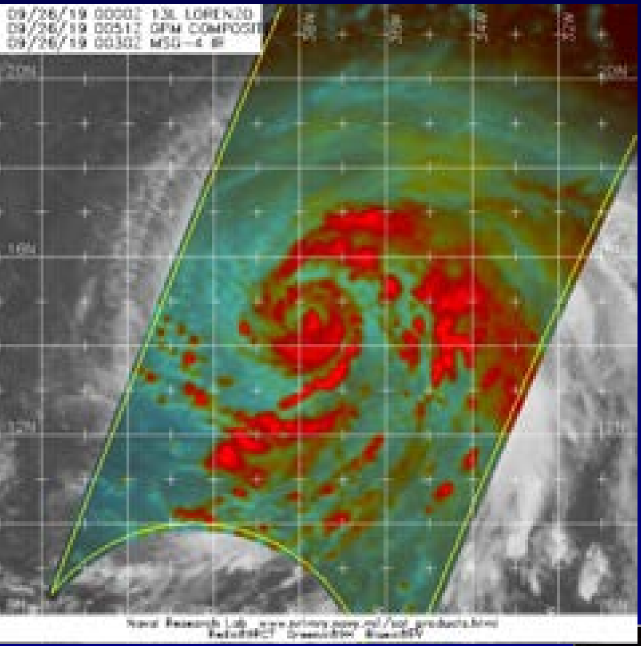
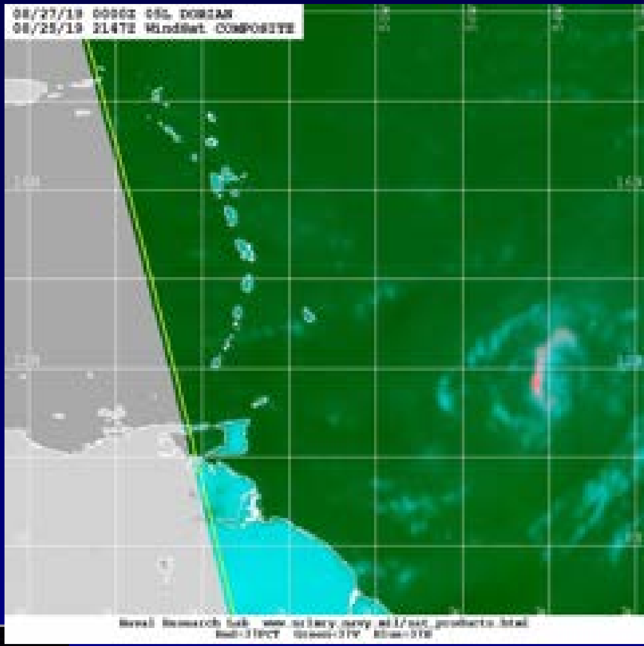
NHC Forecasting and Potential Uses of NASA AOS Data



John L. Beven II & Colleagues

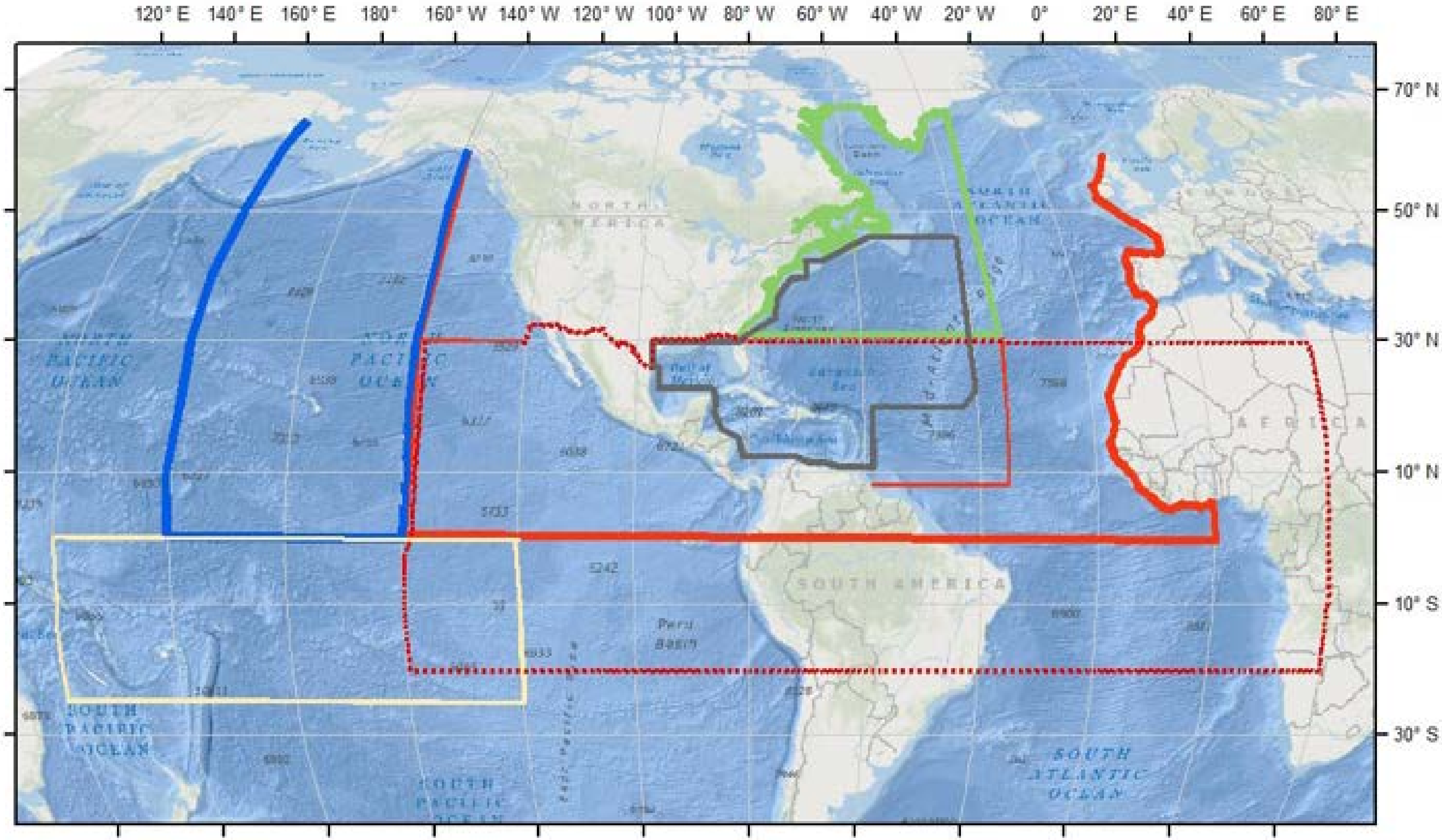
National Hurricane Center



Outline

- The National Hurricane Center and the TC forecast cycle
- Low earth orbiting satellite issues
- How AOS could help the NHC

NHC Area of Responsibility



NHC Tropical Analysis and Forecast Branch forecast area

NHC Tropical Analysis and Forecast Branch surface analysis area

NHC backup area for Aviation Weather Center

NHC backup area for Central Pacific Hurricane Center

NHC backup area for Ocean Prediction Center

NHC backup area for Weather Forecast Office Honolulu

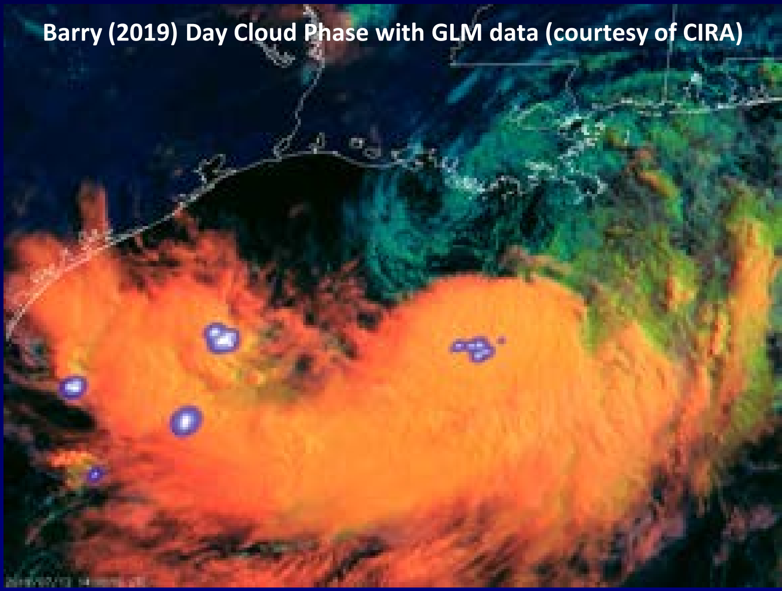
NHC tropical cyclone forecast area

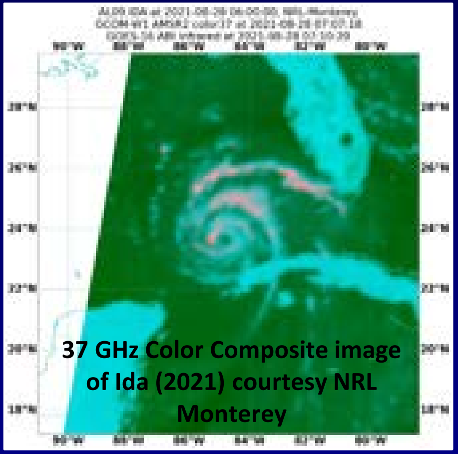
NHC Forecast Cycle

Time (HR : MIN)	Event
00:00	**Issue Tropical Weather Outlook** **Issue Intermediate Public Advisory (if necessary)** ***Synoptic time*** **/ cycle begins**
00:45	**Receive satellite fix data**
01:00	**Initialize models**
01:10	**Receive model guidance and *prepare forecast***
02:00	**NWS / DOD hotline coordination**
03:00	**Advisory deadline**
03:15	**FEMA conference call**
06:00	**New cycle begins**

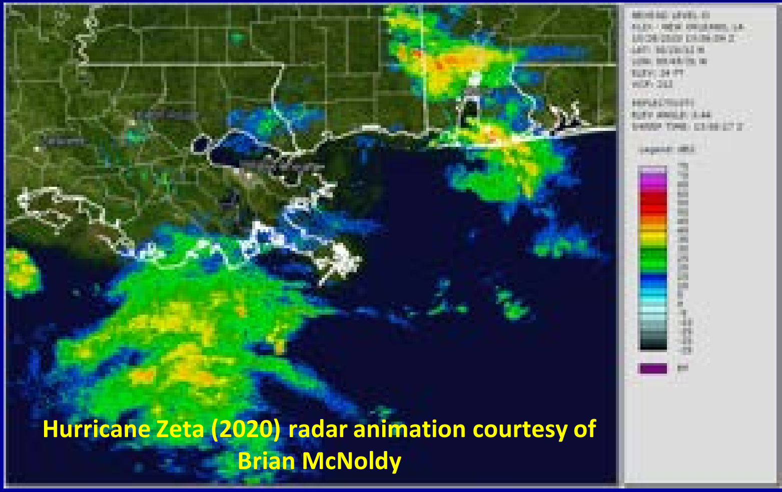
Data NHC uses to track hurricanes

- Geostationary Satellites
- Low-Earth Orbiting Satellites
- Reconnaissance Aircraft
- Surface observations
- Radar


Barry (2019) Day Cloud Phase with GLM data (courtesy of CIRA)

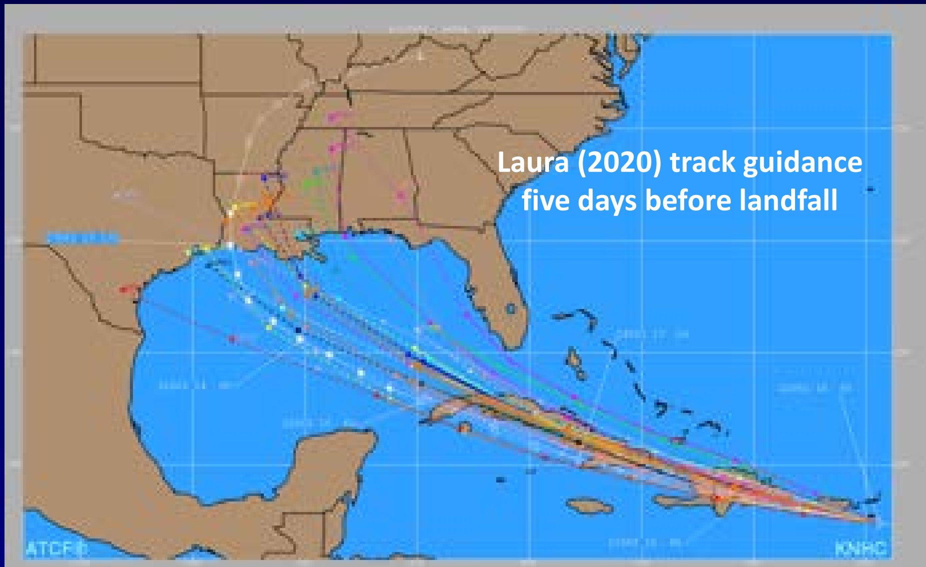

37 GHz Color Composite image of Ida (2021) courtesy NRL Monterey

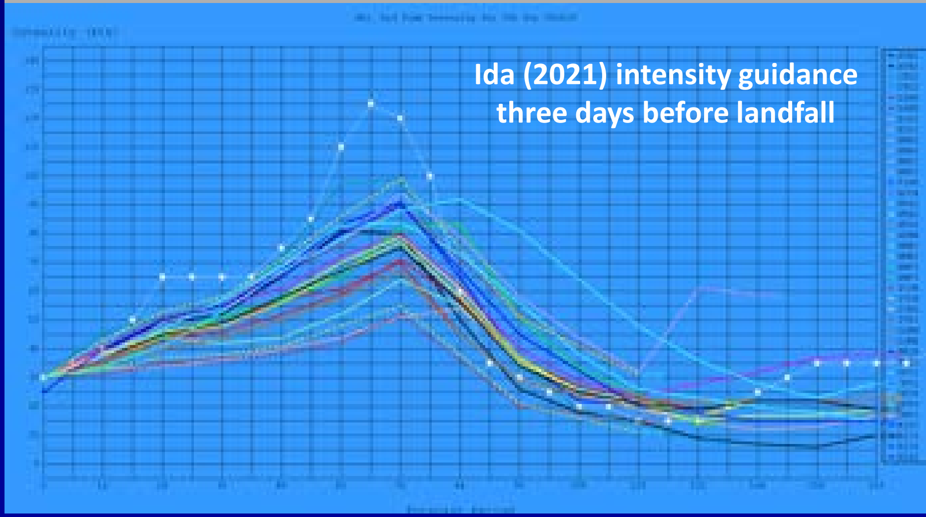

NOS Eugene Island weather station


Hurricane Zeta (2020) radar animation courtesy of Brian McNoldy

Making Hurricane Forecasts

- Every six hours, the NHC makes forecasts of the expected position, intensity, and size of a tropical cyclone out to five days, and to issue the appropriate watches and warnings for winds and storm surge.
- Watches are usually issued for a region 48 hours before the expected impacts start, with warnings usually issued 36 hours before the impacts start.
- The NHC also makes probabilistic forecasts of when and where tropical cyclones may form.
- These forecasts are based on guidance from numerical weather prediction models of both the cyclone and the environment, accompanied by the forecaster's knowledge and experience.

