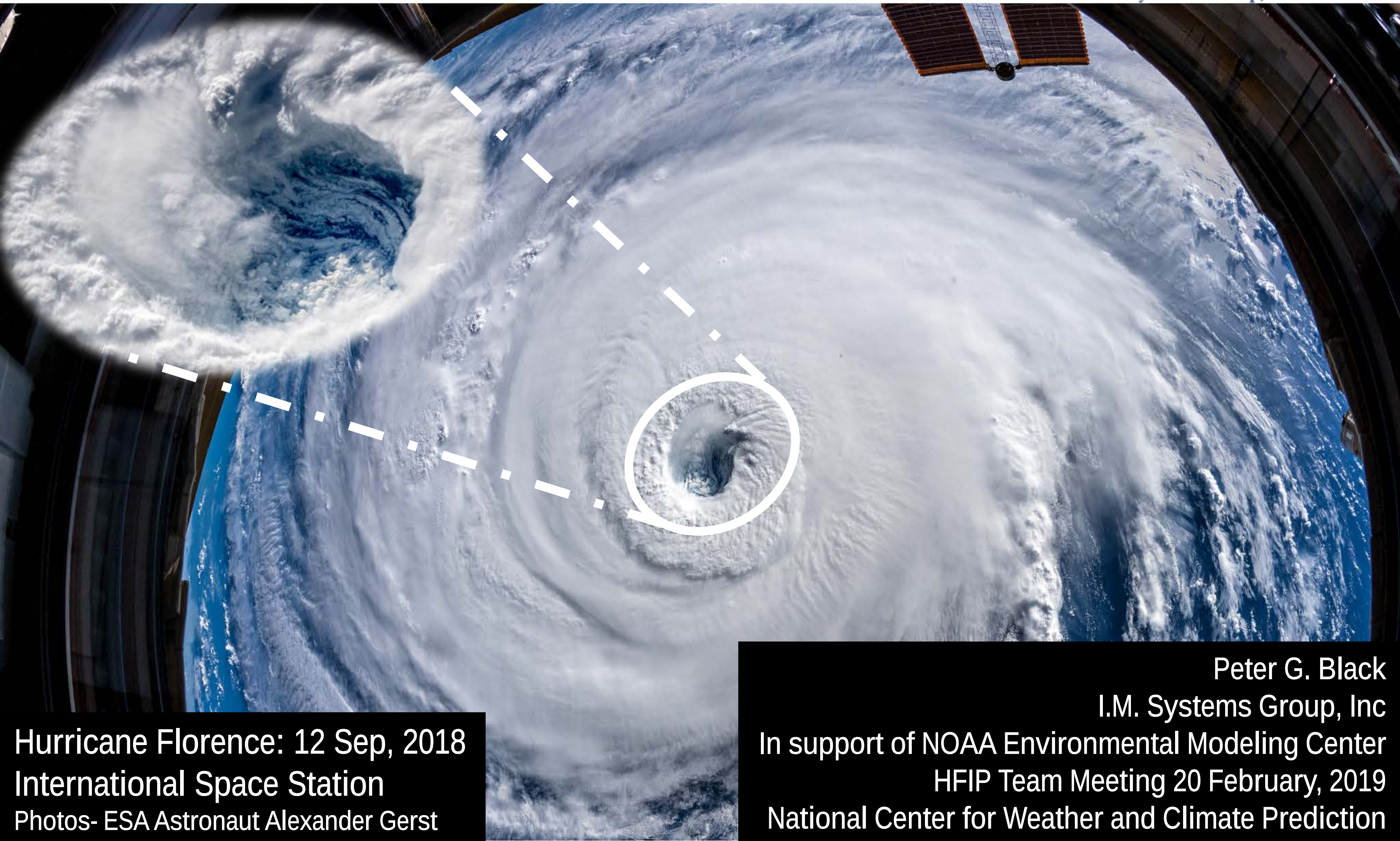
Emerging Airborne Observational Strategies for Improved Tropical Cyclone Prediction



Hurricane Florence: 12 Sep, 2018
International Space Station
Photos- ESA Astronaut Alexander Gerst

Peter G. Black
I.M. Systems Group, Inc
In support of NOAA Environmental Modeling Center
HFIP Team Meeting 20 February, 2019
National Center for Weather and Climate Prediction

Presentation Objective

Provide some insight concerning the scope of airborne observations conducted on a operational basis for use in tropical cyclone model assimilation, especially sondes.

Outline of presentation

- o Aircraft platforms used operationally and for numerical model DA in Tropical Cyclones (TC) impacting the U.S., Mexico, Caribbean and the Western Pacific
  - reconnaissance (inner core flights)
  - surveillance (environmental flights)
- o Recent TC surveillance/ reco examples: Lane, Florence, Michael
- o Florence forecast impact
- o Recent WPAC dropsonde observations: DOTSTAR, China rocketsonde
- o P3, GIV Tail Doppler Radar (TDR)
- o Global Hawk/ high altitude manned aircraft innovative observations
- o Summary

Emerging High Altitude Operational Airborne Technology

NASA

Emerging Technologi es

NOAA

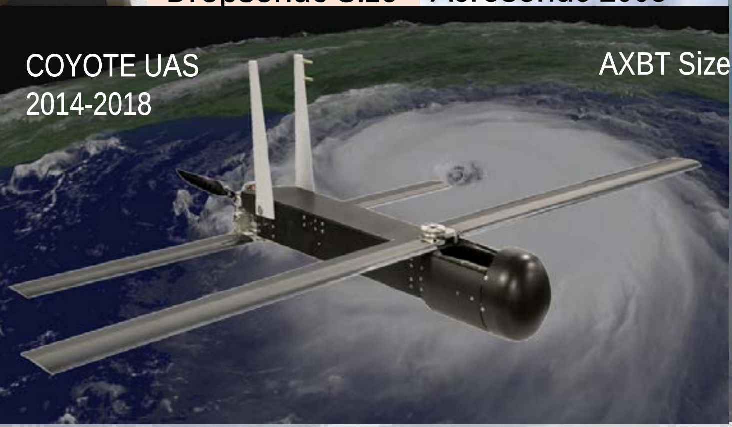
Emerging Operational Airborne Technology Takes Flight in the U.S.

AND THE WORLD

Tropical Cyclone Aircraft of the World


Glider Sonde- Taiwan
Dropsonde Size


CN-1
China PRC
Taiwan USA
Aerosonde 2008


COYOTE UAS
2014-2018
AXBT Size


NASA GLOBAL HAWK UAS
HS3 SHOUT EPOCH 2012-2017


NASA WB-57
TCI 2014-2015


NASA DC-8 2005-2018


NASA
ER-2
2005-
2018

Hurricane Lane

Significance:

First P3 Hawaii deployment

First Hawaii 4-aircraft deployment

First operational wave data- WSRA

Totals:

4 G-IV flts (120 sondes, ~30/flt)

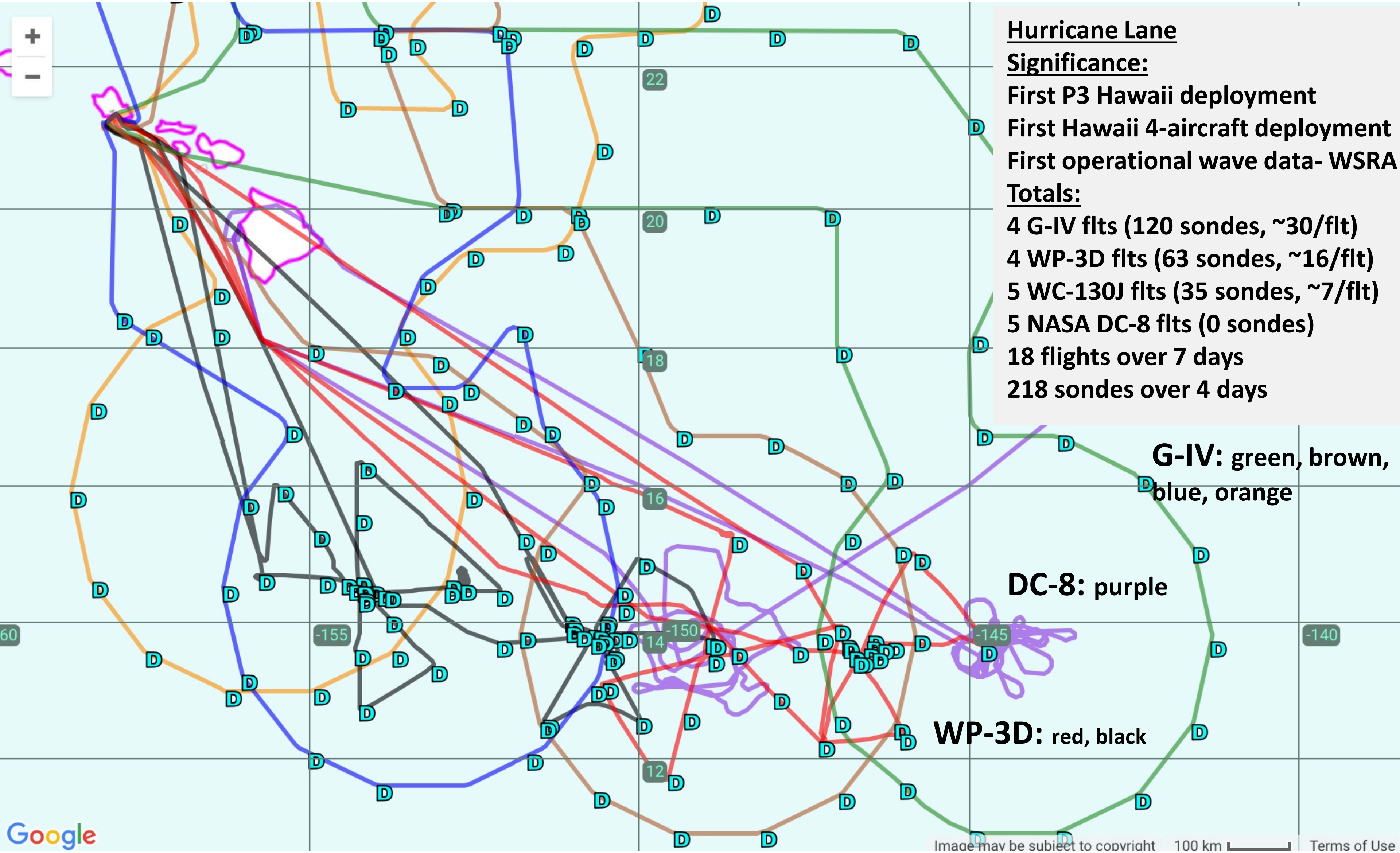
4 WP-3D flts (63 sondes, ~16/flt)

5 WC-130J flts (35 sondes, ~7/flt)

5 NASA DC-8 flts (0 sondes)

18 flights over 7 days

218 sondes over 4 days



Hurricane Florence Brief

Flights/Sondes

- Nine (9) GIV surveillance flights/ 281 sondes (Ryan Torn targeting strategy)
- Three (3) WP-3D research flights / 82 sondes/ 13 good (20 deployed; 35% fail) AXBTs
- Eight (8) WC-130J reco flights/ 196 sondes (700 mb)/20 AXBTs on 5 flights
- Total sondes: 559
- Ten (10) Alamo floats deployed from WC-130J at 03Z 11 Sep; storm passage ~ 21Z 11 Sep

Hurricane Michael Brief

Flights/Sondes

- Three (3) GIV surveillance flights/ 87 sondes (Ryan Torn targeting strategy)
- Six (6) WP-3D research flights (2 post-storm)/ 102 sondes/)/45 good (86 deployed; 48% fail) AXBTs / 18 AXCPs/ 11 AXCTDs
- Eight (8) WC-130J reco flights/ 81 sondes (700 mb)
- Total sondes: 270
- Eight (8) Scripps drifters, 3 EM-APEX floats deployed from WC-130J ahead of Michael on 9 Oct

GIV Tracks (9) and Sondes (281): right

WP-3D Tracks (3) and Sondes (82): below

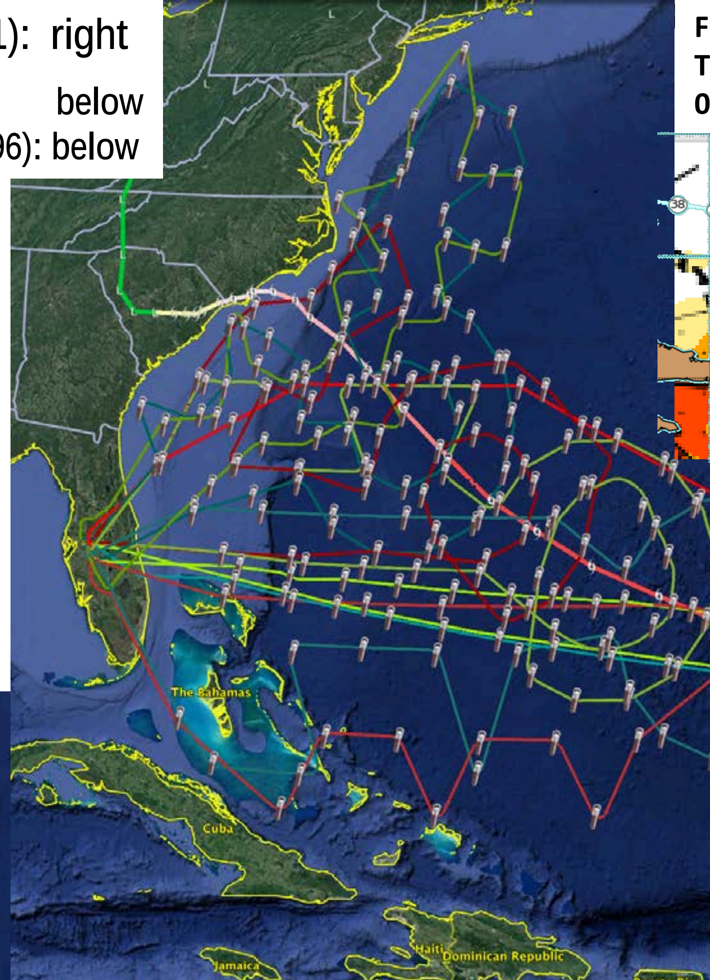
WC-130J Tracks (8) and Sondes (196): below

