



Unit 1:

Tropical Cyclone Basics

Unit 1 Objectives



At the end of this unit, you should be able to:

1. Explain the characteristics of tropical cyclones, including life cycle, factors influencing intensity, and categorization scale.
2. Describe the hazards of tropical cyclones and their impacts.
3. Explain the inland flood threat posed by tropical cyclones, including influencing factors.

Tropical Cyclone Classification



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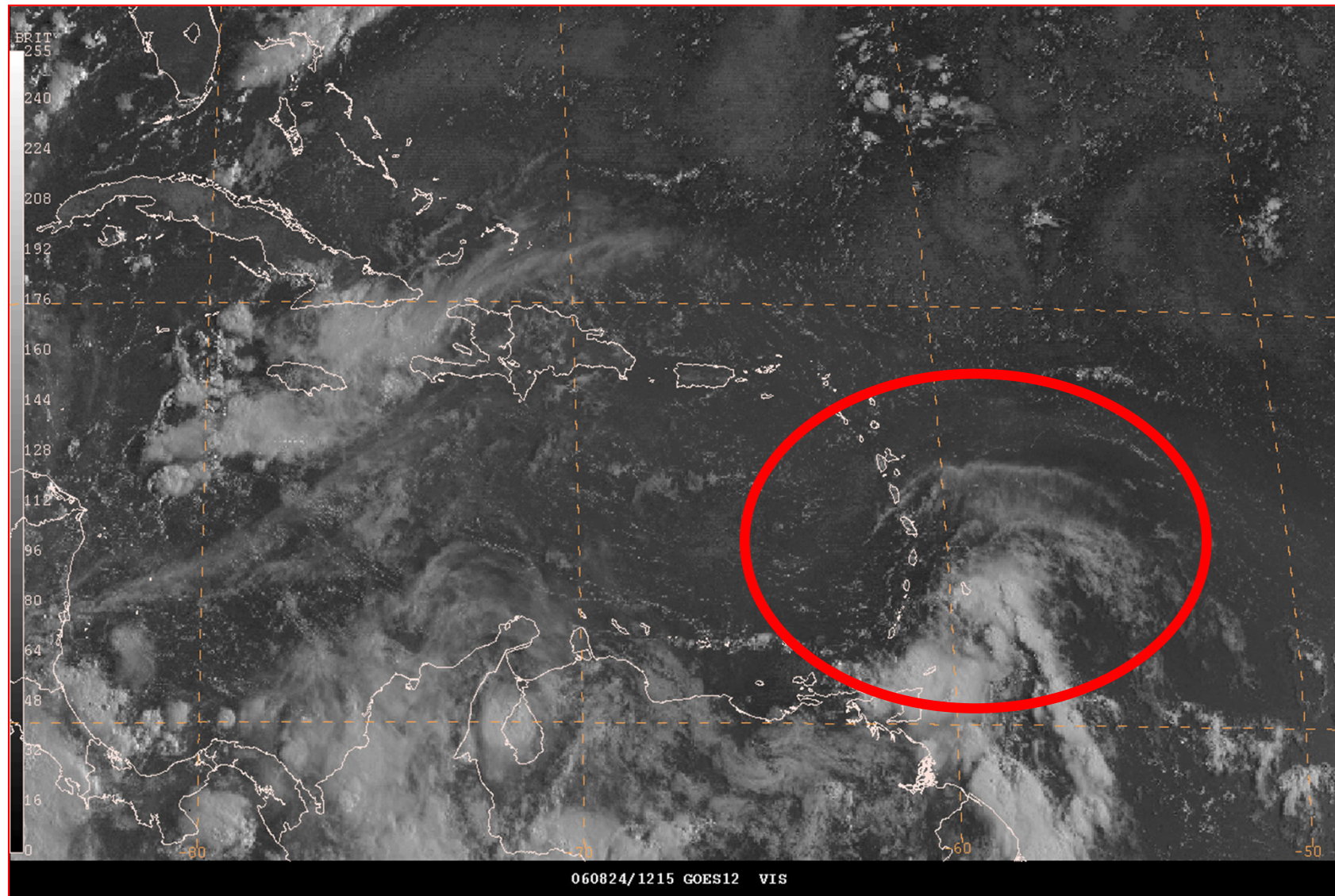
By Maximum Wind Speed:

Tropical Depression	<39 mph
Tropical Storm	39–73 mph
Hurricane	74 mph or greater
Major Hurricane	111 mph or greater

Surface Circulation? Organized?



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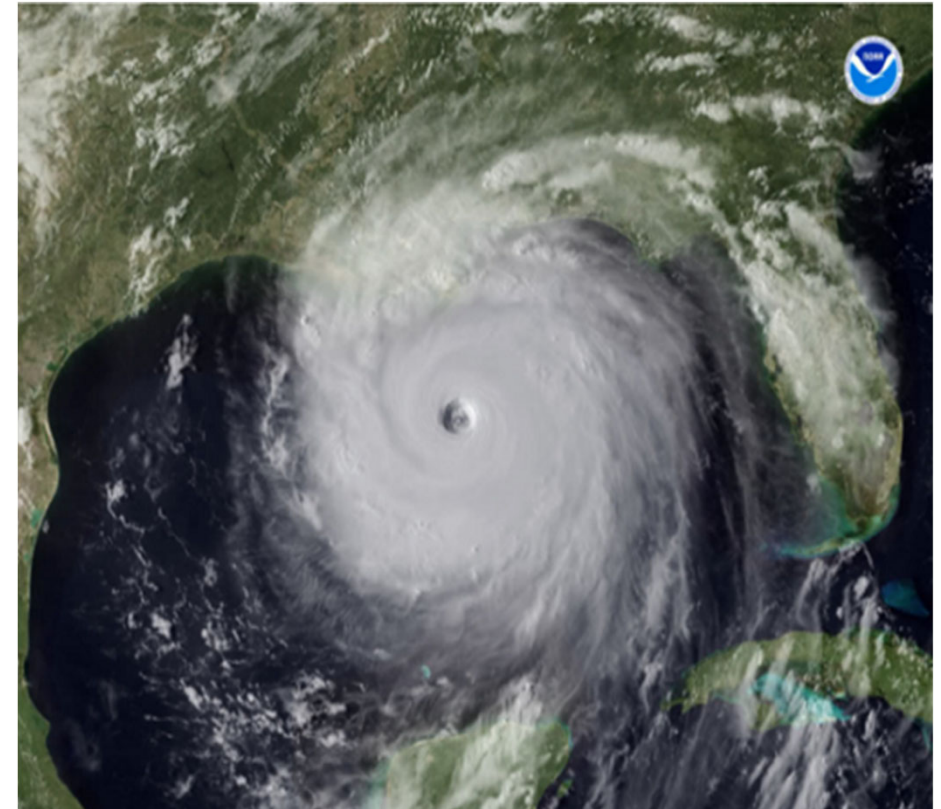
Tropical Cyclones Defined



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Characteristics of Tropical Cyclones

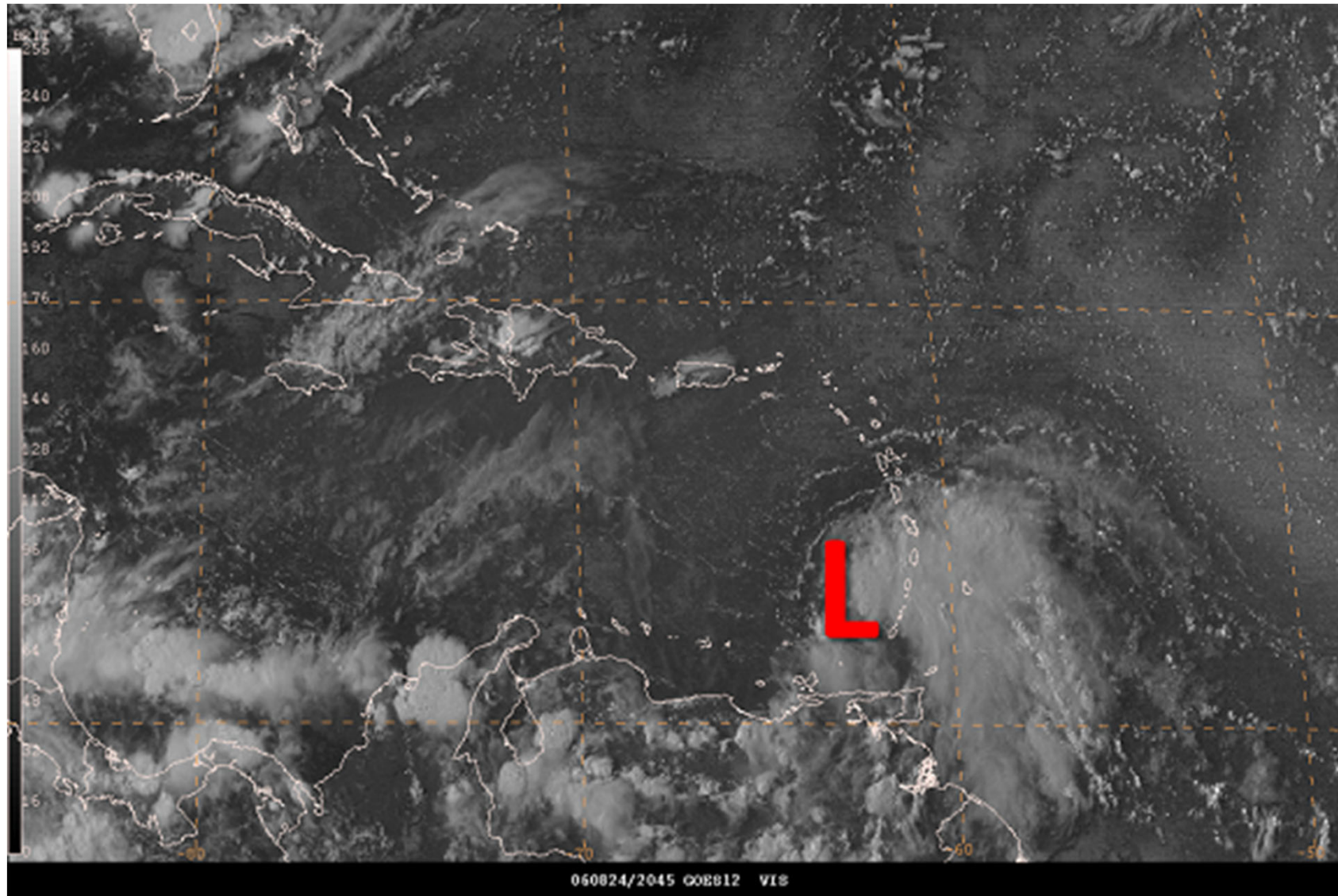
- Hurricane, Tropical Storm, Tropical Depression
- Large, long-lived, low-pressure system (can be hundreds of miles wide, lasting for days)
- Form over sub/tropical oceans
- No fronts attached
- Produce organized thunderstorm activity
- Have a closed surface wind circulation around a well-defined center



Ernesto 2006



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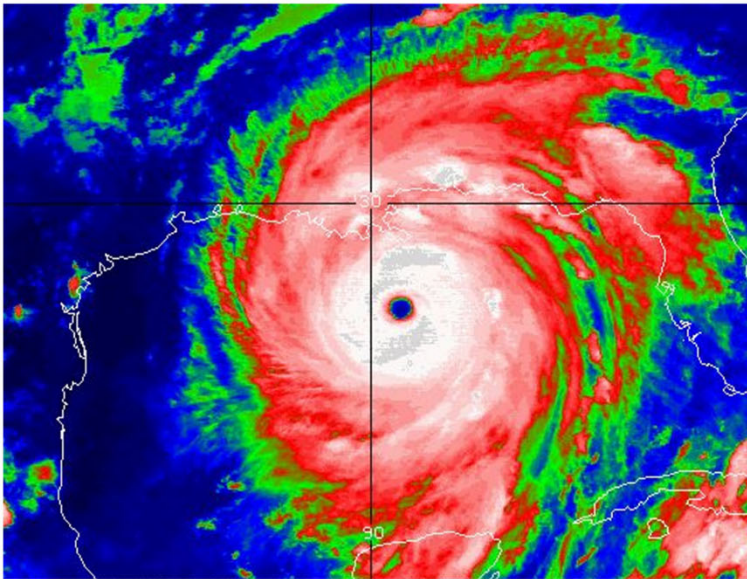


Advisory 1 issued based on aircraft data

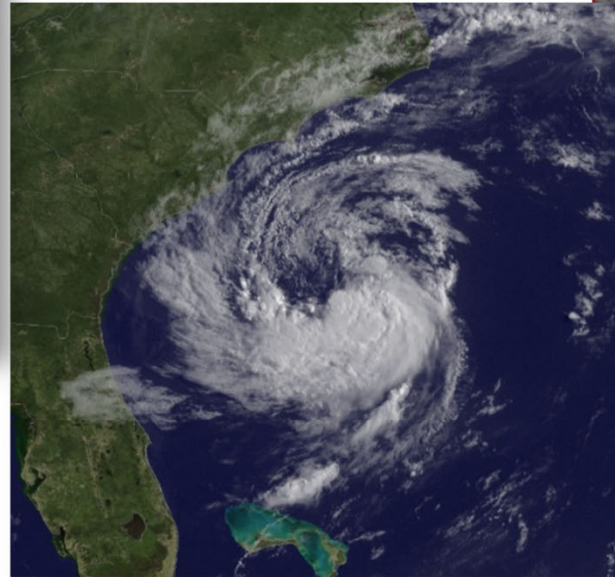
Tropical, Subtropical, & Extratropical



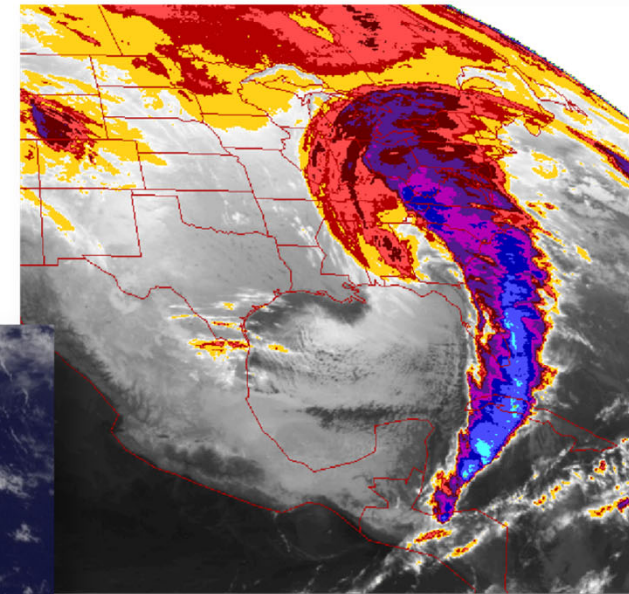
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**Hurricane Katrina
2005**



**Subtropical Storm Ana
2015**

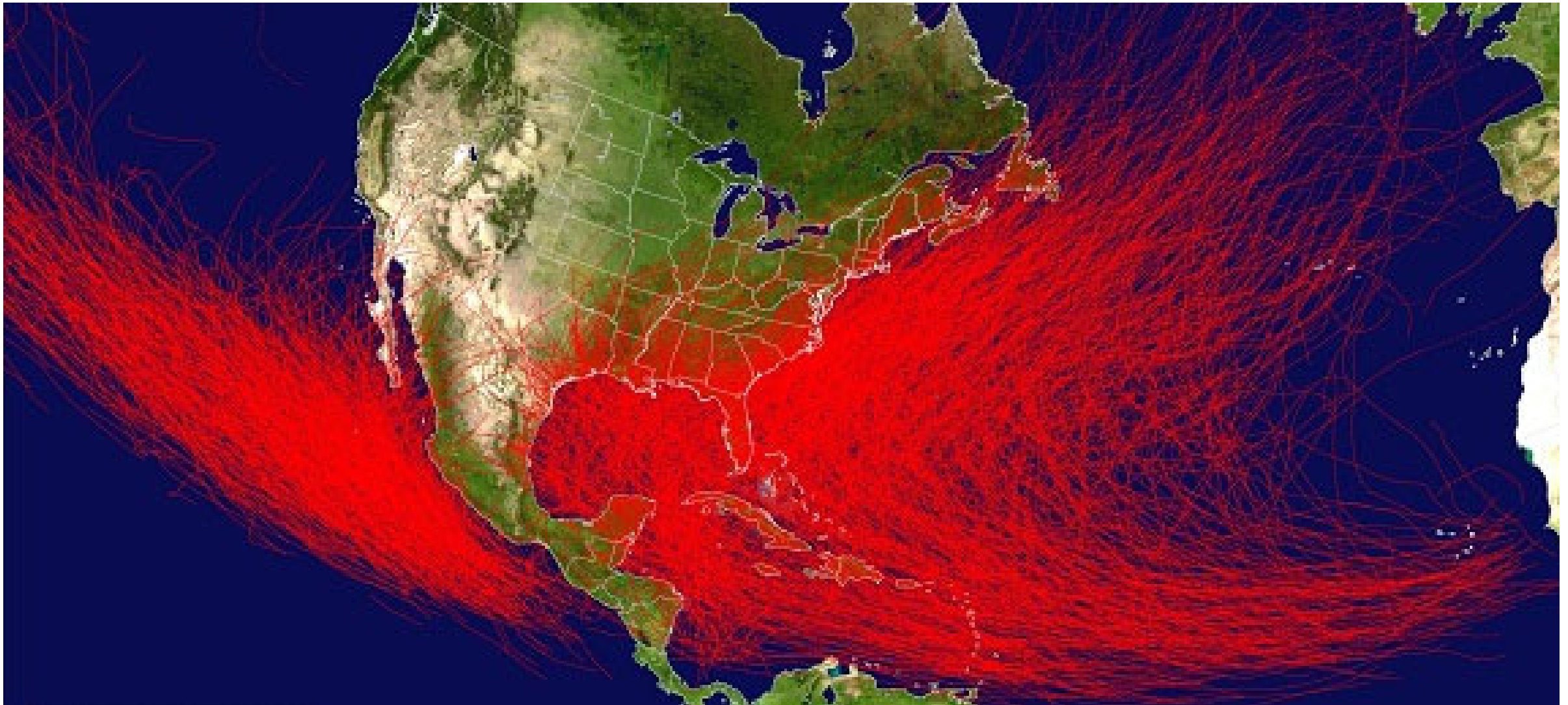


**March Superstorm
1993**

Tropical Cyclone History



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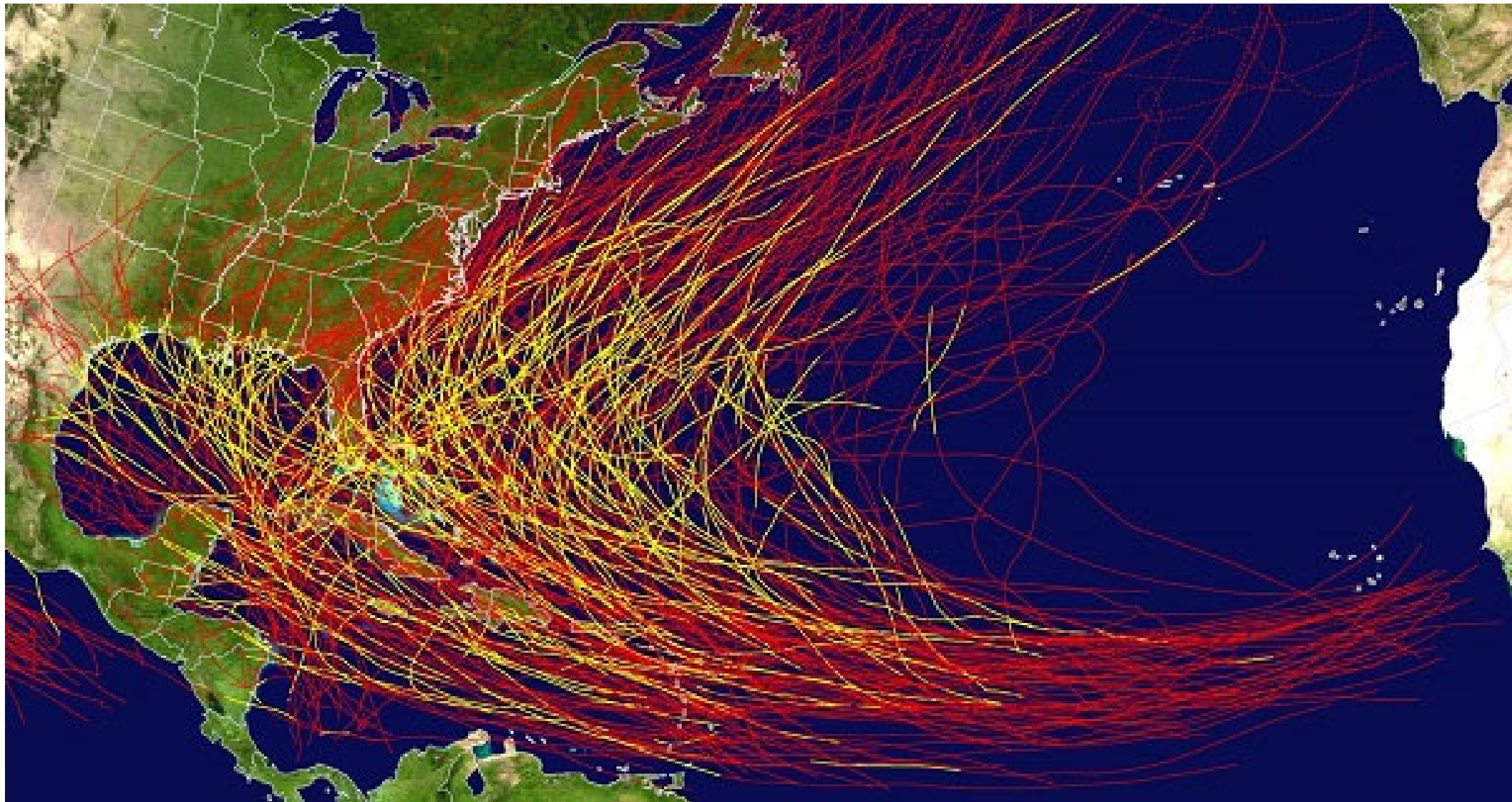


