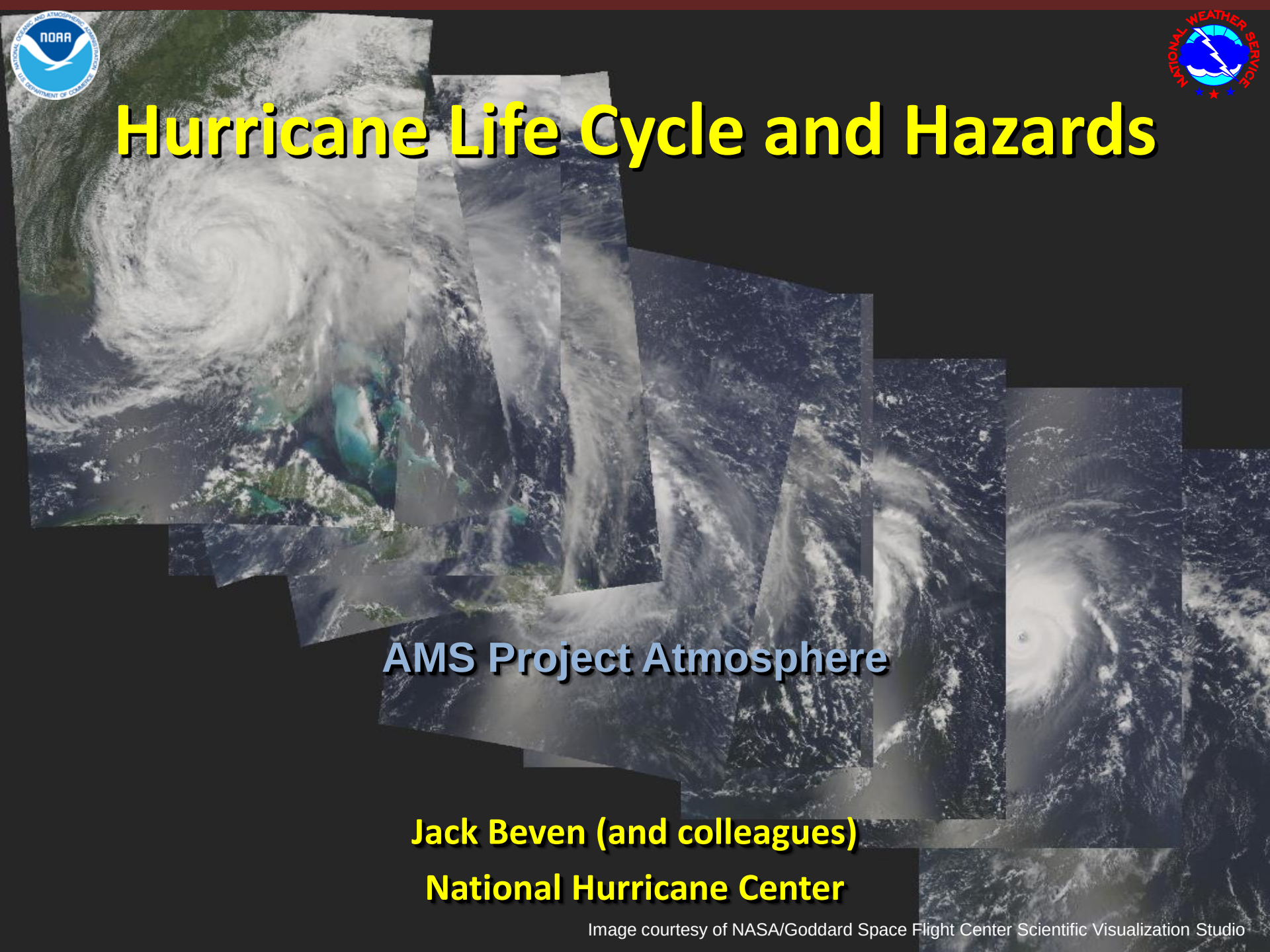
Hurricane Life Cycle and Hazards



AMS Project Atmosphere

Jack Beven (and colleagues)

National Hurricane Center

Image courtesy of NASA/Goddard Space Flight Center Scientific Visualization Studio

True or false?

All synoptic-scale cyclonic storms with 75 mph or greater winds are hurricanes

FALSE!

The NHC Warns On…

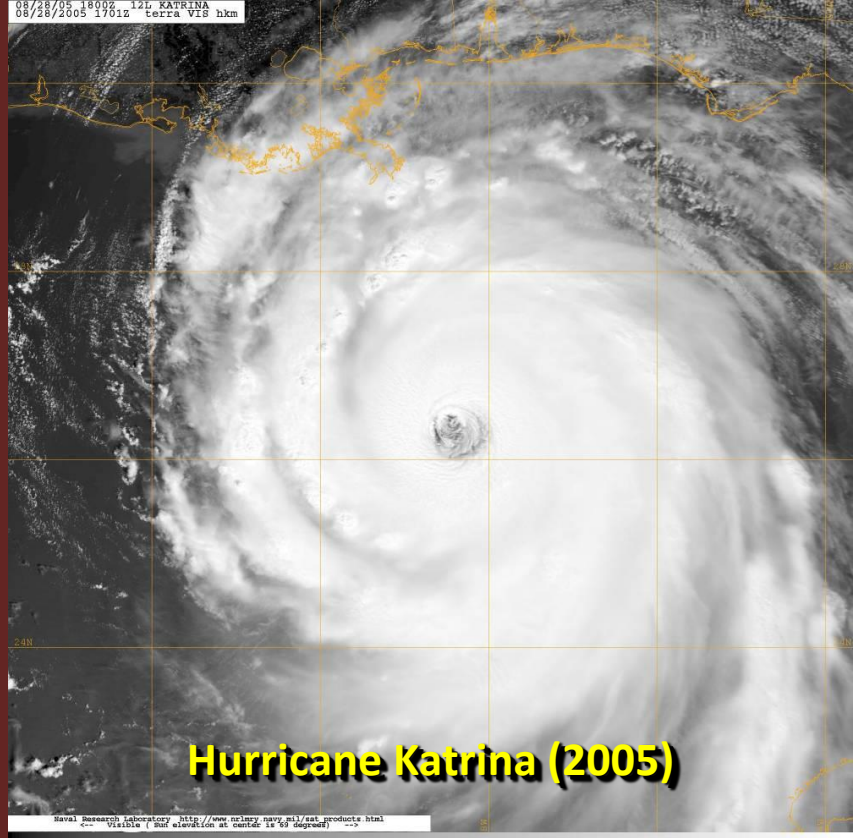
Tropical Cyclone: A warm-core non-frontal synoptic-scale cyclone, originating over tropical or subtropical waters, with organized deep convection and a closed surface wind circulation about a well-defined center. Once formed, a tropical cyclone is maintained by the extraction of heat energy from the ocean at high temperature and heat export at the low temperatures of the upper troposphere. In this they differ from extratropical cyclones, which derive their energy from horizontal temperature contrasts in the atmosphere (baroclinic effects).

Subtropical Cyclone: A non-frontal low-pressure system that has characteristics of both tropical and extratropical cyclones. Like tropical cyclones, they are non-frontal, synoptic-scale cyclones that originate over tropical or subtropical waters, and have a closed surface wind circulation about a well-defined center. In addition, they have organized moderate to deep convection, but lack a central dense overcast. Unlike tropical cyclones, subtropical cyclones derive a significant proportion of their energy from baroclinic sources, and are generally cold-core in the upper troposphere, often being associated with an upper-level low or trough. In comparison to tropical cyclones, these systems generally have a radius of maximum winds occurring relatively far from the center (usually greater than 60 n mi), and generally have a less symmetric wind field and distribution of convection.

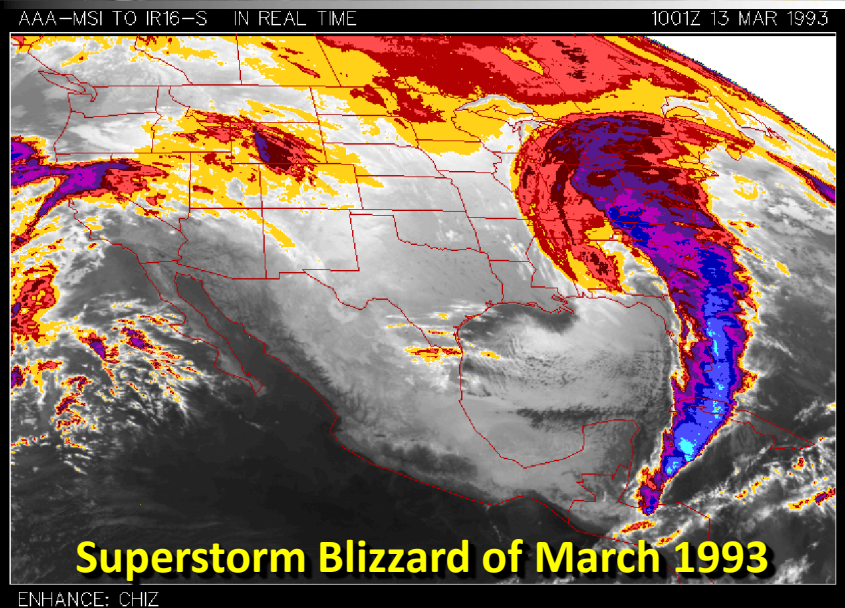
The NHC does not warn on nor'easters or other types of cyclones!

Why are the distinctions important?

- Cyclone type and the associated transitions are ‘shades of grey’ or continuum issues. Nature can mix cyclone types and energy sources.
- Operational handling of cyclone types is a ‘black and white’ or ‘yes or no’ response – TC warnings or non-tropical gale/storm warnings.
- This situation can lead to issues and inconsistencies in the warning process, response, and climatology.
- But, if *you* get hit by high winds, storm surge, and heavy rains, does the nature of the system really matter?



Hurricane Katrina (2005)

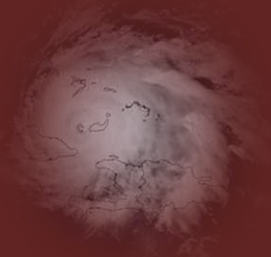


Superstorm Blizzard of March 1993

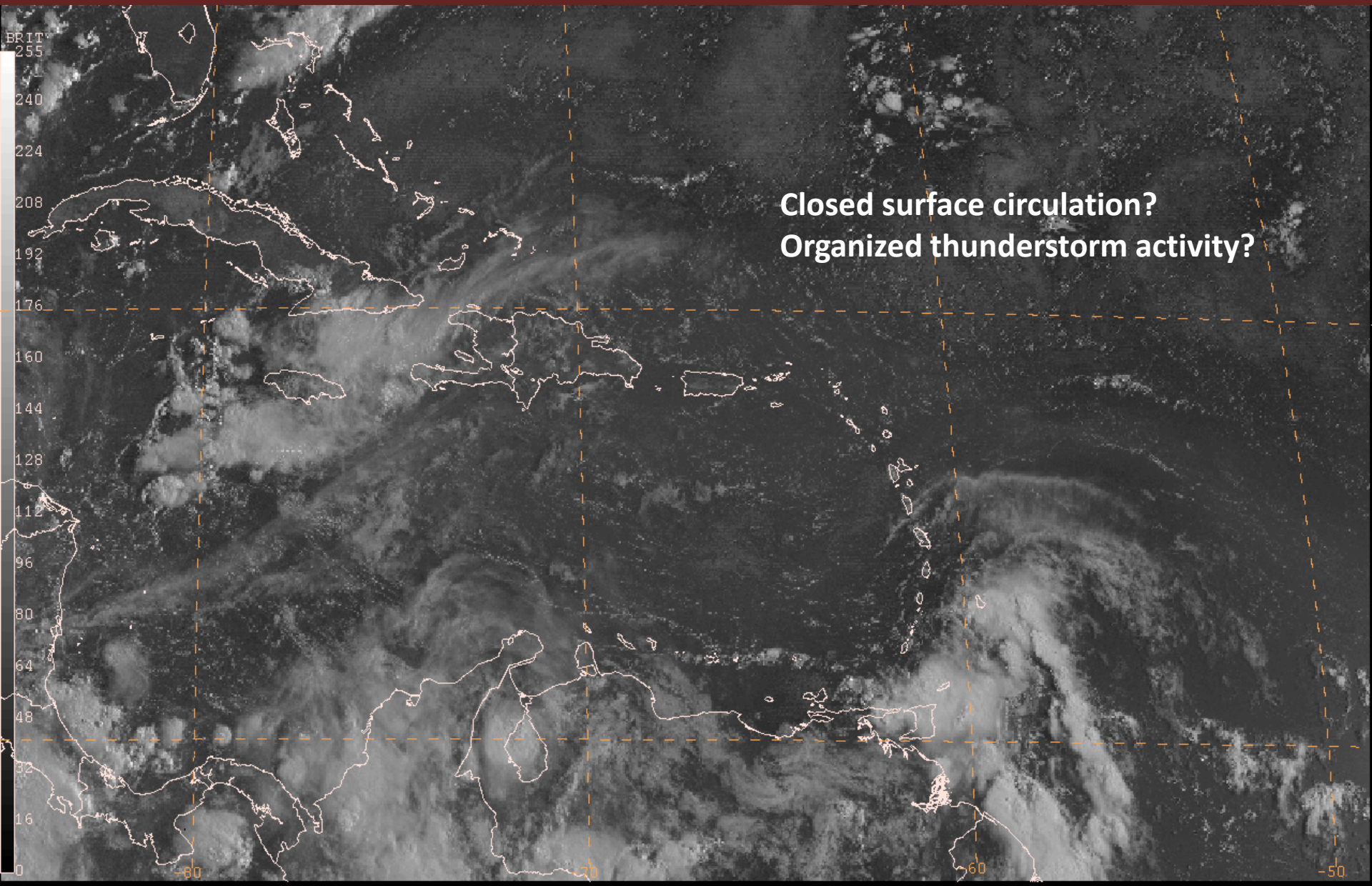
What is a Tropical Cyclone?