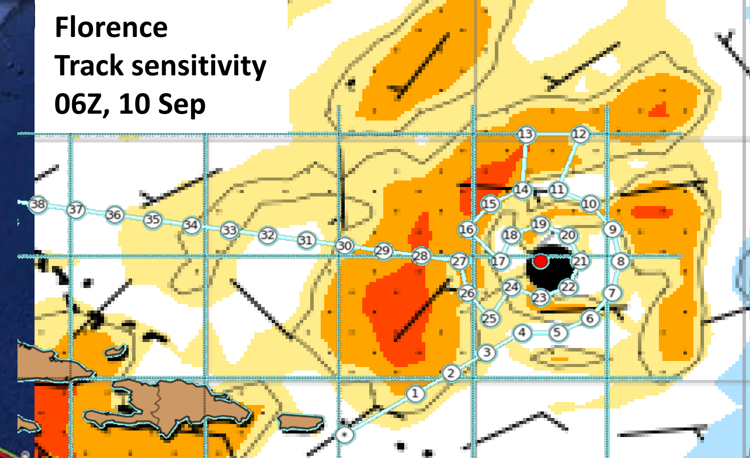
Total flights: 20

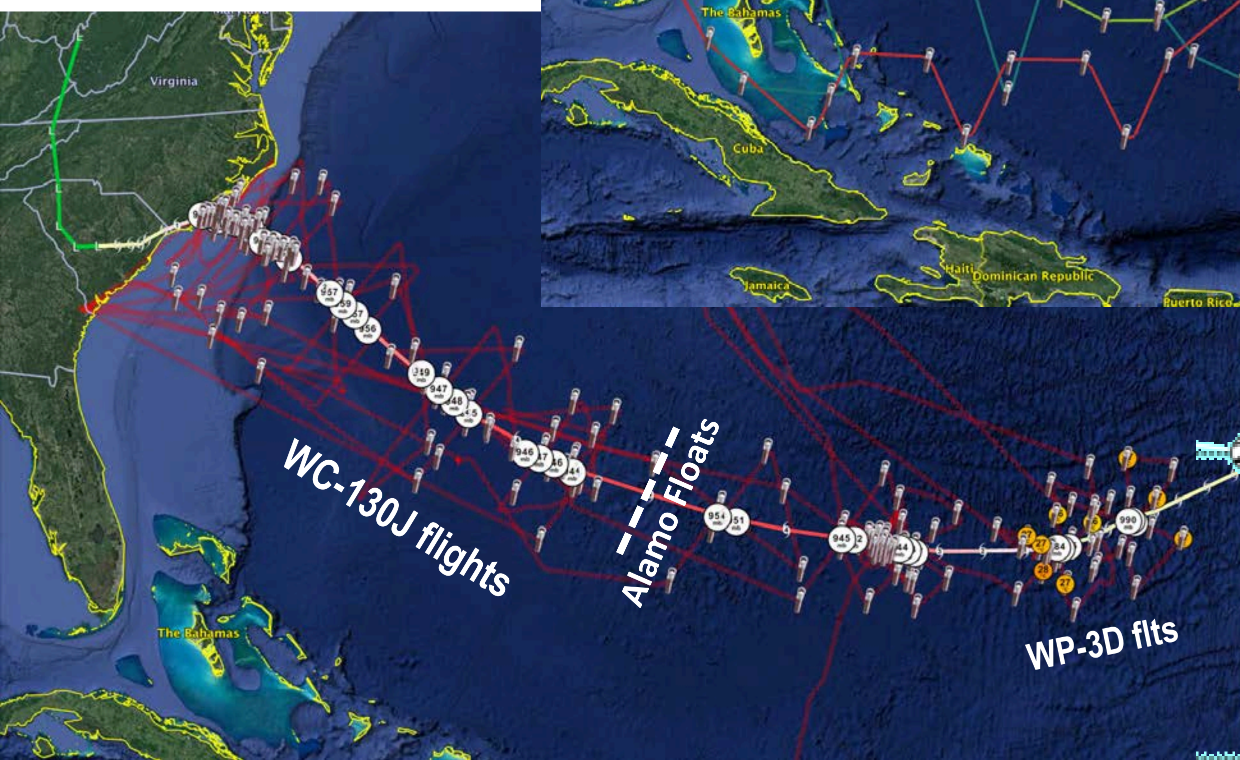
Total Sondes: 559

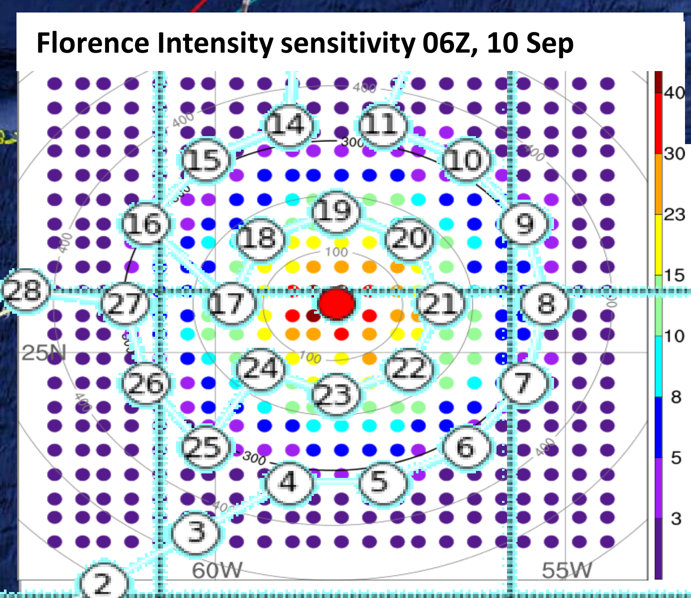
Hurricane Florence

8-15 Sep 2018

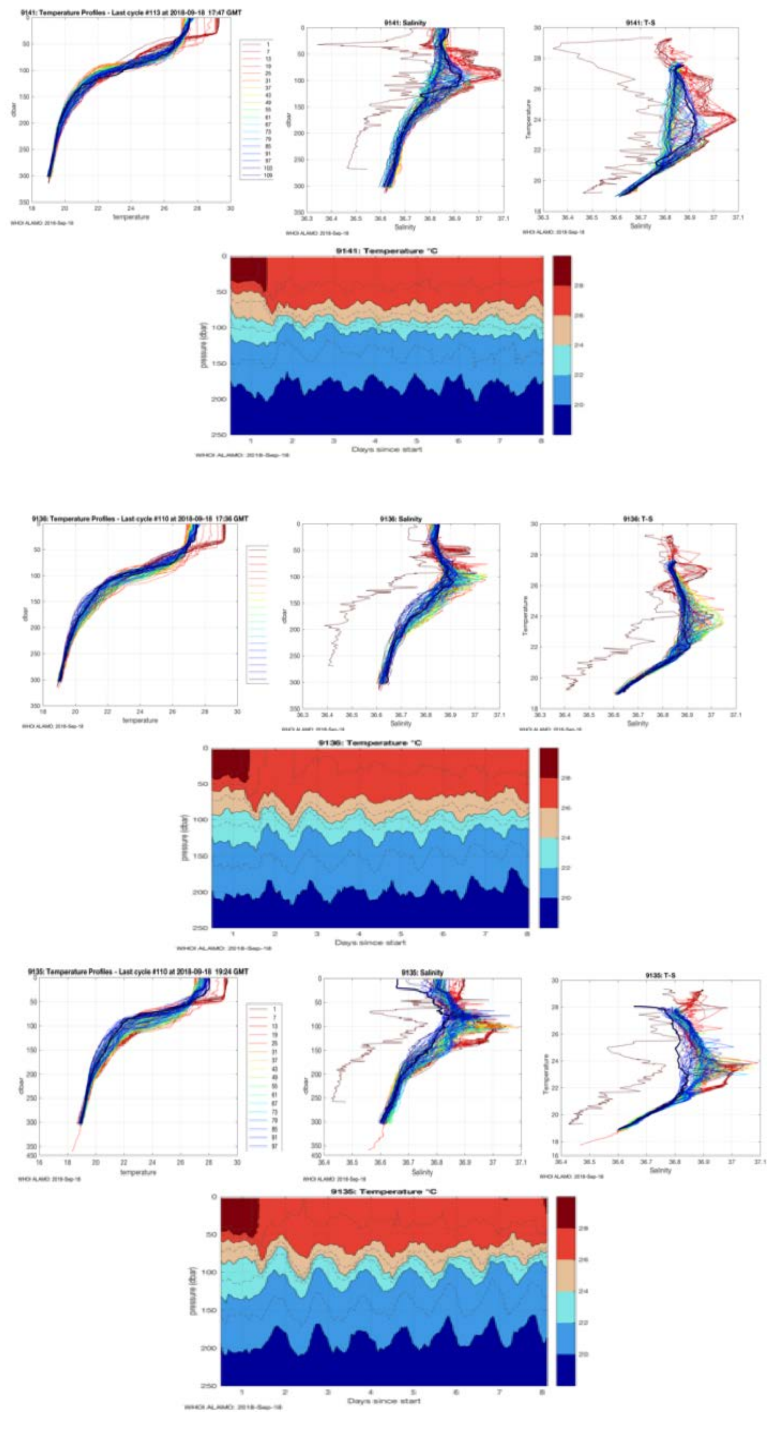


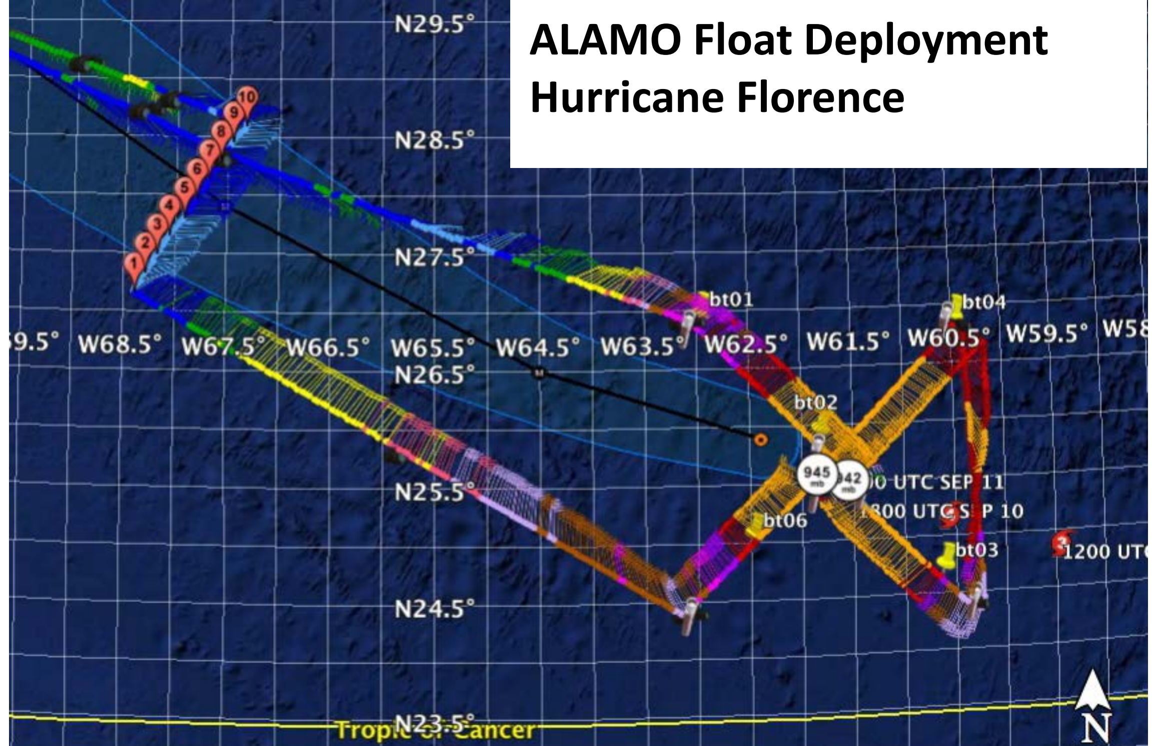






ALAMO Float Deployment Hurricane Florence



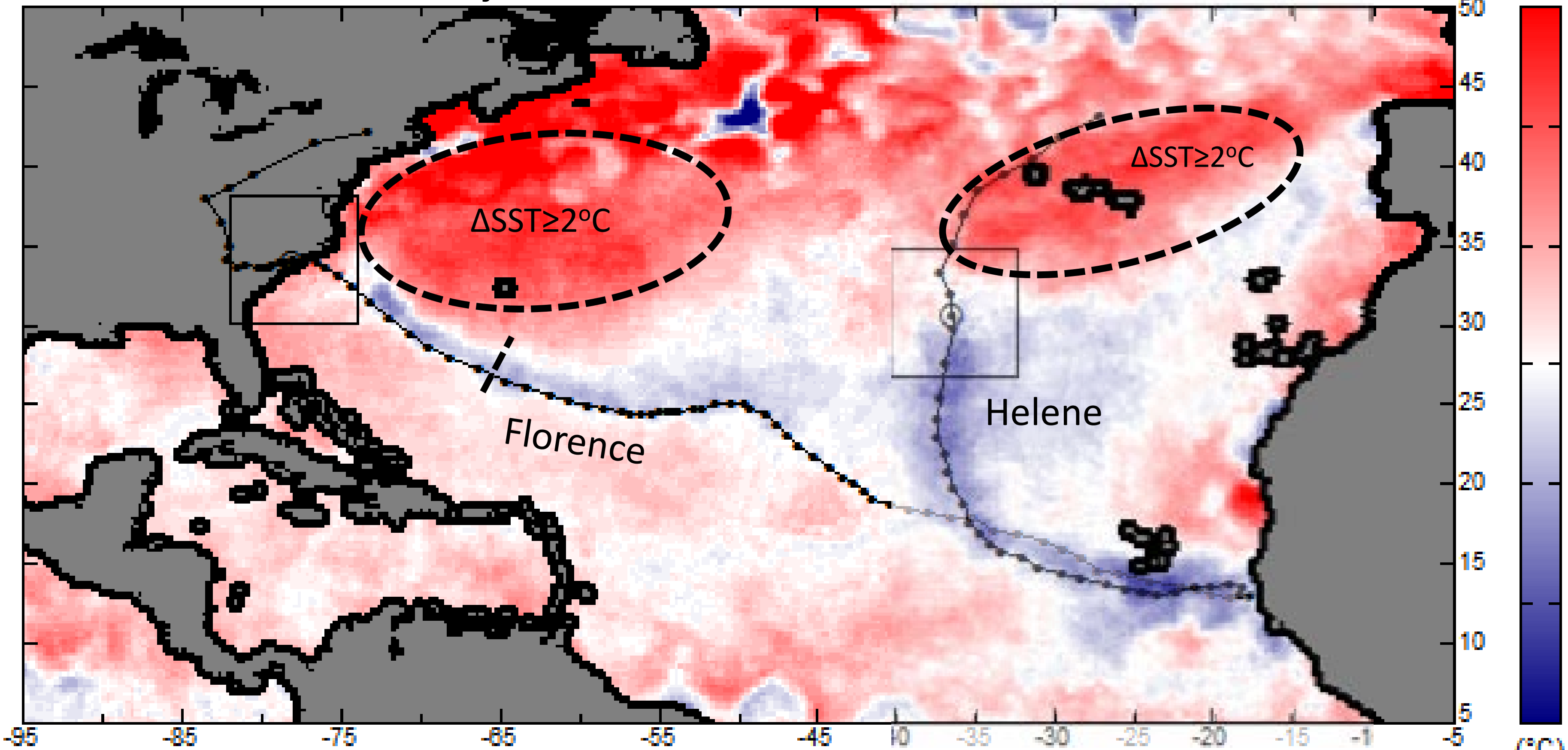


Hurricanes Florence and Helene

--Major Atlantic Basin Wake Cooling

--**Hurricane Cold wakes ≤**-1-3^{o}C

--Major warm anomalies north of 30N

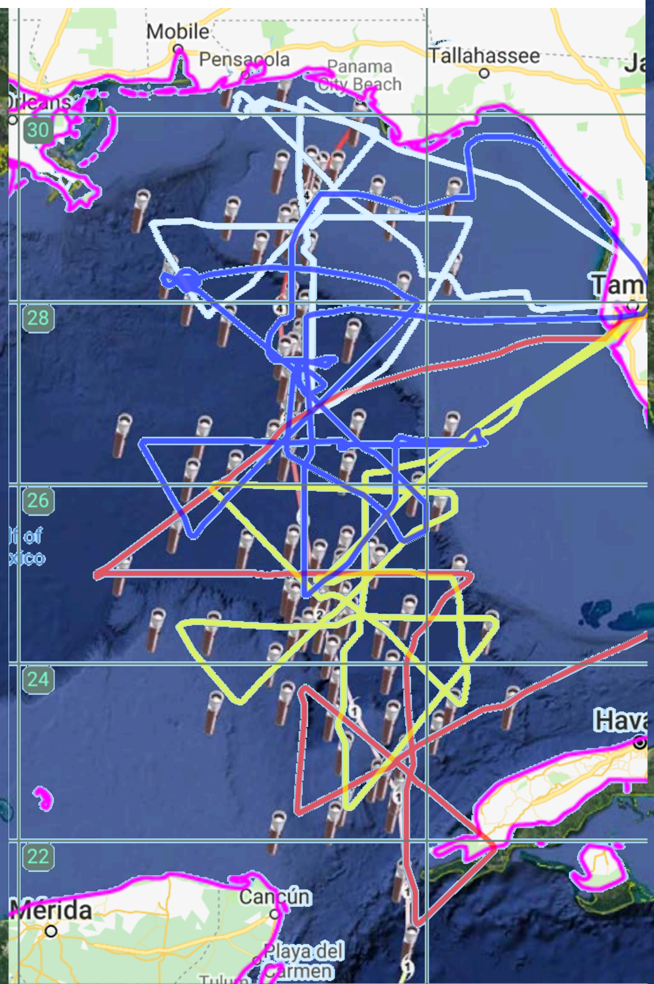


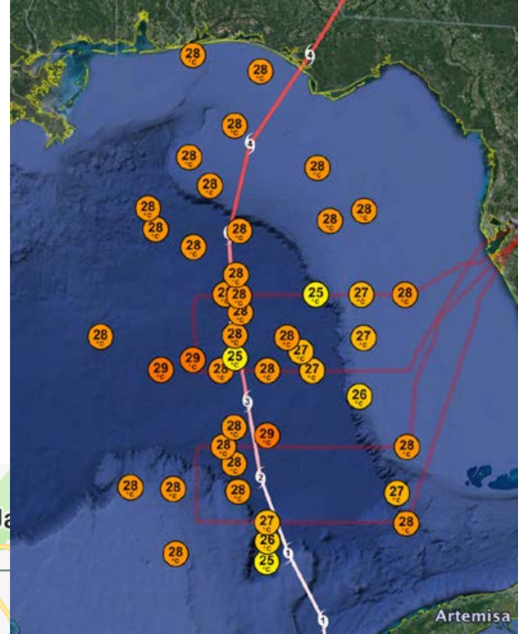
SST Anomaly: (MW - Reynolds Climatology) 2018-Sep-14

Remote Sensing Systems, Inc.
Storm Watch

Hurricane Michael
8-10 Oct 2018

- **P3 Tracks (5) and Sondes (102)**
- **WC-130J reco flights (8) and**
- **sondes (81 fromm 700 mb)**
- **Total sondes: 270**

