WWRP Warning Value Chain Project

Warning Chain Database Questionnaire

I. Purpose

This questionnaire (template) provides for a comprehensive picture of the end-to-end production and flow of information and decision making along the warning chain during a natural hazard event. The template was originally designed for weather events and some guidance may reflect that, but its use is encouraged for other relevant events such as hydrological or geohazard events.

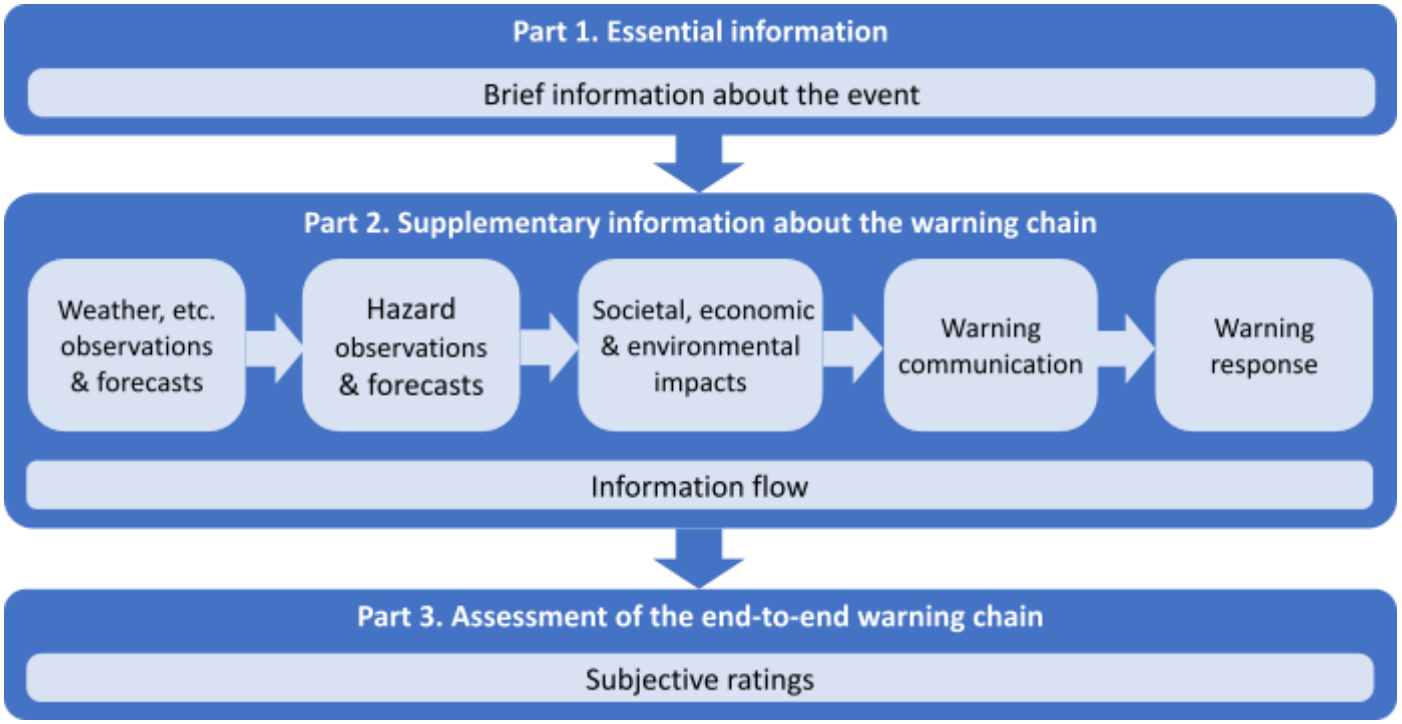
Please use this template to record as much information as possible on the end-to-end warning chain for a particular hazardous event. This information will:

- add to a global database of hazardous events with rich information covering the many components of the warning value chain,
- enable case studies and cross-cutting analysis of end-to-end warning value chains, from simple to complex, to understand effective practices,
- support the value cycle of review and learning from past events to identify improvements that would enhance future warnings.

More information about the WWRP Warning Value Chain Project can be found at http://hiweather.net/Lists/130.html.

II. Structure and format

The questionnaire consists of three main parts.



Part 1. The **essential information table** requests brief facts about a particular event, such as what happened, when, where, impacts and responses. This information will help users to filter events. Please provide numerical and short text entries. Links to this event in other databases and catalogues (e.g., ECMWF Severe Event Catalogue, EM-DAT, DesInventar, etc.) about this event should be provided if

possible.

Part 2. The second part requests **supplementary information** about different stages in the warning value chain. This more detailed information and analysis about the weather/hazard source, hazards, impacts, warning communication and warning response will help users understand what was unique about the warning chain for this event. The questions in Part 2 probe many aspects of the warning chain but are not exhaustive. Information here might include:

- Graphics (for example, forecast charts, reanalysis maps, warning graphics, photos of impacts, etc.).
- Videos (for example, from social media, weather service outlooks, etc.).
- Free-form text (for example, description of meteorology, selected extracts from reports, data analysis, tables, etc.)
- Links (e.g., to external reports, media, national archives, policy documents, protocols, meeting records, etc.)

Each section has an "additional analysis" where you can add further information not covered by the items in the questionnaire.

It is not required to complete Part 2, but please provide what information you can. Try to keep your entries brief and include references and links (URLs) to where additional information can be found. Attribute all material that may be subject to copyright (e.g., images and videos).

Many people may contribute information on this event. Where you disagree with another contributor try to provide evidence or example to support your position. You may wish to acknowledge information providers at the end of the template before Annex 1.

Part 3. The **subjective assessment** asks contributors to rate the effectiveness of the individual elements of the end-to-end warning chain, and its overall effectiveness, on a scale of 1 (poor) to 5 (excellent). This may assist users of the database in choosing cases and performing meta-analysis (recognising the large variability in contributors' judgments).

The accompanying Guide for the Warning Chain Database Questionnaire[1] provides explanation and examples of the type of information that is requested in the questionnaire.

III. How to add resources

Resources for Part 2 (e.g., reports, graphics, data, and other information not easily accessible to the public) should be stored in the event data library of the respective case study. Brief resources such as forecast maps and warning graphics should be inserted directly into the corresponding section of the template. Reports and extensive graphics are not suitable to be embedded in the template but should be referred to. Please store the resources in the event data library first and then insert as a hyperlink to the template. To do so, follow these steps:

1. Go to the event data library on Google Drive (open to anyone).
2. For an existing case study, locate the folder for the event for which you would like to add resources. If the event does not exist yet in the library, refer to the README guide to open a new case study (project members only). If you are a project external contributor, please contact valuechain@bom.gov.au to open a new case study.
3. Place your resource in the folder and give an appropriate name so others know what it is about.

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1 https://docs.google.com/document/d/1xZENrxLcn3250z-cANHpqRtU9gK7OQxj/edit?usp=sharing&ouid=106255653981108702821&rtpof=true&sd=true

4. Right-click the file you want to embed/refer to and select 'Copy link' to retrieve the hyperlink pointing to the file.
5. In the template, use 'Insert Hyperlink' to paste the hyperlink in the appropriate place.

IV. Tips

- The Value Chain Glossary provides a common terminology.
- To assist with searching the database, please use the names of hazard types listed in *Annex 1* of this template.
- A series of prompts (i) in this template provide some quick information to assist with entering the requested data. Simply put your cursor over the information symbol i and text should pop up next to it (ignore the "Ctrl+click to follow link" instruction). *Note, that this feature is only available in the Microsoft Word App, not in the SharePoint or Google Drive browser page.* If this feature does not work for you, please consult the Guide instead.
- A single person may not be able to fill in the entire template. We encourage you to share the template with colleagues who can provide information.
- A worked example of the template is here.
- Questions on the use of this template can be directed to valuechain@bom.gov.au.

V. Completed questionnaire

The completed questionnaire should be stored in the event data library of the respective case study, or sent to valuechain@bom.gov.au.

Part 1. Essential information

Editors (Name & Institute)	Helen Titley, UK Met Office (and others, TBC)

HAZARDOUS EVENT		
Unique identifier i	*(This will be added by the Project Team at a later date)*	
Name of event	Hurricane Ian	
When did it happen i?	September 23 - October 1, 2022	
Where did it happen i?	Cuba, United States (Florida, South Carolina)	☒ rural ☒ urban
Links/UIDs to other databases *(ECMWF catalogue of severe events, WMO CHE, DesInventar, EM-DAT, GLIDE, etc.)*	https://confluence.ecmwf.int/display/FCST/202209+-+Tropical+Cyclone+-+Ian	
WHAT HAPPENED – WEATHER/HAZARD SOURCE, HAZARDS, IMPACTS, WARNINGS, RESPONSES		
Event type/system that caused hazards i *Refer to Annex 1*	Tropical Cyclone	
If possible, provide more detail about weather, etc. observations & forecasts *(link to page)*		
Were any hazards forecast?	☒ yes ☐ no	
Hazards that caused the main impacts i *Refer to Annex* 1	Wind; Storm Surge; Coastal Flood; Estuarine (Coastal) Flood; Flash Flood; Fluvial (Riverine) Flood; Surface Water Flooding	
Classify hazard according to the location's climatology or average frequency of occurrence i		
If possible, provide more detail about hazard observations & forecasts *(link to page)*		
Were any impacts forecast?	☒ yes ☐ no	
Main direct impacts i		
Economic damage in USD i		
Fatalities	Hurricane Ian has caused at least 107 fatalities including 3 people in Cuba, 100 in Florida, and 4 in North Carolina (as of October 3rd - this is likely to increase)	
If possible, provide more detail about impact observations & forecasts *(link to page)*		
Were any warnings issued?	☒ yes ☐ no	
Main warnings issued i		
Who issued the warnings? i		

If possible, provide more detail about the warnings & communication *(link to page)*	
Main responses to warnings i	
If possible, provide more detail about responses to warnings *(link to page)*	

Part 2a. Supplementary information about the source of the hazard i

Wherever possible, please include references to information you provide.

Editors (Name & Institute): Beth Ebert (Bureau of Meteorology) using analysis from NOAA EMC Model Evaluation Group.

Situational overview i

Ian began as a tropical wave east of the Windward Islands on September 19, 2022 and then moved to the west. Ian was named on the 24th and became a hurricane on the 26th. Ian became a major hurricane (high end Cat. 3) just before reaching Cuba on the 27th and remained a major hurricane as it emerged off of Cuba. There were two landfalls in the United States: southwest Florida on the 28th (Cat. 4) and on the South Carolina coast on the 30th (Cat. 1).

========== Weather forecast ==========

(Adapt as required for non-meteorological forecasts)

Special/non-traditional observational data used in the weather forecast or assimilated into NWP i

Comment on the adequacy of the observations available for the weather forecast i

Weather models (short- and long-range) i

Name	Horizontal resolution	Ensemble size	Forecast length
Global ensembles GEFS, ECMWF, UK, CMC			
Global deterministic ECMWF, GFS, UK, CMC			
HWRF, HMON			

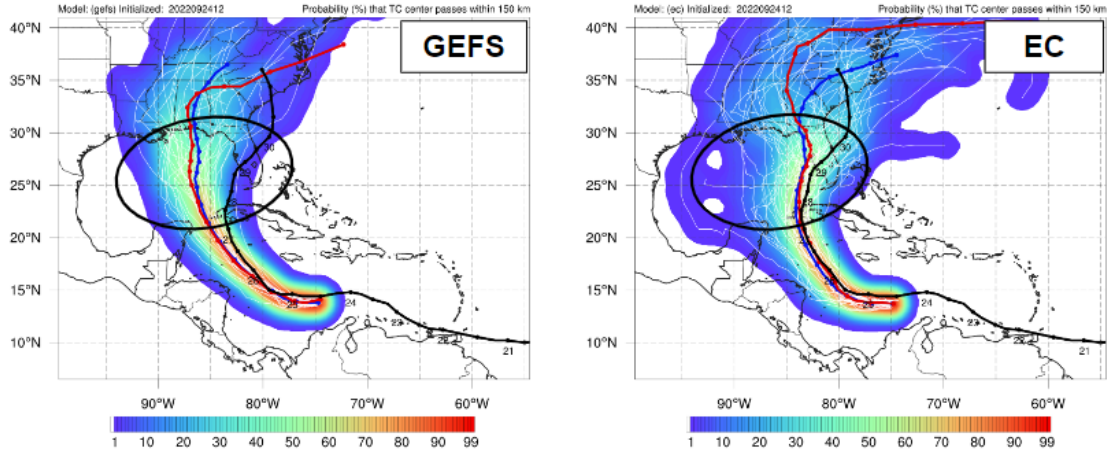
Post-processing/calibration applied to weather model output i

Weather forecast outputs and examples i

NHC advisory archive: https://www.nhc.noaa.gov/archive/2022/IAN.shtml?
NHC graphic archive: https://www.nhc.noaa.gov/archive/2022/IAN_graphics.php
See also NOAA EMC presentation on NWP model guidance in this folder

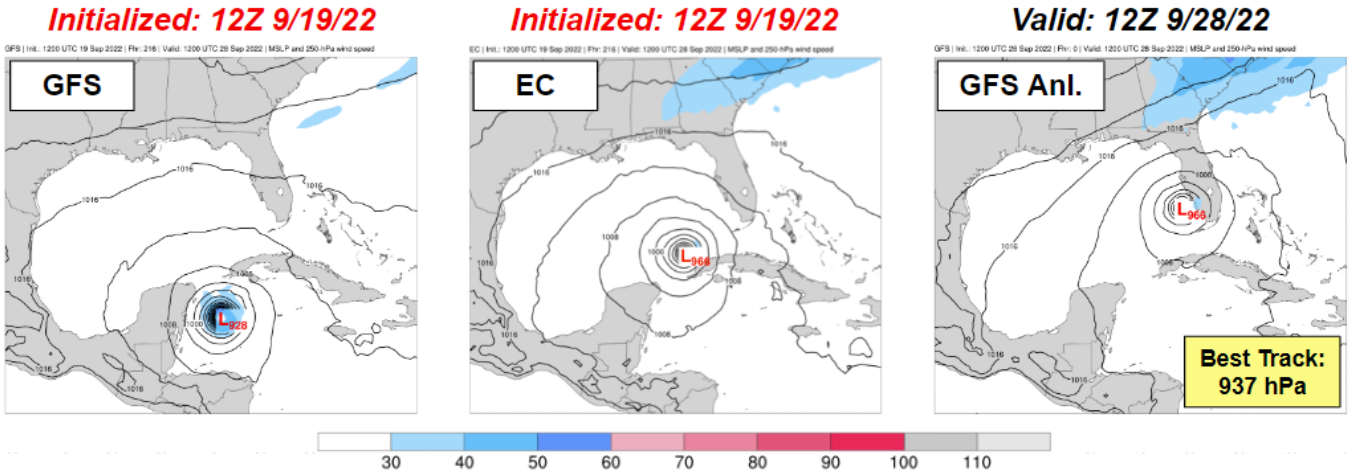
Global ensemble NWP: 12Z 9/24/22 cycles

Ensemble Track Density Maps (shaded, %) and Deterministic/Ensemble Mean Tracks



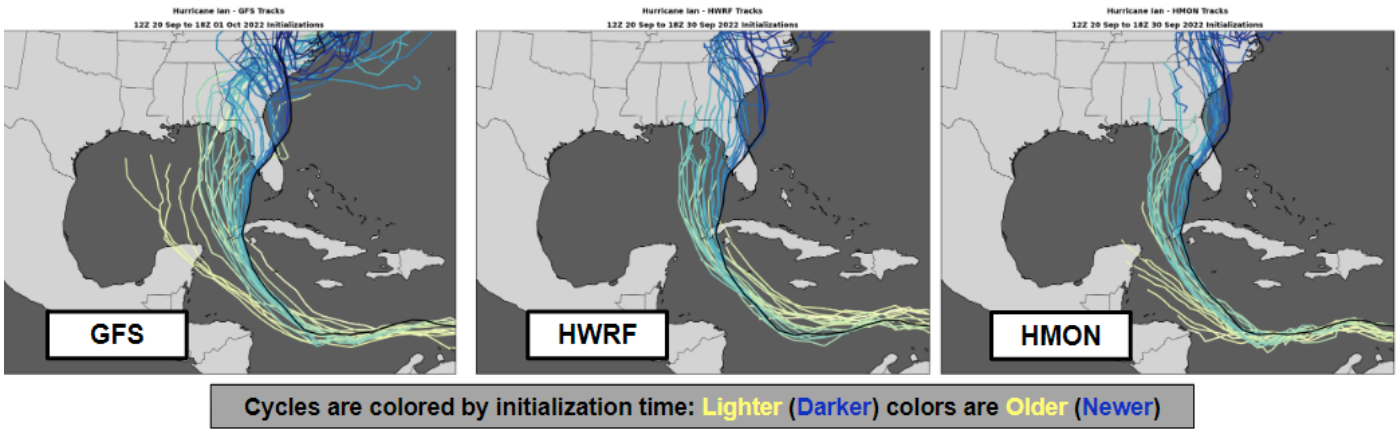
- The position of the large-scale trough over the eastern US was critical to Ian's forecasted track over the Gulf of Mexico, with a less amplified trough resulting in more southerly steering flow/northward track in GFS/GEFS
- Ian's intensity in the GFS/GEFS may have also been a factor (stronger TCs with greater vertical depth are impacted more by steering flow than shallower/weaker TCs)

Global deterministic NWP



- GFS and EC started to forecast a strong TC over the western Caribbean/Gulf of Mexico at 12Z 9/19 (~9 days prior to FL landfall), which corresponds to when the number of <1000-hPa GEFS members increased to ~30%
- All GFS and EC runs initialized after 12Z 9/19 also showed a TC over the Caribbean/Gulf of Mexico, with the GFS forecasting TCs that were typically stronger and further west than those in the EC at Days 6–9

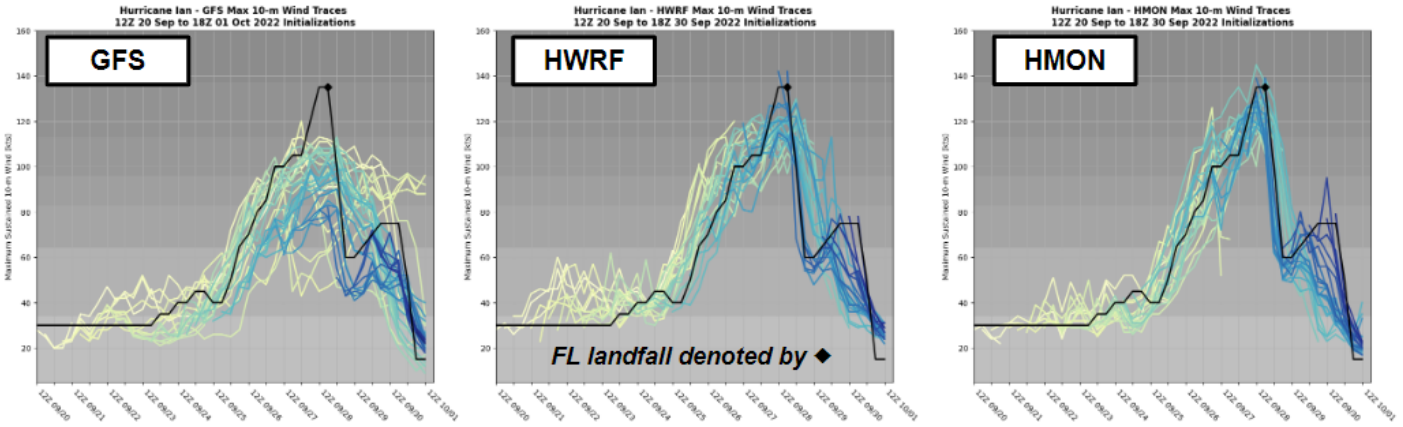
Regional deterministic NWP



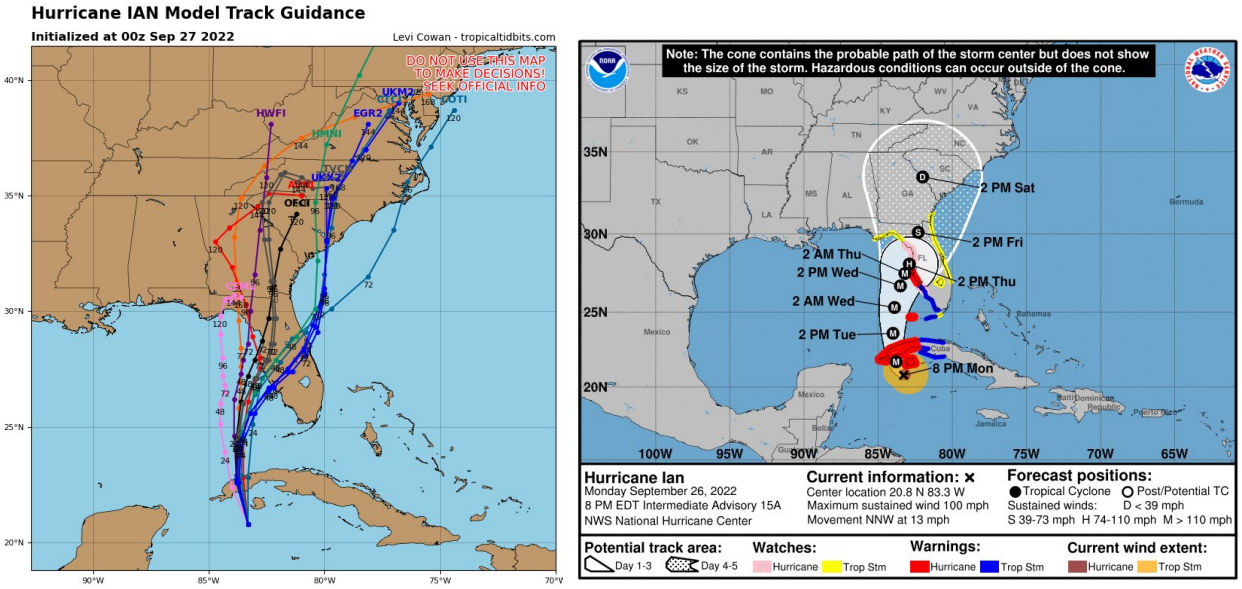
- **HWRF and HMON** also had a left-of-track bias on Ian's northward turn toward Cuba and Florida

- **Initial HWRF and HMON** guidance showing landfall in Florida predicted it would occur along the state's panhandle
- **HMON** guidance adjusted and showed landfall south of Tampa Bay earlier than HWRF

Intensity guidance



Track forecasts



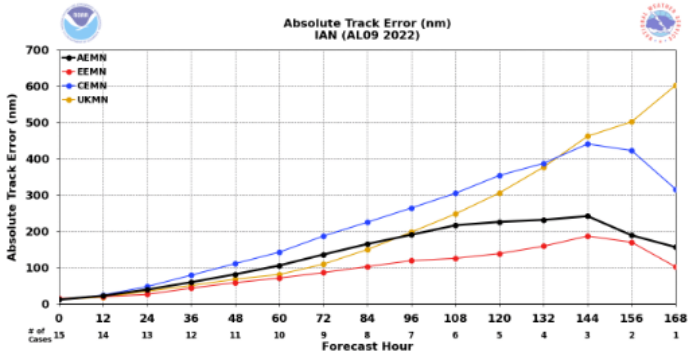
Interpretation/guidance for forecast users

What was the level of agreement between the different forecasts?

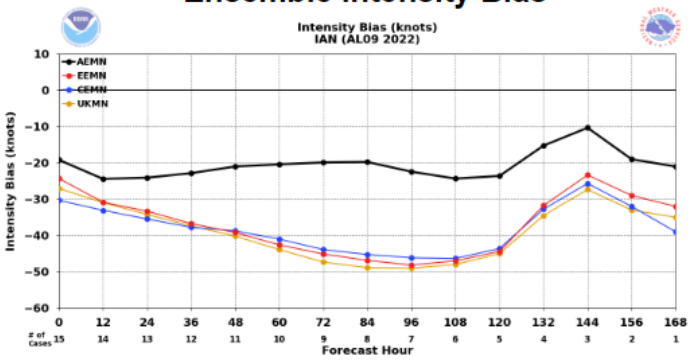
- Track guidance from all global and high-resolution hurricane models consistently displayed some degree of a left-of-track bias in forecasts of Ian's northward trek toward Cuba and Florida
- Track guidance from NCEP's models (GFS, HWRF, and HMON) generally suffered from the largest left-of-track biases. Thus, NCEP's models signaled more of a threat for the Florida Panhandle than southwest Florida until roughly two days prior to landfall
- Track guidance from the EC and especially UKM had smaller left-of-track biases than NCEP's models. The UKM provided the best and most consistent forecasts for Ian's eventual landfall in southwest Florida
- HWRF, HMON, and the GFS correctly predicted that Ian would rapidly intensify into a major hurricane. Although medium-range GFS forecasts incorrectly predicted the location of Ian's landfall, there was an early indication, with over one week's notice, that a major hurricane would move into the Gulf of Mexico

How reliable and accurate were weather forecasts at different lead times?

Ensemble Absolute Track Error

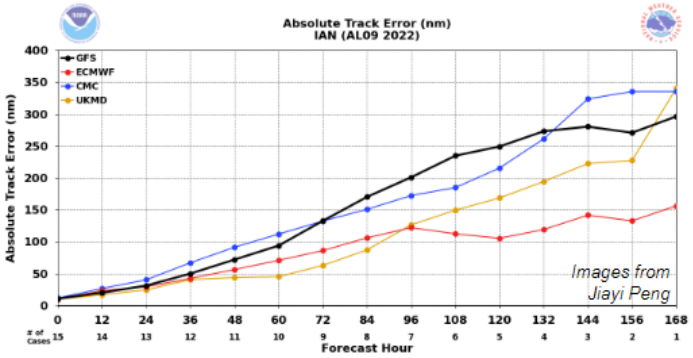


Ensemble Intensity Bias

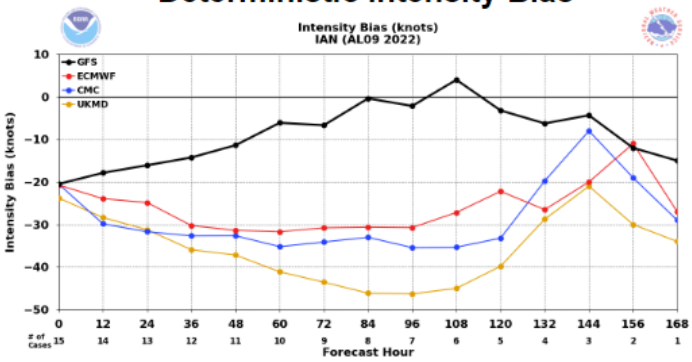


- **EC mean** had the the smallest track error of the four global ensembles at all forecast lead times.
- **CMC mean** had the largest track error of the four global ensembles at Days 1–6 due to its slowness and left-of-track bias. Similarly, **UKM Mean** had large track error at Days 4–7 due to its noteworthy slowness near FL.
- **GEFS mean** had larger track error than the **EC mean** and **UKM Mean** at Days 1–4 and the smallest intensity bias at all lead times due to its strong TCs.

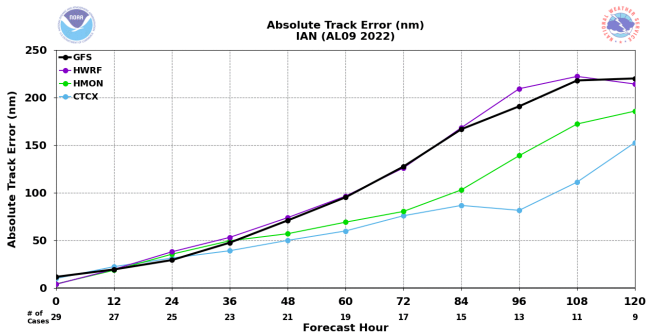
Deterministic Absolute Track Error

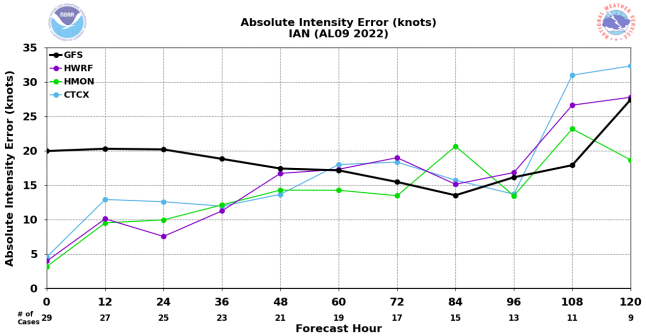


Deterministic Intensity Bias



- **EC** had the the smallest track error of the four global models at longer forecast lead times (Days 5–7)
- **UKM** had the smallest track error of the four global models at shorter forecast lead times (Days 1–4)
- **GFS** had the largest track error of the four global models in the medium range (~Days 3–5.5)
- **GFS** had the smallest intensity bias of the four global models at nearly all lead times due to its strong TCs





- **HWRF** track errors were comparable to **GFS** errors throughout the 5-day forecast period. **HMON** track errors were notably lower, but **COAMPS-TC** had the lowest track errors of the hurricane models
- Smaller track errors were generally correlated with a smaller left-of-track bias for **EC**, **UKM**, and **COAMPS-TC**. **HMON** provided some slight improvements on the **GFS** cross track bias between Days 3-5. **HWRF** had the overall worst left-of-track bias.
- During the first 48 hours of forecasts, **HMON**, **HWRF**, and **COAMPS-TC** had notably less intensity error than the **GFS**. Beyond Day 2, the **GFS** became more comparable to the hurricane models.

QPF performance

- The track forecast being too far north shifted the axis of heaviest rainfall too far to the north; there were

huge implications for the rainfall amounts in the Tampa area
- The high-resolution models did the best with the convection over southern and eastern FL, connected to the tropical moisture surge ahead of Ian and the outermost rainbands

When was the potential event first detected in the models? i
- Global ensembles and deterministic models began to forecast a strong TC over the western Caribbean/Gulf of Mexico by 12Z 9/19/22 (~9 days prior to FL landfall)

========== Observations ==========

Weather observations and analyses i

How did the observed weather relate to climatology and/or previous extreme events? i

Additional analysis i

Successes/issues/challenges experienced i

Part 2b. Supplementary information about hazards i

Wherever possible, please include references to information you provide.

Editors (Name & Institute):

Brief overview of the hazard event(s) i

Hurricane Ian pummelled the Southwest Florida Coast with significant impacts such as major storm surge, flooding rains and extreme winds. Ian made landfall near Cayo Costa, FL as a high-end Category 4 storm with maximum sustained winds of 150 mph at landfall, tying the record of the fifth strongest hurricane on record to impact the United States.

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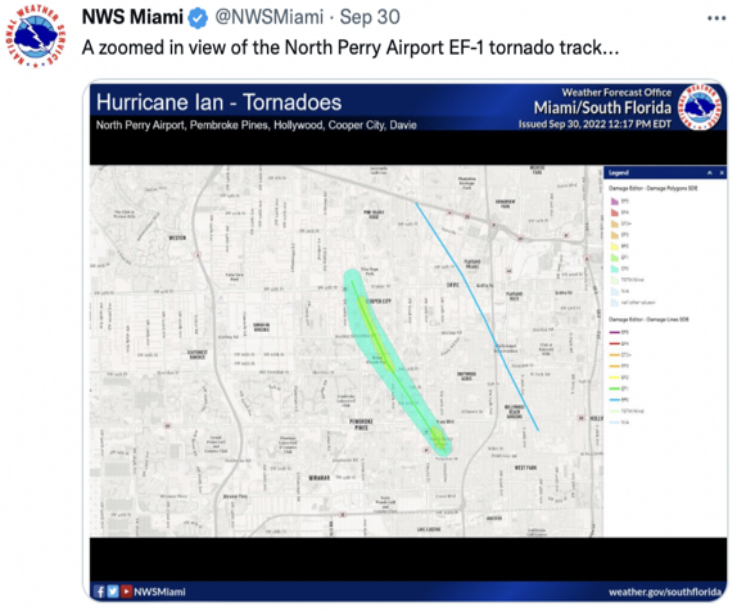
BULLETIN
Hurricane Ian Special Advisory Number  23
NWS National Hurricane Center Miami FL       AL092022
700 AM EDT Wed Sep 28 2022

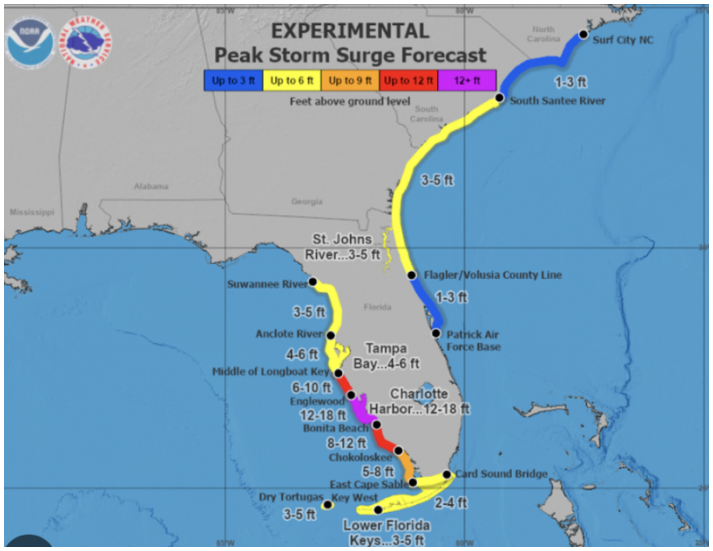
...RAPIDLY INTENSIFYING IAN FORECAST TO CAUSE CATASTROPHIC
STORM SURGE, WINDS, AND FLOODING IN THE FLORIDA PENINSULA...

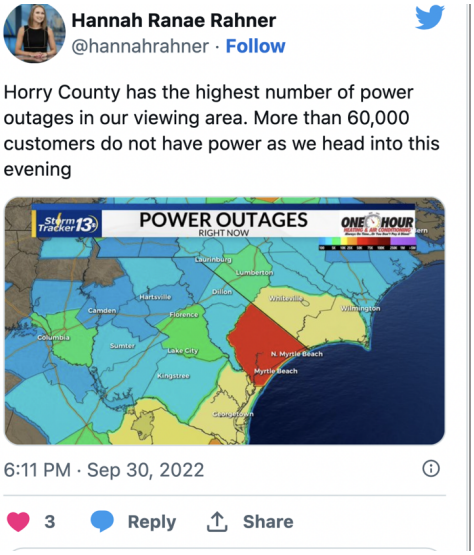

SUMMARY OF 700 AM EDT...1100 UTC...INFORMATION
-----------------------------------------------
LOCATION...25.9N 82.8W
ABOUT 65 MI...100 KM WSW OF NAPLES FLORIDA
ABOUT 80 MI...130 KM SSW OF PUNTA GORDA FLORIDA
MAXIMUM SUSTAINED WINDS...155 MPH...250 KM/H
PRESENT MOVEMENT...NNE OR 15 DEGREES AT 9 MPH...15 KM/H
MINIMUM CENTRAL PRESSURE...937 MB...27.67 INCHES
```

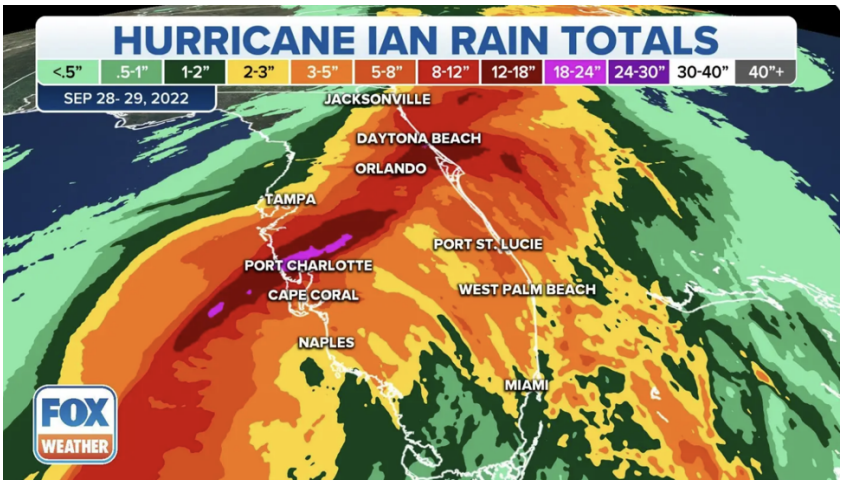
Before Ian's eye had even entered the Gulf of Mexico, outer bands from the storm were impacting areas all across the South Florida area. Tropical storm force winds extended outwards of 140 miles from the center and the storm's outer bands produced tornadoes and flooding all across South Florida. Residents in Broward County cleaned up their damage on September 29th after one of several tornadoes spawned in the area. Tornadoes uprooted trees and damaged roofs and cars in Pembroke Pines, FL. Another confirmed tornado at North Perry Airport flipped quite a few small planes.



The next day, Ian demolished portions of the west coast of Florida and it brought with it catastrophic storm surge with inundation of an unprecedented 12 to 18 feet above ground level was reported along the coastlines. Fort Myers, FL recorded its highest recorded surge in history of 7.26 feet. As the storm traveled inland, it downgraded to a tropical storm yet it brought with it extreme and destructive rainfall. 1 in 1000 year floods were reported across the state. For example, Placida, FL reported more than 15 inches in just 12 hours. Lake Wales, FL reported nearly 17 inches of rain within a day.







Once the storm trekked through the peninsula of Florida, it again went over the open water and then strengthened into a Category 1 storm on September 30th before making its final landfall in South Carolina. Heavy rain, high winds and flooding along the South Carolina coast were reported after Ian was the first landfall of a hurricane in South Carolina in nearly six years. There were many power outages as a result of Ian's intense conditions in the Carolinas as shown in the image below.

Ian weakened over land and became a post tropical cyclone around 5:00 PM on September 30th and eventually dissipated over Southern areas of Virginia late on October 1st.

https://en.wikipedia.org/wiki/Hurricane_Ian
https://www.nesdis.noaa.gov/news/hurricane-ians-path-of-destruction
https://www.local10.com/news/local/2022/09/29/broward-county-residents-clean-up-after-hurricane-ians-outer-bands-spawned-tornadoes-flooding/
https://www.miamiherald.com/news/weather/hurricane/article267368712.html
https://www.usatoday.com/story/news/2022/10/19/hurricane-ian-new-criticism-for-the-cone-of-uncertainty/10529838002/

========== Hazard forecast ==========

Observational data used in the hazard forecast or assimilated into the hazard model i

```
ZCZC MIATCDAT4 ALL
TTAA00 KNHC DDHHMM

Hurricane Ian Special Discussion Number  23
NWS National Hurricane Center Miami FL       AL092022
700 AM EDT Wed Sep 28 2022

This special advisory is being issued to update Ian's current and
forecast intensity.  Recent NOAA and Air Force Reserve Hurricane
Hunter flight-level winds are as high as 160 kt, with SFMR data
around 135 kt, with a central pressure down to 937 mb.  This
supports a current intensity of 135 kt.

