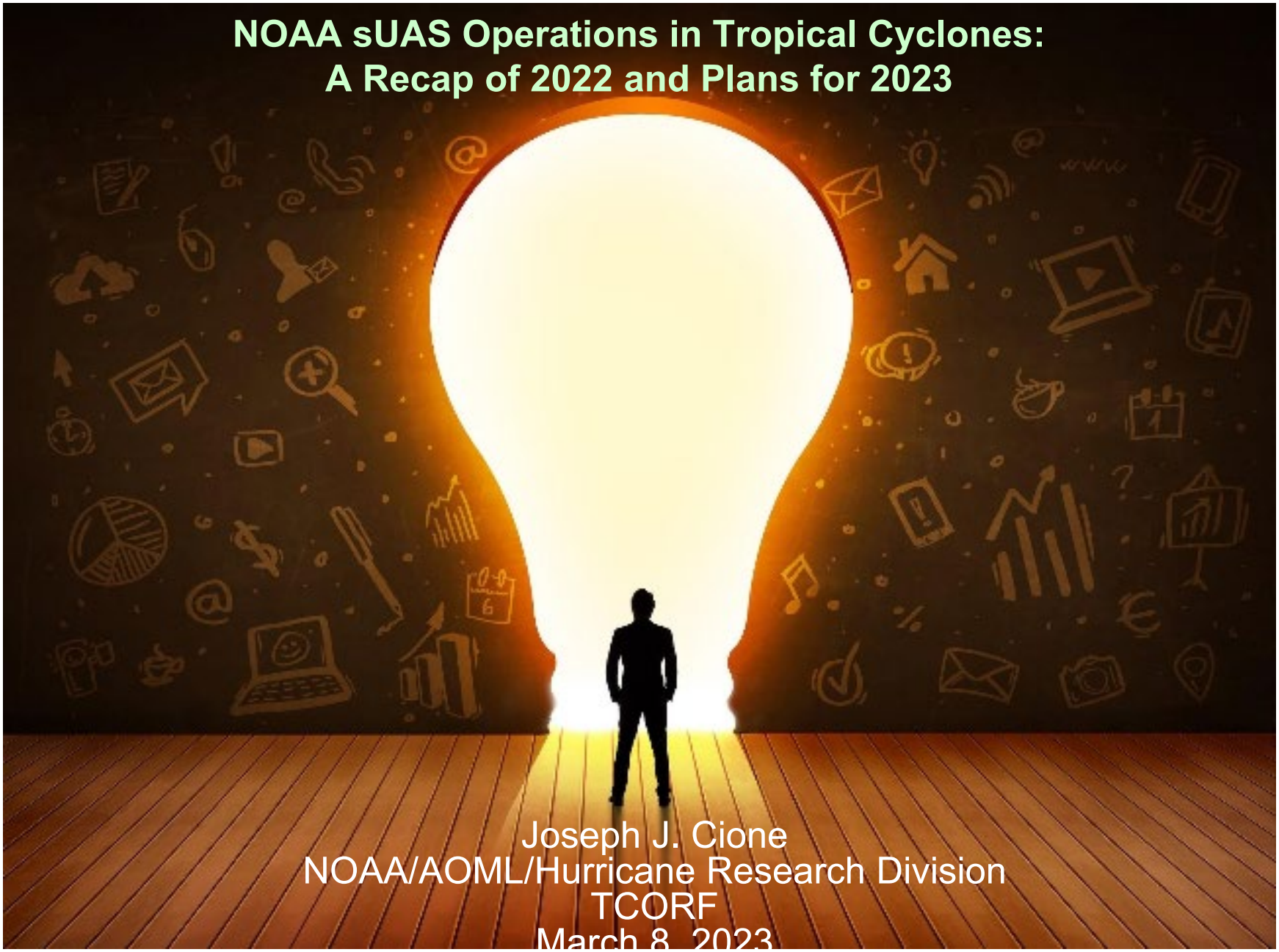
NOAA sUAS Operations in Tropical Cyclones: A Recap of 2022 and Plans for 2023



Joseph J. Cione
NOAA/AOML/Hurricane Research Division
TCORF
March 8, 2023

small Uncrewed Aircraft System (sUAS) Operations in Hurricanes…

Observational Objective:

Leverage key attributes of NOAA's existing Hurricane Hunter aircraft to develop emerging uncrewed technologies designed to enhanced data coverage of the critically important, yet sparsely-sampled tropical cyclone boundary layer environment.

End goal:

Through enhanced observation, improve basic understanding, operational situational awareness and ultimately, hurricane intensity forecast performance.

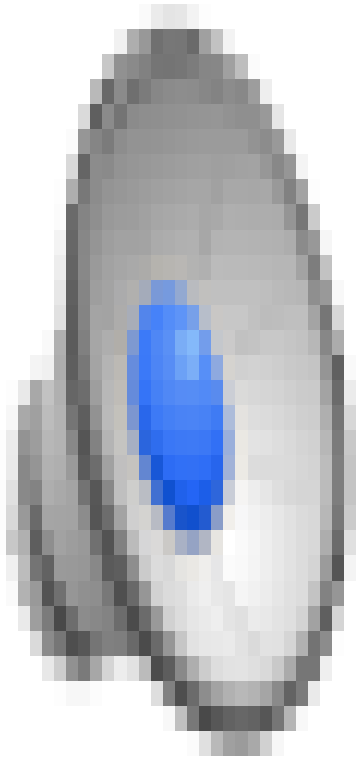
ConOp: Deploy a small, (eventually fully) autonomous “uncrewed” aircraft from a “crewed” aircraft

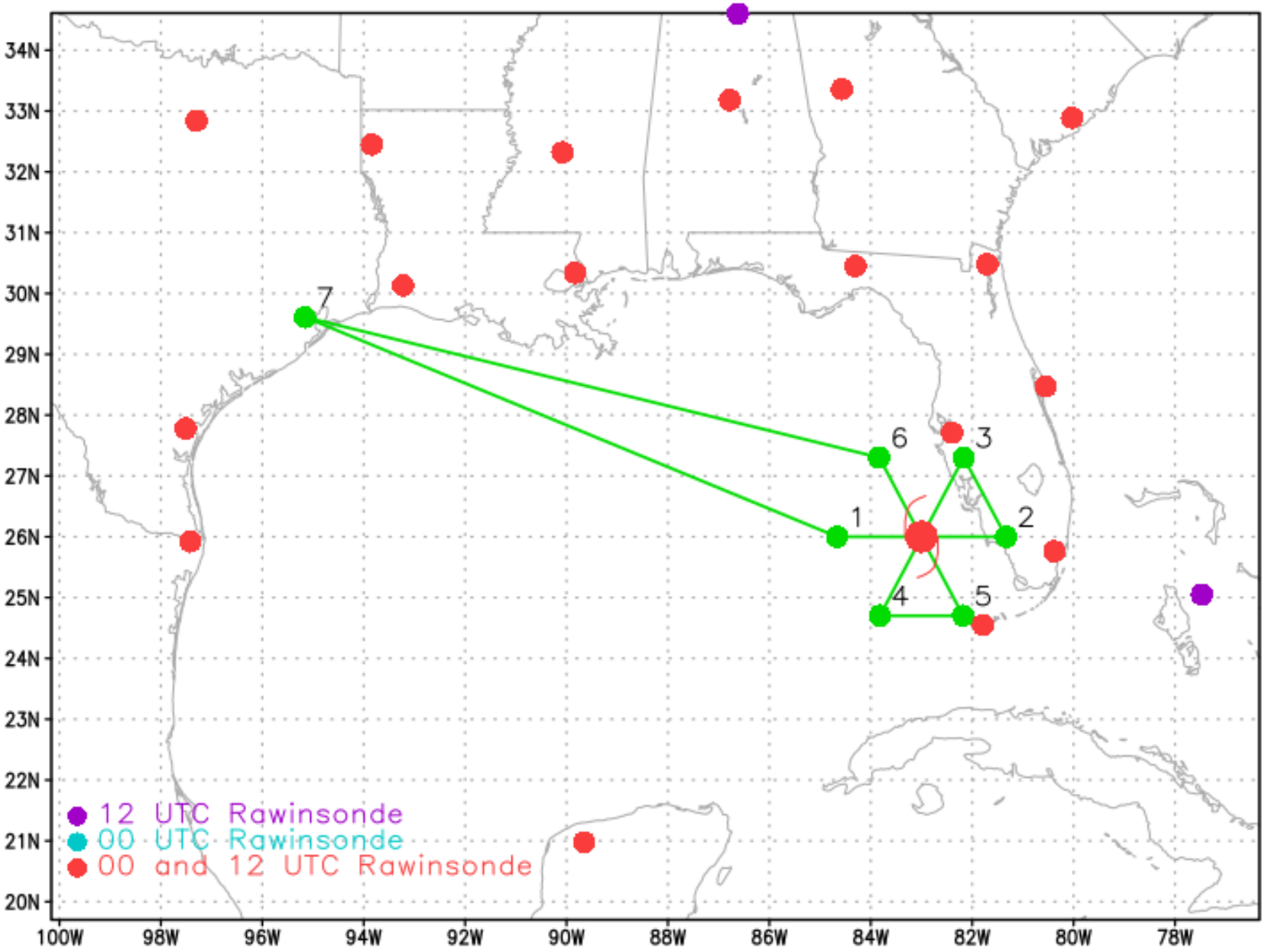
Launch!