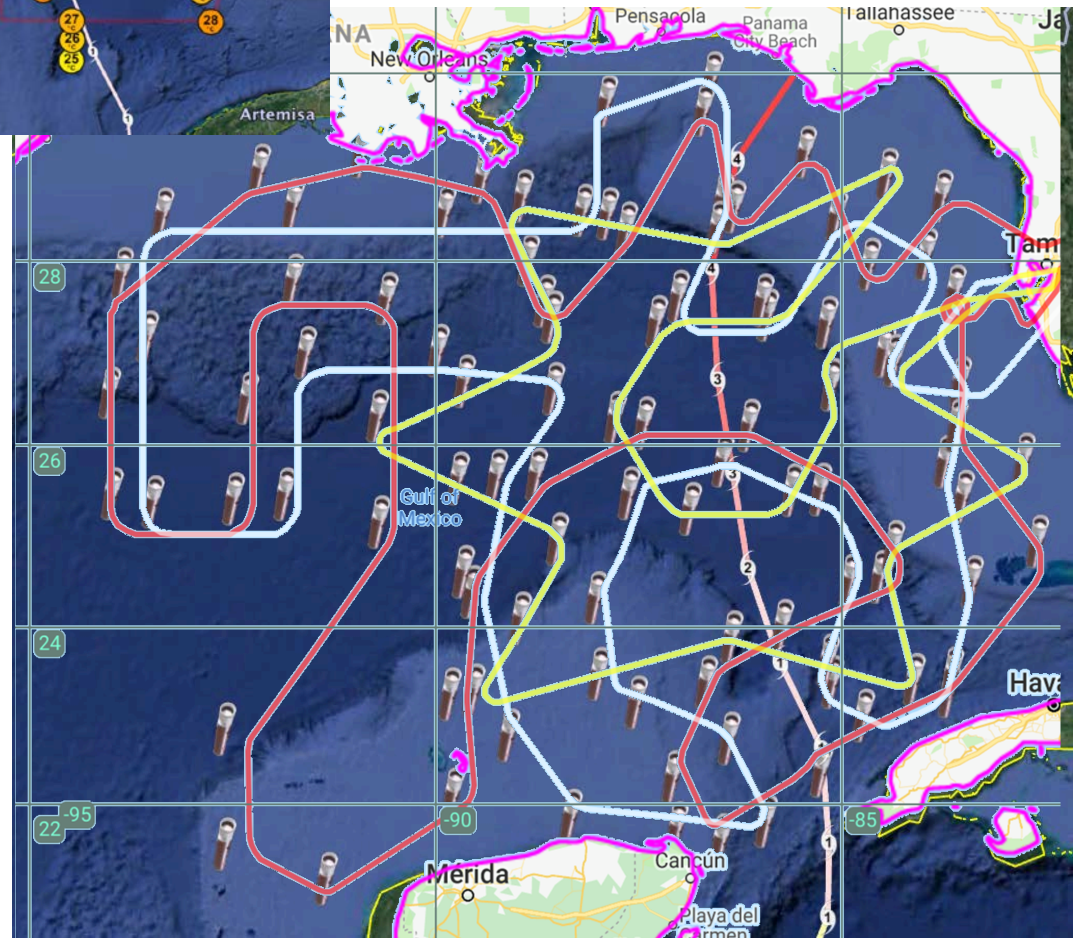




Michael Ocean Obs:

- **WP-3D 6 AXBT flights (2 post-storm- red tracks):**
- **45 good AXBTs (86 deployed; 48% fail)**
- **18 AXCPs/ 11 AXCTDs**
- **Eight (8) Scripps drifters, 3 EM-APEX floats**
- **Deployed from dedicated WC-130J ahead of Michael on 9 Oct**

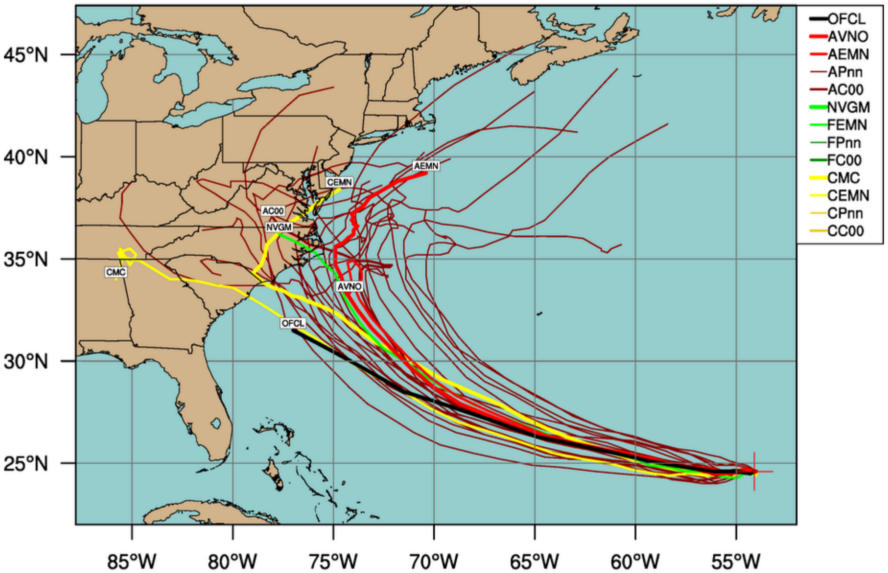
GIV Tracks (3) and Sondes (87)



TROPICAL STORM FLORENCE (AL06)

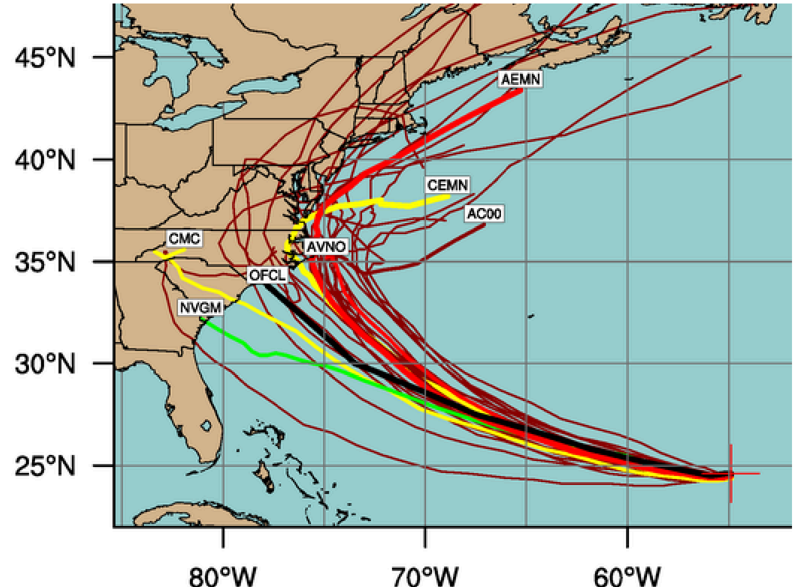
EPS track guidance initialized at 1200 UTC, 08 September 2018

Current Intensity: 55 kt Current Basin: North Atlantic



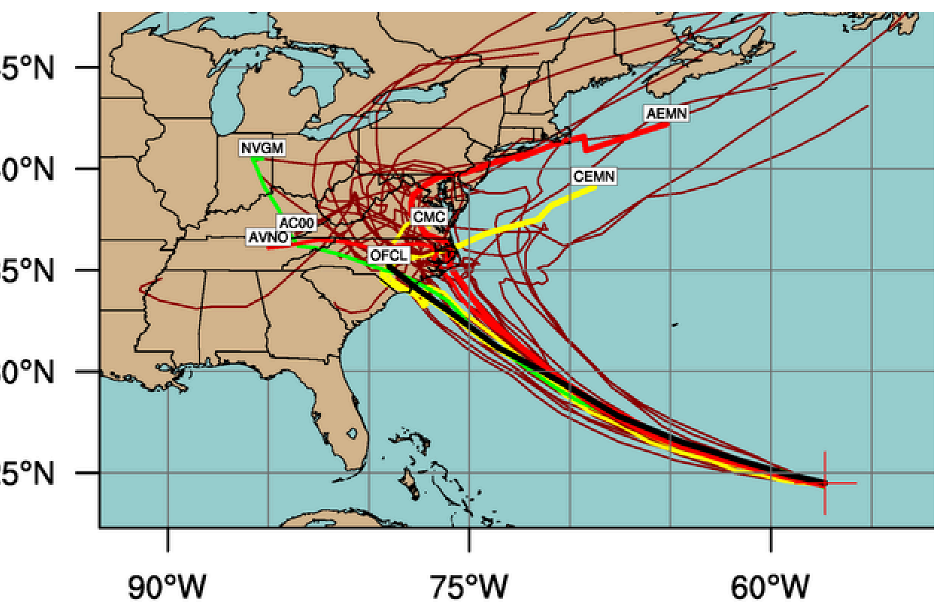
TROPICAL STORM FLORENCE (AL06)

EPS track guidance initialized at 0000 UTC, 09 September 2018



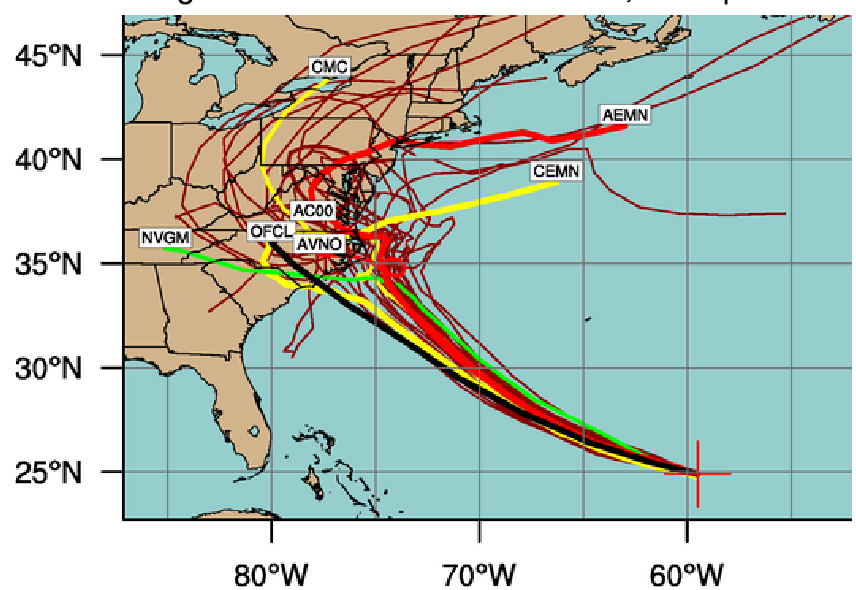
HURRICANE FLORENCE (AL06)

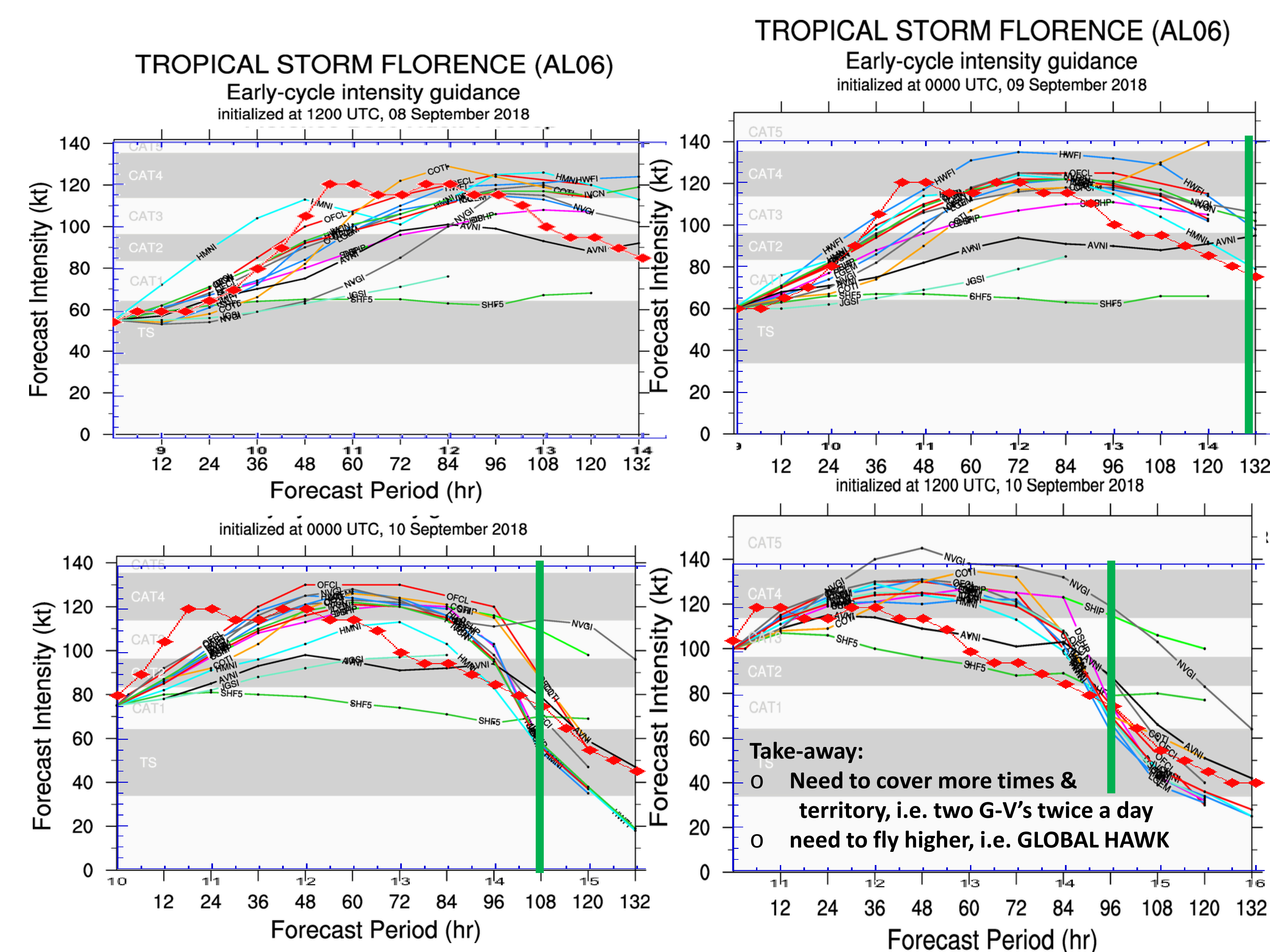
EPS track guidance initialized at 0000 UTC, 10 September 2018



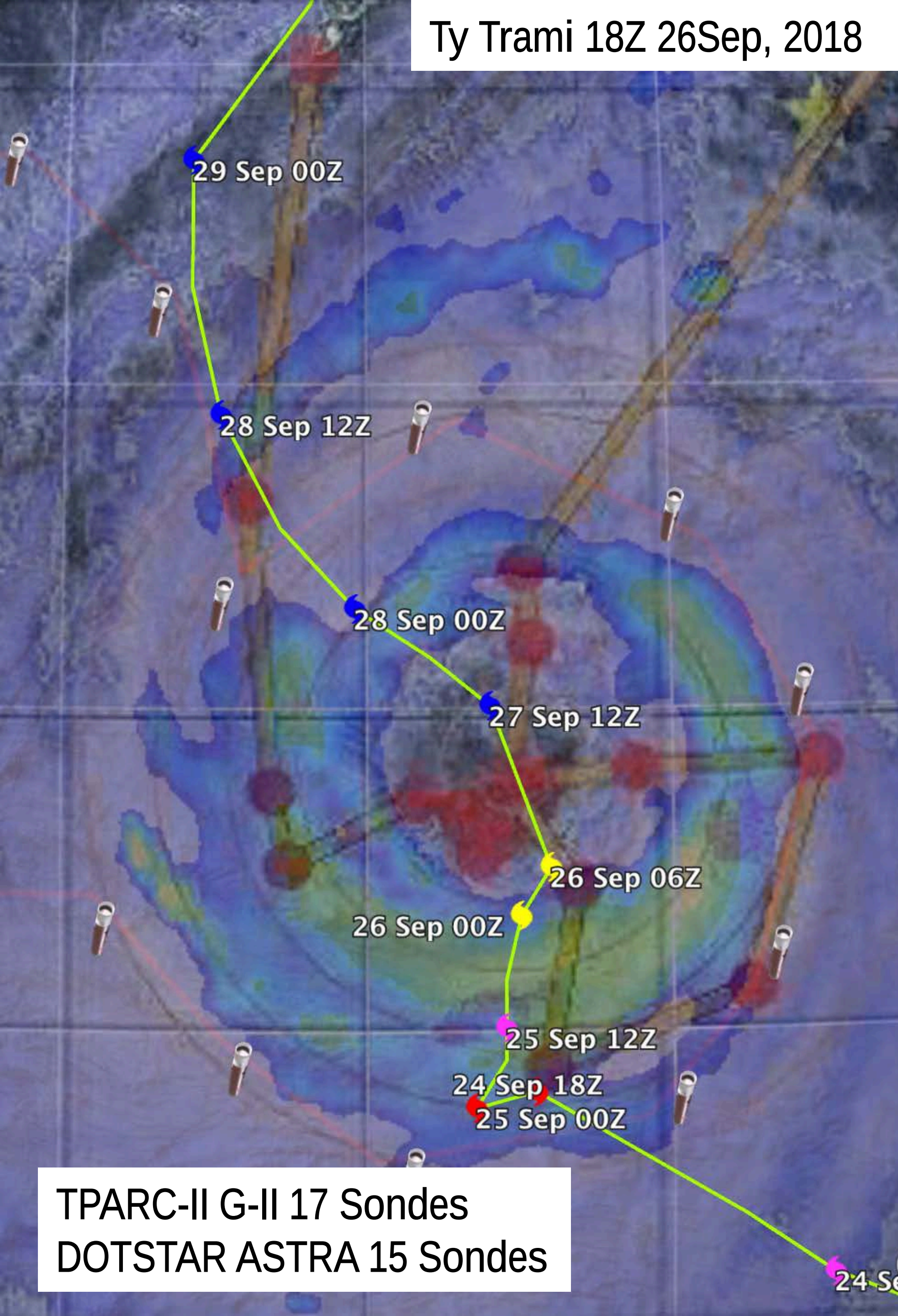
MAJOR HURRICANE FLORENCE (AL06)