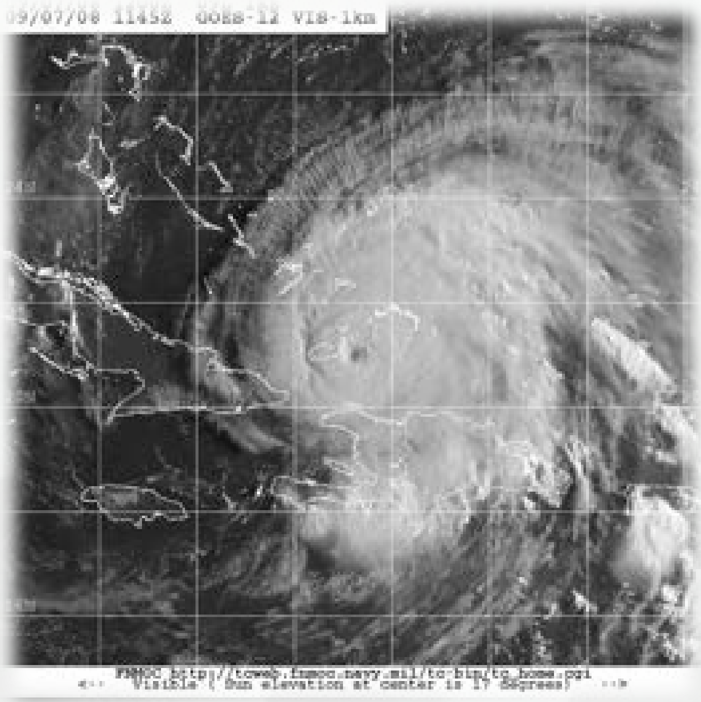




Forecast Cycle Begins

Questions Forecaster Must Answer

1. **Where is the storm located?**
   - **Latitude/Longitude**
   - **From this motion can be determined**

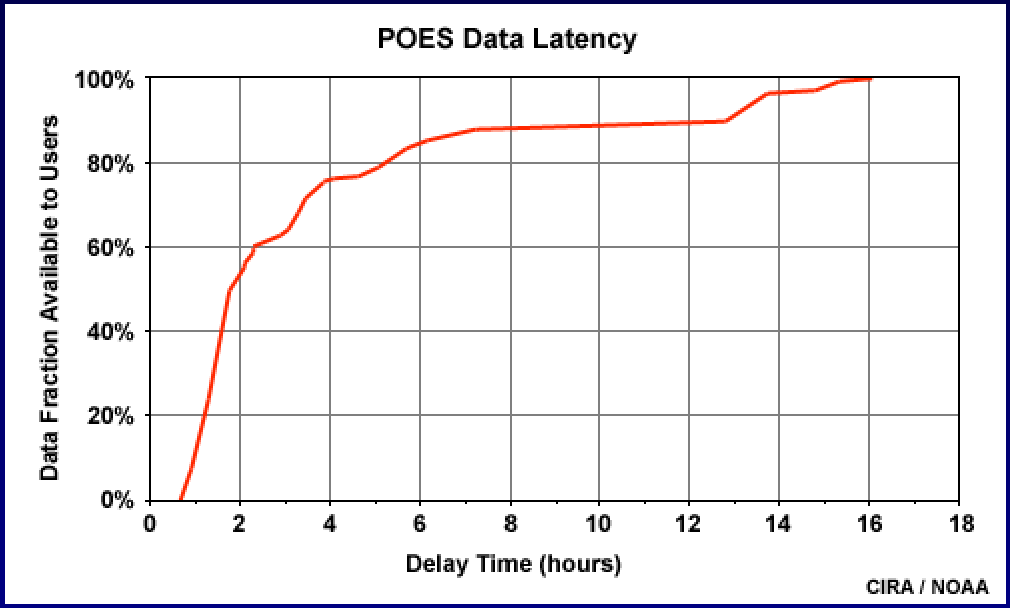


2. **How strong is the storm?**
   - **Maximum sustained winds**

3. **How big is the storm?**
   - **Extent of tropical-storm and hurricane-force winds**

AOS data may help answer some of these questions and provide valuable input to NWP models if it delivered timely.

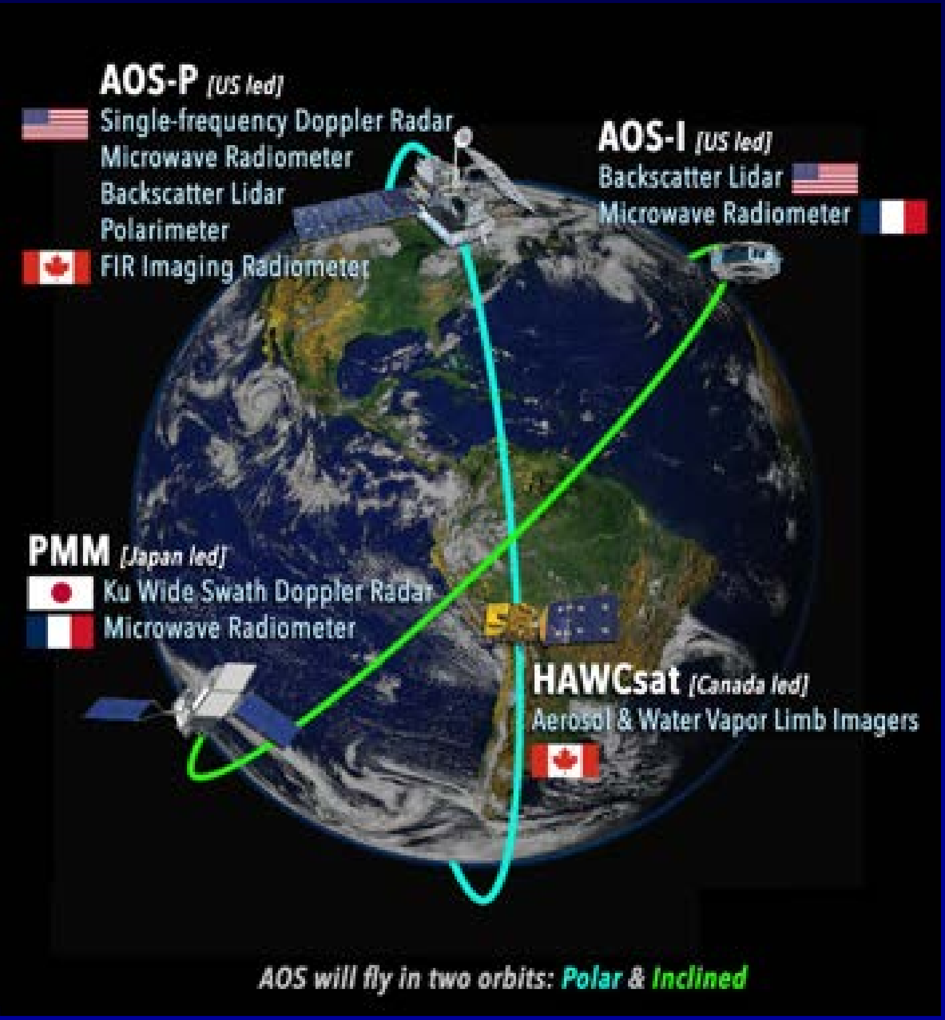
Low Earth Orbiting Satellite Data Latency Issues

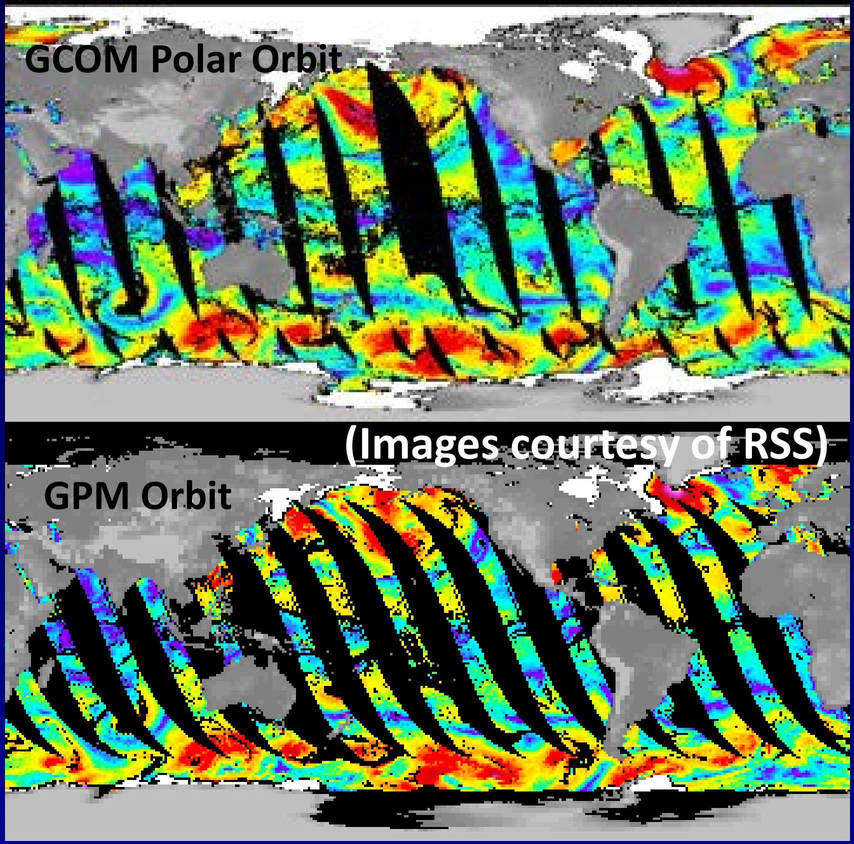


Data latency issues for LEO satellites make it more difficult for the data to neatly fit the NHC 6-h advisory and modelling cycles. Data latency of more than 3 h significantly decreases the real-time utility of the data.

Please make *<u>every</u>* possible effort to get this data to the forecasters and modelers in real time!

MW Sensors – Low Earth Orbiting Satellites Only. ☹

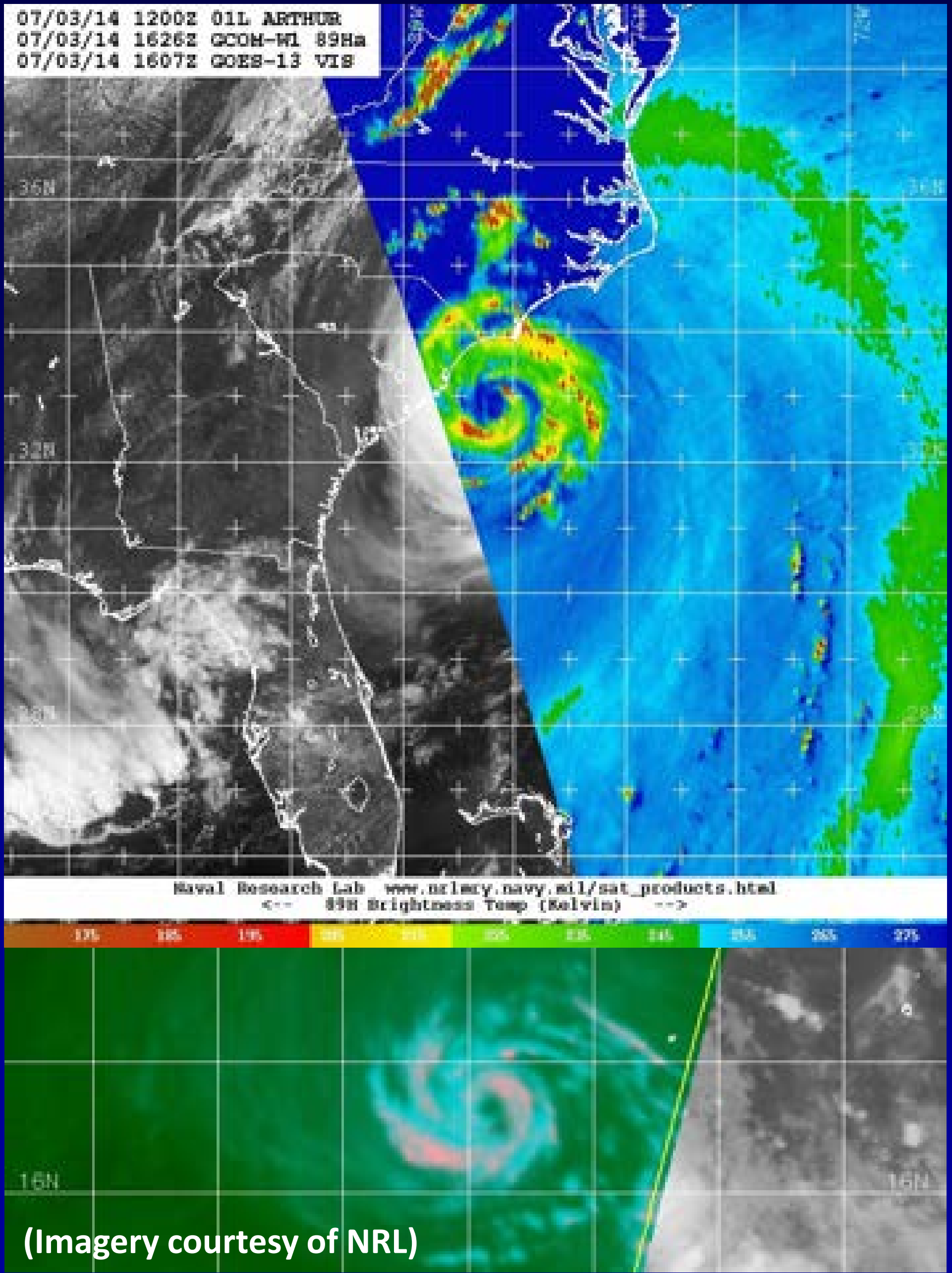




- Between antenna size and resolution issues, microwave (MW) imagers/ sounders/radars fly only on low earth orbiting satellites.
- This allows only limited swaths of data and reduce the temporal coverage of a given TC from a given satellite.
- AOS constellation may somewhat help the temporal coverage issue, but gaps will exist.