- A relatively large and long-lasting low pressure system
  - Can be dozens to hundreds of miles wide, and last for days
- No fronts attached
- Warm core (warmer in the middle than on the outside, especially in the upper troposphere)
- Forms over tropical or subtropical oceans (the energy source)
- Produces organized thunderstorm activity (the energy release mechanism)
- Has a closed surface wind circulation around a well-defined center

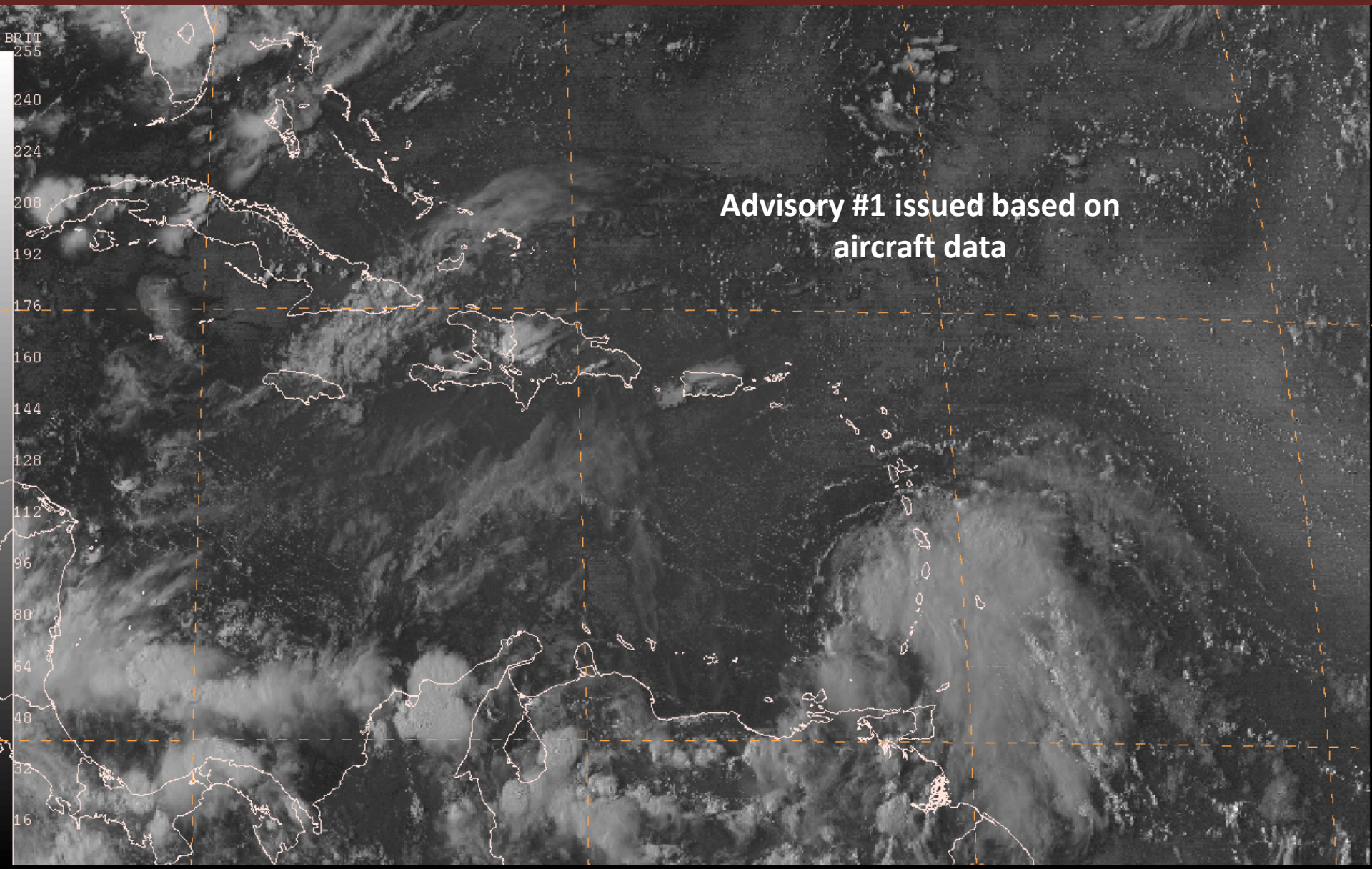
- Classified by maximum sustained surface wind speed
  - Tropical depression: < 39 mph
  - Tropical storm: 39-73 mph
  - Hurricane: 74 mph or greater
    - Major hurricane: 111 mph or greater



Is This a Tropical Cyclone?

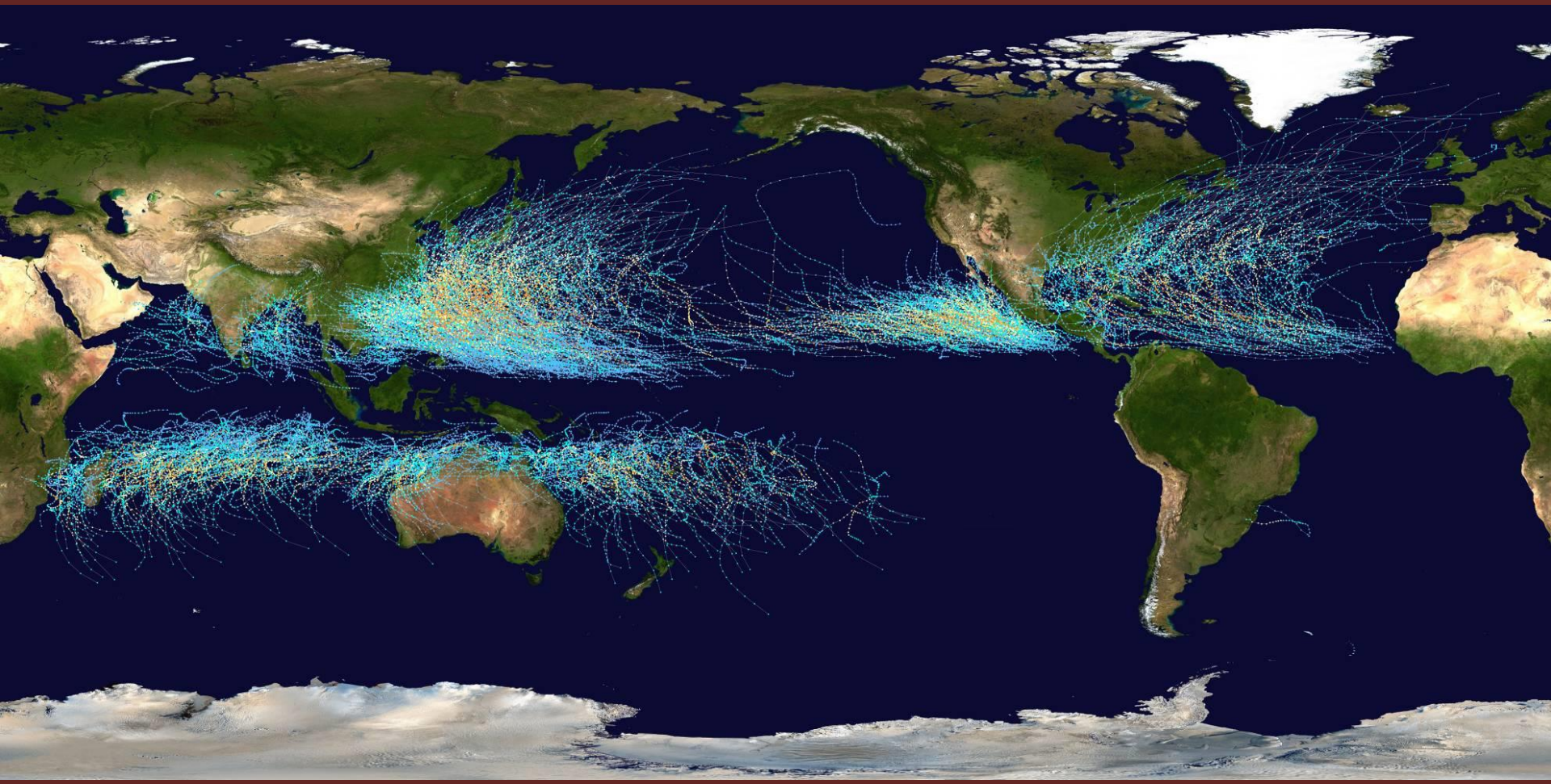


Tropical Depression #5 (later Ernesto)



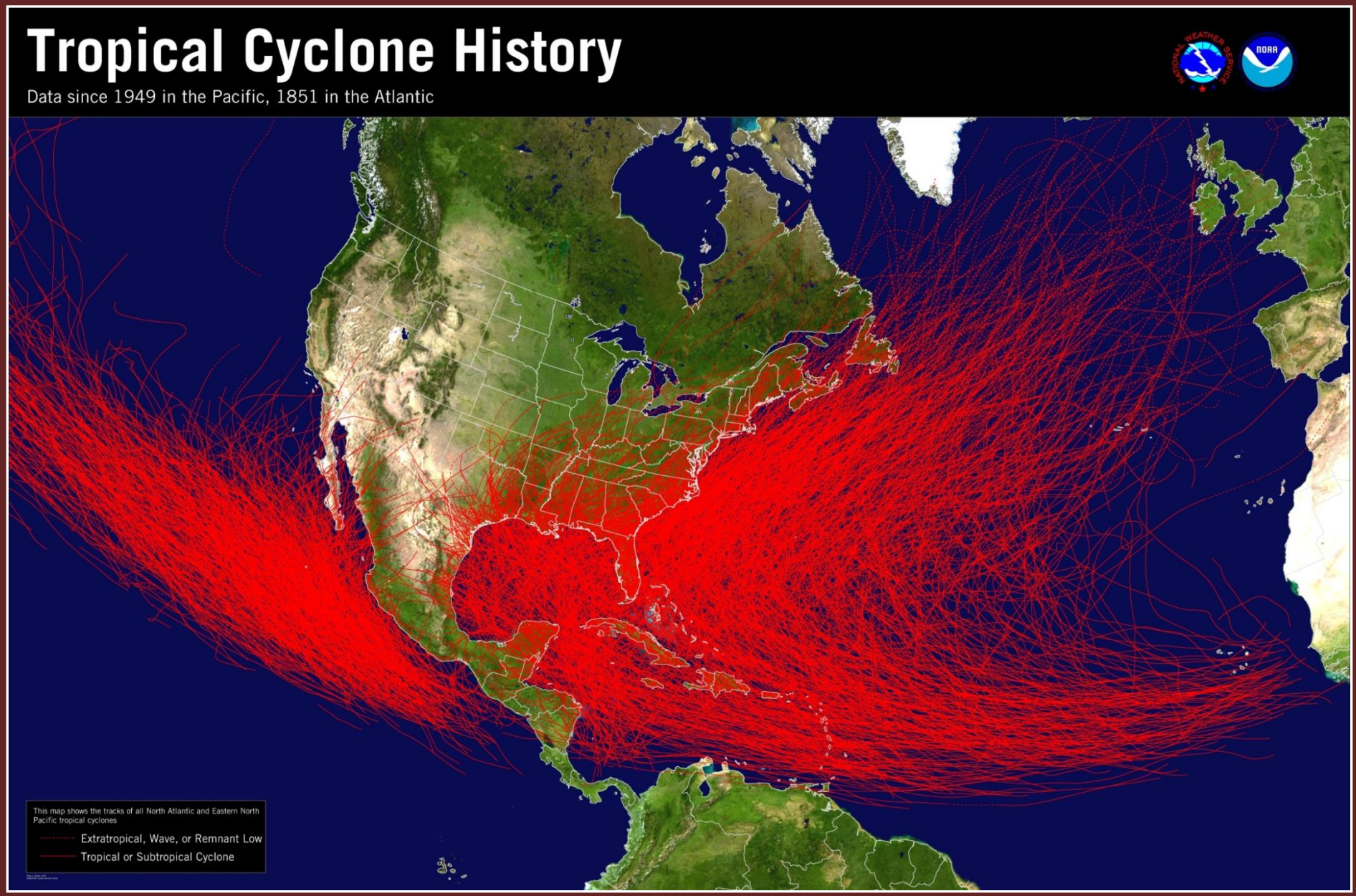
Determining if a tropical cyclone has formed is often a major challenge!

Tropical Cyclones Occur Over Tropical and Subtropical Waters Across the Globe

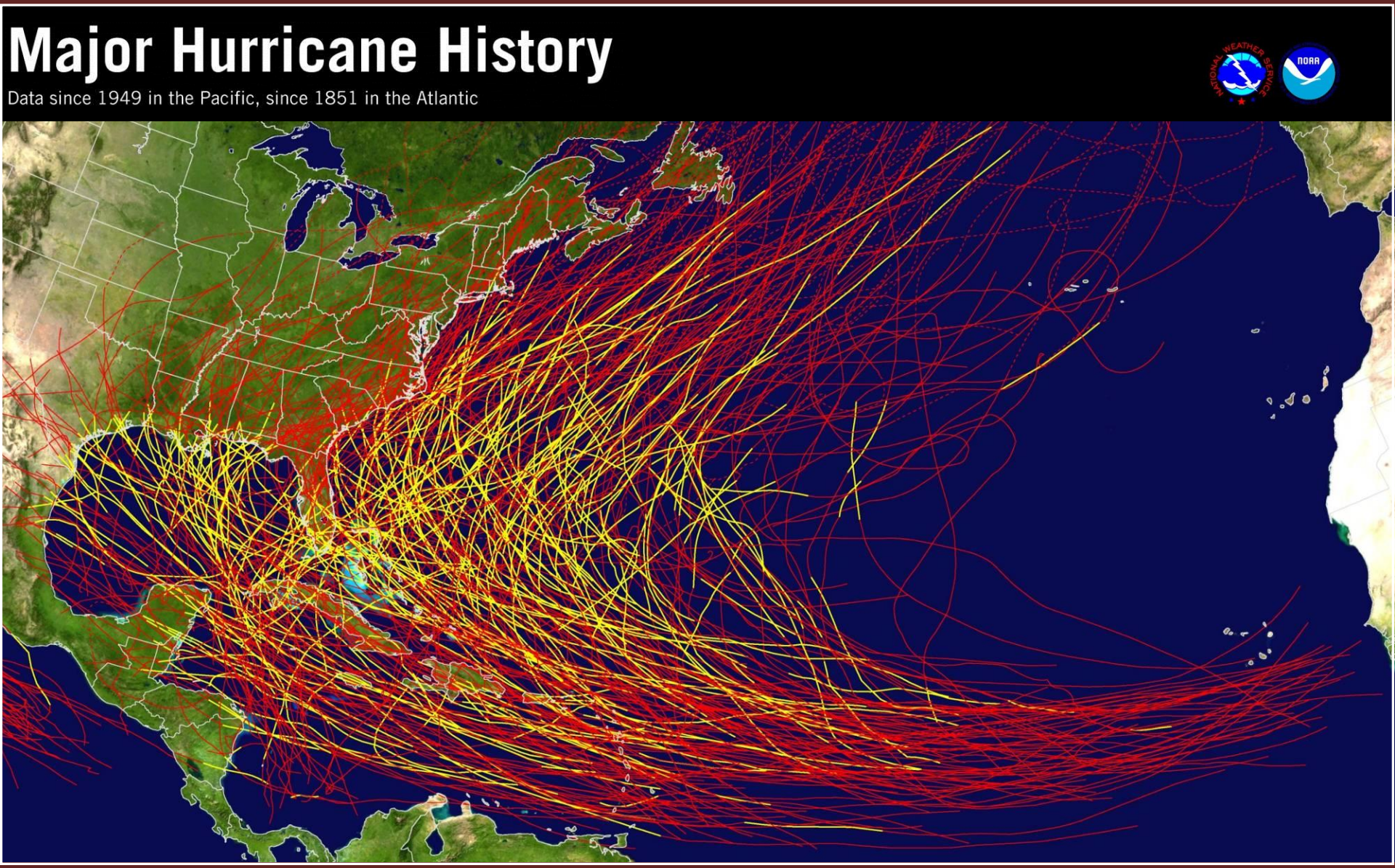


Tropical cyclones tracks between 1985 and 2005

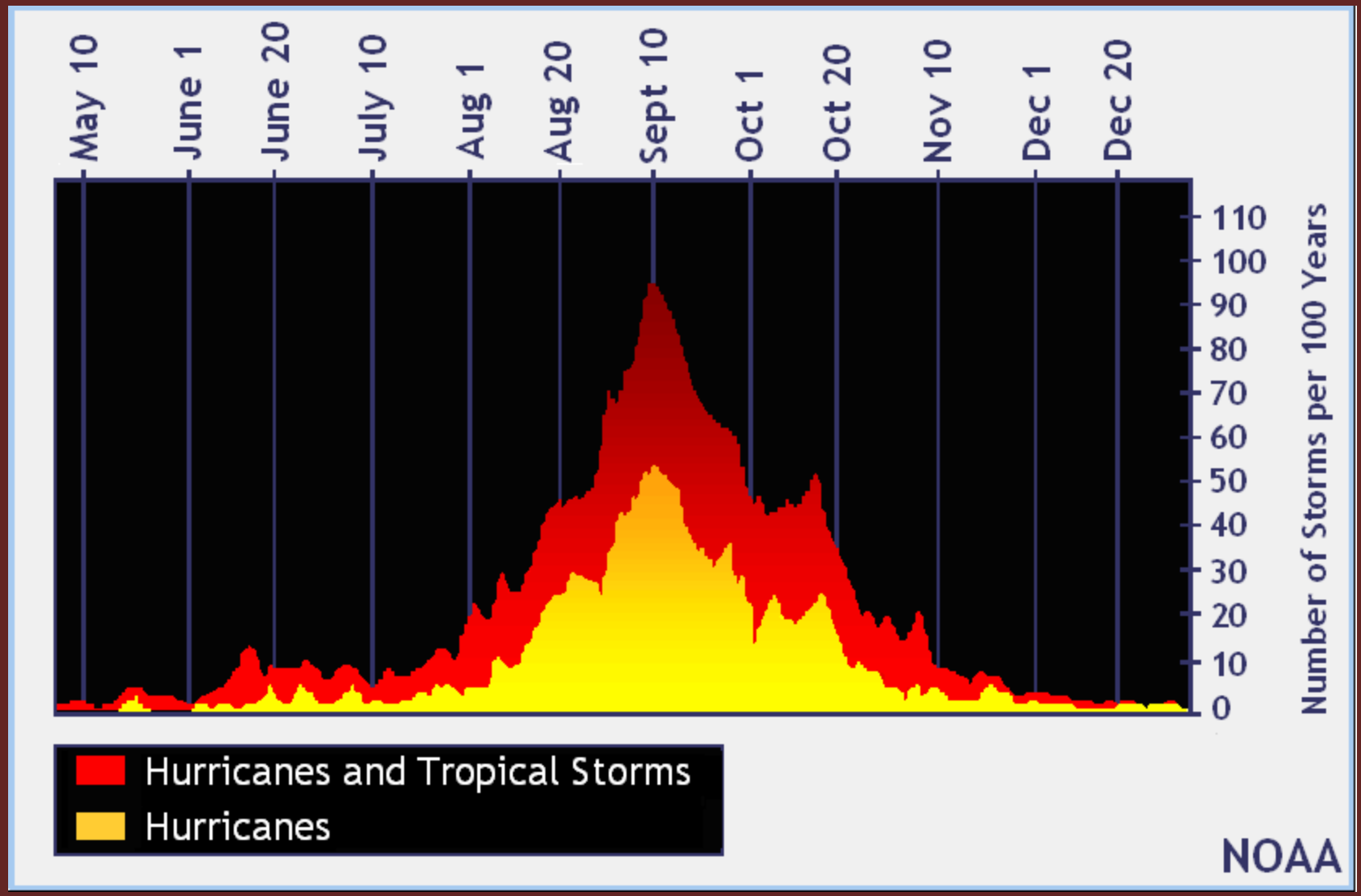
NHC Area of Responsibility Tropical Cyclones



