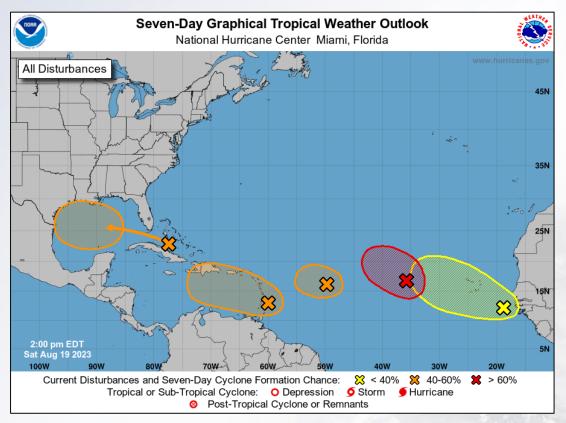
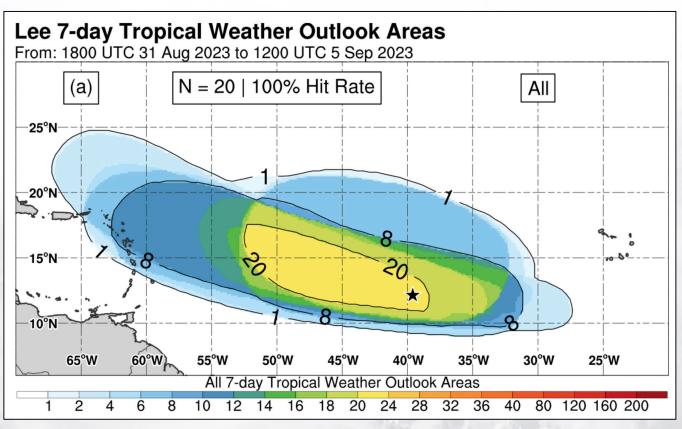


Successes & Challenges in Tropical Cyclone Genesis Forecasting in 2023



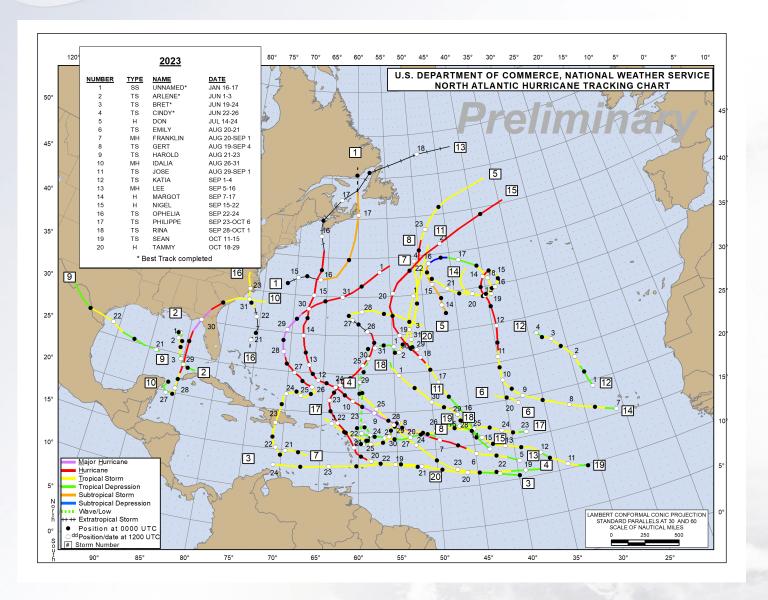




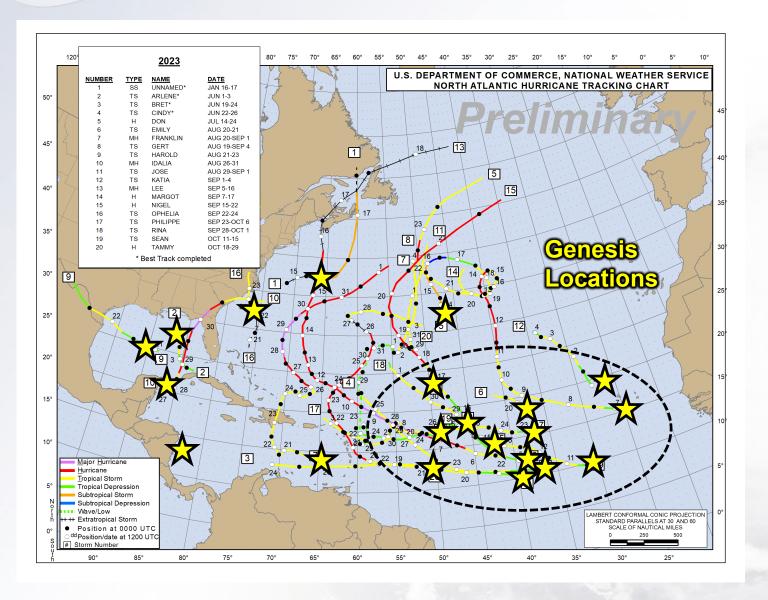
Philippe P. Papin – Hurricane Specialist National Hurricane Center



2024 National Hurricane Conference, Orlando, FL, 27 March 2024



- 20 Named Storms
- 7 Hurricanes
- 3 Major Hurricanes
- 1 Tropical Depression



- 20 Named Storms
- 7 Hurricanes
- 3 Major Hurricanes
- 1 Tropical Depression

- Big easterly wave genesis year
- Inactive Caribbean Sea

Tropical Weather Outlook Overview

Outlooks Issued May 15 – November 30 at regular intervals

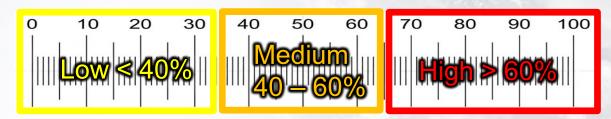
A Special Tropical Outlook can be issued at anytime for significant or unexpected changes

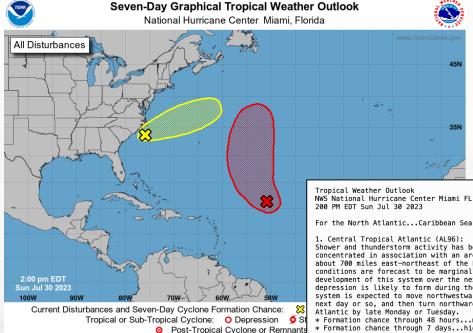
- 2 am Tropical Outlook
- 8 am Tropical Outlook
- 2 pm Tropical Outlook
- 8 pm Tropical Outlook

TIMES IN **EDT**

*2023 was the 1st year of public 7-day outlook

Text and graphic based product that provides 2-day and **7-day*** probabilistic guidance on disturbances that NHC is monitoring for potential for development





10% increments

7-day outlook area also provided

200 PM FDT Sun Jul 30 2023

For the North Atlantic...Caribbean Sea and the Gulf of Mexico:

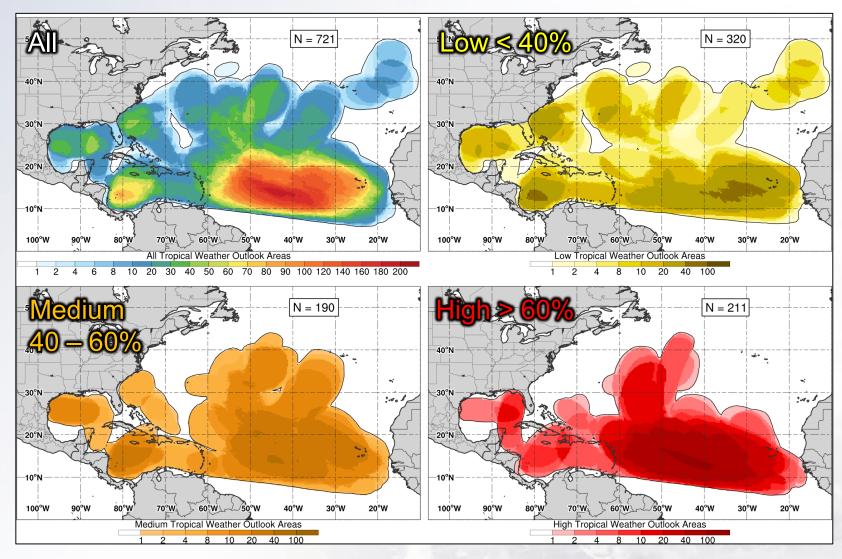
- Shower and thunderstorm activity has become a little more concentrated in association with an area of low pressure located about 700 miles east-northeast of the Leeward Islands. Environmental conditions are forecast to be marginally favorable for gradual development of this system over the next few days, and a tropical depression is likely to form during the early part of this week. The system is expected to move northwestward at about 15 mph during the next day or so, and then turn northward over the central subtropical Atlantic by late Monday or Tuesday.
- * Formation chance through 48 hours...medium...50 percent.
- * Formation chance through 7 days...high...70 percent.

Shower and thunderstorm activity is showing some signs of organization in association with a trough of low pressure located about 100 miles southeast of Morehead City, North Carolina. Environmental conditions appear generally favorable for some additional development over the next day or so as the system gradually accelerates east-northeastward into the northwestern Atlantic Ocean. Afterwards, this system is likely to merge with a

- * Formation chance through 48 hours...low...30 percent.
- * Formation chance through 7 days...low...30 percent.

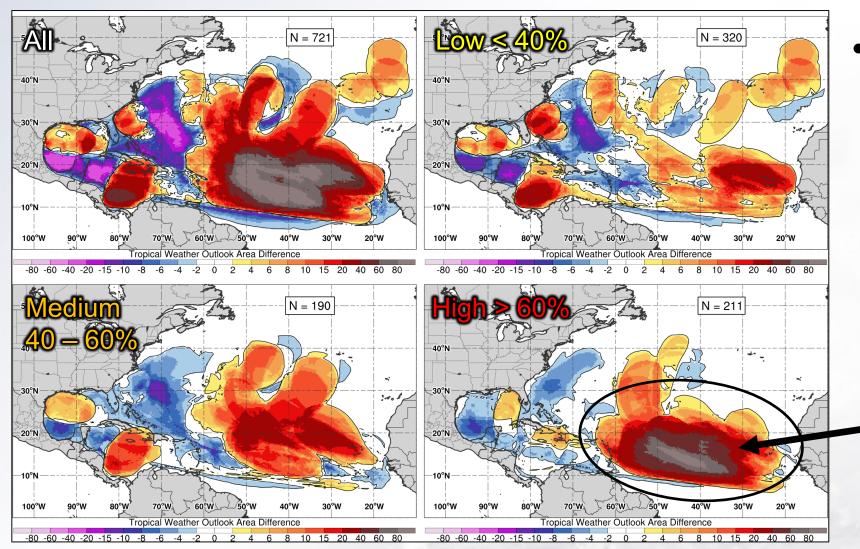
Forecaster Papir

2023



721 Outlook Areas

2023 Outlook Difference vs Prior Years

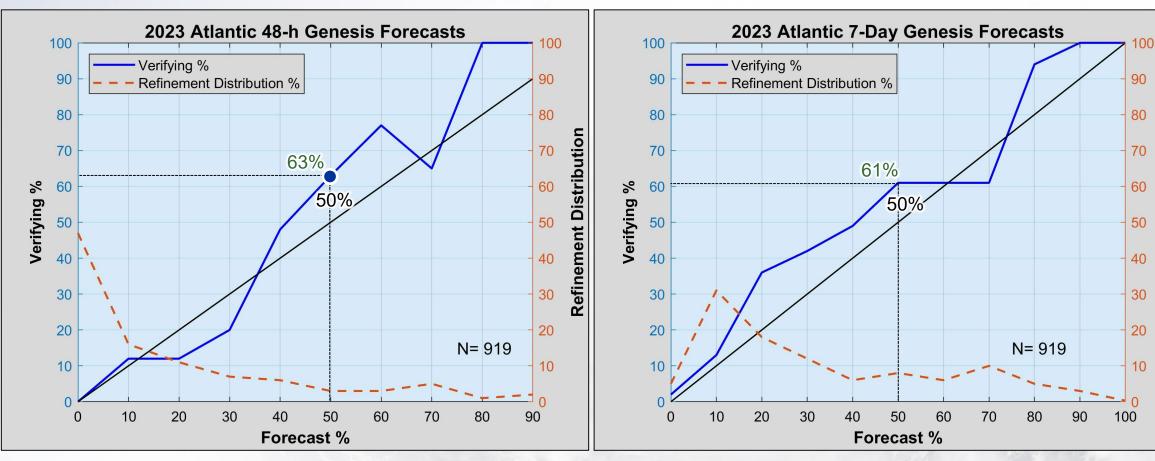


721 Outlook Areas

2023 outlook areas compared prior years

Primary region of enhanced high outlooks was in eastern Main Development Region (10–20N / 20–60W)

2-day 7-day

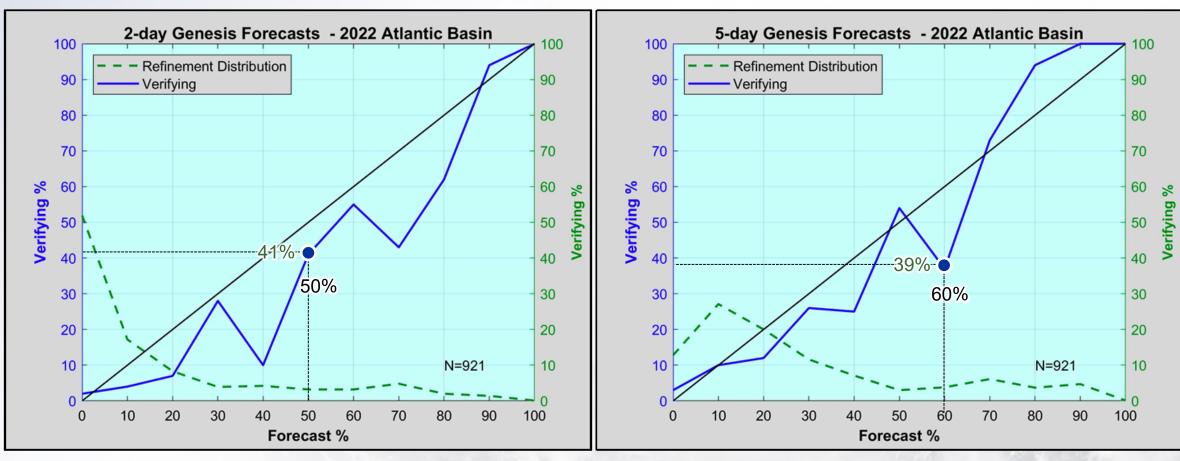


Refinement Distribution

TWO genesis probabilities in 2023 were well calibrated, with a bit of a low bias overall

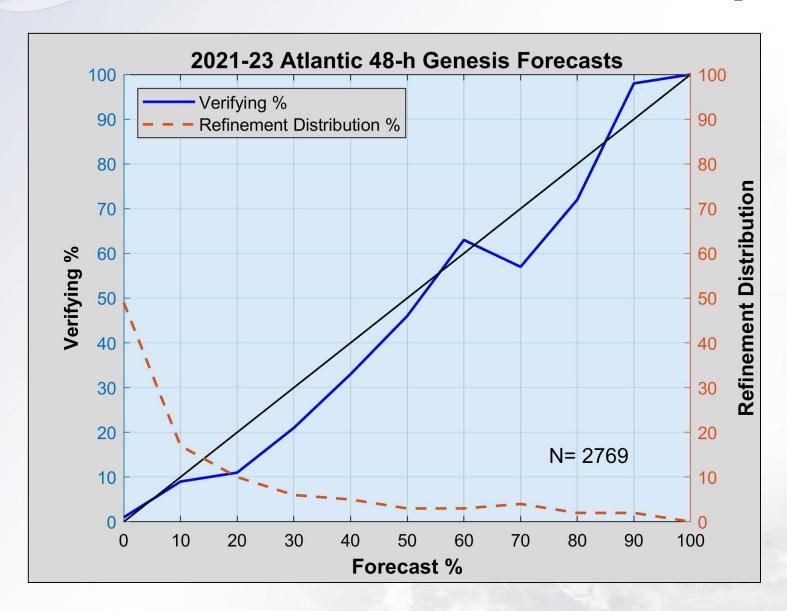
Compare to Last Year - 2022

2-day 7-day



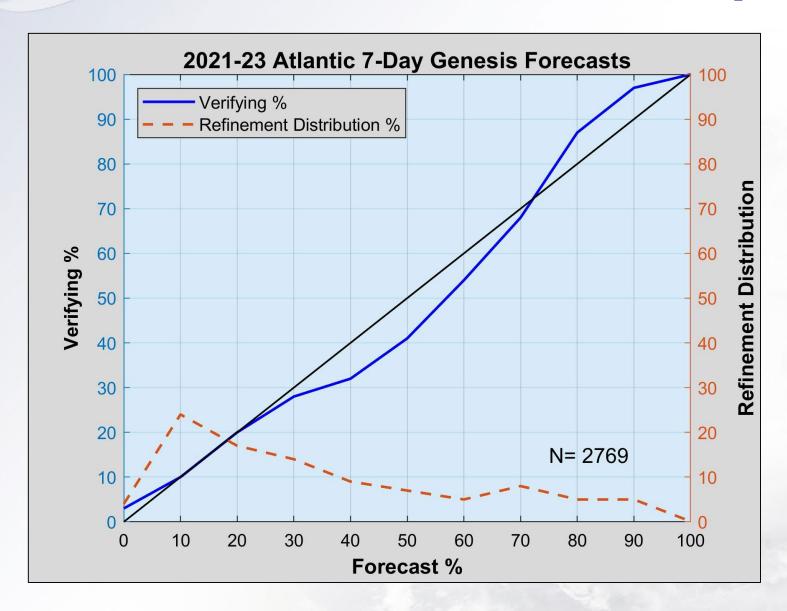
Opposite story last year, where we had a notable high bias in our forecast probabilities

2021–2023 Comparison



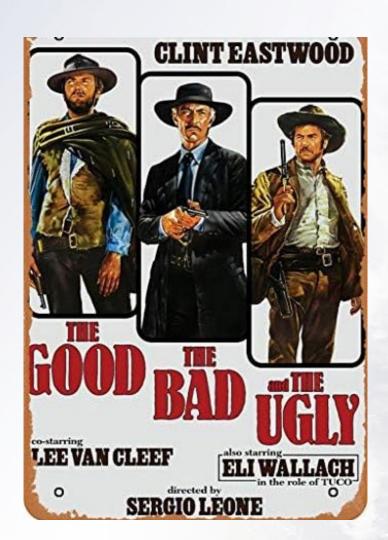
- 3-yr sample helps to smooth out yearly 10% probability bins.
- Over a longer sample, the TWO probabilities come close to the 1:1 line

2021–2023 Comparison

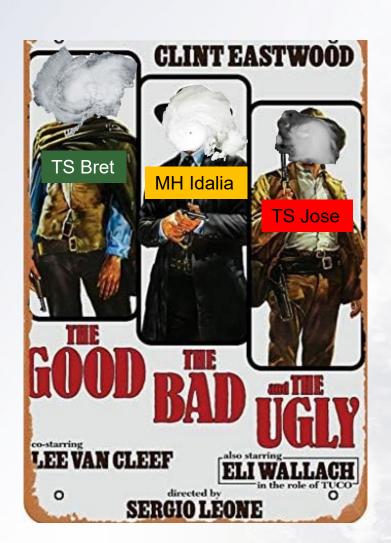


- 3-yr sample helps to smooth out yearly 10% probability bins.
- Over a longer sample, the TWO probabilities come close to the 1:1 line

Individual Cases The Good, The Bad, The Ugly of 2023



Individual Cases The Good, The Bad, The Ugly of 2023



 Good: 7-day outlooks allowed us to achieve significant lead time for developing easterly waves, even early in the season (TS Bret, MH Lee, HU Tammy)

 Bad: Struggled with both developing and non developing areas in the Caribbean Sea & off Eastern US coast (MH Idalia, TS Ophelia, Invest 97L)

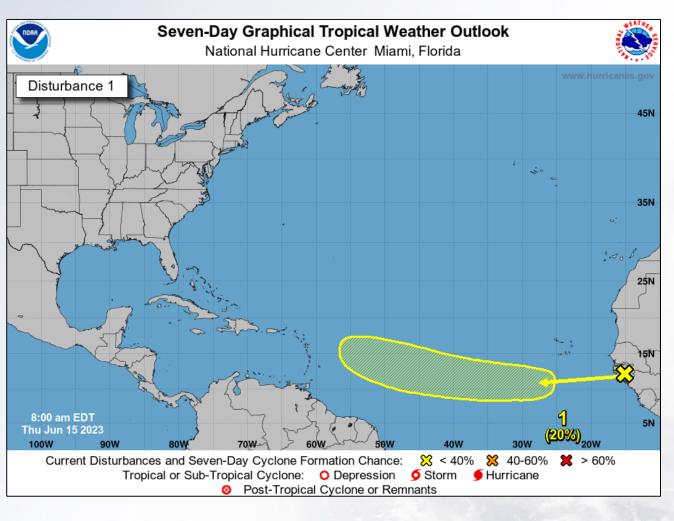
 Ugly: Five Areas at Once in Late August & The two-way miss with TS Jose

Genesis Success

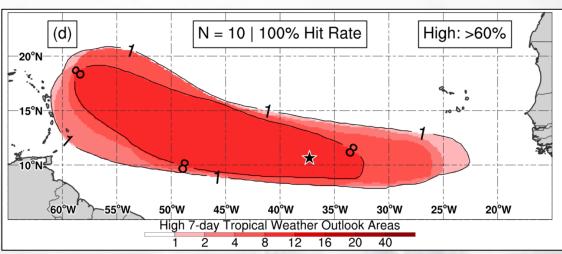
- A tropical cyclone develops at around the correct time frame forecasted from the tropical weather outlook.
- The location of development occurs in the given location that was highlighted in the tropical weather outlook.