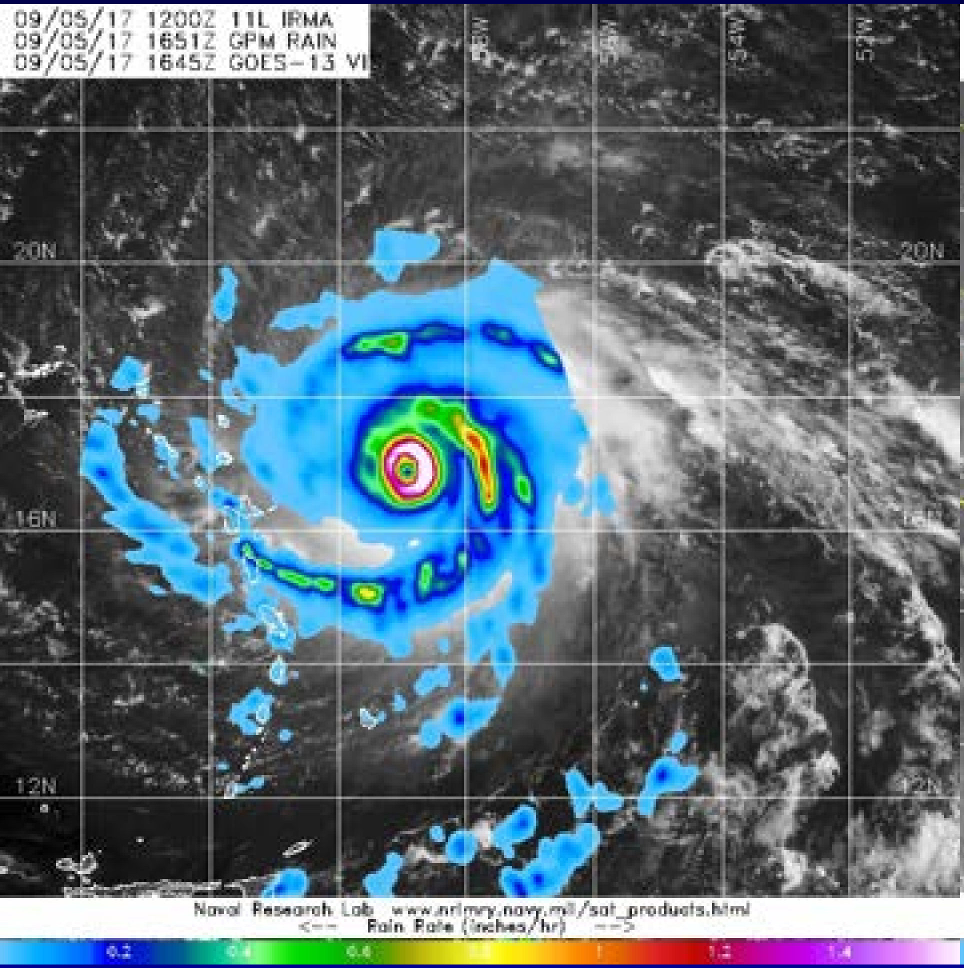
Microwave Imagery Interpretation

- **MW Imagery can penetrate through clouds and reveal TC internal structure, including convective bands, shear patterns, eyewall formation, and eyewall replacement cycles.**
- **In many cases, MW imagery is better at locating TC centers than conventional visible and infrared**
- **85-91 GHz MW Imagery is able to distinguish deep convection, but can not always see low-level clouds that depict circulation centers.**
- ***The AOS microwave radiometer does not have a 37 GHz channel that NHC often uses for low cloud/low-level center location and RI potential. Is there an equivalent channel on the satellites?***
- **These data are used both objectively and subjectively!**

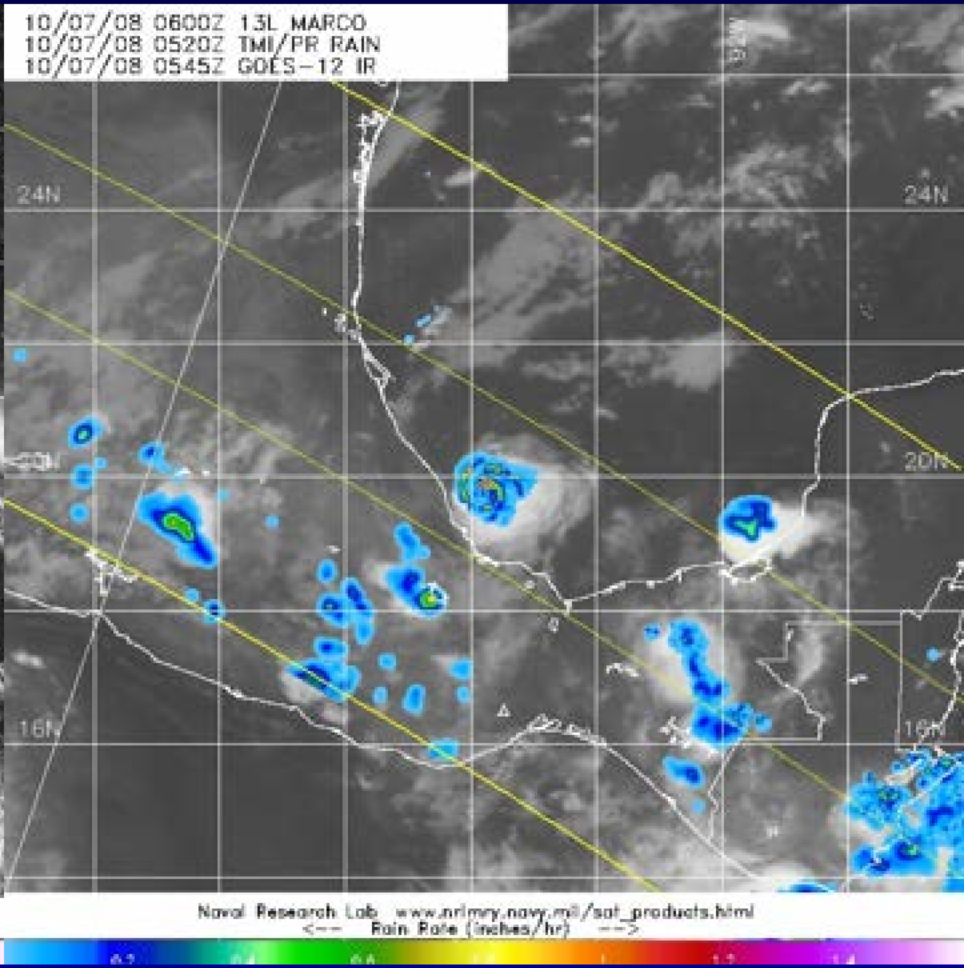


(Imagery courtesy of NRL)

Microwave Satellite Rainfall Data



GPM Observed Rainfall Rate

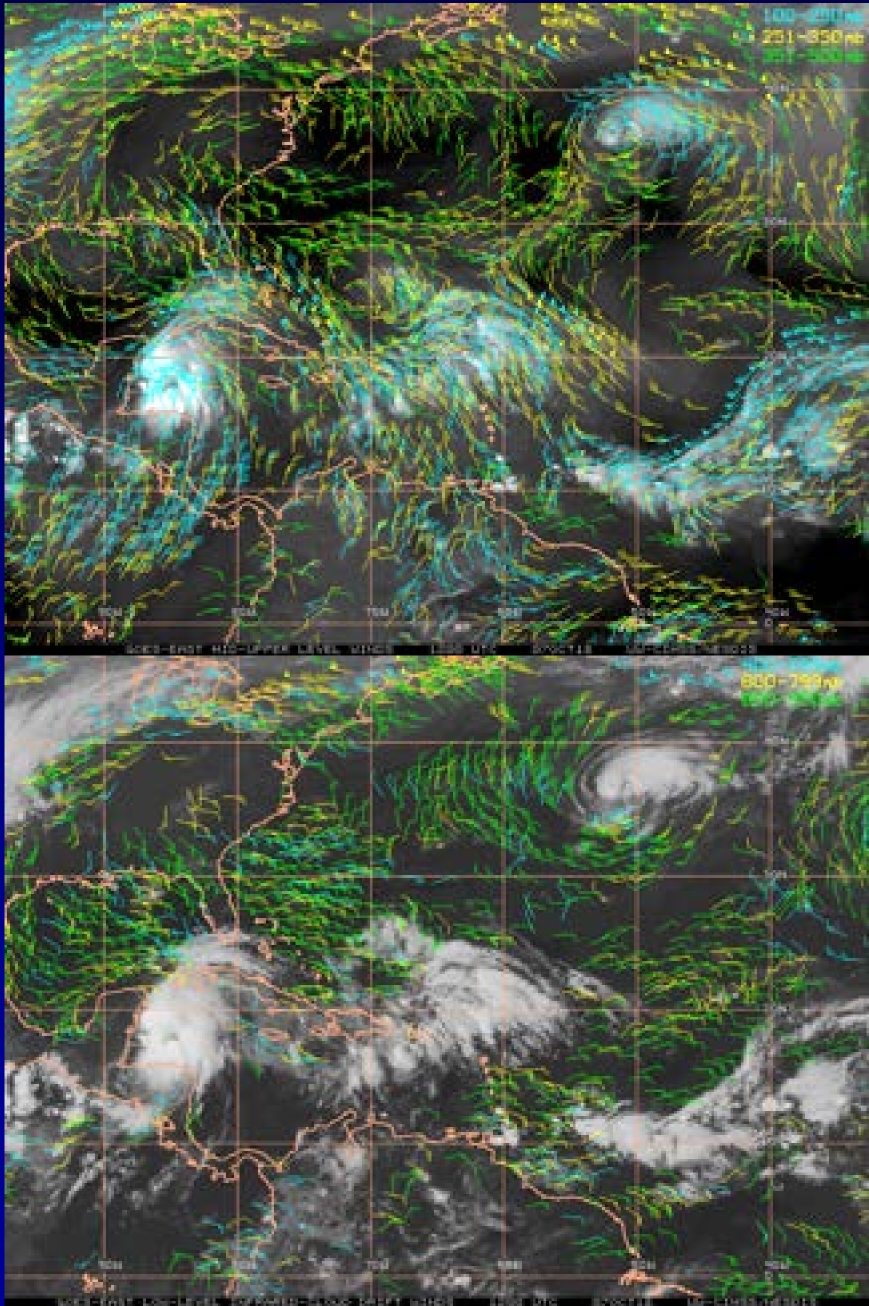


TRM Precipitation Radar

Previously orbiting microwave sensors have given us both passive and active rainfall rate information. Will the AOS instruments be able to do likewise?

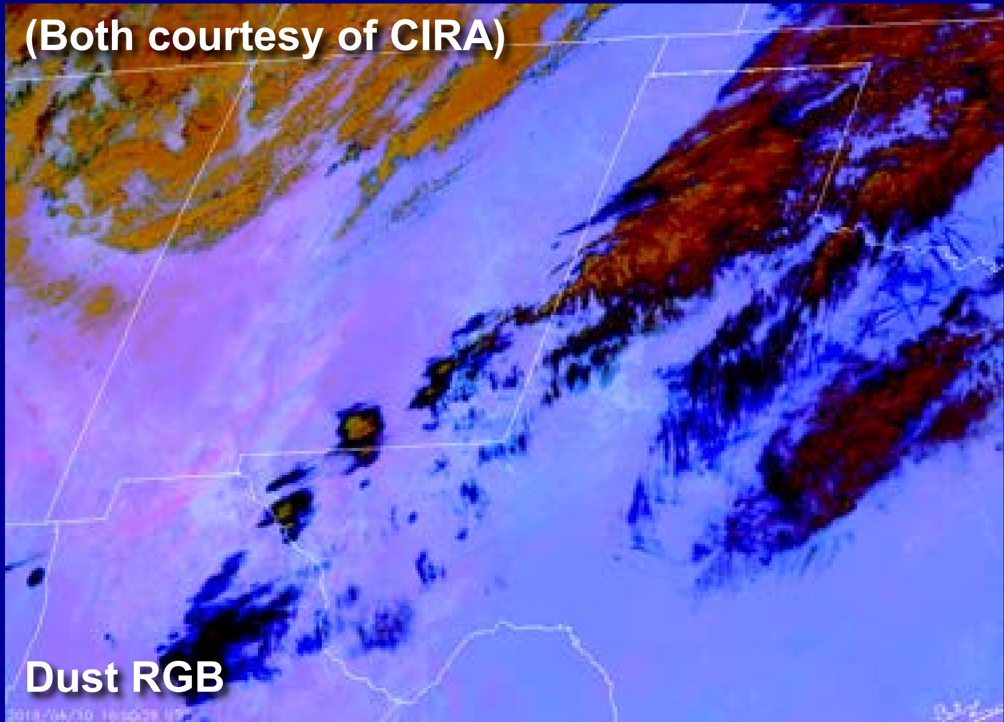
Winds from the Lidar and Doppler Radar?

- Operational satellite winds (also known as Atmospheric Motion Vectors) are computed from displacement of targets on successive geostationary images. (Reference: Velden et al., BAMS, 1997)
- Satellite winds are used for analysis as well as to initialize numerical weather prediction models.
- Will the lidar and doppler radar on the AOS satellites be able to supplement the AMVs available from the geostationary satellites? Can they give us more detailed wind data in and near the tropical cyclone?



Aerosols and Cloud Microphysics

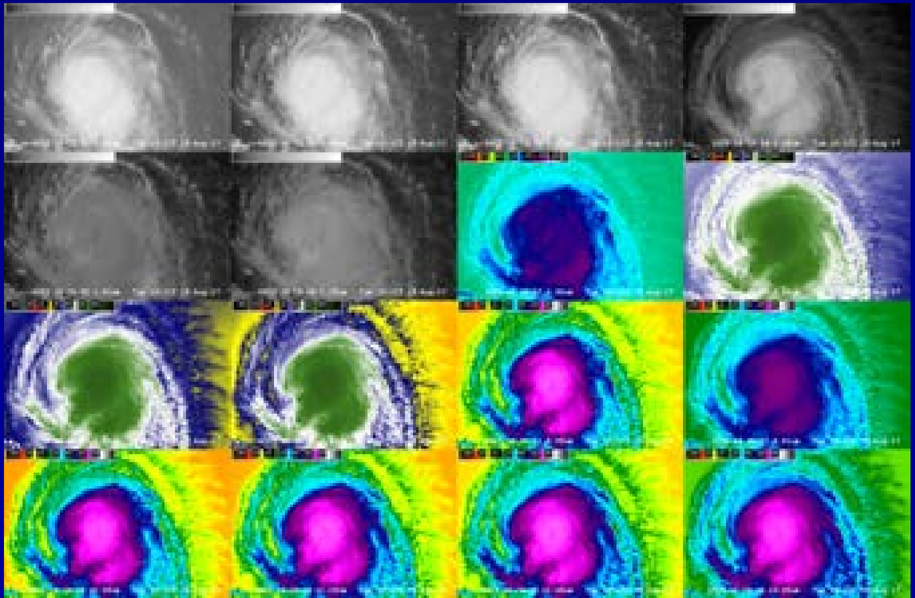
- In analysis and forecasting, NHC qualitatively uses aerosol information through various types of (geostationary) satellite imagery.
- Cloud microphysics data is used less frequently by the forecasters, although data that helps differentiate between convective and non-convective (e. g. cirrus debris) clouds could be useful.
- NWP models could make use of both aerosol and microphysical data to improve TC forecasting, especially the intensity.



Can we relate AOS to geostationary data?

- ABI/AHI-type data are available from multiple satellites in 16 channels with high spatial and very high temporal resolution.
- Can we relate the aerosol and microphysical data in the AOS snapshots to GEO data to use when AOS data is not timely?