Atlantic Major Hurricanes Since 1851

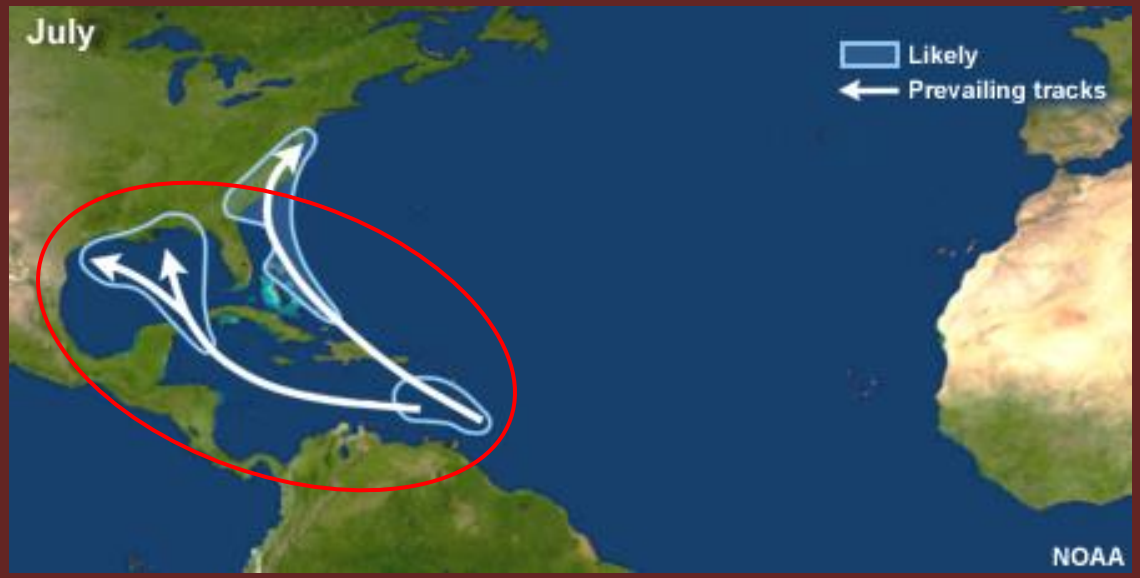


Annual Climatology of Atlantic Hurricanes



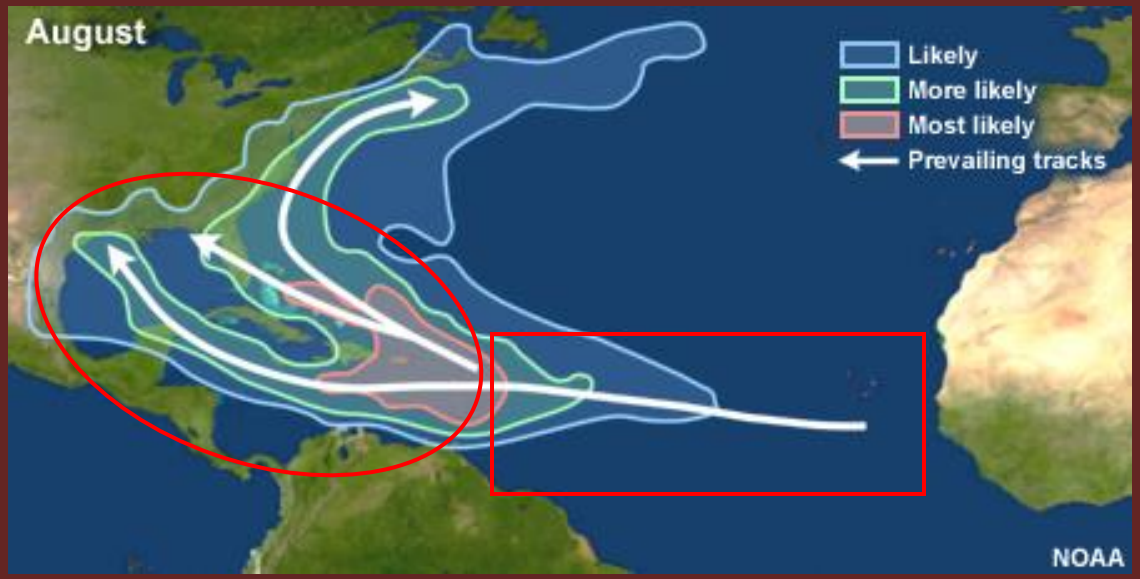
Climatological Areas of Origin and Tracks

June: On average about 1 storm every other year. Most June storms form in the northwest Caribbean Sea or Gulf of Mexico.

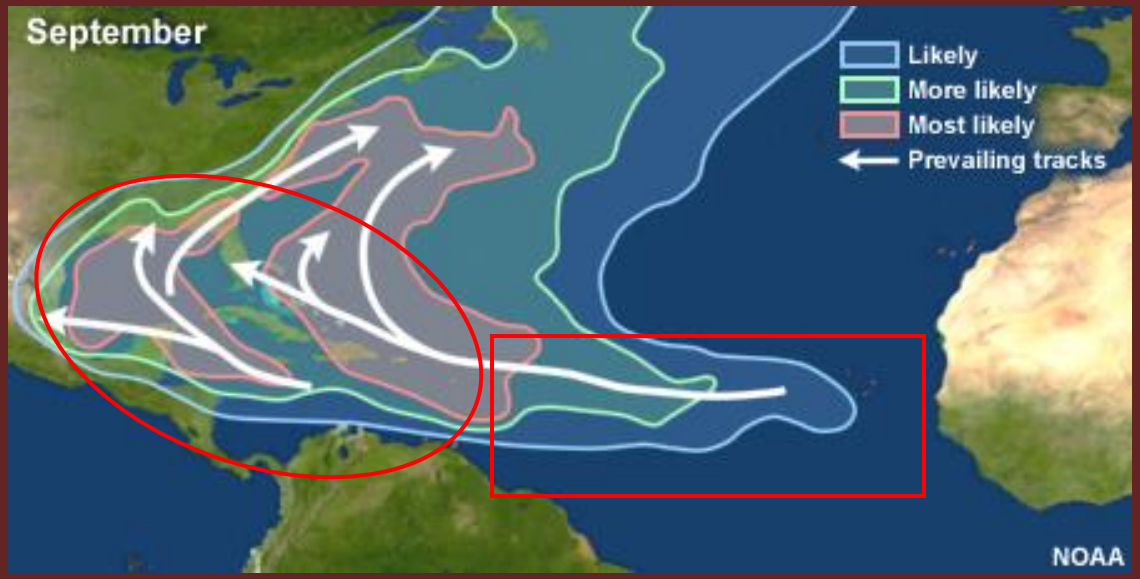


July: On average about 1 storm every July. Areas of possible development spreads east and covers the western Atlantic, Caribbean, and Gulf of Mexico.

Climatological Areas of Origin and Tracks



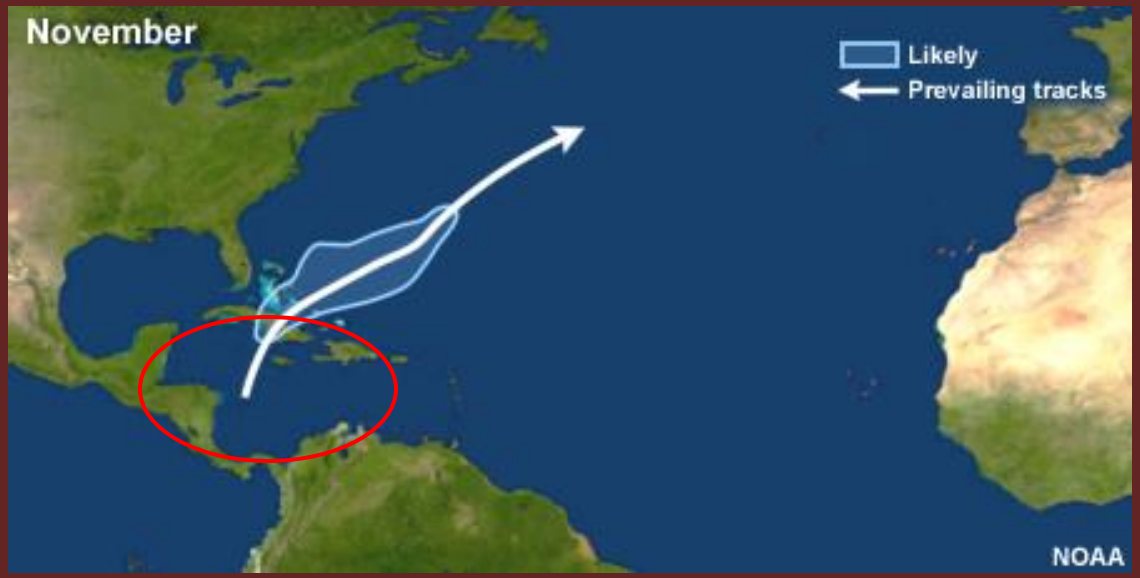
August: Activity usually increases in August. On Average about 2-3 storm for in August. The Cape Verde season begins.



September: The climatological peak of the season. Storms can form nearly anywhere in the basin. Long track Cape Verde storms very possibly.

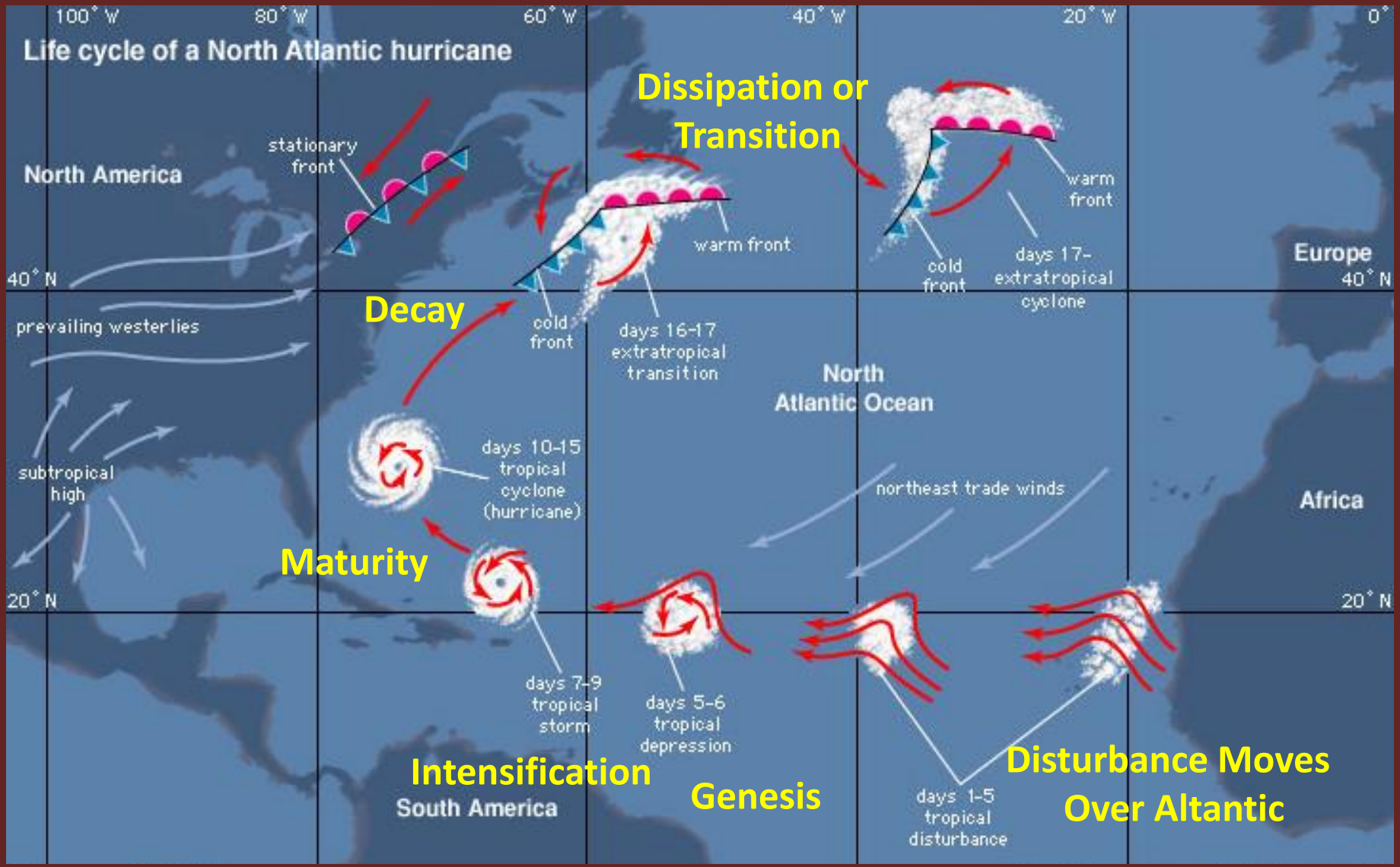
Climatological Areas of Origin and Tracks

October: Secondary peak of season in mid-October. Cape Verde season ends. Development area shifts westward, back into the Caribbean, Gulf of Mexico, and western Atlantic.



