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 Cyclones Defined

Characteristics of Tropical Cyclones

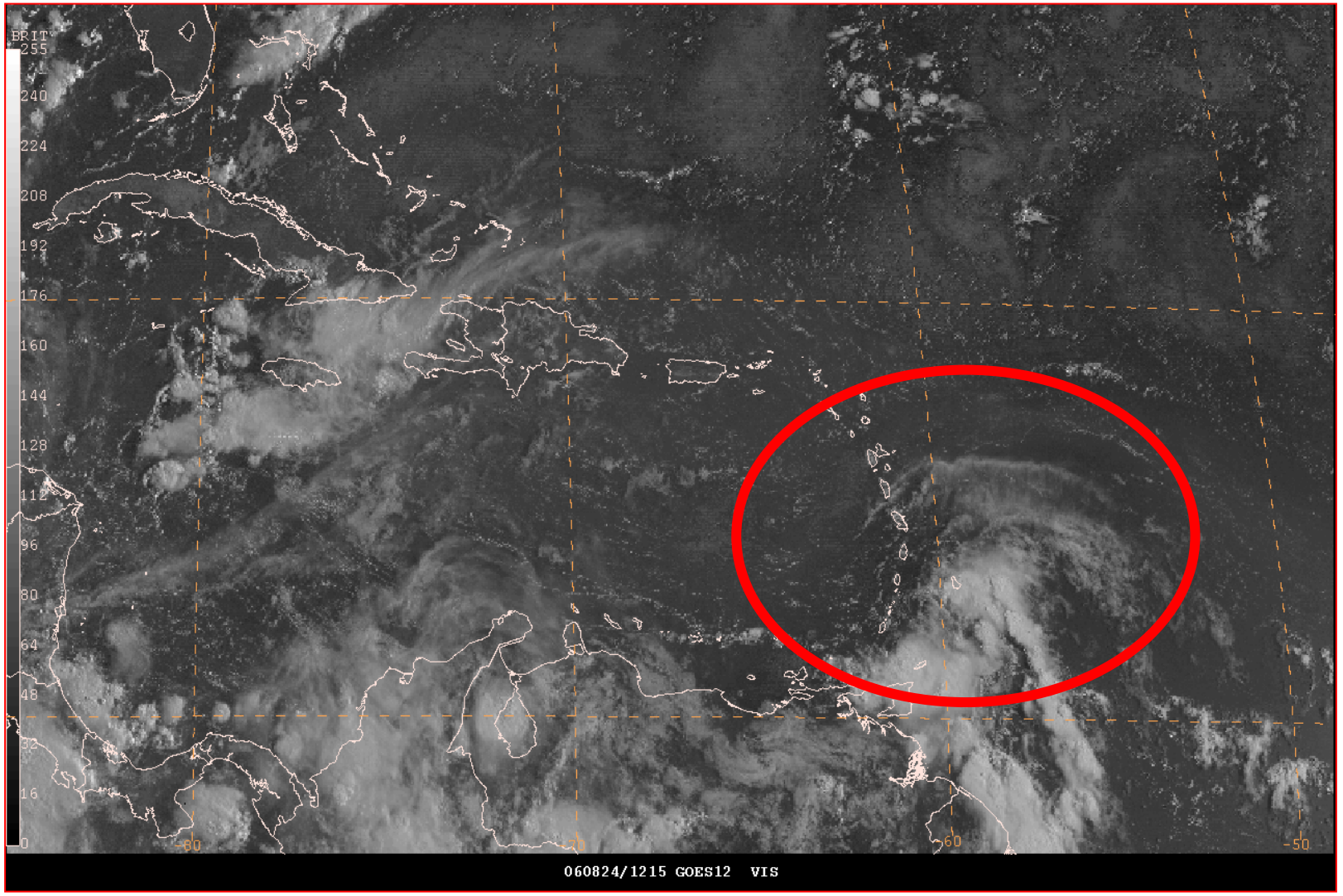
- Hurricane, Tropical Storm, Tropical Depression
- Large, long-lived, low-pressure system (can be hundreds of miles wide, lasting for days)
- Form over sub/tropical oceans
- No fronts attached
- Produce organized thunderstorm activity
- Have a closed surface wind circulation around a well-defined center

Tropical Cyclone Classification

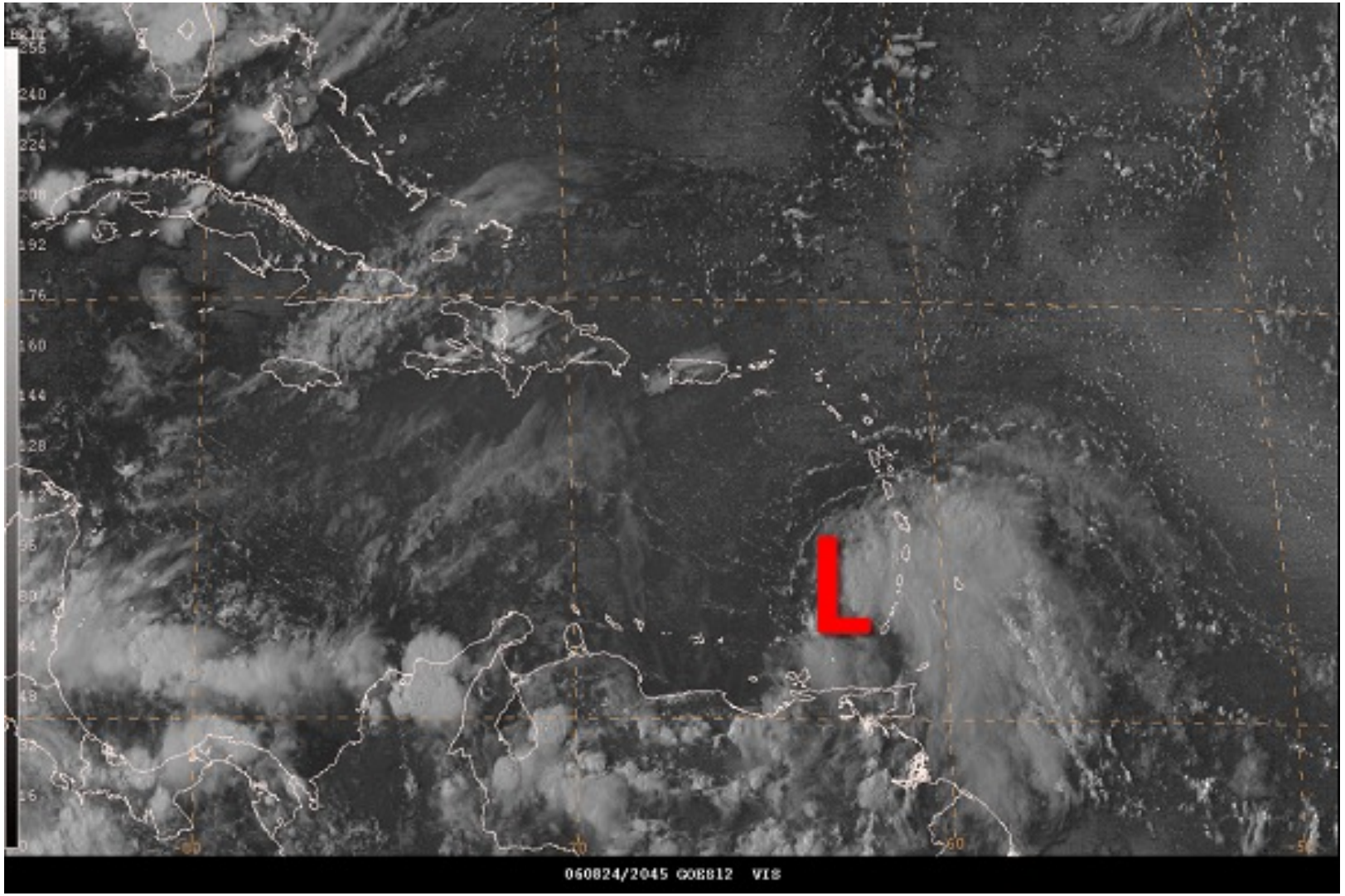
By Maximum Wind Speed:

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

Surface Circulation? Organized?