Table courtesy of Tim Schmit, CIMSS
GOES-16 Imagery below courtesy of CIMSS

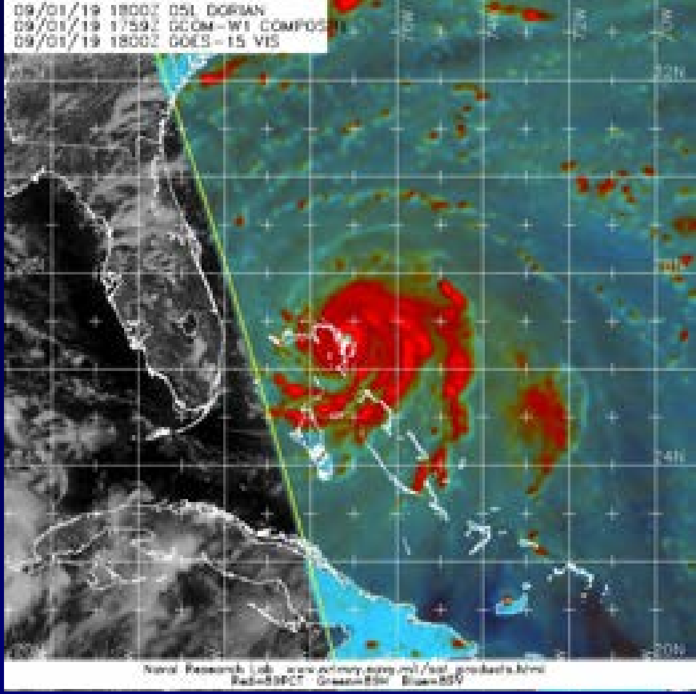


GOES-R Series ABI Imager Channels

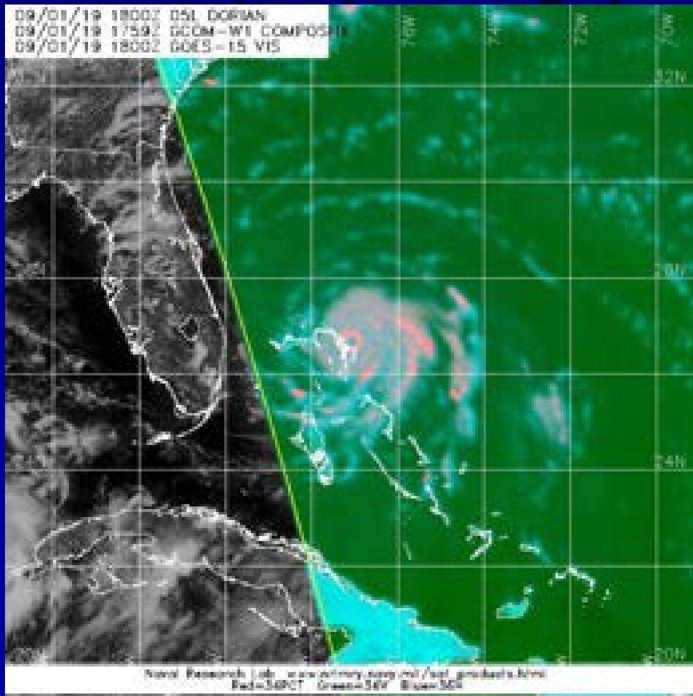
	Future GOES imager (ABI) band	Wavelength range (μm)	Central wavelength (μm)	Nominal subsatellite IGFOV (km)	Sample use
	1	0.45–0.49	0.47	1	Daytime aerosol over land, coastal water mapping
*	2	0.59–0.69	0.64	0.5	Daytime clouds fog, insolation, winds
	3	0.846–0.885	0.865	1	Daytime vegetation/burn scar and aerosol over water, winds
	4	1.371–1.386	1.378	2	Daytime cirrus cloud
	5	1.58–1.64	1.61	1	Daytime cloud-top phase and particle size, snow
	6	2.225–2.275	2.25	2	Daytime land/cloud properties, particle size, vegetation, snow
*	7	3.80–4.00	3.90	2	Surface and cloud, fog at night, fire, winds
	8	5.77–6.6	6.19	2	High-level atmospheric water vapor, winds, rainfall
*	9	6.75–7.15	6.95	2	Midlevel atmospheric water vapor, winds, rainfall
	10	7.24–7.44	7.34	2	Lower-level water vapor, winds, and SO_2
	11	8.3–8.7	8.5	2	Total water for stability, cloud phase, dust, SO_2 rainfall
	12	9.42–9.8	9.61	2	Total ozone, turbulence, and winds
	13	10.1–10.6	10.35	2	Surface and cloud
*	14	10.8–11.6	11.2	2	Imagery, SST, clouds, rainfall
*	15	11.8–12.8	12.3	2	Total water, ash, and SST
	16	13.0–13.6	13.3	2	Air temperature, cloud heights and amounts

Conclusions and Questions

- The AOS constellation can provide useful MW radiometer data for NHC operations.
- AOS data should be very useful for NWP models.
- Can we enhance atmospheric wind data with the lidar and doppler radar?
- Can some of the capabilities of the 37 GHz imagery be matched using the other AOS channels?
- Like the GOES-R satellites, there will be a learning curve for the capabilities and limitations of AOS.



Dorian (2019) MW imagery



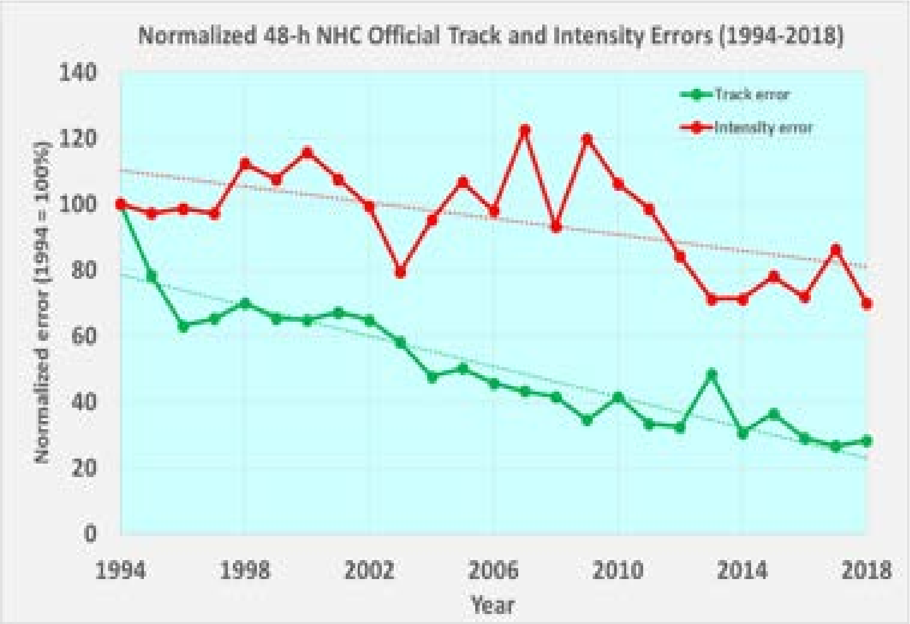
NOAA's Atlantic Oceanographic and Meteorological Laboratory
U.S. Department of Commerce

NOAA Hurricane Research – Physical Processes

Robert Rogers
NOAA/AOML Hurricane Research Division

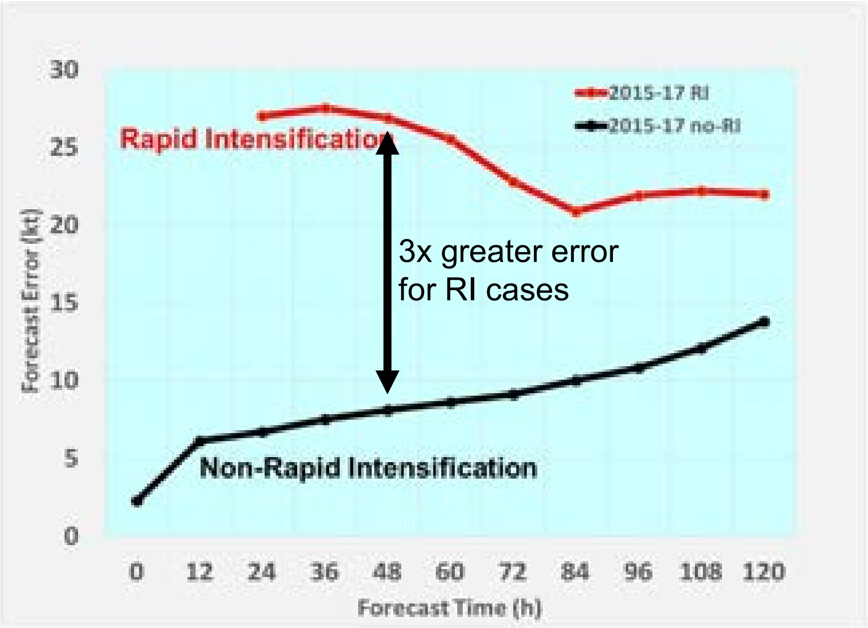
The Challenge: Hurricane Intensity Forecasting

NHC 48-h Track & Intensity Forecast Errors



- Track errors improved by 70%
- Intensity errors improved by 30%

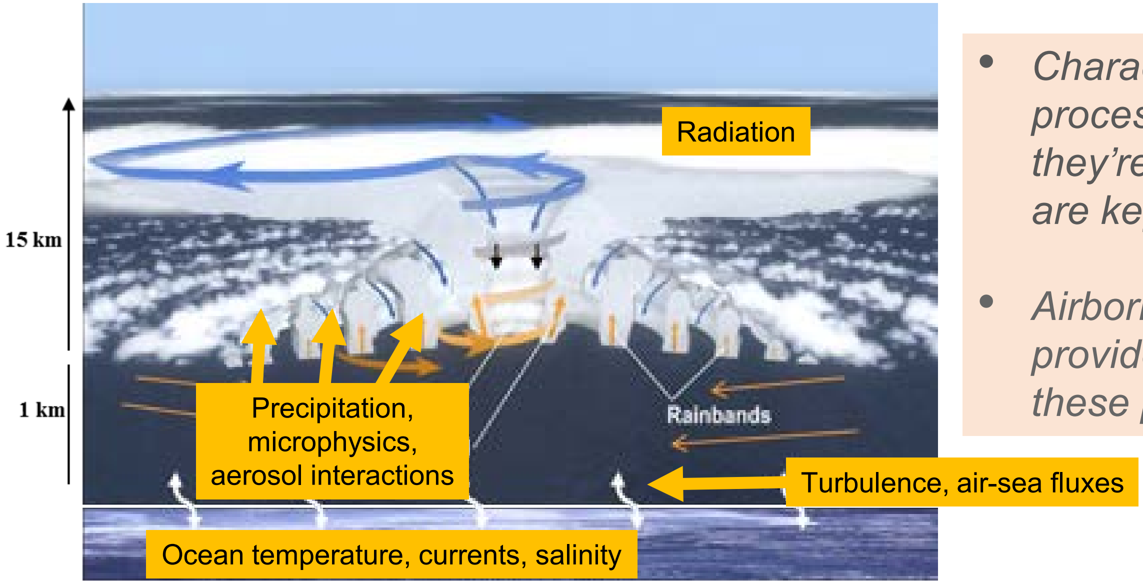
NHC Intensity Forecast Errors – RI vs. non-RI



- Intensity errors 3X great for RI storms than non-RI storms

The Challenge: Hurricane Intensity Forecasting

Major physical processes in hurricanes



- *Characterizing and understanding these processes and their interactions, and how they're represented in numerical models, are key steps in forecast improvement*
- *Airborne and spaceborne observations provide a unique opportunity to study these processes across scales*

NOAA's Hurricane Field Program: APHEX

BAMS
Article

Accomplishments of NOAA's Airborne Hurricane Field Program and a Broader Future Approach to Forecast Improvement

Jonathan Zawislak, Robert F. Rogers, Sim D. Aberson, Ghassan J. Alaka Jr., George R. Alvey III, Altug Aksoy, Lisa Bucci, Joseph Cione, Neal Dorst, Jason Dunion, Michael Fischer, John Gamache, Sundararaman Gopalakrishnan, Andrew Hazelton, Heather M. Holbach, John Kaplan, Hua Leighton, Frank Marks, Shirley T. Murillo, Paul Reasor, Kelly Ryan, Kathryn Sellwood, Jason A. Sippel, and Jun A. Zhang

ABSTRACT: Since 2005, NOAA has conducted the annual Intensity Forecasting Experiment (IFEX), led by scientists from the Hurricane Research Division at NOAA's Atlantic Oceanographic and Meteorological Laboratory. They partner with NOAA's Aircraft Operations Center, who maintain and operate the WP-3D and Gulfstream IV-SP (G-IV) Hurricane Hunter aircraft, and NCEP's National Hurricane Center and Environmental Modeling Center, who task airborne missions to gather data used by forecasters for analysis and forecasting and for ingest into operational numerical weather

(Zawislak et al. 2022)

APHEX (Advancing the Prediction of Hurricanes Experiment)

<u>Goal 1</u>: Collect observations that span the TC life cycle in a variety of environments for model initialization and evaluation

<u>Goal 2:</u> Develop and refine measurement strategies and technologies that provide improved real-time analysis of TC intensity, structure, environment, and hazard assessment

<u>Goal 3:</u> Improve the understanding of physical processes that affect TC formation, intensity change, structure, and associated hazards

- Emphasis here on physical processes (Goal 3)

NOAA Hurricane Research Priorities

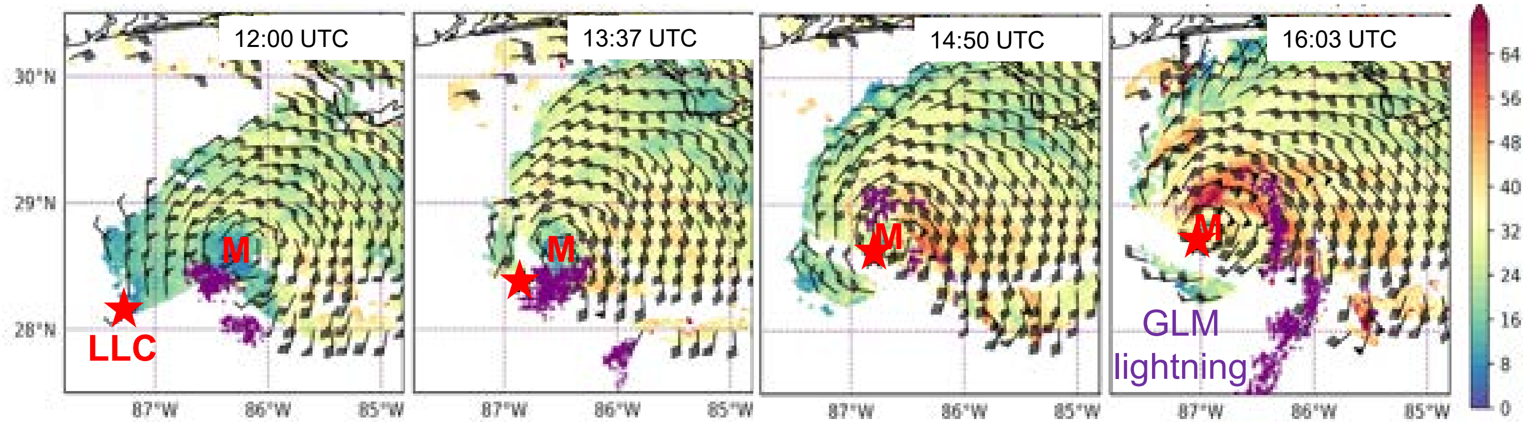
1. Intensity forecasting
   - especially rapid intensification onset
2. Tropical cyclogenesis
   - "pre-TC" advisories out to 7 days necessitates improved genesis forecasts
3. SAL/TC interactions
   - important for both genesis and intensification
4. Hazards
   - rainfall, also storm surge, winds, severe weather