Recent sUAS Observations in Hurricane Ian:

September 28th, 2022…

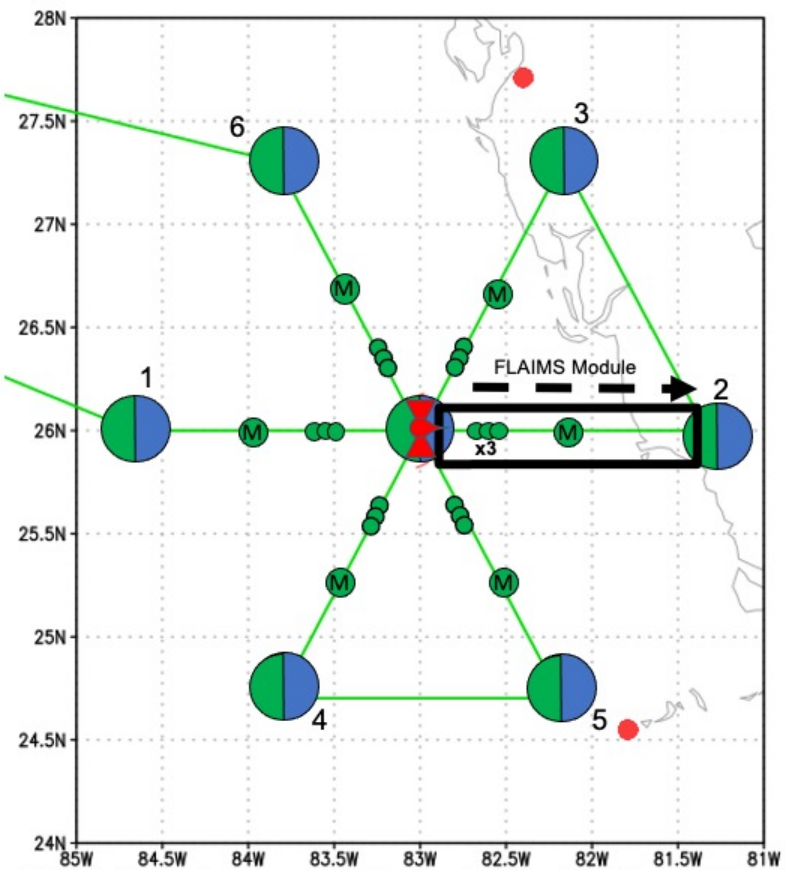
Hurricane Ian - Regional 88-D Composite




34N
33N
32N
31N
30N
29N
28N
27N
26N
25N
24N
23N
22N
21N
20N
100W
98W
96W
94W
92W
90W
88W
86W
84W
82W
80W
78W
7
6
3
1
2
4
5
12 UTC Rawinsonde
00 UTC Rawinsonde
00 and 12 UTC Rawinsonde

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)

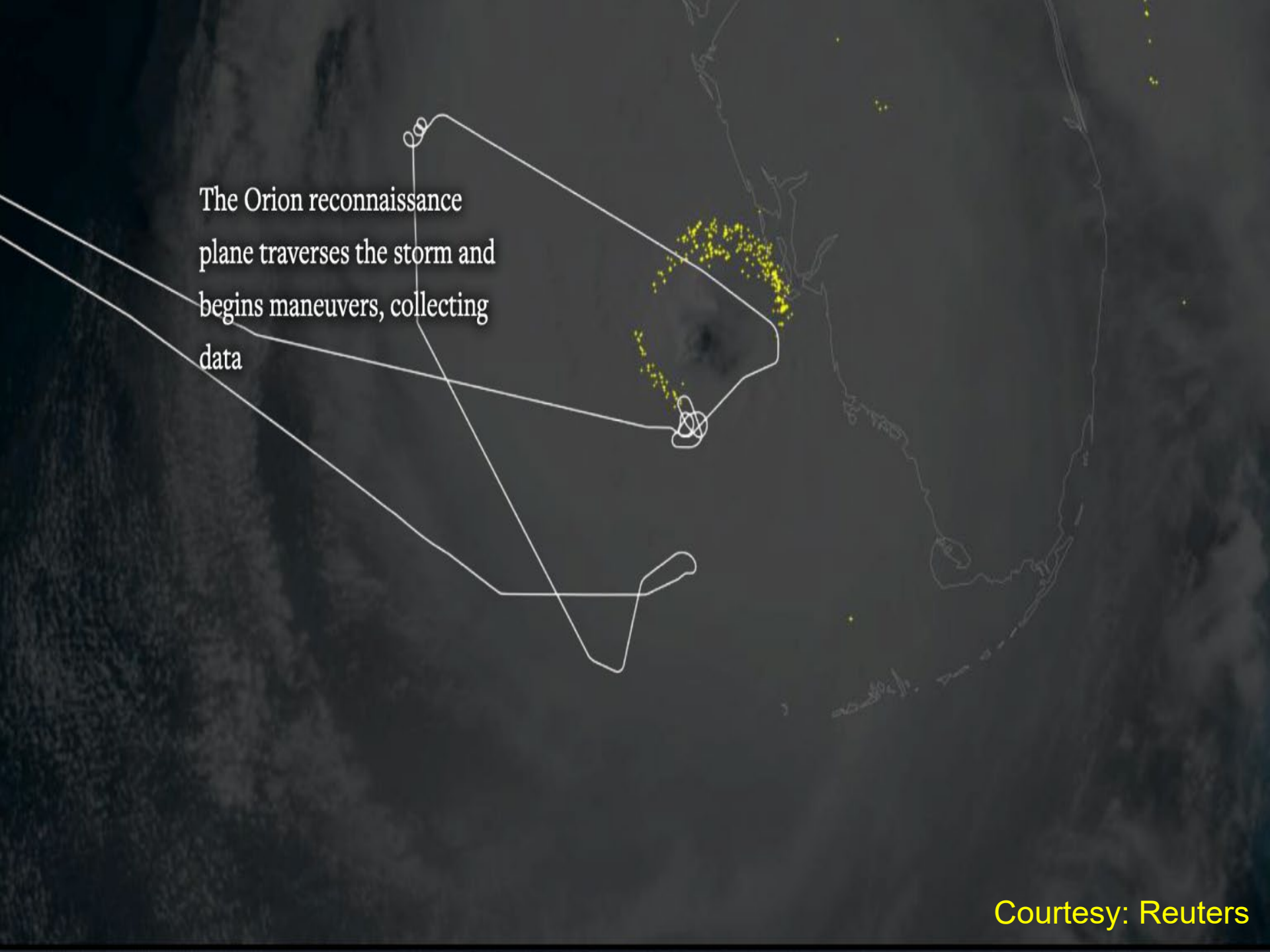
Dropsonde payload:
39 total (15 EMC, 24 ONR)
6 turn point drops (EMC) at 1,4,5,6,7,8 (no drop at 2)
6 mid-point drops (EMC)
3 center drops (EMC) inbound from 1, 5 and 7
24 RMW rapid drops (ONR)

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.

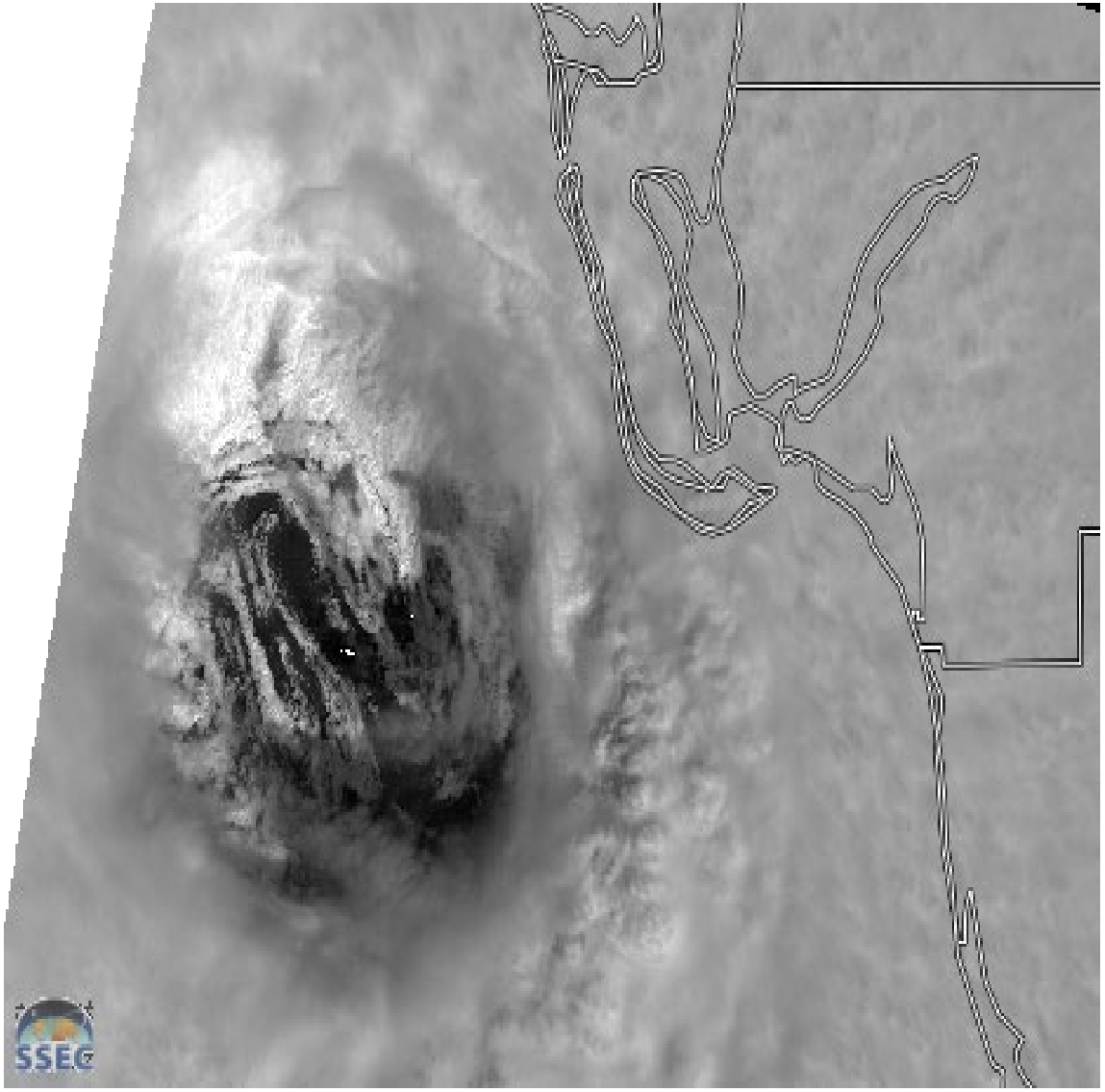
- Possible *Eye-Eyewall Mixing Module* during eye orbit