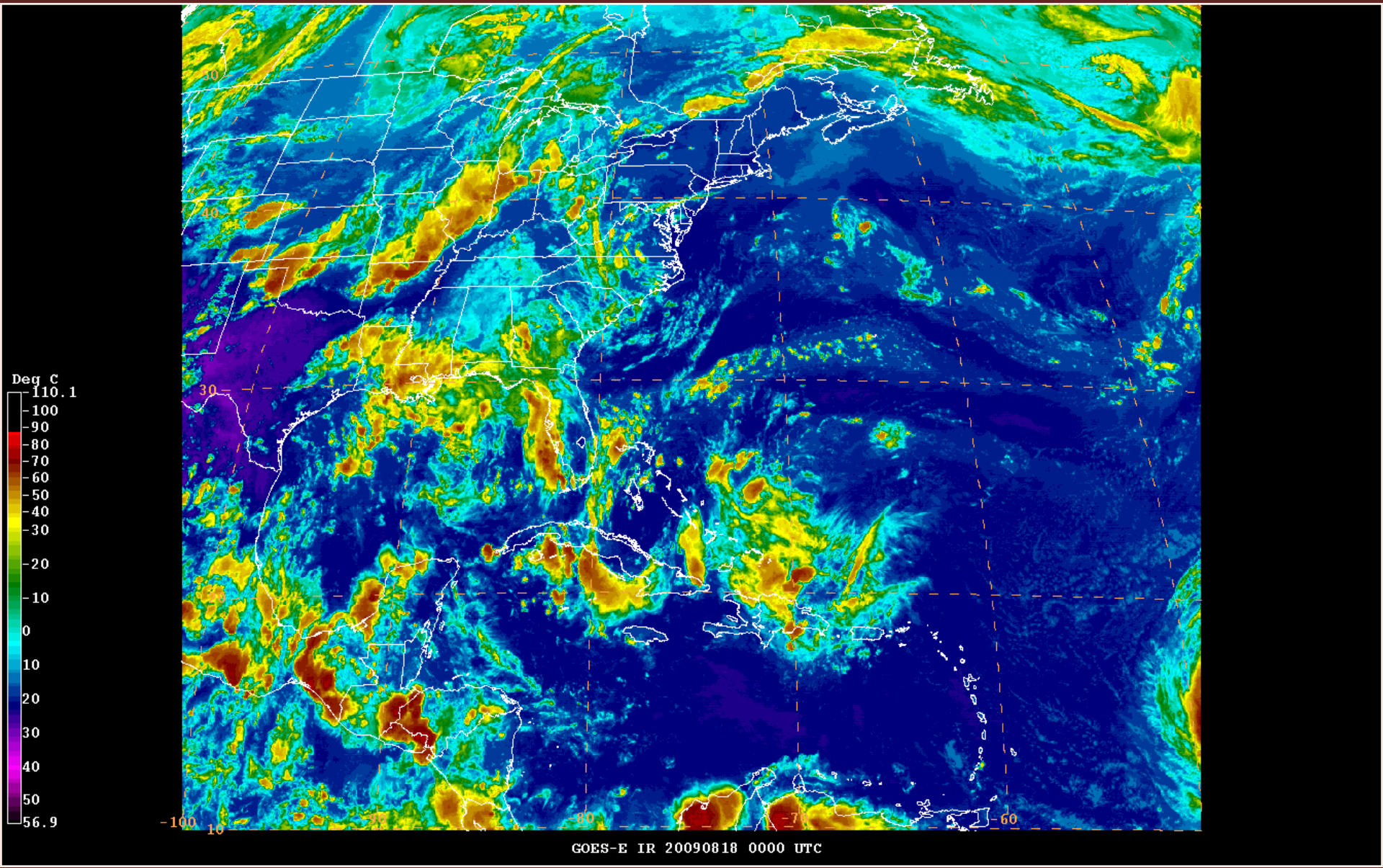
November: Season usually slows down with about 1 storm occurring ever other year. Storm that do form typically develop in central Caribbean.

Life Cycle of a Cape Verde Hurricane



Some tropical cyclones go through multiple episodes of intensification, decay, and dissipation.

Life Cycle of Hurricane Bill (2009)

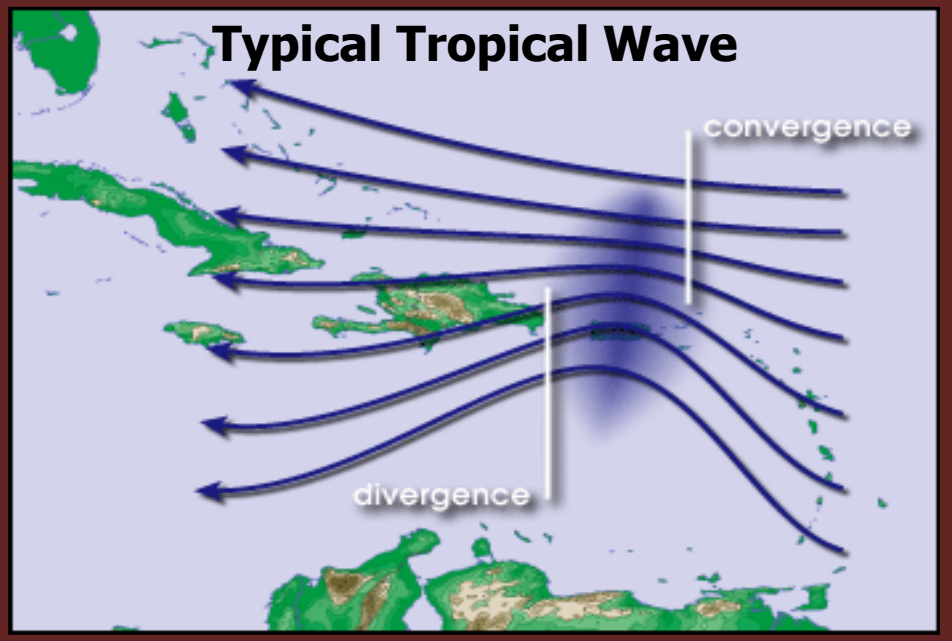


How to Build a Tropical Cyclone

Mechanical	Thermodynamic
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 play a role in about 70% of all Atlantic basin TC formations
- Cold-core low pressure systems in the upper levels of the atmosphere (*i.e.* Grace 2009)
- Decaying frontal systems (*i.e.* T.D. One 2009)
- Thunderstorm clusters produced by non-tropical weather systems (Danny 1997)



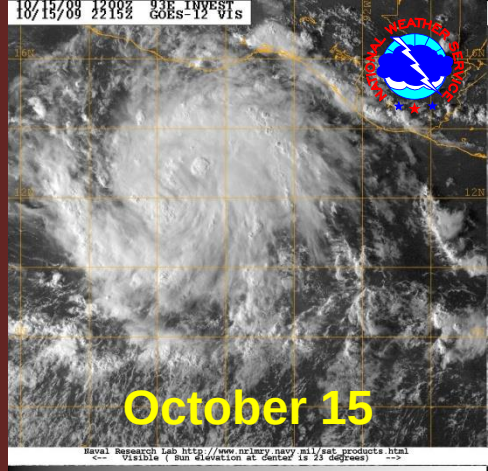
Factors Influencing TC Intensity

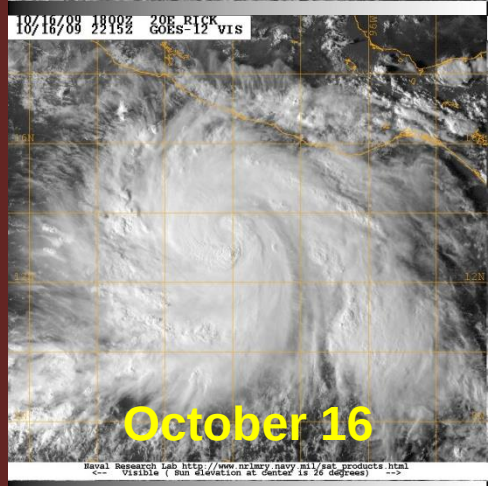
- Sea surface temperature (SST) and upper ocean heat content (OHC)
- Interaction with land
- Vertical wind shear
- Interactions with upper-level troughs, other cyclones (tropical and extratropical)
- Temperature and moisture patterns in the storm environment
- Internal structural changes, such as eyewall replacement cycles

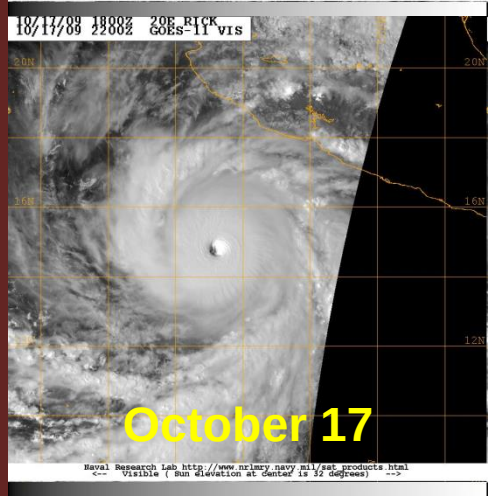
Favorable combinations of these factors lead to intensification. Unfavorable combinations can cause arrested development or decay.

Intensification

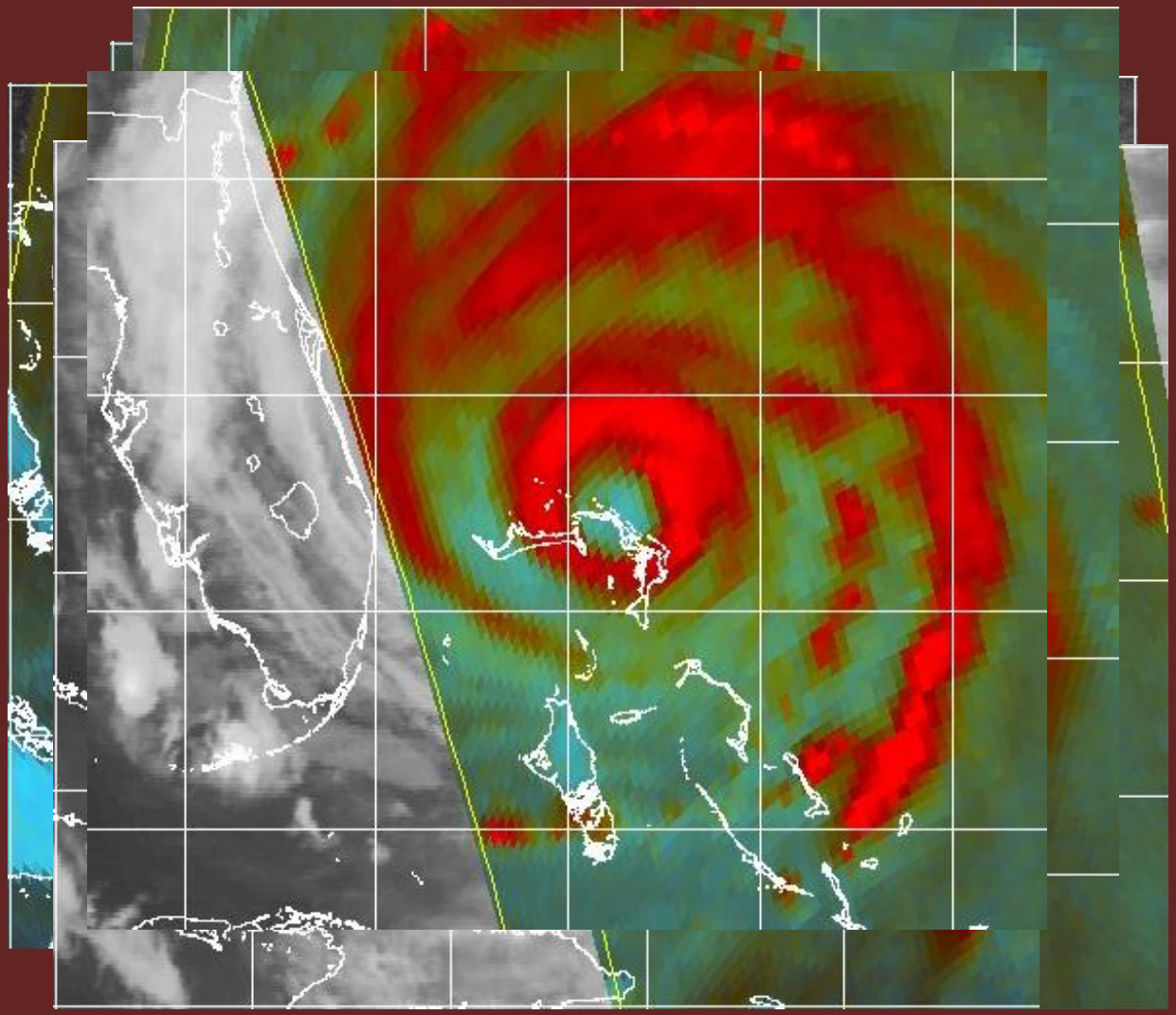
- Thunderstorm activity increases in amount and becomes more symmetric near the circulation center
- The strongest winds move inward toward the center
- The surface pressure falls at the center, while high pressure forms over the cyclone at the upper levels
- The thunderstorms develop into a closed ring – the eyewall – around the (relatively) calm eye
- Additional rainbands form outside the eyewall







Eyewall Replacement



13 / 0116Z

13 / 1122Z

13 / 1347Z

13 / 2240Z

14 / 0104Z

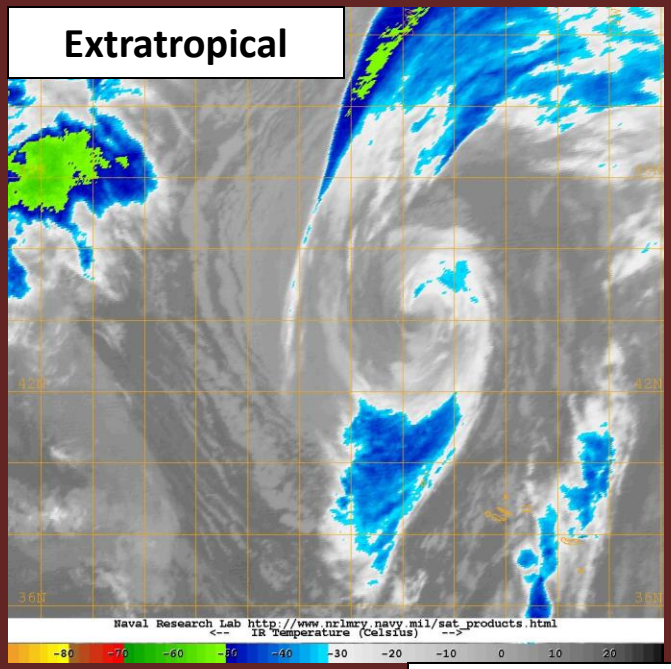
14 / 1110Z

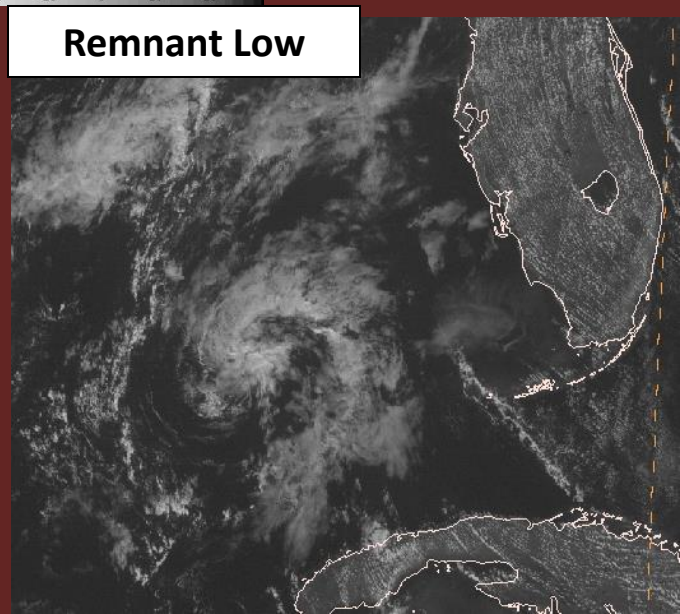
14 / 2228Z

Often causes fluctuations in intensity of strong hurricanes.
These are difficult to predict with any precision.