The Good

Tropical Storm Bret

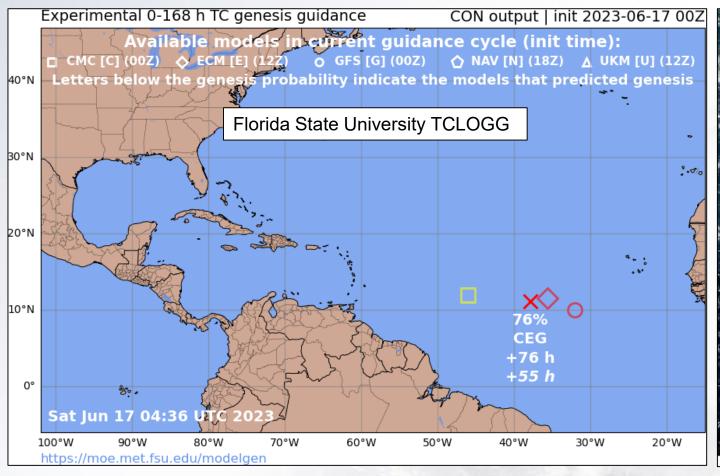


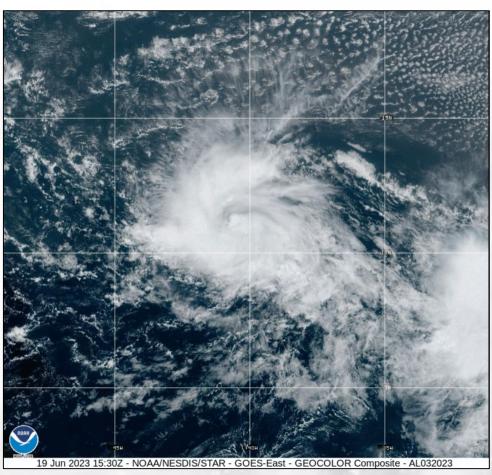
- Very early season development from an Easterly Wave
- First mentioned 90 hours before development (1200 UTC 15 June)
- Quickly raised to high category less than 2 days later (0000 UTC 17 June)



Tropical Storm Bret

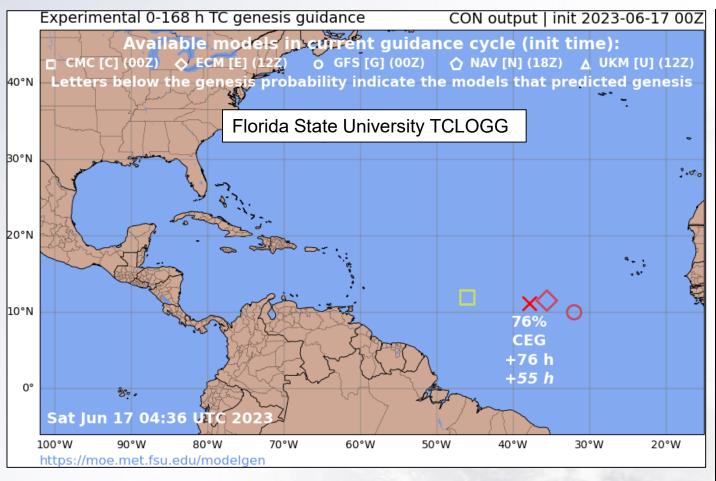
- Guidance very helpful for forecasters to realize atypical event was increasingly likely
- In mid-June, Sea-surface temperatures were already near record highs in the Main Development Region (MDR)

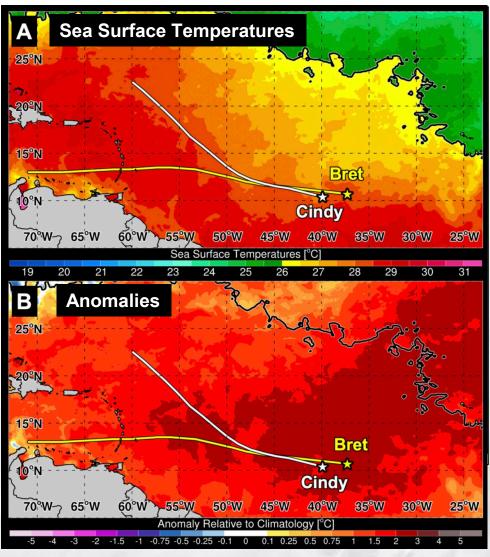




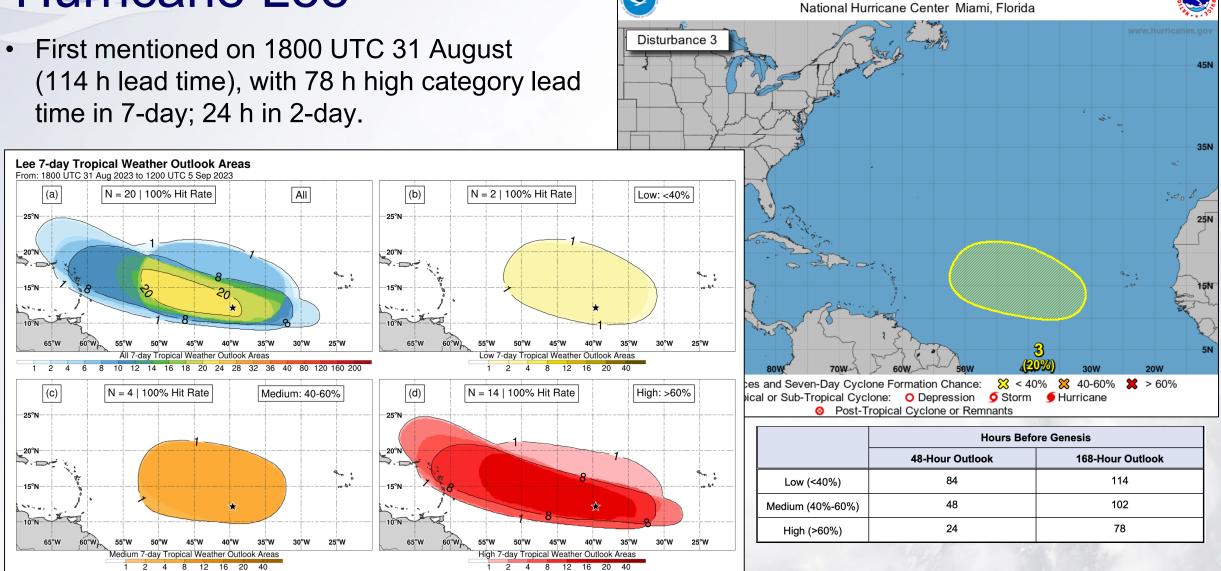
Tropical Storm Bret

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Hurricane Lee

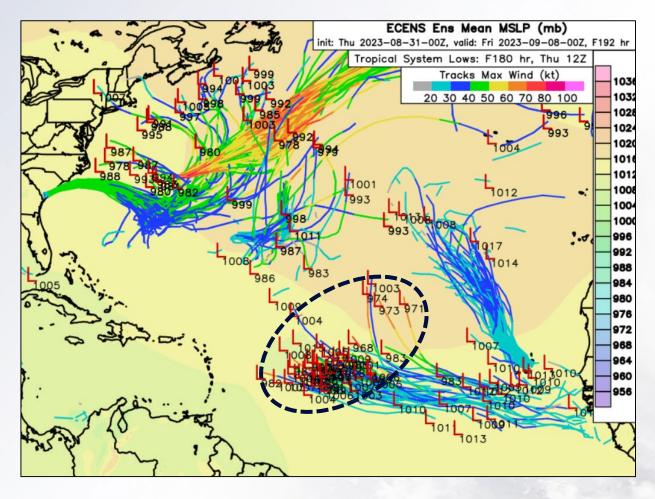


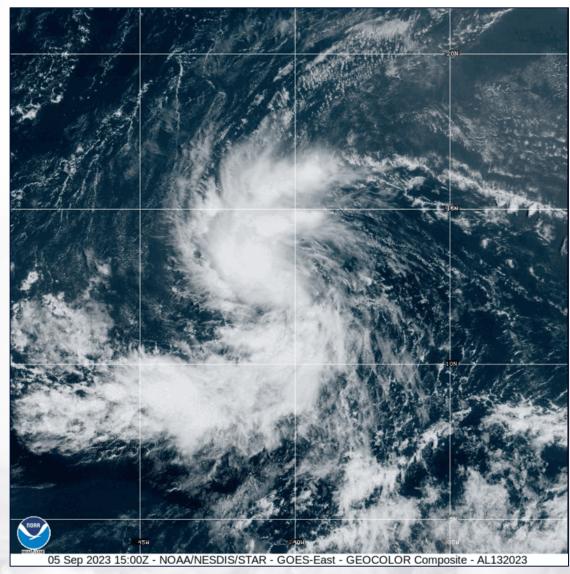
Seven-Day Graphical Tropical Weather Outlook

All outlooks captured the correct location of genesis

Hurricane Lee

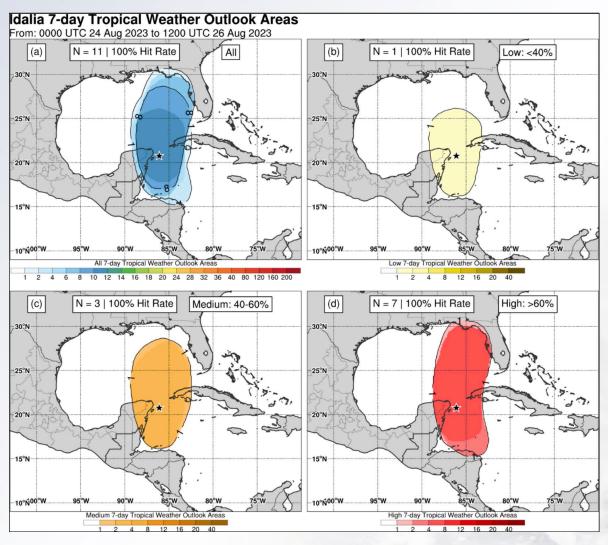
 Ensemble guidance highlighted development in the Central Atlantic of a significant TC.



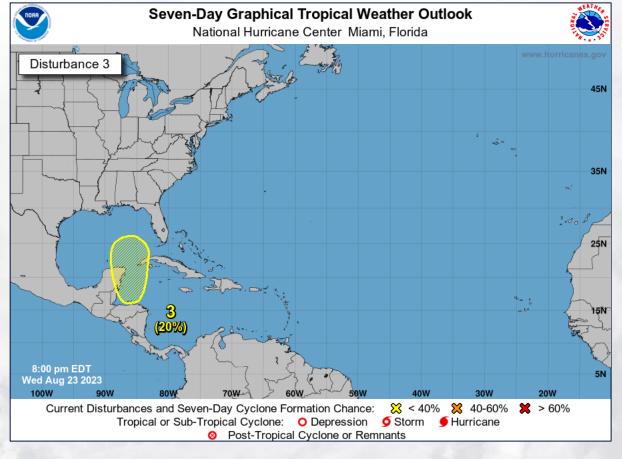


The Bad

Hurricane Idalia

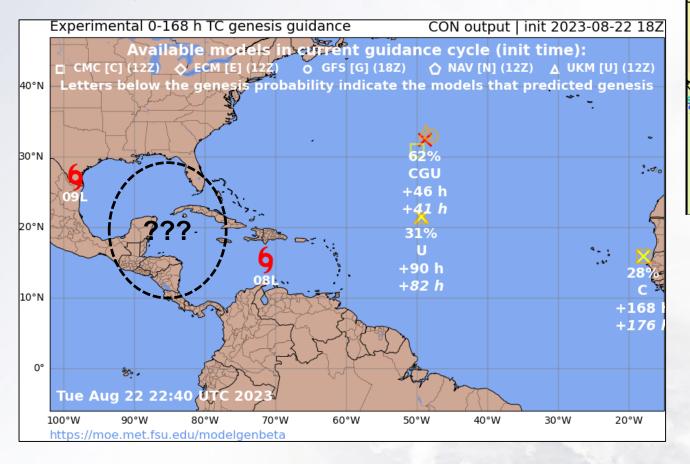


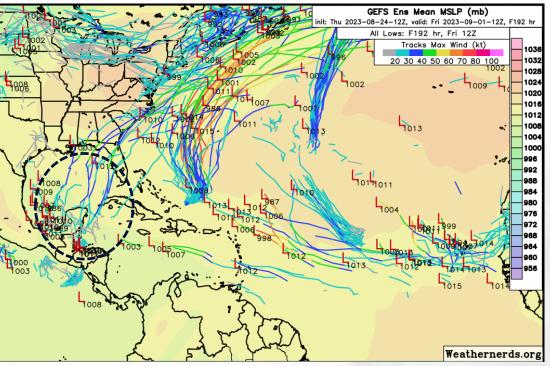
 Despite its excellent post-TC forecasts, the disturbance that resulted in Idalia's formation was only picked up about 2.5 days before development



Hurricane Idalia

 Objective guidance did not show evidence of a system with development chances before 23 August

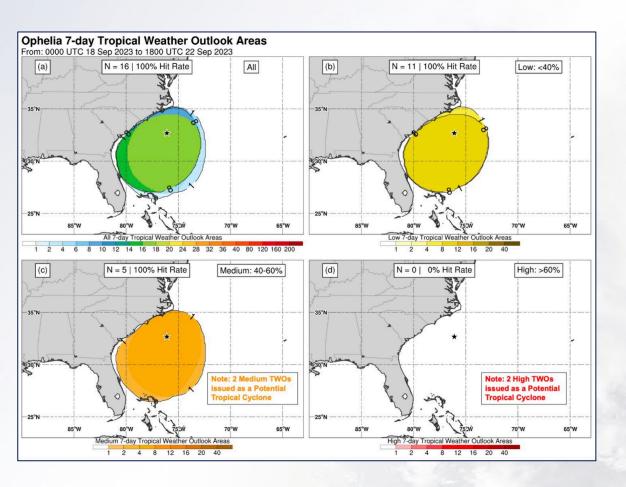


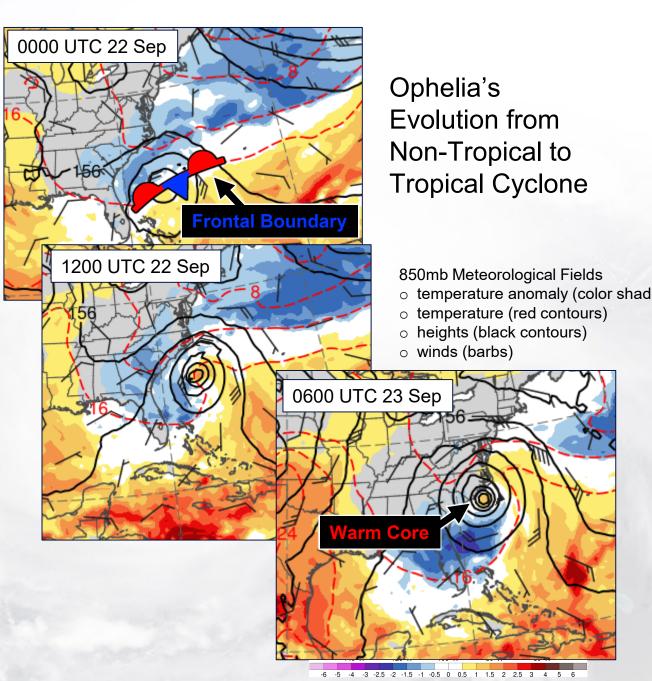


- Development signal for a system in the NW Caribbean was weak in the GFS and its ensemble
- Unusual given its typical bias

Tropical Storm Ophelia

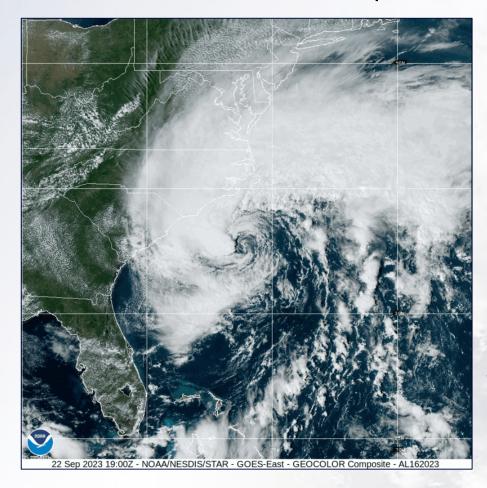
- Uncertainty about the structure prior to formation
- Genesis lead time was lower as a result
- Potential Tropical Cyclone advisories were initiated on 1500 UTC 21 September

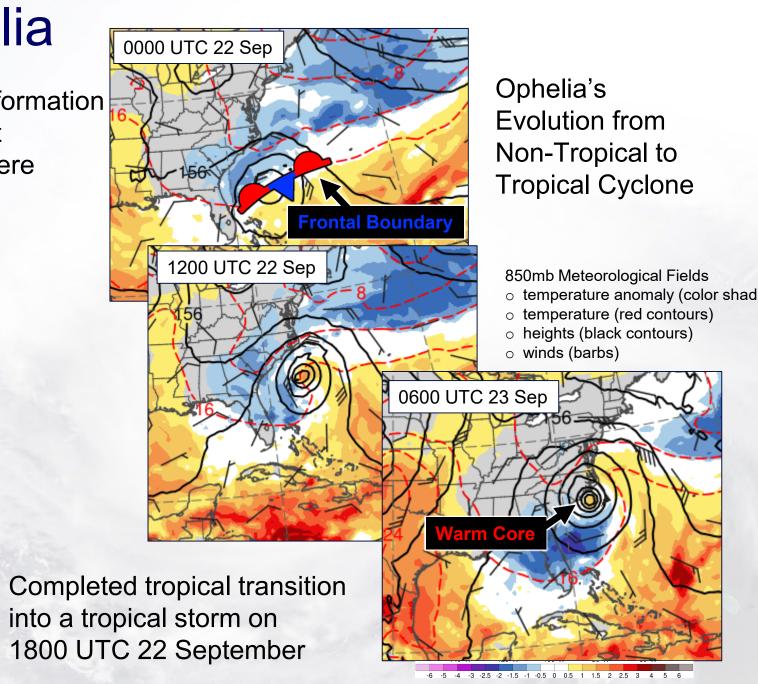




Tropical Storm Ophelia

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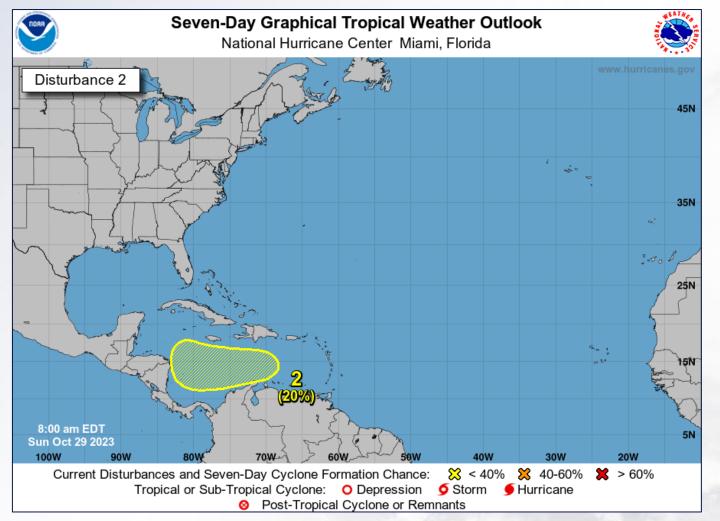