Data since 1949 in Pacific, 1851 in Atlantic

Major Hurricane History



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Data since 1851

Climatology – Knowledge Check



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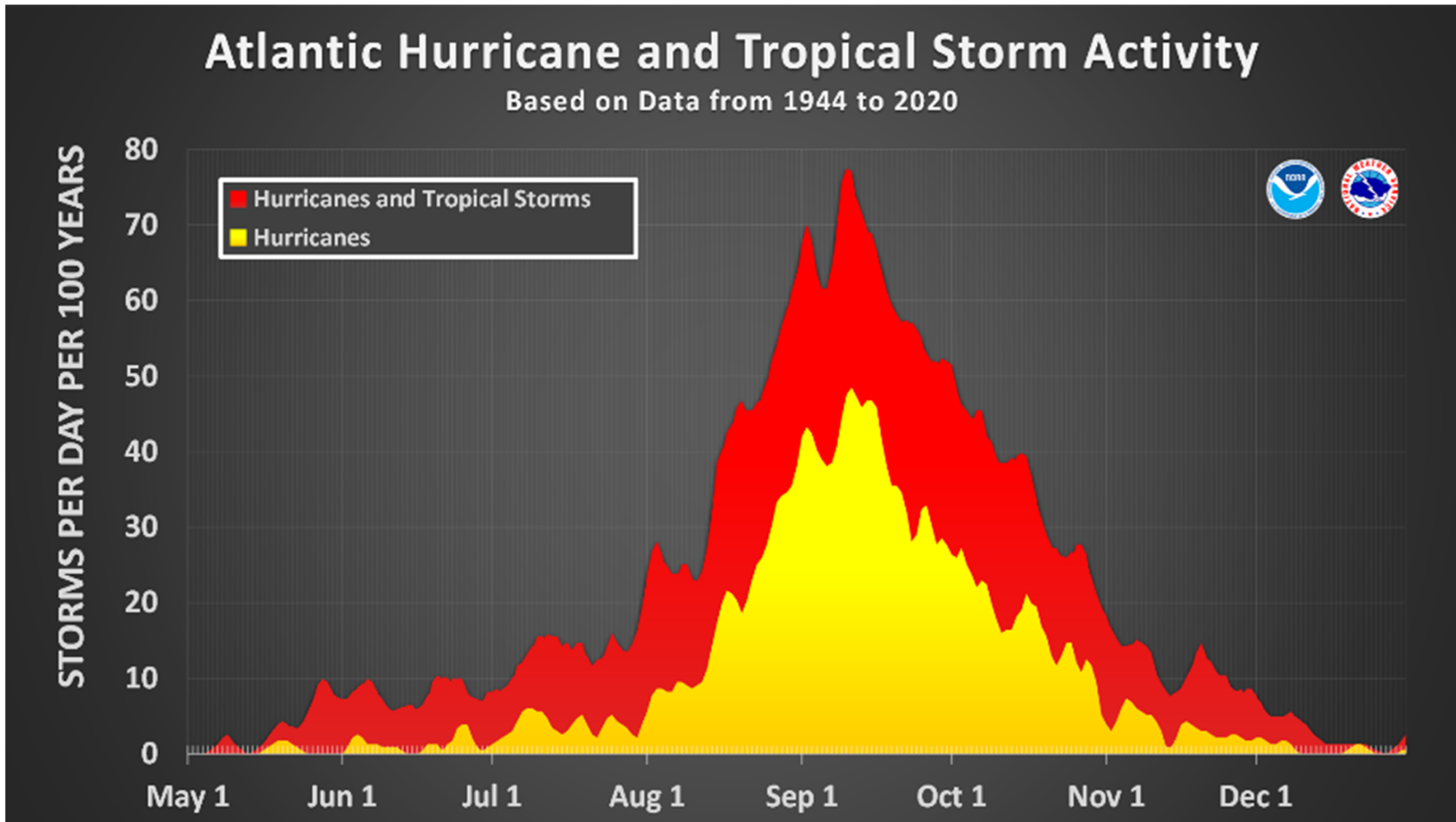
What month has the most hurricane activity in the Atlantic?

- A. December
- B. August
- C. June
- D. September

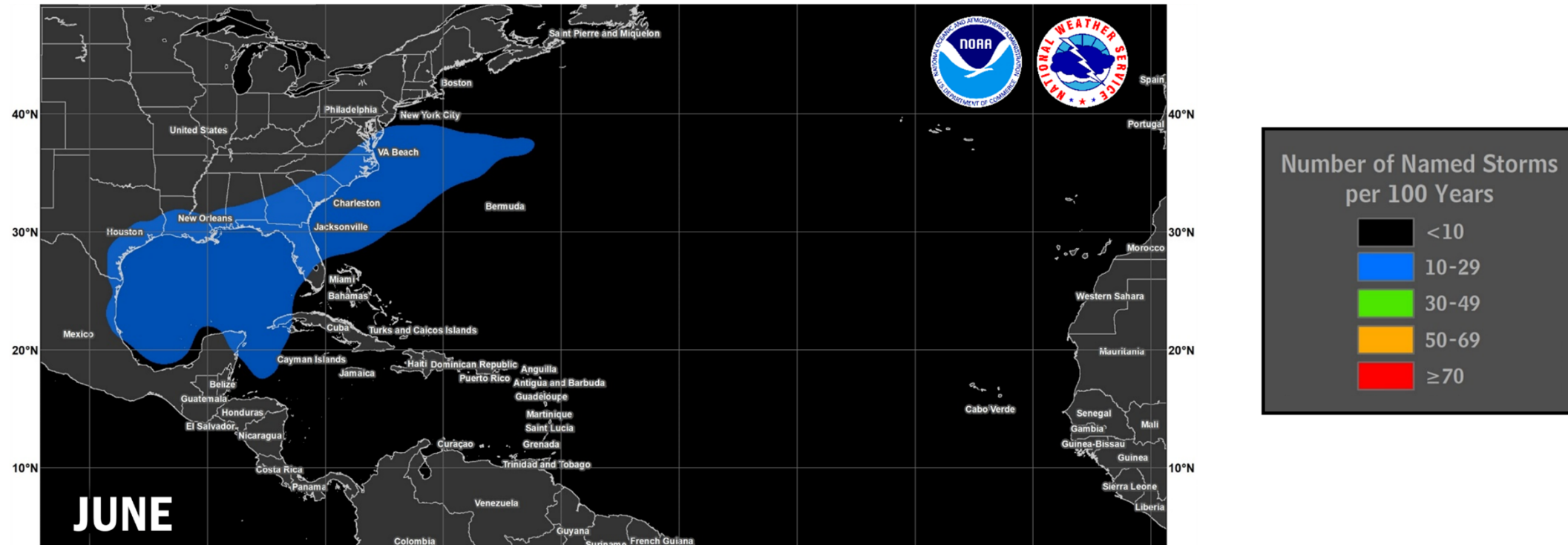
Annual Atlantic Storm Activity



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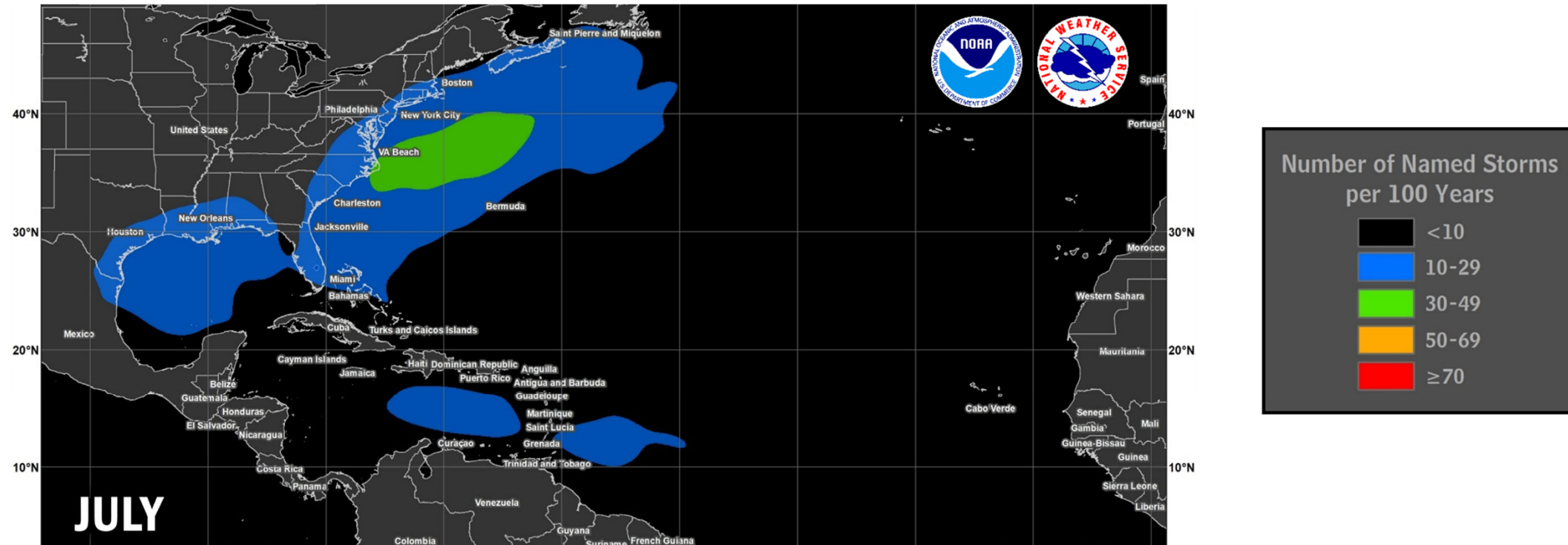


June Areas of Occurrence



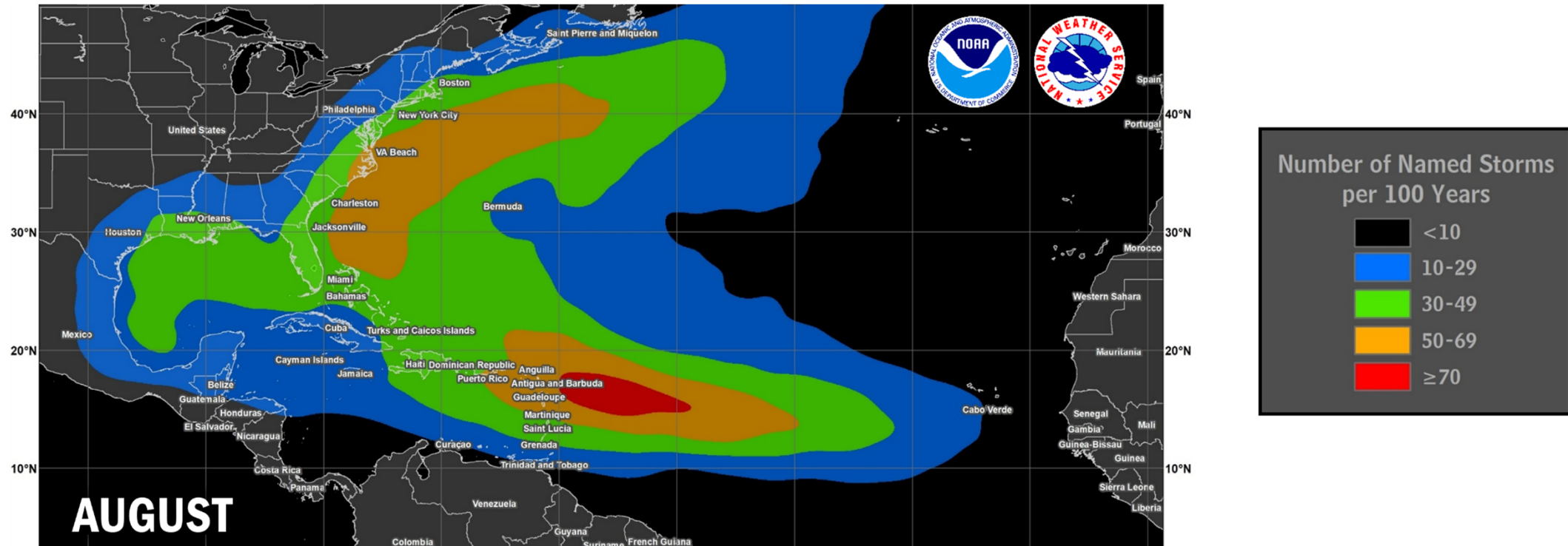
- On average, about one storm every year.
- Most June storms form in the NW Caribbean Sea or Gulf of Mexico.

July Areas of Occurrence



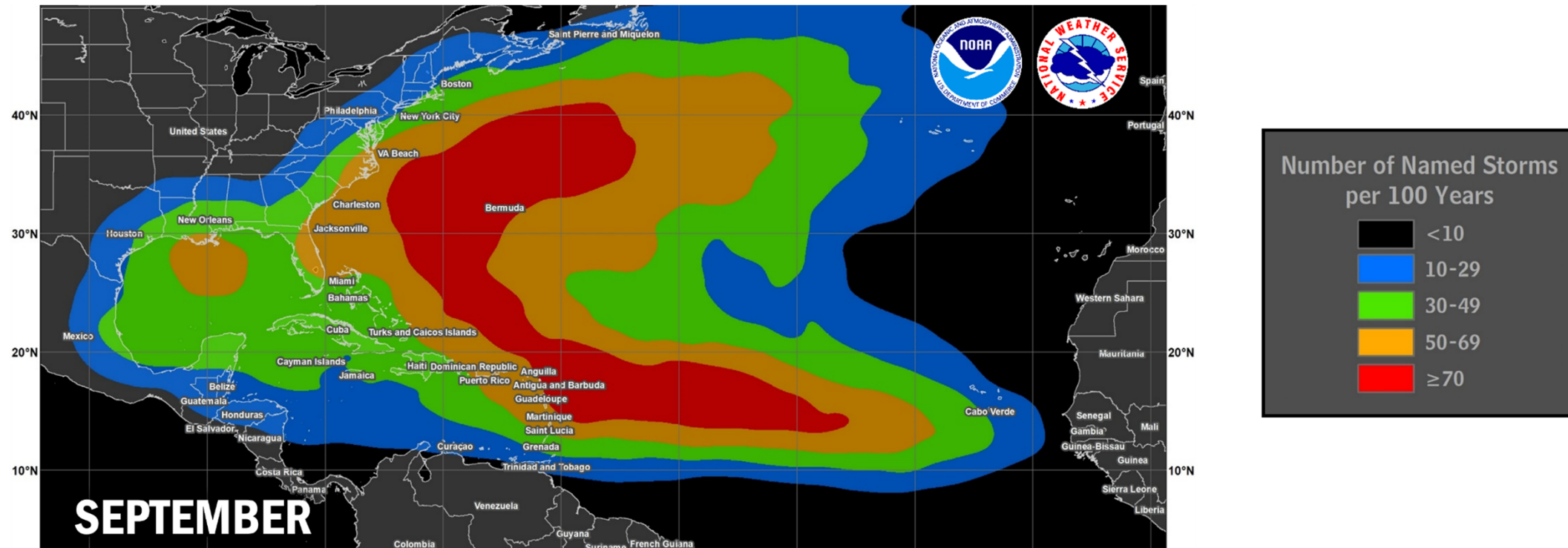
- On average, one to two named storms every year.
- July occurrence areas spread east and cover the western Atlantic, Caribbean, and Gulf of Mexico.

August Areas of Occurrence



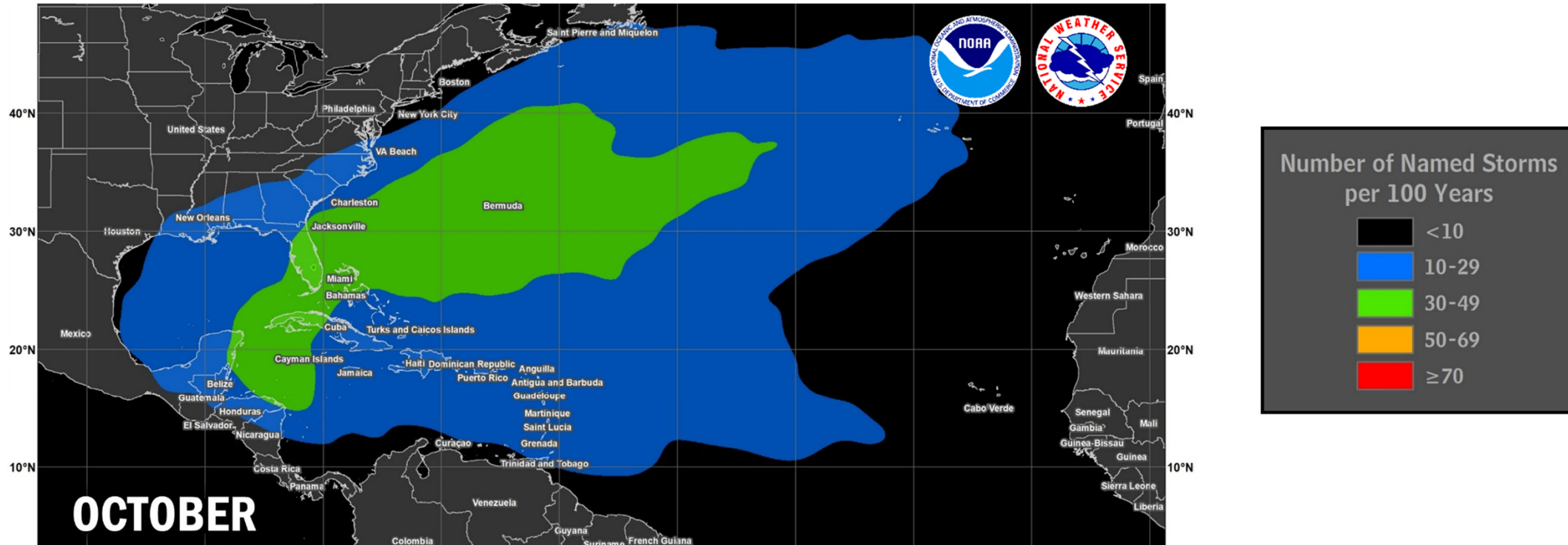
- On average, about three to four storms form each year.
- The Cape Verde season usually begins in August.

