Natural Hazards and Disaster

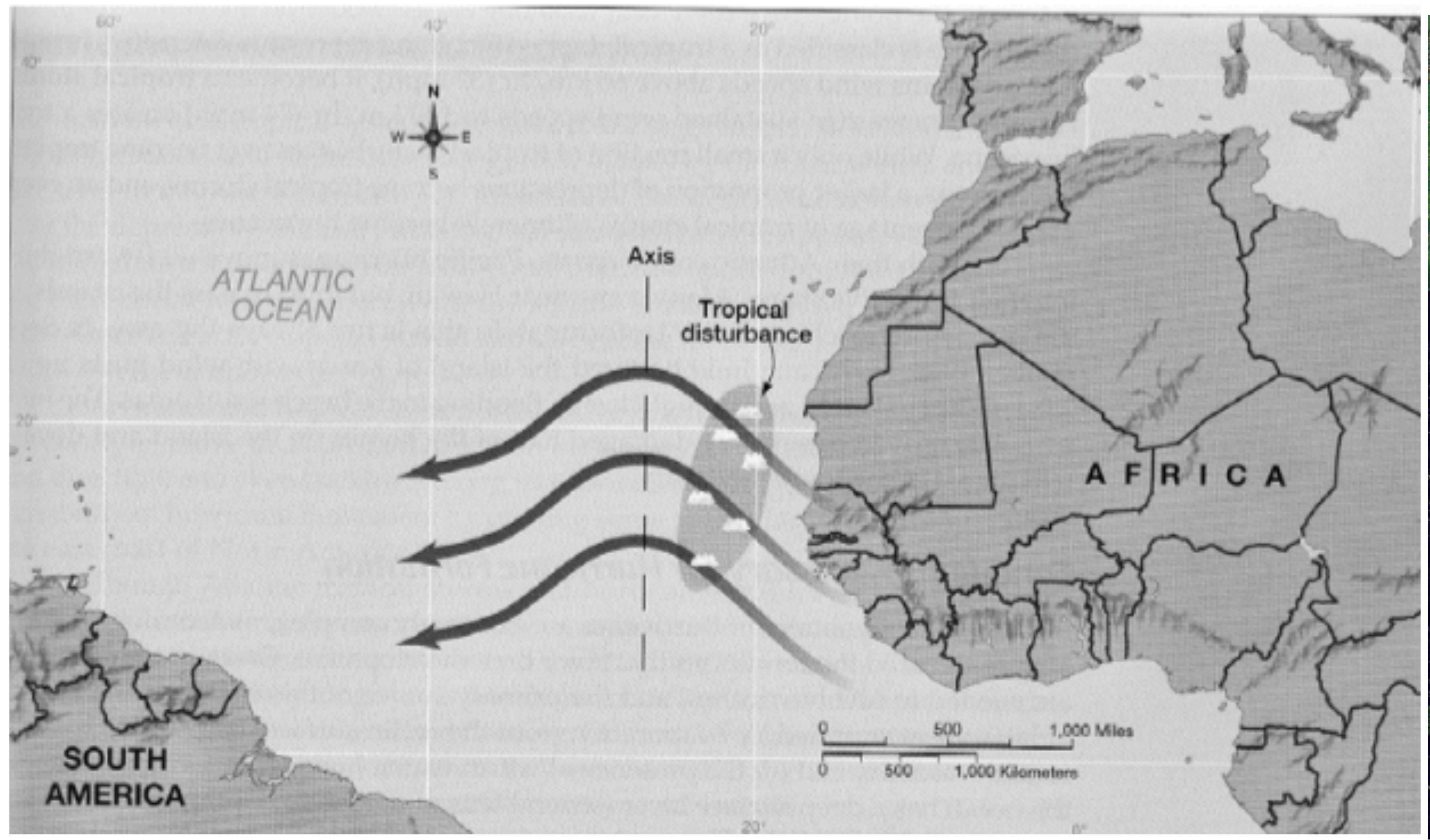
Lab in Class 20: Hurricanes, Typhoons, Cyclones

- Where is Sandy?
- Which was worst?
- Hurricane tracking
- Hurricane return period

Class 20: Hurricanes, Typhoons, Cyclones (continued), Tornados

Lab Hurricane, Typhoons, Cyclones

North Atlantic hurricanes and their southern Pacific Ocean equivalents, called typhoons, have often caused immense damage and significant loss of life. Hurricane prediction and tracking is therefore one of the most important aspects of weather forecasting, and hurricane preparedness is a critical factor for all residents of U.S. A.'s coastal communities. Hurricane formation begins with rising warm air over warm ocean water, which causes the atmospheric pressure in that region to fall and generates waves in the atmosphere, known as tropical waves. Winds are attracted into the low pressure centers, where Earth's Coriolis effect causes a counterclockwise wind circulation, called cyclonic circulation. Ocean water off the west coast of Africa is warmest in summer and autumn, and therefore the North Atlantic hurricane season officially begins on June 1 and ends on November 30, although hurricanes can and do occur well outside of that time range when seawater temperatures are warm enough.



Left : Tropical waves in the atmosphere are generated above warm ocean water off the African coast.
Right : Satellite view of Hurricane Fran off the Florida coast in September 1996.

A Tropical Disturbance occurs when systematically organized clouds form above a low pressure zone. The system is called a Tropical Depression when the wind speeds are below 65 km/h. When wind speeds reach, and are sustained, at 65 km/h or more, the cyclonic circulation is called a Tropical Storm. When sustained wind speeds exceed 118 km/h, the storm is officially called a hurricane and at this stage the clouds form the characteristic spiral hurricane structure.

Lab Hurricane, Typhoons, Cyclones

The intensity of a hurricane, sometimes referred to as its strength, is assessed from its lowest atmospheric pressure reached, measured in hPa (1 millibar = 1 hPa). The category ascribed to a hurricane is based on its maximum wind speeds, which must be sustained for at least one minute, using the Saffir-Simpson scale.

For some of the below exercises, the websites provide wind speeds in knots (kt, or also written as kn). One knot (1 kt) = 1.85 km/h = 1.15 mph

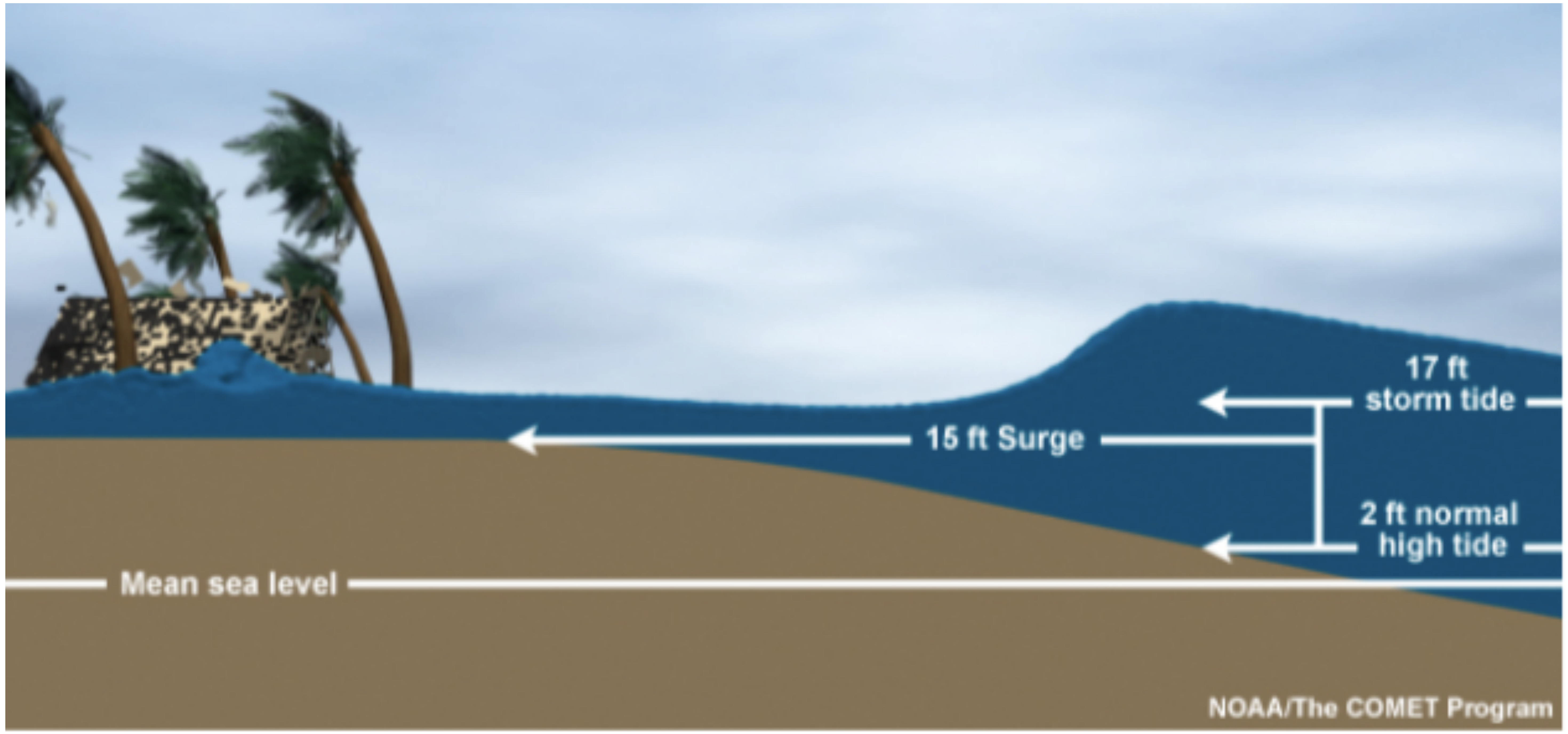
Most of the damage caused by hurricanes is not directly caused by the high winds themselves, but by the storm surge that the winds generate and, occasionally, from tornadoes that are spawned in the trailing edge of the storm system.

Saffir-Simpson Hurricane Wind Scale

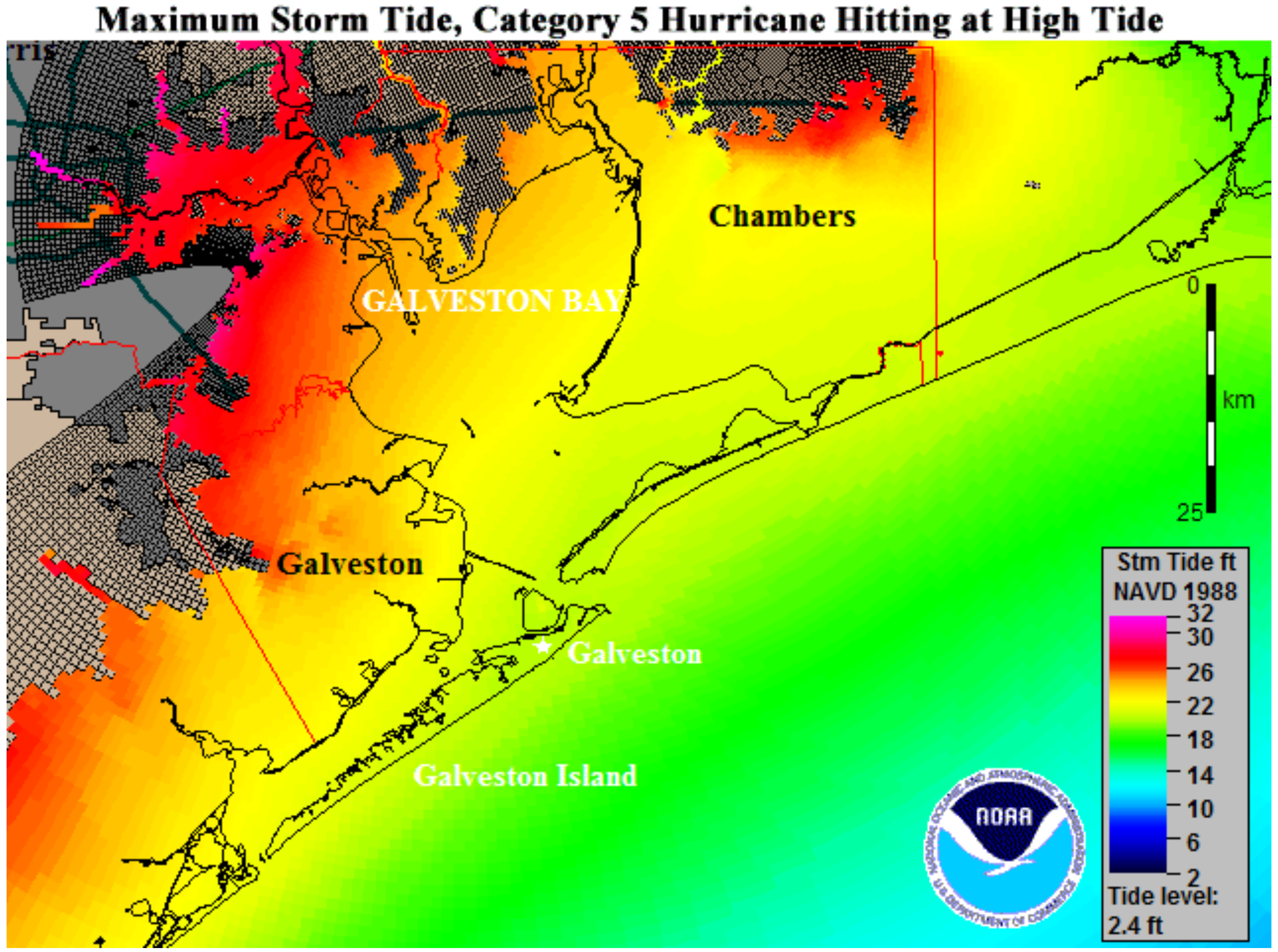
Hurricane Category	Peak 1-min sustained Wind Speeds (mph)	Peak 1-min sustained Wind Speeds (km/h)	Damage
1	74-95	119-153	Minimal
2	96-110	154-177	Moderate
3	111-130	178-209	Extensive
4	131-155	210-249	Extreme
5	>155	>249	Catastrophic

Lab Hurricane, Typhoons, Cyclones

Storm surge is the rise in local coastal sea level caused by the storm's high winds. The storm's low atmospheric pressure center does contribute to the total rise in sea level, but only by a very small amount compared to the surge caused by the wind. Storm surge water can travel tens of km inland in low-lying coastal regions such as along the Texas, Louisiana, and Florida coasts.



Wind-driven storm surge and storm tide.



Computer model of "worst case" storm tide scenario of a category 5 hurricane hitting Galveston, TX at high tide. Not only the city of Galveston, but much of Houston's southeastern suburbs would be inundated by up to 30 ft (10 m) of storm tide water.

Lab Hurricane, Typhoons, Cyclones

Storm tides occur when the storm surge coincides with the astronomical high tide. Thus the worst possible situation for coastal communities is when a hurricane makes landfall at high tide. Unfortunately, there is no simple way to link storm surge with hurricane category.

- Hurricane Katrina (category 3 at landfall) generated an 8.5 m storm surge, which resulted in catastrophic damage when the levees of Lake Pontechrain were breached;
- Hurricane Ike (category 2 at landfall) produced a 6 m storm surge;
- Hurricane Charley (category 4 at landfall) produced a modest, although nonetheless damaging, 2 m storm surge.

Several factors affect the amount of storm surge that a hurricane will produce:

- Low or high tide at the time of landfall
- Slope of the ocean bottom at the position of landfall (shallow slope = greater surge)
- Speed of the storm's approach
- Wind strength on landfall (atmospheric pressure and/or category)
- Size (diameter) of the storm system
- Coastline shape
- Presence or absence of barrier islands
- Angle of storm's approach to the coastline (head-on or glancing angle)

Lab Hurricane, Typhoons, Cyclones

Lists of the top 20 hurricanes from 1880 to 2008, according to different ranking systems.

Top 20 Atlantic Hurricanes Ranked by Minimum Pressure				
Rank	Cyclone name	Season	Peak 1-min sustained wind speeds	Minimum Central Pressure
1	Wilma	2005	295 km/h (185 mph)	882 hPa (26.05 inHg)
2	Gilbert	1988	295 km/h (185 mph)	888 hPa (26.22 inHg)
3	Labor Day	1935	295 km/h (185 mph)	892 hPa (26.34 inHg)
4	Rita	2005	285 km/h (180 mph)	895 hPa (26.43 inHg)
5	Allen	1980	305 km/h (190 mph)	899 hPa (26.55 inHg)
6	Camille	1969	280 km/h (175 mph)	900 hPa (26.58 inHg)
7	Katrina	2005	280 km/h (175 mph)	902 hPa (26.64 inHg)
8	Mitch	1998	285 km/h (180 mph)	905 hPa (26.72 inHg)
9	Dean	2007	280 km/h (175 mph)	905 hPa (26.72 inHg)
10	Ivan	2004	270 km/h (165 mph)	910 hPa (26.87 inHg)
11	Cuba	1924	270 km/h (165 mph)	910 hPa (26.87 inHg)
12	Janet	1955	280 km/h (175 mph)	914 hPa (26.99 inHg)
13	Isabel	2003	270 km/h (165 mph)	915 hPa (27.02 inHg)
14	Cuba	1932	280 km/h (175 mph)	915 hPa (27.02 inHg)
15	Opal	1995	240 km/h (150 mph)	916 hPa (27.05 inHg)
16	Hugo	1989	260 km/h (160 mph)	918 hPa (27.11 inHg)
17	Gloria	1985	230 km/h (145 mph)	919 hPa (27.14 inHg)
18	Hattie	1961	260 km/h (160 mph)	920 hPa (27.17 inHg)
19	Floyd	1999	250 km/h (155 mph)	921 hPa (27.20 inHg)
20	Andrew	1992	280 km/h (175 mph)	922 hPa (27.23 inHg)

Notes:

a) Hurricane categories are given for the time of landfall. Hurricane peak wind speeds are the storm's maximum and not necessarily the same as at the time of landfall.

b) The current naming of hurricanes, using alternating male and female names, did not begin until 1953. Prior to 1953, storms were named for the time of year, state, or specific location that suffered the most severe damage.

c) Fatality numbers for events (see next slide) between 1875 and 1930 are considered underestimates.

Lab Hurricane, Typhoons, Cyclones

Lists of the top 20 hurricanes from 1880 to 2008, according to different ranking systems.