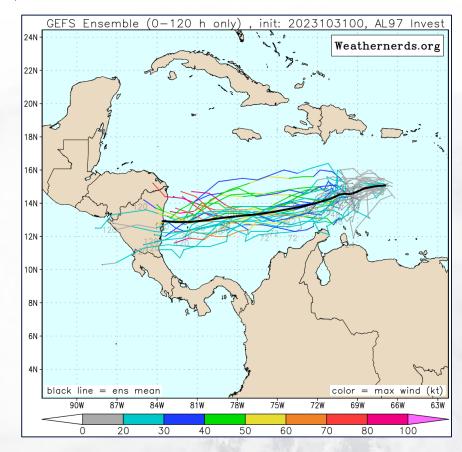


Invest 97L

Broad area of low pressure formed in the eastern Caribbean, but could not consolidate

before it moved inland into Central America



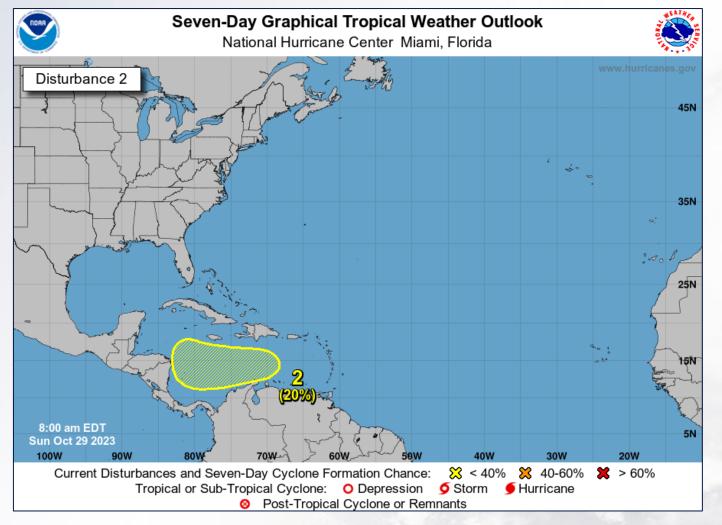


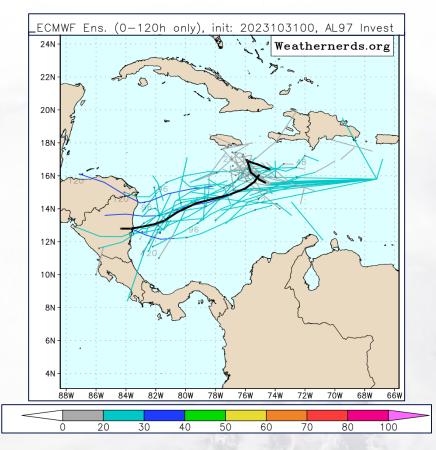
- GFS and its ensemble guidance was too aggressive with development
- ECMWF and its ensembles more realistic

Invest 97L

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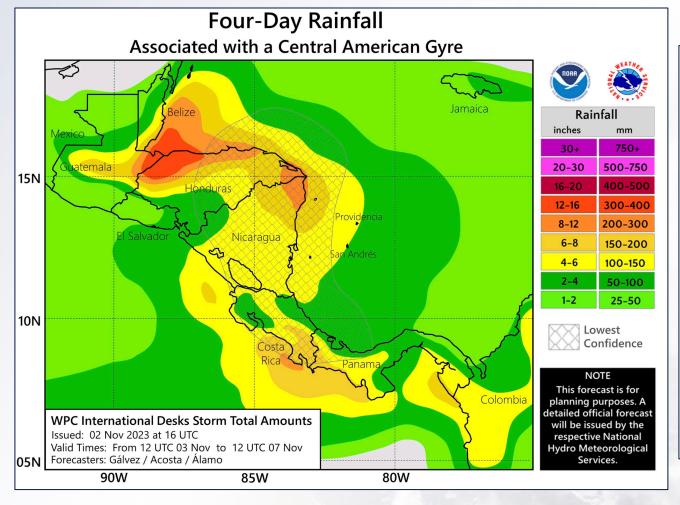


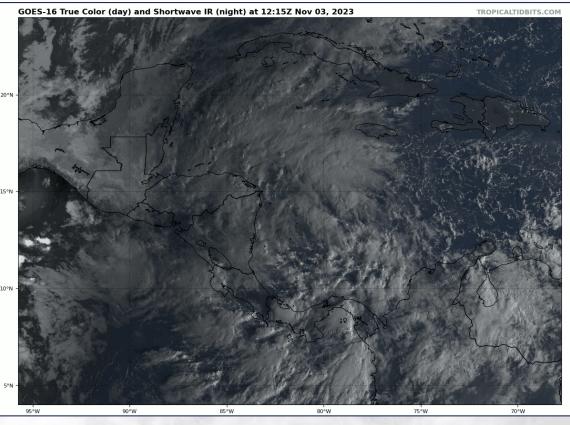


- GFS and its ensemble guidance was too aggressive with development
- ECMWF and its ensembles more realistic

Invest 97L

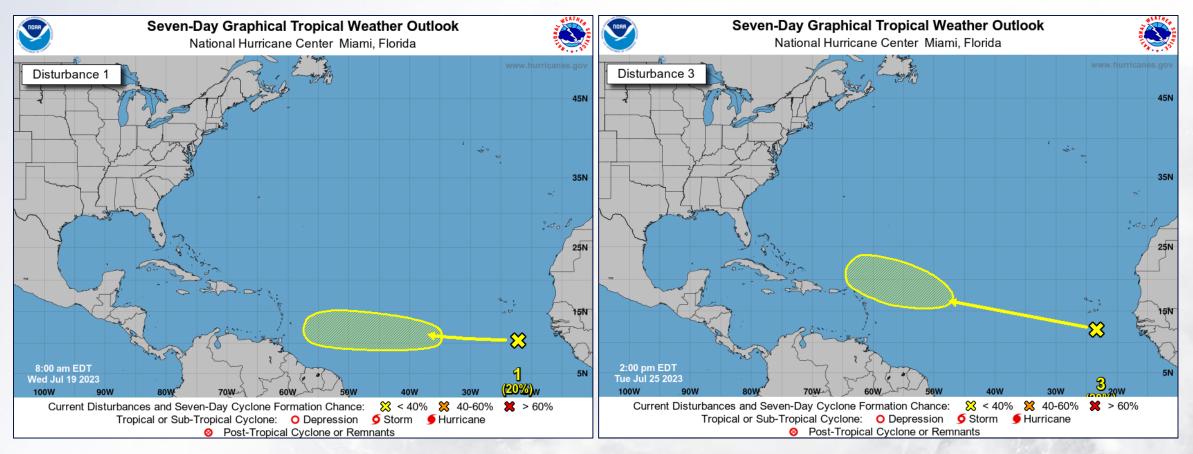
 Despite not becoming a tropical cyclone, the broad disturbance produced significant heavy rainfall over Central America.





A Couple of False Alarms in July/August

Invest 95L Invest 96L

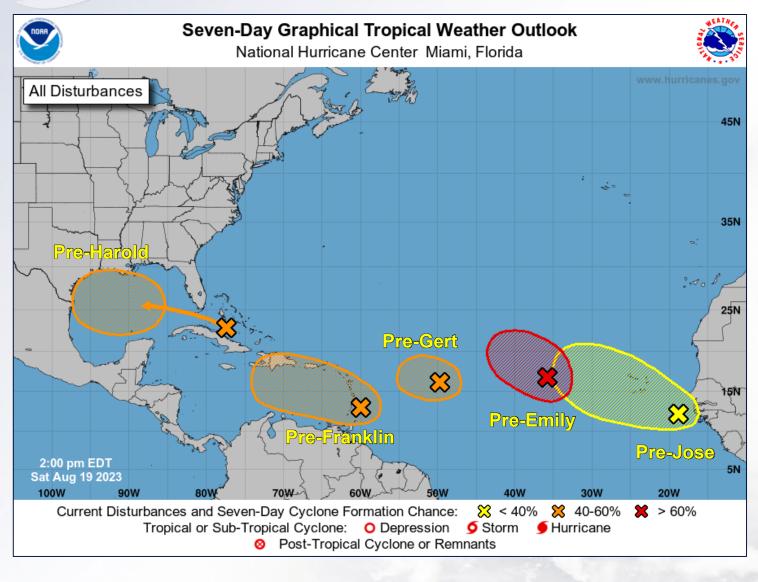


95L Failed to develop due to widespread dry air in its environment

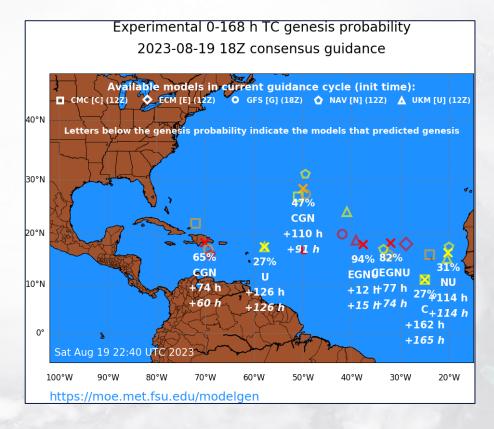
96L encountered significant shear as it began to move northward

The Ugly

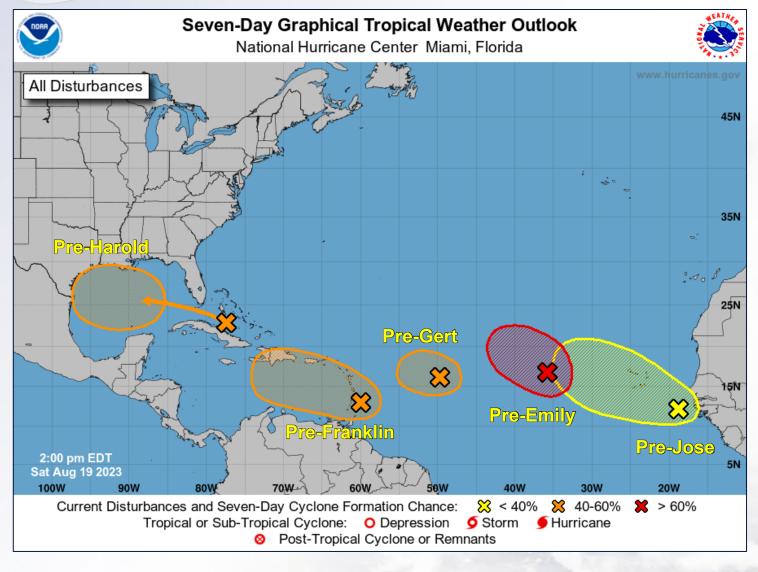
19 August 2023 - Busy Day!



- Five different genesis areas issued on 1800 UTC 19 August
- All went on to become tropical cyclones (Emily, Franklin, Gert, Harold, Jose)



19 August 2023 - Busy Day!



Five diffe 1800 UT(

All went (Emily, F



Tropical Weather Outlook NWS National Hurricane Center Miami FL 200 PM EDT Sat Aug 19 2023

For the North Atlantic...Caribbean Sea and the Gulf of Mexico:

1. Eastern Tropical Atlantic (AL98):

Shower and thunderstorm activity continues in association with a broad area of low pressure located several hundred miles west of the Cabo Verde Islands. Environmental conditions appear generally favorable for further development of this system, and a short-lived tropical depression is likely to form this weekend while it moves west-northwestward or northwestward at about 10 mph across the eastern tropical Atlantic. By early next week, upper-level winds over the system are forecast to increase, and further development is

- * Formation chance through 48 hours...high...70 percent.
- * Formation chance through 7 days...high...70 percent.

2. Central Tropical Atlantic (AL99):

An area of low pressure located roughly halfway between the Cabo Verde Islands and the Lesser Antilles is producing disorganized showers and thunderstorms east of the center. While environmental conditions are only marginally conducive, a short-lived tropical depression could form in the next day or so while the system moves west-northwestward at 10 to 15 mph across the tropical Atlantic. After that time, additional development is not anticipated since upper-level winds are expected to become increasingly unfavorable.

- * Formation chance through 48 hours...medium...50 percent. * Formation chance through 7 days...medium...50 percent.

3. Near the Windward Islands (AL90):

A broad area of low pressure has formed near the Windward Islands, shower and thunderstorm activity has become better organized since yesterday. Some additional development of this system is likely and a tropical depression could form by early next week while this system moves westward to west-northwestward at 10 to 15 mph, across the Lesser Antilles and over the eastern and central Caribbean Sea. Regardless of development, heavy rainfall is possible over portions of the Windward Islands during the next couple of days. Interests in the eastern and central Caribbean should monitor the progress of

- * Formation chance through 48 hours...medium...40 percent.
- * Formation chance through 7 days...medium...60 percent.

4. Western Gulf of Mexico:

An area of disturbed weather located near the northwestern and central Bahamas is expected to move into the Gulf of Mexico by early next week, where a broad area of low pressure is expected to form. Some slow development of this system is possible thereafter, and a tropical depression could form as it moves westward and approaches the western Gulf of Mexico coastline by the middle of next week.

- * Formation chance through 48 hours...low...10 percent.
- * Formation chance through 7 days...medium...50 percent.

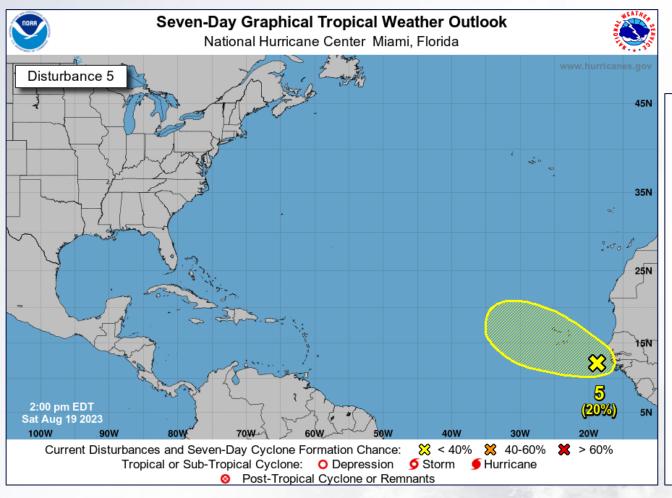
5. Near the coast of Africa:

A tropical wave located near the western coast of Africa is producing a large area of disorganized showers and thunderstorms. Some slow development is possible while it moves generally west-northwestward across the tropical eastern Atlantic during the next several days.

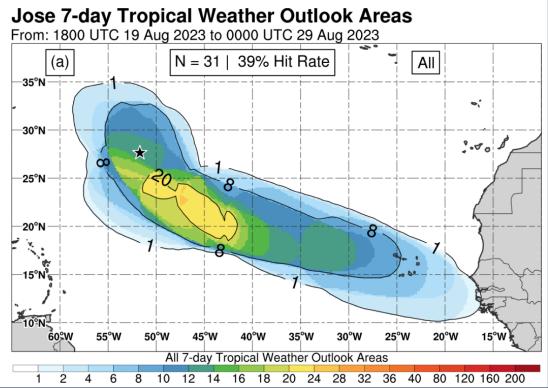
- * Formation chance through 48 hours...low...near 0 percent. * Formation chance through 7 days...low...20 percent.

Forecaster Bucci/Papin/Cangialosi/Brennan

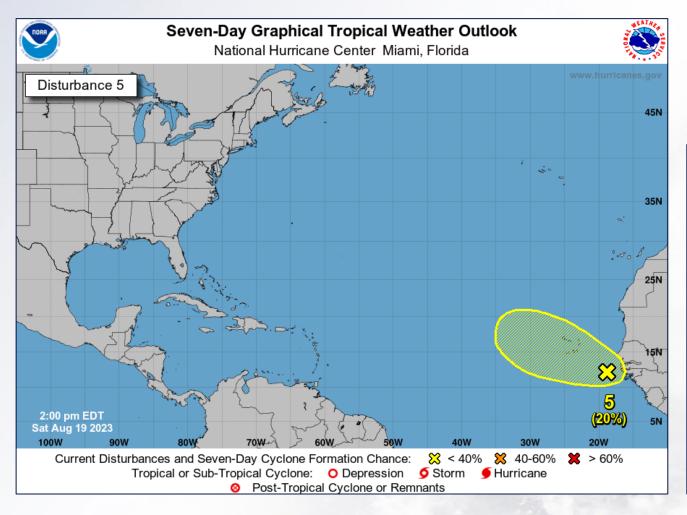
The final outlook area discussed that day ended up as the most challenging



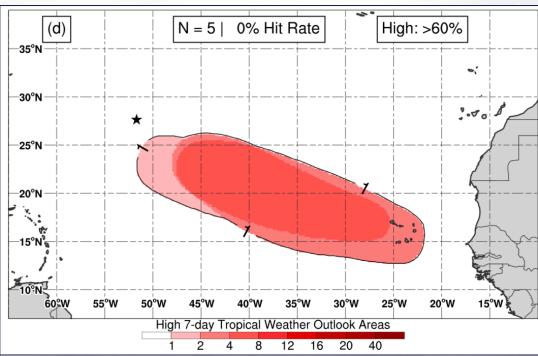
 Only ~40% of all outlooks issued captured the correct location of genesis



The final outlook area discussed that day ended up as the most challenging

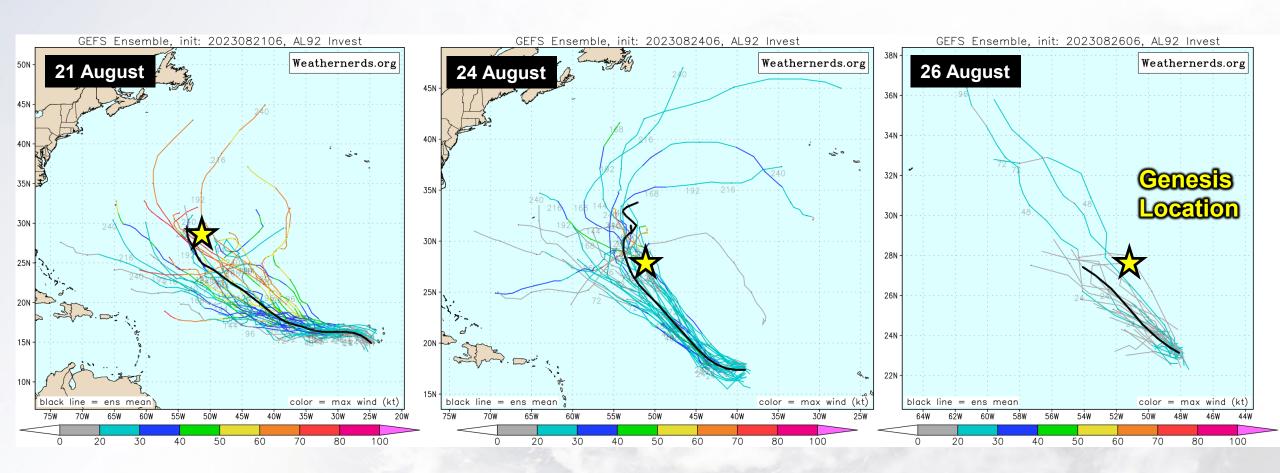


- Only ~40% of all outlooks issued captured the correct location of genesis
- And zero of the high category outlooks!



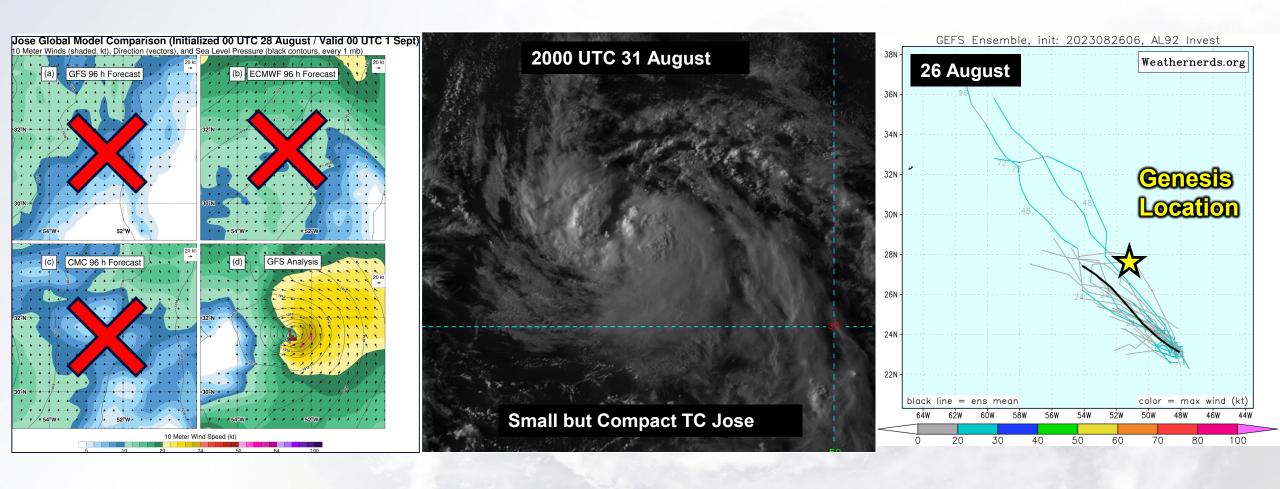
What happened?