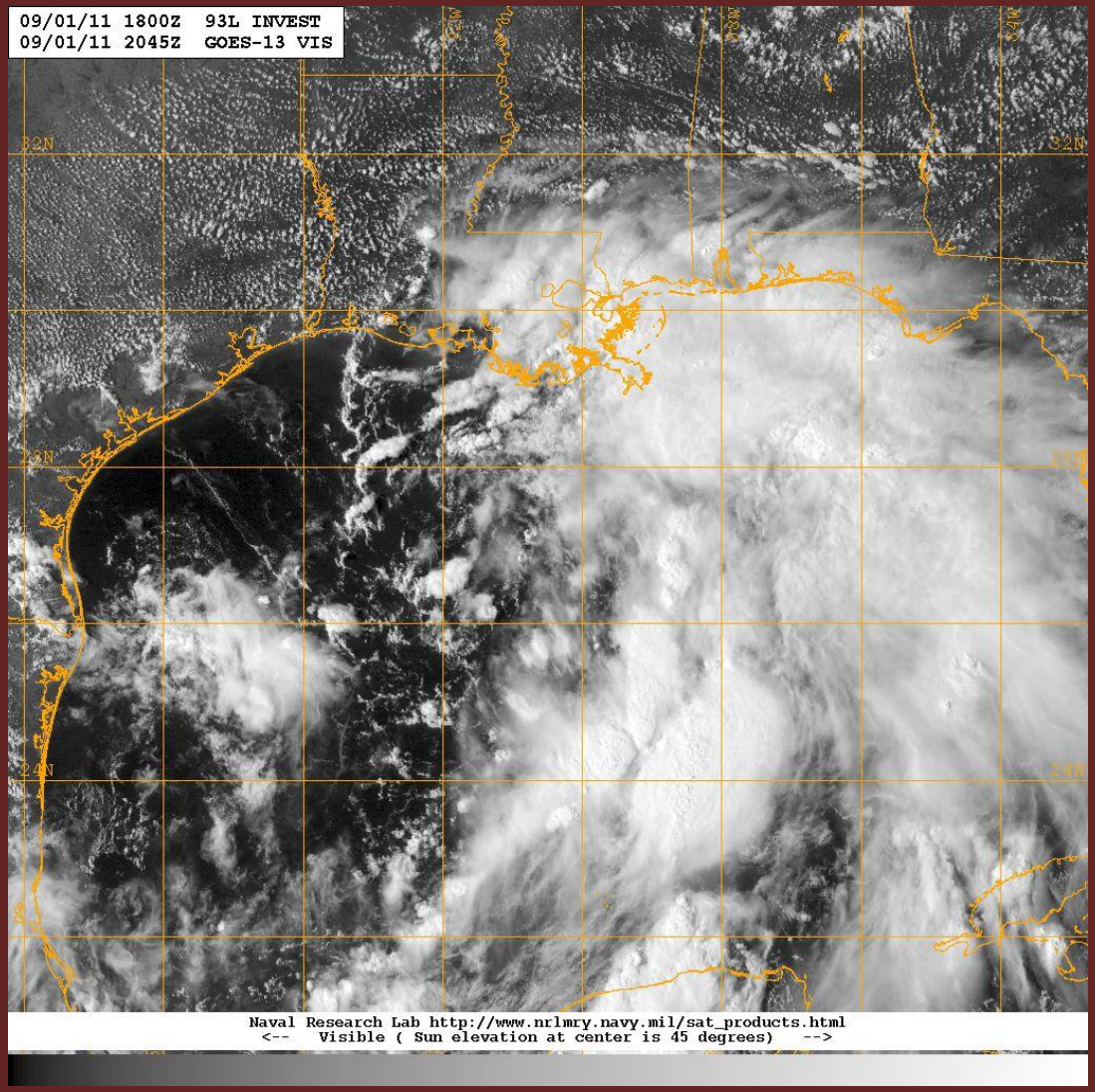
How do Tropical Cyclones die?

- Weaken over land
- Become "post-tropical"
  - Transform into an extratropical cyclone
  - Weaken over water due to hostile environmental conditions such as strong wind shear or cool SSTs, leaving a remnant low
- Merge with or be absorbed by a larger weather system (usually an extratropical cyclone or front)

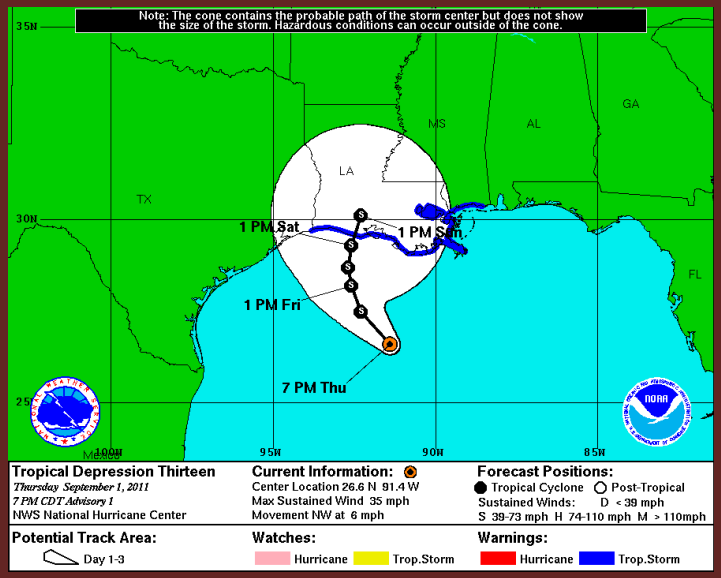




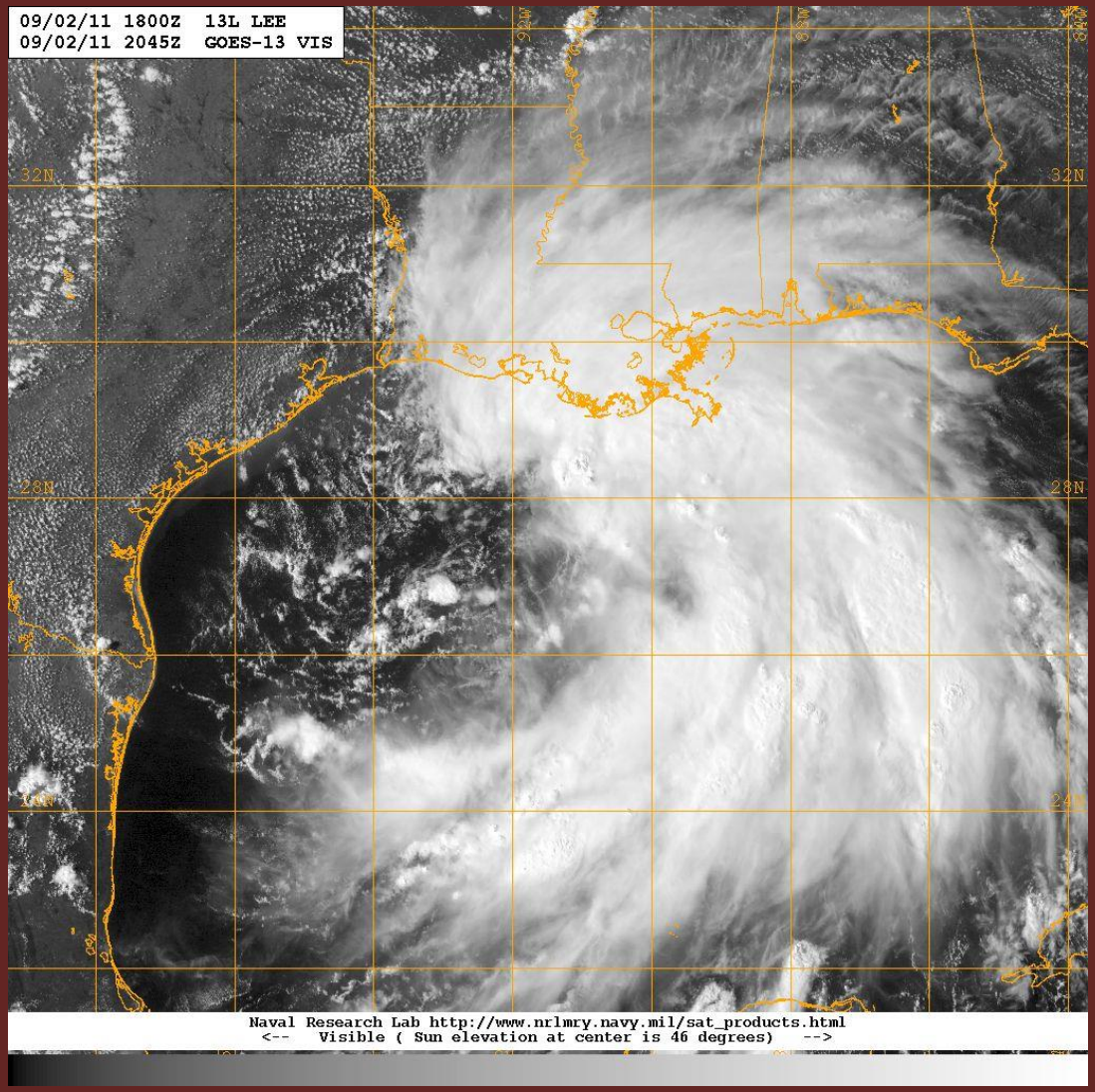
Life Cycle of Tropical Storm Lee



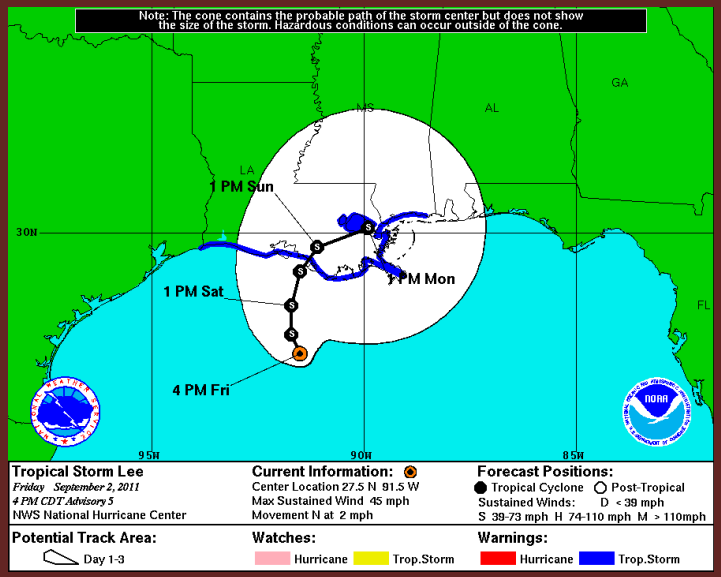
Day 1 - Forms over central Gulf of Mexico



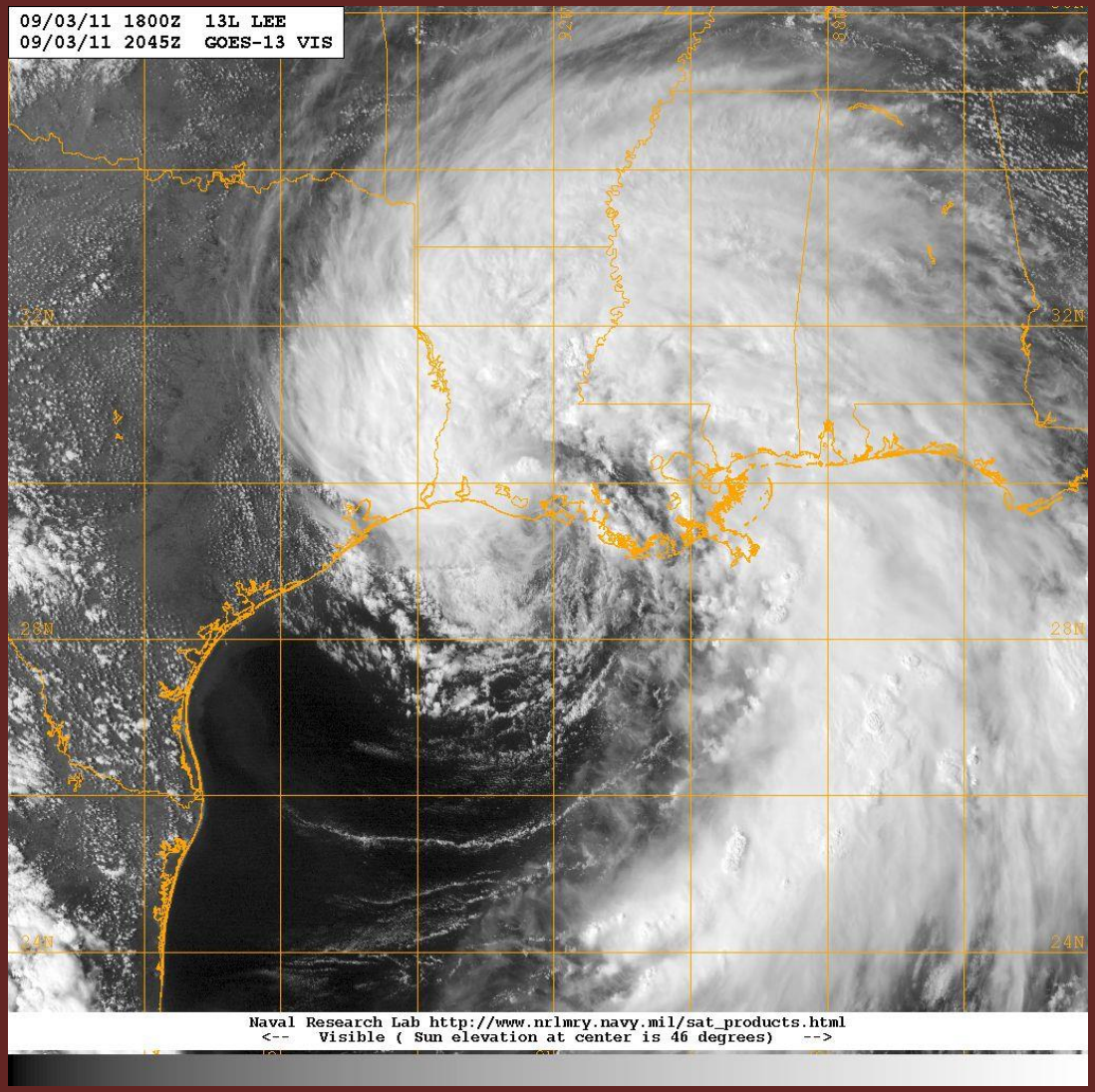
Life Cycle of Tropical Storm Lee



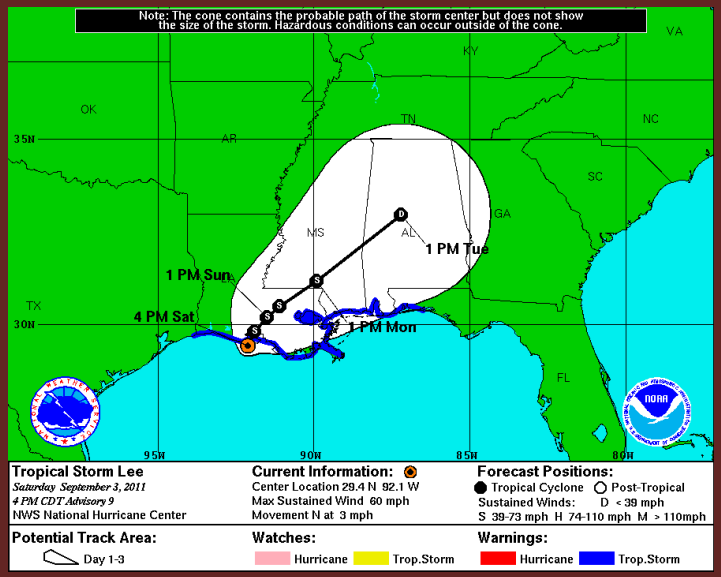
Day 2 – Strengthens into a tropical storm