Top 20 Atlantic Hurricanes Ranked by Damages in U.S. $

Rank	Cyclone name	Season	Category	Damage estimate (billions $)
1	Katrina	2005	3	108
2	Ike	2008	2	29.5
3	Andrew	1992	5	26.5
4	Wilma	2005	3	21.0
5	Ivan	2004	3	18.8
6	Charley	2004	4	15.1
7	Rita	2005	3	12.0
8	Frances	2004	2	9.5
9	Allison	2001	0 (T.S.)	9.0
10	Jeanne	2004	3	7.7
11	Hugo	1989	4	7.0
12	Floyd	1999	2	6.9
13	Isabel	2003	2	5.4
14	Opal	1995	3	5.1
15	Gustav	2008	2	4.6
16	Fran	1996	3	4.1
17	Georges	1998	2	2.8
18	Dennis	2005	3	2.5
19	Frederic	1979	3	2.3
20	Agnes	1972	1	2.1

Top 20 Atlantic Hurricanes Ranked by Fatalities

Rank	Cyclone name	Season	Category	Fatalities
1	Galveston, TX	1900	4	8,000
2	Lake Okeechobee, FL	1928	4	2,500
3	Katrina	2005	3	1,200
4	Cheniere Caminanda, LA	1893	4	1,100
5	Sea Islands, GA/SC	1893	3	1,000
6	unnamed GA/SC	1881	2	700
7	Audrey	1957	4	416
8	Florida Keys	1935	5	408
9	Last Island, LA	1856	4	400
10	Miama. FL	1926	4	372
11	Grand Isle, LA	1909	3	350
12	Florida Keys & TX	1919	4	287
13	New Orleans	1915	3	275
14	Galveston, TX	1915	4	275
15	unnamed New England	1938	3	256
16	Camille	1969	5	256
17	Diane	1955	1	184
18	unnamed GA, NC, NC	1898	4	179
19	unnamed TX	1875	3	176
20	unnamed SE FL	1906	3	164

EXERCISE: Where is Sandy?

Hurricane Sandy, which had a devastating effect on the New Jersey and New York coast in 2012, is not on any of these charts because they only go to 2008.

A. Indicate clearly on each of the three lists above where Sandy would be placed. You can use the document provided by the National Hurricane Center at http://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf or do an internet search as needed to find the relevant data.

B. Add the information that you find to each list in its appropriate position.

EXERCISE: Which was the worst? (working in teams of 3 or 4 is recommended)

Review the three data tables above and answer the following questions:

A. Describe the relationship, if any, between a hurricane's strength and the damage and/or deaths that it caused.

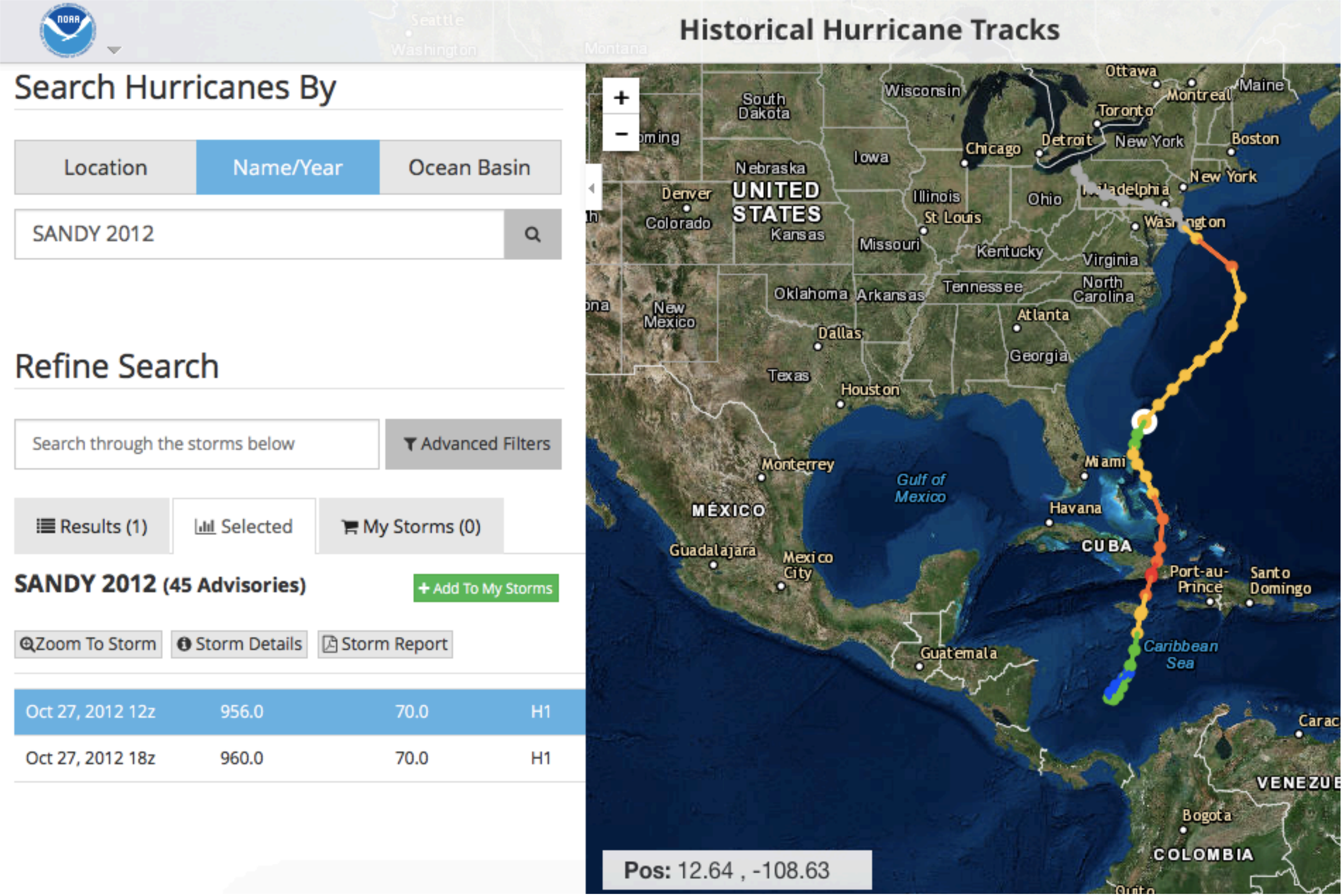
B. Since 1950, which have been the top three seasons (in ranked order) for hurricane disasters in terms of total damages?
1. Season _________ combined total damages = ________ billions US dollars
2. Season _________ combined total damages = ________ billions US dollars
3. Season _________ combined total damages = ________ billions US dollars

C. Discuss the correlation, if any, between your answers in B and the most fatalities caused in each of the same 3 years.

D. What factors could produce more damage and/or deaths from a "weaker" or lower category storm?

E. What are some of the reasons why the estimates of fatalities and damages in the older records may be less accurate than for the more recent events?

Lab Hurricane, Typhoons, Cyclones



EXERCISE: Hurricane Tracking (working in pairs is recommended

A. Load the NOAA hurricane website http://coast.noaa.gov/hurricanes/. Type Sandy 2012 into the Search by Name/Year window. You should see a window similar to the one at right. Hover the mouse over the hurricane tracks; observe that the data for each position is shown on the left half of the window.

i. How many hours apart are the positions on the storm's track for the majority of its progress? __________hours apart

ii. What was the highest category reached by Sandy, and where was it at the time?
Category ___ Position (lat; lon) _________ Nearest geographic locality_______

iii. What was the Sandy's wind speed in km/h when it made landfall in Atlantic City? Wind speed = ________km/h

iv. Use the "Search by Location" window to search for Norfok, Va, and reduce the search area to 15 km. How many severe storms are listed? __________storms

v. How many of the listed storms for this area were at hurricane strength? _________ hurricanes

Lab Hurricane, Typhoons, Cyclones

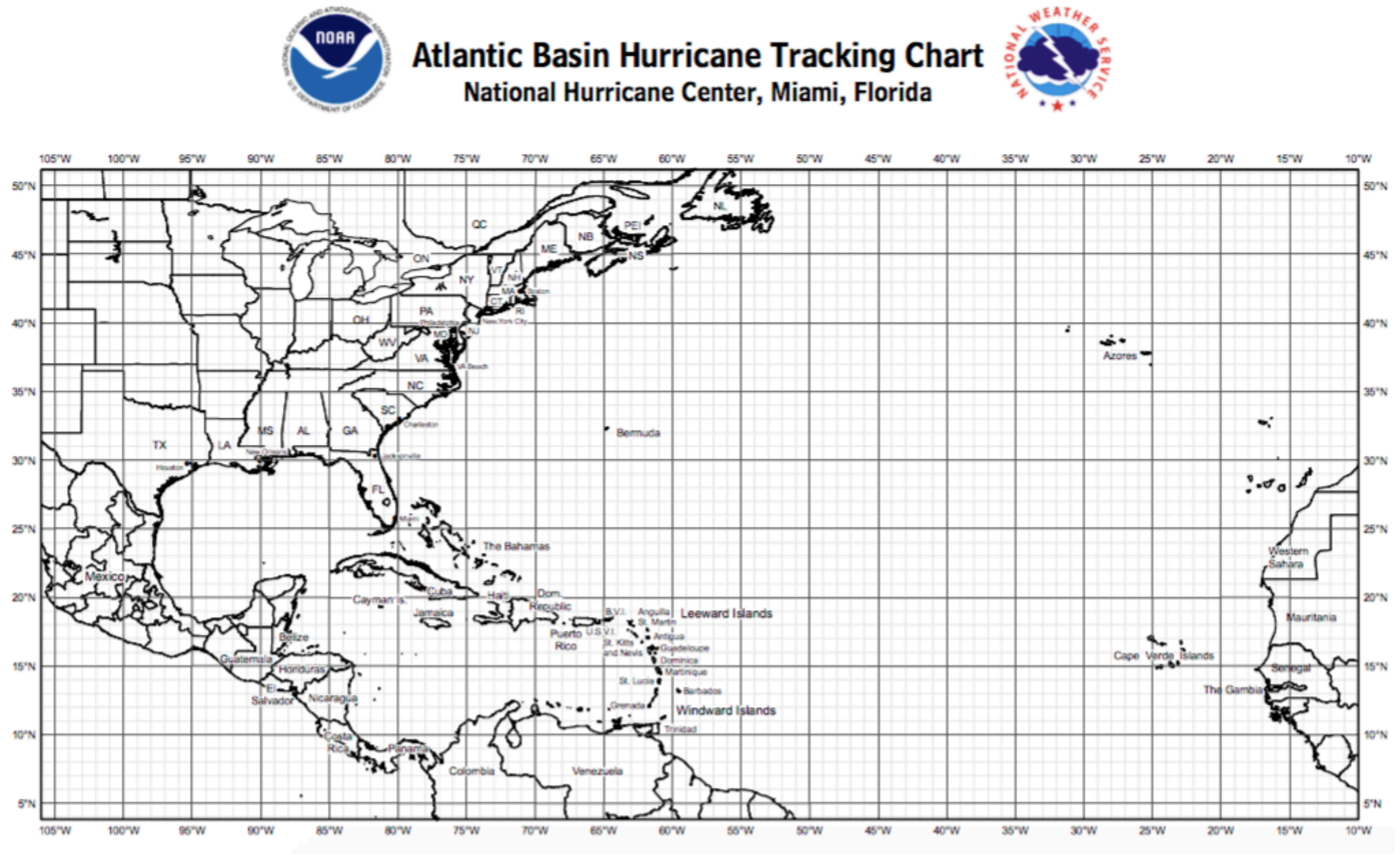
B. Search the NOAA hurricane website http://coast.noaa.gov/hurricanes/ for the hurricane Isabel 2003. Use the hurricane tracking chart below and the data provided on the website to plot the track of Isabel's eye at noon each day, from September 11, 2003 to September 19, 2003. Label each point with its date (9/11, 9/12, etc.).

i. Over which 24 hour period did the storm move forward the fastest? __________

ii. Over which 24 hour period was the hurricane's wind speed at its maximum?________

iii. If the answers to (i) and (ii) are not the same, explain why they differ.

iv. Hurricane Isabel passed well to the south of Norfolk, and yet it caused extreme flooding and power outages throughout this region. Why? (hint: think about the storm's rotation and the wind direction before, during and after landfall).



EXERCISE: Hurricane return periods

NOAA's National Hurricane Center has assembled records of all major storms that have impacted coastal U.S.A. since the late 1800's. From these records they have determined the average return period (also known as the recurrence interval) for the different categories of hurricanes. On the next slide are two of these charts, each made in 2011, for Category 1 and Category 3 hurricanes, respectively. Numbers inside the

Locate and label the cities of Galveston, New Orleans, and Norfolk on each of the maps. You may use GoogleEarth or any map application – or even an atlas (!) – if you are not certain of the exact location.

i. What is the estimated return period for a Category 1 hurricane for the City of Galveston? ___________ years

ii. What is the estimated return period for a Category 3 hurricane for the City of New Orleans? _____________years

B. Why are the regions with green circles around the Gulf Coast considered less likely to have a hurricane landfall than the regions with red circles?

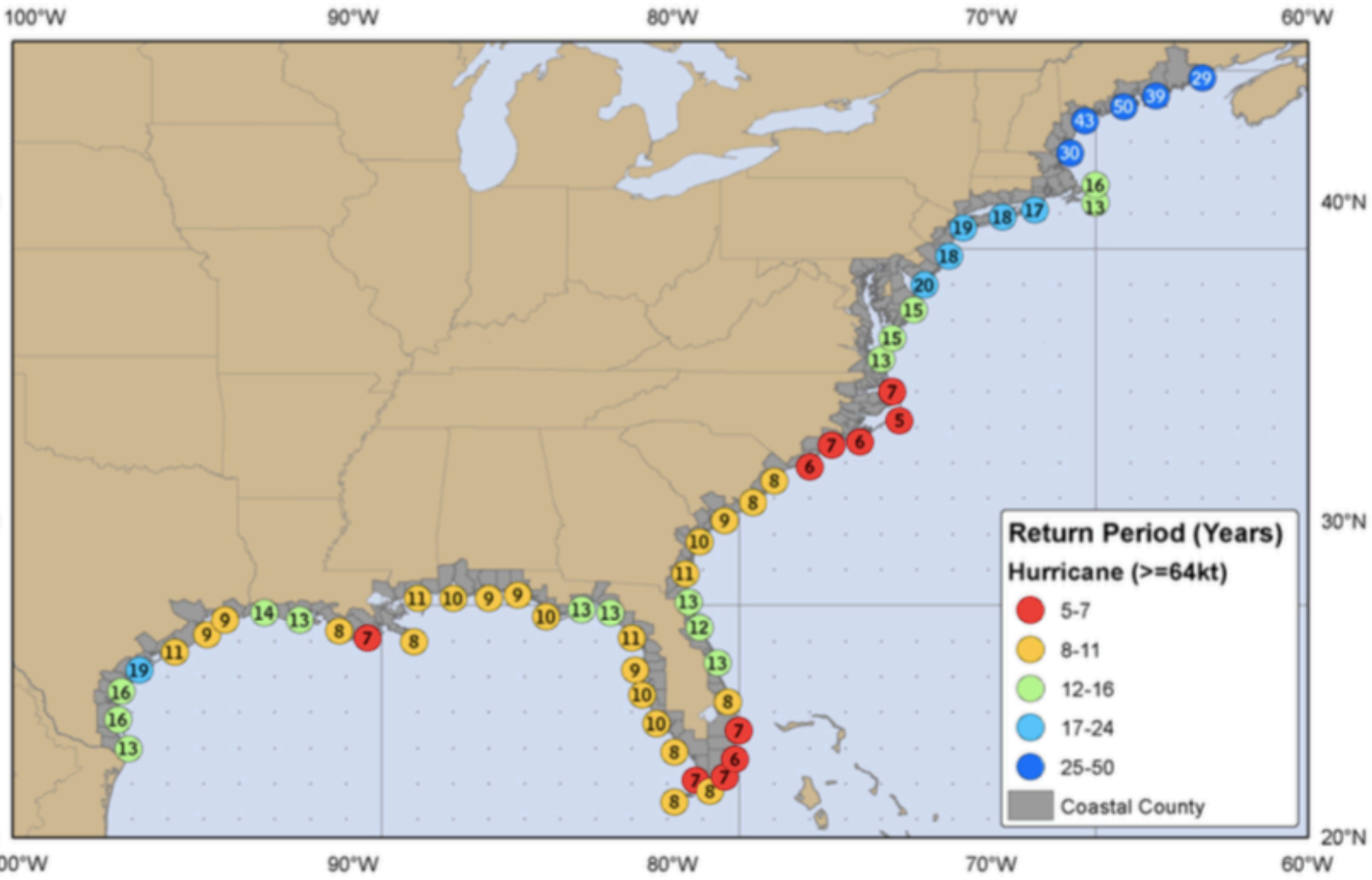
C. How frequently can the citizens of Norfolk expect to see:

i. A Category 1 hurricane? every ___________ years

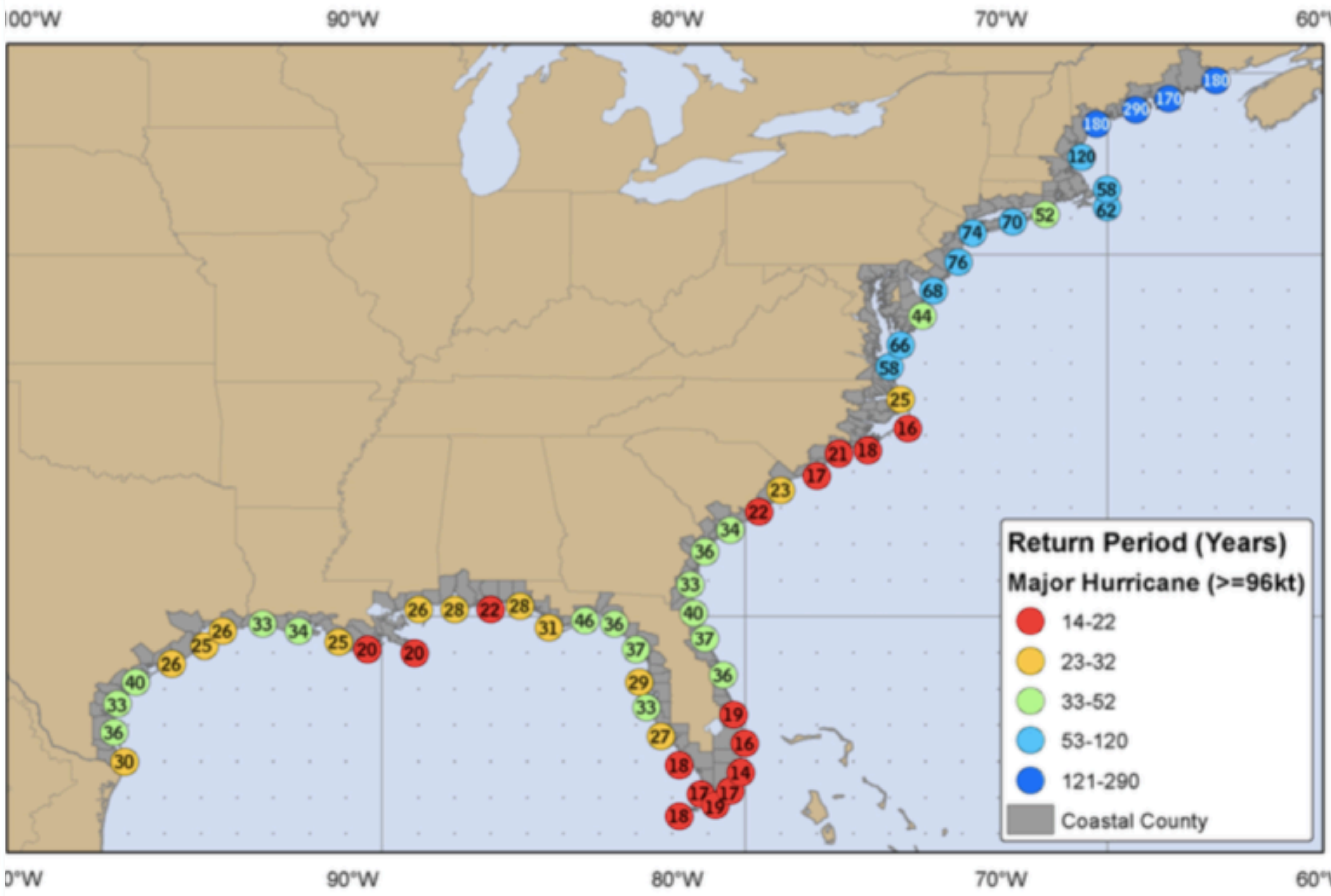
ii. A Category 3 hurricane? every ___________ years