 Model guidance, which started out agressive gradually waned, with even the most aggressive model (GFS) no longer showing development by 26 August



What happened?

 Model guidance, which started out aggressive gradually waned, with even the most aggressive model (GFS) no longer showing development by 26 August



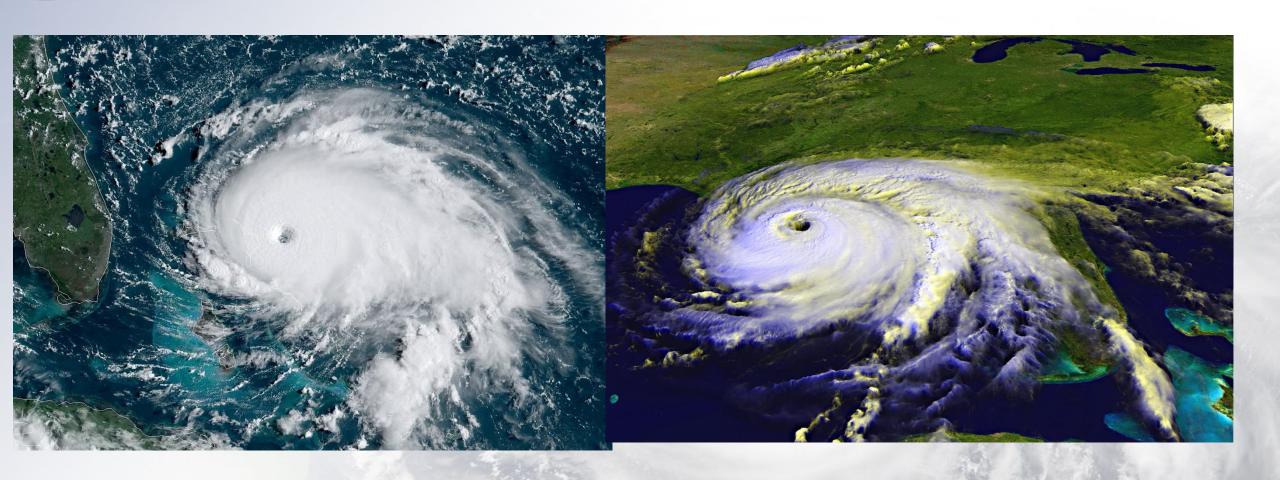
Summary

- Tropical cyclone activity above average in 2023 for named storms
- Many genesis events from tropical waves in the eastern Atlantic MDR
- Good genesis lead time & placement for many cases
- Despite excellent Idalia forecasts after it became a TC, prior genesis was more challenging (short lead time)
- Some false alarms (95L, 96L, 97L) with other short leads (Ophelia)
- Jose most difficult genesis case of the year (both too high & low)



Questions?

Rapid Strengthening: Can We Predict It?





John Cangialosi National Hurricane Center

What is Rapid Intensification

An increase in a tropical cyclone's maximum sustained winds of at least 35 mph in a 24-hour period

Rapid intensification is a possibility when all environmental conditions become ideal for the tropical cyclone (warm water, low wind shear, high moisture, development of an eye/eyewall)

Category 5 Landfalls – 5 Days Out

Cat 5 Landfalls

- Labor Day (1935)
- Camille (1969)
- Andrew (1992)
- Michael (2018)

Where were these hurricanes

-----before landfall



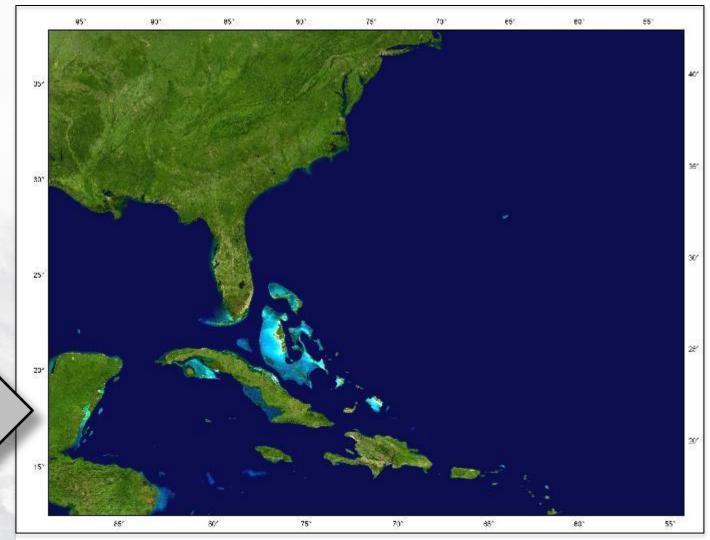
Category 5 Landfalls – 3 Days Out

Cat 5 Landfalls

- Labor Day (1935)
- Camille (1969)
- Andrew (1992)
- Michael (2018)

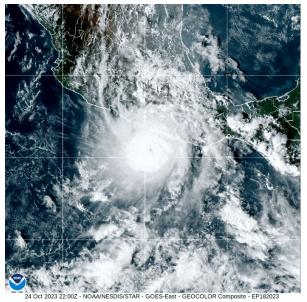
Where were these hurricanes

-----before landfa



2023 Hurricane Season







- Dora: 65 kt -- 110 kt
- Hilary: 55 kt -- 120 kt
- Jova: 75 kt -- 140 kt
- Lidia: 70 kt -- 120 kt
- Norma: 65 kt -- 115 kt
- Otis: 55 kt -- 145 kt



Atlantic (max 24-h change)

- Franklin: 85 kt -- 130 kt
- Idalia: 65 kt -- 105 kt
- Lee: 70 kt -- 145 kt

What tools help us predict intensity?

Weather models, but have you ever heard of any of these?

HAFS, HWRF, HMON, COAMPS-TC – dynamical hurricane regional DSHP, LGEM – statistical-dynamical IVCN, FSSE, HCCA, NNIC – consensus/blends of the above

What tools help us predict intensity?

```
(SHIPS-RII PREDICTOR TABLE for 30 KT OR MORE MAXIMUM WIND INCREASE IN NEXT 24-h)
```

```
Predictor
                             Value
                                    RI Predictor Range Scaled Value(0-1) % Contribution
12 HR PERSISTENCE (KT)
                             10.0
                                     -49.5 to
                                                 38.5
                                                            0.68
                                                                          6.4
                                                            0.49
850-200 MB SHEAR (KT)
                             16.5
                                      30.1 to
                                                 2.3
                                                                          2.1
                              50.8
                                                                          1.4
HEAT CONTENT (KJ/CM2)
                                       0.0 to 157.3
                                                            0.32
                                      36.6 to
                                                            0.61
                                                                          2.3
STD DEV OF IR BR TEMP
                              16.1
2nd PC OF IR BR TEMP
                               0.9
                                                -2.9
                                                            0.34
                                    22.5 to 132.0
MAXIMUM WIND (KT)
                                                            0.47
                                                                          0.9
                             40.0
                          : 124.6 893.2 to
                                               -67.1
                                                            0.80
                                                                          2.1
BL DRY-AIR FLUX (W/M2)
POT = MPI-VMAX (KT)
                          : 103.9
                                    28.4 to 141.4
                                                            0.67
                                                                          0.4
D200 (10**7s-1)
                              44.2
                                                            0.34
                                                                          0.2
                                    -29.7 to 185.9
%area of TPW <45 mm upshear :
                                     100.0 to
                                                            1.00
                                                                          0.2
                               0.0
```

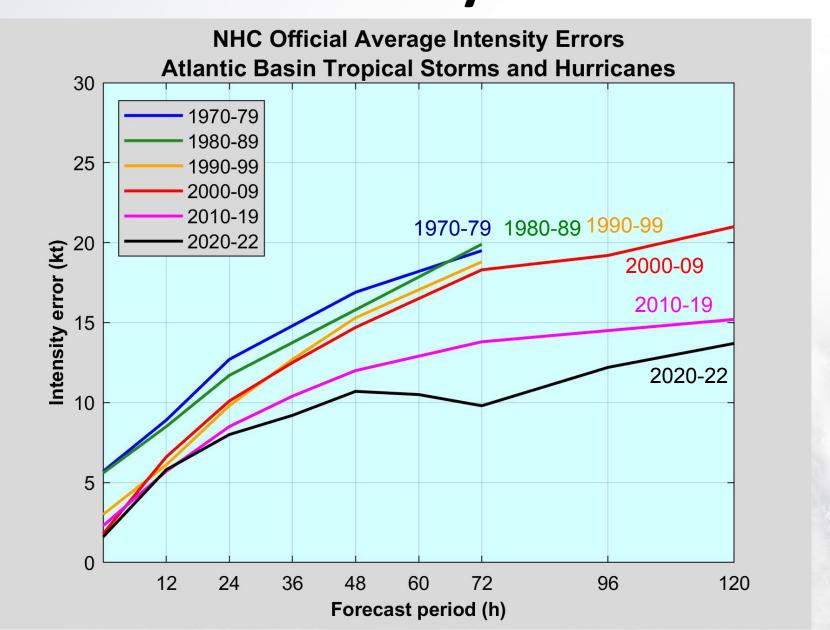
```
SHIPS Prob RI for 20kt/ 12hr RI threshold= 8% is 1.6 times climatological mean (5.0%) SHIPS Prob RI for 25kt/ 24hr RI threshold= 21% is 2.0 times climatological mean (10.9%) SHIPS Prob RI for 30kt/ 24hr RI threshold= 17% is 2.6 times climatological mean (6.7%) SHIPS Prob RI for 35kt/ 24hr RI threshold= 12% is 3.1 times climatological mean (3.8%) SHIPS Prob RI for 40kt/ 24hr RI threshold= 10% is 4.0 times climatological mean (2.4%) SHIPS Prob RI for 45kt/ 36hr RI threshold= 12% is 2.8 times climatological mean (4.5%) SHIPS Prob RI for 55kt/ 48hr RI threshold= 12% is 2.6 times climatological mean (4.6%) SHIPS Prob RI for 65kt/ 72hr RI threshold= 21% is 3.9 times climatological mean (5.4%)
```

Matrix of RI probabilities

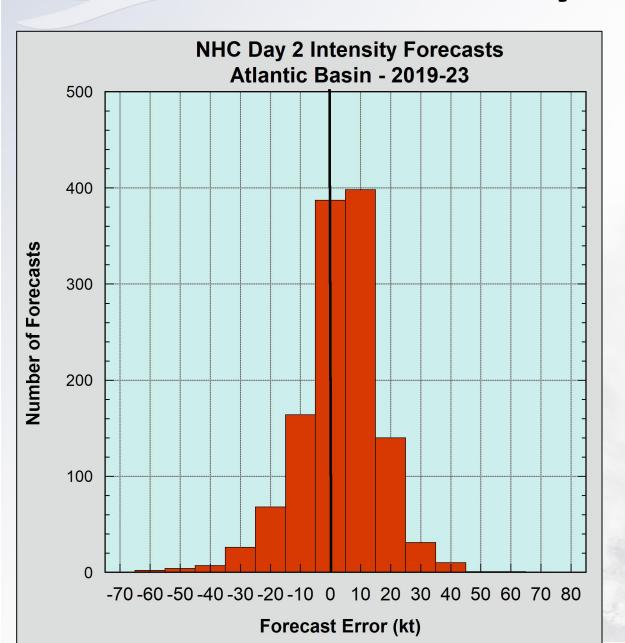
u									
	RI (kt / h)	20/12	25/24	30/24	35/24	40/24	45/36	55/48	65/72
	SHIPS-RII:	7.9%	21.5%	17.2%	11.9%	9.6%	12.4%	12.0%	20.9%
	Logistic:	4.9%	12.6%	6.9%	3.6%	1.2%	4.7%	5.3%	10.1%
	Bayesian:	3.2%	3.5%	1.3%	1.0%	0.2%	0.3%	0.1%	0.4%
	Consensus:	5.3%	12.5%	8.4%	5.5%	3.7%	5.8%	5.8%	10.5%
	DTOPS:	10.0%	46.0%	34.0%	22.0%	8.0%	18.0%	26.0%	2.0%

Probability of significant and/or rapid intensification based on environment and statistics

Atlantic Intensity Error Trends



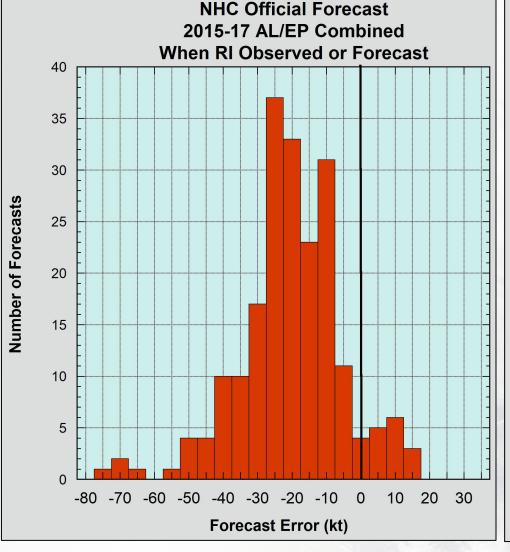
Do NHC intensity forecasts have a bias?



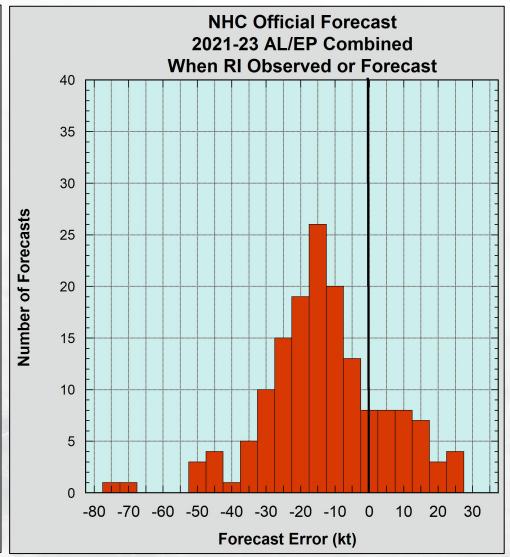
NHC intensity forecasts are generally in the ball park, and there is little bias

What about the Rapid Intensifying Cases?



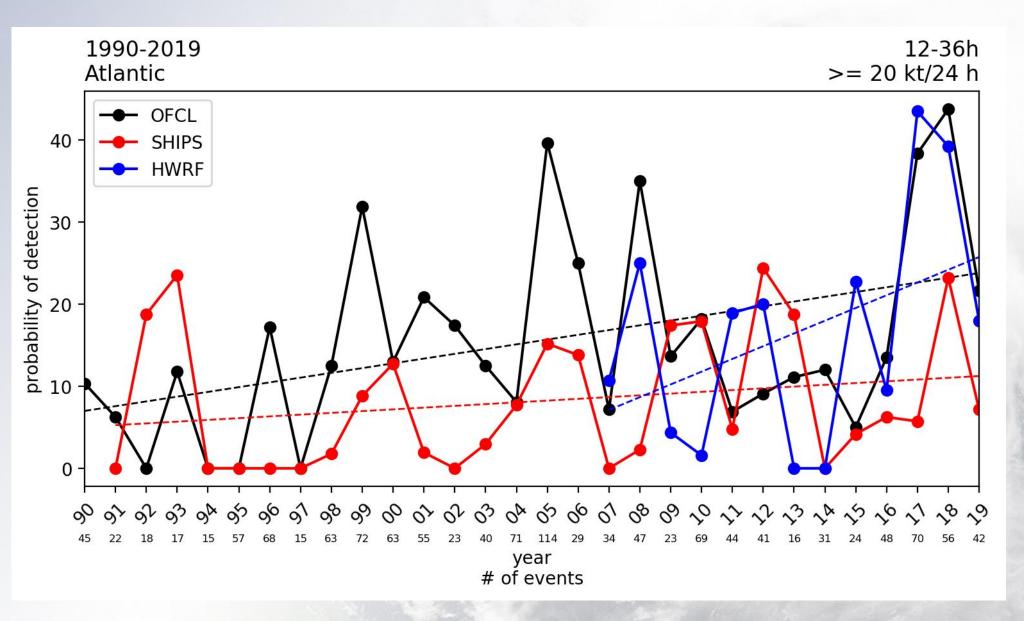


2021-23



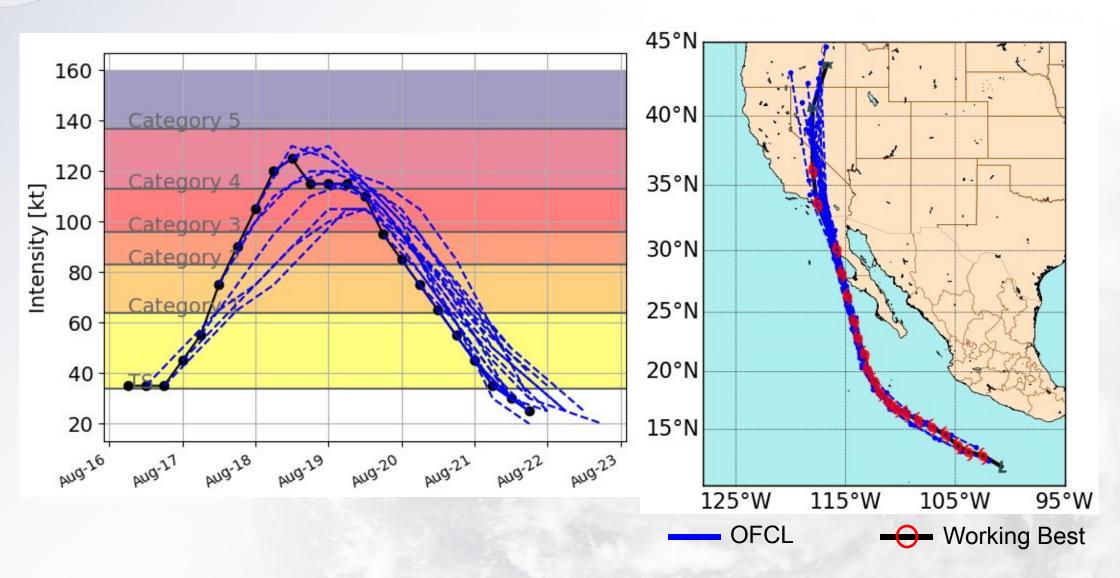
Years	Median Error
2015-17	-22 mph
2021-23	-13 mph

Predicting Rapid Intensification

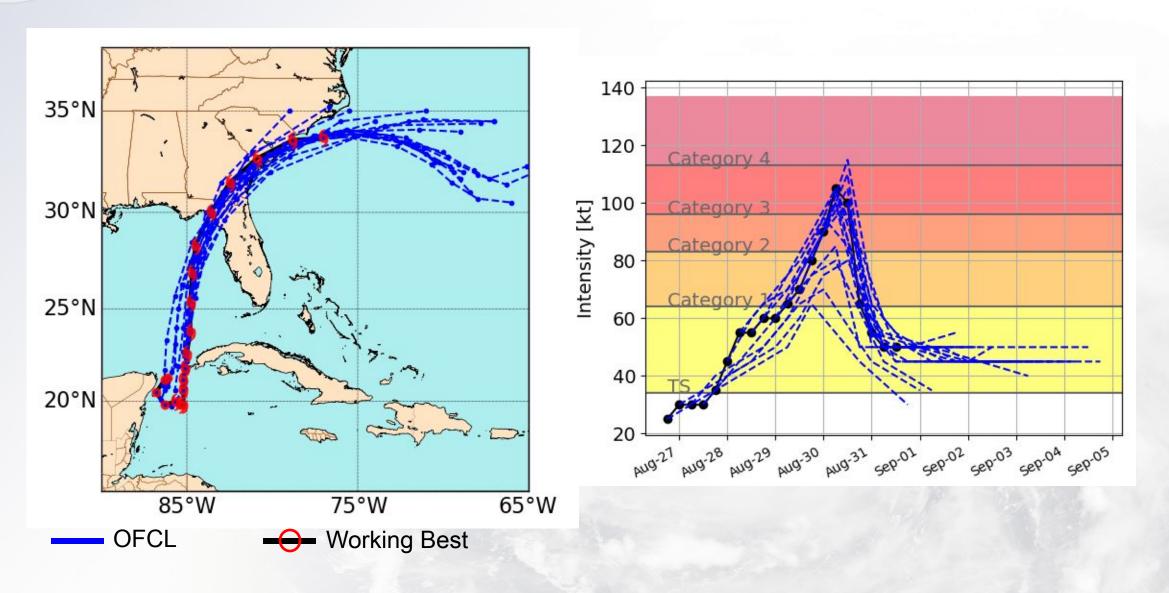


* NHC and some of the models are getting better at detecting when significant strengthening could occur.