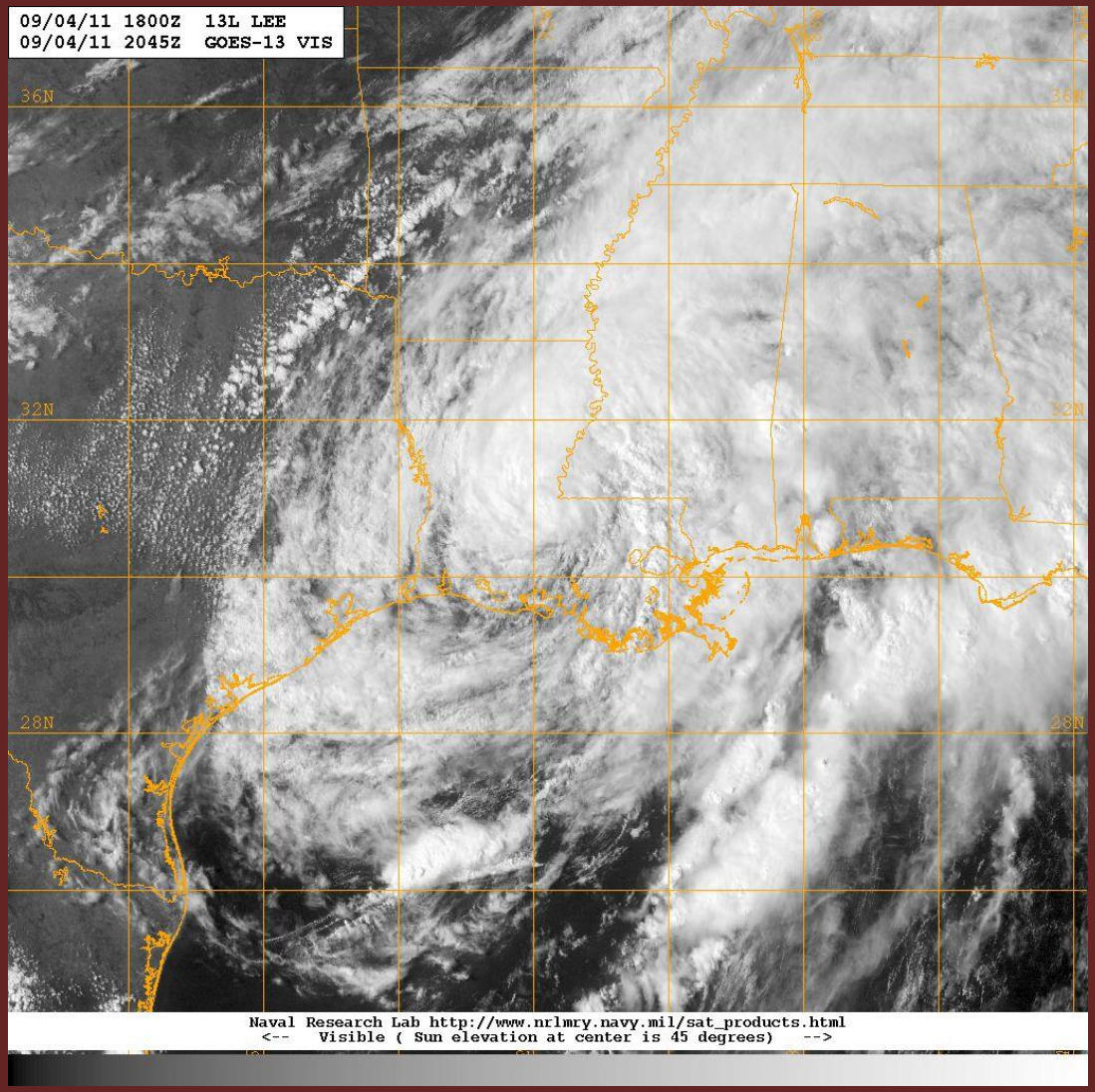
Life Cycle of Tropical Storm Lee



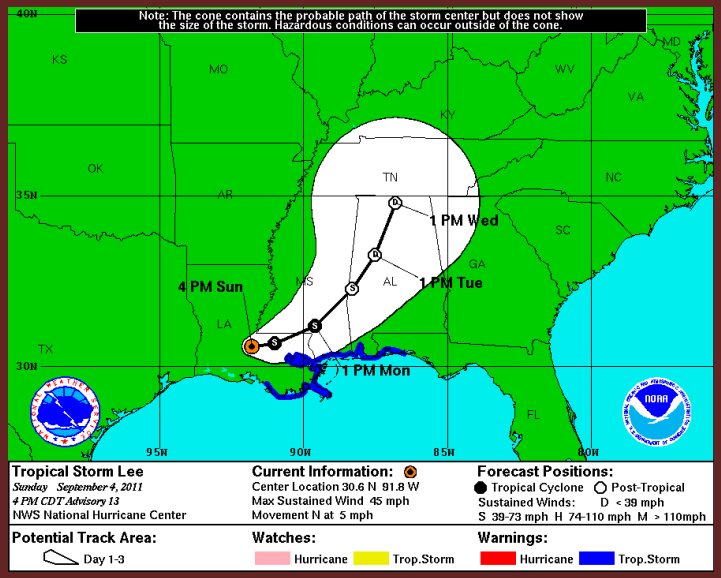
Day 3 – System evolves into a subtropical storm near the coast

