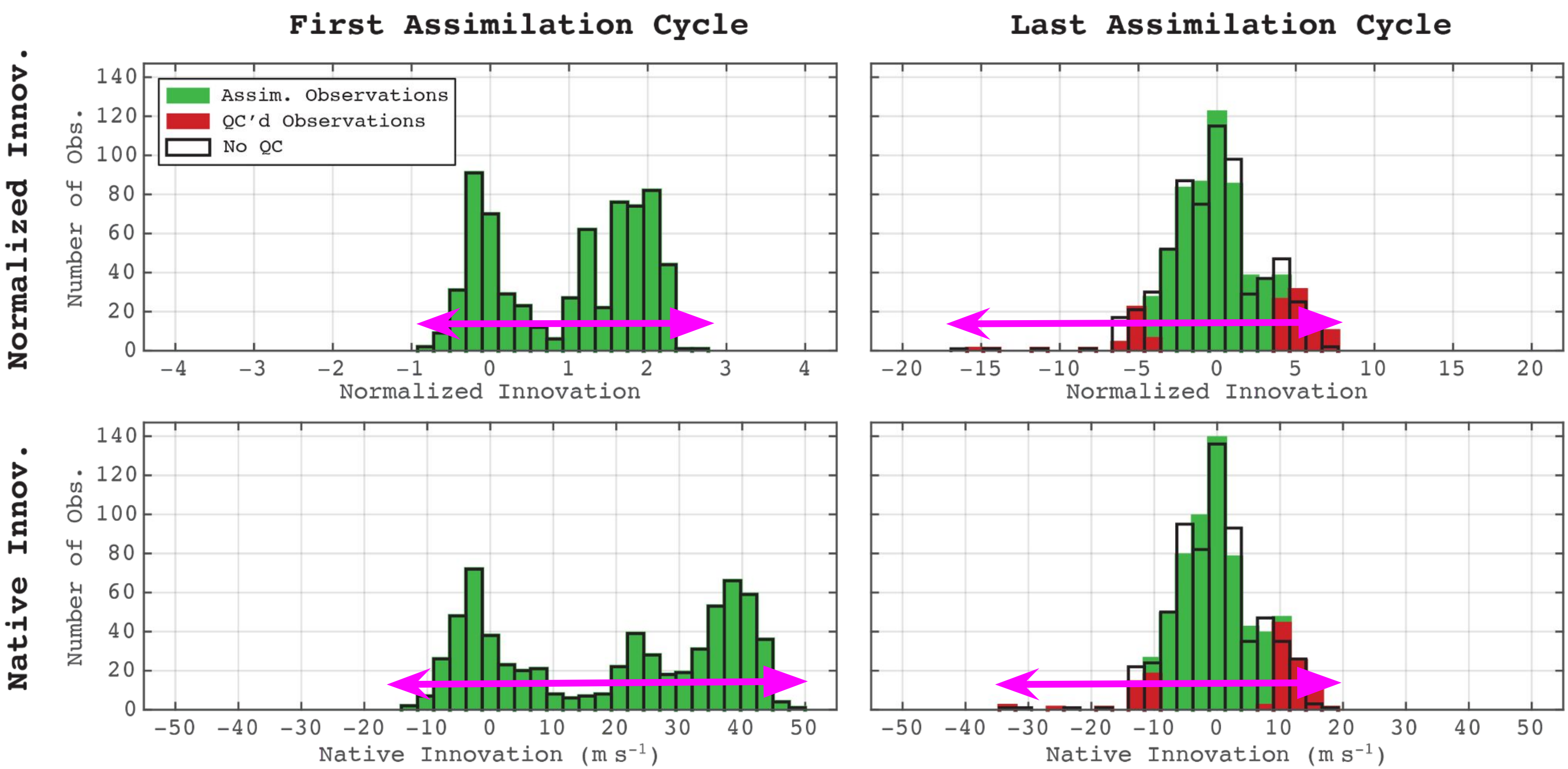

- Small Normalized Innov. Despite Large Actual Innov.
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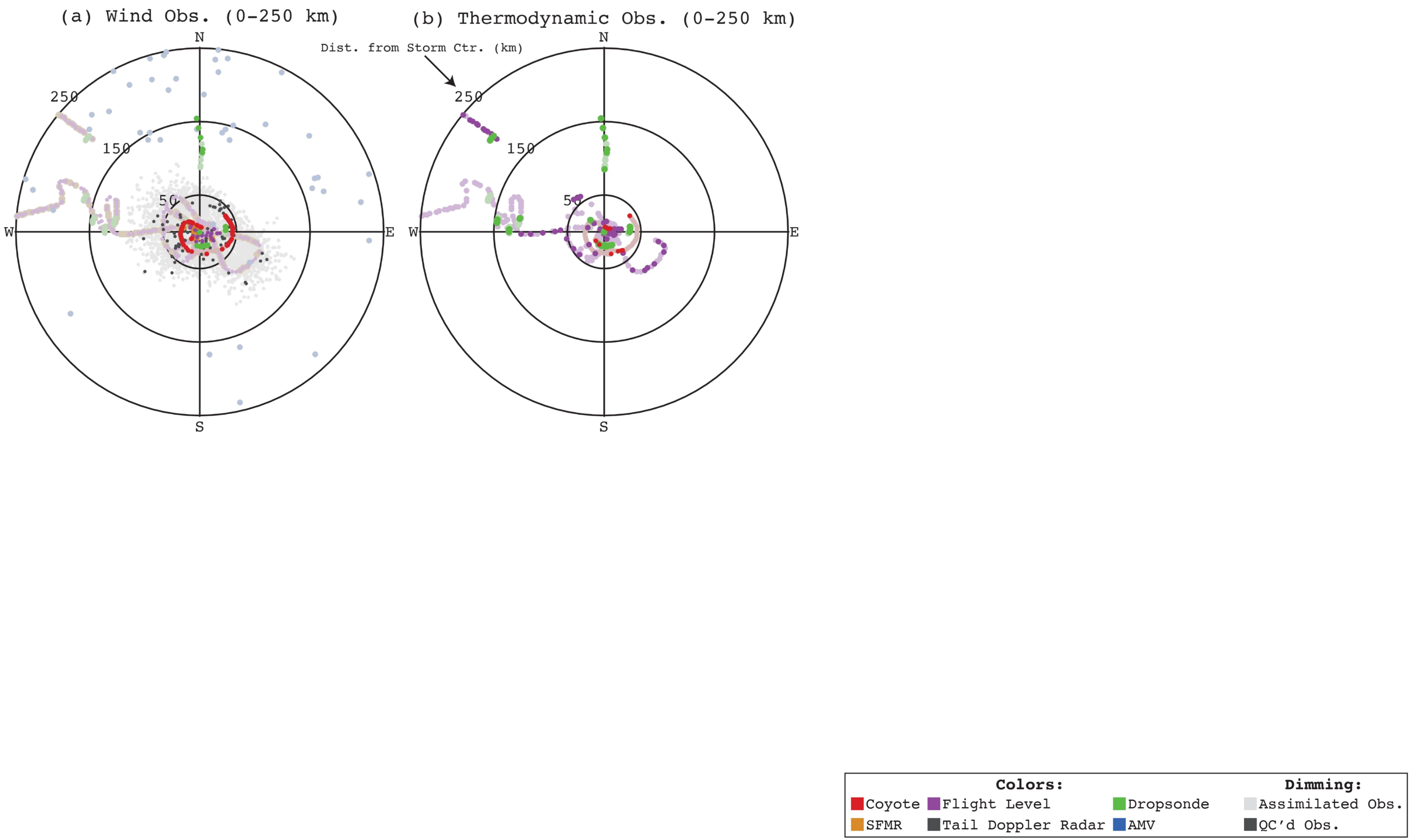
- Large Norm. Innov. Despite Smaller Actual Innov.
- More Restrictive In The Tails

Online Quality Control: Where Were The Filtered Obs?

Part 3



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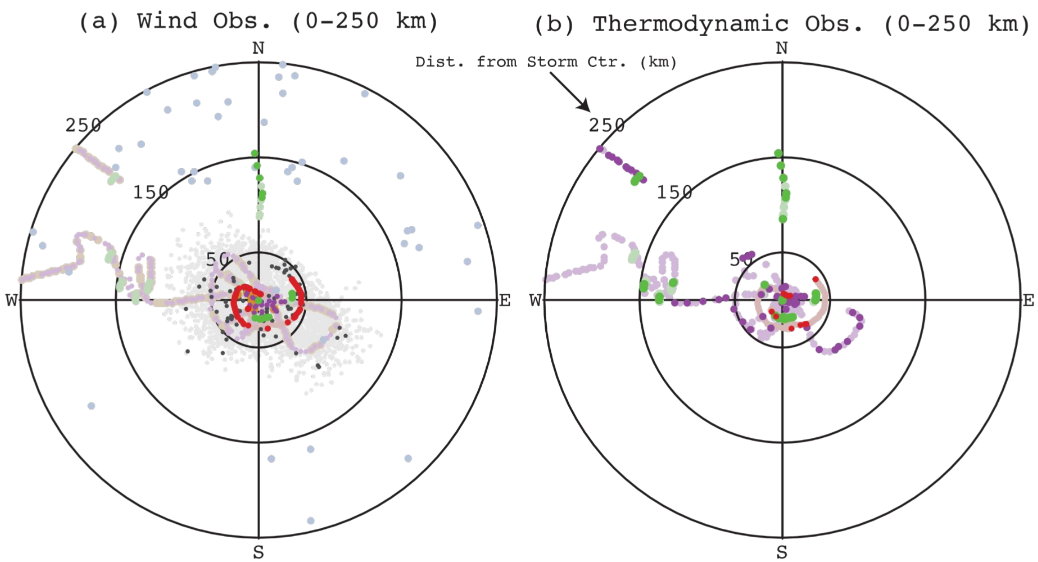

- Filtered-Out Wind Observations Concentrated Further Toward The Center, Suggesting Higher Normalized Errors In That Region (Due To Both Position & Intensity Errors)
- Filtered-Out Thermodynamic Observations Spread Further Out From The Center

Colors: Coyote, Flight Level, Dropsonde, SFMR, Tail Doppler Radar, AMV

Dimming: Assimilated Obs., QC'd Obs.