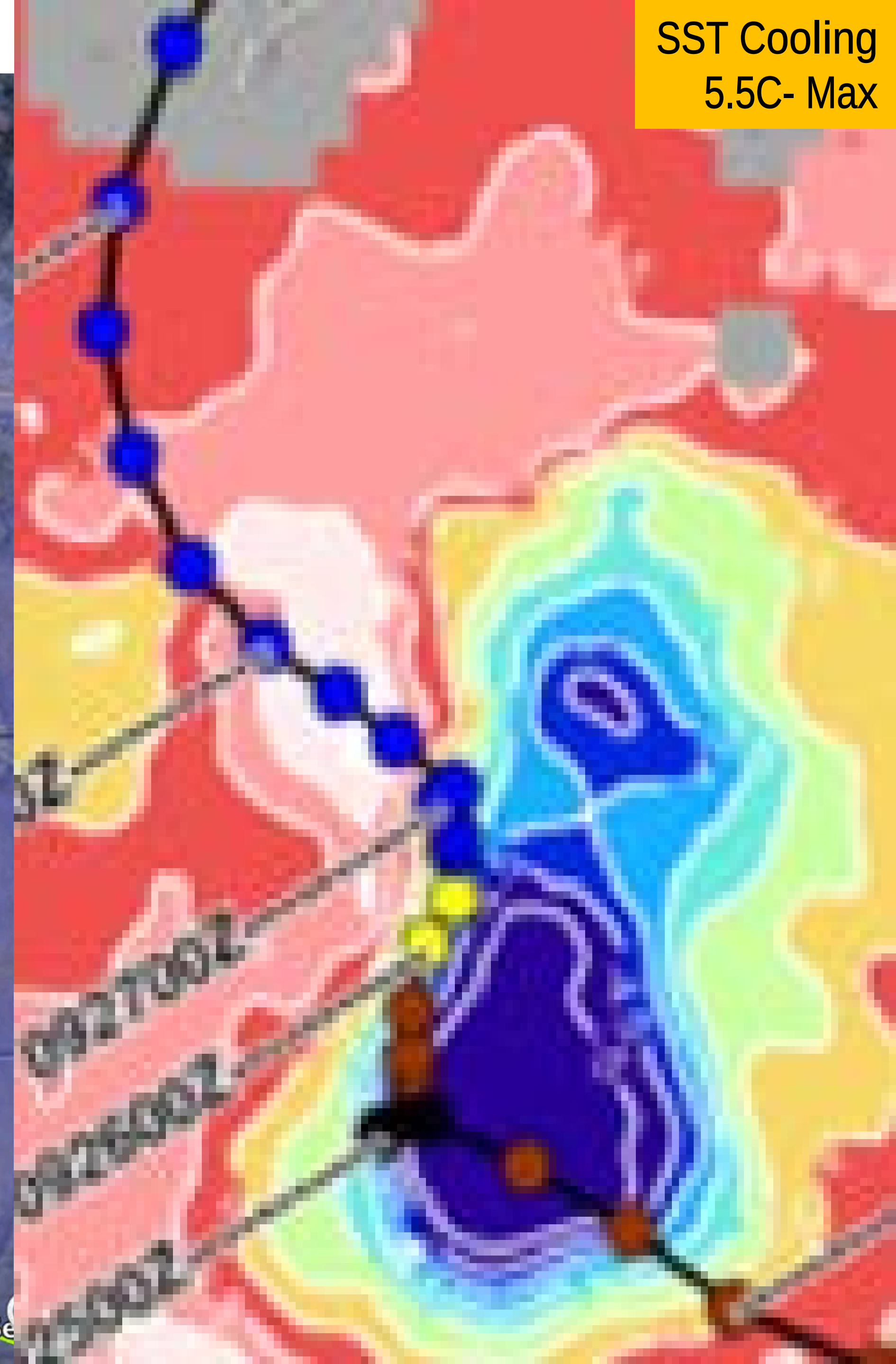
EPS track guidance initialized at 1200 UTC, 10 September 2018





TROPICAL STORM FLORENCE (AL06)
Early-cycle intensity guidance
initialized at 1200 UTC, 08 September 2018
Forecast Intensity (kt)
Forecast Period (hr)
TROPICAL STORM FLORENCE (AL06)
Early-cycle intensity guidance
initialized at 0000 UTC, 09 September 2018
Forecast Intensity (kt)
initialized at 0000 UTC, 10 September 2018
Forecast Intensity (kt)
Forecast Period (hr)
initialized at 1200 UTC, 10 September 2018
Forecast Intensity (kt)
Forecast Period (hr)
CAT5
CAT4
CAT3
CAT2
CAT1
TS
Take-away:
o Need to cover more times & territory, i.e. two G-V's twice a day
o need to fly higher, i.e. GLOBAL HAWK

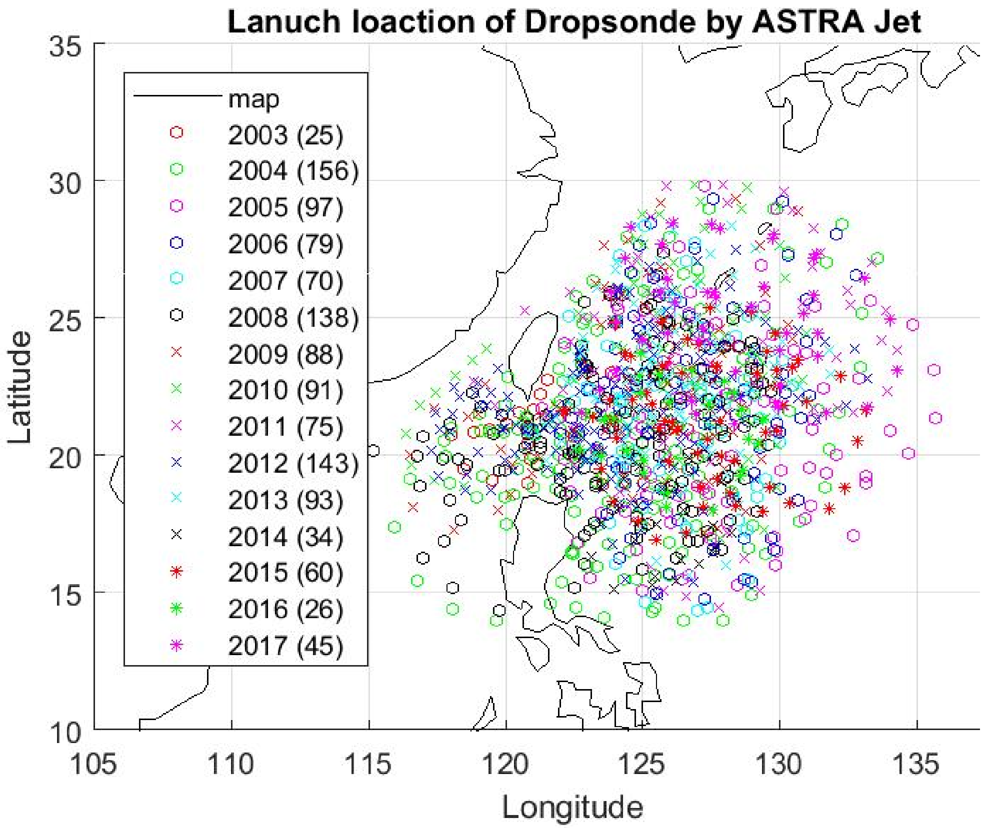

Ty Trami 18Z 26Sep, 2018
29 Sep 00Z
28 Sep 12Z
28 Sep 00Z
27 Sep 12Z
26 Sep 06Z
26 Sep 00Z
25 Sep 12Z
24 Sep 18Z
25 Sep 00Z
TPARC-II G-II 17 Sondes
DOTSTAR ASTRA 15 Sondes

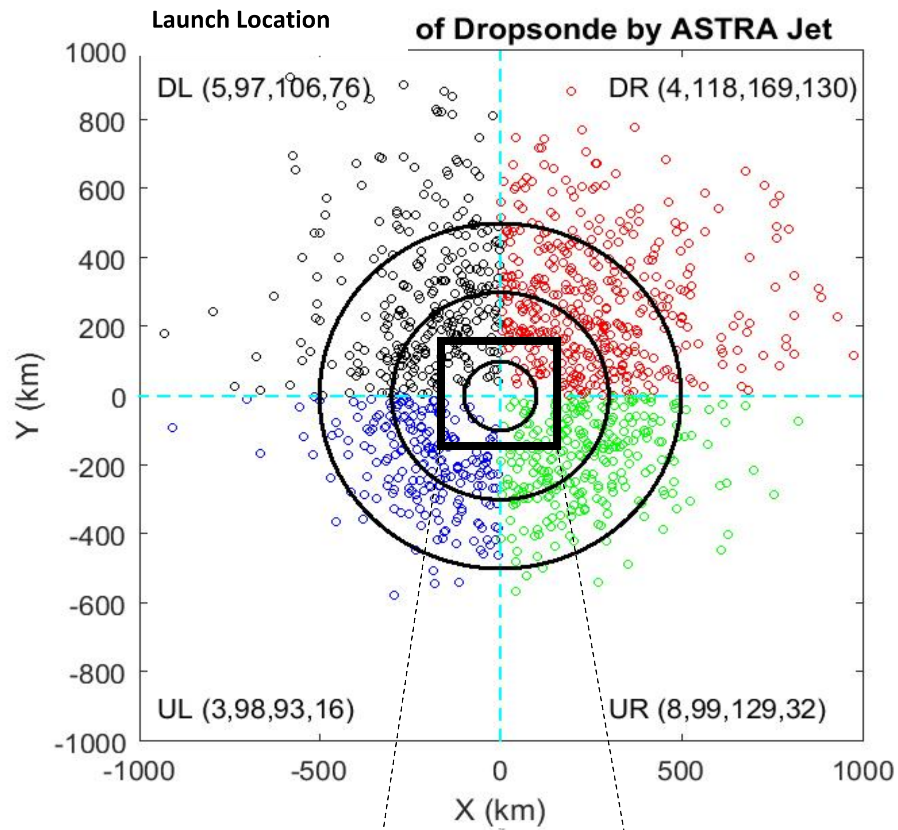

SST Cooling
5.5C- Max

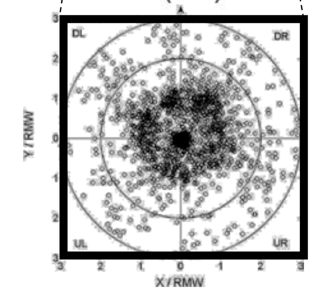
DOTSTAR ASTRA 2003-2017
Flights: 80, TY : 64

Dropsonde: 1325, Fail: 105 (8%)
Outer Radius: 900km
Po-Hsiung, C-C. Wu et al., AVAPS 2018

- 0-100 km (inner core) :020
- 100-300 km (outer core) :412
- 300-500 km (near environ):497
- 500-900 km (far environ) :254

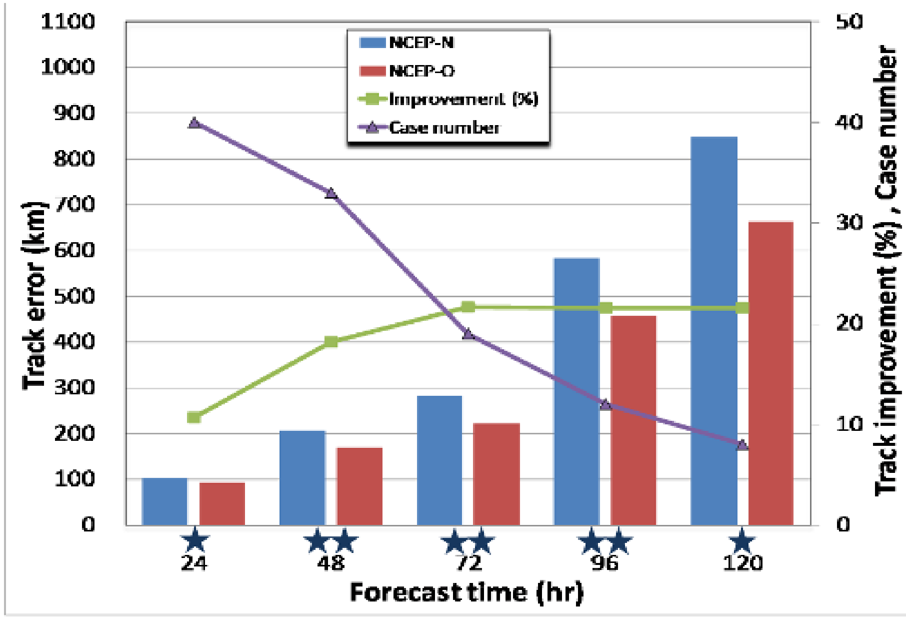




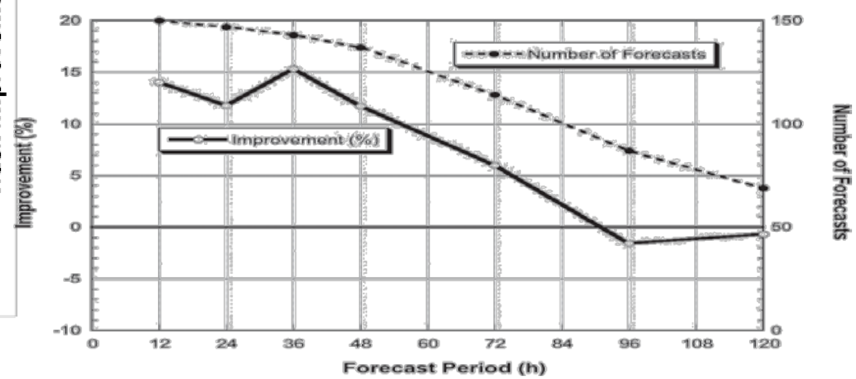


P3+GIV 1998-2010
PBL TCs: 208
PBL Dropsondes: 1878
Outer Radius: 330km
Jun Zhang et al., 2013 MWR

Different Results from DOTSTAR Astra dropsondes in WPAC vs NOAA G-IV dropsondes in NATL