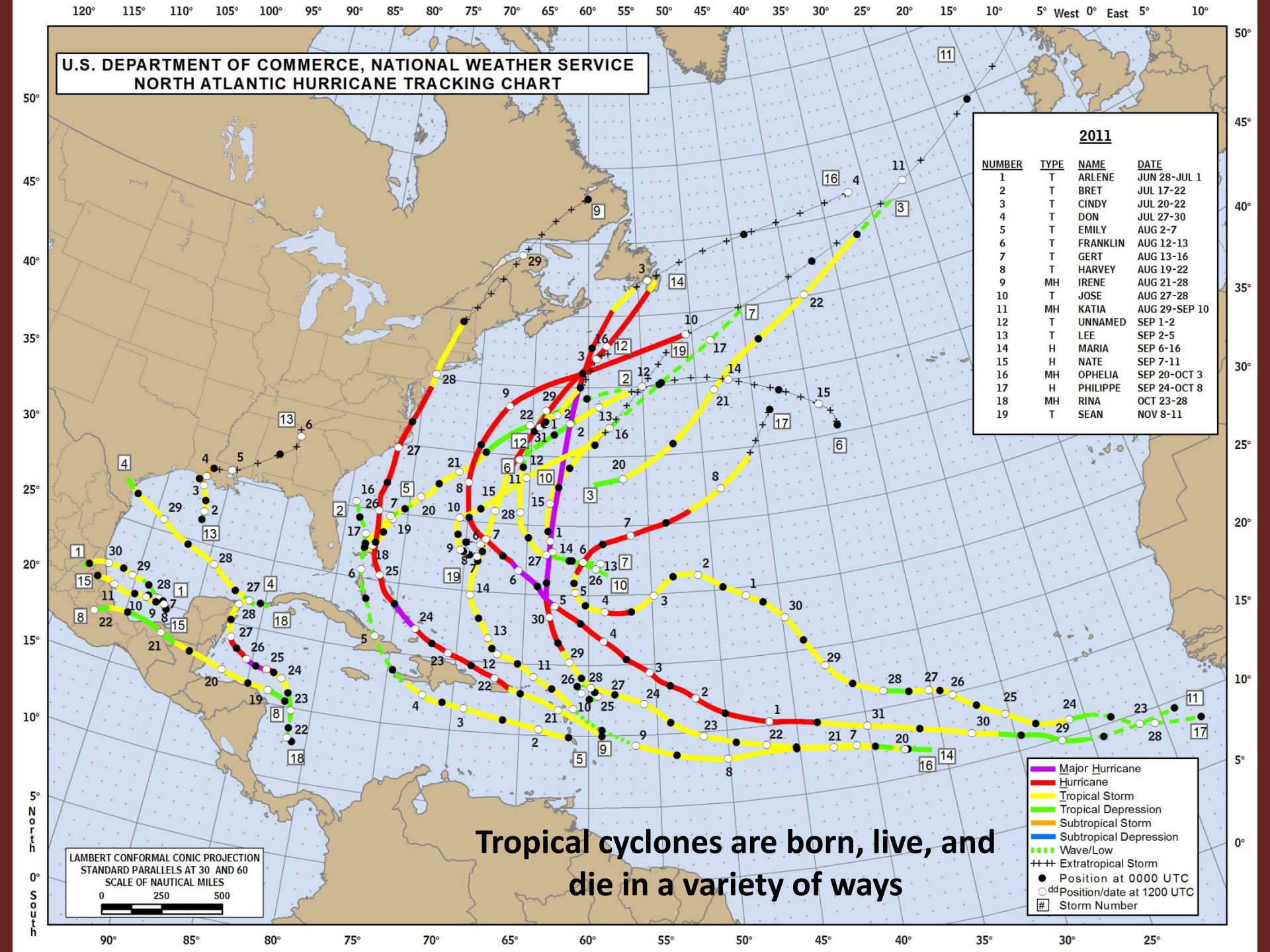


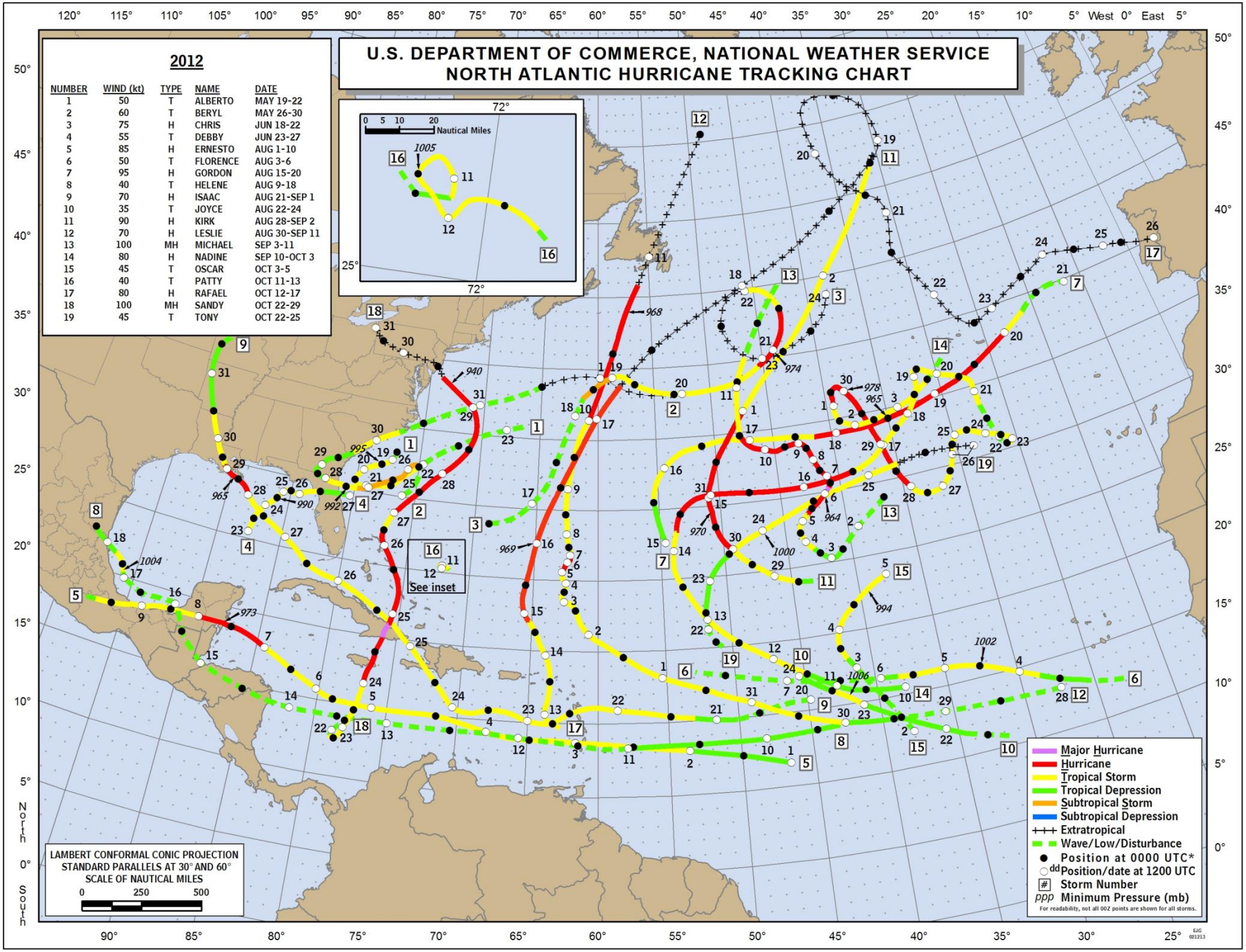
Life cycle of Tropical Storm Lee

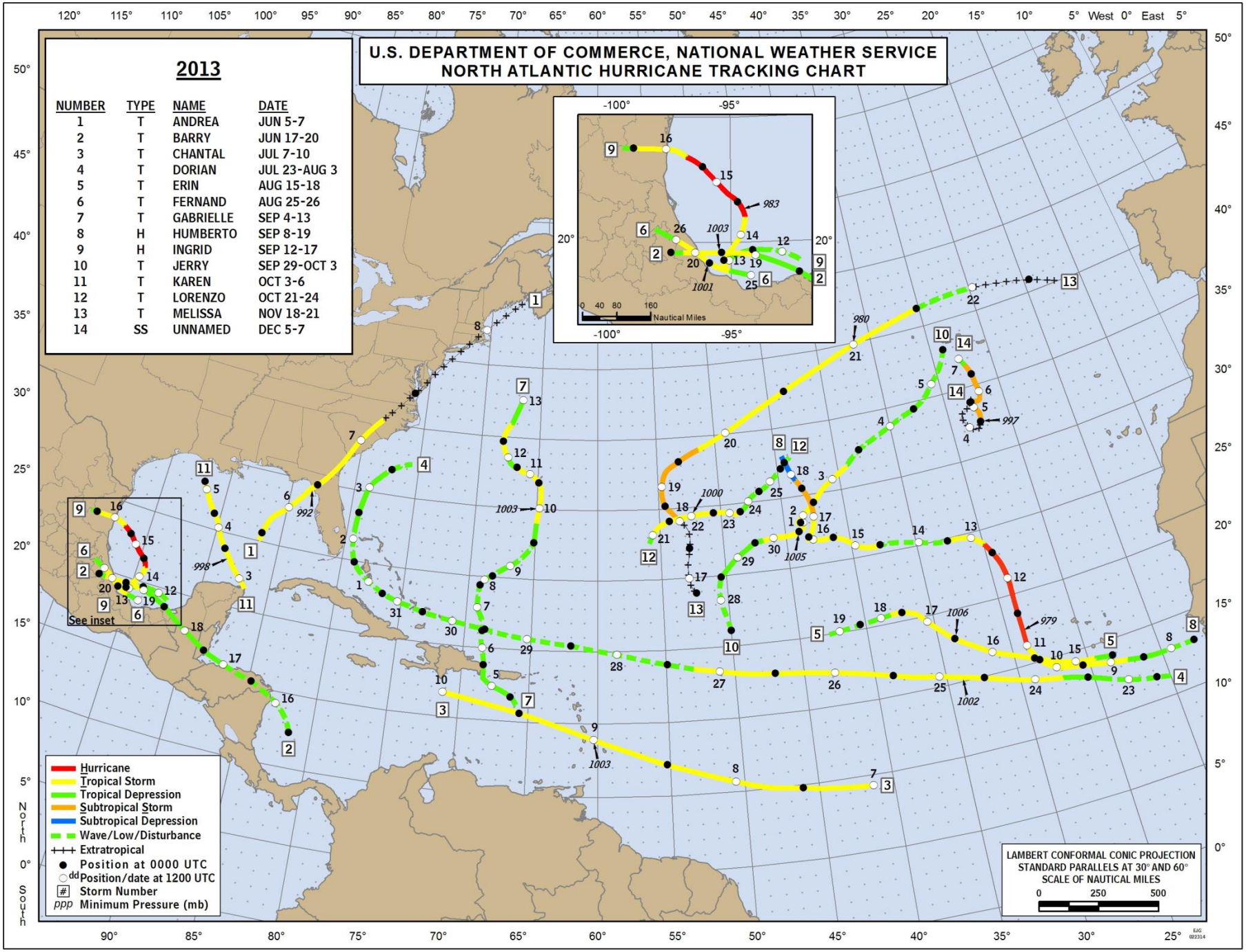


Day 4 – System slowly weakens over Louisiana

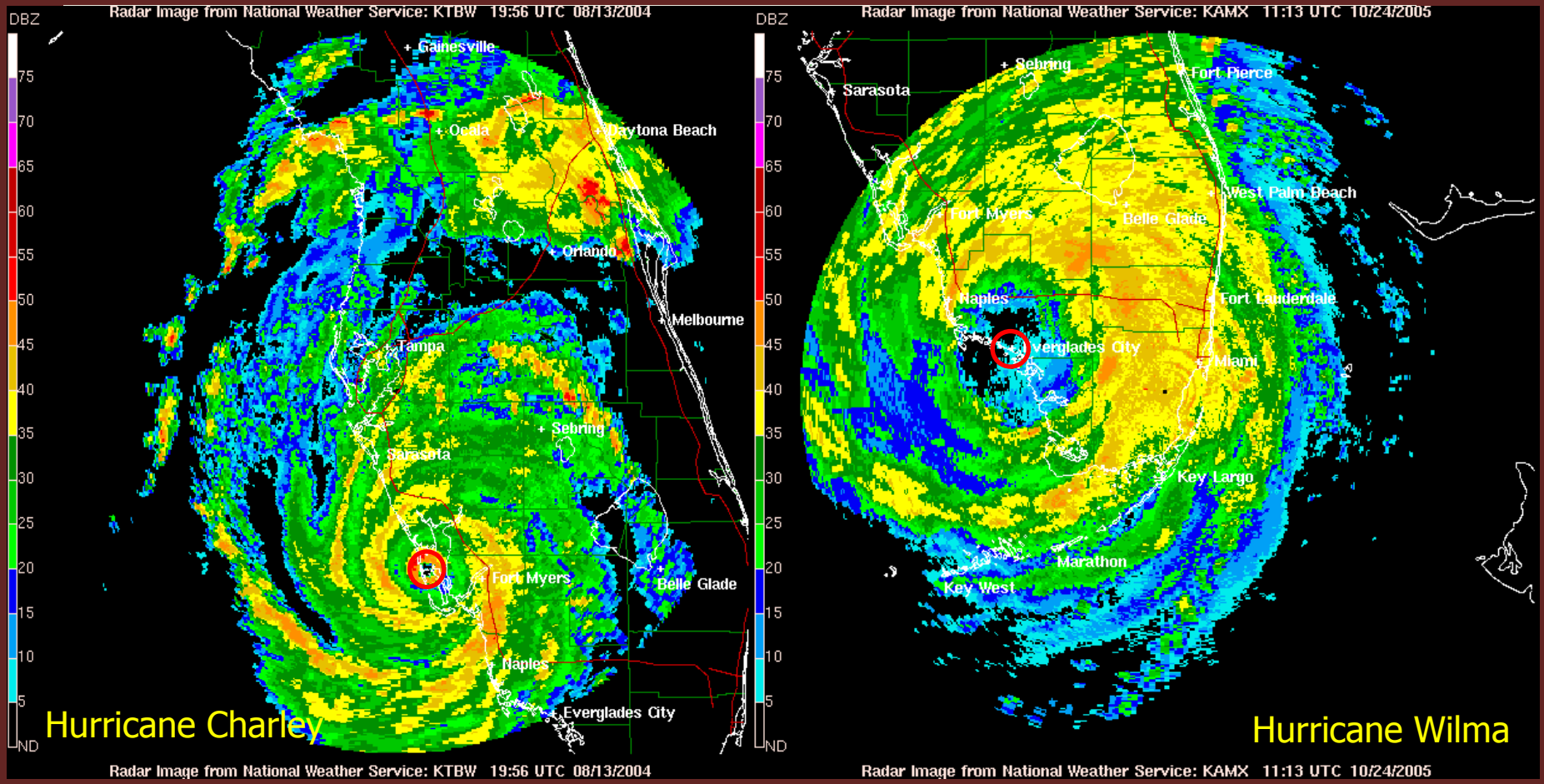



U.S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
2011
NUMBER TYPE NAME DATE
1 T ARLENE JUN 28-JUL 1
2 T BRET JUL 17-22
3 T CINDY JUL 20-22
4 T DON JUL 27-30
5 T EMILY AUG 2-7
6 T FRANKLIN AUG 12-13
7 T GERT AUG 13-16
8 T HARVEY AUG 19-22
9 MH IRENE AUG 21-28
10 T JOSE AUG 27-28
11 MH KATIA AUG 29-SEP 10
12 T UNNAMED SEP 1-2
13 T LEE SEP 2-5
14 H MARIA SEP 6-16
15 H NATE SEP 7-11
16 MH OPHELIA SEP 20-OCT 3
17 H PHILIPPE SEP 24-OCT 8
18 MH RINA OCT 23-28
19 T SEAN NOV 8-11
Major Hurricane
Hurricane
Tropical Storm
Tropical Depression
Subtropical Storm
Subtropical Depression
Wave/Low
Extratropical Storm
Position at 0000 UTC
dd Position/date at 1200 UTC
Storm Number
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30 AND 60
SCALE OF NAUTICAL MILES
0 250 500
Tropical cyclones are born, live, and die in a variety of ways


U.S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
2012
NUMBER WIND (kt) TYPE NAME DATE
1 50 T ALBERTO MAY 19-22
2 60 T BERYL MAY 26-30
3 75 H CHRIS JUN 18-22
4 55 T DEBBY JUN 23-27
5 85 H ERNESTO AUG 1-10
6 50 T FLORENCE AUG 3-6
7 95 H GORDON AUG 15-20
8 40 T HELENE AUG 9-18
9 70 H ISAAC AUG 21-SEP 1
10 35 T JOYCE AUG 22-24
11 90 H KIRK AUG 28-SEP 2
12 70 H LESLIE AUG 30-SEP 11
13 100 MH MICHAEL SEP 3-11
14 80 H NADINE SEP 10-OCT 3
15 45 T OSCAR OCT 3-5
16 40 T PATTY OCT 11-13
17 80 H RAFAEL OCT 12-17
18 100 MH SANDY OCT 22-29
19 45 T TONY OCT 22-25
0 5 10 20 Nautical Miles
See inset
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30° AND 60°
SCALE OF NAUTICAL MILES
0 250 500
Major Hurricane
Hurricane
Tropical Storm
Tropical Depression
Subtropical Storm
Subtropical Depression
Extratropical
Wave/Low/Disturbance
Position at 0000 UTC*
dd Position/date at 1200 UTC
Storm Number
ppp Minimum Pressure (mb)
For readability, not all 00Z points are shown for all storms.


U.S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
2013
NUMBER TYPE NAME DATE
1 T ANDREA JUN 5-7
2 T BARRY JUN 17-20
3 T CHANTAL JUL 7-10
4 T DORIAN JUL 23-AUG 3
5 T ERIN AUG 15-18
6 T FERNAND AUG 25-26
7 T GABRIELLE SEP 4-13
8 H HUMBERTO SEP 8-19
9 H INGRID SEP 12-17
10 T JERRY SEP 29-OCT 3
11 T KAREN OCT 3-6
12 T LORENZO OCT 21-24
13 T MELISSA NOV 18-21
14 SS UNNAMED DEC 5-7
See inset
0 40 80 160
Nautical Miles
Hurricane
Tropical Storm
Tropical Depression
Subtropical Storm
Subtropical Depression
Wave/Low/Disturbance
Extratropical
Position at 0000 UTC
dd Position/date at 1200 UTC
Storm Number
ppp Minimum Pressure (mb)
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30° AND 60°
SCALE OF NAUTICAL MILES
0 250 500

Tropical Cyclones Come in All Sizes



Structure of a Hurricane

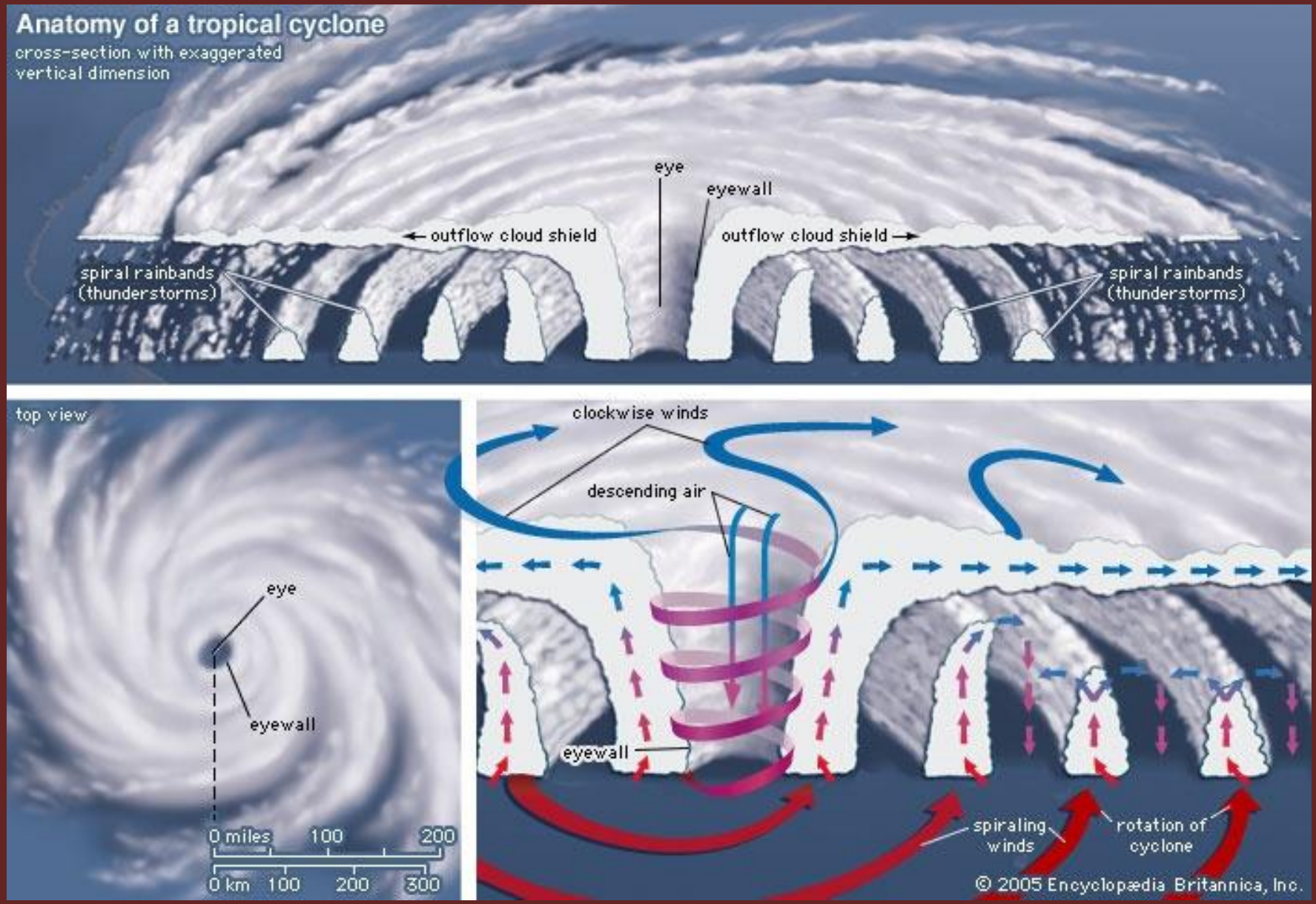


Image courtesy of NOAA / AOC

Hurricane Hazards

Wind

Waves / Rip Currents

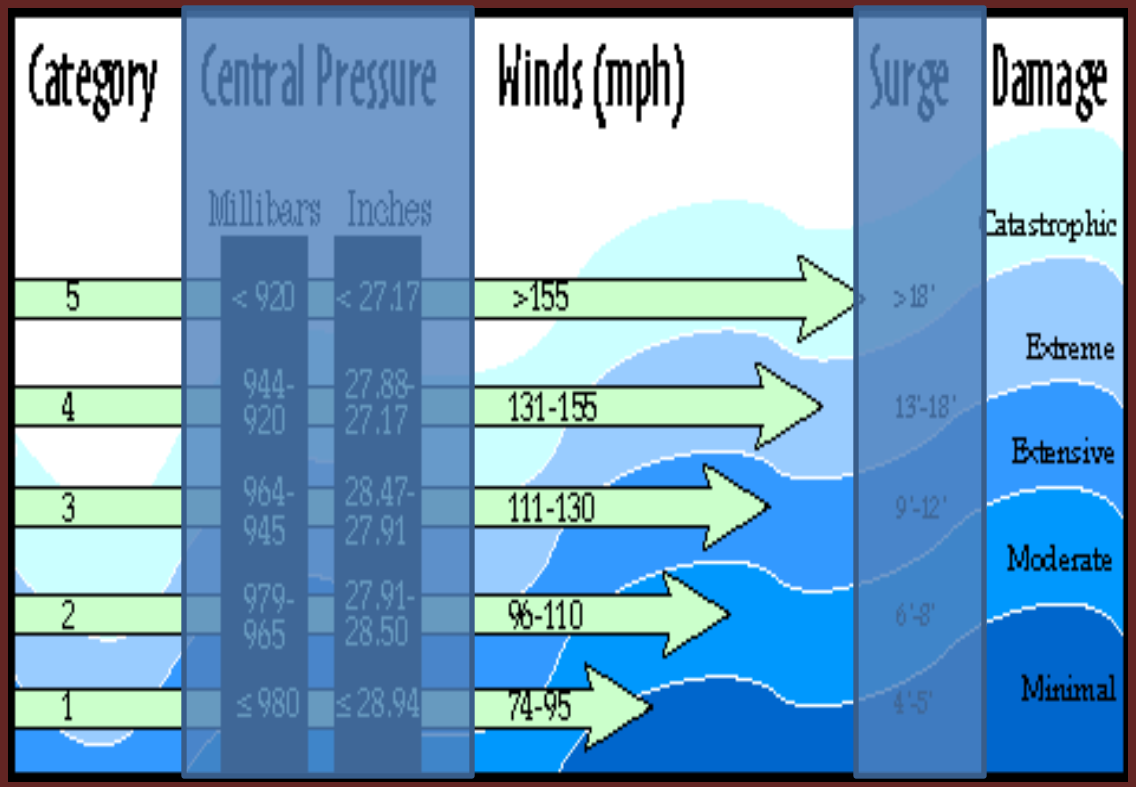
Tornadoes

Storm Surge

Rainfall / Inland Flooding

Saffir-Simpson Hurricane Wind Scale

Surge, rainfall, and pressure fit the scale
like a square peg in a round hole



KATRINA (3)

IKE (2)

CHARLEY (4)

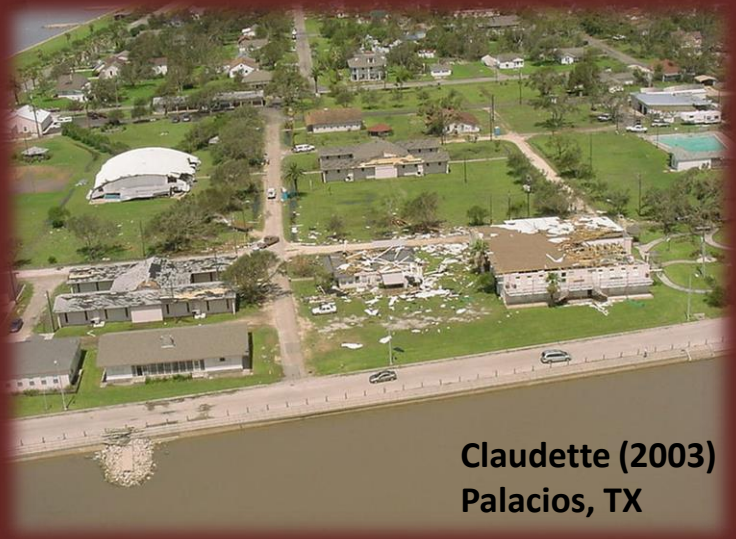
http://www.nhc.noaa.gov/aboutsshs.shtml

Category 1 (74 – 95 mph)

Very dangerous winds will produce some damage

Humberto (2007)
Southeast TX

Katrina (2005)
Miami, FL



Claudette (2003)
Palacios, TX

Lili (2002)
Louisiana

Category 2 (96 – 110 mph)

Extremely dangerous winds will cause extensive damage

Category 3 (111 – 129 mph)

Devastating damage will occur

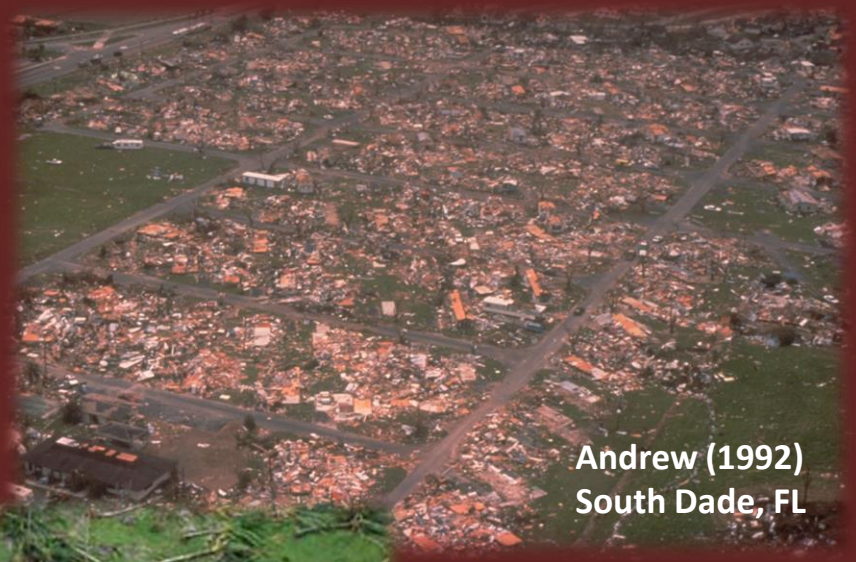
Category 4 (130 – 156 mph)