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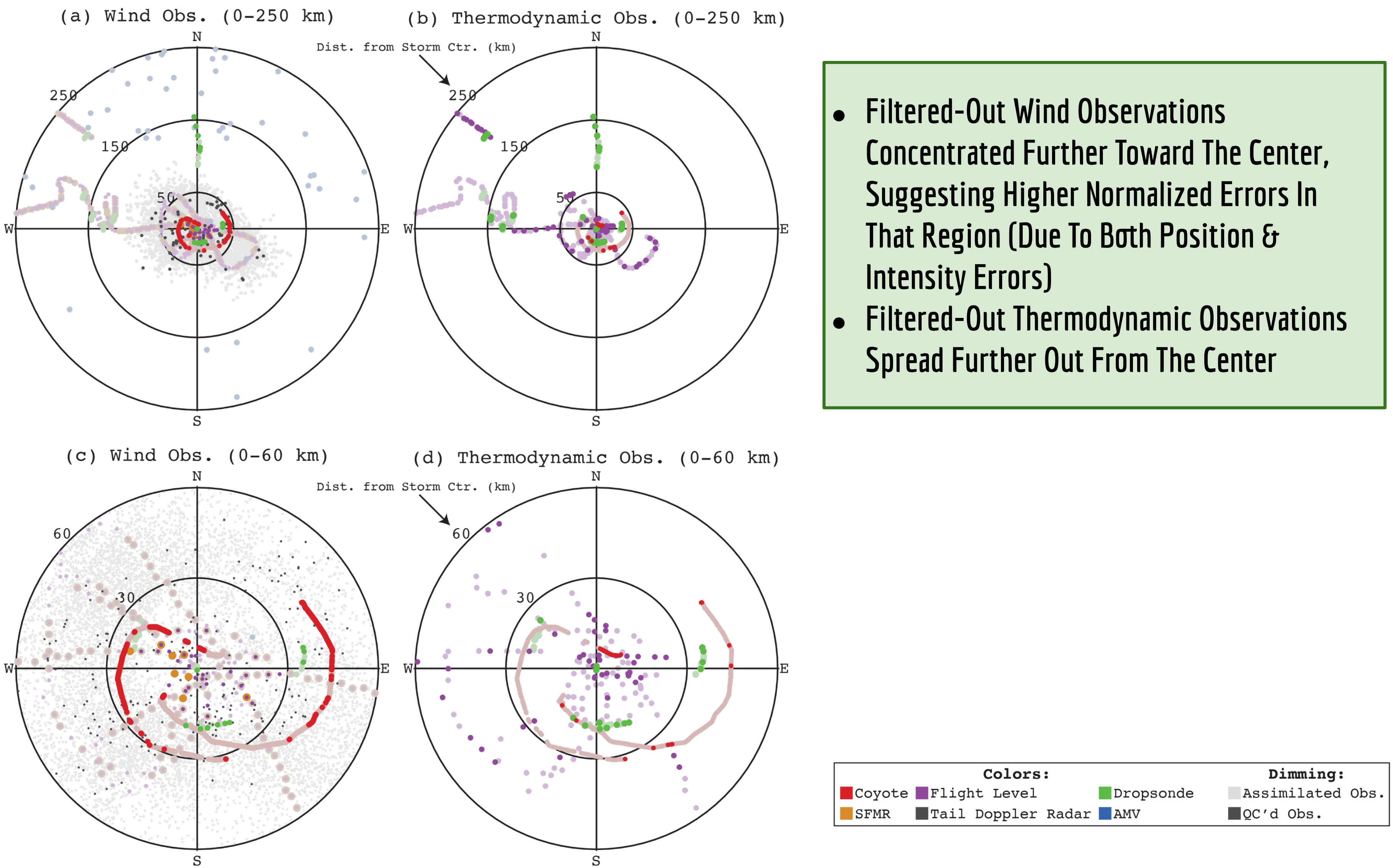

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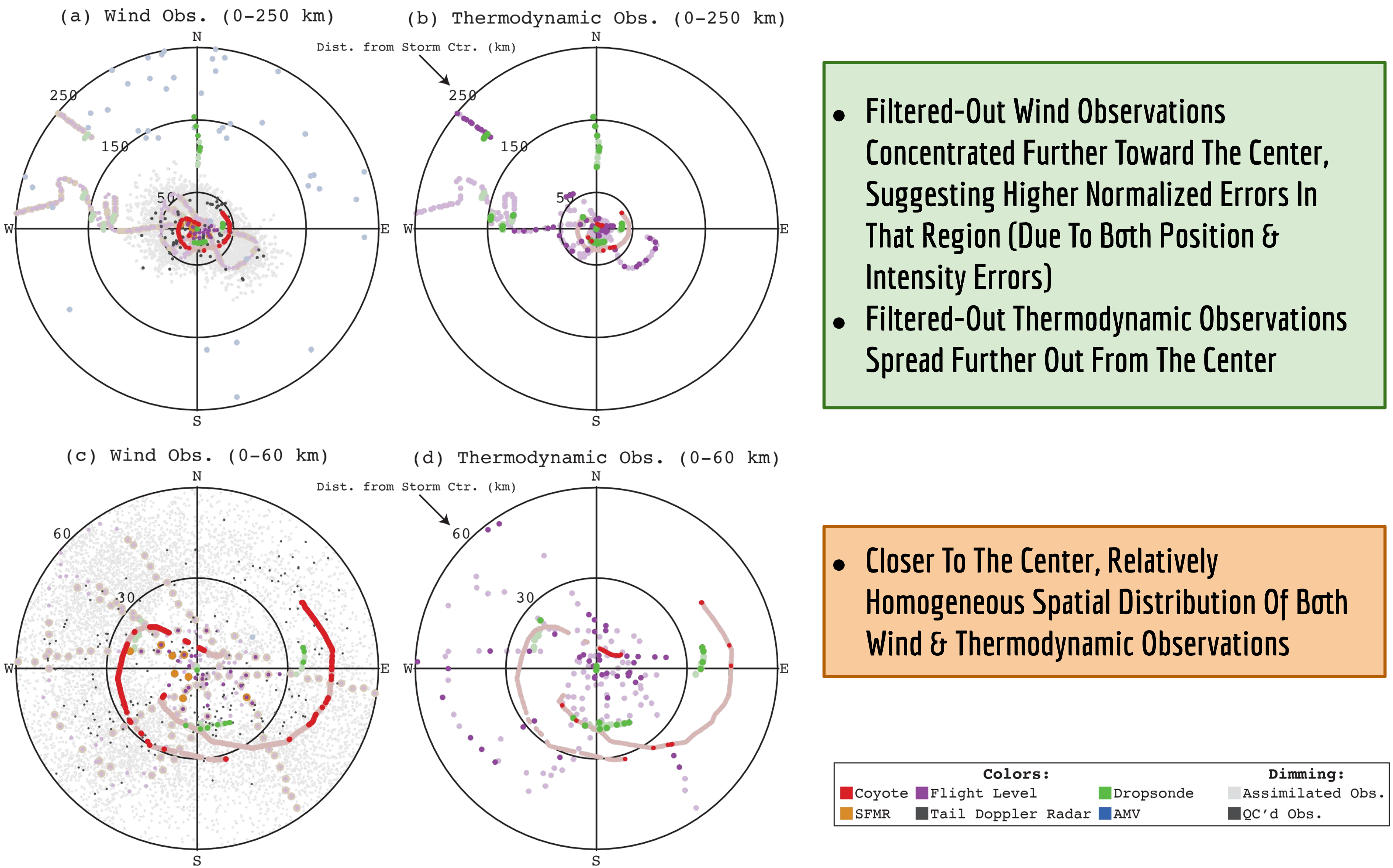