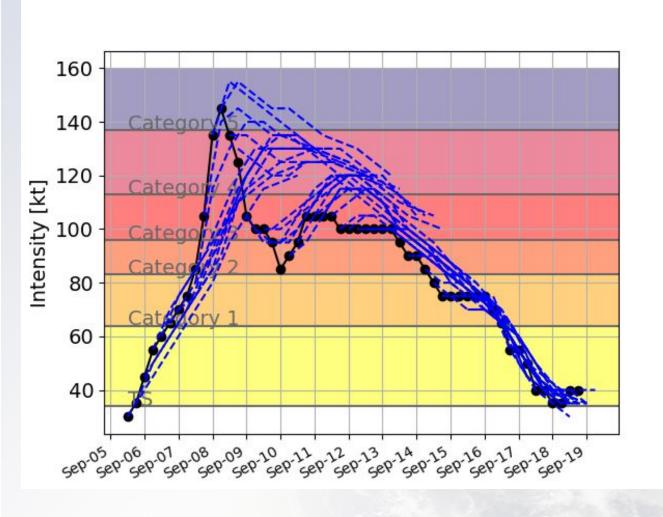
Hilary Track and Intensity Forecast



Idalia Track and Intensity Forecast

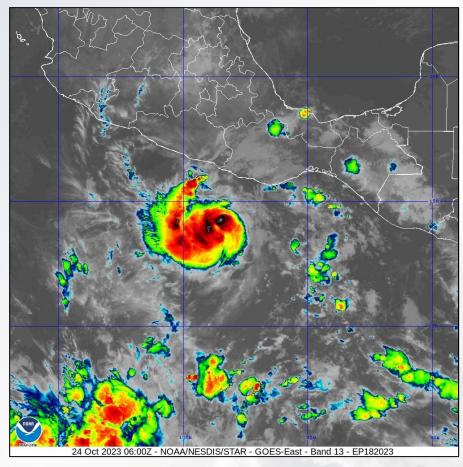


Hurricane Lee – Rapid Intensification

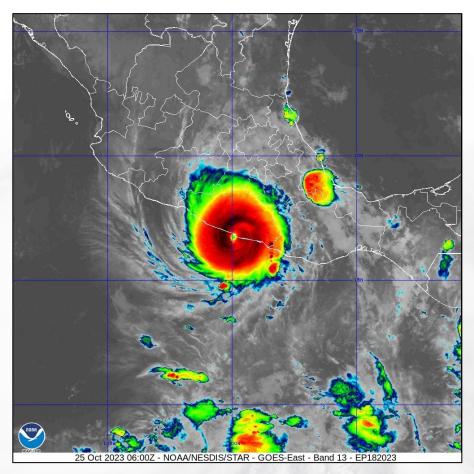


- NHC anticipated the potential for RI beginning with the first forecast
- Second NHC Discussion: "It is becoming a question of when and not if RI occurs with Lee."
- RI occurred sooner than anticipated and Lee weakened faster after reaching its peak as a category 5 hurricane

Hurricane Otis (EPAC) - Rapid Intensification

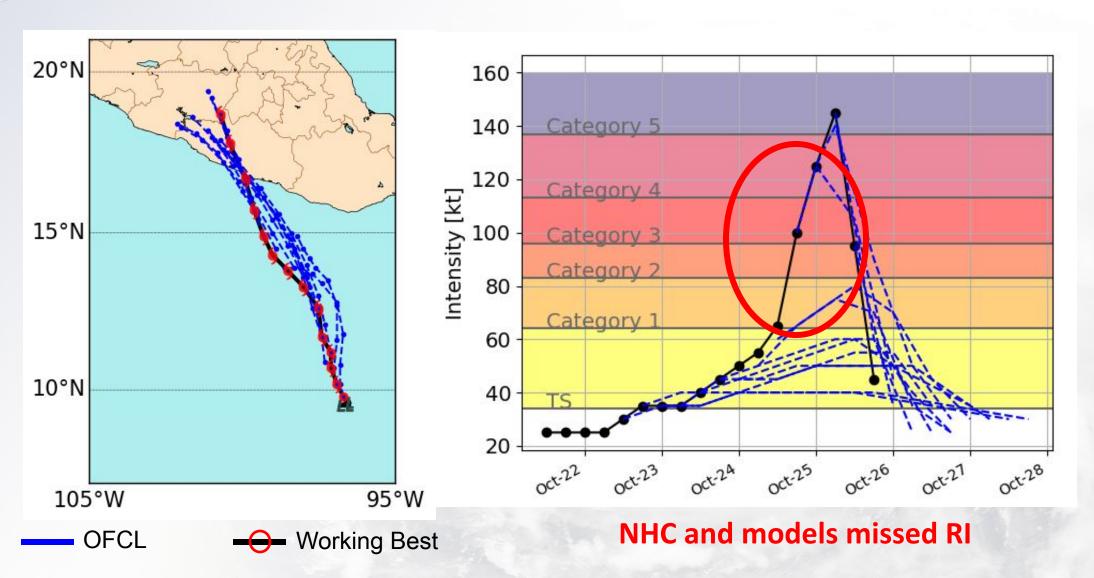


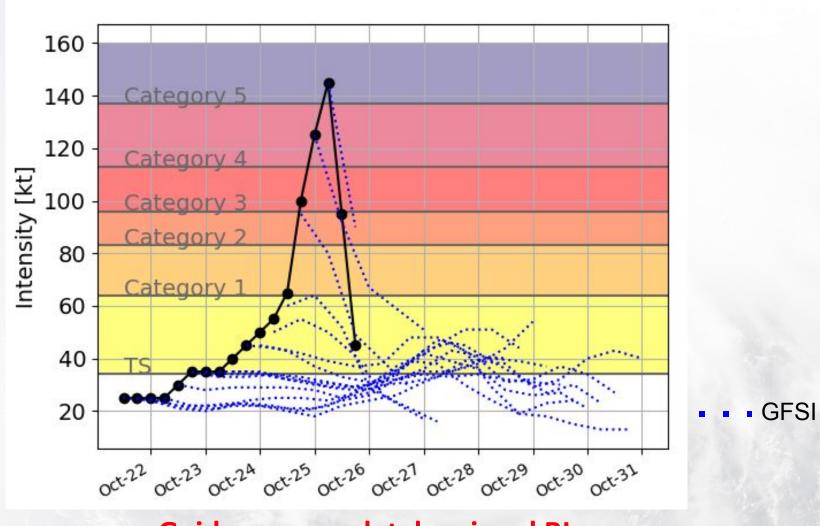
50 MPH - 1 AM CDT Oct. 24



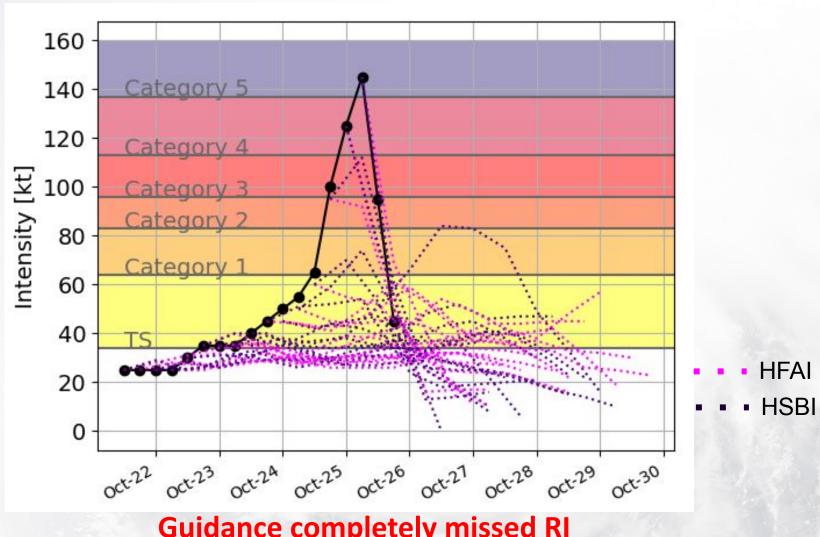
165 MPH - 1 AM CDT Oct. 24

Explosive intensification before catastrophic landfall near Acapulco, Mexico on Oct. 24

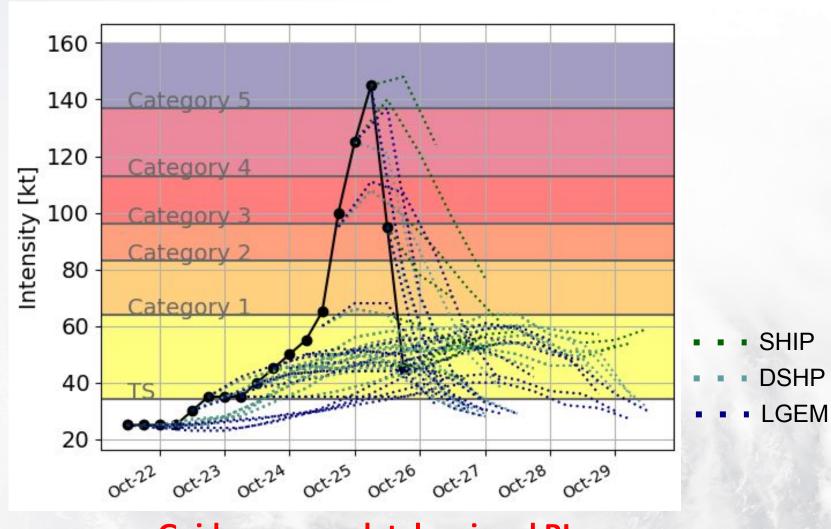




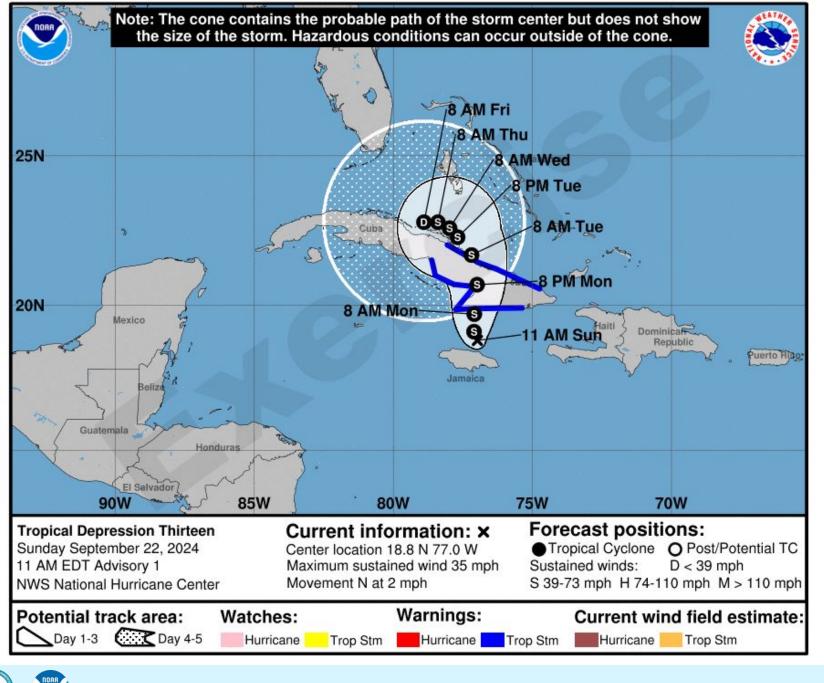
Guidance completely missed RI



Guidance completely missed RI



Guidance completely missed RI



Tropical Depression 13 has formed near Jamaica.

You are based in Miami, Florida

Forecast to cross
Cuba as a tropical
storm but then
weaken

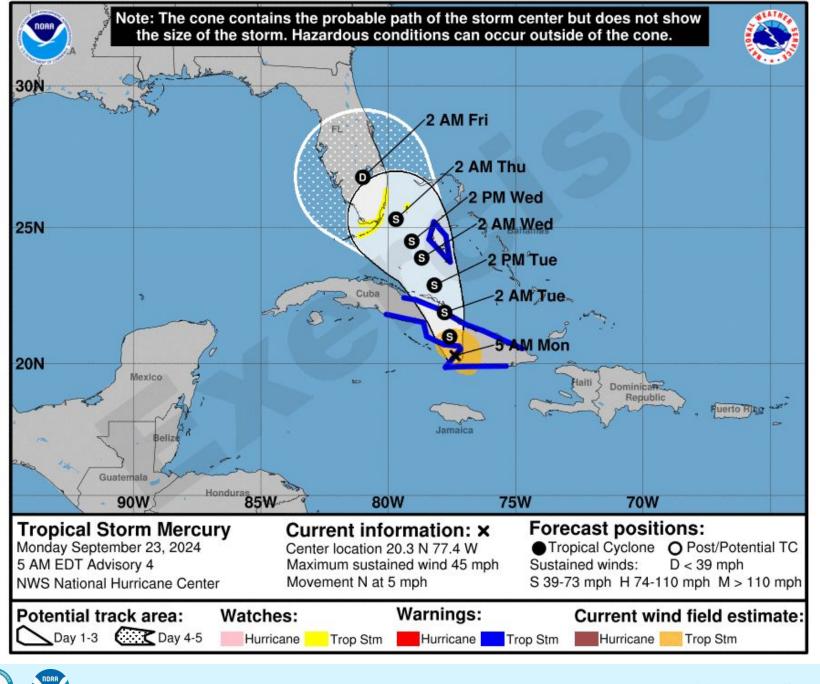


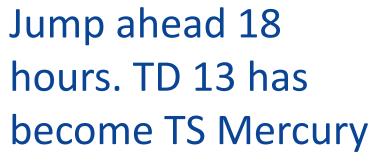
100 To

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TS Watch issued for SE Florida

60-mph TS now forecast for SE Florida

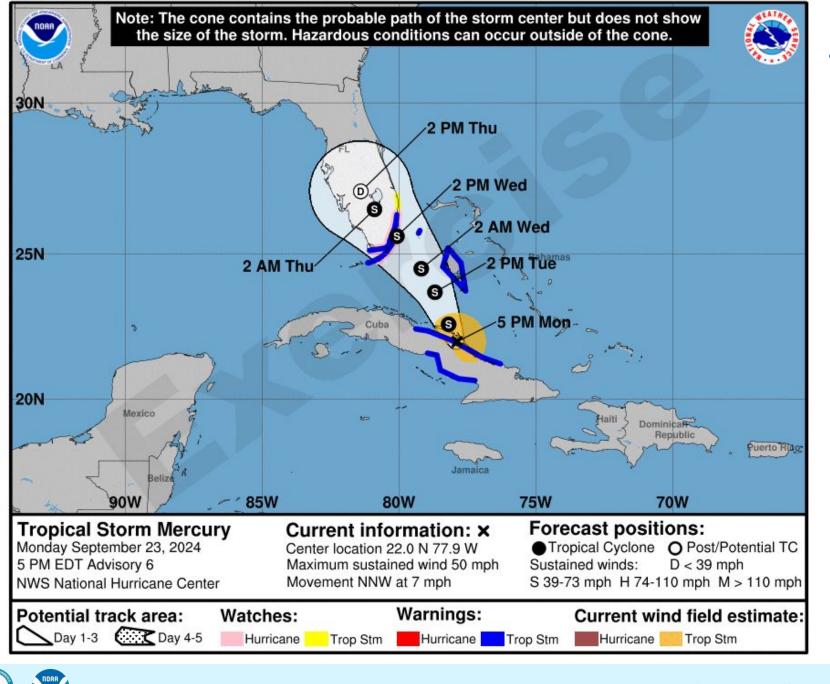


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Mercury now has 50-mph winds.

70-mph TS forecast in SE Florida. TS Warning and Hurricane Watch now in effect

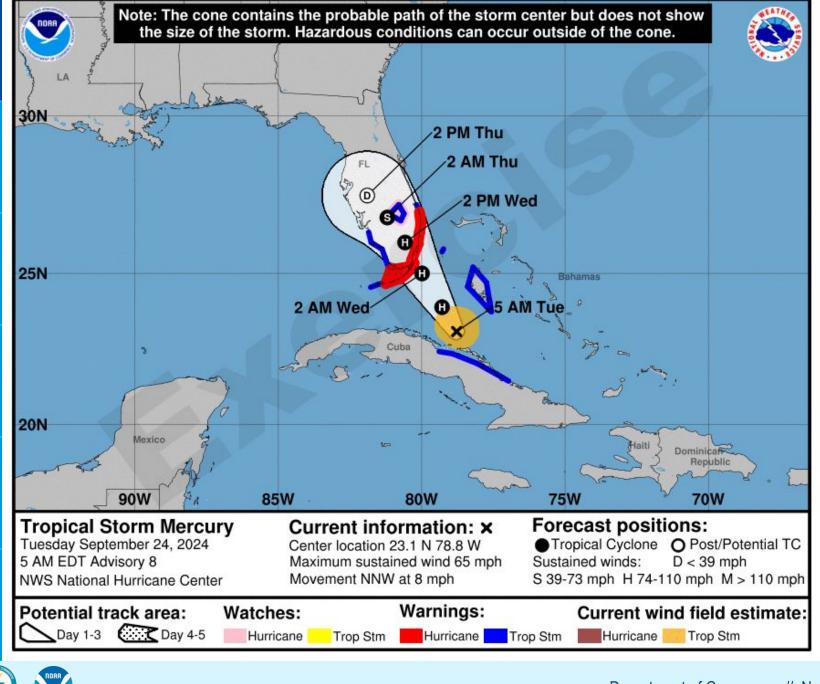


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Mercury now has 65-mph winds.

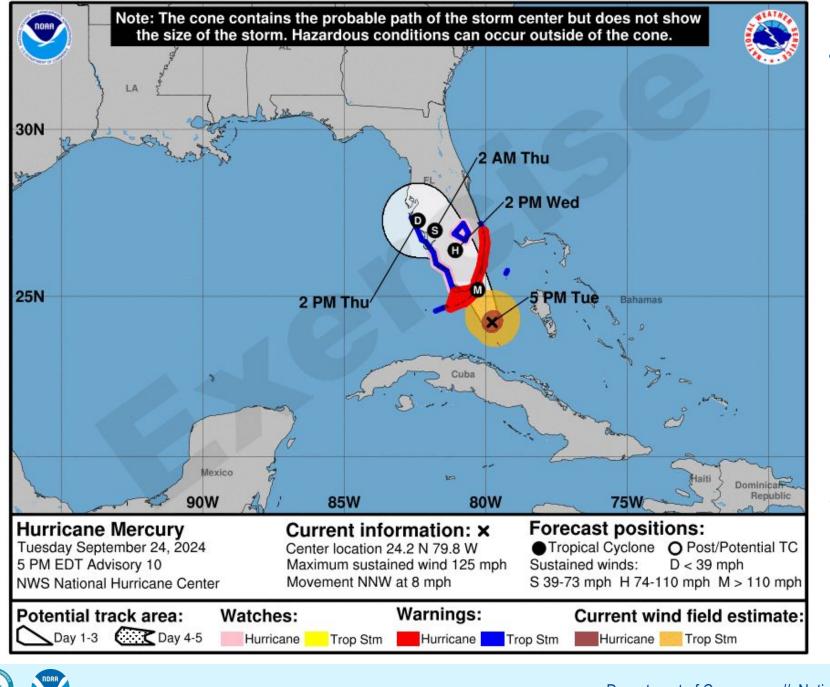
Mercury forecast to reach S Florida as a category 1 hurricane. **Hurricane Warning** now in effect.



100 To

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Mercury a category
3 hurricane with
125-mph winds

Landfall forecast tonight as a category 4 hurricane



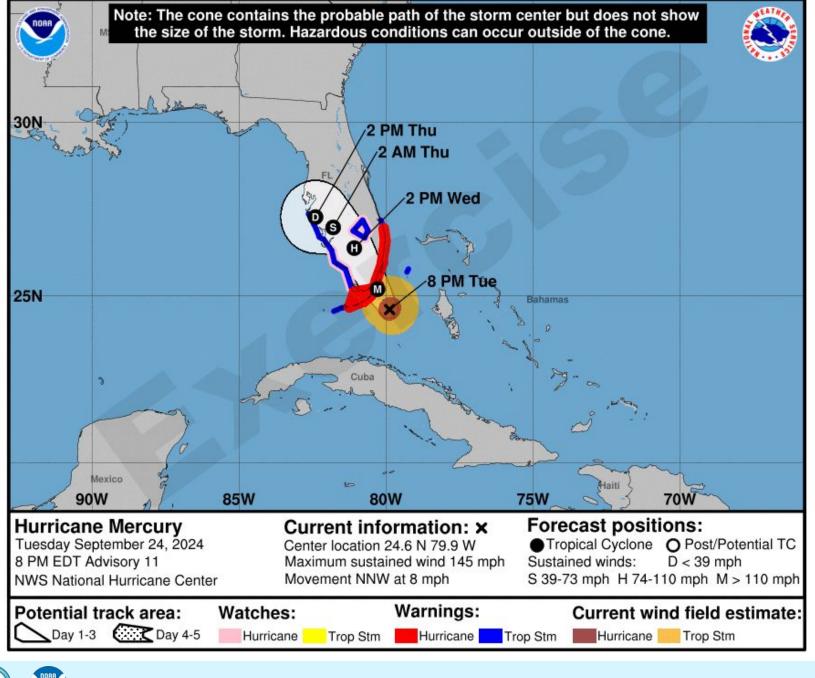
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Special Advisory issued at 8 pm.