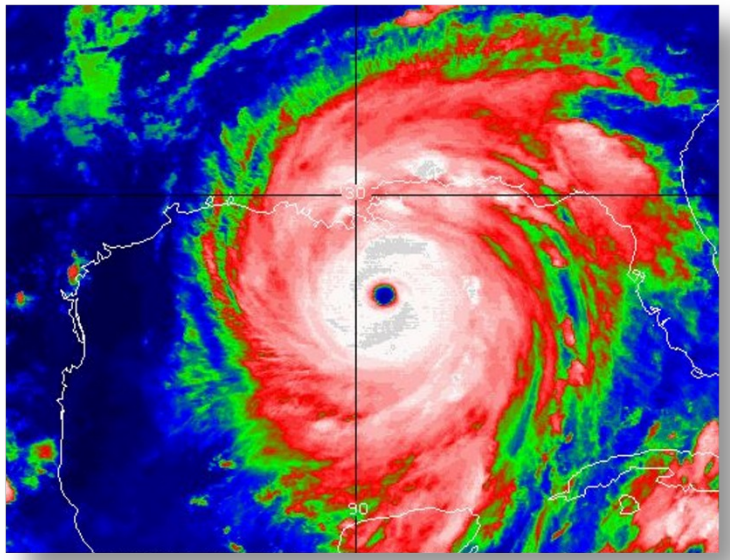


Ernesto 2006

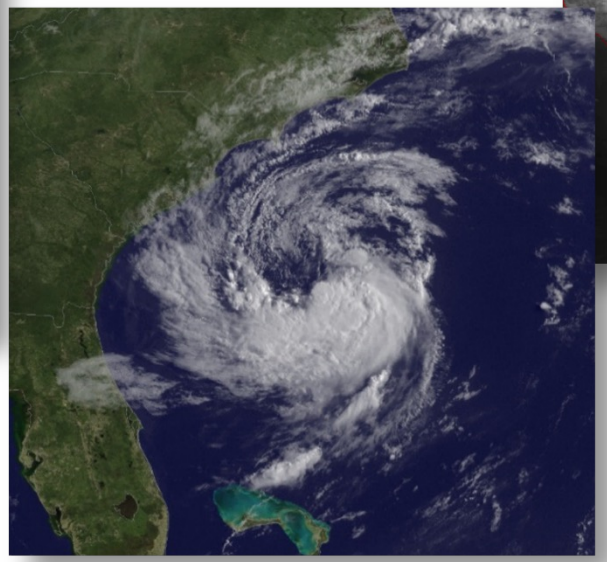


Advisory 1 issued based on aircraft data

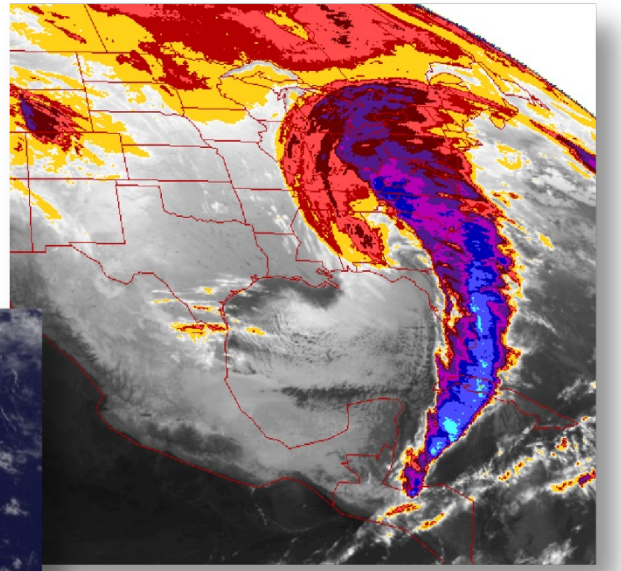
Tropical, Subtropical, & Extratropical



Hurricane Katrina
2005



Subtropical Storm Ana
2015

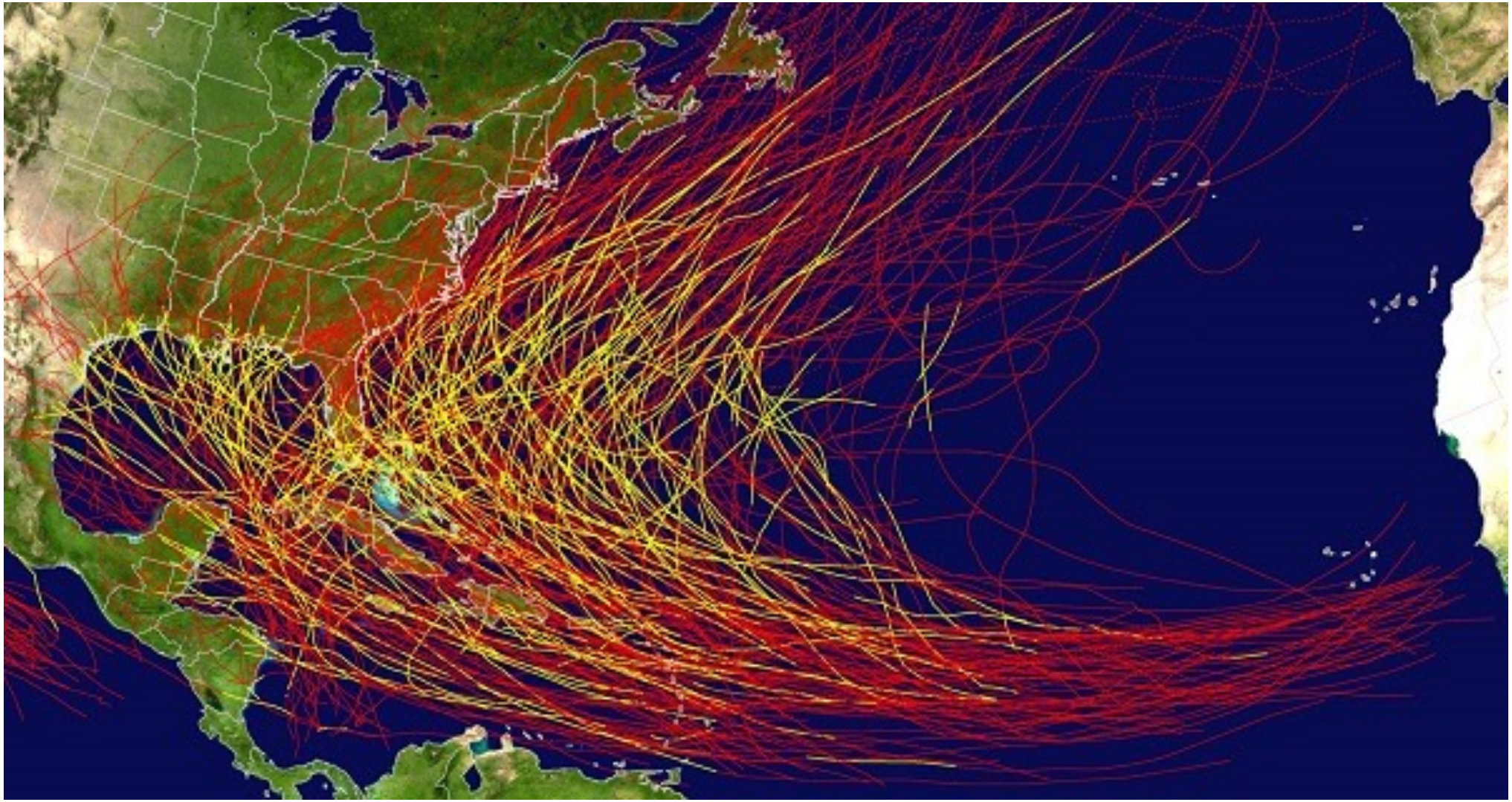


March Superstorm
1993

Tropical Cyclone History

Data since 1949 in Pacific, 1851 in Atlantic

Major Hurricane History



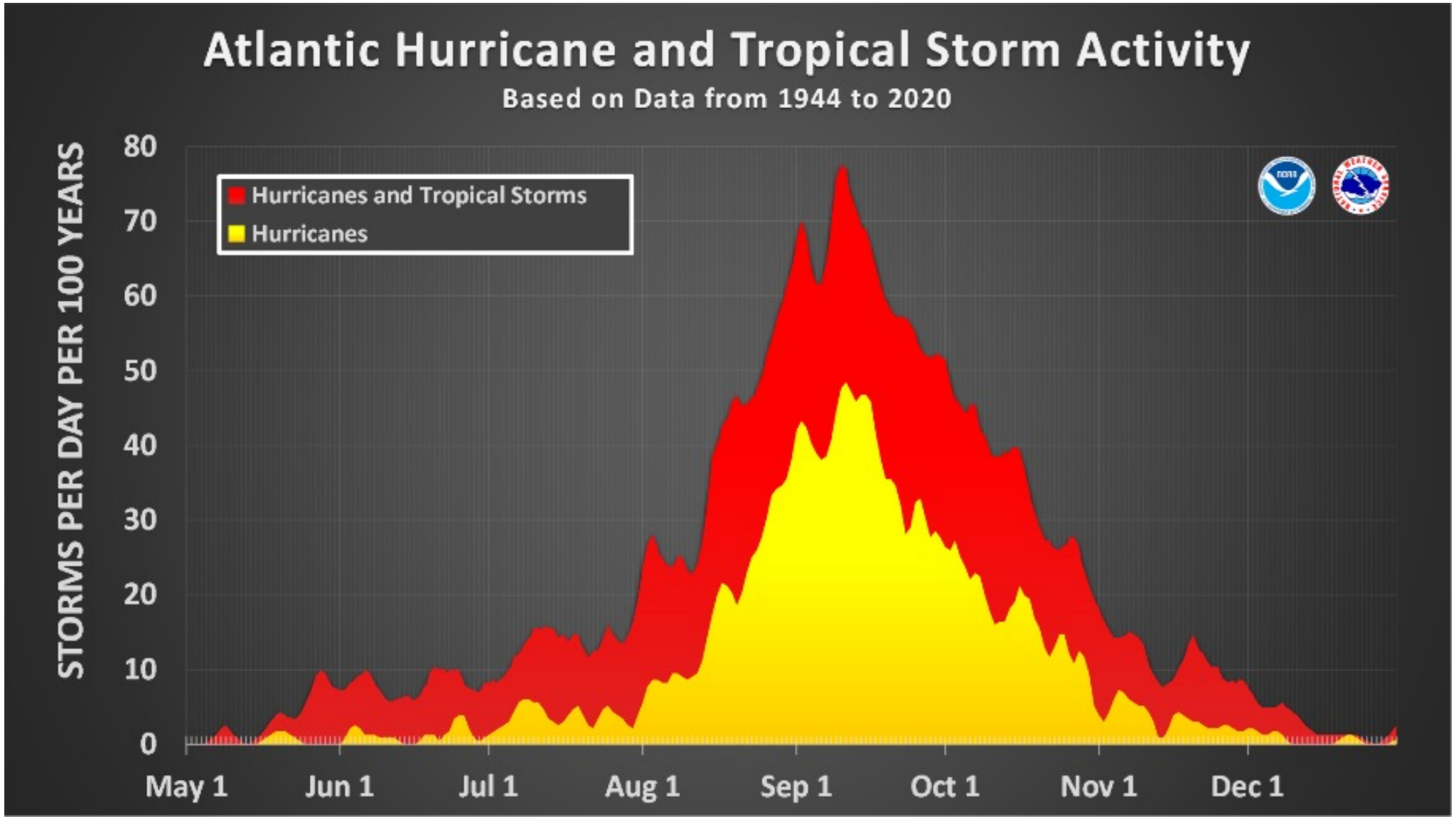
Data since 1851

Climatology – Knowledge Check

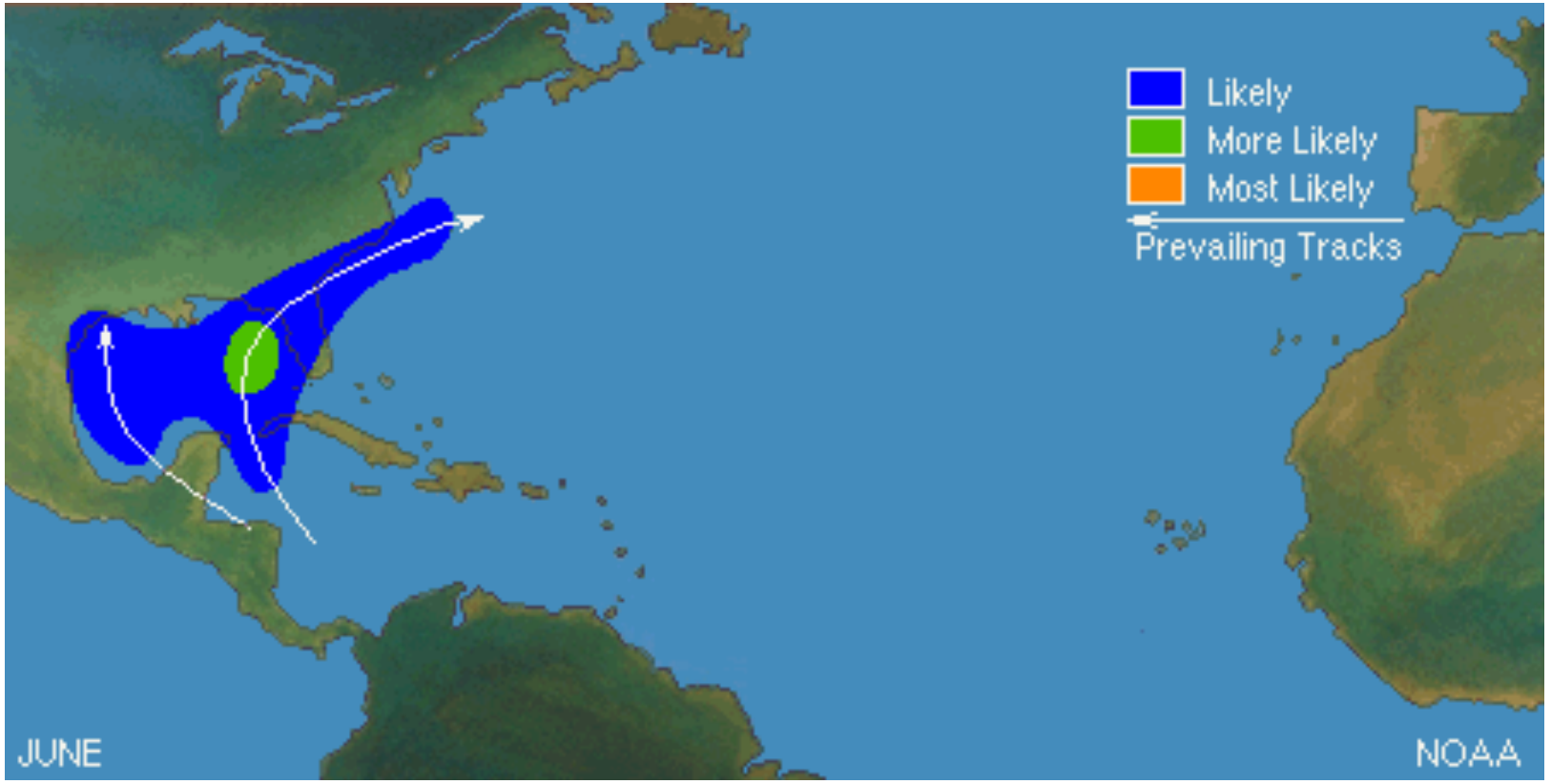
What month has the most hurricane activity in the Atlantic?

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

Annual Atlantic Storm Activity

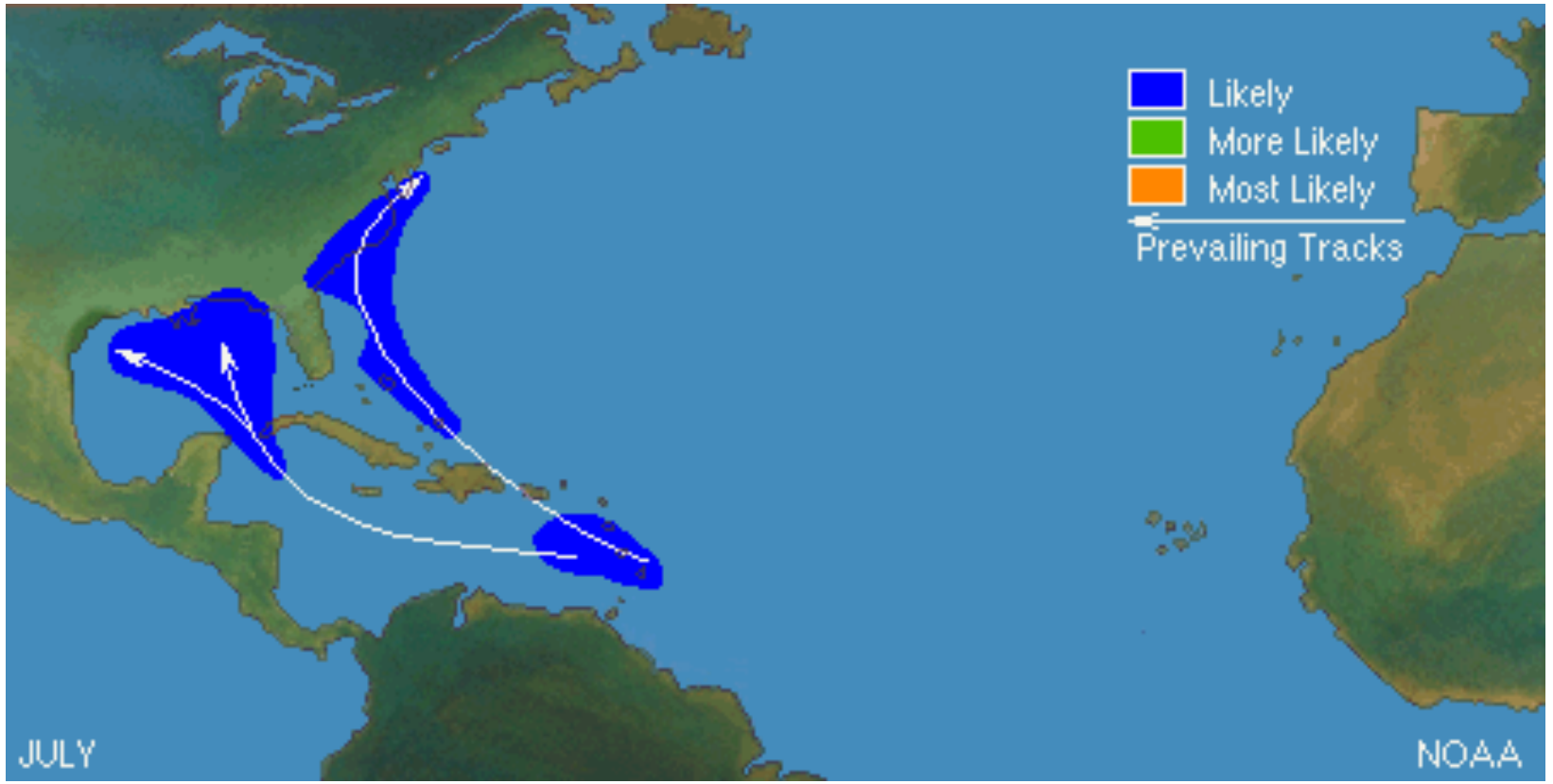


June Formation Areas



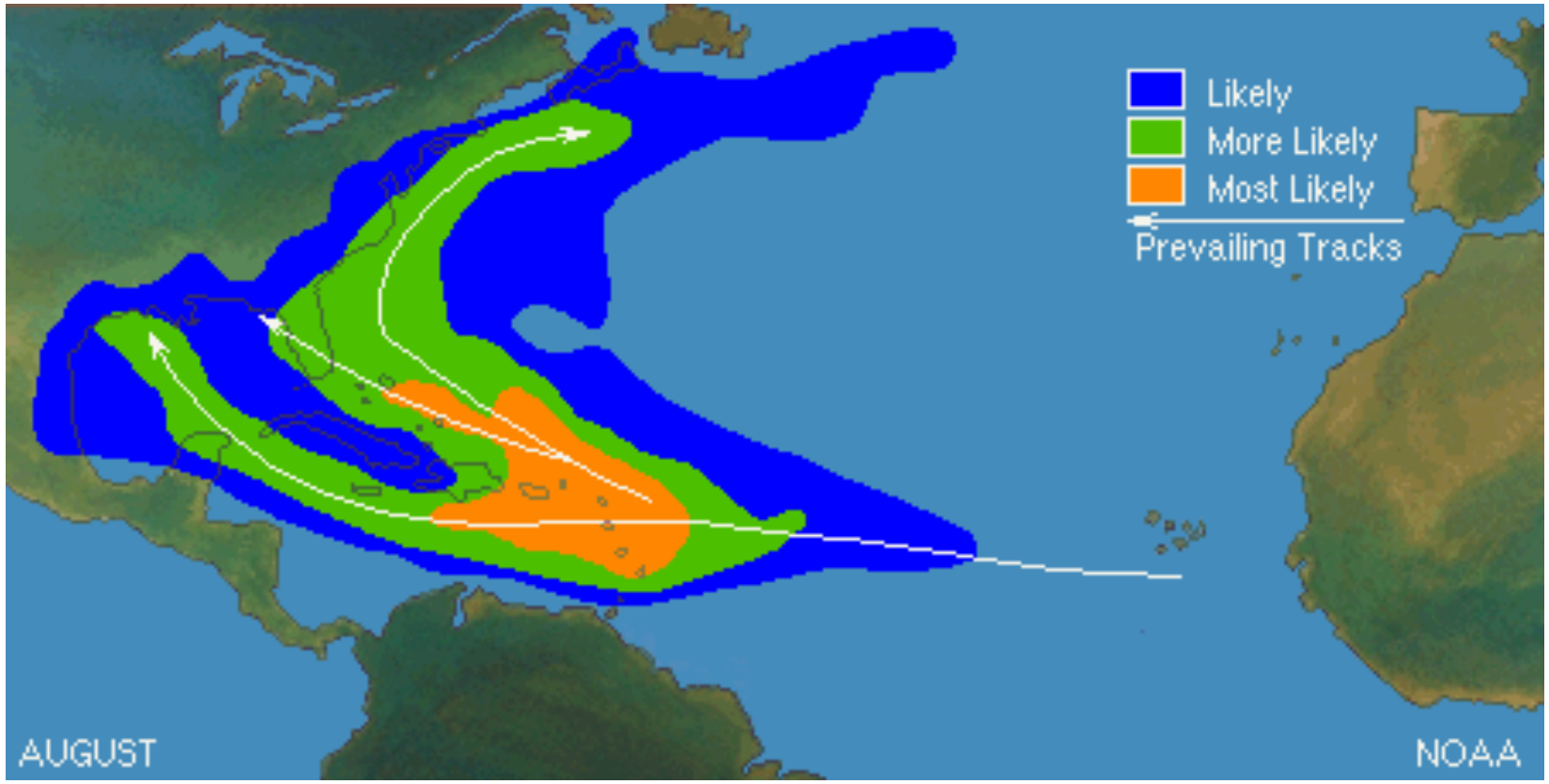
- On average about one tropical storm (TS) every year
- Most June tropical storms form in the NW Caribbean Sea or Gulf of Mexico

July Formation Areas



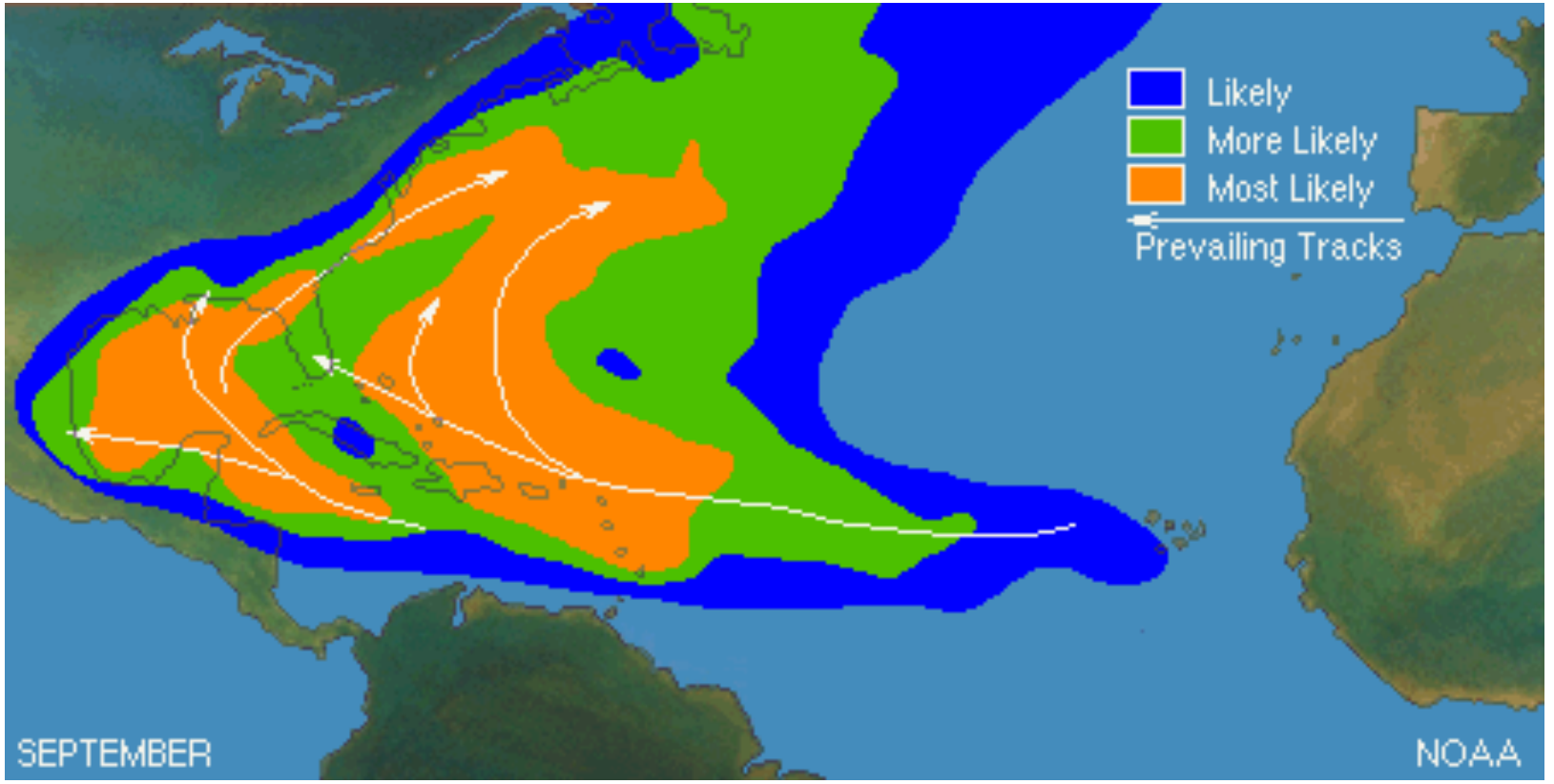
- On average 1-2 named tropical storms every year
- July occurrence areas spread east and cover the western Atlantic, Caribbean, and Gulf of Mexico

August Formation Areas



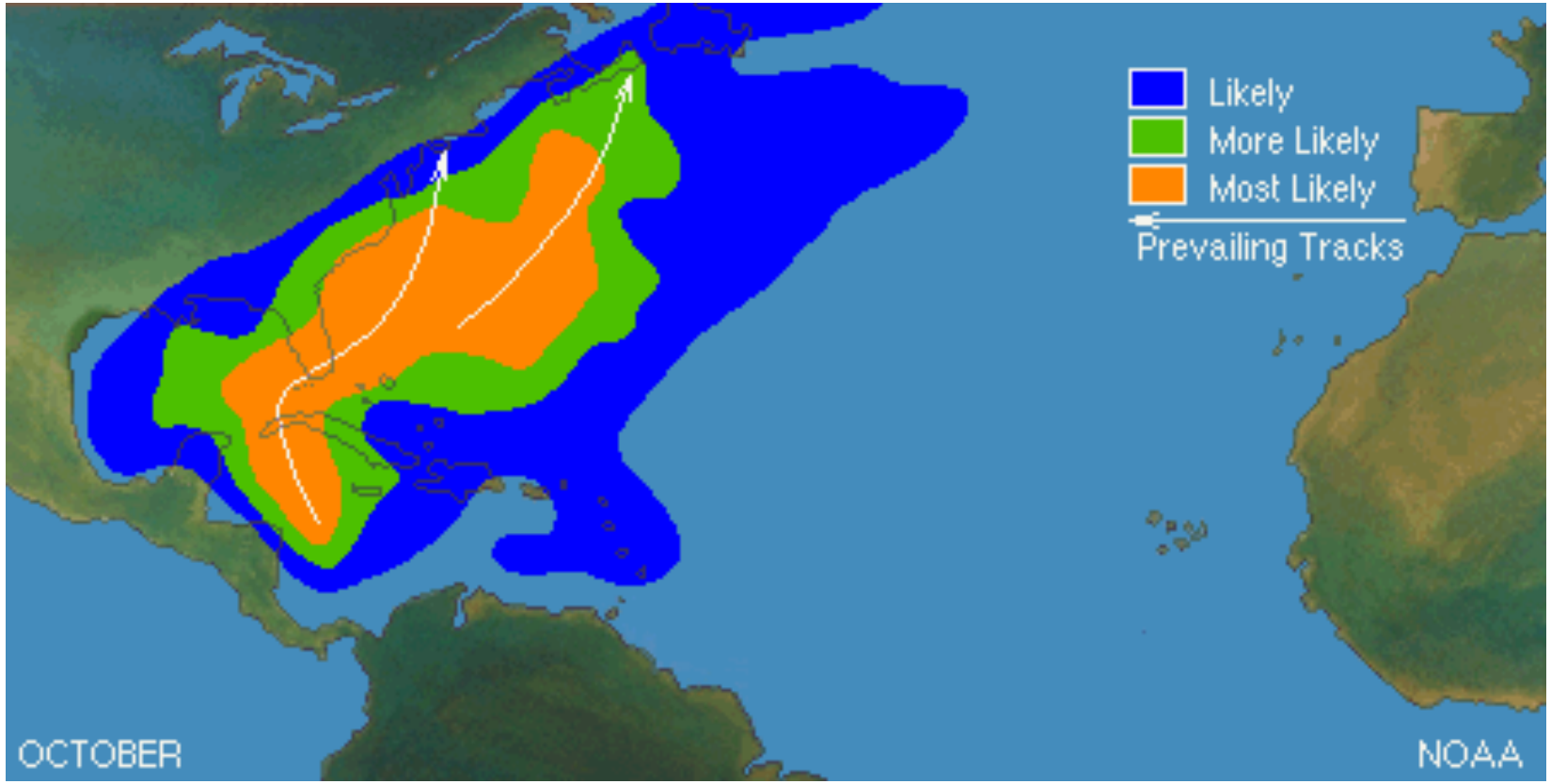
- On average, about 3-4 tropical storms each year
- The Cape Verde season usually begins in August