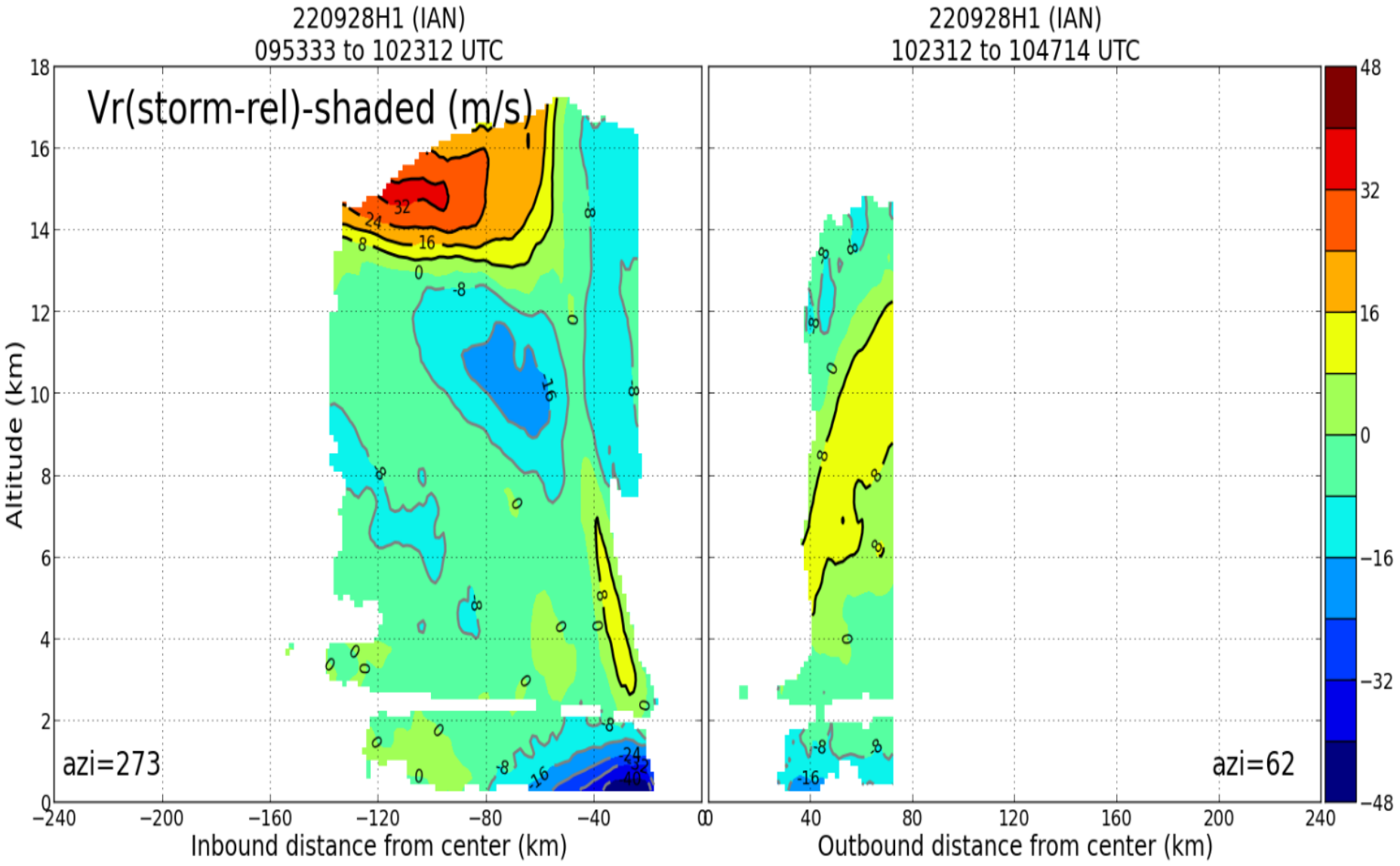
Courtesy: Reuters

The P-3 likely went through the ‘scallops’ on the W-SW eyewall…

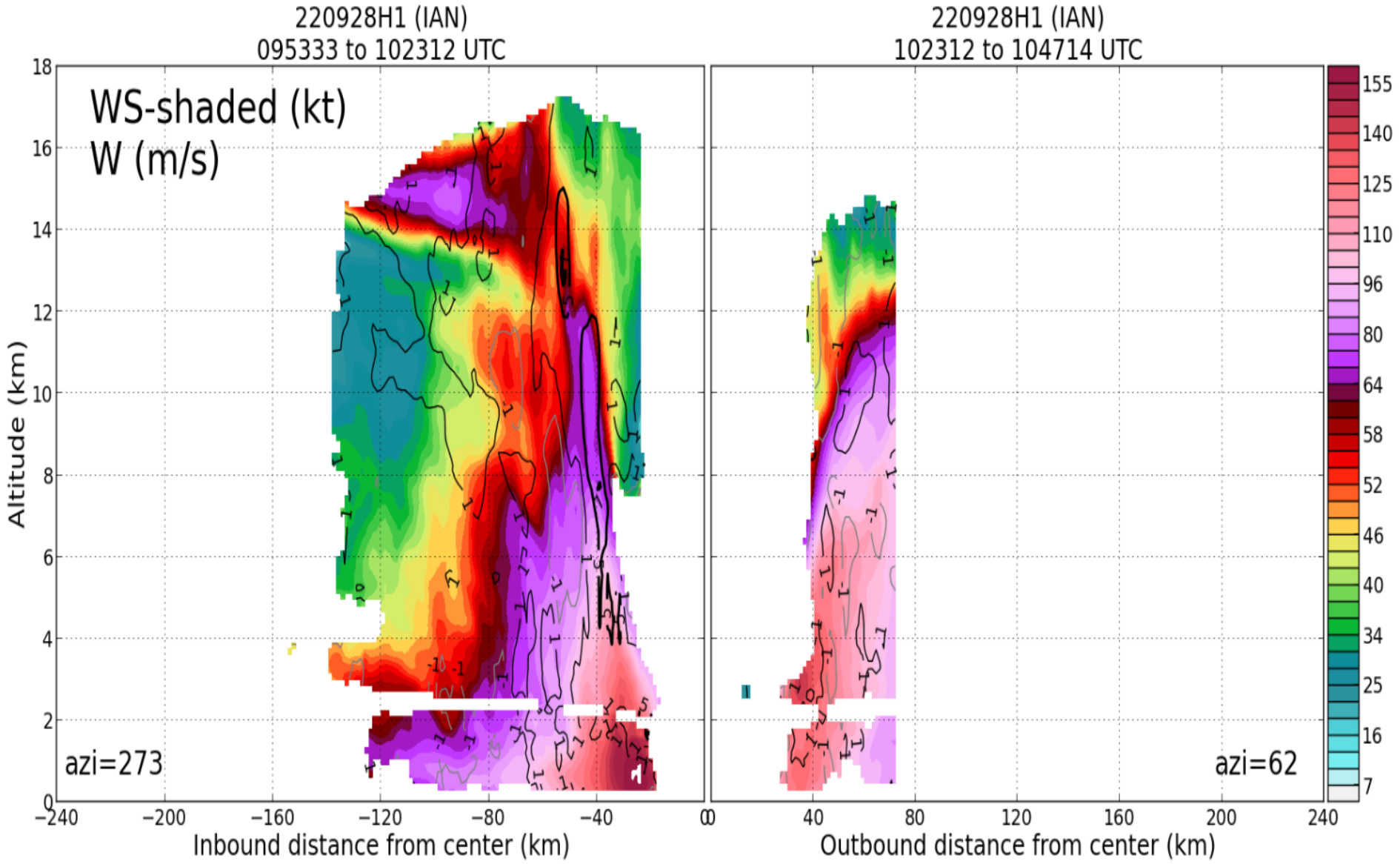
15-m resolution visible imagery



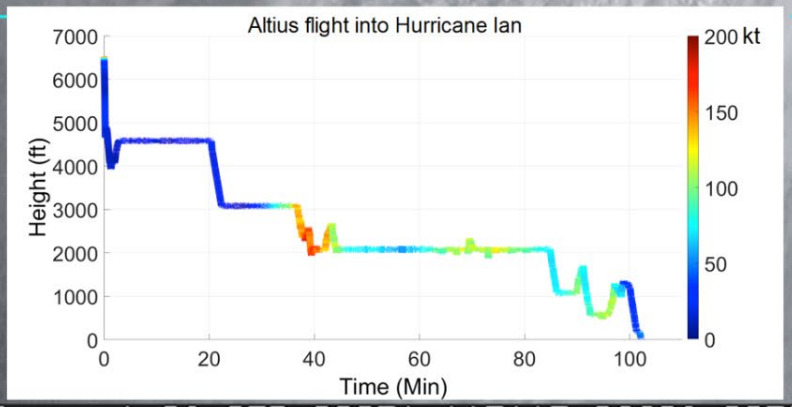
P3 Doppler Profile Data



P3 Doppler Profile Data



Hurricane Ian Visible Satellite Imagery: 1151Z
Altius in-flight period: 1030z - 1212z