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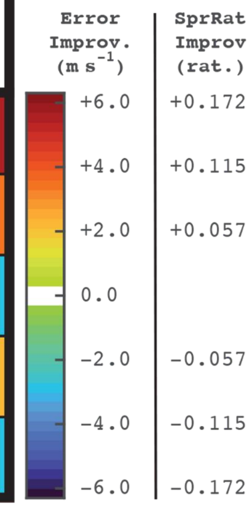
- Closer To The Center, Relatively Homogeneous Spatial Distribution Of Both Wind & Thermodynamic Observations

Online Quality Control: Observation-Space Impact

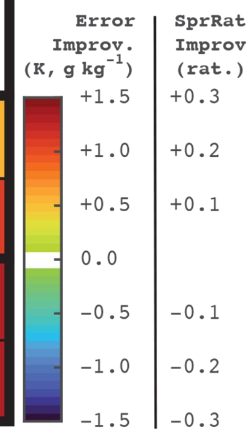
(a) Wind Observations

	RMS Error Improv.	Bias Improv.	Total Error Improv.	Spread Ratio Improv.
Coyote U/V	+55.1%	+64.1%	+57.0%	+35.6%
TDR Superobs	+23.1%	+29.2%	+23.6%	+15.0%
AMV U/V	+4.6%	-35.6%	-0.5%	-6.8%
Other U/V	+22.0%	+36.7%	+24.8%	+9.0%
SFMR Wind Speed	+15.7%	-72.0%	-0.6%	-10.4%



(b) Thermodynamic Observations

	RMS Error Improv.	Bias Improv.	Total Error Improv.	Spread Ratio Improv.
Coyote T	+28.3%	+84.2%	+51.6%	+16.9%
Other T	+50.4%	+20.8%	+43.8%	+44.0%
Coyote Q	+45.1%	+65.4%	+57.6%	+39.0%
Other Q	+66.0%	+55.5%	+64.2%	+78.0%



Online Quality Control: Observation-Space Impact

- Almost All Positive Impact On Error Statistics For All Observation Types Assimilated

(a) Wind Observations

	RMS Error Improv.	Bias Improv.	Total Error Improv.	Spread Ratio Improv.
Coyote U/V	+55.1%	+64.1%	+57.0%	+35.6%
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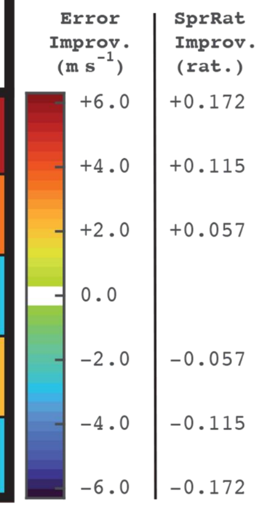

(b) Thermodynamic Observations

	RMS Error Improv.	Bias Improv.	Total Error Improv.	Spread Ratio Improv.
Coyote T	+28.3%	+84.2%	+51.6%	+16.9%
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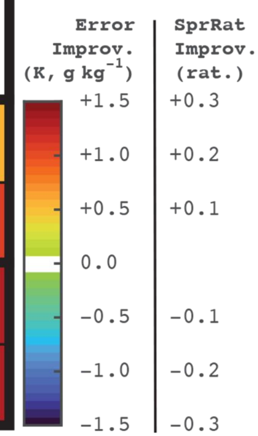

Online Quality Control: Observation-Space Impact

- Almost All Positive Impact On Error Statistics For All Observation Types Assimilated
- Positive Impact Even In Observation Types Other Than The Coyote sUAS (Indirect Impact)

(a) Wind Observations

	RMS Error Improv.	Bias Improv.	Total Error Improv.	Spread Ratio Improv.
Coyote U/V	+55.1%	+64.1%	+57.0%	+35.6%
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SFMR Wind Speed	+15.7%	-72.0%	-0.6%	-10.4%

Error Improv. ($m\ s^{-1}$)	SprRat Improv. (rat.)
+6.0	+0.172
+4.0	+0.115
+2.0	+0.057
0.0	
-2.0	-0.057
-4.0	-0.115
-6.0	-0.172

(b) Thermodynamic Observations

	RMS Error Improv.	Bias Improv.	Total Error Improv.	Spread Ratio Improv.
Coyote T	+28.3%	+84.2%	+51.6%	+16.9%
Other T	+50.4%	+20.8%	+43.8%	+44.0%
Coyote Q	+45.1%	+65.4%	+57.6%	+39.0%
Other Q	+66.0%	+55.5%	+64.2%	+78.0%

Error Improv. (K, $g\ kg^{-1}$)	SprRat Improv. (rat.)
+1.5	+0.3
+1.0	+0.2
+0.5	+0.1
0.0	
-0.5	-0.1
-1.0	-0.2
-1.5	-0.3