- Work is ongoing in NOAA to address these priorities, but work would benefit from NASA AOS

Rapid Intensification onset

Vortex alignment and precipitation structure

Midlevel (5-km) winds from ground-based radar, low-level aircraft fixes for Sally (2020)

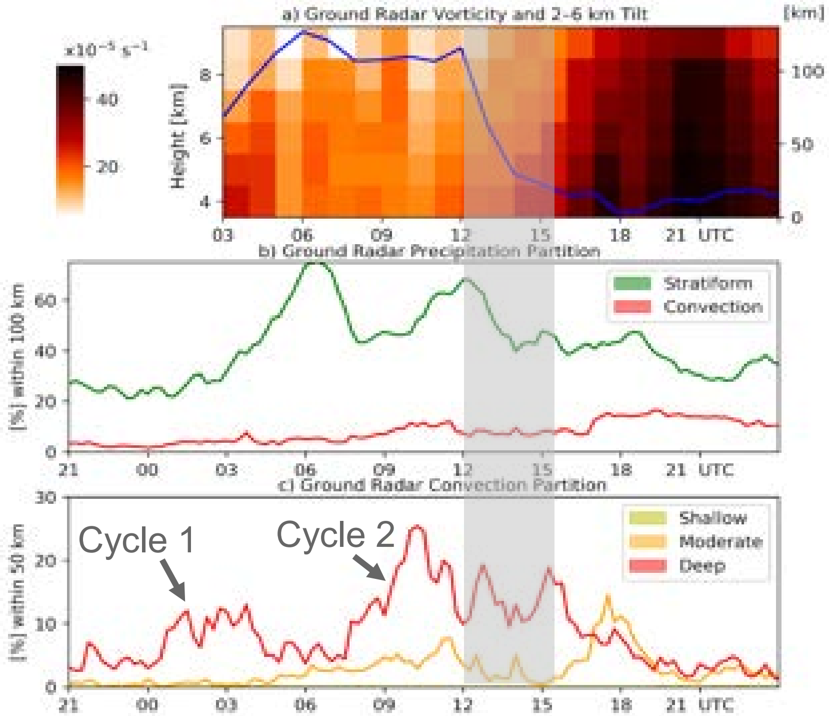


(Stone et al. 2023)

- Development of an aligned vortex is a crucial step in RI onset
- Low-level circulation ("★") repositions toward midlevel circulation ("**M**"), coincident with GLM-detected lightning
- TC intensifies (5 km winds increase)

Rapid Intensification onset

Vortex alignment and precipitation structure



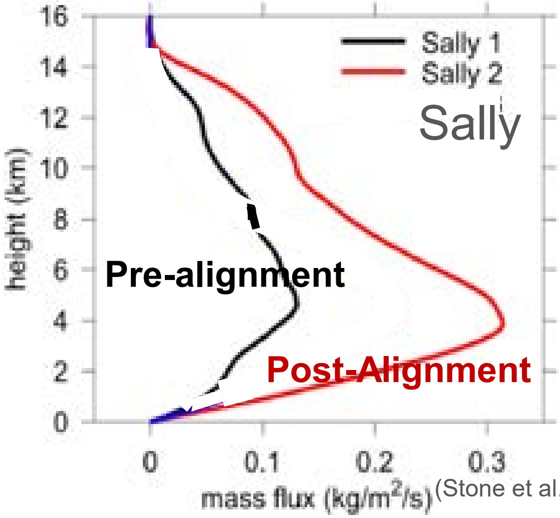
(Stone et al. 2023)

- Rapid tilt reduction and vortex amplification starting 12 UTC
- Two cycles of deep convection in 12 h prior to alignment
- Increase of moderate convection during 2nd cycle
- Increased coverage of stratiform precipitation 1-3 h after each cycle

Rapid Intensification onset

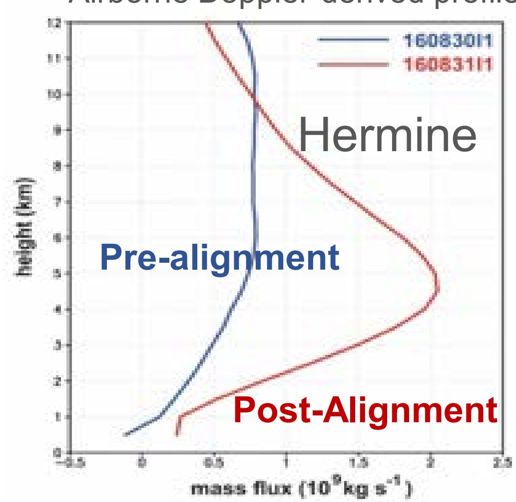
Mass flux profiles and alignment

Dropsonde-derived profile



(Stone et al. 2023)

Airborne Doppler-derived profile

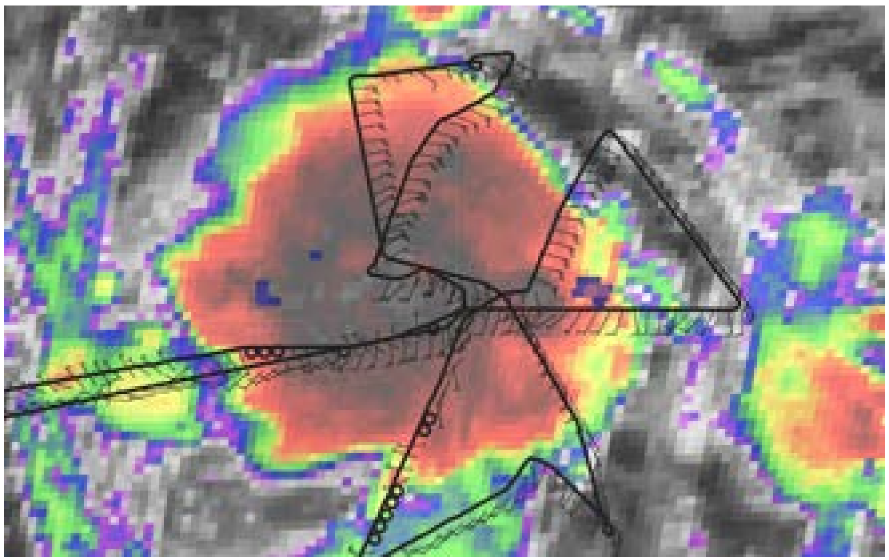


(Rogers et al. 2020)

- Vertical mass flux proportional to vertical velocity, a proxy for latent heating
- Profile peaks in lower troposphere, favors low-level convergence, vorticity stretching, alignment
- Profiles increase in magnitude during alignment period of both TCs
- Consistent relationship between mass flux profiles and alignment

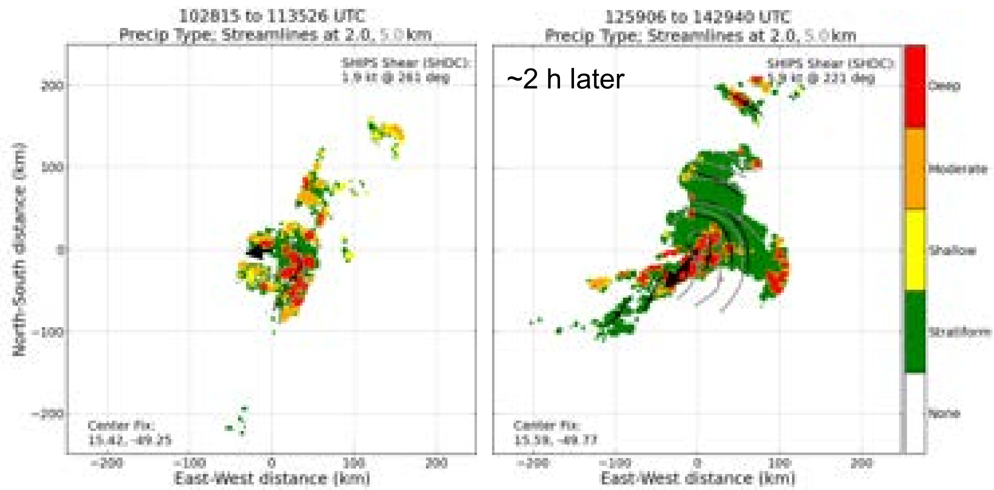
Tropical Cyclogenesis

P-3 flight track during pre-Earl



- Extensive cold cloud shield indicative of a mature mesoscale convective system
- Mission sampled core of cloud shield over ~4 h period

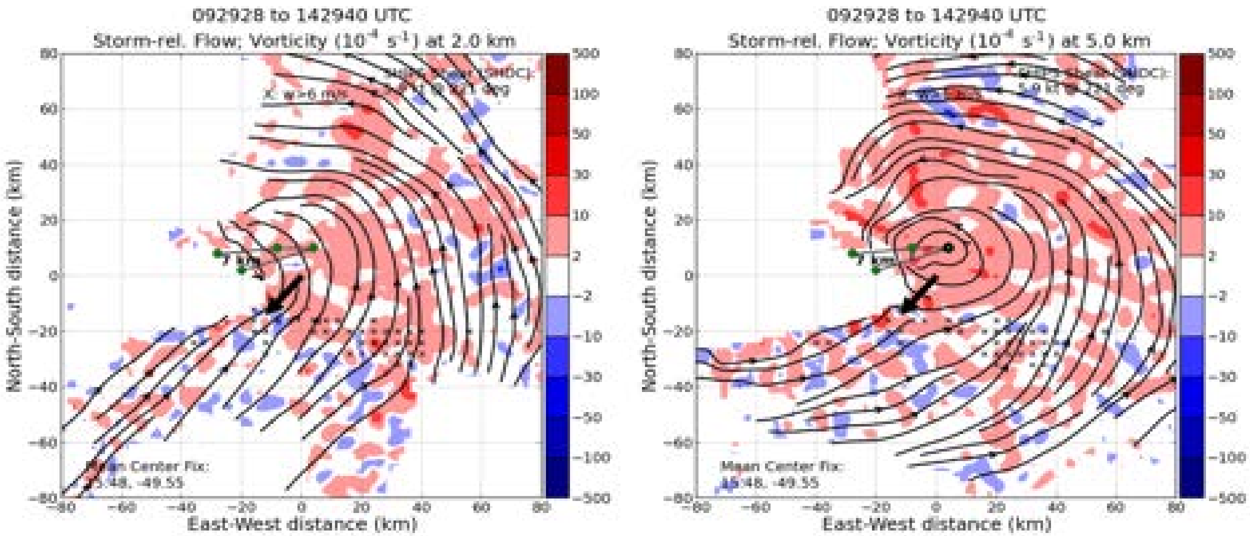
P-3 radar-derived precipitation structure



- Extensive areas of deep convection, some moderate convection
- Broad region of stratiform precipitation by later pass – possible evolution (stratiform transition) of convective system, or perhaps just sampling variability

Tropical Cyclogenesis

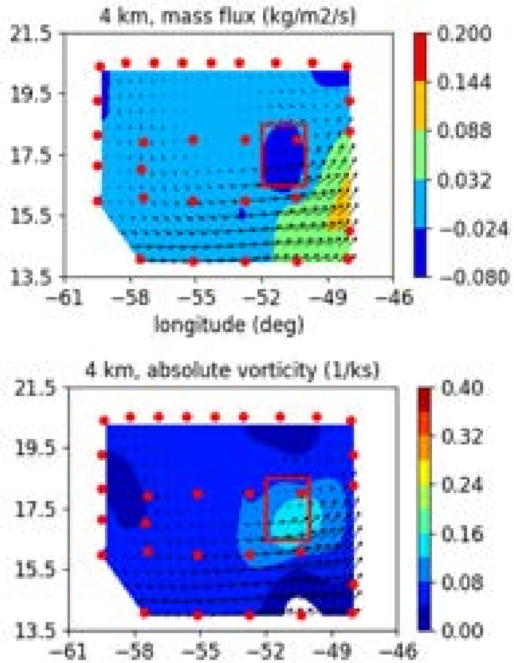
P-3 radar-derived winds, vorticity during pre-Earl



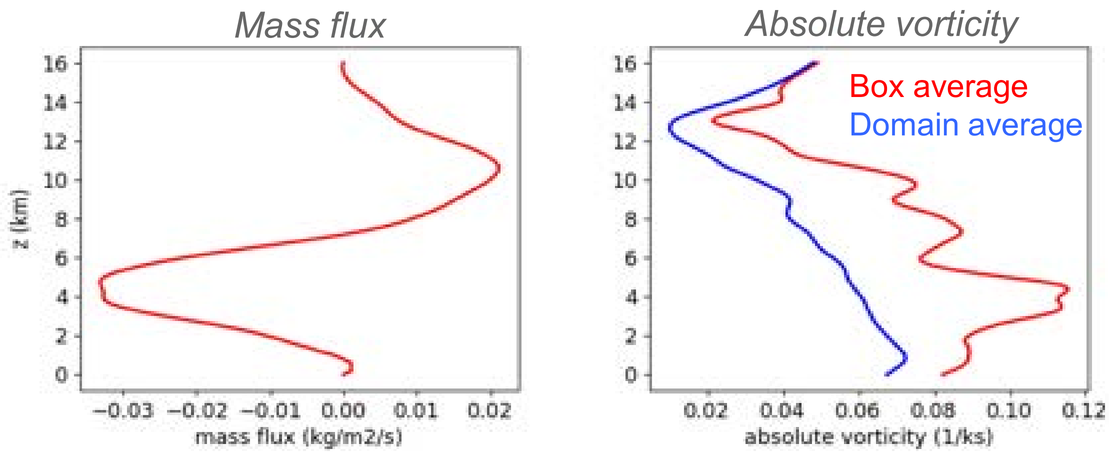
- Development of closed low-level circulation key step marking tropical cyclogenesis
- Midlevel circulation and vorticity maximum evident at this time, displaced about 30 km ENE of elongated low-level circulation/shear axis (no closed low-level circulation yet)

Tropical Cyclogenesis

G-IV dropsonde analysis-derived mass flux, vorticity



- Define averaging box based on peak downward mass flux at 4 km
- Box also includes peak 4-km vorticity



- Mass flux profile peaks at 10 km, local minimum at 4 km
- Mass flux profile typical of stratiform precipitation
- Vorticity profile peaked in midlevels (at 4 km). Consistent with TDR-derived vorticity maximum 12 h previously
- Ability to track midlevel circulation over time – still no closed low-level circulation though