D. Discuss what the citizens of Hampton Roads might do to prepare for the next hurricane.

Lab Hurricane, Typhoons, Cyclones



Category 1



Category 3

Natural Hazards and Disaster

Class 20: Hurricanes, Typhoons, Cyclones (continued)

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Natural Hazards and Disaster

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Where, When, Why

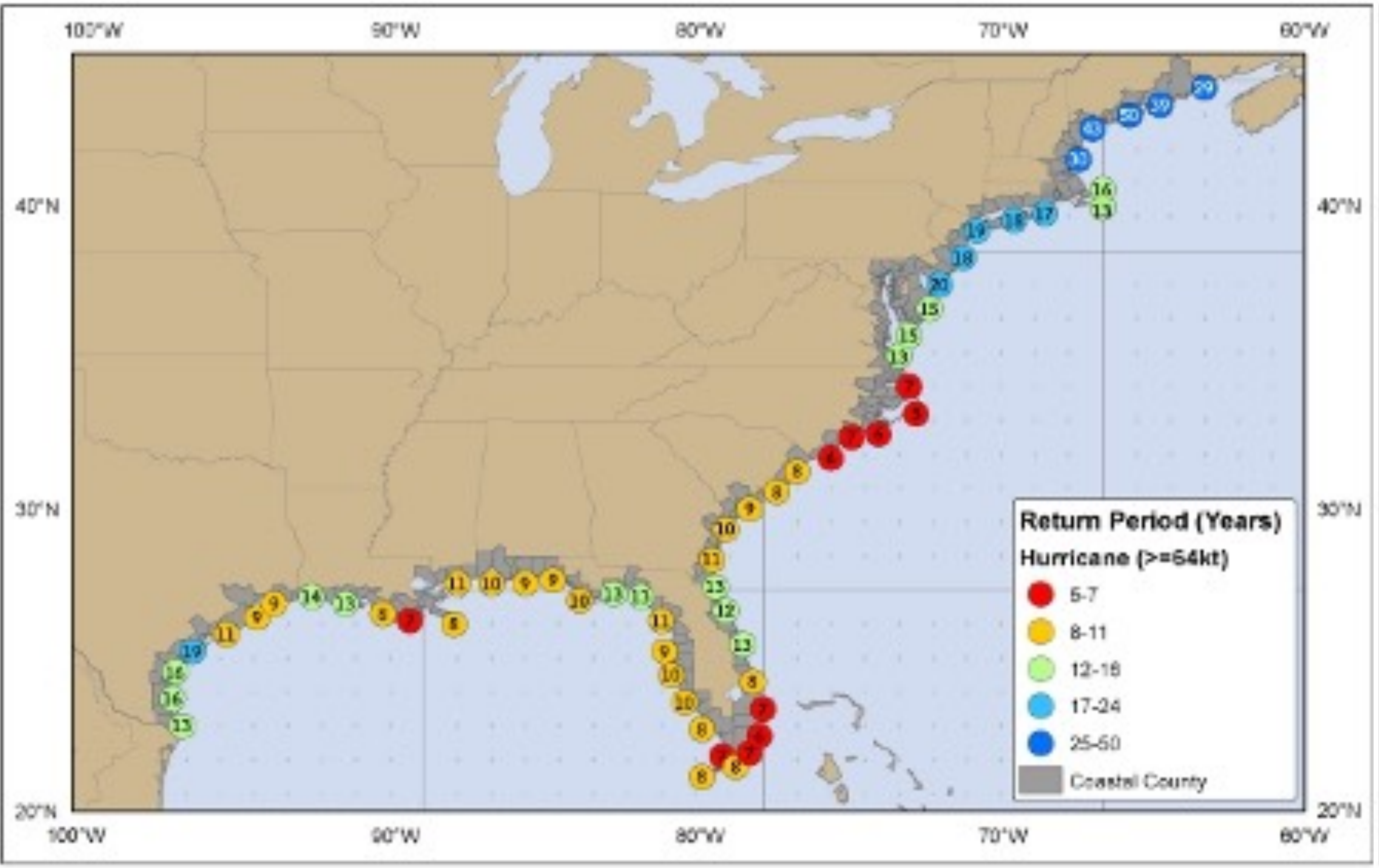
Table 14. Deadliest & Costliest Tropical Cyclones (1900-2010) for Hawaii, Puerto Rico and the U.S. Virgin Islands.

Name	Date		Island or CPA	Unadjusted Damage ($000)	Adjusted for Inflation [3]	Deaths
Mokapu Cyclone	Aug 19,1938		25 mi NE Oahu	Unk	Unk	Unk
Hiki	Aug 15,1950		100 mi NE Hawaii	Unk	Unk	Unk
Nina	Dec 02,1957		100 mi SW Kauai	200	1,636	4
Dot	Aug 06,1959		Kauai	6,000	49,657	0
Iwa	Nov 23,1982		25 mi NW Kauai	312,000	733,237	1
Iniki	Sep 11,1992		Kauai	1,800,000	3,094,737	4
San Hipolito	Aug 22,1916		Puerto Rico	1,000	36,000	1
San Liborio	Jul 23,1926	1	SW Puerto Rico	5,000	103,353	25
San Felipe	Sep 13,1928		Puerto Rico	85,000	1,757,006	312
San Nicolas	Sep 10,1931	1	Puerto Rico	200	4,386	2
San Ciprian	Sep 26,1932	1	USVI, PR	30,000	657,893	225
San Mateo	Sep 21,1949		St. Croix	Unk	-	Unk
Santa Clara (Betsy)	Aug 12,1956		Puerto Rico	40,000	336,855	16
Donna	Sep 05,1960	1	PR & St. Thomas	Unk	-	107
Eloise (T.S.)	Sep 15,1975	1	Puerto Rico	Unk	-	44
David	Aug 30,1979	2	S. of Puerto Rico	Unk	-	Unk
Frederic (T.S.)	Sep 04,1979	2	Puerto Rico	125,000	357,143	7
Hugo	Sep 18,1989		USVI, PR	1,000,000	1,824,953	5
Marilyn	Sep 16,1995		USVI, E. PR	1,500,000	2,254,601	8
Hortense	Sep 10,1996		SW Puerto Rico	500,000	737,952	18
Georges	Sep 21,1998		USVI & PR	1,800,000	2,512,821	0
Lenny	Nov 17,1999		USVI & PR	330,000	441,201	0

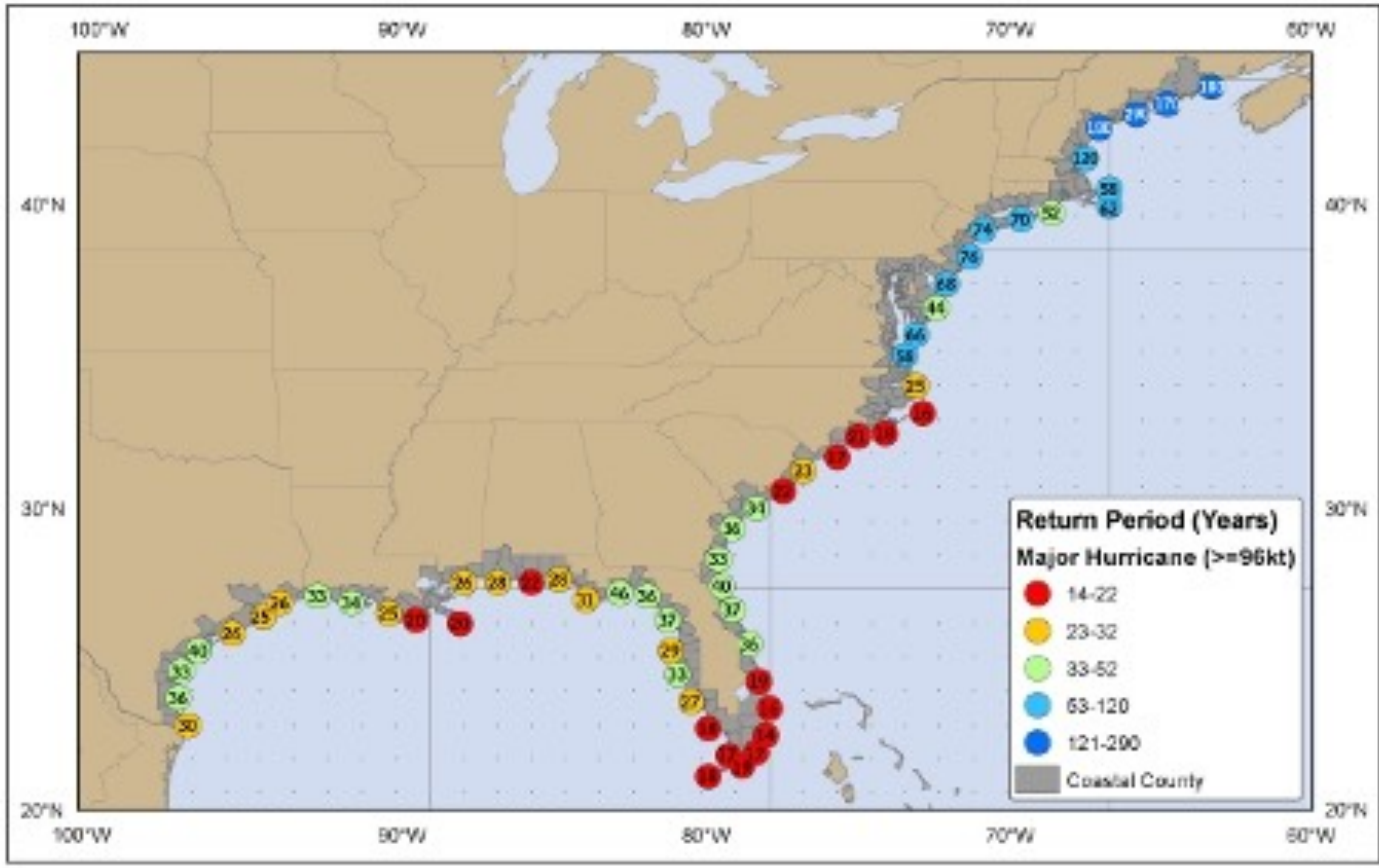
[1] Effects continued into the following day. [2] Damage and Casualties from David and Frederic are combined.
[3] Adjusted to 2010 dollars based on U.S. Census Bureau Price Deflator (Fisher) Index for Construction

http://www.nhc.noaa.gov/pdf/nws-nhc-6.pdf

Where, When, Why



Estimated return period in years for hurricanes passing within 50 nautical miles of various locations on the U.S. Coast



Estimated return period in years for major hurricanes passing within 50 nautical miles of various locations on the U.S. Coast

http://www.nhc.noaa.gov/climo/

Table 5. Hurricane strikes on the mainland United States (1851-2010).

Category	Strikes
5	3
4	18
3	75
2	75
1	113
TOTAL	284
MAJOR	96

Major hurricanes are categories 3,4 & 5.

Table 6. Number of hurricanes by category to strike the mainland U.S. each decade. (Updated from Blake et al., 2007)

	Category					ALL	Major
DECADE	1	2	3	4	5	1,2,3,4,5	3,4,5
1851-1860	7	5	5	1	0	18	6
1861-1870	8	6	1	0	0	15	1
1871-1880	7	6	7	0	0	20	7
1881-1890	8	9	4	1	0	22	5
1891-1900	8	5	5	3	0	21	8
1901-1910	10	4	4	0	0	18	4
1911-1920	8	5	4	3	0	20	7
1921-1930	8	2	3	2	0	15	5
1931-1940	4	7	6	1	1	19	8
1941-1950	8	6	9	1	0	24	10
1951-1960	8	1	6	3	0	18	9
1961-1970	3	5	4	1	1	14	6
1971-1980	6	2	4	0	0	12	4
1981-1990	9	2	3	1	0	15	4
1991-2000	3	6	4	0	1	14	5
2001-2010	8	4	6	1	0	19	7
1851-2010	113	75	75	18	3	284	96
Average per decade	7.1	4.7	4.7	1.1	0.2	17.8	6.0

Note: Only the highest category to affect the U.S. is used

http://www.nhc.noaa.gov/pdf/nws-nhc-6.pdf

Natural Hazards and Disaster

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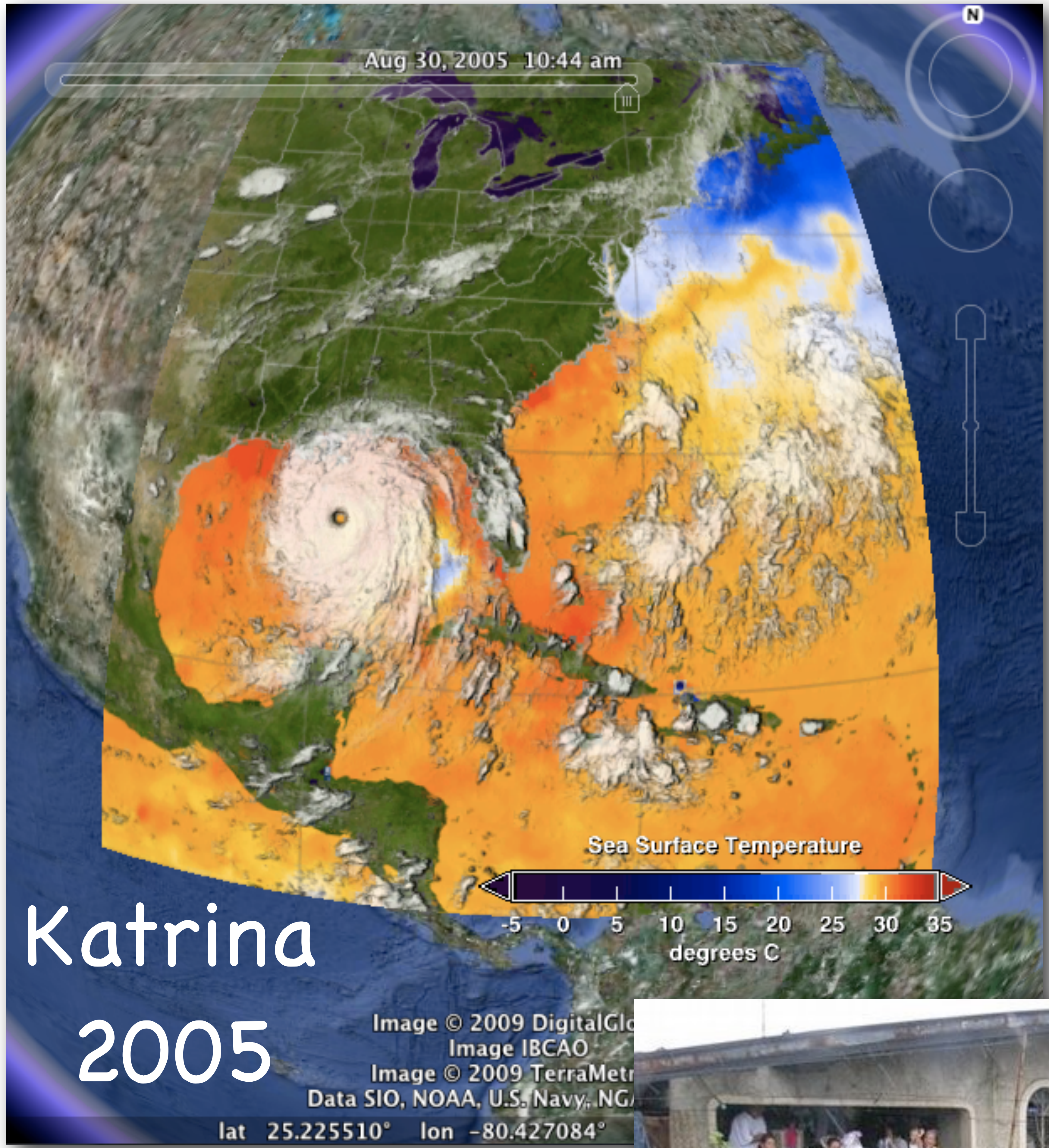
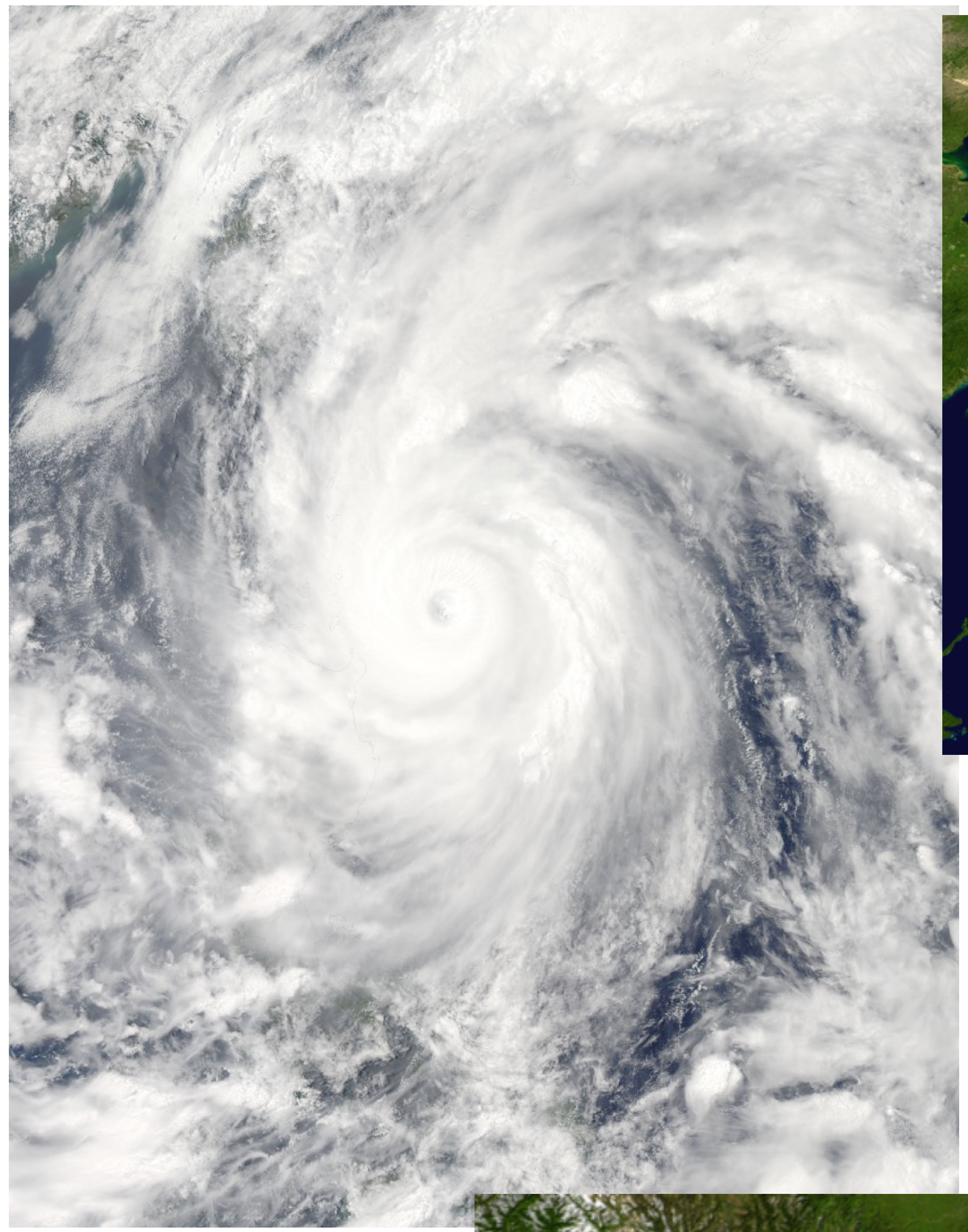
Cases