September Areas of Occurrence



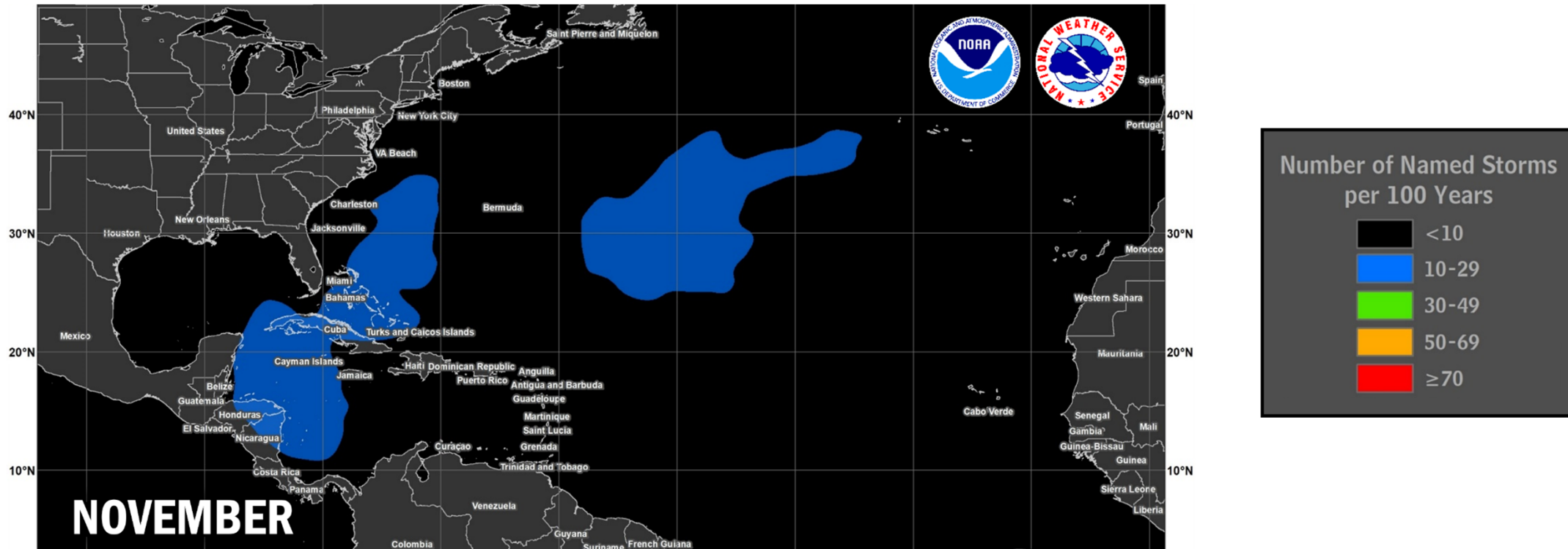
- Climatological peak of the season; on average, four to five storms every year.
- Storms can form nearly anywhere in the basin; Long-track Cape Verde storms are more likely.

October Areas of Occurrence



- On average, two to three storms every year.
- Cape Verde season ends, and activity shifts to the Gulf of Mexico, Caribbean Sea, and western Atlantic Ocean.

November Areas of Occurrence



- On average, about one storm every other year.
- Storms typically occur in the western Caribbean Sea or western and central Atlantic Ocean.

Cape Verde Hurricane Lifecycle 1



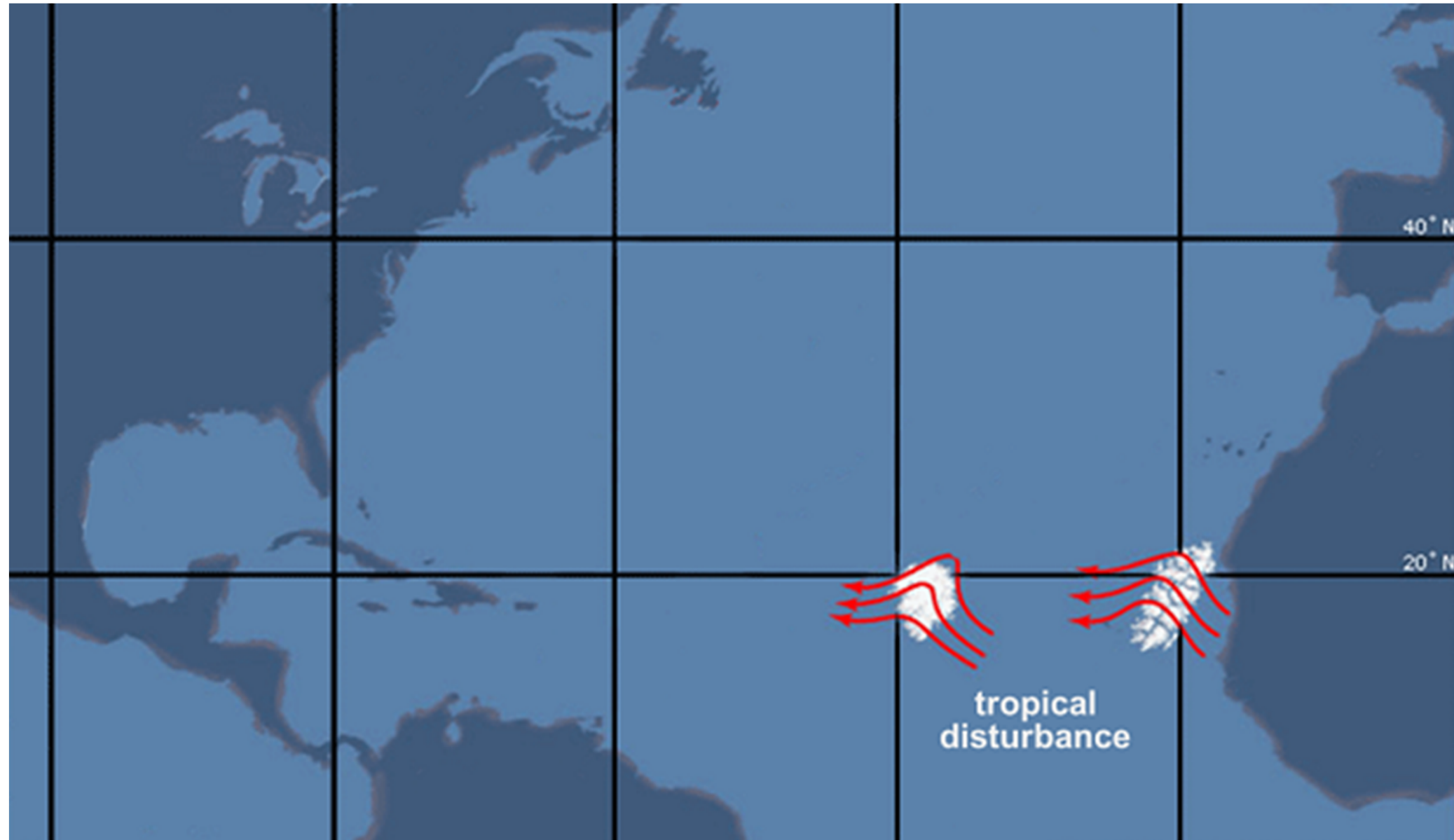
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Cape Verde Hurricane Lifecycle 2



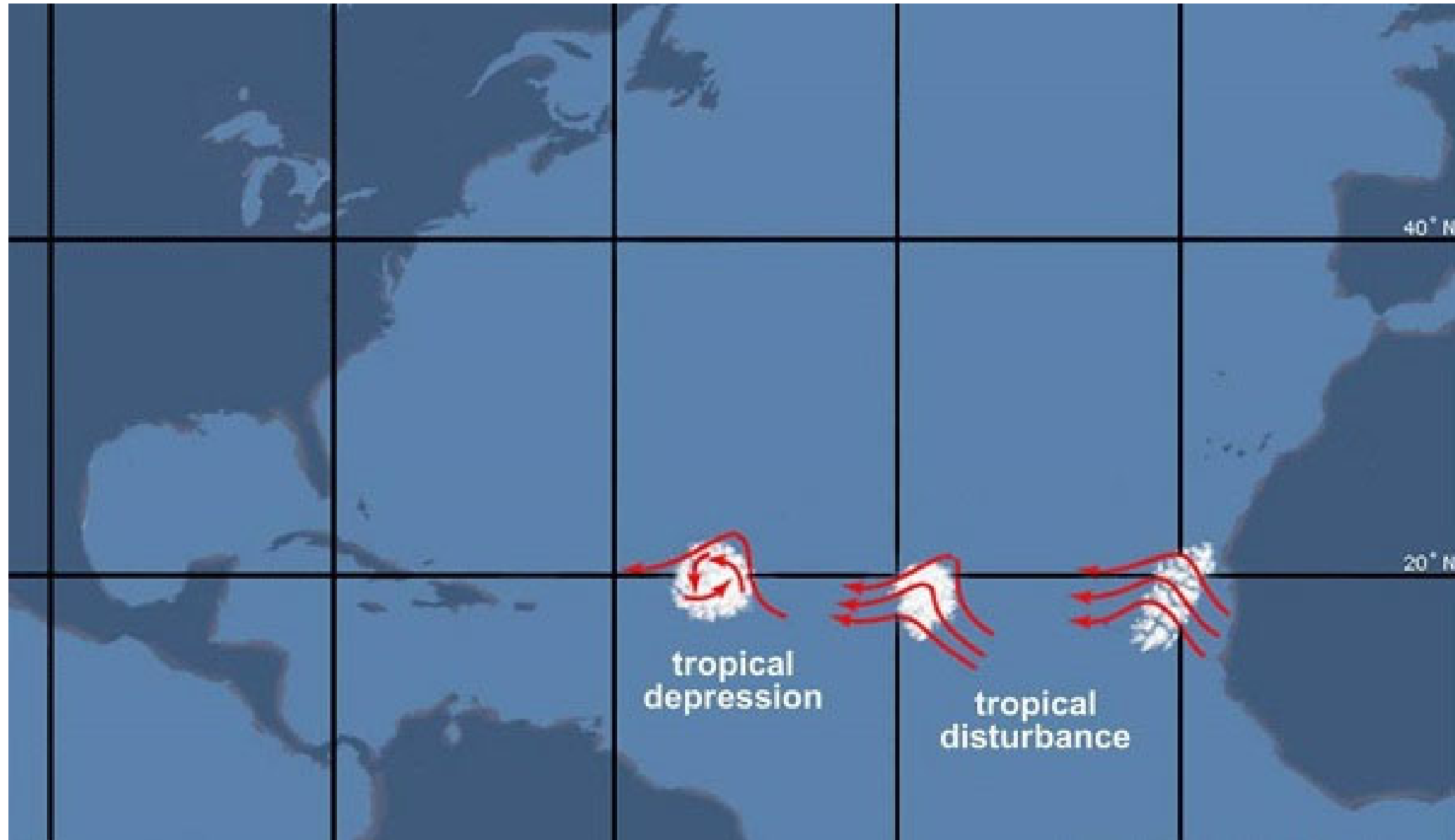
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Cape Verde Hurricane Lifecycle 3



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Cape Verde Hurricane Lifecycle 4



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Cape Verde Hurricane Lifecycle 5



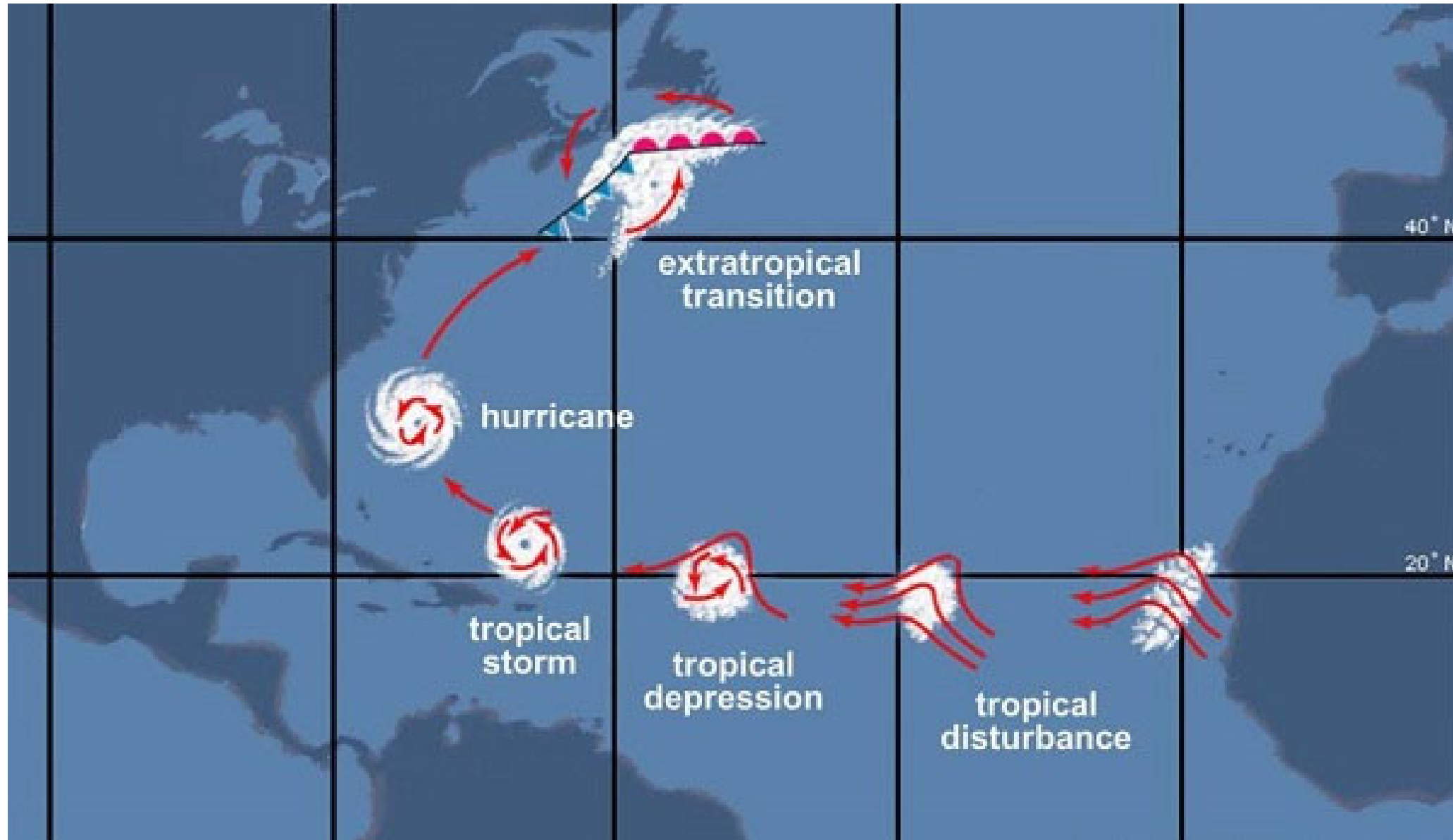
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Cape Verde Hurricane Lifecycle 6



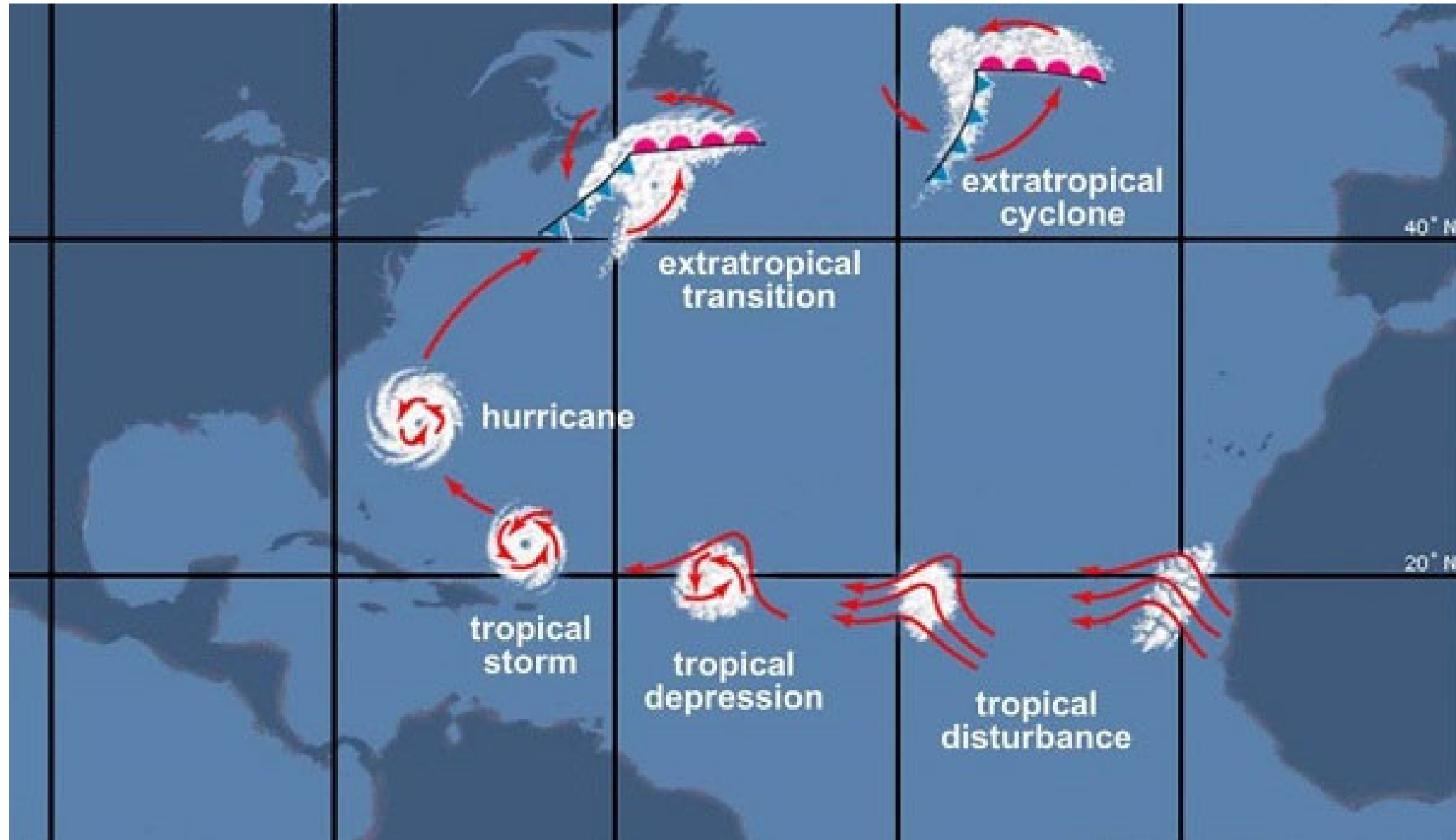
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Cape Verde Hurricane Lifecycle 7



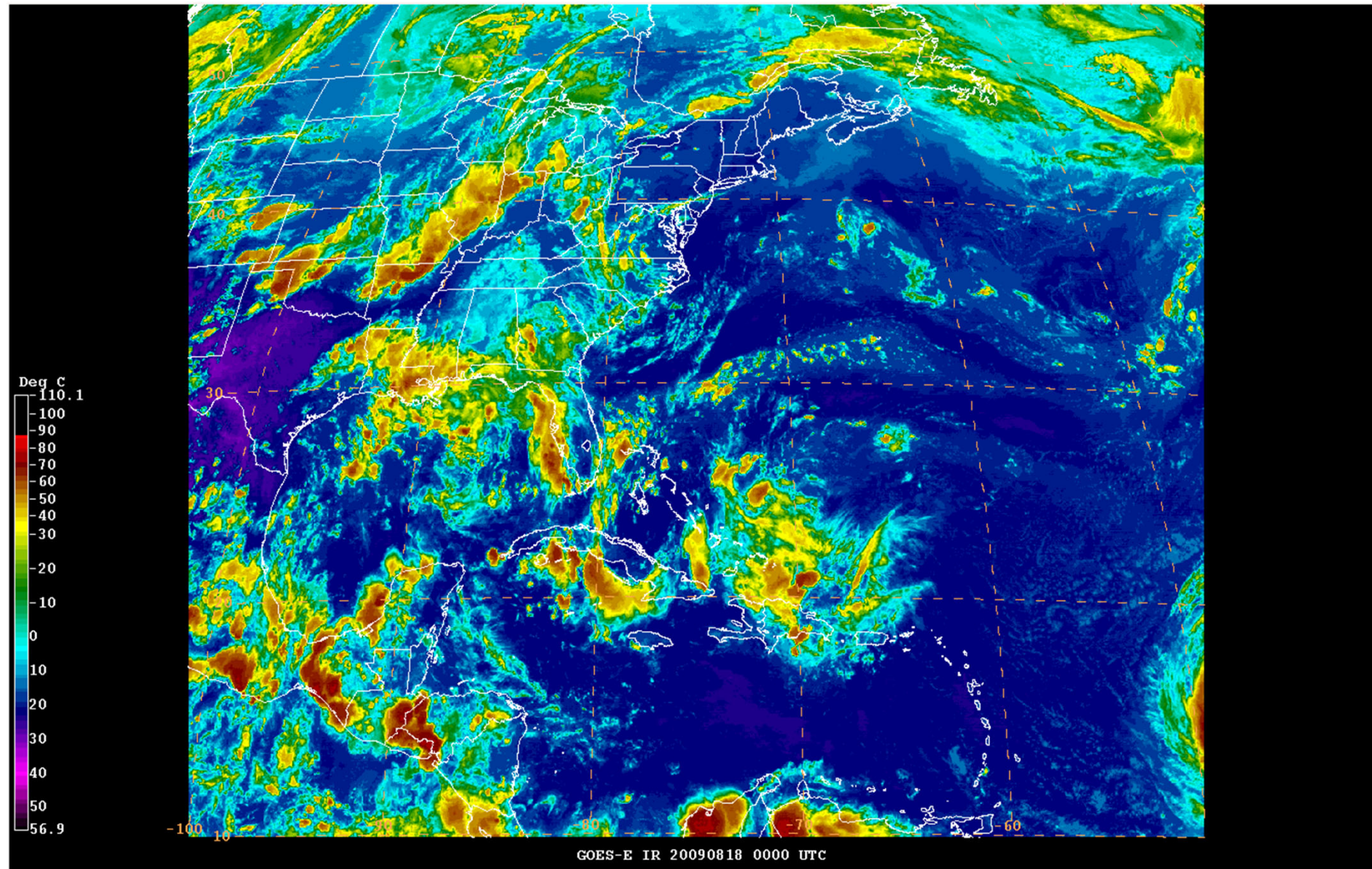
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Hurricane Bill (2009)



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Hurricane Forecasting – Knowledge Check



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Which of the following are ingredients for hurricane development?