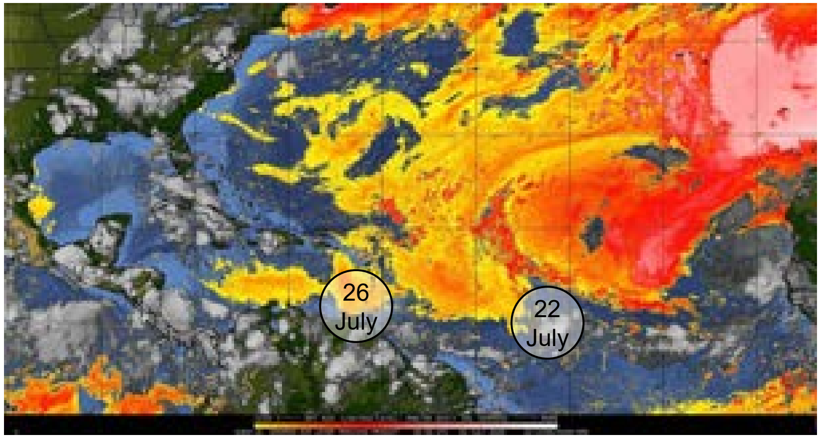
Saharan Air Layer – Tropical Cyclone Interactions

Advancements in satellite sensors and products have significantly improved our monitoring of the SAL

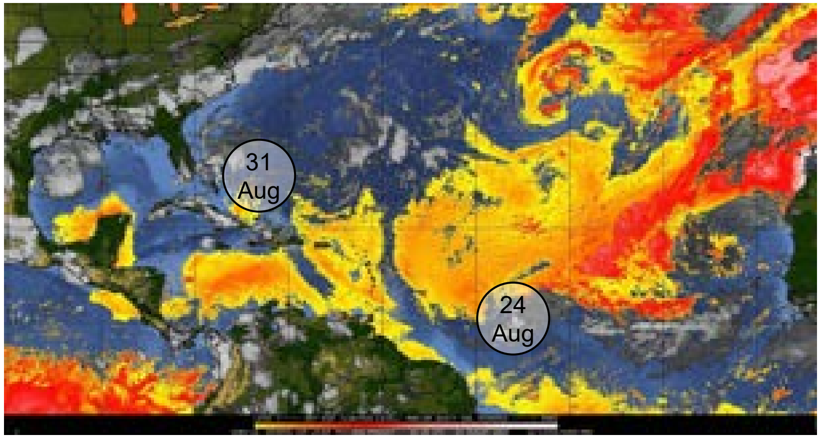
Tropical Storm Gonzalo: 23 July 2020, 12 UTC

Saharan Air Layer – Tropical Cyclone Interactions

Tropical Storm Gonzalo: 22-26 July 2020



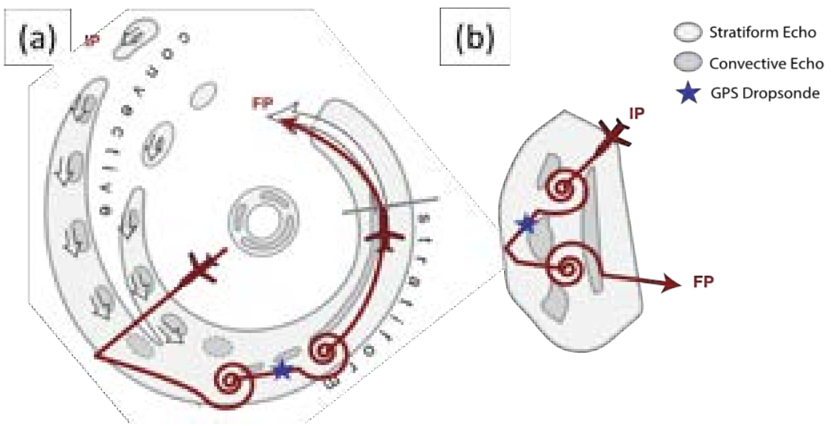
Hurricane Dorian: 24-31 August



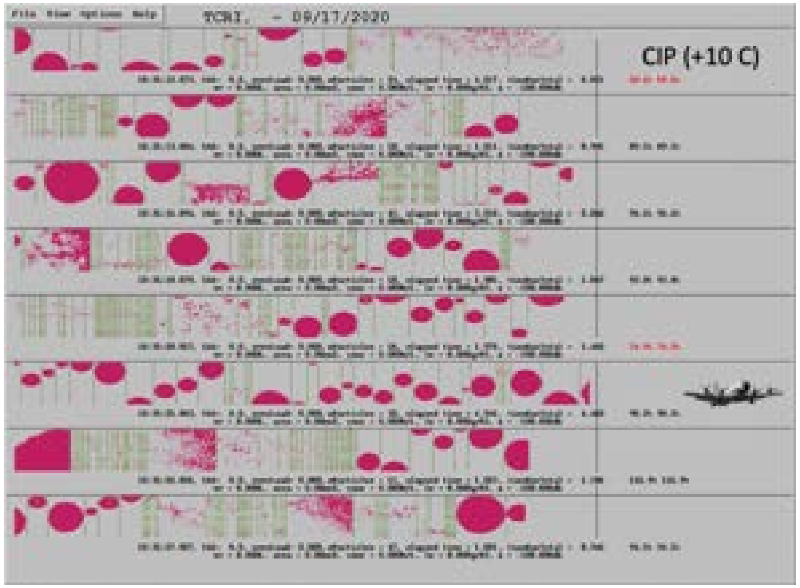
- Gonzalo appeared to be interacting with the SAL early in its lifecycle
- NHC: noted dry mid-level air likely inhibiting the storm
- NHC: enhanced vertical wind shear + dry air >> convective structure eroded before landfall in Trinidad

- Dorian appeared to be interacting with the SAL early in its lifecycle
- NHC: continuous intrusions of dry air might have contributed to its ragged structure up to 24-27 Aug.
- Dorian overcame a marginal environment: RI on 31 Aug

Microphysics studies



- P-3 Stratiform Spiral module: spiral ascent/descent across the freezing level in the stratiform portion of a primary rainband or MCS
- Microphysics measurements can help with rainfall, possibly intensity forecasts from numerical models



- Hurricane Teddy Cloud Imaging Probe (CIP) measurements of rain droplets, ice crystals, and snow. Hydrometeors transition from water to ice as the P-3 flies through and above the freezing level.

Knowledge gaps likely to be aided by NASA AOS

1. Intensity forecasting and RI onset
   - What is dominant precipitation mode associated with vortex alignment?
   - What governs latent heating, vertical velocity, and mass flux profiles (environmental vs. local processes)?
2. Tropical cyclogenesis
   - Importance of midlevel center in low-level center formation (spatiotemporal variability of precipitation structure)?
   - What is role of SAL/aerosol interactions in precipitation structure and distribution?
3. SAL/TC interactions
   - Are there different modes of SAL outbreaks that are more/less effective at suppressing TC intensity?
   - How do convectively driven downdrafts resulting from SAL-TC interactions affect the TC environment, the marine boundary layer, and what are the time scales for MBL recovery?
   - How does Saharan dust impact static stability in TC environment (warming, enhanced convective inhibition)?
4. Hazards/Rainfall
   - What are key microphysical processes in hurricane environment, and how do they differ from other environments?

THANK YOU

QUESTIONS?

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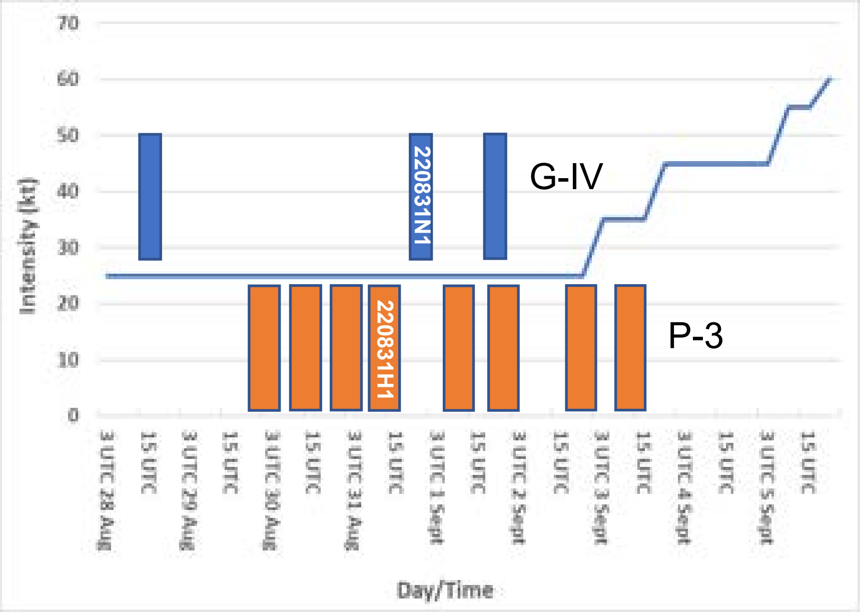
Tropical Cyclogenesis

Sequence of aircraft missions into pre-Earl (2022)



Relevant processes likely to be aided by NASA AOS

1. Intensity forecasting and RI onset
   - vortex alignment, convective/precipitation structure, latent heating/vertical velocity/mass flux profiles, microphysics
2. Genesis
   - convective/precipitation structure, latent heating profiles/microphysics, SAL/aerosol interactions
3. Hazards - Rainfall
   - microphysics important for rainfall, possibly intensity forecasting

Utilizing Observations, DA, & Models to Accelerate Hurricane Research & Prediction

Frank Marks

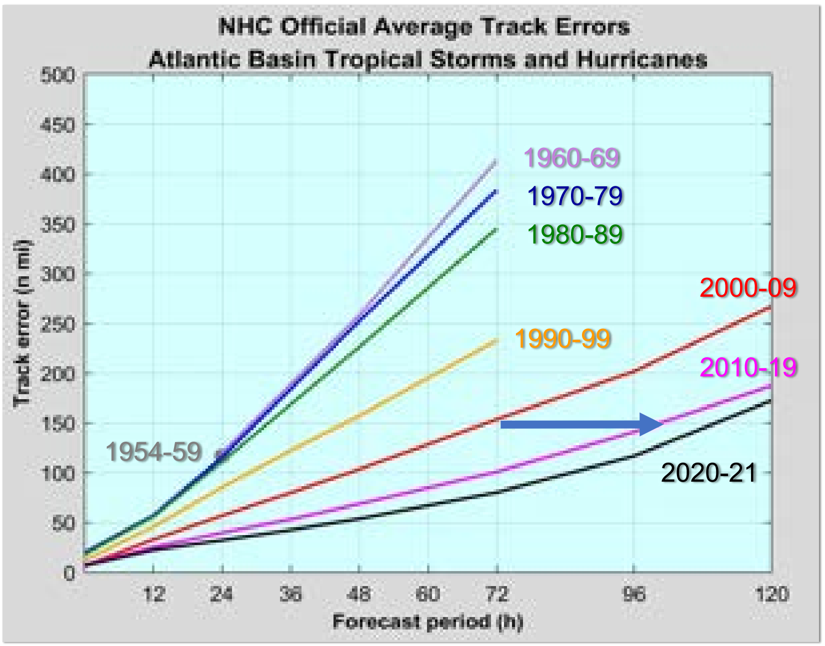
Mission

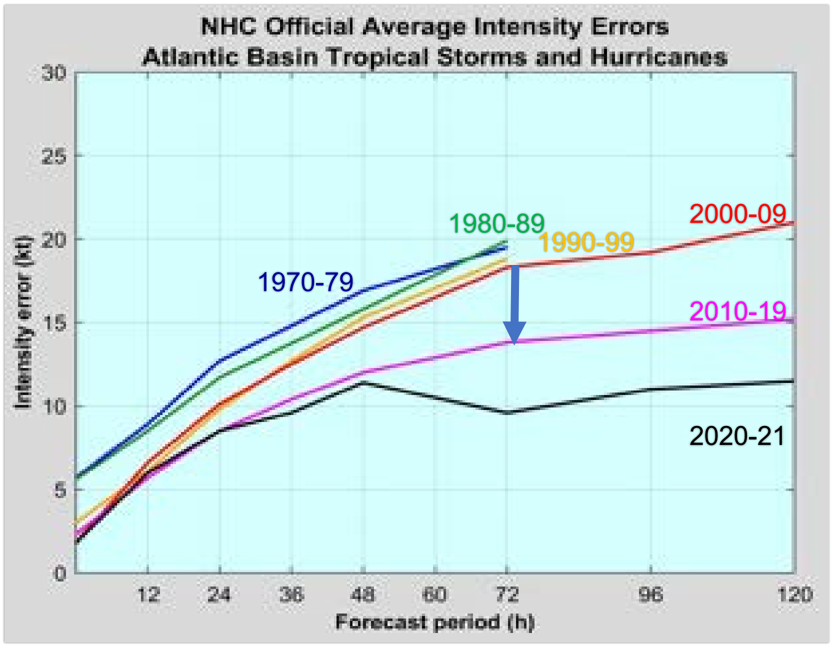
Advance understanding & prediction of tropical cyclone (TC) track, intensity, & structure change & their impacts utilizing observations, numerical models, & theory

NOAA's hurricane research focus for >65 years

Current State of the Art

Operational Forecast Performance





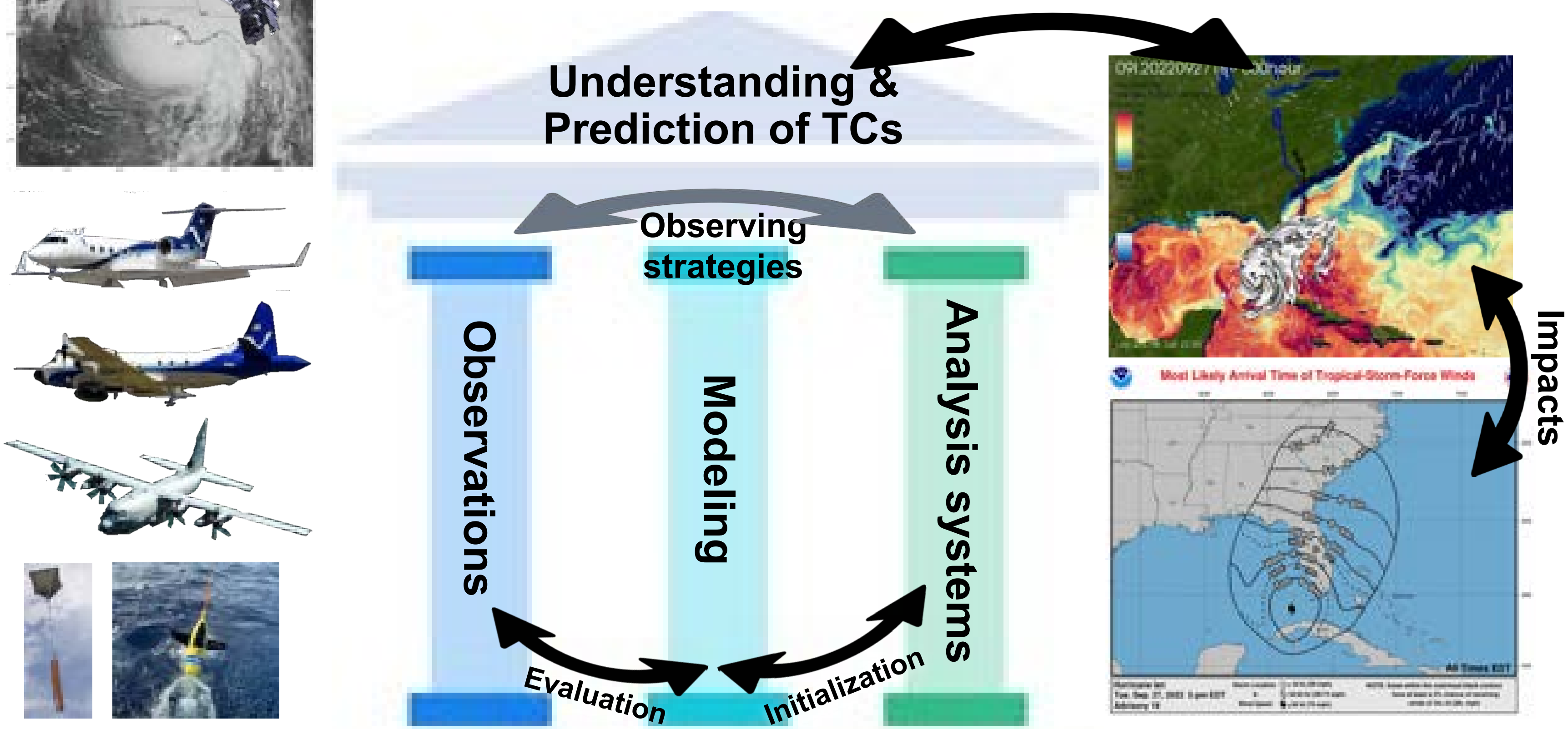
Courtesy John Cangialosi & James Franklin (NWS/NHC)

Hurricane Forecast Improvement Program

- Unified approach to guide & accelerate forecast improvements since 2009
  - improve prediction of rapid intensification & track
  - improve forecasts & communication of storm hazards
  - incorporate risk communication research to create more effective products

http://www.hfip.org

How?