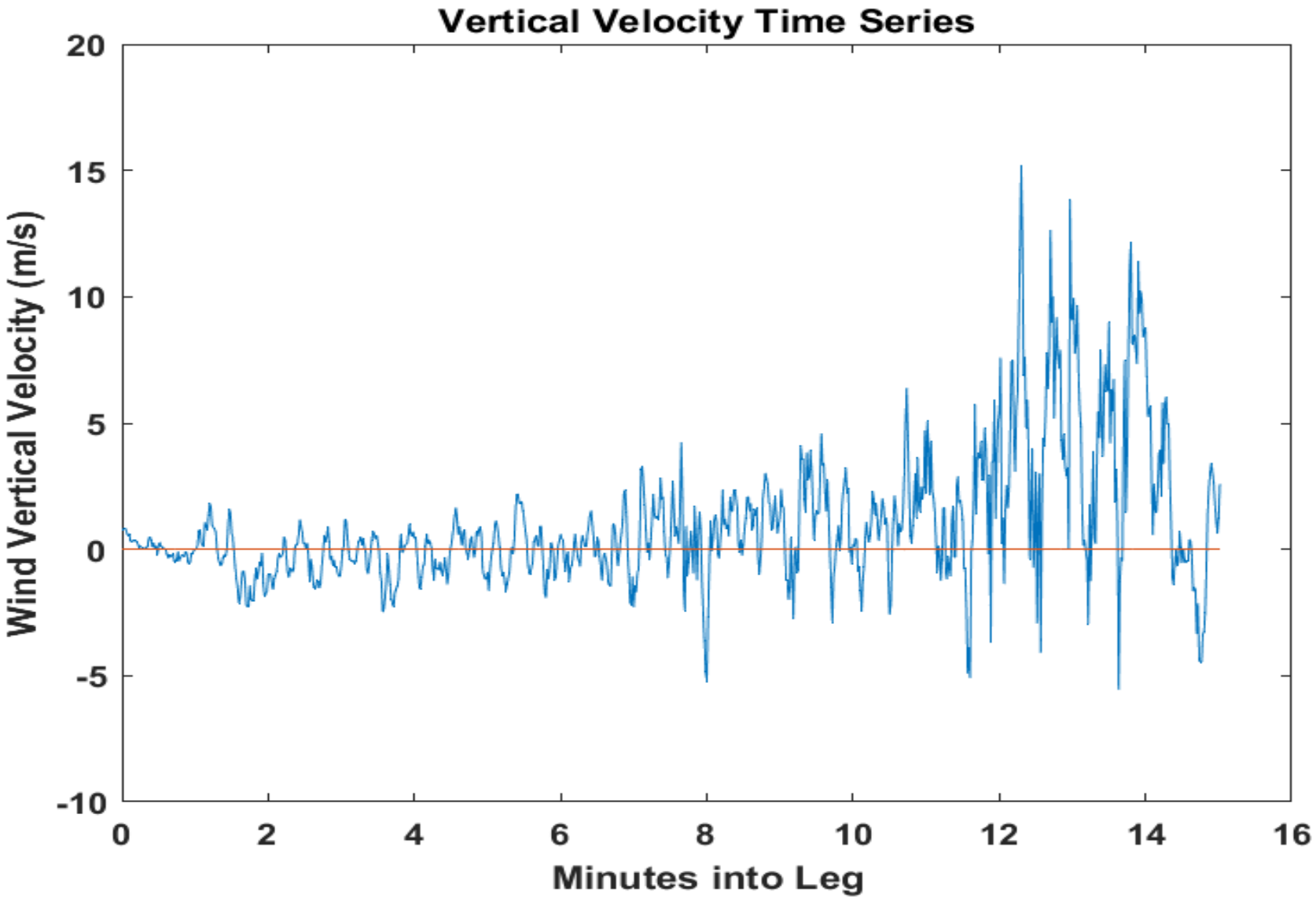
25

85

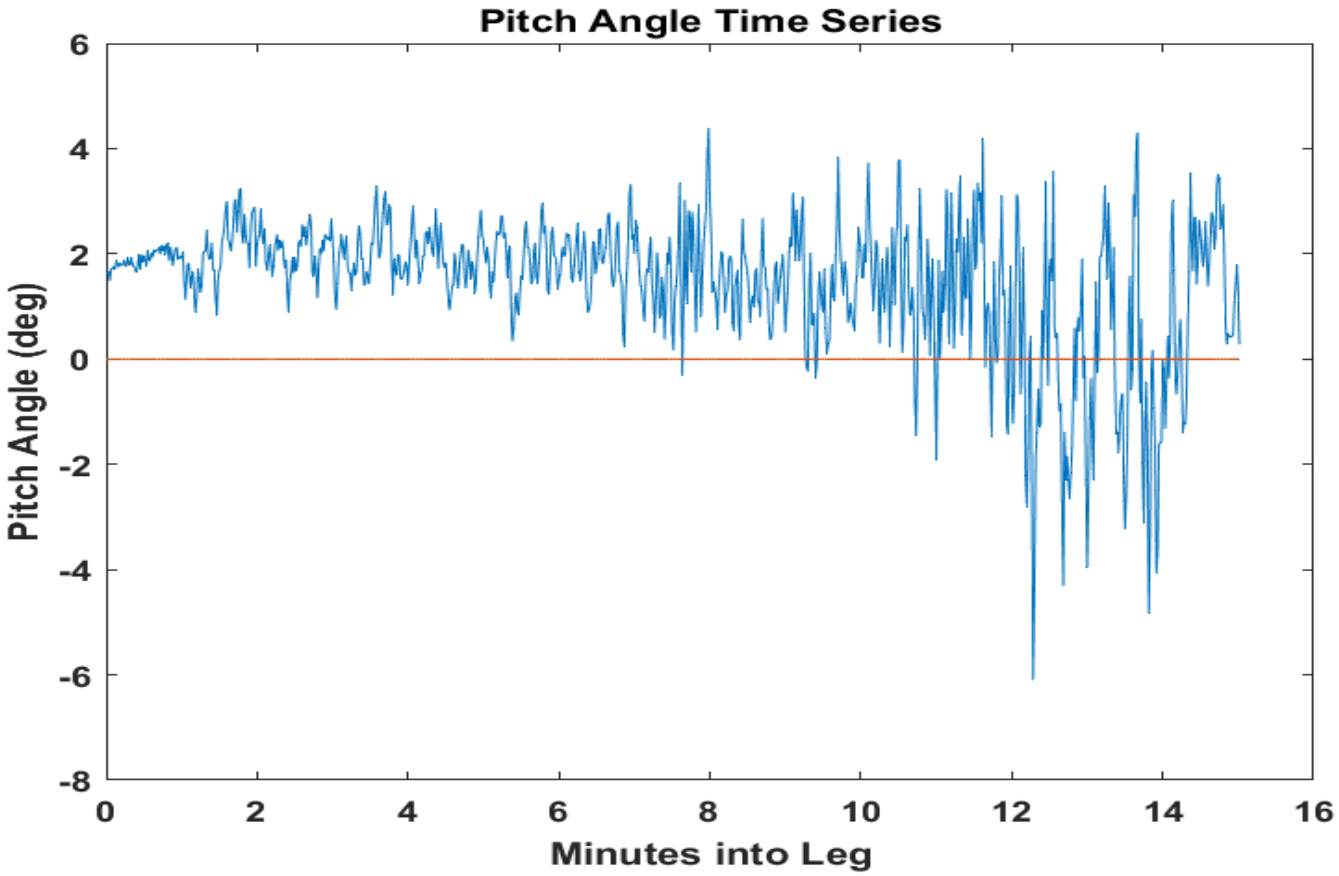
1 0001 GOES-16 1 28 SEP 22271 115117 06698 09701 01.00McIDAS

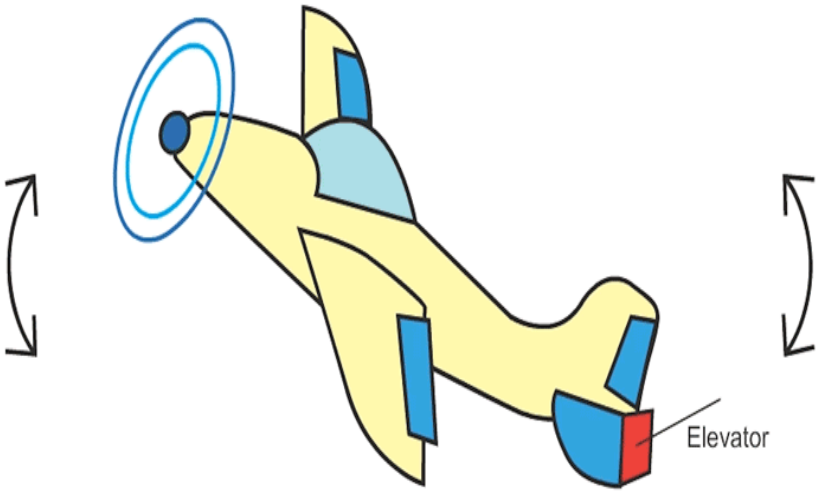
The following slides show the leg of the P-3 with ‘extreme turbulence’…

P-3 Flight Level Data: NW-SE Eyewall Penetration into Major Hurricane Ian (September 28, 2022)