Catastrophic damage will occur

Category 5 (greater than 156 mph)

Catastrophic damage will occur

Andrew (1992)
Florida City, FL



Andrew (1992)
South Dade, FL

Felix (2007)
Nicaragua

3:54 PM

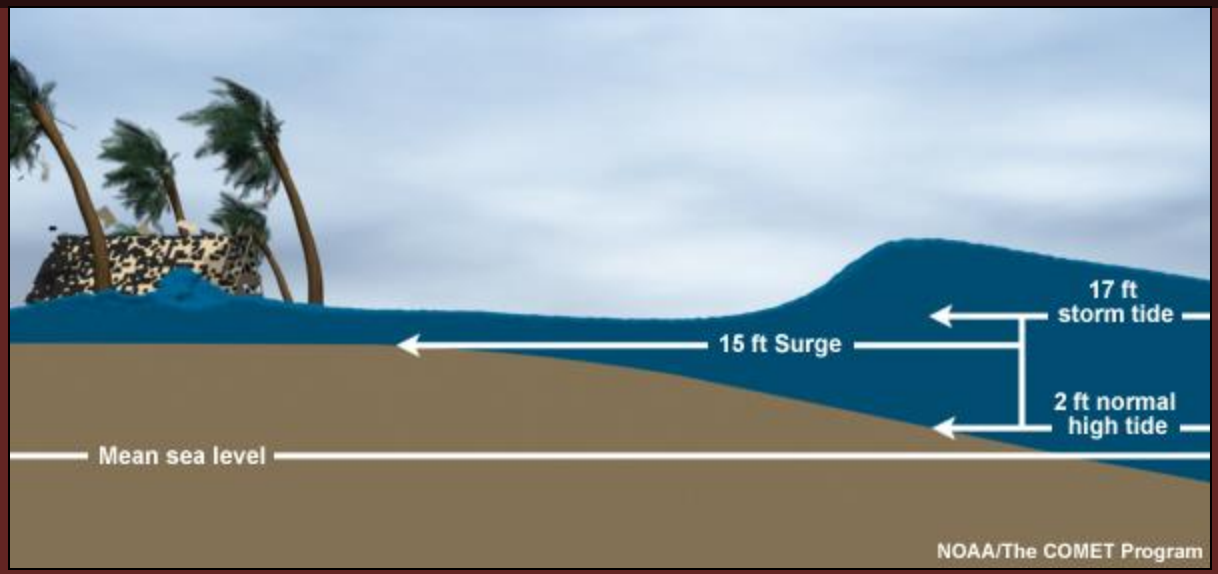
Wind-blown Debris can Become Deadly Projectiles in a Hurricane

Hurricane wind hazards can extend well inland along the track of the cyclone.

What is Storm Surge?

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

STORM TIDE is the water level rise during a storm due to the combination of storm surge and the astronomical tide



Storm Surge: Hurricane Katrina (2005) – Mississippi - 1200 deaths, $108 billion damage

Storm Surge: Hurricane Ike (2008) - Bolivar Peninsula, Texas - 20 deaths, $29.5 billion

Heavy Rainfall and Fresh Water Flooding

Fresh water flooding causes a significant number of tropical cyclone related deaths each year

The main factor is how much rain a tropical cyclone produces is the *speed of motion*. Intensity is <u>not</u> a major factor.

About one quarter of all deaths from 1970-1999 occurred to people who drowned in, or attempted to abandon, their vehicles.

Fort Washington, PA

Times Herald

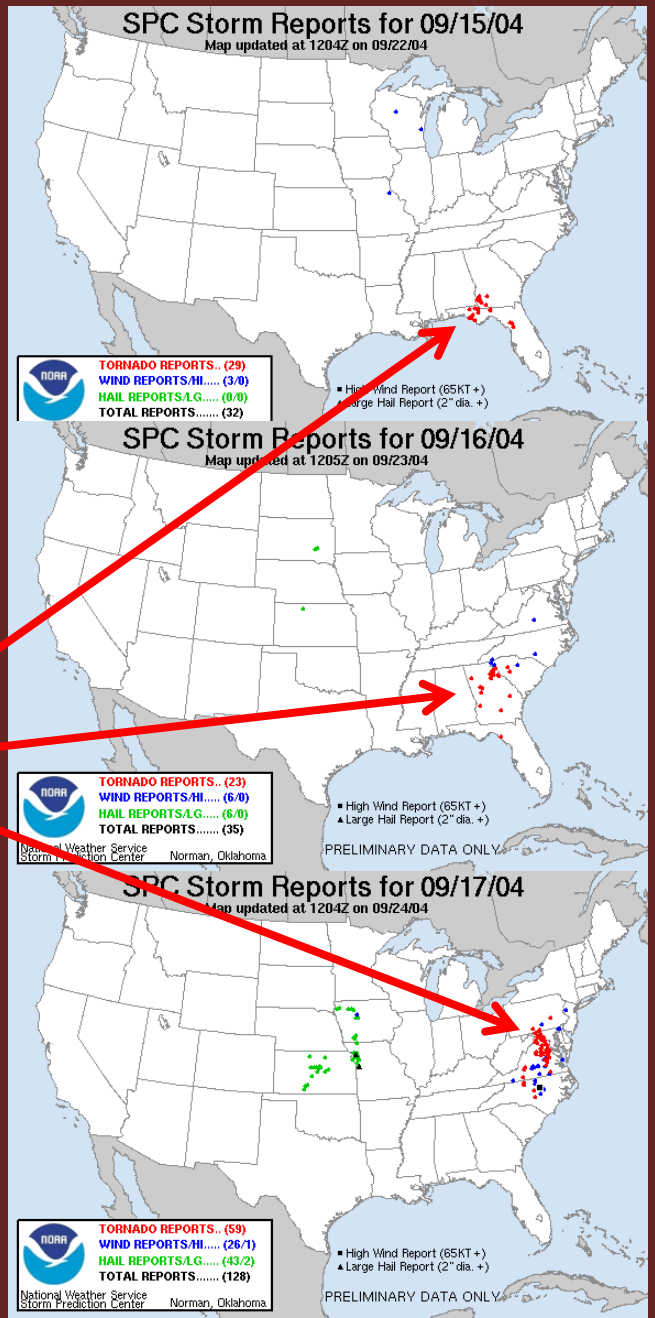
Interstate 10, Looking West, Houston, Texas

Interstate 10, Looking West, Houston, Texas
Tropical Storm Allison (2001)

Houston Chronicle

Hurricane-Induced Tornadoes

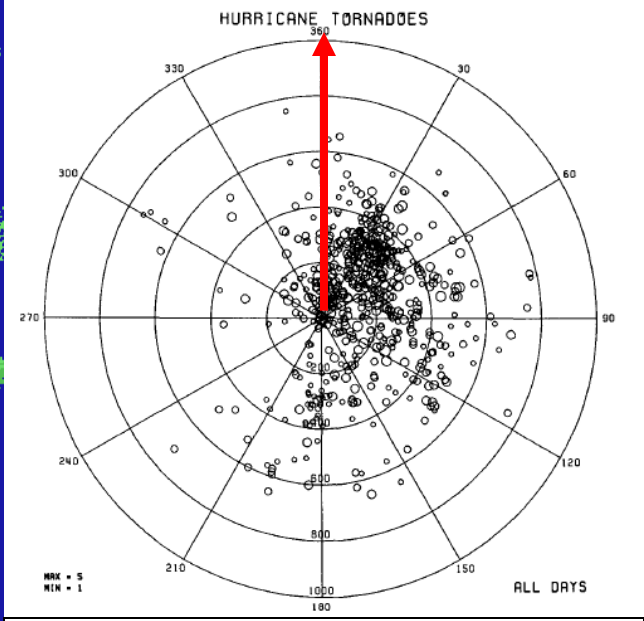
- Nearly 70% of landfalling hurricanes (1948-2000) spawned at least 1 tornado
- 40% of landfalling hurricanes spawn more than 3 tornadoes
- Some hurricanes produce tornado “outbreaks”
  - Hurricane Beulah (1967): 141
  - Hurricane Ivan (2004): 117
  - Hurricane Frances (2004): 101
  - Hurricane Rita (2005): 90
  - Hurricane Camille (1969): 80
  - Hurricane Katrina (2005): 43



Right Front Quadrant

Storm Motion

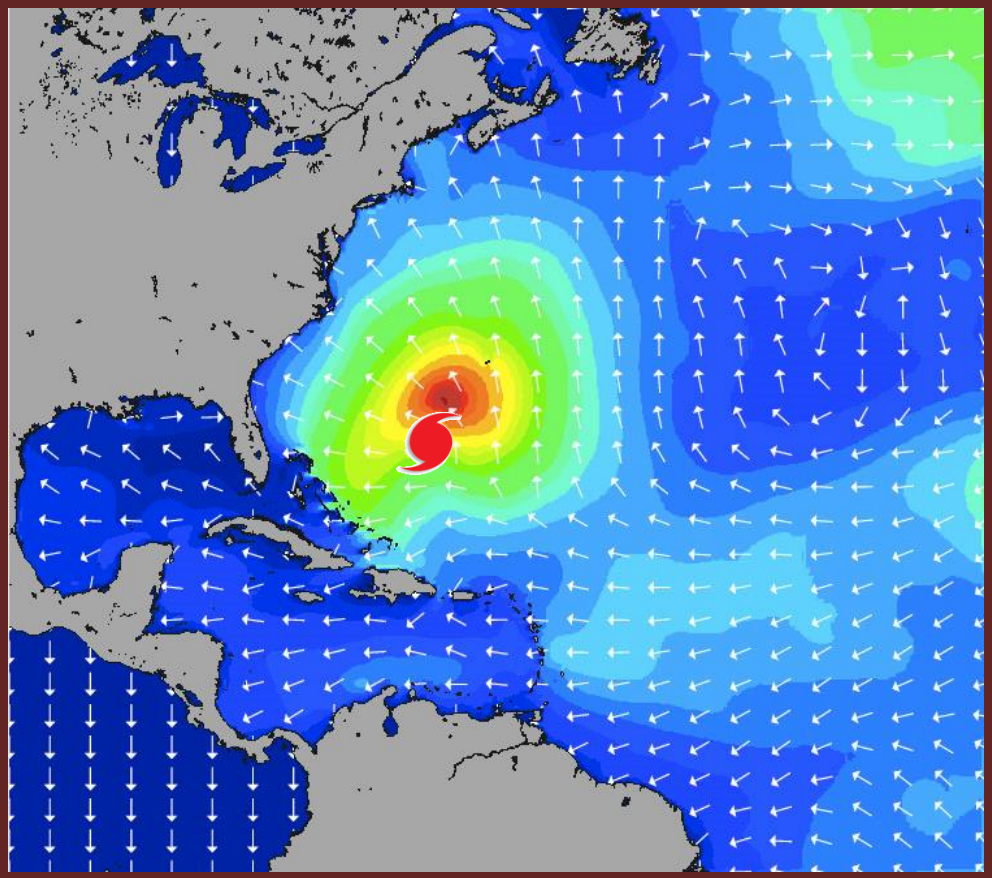
Friction over land creates low-level wind conditions favorable for the development of tornadoes



Location of all reported hurricane tornadoes from 1948-1986 plotted with respect to the storm motion at the time of the tornado (McCaul 1991)

Waves and Rip Currents

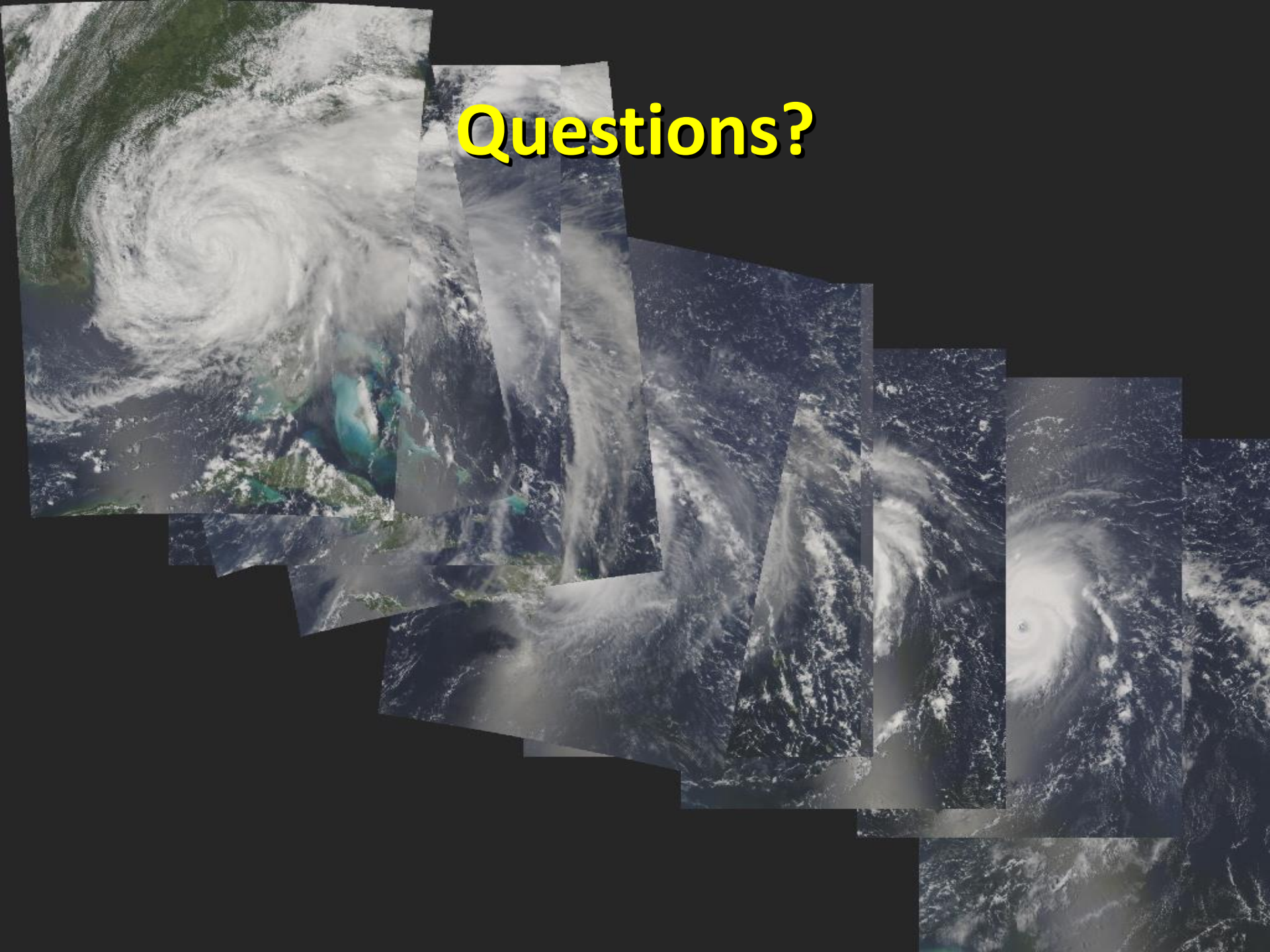
Swell from a large hurricane can affect the beach of the entire western Atlantic



Hurricane Bertha (2008):
- Over 1500 rescues in Ocean City, Maryland
- 3 people drowned along the coast of New Jersey

Hurricane Bill (2009)
- 1 person died in Maine
- 1 person died in Florida

Hurricane Danielle (2010)
- 1 person died in Florida


Questions?