The forecast intensity is raised to 135 kt at landfall, and we are
now forecasting a catastrophic storm surge of 12 to 16 ft from
Englewood to Bonita Beach, Florida.  No other significant changes
were made to the forecast.
```

In order to assist in predicting hazards, the National Oceanographic and Atmospheric Administration (NOAA) used Hurricane Hunters in order to retrieve aircraft data of the atmosphere and inside the storm before landfall in order to predict possible intensification events and impacts on land. This data is used in a variety of models for hazard forecasts. The Stepped Frequency Microwave Radiometers (SFMR) aid in storm surge forecasts as they measure wind

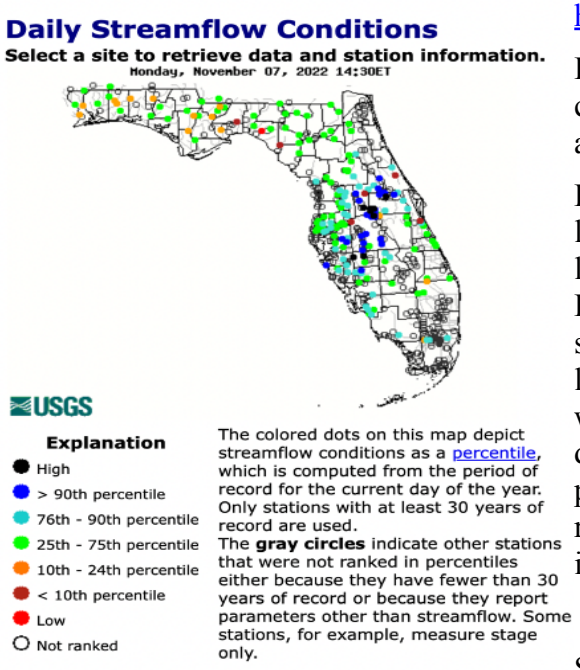
speeds over the ocean and rain rate. This data is assimilated into models for storm surge forecasts.

https://www.nhc.noaa.gov/archive/2022/al09/al092022.discus.023.shtml?text

Shown above is an example of aircraft data used in the National Hurricane Center forecast advisory for Hurricane Ian on Wednesday, September 28, referencing instruments such as the SFMR.

Additionally, The USGS uses information gathered across the country to assemble the Coastal Change Hazards Portal that makes predictions of storm surge and potential flooding impacts. It utilizes observations of beach morphology to predict impact on specific beaches when come into contact with storm surge.

The USGS gathers streamflow data by constructing a gage house along a river with equipment that measures the water surface, using a stilling well, bubble system, or wire-weight gage. Additionally, instruments measure water quality. Velocity is also measured using a current meter. This data is used to forecast floods.
https://www.usgs.gov/centers/dakota-water-science-center/howwhy-does-usgs-collect-streamflow-data

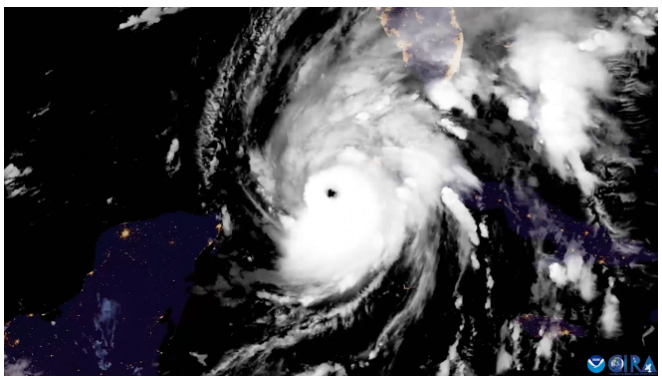


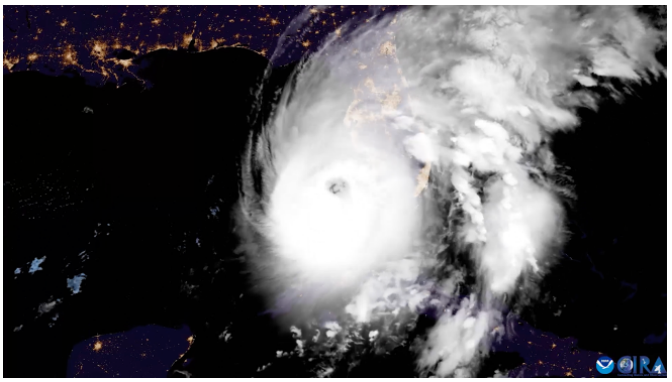
https://waterdata.usgs.gov/fl/nwis/rt

Example of current streamflow conditions. Past streamflow conditions, such as conditions during Hurricane Ian, are not accessible.

Basic satellite imagery data is used to observe Ian before landfall in order to predict possible size changes and adjust locations of forecasted hazards. For example, when Hurricane Ian began shifting more towards the southwestern coast of Florida, scientists could adjust the location of inland flooding predictions and which counties would be affected by significant storm surge. More detailed, IR images of Hurricane Ian could help forecasters predict events such as an eyewall replacement cycle or rapid intensification event, which would possibly have increased the extent of storm surge predictions.

Shown below is GOES-16 satellite images of Hurricane Ian at two different times as it approaches Florida.





Comment on the adequacy of observations available for the hazard forecast i

Like any other infrastructure, hazard observation networks are at risk of taking damage during a tropical cyclone. Florida's forecast buoys, sail drones, webcams, radar stations, and cell phone towers are all parts of this network and were all potentially impacted by hurricane Ian. It appears that most of the buoys of the Florida coast in Ians path withstood the storm's powerful wind and waves. The data they collected was instrumental in determining Ian's power offshore, especially as it rapidly intensified on the days leading up to landfall. Saildrone data seems to be difficult to find for Ian but since the drones have been carefully

designed to withstand the forces of hurricanes it is reasonable to assume they performed adequately if deployed into Ian. Webcams placed on the beaches near Ians landfall proved to be important indicators of the storm's power to the everyday citizen. Much of the webcam footage is easily available on the internet, and social media has allowed individuals and media sources to quickly share the images and video footage. Hundreds of re-posts of the footage spread the data quickly around the country. Some webcams placed in storm-surge impacted areas may have been swept away with the buildings they were perched on but many likely survived as, unlike the buoys and drones, they are commonly attached to large, grounded structures. All the radar stations in the state appeared to remain intact throughout the duration of the storm. This is likely due to the fact that none of Florida's doppler radar stations are located near the area of Ian's landfall, meaning that none of them would have suffered the worst impacts of the storm.

About ⅕ Florida cell phone towers within Ian's path were knocked out during the storm. This meant that many people couldn't call for the help they may have needed and that researchers may have been unaware of the full scope of Ian's impacts in these receptionless areas. It is not uncommon for hurricane researchers, forecasters or local officials to use on the ground footage of storm damage sent in by the citizens actually living through the event. This data can be a valuable resource when trying to understand the full scope of a storm's power, whether that be for academic purposes or to warn others in the storm's path of its danger. Without the loss of these cellphone towers there could have been more of this data available.

http://www.hurricanescience.org/science/forecast/forecasting/forecastprocess/

https://secoora.org/eyes-on-ian-data-resources/

https://mashable.com/article/hurricane-intensity-climate-change-drones

https://mashable.com/article/hurricane-ian-landfall-fort-myers-florida-webcams-road-conditions

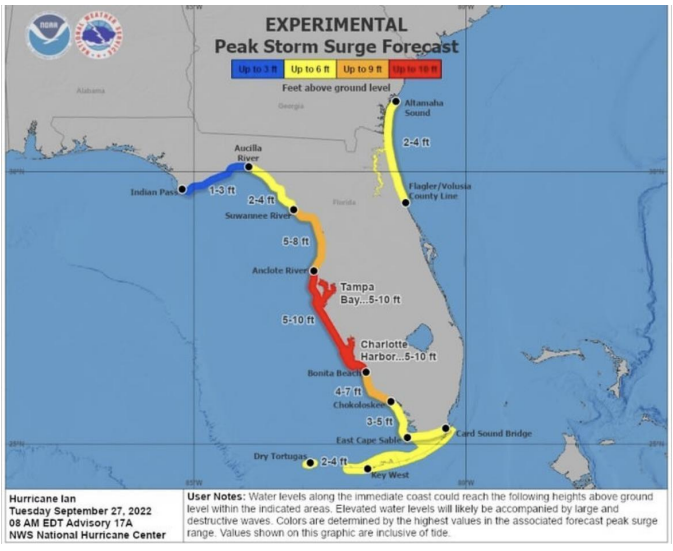
http://climateviewer.org/history-and-science/atmospheric-sensors-and-emf-sites/maps/nexrad-doppler-radar-stations/

https://www.benton.org/headlines/how-cellular-carriers-prepared-and-responded-hurricane-ian

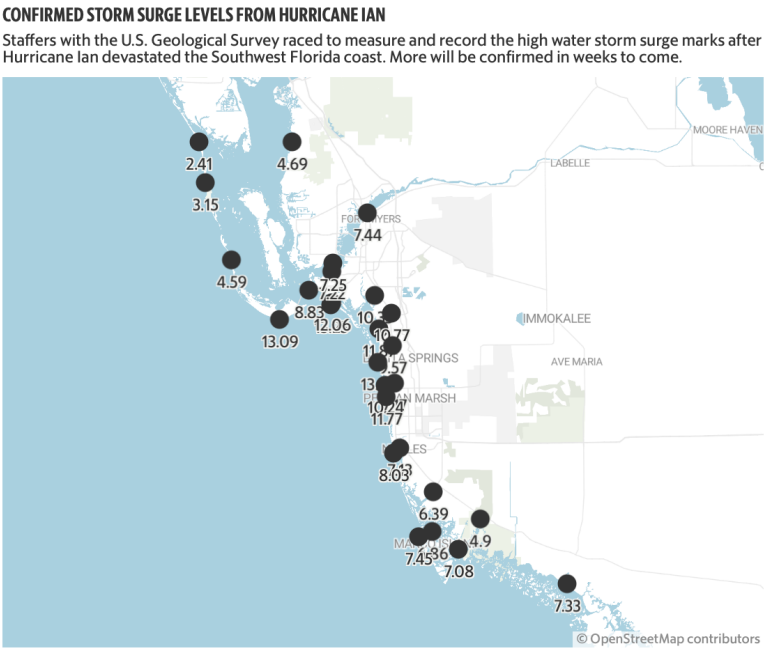
Hazard prediction models/tools i

Name	Resolution	Ensemble size	Forecast length

Storm surge was an intense factor in Hurricane Ian and it absolutely demolished areas. Modeling storm surge incorporates statistical data such as historical data to develop relationships between statistics, deterministic numerical models and numerical model ensembles. Surge forecasts can be made from physical equations and are dependent on accurate meteorological input. Storm surge vulnerability can be best approached through numerical model ensemble. For Hurricane Ian, the storm surge forecast is shown in Figure __. SLOSH has many different strengths from estimating flow through barriers/gaps/passes, inland inundation, overtopping of levees and incorporation of astronomical tide. Storm surge models are extremely dependent on the accuracy of the meteorological input and this dominates over storm surge model specifications. For Hurricane Ian, the storm surge prediction forecast had to be changed.



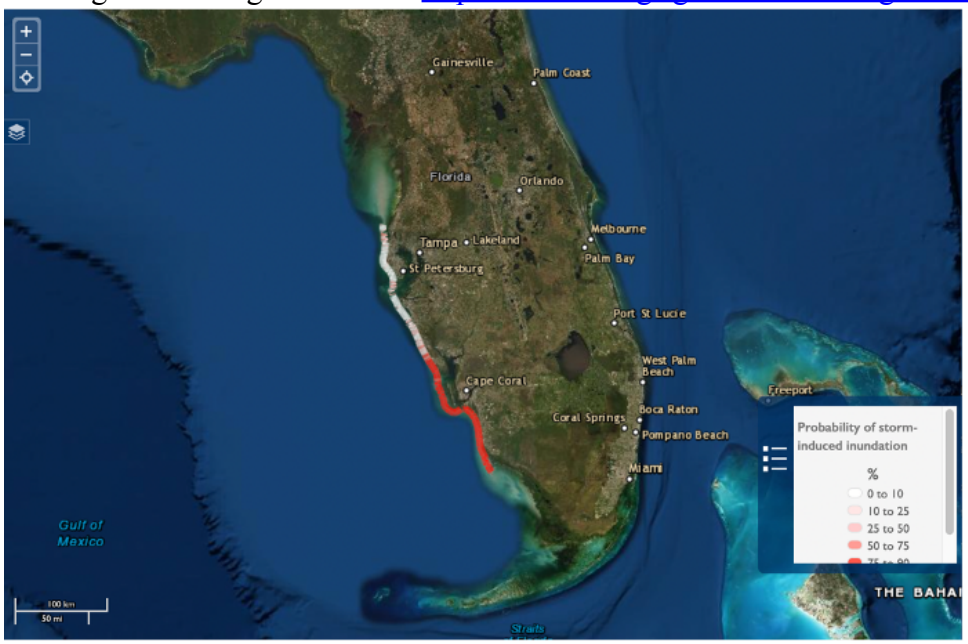
The first image shows the prediction for storm surge on Tuesday, September 27th, 2022 for Hurricane Ian. As shown, main values of 5-10 feet were forecast for areas from Tampa Bay to Charlotte Harbor with other values ranging from 2-4 feet to 5-8 feet. However, this model forecast drastically changed within a day. By the time of 11 AM on Wednesday, September 28th, 2022, all values changed. The new forecast had forecasted a 12-18 foot surge for areas ranging from Charlotte Harbor to Englewood with higher values along the Southwestern Florida coast and lower values to the North.



USGS data analyzed that surge rose as high as 13.23 feet in Fort Myers Beach which equates to more than 9 feet of ocean water above buildings that are normally dry and sit a few feet above sea level. This matches for the most part with the last forecast for storm surge in Hurricane Ian. However there was some discrepancy in Lee County where values were forecasted to be 8-12 feet but there are multiple values that reached above 12 feet.

Hazard forecast outputs and examples i

Flooding/Storm Surge Forecasts: https://marine.usgs.gov/coastalchangehazardsportal/



The USGS, United States Geological Survey, provided a variety of coastal erosion hazard forecasts on an online portal, Coastal Change Hazards Portal, that was accessible by the public and local officials.
Pictured above is an example of just one hazard predicted by the USGS, which is probability of storm-induced inundation. This graphic depicts that storm surge would cause inundation during a direct landfall of Hurricane Ian, which was developed from NHC Advisory 23 on 8:00 a.m. September 28th, 2022.

Wind Speed Probabilities – National Hurricane Center
https://www.nhc.noaa.gov/archive/2022/IAN.shtml

Tuesday, September 27 2100 UTC

- - - - WIND SPEED PROBABILITIES FOR SELECTED LOCATIONS - - - -

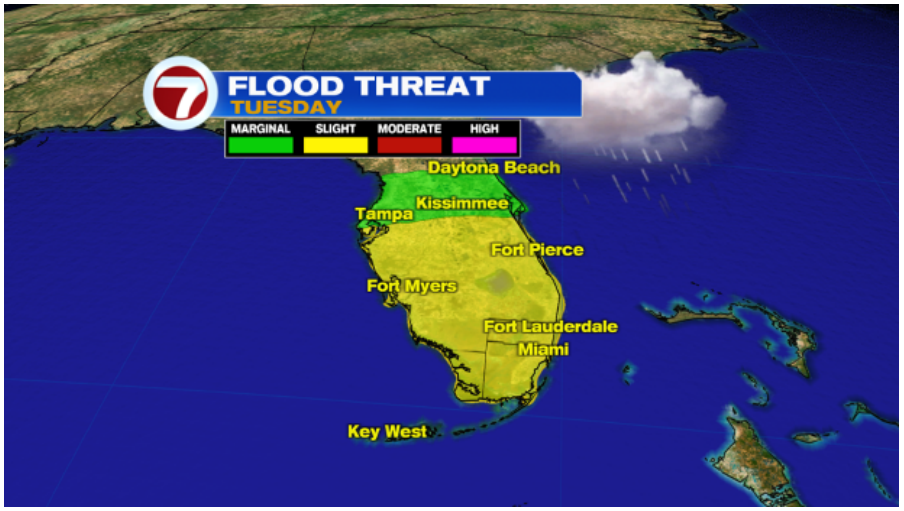
TIME PERIODS		FROM 18Z TUE TO 06Z WED	FROM 06Z WED TO 18Z WED	FROM 18Z WED TO 06Z THU	FROM 06Z THU TO 18Z THU	FROM 18Z THU TO 18Z FRI	FROM 18Z FRI TO 18Z SAT	FROM 18Z SAT TO 18Z SUN
FORECAST HOUR		(12)	(24)	(36)	(48)	(72)	(96)	(120)
LOCATION	KT							
KEY WEST FL	34	99 X(99)	X(99)	X(99)	X(99)	X(99)	X(99)	
KEY WEST FL	50	27 3(30)	1(31)	X(31)	X(31)	X(31)	X(31)	
KEY WEST FL	64	5 1(6)	X(6)	X(6)	X(6)	X(6)	X(6)	
NAPLES FL	34	89 10(99)	1(99)	X(99)	X(99)	X(99)	X(99)	
NAPLES FL	50	24 57(81)	3(84)	X(84)	1(85)	X(85)	X(85)	
NAPLES FL	64	4 37(41)	4(45)	X(45)	1(46)	X(46)	X(46)	
FT MYERS FL	34	69 29(98)	1(99)	X(99)	X(99)	X(99)	X(99)	
FT MYERS FL	50	6 70(76)	8(84)	1(85)	1(86)	X(86)	X(86)	
FT MYERS FL	64	1 40(41)	12(53)	1(54)	1(55)	X(55)	X(55)	
VENICE FL	34	64 34(98)	1(99)	X(99)	1(99)	X(99)	X(99)	
VENICE FL	50	6 76(82)	10(92)	1(93)	X(93)	X(93)	X(93)	
VENICE FL	64	2 48(50)	20(70)	2(72)	X(72)	X(72)	X(72)	
TAMPA FL	34	11 69(80)	13(93)	1(94)	1(95)	X(95)	X(95)	
TAMPA FL	50	2 28(30)	30(60)	4(64)	2(66)	X(66)	X(66)	
TAMPA FL	64	X 7(7)	21(28)	5(33)	2(35)	X(35)	X(35)	
CEDAR KEY FL	34	4 24(28)	26(54)	8(62)	6(68)	X(68)	X(68)	
CEDAR KEY FL	50	X 3(3)	8(11)	6(17)	4(21)	X(21)	X(21)	
CEDAR KEY FL	64	X X(X)	2(2)	3(5)	3(8)	X(8)	X(8)	

Wednesday, September 28 0900 UTC

- - - - WIND SPEED PROBABILITIES FOR SELECTED LOCATIONS - - - -

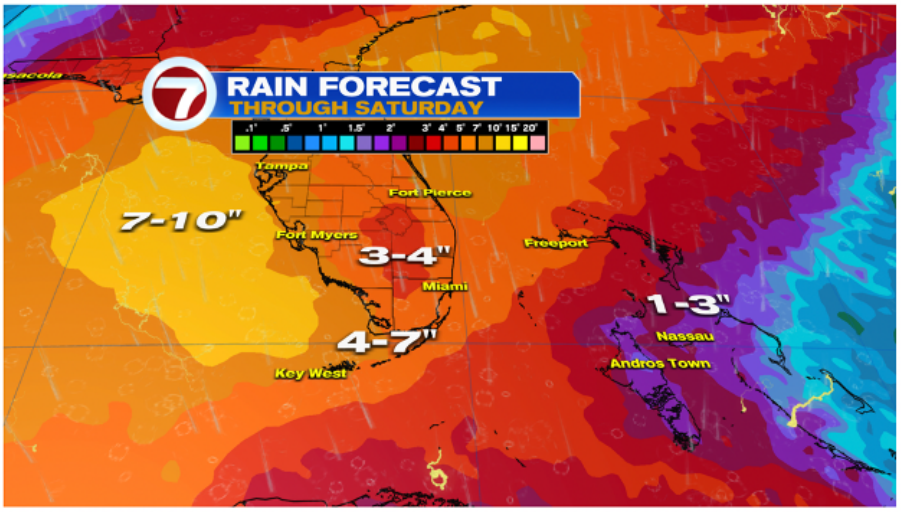
TIME PERIODS		FROM 06Z WED TO 18Z WED	FROM 18Z WED TO 06Z THU	FROM 06Z THU TO 18Z THU	FROM 18Z THU TO 06Z FRI	FROM 06Z FRI TO 06Z SAT	FROM 06Z SAT TO 06Z SUN	FROM 06Z SUN TO 06Z MON
FORECAST HOUR		(12)	(24)	(36)	(48)	(72)	(96)	(120)
LOCATION	KT							
KEY WEST FL	34	99 X(99)	X(99)	X(99)	X(99)	X(99)	X(99)	
KEY WEST FL	50	3 1(4)	X(4)	X(4)	X(4)	X(4)	X(4)	
NAPLES FL	34	99 X(99)	X(99)	X(99)	X(99)	X(99)	X(99)	
NAPLES FL	50	93 1(94)	X(94)	X(94)	X(94)	X(94)	X(94)	
NAPLES FL	64	29 3(32)	X(32)	X(32)	X(32)	X(32)	X(32)	
FT MYERS FL	34	99 X(99)	X(99)	X(99)	X(99)	X(99)	X(99)	
FT MYERS FL	50	95 2(97)	X(97)	X(97)	X(97)	X(97)	X(97)	
FT MYERS FL	64	55 12(67)	X(67)	X(67)	X(67)	X(67)	X(67)	
VENICE FL	34	99 X(99)	X(99)	X(99)	X(99)	X(99)	X(99)	
VENICE FL	50	94 3(97)	X(97)	X(97)	X(97)	X(97)	X(97)	
VENICE FL	64	67 16(83)	X(83)	X(83)	X(83)	X(83)	X(83)	
TAMPA FL	34	94 4(98)	1(99)	X(99)	X(99)	X(99)	X(99)	
TAMPA FL	50	28 38(66)	3(69)	X(69)	X(69)	X(69)	X(69)	
TAMPA FL	64	4 20(24)	2(26)	X(26)	X(26)	X(26)	X(26)	
CEDAR KEY FL	34	26 31(57)	8(65)	X(65)	X(65)	X(65)	X(65)	
CEDAR KEY FL	50	3 4(7)	3(10)	X(10)	X(10)	X(10)	X(10)	
CEDAR KEY FL	64	X 1(1)	1(2)	X(2)	X(2)	X(2)	X(2)	

Shown above are two times depicting the wind speed probability hazard forecasts from the National Hurricane Center. These tables show probabilities for one minute sustained winds of at least 34, 50, and 64 kt, as seen in the leftmost column of values. These forecasts range from An X represents less than 1% probability. The first table shows forecasts from 18Z Tuesday all the way to 18Z Sunday, and the second table shows forecasts for 06Z Wednesday, spanning to 06Z Monday.



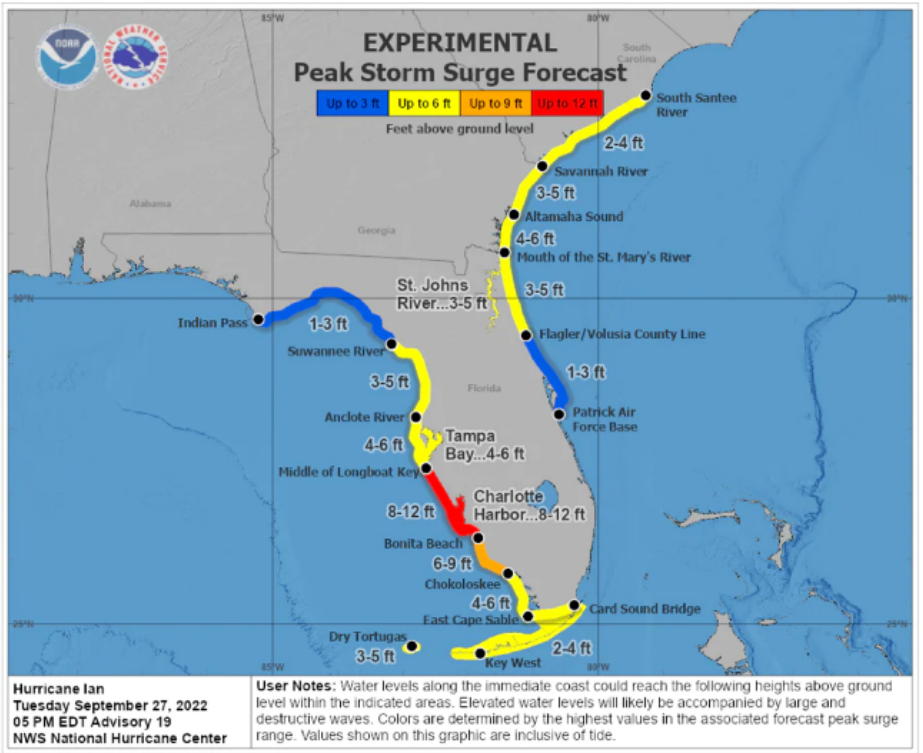
https://wsvn.com/weather-blog/tropical-storm-ian-expected-to-rapidly-intensify-with-impacts-to-florida-this-week/

Flood threat for Tuesday, September 27 in Southern Florida*



Total rain forecast*

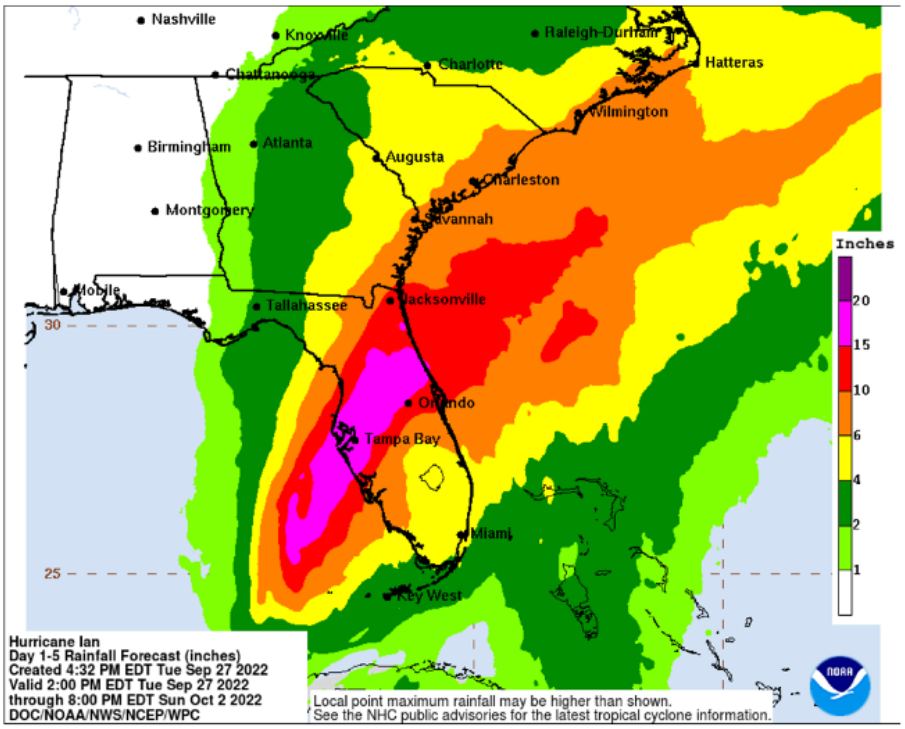
*Both of these charts were published on Monday, September 25



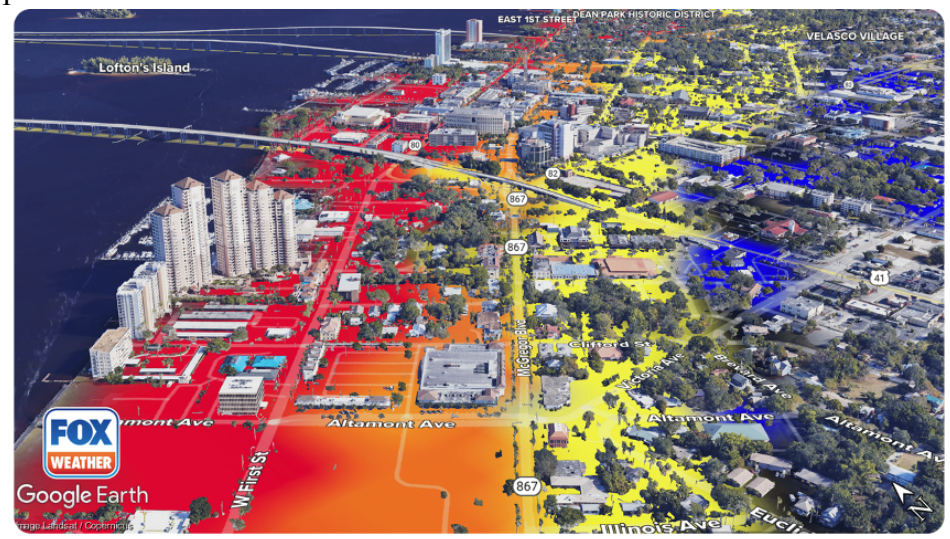
Storm Surge and Freshwater Flooding

https://www.washingtonpost.com/climate-environment/2022/09/27/hurricane-ian-forecast-florida-track/

Peak storm surge forecast provided by the National Hurricane Center on Tuesday, September 27

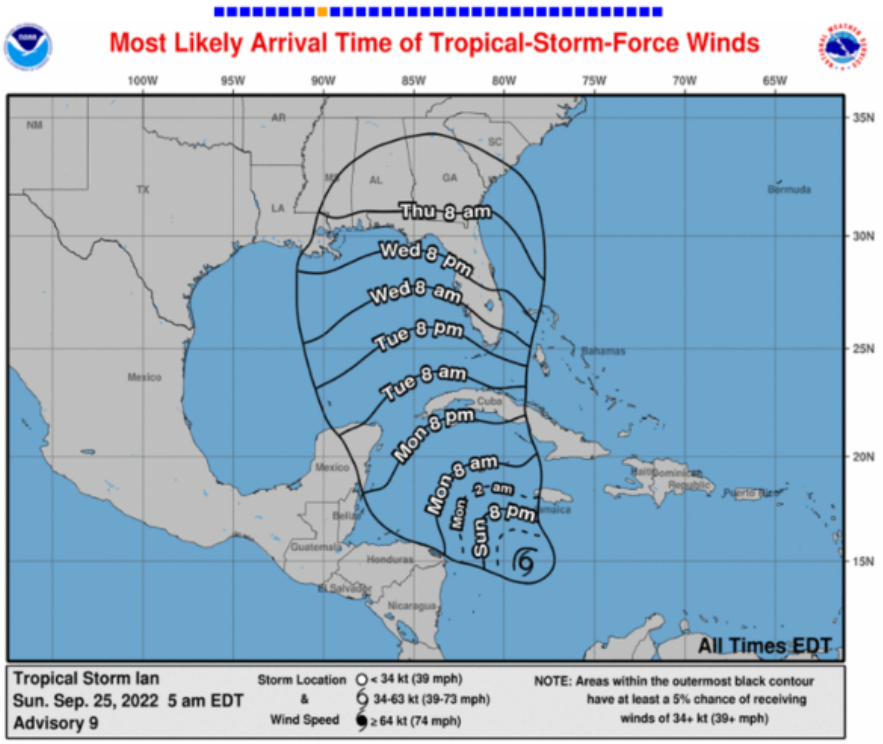


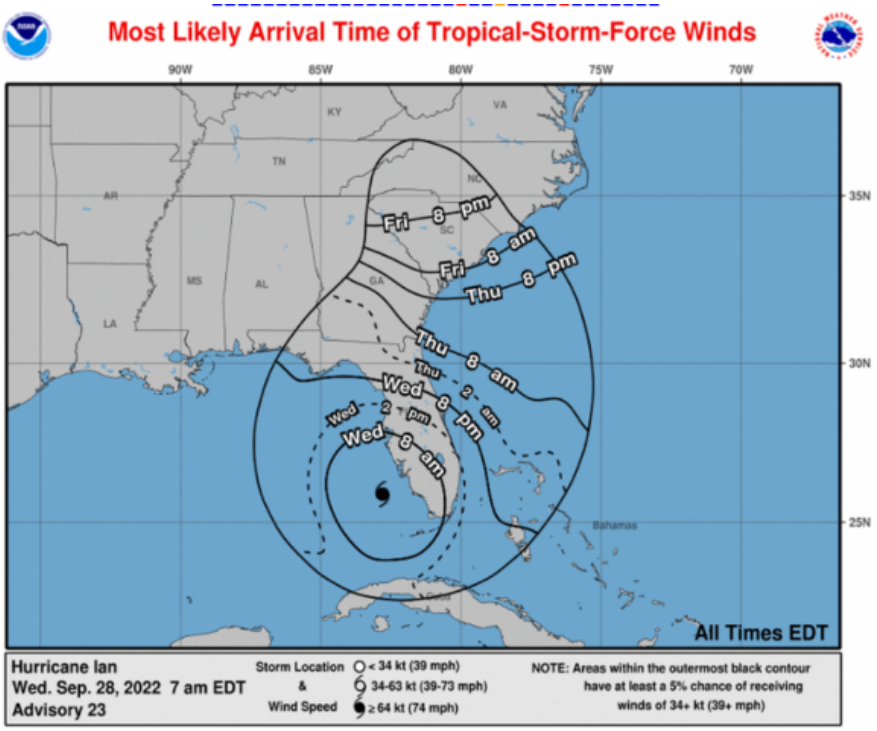
Rain and freshwater flooding forecast from the National Hurricane Center, valid 2:00 P.M. Tuesday, September 27th to 8:00 P.M. October 2nd.



Model of downtown Fort Myers and the potential storm surge flooding. Red shows areas that could receive over 9 feet of flooding, orange is up to 9 feet of flooding, yellow is may see up to 6 feet of flooding, and blue is up to 3 feet of flooding.

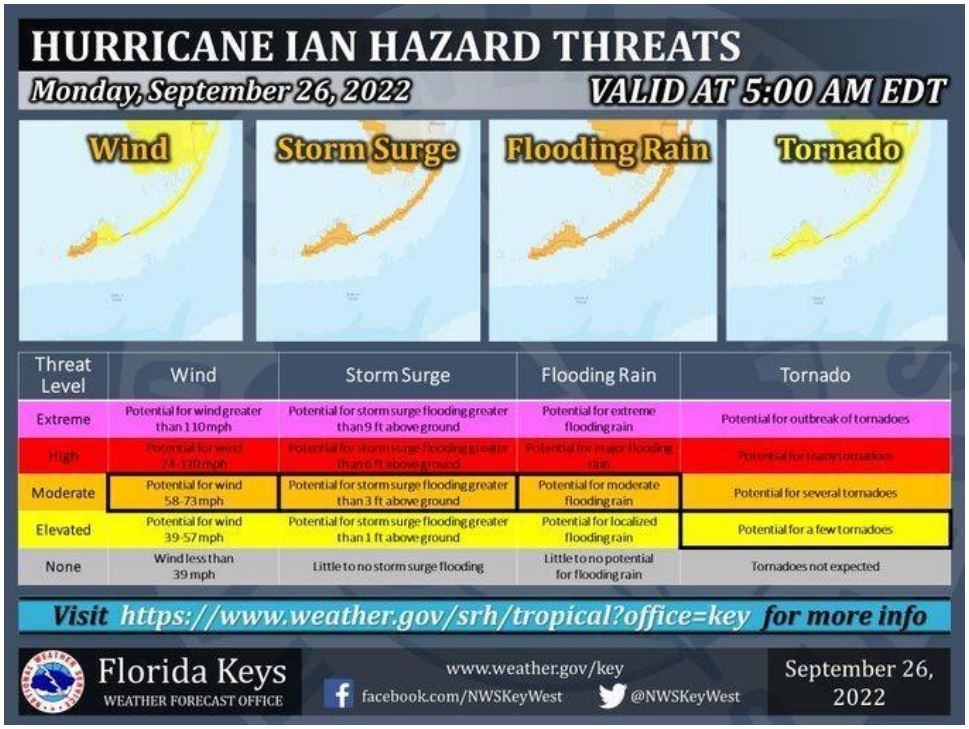
https://www.foxweather.com/extreme-weather/hurricane-ian-flood-florida-worst-case-scenario-nhc





https://www.nhc.noaa.gov/archive/2022/IAN_graphics.php?product=most_likely_toa_no_wsp_34

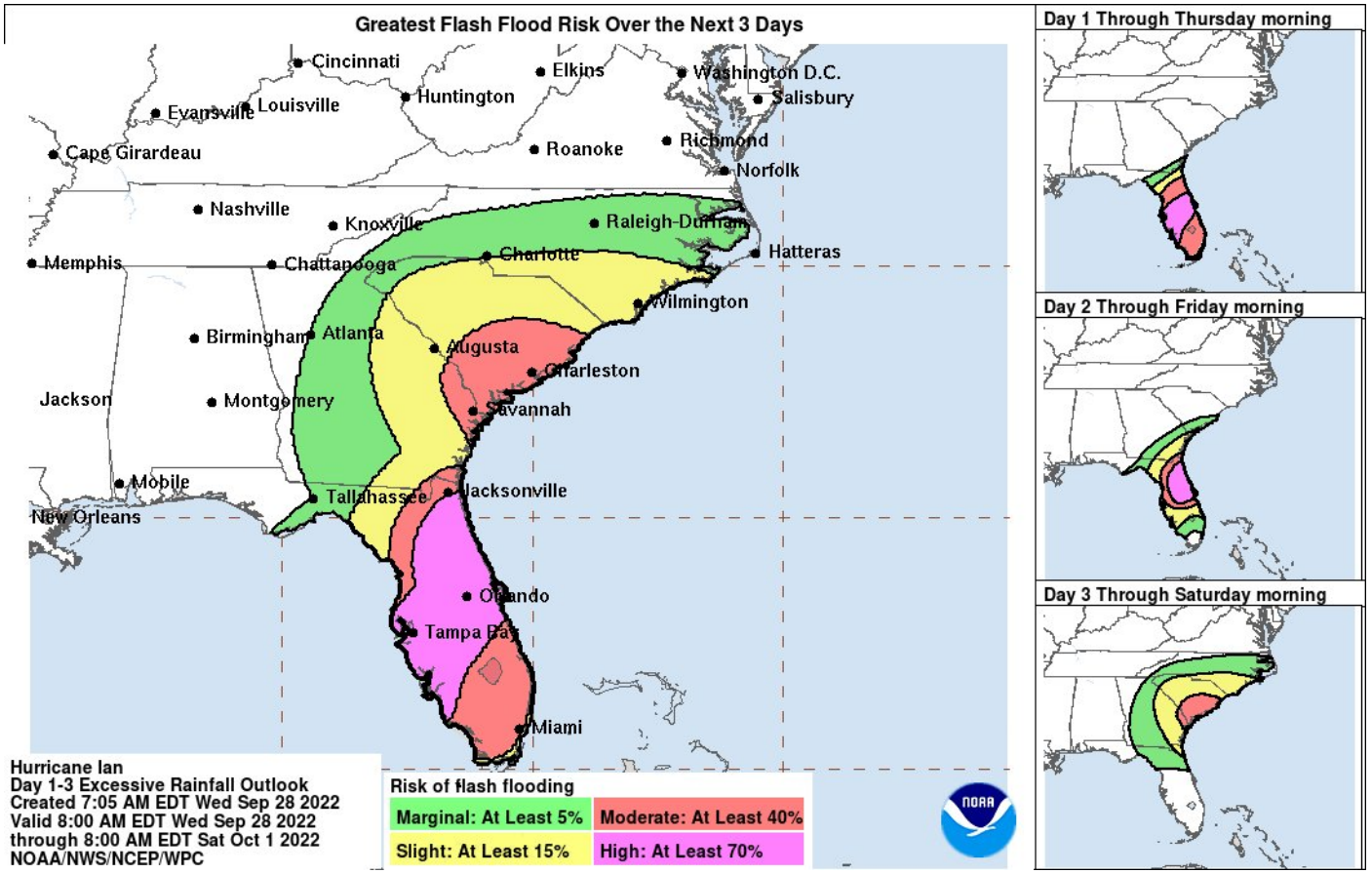
Shown above is two different time steps from the most likely arrival time of tropical-storm force winds produced by the National Hurricane Center.



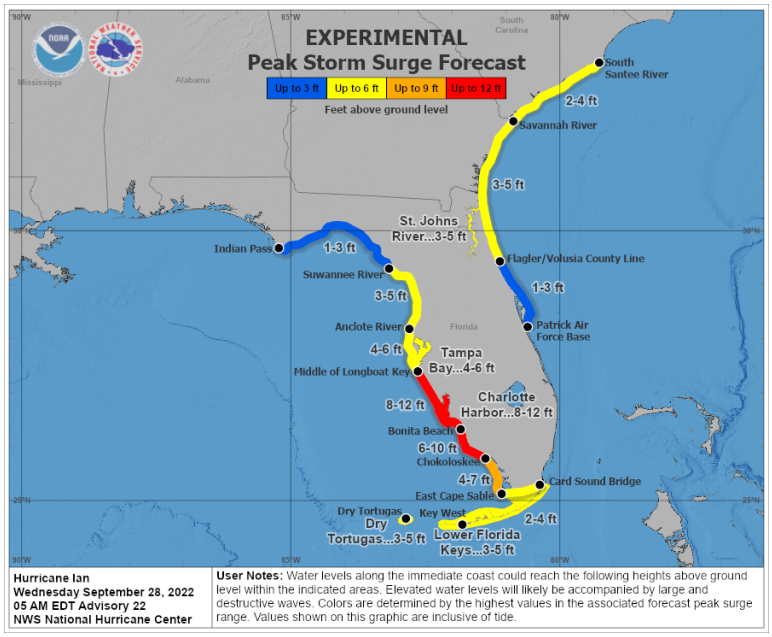
Hazard analysis for Key West on September 26, 2022

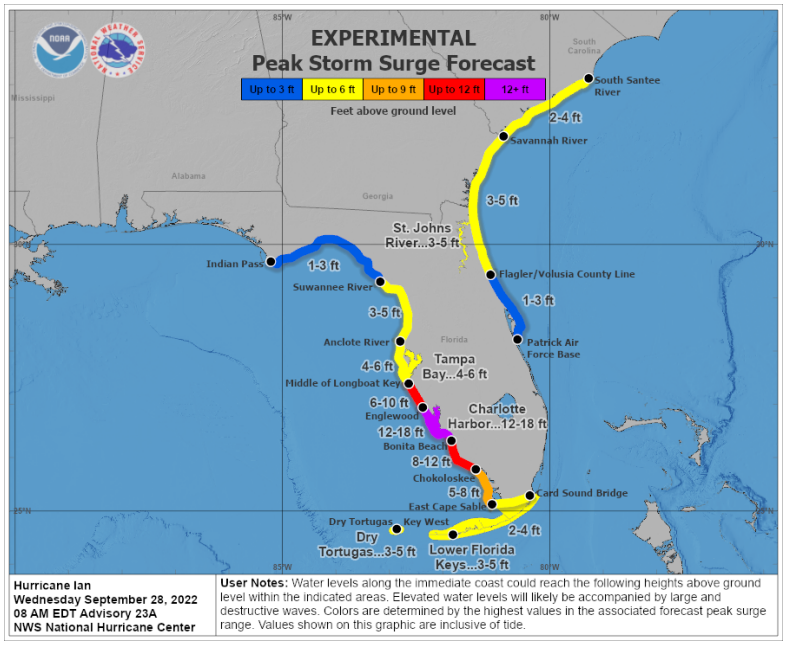
https://twitter.com/NWSKeyWest/status/1574375843366899712?ref_src=twsrc%5Etfw|twcamp%5Etweetembed|twterm%5E1574375843366899712|twgr%5E3c33e8a14b455caf9f989846181550fc4ec6b7ad|twcon%5Es1_&ref_url=https%3A%2F%2Fwww.wlrn.org%2Fweather%2F2022-09-26%2Fian-becomes-a-hurricane-alerts-issued-from-tarpon-springs-southward

Flash flood risk forecasts from NWSWPC (don't think these are archived? Got it from twitter)



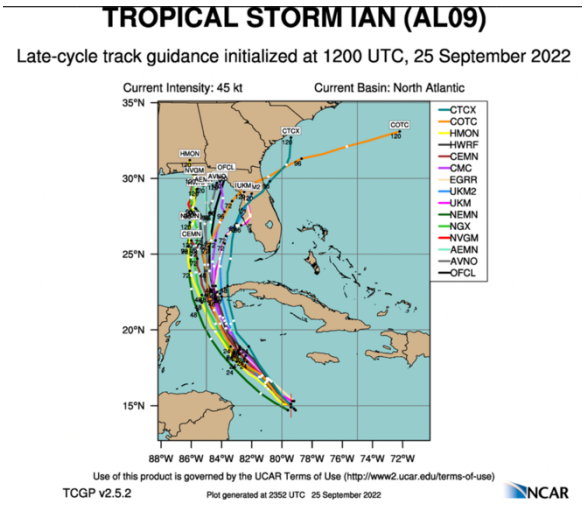
Storm surge forecasts from NHC (can't see these in the archive so these are from twitter)





How reliable and accurate were the hazard forecasts? i

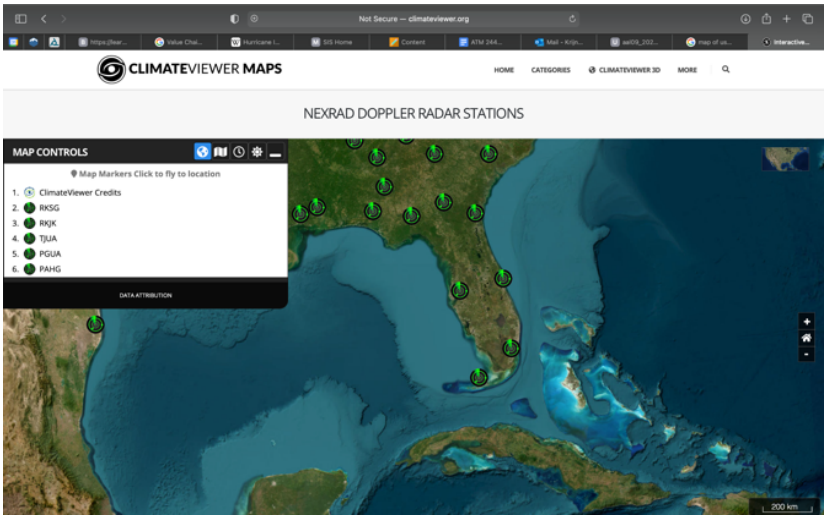
Hurricane Ian has proved to be a notoriously difficult storm to predict. Just a few days prior to the hurricane's strike, the ECMWF and UKMET predicted landfall over Tampa Bay while the GFS predicted landfall north of that, somewhere over the Florida Panhandle. In actuality, the storm landed 89 miles south of Tampa in Cayo Costa (Fort Myers area).



The United States' Global Forecasting System (GFS), which had performed the best during the 2021 hurricane season, was consistently more inaccurate than the other major models and the last to shift its landfall prediction to the correct location. This has caused many US media sources to question the overall validity of the model. In the aftermath of the storm, it was common to read headlines like "How a trusted weather model fumbled the forecast for Hurricane Ian" issued by the Washington Post, or "How One Computer Forecast Model Botched Ian" issued by AP News.

Since its folly, the GFS has been under review by meteorologists attempting to pinpoint the factors it seemed to have overlooked. Many have pointed to the model's failure to predict the strength of a cold air mass moving south from canada which interrupted a high pressure system over the northeastern United States and allowed Ian to veer eastward. Experts have acknowledged this error as critical and will continue to investigate the GFS's shortcomings and improve the system accordingly. In the short term though, the forecasting of one storm cannot determine the value of the model as a whole, so it's unlikely any immediate update will be necessary.

Meanwhile, some meteorologists argue that the greatest failure associated with predicting Ian's path was not in the computer model forecasts themselves, but in the communication of those forecasts to the public. The cone of uncertainty, a popular graphic which highlights an area in which all points have a ⅔ likelihood of receiving the center of an incoming hurricane, is viewed as a major culprit in this regard. Technically, Ian's actual landfall location was never outside the cone. This means that throughout every forecast beginning 5 days prior to landfall, there was always at least a 67% chance landfall would occur where it did. Yet, as the storm crept closer to Cayo Costa, this reality was not reflected in the public's perception.



While forecasts fell short in Ian's track predictions, they remained accurate when it came to Ian's intensity predictions. NOAA's HWRF models confidently predicted Ian's rapid intensification over the Gulf of Mexico's warm waters days prior to the event. The storm's maximum windspeed was predicted to be 168 mph, just 13 mph off from the highest recorded wind speed of 155 mph. It's important to note this is the highest RECORDED wind speed. At some point or another a portion of the storm's winds may very well have reached the predicted maximum speed. Forecasts also promised and delivered on the fact that Ian would be a major hurricane (category 3 or above) at the time of landfall.

https://www.washingtonpost.com/climate-environment/2022/10/07/weather-models-hurricane-ian-gfs/

https://www.youtube.com/watch?v=FuE4X2hktpA

https://apnews.com/article/hurricanes-science-storms-weather-national-oceanic-and-atmospheric-administration-358096c1e7cbff4034015b81b6d86bb3

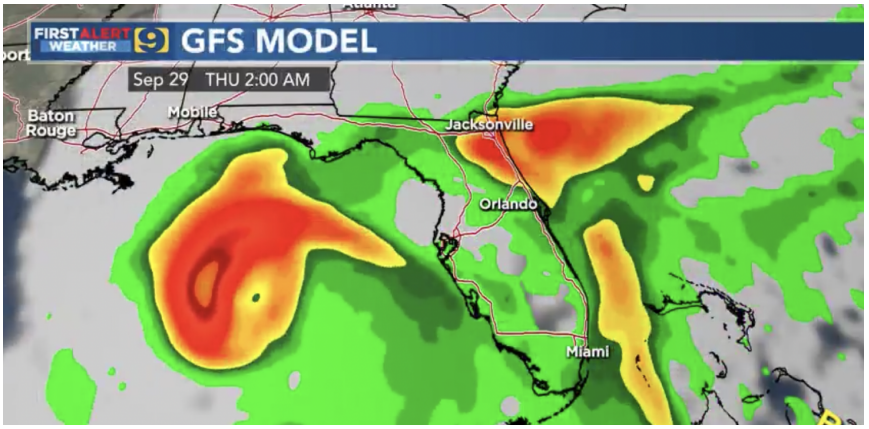
https://www.forbes.com/sites/marshallshepherd/2022/10/03/was-the-forecast-for-hurricane-ian-baddepends-on-your-perspective/?sh=11508f02676a

https://www.cnn.com/2022/10/03/weather/weather-news-ians-forecast-accuracy-mid-atlantic-flooding-wxn

https://www.washingtonpost.com/climate-environment/2022/10/01/hurricane-ian-forecast-accuracy-cone/

What process or trigger(s) identified the event as hazardous and started the warning process? i

The national hurricane center continuously monitored the progress of Hurricane Ian. There are different criteria in which the hazard becomes serious enough to provide warning advice. According to the National Weather Service, a hurricane warning is issued when "sustained winds of 64 kt (74 mph) or higher associated with a tropical cyclone are expected in 36 hours or less. These winds may be accompanied by storm surge, coastal flooding, and/or river flooding. A hurricane warning can remain in effect when dangerously high water or a combination of dangerously high water and exceptionally high waves continue, even though winds may be less than hurricane force." As Ian rapidly strengthened as it neared its approach to the state of Florida, meteorologists and the National Hurricane Center issued Hurricane Warnings due to the hazardous conditions expected to come.



For the GFS and European models, when forecasting Hurricane Ian, there were many discrepancies in where the location of the center would occur. As seen in the images, the preliminary forecasts for hurricane Ian have the GFS bringing it towards the Panhandle while the European model had more of a closer path towards Florida. Regarding intensity, the best model predicting the winds was the GFS due to the fact it had the lowest intensity errors than any of the global models. This was relevant in the understanding of when to start the warning process and when conditions would become hazardous.

Other aspects of warnings that were incorporated during Hurricane Ian was the use of high wind warnings and extreme wind warnings in areas like Sanibel, FL that required one. The criteria for a High wind warning is having sustained winds of 40 mph or higher for one hour or more or wind gusts of 58 mph or higher during any duration. An Extreme Wind Warning is issued for surface winds of 100 knots (115 MPH) or greater associated with non-convective, downslope, derecho (NOT associated with a tornado), or sustained hurricane winds expected to occur within one hour.