- A. Warm Water
- B. Cold Air
- C. Lots of Moisture
- D. Strong Winds Aloft
- E. Icebergs

Ingredients for TC Formation

BUILDING BLOCKS

1) A pre-existing disturbance (vorticity or spin)



2) Location several degrees north of the equator



3) Little change in wind speed and/or direction with height (vertical wind shear)



FUEL

4) Warm sea-surface temperatures (usually at least 80° F)



5) Unstable atmosphere (temperature goes down as you go up)



6) High atmospheric moisture content (relative humidity)



Pre-existing Disturbances



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Tropical waves

- About 70% of all Atlantic basin formations
- Most major hurricanes

Decaying cold fronts

- Formation often near Gulf of Mexico and southeastern United States
- Typically early- or late-season storms

Non-tropical lows and thunderstorm complexes

- Often subtropical systems

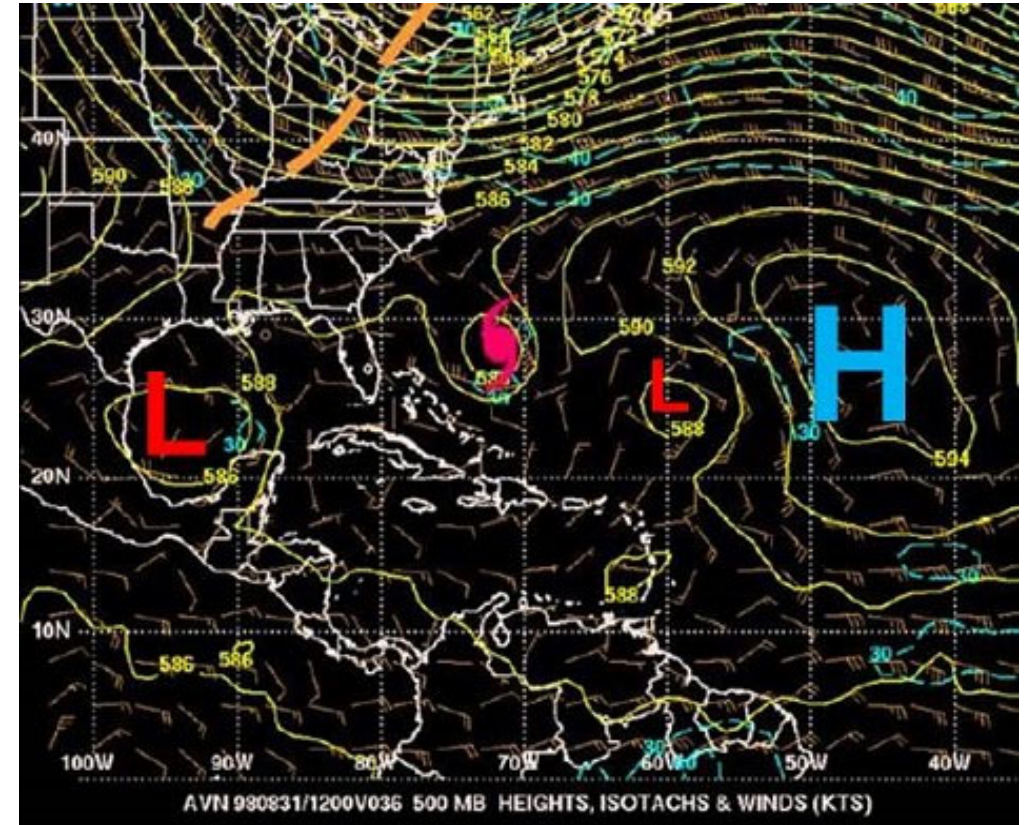
Storm Motion and Track

Track forecast is usually controlled by large-scale weather features

- “Cork in the stream” analogy

Numerical computer models forecast track quite well

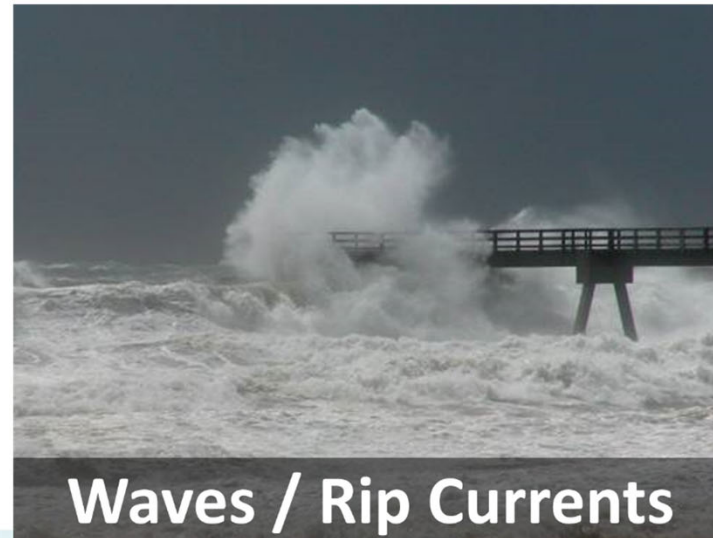
- Constantly upgrading model physics and resolution
- Long ago surpassed statistical models in accuracy



Hurricane Hazards



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Tropical Cyclone Hazards – Knowledge Check



Which hazard has the greatest potential for large loss of life?

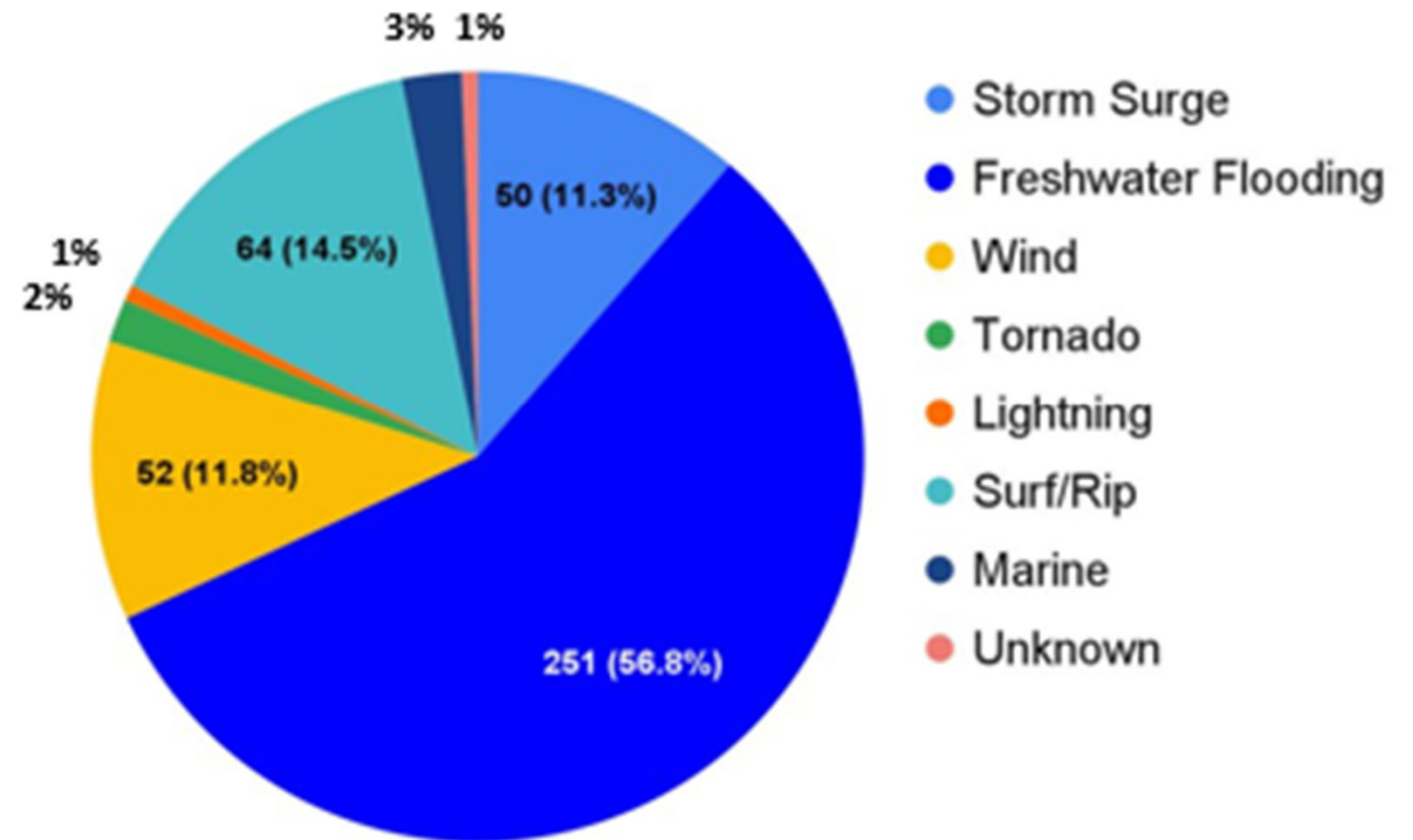
- A. Wind
- B. Rain-induced flooding
- C. Tornadoes
- D. Storm Surge

Atlantic Tropical Cyclone Deaths



U.S. tropical cyclone fatalities

- 2013–2022



Wind Intensity Factors



Intensity Factors

Upper-Ocean Temperatures	More heat favors a stronger storm
Interaction with Land/Topography	Land weakens the storm
Vertical Wind Shear	Shear limits strengthening
Moisture in Storm Environment	Dry air can limit strengthening
Structural Changes and Eyewall Replacement	Difficult to forecast and not straightforward
Interactions with Other Weather Systems	Depends on the interaction

Saffir-Simpson Scale



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MAJOR HURRICANES

TROPICAL STORM

39 – 73 mph
(34 – 63 kt)



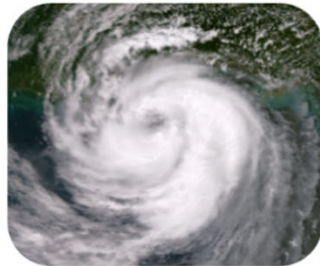
Debby
(2012)



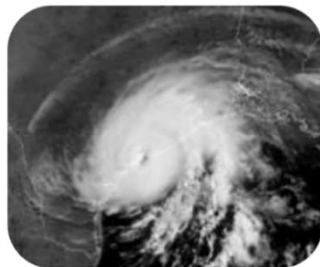
Allison
(2001)

CATEGORY 1

74 – 95 mph
(64 – 82 kt)



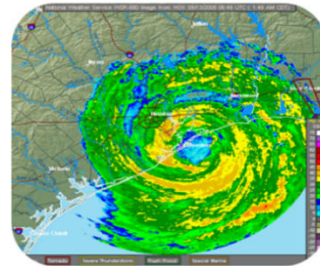
Isaac
(2012)



Claudette
(2003)

CATEGORY 2

96 – 110 mph
(83 – 95 kt)



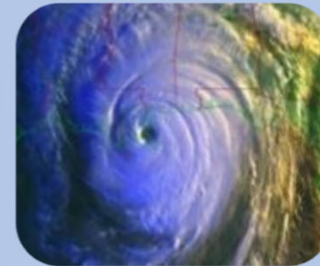
Ike
(2008)



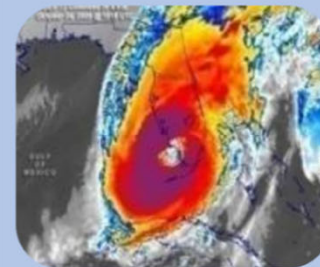
Isabel
(2003)

CATEGORY 3

111 – 129 mph
(96 – 112 kt)



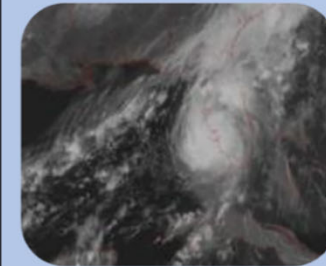
Katrina
(2005)



Wilma
(2005)

CATEGORY 4

130 – 156 mph
(113 – 136 kt)



Charley
(2004)



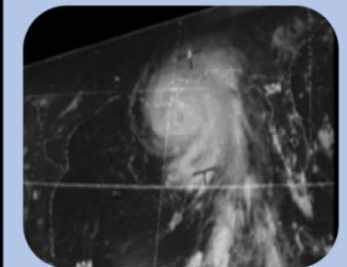
Hugo
(1989)

CATEGORY 5

> 156 mph
(> 136 kt)

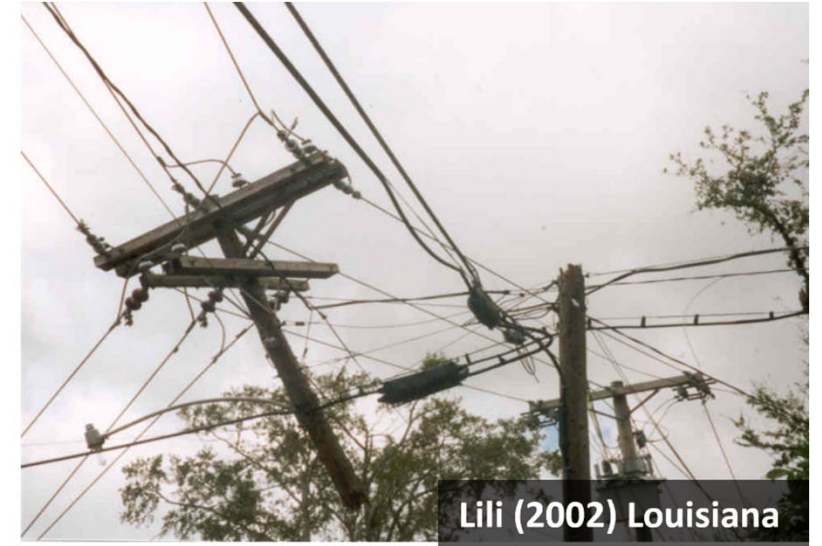
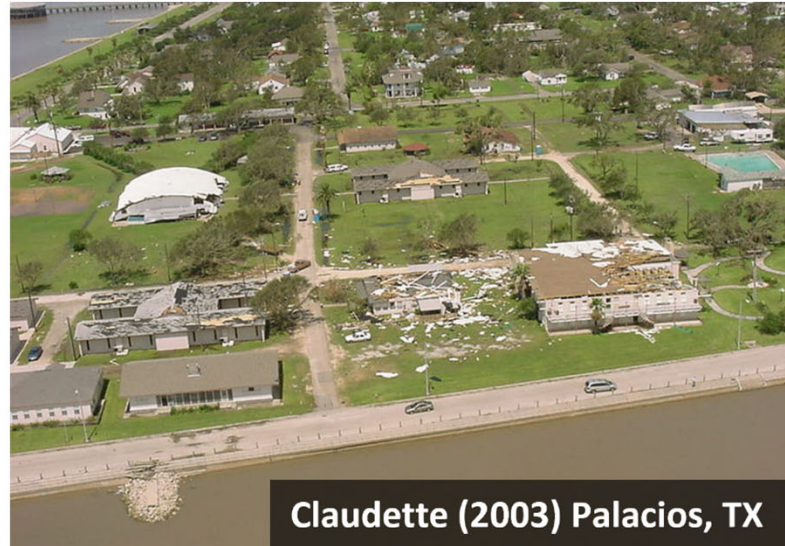


Andrew
(1992)



Camille
(1969)

Category 1 (74–95 mph)



Some damage

- Well-constructed frame homes could have roof damage.
- Large tree branches will snap; shallow-rooted trees may topple.
- Damage to power lines and poles; outages could last several days.

Category 2 (96–110 mph)



Category 2 - Extensive damage

- Well-constructed frame homes could sustain major roof damage.
- Many shallow-rooted trees will be snapped or uprooted.
- Near total power loss is expected that could last several weeks.

Category 3 (111–129 mph)



Devastating damage

- Well-constructed frame homes may incur major damage.
- Many trees will be snapped or uprooted.
- Electricity and water will be unavailable for several days to weeks.

Category 4 (130–156 mph)



Catastrophic damage

- Well-constructed frame homes may sustain severe damage.
- Most trees will be snapped or uprooted; power poles downed.
- Power outages will last weeks to possibly months.

Category 5 (>156 mph)



Catastrophic damage

- A high percentage of framed homes will be destroyed.
- Fallen trees and power poles will isolate residential areas.
- Power outages will last weeks to possibly months.