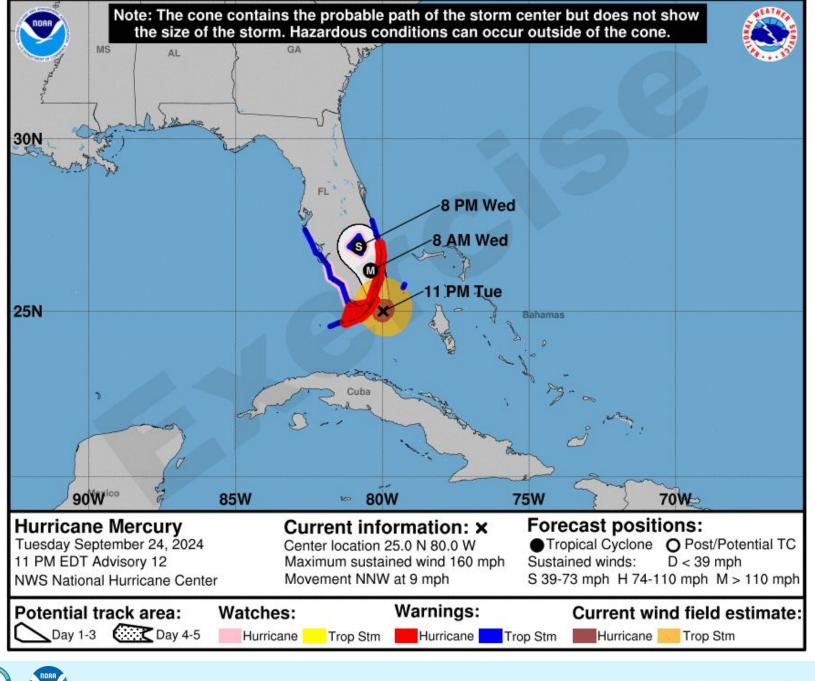
Mercury now at category 4 strength, forecast to reach category 5 intensity before landfall



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Mercury becomes a category 5 hurricane.

TS winds over S
Florida,
hurricane-force
winds beginning



100 To

**>

















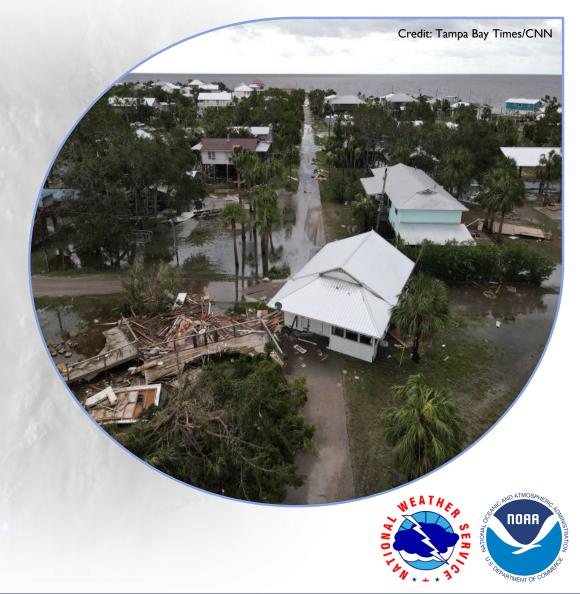
This scenario is entirely plausible



REVIEW OF THE 2023 STORM SURGE FORECASTS

National Hurricane Conference March 24th - 28th, Orlando, FL

Cody Fritz, Ph.D.
Storm Surge Unit (SSU) Team Lead
National Oceanic and Atmospheric
Administration (NOAA)
National Hurricane Center (NHC)
Miami, FL



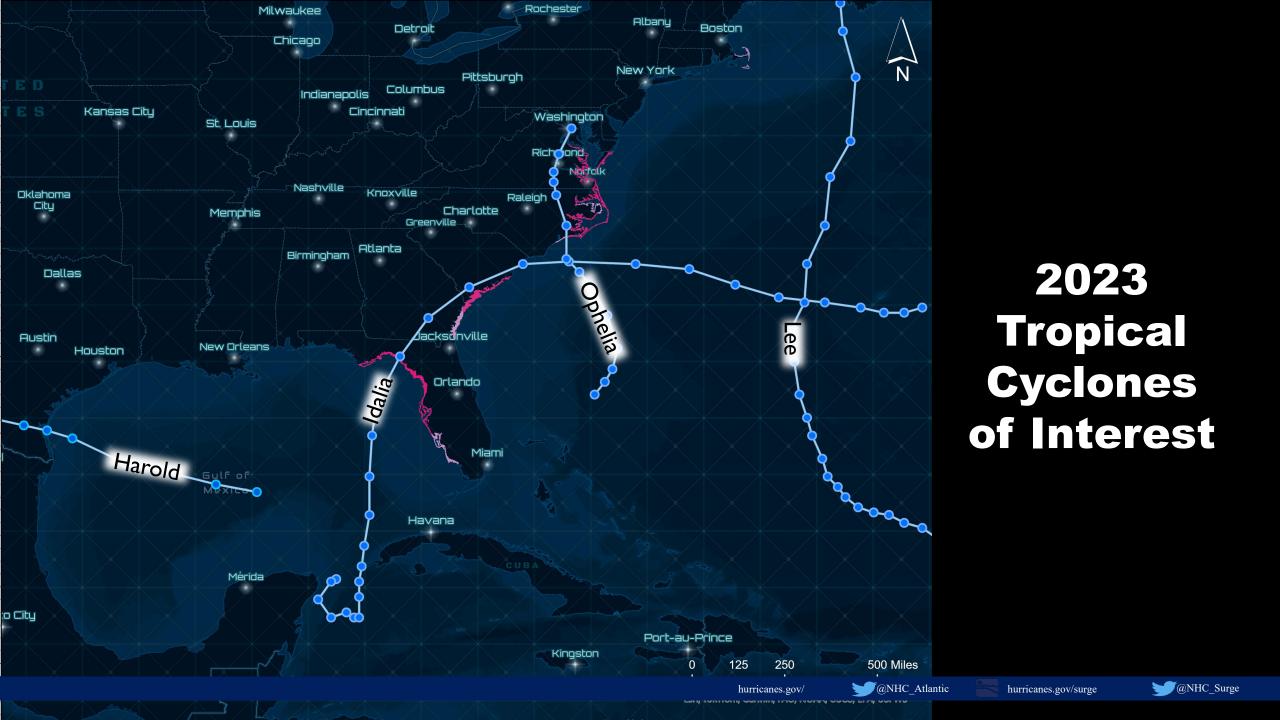


TOPICS

- Tropical cyclones making landfall in the US during the 2023 hurricane season
- Storm surge impacts from Hurricane Idalia (2023)
- Critique of storm surge watches and warnings issued for Hurricane Idalia
- Performance of P-Surge during the 2023 hurricane season







Tropical Storm

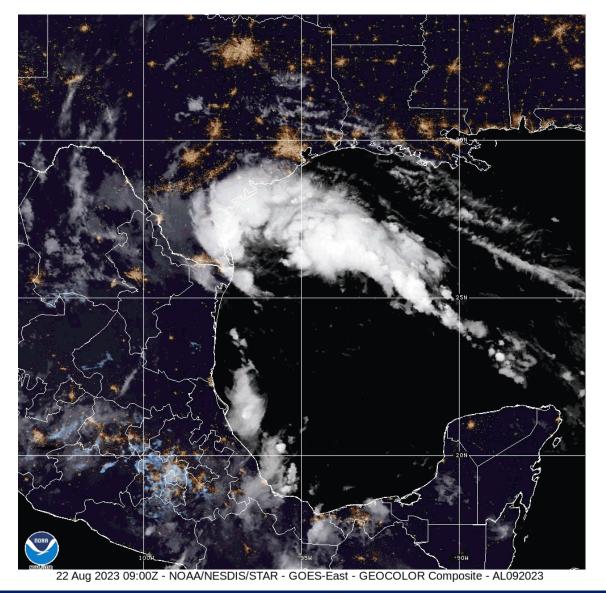
HAROLD (2023)

Landfall Intensity: 60 mph

• 48 mph (G 67 mph) at Loyola Beach

Storm Surge: 1 to 3 ft AGL

2.56 ft MHHW at Nueces Bay



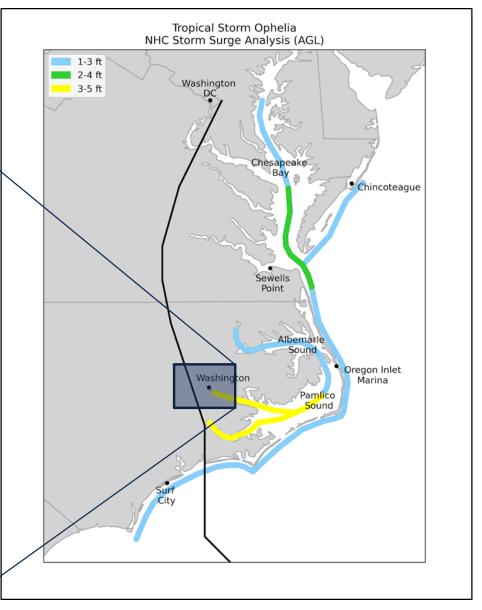




Tropical Storm

OPHELIA (2023)







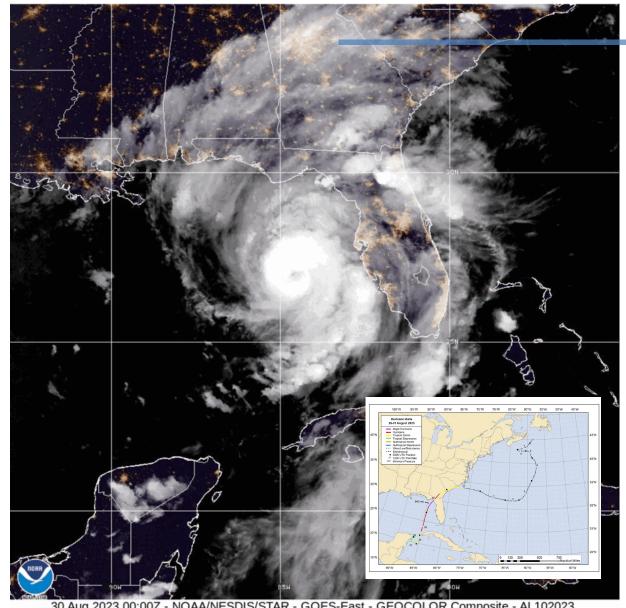
Hurricane

IDALIA (2023)

Became a hurricane on August 29th 06Z

Landfall: Keaton Beach, Florida (August 30)

Landfall Intensity: 115 mph (Cat. 3)



30 Aug 2023 00:00Z - NOAA/NESDIS/STAR - GOES-East - GEOCOLOR Composite - AL10202:











Large area of debris

Extreme flooding damage likely resulting from significant wave action

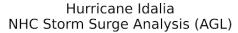


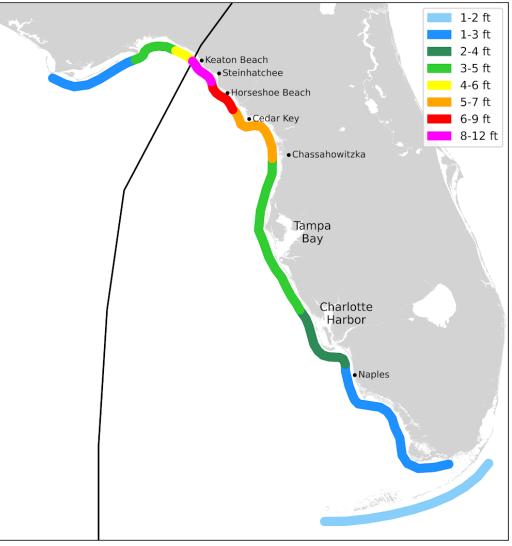
Large area of debris

Extreme flooding damage likely resulting from significant wave action

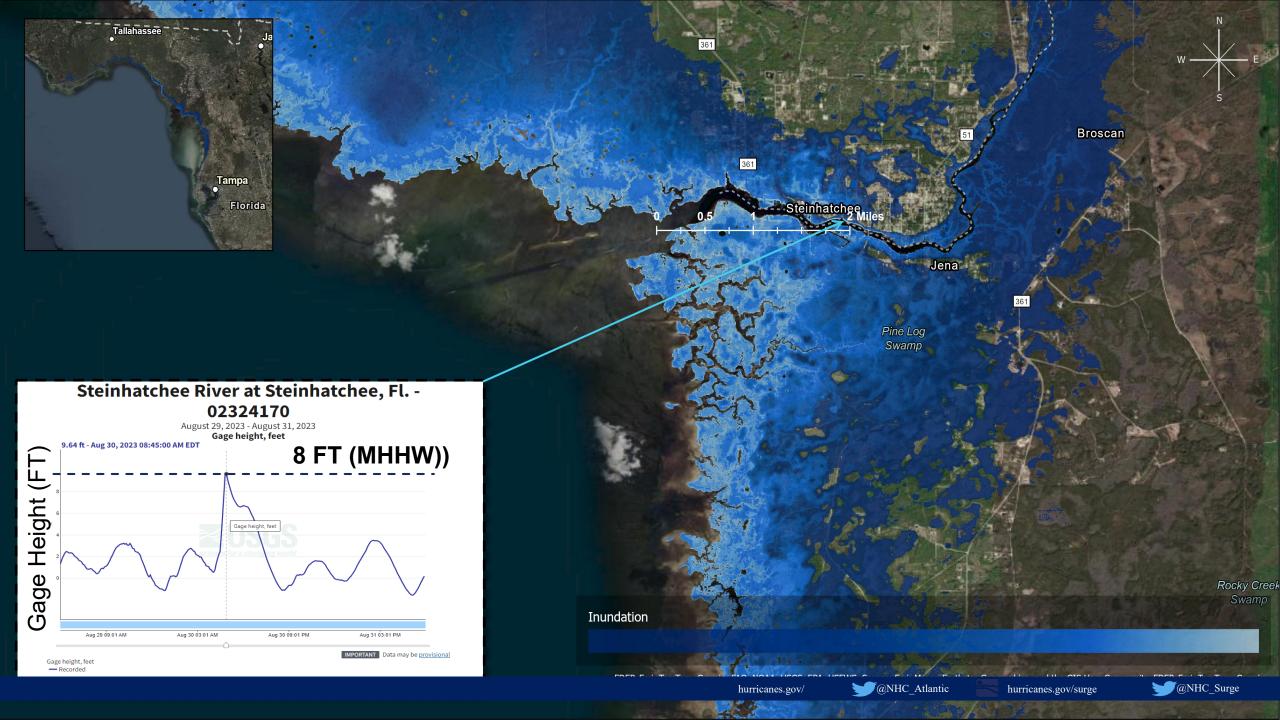
IDALIA (2023) Peak Storm Surge

- Peak storm surge of **8 to 12 feet** occurred between Keaton Beach and Steinhatchee, Florida
- Peak storm surge of 6 to 9 feet occurred south of Steinhatchee to the Suwanee River, including Horseshoe Beach





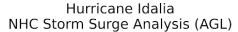


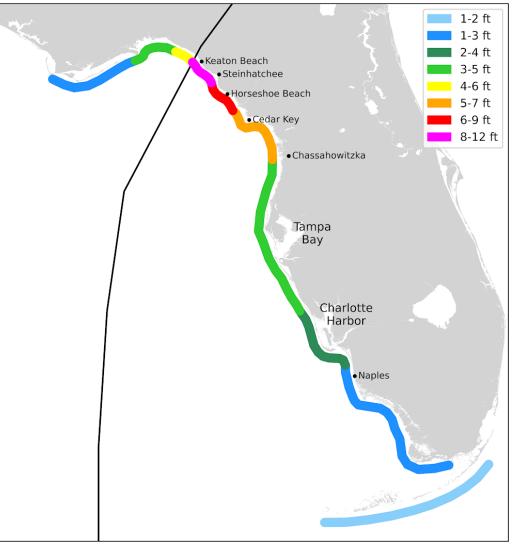




IDALIA (2023) Peak Storm Surge

- Peak storm surge of **8 to 12 feet** occurred between Keaton Beach and Steinhatchee, Florida
- Peak storm surge of 6 to 9 feet occurred south of Steinhatchee to the Suwanee River, including Horseshoe Beach
- 5 to 7 feet of storm surge occurred south of Cedar Key to Chassahowitzka
- 3 to 5 feet of storm surge was observed through the Tampa Bay area.









NOAA/NOS/CO-OPS Winds at 8727520, Cedar Key FL Hurricane From 2023/08/29 00:00 GMT to 2023/08/31 23:59 GMT **IDALIA Winds** 60 40 Hurricane Idalia TBW Radar 11:35 UTC Aug 30 NOS Tide Gauges and USGS streamgages Speed in knots 20 NOAA/NOS/CO-OPS Winds at 8726607, Old Port Tampa FL From 2023/08/29 00:00 GMT to 2023/08/31 23:59 GMT 50 40 20 30 Speed in knots 20 O NOS tide gauge 0 ∆ USGS streamgage -10 29. Aug 30. Aug 12:00 12:00 12:00 31. Aug

6 ft

Water Level (ft MHHW)

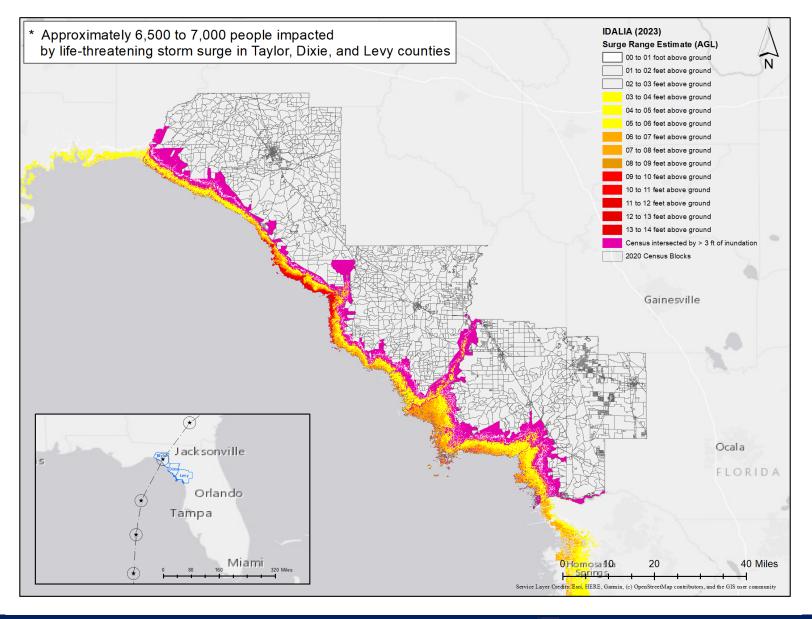
Winds

Gusts

NOAA/NOS/Center for Operational Oceanographic Products and Services

Storm Surge Inundation from IDALIA (2023)

More than 6K people impacted by life-threatening storm surge within the harder hit areas of Taylor, Dixie, and Levy counties