September Formation Areas



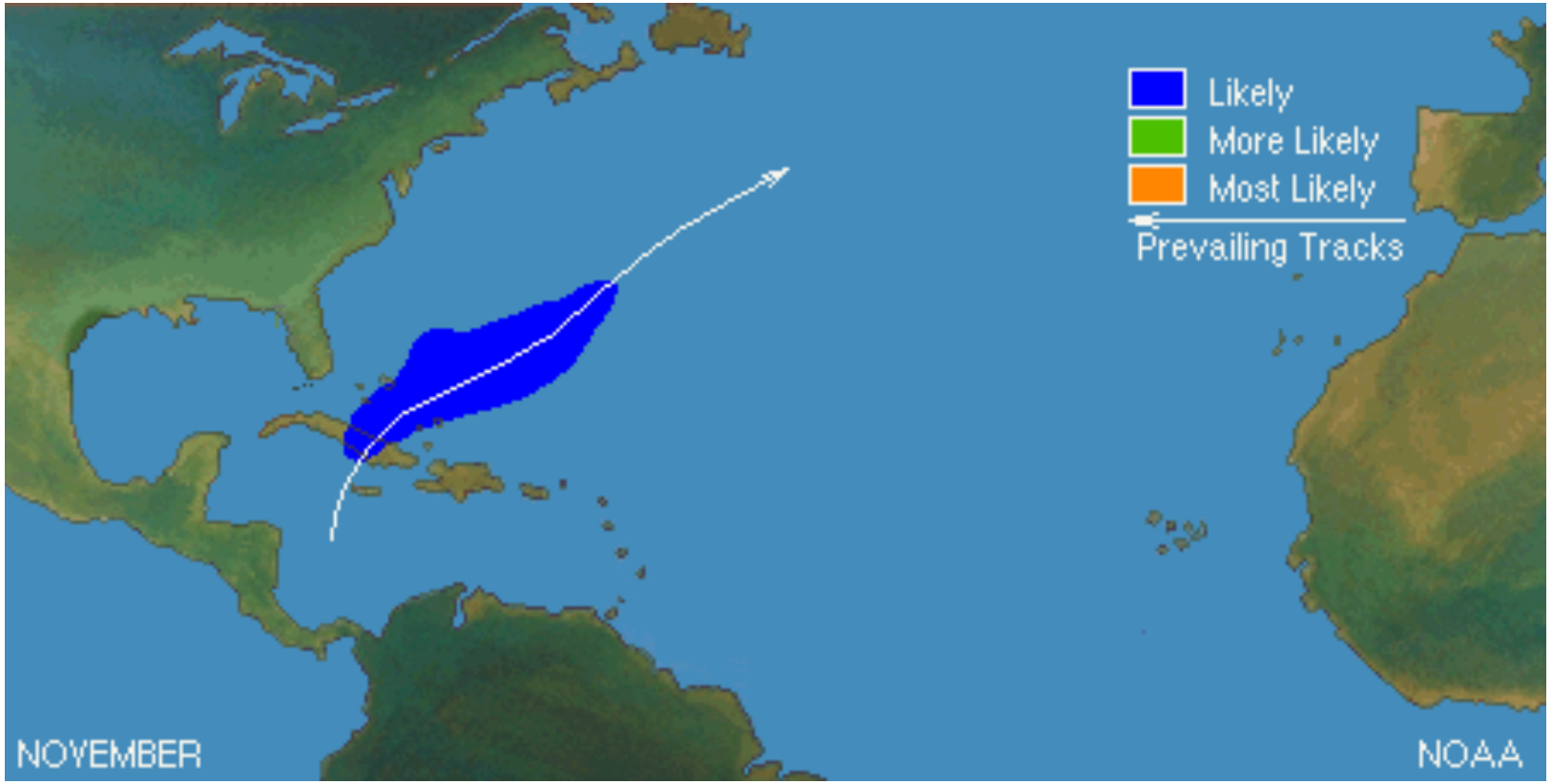
- Climatological peak of the season
- On average, 4-5 tropical storms every year
- Tropical storms can form nearly **anywhere** in the basin
- Long-track Cape Verde storms very possible

October Formation Areas



- On average, 2-3 named storms every year
- Cape Verde season ends and activity shifts to the Gulf of Mexico, Caribbean Sea, and western Atlantic Ocean

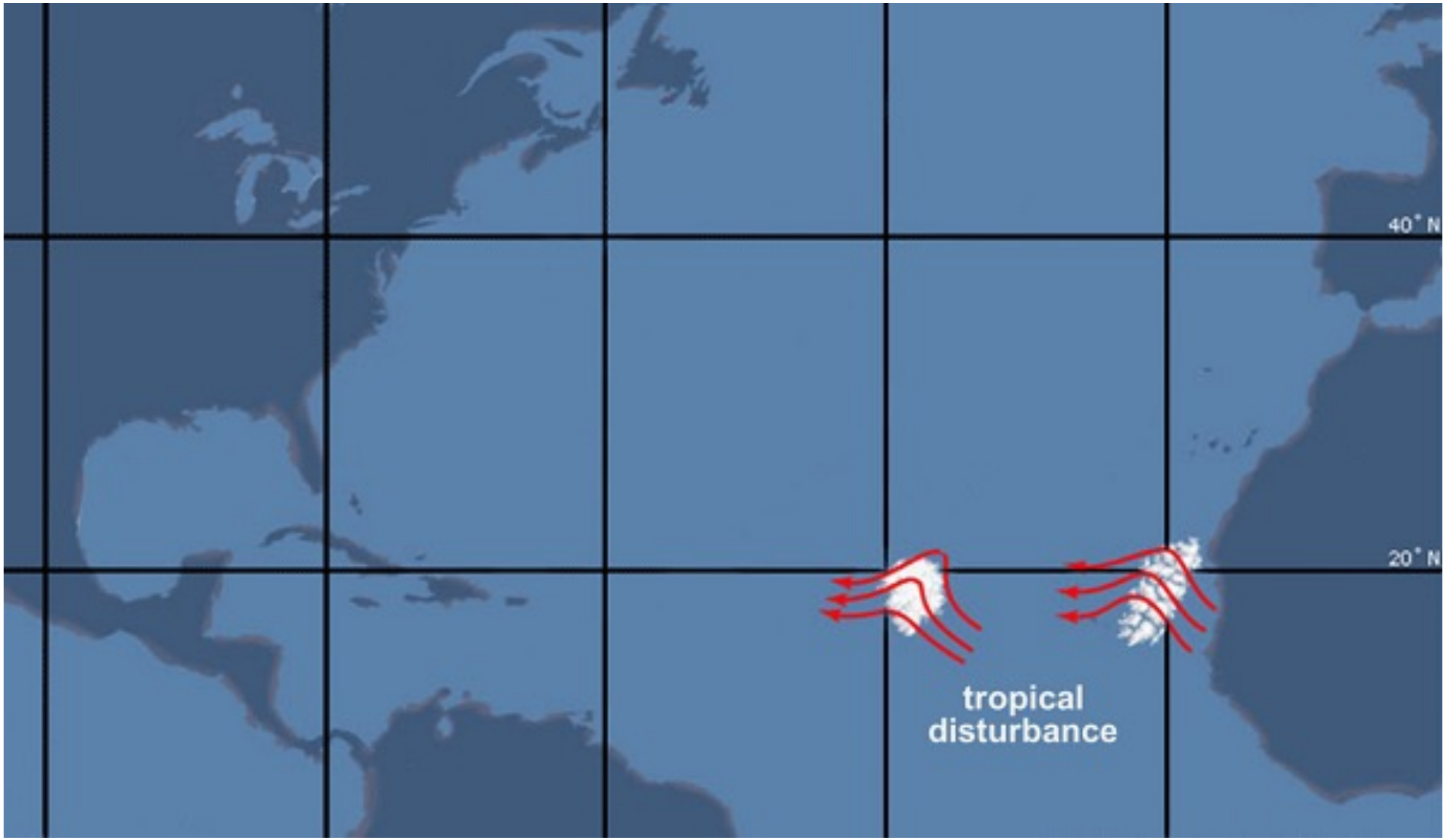
November Formation Areas



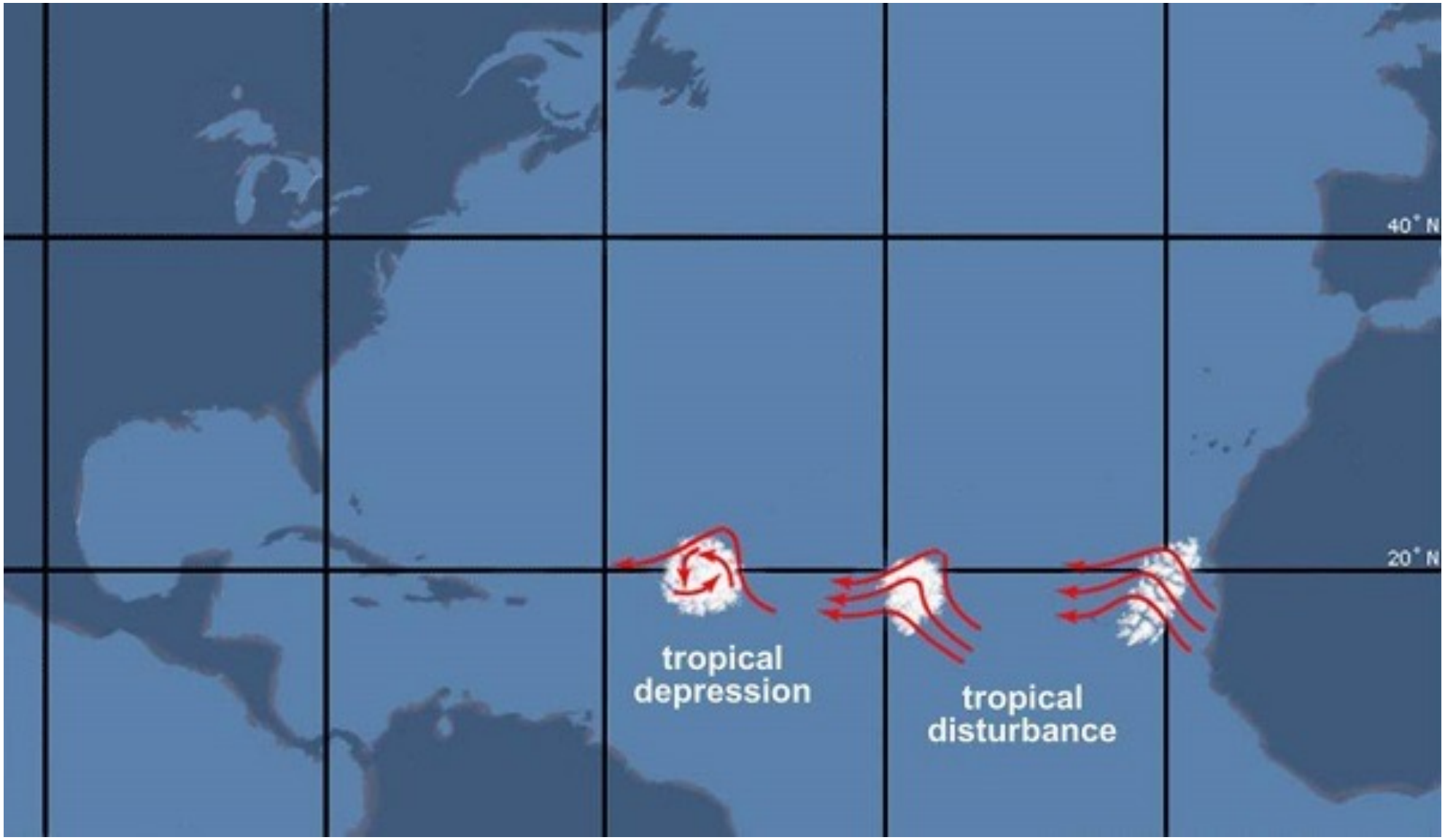
- On average about 1 tropical storm every other year
- Tropical storms typically occur in the western Caribbean Sea or western and central Atlantic Ocean

Hurricane Lifecycle – Cape Verde Hurricanes 1

Hurricane Lifecycle – Cape Verde Hurricanes 2

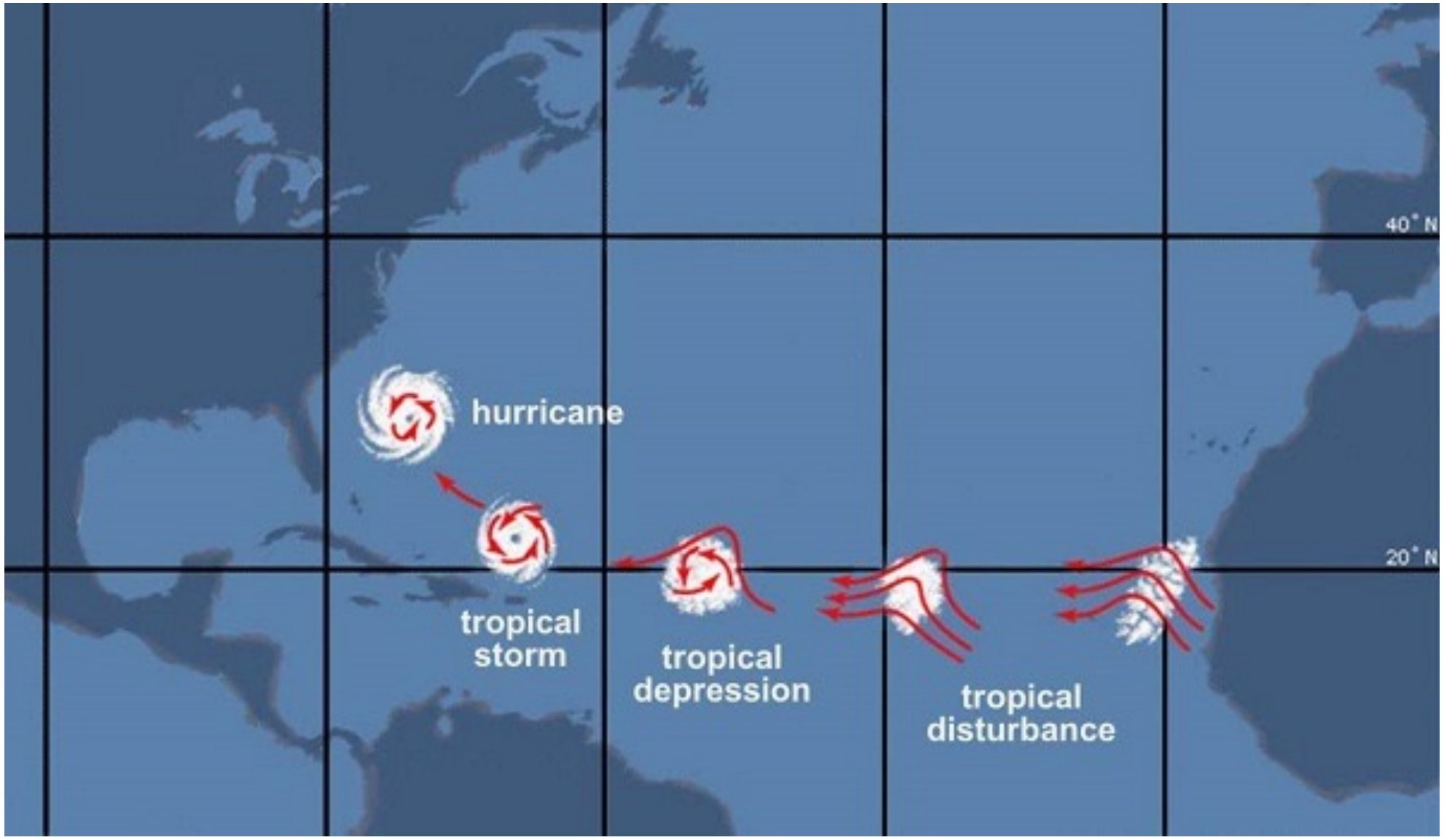


Hurricane Lifecycle – Cape Verde Hurricanes 3



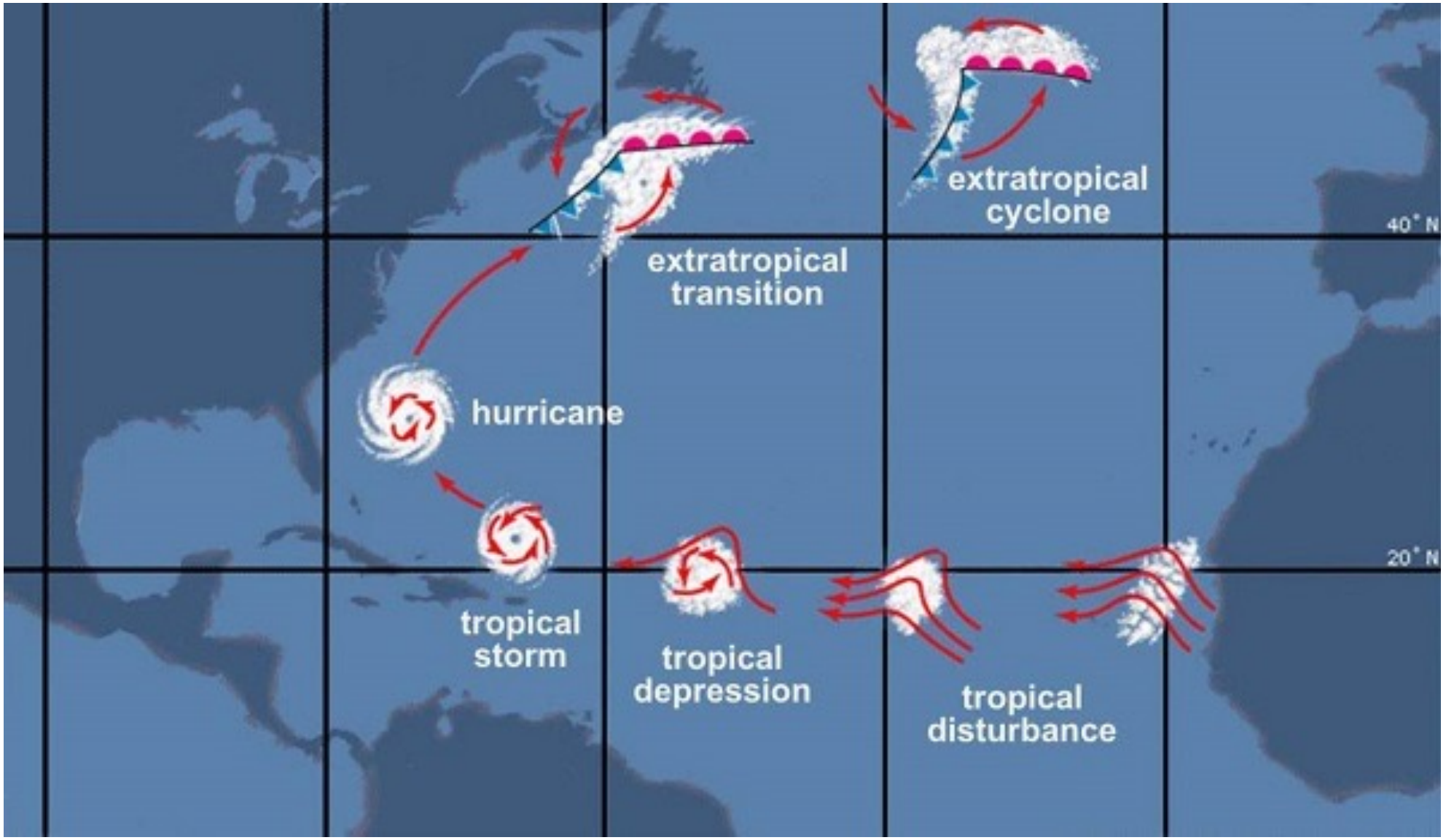
Hurricane Lifecycle – Cape Verde Hurricanes 4