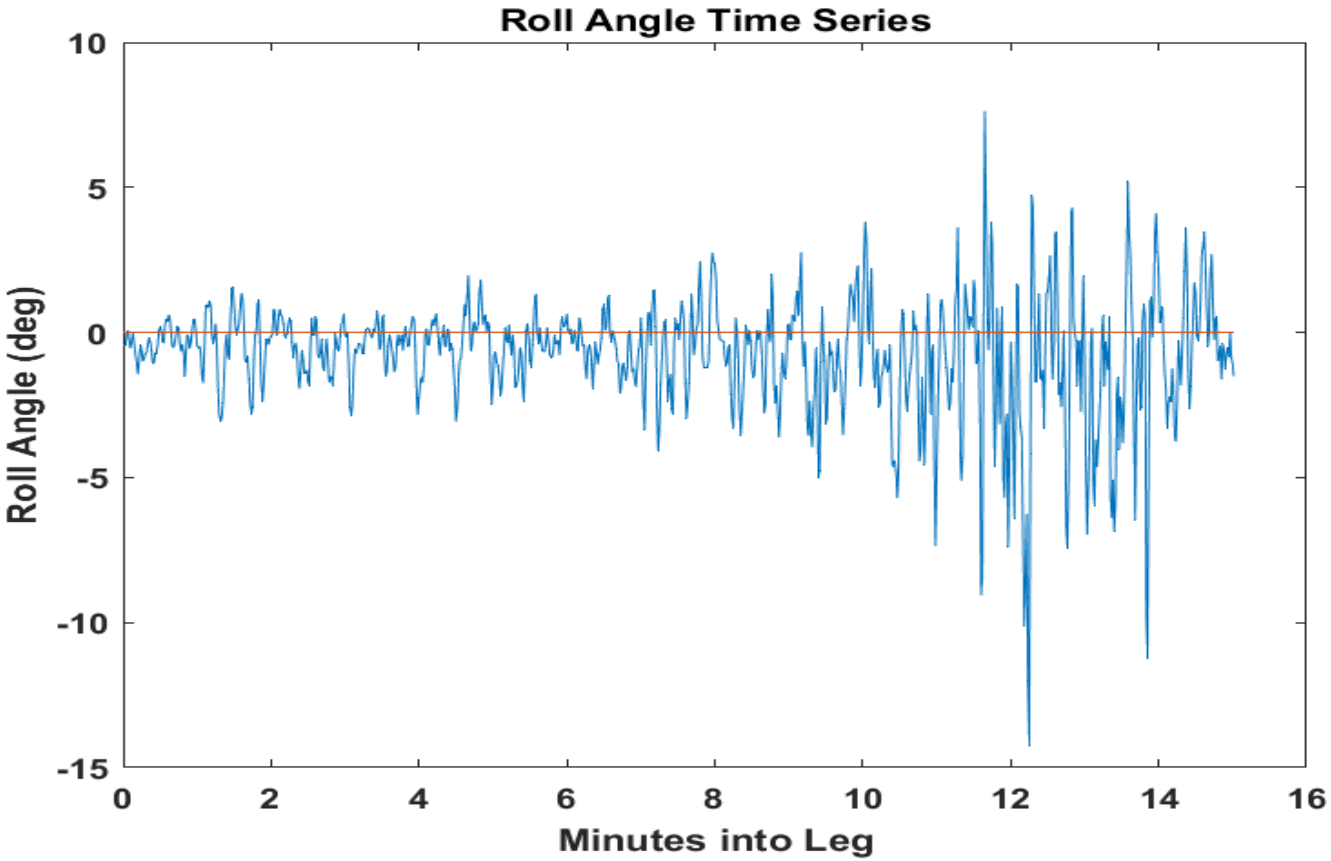


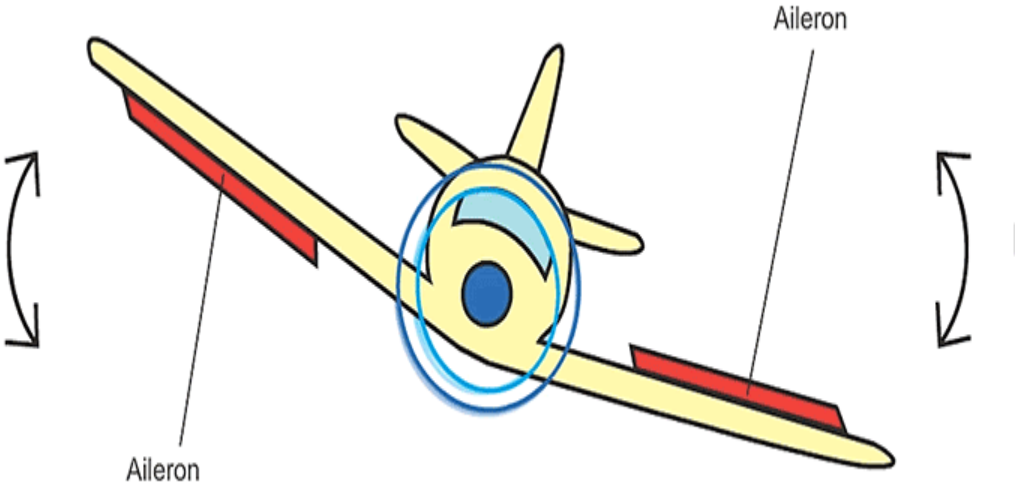
P-3 FL Data:


Pitch Angle Time Series
Pitch Angle (deg)
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
16
Minutes into Leg

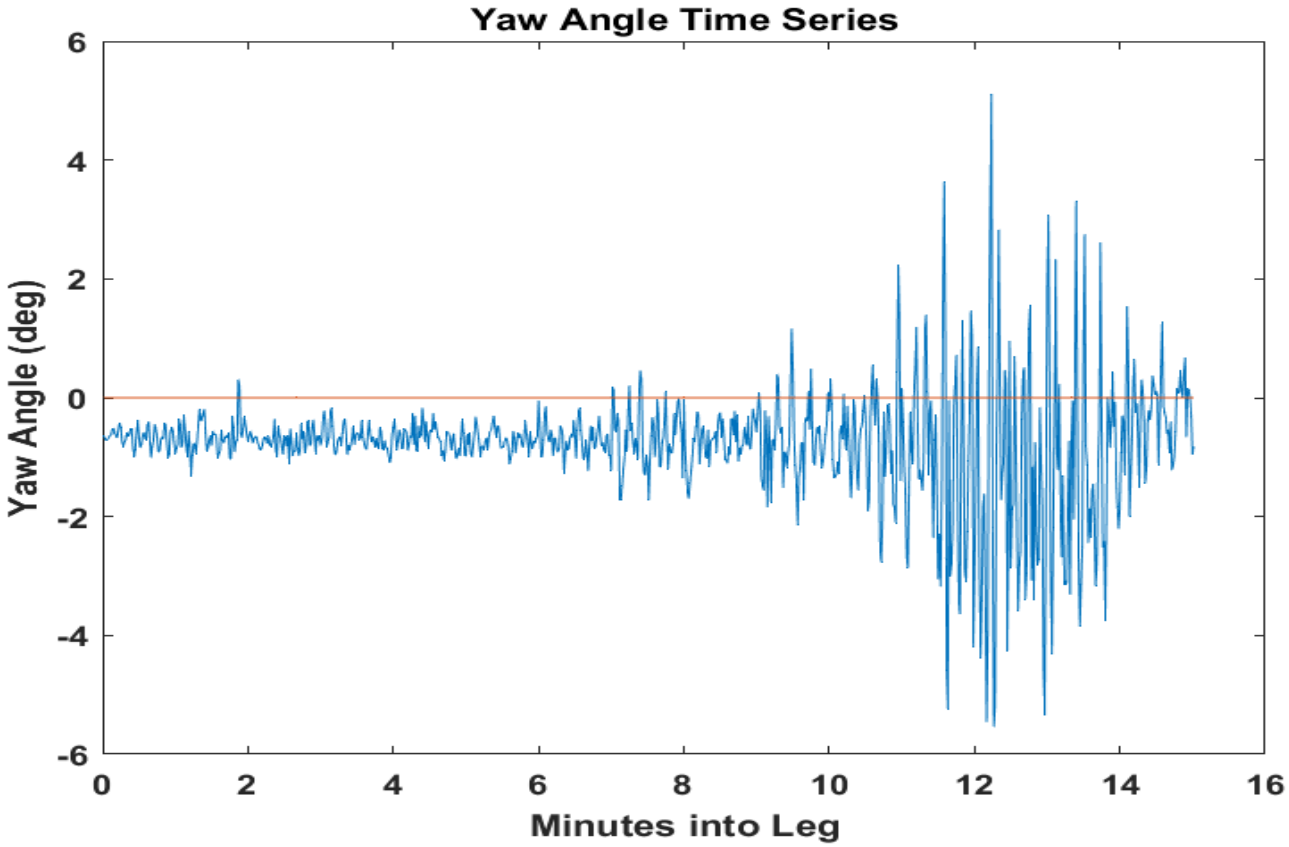

Elevator

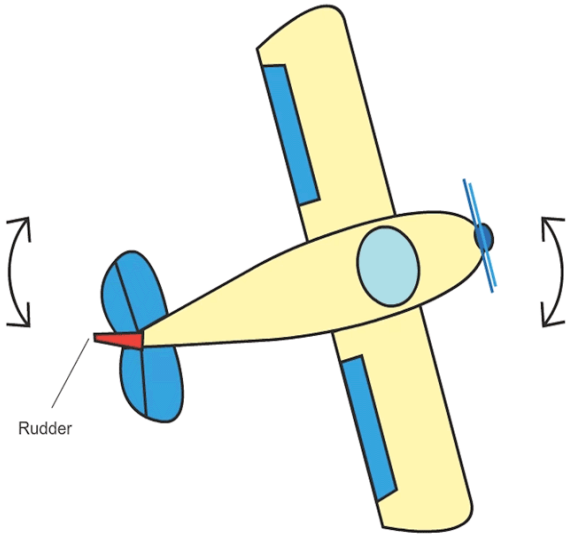
P-3 FL Data:

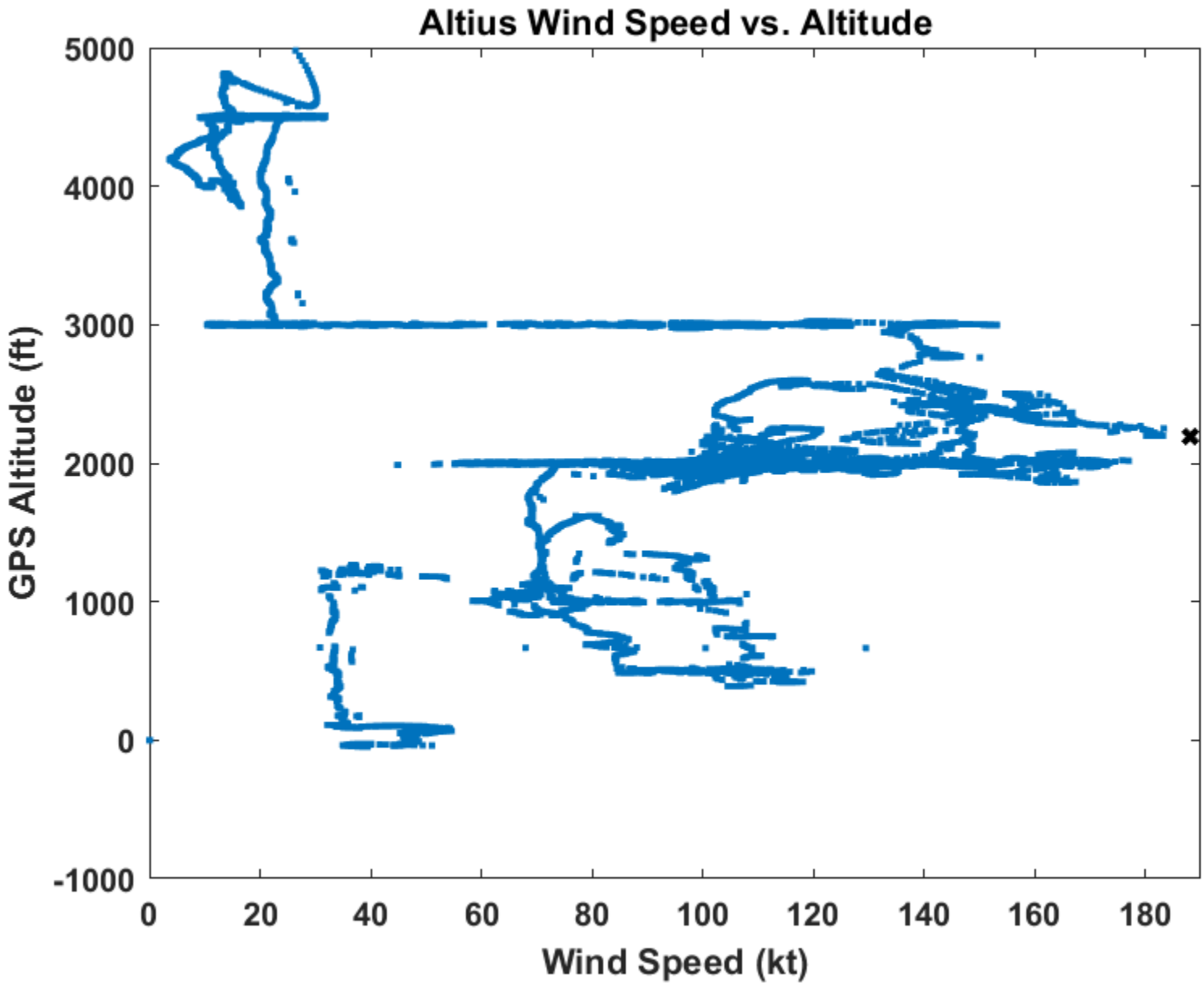

Roll Angle Time Series
Roll Angle (deg)
Minutes into Leg
10
5
0
-5
-10
-15
0
2
4
6
8
10
12
14
16

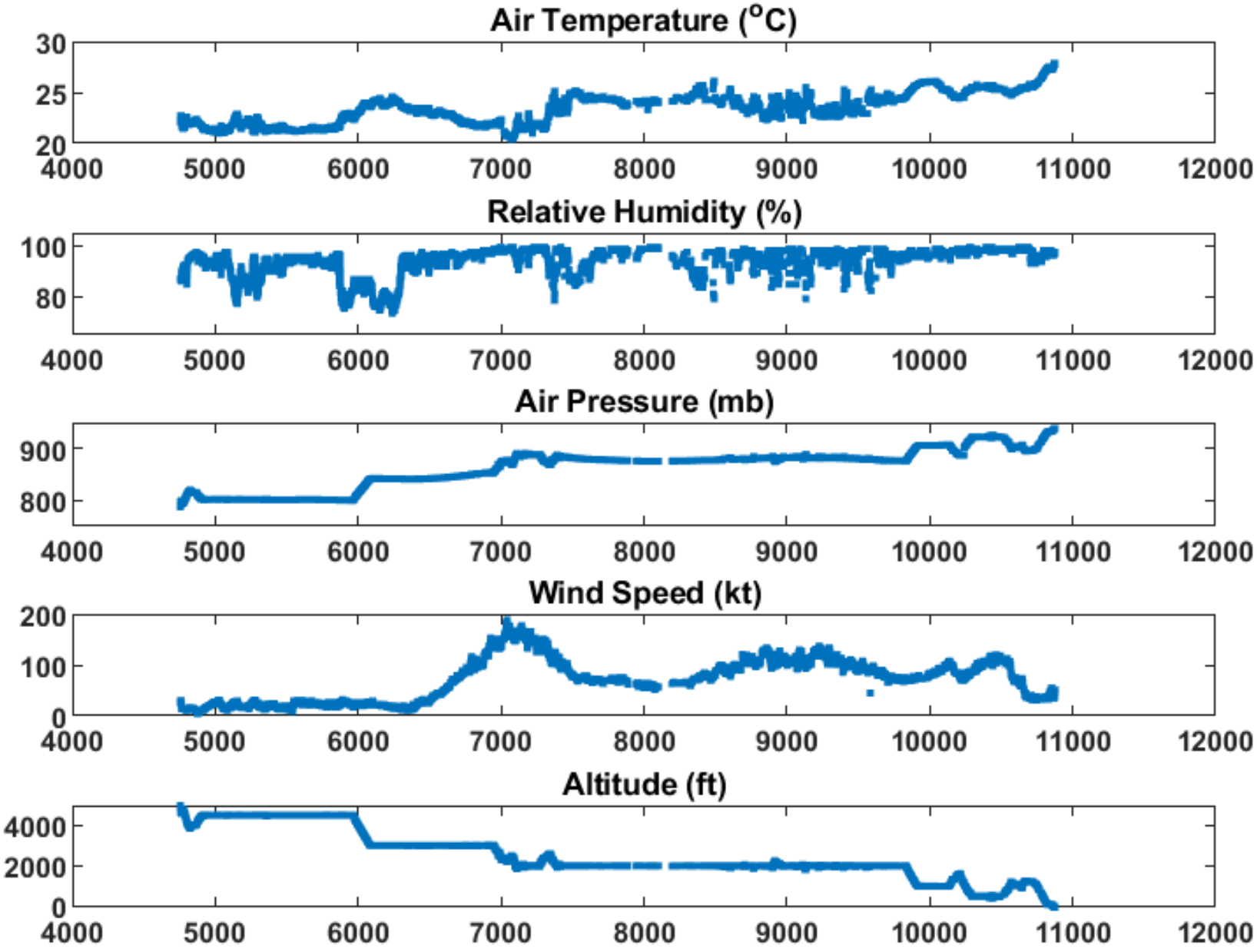

Aileron
Aileron

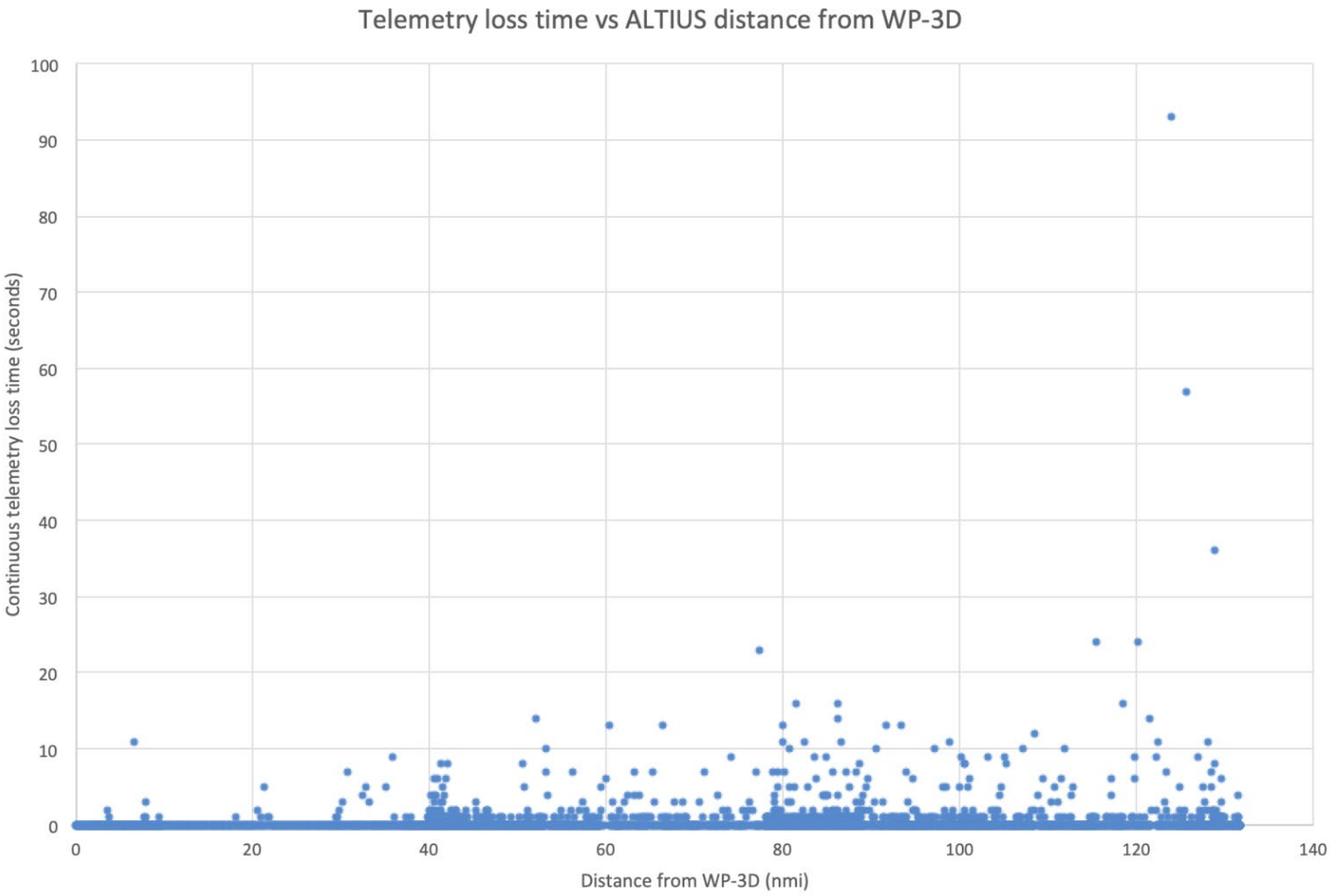
P-3 FL Data:


Yaw Angle Time Series
Yaw Angle (deg)
Minutes into Leg
6
4
2
0
-2
-4
-6
0
2
4
6
8
10
12
14
16


Rudder


Altius Wind Speed vs. Altitude
GPS Altitude (ft)
5000
4000
3000
2000
1000
0
-1000
0
20
40
60
80
100
120
140
160
180
Wind Speed (kt)


Air Temperature (°C)
30
25
20
4000
5000
6000
7000
8000
9000
10000
11000
12000
Relative Humidity (%)
100
80
4000
5000
6000
7000
8000
9000
10000
11000
12000
Air Pressure (mb)
900
800
4000
5000
6000
7000
8000
9000
10000
11000
12000
Wind Speed (kt)
200
100
0
4000
5000
6000
7000
8000
9000
10000
11000
12000
Altitude (ft)
4000
2000
0
4000
5000
6000
7000
8000
9000
10000
11000
12000