Online Quality Control: Observation-Space Impact

Part 3

- Almost All Positive Impact On Error Statistics For All Observation Types Assimilated
- Positive Impact Even In Observation Types Other Than The Coyote sUAS (Indirect Impact)
- Largest Positive Impact On Thermodynamic Observations, Which Are Usually Hard To Obtain In The PBL

(a) Wind Observations

	RMS Error Improv.	Bias Improv.	Total Error Improv.	Spread Ratio Improv.
Coyote U/V	+55.1%	+64.1%	+57.0%	+35.6%
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0.0	
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(b) Thermodynamic Observations

	RMS Error Improv.	Bias Improv.	Total Error Improv.	Spread Ratio Improv.
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Error Improv. ($K,\ g\ kg^{-1}$)	SprRat Improv. (rat.)
+1.5	+0.3
+1.0	+0.2
+0.5	+0.1
0.0	
-0.5	-0.1
-1.0	-0.2
-1.5	-0.3

Online Quality Control: Observation-Space Impact

- Almost All Positive Impact On Error Statistics For All Observation Types Assimilated
- Positive Impact Even In Observation Types Other Than The Coyote sUAS (Indirect Impact)
- Largest Positive Impact On Thermodynamic Observations, Which Are Usually Hard To Obtain In The PBL
- Further Improvements In The Optimality Of Ensemble Spread

(a) Wind Observations

	RMS Error Improv.	Bias Improv.	Total Error Improv.	Spread Ratio Improv.
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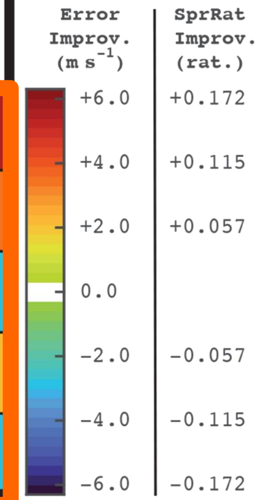

(b) Thermodynamic Observations

	RMS Error Improv.	Bias Improv.	Total Error Improv.	Spread Ratio Improv.
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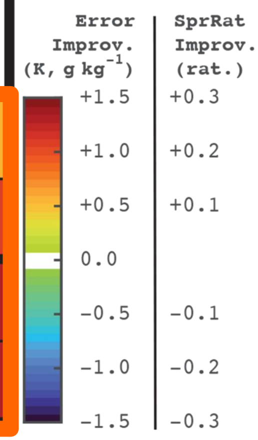

Online Quality Control: Application In HAFS-DA

Important To Remember That Normalized Online QC Only Works In Observation Space:

$$\Delta y' = OMB / [\sigma^{b2} + y^{o2}]^{1/2}$$

Online Quality Control: Application In HAFS-DA

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Therefore, This Approach Can Only Be Implemented
In The EnKF Part Of The HAFS-DA System,
But Regardless Of Its Being A Pure EnKF Or EnVar Application

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Therefore, This Approach Can Only Be Implemented
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We Have Already Implemented Online QC In The EnKF Part Of HAFS-DA:

1. Availability Of All Ob-Space Statistics Needed Online During DA
2. Online QC Code In EnKF
3. Output Of All Useful Diagnostics Into Files

Online Quality Control: Application In HAFS-DA

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We Have Already Implemented Online QC In The EnKF Part Of HAFS-DA:

1. Availability Of All Ob-Space Statistics Needed Online During DA
2. Online QC Code In EnKF
3. Output Of All Useful Diagnostics Into Files

On The GSI Side (Necessary For The EnVar Applications) "Manual" Implementation Is Available:

1. Filtering Of Online QC Needs To Be Consistent Between EnKF & GSI Parts
2. Waiting For The Latest Self-Cycled HAFS-DA Code To Become Available

Online Quality Control: Comparison To Existing QC

Complication 1: Impact On Performance Of Online QC With Existing QC Mechanisms

Online Quality Control: Comparison To Existing QC

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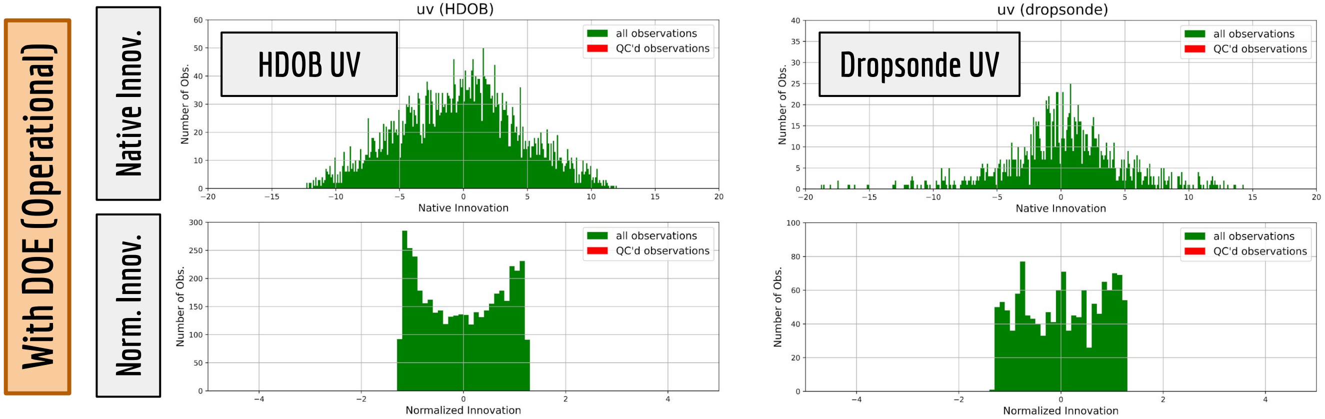
Dynamic Observation Errors (DOE): In The TC Inner Core, Observation Errors Are Inflated To Account For Large Innovations