Hurricane Lifecycle – Cape Verde Hurricanes 5

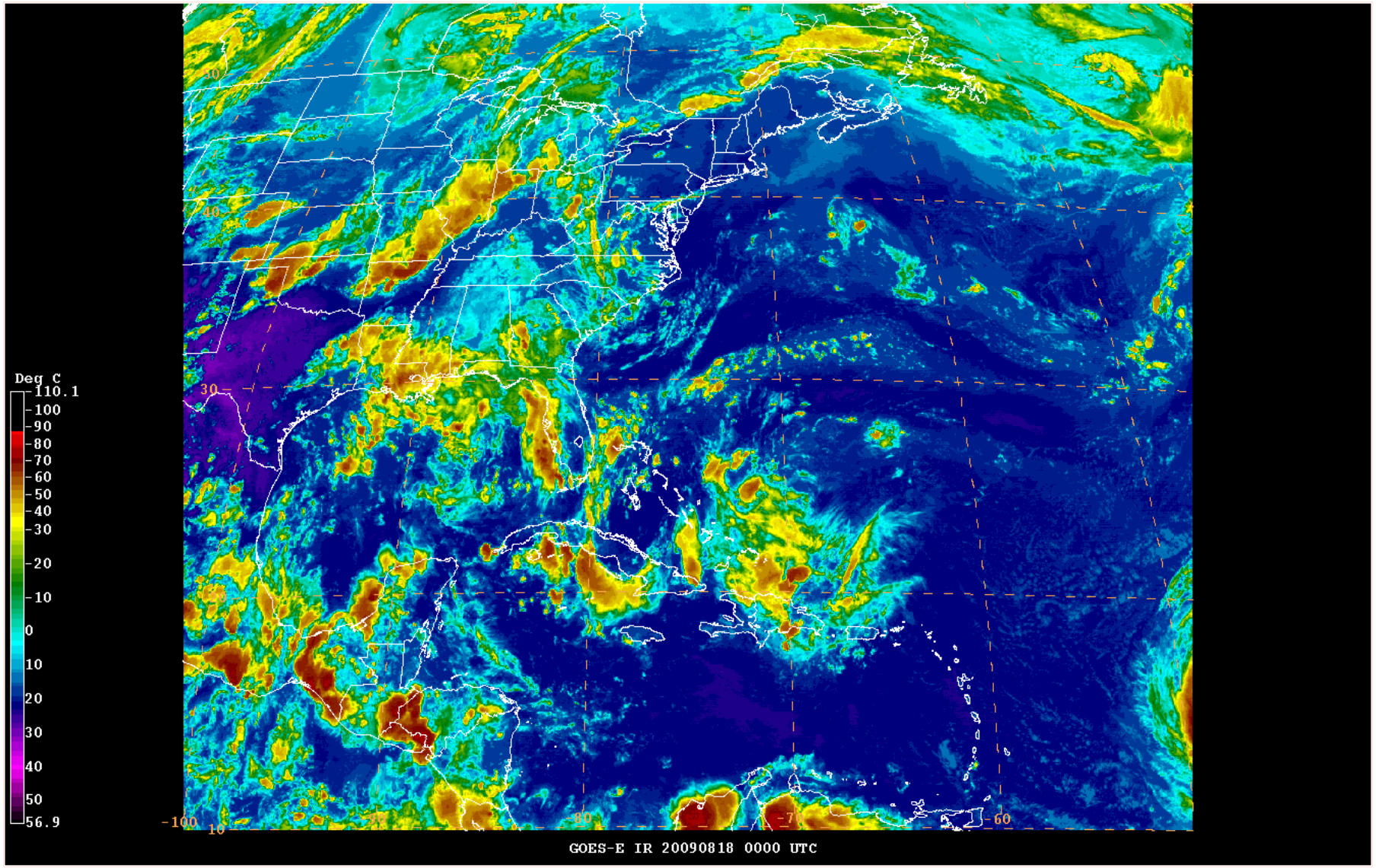


Hurricane Lifecycle – Cape Verde Hurricanes 6

Hurricane Lifecycle – Cape Verde Hurricanes 7



Hurricane Bill (2009)



Hurricane Forecasting – Knowledge Check

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 TS Formation

FEMA

BUILDING BLOCKS	FUEL
1) A pre-existing disturbance (vorticity or spin) 	4) Warm sea-surface temperatures (usually at least 80°F) 
2) Location several degrees north of the equator 	5) Unstable atmosphere (temperature goes down as you go up) 
3) Little change in wind speed and/or direction with height (vertical wind shear) 	6) High atmospheric moisture content (relative humidity) 

Pre-existing Disturbances

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

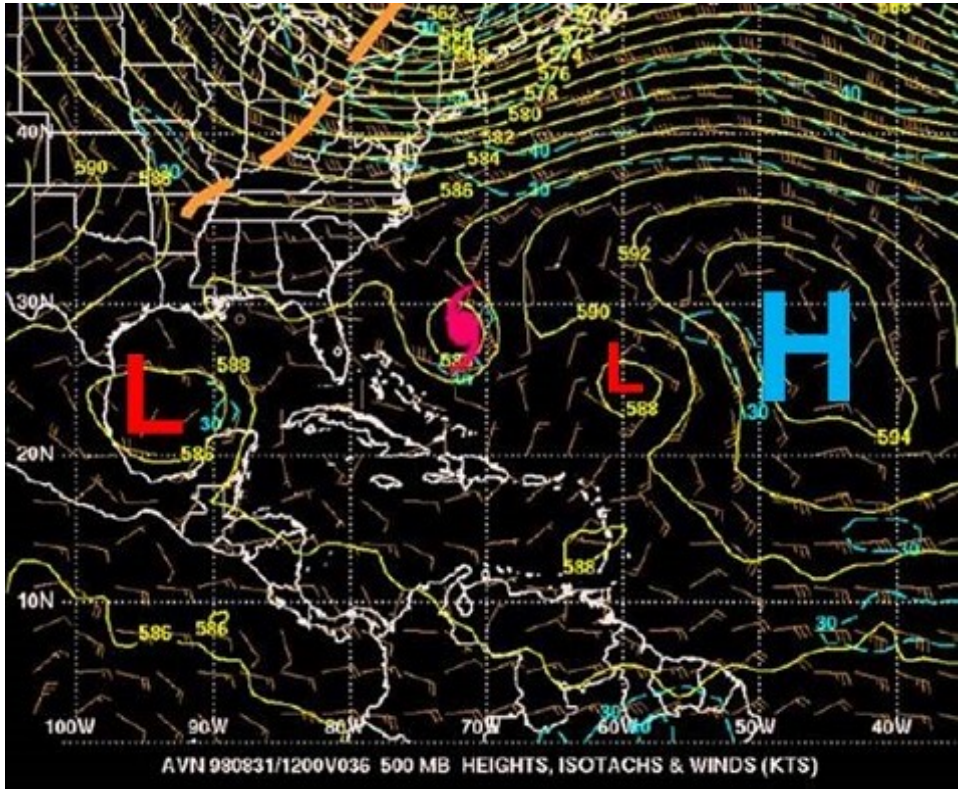
Storm Motion and Track

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

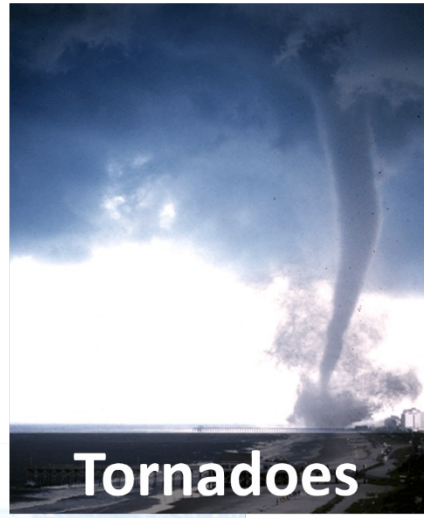


Wind Intensity Factors

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

Hurricane Hazards



Tropical Cyclone Hazards – Knowledge Check

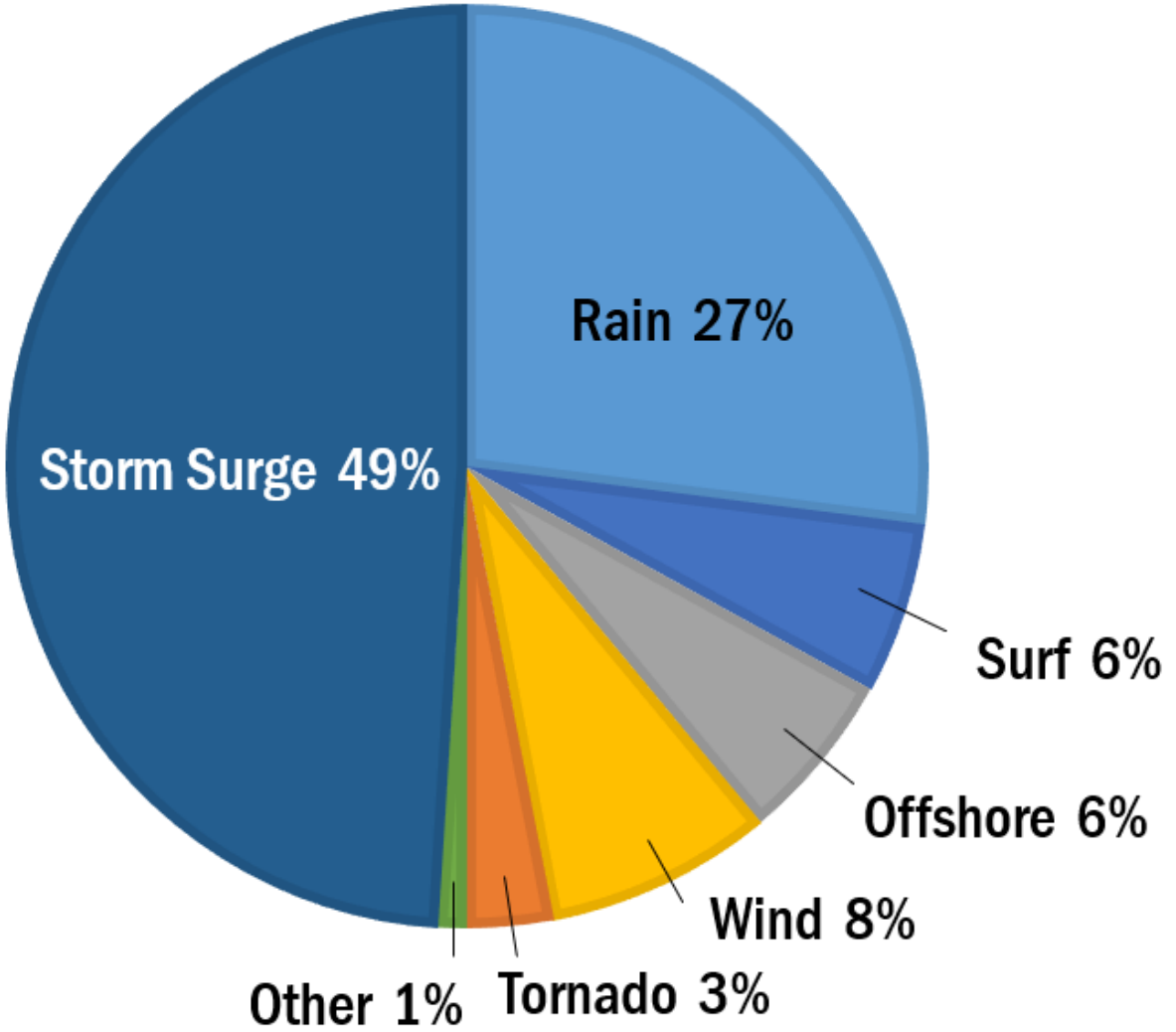
Which hazard has the greatest potential for large loss of life?

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

Atlantic Tropical Cyclone Deaths

U.S. tropical cyclone fatalities

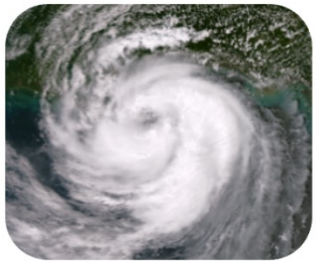
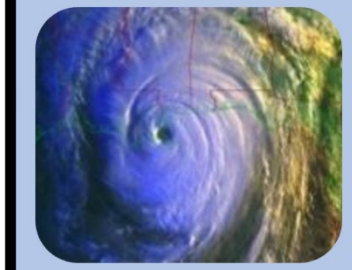
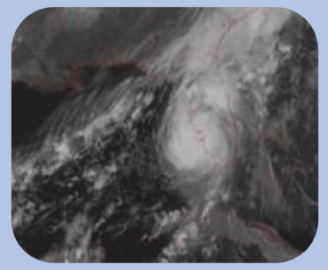
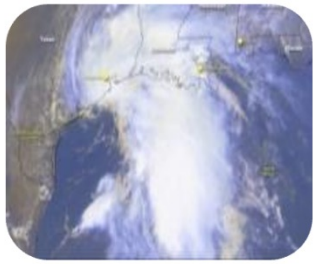
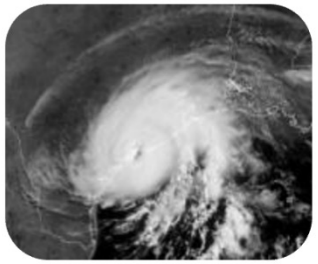
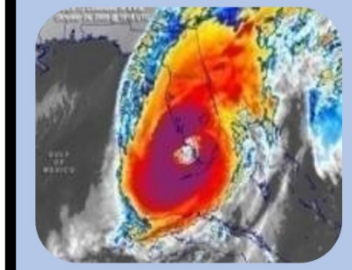
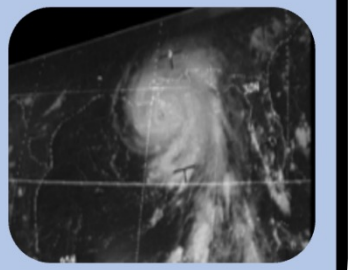
- 1963-2012



Saffir-Simpson Scale

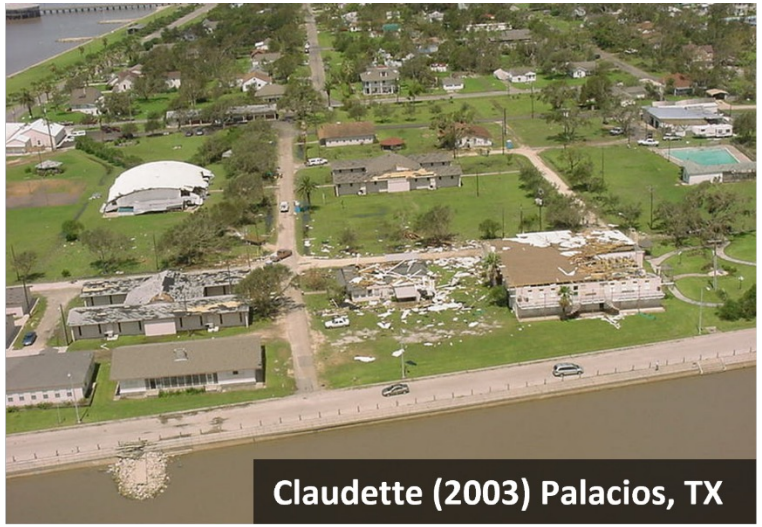
FEMA

MAJOR HURRICANES

TROPICAL STORM 39 – 73 mph (34 – 63 kt)	CATEGORY 1 74 – 95 mph (64 – 82 kt)	CATEGORY 2 96 – 110 mph (83 – 95 kt)	CATEGORY 3 111 – 129 mph (96 – 112 kt)	CATEGORY 4 130 – 156 mph (113 – 136 kt)	CATEGORY 5 > 156 mph (> 136 kt)
 Debby (2012)	 Isaac (2012)	 Ike (2008)	 Katrina (2005)	 Charley (2004)	 Andrew (1992)
 Allison (2001)	 Claudette (2003)	 Isabel (2003)	 Wilma (2005)	 Hugo (1989)	 Camille (1969)

Category 1 (74-95 mph)


Humberto (2007) Southeast TX


Claudette (2003) Palacios, TX


Lili (2002) Louisiana

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)


Ike (2008) Houston, TX


Juan (2003) Halifax, NS


Wilma (2005) SE Florida

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)


Charley (2004) Punta Gorda, FL


Maria (2017) Puerto Rico


Laura (2020) Lake Charles, LA

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)


Michael (2018) Florida – Getty Images


Felix (2007) Nicaragua


Andrew (1992) South Dade, FL

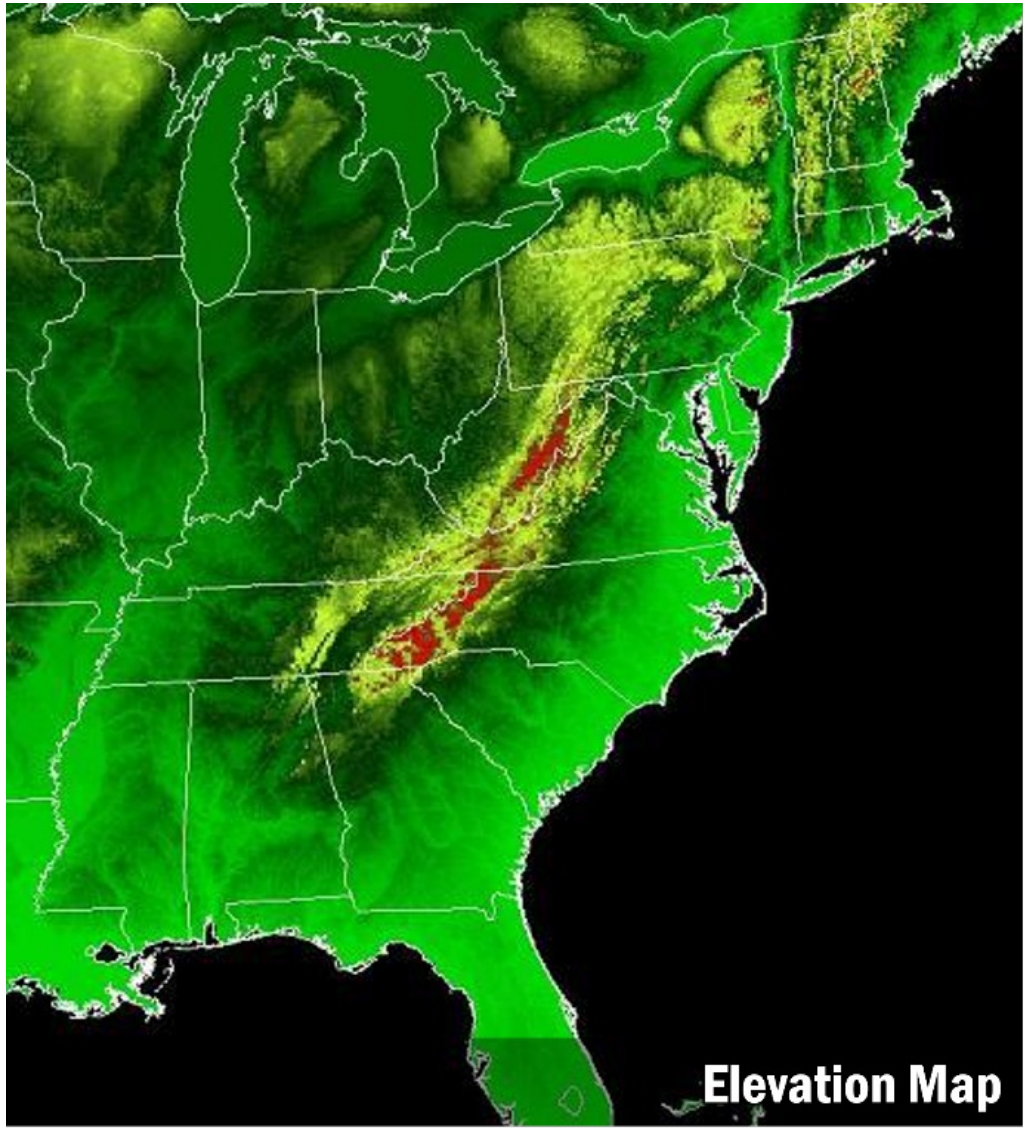
Catastrophic damage

- 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.