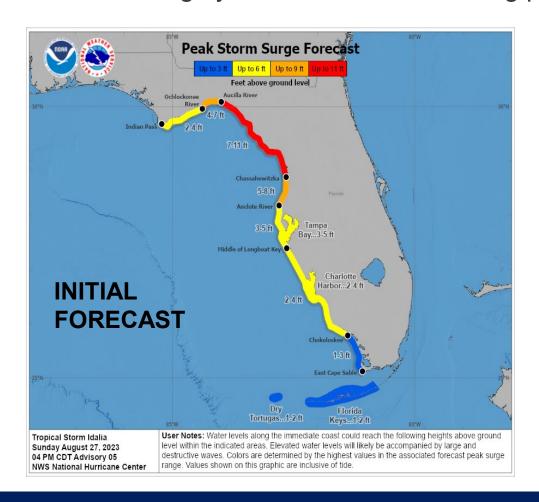


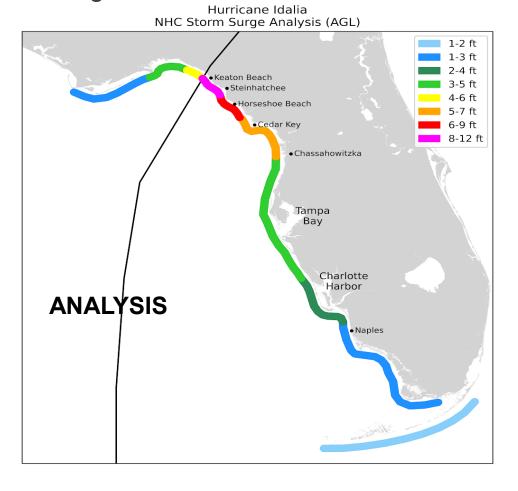




IDALIA (2023) Peak Storm Surge Forecast

Initial forecast largely consistent with resulting peak storm surge forecast



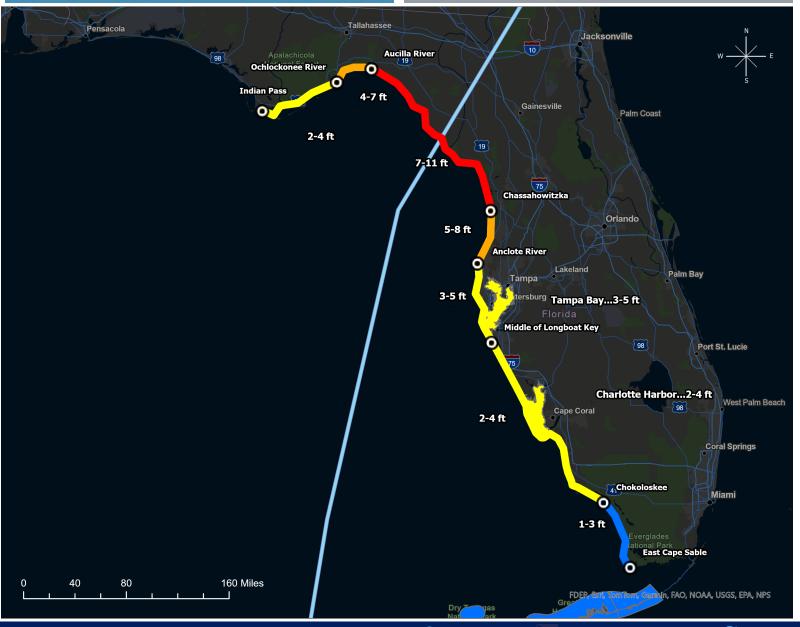






IDALIA (2023) Peak Storm Surge Forecast

Consistency in where the peak storm surge would occur is in large part due to confidence in Idalia's track

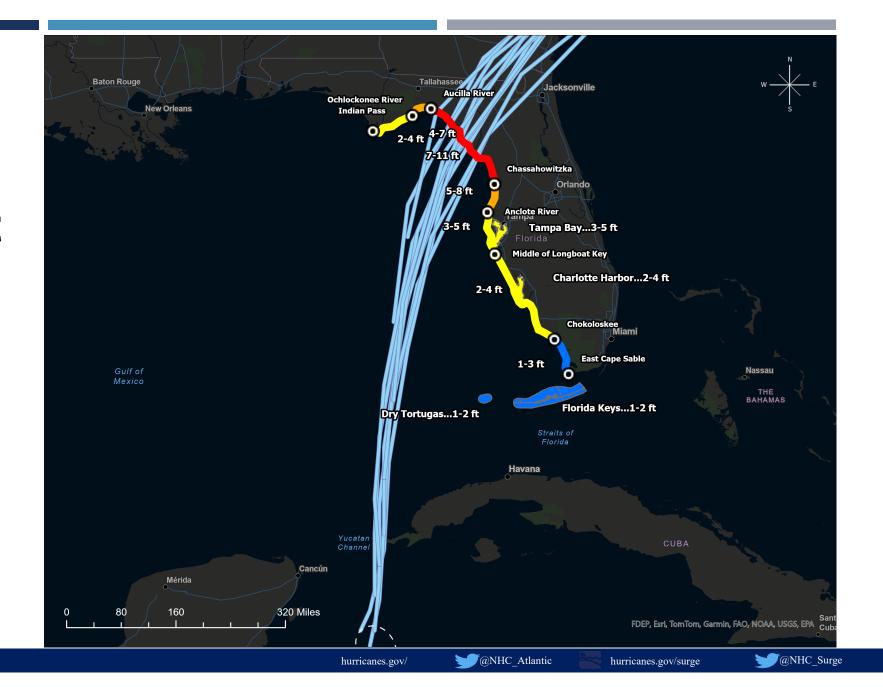




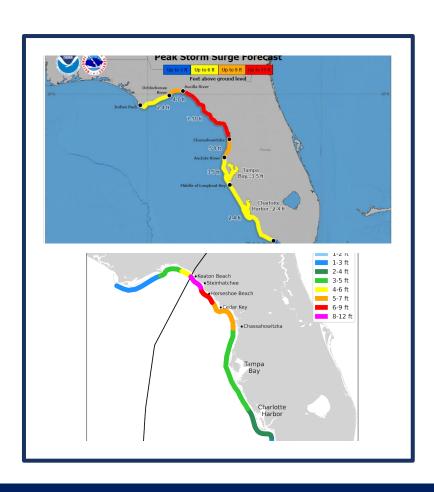


IDALIA (2023) Peak Storm Surge Forecast

Changes in peak storm surge forecast were largely driven by adjustments to the forecast intensity and predictions in the expanding wind field



IDALIA (2023) Peak Storm Surge

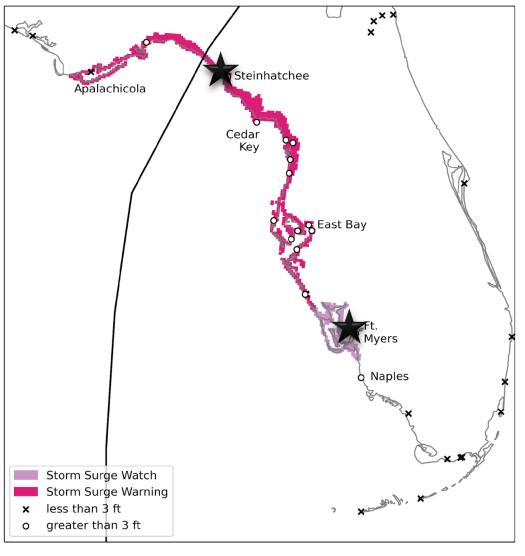


- Initial forecast largely consistent with resulting peak storm surge forecast
- Changes in peak storm surge forecast were largely driven by NHC official forecast intensity adjustments
- Consistency in storm surge forecast in part due to small track error in NHC official forecast
- Idalia's landfall at low tide in addition to weakening prior to landfall reduced the peak storm surge inundation



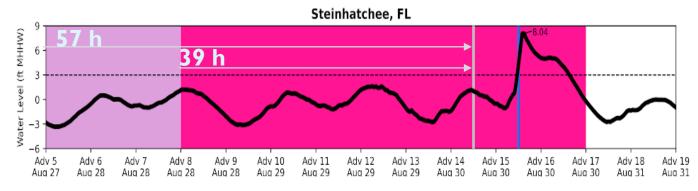


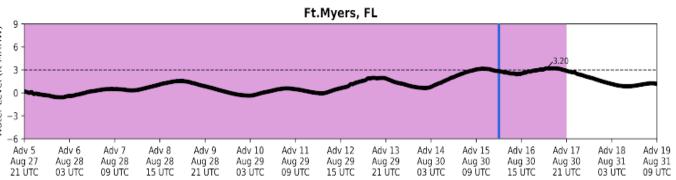
Hurricane Idalia Storm Surge Watch/Warnings (Adv 15) Water Level Observations



IDALIA (2023) Storm Surge Watch and Warning

Consistency in peak storm surge forecast led to timely issuance of the storm surge watch and storm surge warning for communities along the west Florida coastline









PROBABILISTIC STORM SURGE MODEL UPGRADE PRIOR TO THE START OF THE 2023 HURRICANE SEASON

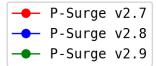
P-Surge v2.7 (2018): RMW based on SLOSH parametric wind profile. RMW often inconsistent with observations.

P-Surge v2.8 (2020): BEST track RMW used to initialize P-Surge. Led to improvements in storm structure

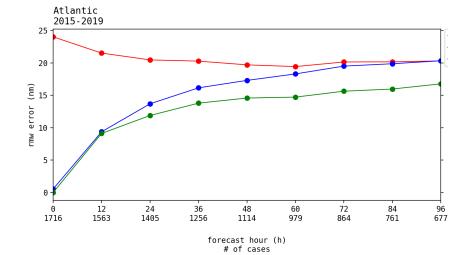
P-Surge v2.9 (2021): RMW forecasts based on NHC forecast parameters. RMW forecasts have lower MAE and less negative bias

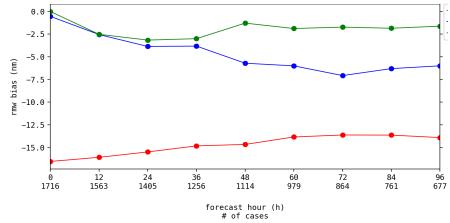
P-Surge v3.0 (2023): non-uniform Manning-N bottom slip coefficients, Puerto Rico and US Virgin Islands with Waves

RMW error



RMW bias



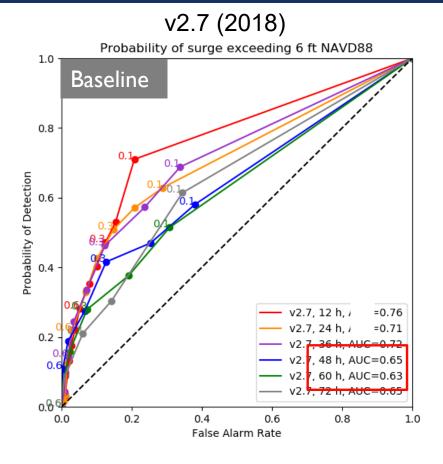


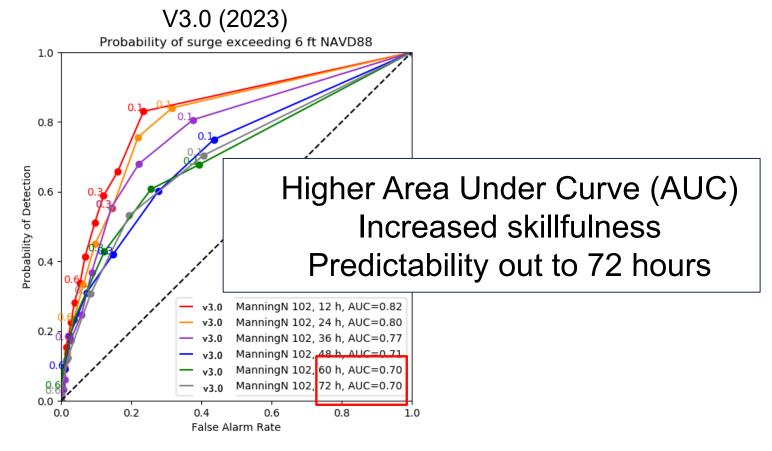






PROBABILISTIC STORM SURGE MODEL UPGRADE PRIOR TO THE START OF THE 2023 HURRICANE SEASON



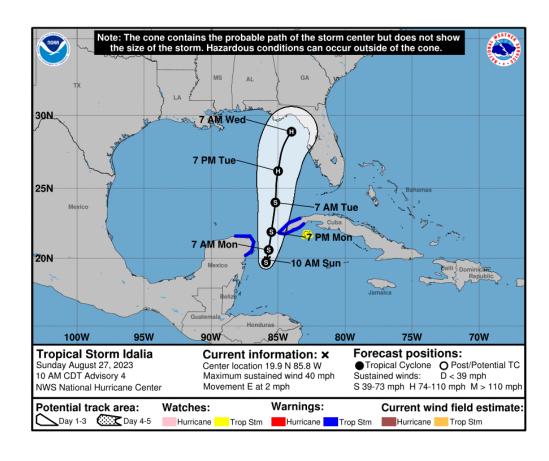


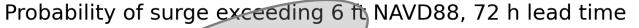


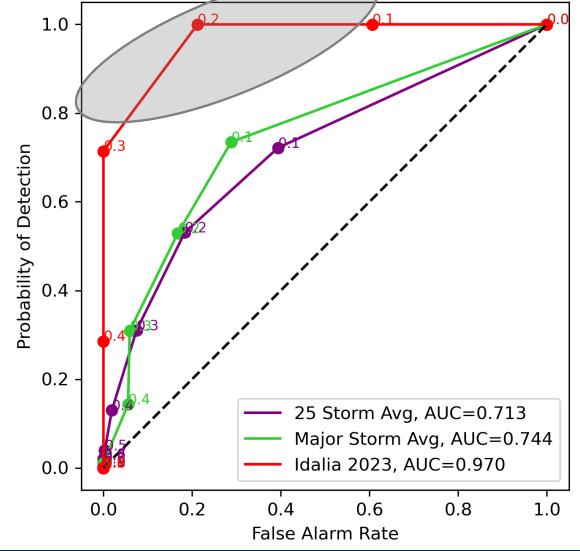


IDALIA (2023)

72 hours before landfall









TOPICS COVERED

- Tropical cyclones making landfall in the US during the 2023 hurricane season
- Storm surge impacts from Hurricane Idalia (2023)
- Critique of storm surge watches and warnings issued for Hurricane Idalia
- Performance of P-Surge during the 2023 hurricane season





QUESTIONS?

National Hurricane Conference March 24th - 28th, Orlando, FL

Cody Fritz, Ph.D. Storm Surge Unit (SSU) Team Lead National Oceanic and Atmospheric Administration (NOAA) National Hurricane Center (NHC) Miami, FL



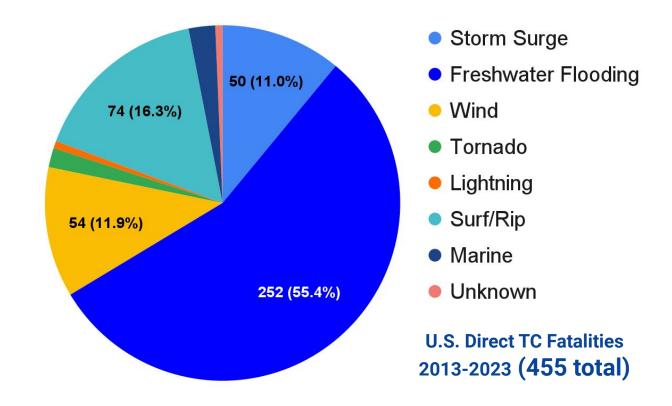


2023 Hurricane Season Rainfall Review



In U.S. Rainfall is Most Consistently Deadly

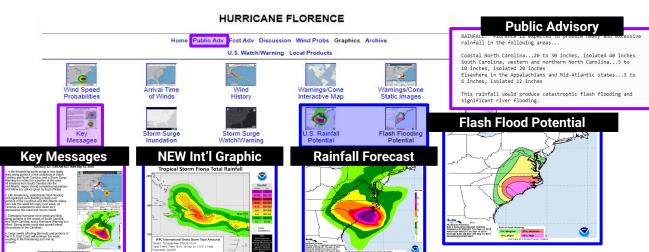
- Storm surge still has the potential to cause the greatest single event fatalities, but...
- Rainfall-induced flooding is the most consistently deadly hazard
- 55% of all direct U.S. tropical cyclone fatalities in the past 11 years
- Follows Rappaport (2014) study that found freshwater flooding was the most common cause

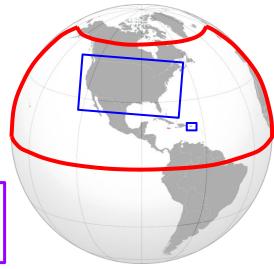


WPC Role and Partnership with NHC

National center of expertise for precipitation forecasting:

- Produces <u>Rainfall Statements and Key Messages</u> for all NHC domain tropical cyclones
- Collaboratively produces those items for U.S. areas with the National Water Center to best incorporate flooding information

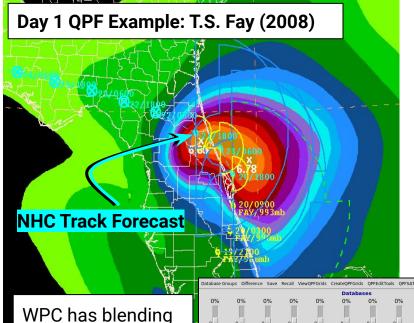




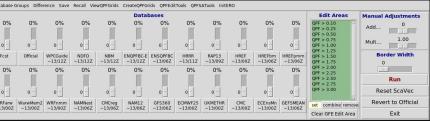
Rainfall information for tropical cyclones is integrated directly into hurricanes.gov



Background: The Rainfall Forecast



- Primary determinant of tropical cyclone rainfall forecast errors is track forecast error
- A good place to start is the model(s) or model cluster closest to the NHC track forecast
- Storm structure and forward speed is very important!
- Model *trends* are also important. Look at several runs of a particular model to see if a trend persists
- Run-to-run consistency and model-to-model consistency can increase confidence





and statistics tools to combine models

Don't Just Stop at the Rain Forecast!

Let's say a hurricane is forecast to bring 3-5 inches of rain

Is it going to fall at a steady rate over the whole day?

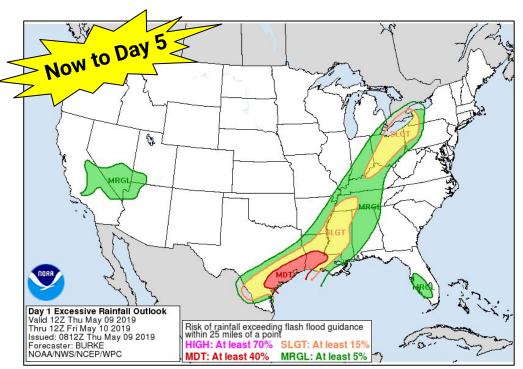






Context matters!

Background: Excessive Rainfall Outlook



Graphic legend updated for new probability definitions as of February 10, 2022

Answers the question:

What are the chances of rainfall intense enough that it would be expected to cause flash flooding?

Other things to know:

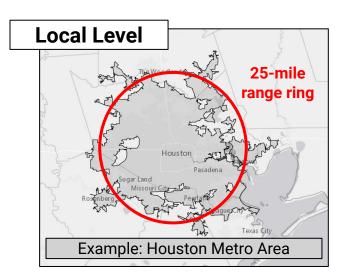
- A situational awareness and planning tool that "gets your head in the game".
- Not an explicit forecast of flash flooding at a specific location.
- Accounts for uncertainty in placement, timing of intense rainfall and summarizes the larger scale risk factors.



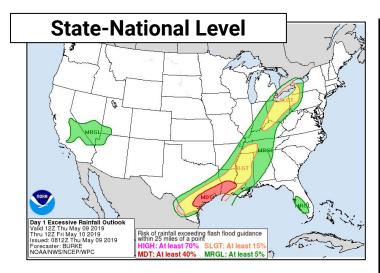
Know your vulnerability! Lower risk categories may still be meaningful decision thresholds.



Background: Interpretation of the ERO



- Describes the probability of excessive rainfall leading to flash flooding within an area approximately the size of a large metro area or county/parish.
- "What are the chances I'll be dealing with flash flooding today?"



- Where are the potential problem spots for intense rainfall and resulting flash flooding, and where is the relative risk higher?
- Days with a much stronger signal, or higher risk levels, may generally require a greater response

IN THIS EXAMPLE

State Level: Texas

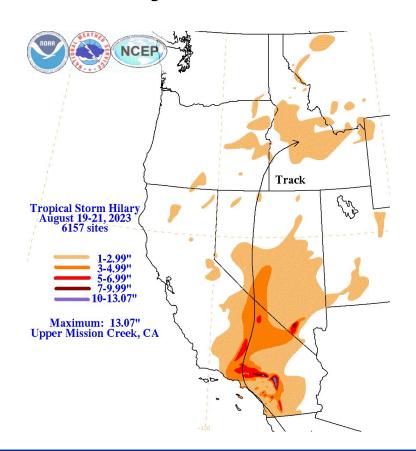
Flash flooding issues due to excessive rainfall are most likely in the southeast part of Texas. And the risk is at the second highest level, so overall confidence is higher than usual.

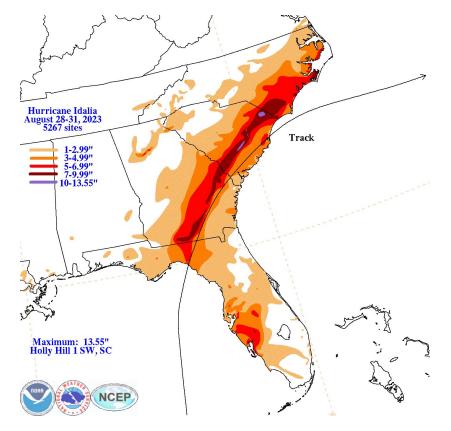
Local Level: Houston

The chances of excessive rainfall in Harris County and the Houston metro area would be about 40 to 70 percent on this day.