Telemetry loss time vs ALTIUS distance from WP-3D
Continuous telemetry loss time (seconds)
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
Distance from WP-3D (nmi)

```
URNT15 KUAS 281115
UAS01 WK09A IAN                     HDOB 09 20220928
110531 2555N 08259W 8520 00940 9550 +217 +175 024102 104 /// /// 24
110601 2554N 08300W 8528 00938 9556 +218 +176 018121 124 /// /// 24
110631 2553N 08301W 8533 00939 9562 +219 +178 145139 146 /// /// 24
110702 2551N 08301W 8565 00908 9562 +219 +179 297141 145 /// /// 24
110739 2549N 08301W 8688 00791 9561 +220 +180 344142 148 /// /// 24
110821 2547N 08301W 8750 00723 9550 +209 +170 333166 183 /// /// 24
110900 2544N 08300W 8720 00755 9554 +206 +167 324160 177 /// /// 24
110930 2542N 08259W 8845 00636 9553 +216 +170 322155 160 /// /// 24
111001 2541N 08258W 8864 00636 9572 +218 +173 324167 171 /// /// 24
111031 2539N 08257W 8874 00639 9587 +215 +175 314159 164 /// /// 24
111102 2538N 08255W 8886 00634 9593 +220 +178 310153 163 /// /// 24
111139 2537N 08252W 8881 00633 9587 +218 +179 297146 149 /// /// 24
111213 2537N 08251W 8865 00654 9594 +218 +179 292137 142 /// /// 24
111243 2537N 08249W 8775 00739 9595 +216 +177 293144 148 /// /// 24
111314 2537N 08248W 8716 00786 9585 +226 +179 292131 142 /// /// 24
111344 2537N 08247W 8742 00739 9560 +237 +181 286107 119 /// /// 24
111414 2538N 08247W 8830 00648 9550 +238 +186 283114 120 /// /// 24
111445 2538N 08246W 8841 00635 9547 +232 +190 278100 115 /// /// 24
111524 2539N 08245W 8833 00633 9535 +236 +190 272094 098 /// /// 24
111556 2539N 08245W 8820 00633 9523 +248 +189 272082 086 /// /// 24
```

sUAS Records set:

1. ***Wind speed 216mph (@2150 ft)***
2. ***Endurance (102 min)***
3. ***sUAs-P3 distance (130nmi)***

Ian (2022) Summary

- **small Unmanned Aircraft Systems (sUAS) observations can improve scientific understanding of dangerous and difficult to observe regions of the Tropical Cyclone, including the critical air-sea transition zone.**
- **These unique data have the potential to improve operational situational awareness, boundary layer physics and future forecasts of Tropical Cyclone intensity (and possibly short term track with enhanced center fix capabilities).**
- **As this technology advances towards operational transition, small drones will fly lower, longer and for less money.**

What's Next for Altius?

- **Altius: post-processing, Ian sUAS data impact, BL analysis, add multi-hole turbulence probe and possible video for 2023. Incorporate Ian lessons learned.**

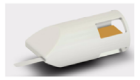
Project Support: NOAA/OMAO/AOC, NOAA/SBIR, NOAA/OAR/WPO, NOAA/JPA

NEw and Improved Observing Technologies And Enhanced Concept of Operations Working Group

Federal civilian and DoD partners, Academic Institutions, Private Sector collaborators

V2.0 (ongoing)

Field testing for the most promising technologies



Skyfora's
StreamSonde DS

A new weather instrument providing complementary data

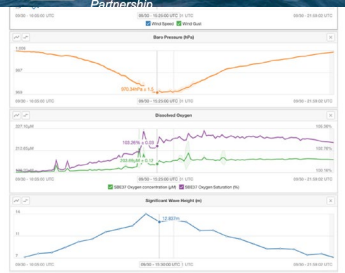
FEATURES:
- Weight: < 15 gram
- Size: 66mm in diameter
- Terminal free-fall velocity: below 5m/s (a.s.l.)
- 403MHz meteorological band
- 2h operation time
- Re-chargeable Li-Ion battery
- Ultra-low power consumption

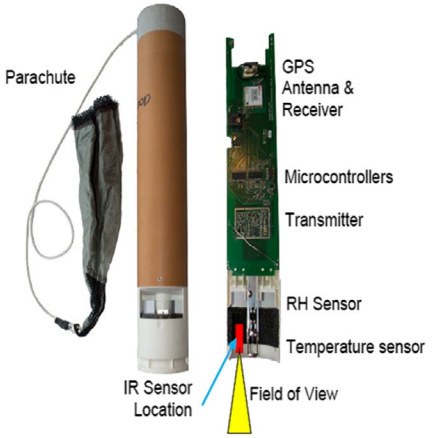
INTEGRATED SENSORS:
- Pressure
- Temperature
- Humidity
- Accurate, custom build GNSS
- 3D Gyro
- 3D Accelerometer
- 3D Magnetometer
- Optional Air Quality sensor

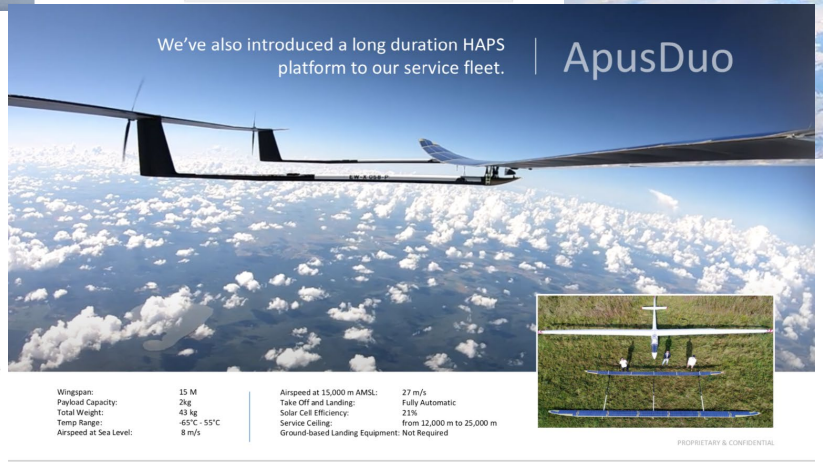
OPERATIONS:
- Deployment from flying platform equipped with AVAPS launchers.
- No parachute needed
- Floats on water surface (not tested)
- 2 patent applications filed

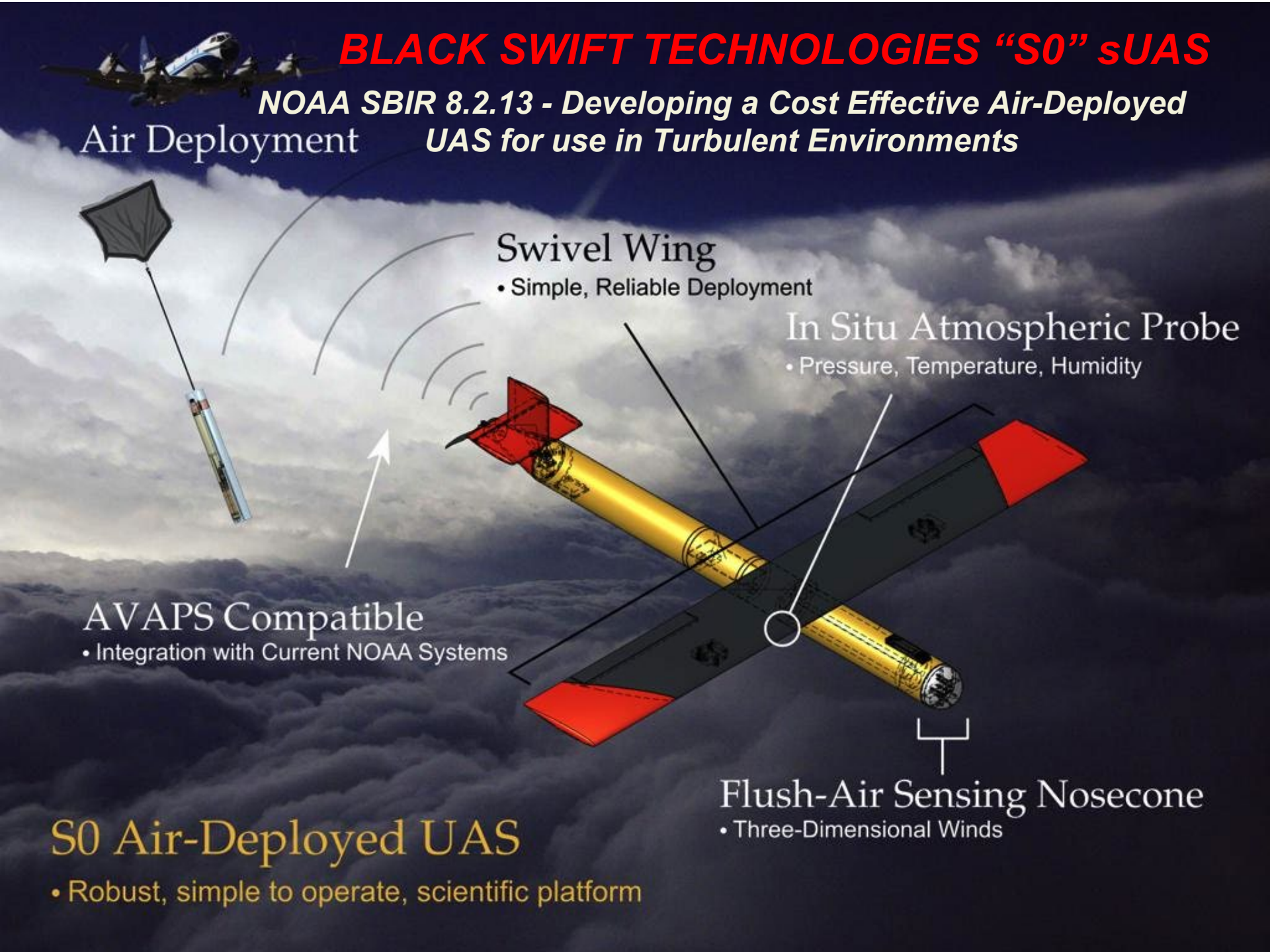
DRAGOON

Hurricane Weather Sensing
- An example use-case of the concept.
- One-time use, 30 hr endurance.
- Long distance, 1500 mi, no wind.
- 30 lb, 10 ft wingspan.
- MET sensor plus 1 lb additional payload.
- Minimal number of launch sites can cover large portion of ocean.
- Non-specialist launch (private pilot, local resources) keeps crew cost down.
- Initially, flight monitoring is remote. Soon, monitoring can be automated.
- Iridium SBD or store-and-forward data retrieval.