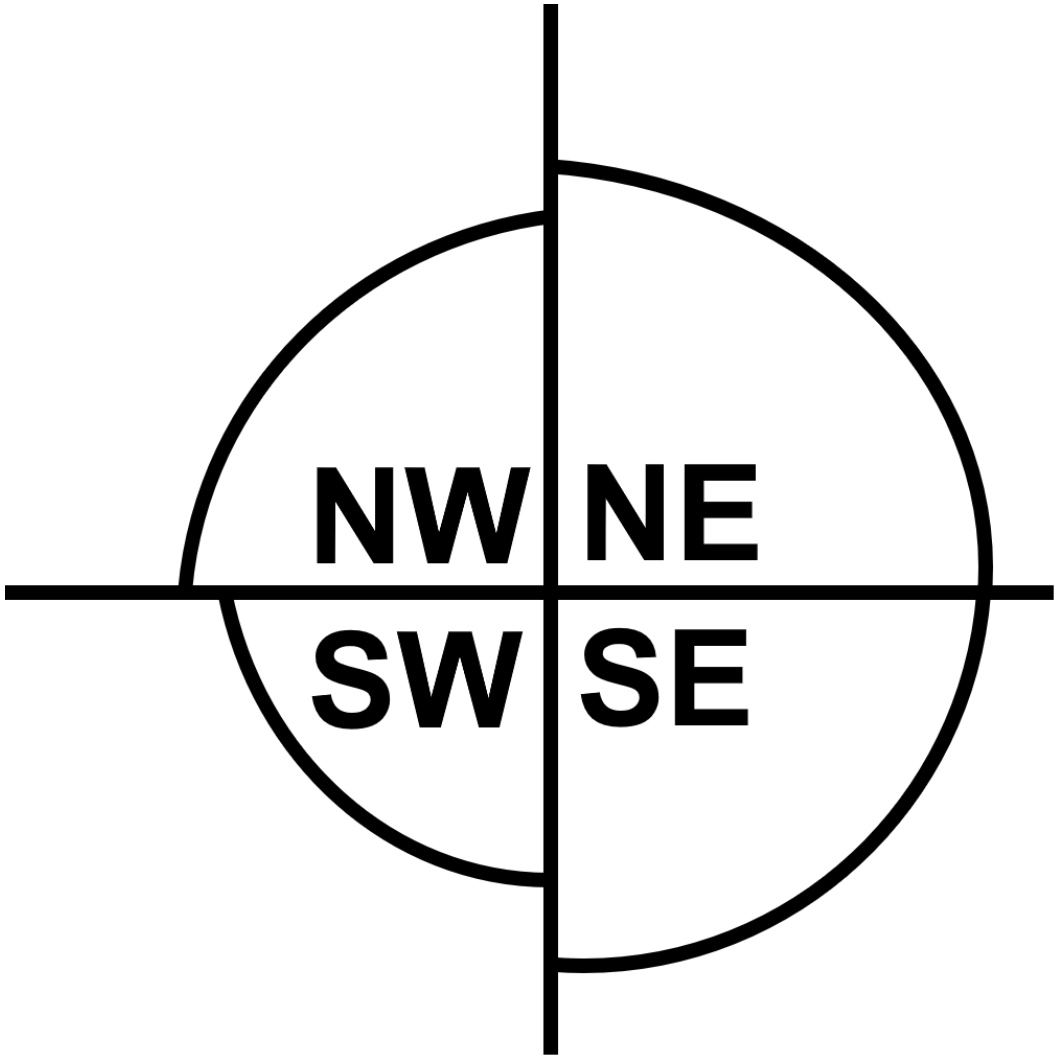
How Are Winds Altered by High Terrain?

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 60mph -> Gusts to 80mph
- Complex terrain/eyewall = x1.65
  - Sustained 60mph -> Gusts to 100mph



Wind Distribution and Storm Quadrants



Storm Surge

Hurricane Sandy (2012)

73 deaths
$75 billion damage (2020 USD)

Hurricane Katrina (2005)

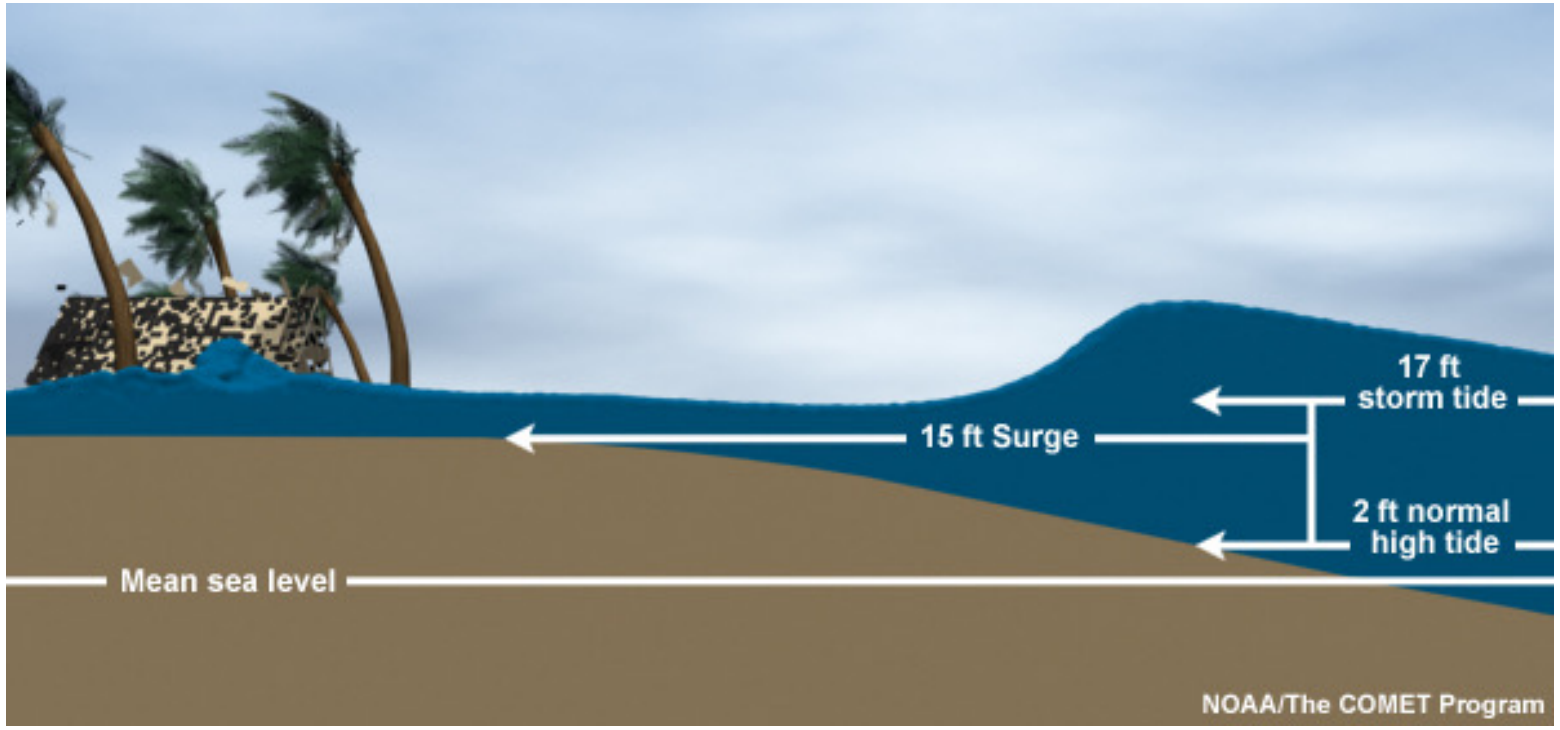
1200 deaths
$170 billion damage (2020 USD)

Storm Surge vs. Storm Tide vs. Inundation

STORM SURGE – An abnormal rise of water generated by a storm, over and above the predicted astronomical tide.

STORM TIDE – Water level due to the combination of storm surge and the astronomical tide.

INUNDATION – The flooding of normally dry land, resulting from storm tide and possibly other factors.



Factors Affecting Storm Surge

Storm Surge Factors:

Intensity	Stronger storm = More storm surge
Size (Radius of Maximum Winds)	Larger storm = More storm surge
Forward Speed	Slower storm = Storm surge farther inland
Angle of Approach	Alters focus of storm surge
Width and Slope of Shelf (Bathymetry)	Gradual sloping shelf = More storm surge

Waveland, Mississippi

Storm Surge: Gulf Coast

FEMA

Hurricane Zeta (2020)
Biloxi, Mississippi

Hurricane Laura (2020)
Cameron, Louisiana

Hurricane Michael (2018)
Mexico Beach, Florida

Hurricane Hanna (2020)
Corpus Christi, Texas

Storm Surge: Southeast

Storm Surge: Mid-Atlantic

Storm Surge: New England

Inland Flooding


Times Herald

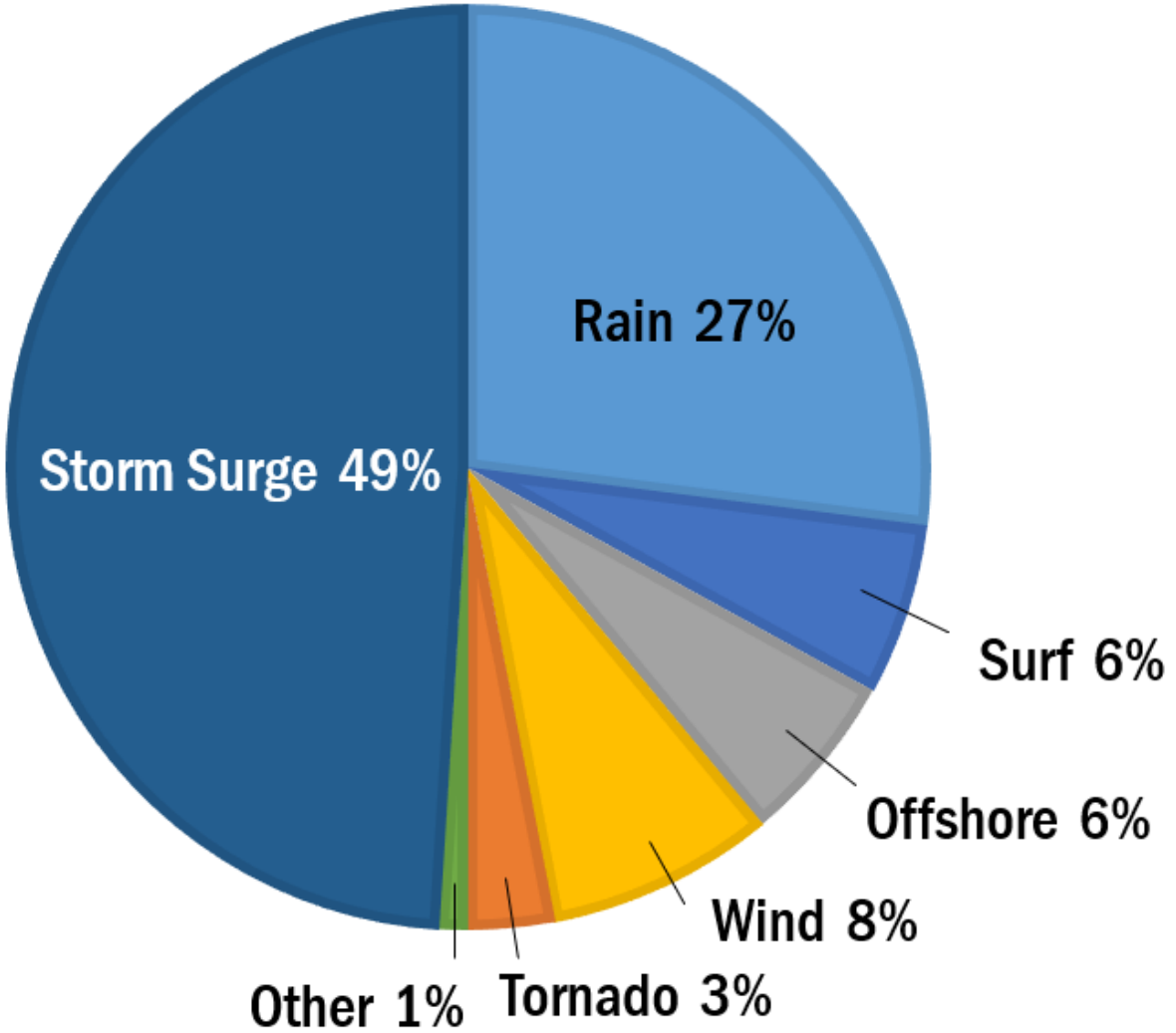

Reuters


Mansfield Heliflight


US Army Corps of Engineers

Atlantic Tropical Cyclone Deaths – Knowledge Check 2

What percentage of fatalities were caused by rainfall-induced flooding?



U.S. tropical cyclone fatalities

- 1963-2012

Hurricane Harvey (2017) Flooding

Hurricane Irene (2011) Flooding


Photo courtesy of L. Gange, Mansfield Helifight


Prattsville, NY Damage (Jimmy Vielkind/Times Union)

Hurricane Irene (2011) Flooding 2

Types of Flooding

Flash Flooding:

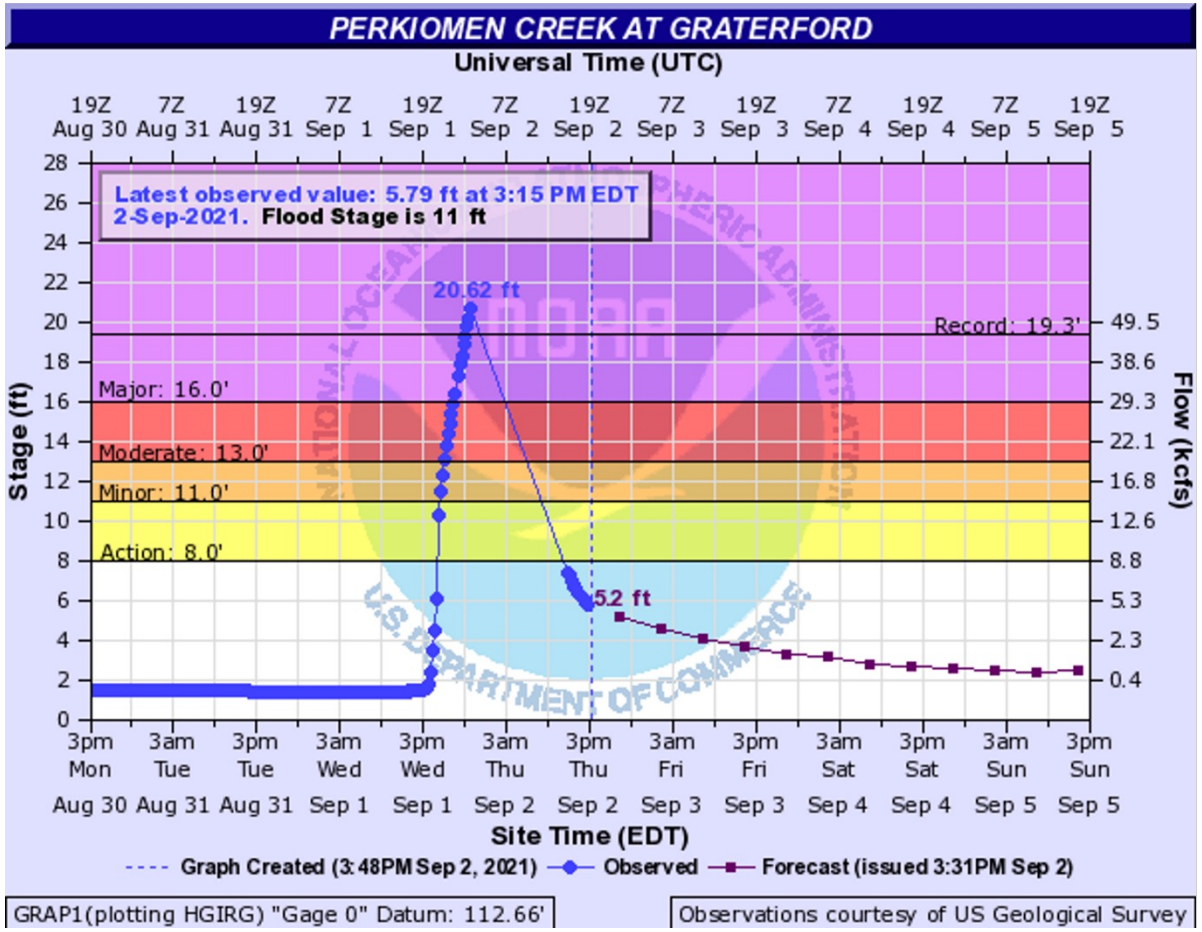
Usually develops within 6 hours of the heavy rainfall (e.g. small stream flooding, debris flows/mudslides, urban flooding, levee or dam failures). Usually shorter duration.

River Flooding (Large Rivers):

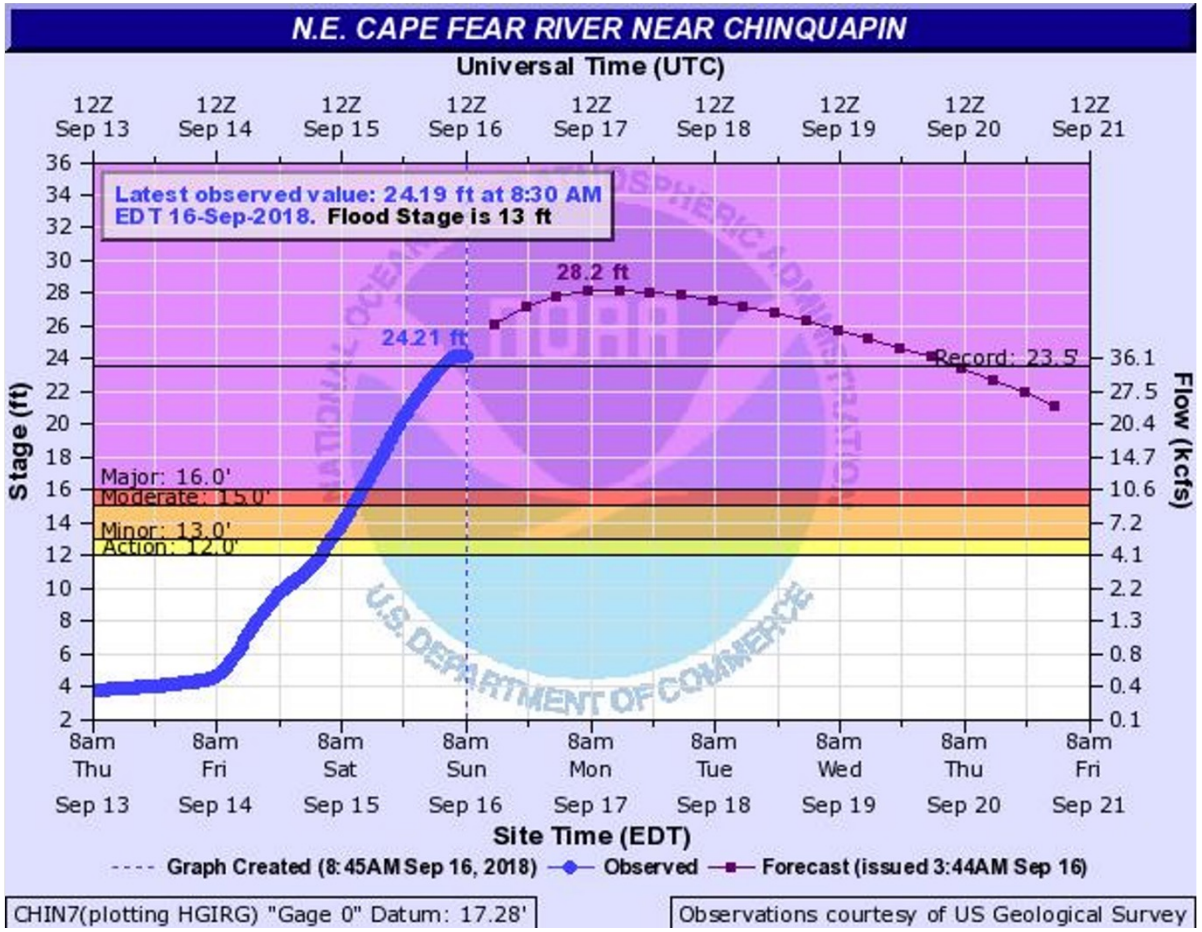
Stormwater drains from the smaller tributaries into the larger mainstem rivers. Water levels rise and overflow banks, inundating normally dry areas. Usually longer duration.

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 action in preparation for possible significant hydrologic activity.