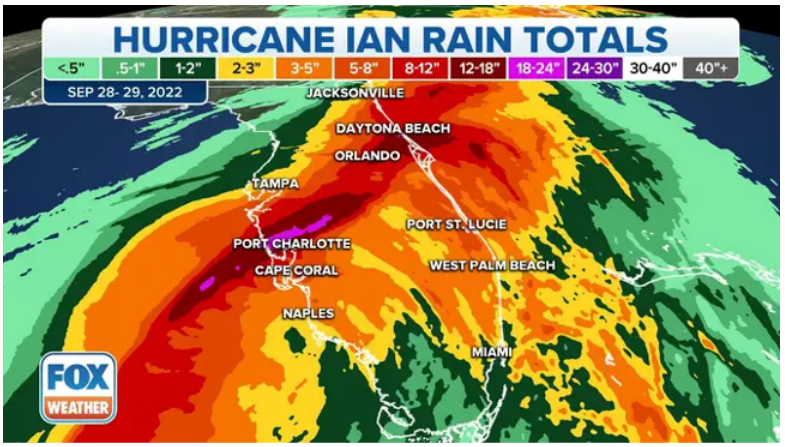
========== Hazard Observations ==========

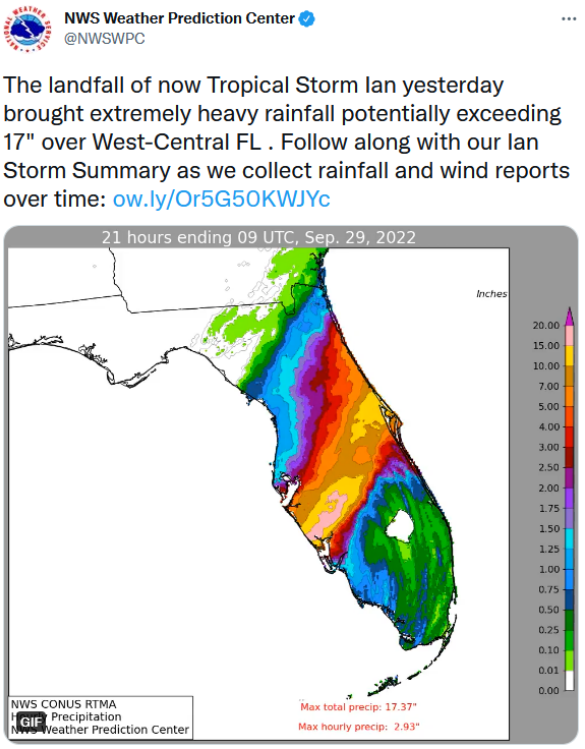
Hazard observations and analyses i

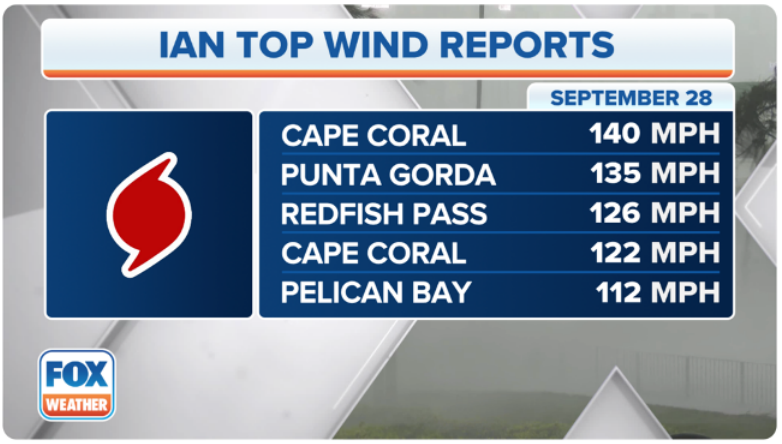
Because Hurricane Ian is so recent, there are not too many graphics that depict the locations and totals of values such as storm surge and flooding.

Rainfall

The following graphic from Fox Weather shows Hurricane Ian rain totals in the Florida peninsula accumulated from September 28th and 29th.





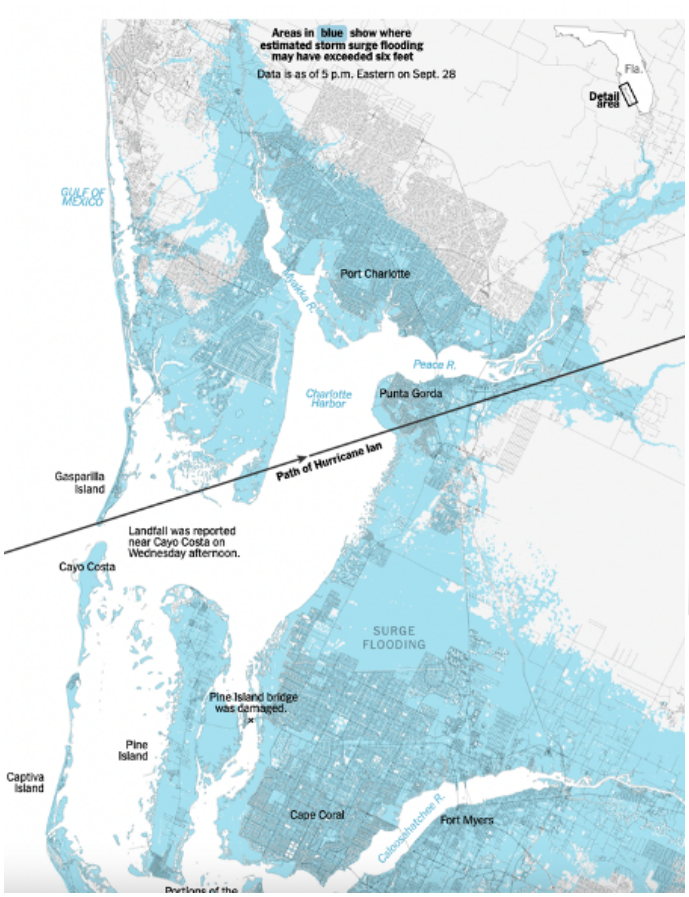


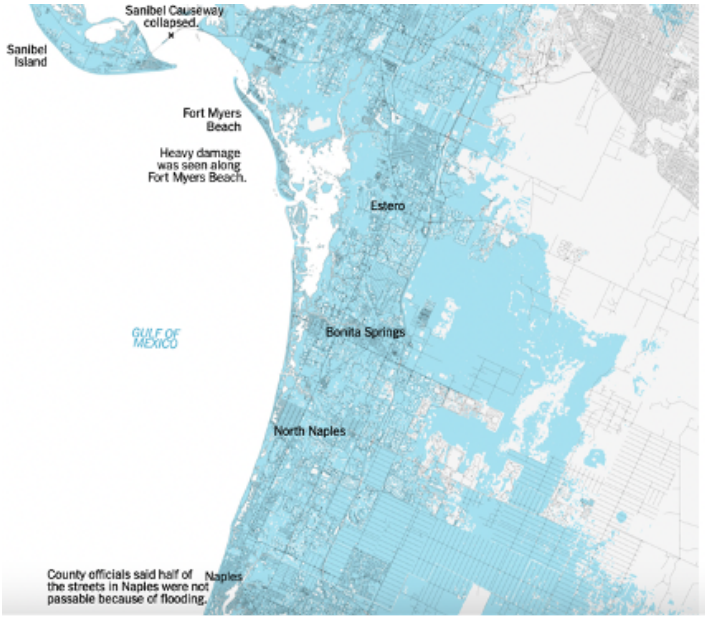
The top wind values that Hurricane Ian reached on September 28th can also be seen by location above. It is evident that Hurricane Ian reached top winds of 140 mph at Cape Coral, Florida, the location just about at landfall, classifying it a category 4 on the Saffir-Simpson scale.

The article from Fox Weather also mentions that the highest gauge data received was 7.21 feet of storm surge in Fort Myers, Florida. This is data previous to the National Hurricane Center post-storm analysis of storm surge. Governor Ron DeSantis also reported that he received reports of at least 12 feet of storm surge. https://www.foxweather.com/weather-news/by-the-numbers-hurricane-ian-catastrophic-damage

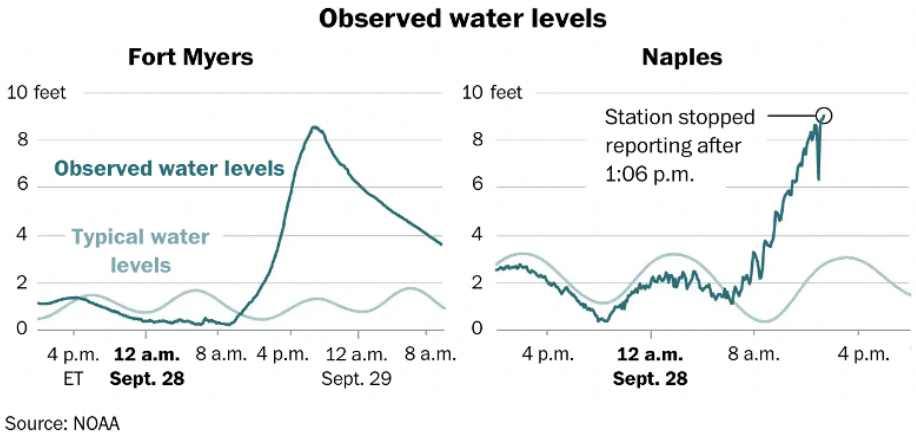
Storm surge

The graphic below shows the coastline of Southern Eastern Florida with specific key cities and towns that were affected the most by storm surge and flooding. As stated on the image from New York Times, who cited the NOAA, the areas shaded blue indicate where storm surge flooding may have exceeded six feet. It also shows the path of hurricane Ian where it made direct landfall and we see the observed hazards on the area around landfall and beyond.





https://www.nytimes.com/interactive/2022/09/29/us/hurricane-ian-flooding-fort-myers-florida.html

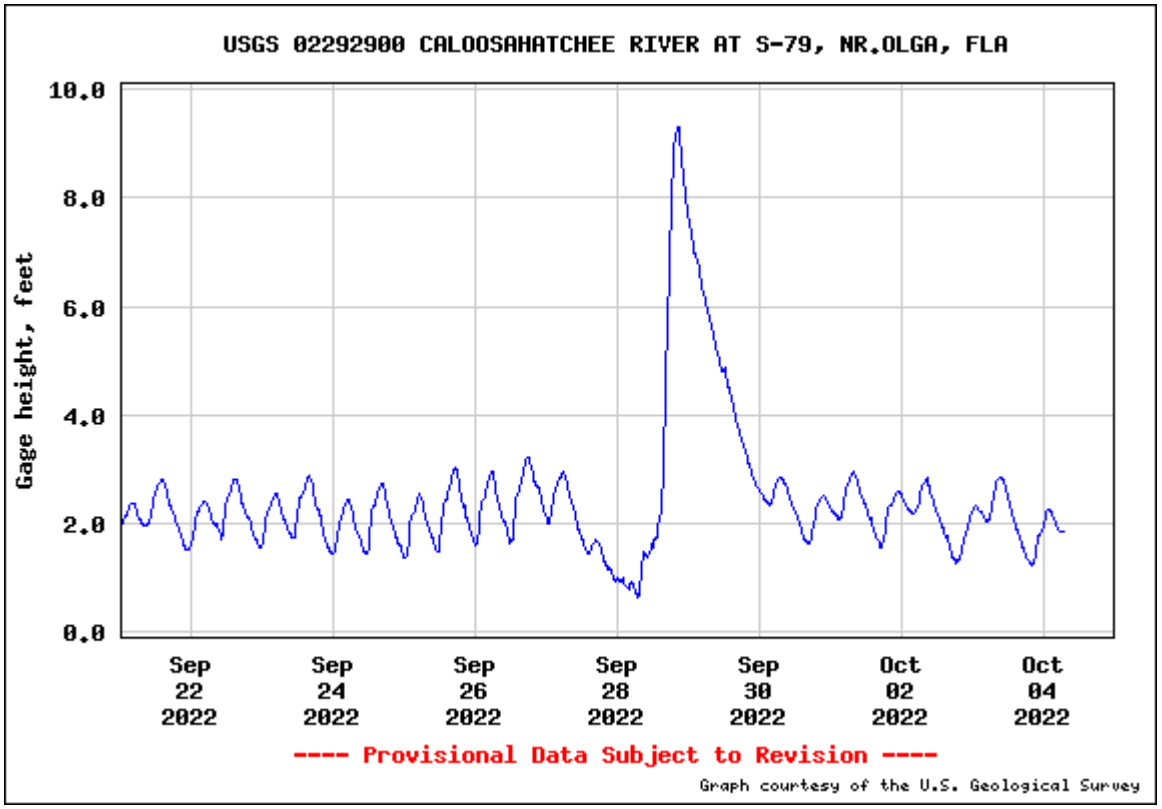


Source: NOAA

This graph depicts observed water levels and the difference from typical water levels in both Fort Myers and Naples. It can be seen that the station in Naples stop reporting after 1:06 p.m., in which it most likely stopped functioning.

https://www.washingtonpost.com/weather/2022/09/24/ian-storm-tracker-map/

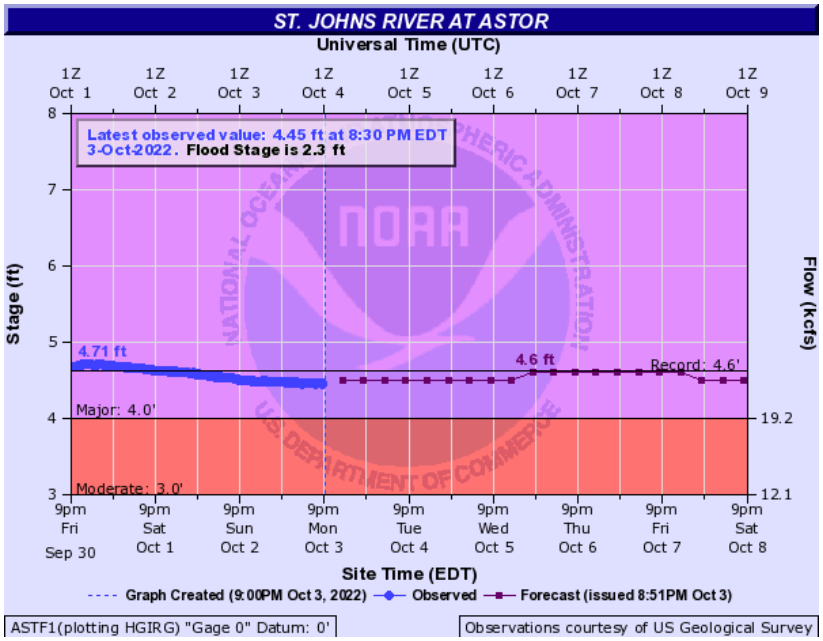
This graph of the surge on the Caloosahatchee River near Fort Myers was created from the following USGS website: https://waterdata.usgs.gov/fl/nwis/uv



River flooding

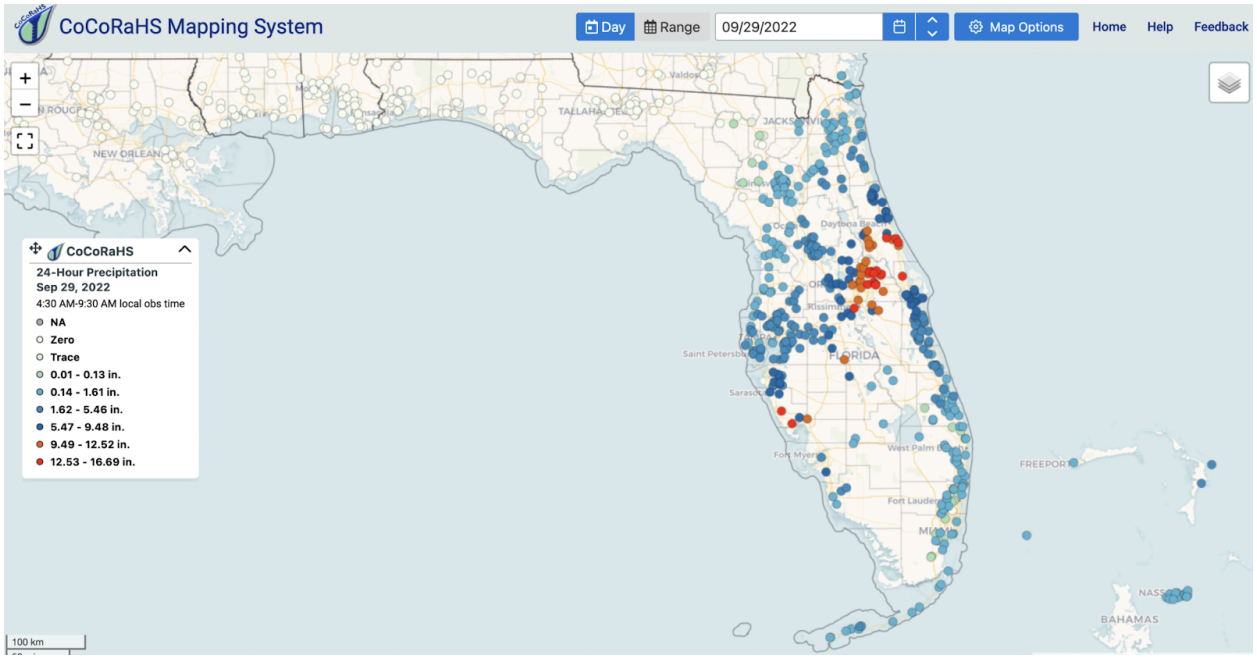
This website was really useful in real time but doesn't seem to have an archive and I didn't take screenshots at the time… https://water.weather.gov/ahps2/index.php?wfo=tbw

Record flooding on St John's River in Volusia County (east-central Florida).

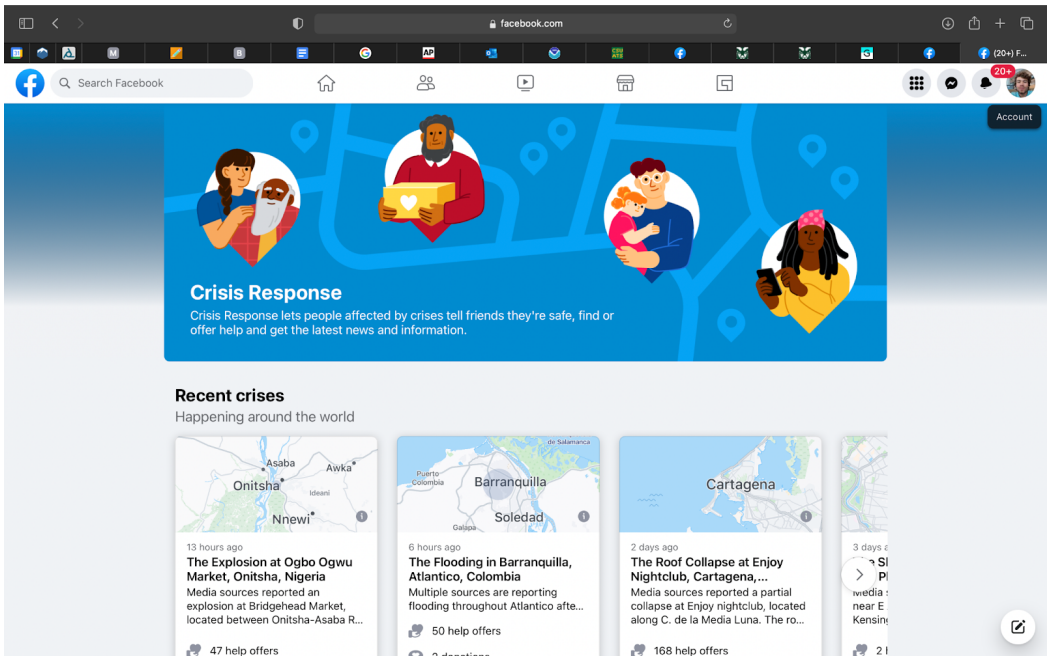


What crowdsourcing/citizen science was used for hazard observations? i

A team of citizen scientists collected rainfall data in Florida throughout the duration of the storm as a part of a Colorado State University project called The Community Collaborative Rain, Hail and Snow Network (CoCoRaHS). The network, which has grown to encompass 25,000 people since its inception in 1997, sent the hundreds of data points its volunteers collected to the National Weather Service which used the valuable on-the-ground data to update their storm analysis and check their radar images and computer models. Thanks to this particular citizen science program, meteorologists were able to confirm their seemingly outrageous rainfall predictions in areas that received over 14 inches of rain in just 24 hours.



Social media played an important role in understanding the hazards associated with hurricane Ian. It impacted public perception as images and videos uploaded to sites such as TikTok, Facebook, Twitter, etc… showcased the storm's destructive power to the rest of the country. Images of the devastation and destruction Ian caused early on may very well have motivated others further along Ian's path to take extra precautions to be safe. Social media also had a huge impact on the rescue effort during and after the storm. Countless stories surfaced of people trapped in their flooding basements or standed after their homes with inadequate supplies who had received help from nearby neighbors and strangers after posting their problems on social media. In some cases, trained rescue teams were even able to spot storm victims on social media and come to their aid. While this was certainly a positive thing, authorities still urged people to try the traditional channels for help first (i.e. calling 911) as the help they receive through those systems are likely to be the most reliable. However, they agreed that social media has become a great way for people to keep tabs on their family members who may have been unable to evacuate. Sites have begun to embrace this application of their power and are developing ways to make emergency communication easier. Facebook in particular has created a page dedicated to crisis response which allows users to connect with people in their communities and find help getting transportation, food and supplies.

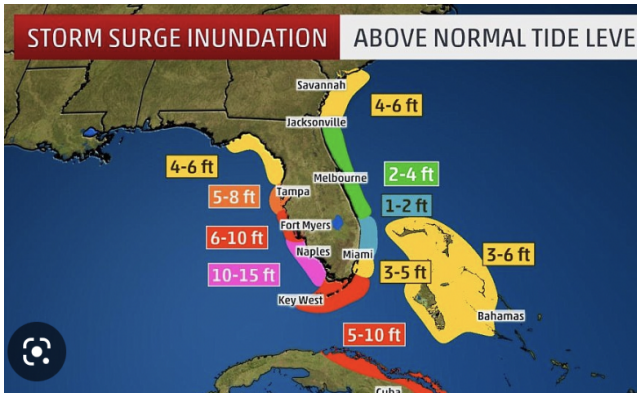


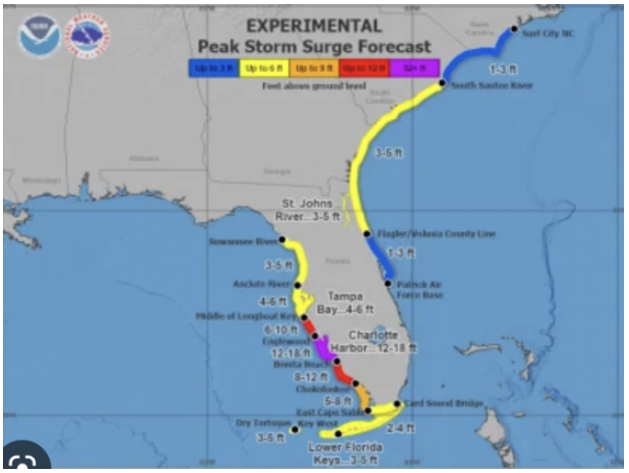
Unfortunately, social media's influence isn't all positive. Some people, chasing more views and likes on their posts, chose to stay in their homes despite evacuation orders from the government so that they could document the storm for their followers. By staying behind during powerful storms such as Ian, these

"disaster influencers" put themselves at risk and could impose further, unnecessary strain on governments and first responders. To make matters worse, many of them do not take hurricanes such as Ian seriously, evident by posts like "Give me a thousand followers, I'll go live during the hurricane, bro" and "I'll run out there butt-ass naked."

How did the hazard(s) relate to climatology? i

Many different storms have made landfall in areas similar to where Hurricane Ian made landfall. Hurricane Ian slammed Florida's west coast with catastrophic storm surge. In fact, of the notable storms that have impacted the west coast of Florida. Hurricane Ian surpassed values of storm surge by far. Hurricane Charley was a storm that impacted the west coast and made landfall in Punta Gorda, FL as a category 4 storm. Despite its intensity, storm surge values were maximized at 6 to 7 feet across different areas of Southwest Florida. Hurricane Irma, in 2017, made landfall near Marco Island as a category 3 storm and had storm surge inundation forecasts with high values (10-15 feet). However, Irma's maximum surveyed inundation value was 8 feet in Chokoloskee, FL. Hurricane Wilma, in 2005, made landfall in Collier County and had storm surge values ranging from 4 to 8 feet. Hurricane Ian had storm surge values of 12-18 feet which are values that go well beyond other storms that have impacted Southwest Florida.



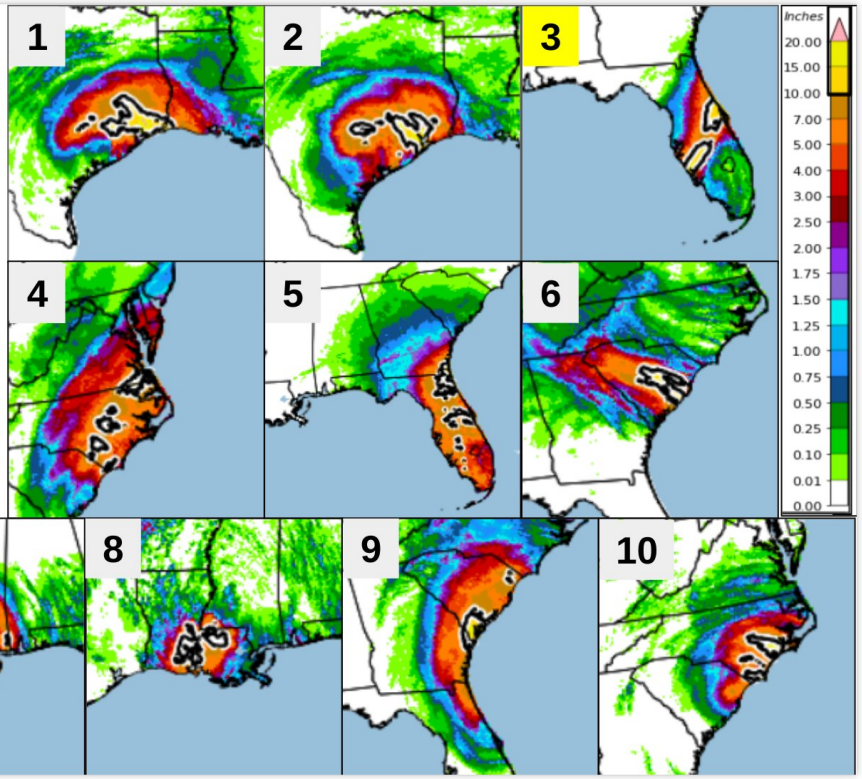


Top 10
Most Prolific Tropical Rainfall Days since 2005*

Rank	Storm	Day	24h Ending Date	Area (km^2)
1.	Harvey	Day 3	08/28/2017	14,768
2.	Harvey	Day 2	08/27/2017	11,370
3.	Ian		09/29/2022	9,149
4.	Matthew	Day 2	10/09/2016	9,033
5.	Irma		09/11/2017	8,768
6.	Joaquin		10/04/2015	8,271
7.	Isaac		08/30/2012	8,122
8.	No Name (LA)		08/13/2016	7,525
9.	Matthew	Day 1	10/08/2016	6,597
10.	Florence	Day 2	09/15/2018	6,448

** Ranked by area covered with 10 or more inches of 24h rainfall during the 8am-8am EDT time period. Calculated using NWS AHPS precipitation grids available at: https://water.weather.gov/precip/*

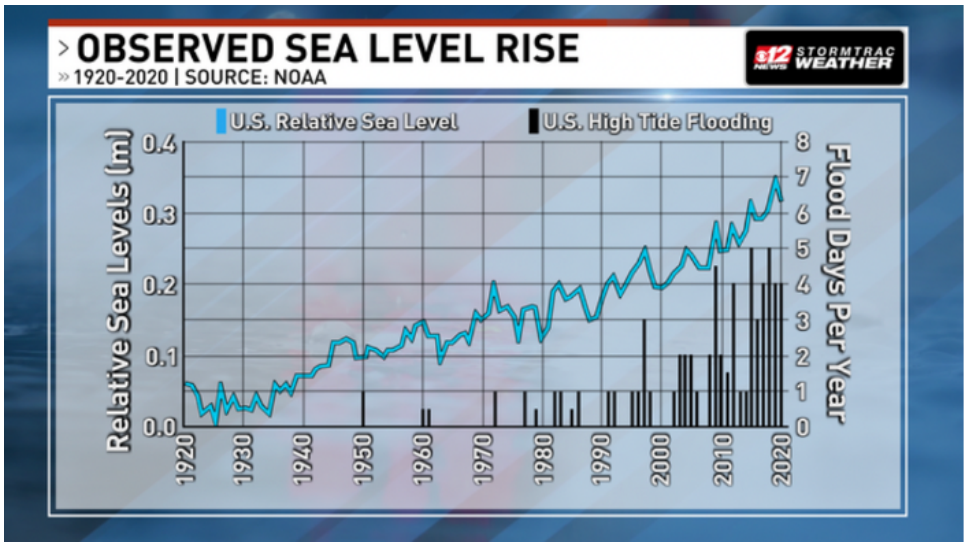
National Weather Service
Weather Prediction Center



How was the hazard(s) made worse by pre-existing conditions? ⓘ

Although there were not many pre-existing environmental conditions in Southern Florida at the time leading up to Hurricane Ian, South Florida was experiencing the King Tide, which is an especially high spring tide that can produce coastal flooding in usually low lying areas, such as a lot of the Florida coast. This may have influenced the magnitude of coastal flooding, particularly along the Miami and Southeast coast of Florida as Ian approached land.

Additionally, scientists have said that due to climate change induced sea level rise may have made the storm surge height worse, which could have caused up to $10 billion in extra damages. As the atmosphere and oceans continue to warm, thermal expansion and melting of land ice have been gradually raising sea levels across the world, contributing to major flooding and storm surge events. It has also been found that climate change added at least 10% more rain during Hurricane Ian. This has been predicted from comparing computer simulated models of Hurricane Ian with those of no human induced climate change. For every degree (Celsius) increase in temperature, the atmosphere can hold 7% more water, which would mean more precipitation in a storm such as Hurricane Ian.



NOAA reported that we're seeing an increase in flood days per year in Southern Florida in addition to sea level rise and King Tide cycles.

Florida is also composed of the everglades and marshes, which already provide a source of saturated ground. This combined with Florida's normal humidity and warm waters could have contributed to the intensity and resulting flooding in many areas of Florida, not just along the coast.

https://www.preventionweb.net/news/hurricane-ian-how-climate-change-making-north-atlantic-tropical-storms-worse

https://cbs12.com/news/local/noaa-centurys-worth-of-sea-level-rise-is-expected-in-the-next-30-years

River levels were already high in Florida following recent rainfall.

Additional analysis ⓘ

The uncertainty in Ian's path definitely played a huge role in hazard forecasts. It originally was projected to go more north up to the coastline, and even possibly into the panhandle of Florida, but it ended up going more south, resulting in worse hazard forecasts.

The Weather Channel and AccuWeather do a good job at estimating the threshold of how detrimental impacts will be in certain areas during a hurricane. There is a chart that lists hazards predicted and a map with a color coded scale that ranges from Minimal to Some to High, etc.

Successes/issues/challenges experienced ⓘ

Things that went particularly wrong was the projected path of Hurricane Ian, hence interfering with the scope and location of various of the hazards, leaving many without proper warning of the extent of the hazards in their area.

Things that were done well was the prediction of the most storm surge further south down the Florida west coast instead of concentrated around only Tampa.

A struggle in personal research for these questions is the short turnaround from the occurrence of Hurricane Ian. Many agencies and teams are still working on reports and findings from Hurricane Ian, so it is very hard to tell the true extent of the hazards and what hazards really came into play.

Part 2c. Supplementary information about impacts i

Wherever possible, please include references to information you provide.

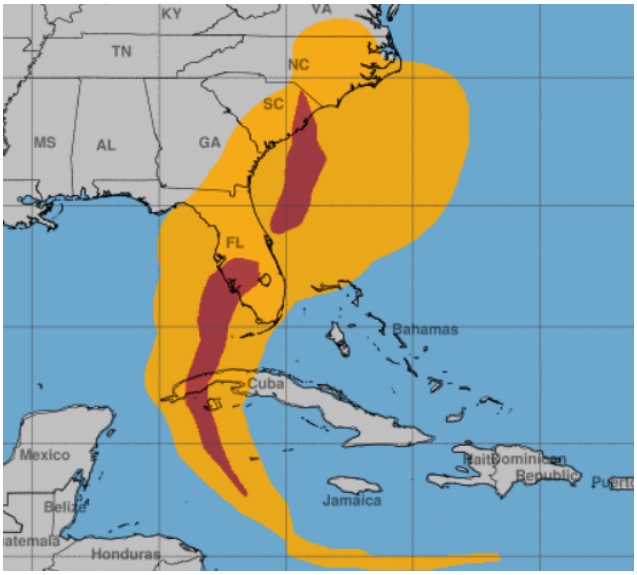
Editors (Name & Institute):

Brief overview of the impact(s) i

Hurricane Ian's track led to catastrophic impacts to the island of Cuba and Florida's west coast, as well as moderate damage to the coastal region of South Carolina. The loss of life and massive amounts of property damage to due Ian has left a permanent scar across western Cuba and Florida, and it's effects on the economy will be felt for years to come.

Ian's first contact with land was on the western, less mountainous side of Cuba as a category 3 hurricane on September 27th. At this time, Ian had 125 mph sustained winds which caused widespread damage to property and took out the islands power grid, leading to 11 million people without power for several days. Heavy rain and storm surge also caused widespread flooding and dangerous flash floods that damaged infrastructure and cropland. These natural disasters resulted in at least 5 confirmed deaths and damage costs of greater than $200 million.

Hurricane Ian: Pictures show damage in western Cuba | wtsp.com



After devastating Cuba, Ian made a second and even worse landfall on the western coast of Florida at 3pm EDT on September 28th. Ian had strengthened into a strong category 4 hurricane with 150 mph winds and gusts up to 185mph. By the time it had crossed Florida, Ian had weakened into a strong tropical storm with winds of 65 mph. These winds destroyed thousands of buildings and fell trees and power lines leading to over 4 million people without power.

IAN Graphics Archive:
 Wind Field History Graphic (noaa.gov)

Due to the flat topography of Florida, storm surge was allowed to travel several miles inland on Florida's west coast and up to 15 feet of storm surge was reported in Fort Myers. Storm surge was easily the most costly factor of Hurricane Ian. It completely inundated the first and even second stories of buildings, sweeping many of them off of their foundation. Piers, ports, and hundreds of docked boats were destroyed. Bridges and even roads themselves were destroyed like that of the Sanibel Causeway, trapping many people that did not evacuate the island leading to hundreds of airlift rescues. Damage along the coast was also aided by massive

waves as evidenced by the buoy readings before landfall that showed wave heights of up to 20ft. Photo: Sanibel Causeway

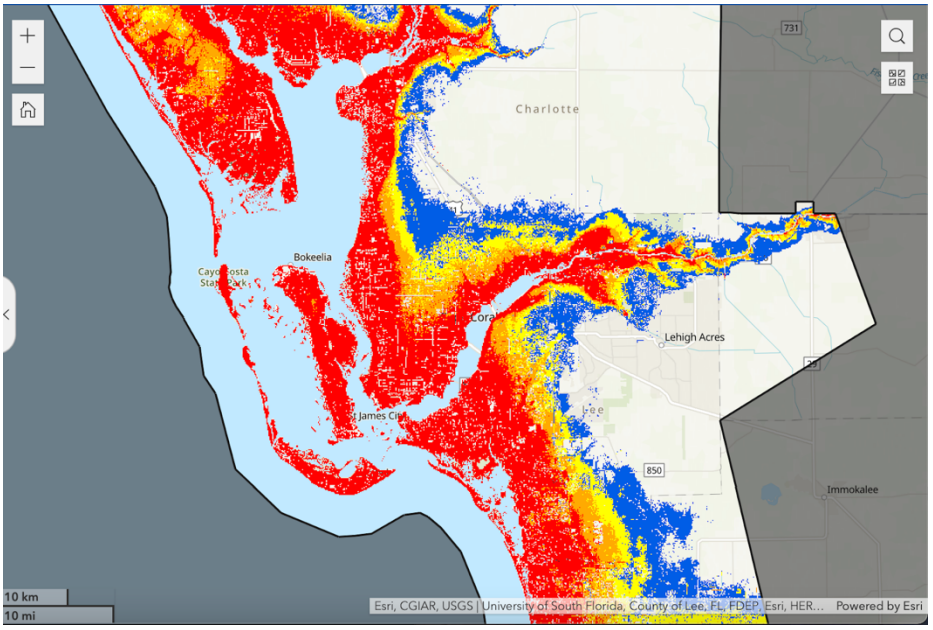
Widespread rainfall totals of 10-20” of rain also contributed to flooding. The highest rainfall total was in New Smyrna beach of 21.09”. Damage assessments in the aftermath of Hurricane Ian have estimated about $50 billion dollars in damage. The death toll for Florida is at 146 people according to the New York Times, many of which were caused by drowning due to the high flooding and storm surge.

Sources:
- Hurricane Ian - Wikipedia
- Hurricane IAN Advisory Archive (noaa.gov)
- Real-time weather data Russ Schumacher, Colorado State University Department of Atmospheric Science (colostate.edu)
- Hurricane Ian wreaked havoc in Cuba with five dead and more than 100,000 homes destroyed - El Diario NY
- NOPP NHCI (sofarocean.com)
- Many of Hurricane Ian’s Victims Were Older Adults Who Drowned - The New York Times (nytimes.com)

========== Impact forecast ==========

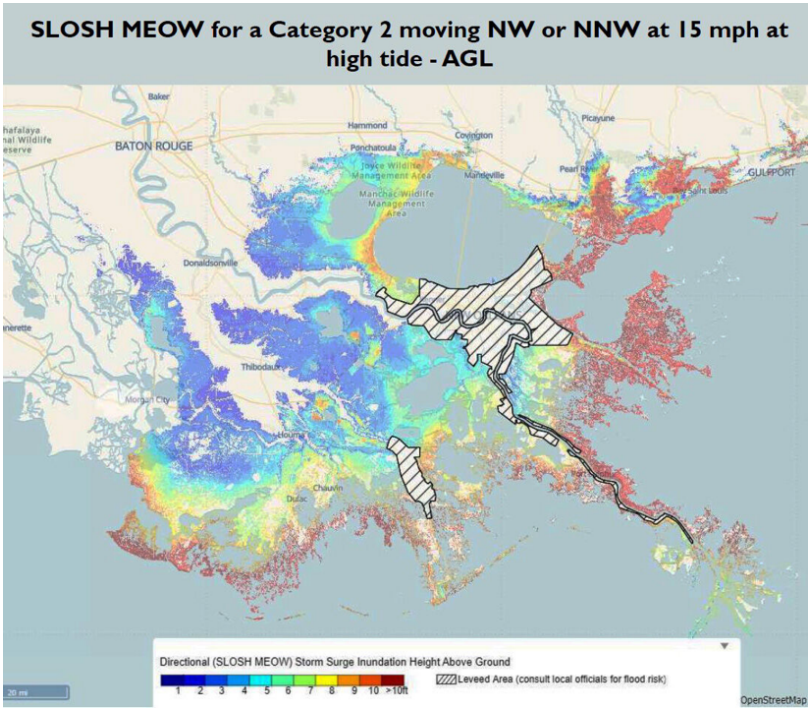
Data used in the impact forecast or model i

One type of data that is used to predict the impacts of hurricane Ian is the SLOSH model. The SLOSH model according to the national weather service is “a model that is used to simulate storm surge from tropical cyclones”. The SLOSH model doesn’t use actual data from the specific storm, instead it uses things called MEOWs and MOMs. The MEOWs are a combination of different factors to create different scenarios for different storm strengths. Because storm surge depends a lot on the angle of the storm, the tide phase, and the forward speed, each combination of these is used to predict surge levels. The MOMs however are the worst case scenarios of the unique strength, angle, tide, and speed combinations and list the maximum surge height for each category storm at a specific location. The SLOSH model also utilizes the topographical makeup of an area to accurately predict storm surge levels.



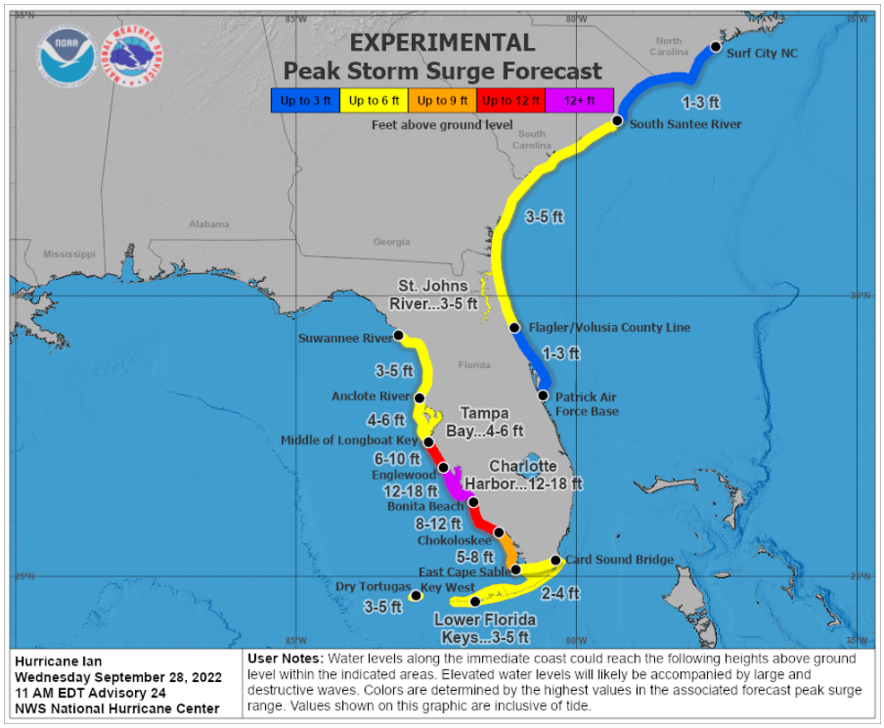
For example, this is an example of the storm surge risk map from a CAT 4 storm in the area that Ian made landfall in. This model is an example of the MOM used in the SLOSH model, because it is the worst case scenario of the storm surge from a category 4 storm. This risk map is mainly used for evacuation purposes and public planning, because it is a general risk map. The input data is static because it isn’t from an actual storm, but it's useful because we should always plan for the worst to minimize the damage to life and property.

Another type of data used is an experimental peak storm surge forecast. This model, unlike the risk map shown above, takes in the actual data from the storm and uses the MEOWs to predict the storm surge level for that area. The model is run with the dynamic data from the storm such as its forecasted forward speed, its



forecasted strength, its forecasted storm angle, and the forecasted tide phase, at the time when the storm moves over the affected area.

Sample MEOW showing the combination of storm strength, angle, speed, and tide phase.

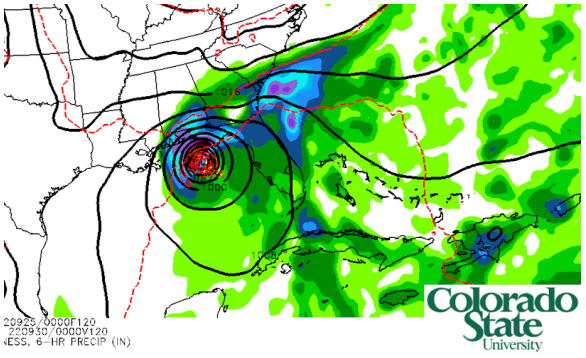


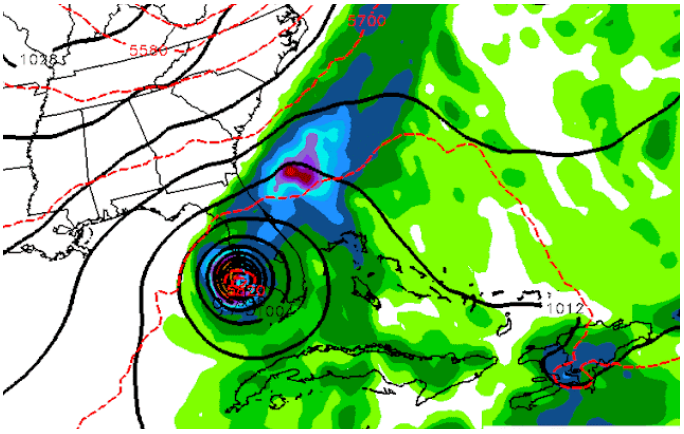
This is an example of the peak storm surge forecast just before Ian made landfall. This model is fairly accurate because all of the factors that determine storm surge levels are more accurate because it is a shorter range forecast.

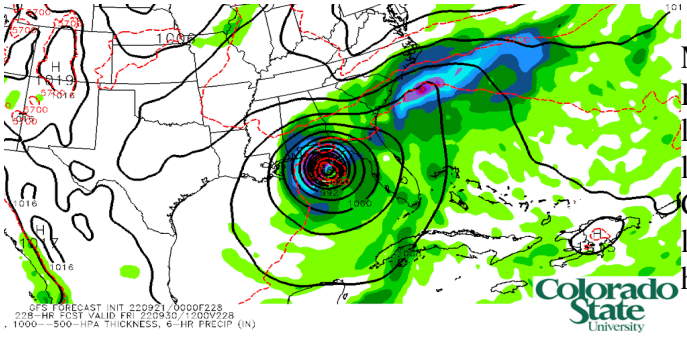
https://www.nhc.noaa.gov/nationalsurge/
https://experience.arcgis.com/experience/203f772571cb48b1b8b50fdcc3272e2c
https://thehill.com/homenews/state-watch/3665006-catastrophic-forecasters-warn-of-18-foot-storm-surge-from-hurricane-ian/

Impact prediction models/tools (if used) i

Name	Method

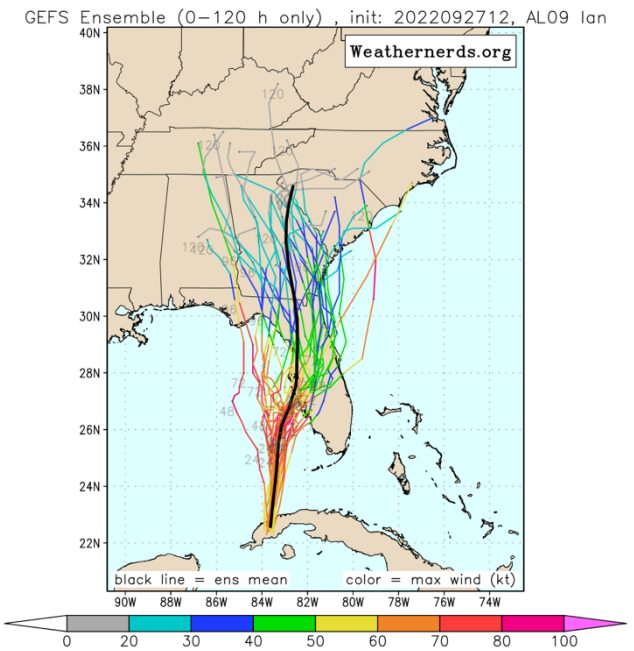


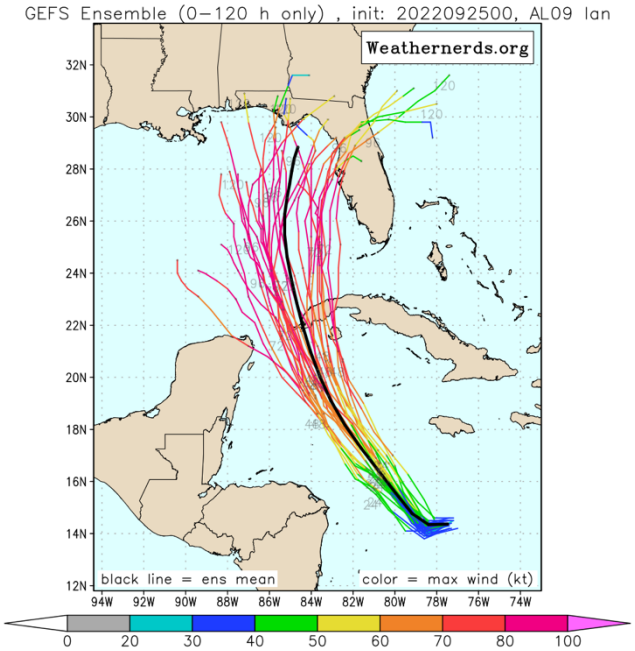




Many forecast models predicted Ian's landfall in Florida, but Ian's track was expected to make landfall in Florida at a much more northerly location than the Fort Myers area. For example, the GFS model track varied greatly over the days leading up to Ian's landfall, predicting the storm to hit the panhandle.

The top left model forecast shows the GFS forecast initialised at 00Z on September 21st, approximately a week before the storm made landfall. The GFS predicted Ian to make landfall near Panama City Beach on September 30th, 2 days after Ian actually made landfall. The top right model forecast is the GFS at 00Z on September 25th. Still, 3 days before the storm, this model predicted its track to hit the panhandle head on, leaving Fort Myers on the outskirts of the storm. In the bottom model forecast, initialised at 12Z September 27th, provides a more accurate image of the storm's track. Though the GFS model eventually corrected itself, the wide variation of storm tracks indicates a large uncertainty in the model's ability to predict storm track. This model was not the most reliable to predict hurricane Ian because it allowed such little time for decision makers to encourage evacuation and decipher potential flood zones.





The first image above reflects track forecasts from the GEFS model on 00Z September 25th, and the second image shows track forecasts on 12Z September 27th. As reflected in the GFS images before, the Global Forecast System struggled to predict Ian's landfall location and intensity just 3 days before landfall. Of all the ensemble members in the first image, none of them predicted Ian to shift South towards Fort Myers, but instead suggested landfall near Tallahassee. It's maximum wind speeds near the west coast of Florida were not expected to exceed 100 knots, meaning the model predicted at most a

Category 3 hurricane. Additionally, when Ian hit land 3 days after this ensemble was initialised, it only predicted the storm to be as far north as Key West. Though the second image is more accurate than the first, no ensemble members predicted winds above 70 knots at landfall, equivalent to a Category 1 storm.

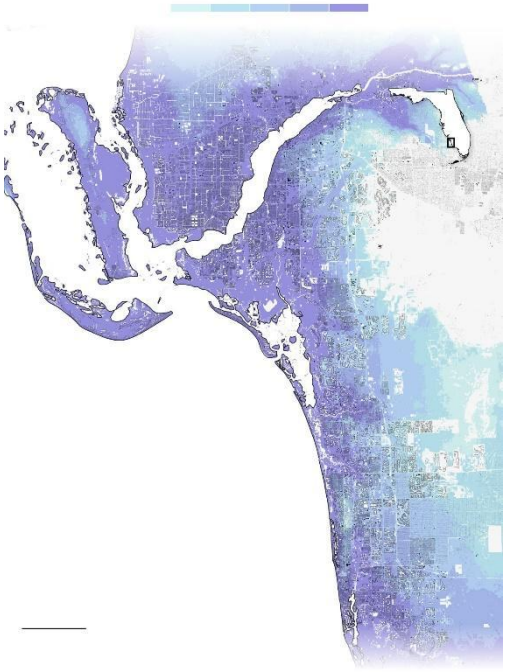