Online Quality Control: Comparison To Existing QC

Complication 1: Impact On Performance Of Online QC With Existing QC Mechanisms

Dynamic Observation Errors (DOE): In The TC Inner Core, Observation Errors Are Inflated To Account For Large Innovations



Online Quality Control: Comparison To Existing QC

Complication 1: Impact On Performance Of Online QC With Existing QC Mechanisms

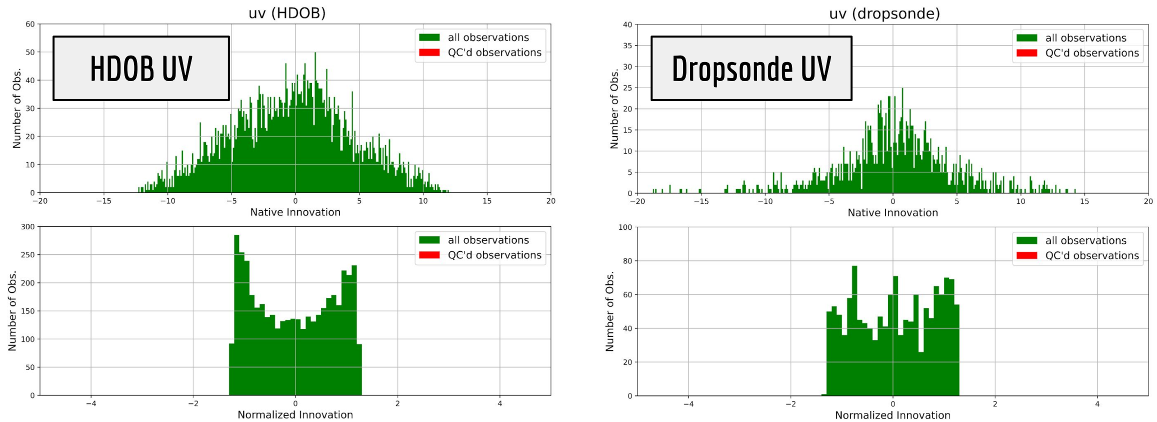
Dynamic Observation Errors (DOE): In The TC Inner Core, Observation Errors Are Inflated To Account For Large Innovations

- Online QC Doesn't Do Much Filtering With DOE Active
- Innovation Distributions Are Cut Off At The Tails In Normalized Space

With DOE (Operational)

Native Innov.

Norm. Innov.



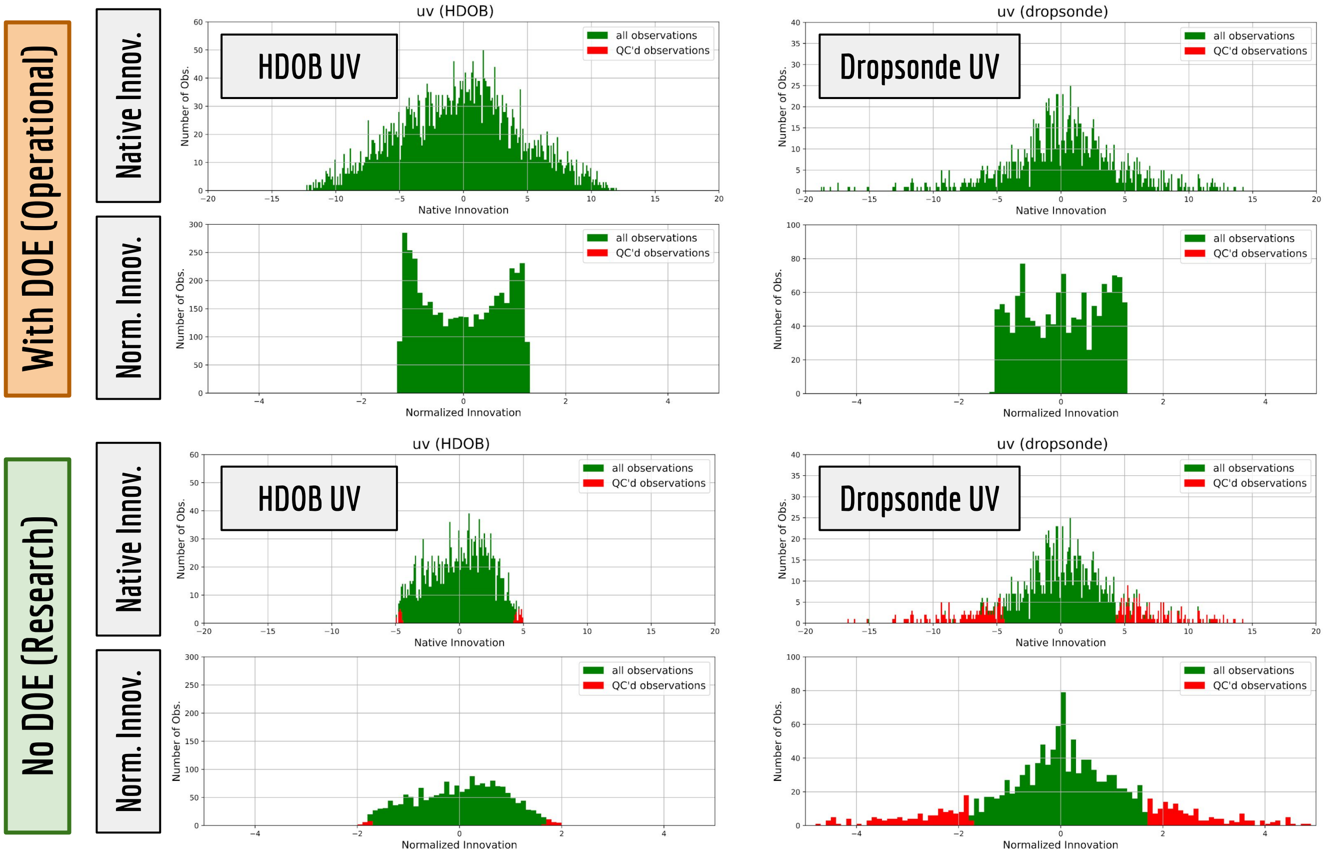
Online Quality Control: Comparison To Existing QC