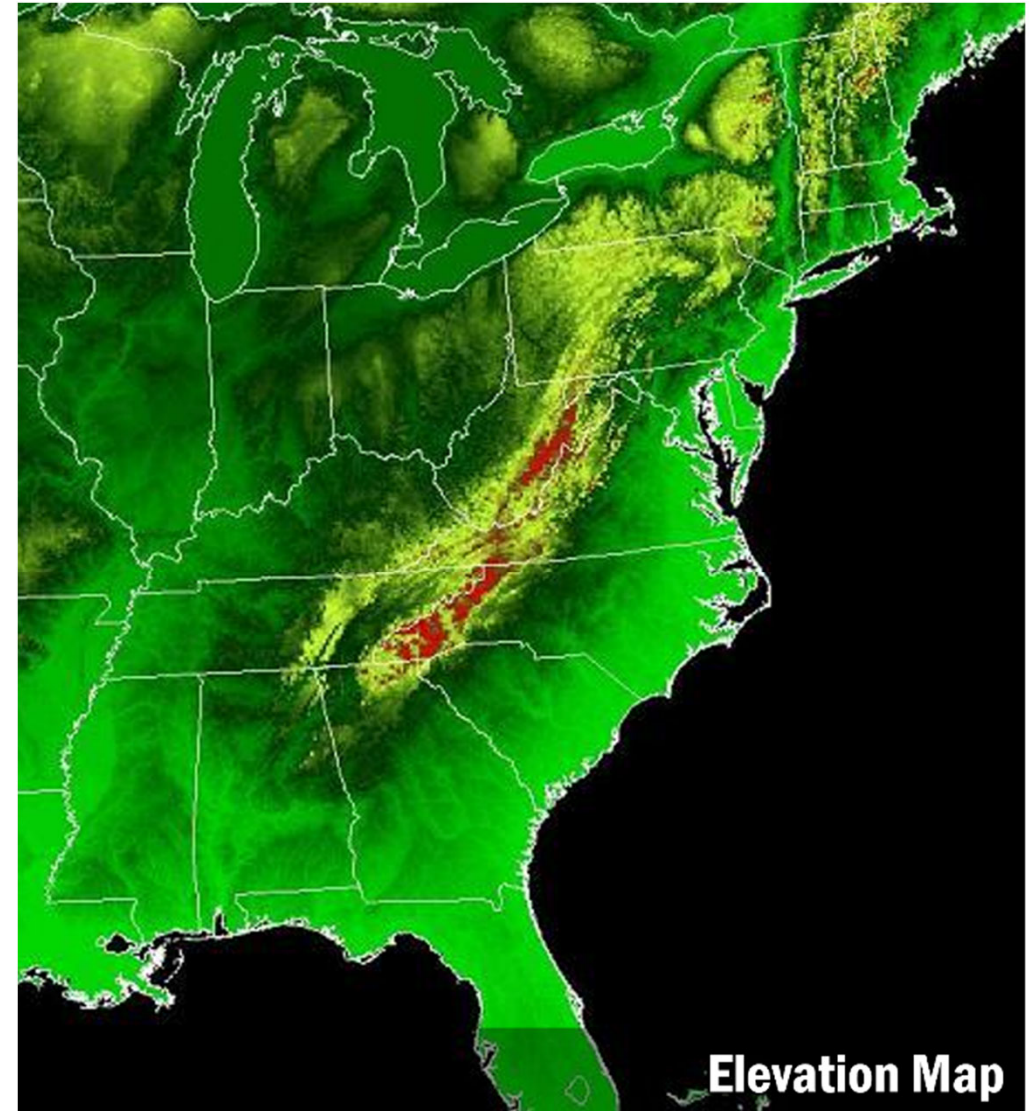
How Are Winds Altered by High Terrain?



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ELEVATION AND GUSTS

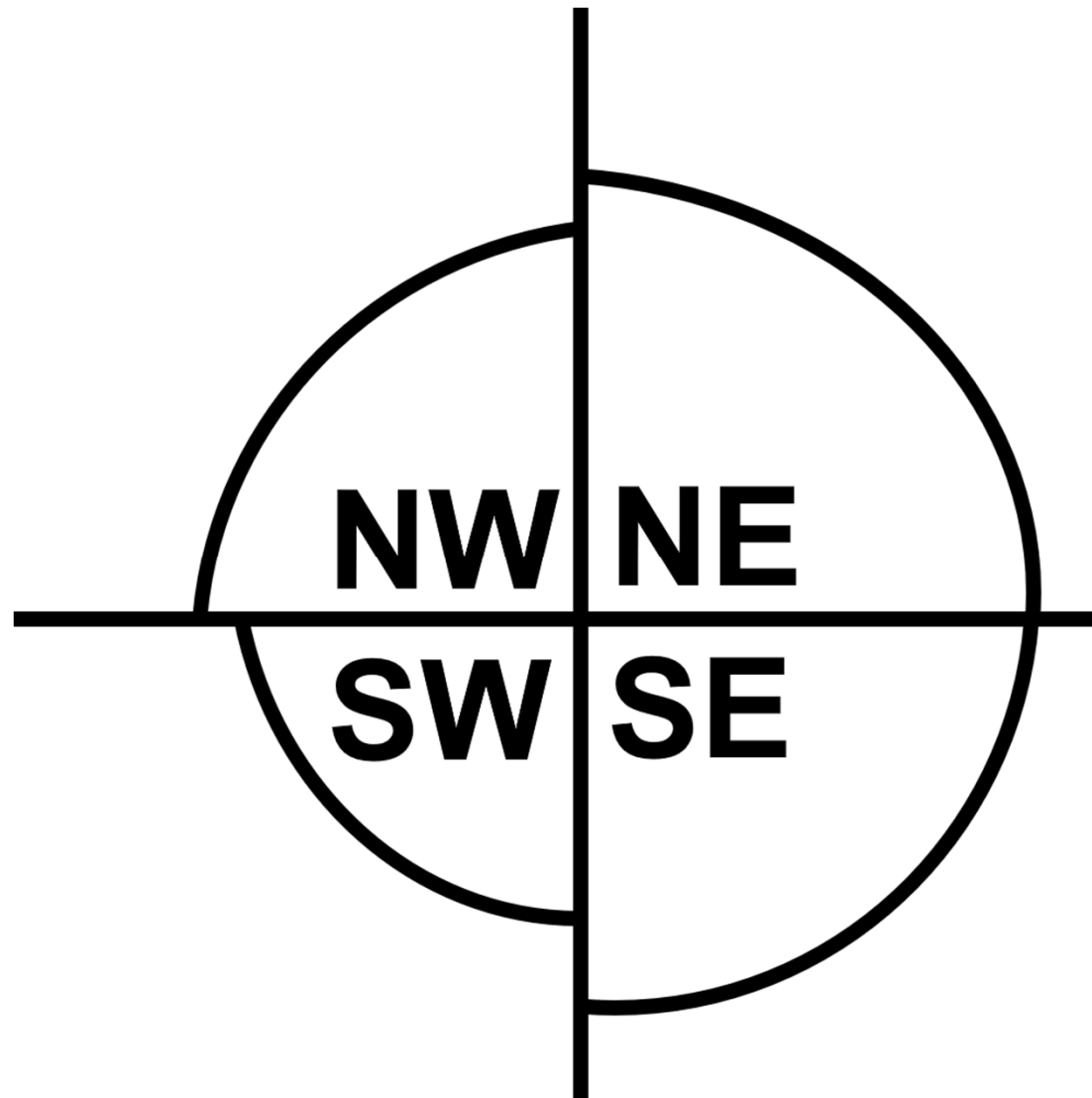
- **Elevated Terrain**
 - Can experience higher sustained winds and higher gusts
 - Also true for high-rise buildings
- **Normal wind gust factor = x1.3**
 - Sustained 60 mph -> Gusts to 80 mph
- **Complex terrain/eyewall = x1.65**
 - Sustained 60 mph -> Gusts to 100 mph



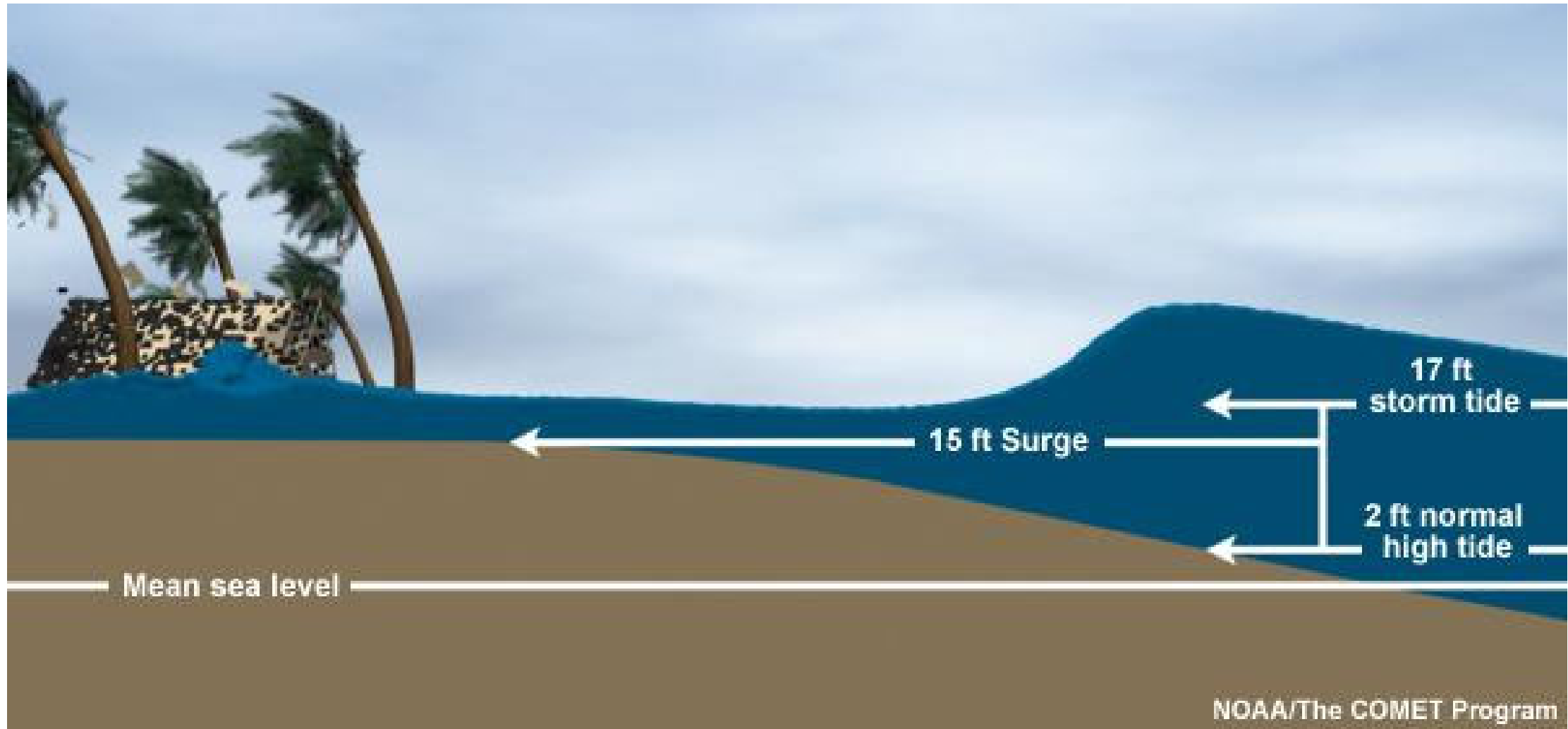
Wind Distribution and Storm Quadrants



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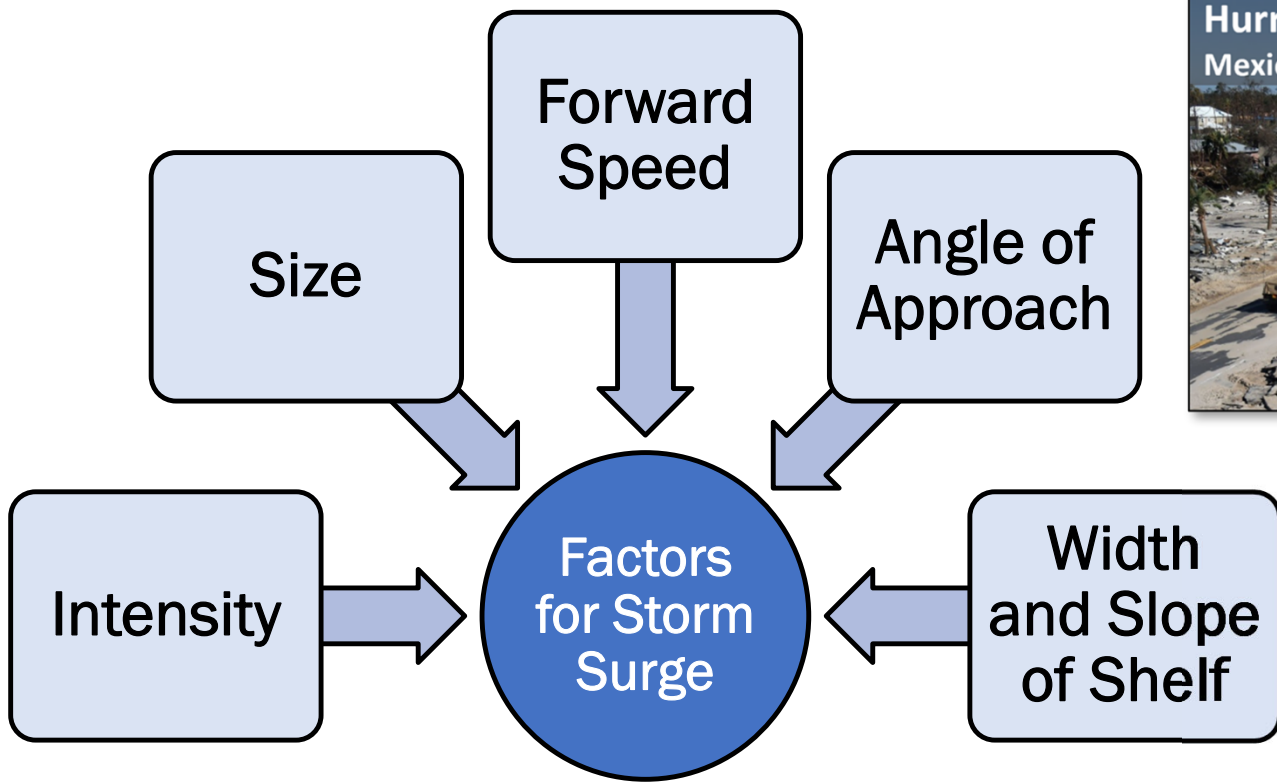


Storm Surge



The abnormal rise of water generated by a storm, over, and above the predicted astronomical tides

Storm Surge: Factors



Inland Flooding



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Times Herald



Mansfield Heliflight



Reuters



US Army Corps of Engineers

Hurricane Harvey (2017) Flooding



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MARKET STREET, HOUSTON



GOOGLE MAPS, 2016

AUG. 27, 2017



Hurricane Irene (2011) Flooding 1



Photo courtesy of L. Gange, Mansfield Heliflight



Prattsville, NY Damage (Jimmy Vielkind/Times Union)

Hurricane Irene (2011) Flooding 2

Rochester, VT Flash Flooding



Gilboa Dam – Significant scouring & erosion

Types of Flooding



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Flash Flooding:

Usually develops within 6 hours of the heavy rainfall (e.g., small stream flooding, debris flows/mudslides, urban flooding, levee or dam failures). Usually shorter duration.

River Flooding (Large Rivers):

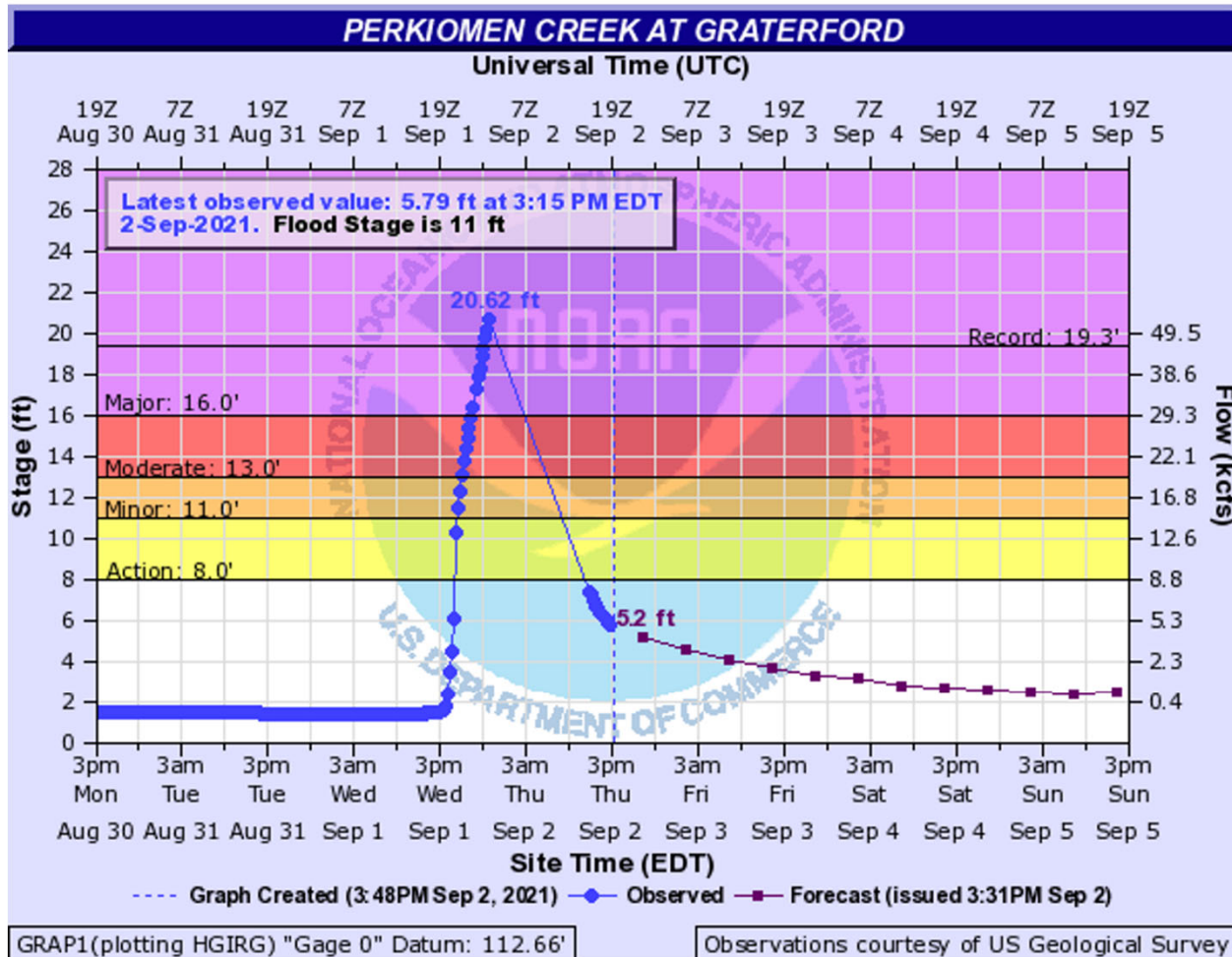
Stormwater drains from the smaller tributaries into the larger mainstem rivers. Water levels rise and overflow banks, inundating normally dry areas. Usually longer duration.