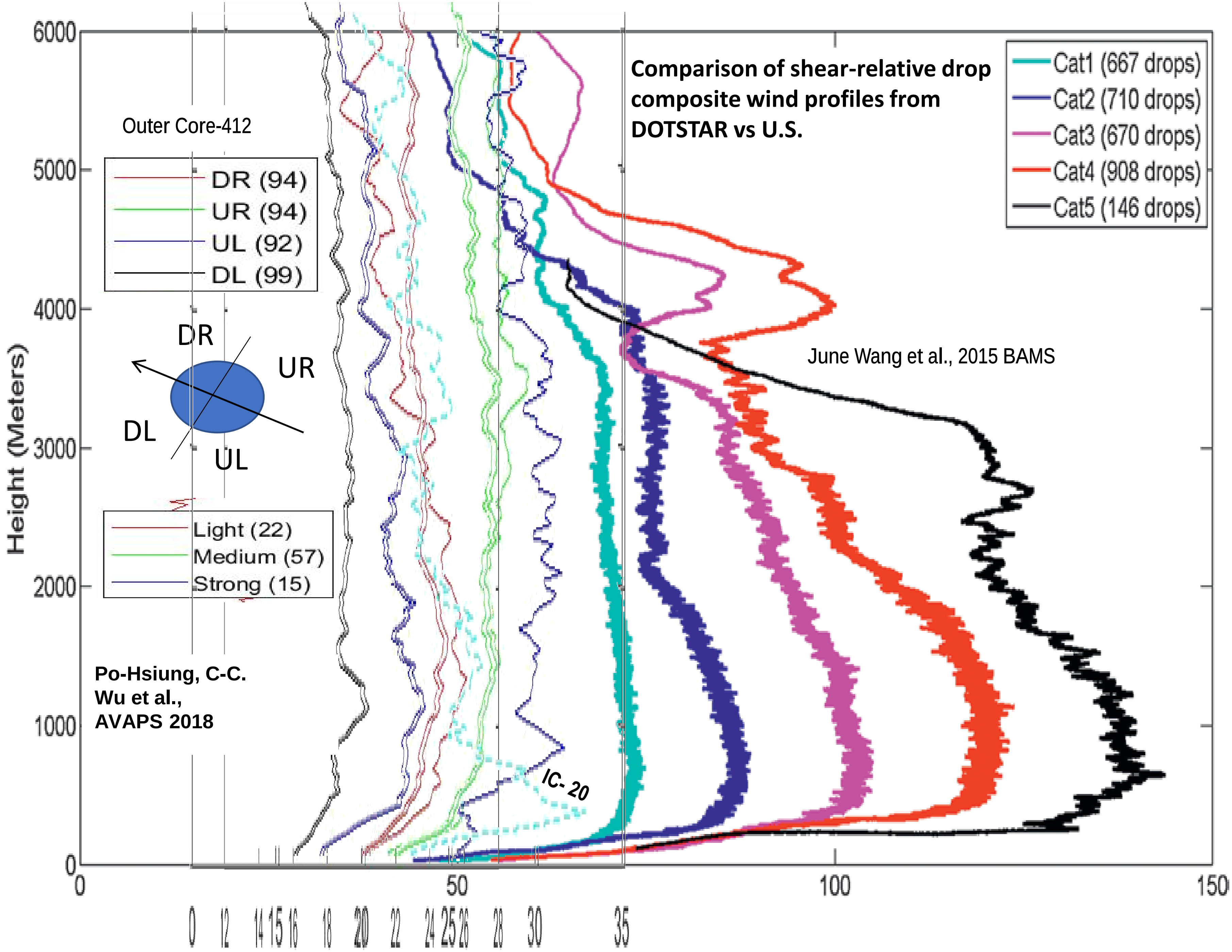
DOTSTAR sonde impact by NCEP GFS: 2003-2009 45 TCs (35 cases)
Track error reduction: 12-18%: 15% 24-36Hr UP to 18% 72-120 hr
Chou, et al., 2011 MWR

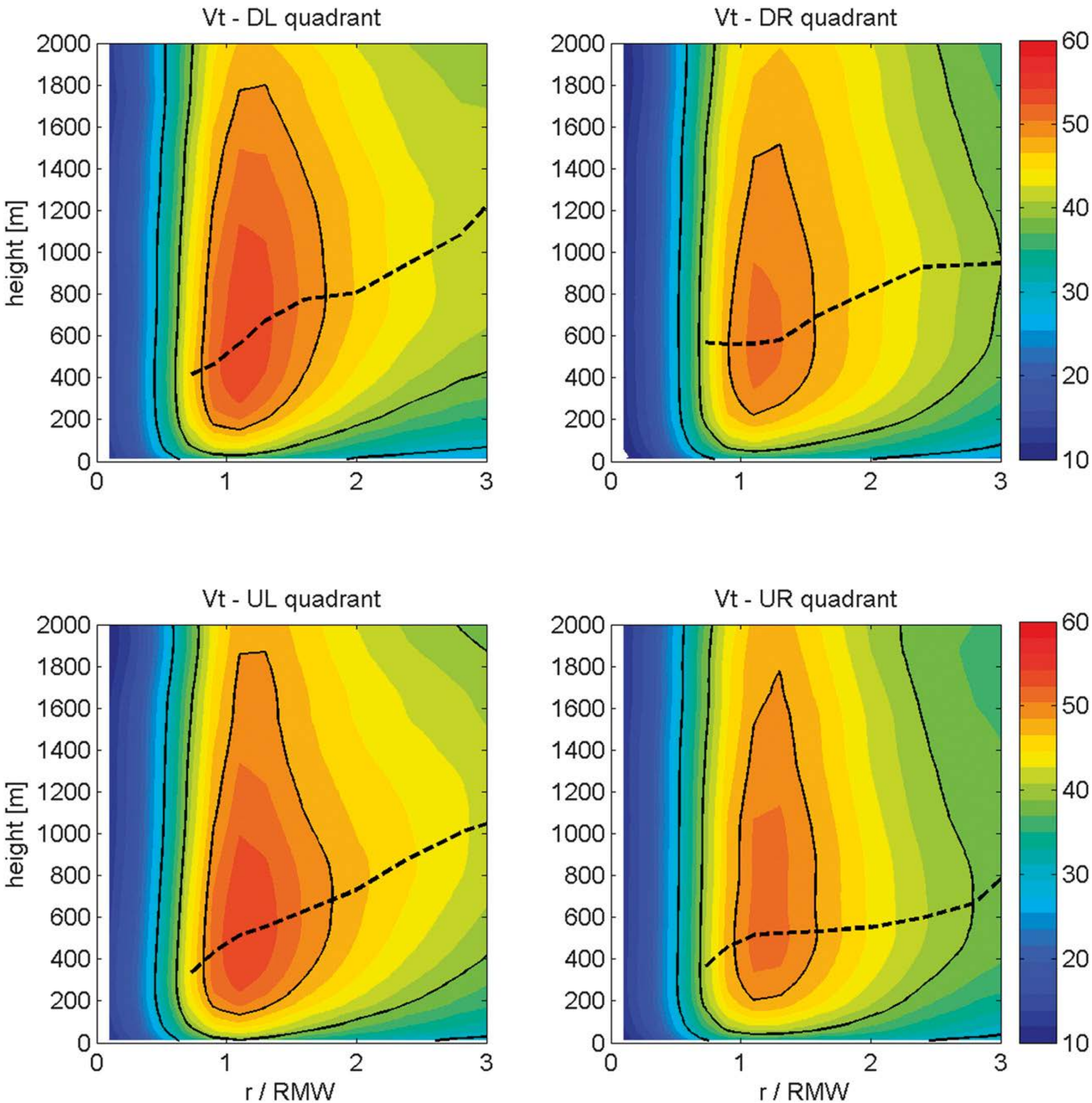


Improvement of mean hurricane-track forecast in the GFS model as a result of assimilating G-IV synoptic surveillance dropsondes

DOTSTAR sonde impact by CWB TWRF: 2008-2016 37 TCs (49 cases):
Track error reduction: only 6-8%
Po-Hsiung, C-C. Wu et al., AVAPS 2018

GIV 1999–2005
Track Skill Improve:
15% to 36hr, DOWN to 6% at 72 hr and 0% at 96 hr
June Wang et al., 2015 BAMS


Comparison of shear-relative drop composite wind profiles from DOTSTAR vs U.S.
Cat1 (667 drops)
Cat2 (710 drops)
Cat3 (670 drops)
Cat4 (908 drops)
Cat5 (146 drops)
June Wang et al., 2015 BAMS
Outer Core-412
DR (94)
UR (94)
UL (92)
DL (99)
DR
UR
DL
UL
Light (22)
Medium (57)
Strong (15)
Po-Hsiung, C-C. Wu et al., AVAPS 2018
IC- 20
Height (Meters)
6000
5000
4000
3000
2000
1000
0
0
50
100
150
0 12 14 15 16 18 20 22 24 25 26 28 30 35

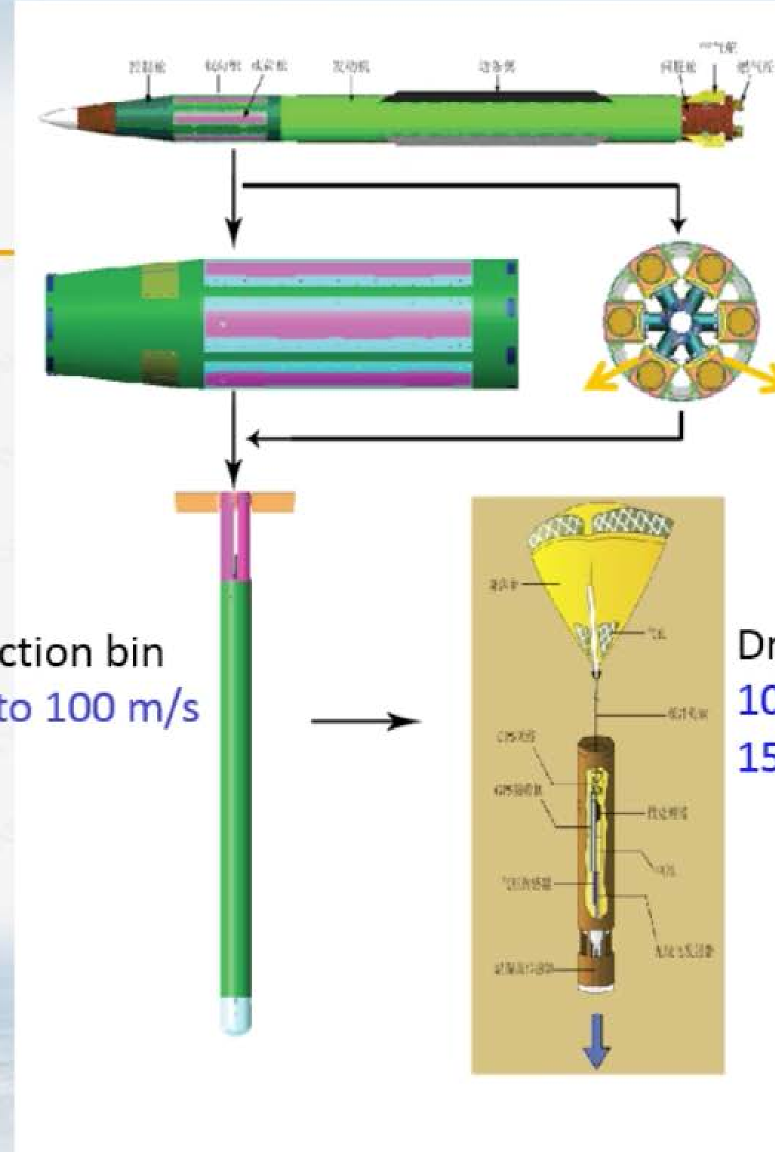


U.S. Dropsonde PBL Composite TC tangential wind vs radius normalized by RMW, radius of maximum wind, for 4 TC quadrants relative to shear:

DL- Downshear Left
DR- Downshear Right
UL- Upshear Left
UR- Upshear Right

Zhang, et al., 2013

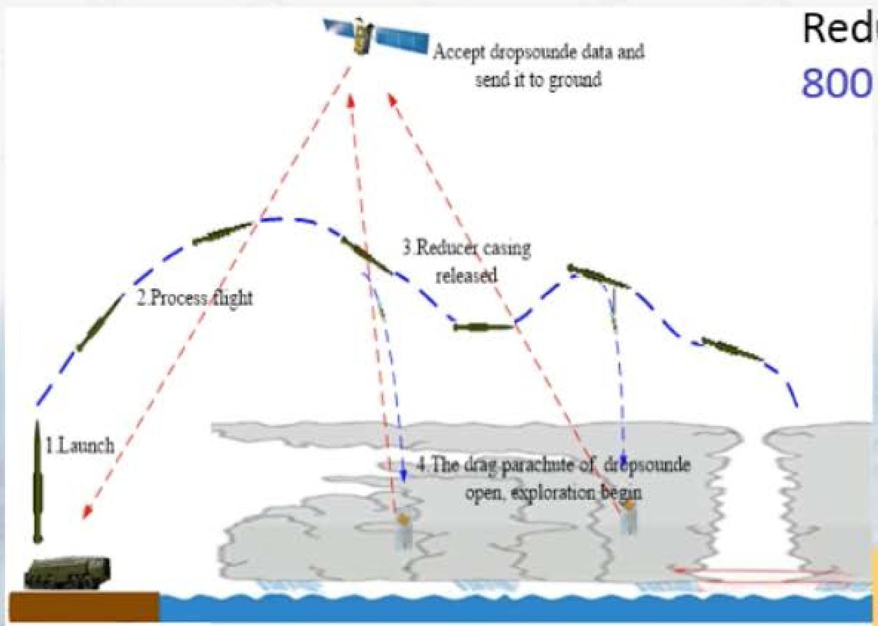
Scheme of the rocket dropsondes by COSIC and CMA since 2012