Part 3

Complication 1: Impact On Performance Of Online QC With Existing QC Mechanisms

Dynamic Observation Errors (DOE): In The TC Inner Core, Observation Errors Are Inflated To Account For Large Innovations

- Online QC Doesn't Do Much Filtering With DOE Active
- Innovation Distributions Are Cut Off At The Tails In Normalized Space



Online Quality Control: Comparison To Existing QC

Complication 1: Impact On Performance Of Online QC With Existing QC Mechanisms

Dynamic Observation Errors (DOE): In The TC Inner Core, Observation Errors Are Inflated To Account For Large Innovations

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With DOE (Operational)

Native Innov.

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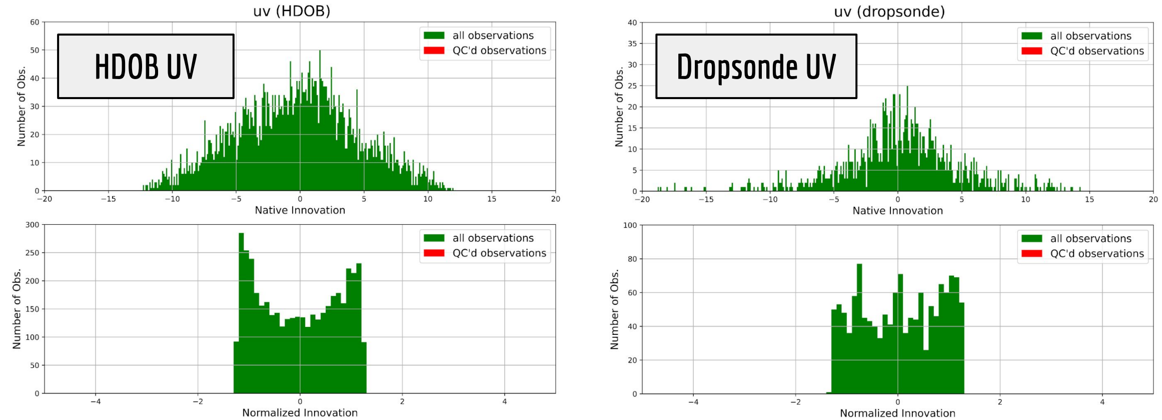
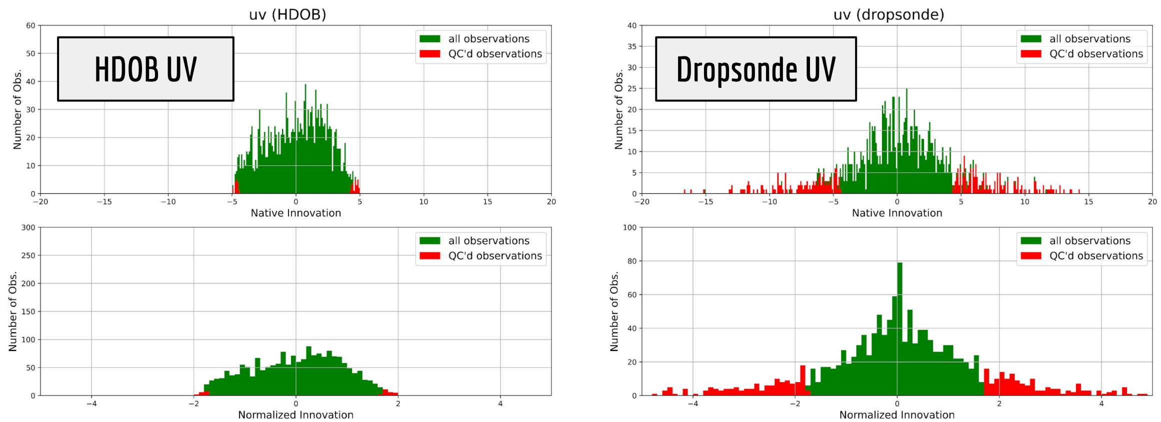


- Without DOE, Online QC Is Much More Effective
- Innovation Distributions Look More Reasonable

No DOE (Research)

Native Innov.

Norm. Innov.



Online Quality Control: Comparison To Existing QC

Complication 2: Need For Retuning Of Observation Errors

Online Quality Control: Comparison To Existing QC

Complication 2: Need For Retuning Of Observation Errors

Experimental Design

Online Quality Control: Comparison To Existing QC

Complication 2: Need For Retuning Of Observation Errors

Experimental Design

		Exp1: Default	Exp2: No DOE	Exp3a	Exp 3b	Exp 3c	Exp 3d
GSI Namelist Parameter	tdrerr_inflate	T	F	F	F	F	F
	aircraft_recon	T	F	F	F	F	F
Obs Error	Flight-level U+V (m/s)	2.5	2.5	4.0	3.0	2.0	4.0
	Flight-level T(K)	0.75	0.75	0.9	0.75	0.6	0.6
	Flight-level Q(RH)	0.7	0.7	double	0.7	0.7	0.7
	Dropsonde U+V (m/s)	2.5	2.5	4.0	2.5	2.0	2.0
	Dropsonde T(K)	0.75	0.75	0.9	0.75	0.6	0.6
	Dropsonde Q(RH)	0.7	0.7	20% increase	0.7	0.7	0.7