The two images above reflect the ECMWF ensemble forecast for storm intensity and track on 00Z September 25th and 12Z September 27th, respectively. The forecast on the 25th is much more accurate in predicting the storms track than the GEFS, but greatly miscalculates Ian's maximum wind speeds. The ensemble members in this forecast are much closer together, indicating less uncertainty in the tracks. However, green and yellow lines near Florida's coast indicate maximum wind speeds of just 50-60 knots, which is too weak to be considered a hurricane. As the storm progressed, the model seemed to have less certainty as to where Ian would land, with a few ensemble members predicting the storm to shift West within the next 2 days. Additionally, its wind speed predictions improved minimally, predicting at most a weak Category 1 cyclone hitting the west coast.

Though the GEFS predicted Ian's intensity better and the ECMWF predicted his track better, the inconsistencies between models reflect the inability to predict the randomness of the atmosphere. A forecaster examining these images at the time they were created would struggle to make legitimate estimates on hurricane strength, landfall, and landfall times without the help of other atmospheric analyses.

Sources:
GFS Model: http://schumacher.atmos.colostate.edu/weather/gfs.php
GEFS and ECMWF Ensemble: https://www.weathernerds.org/tc_guidance/archive.html?tcid=AL09

Informal rules/tools used to identify impacts i

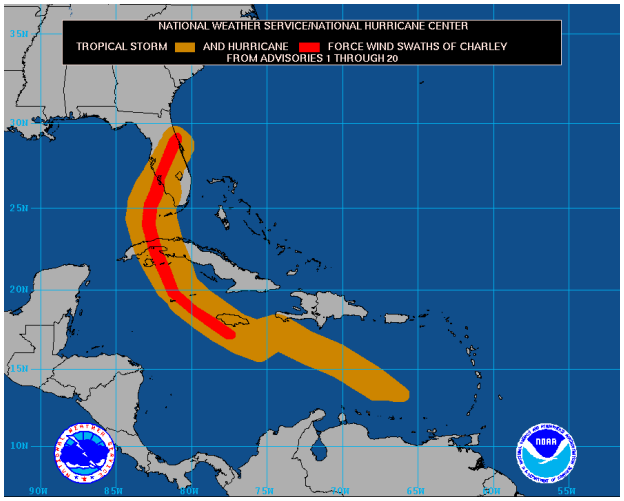
The NHC hurricane forecasting and preparedness website explains how storm surge and flooding are the most damaging aspects of a hurricane, accounting for roughly 75% of all deaths on average. Knowing that these are the most dangerous factors, a map of the expected storm surge for a given track can be used to predict what regions will be underwater based on their elevation and distance in relation to the coast. These maps can be created using models like SLOSH (Sea Lake and Overland Surges from Hurricanes) on topography sources such as ArcGIS and then used to estimate impacts and damage costs. These estimates can also be altered manually by forecasters to make up for factors that cannot be shown in the models such as waves, runoff, and especially the angle at which the storm makes landfall.

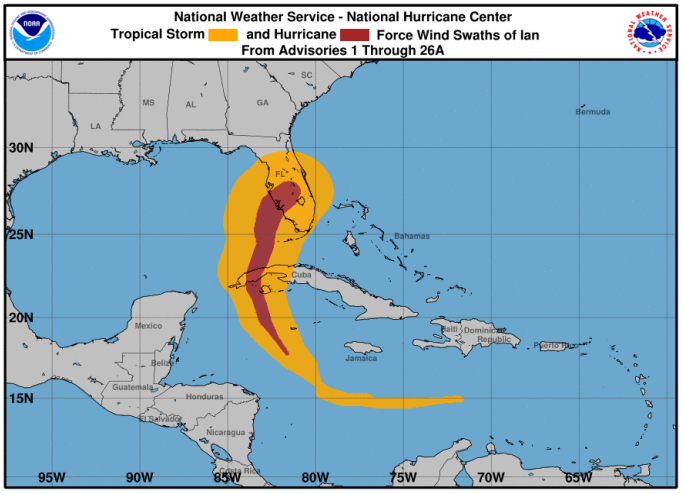


[Hurricane Ian impact in maps - The Washington Post]

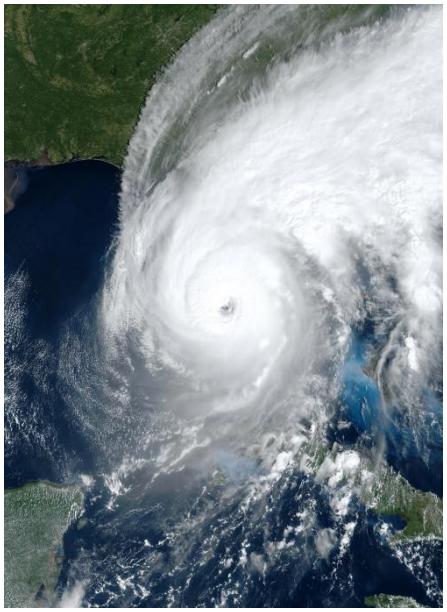
Another informal mechanism that was used in predicting Hurricane Ian was the NHC's conservative approach to forecasting to limit the uncertainty in a forecast. By only shifting forecasts by small amounts at a time, the public will have more confidence in the forecast and therefore respond more seriously to the hurricane threat. An example of this includes images such as the cone of uncertainty and the probability of tropical storm force winds that were used by officials to help decide what regions might be effected and should be evacuated.

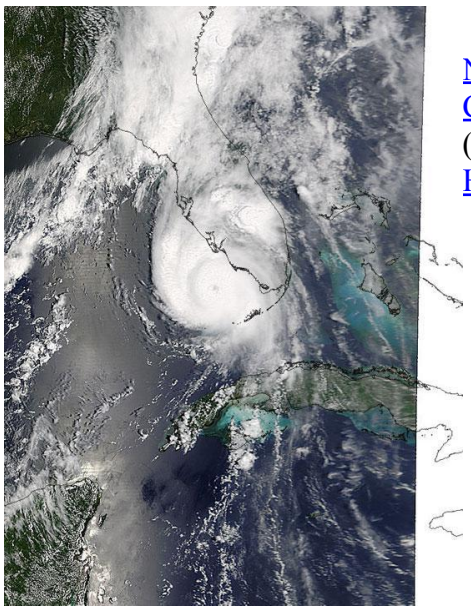
Hurricane Ian reminded people a lot of Hurricane Charley which made landfall in almost the exact same location in 2004. The data from Hurricane Charley provided some insight into the potential impacts that Hurricane Ian would have on the west coast of Florida. For example, Charley had a storm surge of only 7 feet due to its smaller radius winds and the fact that it was a faster moving storm. Data like this from Charley was used to help predict the storm surge of Ian which had a much larger radius of winds and was moving slower. It also may have been used to predict rainfall totals and wind predictions as Ian crossed relatively slowly across Florida.





[IAN Graphics Archive: Wind Field History Graphic (noaa.gov)] (right)
[CHARLEY Graphics Archive (noaa.gov) (left)]



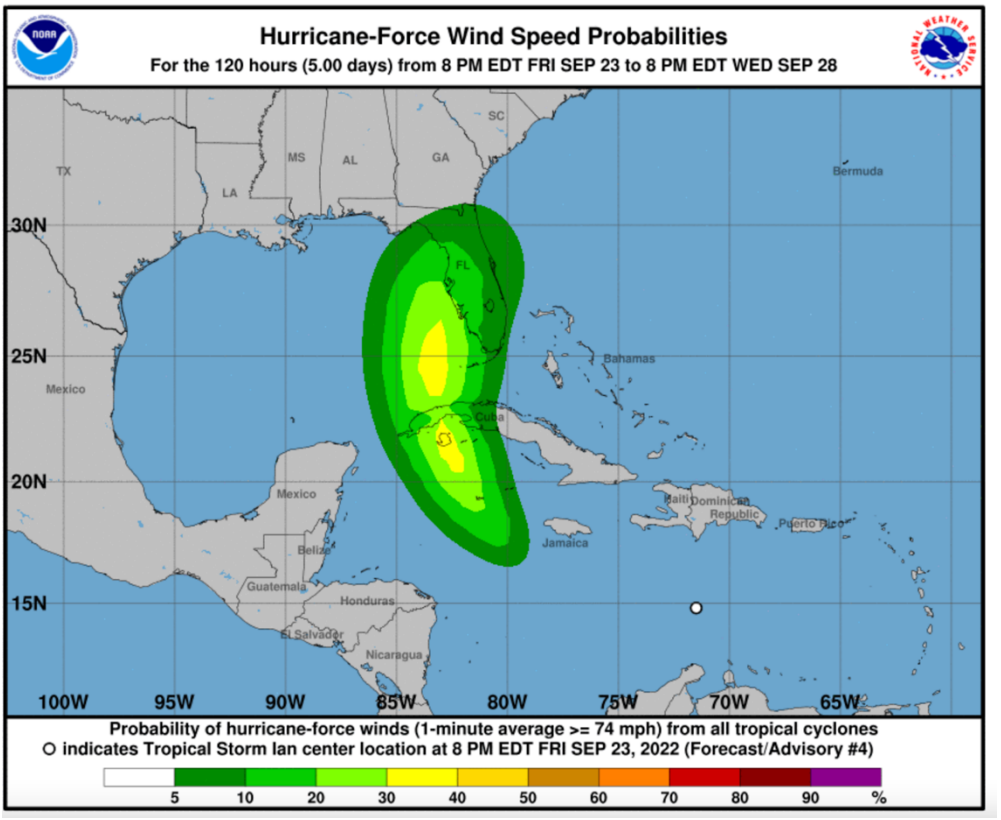


[NASA - NASA Sees Hurricane Charley Slice a Florida Island] (right)
[Hurricane Ian - Wikipedia] (left)

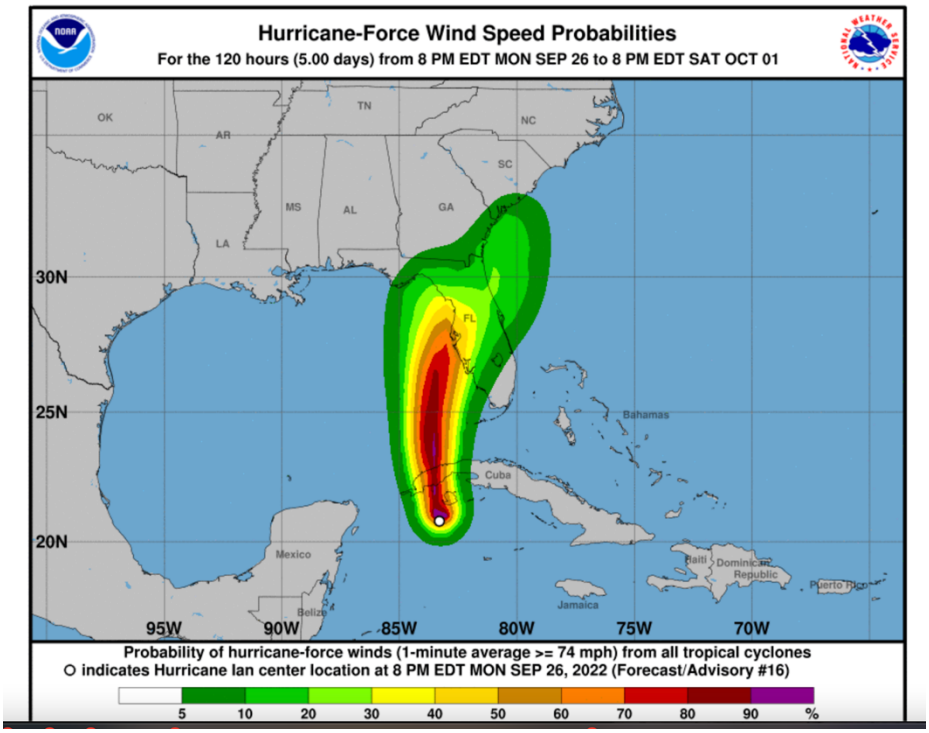
Sources:
-[Hurricane Ian Vs. Charley: Similar Landfalls, Different Storms | The Weather Channel]
-[Hurricane forecasting | National Oceanic and Atmospheric Administration (noaa.gov)]
-[Map hurricane storm surges | Learn ArcGIS]

Impact forecast outputs and examples i

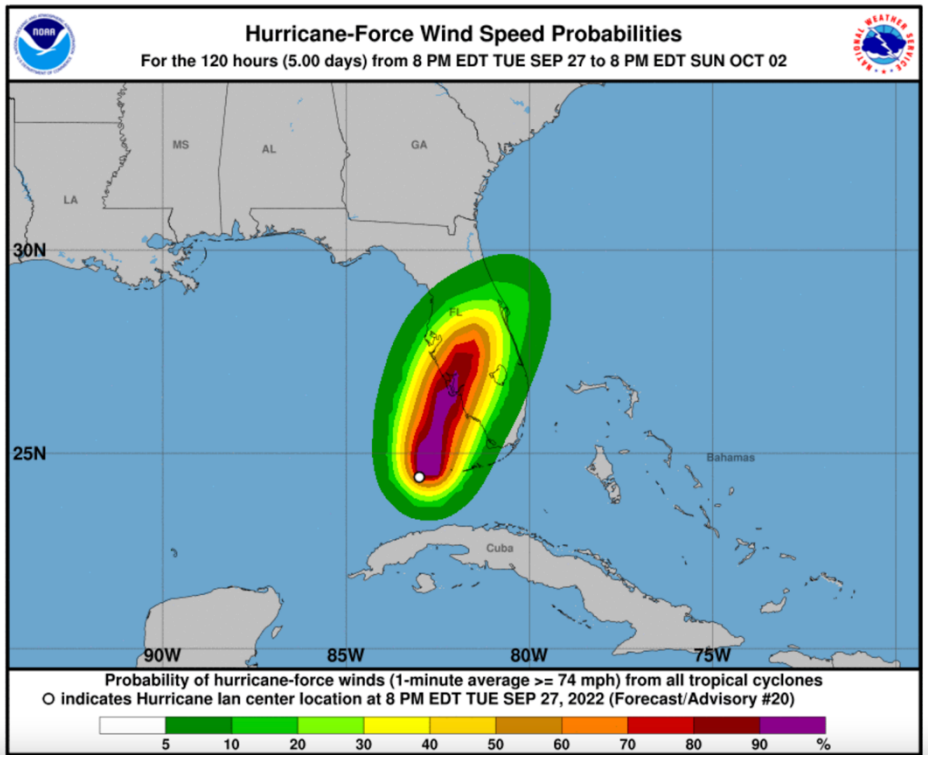
Looking at the archives for Ian's advisory on hurricane Ian's approach to south western Florida a lot of charts and texts are available from the impact forecasts. The main impacts that the national hurricane center forecast are storm surge, wind speeds, and rainfall potential. Looking back at the archive around 5 days before landfall we can see the following graphic which shows the probability of an area receiving hurricane force winds 5 days or sooner from the time that the image is initialized.



This graphic shows that the place where Ian would eventually make landfall had only a 20-30 percent chance of receiving hurricane force winds within 5 days. In hindsight this location did end up receiving hurricane force winds, but just 5 days out we were only 30% confident that this would happen. Fast forwarding 3 days to the wind probabilities just 2 days out from landfall, the probability of receiving hurricane force winds is show in the graphic below.

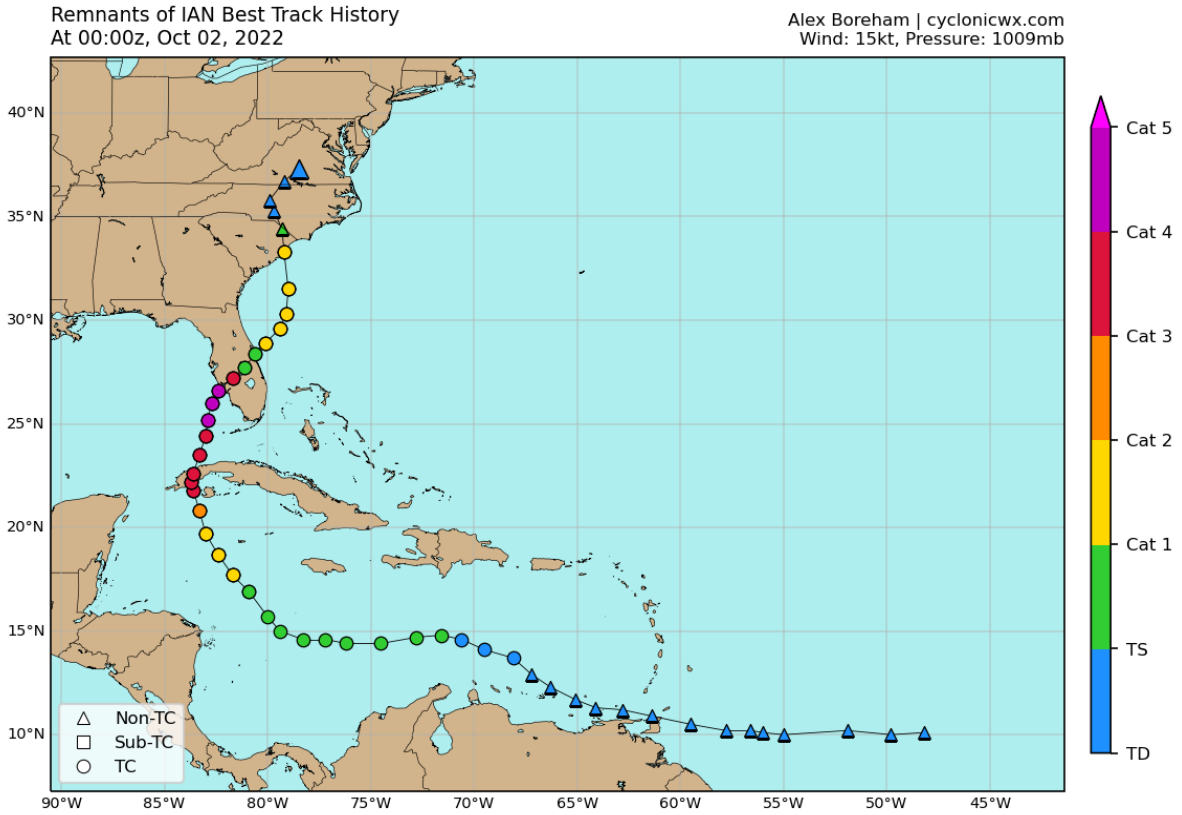


This image, just 2 days out from landfall, still doesn't show full confidence in where the storm's hurricane force winds will be. This image shows that the highest probability is found in the Tampa Bay region with over a 50% chance of receiving hurricane force winds. Where Ian will ultimately make landfall at this point in time only had a less than 40% chance of receiving those winds.

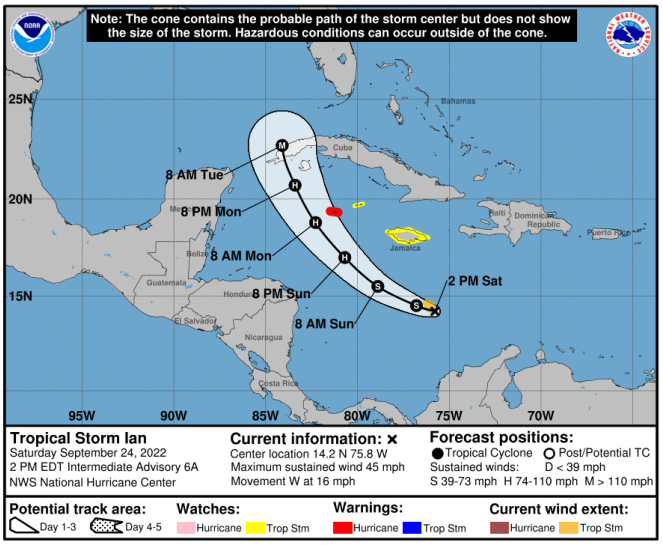


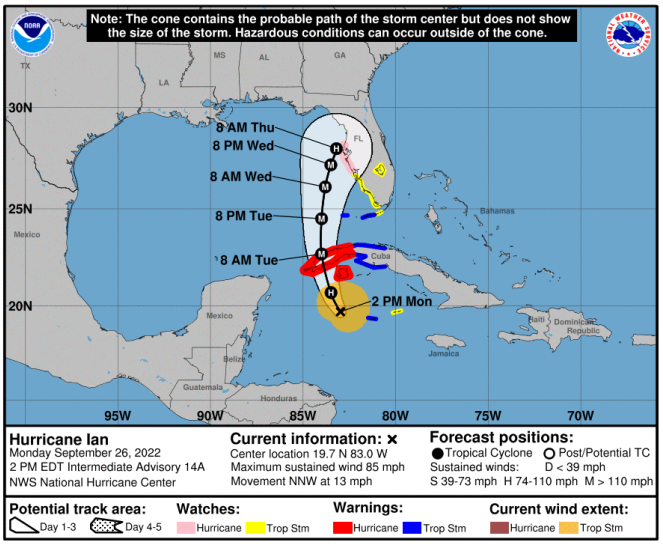
This image is just about 1 day out from landfall and the probability of winds have shifted completely, but in the more correct direction. The place where Ian will end up making landfall has a near 100% chance of receiving hurricane force winds, but the place where Ian was forecasted to impact the most just a day ago now has less than a 40% chance of receiving hurricane force winds. The progression of the impact predictions shows that we still aren't able to completely have an accurate forecast just 2 days out from landfall, and it also shows the general trend that we become more confident as time goes on.
https://www.nhc.noaa.gov/archive/2022/IAN_graphics.php

Comparison of predicted/expected and actual impacts i

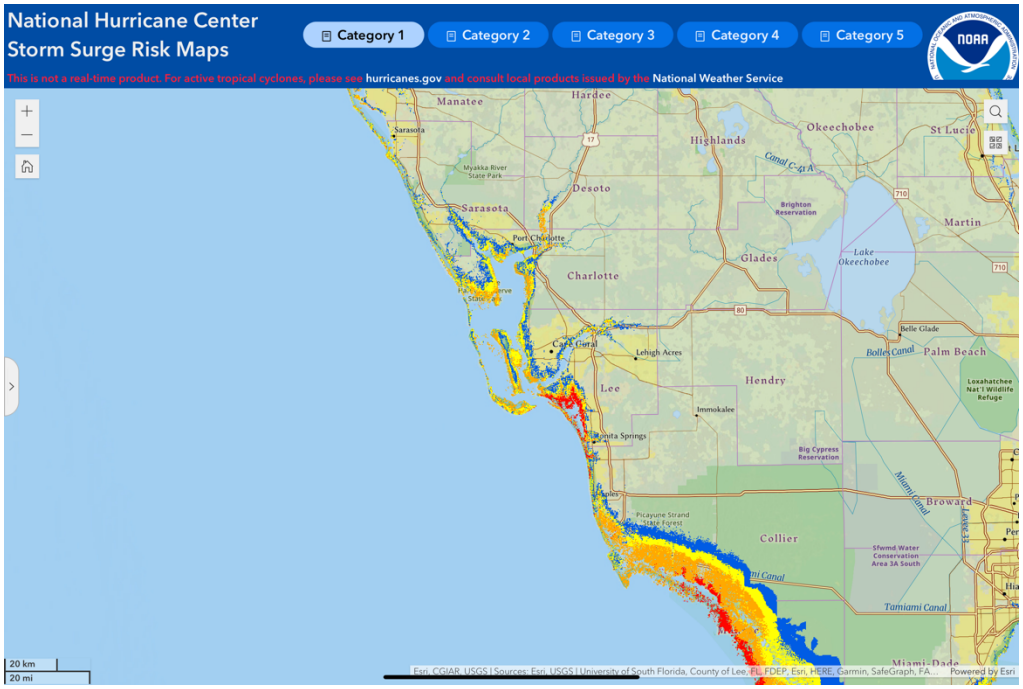


The image above shows Ian's track history starting from when it became a tropical depression in the Atlantic, to the storm strengthening into a category 4, to its weakening back into a tropical depression over the continental US.

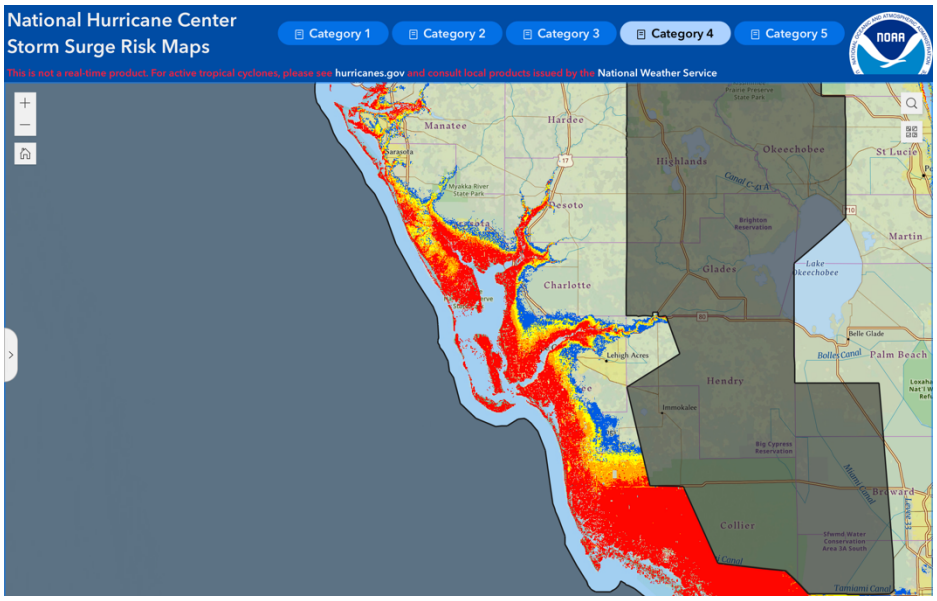


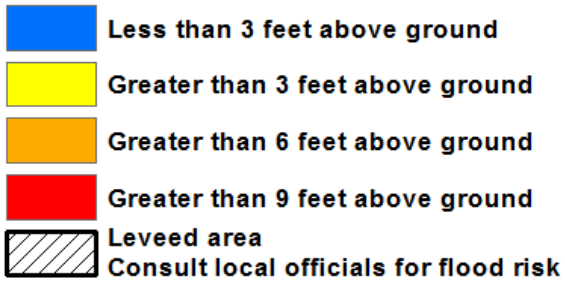


The two cone images reflect NOAA's forecasted paths of hurricane Ian on Saturday, September 24th at 18Z and Monday, September 26th at 18Z, respectively. Comparing these images with the actual track history above, the predictions of Ian traveling over the Western tip of Cuba were mostly correct. The actual track is near the center of the cone, and Ian did become a major hurricane near the exact location it was predicted to intensify at. However, the forecast Monday predicted Ian to travel more northwards than the storms actual path did. Areas near Tampa were expecting large-scale flooding into the bay as the cone predicted they would be on the western end of the storm. When the storm traveled more east than north in the Gulf of Mexico, areas on the southwest coast of Florida near Fort Myers had little time to prepare. The areas that were directly hit with the storm were only under a tropical storm watch just 2 days before the storm made landfall, leaving little time to evacuate and prepare for flooding.

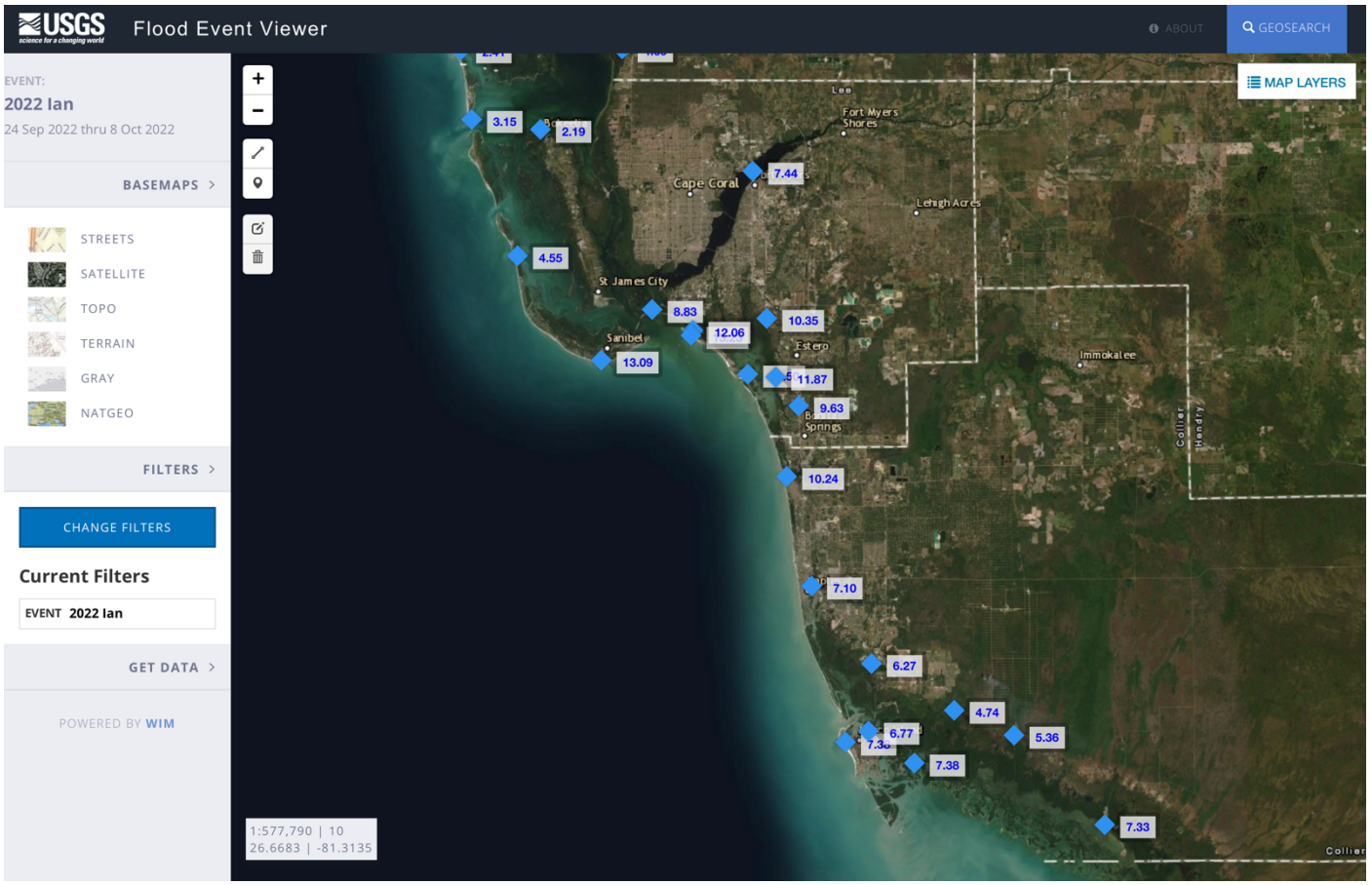


The above image shows the potential of storm surge under a category 1 storm near the Cape Coral/Fort Myers area. Since the NOAA forecast placed this area under a tropical storm watch just 2 days before the storm made landfall, storm surge was expected to be even weaker than what the graphic shows.





This image shows the potential of storm surge under a category 4 storm, what actually happened. Flooding was widespread and went much further inland, and many coastal areas had flooding over 1 story high. Those directly on the coast, who were expecting to be lightly impacted by storm surge, experienced flooding above 9 feet. Many people further inland who did not anticipate any storm surge likely received storm surges to similar magnitudes. The forecast error left residents in the Cape Coral, Sanibel Island, and Bonita Springs area with little time to prepare or evacuate.



The above image reflects the storm surge maximum values recorded by the USGS. From this, it can be seen that Sanibel Island received the greatest storm surge at over 13 feet. Other heavily impacted areas with surges over 10 feet include Fort Myers Beach, Estero, Bonita Springs, and Bonita Shores. These deadly storm surge values reflect the necessity to correctly predict the track in order to forecast storm surge. It also highlights the idea that people in areas near the cone of uncertainty should still take major precautions and be consistently tracking the storm's path just in case the storm shifts position like Ian did.

Ian Track History: https://cyclonicwx.com/data/tracks/al092022track.png
NOAA Ian Graphic Archives: https://www.nhc.noaa.gov/archive/2022/IAN_graphics.php
NHC Storm Surge Risk Maps:
https://experience.arcgis.com/experience/203f772571cb48b1b8b50fdcc3272e2c
USGS Flood Event: https://stn.wim.usgs.gov/fev/#2022Ian

========== Impact Observations ==========

Observed impacts:

Health and social impacts i: As mentioned previously, 146 people have so far been confirmed dead to Hurricane Ian. While the majority of these were due to drowning, roughly 40% of the deaths are from indirect causes such as vehicle accidents, heart attacks, diseases, and even suicide. Flooding in some areas caused sewage spills that became a health hazard to those wading in the water. In particular, Vibrio Vulnificus, a flesh eating bacteria, has led to several infections and delayed deaths. This bacteria thrives in the polluted warm saltwater that was caused by storm surge. Many other water-born health hazards and mold cases are also on the rise. Hurricane Ian is going to take years to recover from and has caused a lot of human suffering. Losing family members, property, and/or jobs can lead to a major increase in mental illnesses. While it is too early to get a count on the number of cases, an increase will certainly be observed within the next couple of months.

Property and business impacts i: The property damages adding up to over $50 billion from Hurricane Ian came from virtually everywhere in Florida except the Panhandle. Between the 27th and 28th, NOAA's Storm Prediction Center confirmed 11 tornado reports from the outer rainbands of Hurricane Ian. An EF1 hit Broward County airport, damaging hangar bays and many aircraft.

Another EF2 tornado plowed through Palm Beach County, toppling trees and severely damaging several buildings and cars. Wind damage was responsible for over 2 million power outages across Florida due to downed power lines, with Lee and Charlotte county being hit the worst. Storm surge flooding damaged homes all the way from just South of Tampa Bay to the Florida Keys. Combined with the winds and rainfall, over 5,000 buildings were completely destroyed and tens of thousands of others with varying degrees of damage. Lee County had the most, with over 52,000 buildings affected according to the NWS.

Critical infrastructure damage and service disruption i: The destruction and flooding of roads and bridges across Florida made it extra difficult to provide rescues and relief to the hardest hit communities. Drinking water supplies ran low in Lee County and surrounding areas in the days after the hurricane due to both severed water lines and polluted water. Sewage filled floodwaters contaminated large areas of Lee County and which will take weeks to clean up. This all led to massive relief efforts that brought drinking and also fuel for a water treatment plant. Trade of farmed goods like oranges and the fishing industry have been slowed dramatically. Flooding and winds ruined farmland, much of which was just beginning to be harvested. Thousands of boats have been left unusable and damage to waterways and boating facilities in general will take months to repair. The fishing industry in west Florida may take years to fully recover due to the environmental damage from Hurricane Ian.

Hurricane Ian - Maps and images showing destruction - BBC News

Environmental damage i: According to Environmental Watch, coral reefs have been destroyed by a combination of the storm surge, increased freshwater, and a lack of sunlight due to huge amounts of runoff. Large toxic algae blooms also followed in the coming days of the hurricane as bacteria levels in the gulf skyrocketed. This has likely killed large quantities of fish, manatees, and other marine creatures.

Astronaut on ISS spots Florida's muddy wounds left from Hurricane Ian (fox9.com)

Sources:

https://www.npr.org/2022/10/19/1129865243/flesh-eating-bacteria-florida-floodwater
Storms like Hurricane Ian exact a long-term toll on public health (grid.news)
Some Southwest Florida counties "off the grid" after Hurricane Ian wiped out power to millions - CBS News
IEM :: PSH from NWS TBW (iastate.edu)
Hard-Hit Parts of Florida Struggle to Find Clean Drinking Water in Ian Aftermath - The New York Times (nytimes.com)
Report: Hurricane Ian farm loss could reach $1.56B (phys.org)
Governor DeSantis Requests Federal Fisheries Disaster Declaration to Support Fishing Industry Impacted by Hurricane Ian (flgov.com)
Hurricane Ian Hit the Sea Hard, Too - Environmental Watch (environmental-watch.com)

What crowdsourcing/citizen science was used for impact observations? i

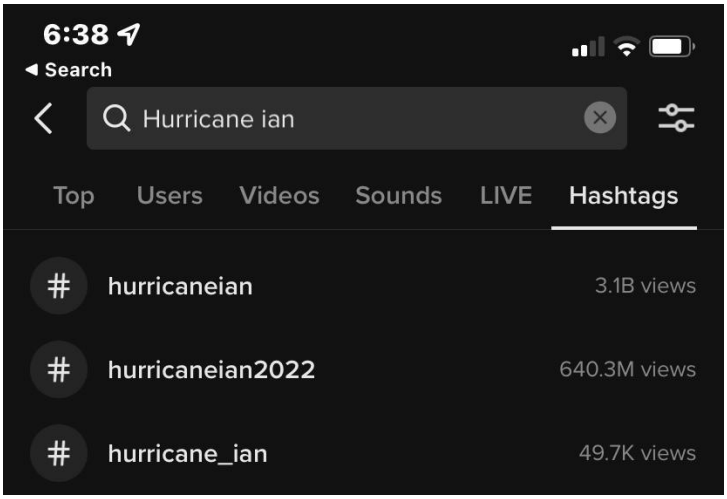
There are a few spotter programs that currently exist that are run by the national weather service that seem to be mainly for spotting tornados, funnel clouds, hail, etc. In events like these time is critical as tornados are short lived events, so spotting the storm is an important issue. But unlike tornadoes hurricanes are multi day events, so spotting the storm is not critical. Furthermore, Due to the extensive impacts from tropical storms including the loss of power and cell service, it is rather difficult to post real time reports inside the storm, therefore the impact observations that were received were videos taken during the storm and later posted to the internet.

In the age of social media, videos and images from significant weather events are spread much easier than in previous years. Just a simple search of #hurricaneian on twitter resulted in thousands of posts about the impacts that people are feeling in their own backyard. The spotter programs that currently exist, run by the national weather service seem to be mainly for spotting tornados, funnel clouds, hail, etc. Due to the extensive impacts from tropical storms including the loss of power and cell service, it is rather difficult to post real time reports inside the storm, therefore the impact observations that were received were videos taken during the storm and later posted to the internet.

This incredible tweet is a perfect example of the way that social media has allowed the impacts of hurricanes to be shared to the general public. This video has nearly 80,000 views, meaning without Twitter and other social media sites many people would have no idea how impactful this weather event was.

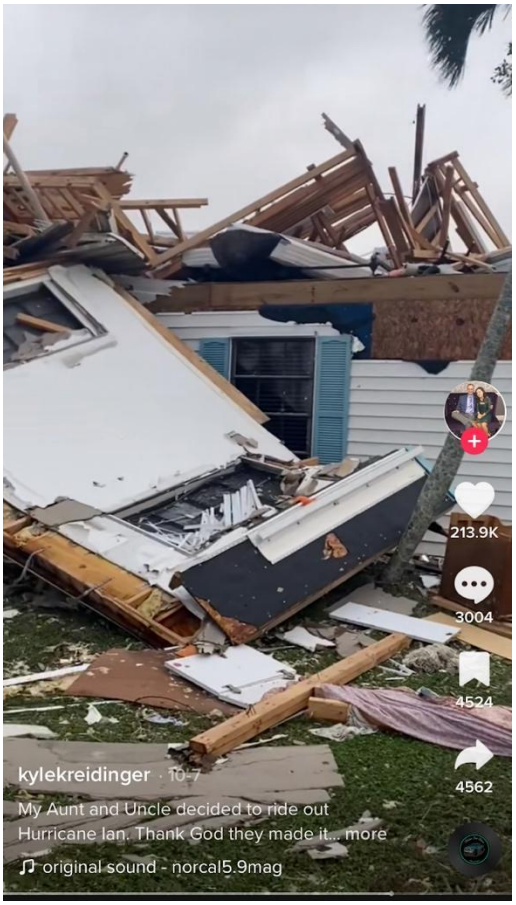
There unfortunately aren't any apps on the apple app store that allow people to post the impacts from storms that they are experiencing, but there is always room for improvement. That would be an interesting concept, a form of social media that allows people to only post weather related media and discuss it.

Besides Twitter there are other social media apps that have allowed people to post the impacts that were felt from hurricane Ian. One app that has risen in popularity is tiktok. On the app Tiktok, they have a thing called the For You Page which is basically just a feed of recommended videos for the user. Me personally for at least a week after hurricane Ian made landfall in Florida, videos of the impacts from Ian were on my For You Page. This is yet another outlet for the general public to show the impacts from a storm on Social Media.



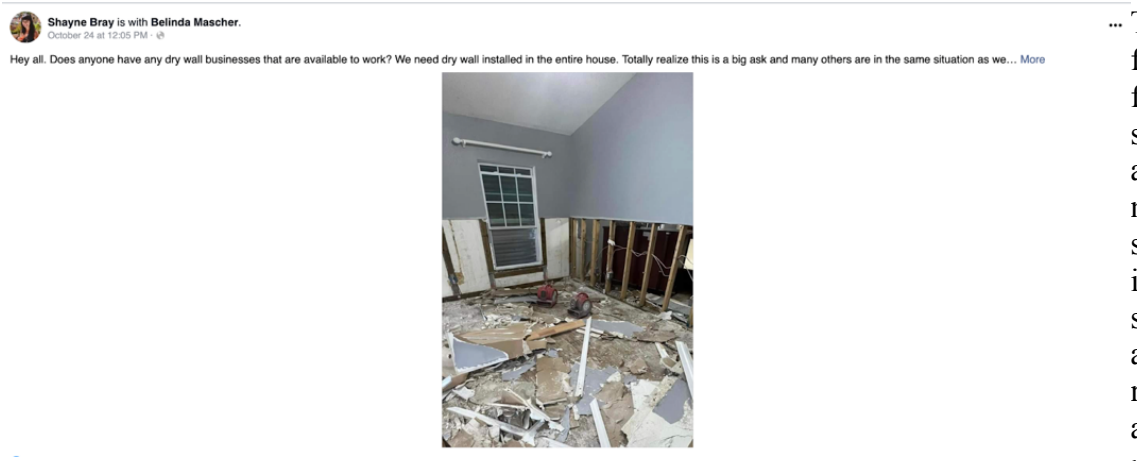
This image shows that the hashtag for Hurricane Ian has over 3 billion views. That is an incredible amount of people and shows how much of an influence TikTok has on the reporting of impacts from Hurricane Ian. This allowed people from all over the world to see the devastation that occurred from the landfall of a major hurricane and it arguably had more of an impact than Twitter. Without TikTok 3 billion people would not have been able to see the devastating impacts from this storm.

This screenshot from one of the thousands of TikToks under #hurricaneian shows the utter destruction of a TikTok users house. The use of social media allows a more intimate showing of the impacts from a storm, as



we are able to see the person by person impacts rather than the impacts felt in just a general area. We get an on the ground look of the aftermath of a storm which before social media that was difficult.

Besides TikTok and Twitter, Facebook has another awesome feature that allows all the victims from hurricane Ian to connect and share their differences. Facebook groups are a great way for people to connect and get help from the impacts they felt from the storm.



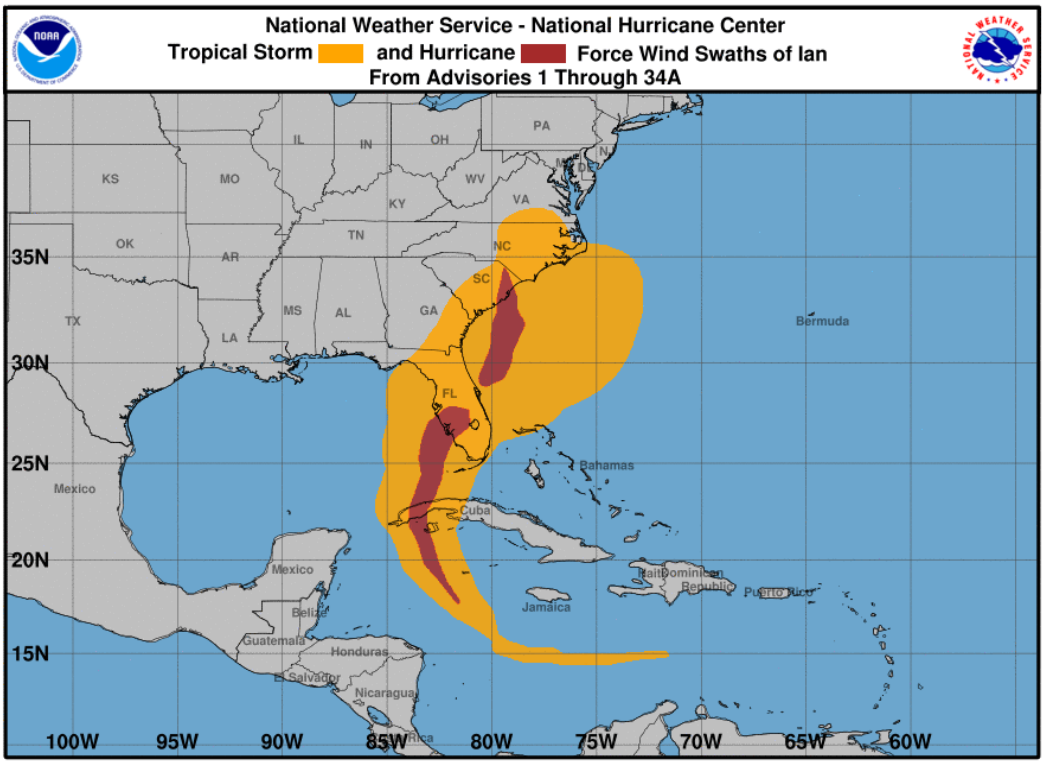
This screenshot from one of the facebook groups shows the feature in action. It allows for not only people to share their personal impacts from the storm, but it also allows people to reach out for any assistance that they may need during the recovery process. This shows how important of a resource that Facebook is.

https://m.facebook.com/groups/3219485791712972/?_se_imp=0uikZzhHwGfU2chOl

https://twitter.com/search?q=%23ian&src=hash&f=live

https://www.tiktok.com/t/ZTRx4SrCA/

Who and what were exposed to the hazards, when, for how long? i



As shown by the above graphic, the main areas that received hurricane-force winds include: Pinar Del Rio, Cuba; Cape Coral, Florida; Georgetown, South Carolina. Tropical storm-force winds were much more widespread, spanning from northwest Cuba, across nearly all of Florida except the panhandle, and coastal areas of Georgia and the Carolinas.

Starting with Cuba, 50,000 residents were evacuated before landfall. Nearly 8,000 homes were lost in Pinar Del Rio due to the magnitude of hurricane winds and rain, and another 60,000 received significant damage. The storm hovered over Pinar Del Rio for several hours, and weaker but still dangerous winds were present hours before and after landfall. Because Ian was a slow moving storm and such a wide storm, its outer bands inflicted damage outside of when the eye remained over land. Lower-lying coastal towns experienced severe flooding from storm surge and rainfall. With another 9,000 homes damaged, many people in Artemisa, Cuba, were exposed directly to the hazards as many homes lost some or all of their roofs.

The area that Ian hit in Cuba happened to be the nations dominant agricultural region for tobacco production. An owner of a prominent cigar producer shared social media images of damages from the storm, leaving community members and workers without shelter and farms eroded. With the growing season of tobacco starting in October, the hours-long strike of Hurricane Ian on western Cuba weakened this large economic sector in the country.