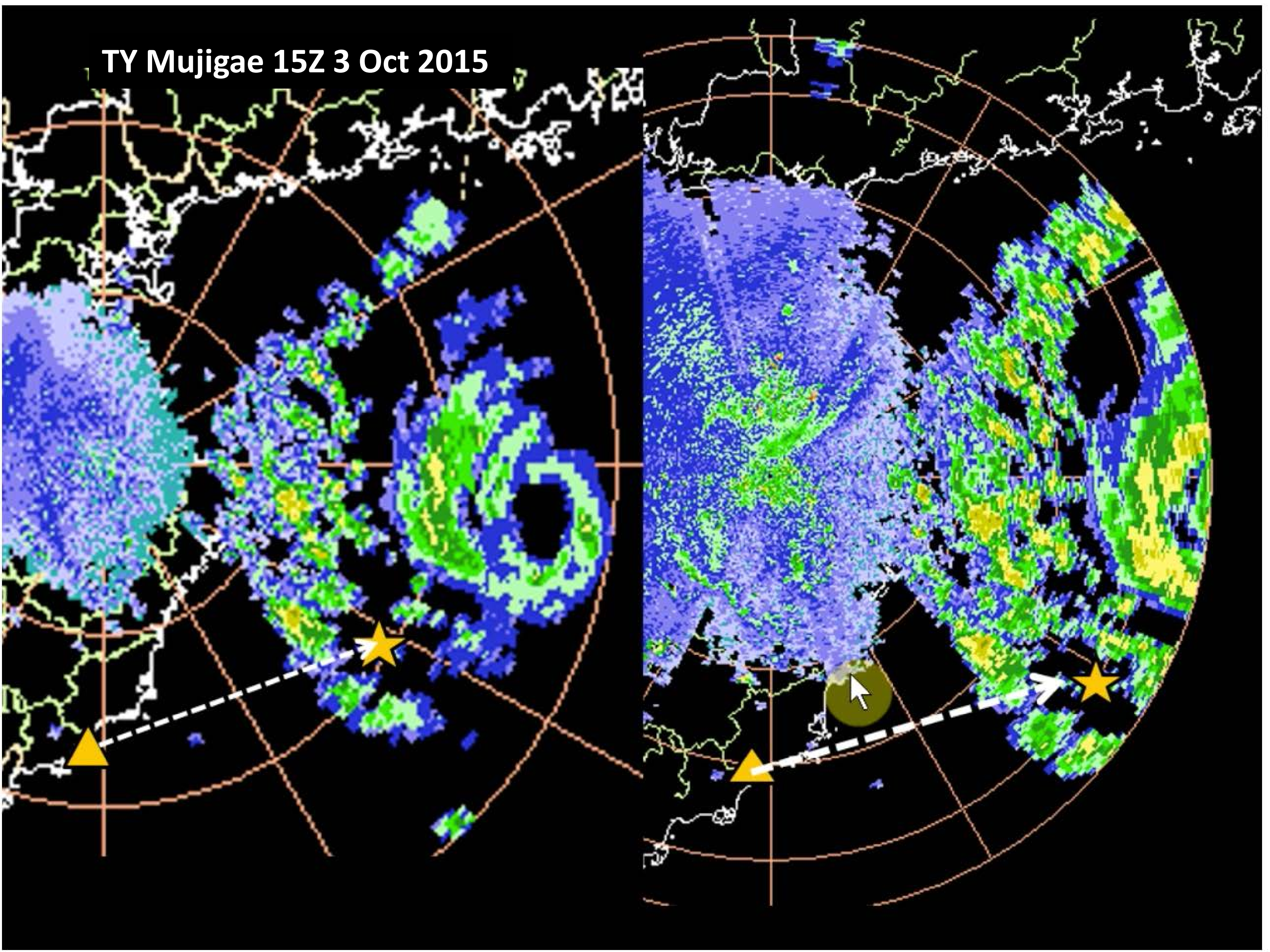
Revolver
3000 to 800 m/s

Reduction bin
800 to 100 m/s

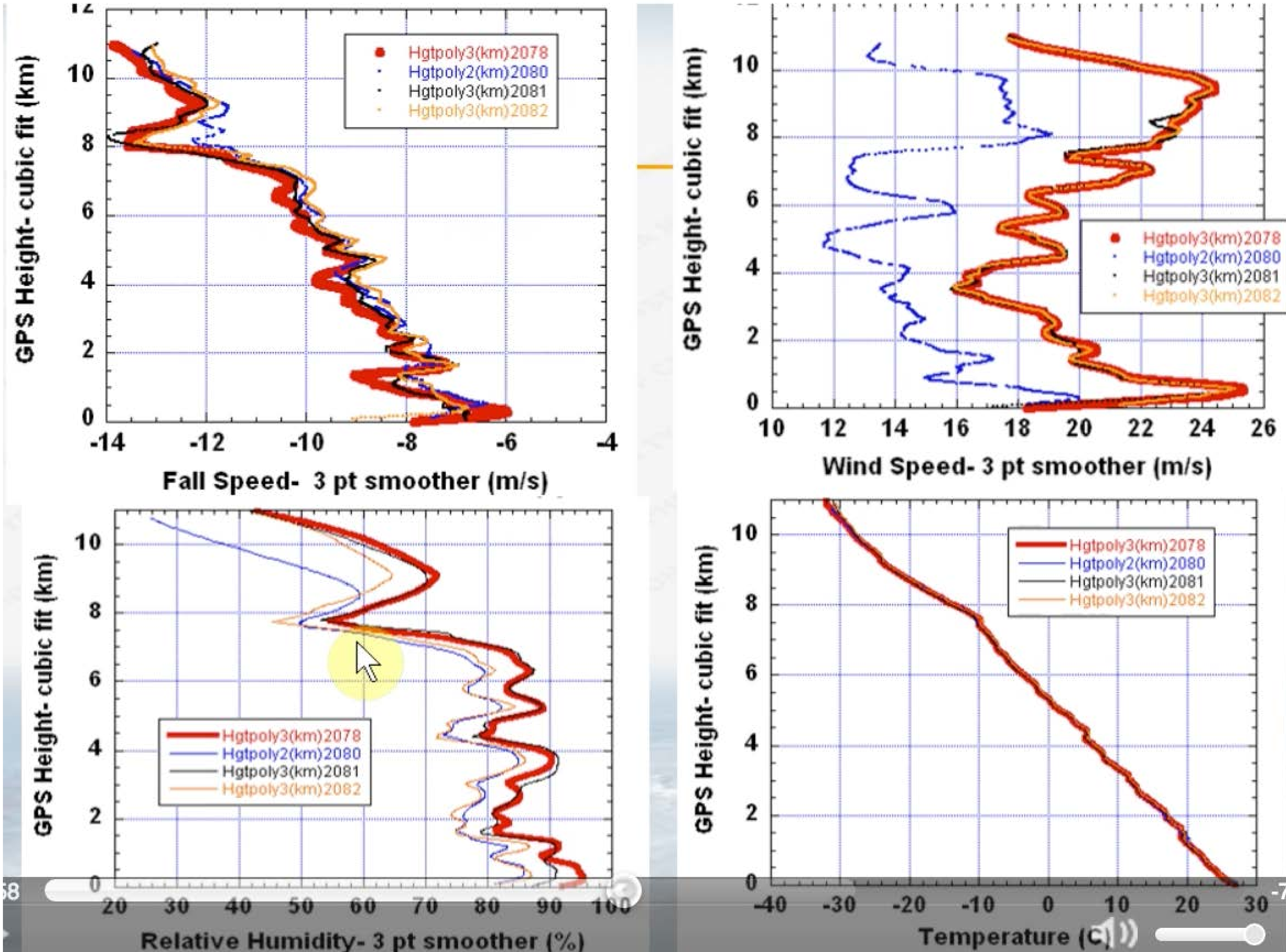
Dropsonde
100 m/s to 15m/s

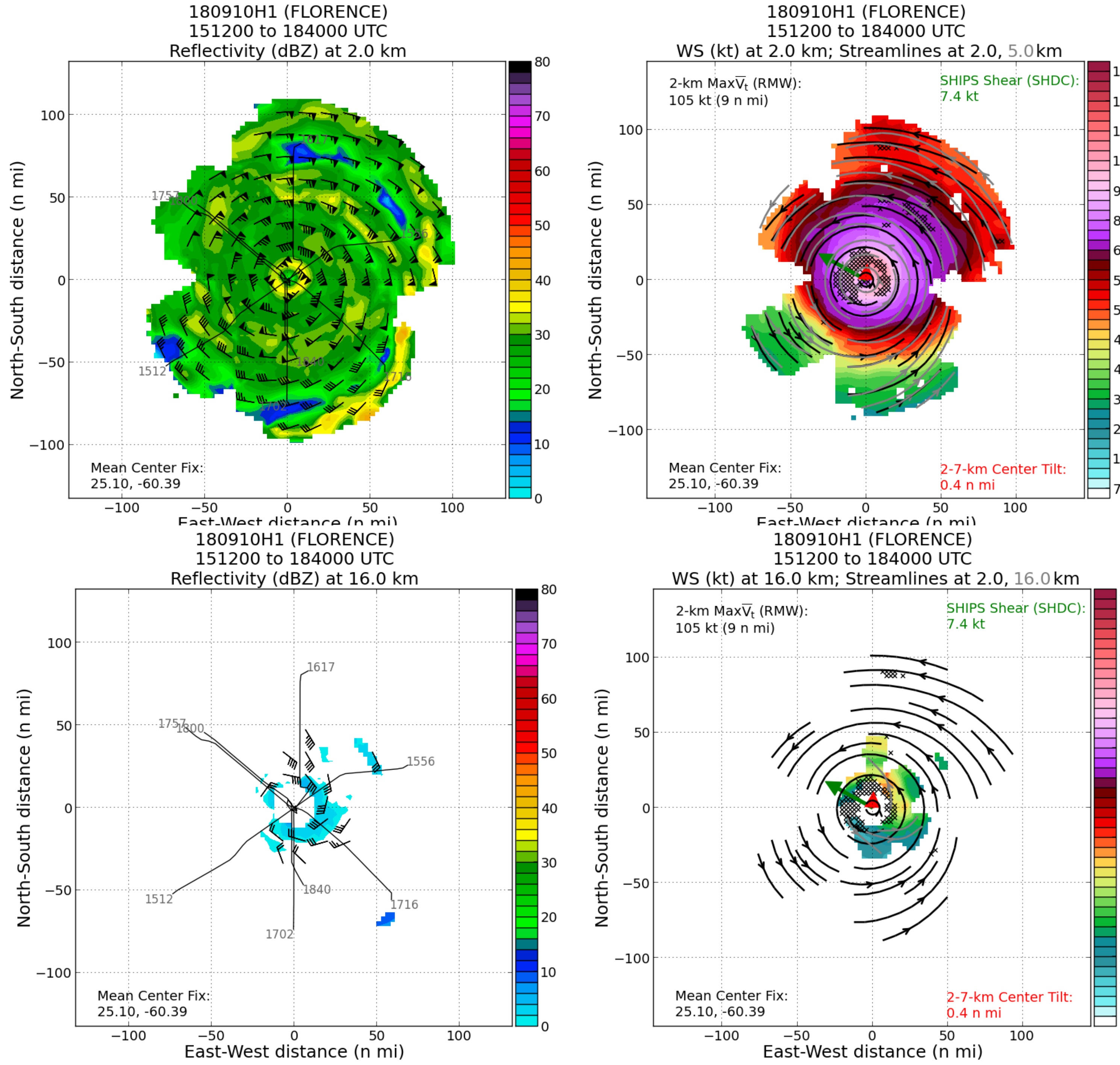


Beat the swords into ploughshares


TY Mujigae 15Z 3 Oct 2015

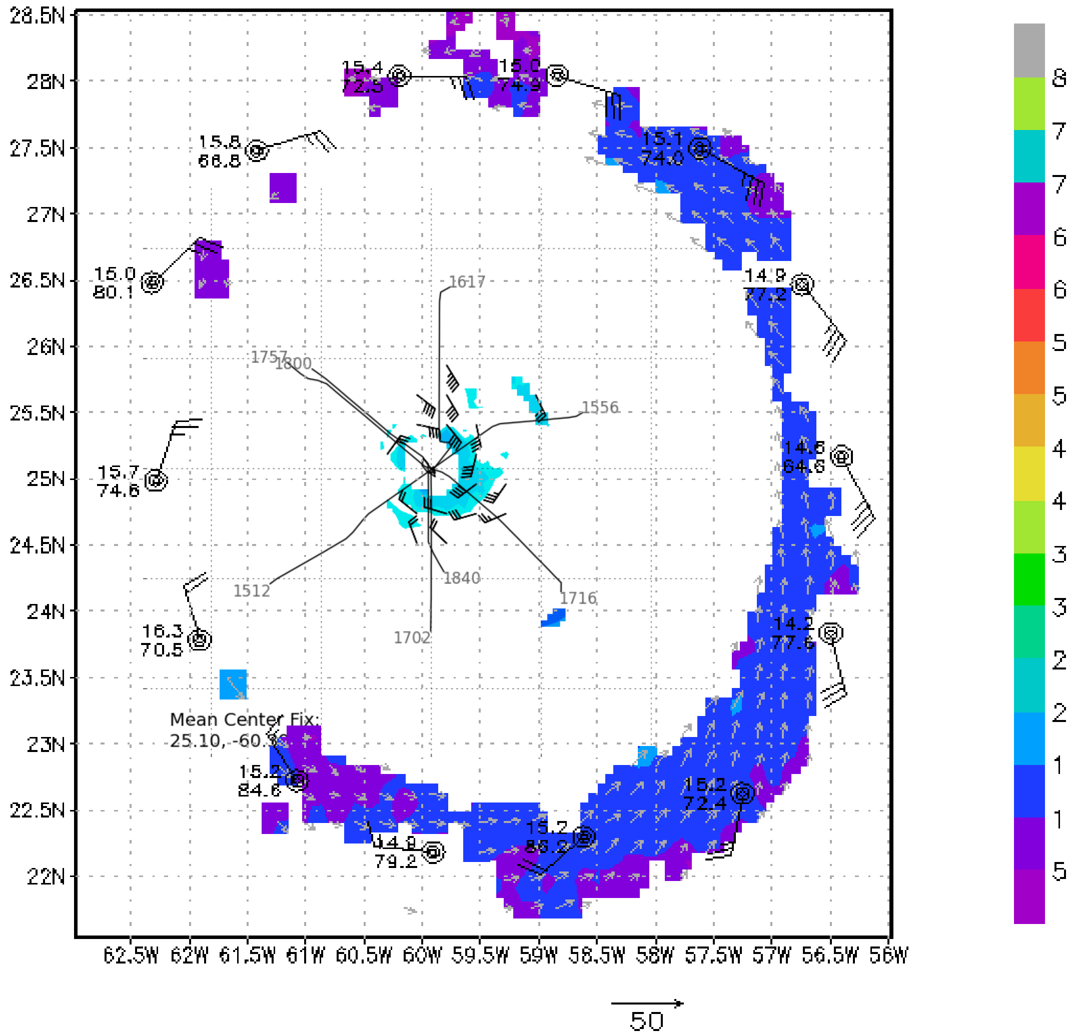
Overview of the dropsondedata

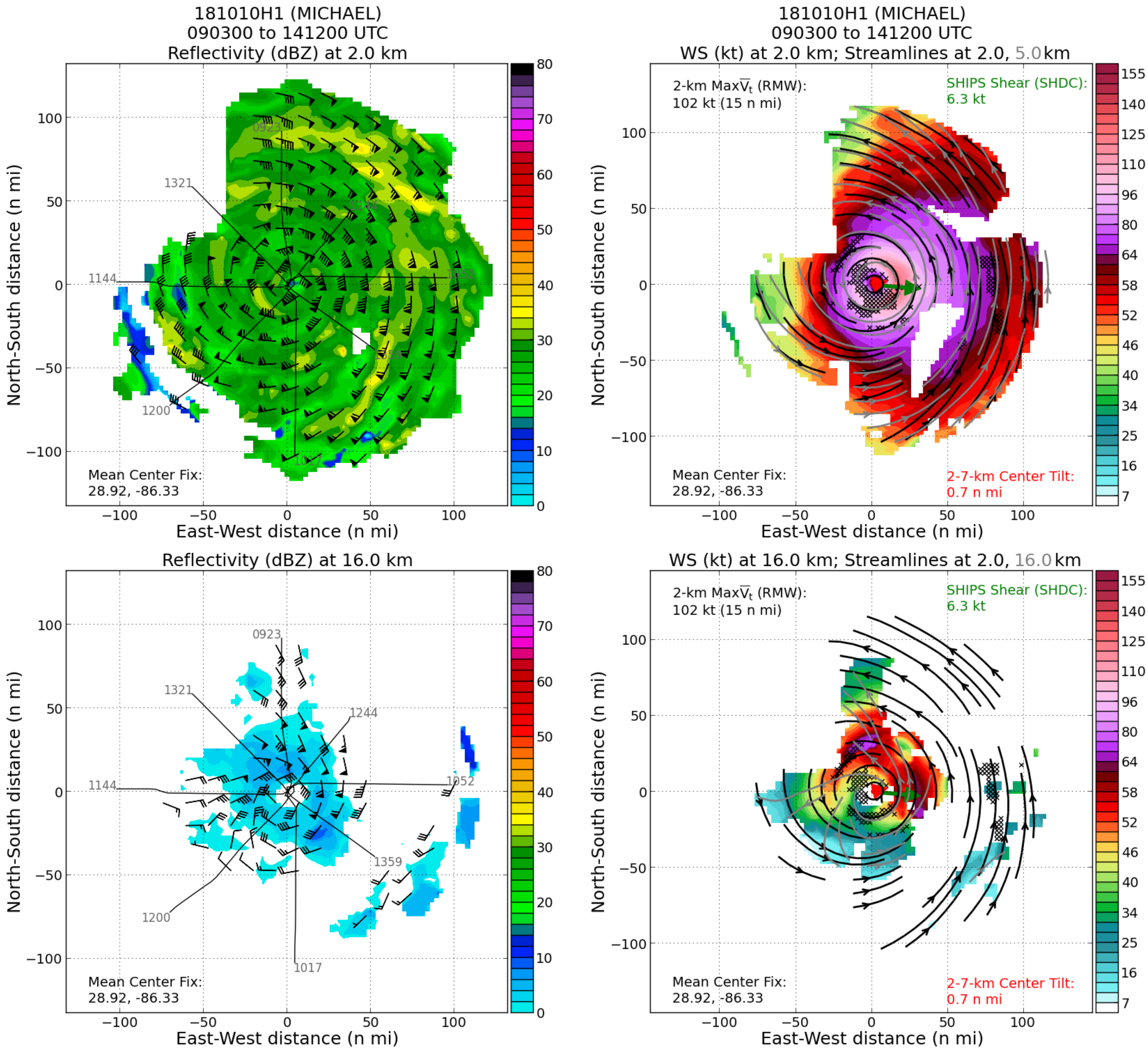




180910H1 (FLORENCE)
151200 to 184000 UTC
Reflectivity (dBZ) at 2.0 km
North-South distance (n mi)
East-West distance (n mi)
Mean Center Fix:
25.10, -60.39
1757
1800
1556
1512
1840
1716
1702
1617
180910H1 (FLORENCE)
151200 to 184000 UTC
WS (kt) at 2.0 km; Streamlines at 2.0, 5.0 km
2-km Max$\overline{V}_t$ (RMW):
105 kt (9 n mi)
SHIPS Shear (SHDC):
7.4 kt
Mean Center Fix:
25.10, -60.39
2-7-km Center Tilt:
0.4 n mi
180910H1 (FLORENCE)
151200 to 184000 UTC
Reflectivity (dBZ) at 16.0 km
180910H1 (FLORENCE)
151200 to 184000 UTC
WS (kt) at 16.0 km; Streamlines at 2.0, 16.0 km

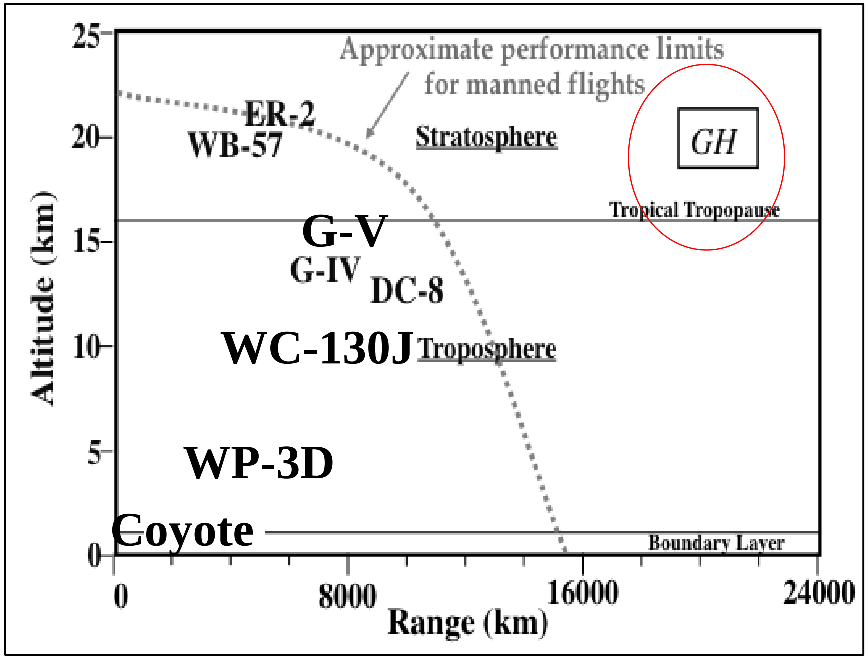
180910N1 Florence at 2 km (m/s) Valid 20180910 1200Z