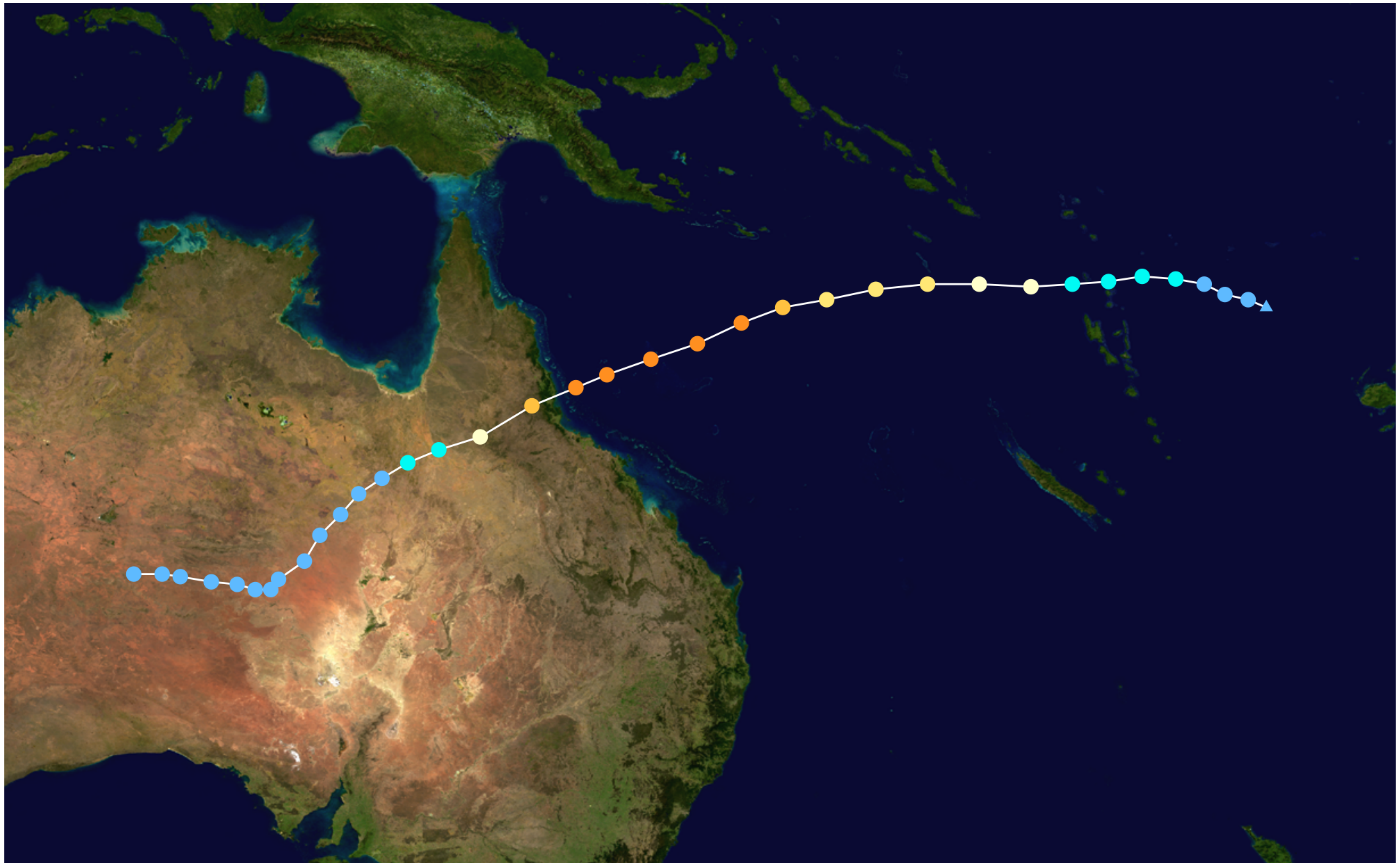


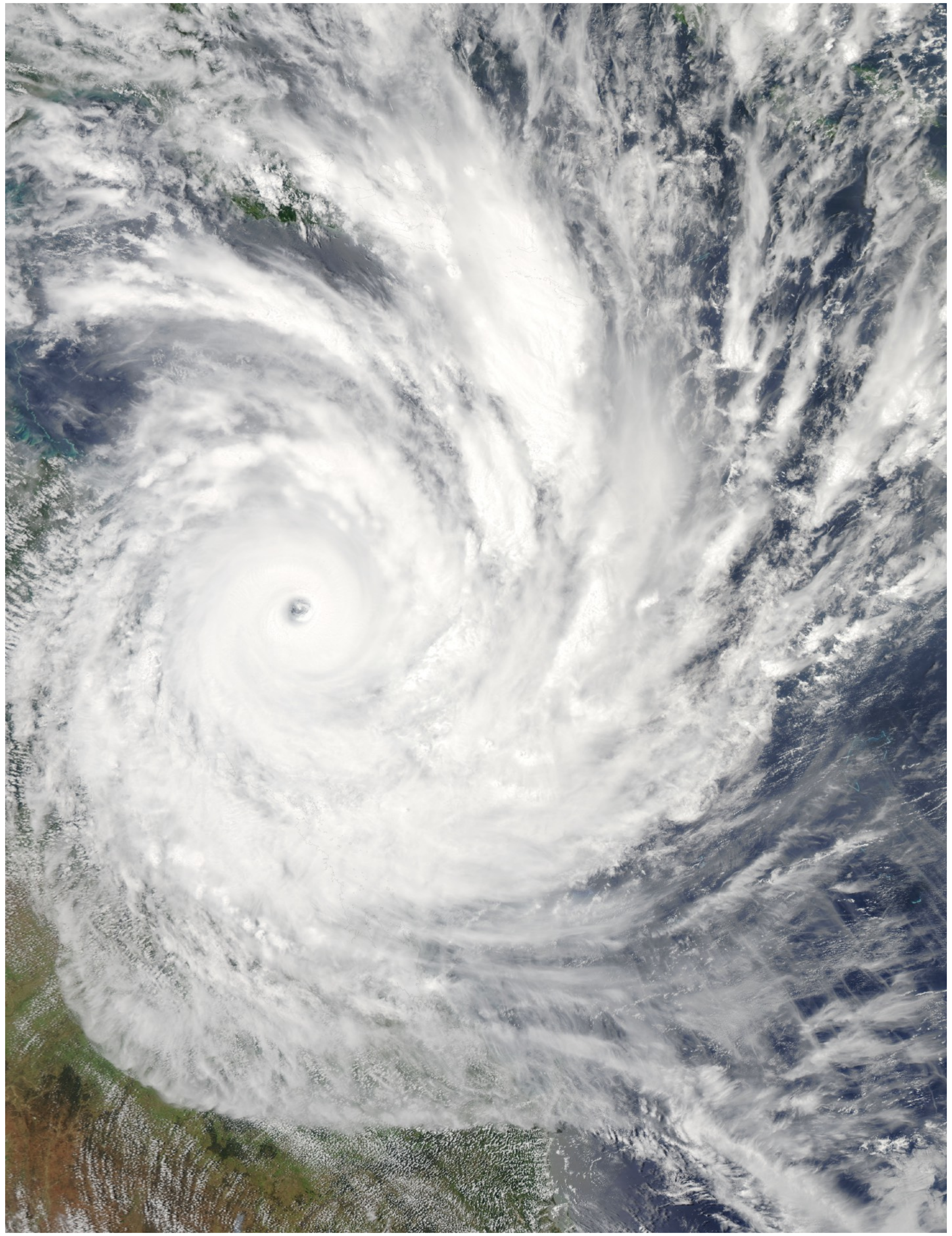


Typhoon Songda "Chedeng": Public Storm Warning Signal Number One areas in yellow, Signal Number Two areas in pink.

Cases

At about 12:00 AM AEST (14:00 UTC) on February 3, Yasi crossed the coastline as a severe Category 5 cyclone near Mission Beach, with estimated maximum 3-second gusts of 285 km/h spanning an area from Ingham to Cairns. A record low pressure of 929 hPa (27.43 inHg) was measured as the eye passed over Tully. https://en.wikipedia.org/wiki/Cyclone_Yasi





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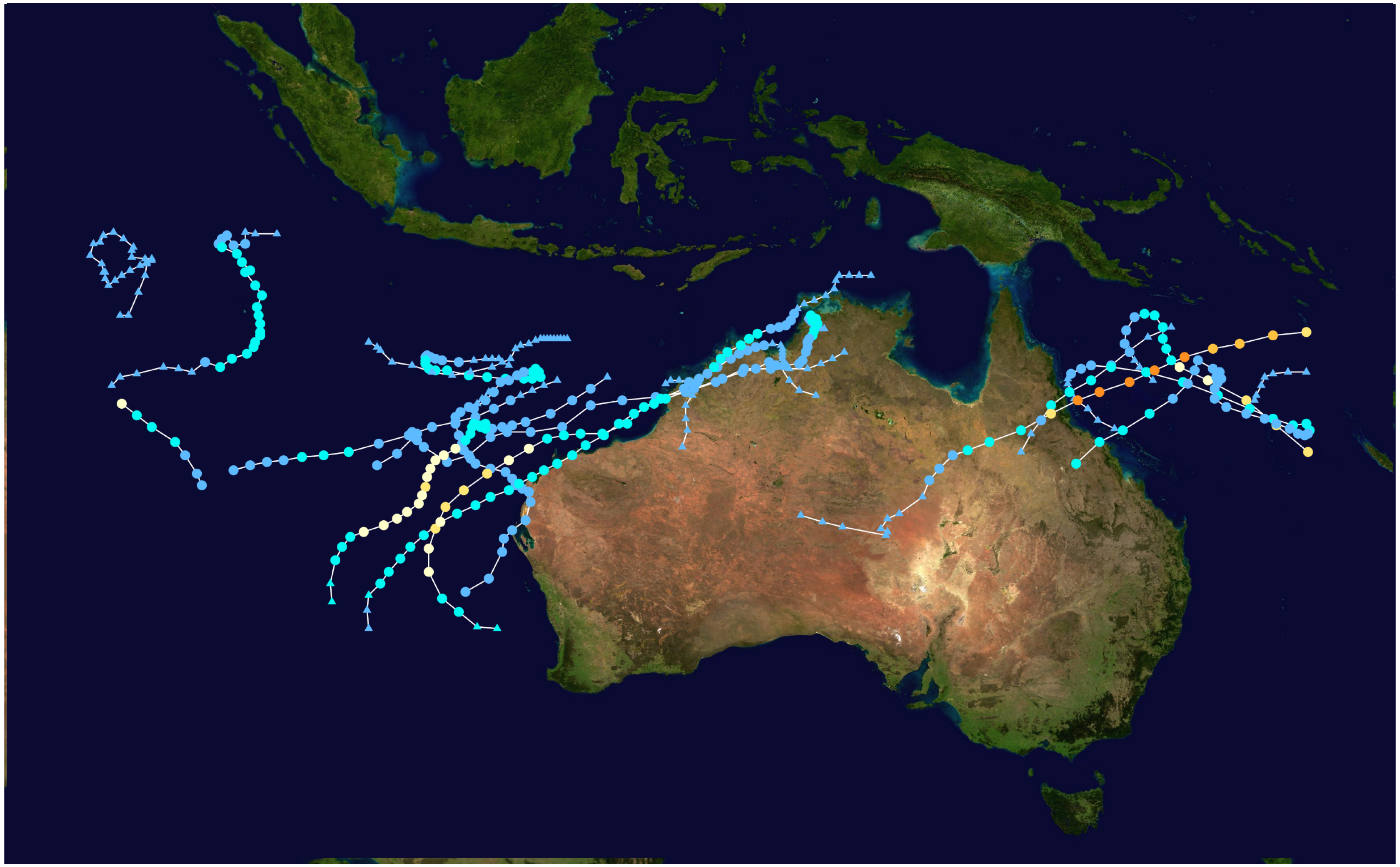
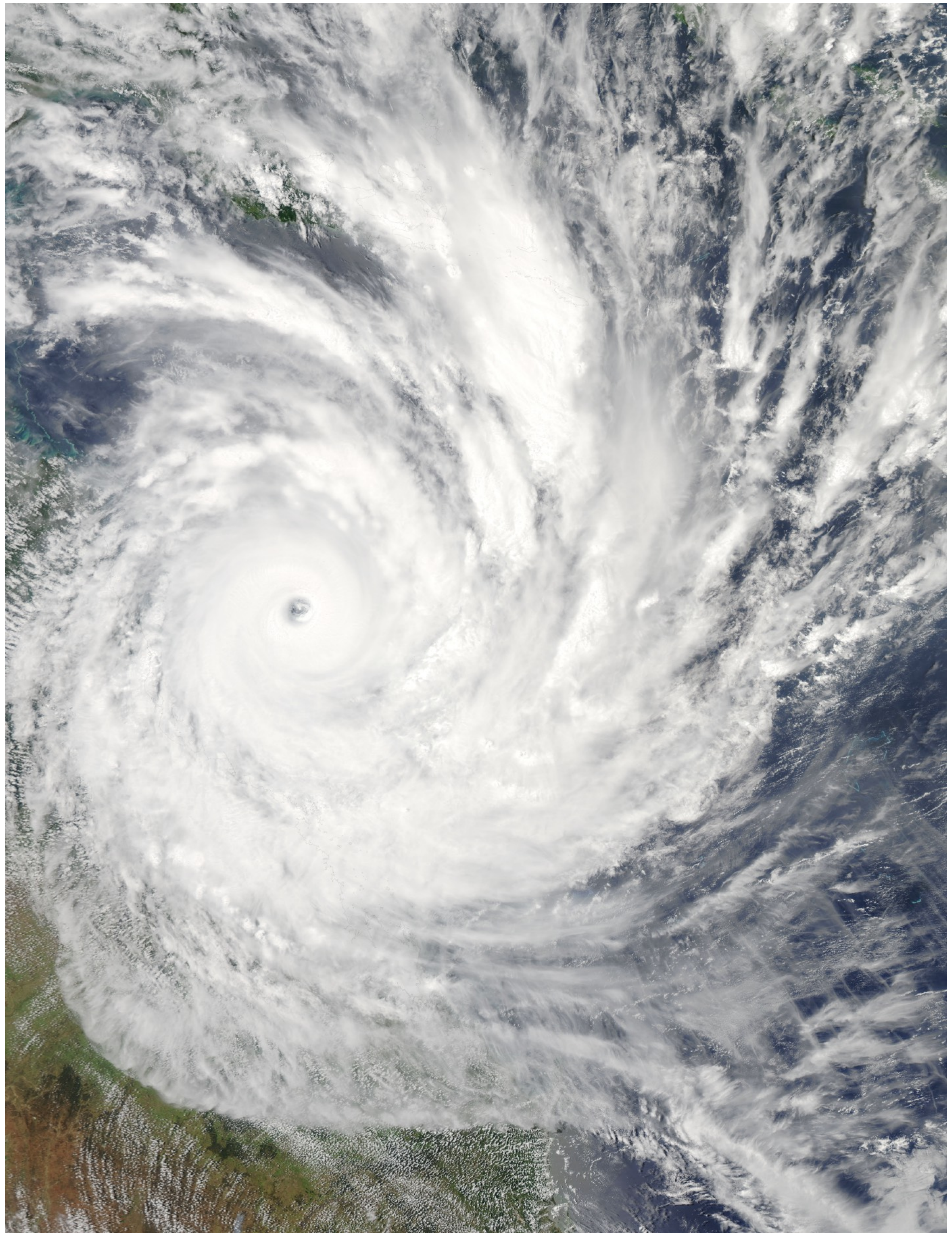
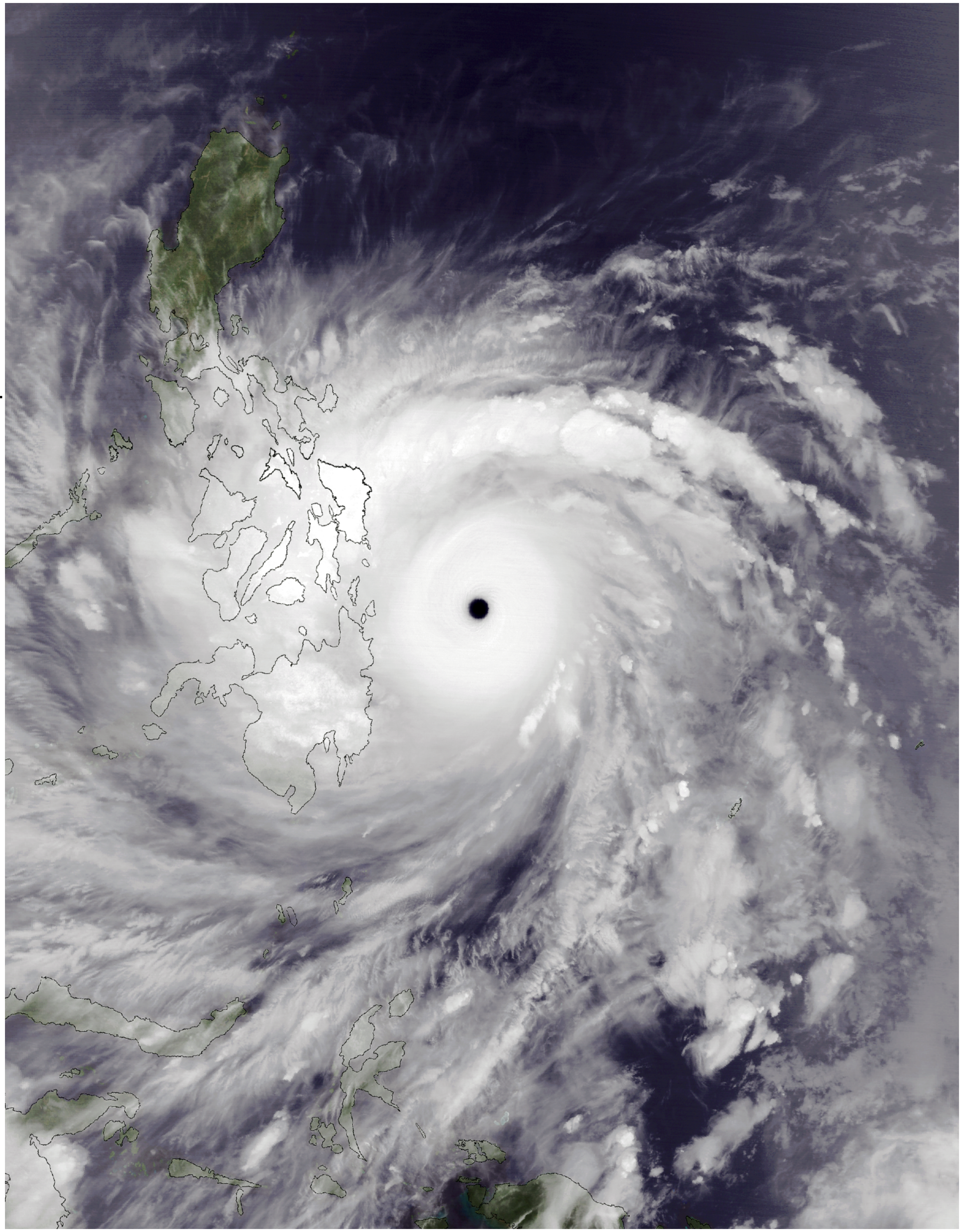