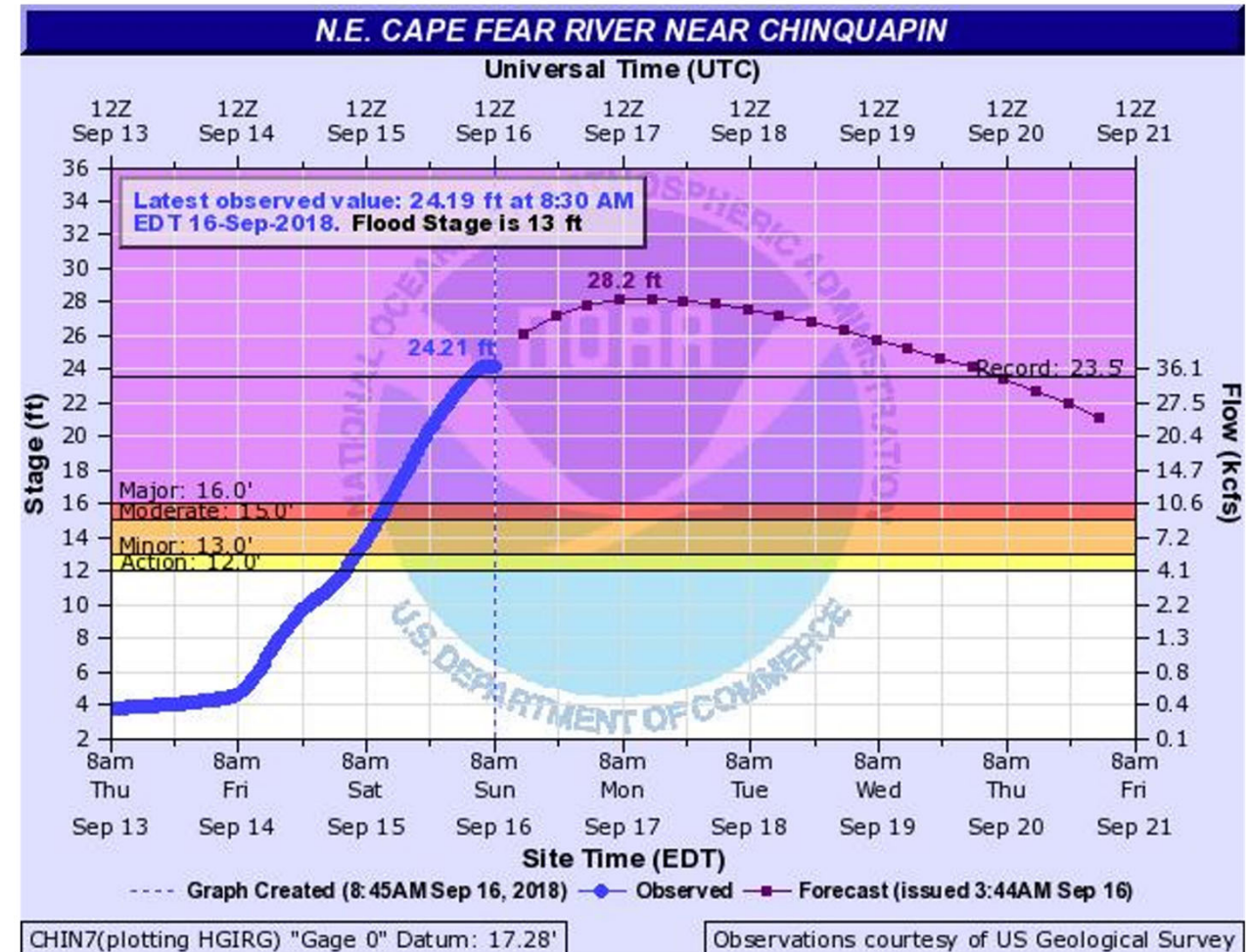
Types of Flooding



Flash Flooding



Mainstem River Flooding



Flood Stages



Major Flooding	Extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations.
Moderate Flooding	Some inundation of structures and roads near the stream or river. Some evacuations of people and/or transfer of property to higher elevations.
Minor Flooding	Minimal or no property damage, but possibly some public threat.
Action Stage	Represents the level where the NWS or a partner/user needs to take some type of mitigation actions in preparation for possible significant hydrologic activity.

Flood Stage Examples



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Action Stage



Minor Flood Stage



Moderate Flood Stage



Major Flood Stage

Factors Affecting Rainfall



Storm Track	Alters geographic focus of rainfall
Forward Speed	Slower storm = More rain
Size	Larger storm = More rain
Topography and Mountains	More rain on windward side
Fronts and Upper-Level Troughs	Enhance rainfall

The Big Challenge



All Tropical Cyclones
Have Rain

*“So what?” factor
Already obvious*

Many produce
localized “hot spots”

*Tough to motivate large response
Placement is difficult days in advance*

Few with widespread,
catastrophic rain

*People want us to get these right
Need to minimize false alarms*



Ordinary



Extraordinary

← How best to differentiate storms along this spectrum? →

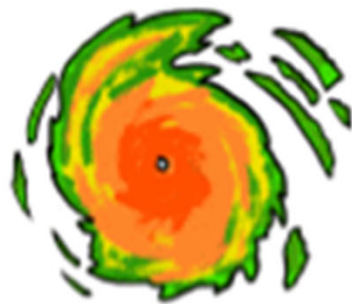
Storm Forward Speed



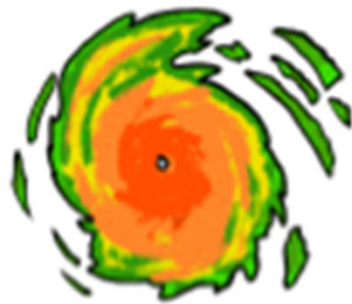
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Situations that favor the “Big Extraordinary Ones”

- Slow-moving storms that create multi-day opportunity for repetitive, high-intensity rainfall
- Storm speed being equal: larger, higher-intensity storms that approach areas with terrain or urban development are factors



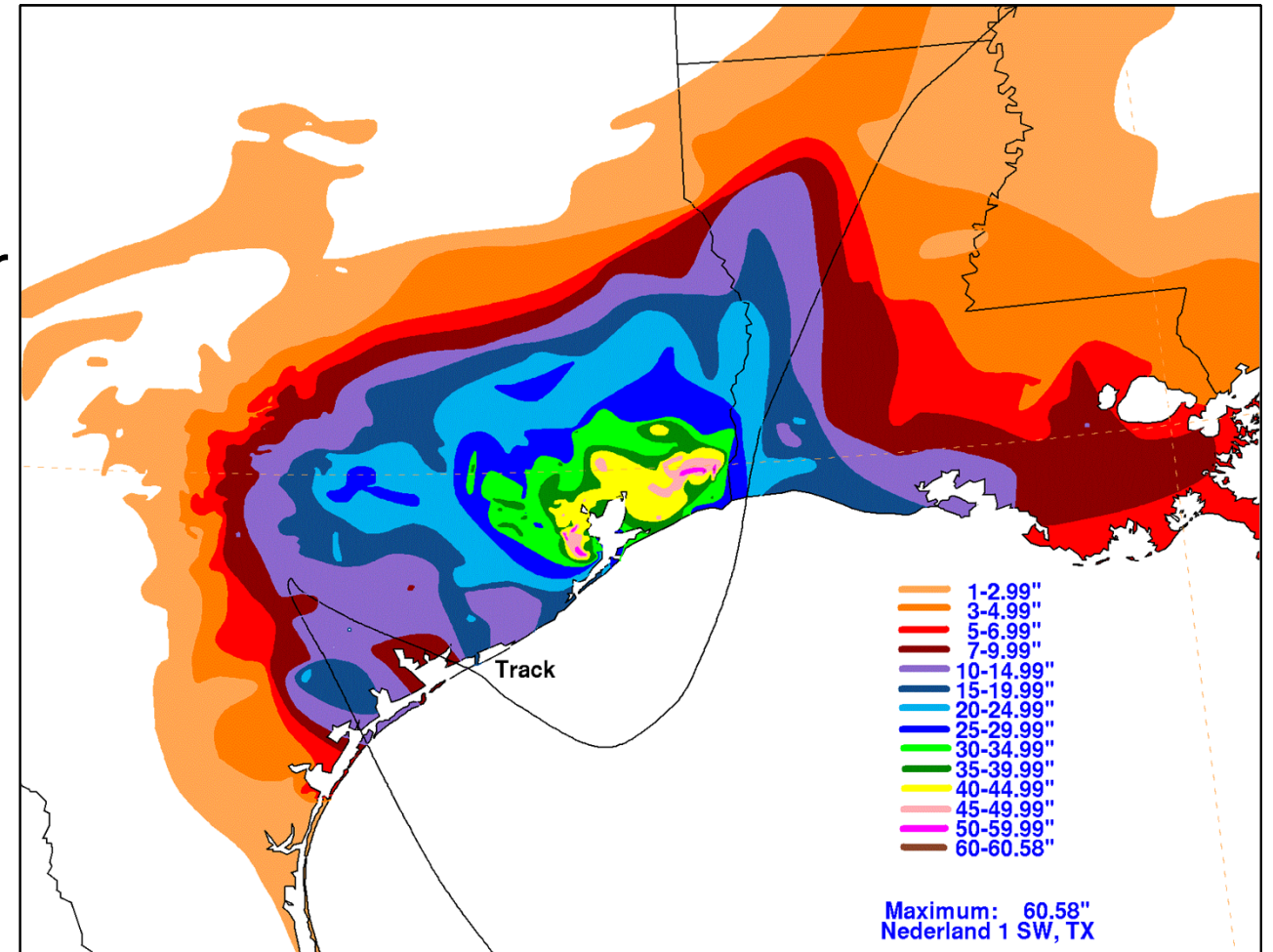
Rainfall at Time Increments →



Rainfall at Time Increments →

Hurricane Harvey (2017)

- Forward speed plays a major role in inland flooding threat potential.
- After making landfall, Harvey stalled, with its center over or near the Texas coast for 4 days, dropping historic amounts of rainfall of more than 60 inches over southeastern Texas.

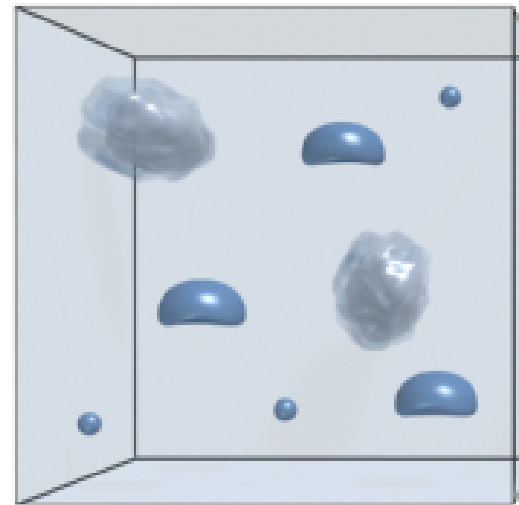


Rainfall Rates (“Efficiency”)

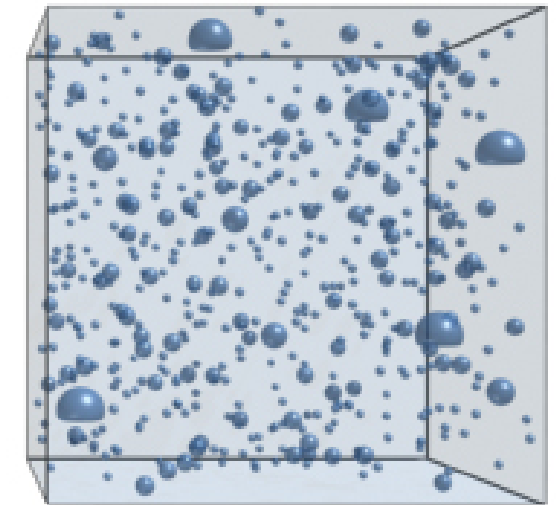
Tropical Rainfall Efficiency

- Tropical cyclones generally build heavy rain through a warm rain process, without melting ice crystals or hail.
 - Result: a lot of smaller water droplets.

Cold Rain Process



Warm Rain Process



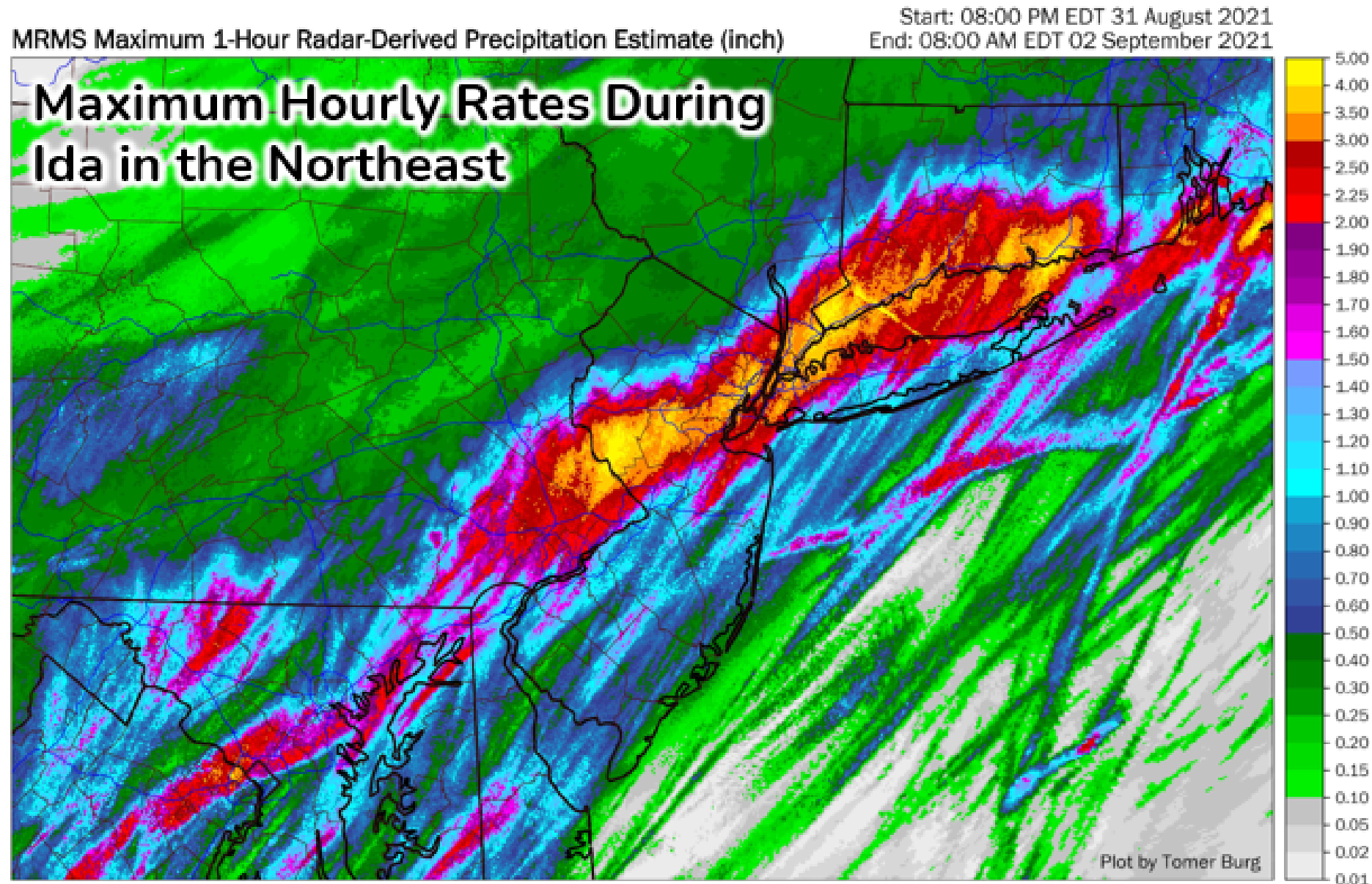
Greater
rainfall rate

FEWER Ice Crystals = MORE Rainfall Droplets

Rainfall Rates Example – Hurricane Ida (2021)



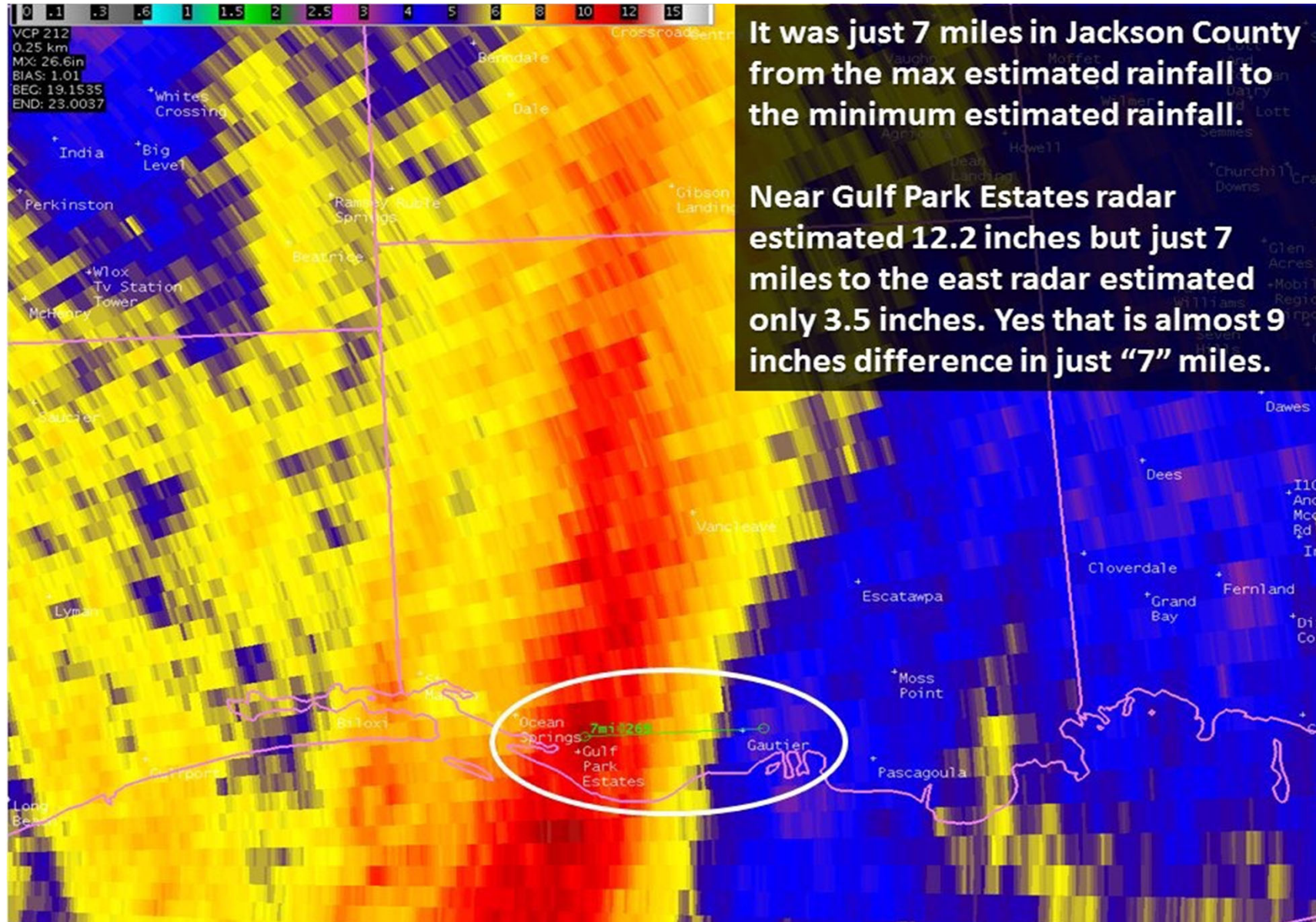
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Rainfall Gradient Example - TS Cindy (2017)



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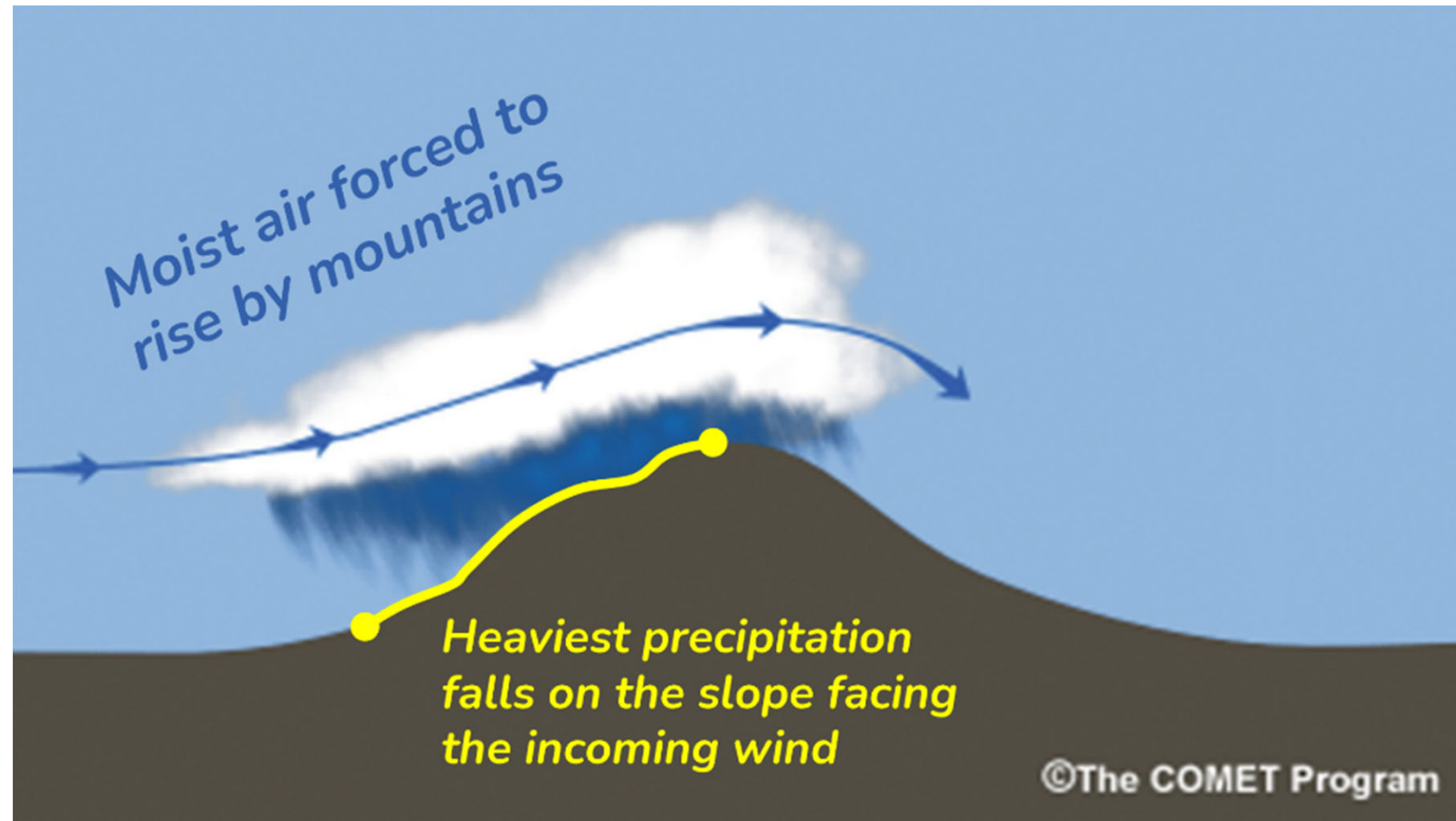
Terrain Effects