181010H1 (MICHAEL)
090300 to 141200 UTC
Reflectivity (dBZ) at 2.0 km
Mean Center Fix:
28.92, -86.33
181010H1 (MICHAEL)
090300 to 141200 UTC
WS (kt) at 2.0 km; Streamlines at 2.0, 5.0 km
2-km Max$\overline{V}_t$ (RMW):
102 kt (15 n mi)
SHIPS Shear (SHDC):
6.3 kt
2-7-km Center Tilt:
0.7 n mi
Reflectivity (dBZ) at 16.0 km
WS (kt) at 16.0 km; Streamlines at 2.0, 16.0 km
0923
1321
1244
1144
1052
1359
1200
1017
North-South distance (n mi)
East-West distance (n mi)

Background: Global Hawk (GH)

- GH has been used since 2010 for hurricane reconnaissance and surveillance
- Much longer range than manned aircraft
- Data from GH dropsondes has been shown to improve forecasts
- Dropsonde data from GH first used in HWRF in 2015
- Dropsonde data from GH first used in GFS in 2017



Global Hawk

SHOUT TCRR Operational Demo Observational Objectives

Sensing Hazards with Operational Unmanned Technologies (SHOUT)

Tropical Cyclone Rapid Response (TCRR)

Measure & Evaluate: transition from research (HS3) to operations (SHOUT)

Hurricane and Severe Storm Sentinel (HS3)

- **Operational Impact on model predictions:**
  - **Hurricane intensity/ size/ structure change: V_{max}, P_{min}, RR, RMW, R_{64}, R_{50}, R_{34}**
  - **Hurricane track change**
  - **Global Downstream Environmental Adjustment (Sipple, Tallapragada, Howard)**

TC Model Real-Time Data Assimilation

- **Improve targeting (timing/location/pattern) of *Real Time* dropsondes**
- **Optimal sonde input format, i.e. BUFR (full res) vs Temp Drop (single location)**
- **Techniques for data thinning/ super-obing (averaging) to match model resolution**
- **Instrumentation strategy for input to TC models: AVAPS/HIWRAP/HAMSR**

  High Altitude MIMIC Sounding Radiometer/High-altitude Wind and Rain Atmospheric Profiler
- **In future: HIRAD (surface wind/ rain rate)-** Hurricane Imaging RADiometer

Satellite GAP Mitigation for High-Impact Weather

- **Operational Impact Studies for alternatives to satellite data**

GLOBAL HAWK HS3 SHOUT 2012-2016

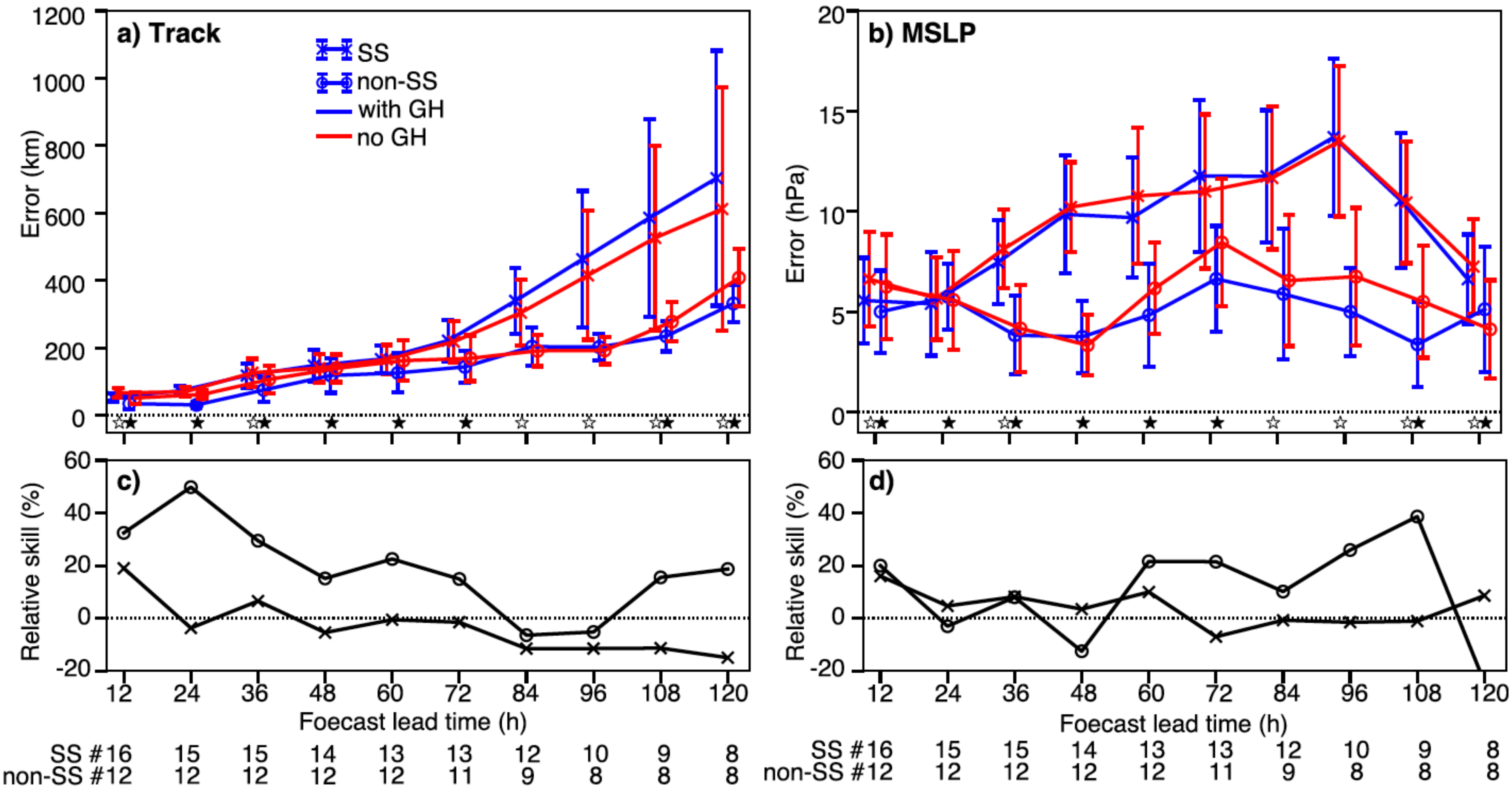
Track Skill IMPROVE non-Steady State: 20-30%

Track Skill DEGRADE Steady State: 0 to -10%

Intensity Skill IMPROVE non-Steady State: 10-20%

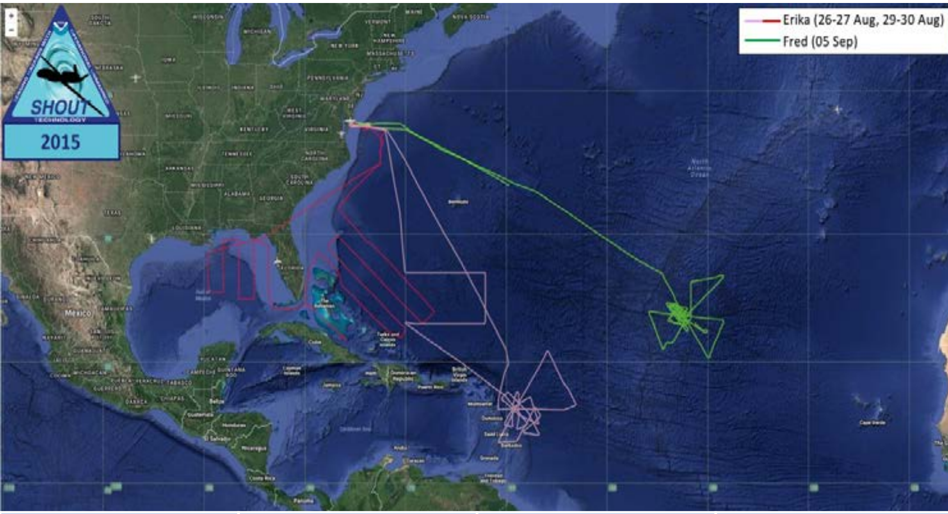
Intensity Skill IMPROVE Steady State: 0-5%

Christophersen, et al., 2018



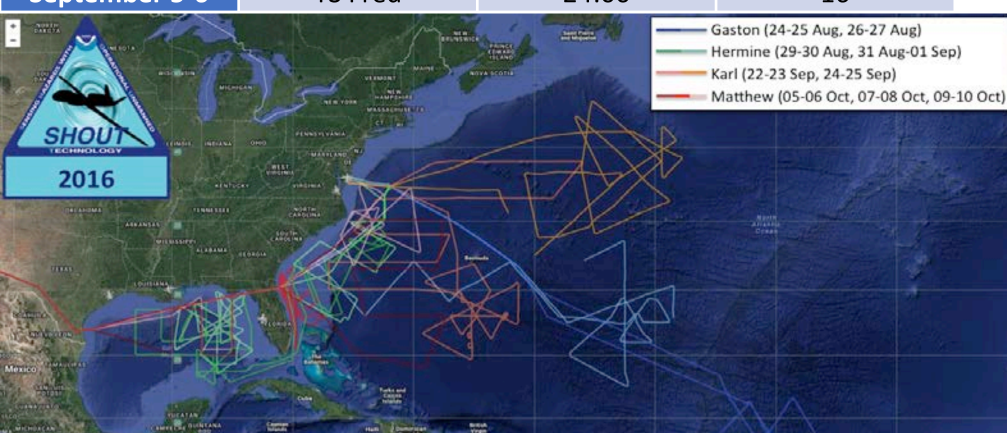
Observational History- Global Hawk UAS SHOUT/EPOCH 2015-2017

Dates (2016)	Duration (hours)	# Sondes Deployed
12-13 February	22.9	2
15-16 February	24.5	22
21-22 February	23.6	66



Dates (2016)	Target	Duration (hours)	# Sondes Deployed
24-25 August	Gaston	23.9	85
26-27August	Gaston	23.8	55
29-30 August	Hermine	23.8	90
31 August – 1 September	Hermine	22.8	87
22-23 September	Karl	24.0	82
24-25 September	Karl	22.8	81
5-6 October	Matthew	24.7	62
7-8 October	Matthew	23.7	43
9-10 October	Matthew	24.8	63

Dates (2015)	Target	Duration (hours)	# Sondes Deployed
August 26-27	TS Erika	23:43	14
August 29-30	TS Erika	23:44	58
September 5-6	TS Fred	24:00	16



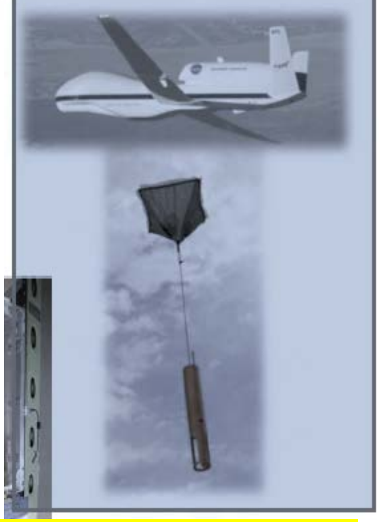
SHOUT/EPOCH Flight & Sonde Observational History

(For additional details see AMS 33HURR Hock, Poster #4, Vömel, 5A.2)

- **2012-14:** NASA Hurricane and Severe Storms Sentinel (HS3) program: 21 research missions over 9 TCs
- **2015-16:** NOAA Sensing Hazards with Operational Unmanned Technology (SHOUT): 15 Rapid Response (RR) flights: 3 in EPAC El Niño/ Atmospheric River (AR) winter storm systems; 12 TCs
- **647 sondes in SHOUT**: all assimilated in ECMWF, UKMET, NAVGEM global models <u>and HWRF</u>, COAMPS-TC regional models.
- **2017:** East Pacific Origins and Characteristics of Hurricanes (**EPOCH**): 3 flights in 3 storms (GoM-Franklin, Harvey; EPAC- Lidia), **218 sondes total**: first Global Hawk minisonde assimilation in GFS

AVAPS II Dropsonde
Vaisala RD94, RD-41

AVAPS II Minisonde
NCAR NRD94
automated launches
Soon NRD41



3rd Generation RD-41 dropondes have recently undergone preliminary testing over GoM (G-IV: March 9, 2018) and during IFEX flights into and around Hurricane Nate (Oct 5-7, 2017) showing excellent results: Holger Vömel, Terry Hoke-NCAR/EOL

System Name: Global Hawk UAS High Impact Weather Surveillance & Reconnaissance Capability

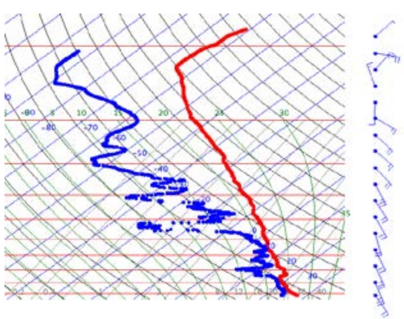
Instrument Capability:

Airborne Vertical Atmospheric Profiling System (AVAPS)

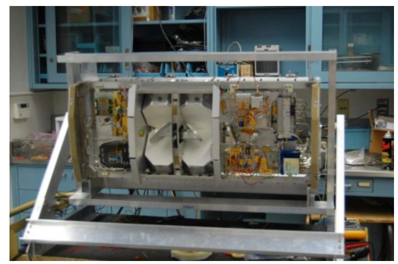
PI: Terry Hock, NCAR / Gary Wick, NOAA

Measurements: ***REAL-TIME Assimilation***
- *temperature, pressure, wind, humidity (vertical profiles)*
- *90 dropsondes per flight*

Resolution:
- *~2.5 m (winds), ~5 m (PTH)*



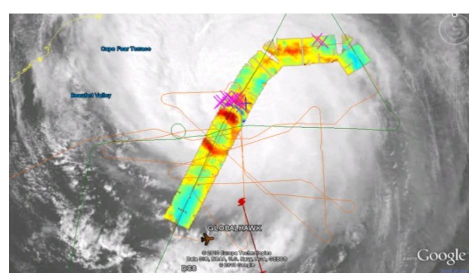
High Altitude Monolithic Microwave Integrated Circuit (MMIC) Sounding Radiometer (HAMSR)



PI: Dr. Bjorn Lambrigtsen, JPL

Measurements: ***Real-Time Display***
- *Microwave AMSU-like sounder;*
- *25 spectral channels in 3 bands;(50-60 GHz, 118 GHz, and 183 GHz)*
- *3-D distribution of temperature, water vapor, & cloud liquid water;*

Resolution:
- *2 km vertical; 2 km horizontal (nadir)*
- *40 km wide swath*



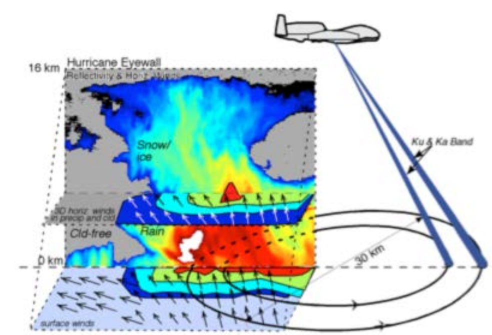
High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)

Belly Doppler Radar

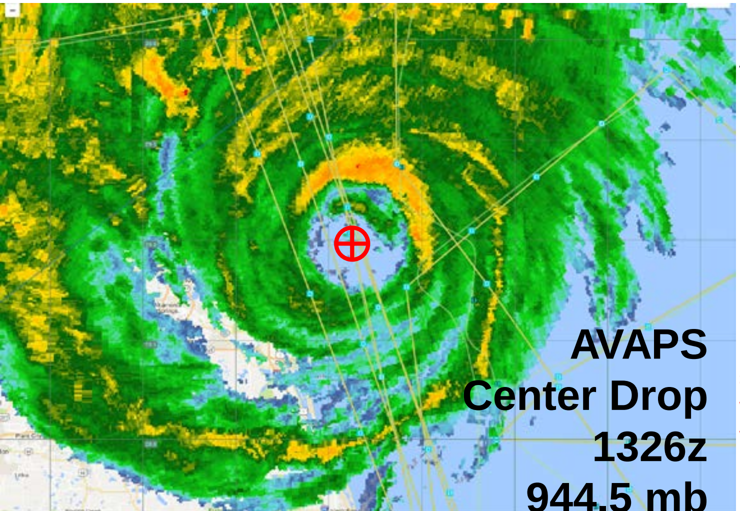
PI: Dr. Gerald Heymsfield, NASA GSFC

Measurements: ***Real-Time Display***
- *Dual-frequency (Ka- & Ku-band), dual beam, conical scanning Doppler radar*
- *3-D winds, ocean vector winds, and precipitation;*

Resolution:
- *60 m vertical, 1 km horizontal;*



Global Hawk Instrument Suite



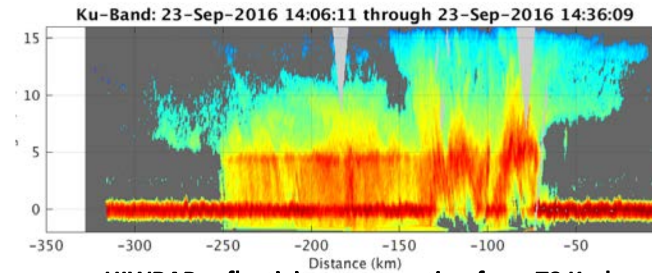
AVAPS IMPACT:

HURRICANE GASTON TROPICAL CYCLONE UPDATE
NWS NATIONAL HURRICANE CENTER MIAMI FL AL072016
1215 AM AST THU AUG 25 2016

...GASTON BECOMES THE THIRD HURRICANE OF THE ATLANTIC SEASON...