Flood Stage Examples

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

FEMA

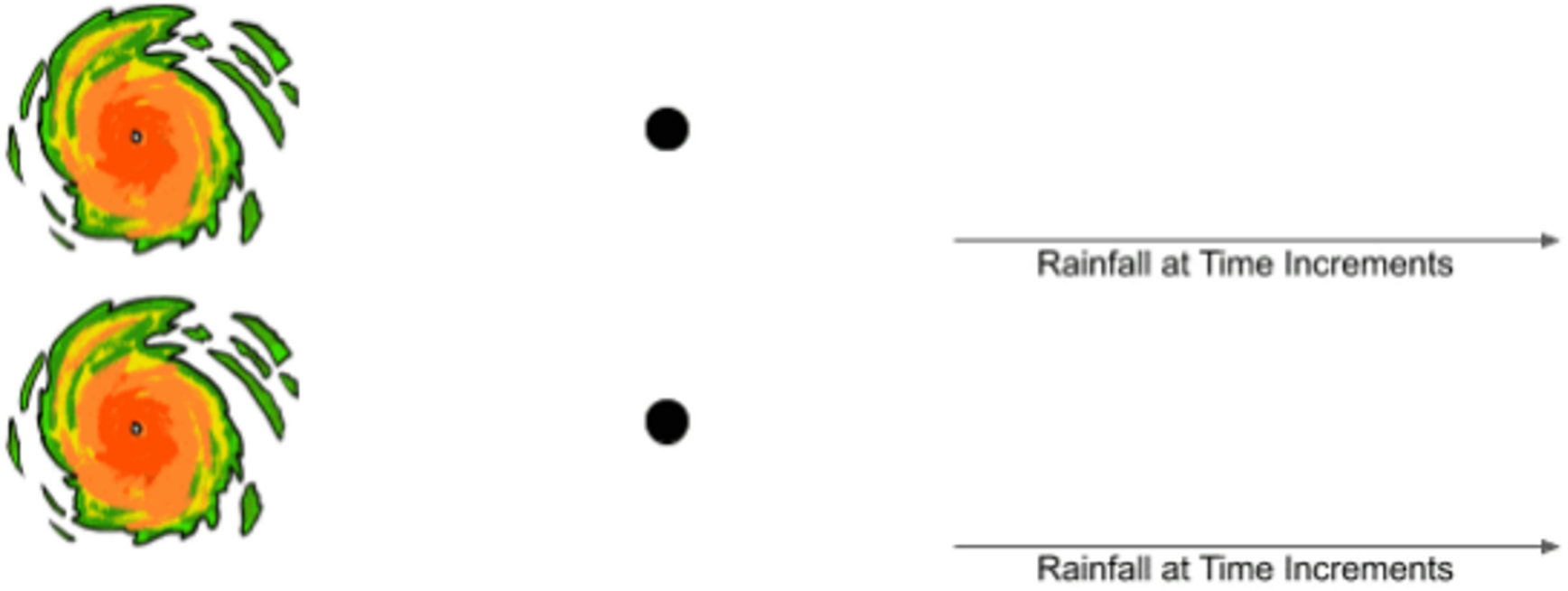
All Tropical Cyclones Have Rain	Many produce localized "hot spots"	Few with widespread, catastrophic rain
"So what?" factor *Already obvious*	*Tough to motivate large response* *Placement is difficult days in advance*	*People want us to get these right* *Need to minimize false alarms*

How best to differentiate storms along this spectrum?

Storm Forward Speed

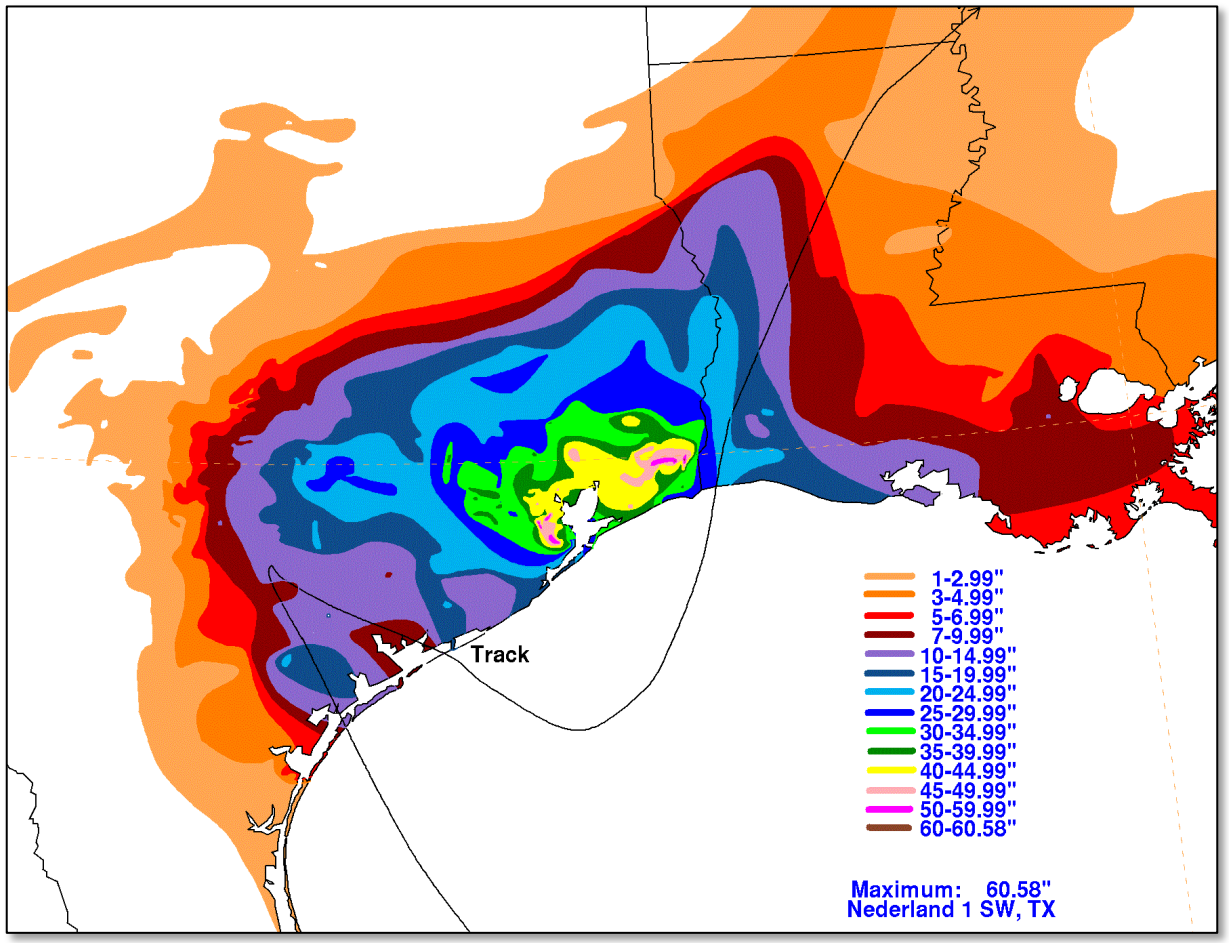
Situations that favor the "Big Extraordinary Ones"

- 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



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 four days, dropping historic amounts of rainfall of more than 60 inches over southeastern Texas.



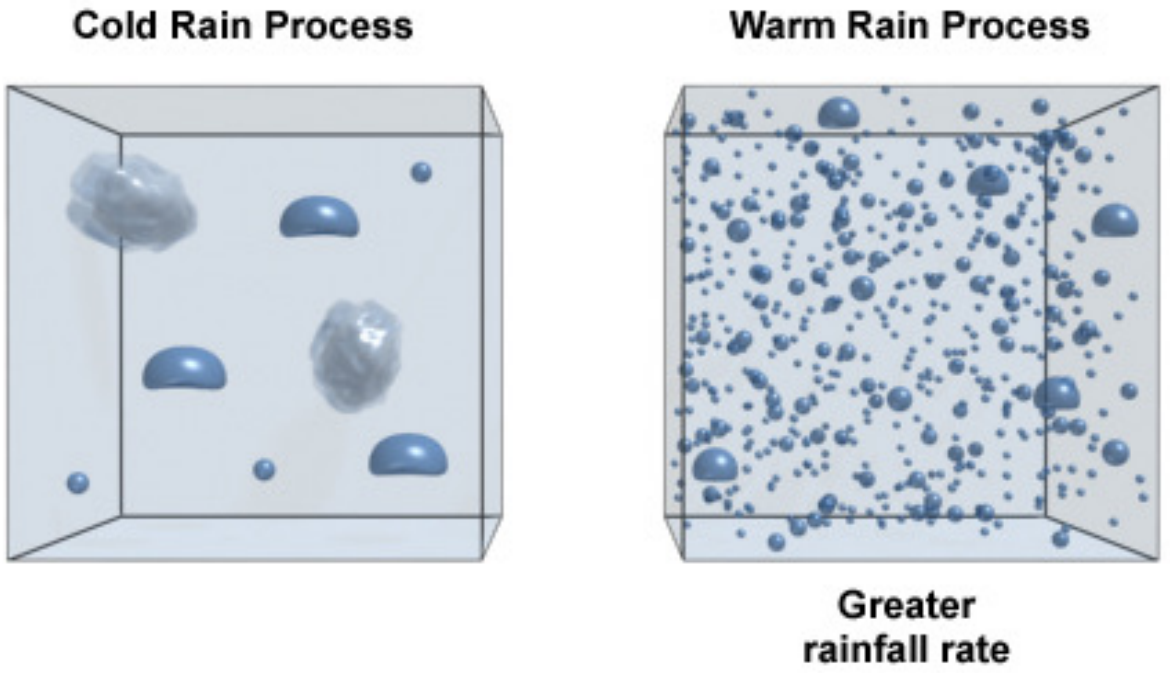
Rainfall Rates/Efficiency

Tropical Rainfall Efficiency

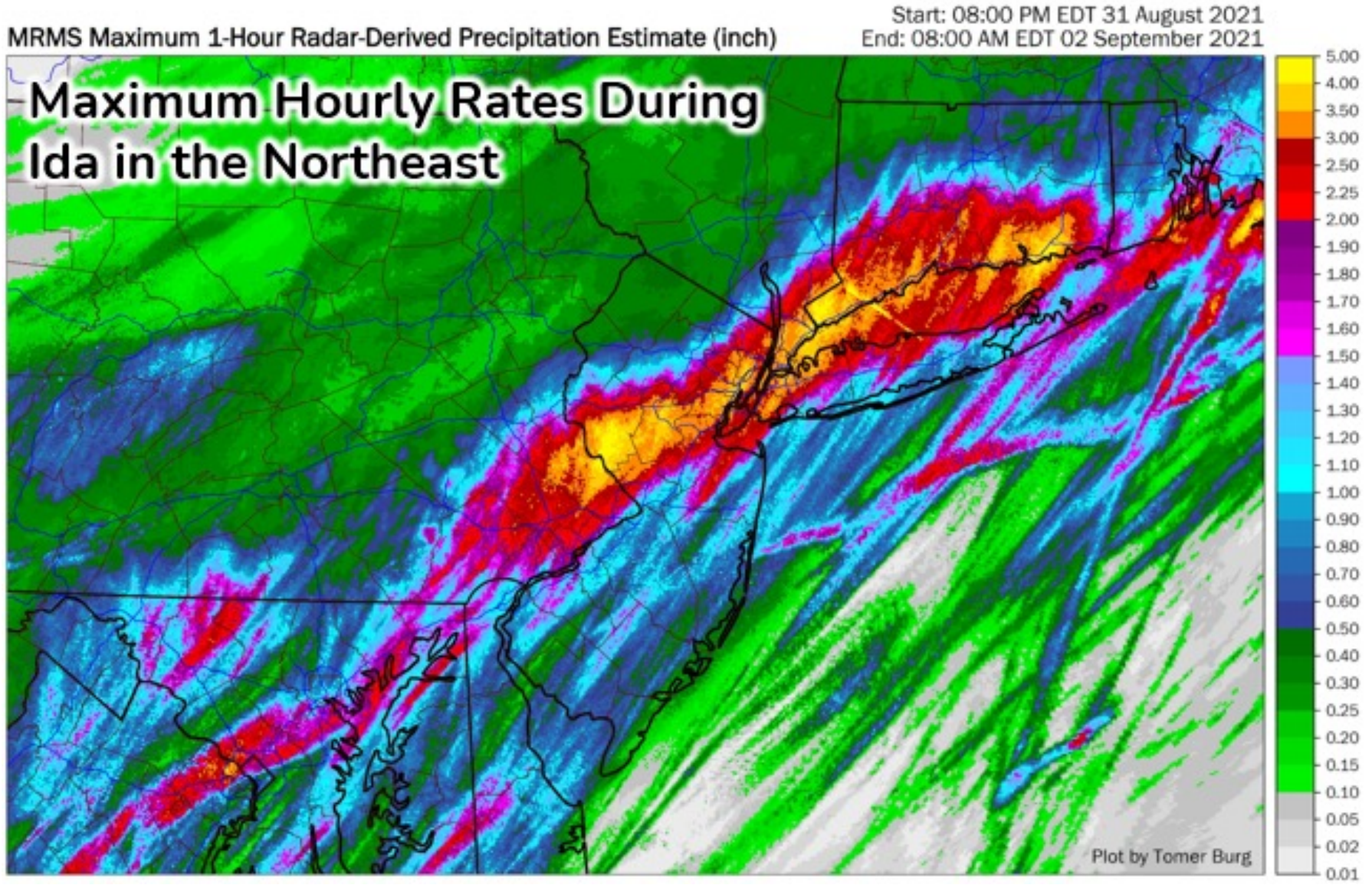
- Tropical cyclones generally build heavy rain through a warm rain process, without melting ice crystals or hail,
  - Result: a lot of smaller water droplets.

This is more efficient and tends to produce higher rainfall rates!

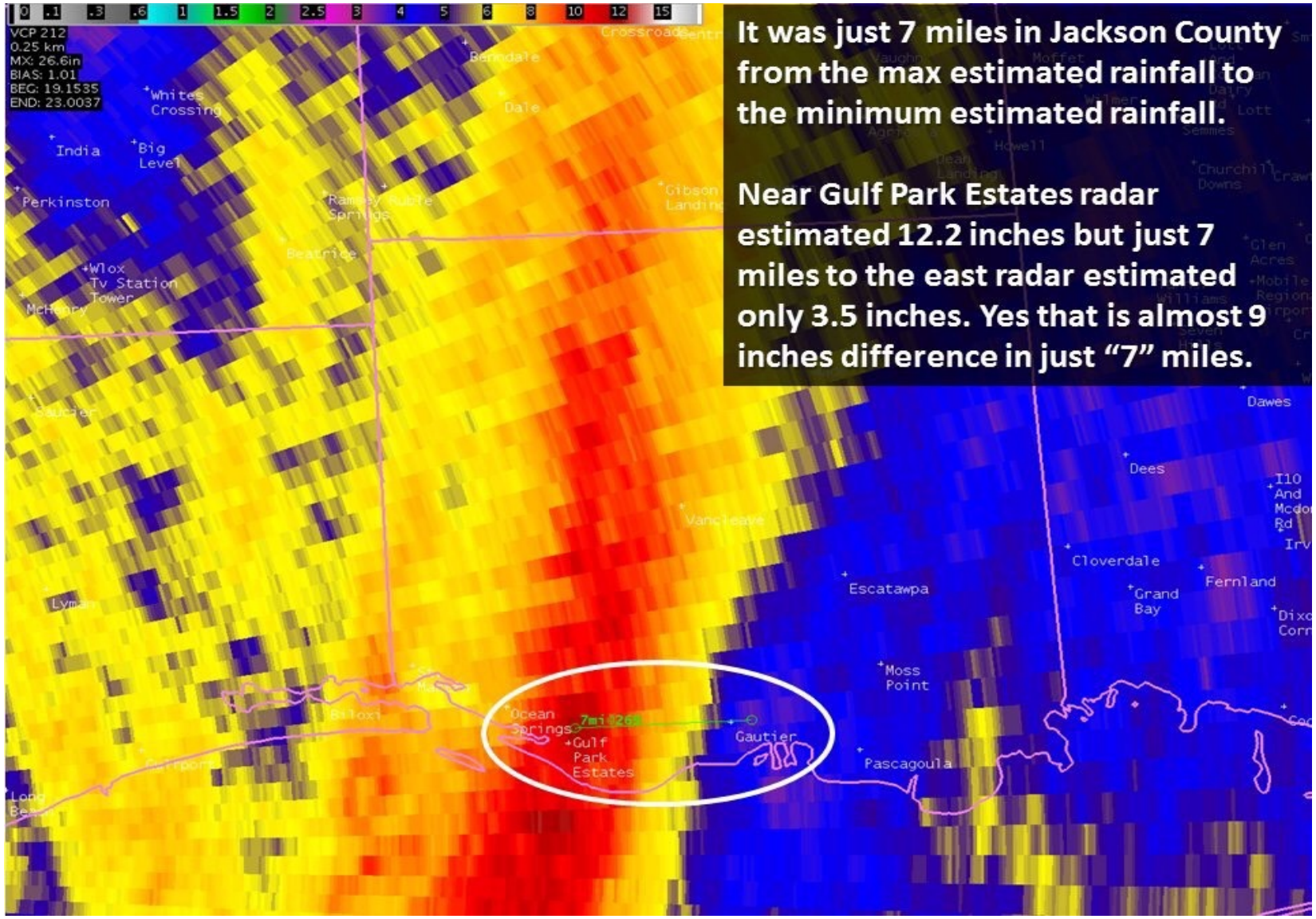
- If you concentrate the extreme rainfall rates in urban areas, as occurred with Hurricane Ida (2021), devastating flooding can result.



Rainfall Rates Example – Hurricane Ida (2021)



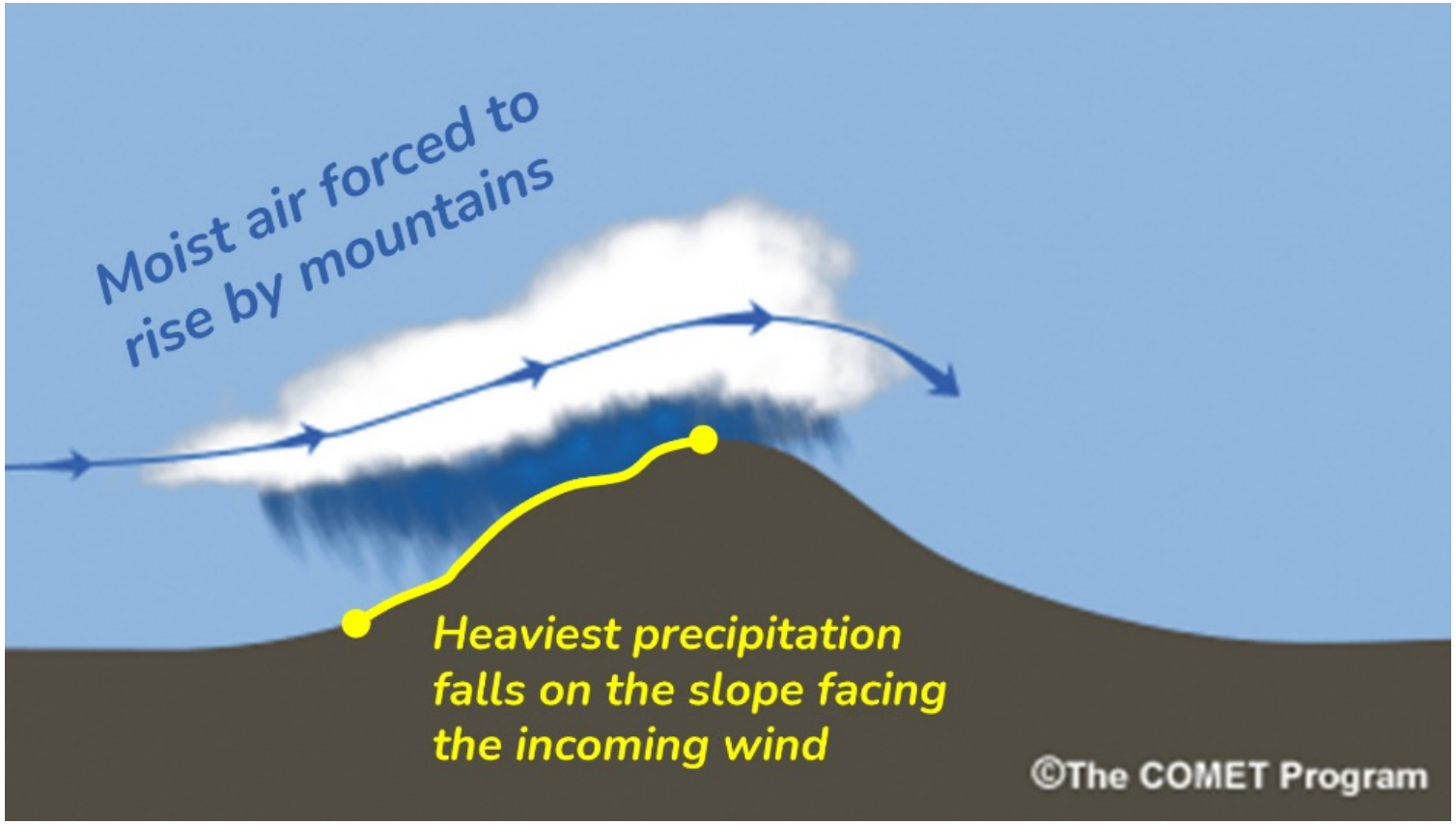
TS Cindy (2017)