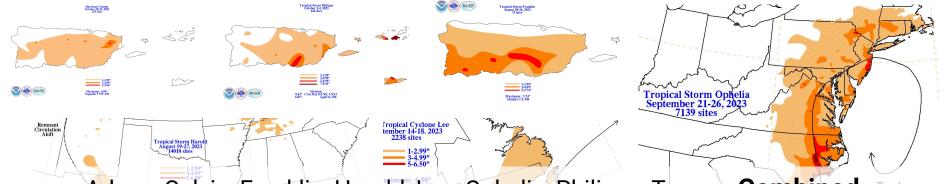
Two Cyclones With Greater Rainfall Impacts







Other Cyclones: Limited Rainfall Impacts



Arlene, Calvin, Franklin, Harold, Lee, Ophelia, Philippe, Tammy Combined:

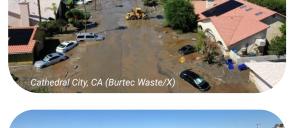
63 reports, 0 fatalities and injuries, \$116K damages in Storm Data



Hilary's Impacts on the Western U.S.







- Hilary was the costliest natural disaster in the county's history
- County estimate of at least \$126M damage from August 2023
- Coachella Valley and sections of Interstate-10 hit hard
- 13.07" event max in Upper Mission Creek is in northern Riverside County



KESQ Photo - I-10 near Thousand Palms, CA in Coachella Valley

New state records for rainfall from a tropical cyclone or its remnants



Nevada: 9.20"

3.29" Oregon:

Idaho: 3.00"

2.30" Montana:



Hilary's Impacts on the Western U.S.





State Route 190 Death Valley NP (CHP)

- Storm Data estimate of \$500M damages in the county
- Longest closure for Death Valley National Park in its history (2 months) with about 400 miles of roads damaged or destroyed
- Wettest day on record in Death Valley (2.20"), exceeds annual average (2.15")



Wildrose Road (National Park Service)



Badwater Road (National Park Service)



Additional Photos From the Southwest



Grader plowing deep mudflows off road in Death Valley NP (NPS)



Mobile home debris swept away by Santa Ana River (San Bernardino County Fire Department)



Debris field from flash flooding on Mt. Charleston (Jeff Scheid, Nevada Independent)

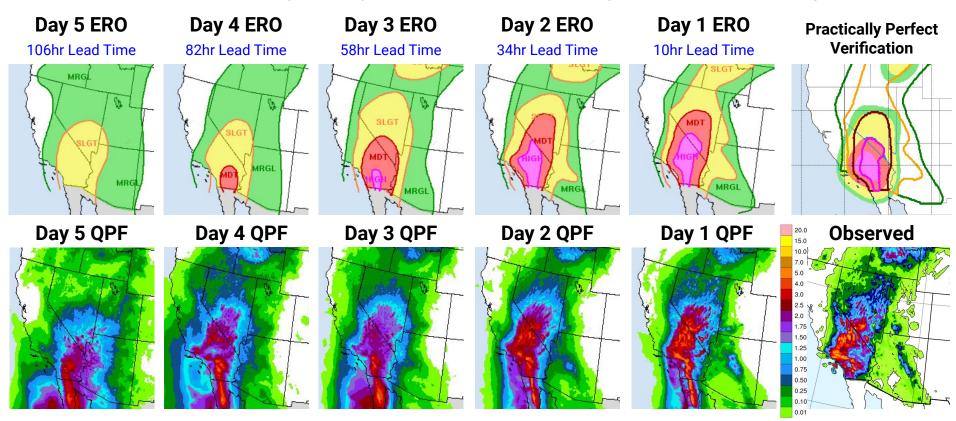


Flooding closes I-10 in Cathedral City (Josh Edelson/AFP)

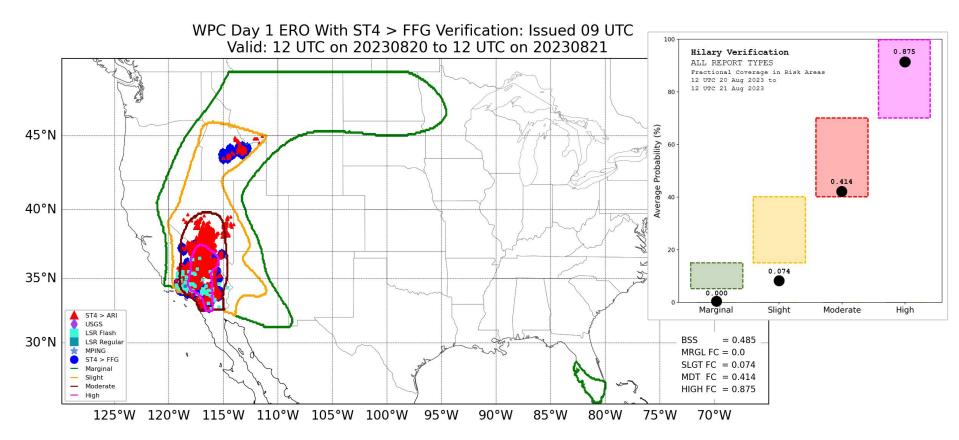


Hilary Forecast Progression

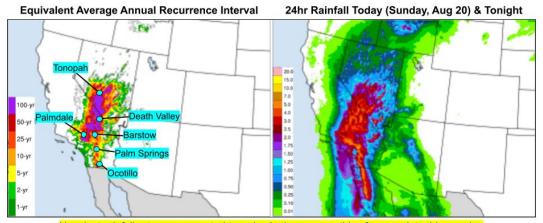
Lead time values are presented prior to the first Flash Flood Warning issuance from WFO San Diego



Day 1 ERO Verification for Hilary



Extreme Precipitation Monitor



Heaviest rainfall rates are expected to arrive in these areas this afternoon into this evening

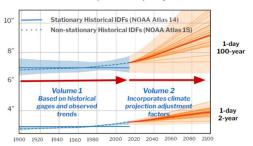
Answers the question: How rare would that amount of rainfall be? Helps to pinpoint where the official rainfall forecast is more unusual, and there are options for the official forecast and a reasonable worst case scenario.

Future Work:

- Extend products beyond Day 3
- Provide data in GIS formats
- Expand QPF options
- Develop an interactive display
- Incorporate updated precipitation frequency estimates from HDSC

NOAA Atlas 15

New National Precipitation Frequency Standard

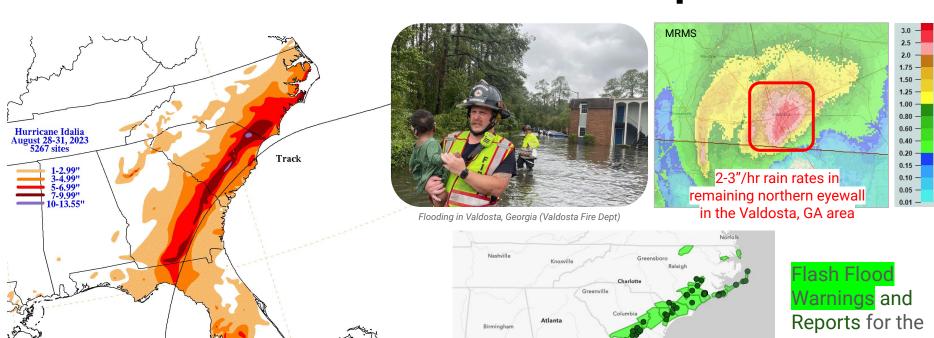


Updates coming in 2026-2027 due to BIL funding

Historical and future intensity-duration-frequency estimates (IDFs)



Hurricane Idalia Rainfall Impacts



24-hour period

12 UTC 30 Aug to 12 UTC 31 Aug

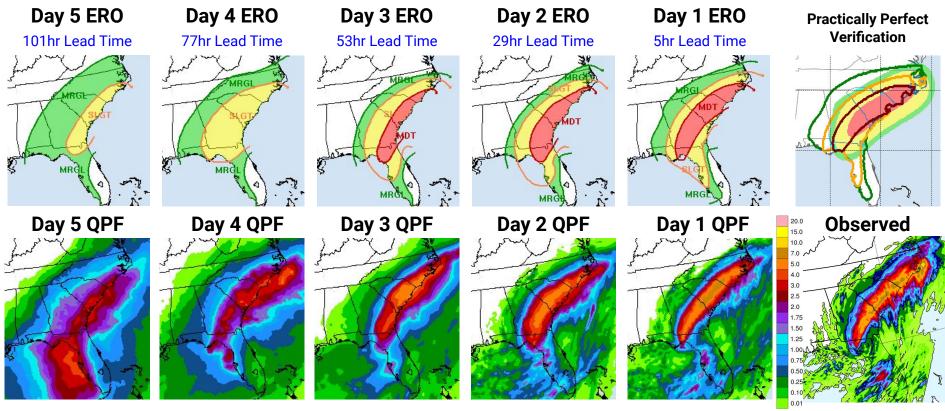


Montgomery

Maximum: 13.55" Holly Hill 1 SW, SC

Idalia Forecast Progression

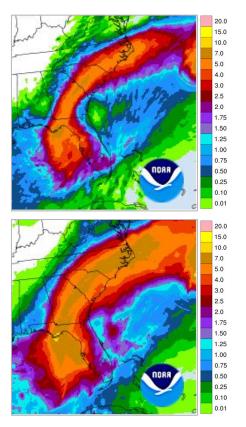
Lead time values are presented prior to the first Flash Flood Warning issuance from WFO Tallahassee

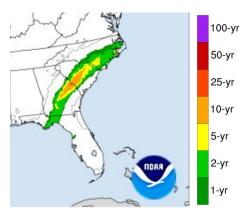


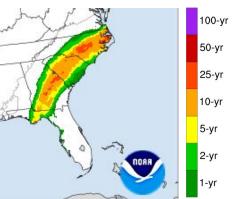
Idalia Extreme Precip Monitor Example

Expected rainfall swath of 5-7 inches (the official WPC forecast)

Reasonable worst-case scenario of 7-10+ inches (10% chance)





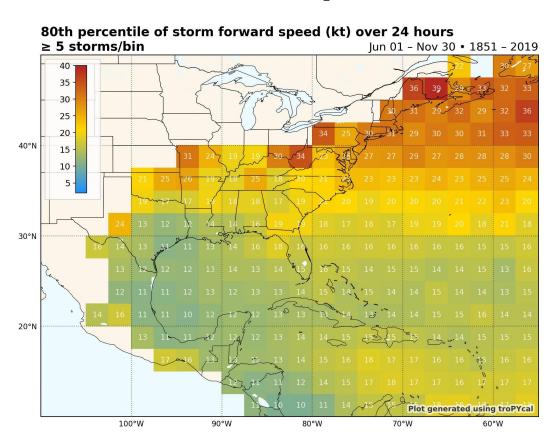


Translates into an average recurrence interval of about a once-a-decade type event

...with about a 10% chance of exceeding a once-in-25 years type event



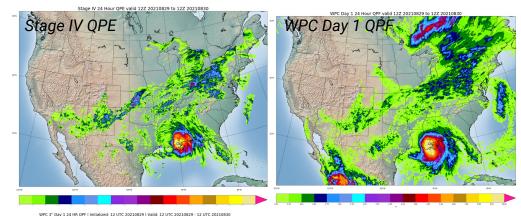
Forward Speed an Underrated Factor

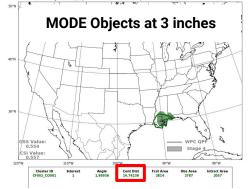


- Idalia moved steadily around
 16-18 knots over the Southeast
- Just under the 80th percentile for forward speed in that region (well above average)
- We've found that fast storms generally don't verify at the High Risk level in the ERO, even with significant banding
- Can help us calibrate our messaging based on a fundamental and fairly predictable aspect of the storm

How We're Doing: Tropical Cyclone QPF

- Use WPC Day 1, 2, 3, 4, and 5 24-hour QPF valid at the landfall and subsequent dates of each chosen storm
 - Dates beyond the initial landfall were examined as long as the tropical cyclone's precipitation could be easily identified and separated from other systems.
- Stage IV QPE used as verification
- Use the method for Object-Based
 Diagnostic Evaluation (MODE) tool
- 27 total storms from 2016 through 2023
- 65 total dates used





How do we calculate displacement? Centroid Distance = 14.74238 Grid = 5 km Displacement = 14.74238 x 5 km = 73.71 km or 45.80 miles



How We're Doing: Tropical Cyclone QPF

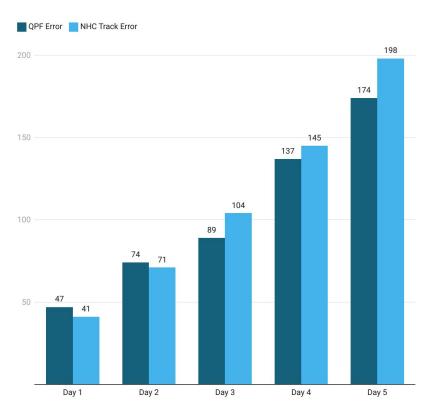


Chart: Alex Lamers • Source: Weather Prediction Center, National Hurricane Center • Created with Datawrapper

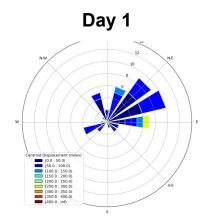
- QPF errors are the displacement of the centroid of the 1" QPF object from the observed centroid
- NHC track errors are from the 2018-2022 report on verification trends for Atlantic
- Values shown are in miles
- It makes sense given WPC QPF methodology, but the rainfall placement errors closely track NHC track errors
- Therefore, tropical cyclone rainfall forecasts continue to benefit from improved NHC track forecasts

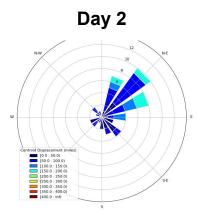
Working to Mitigate Typical Upshear Bias

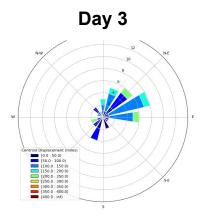
Verification of WPC 2" QPF directional displacement with tropical cyclone cases (2016-2021) shown below. These show the observed rainfall is often centered **to the northeast** of where it is forecast, even though it's usually fairly close in proximity. Likely due to the usual shear vector in the U.S. coming from a westerly direction and preference for rain to fall in the downshear left quadrant (as well as banding in stronger instability).

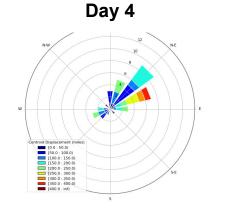


Example from Ida (2021). Shaded is forecast 2". Outline is observed.

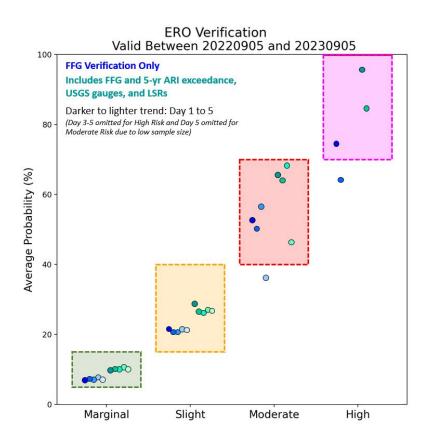








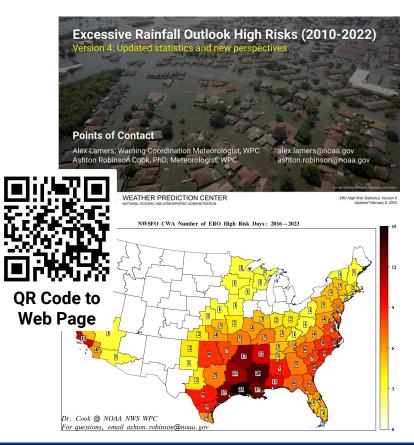
How We're Doing: Excessive Rainfall Outlooks



- This is general verification over a one year period, but captures the trends well
- For a well-calibrated probabilistic product, we want to be hitting these buckets over a long period of time
- In other words, if we say there's a 30% chance of flash flooding near you, it actually happens 30% of the time
- Series of dots indicate two different verification methodologies, but both show the ERO IS RELIABLE
- Small sample size issues with some of the Moderate and High Risk verification



ERO Climatology Updates



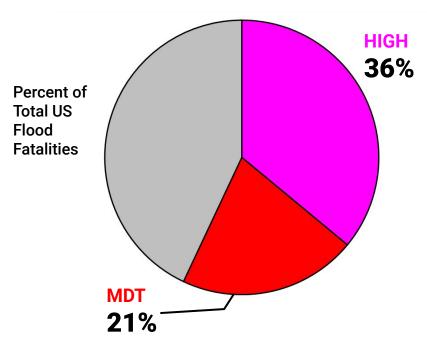
- We continue to update and expand the climatology information for the Excessive Rainfall Outlook
- High Risk statistics (which I'll share next)
- Ability to find lists of all Slight, Moderate, and High Risk Days by...
 - CONUS
 - State
 - NWS local forecast area
 - Metropolitan area
 - County
- Shapefile archive dating back to Aug 2015



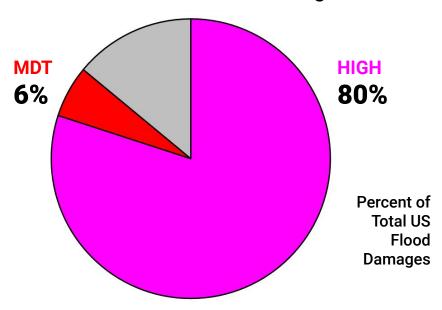
WPC High Risk Days are a **BIG DEAL**

High Risks are only issued by WPC on ~4% of days, but "High Risk Days" have accounted for:

1/3 of ALL Flood-related Fatalities



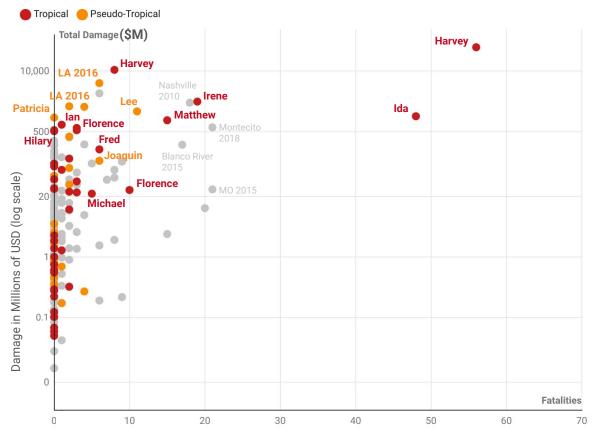
4/5 of ALL Flood-related **Damages**



From 2010 to 2022. Includes flood, flash flood, heavy rain, and debris flow Storm Data. Excludes Oso, WA landslide which occurred well after rainfall and on a sunny day.



Tropical Cyclone or Remnant High Risk Days

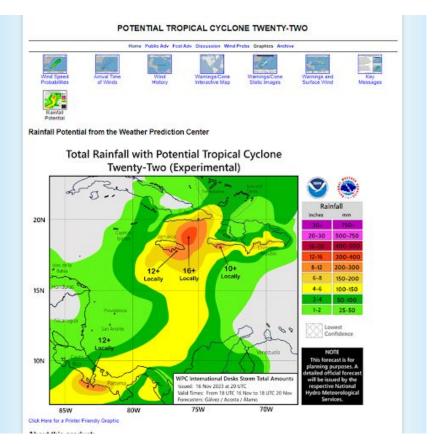


- What is presented here are individual 24-hour periods, so some names may show up more than once (if events lasted longer than a day)
- Nearly all of the most damaging High Risk days were tropical cyclones, their remnants, or tropical disturbances
- Deadliest High Risk days are more of a mixture of tropical and non-tropical cases
- Harvey and Ida stand out for their combination of large number of fatalities with extreme damage costs. Irene and Matthew to a slightly lesser extent.



New International Rainfall Graphic in 2024

- Special graphic actually debuted in November 2023, but will be on hurricanes.gov for the entire 2024 season
- WPC International Desk coordinates to ensure consistency with official advisory
- Be mindful of the timestamp on the graphic as it may not be updated each advisory
- International Desk provides formal meteorological training for the Americas since 1989, in partnership with WMO, State Department, and USAID
- Special rainfall graphics assist U.S. and international partners





Closing Thoughts

- Watch out for the slow storms
- Rainfall forecasts for tropical cyclones generally do a good job with the big picture, but the details and context is important!
- The Excessive Rainfall Outlook is our best reflection of all that context
- High Risks on the ERO signal a much increased chance of a deadly and damaging flash flood day
- Hilary was a significant rainfall and flood disaster for interior/desert portions of southern California

QR Code: Digital
Business Card with
my Contact Info



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