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Upslope Rainfall Enhancement

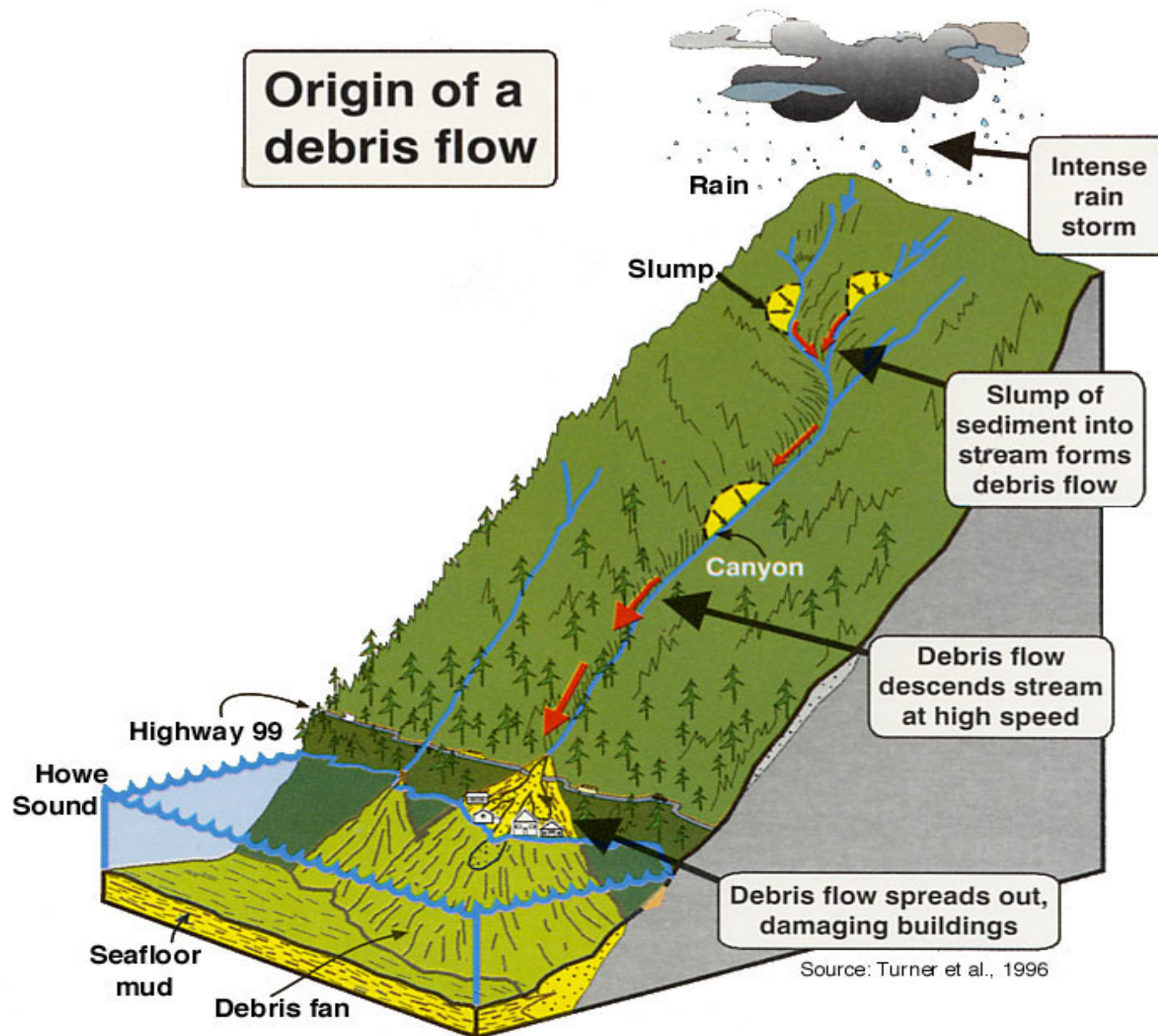
Extreme rainfall maxima can be focused in areas of terrain where winds around a tropical low can feed significant tropical moisture into mountainous areas.



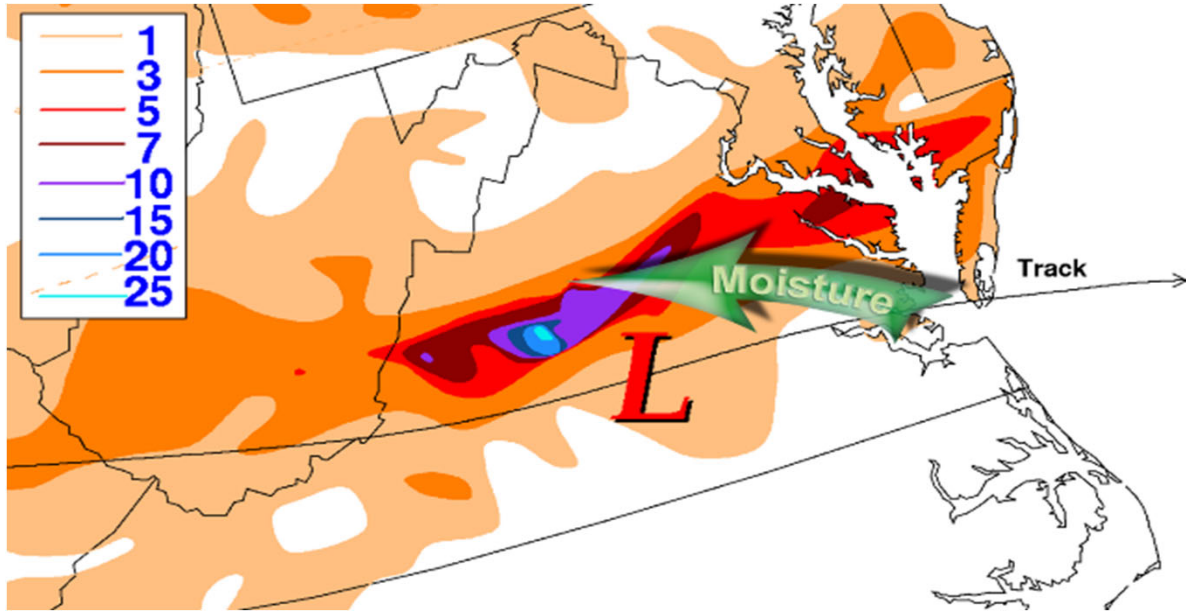
Debris Flow



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Hurricane Camille (1969) - Virginia



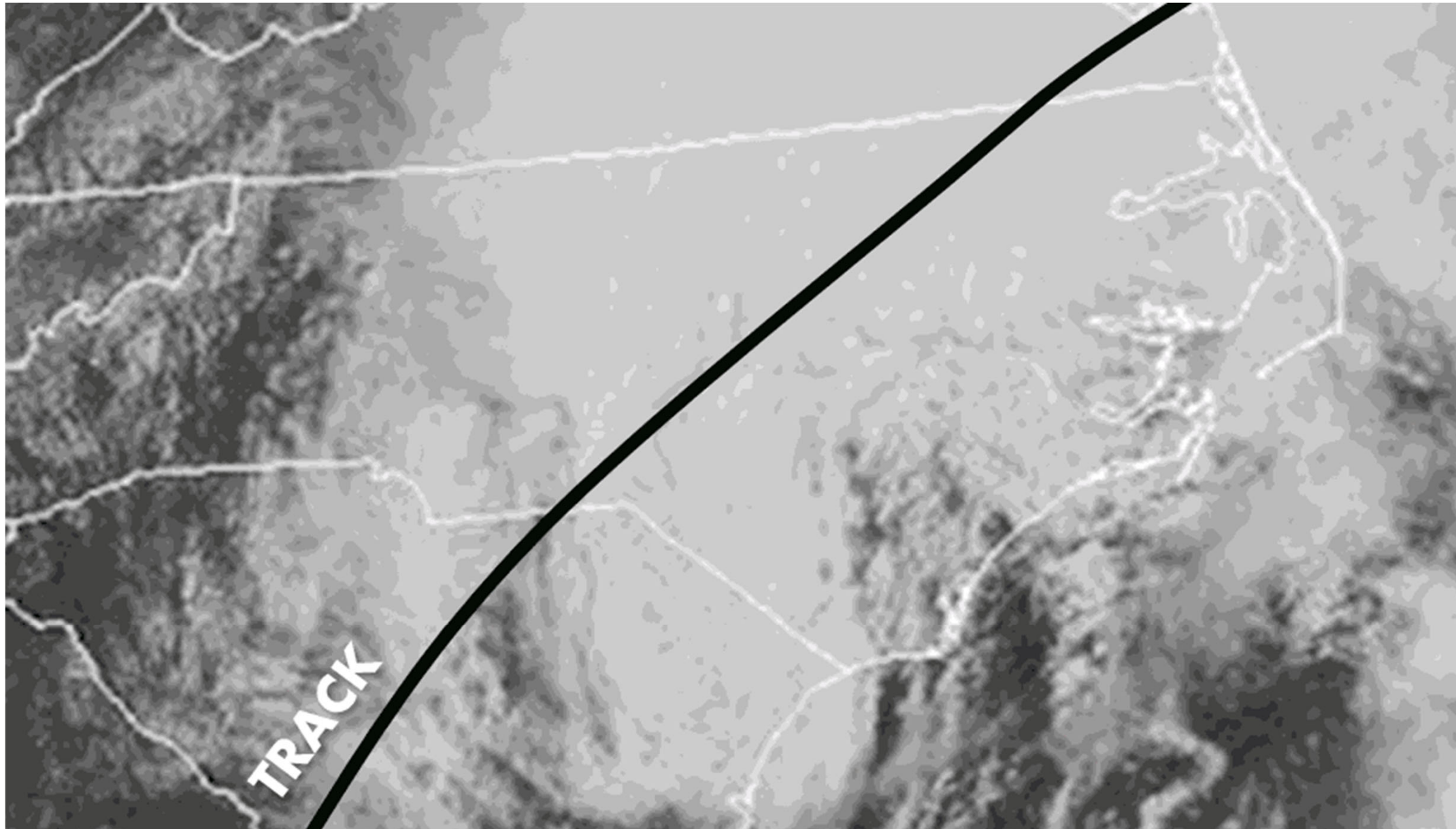
Hurricane Camille (1969) provides an excellent example of a very localized heavy rain where persistent easterly winds met the Virginia mountains, leading to catastrophic flooding, mudslides and debris flows that killed at least 124 people.



TS Alberto (2016)



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Urban Flooding



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- Streets can become swift-moving rivers, and basements can fill with water.
- Flooding of low spots, underpasses, poorly-drained locations, culverts, and drainages.



Why “Urban” Flooding



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More concrete

=

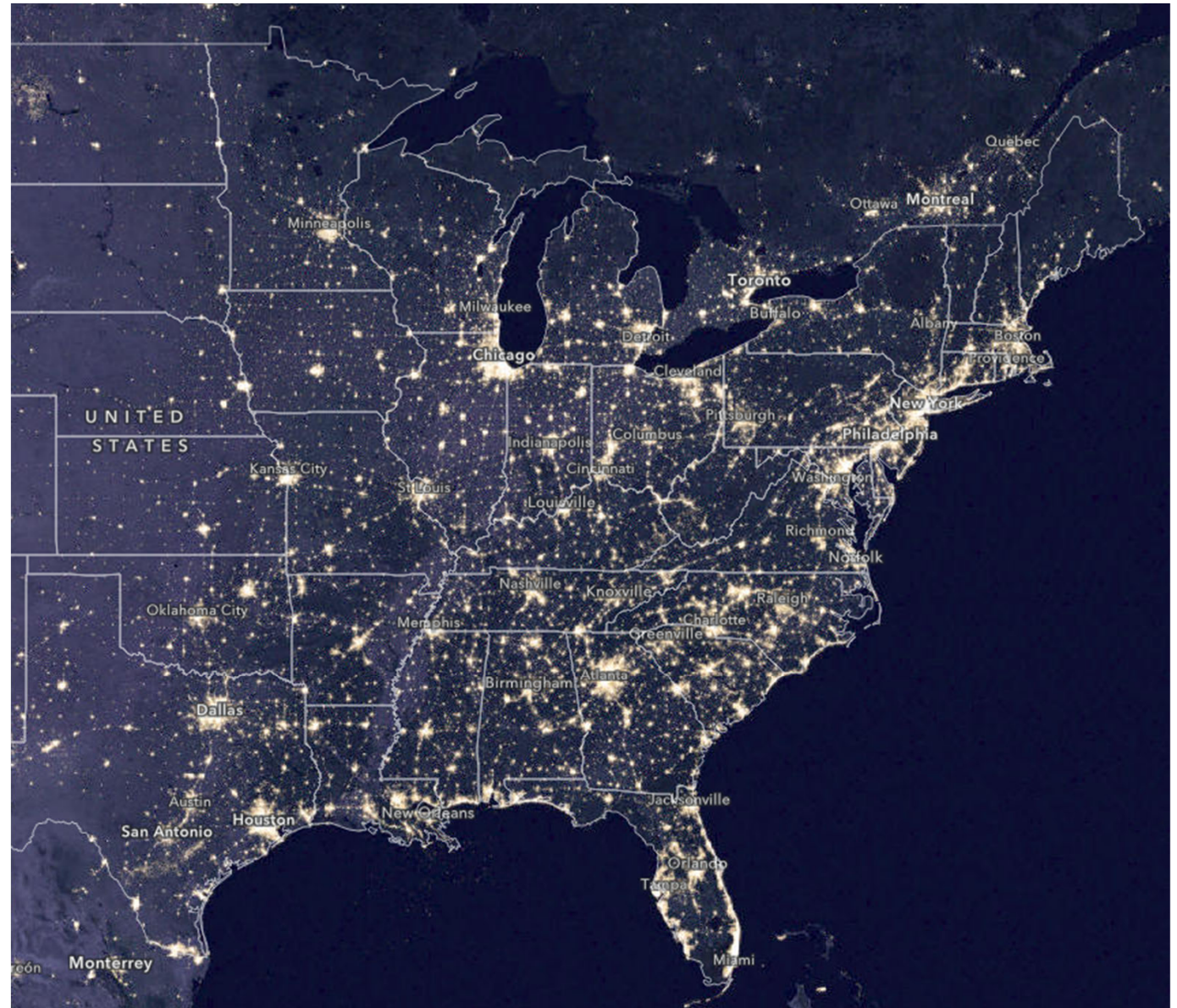
More impervious surface

=

Faster and greater runoff

=

Increased flooding risk



Hurricane Harvey (2017) Flooding: I-10



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TS Allison (2001) – I-10



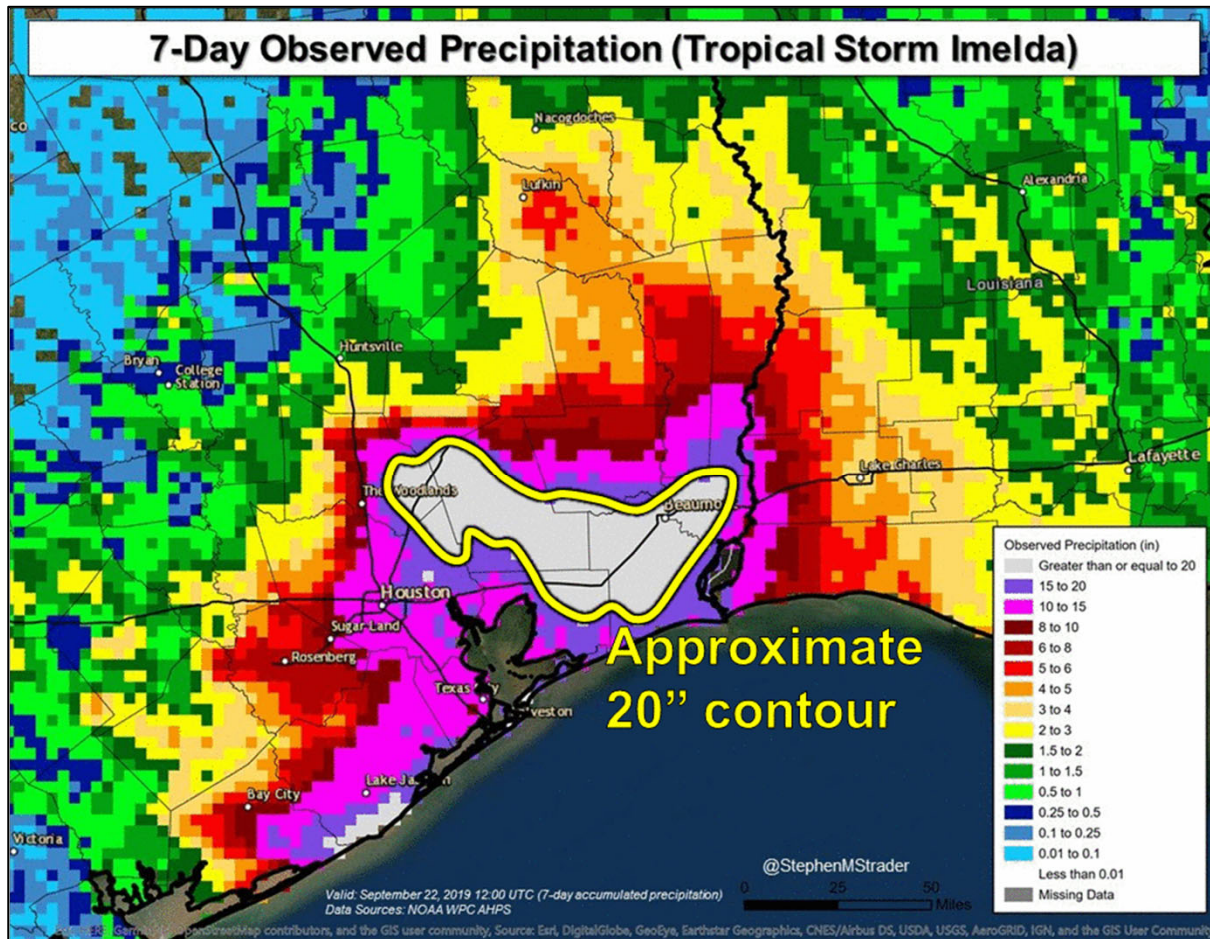
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Interstate 10 – West View