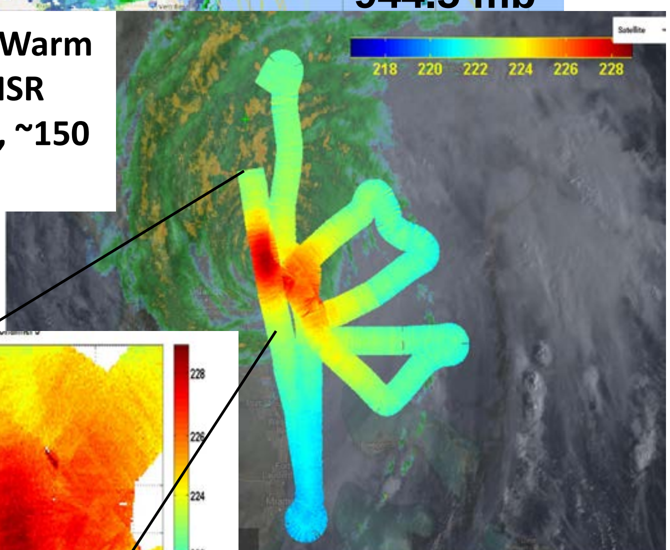
Dropsonde data from a NASA/NOAA Global Hawk mission indicate that Gaston has strengthened to a hurricane. The maximum winds are estimated to be 75 mph (120 km/h) with higher gusts.

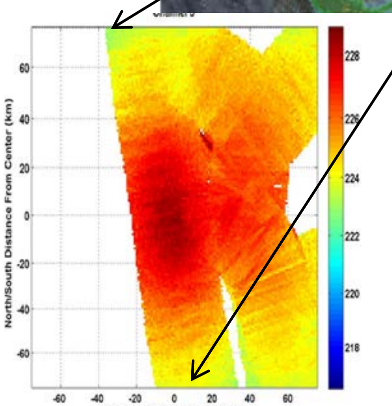
HIWRAP Doppler radar profiler



HIWRAP reflectivity cross section from TS Karl: convective cores, high tops and extensive stratiform precipitation

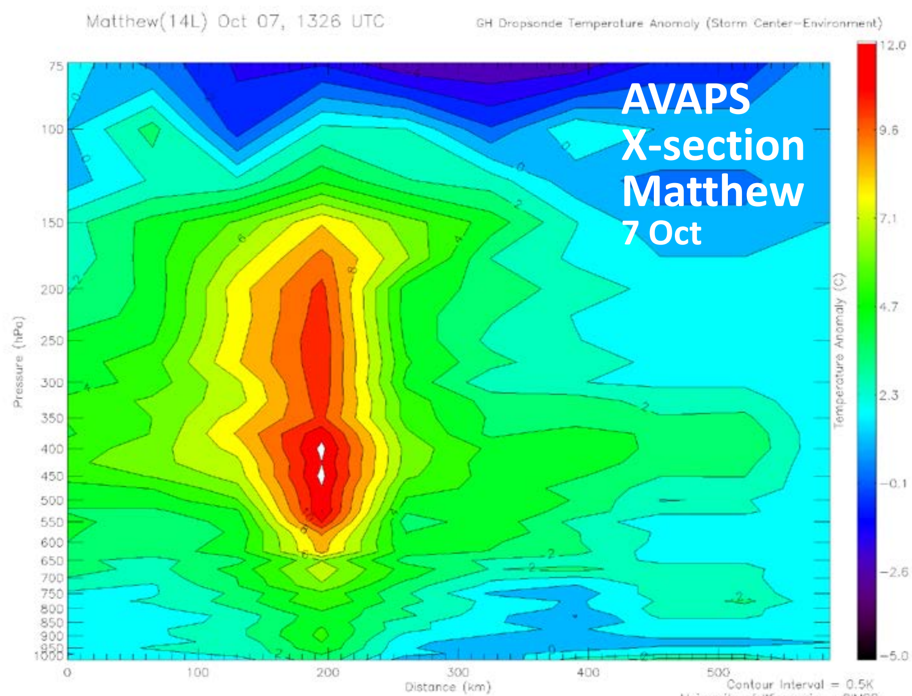
Matthew Warm Core HAMSR (54.4 GHz, ~150 hPa)





Warm core of Matthew

HAMSR passive microwave radiometric temperature and humidity profiler

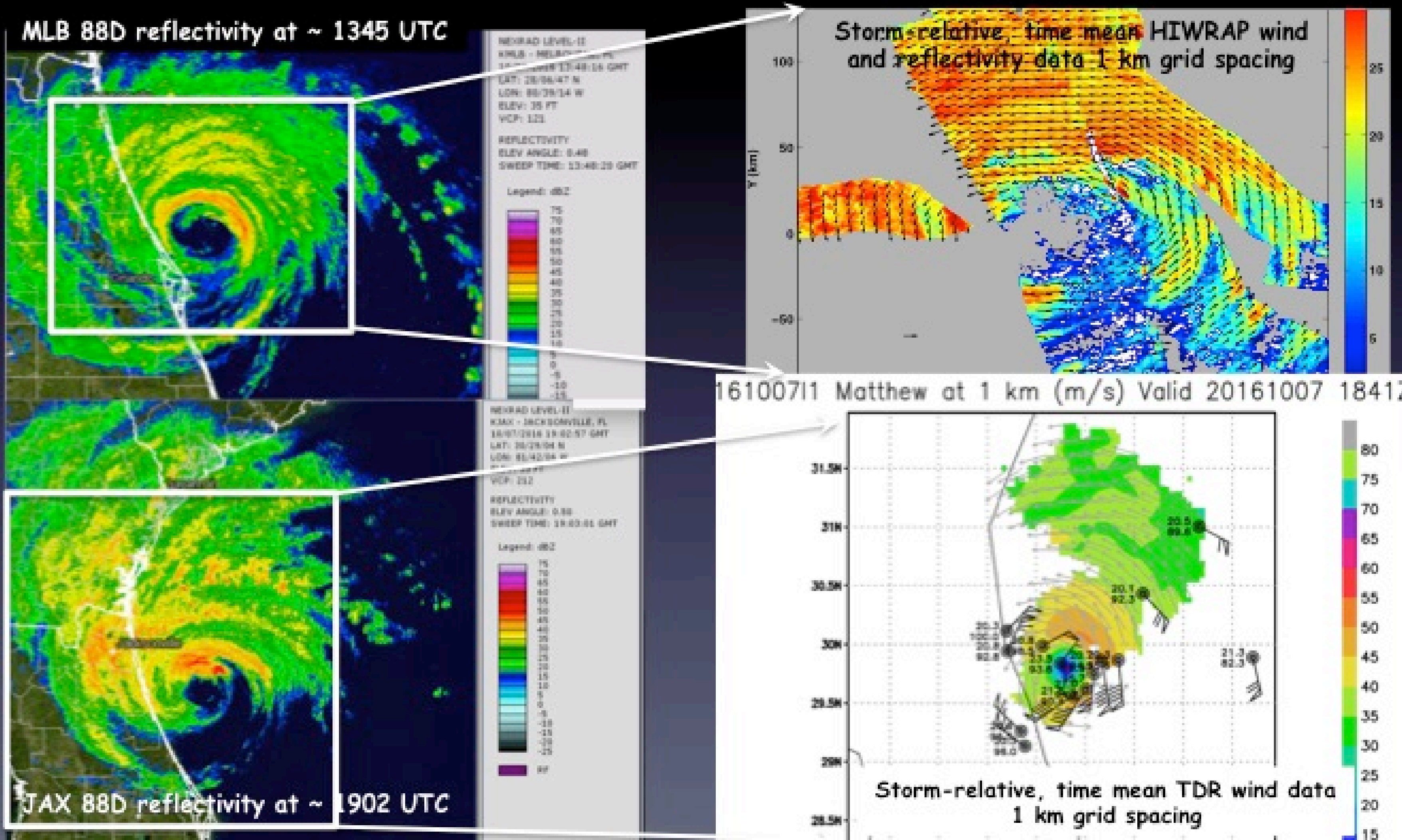


NOAA SHOUT – Hurricane Matthew October 7, 2016 (~ 09 – 19 UTC)
HIWRAP Ku Band Reflectivity and Wind Vectors at 1 km Height

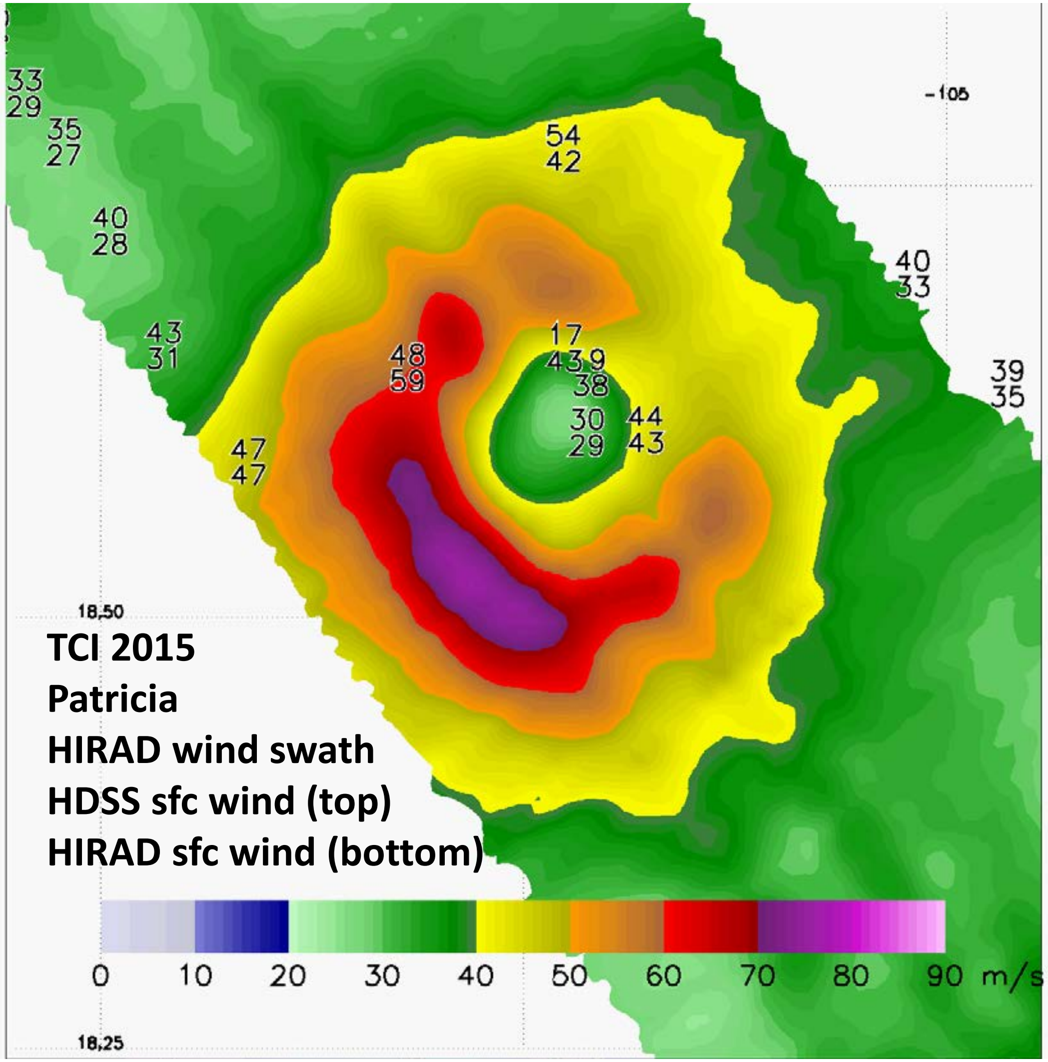
By Steve Guimond (UMD/NASA GSFC), Matt McLinden (NASA GSFC) and Gerald Heymsfield (NASA GSFC)

NOAA IFEX – Hurricane Matthew October 7, 2016 (~ 1830 UTC)
WP-3D LF Reflectivity and TDR/dropsonde Wind Vectors at 1 km Height

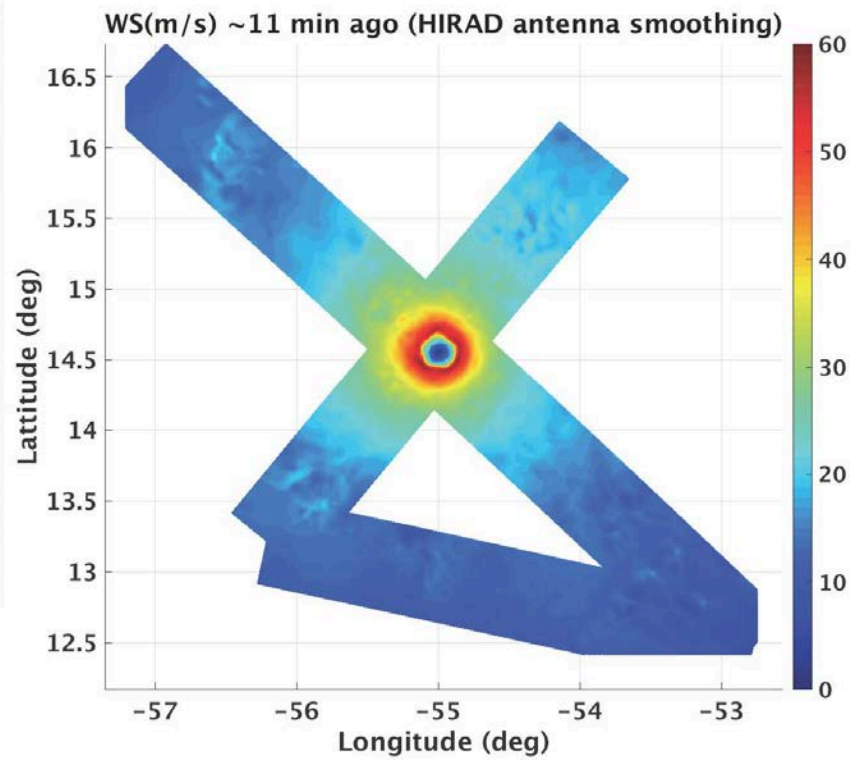
By Rob Rogers (NOAA/OAR/AOML/HRD), Frank Marks (NOAA/OAR/AOML/HRD) and Peter Black (NOAA/UASPO/CNT)



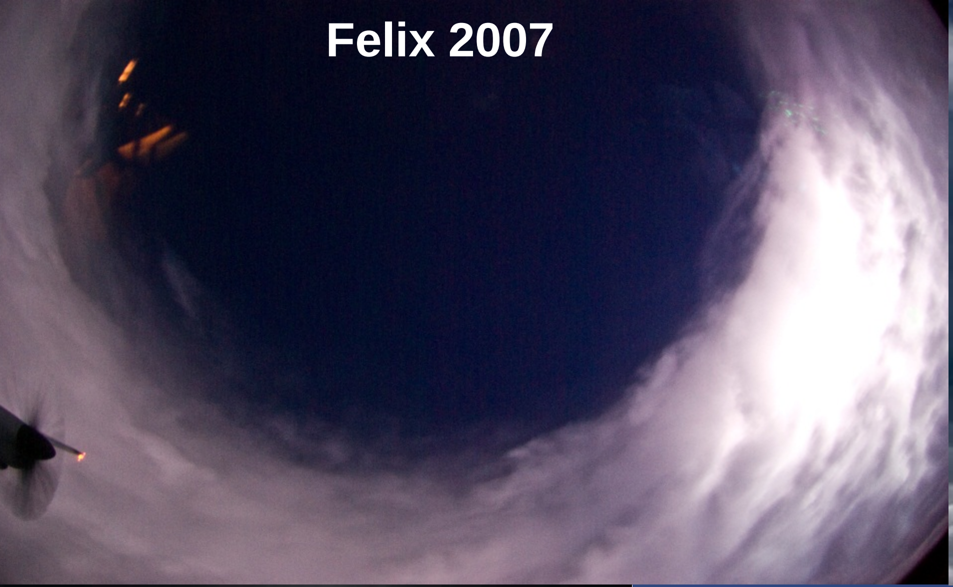
HIRAD example
In the future for GH



Eyewall surface winds mapped In 5 minutes



Courtesy Dan Cecil, IHC 2017


Felix 2007


Irma 2017


Irma 2017


Katrina 2005
QUESTIONS?