In Florida, about 2.5 million residents were under evacuation orders before the storm made landfall. Mandatory evacuations were in place for 250,000 residents in Fort Myers Beach, Sanibel Island, and Bonita Beach, where storm surge was expected to be the highest. Those in these low-lying locations were subject to severe storm surge up to 12 feet, with the death toll up to 110 as of October 5th. Though the majority of these deaths can be attributed to drowning, other hazards including loss of power caused issues for many residents, including a couple who died because their oxygen machines had no electricity to power them.

The worst of the storm was seen along the southwest Florida coast, but additional fatalities were reported in North Carolina as the storm transitioned from a hurricane back into a tropical storm. When it was downgraded to this level, extreme rainfall struck areas of the Carolinas, reaching up to 15 inches of rain in 12 hours.

Though the wind speeds of Ian reached up to 155 mph, the storm itself only moved at about 9 mph. Since Ian was a slow moving system, those who were exposed to the hazards were exposed for a much longer time period. It's slow motion increased rainfall and wind damage relative to other faster-moving storms.

On the outer bands of the storm, tornadoes formed due to the tropical-storm-force winds further away from the eye. 11 Tornadoes were confirmed in South Florida, damaging aircrafts, vegetation, and homes in Palm Beach and Broward Counties.

Hurricane Ian Wind History: https://www.nhc.noaa.gov/archive/2022/IAN_graphics.php?product=wind_history

Cuba Articles: https://www.pressherald.com/2022/10/06/hurricane-ian-destroyed-close-to-8000-homes-in-cuba-damaged-another-68000-government-says/

https://www.france24.com/en/live-news/20220929-hurricane-ian-a-catastrophe-for-cuba-s-vital-cigar-sector

Cuba and Florida Article: https://www.cnbc.com/2022/09/27/hurricane-ian-makes-landfall-in-cuba-en-route-to-florida.html

Florida Article: https://www.accuweather.com/en/hurricane/florida-faces-grim-reality-hurricane-ian-is-deadliest-storm-in-state-since-1935/1257775

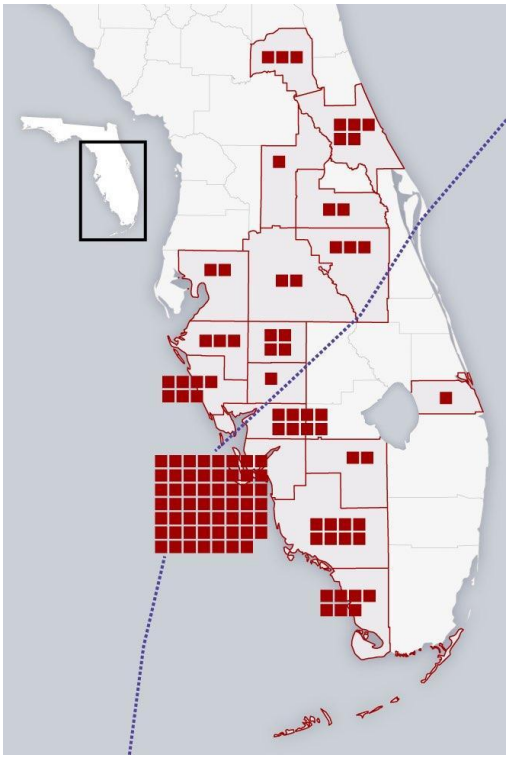
Additional Articles: https://www.nesdis.noaa.gov/news/hurricane-ians-path-of-destruction

https://www.bbc.com/news/world-us-canada-63052558

https://www.weatherandradar.com/weather-news/because-of-hurricane-ian-11-tornadoes-confirmed-in-south-florida--b9e46338-6a09-46b7-b172-97f86317cd38

Of those exposed, who and what were vulnerable to the hazards and why? i

Of the 146 individuals that perished, roughly 2/3rds of them were over the age of 60 and suffered from medical issues. The majority of the deaths were also in the coastal areas in and around Lee County. A lot of the older individuals had a more difficult time evacuating their homes so many stayed to weather out the storm. Others wanted to stay since they owned their home and had lived through past storms that were not as bad. However, when the storm surge hit, many were unable to escape and drowned.



https://www.nytimes.com/2022/10/21/us/hurricane-ian-victims.html

People who were poor and did not have flood insurance were also most vulnerable to Ian's devastation. Only about a third of homeowners that were affected by flooding actually own flood

insurance. Due to FEMA's policies, those who do not have insurance also are disqualified from receiving certain types of government aid. Thousands of people have lost everything they owned and for those without insurance, it will take years, if not decades to make up that money. Even with government aid, thousands of families will be forced to relocate and will never fully recover financially. One community that was hit particularly hard was mobile home communities as the homes were easily picked up and thrown around by the storm surge.

Flood Map: Where Hurricane Ian Hit Florida Hardest - The New York Times (nytimes.com)

Sources:

Vulnerable and Trapped: A Look at Those Lost in Hurricane Ian - The New York Times (nytimes.com)

Hurricane Ian exposes cracks in Florida's flood insurance market - Harvard Law School | Harvard Law School

Additional analysis i

Successes/issues/challenges experienced i

Though many graphics were difficult to find, the majority of NOAA and NHC forecasts, as well as forecast track and intensity models were easy to find online. An NHC storm surge archive was available, but there was some coding error on the archive site that made the NHC surge warnings not viewable. It is also difficult to determine the total number of people impacted by this storm, as well as the total fatalities, both because the storm was so recent and because the intensity of storm surge likely means some bodies will not be recovered. Many products, including the storm surge risk map, were not downloadable as images, so a screenshot had to be taken instead.

Part 2d. Supplementary information about warning communication

Wherever possible, please include references to information you provide.

Editors (Name & Institute):

Brief overview of the communication "story" i

As hurricane Ian approached the Western Florida coast, a number of measures were taken to ensure all citizens and stakeholders were notified of the impending event. Most initial information and subsequent warnings came from the National Hurricane Center.

On September 14th 2022, an easterly African wave broke free from the continent and moved westward across the tropical Atlantic Ocean. The disturbance struggled to gain much strength at first due to the high wind shear created by hurricane Fiona's upper level outflow. Still it was labeled as an invest around this time and eventually managed to organize and gain convection. The NHC officially declared the storm a tropical depression on the morning of September 23rd. By this point, forecast models were confidently predicting the storm would make landfall as a hurricane somewhere on the Gulf Coast, likely in Florida. Weather channels, news outlets, and social media in the United States began to discuss and track the storm. At 900 UTC on September 23rd the NHC released its first public statement alerting the following nations of significant amounts of rainfall to be expected with the arrival of Tropical Depression 09: Aruba, Bonaire, Curacao, Venezuela, Colombia, Jamaica, Cayman Islands, Haiti, Dominican Republic. At 2100 UTC on September 23rd, the government of Jamaica issued a Tropical Storm Watch, notifying Jamaicans that tropical storm conditions were possible within the next 48 hours. At this same time, the government of the Cayman Islands issued a hurricane watch, indicating to its citizens that hurricane conditions were possible in the nation within the next 48 hours. As is typical, the hurricane watch was also issued before the arrival of any tropical storm conditions so that people may safely and adequately prepare. By 1500 UTC on September 24th, the hurricane center posted that "Interests in western and central Cuba, the Florida Keys, and the Florida Peninsula should monitor the progress of Ian." This is the first official statement the NHC had issued directly addressing the continental United States, specifically Florida. Simultaneously, the NHC issued a public advisory notifying Florida residents of potential heavy rain in the forthcoming days. That night, Florida governor Ron Desantis issued a state of emergency for the entire state, attracting the attention of any citizens that had previously not known about the impending storm. The state of emergency declaration was approved by President Biden that same day. By the 25th, it had become fairly certain that Hurricane Ian would make landfall somewhere along the western Florida Coastline although the exact location could not be determined yet. At 11pm that night the NHC issued a tropical storm warning (tropical storm conditions expected within 36 hours) and a storm surge watch (possibility for life threatening storm surge within 48 hours) for the lower Florida Keys. It also issued a storm surge watch for much of Florida's west coast specifying that "life threatening inundation" was possible with water levels rising 4-7 feet. On the morning of the 26th the NHC issued a full on tropical storm watch for much of the Florida coastline south of Tampa Bay. The hurricane center also made clear that the location of landfall along the Florida coast was still unclear but that intense storm surge, strong wind and heavy rain were possible along the entire coastline as early as Tuesday Night (the next day). Most media sources (following forecast models) pointed to Tampa Bay as the most likely location for landfall. After receiving this information many county officials announced mandatory evacuations in Tampa and Charlotte, Hillsbourgh, Pinellas, and Manatee counties. Lee county is a notable exception as it did not announce an evacuation despite receiving the same forecast. Its officials cited "uncertainty" as the reason for withholding the decision. Later on the 26th, the NHC upgraded its advisory to a hurricane warning (hurricane conditions possible in 24-36 hours) for counties along the west Florida coast including Tampa Bay. An early morning report from the NHC on the 27th indicated that the storm would stay further south than previously anticipated, making landfall within Lee county. The county finally issued an evacuation order that same morning. As Floridians prepared for the storm, officials and media outlets focused discussion on the potential dangers of storm surge. Throughout the night of the 27th, the cell phones of many Lee and Charlotte county residents buzzed with tornado warnings. That same night a tropical storm warning was issued for the eastern coast of Florida. At 3pm EST Hurricane Ian made landfall at Cayo Costa in Lee county. Many of the residents had not evacuated. Later that day a hurricane warning was issued for central Florida and the central Eastern coast. By the morning of

the 29th, the hurricane had moved off the eastern coast of Florida, a storm surge warning was still in effect for much of the west coast and a tropical storm warning was still in effect for much of the east coast.

https://www.nhc.noaa.gov/archive/2022/IAN.shtml

https://www.washingtonpost.com/nation/2022/10/14/lee-county-hurricane-ian-evacuation-timeline/

What information was provided to emergency responders, government and other stakeholders about the hazard and its possible impact(s), and by whom? i

The main information provided to partner agencies, emergency managers, etc. are the track and projected magnitude of Hurricane Ian, as well as possible storm surge and flooding impacts. This allows local decision makers to prepare to evacuate certain areas or communicate with the public about the threat. Much of the information communicated to officials was earlier than that communicated to the public. This was in order to avoid "unnecessary panic".

The National Weather Service specifically is working to build relationships with local governments in order to achieve efficient communication not only before a storm, but during and after as well.

https://thehill.com/opinion/energy-environment/3663575-as-hurricane-ian-threatens-florida-the-national-weather-service-shines/

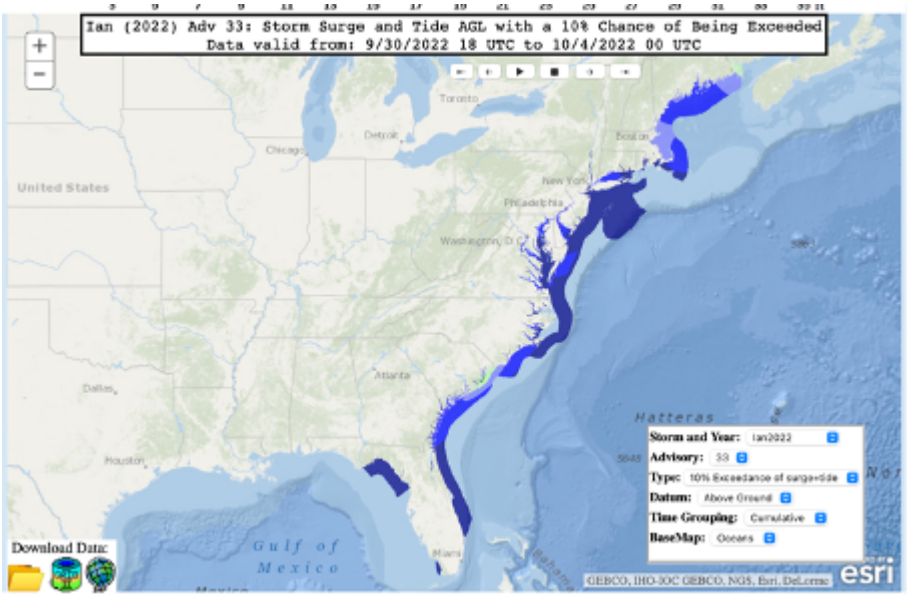
Specifically for Hurricane Ian, many state officials, for example Governor Ron DeSantis, utilized National Weather Service forecasts. When the National Weather Service forecasted that Ian would become a major hurricane, Governor Ron DeSantis declared a state of emergency for Florida.

Many meteorologists were in direct coordination with local officials, such as coordinating warning meteorologist Daniel Noah from the National Weather Service in Tampa Bay, who said he was in close contact with the Lee County emergency management team, providing information through phone calls. He said specifically on Monday and Tuesday, he warned them of the storm surge threat, as it was becoming more and more imminent.

Within Lee County's emergency management operations center, presentations were conducted to emergency responders by Commissioner Kevin Ruane, which advised to lean to the "pessimistic side in decision making". This makes it evident that emergency management officials received information more on the pessimistic and the worst scenario side.

https://www.winknews.com/2022/10/24/hurricaneianevacuations/

There is not a ton of widespread information of how exactly information was provided and what specific pieces of information was provided to partner agencies, government officials, etc., or it is not yet available to the public domain, but many local officials use the P-surge model of probabilistic storm surge for certain areas. This allowed local officials to issue evacuation warnings based on the areas included in the P-surge model. An example of the model for Hurricane Ian is included below.



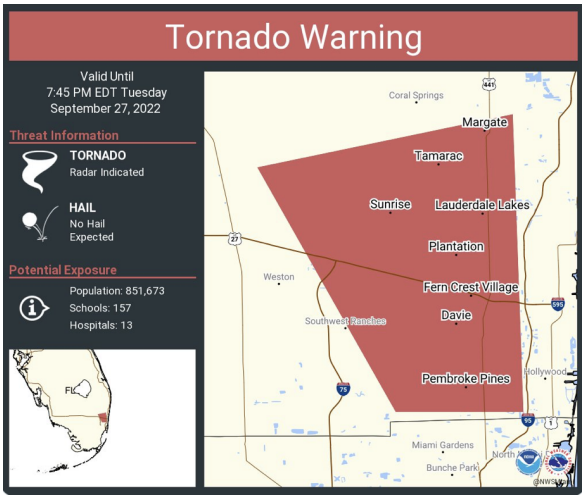
https://slosh.nws.noaa.gov/psurge/index.php?S=Ian2022&Adv=33&Ty=e10&Z=m1&D=agl&Ti=cum&Msg=17&Mp=Ocean_Basemap&Help=about

Public warnings i

Warning name	Icon / colour	Lead time	Frequency	Issued by i	Warning area i	Type of warning i	Did it include safety advice?	Scaled i	Channels i

- On September 25, 2022 at 5 PM, the first Tropical Storm watches were issued for the Florida Keys.
    - All watches from the NWS were given at least a 48 hour lead time when issuing.
- By 11 PM on the 25th, those watches became Tropical Storm Warnings for the Keys and more tropical storm watches were issued for the Southwest Florida Coast from Chokoloskee through Punta Gorda.
- On September 26th, storm surge watch was in effect from the Card Sound Bridge up through portions of the Florida west coast.
- By 11 AM EST on the 26th, Hurricane Watches became in effect along the Florida Gulf Coast extending from Punta Gorda through Tampa Bay. Watches still in effect for the rest of SW Florida Coast and Lake Okeechobee.
- By 11 PM, Hurricane Warnings were issued for Key West and the coastlines from Punta Gorda through Tampa Bay with Tropical Storm warnings from the Keys up the SWFL Coastline through Fort Myers. Hurricane watches extended into the Big Bend region with Tropical Storm watches along the panhandle and Florida's east coast.
- By the 27th, hurricane warnings were extended to include Lee and portions of Collier County. Tropical Storm warnings became in effect from West Palm Beach through Daytona Beach and the Lake Okeechobee region.
    - Storm Surge warnings were in place from Flamingo, FL through Naples, FL and a Storm Surge Watch was in place for South Miami Dade County with a coastal flood statement extending through Miami-Dade, Broward and Palm Beach counties.
- Flood Watches were issued on the 27th for the entirety of South Florida.
- On September 27th, a tornado watch was issued from the Keys through the entirety of South Florida (Bonita Springs and Jupiter Farms southward).
- At 11 AM on the 27th, tropical storm watches remained in place for Miami Dade and Broward counties with warnings extending through Monroe, Collier, Hendry, Glades and Palm Beach counties.
- There were numerous tornado warnings reported with a lead time of less than 15 minutes before.
    - On the 27th until 2:45 pm a tornado warning was in place in Everglades National Park as Ian's outer bands flared into our region.
    - On the 27th until 4:15 PM, a tornado warning was in place for portions of Broward County and another in Miami Dade county.
    - Another warning was in place on the cusp of the Monroe and Collier counties border until 4:45 PM. Also another was in place in Miami Dade/Monroe counties at this time as well.
    - Multiple others were reported as well. Alerts were sent out with images indicating where the estimated area and path of tornado would occur with detailed threat information and potential exposure.
- On September 28, 2022, the tornado watch for South Florida extended a little further north and the time was until 5 AM.

- On September 27th, the Collier County Government put Zone A of Collier County under mandatory evacuations with color coded maps of where each zone is.
- A flash flood warning was issued including Miami Gardens FL, North Miami and North miami Beach until 10 PM on the 27th.
- By 11 PM on the 27th, Tropical Storm warnings were issued along Florida's East coast into the Carolonas, portions of the Bahamas, north of Tampa into the Peninsula and the Florida Keys. Hurricane Warnings were in place for the SWFL coast into Tampa Bay.
    - Hurricane warnings were extended inland. Storm Surge Warnings extended up the Gulf Coast.
- On the 28th at 5PM the Tornado watch was extended to 5 PM and expanded to include the majority of the Florida Peninsula from Orlando to Miami to the Gulf Coast.
- An extreme wind warning was placed in effect for Cape Coral FL, Bonita Springs FL, Estero FL until 12:45 PM EDT on the 28th for extremely dangerous hurricane winds. The national weather service said to "treat these imminent extreme winds as if a tornado was approaching and move immediately to an interior room or shelter NOW!"
- By the 28th, Hurricane Warnings extended to Include the Space Coast and Hurricane Watches extended from the Georgia Coastline up through Charleston SC. Tropical storm warnings and watches extended up through North Carolina.

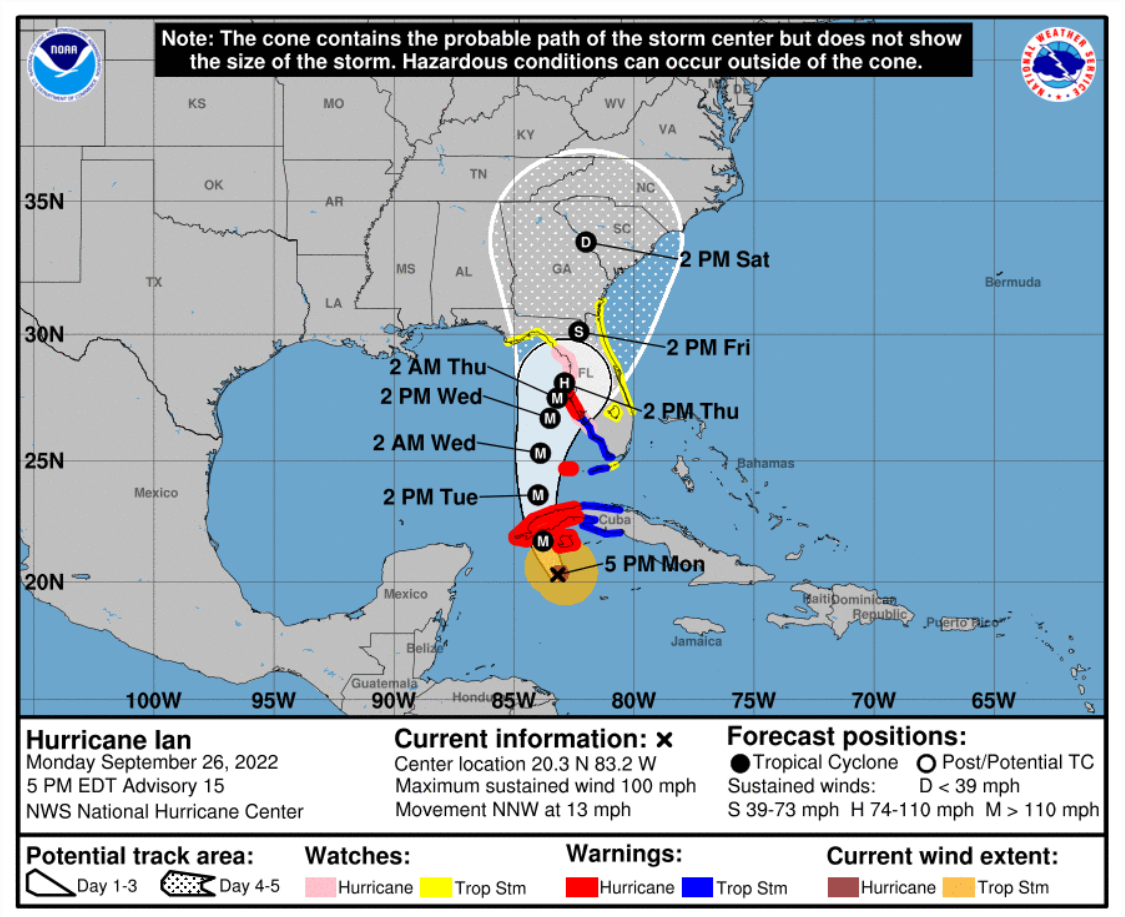


How was warning information communicated by other organizations including media? i

In the days leading up to Ian many media sources chose to put emphasis on the uncertainty in hurricane Ian's forecasted track. While the exact location of Ian's landfall was highly uncertain, pretty much until the day before, the area of actual landfall was always within the cone of uncertainty, indicating that landfall there had been possible all along. By focusing so much on the exact location of the storm's center, media outlets may have provided a false sense of security to communities that were not explicitly mentioned as one of these possible landfall locations but were still within the cone of uncertainty. Take Lee County for example, the actual landfall location of the storm. County officials in Lee failed to order an evacuation in a timely manner, even when all the adjacent counties had already done so. The cited reason for the decision not to evacuate when they probably should have was the high uncertainty of the landfall location. If the media had emphasized the possibility of damages and dangerous conditions all throughout the cone of uncertainty, perhaps this could have been avoided.

Because of the high degree of uncertainty, the most reliable sources, other than the official public warnings, seemed to be academic rather than journalistic. Universities, including the University of Florida and the University of Tampa issued their own warnings, closures and evacuations which residents of their surrounding communities also took into account during their storm preparation.

Other than the general uncertainty, any media shortcomings could have been caused by heavily referencing the cone of uncertainty. Many people who are unfamiliar with the cone wrongly believe that the storm's eyewall always tracks through its center. This is heavily misleading and although many media sources have attempted to explain the cone, it is evident that there are still people who do not understand it. Perhaps the graphic is due for some remodeling?



https://news.ufl.edu/2022/09/hurricane-ian---uf-update-5-/

https://www.insidehighered.com/news/2022/09/28/florida-colleges-close-campuses-hurricane-ian-nears

Warning outputs and examples i