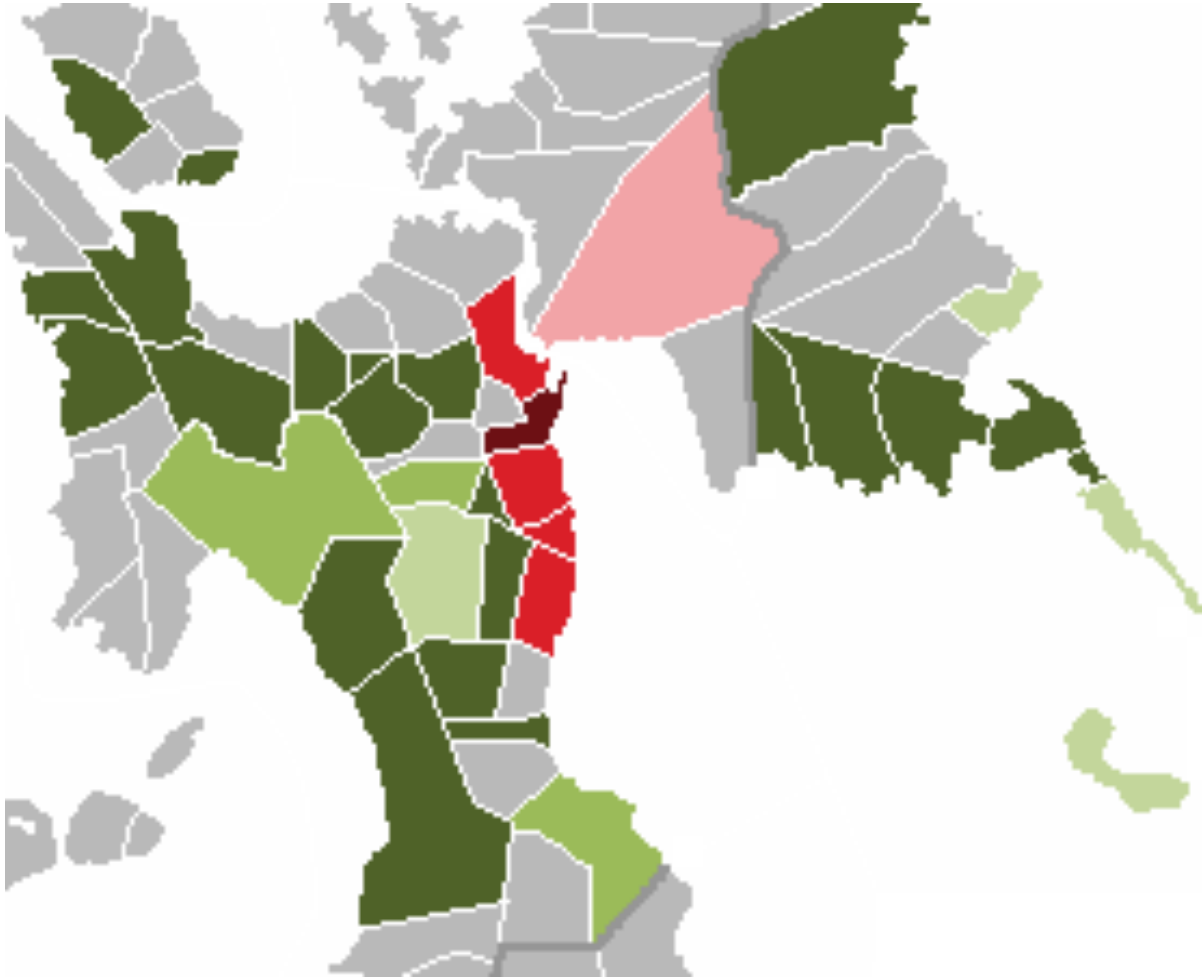
Cases

Typhoon Haiyan was an extremely deadly and intense typhoon, known as Super Typhoon Yolanda in the Philippines. On making landfall, Haiyan devastated portions of Southeast Asia, particularly the Philippines. It is the deadliest Philippine typhoon on record, killing at least 6,300 people in that country alone. In terms of JTWC-estimated 1-minute sustained winds, Haiyan is tied with Meranti for being the strongest landfalling tropical cyclone on record. In January 2014, bodies were still being found.

https://en.wikipedia.org/wiki/Typhoon_Haiyan

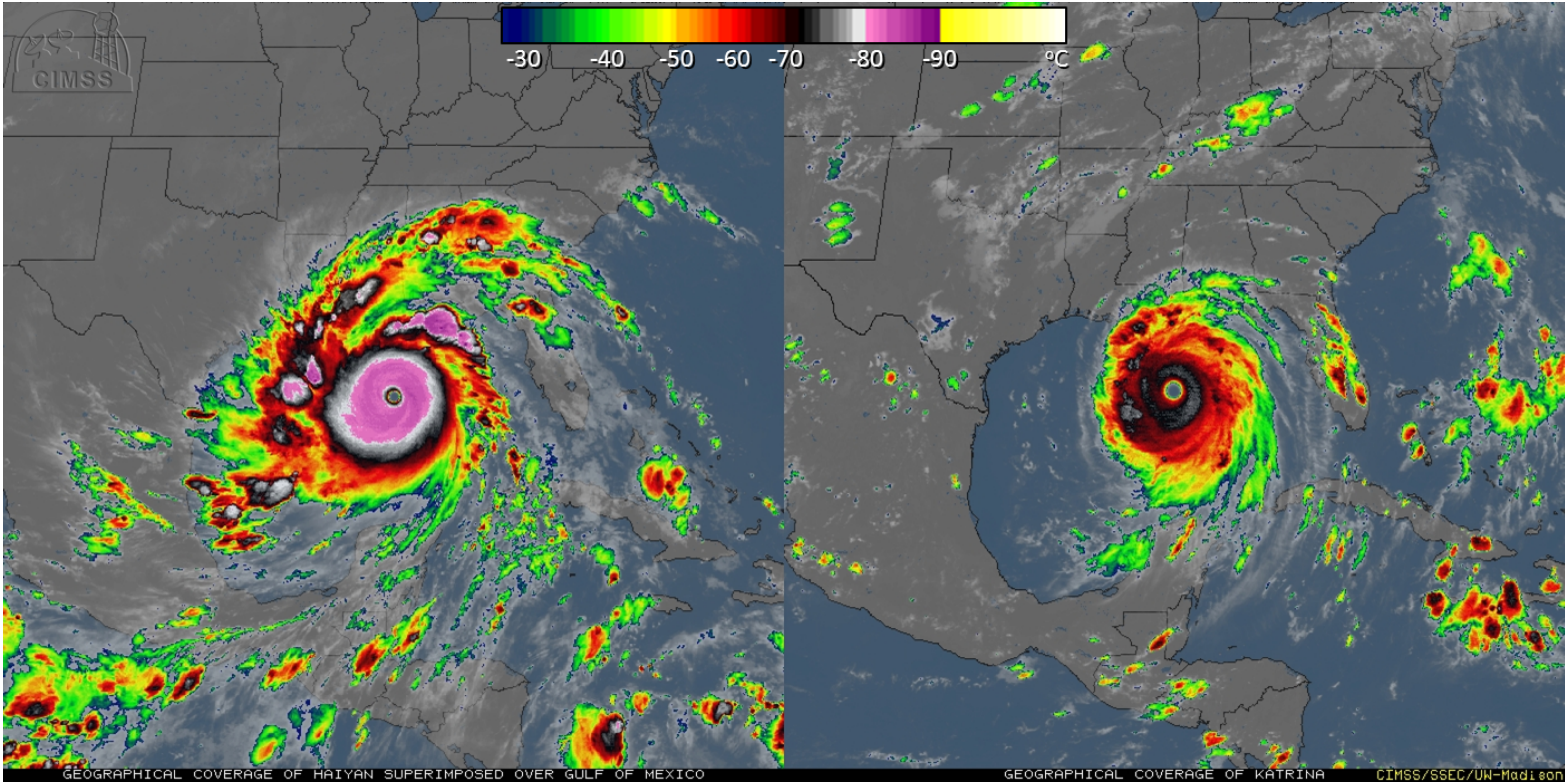


Cases



Color coded map of Eastern Visayas showing the number of deaths caused by Typhoon Haiyan. More than 1,000 500-999 100-499 50-99 25-49 1-24 0

Comparison of Katrina and Haiyan



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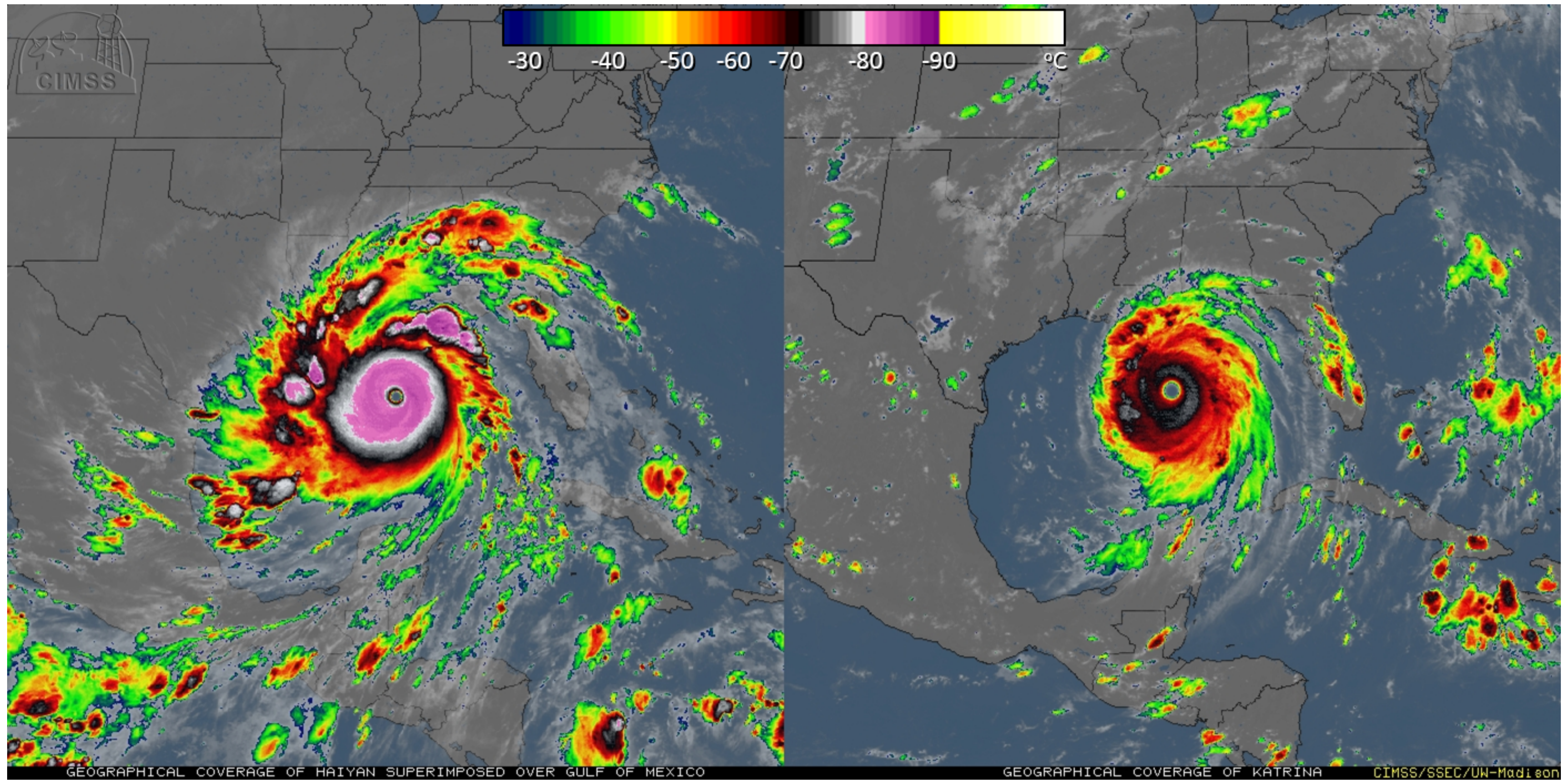
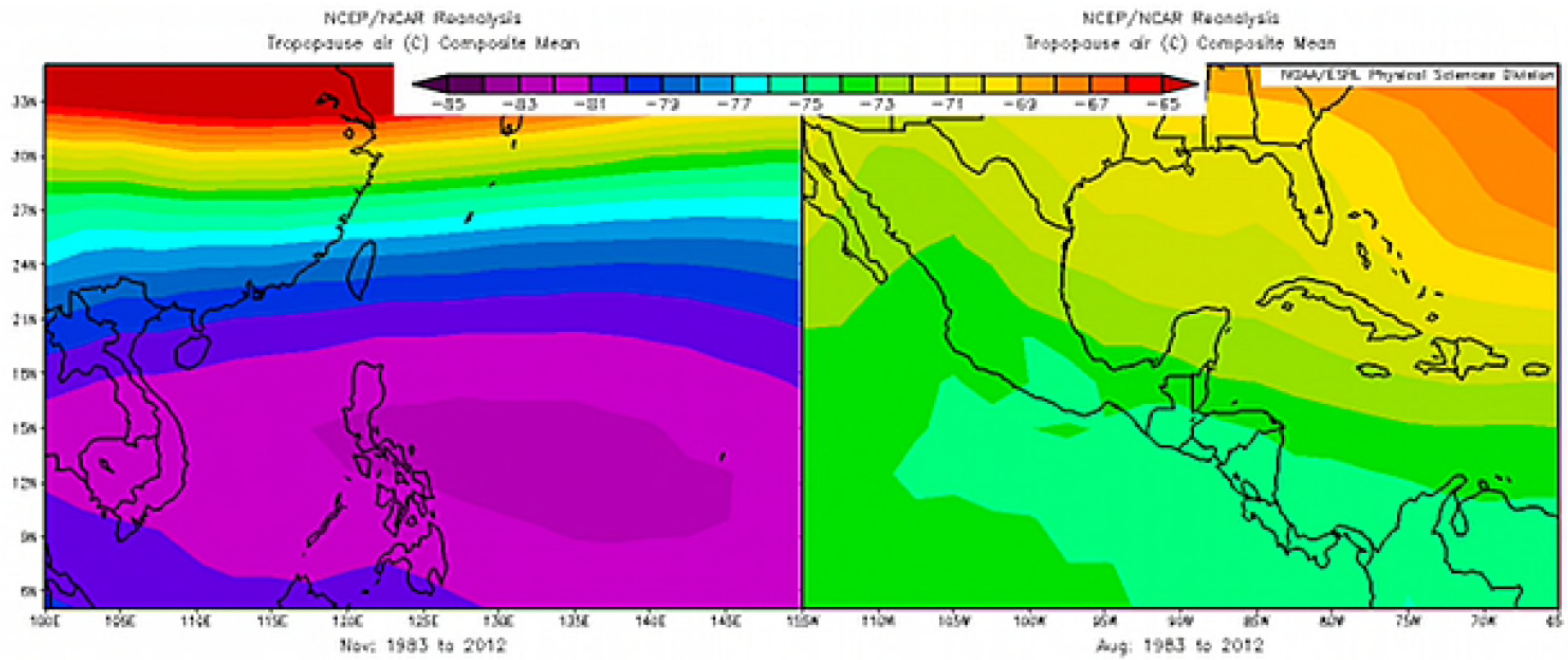
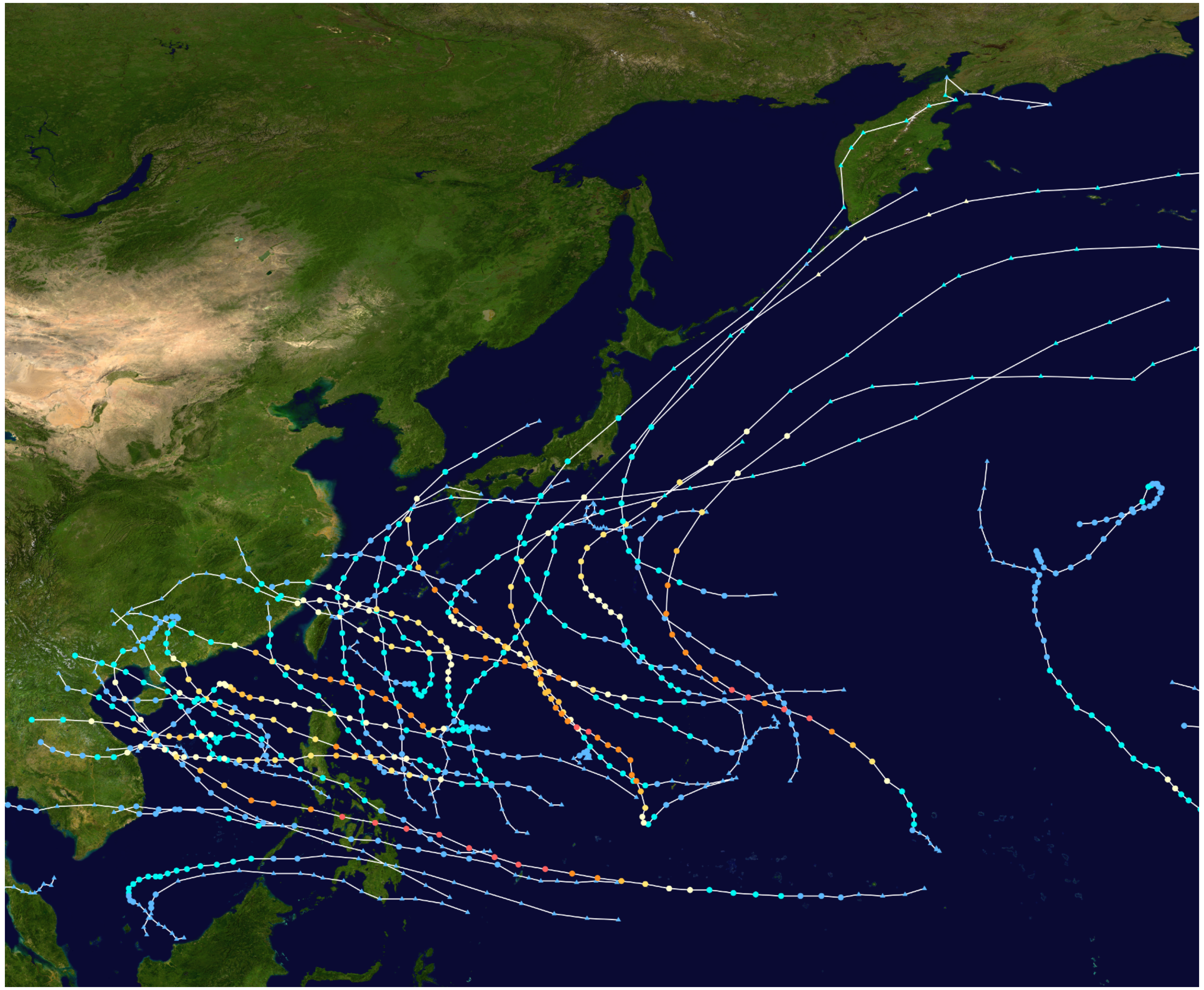