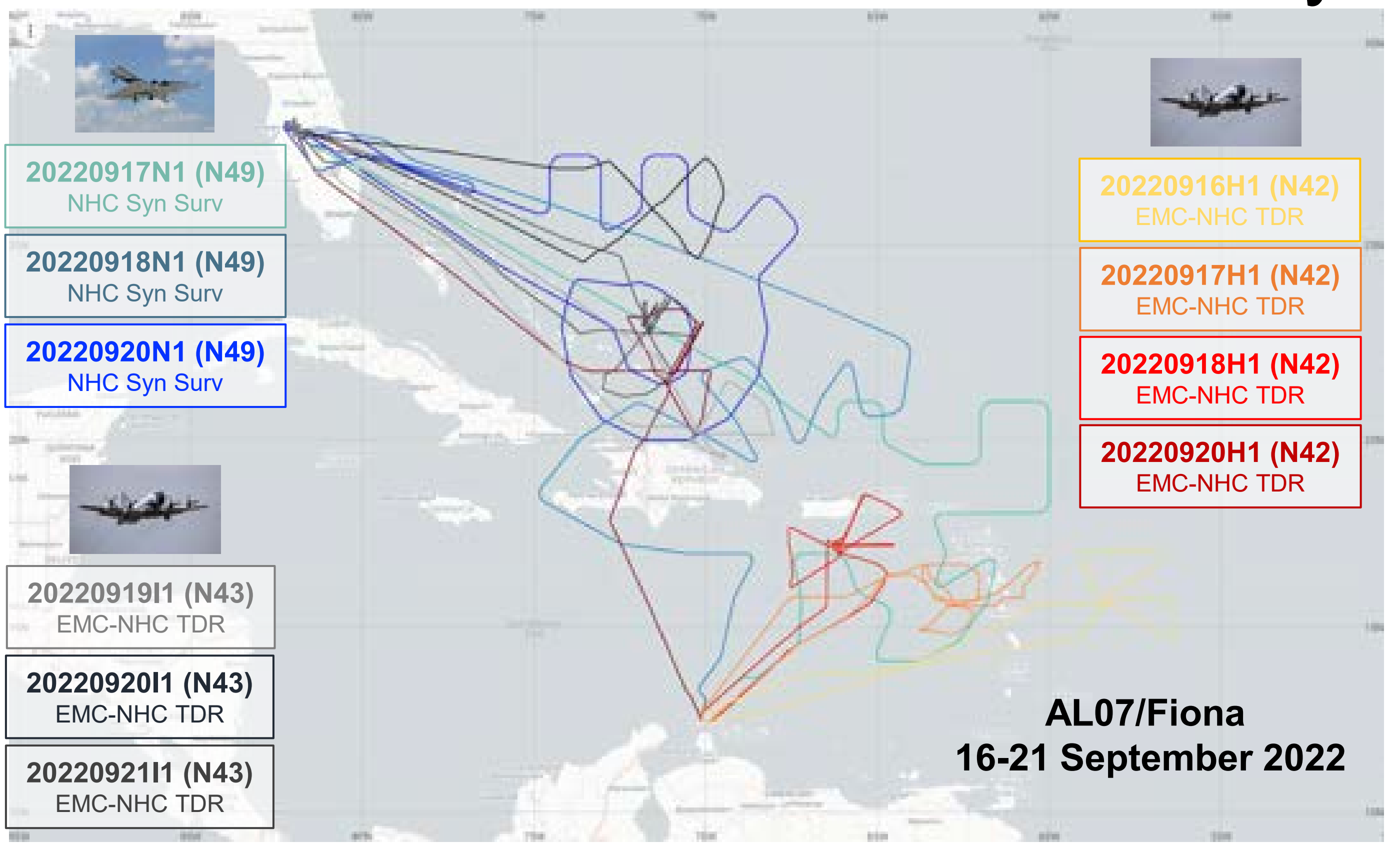

Understanding & Prediction of TCs
Observing strategies
Observations
Modeling
Analysis systems
Evaluation
Initialization
Impacts

Advancing Prediction of Hurricanes Experiment

1) Collect observations over TC's life cycle
2) Develop measurement technologies to improve situation awareness
3) Improve understanding of physical processes affecting TC formation, intensity change, structure, & associated hazards

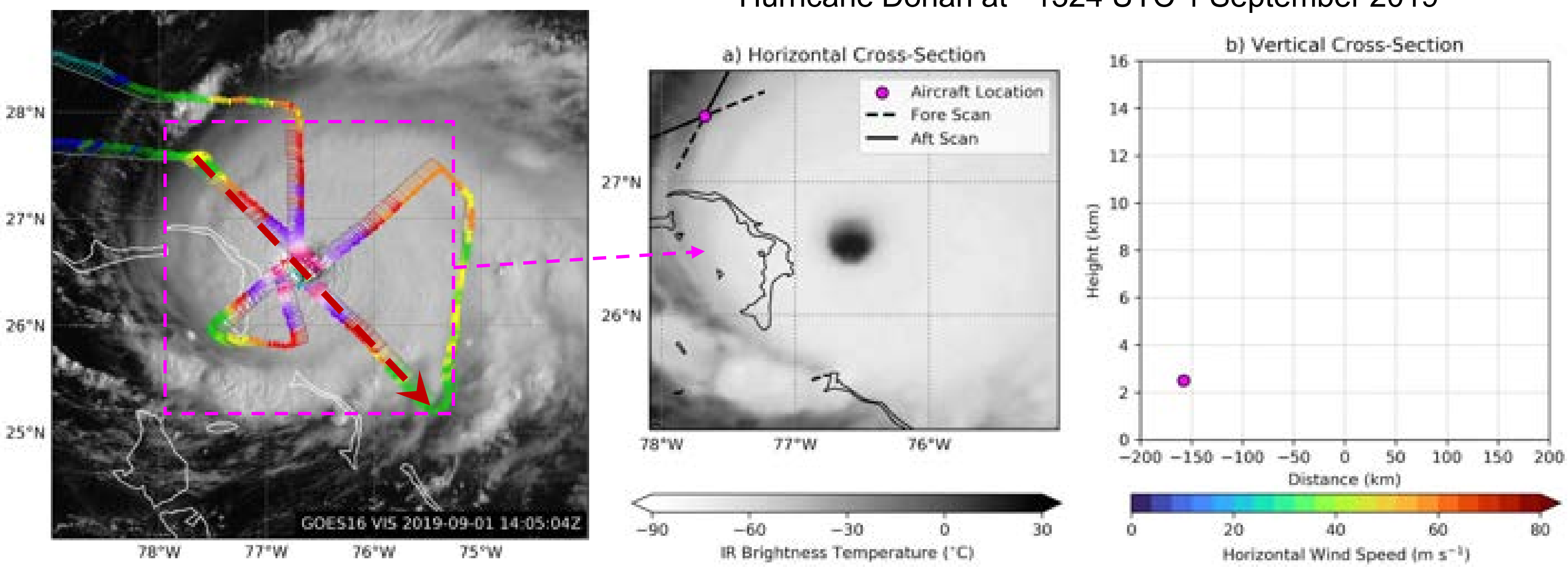
https://www.aoml.noaa.gov/2022-hurricane-field-program/

Collect Observations Over TC's Life-Cycle



Provide High-Quality Observations

Hurricane Dorian at ~1324 UTC 1 September 2019

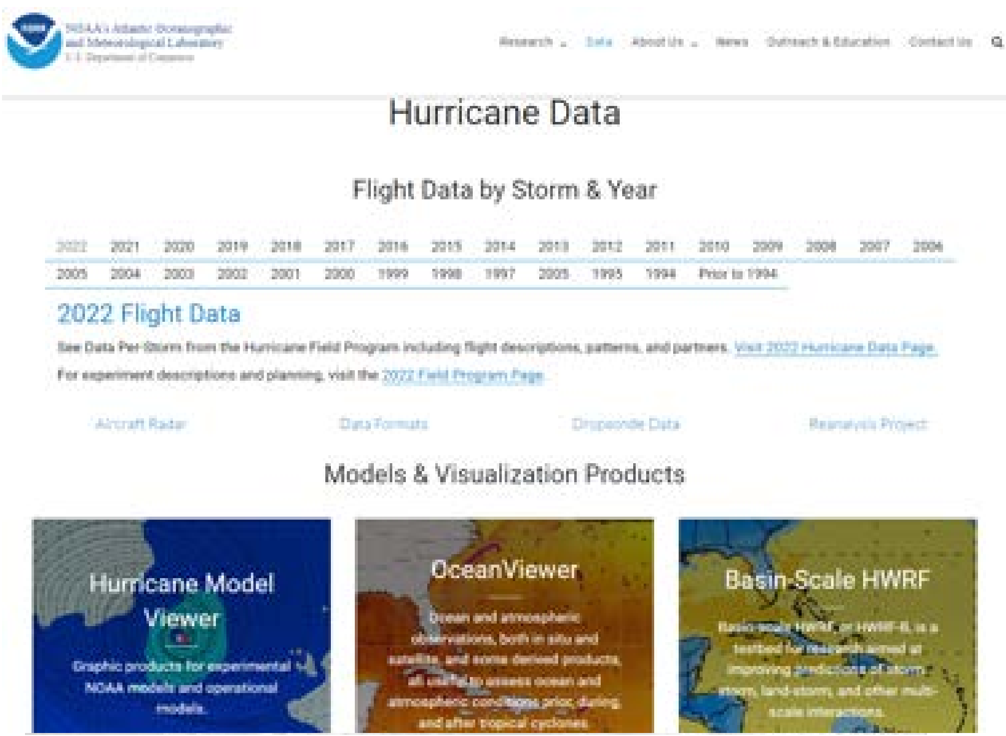


Courtesy Michael Fischer (HRD/CIMAS)

https://www.aoml.noaa.gov/hrd/Storm_pages/dorian2019/mission.html

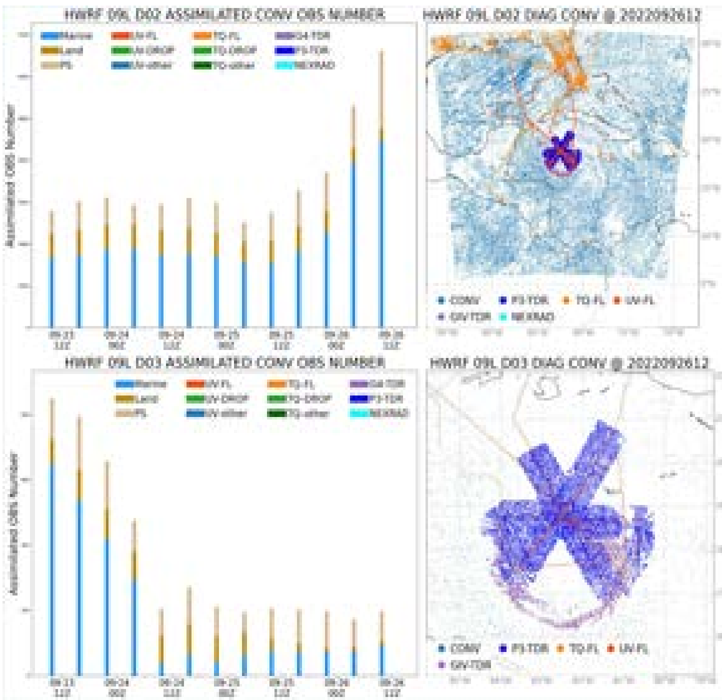
https://www.aoml.noaa.gov/dynamics-and-physics/

Initialize Hurricane Models



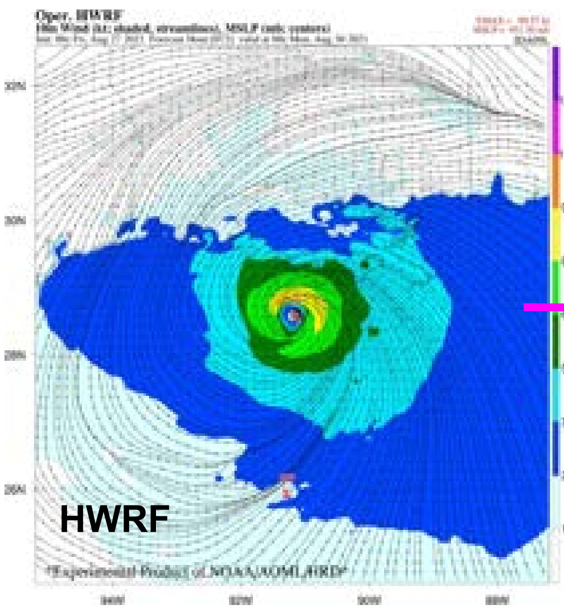
https://www.aoml.noaa.gov/data-products/#hurricanedata