```
WATCHES AND WARNINGS
--------------------
CHANGES WITH THIS ADVISORY:

A Hurricane Warning has been issued for the Dry Tortugas.

A Storm Surge Warning has been issued for Anclote River southward
to Flamingo, including Tampa Bay.

A Storm Surge Watch has been issued for Altamaha Sound to the
Flagler/Volusia County Line, including the St. Johns River.

The Tropical Storm Watch has been upgraded to a Tropical Storm
Warning from Englewood southward to Flamingo. A Hurricane Watch has
been issued from Bonita Beach to Englewood.

The Hurricane Watch from Englewood to the Anclote River, including
Tampa Bay, has been upgraded to a Hurricane Warning. A Hurricane
Watch has been issued from the Anclote River to the Suwannee River.

A Tropical Storm Watch has been issued from the Suwannee River to
Indian Pass, and from Jupiter Inlet to Altamaha Sound.

The government of the Cayman Islands has discontinued the Tropical
Storm Warning for Grand Cayman and the Tropical Storm Watch for
Little Cayman and Cayman Brac.
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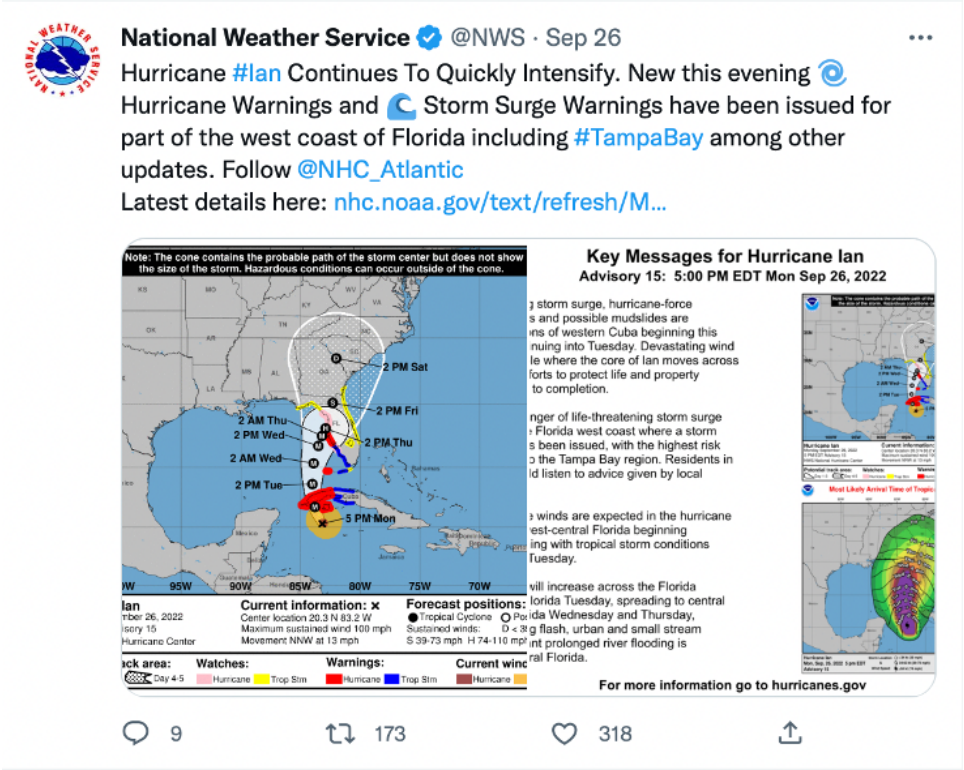
Shown above is the first National Hurricane Center report on Monday, September 26th at 5:00 P.M. that issues any type of hurricane watch/warning for any part of the Florida West Coast. This includes a storm surge warning for Tampa Bay area as well.

Watches and warnings graphic communicated on September 26th at 11:18 P.M.

https://www.wftv.com/weather/eye-on-the-tropics/hurricane-ian-forms-expected-rapidly-strengthen-monday/ZFDMBLUUQRDGHAPBUNF5W7MWBU/

Map of watches and warnings communicated when Hurricane Ian strengthened into a hurricane, published September 26th at 6:17 A.M.

https://www.wlrn.org/weather/2022-09-26/ian-becomes-a-hurricane-alerts-issued-from-tarpon-springs-southward



https://twitter.com/NWS

Additional example of the first hurricane warnings and storm surge warnings for the west coast of Florida on Monday, September 26th at 5:00 P.M.

https://www.youtube.com/watch?v=O8fPA3AqWMg

This video clip shows an example of tornado warnings going into effect for many regions along the East coast of Florida on September 28th, 2022

The National Weather Service in Miami issued the following update at 2:10 PM CDT Wednesday.