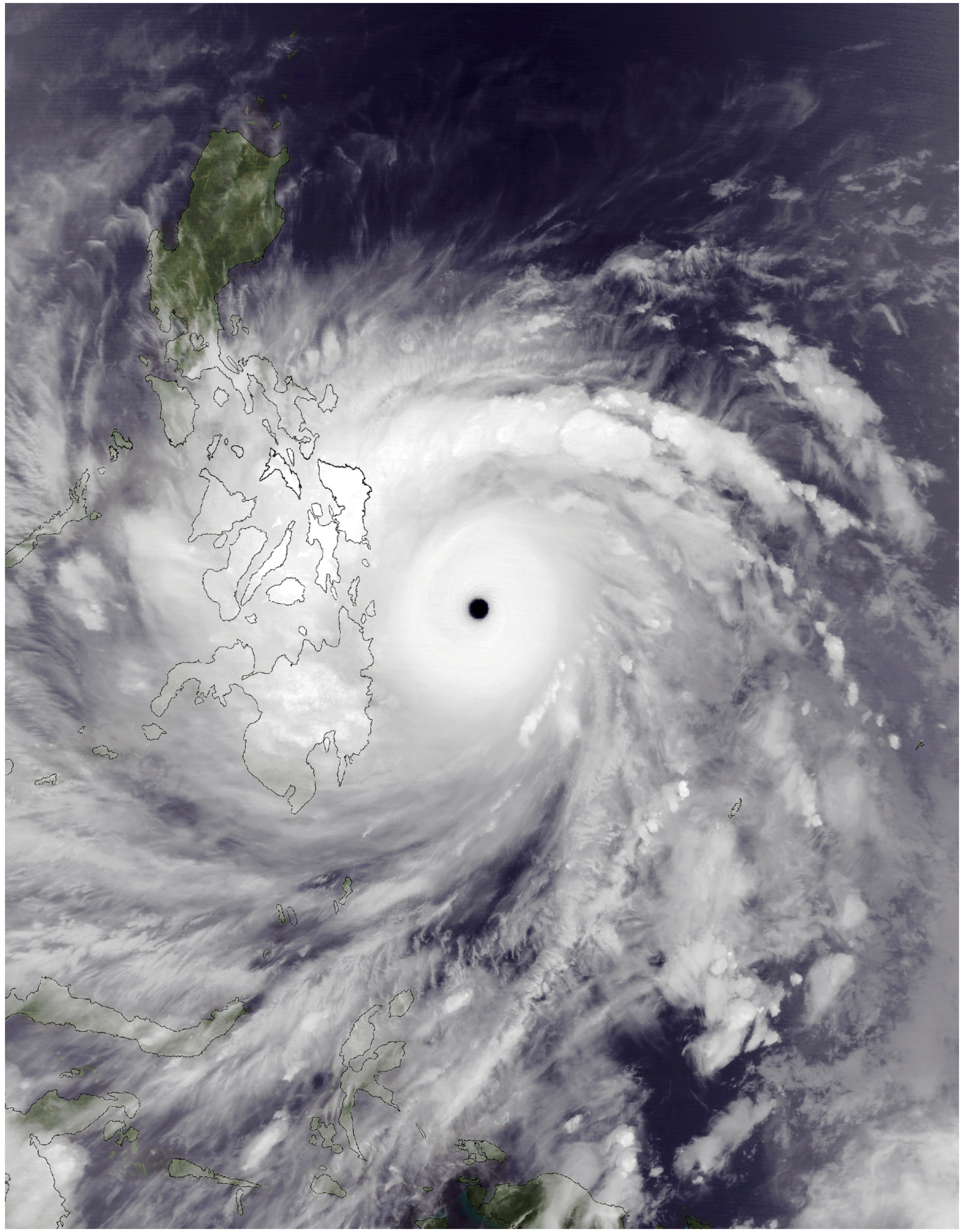


Haiyan (left) was more intense than Katrina (right) at its peak. The ring of clouds over the eyewall is much colder and thicker in Haiyan. While both storms were over very warm water – around 30ºC, the tropopause is higher and colder in the western tropical Pacific than it is in the tropical Atlantic, giving storms a decided intensity advantage. The average November tropopause temperature in the West Pacific (corresponding to Haiyan) is about 12ºC colder than the average August tropopause temperature in the Gulf of Mexico (corresponding to Katrina).

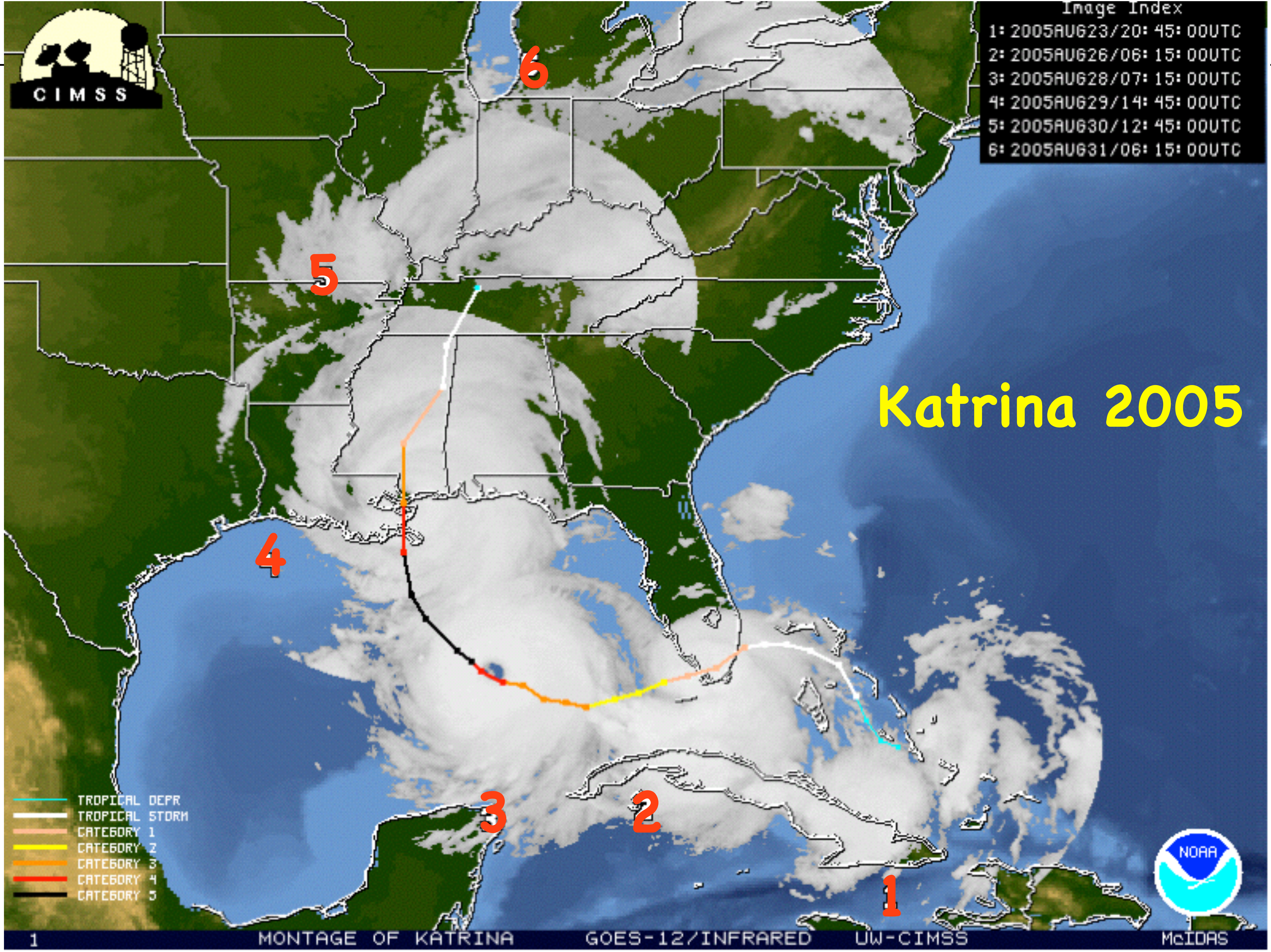
Cases

This map shows the tracks of all tropical cyclones in the 2013 Pacific typhoon season. The points show the location of each storm at 6-hour intervals. The colour represents the storm's maximum sustained wind speeds as classified in the Saffir-Simpson Hurricane Scale (see below), and the shape of the data points represent the type of the storm.





Cases



CIMSS
Image Index
1: 2005AUG23/20:45:00UTC
2: 2005AUG26/06:15:00UTC
3: 2005AUG28/07:15:00UTC
4: 2005AUG29/14:45:00UTC
5: 2005AUG30/12:45:00UTC
6: 2005AUG31/06:15:00UTC
Katrina 2005
6
5
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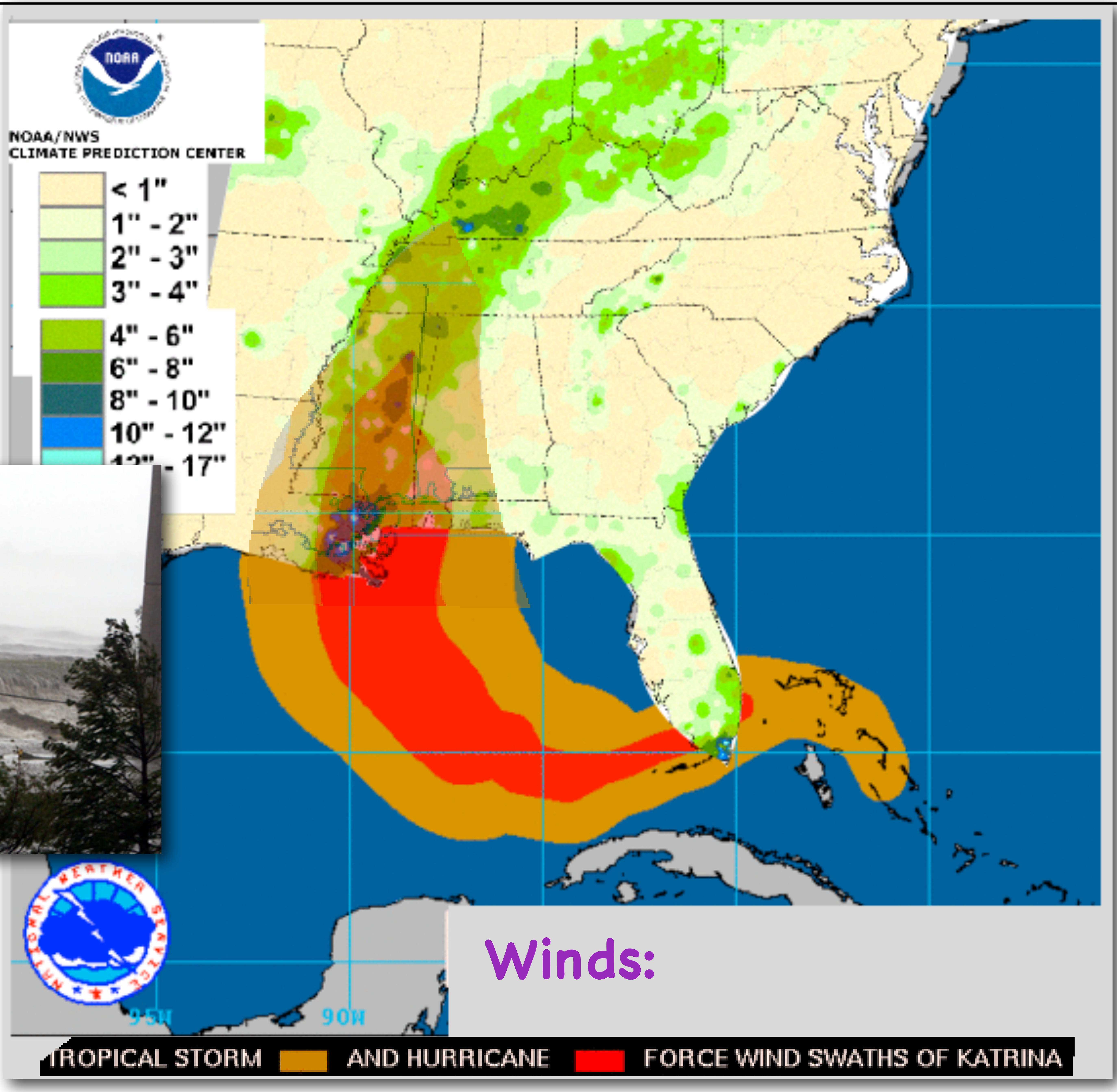
1
TROPICAL DEPR
TROPICAL STORM
CATEGORY 1
CATEGORY 2
CATEGORY 3
CATEGORY 4
CATEGORY 5
NOAA
1
MONTAGE OF KATRINA
GOES-12/INFRARED
UW-CIMSS
McIDAS

Cases

Rain:

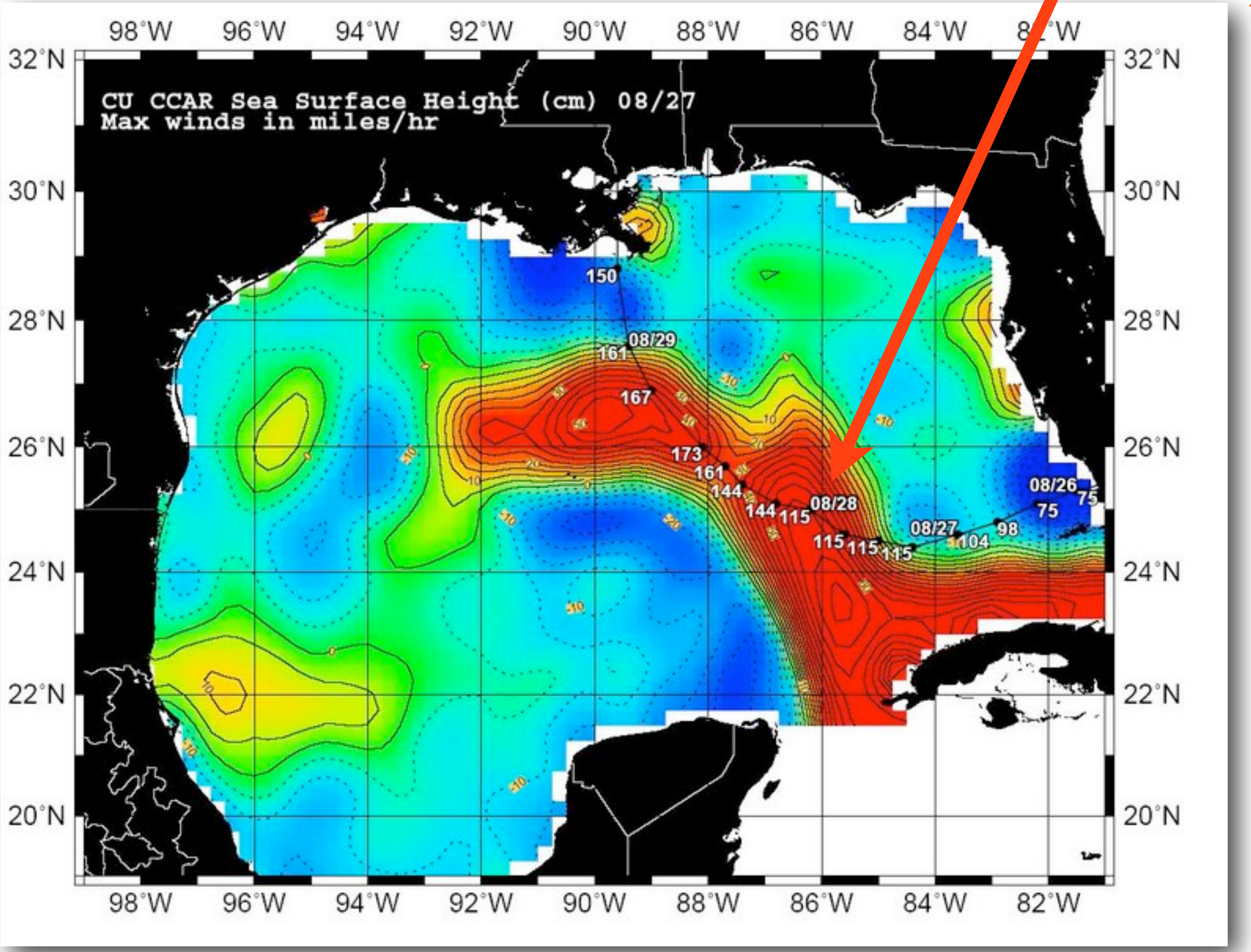
Storm surge:

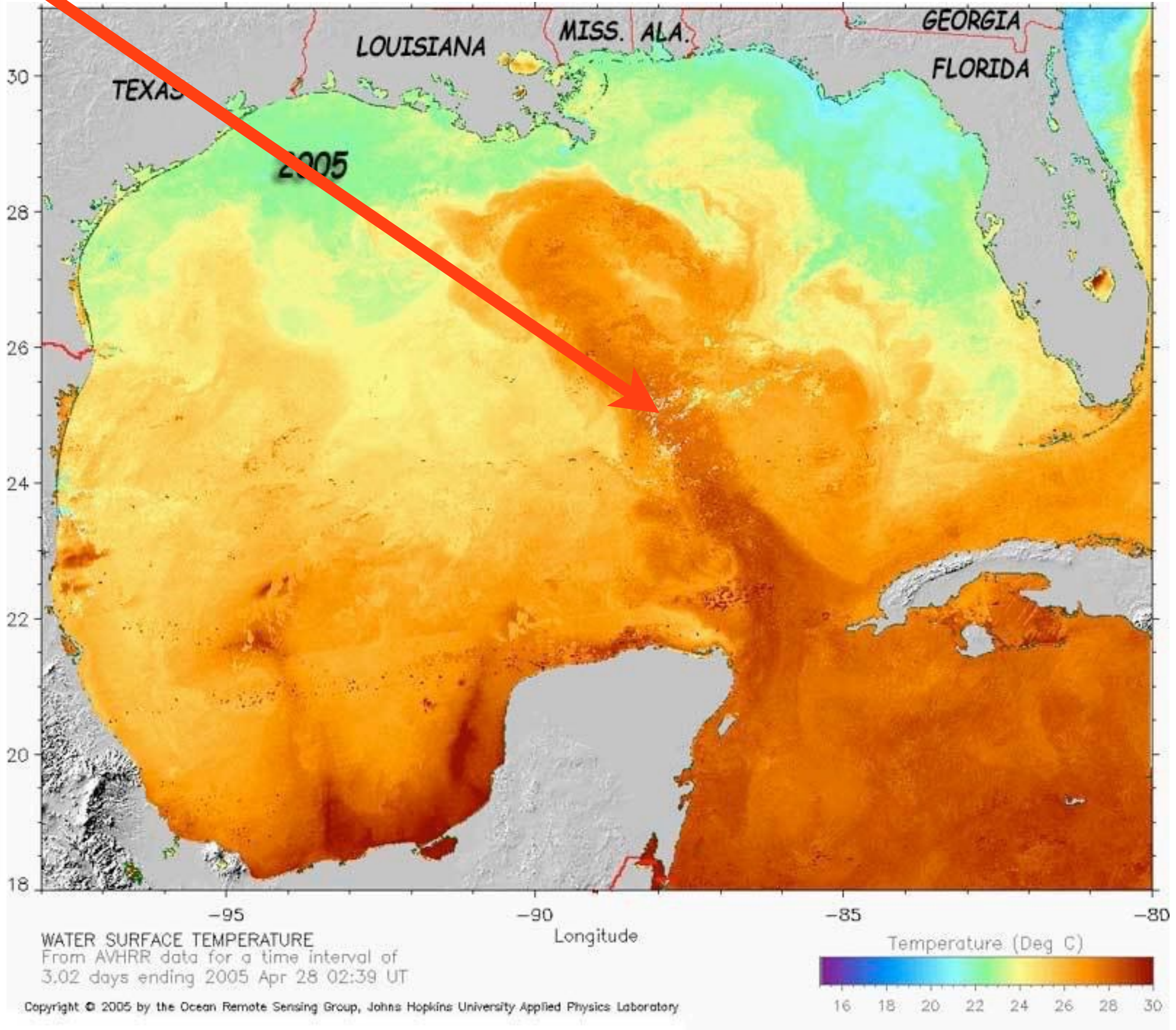
usace/army.mil

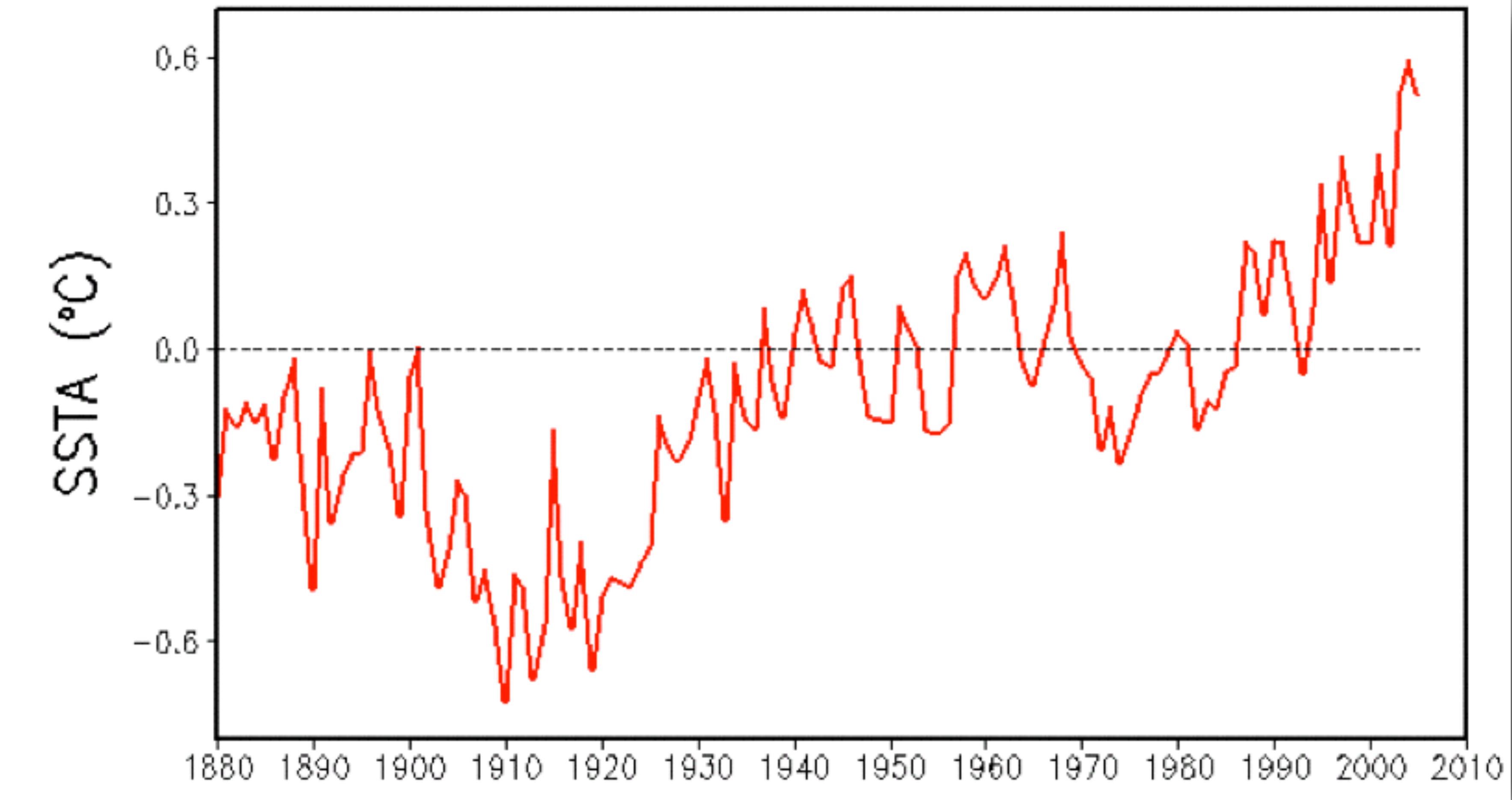


Cases

In Gulf, the “Loop Current” affects track - warm water gives “fuel” to the storm







...and Gulf water is getting warmer!

Natural Hazards and Disaster

Class 20: Hurricanes, Typhoons, Cyclones (continued)

- Definitions, Scales
- Basics
- El Niño - La Niña
- Data Sources
- Where, When, Why
- Cases
- Climate Change Impacts

Natural Hazards and Disaster

Class 20: Hurricanes, Typhoons, Cyclones (continued)

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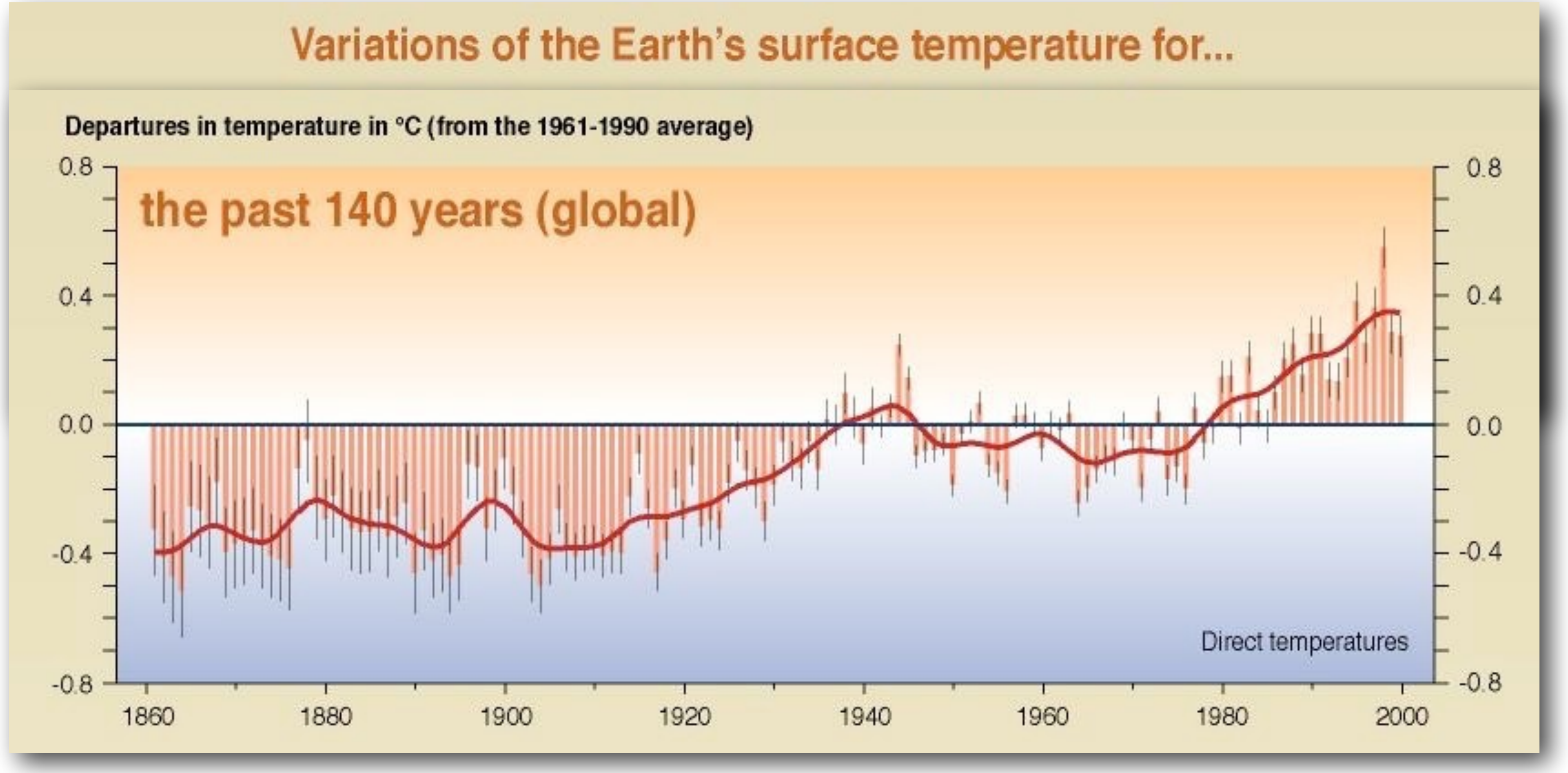
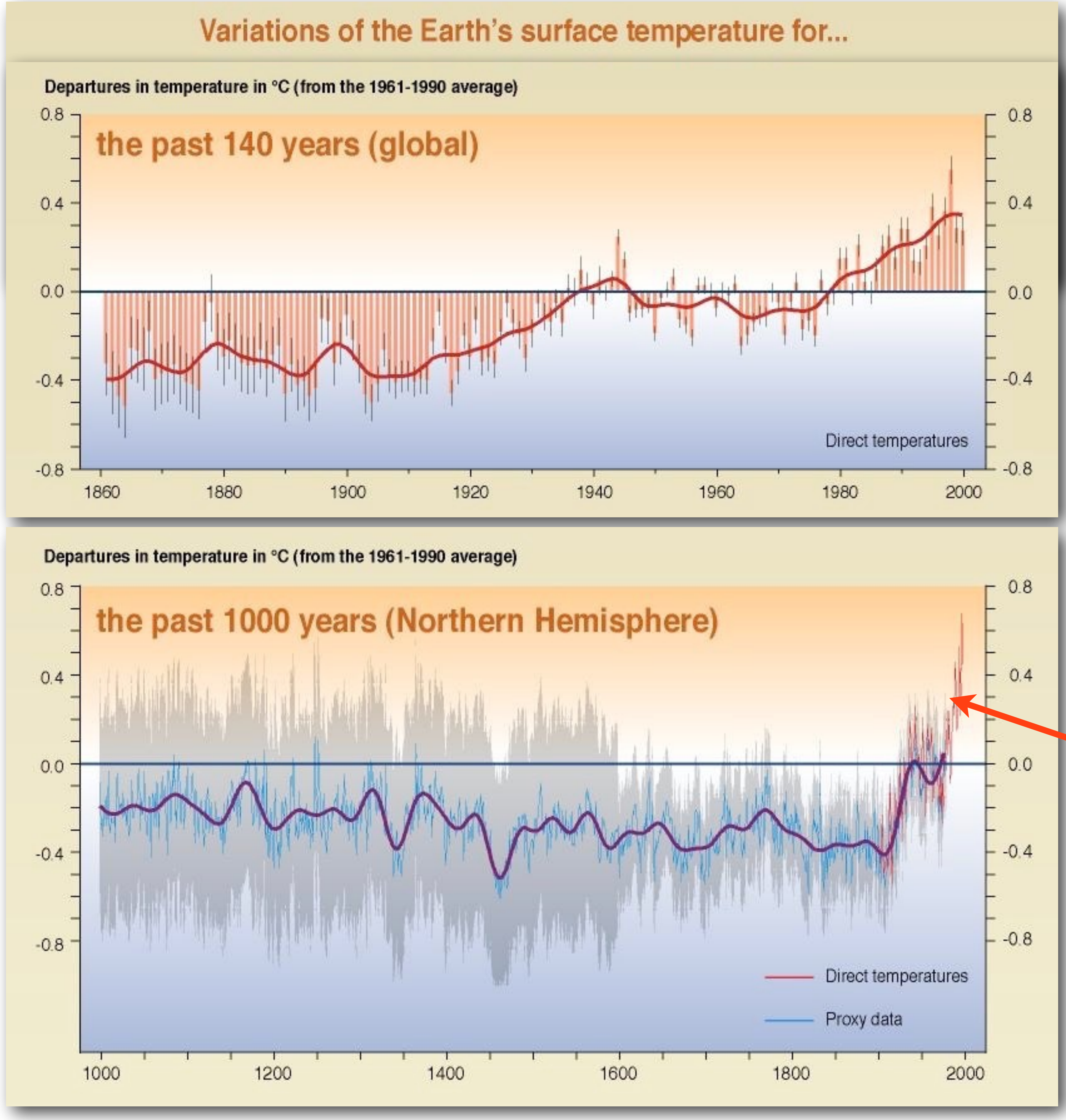
Climate Change Impacts

Is it all getting worse?



Climate Change Impacts

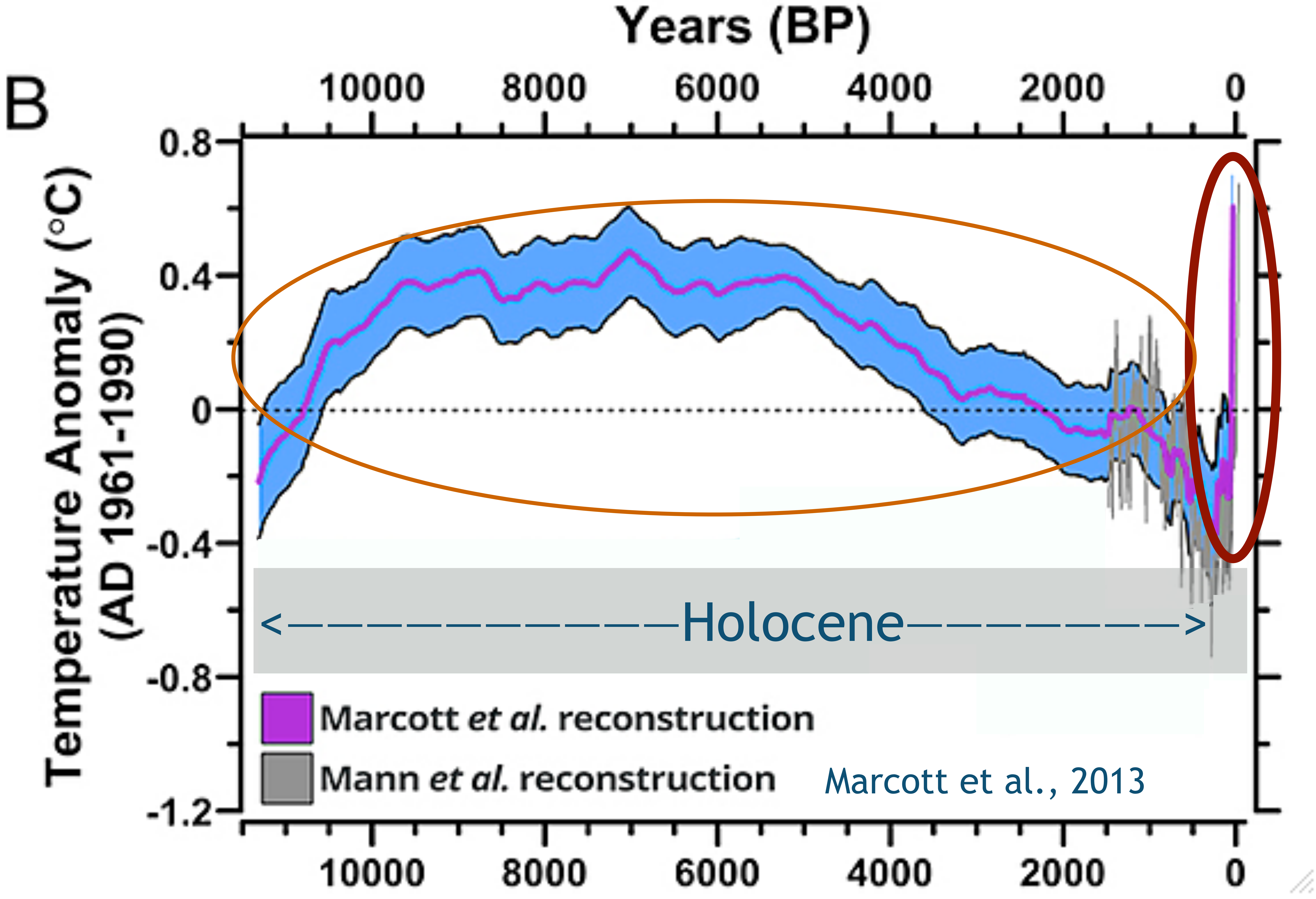
Is it all getting worse?



temperature increase is real, but looks a lot worse if we compress the horizontal scale!

Climate Change Impacts

Is it all getting worse?