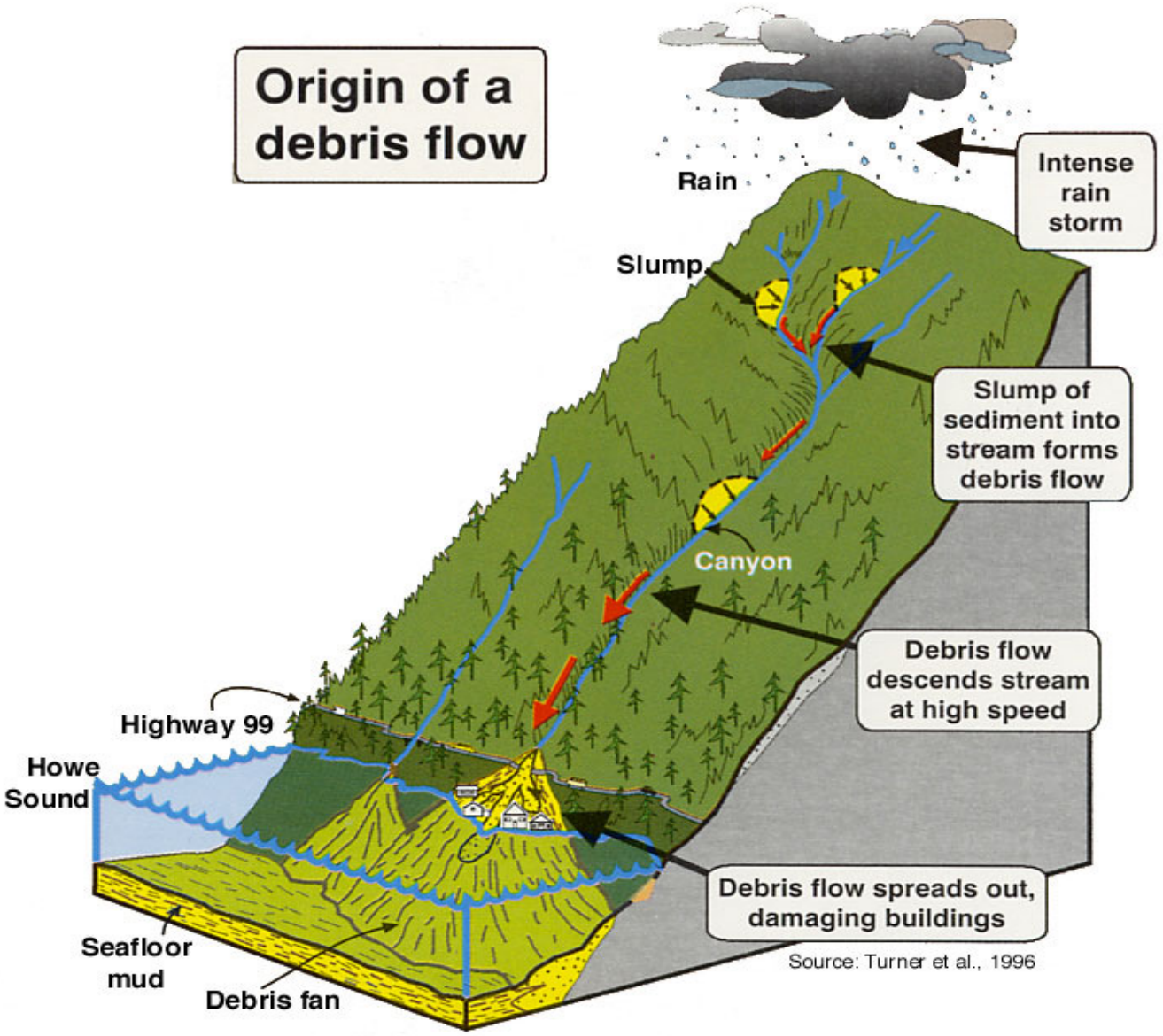
Terrain Effects

Upslope Rainfall Enhancement

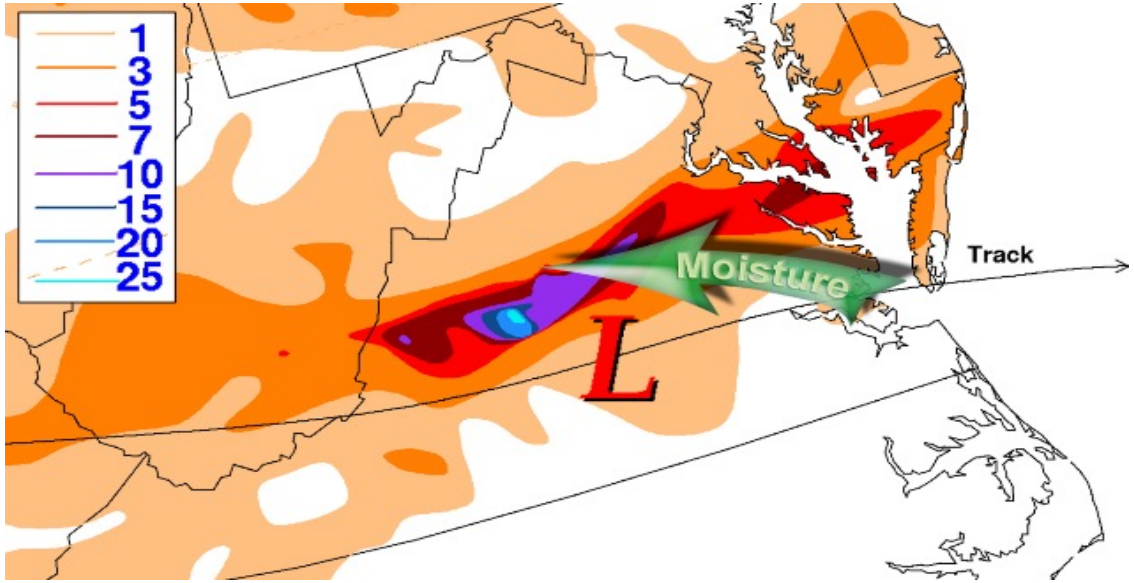
Extreme rainfall maxima can be focused in areas of terrain where winds around a tropical low can feed significant tropical moisture into mountainous areas.



Debris Flow

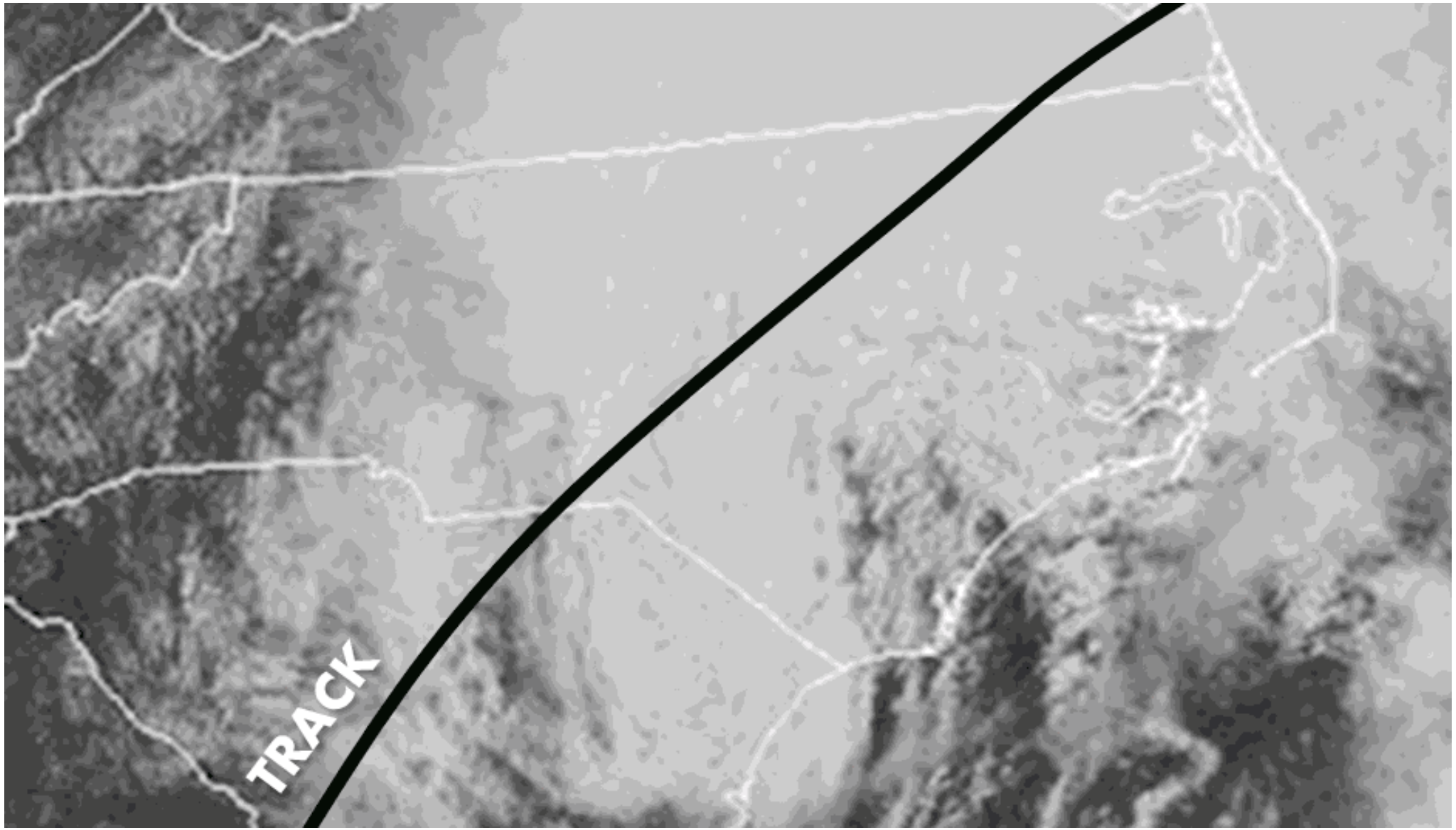

Origin of a debris flow
Rain
Intense rain storm
Slump
Slump of sediment into stream forms debris flow
Canyon
Debris flow descends stream at high speed
Highway 99
Howe Sound
Debris flow spreads out, damaging buildings
Seafloor mud
Debris fan
Source: Turner et al., 1996

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)