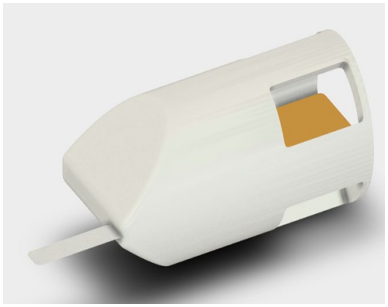







BLACK SWIFT TECHNOLOGIES "S0" sUAS
NOAA SBIR 8.2.13 - Developing a Cost Effective Air-Deployed UAS for use in Turbulent Environments
Air Deployment
Swivel Wing
• Simple, Reliable Deployment
In Situ Atmospheric Probe
• Pressure, Temperature, Humidity
AVAPS Compatible
• Integration with Current NOAA Systems
Flush-Air Sensing Nosecone
• Three-Dimensional Winds
S0 Air-Deployed UAS
• Robust, simple to operate, scientific platform

SKYFORA StreamSonde



FEATURES:

- Weight: < 15 gram
- Size: 66mm in diameter
- Terminal free - fall velocity: below 5m/s (a.s.l.)
- 403MHz meteorological band
- 1.5h operation time
- Re-chargeable Li - Ion battery
- Ultra-low power consumption

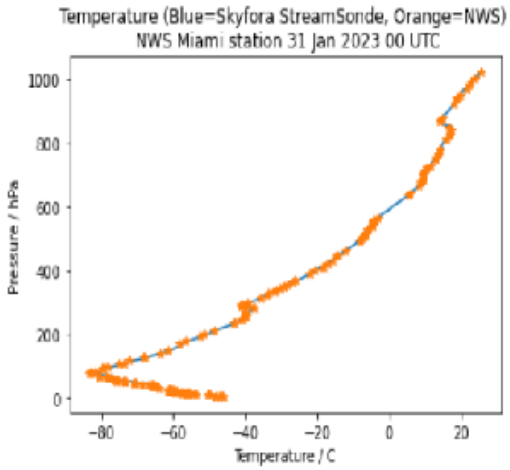
INTEGRATED SENSORS:

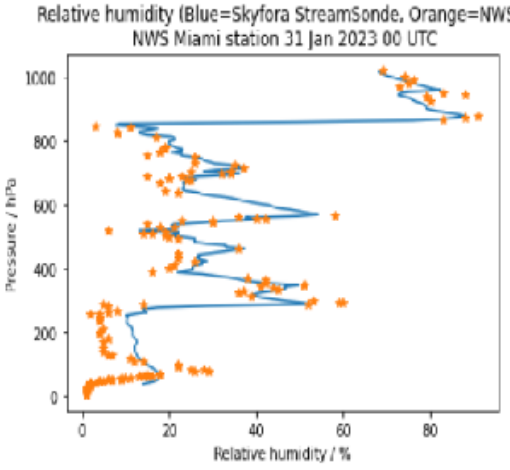
- Pressure
- Temperature
- Humidity
- Accurate, custom built GNSS
- 3D Gyro
- 3D Accelerometer
- 3D Magnetometer
- Air Quality sensor
- Ambient light sensors

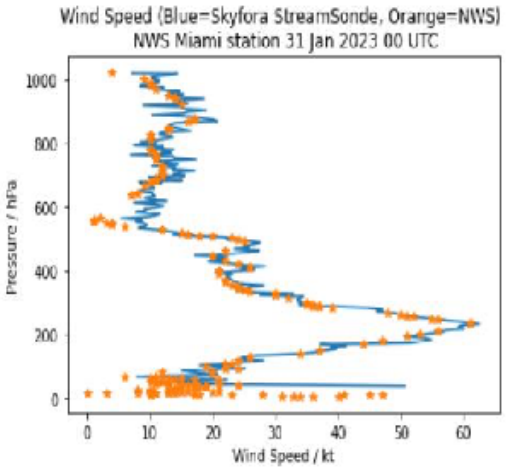
OPERATIONS:

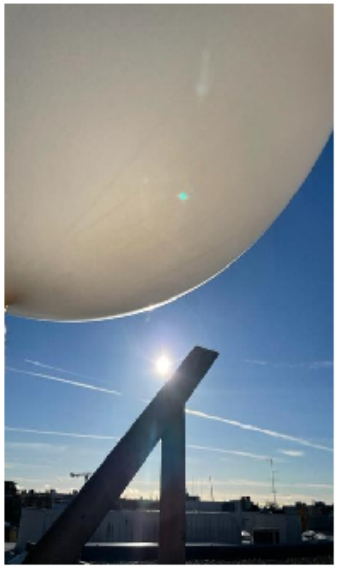
- Deployment from airplanes equipped with AVAPS launchers.
- No parachute needed
- Descent with natural winds
- Floats on water surface
- 4 patent applications filed

Sounding Miami 31 Jan 2023 00 UTC









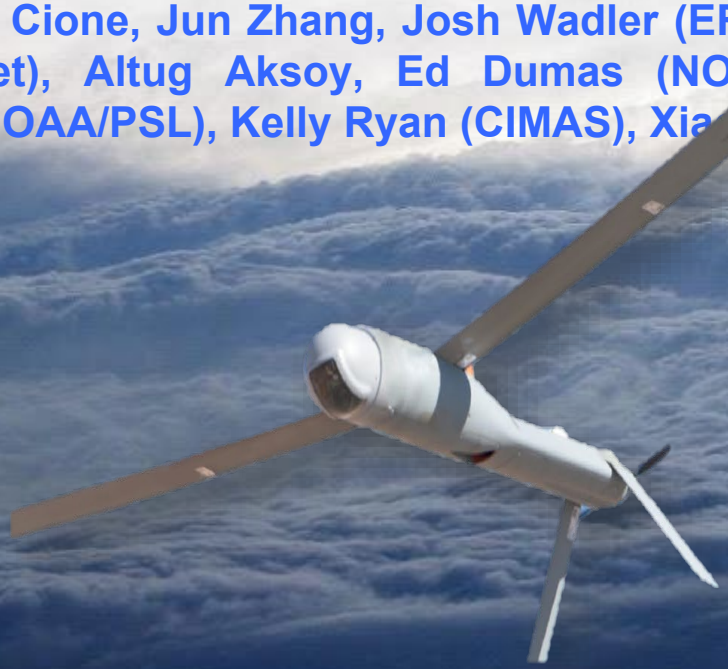
- In general, good agreement between the Skyfora StreamSonde and the NWS Vaisala RS-41, especially considering that the sondes were launched on separate balloons
- StreamSonde humidity likely wrong above 250 hPa (~11 km) – sensor inertia time lag corrections are still in development and none were applied in this case
- Radiation corrections not necessary in the twilight conditions

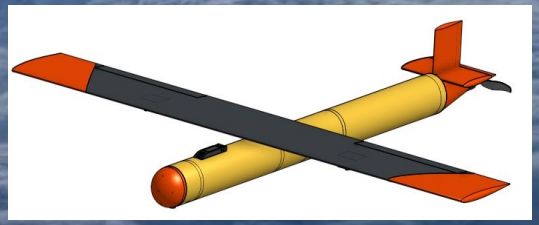
(The data shown are interpolated to pressure levels with 5 hPa spacing with no other post processing or corrections done)

2023 NOAA/AOML/HRD Hurricane Field Program
Advancing the Prediction of Hurricanes Experiment (APHEX)

RESEARCH IN COORDINATION WITH OPERATIONS
SMALL UNMANNED AIRCRAFT VEHICLE EXPERIMENT
(RICO SUAVE)

Science Team: Joseph Cione, Jun Zhang, Josh Wadler (ERAU), George Bryan (NCAR), Ron Dobosy (NOAA/ARL-ret), Altug Aksoy, Ed Dumas (NOAA/ARL), Rosimar Rios-Berrios (NCAR), Gijs deBoer (NOAA/PSL), Kelly Ryan (CIMAS), Xia[illegible]in Chen (UAH)



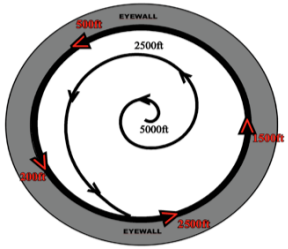


Plain Language Description: Use small drones to sample the lowest and most dangerous regions of the tropical cyclone. Observations from these unique platforms have the potential to improve basic understanding and enhance situational awareness. Analyses of data collected from these small drones also have the potential to improve the physics of numerical models that predict changes in storm intensity.

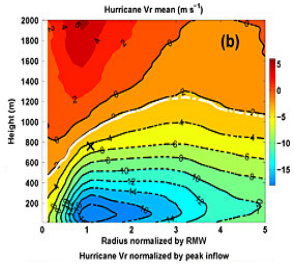
2023 MATURE STAGE EXPERIMENT
RICO SUAVE

Objectives:

Eyewall Module: Provide sUAS HDOBS at multiple altitudes and azimuths to NHC in near real time. Post storm, comparing sUAS atmospheric and SST high wind observations with operational analysis and forecast fields from coupled HWRF and HAFS.



Inflow Module: Provide sUAS HDOBS in near-real-time to NHC. Post storm, compare sUAS TC boundary layer thermodynamic, kinematic and SST radial structure with model output to improve TC boundary layer parameterizations and ocean response in HWRF and



Center Fix/Eye-Eyewall Module: Provide sUAS HDOBS and center fix estimates in near-real-time to NHC. Post storm, compare sUAS TC boundary layer thermodynamic, kinematic and SST structure within the eye and eye/eyewall interface with mode output to improve TC boundary layer parameterizations esponse in HWRF and HAFS.


Questions ?