Online Quality Control: Comparison To Existing QC

Complication 2: Need For Retuning Of Observation Errors

Experimental Design

		Exp1: Default	Exp2: No DOE	Exp3a	Exp 3b	Exp 3c	Exp 3d
GSI Namelist Parameter	tdrerr_inflate	T	F	F	F	F	F
	aircraft_recon	T	F	F	F	F	F
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	Flight-level Q(RH)	0.7	0.7	double	0.7	0.7	0.7
	Dropsonde U+V (m/s)	2.5	2.5	4.0	2.5	2.0	2.0
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Online Quality Control: Comparison To Existing QC

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Experimental Design

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Online Quality Control: Comparison To Existing QC

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Online Quality Control: Comparison To Existing QC

Complication 2: Need For Retuning Of Observation Errors

Online Quality Control: Comparison To Existing QC

Complication 2: Need For Retuning Of Observation Errors

Observation-Space Diagnostics

platform \ Consistency Ratio		Exp1: Default	Exp2: No DOE	Exp 3a	Exp 3b	Exp 3c	Exp 3d
Dropsonde	T	2.07 /	0.87	2.12	1.87	1.54	1.53
	Q	1.52	0.5	1.34	1.19	1.19	1.19
	U+V	1.38	0.39	1.85	1.45	1.34	1.35
HDOB	T	2.19	0.79	1.79	1.57	1.40	1.40
	Q	2.78	1.45	2.13	1.57	1.57	1.57
	U+V	1.45	1.40	1.58	1.60	1.55	1.58

Online Quality Control: Comparison To Existing QC

Complication 2: Need For Retuning Of Observation Errors

Observation-Space Diagnostics

platform \ Consistency Ratio		Exp1: Default	Exp2: No DOE	Exp 3a	Exp 3b	Exp 3c	Exp 3d
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HDOB	T	2.19	0.79	1.79	1.57	1.40	1.40
	Q	2.78	1.45	2.13	1.57	1.57	1.57
	U+V	1.45	1.40	1.58	1.60	1.55	1.58

Spread Consistency Becomes More Optimal (Closer To 1)

Online Quality Control: Comparison To Existing QC

Part 3

Complication 2: Need For Retuning Of Observation Errors

Observation-Space Diagnostics

platform	Consistency Ratio	Exp1: Default	Exp2: No DOE	Exp 3a	Exp 3b	Exp 3c	Exp 3d
Dropsonde	T	2.07 /	0.87	2.12	1.87	1.54	1.53
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	Q	2.78	1.45	2.13	1.57	1.57	1.57
	U+V	1.45	1.40	1.58	1.60	1.55	1.58

Spread Consistency Becomes More Optimal (Closer To 1)

		Average O-min-A				
Description	Average O-Min-F	Exp. 1	Exp 3a	Exp 3b	Exp 3c	Exp 3d
T / Q (dropsonde)	0.68 / 0.37	0.72 / 0.32	0.33 / 0.27	0.24 / 0.27	0.18 / 0.27	0.18 / 0.27
U+V (dropsonde)	-0.141	-0.116	0.20	0.11	0.06	0.05
T / Q (HDOB)	0.74 / 0.079	0.62 / 0.076	0.18 / 0.01	0.12 / -0.036	0.08 / -0.04	0.07 / -0.04
U+V (HDOB)	-0.398	-0.23	0.033	0.085	0.176	-0.04

Online Quality Control: Comparison To Existing QC

Complication 2: Need For Retuning Of Observation Errors

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	Q	2.78	1.45	2.13	1.57	1.57	1.57
	U+V	1.45	1.40	1.58	1.60	1.55	1.58

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Analysis Errors (Distance From Observations, OMA) Become Smallest

Online Quality Control: Comparison To Existing QC

Complication 2: Need For Retuning Of Observation Errors

Observation-Space Diagnostics

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	U+V	1.38	0.39	1.85	1.45	1.34	1.35
HDOB	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.40
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.57
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.58

Description	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Exp 3d
T / Q (dropsonde)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.18 / 0.27
U+V (dropsonde)	-0.141	-0.116	0.20	0.11	0.06	0.05
T / Q (HDOB)	0.74 / 0.079	0.62 / 0.076	0.18 / 0.01	0.12 / -0.036	0.08 / -0.04	0.07 / -0.04
U+V (HDOB)	-0.398	-0.23	0.033	0.085	0.176	-0.04

This Optimization Exercise
Will Need To Be Repeated With:

- The Latest Self-Cycled HAFS-DA Code With EnVar
- Using A Large Number Of Cases

Spread Consistency Becomes More Optimal (Closer To 1)

Analysis Errors (Distance From Observations, OMA) Become Smallest

Summary / Final Thoughts

1. Collaboration between AOML/HRD and University of Miami allows for expertise and research applications ranging from collection of observations to assimilation in operational models

2. Expertise with the depth and technical details of available inner-core observing platforms allows improvements with implications up to NHC operations

3. New DA research being conducted with experimental observing platforms such as sUAS and CYGNSS has potential to improve operational models

4. Research is actively being carried out with both operational HAFS-A and HAFS-B systems and the experimental self-cycled HAFS system to test assimilation of new observations as well as implementation of new DA techniques

Publications Of Note

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- Aksoy, A., J. J. Cione, B. A. Dahl, and P. D. Reasor, 2022: Tropical cyclone data assimilation with Coyote Uncrewed Aircraft System observations, very frequent cycling, and a new online quality control technique. *Monthly Weather Review*, **150**, 797-820, https://doi.org/10.1175/MWR-D-21-0124.1.
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