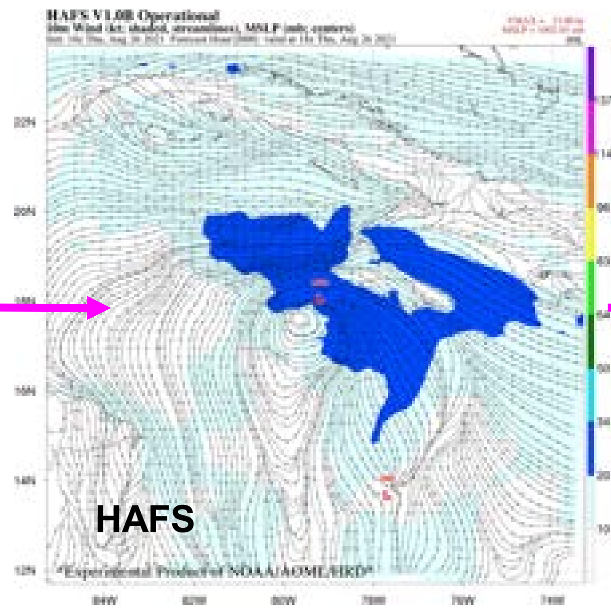
Hurricane Ian 26 September 2022

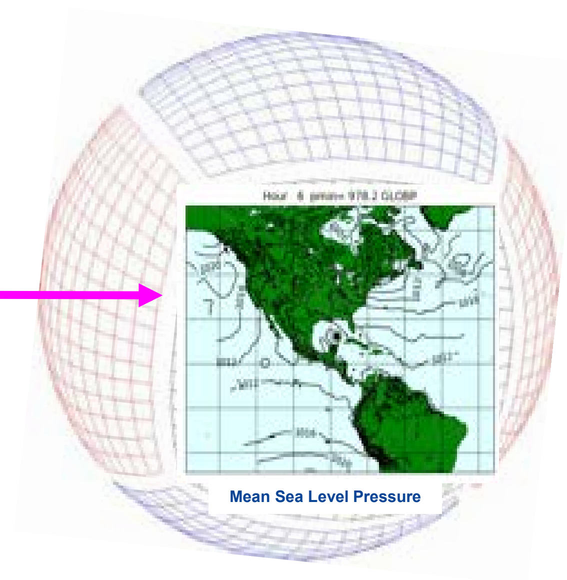


https://www.emc.ncep.noaa.gov/gc_wmb/vxt/HATCF/ Courtesy Zhan Zhang (NWS/EMC)

Advance Hurricane Forecast Guidance: HWRF->HAFS







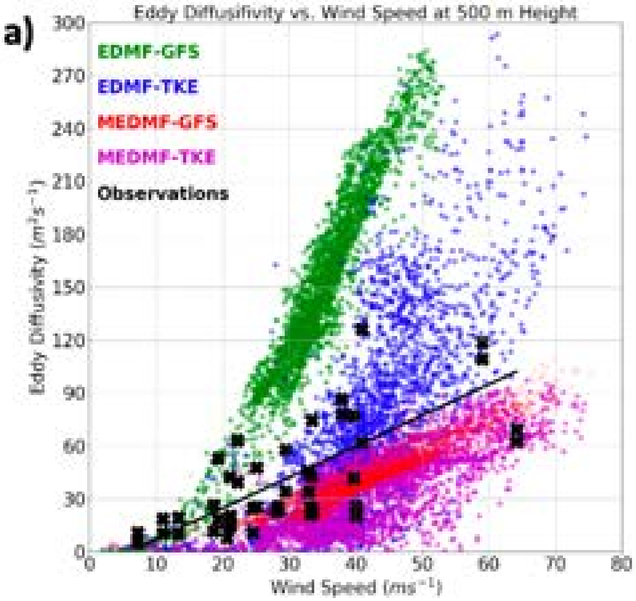
Hurricane Ida (09L) 00 UTC 27 August 2021

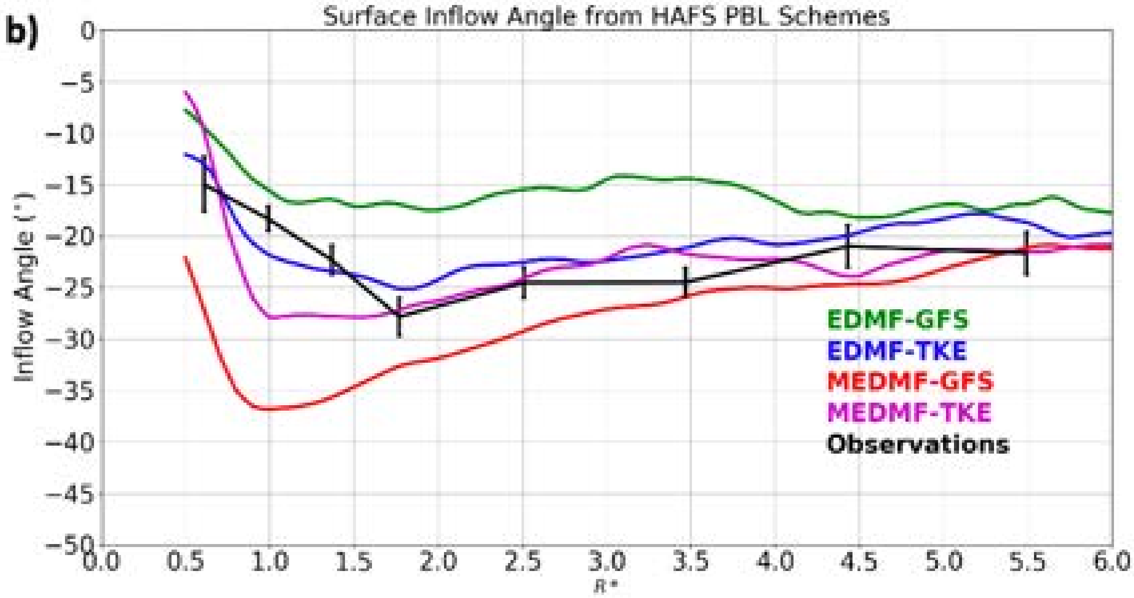
HAFS: Moving Nests in Global FV3

Courtesy Bill Ramstrom (AOML/HRD)

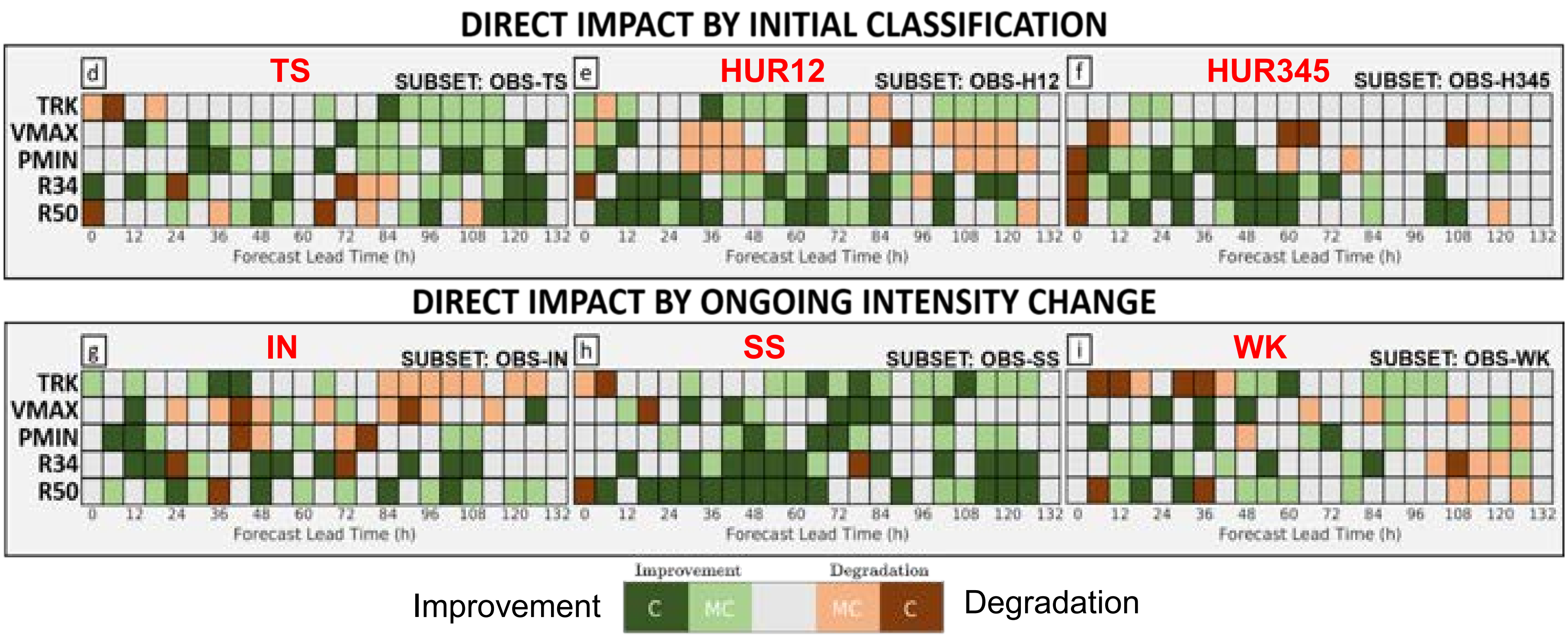
Observations-Based Model Physics

Evaluate & modify PBL & microphysics schemes based on P-3 observations & LES for improved prediction of TC structure & intensity change.





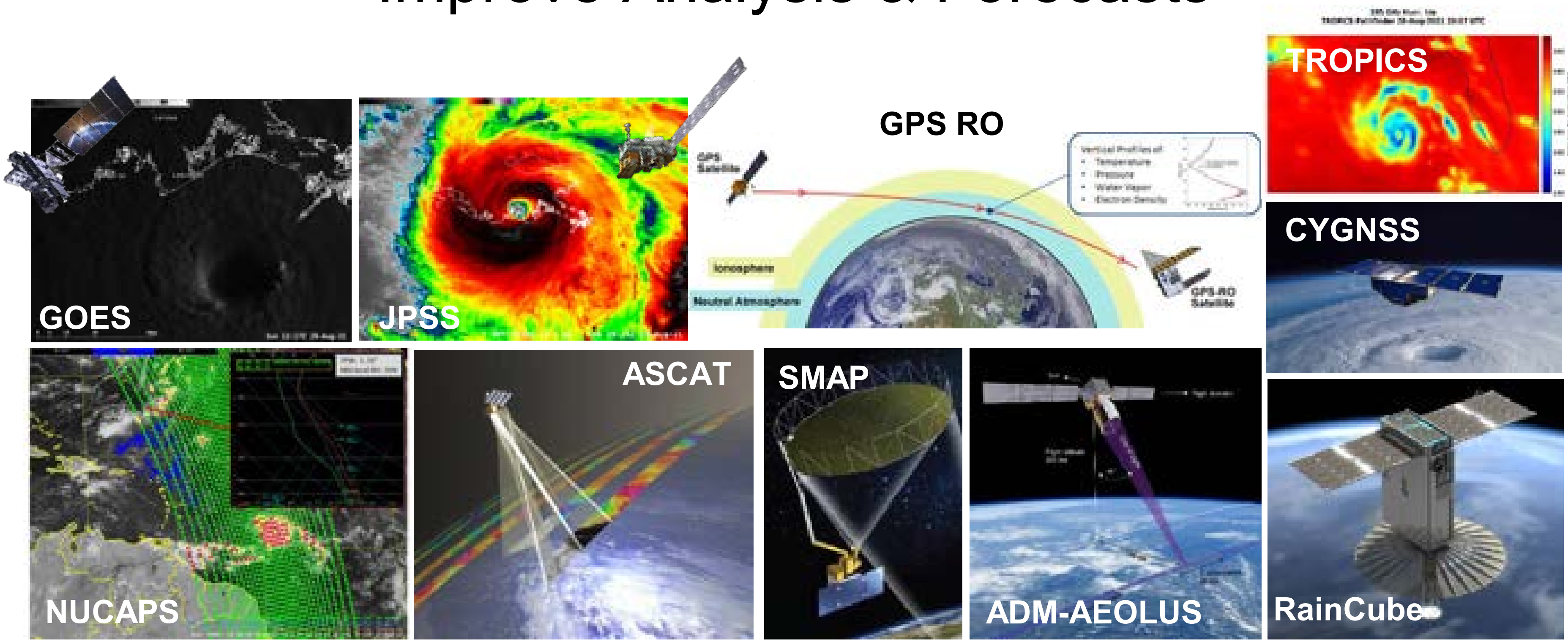
Dropsonde Impacts in HWRF



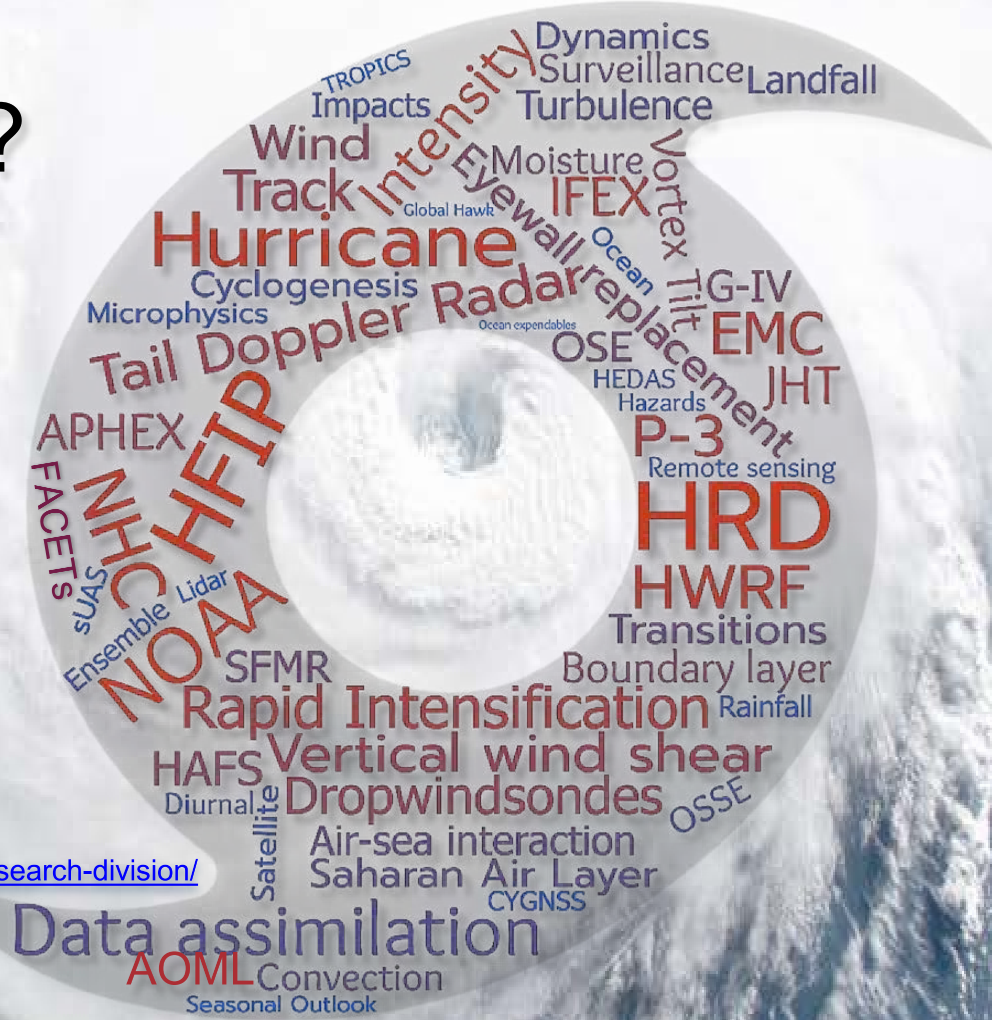
Improvement Degradation

Courtesy Sarah Ditchek & Jason Sippel (AOML/HRD)

Optimize use of Satellite Observations to Improve Analysis & Forecasts



Questions?



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http://www.hfip.org
https://noaahrd.wordpress.com/
https://www.aoml.noaa.gov/hurricane-research-division/
REDDIT AMA
Hurricanes FAQ