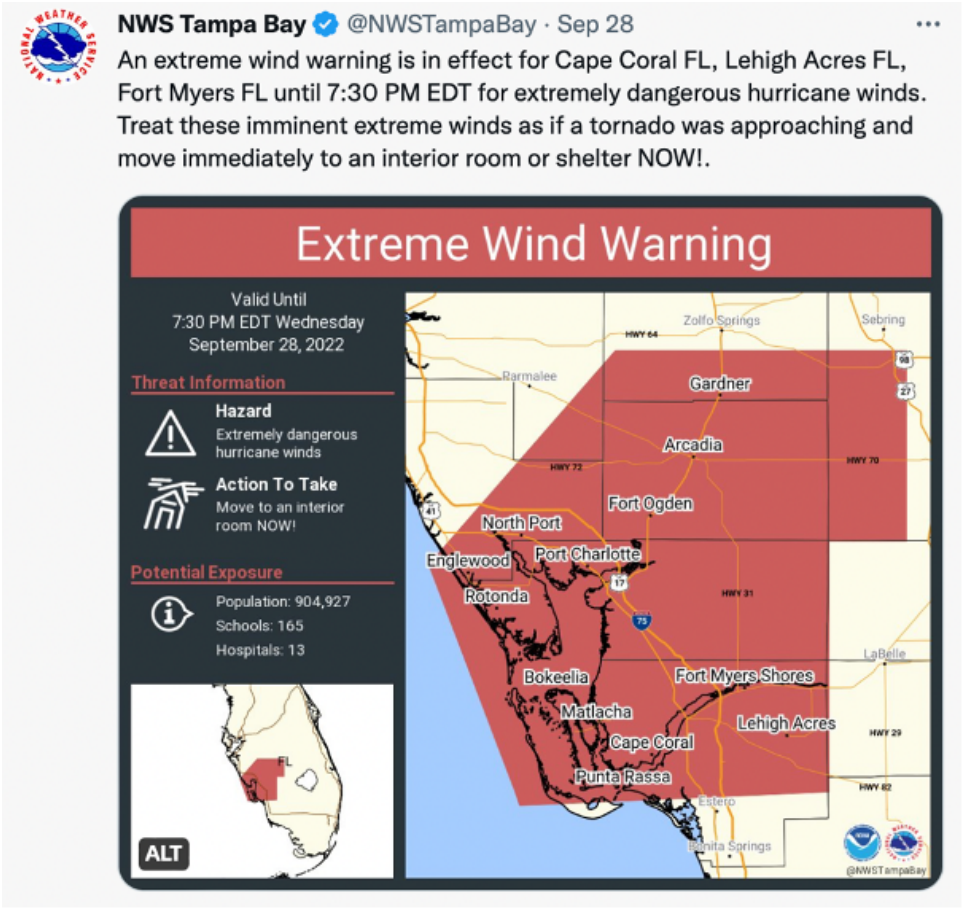
...EXTREMELY DANGEROUS CATEGORY 4 HURRICANE IAN MAKES LANDFALL IN SOUTHWESTERN FLORIDA...

NOAA DOPPLER RADAR IMAGERY INDICATES THAT THE EYE OF IAN MADE LANDFALL ALONG THE SOUTHWESTERN COAST OF FLORIDA NEAR CAYO COSTA AROUND 305 PM EDT (1905 UTC). DATA FROM AN AIR FORCE RESERVE RECONNAISSANCE AIRCRAFT INDICATE THAT IAN'S MAXIMUM SUSTAINED WINDS WERE ESTIMATED TO BE NEAR 150 MPH (240 KM/H). THE LATEST MINIMUM CENTRAL PRESSURE ESTIMATED FROM RECONNAISSANCE DATA IS 940 MB.

— *National Weather Service*

The national weather service gives an update on Hurricane Ian as it makes landfall on September 28th.

https://www.kbtx.com/2022/09/28/hurricane-ian-makes-landfall-florida/



Extreme wind warning communicated on Twitter September 28th at 5:27 P.M.

https://twitter.com/NWSTampaBay/status/1575235739914145792?cxt=HHwWgMCoseejrtwrAAAA

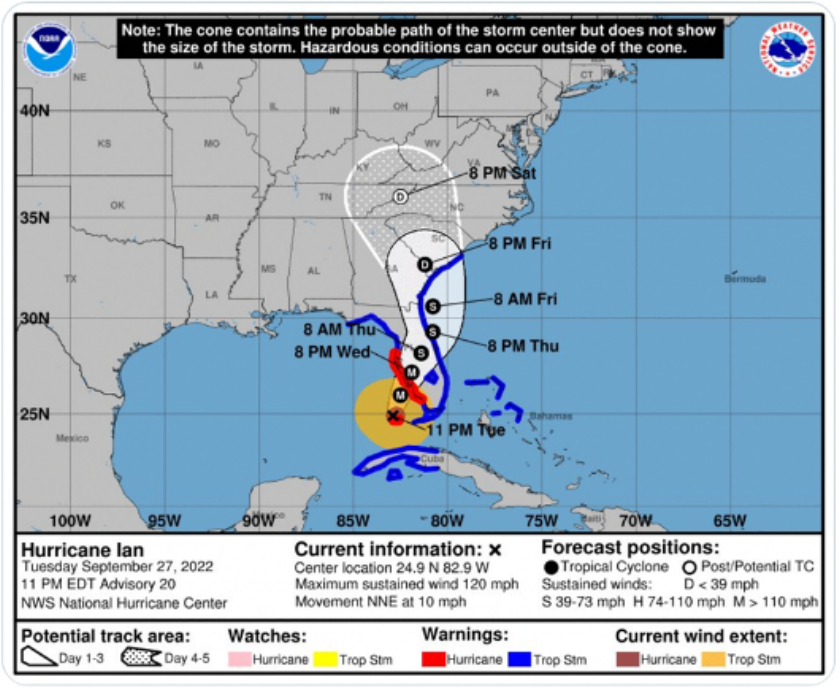
National Weather Service provides information on an extreme wind warning.

https://twitter.com/NWS

National Weather Service @NWS · Sep 27

The only change to existing watches and warnings with the 11pm update: The Tropical Storm Watch north of Altamaha Sound to South Santee River is changed to a Tropical Storm Warning.

hurricanes.gov for the latest updates.

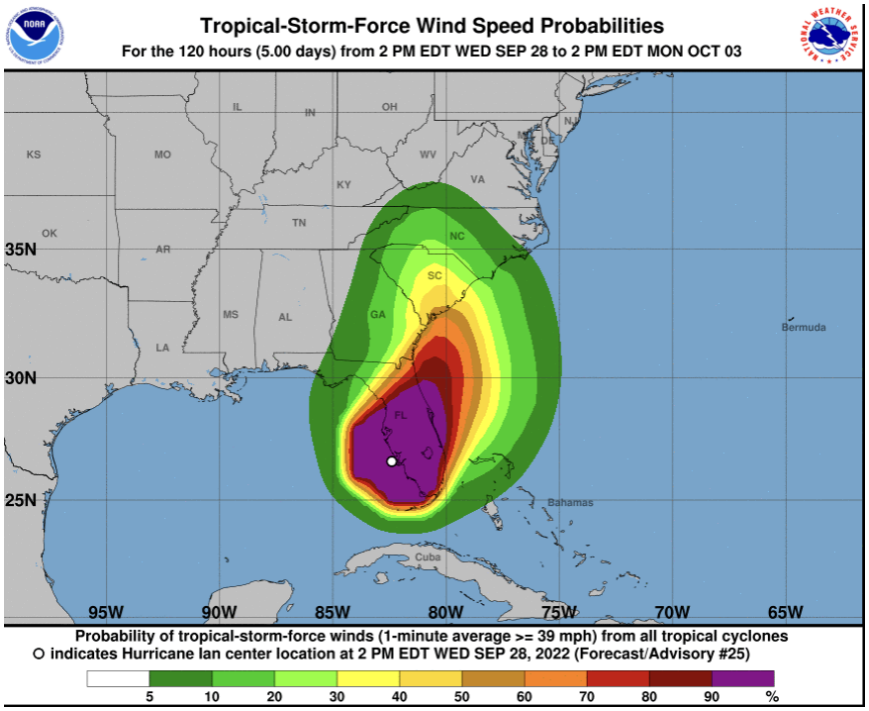


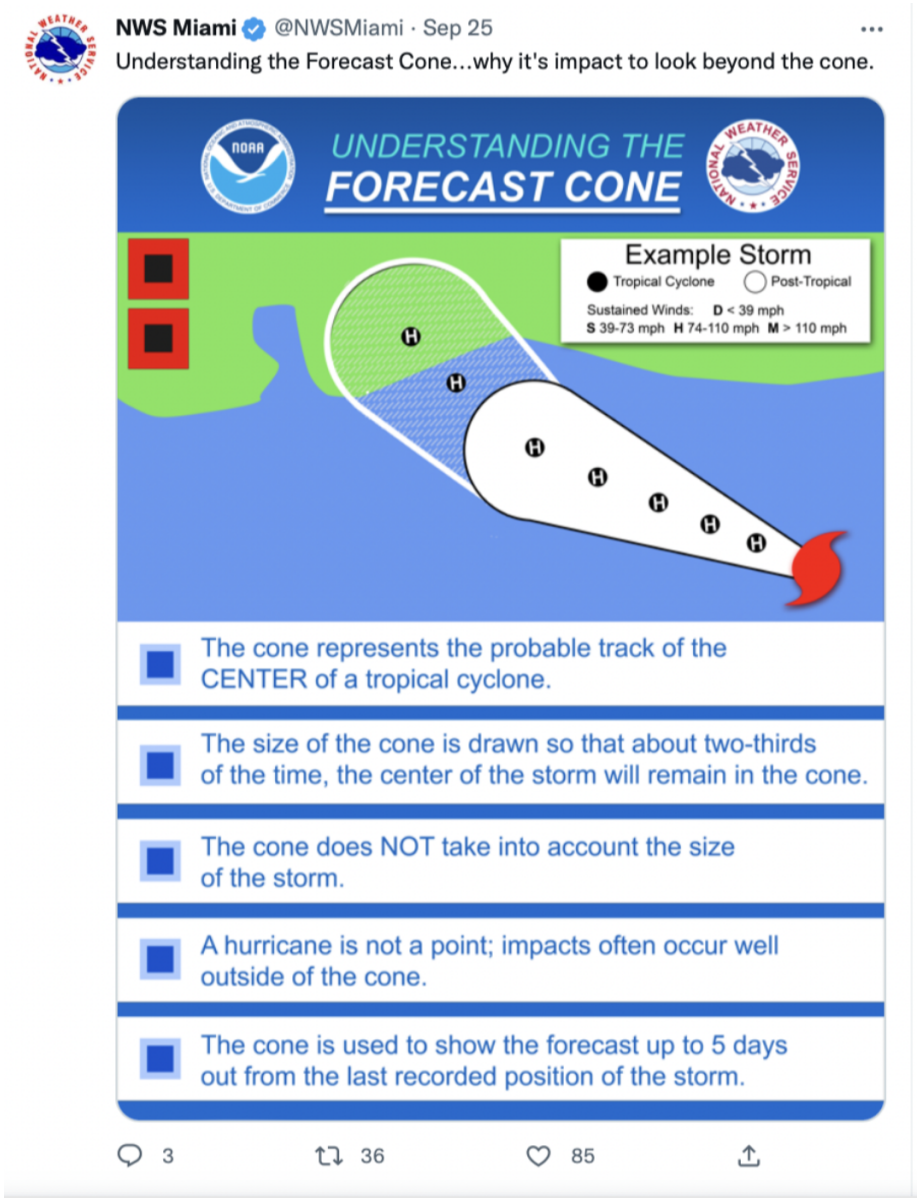
Watches and warnings as of Tuesday, September 22nd 11:00 P.M., day before landfall

https://twitter.com/NWS

Comment on the use of uncertainty information in the warning i

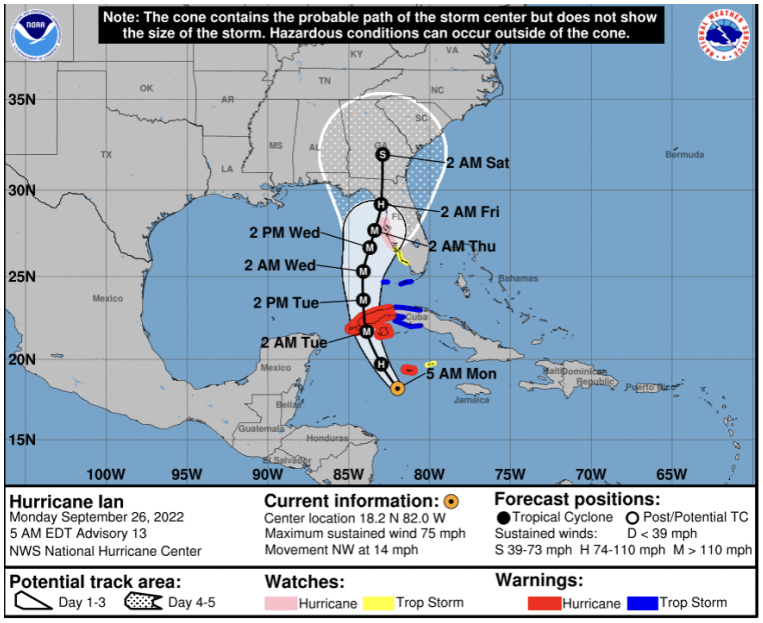
Uncertainty plays an important role in forecasting weather. The National Weather service included uncertainties when they used the tropical storm force wind probability map. This graphic expressed the probability percentage of tropical storm force winds to occur. This expresses the probability it will happen, but also with this comes the percent uncertainty as well.

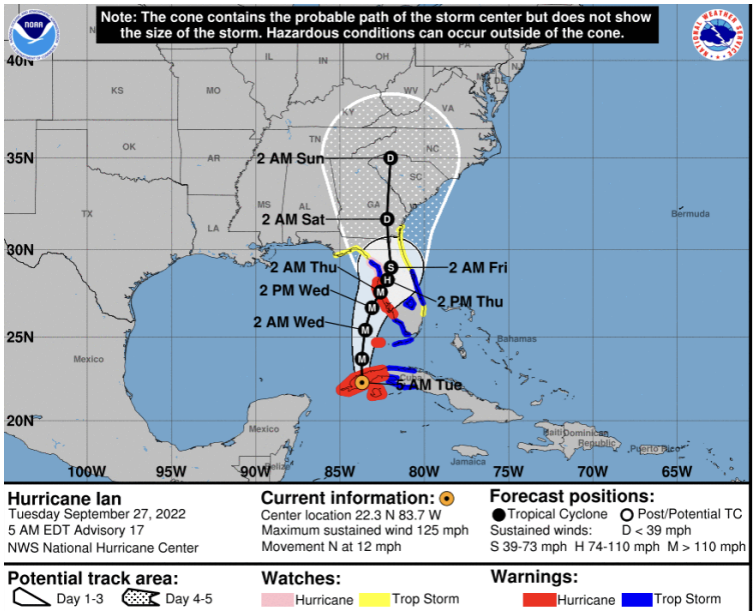


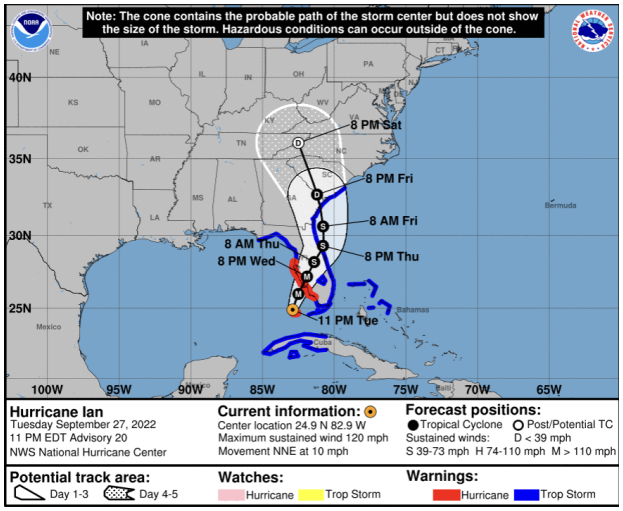


Additionally, when forecasting Ian, many people have a difficult time understanding the cone of uncertainty. The cone communicates the most likely track of the center of the storm. It is connected by time frames and circles are drawn to express a percentage amount of forecast errors and are eventually connected to make a

cone. Over just three days in the forecast of Ian, the cone of uncertainty went from Tampa Bay to the Big Bend then back to Tampa before going down South towards the Lee County coast. The National Hurricane Center's acting direction mentioned how Ian's center stayed within or on the edge of the cone throughout the entire forecast. Earlier in 2022, the American Meteorological Society published a study by a group of University of Miami researchers surveyed more than 2,800 people about their understanding of the cone of uncertainty. Unfortunately, the results do suggest that communications on uncertainty need to be readdressed. Only 18% of the responders correctly answered all questions about the cone graphic. FOX Weather Hurricane Specialist Bryan Norcross said people need to "stop looking at the cone once watches and warnings come out and focus on those instead . . . the cone has acquired an outsized influence in modern hurricane communications".







To what extent were communication systems in place and operating effectively? i

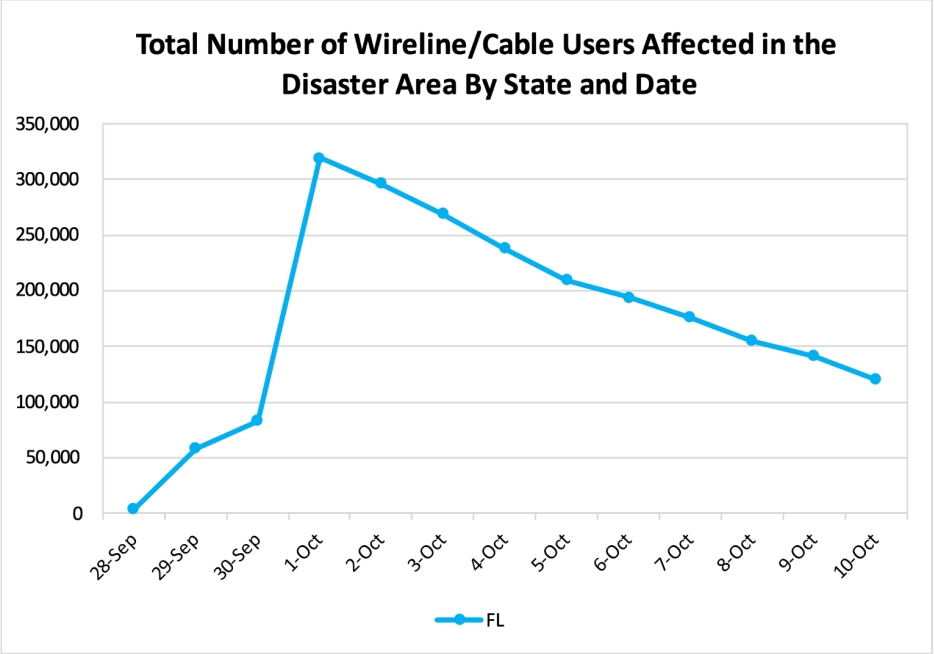
Tornado warnings were issued by cell phone notifications to citizens in Charlotte and Lee counties as hurricane Ian made landfall. This did not appear to be an issue as relatively little damage was done to cellular infrastructure in the counties as seen below. An overall total of 21 cell sites were left out of order by the storm. Although this is only less than 4% of sites in the surveyed area and the sites are designed to have overlapping coverage, the storm still left over 300,000 people without cellular service. This made receiving helpful information or reaching notifying first responders exceedingly difficult for those affected.

Federal Communications Commission

Florida

State	Affected Counties	Cell Sites Served	Cell Sites Out	Percent Out	Cell Sites Out Due to Damage	Cell Sites Out Due to Transport	Cell Sites Out Due to Power	Cell Sites Up but On Back-up Power
FL	CHARLOTTE	114	1	0.9%	0	0	1	3
FL	DESOTO	25	1	4.0%	0	0	1	1
FL	LEE	394	19	4.8%	1	13	5	21
TOTAL		**533**	**21**	**3.9%**	**1**	**13**	**7**	**25**

The number of cell site outages in a specific area does not necessarily correspond to the availability of wireless service to consumers in that area. *See* Improving the Resiliency of Mobile Wireless Communications Networks, Order, 31 FCC Rcd 13745, para. 10 (2016) (recognizing the difficulties in accurately depicting the ongoing status of a wireless provider's service during emergencies). Wireless networks are often designed with numerous, overlapping cell sites that provide maximum capacity and continuity of service even when an individual site is inoperable. In addition, wireless providers frequently use temporary facilities, such as cells-on-wheels (also known as COWs), increase power at operational sites, initiate roaming agreements, or take other actions to maintain service to affected consumers during emergencies or other events that result in cell site outages.



Most Florida municipalities do not currently have a hurricane or tornado siren system in place. Many communities in other impacted states like Georgia and South Carolina sounded their local tornado sirens ahead of hurricane Ian's second US landfall.

Most news sources and many social media outlets, including Governor Ron Desantis's twitter page, encouraged Florida residents to examine the NHS webpage, and heed announcements from local officials.

https://www.nhc.noaa.gov/spanishtcd.php

https://www.wtsp.com/video/weather/hurricane/red-cross-looking-for-spanish-speakers-to-assist-with-hurricane-ian-relief/67-47c55b29-0441-4bed-aa77-da0dd86082ba

https://www.wtvr.com/news/local-news/red-cross-searching-for-volunteers-fluent-in-spanish-hurricane-ian-october-3-2022

https://www.ladrc.org/disasters/seminole-tribe-of-florida-hurricane-ian/

https://www.rubio.senate.gov/public/index.cfm/2022/10/rubio-rick-scott-expedite-aid-for-seminole-tribe

http://www.native-languages.org/seminole.htm

To what extent were warning messages received and understood by the public? i

One of the major sources of information about hazards and the impacts is the cone of uncertainty. This is misinterpreted by many, possibly causing under preparedness, especially in the Fort Myers area and further south. An example of the cone of uncertainty is shown below:

https://www.usatoday.com/story/news/2022/09/28/track-shifts-uncertainties-all-part-hurricane-ian-forecast/10452213002/

A significant region of southwestern Florida is not within the cone on Sunday, September 25th, which perhaps led many to believe they were not in danger at all, a common confusion with the cone of uncertainty, leading people to ignore all warning messages from there on out.

In addition to individual confusion about the cone, this incorrect assumption could be shared among family members and friends, causing a chain reaction of unpreparedness when warnings moved into their area, even if their area wasn't originally in the cone, such as Cape Coral. The chief of forecasting for the National Hurricane Center discusses the cone of uncertainty in saying "I found it frustrating to hear all the back and forth whether Lee County was in the cone or out of the cone when that really shouldn't have been the focus and it shouldn't have been a part of anybody's decision-making." (https://www.gpb.org/news/2022/10/08/ians-death-toll-rises-questions-swirl-on-why-more-floridians-didnt-evacuate)

An article by WINK news discusses the timing of evacuation orders from Lee County. It mentions that evacuation orders were made only one day before landfall of Hurricane Ian in order to avoid "over evacuation". This short timing of evacuation orders could have led the public to interpret it as not urgent and just as precautionary, leading many to not evacuate. Many people tend to follow the majority, so if a certain family member wasn't evacuating, their close friends and family may have followed them and also not evacuated.

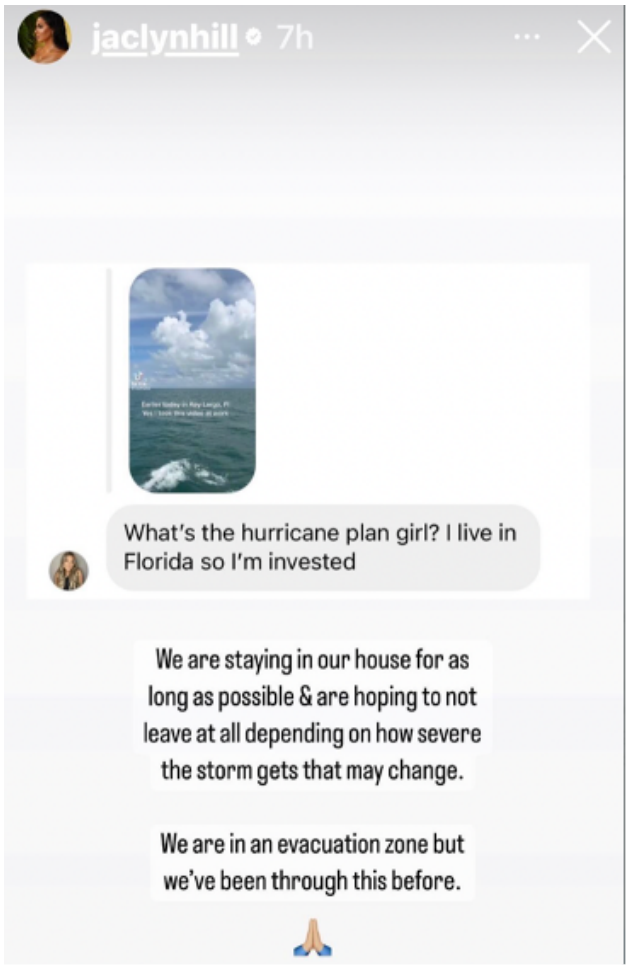
Sanibel Island, one of the worst hit areas of Hurricane Ian, had begun anticipating an evacuation on September 24th, although many residents still did not evacuate at all.

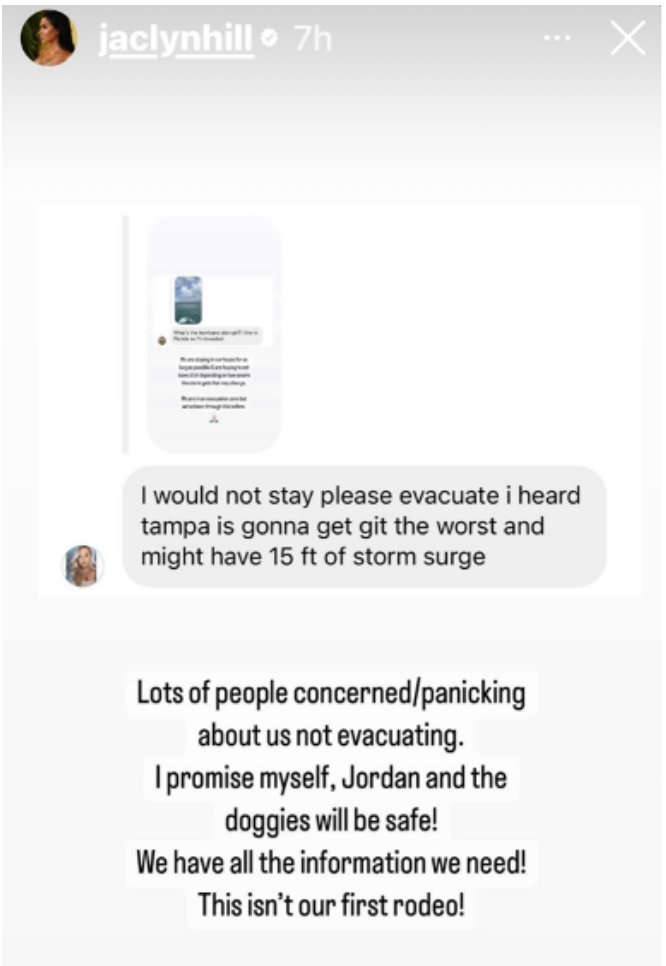
TV stations such as WINK-TV in Fort Myers, Florida continued to share information and warnings with the public on social media, despite their TV studio being flooded by storm surge, and further continued broadcasting despite the flooded studio.
https://deadline.com/2022/09/fort-myers-tv-station-continues-reports-even-after-hurricane-ian-damage-forced-it-off-air-1235132450/

It can inferred that a large portion of the public receive warnings and information from social media, such as Instagram and Twitter. The National Weather Service twitter page, with three million followers, posted

updates of warnings and information about warnings for the public to access. These same warnings and graphics were also forecasted across various news stations in the cities and towns that were to be impacted.

However, there is a widespread belief on social media platforms such as Instagram and Twitter that "a true Floridian doesn't evacuate" – a dangerous mindset that many people on media hold when presented with warnings. An example is shown below from a celebrity, Jaclyn Hill, who was within an evacuation zone, who decided not to evacuate despite the warnings. Additionally shown is a tweet in response to Jaclyn Hill's statements.





https://twitter.com/RichLux713/status/1574930886839390209

Some of the public receive warnings lightly, especially in Florida, by assuming they are just like every other time, and they infer that the storm won't be that bad by comparing it to past instances. This leads to even more deaths and emergency when the storm does turn out to be extremely dangerous.

Overall, the main source of confusion in response to access to warnings was the timing of the warnings in areas such as Sanibel Island and Fort Myers. When many people were asked following Hurricane Ian why they didn't evacuate despite adequate access to warnings, many people said it was because of the sudden and late change in Ian's projected path.

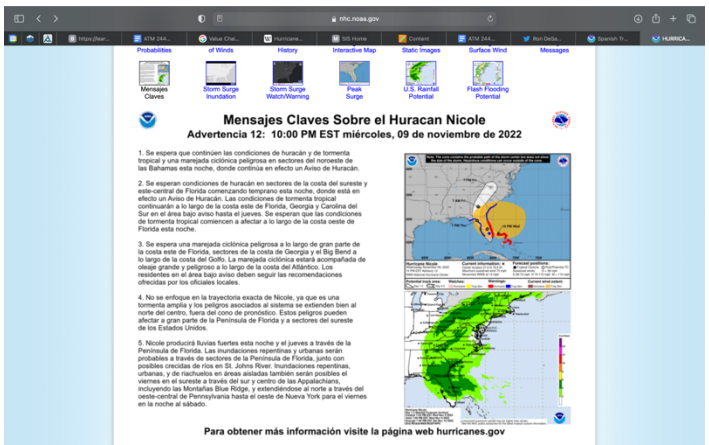
https://www.gpb.org/news/2022/10/08/ians-death-toll-rises-questions-swirl-on-why-more-floridians-didnt-evacuate

In the modern era of social media and communication, the public had methods to access warnings in a variety of ways, whether being told over the phone by a family member after that family member saw the warning on TV, or whether someone saw the hurricane warning for their area on the National Weather Service Twitter. However, as always, despite the method and frequency of warnings communicated, there is always confusion in the public, which acts as a chain reaction of inadequate responses to the warnings, such as not evacuating.

To what extent was crowdsourcing/citizen science used for warning dissemination? i

Social media is a great way for citizens as part of a citizen science project to provide warnings for others. With social media platforms like TikTok, Snapchat, Instagram and Twitter dominating the world it is easy for people to share their own experiences in a storm or provide videos or statistics with what is ongoing in specific areas. This can provide information to individuals that are still waiting to feel the impacts. Residents in Fort Myers posted videos on TikTok and other social media platforms of the surge pummeling into residences and streets. This can cause citizens in Orlando to see the damage being done and take further precautions and preparations.

Comment on how the needs of specific communities and populations were addressed i



The state of Florida is home to over 4 million native Spanish speakers, making up almost 20% of the state's overall population. For this reason, it is important for all advisory messages issued throughout the state be translated in both English and Spanish. The National Hurricane Center releases Spanish versions alongside all its advisories to ensure that Spanish speakers remain up to date on the latest information. I couldn't find any translated information on any local or state government social media pages, however; most social media sites include a built-in feature which translates posted text into the user's native language. The American Red Cross, the nation's foremost natural disaster related response organization, has admitted to its shortcomings when it comes to communicating with victims in Spanish. In an effort to improve its services, the organization has advertised the need for more Spanish speaking volunteers to help with Ian relief.

The Seminole Native American tribe, which occupies reservations throughout Florida was heavily impacted by Hurricane Ian. Just after the storm, President Biden declared a "major disaster" for the Seminole tribe (which was initially requested by senators Marco Rubio and Rick Scott) which granted the tribe access to additional funding and aid from the federal government. I have been unable to find any information that indicates the tribe received any special notifications before the storm's arrival. Since most Seminole's alive today speak English, and have internet connection on their reservations, it's safe to assume they were able to receive the same NHC and government advisories as the rest of the state.

In order to accommodate any hard-of-hearing Florida residents, all official state government videos posted to social media or aired on TV included either closed captions or a sign language translator.

https://www.nhc.noaa.gov/spanishtcd.php

https://www.wtsp.com/video/weather/hurricane/red-cross-looking-for-spanish-speakers-to-assist-with-hurricane-ian-relief/67-47c55b29-0441-4bed-aa77-da0dd86082ba

https://www.wtvr.com/news/local-news/red-cross-searching-for-volunteers-fluent-in-spanish-hurricane-ian-october-3-2022

https://www.ladrc.org/disasters/seminole-tribe-of-florida-hurricane-ian/

https://www.rubio.senate.gov/public/index.cfm/2022/10/rubio-rick-scott-expedite-aid-for-seminole-tribe

http://www.native-languages.org/seminole.htm

Additional analysis i

Beliefs, such as the ones mentioned in section viii, of "true Floridians not evacuating" affected warning communication greatly for this event. This widespread belief downplayed the gravity of such warnings, leading to a chain reaction of inadequate responses to warnings.

Communication success/issues/challenges experienced i

Things that were done especially well included the utilization of social media such as Twitter, Instagram, and Tik Tok. This educated and informed younger people, who spread the information themselves to family members and friends. These social media platforms also offered a very quick and efficient way of communicating information with no delay.

Things that were done particularly wrong included the timing of evacuation orders, especially for areas such as Sanibel Island and Fort Myers, due to the uncertainty in Ian's path.

Part 2e. Supplementary information about responses

Wherever possible, please include references to information you provide.

Editors (Name & Institute):

Brief overview of the response to the hazard by emergency services and other partners i

Despite the widespread difficulty in determining Hurricane Ian's track and intensity upon landfall in the US, the disaster response in the state of Florida began on September 23rd. Governor Ron DeSantis issued a state of emergency for 24 counties, well before Ian had became a tropical storm. This declaration put the Florida National Guard on standby, prepared to respond to the storm's damages. The Federal Emergency Management Association approved this declaration on the 24th, and a day later, on September 25th, DeSantis expanded this state of emergency statewide. Doing so acknowledged the National Hurricane Center's forecast of Ian intensifying, thus encouraging Floridians that this was a serious issue that needed preparation.

On September 26th, the Florida Division of Emergency Management announced official measures in place to assist citizens in storm preparation, evacuation, and response. FDEM began loading trailers with food and water to bring post-landfall to the heaviest impacted areas. The Florida National Guard activated 2500 members in the state, sending them to areas along the western coastline. The Florida Agency for Health Care Administration visited nursing homes across the southwestern portion of the state to supply generators. The Florida Department of Transportation cleared roadways and drainage areas, and the Florida Wildlife Commission contributed high-water vehicles to assist in storm response. Multiple School districts, colleges, and universities on the southwest Florida coast closed schools beginning on September 27th.

Preparations for landfall continued on September 27th, with evacuation orders issued for the counties of Charlotte, Hillsborough, Levy, Lee, Manatee, Pasco, Pinellas, and Sarasota. As of this day, FDEM had 160 truckloads of reinforcements prepared for deployment, with some already in route to the most at risk areas. The number of national guard members deployed doubled to 5,000 guardsmen, and additional guardsmen from Tennessee, Georgia, and North Carolina were activated. The department of health had deployed over 300 ambulances, with more on standby. Multiple tolls were suspended by the FDOT to encourage evacuation amongst residents.

On September 28th, the Florida Disaster Fund was activated to assist communities in rebuilding after the storm's passage. Since the hurricane made landfall early on the 28th, 200 shelters were open as of that evening. The FDEM reported that ¾ of a million residents were experiencing power outages that evening, but utility companies had over 40,000 staff on standby to restore power when it was safe to do so. 10 helicopters were prepared to make rescue missions post-landfall, and this number was expected to increase. More tolls were suspended by the FDOT to encourage evacuation in central Florida as Ian passes over, and the Florida Highway Patrol was preparing escorts of initial response crews to allow for immediate assistance once weather conditions permit it.

Search and rescue missions began at approximately 1am on September 29th, with over 800 Urban Search and Rescue members assisting. The utility company staff that were on standby the day before began responding to over 2 million power outages, nearly 3 times that of the day before. All operating long-term care facilities have been equipped with a generator to ensure elderly citizens maintain the resources and healthcare necessary. In addition to assisting with search and rescue missions, national guard members assessed southwest Florida counties to assess the initial damages of Ian. Shelters were providing housing to 34,000 Floridians on the 29th, and private companies including Walmart and Public have announced they are restocking their inventory consistently to provide necessary support. To provide citizens with communication, 100 temporary cell phone towers were being deployed in the areas of strongest destruction. As Florida begins recovery, Georgia and the Carolinas brace for the impacts of Ian, as Governor Brian Kemp declared a state of emergency in effect at 7am on the 29th.

On the 30th, search and rescue missions continued, with National Guardsmen and the USCG flying helicopters into barrier islands with limited or no access to the main land. The FDEM began deployment of 255 ambulances, 200 trucks of food and water, 500,000 tarps, 10 truckloads of blankets of cots, and other reinforcements to support heavily impacted areas. Though power had already been restored for nearly ¾ of a million Floridians, another 1.9 million remained without power.

Hazard response continued on the 1st of October, with an increasing number of individuals assisting in search and rescue missions. The FDEM continues to mobilise trucks of food, water, generators, pet food and pet supplies across southwest Florida. Points of Distribution (PODs) for these supplies continue to be identified, including 7 in Lee county and 6 in Sarasota county, areas where the storm made landfall and storm surge was at its highest. With over 52 major roads and bridges closed at this point, these PODs are pertinent in keeping displaced residents fed and keeping their basic necessities met.

With disaster recovery continuing over the first week of October, the first Disaster Recovery Center opened in Fort Myers on October 4th. The DRC provides numerous resources to survivors of Ian, including an Initial Payment Center for residents to file claims with their insurance companies, mental health professionals for counselling, internet and cellular access, the Florida Department of Economic Opportunity, and CareerSource Southwest Florida.