Urban Flooding

- 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

More concrete

=

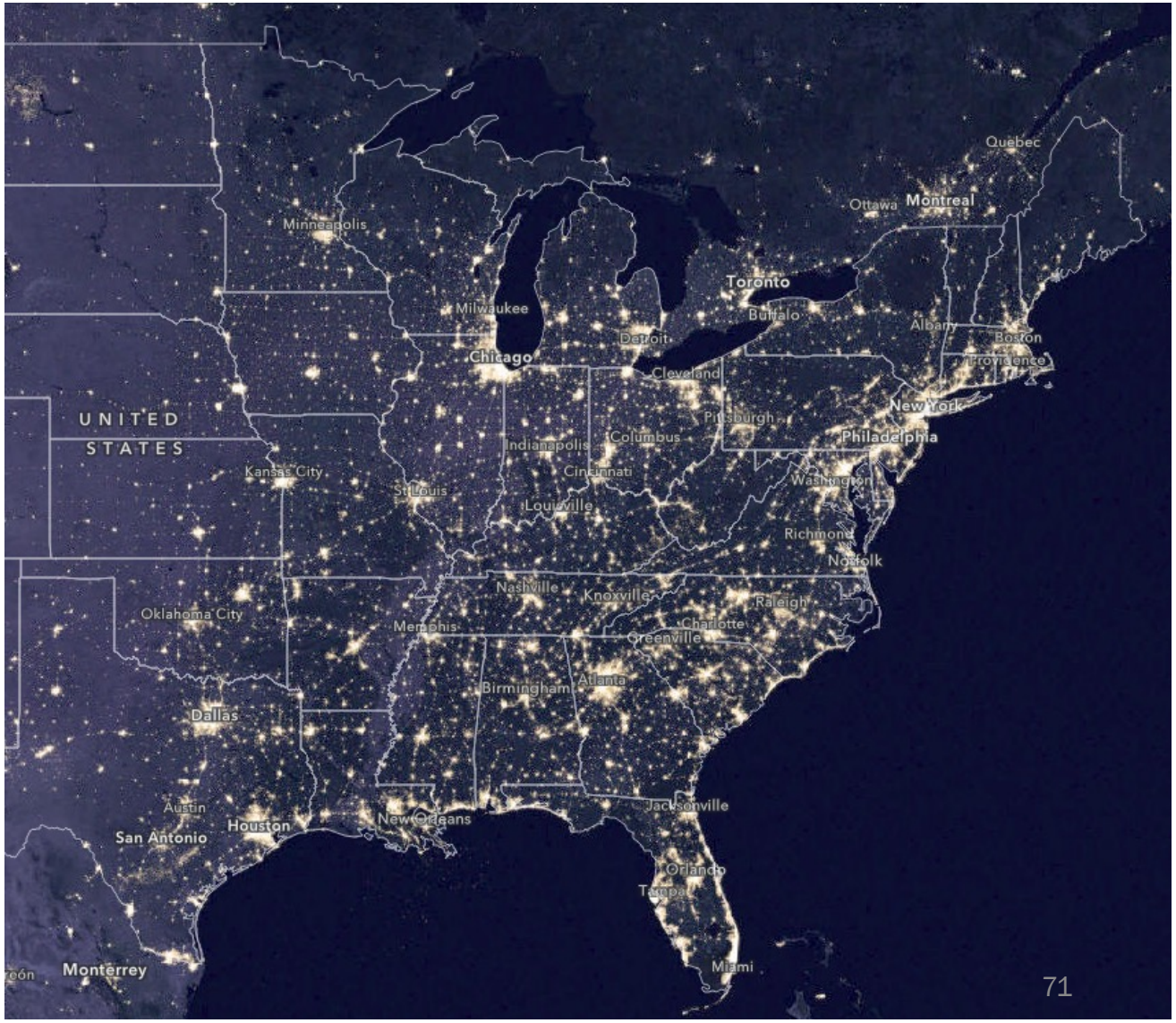
More impervious surface

=

Faster and greater runoff

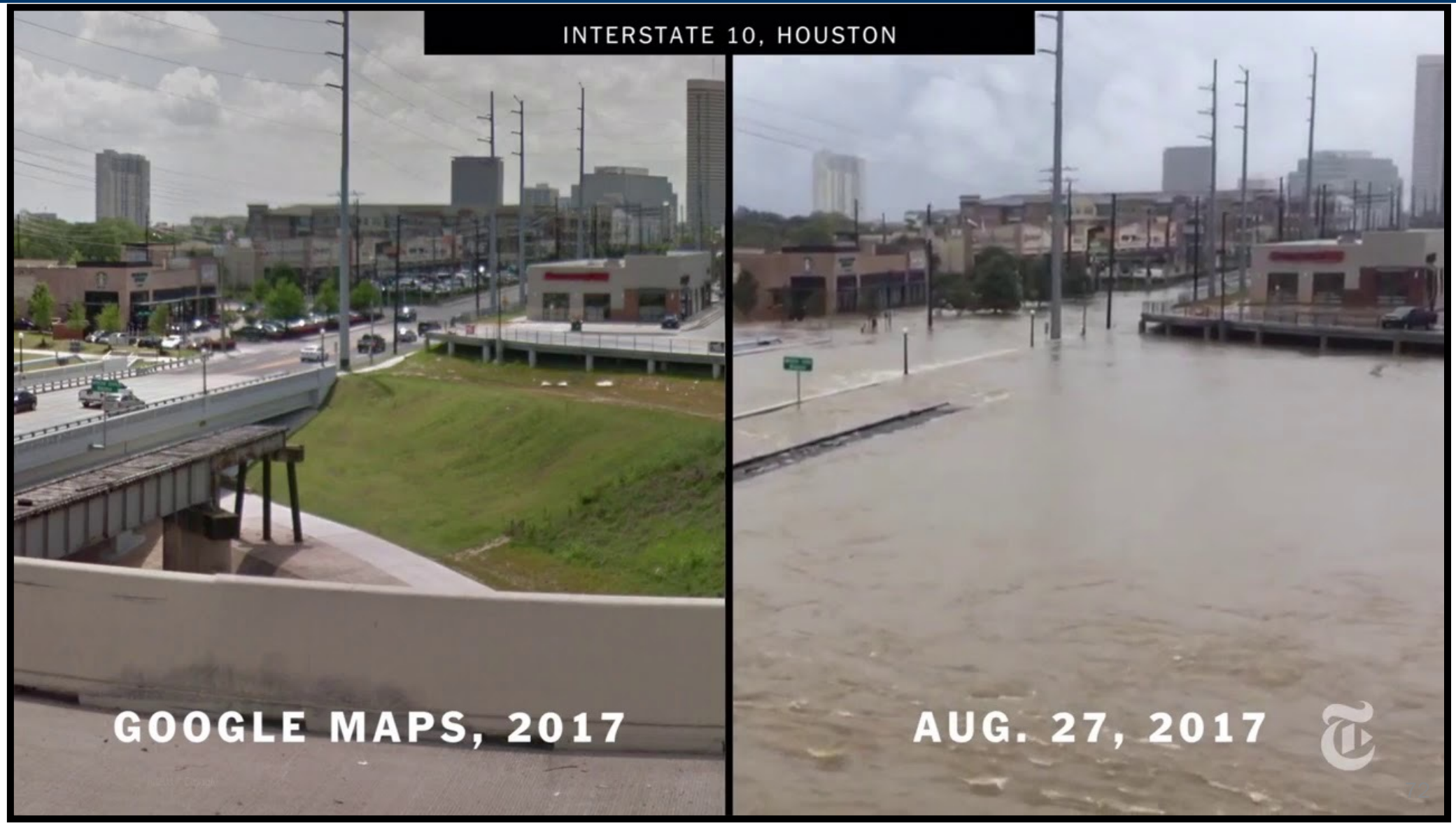
=

Increased flooding risk



Hurricane Harvey (2017) Flooding: I-10

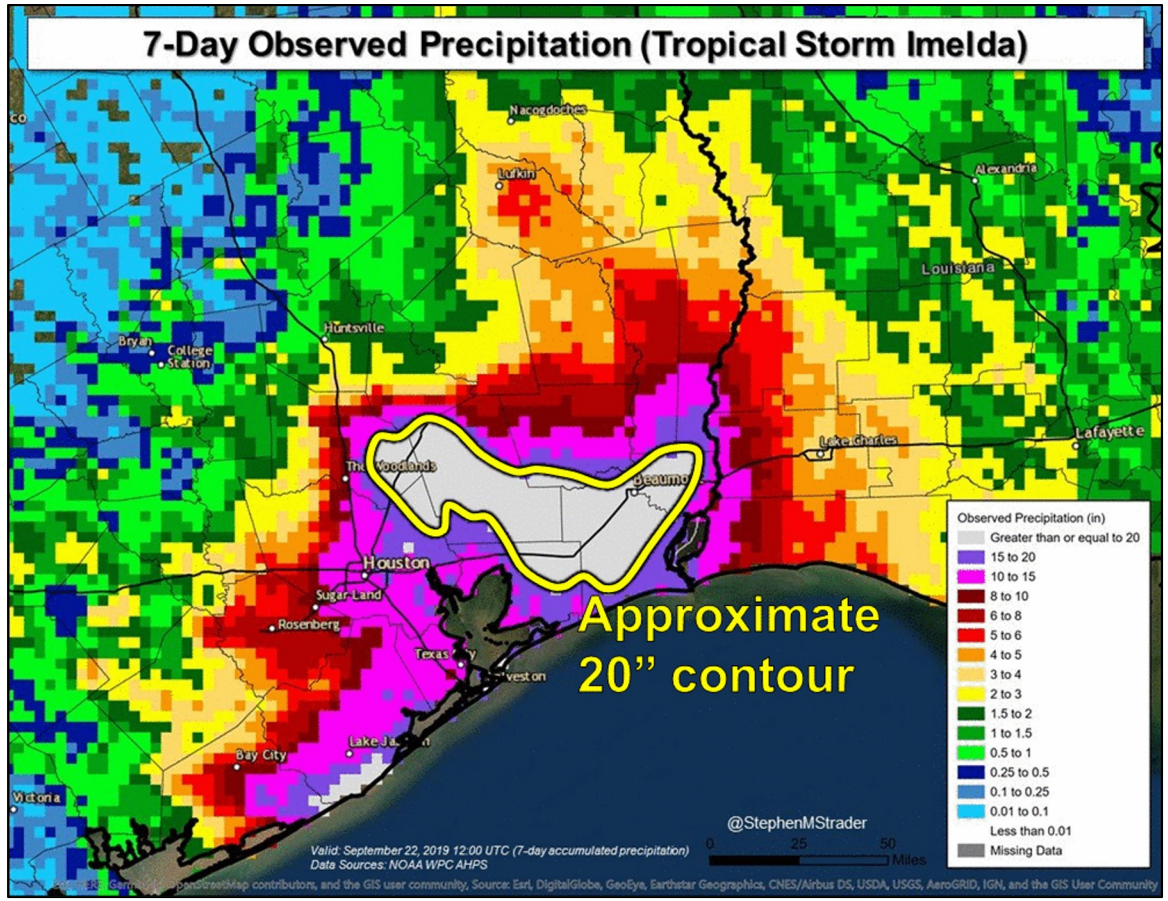
FEMA



TS Allison (2001) – I-10

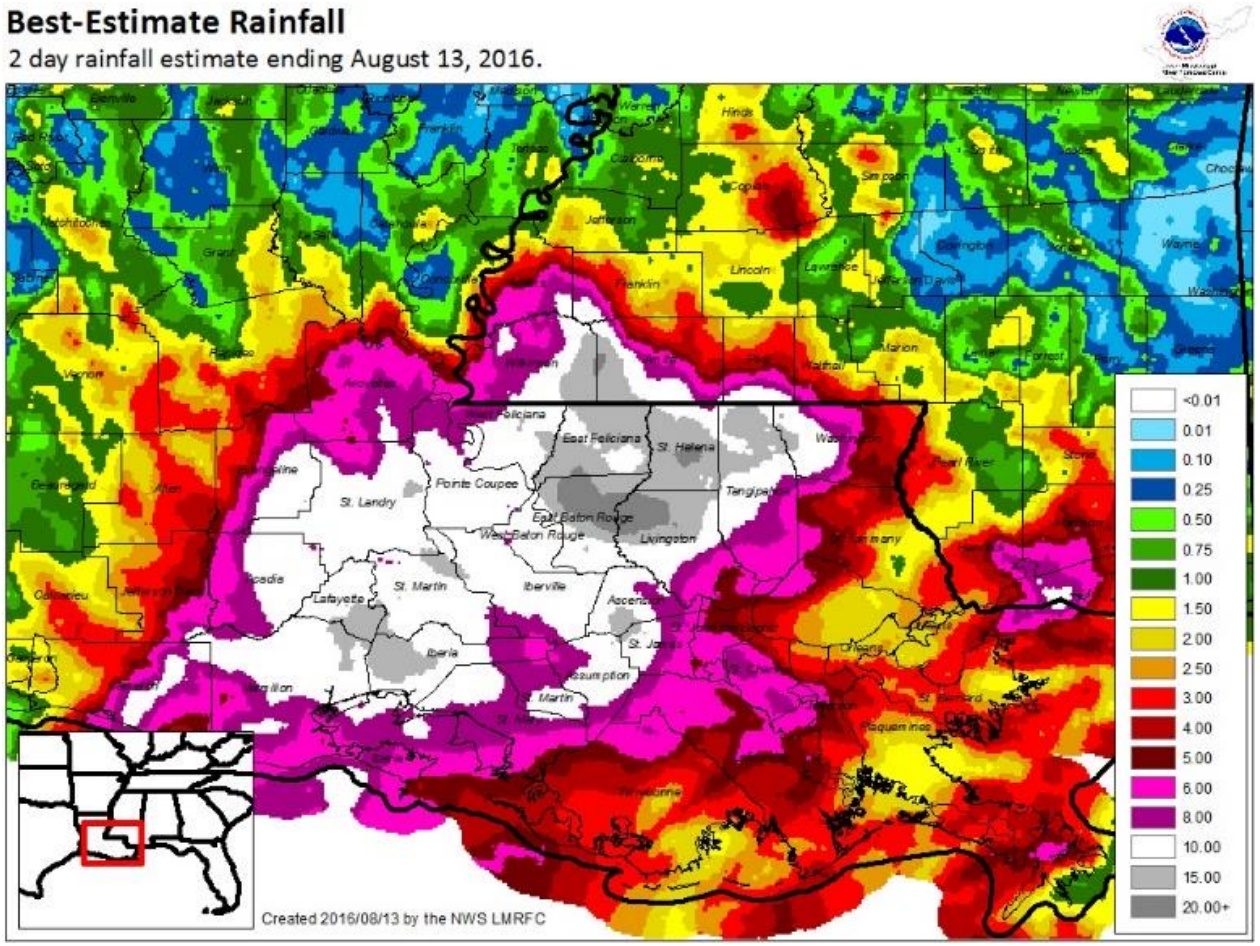
Urban Growth and Flooding

Expanding Urban Areas Make a Difference



Unnamed Low (2016) - Louisiana

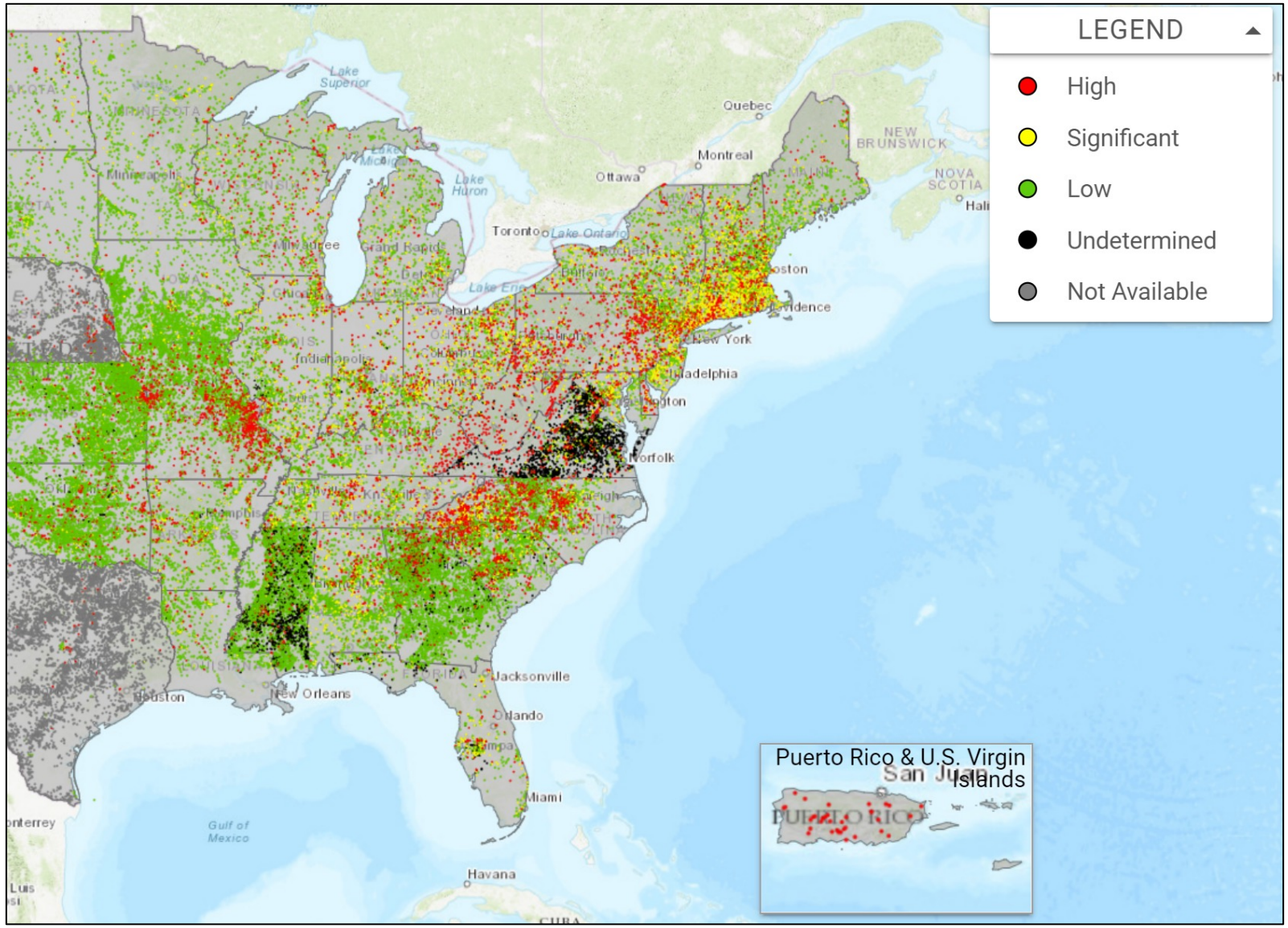
- Notice that the list of rainfall factors did not include level of organization and wind strength.
- A tropical system doesn't need to be an organized cyclone to have catastrophic impacts.
- In 2016, a disorganized tropical system stalled over Louisiana, dropping 3x the amount of rainfall that Katrina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



Lake Overflow and Dam Breaks

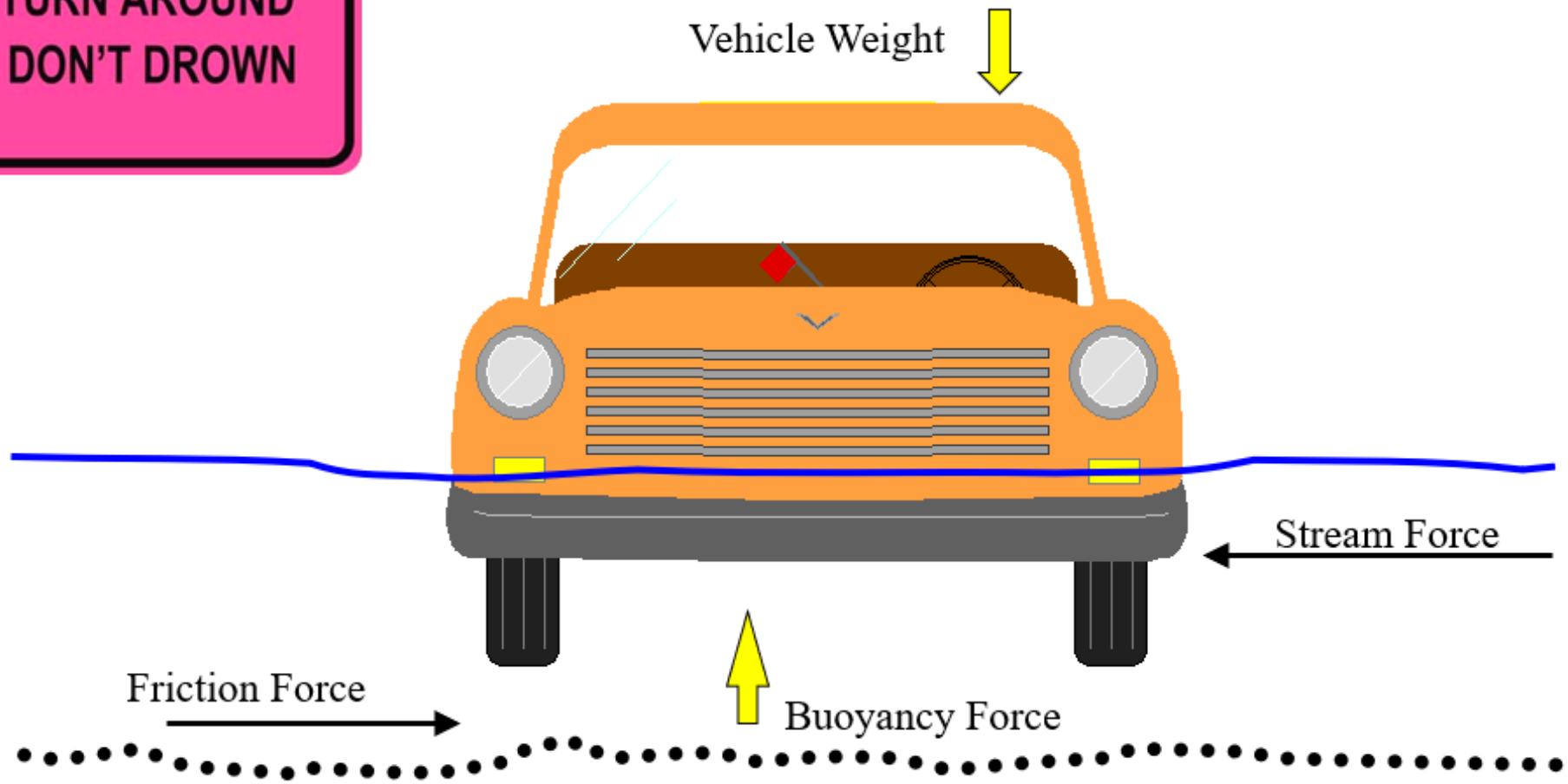
- Dam breaks are more likely to occur on smaller, poorly-maintained dams
- Overflow of lakes
- Know what is upstream

National Inventory of Dams (NID)



Flooding Forces on Vehicles

The car will float downstream when:
Stream Force > Friction Force



Landfalling Hurricanes Spawn Tornadoes

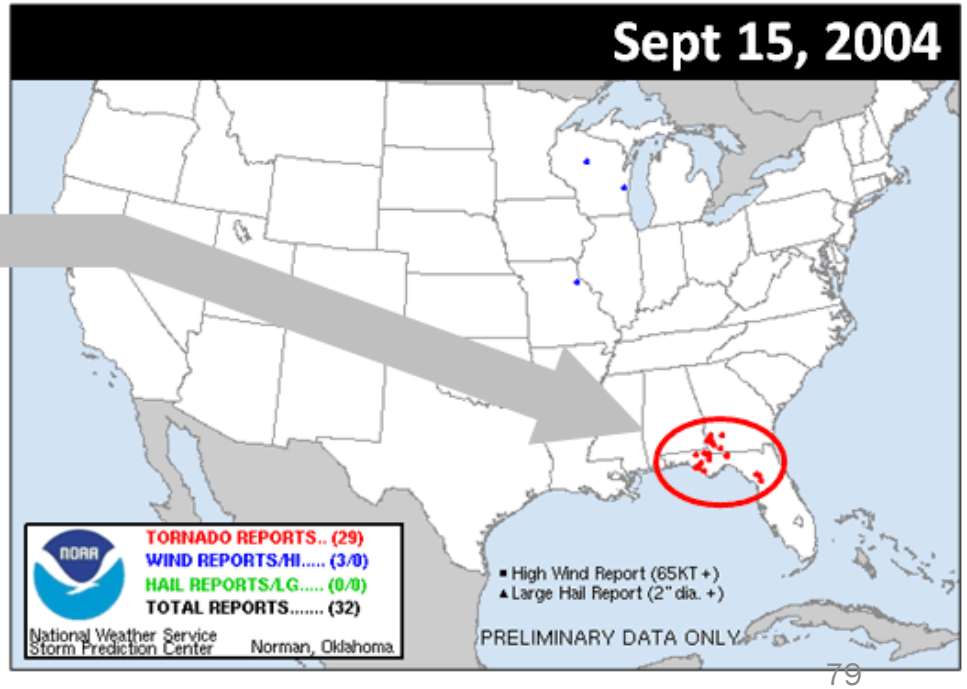
Landfalling Hurricanes:

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

Tornado "outbreak"

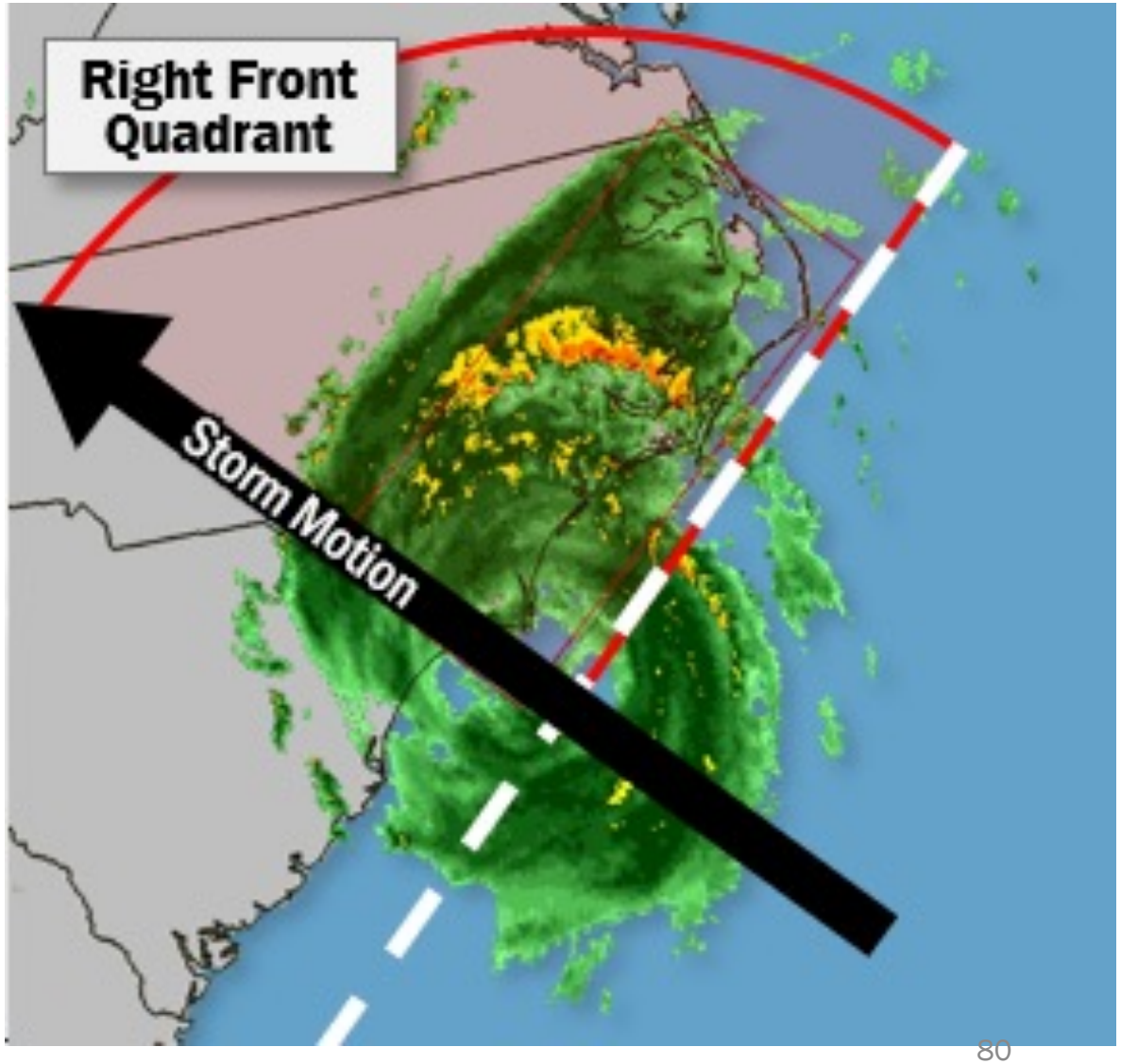
Hurricane Ivan (2004)

– 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?