Urban Growth and Flooding

Expanding Urban Areas Make a Difference



Unnamed Low (2016) - Louisiana

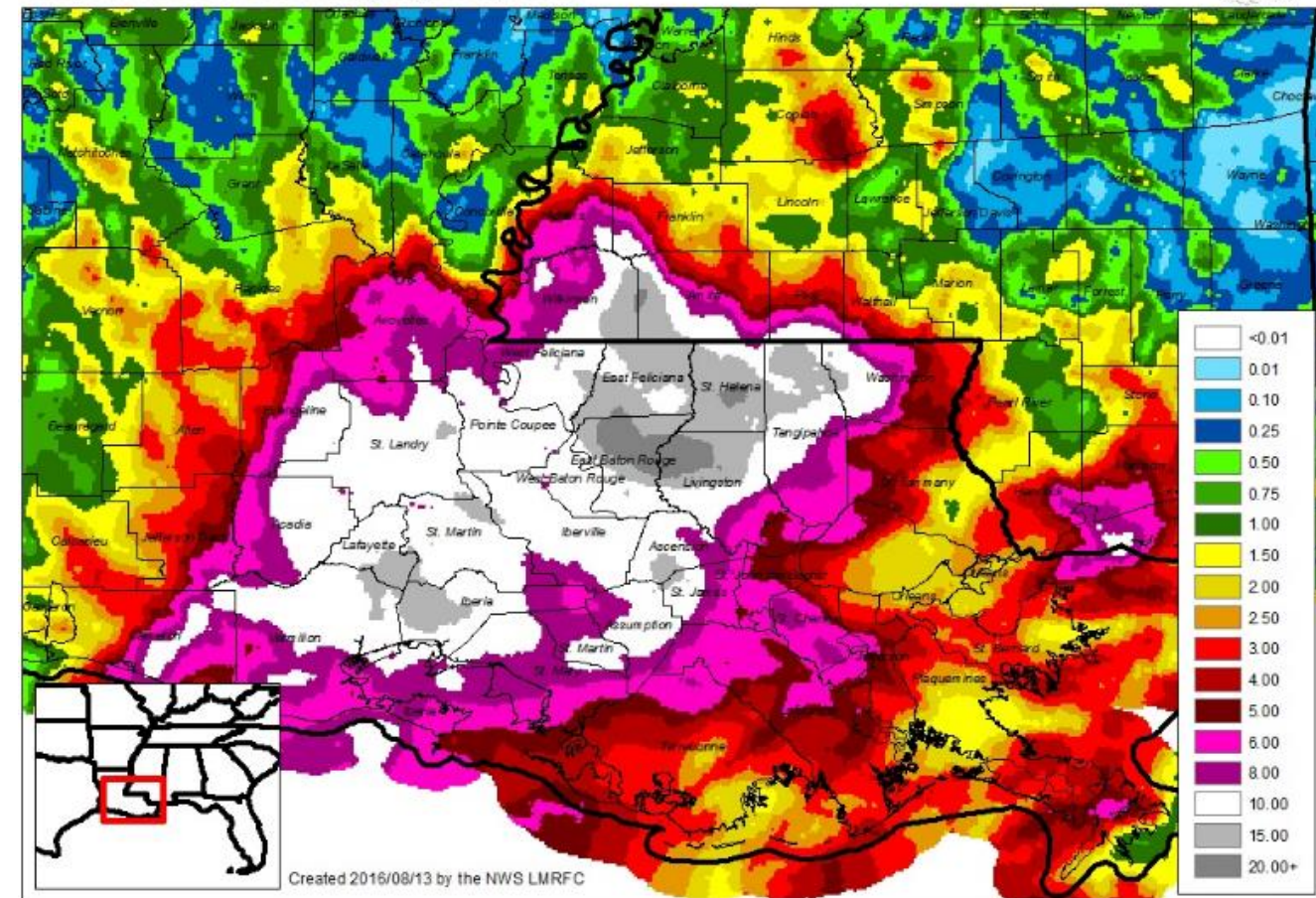


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- Notice that the list of rainfall factors did not include level of organization and wind strength.
- A tropical system doesn't need to be an organized cyclone to have catastrophic impacts.
- In 2016, a disorganized tropical system stalled over Louisiana, dropping 3x the amount of rainfall that Katrina brought to the State in 2005.

Best-Estimate Rainfall

2 day rainfall estimate ending August 13, 2016.



Lake Overflow and Dam Breaks



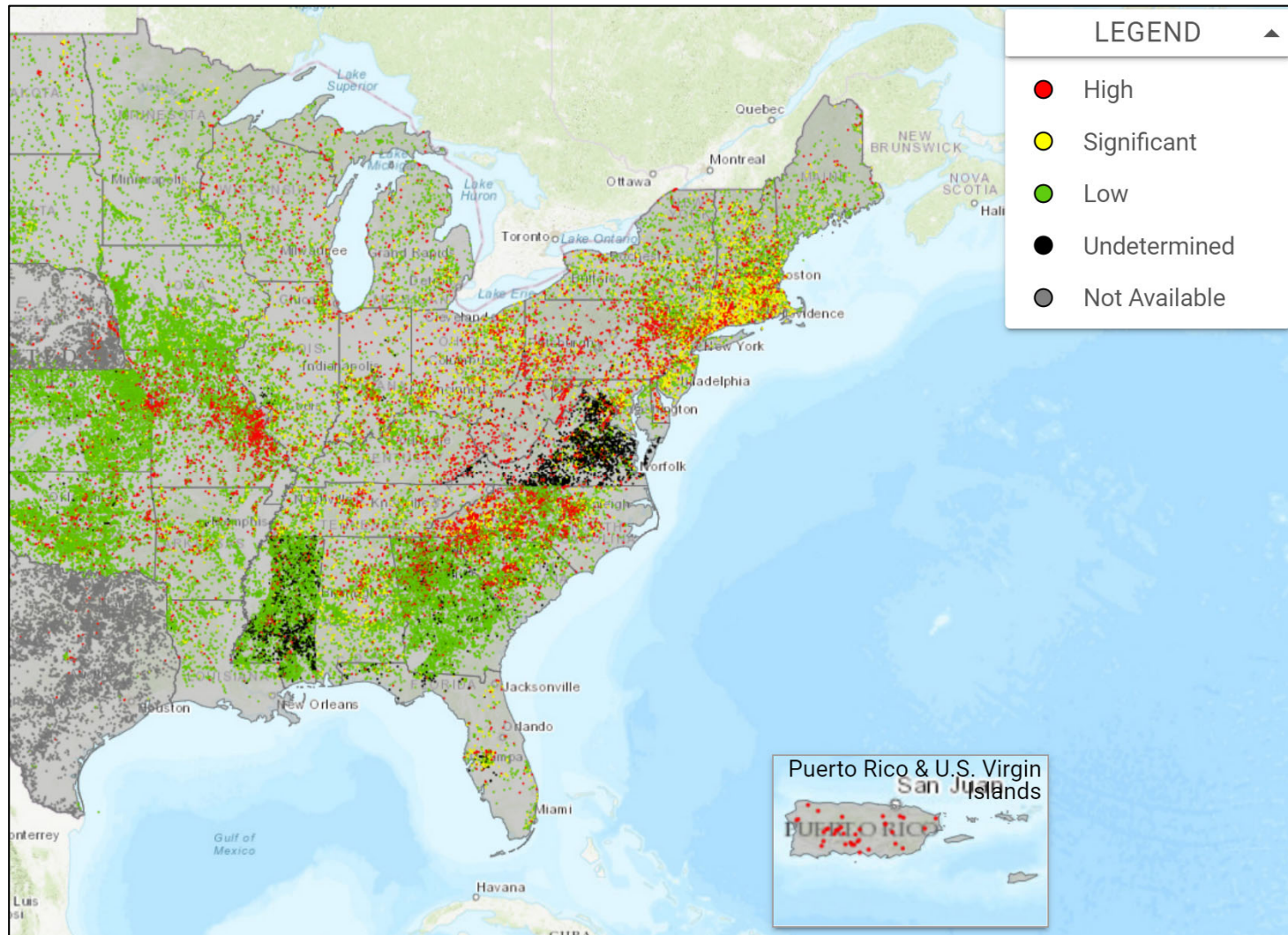
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- Dam breaks are more likely to occur on smaller, poorly maintained dams.
- Overflow of lakes.
- Know what is upstream.



Dams Failure Risk Levels

USACE National Inventory of Dams



Hazard Potential Classification	Loss of Human Life	Economy, Environment, Lifeline Losses
High	Probable. One or more expected	Yes (but not necessary for this classification)
Significant	None Expected	Yes
Low	None Expected	Low and generally limited to owner

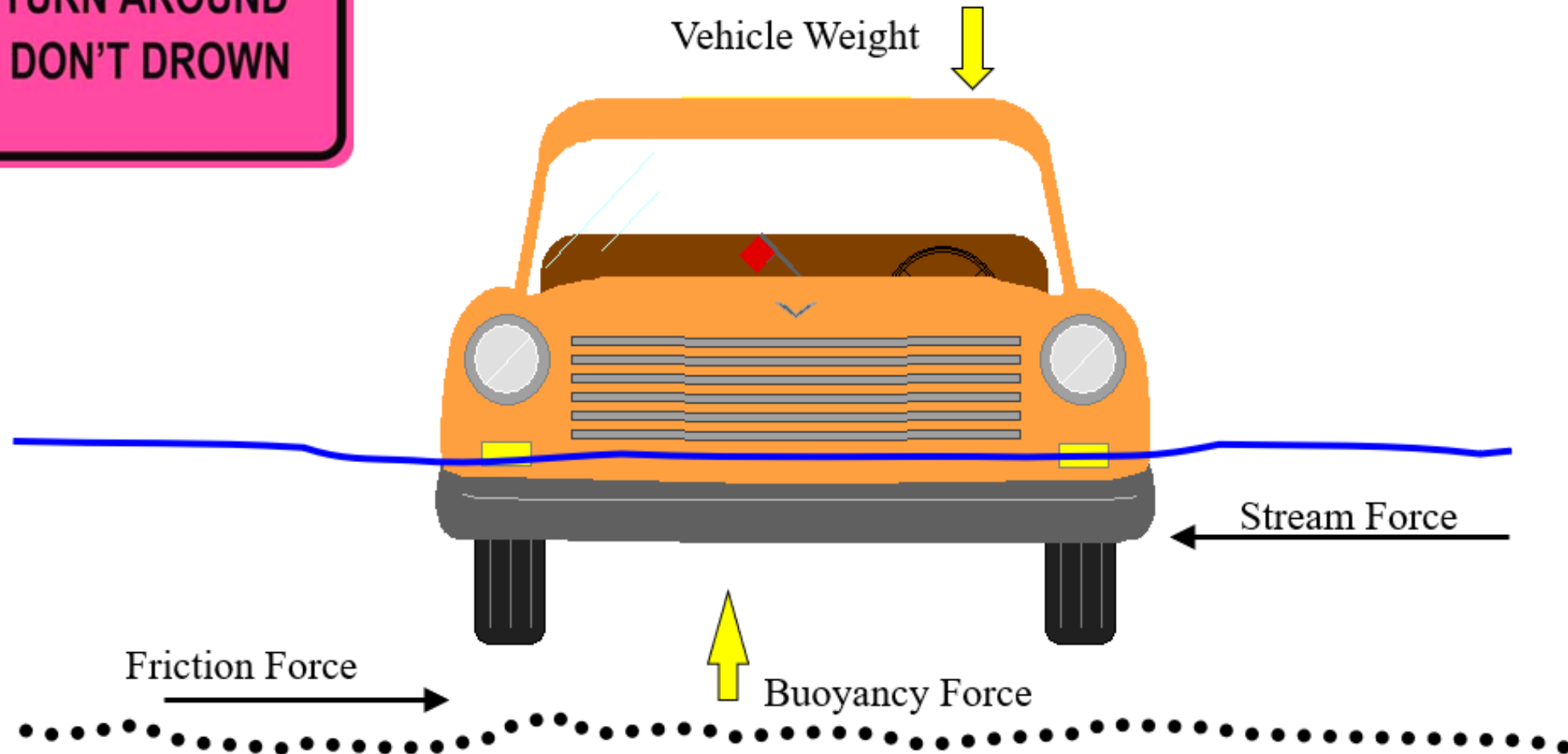
Flooding Forces on Vehicles



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**FLOODING AHEAD
TURN AROUND
DON'T DROWN**

The car will float downstream when:
 $\text{Stream Force} > \text{Friction Force}$



Landfalling Hurricanes Spawn Tornadoes



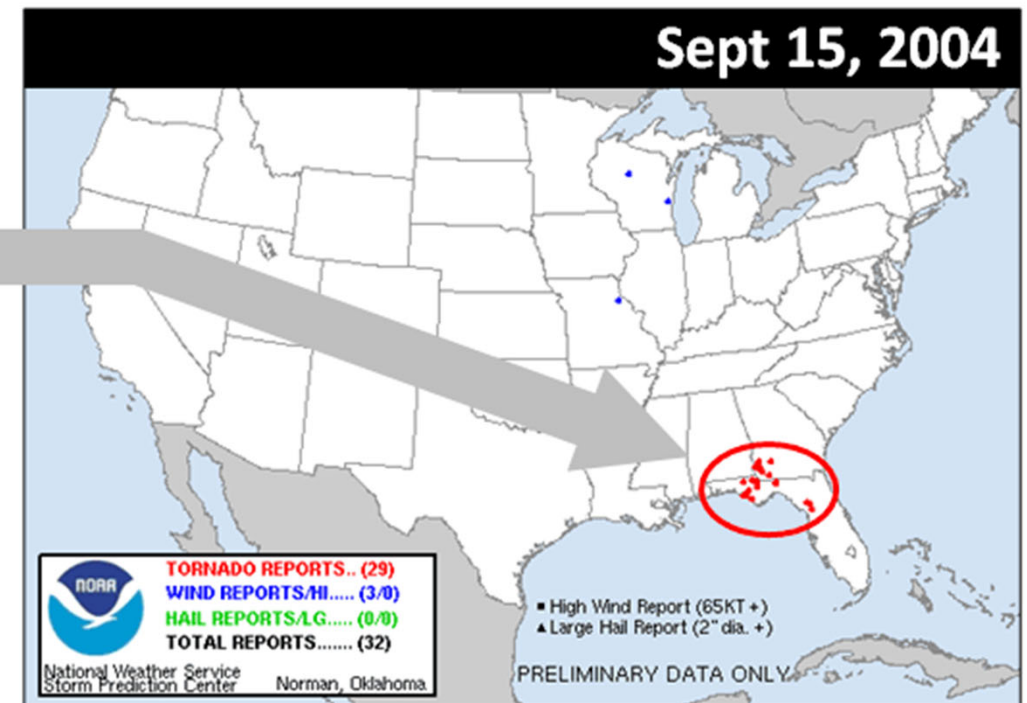
Landfalling Hurricanes:

- 70% produce at least one tornado.
- 40% produce more than three tornadoes.

Tornado “outbreak”

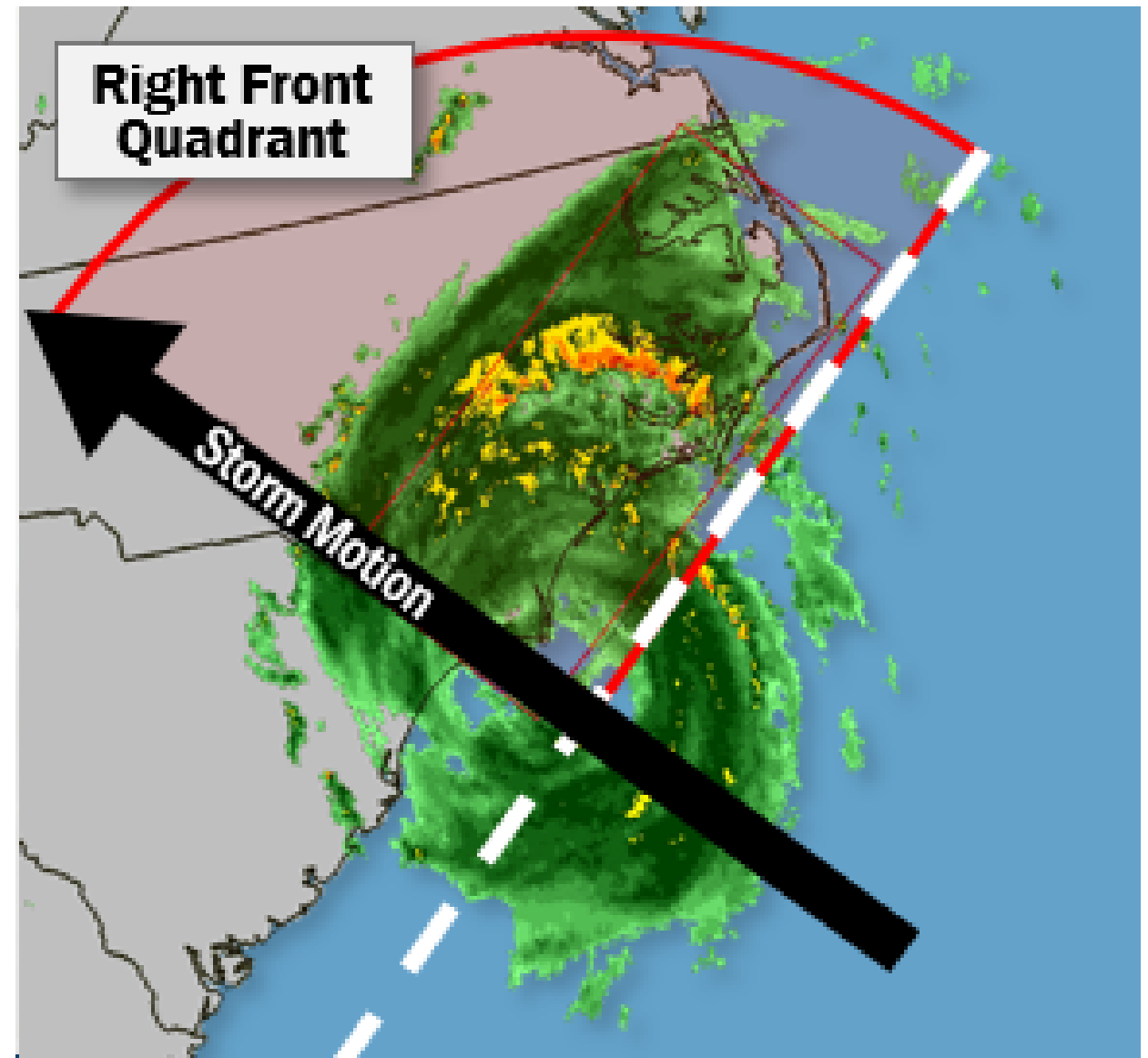
Hurricane Ivan (2004)

– 117 Tornadoes



Tornado Development

- Right-front quadrant.
- Friction over land creates low-level wind conditions favorable for the development of tornadoes.
- Tornadoes can be far from the center.



Tornado Meteorology



What is happening to make tornadoes develop?

- In the front-right quadrant, wind speed and orientation create **vertical shear profiles** resembling Great Plains supercells.
 - Generally, the **bigger and stronger** the wind fields are with a tropical cyclone, the **bigger** the area of favorable wind shear for supercells and tornadoes.
- Occasionally a tornado will form in the inner bands, but the majority form *outside* the hurricane-force wind zone.

Questions/Comments?



FEMA

A composite image showing a screenshot of the National Hurricane Center (NHC) website on the left and a photograph of an "EVACUATION ROUTE" sign on the right. The website screenshot includes the NHC logo, navigation tabs (Home, News, Organization, Search), and a "Top News of the Day" section with the following items:

- **NHC Issuing advisories on Hurricane ARTHUR and TD DOUGLAS**
- Inside the Eye: Storm Surge—Plain and Simple (Part 2)
- Five-day Graphical Tropical Weather Outlook introduced (PDF) - video overview
- Update on NHC Products and Services for 2014 (PDF)

Below the news is a map titled "Atlantic Tropical Cyclone Activity" showing the Atlantic Ocean and parts of North and South America. A red dot on the map is labeled "ARTHUR". The map is dated "3:00 am EDT Fri Jul 4 2014". The "EVACUATION ROUTE" sign is a blue circular sign with a white hurricane symbol and the text "EVACUATION ROUTE" in white. Below it is a blue rectangular sign with a white arrow pointing to the right.