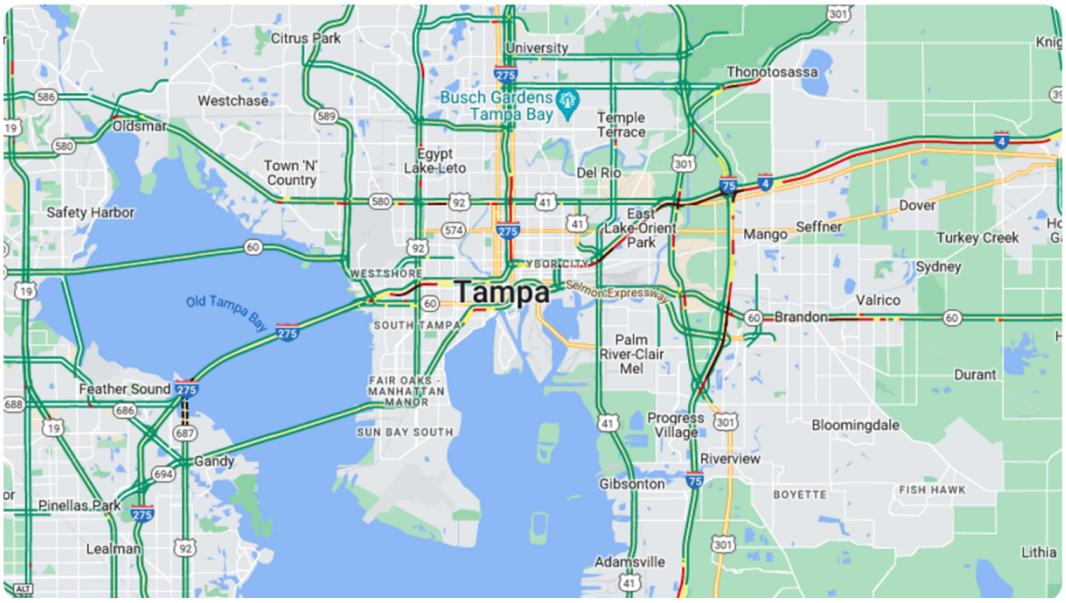
Altogether, the state of Florida was well prepared for Hurricane Ian. From the Department of Emergency Management opening up shelters and providing meals and water, to the National Guard performing search and rescue missions on islands that lack access to the mainland, to utility companies working around the clock to restore power, the state's response was immediate and thorough.

A month after the storm's landfall, FDEM is working on providing temporary housing to those displaced by Ian. Satellite imagery is being utilized to assess all damages, and nearly 14,000 'Blue Roofs' have been installed, allowing residents to return home with temporary roof protection. Debris has been removed from nearly 5,000 miles of roads, and just 2 roads remain closed. While along road lays ahead in helping these communities return back to their normal functioning, initial response by state officials has expedited this process tremendously.

Florida Division of Emergency Management, Press Release Archives: https://www.floridadisaster.org/news-media/news/?p=8

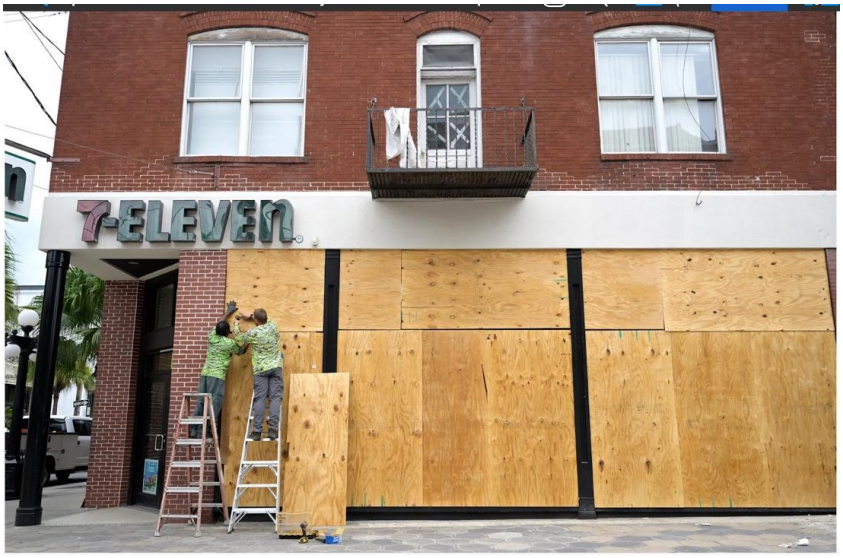
What were the main response actions by the public to the warnings? i

Because Hurricane Ian rapidly intensified mandatory evacuations were ordered for over 2.5 million Florida residents. As a result all of these people had to hit the road as well as any other floridians who were being cautious. This caused an influx of people on major interstates causing numerous standstill traffic jams.



This live traffic map shows how busy the roads are on I-4 which is the main easterly route out of town. The traffic map shows just how many people heeded the warnings from local emergency officials and got out of town in an attempt to protect their lives and property. The governor of Florida, DeSantis issued evacuations for 12 counties including the county that Tampa is in, and all the traffic shows that people are in fact leaving.

Besides the evacuation orders from government officials, individual people followed their own preparation plan to keep themselves and their homes safe. At the end of the day you and only you are responsible for your own safety.



This is a perfect example of an individual safety plan. This business owner is hoping to protect his business from damaging winds and debris by boarding up his windows. No government made him do that, but it is his choice to protect his own property. Most neighborhoods look like this ahead of a storm with no government intervention, because most people that live in hurricane prone areas have their own individual safety plan.

As with any natural disaster panic from the general public is expected and very common. Panic from the public is very evident in what people call “panic buying”. That is the stripping of grocery store shelves of any necessities that people might need during or after the storm. This can include water, toilet paper, canned food, etc.

These are what shelves looked like all over Florida, with this picture being taken at a Publix in Venice. This is in the meat aisle of the store and to be frank people don't need pounds and pounds of meat to get through a hurricane, this is simply panic buying. They will buy out the store because it gives them a sense of security in times of insecurity, which is the main reason why people will panic buy.

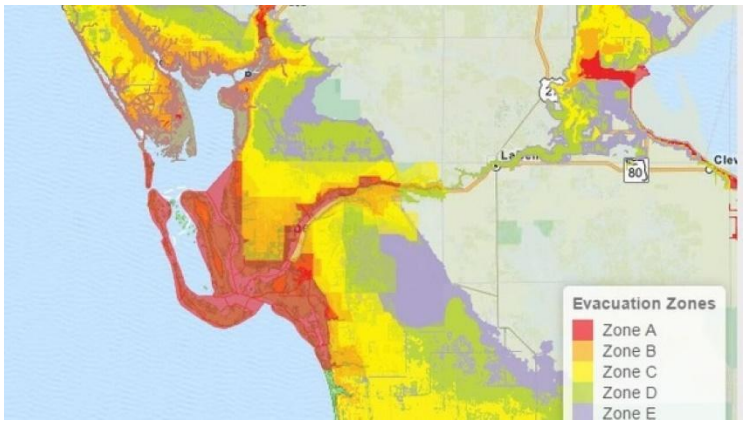
https://www.wfla.com/news/florida/hurricane-ian-photos-show-completely-empty-shelves-at-publix-in-venice/
https://www.usatoday.com/story/news/nation/2022/09/28/hurricane-ian-photos-florida-board-homes/10447563002/
https://www.foxweather.com/extreme-weather/florida-traffic-cams-evacuations-hurricane-ian

Institutional responses i

Response actions	Taken by whom	When taken	On the basis of what information?	Benefit (if any)	Cost

In the preparation before hurricane Ian, Florida instituted mandatory evacuations in up to 12 counties that were forecasted to be in the storm’s path. These messages were enforced by local and state officials that drove through communities. These mandates were largely in response to the storm surge warnings put in place by NOAA that were predicted many days in advance. Regions with the least elevation that are closest to the coast or any sort of waterway are represented under Zone A and were in the most danger.

Every zone above that represents a lesser risk to flooding and storm surge. However, many regions up through zone C or more were evacuated.



How to find which evacuation zone you live in (fox4now.com)

However, the hurricane and tropical storm warnings also prompted communities to protect their homes and buy emergency supplies several days before Ian arrived. Organizations such as FEMA recommended having a radio on hand to listen to news on the storm even without power. Other essential items included food, water, maps, flashlights, whistles, and portable chargers for phones. Informing the public that they should have these items helps to limit the amount of rescues that need to be made.


Shopping for Hurricane Ian

The White House also coordinated with Florida to have emergency supplies and first responders positioned so that they can help people as quickly as possible. This included thousands of people to assist with cleaning up, medical responders, the Coast Guard, military personel to assist rescues, and engineers. In terms of supplies, hundreds of ambulances and generators were moved to strategic locations. Massive amounts of fuel, food, and water were also transported to emergency personel teams to be distributed once the storm passed.

Hurricane Ian: Floridians rescue dogs and cats amid flooding (today.com)

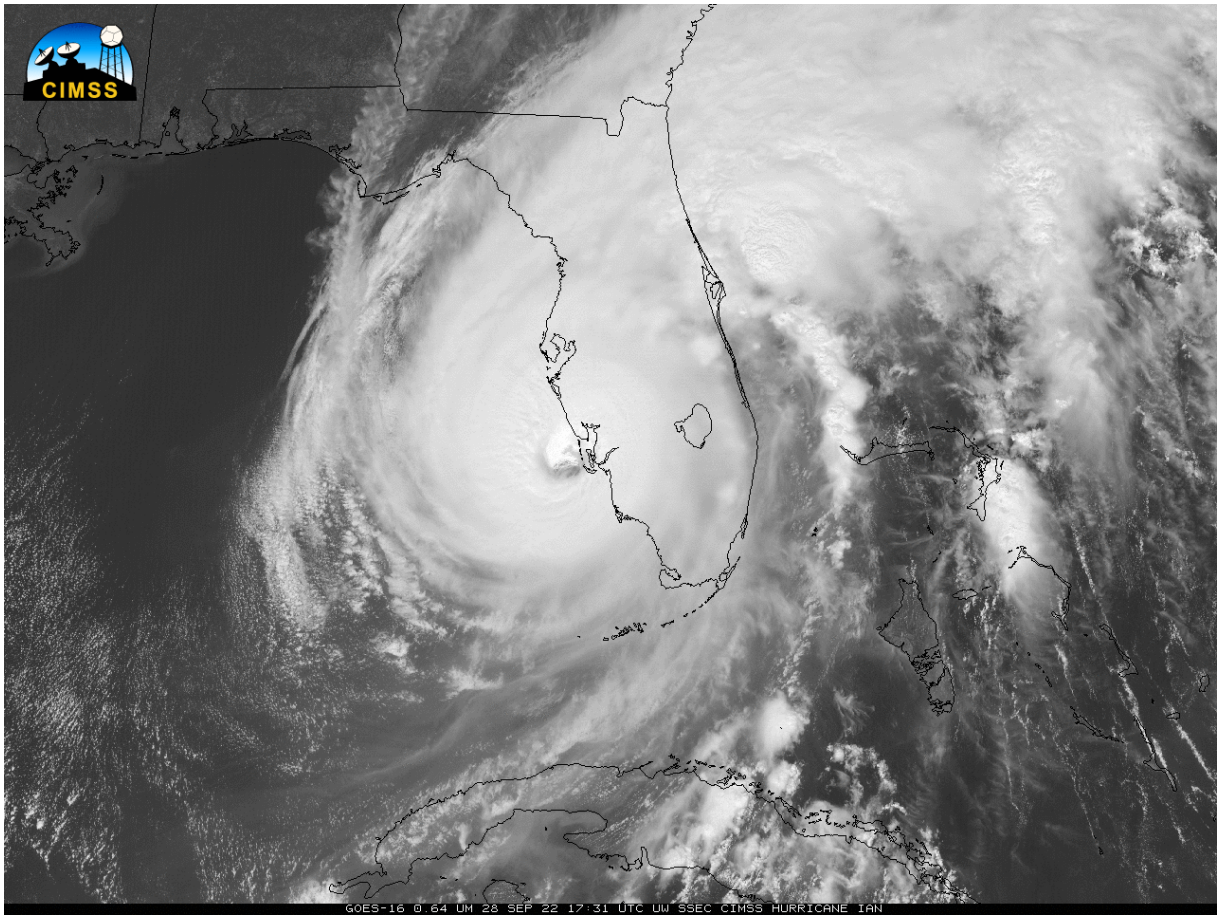
Sources:

Florida Hurricane Ian Evacuations: Do You Need To Evacuate? | The Weather Channel

FACT SHEET: The Biden Administration's Preparation for Hurricane Ian | The White House

Just in Time Preparedness for Hurricane Ian | FEMA.gov

How did the overall response to this event compare to similar previous events? i



The image above compares Hurricane Charley of 2004, the smaller storm, with the recent Hurricane Ian. These two hurricanes are the two main storm systems that have made landfall near in the Fort Myers area, but differ greatly in strength, effects, and consequently responses. The spread of Ian's outer bands differentiate the two, as Ian's impacts like hurricane-force winds and storm surge were much more widespread. Ian was also a slower moving system, traveling about 9 mph across on its approach, whereas Charley's speed doubled this.

Despite their differences in size and intensity, communities impacted by the two storms received immediate assistance from various Floridian governmental organisations in both cases. Just like in hurricane Ian, the Florida Department of Transportation prioritised clearing and repairing roadways for search and rescue and emergency response services in 2004. The Federal Highway Administration describes the response to Hurricane Charley as successful overall, with necessities like water, food, medical assistance, and shelter all available. The same has been seen with Ian, as hundreds of truckloads had been transported to the areas with the greatest damage and shelters were open across the southwestern portion of the state.

Beyond the initial response to the storms, it is difficult to compare Charley to Ian. Within the month following Charley, 3 additional hurricanes, named Frances, Ivan, and Jean, struck various locations across the Florida peninsula and up into the panhandle. While the FDEM was and continues to focus their attention on the areas directly impacted by Ian, emergency response groups were dispersed across the state following Charley.

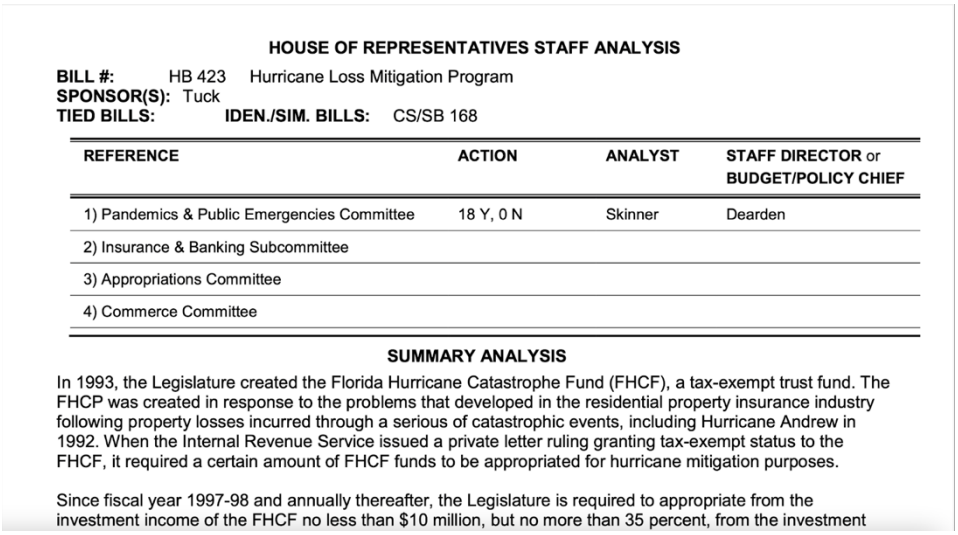
With the shock of the 2004 hurricane season, many lessons were learned that helped prepare the state for future hurricanes like Ian. A member of the Florida Department of Transportation discussed the lack of local agency attendance in emergency management training sessions, and how this training was taken more seriously in 2005 and on. Another FDOT spokesperson mentioned how aluminium hangers used to hold traffic signal lights were not strong enough to withstand hurricane-force winds, and a new design was in the works following Charley. Additionally, power generators were in much lower supply, causing the FDOT to make more available in their statewide inventories. Other upgrades to the FDOT's emergency operations included an internal tracking system of FDOT emergency missions and standardised reports that allowed for more efficient communication between the department of transportation and its districts across the state.

All in all, many of the issues encountered during Charley in 2004 paved the way for a more efficient emergency response in 2022. Charley and the 3 storms that followed shortly after encouraged emergency response teams to prepare for the worst possible scenario. Though the circumstances following Hurricane Charley were much different than that following Ian, the response to the 2004 hurricane season developed the infrastructure to make Ian's response more efficient.

Charley vs Ian Image: https://cimss.ssec.wisc.edu/satellite-blog/archives/48129
Charley vs Ian intensity differences: https://www.wunderground.com/article/storms/hurricane/news/2022-09-27-hurricane-ian-different-than-charley
Federal Highway Administration Article: https://highways.dot.gov/public-roads/novemberdecember-2005/learning-disaster

Comment on the existence and use of disaster preparedness and response plans i

A lot of the preparedness and response plans in Florida are often empowered by law, specifically the hurricane loss mitigation program. This is a program that is run by the emergency management division in Florida. This program doesn't directly work with the evacuation process of emergency responders, it is more of a response for the cost of damages following the storm. After hurricane Andrew, the insurance market was destroyed, so some amendments were made in Florida to prevent this from happening. The hurricane loss mitigation program has an annual budget of 7 million in assisting homeowners and business owners with damages from storms, to prevent damage to the insurance market.



HOUSE OF REPRESENTATIVES STAFF ANALYSIS

BILL #: HB 423 Hurricane Loss Mitigation Program
SPONSOR(S): Tuck
TIED BILLS: **IDEN./SIM. BILLS:** CS/SB 168

REFERENCE	ACTION	ANALYST	STAFF DIRECTOR or BUDGET/POLICY CHIEF
1) Pandemics & Public Emergencies Committee	18 Y, 0 N	Skinner	Dearden
2) Insurance & Banking Subcommittee			
3) Appropriations Committee			
4) Commerce Committee			

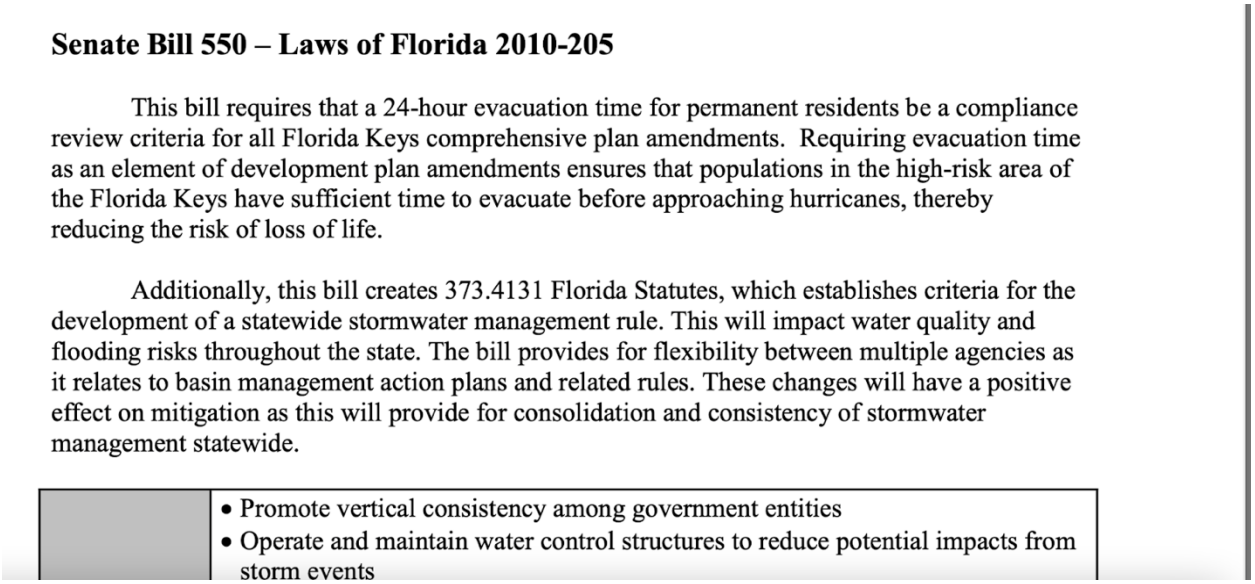
SUMMARY ANALYSIS

In 1993, the Legislature created the Florida Hurricane Catastrophe Fund (FHCF), a tax-exempt trust fund. The FHCP was created in response to the problems that developed in the residential property insurance industry following property losses incurred through a serious of catastrophic events, including Hurricane Andrew in 1992. When the Internal Revenue Service issued a private letter ruling granting tax-exempt status to the FHCF, it required a certain amount of FHCF funds to be appropriated for hurricane mitigation purposes.

Since fiscal year 1997-98 and annually thereafter, the Legislature is required to appropriate from the investment income of the FHCF no less than $10 million, but no more than 35 percent, from the investment

This is just a small portion of the bill that added the hurricane loss mitigation program into the state legislature. This shows that there are some hurricane response plans that are signed into law.

Besides the hurricane response plans there are also hurricane preparedness plans that are signed into law. One such law is a law that requires a 24 hour notice for all evacuation mandates in the Florida keys. Because of the key's seclusion and the fact that there is only one road in and out of the keys, it is required by law that evacuations must be given a 24 hour notice to allow anyone affected to evacuate.This will help with reducing the risk of loss of life.



Senate Bill 550 – Laws of Florida 2010-205

This bill requires that a 24-hour evacuation time for permanent residents be a compliance review criteria for all Florida Keys comprehensive plan amendments. Requiring evacuation time as an element of development plan amendments ensures that populations in the high-risk area of the Florida Keys have sufficient time to evacuate before approaching hurricanes, thereby reducing the risk of loss of life.

Additionally, this bill creates 373.4131 Florida Statutes, which establishes criteria for the development of a statewide stormwater management rule. This will impact water quality and flooding risks throughout the state. The bill provides for flexibility between multiple agencies as it relates to basin management action plans and related rules. These changes will have a positive effect on mitigation as this will provide for consolidation and consistency of stormwater management statewide.

- Promote vertical consistency among government entities
- Operate and maintain water control structures to reduce potential impacts from storm events

Here is a picture of the actual law that is written in the Florida state legislature. This is a perfect example of a preparedness plan that is written into law in Florida. In Florida not only are response plans written into law, but preparedness plans are written as well. This shows the organization that Florida has with response to any tropical storm that poses a threat on the state of Florida.

The response plan after hurricane Ian could have been followed, but it is still too early to tell. We can't tell if the hurricane loss mitigation plan has been followed as it takes a while for insurance claims to be processed. The hurricane preparedness plan was not followed because hurricane Ian didn't impact the Florida keys.
https://myfloridalegal.com/webfiles.nsf/WF/GPEY-CEQLX7/$file/2022+Hurricane+Preparedness+Guide+FINAL+English.pdf
https://www.floridadisaster.org/dem/mitigation/hurricane-loss-mitigation-program/

How did the key decision makers and institutions interact before, during and after the event?

There is minimal public information regarding the interactions between key decision makers and national weather services. It is likely that the National Weather Service forecast office in Tampa and the National Hurricane Center in Miami communicated with the Florida Department of Emergency Management, Florida Department of Transportation, and other emergency services personnel in Southwest Florida, but it is difficult to find information on the internet regarding this.
The Florida State Emergency Response Team (SERT) news archive shows all SERT news articles released regarding Hurricane Ian. The team notes how the Florida Department of Emergency Management is "in constant communication with all 67 county emergency management offices," but does not comment on any interactions with the NWS or NHC. However, SERT does supply readers with watches and warnings for hurricanes, tropical storms, tornadoes, and storm urge, indicating that there is some level of communication between emergency response teams and weather services.

How knowledgeable was the community about the hazard and its associated risks? i

Since hurricanes are not an uncommon occurrence for both Cuba and Florida, most people have at least some awareness on how to respond. However, a lot of people in Florida were not aware of the utter devastation that could potentially occur. Since many homeowners have experienced minor hurricanes and been perfectly fine with not evacuating, many people did not take the hurricane warnings as seriously as they should have.

Before Hurricane Ian, the Cuban Civil Defense System was already in place and well prepared to deal with any sort of hurricane disaster. They have strict protocols in place for whenever a hurricane hits. To prepare for Ian, shelters were put in place, drainage systems unclogged, and vessels such as boats were removed from the water. When Ian was nearing landfall, virtually everyone was evacuated from the west side of the island. So although their infrastructure and farmland took large amounts of damage, there were very few fatalities.

Prior to hurricane Ian, there were a few programs in place for educating the public about the impacts of hurricanes. The main one is the Hurricane Loss Mitigation Program which receives government funds to fortify buildings to make them more resilient to hurricanes. This can save a lot of money for both insurance companies as well as the building owners. The program also does education outreach to schools as well as preforms hurricane research to better understand hurricane impacts. A lot of the necessary information for how to react to a hurricane can also be found online these days. Simply searching "hurricane preparedness" will provide anyone with the knowledge of how to understand the severity of a hurricane and what to buy in preparation for a hurricane.

Hurricane Preparedness Flyer

Sources:

https://www.floridadisaster.org/dem/mitigation/hurricane-loss-mitigation-program/

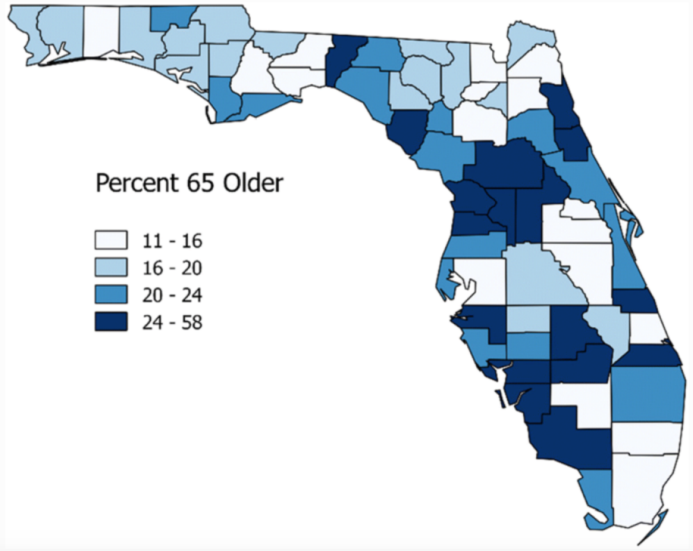
How Cuba is Dealing With the Devastation of Hurricane Ian - CounterPunch.org

Hurricane Ian nears Cuba on path to strike Florida as Cat 4 (newschannel6now.com)

What capacity did the community have to respond to warnings? i

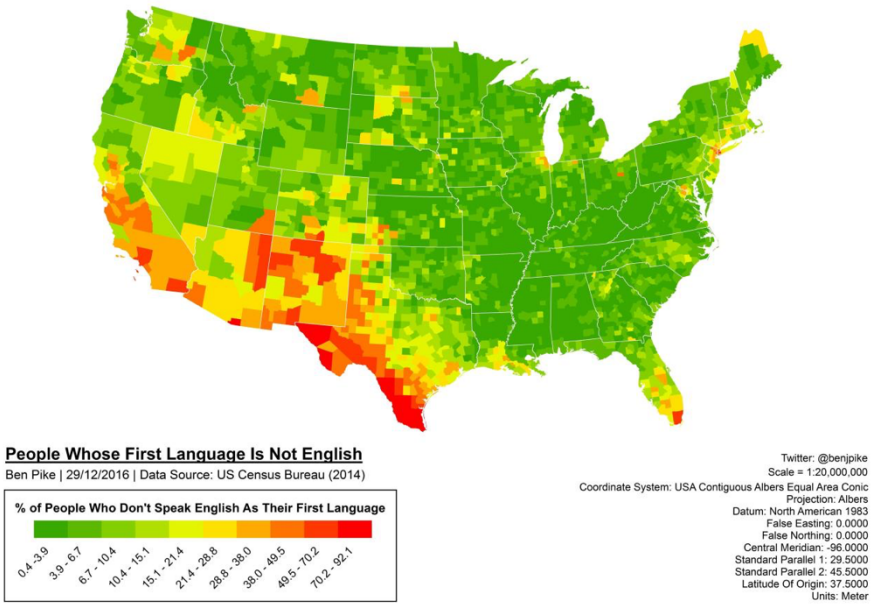
Because Florida has such nice weather most of the year, it is an awesome place to retire. Because of this, Florida has a high percentage of older citizens which can cause some Floridians to have a greater than normal difficulty heading warnings and evacuating ahead of an incoming storm.

Fig. 1



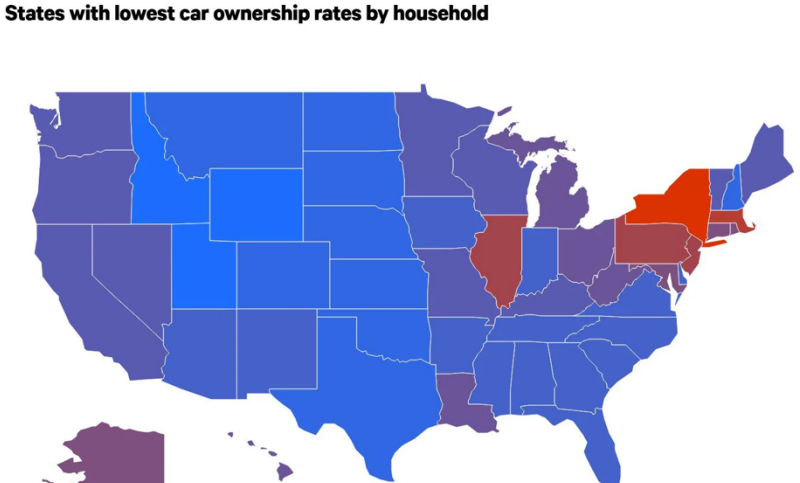
This is the age distribution of the state of Florida. This map shows that south west Florida is the part of the coast with the highest percentage of citizens older than 65. This region is the exact region where hurricane Ian made landfall. Because older people might not have the same resources or ability to evacuate, hurricane Ian made landfall in the worst case scenario part of the Florida coast line.

Another demographic that could have influenced the ability for the community to evacuate could have been if they were English speaking. A lot of immigrants that come to Florida are from central or south America which are common Spanish speaking countries. Because all of the evacuation orders are in English and any information on the storm are in English, if a family only spoke Spanish or another language there is a chance that they would not be able to heed the warnings and evacuate in time.



This map shows the distribution of people whose first language isn't English. When looking towards southern Florida one can see a higher percentage than the rest of Florida. Hurricane Ian made landfall in an area where greater than 30% of the population doesn't have English as their first language. This further shows another influence in the ability for a community to heed government officials' warnings. Over 30% of the area might not have been able to fully understand the warnings from the National Hurricane Center which could have caused a greater risk to life and property.

One other demographic that could influence people's response to the storm, is the percentage of a population that owns a car. Florida doesn't have a complete 100% of the population who has access to cars, so some people might have been unable to evacuate to safer ground simply because they didn't have the means to do so. As every life counts anything that could prevent someone from evacuating to a safer place must be taken into account.



This image shows that the state of Florida has around 8 percent of households who don't own a car. 8% is still a significant number, and to just think that some people could potentially lose their lives because they didn't have the means to evacuate is gut wrenching.

https://claudepeppercenter.fsu.edu/long-term-care-options-in-florida-their-availability-by-county-demographics/
https://mapsontheweb.zoom-maps.com/post/155217770504/people-who-dont-speak-english-as-their-first
https://www.valuepenguin.com/auto-insurance/car-ownership-statistics

Additional analysis i

Success/issues/challenges experienced i

The state of Florida had plenty of resources to show what actions they were taking in responding to the hurricane. The Florida State Emergency Response Team had press archives available back to the start of the storm, all of which went in detail on different emergency management sectors, including FDOT and FDEM. The most difficult part was finding information on communications between key decision makers and weather services. There were no online resources that stated this relationship, but the communications between the two were implied in many instances. In comparing Ian to other hurricanes, it was a bit of a challenge because the only other prominent hurricane to hit southwest Florida occurred under completely different circumstances.

Part 2f. Analysis of the warning chain

Wherever possible, please include references to information you provide.

Editors (Name & Institute):

Information flow through the warning chain i

Warning chain	**Was all necessary input information available? (yes/partially/no)**	**If not or partially available, what input information was missing?**	**Who should have provided the missing information?**
Weather, etc. forecast			
Hazard forecast			
Impacts forecast			
Warning communication			
Response			

Tools and operational workflows for sharing information between partners i

How useful were social media/crowdsourcing/citizen science in the warning chain? i

Evidence that warning chain was effective in reducing fatalities, injuries, damage, and/or disruption i

What were the strongest links (information flow) in the warning chain? i

What were the weakest links (information flow) in the warning chain? i

What procedures were used to identify lessons learned from the event? i

Comment on lessons learnt from previous events and their contributions to greater warning success for this event i

Additional analysis i

Part 3. Assessment of the end-to-end warning chain

Your profession:
Please rate your level of expertise on a scale of 1 (no expertise) to 5 (established expert) for:

Hazard source (e.g., weather):

Hazard:

Impact:

Warning/communication:

Response:

High-impact weather event evaluation:

HOW SUCCESSFUL WERE THE FORECASTS, WARNINGS AND RESPONSES?

How well do you think the event was observed? *Scale of 1 (poor) to 5 (excellent)*
Reason for this rating i

How well do you think the source of the hazard (e.g., weather) was forecast? *Scale of 1 (poor) to 5 (excellent)*
Reason for this rating i

How well do you think the hazards were forecast? *Scale of 1 (poor) to 5 (excellent)*
Reason for this rating i

How well do you think the impacts were predicted? *Scale of 1 (poor) to 5 (excellent)*
Reason for this rating i

How well do you think warnings were communicated? *Scale of 1 (poor) to 5 (excellent)*
Reason for this rating i

How well do you think the warnings were used? *Scale of 1 (poor) to 5 (excellent)*
Reason for this rating i

How well do you think the entire warning chain performed overall? *Scale of 1 (poor) to 5 (excellent)*

Thank you very much for contributing to the WWRP Warning Value Chain Project database!

Acknowledgements of information providers (optional):

Annex 1: *List of hazards adapted from the UNDRR-ISC Hazard Information Profiles*

* = not in UNDRR-ISC list of hazardous events

1. Convective-related
   - Downburst
   - Lightning (Electrical Storm) Thunderstorm

2. Flood
   - Coastal Flood
   - Estuarine (Coastal) Flood
   - Flash Flood
   - Fluvial (Riverine) Flood
   - Groundwater Flood
   - Ice-Jam Flood Including Debris Ponding (Drainage)
   - Snowmelt Flood
   - Surface Water Flooding
   - Glacial Lake Outburst Flood

3. Lithometeors
   - Black Carbon (Brown Clouds)
   - Dust storm or Sandstorm
   - Fog
   - Haze
   - Polluted Air
   - Sand haze
   - Smoke
   - Volcanic gases and aerosols

4. Marine
   - Ocean Acidification
   - Rogue Wave
   - Sea Water Intrusion
   - Sea Ice (Ice Bergs)
   - Ice Flow
   - Seiche
   - Storm Surge
   - Storm Tides
   - Tsunami
   - Pumice*

5. Pressure-related
   - Depression or Cyclone (Low Pressure Area)
   - Extra-tropical Cyclone
   - Sub-Tropical Cyclone

6. Precipitation-related
   - Acid Rain
   - Rain*
   - Blizzard
   - Drought
   - Hail
   - Ice Storm
   - Snow
   - Snow Storm
   - Ash/Tephra Fall

7. Temperature-related
   - Cold Wave
   - Dzud
   - Freeze
   - Frost (Hoar Frost)
   - Freezing Rain (Supercooled Rain)
   - Glaze
   - Ground Frost
   - Heatwave
   - Icing (Including Ice)
   - Thaw

8. Terrestrial
   - Avalanche
   - Mud Flow
   - Rockslide
   - Landslide
   - Lahar
   - Lava Flows
   - Ballistics
   - Pyroclastic Density Current
   - Ground Shaking

9. Wind-related
   - Derecho
   - Gale (Strong Gale)
   - Squall
   - Subtropical Storm
   - Tropical Cyclone (Cyclonic Wind, Rain [Storm] Surge)
   - Tropical Storm
   - Tornado
   - Wind

10. Environmental
    - Wildfires
    - Crown fire*
    - Surface fire*
    - Ground fire*
    - Coastal Erosion