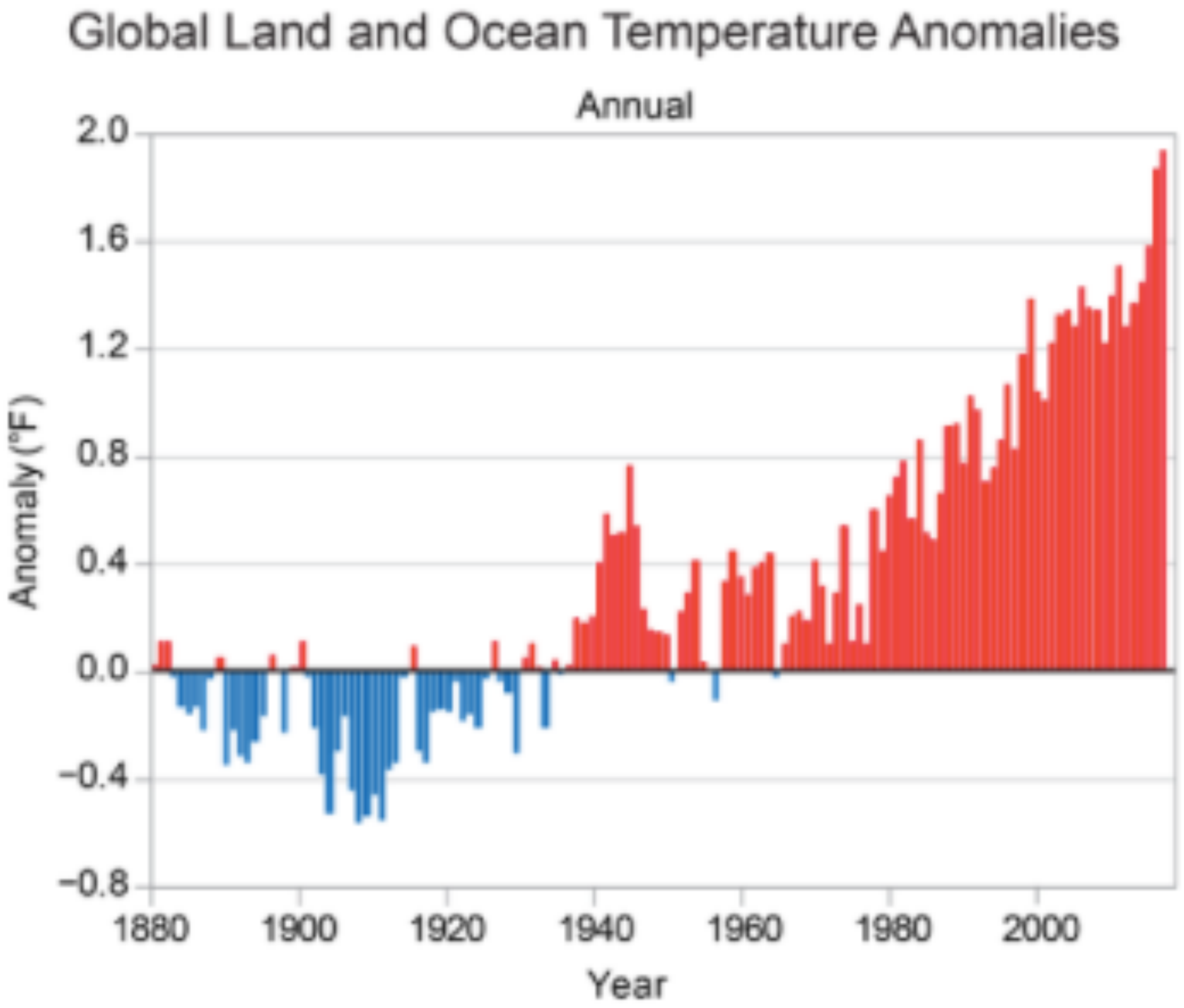


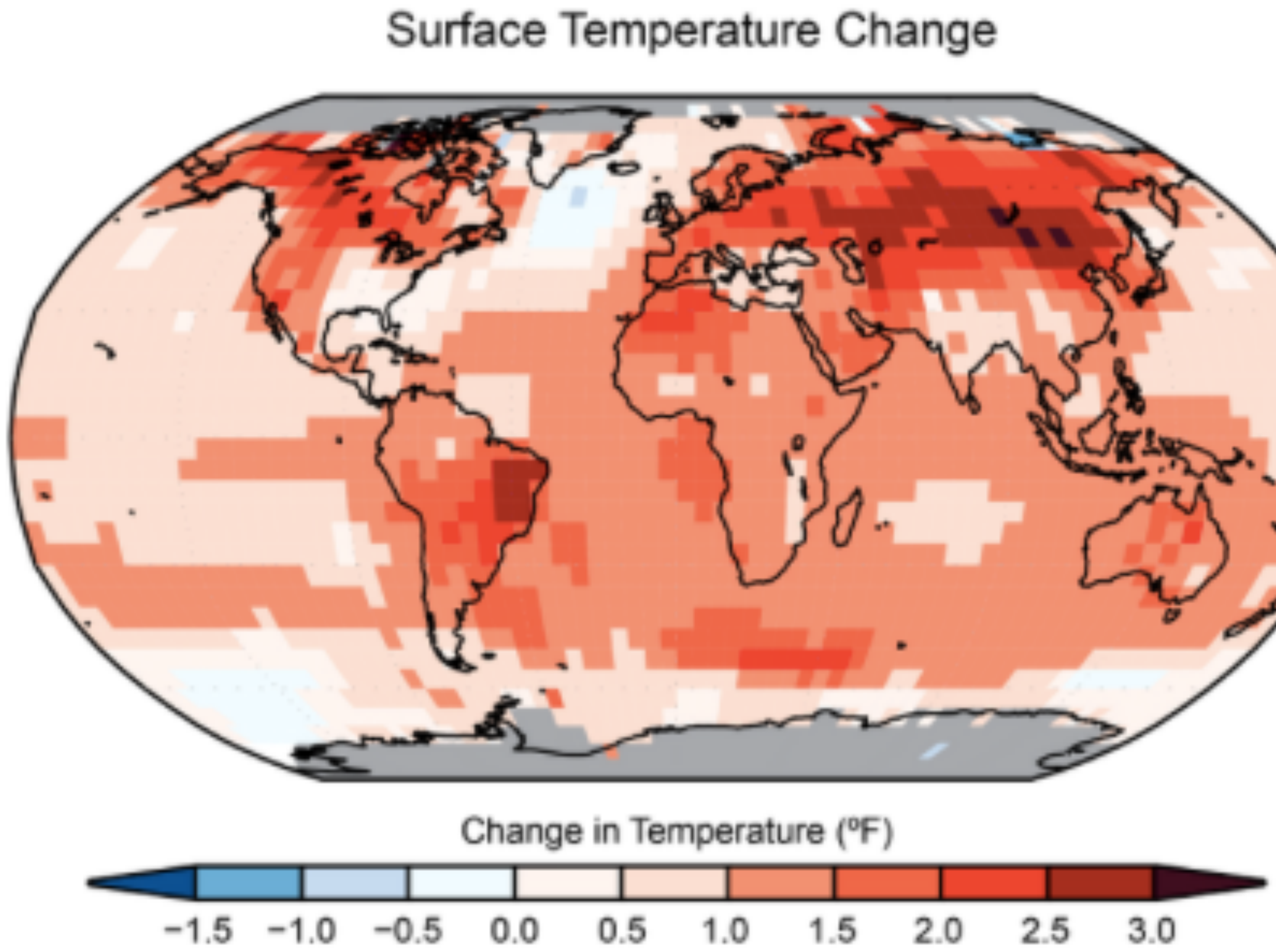
Climate Change Impacts

Is it all getting worse?

Climate Change Impacts

Is it all getting worse?





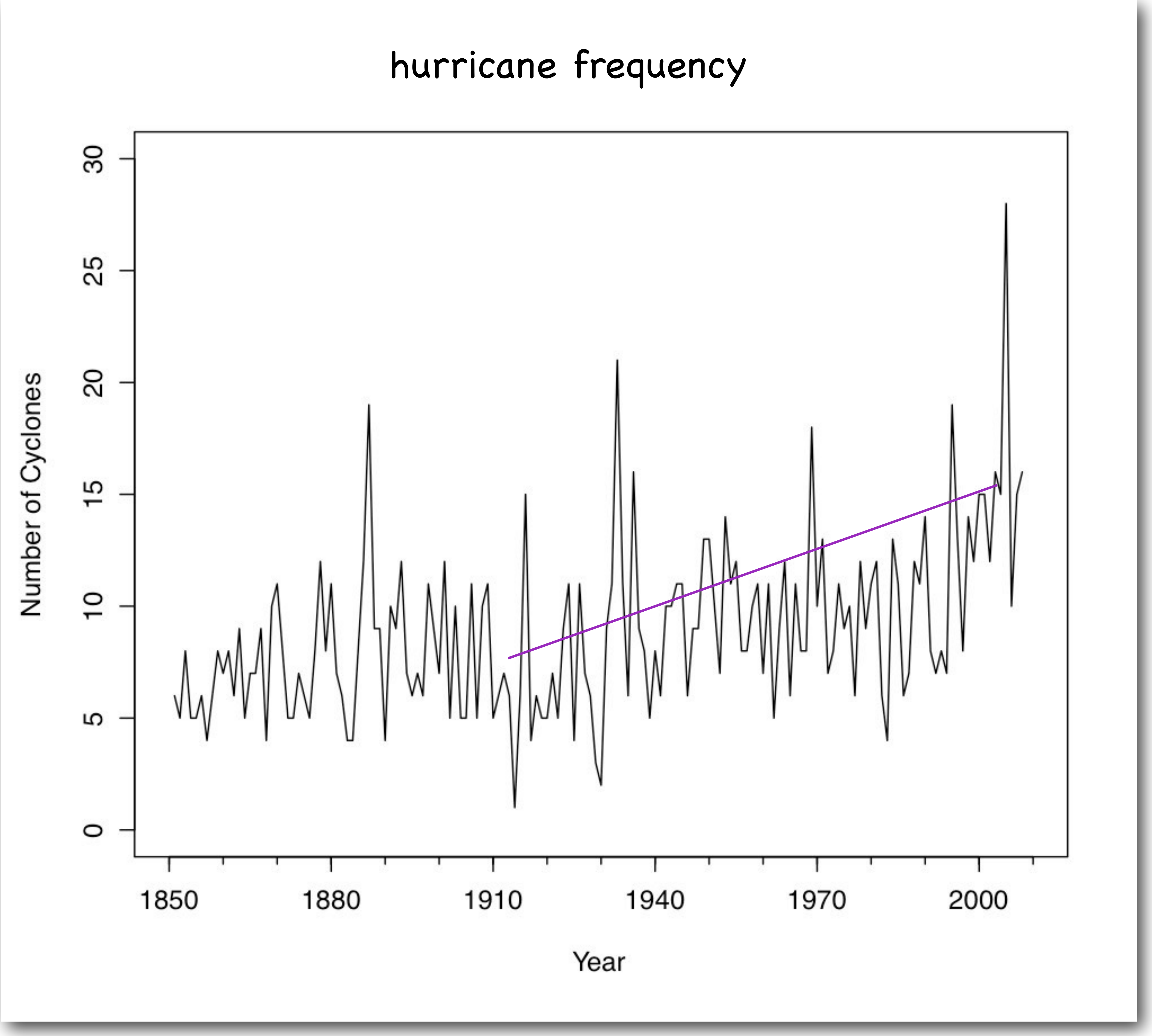
(left) Global annual average temperature has increased by more than 1.2°F (0.7°C) for the period 1986–2016 relative to 1901–1960. Red bars show temperatures that were above the 1901–1960 average, and blue bars indicate temperatures below the average. (right) Surface temperature change (in °F) for the period 1986–2016 relative to 1901–1960. Gray indicates missing data. *From Figures 1.2. and 1.3 in Chapter 1.*

Climate Change Impacts

Is it all getting worse?

Climate Change Impacts

Is it all getting worse?   Let's look at the data:



http://www.clemson.edu/media-relations/files/articles/2009/2262_233_hurricanegraph.jpg

Table 7. Average number of tropical cyclones* which reached storm, hurricane and major hurricane status. Updated from Blake et al. (2007).

PERIOD	Number of Years	Average number of Tropical Storms	Average number of Hurricanes	Average number of Major Hurricanes
1851 - 2010	160	9.0	5.4	1.9
1944# - 2010	67	10.8	6.2	2.7
1966$ - 2010	45	11.4	6.3	2.4
1981 - 2010	30	12.1	6.4	2.7
1995^ - 2010	16	14.8	7.9	3.8

*Includes subtropical storms after 1967

#Start of aircraft reconnaissance

$Start of polar orbiting satellite coverage

^Start of the most recent warm Atlantic era (Goldenberg et al. 2001)

http://www.nhc.noaa.gov/pdf/nws-nhc-6.pdf

Climate Change Impacts

Table 8a. Years of maximum and minimum tropical storm, hurricane, and major hurricane activity in the Atlantic basin 1851-2010. Updated from McAdie et al. (2009).

MAXIMUM ACTIVITY					
TROPICAL STORMS[1]		HURRICANES		MAJOR HURRICANES	
Number	Years	Number	Years	Number	Years
28	2005	15	2005	8	1950
21	1933	12	1969,2010	7	1961, 2005
19	1887,1995,2010	11	1887,1950,1995	6	1926,1955,1964, 1996,2004
18	1969	10	1870,1878,1886, 1893,1916,1933, 1998	5	1893,1916,1933, 1951,1958,1969, 1995,1999,2008, 2010
16	1936,2003,2008	9	1880,1955,1980, 1996,2001,2004		
15	1916,2000,2001 2004, 2007				
14	1953,1990,1998				

MINIMUM ACTIVITY*					
TROPICAL STORMS[1]		HURRICANES		MAJOR HURRICANES	
Number	Years	Number	Years	Number	Years
1	1914	0	1907,1914	0	In 31 years last in 1994
3	1930	1	1905,1925	1	In 48 years last in 1997
4	1857,1868,1883, 1884,1890,1917, 1925,1983	2	1890,1895,1917, 1919,1930 1931,1982		
5	In 18 years last in 1962	3	In 30 years last in 2009		

Notes

[1] Includes subtropical storms after 1967.

*likely underestimated before satellite imagery in 1966

http://www.nhc.noaa.gov/pdf/nws-nhc-6.pdf

Climate Change Impacts

Table 8b. Years of maximum United States hurricane and major hurricane strikes 1851-2010.

MAXIMUM U.S. ACTIVITY			
HURRICANE STRIKES		MAJOR HURRICANE STRIKES	
Number	Years	Number	Years
7	1886	4	2005
6	1985,2004,2005	3	1893,1909,1933, 1954,2004
5	1893,1909,1933		
4	1869,1880,1887, 1888,1906,1915, 1916,1926,1964	2	1879,1886,1915, 1916,1926,1944, 1950,1955,1985

http://www.nhc.noaa.gov/pdf/nws-nhc-6.pdf

Table 9c. Monthly records for the numbers of tropical storms, hurricanes and major hurricanes observed in the Atlantic basin by month of formation.

	TROPICAL STORMS[1]		HURRICANES		MAJOR HURRICANES	
MONTH	Record	Year	Record	Year	Record	Year
MAY	2	1887*	1	1970*	1	1951
JUNE	3	1968*	3	1886	1	1966*
JULY	5	2005	3	2005*	2	2005*
AUGUST	8	2004	5	2004*	3	2004*
SEPTEMBER	8	2010*	5	2005*	4	1961*
OCTOBER	7	2005	6	1870	2	2005*
NOVEMBER	3	2005*	3	2001	1	2008*
DECEMBER	2	2003*	1	2005*	0	-

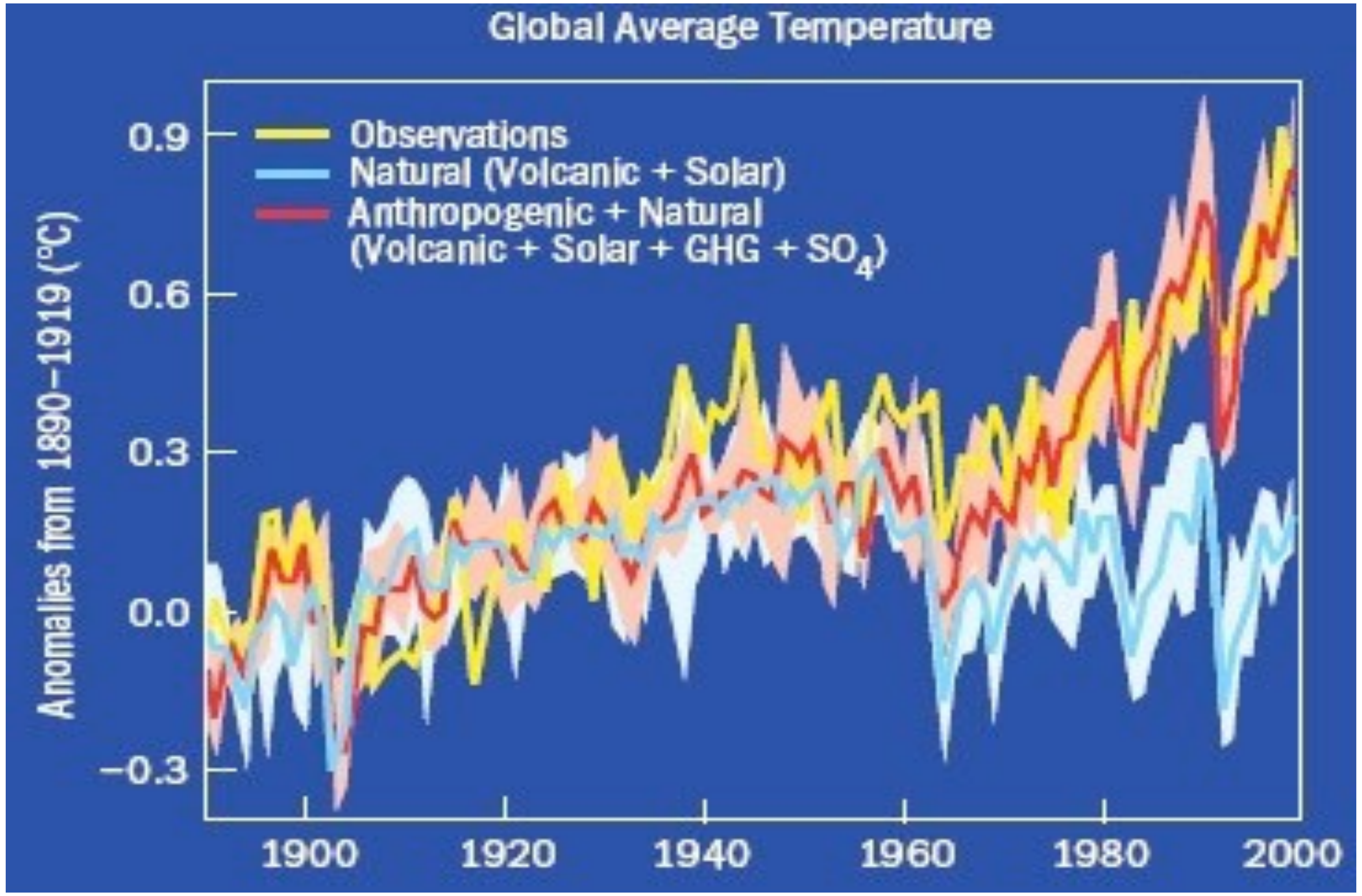
[1] Includes subtropical storms after 1967. See McAdie et al. (2009) for details.

* occurred in other years, latest occurrence shown.

http://www.nhc.noaa.gov/pdf/nws-nhc-6.pdf

Is human activity the main cause?

Is human activity the main cause?



http://www.scidacreview.org/0702/images/interview01.jpg

Natural Hazards and Disaster

Lab in Class 20: Hurricanes, Typhoons, Cyclones

Class 20: Tornadoes

- Basics: What, Where, When
- Strength
- Origin

Natural Hazards and Disaster

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Tornadoes: Basics: What, Where, When

A tornado is "a violently rotating column of air, in contact with the ground, either pendant from a cumuliform cloud or underneath a cumuliform cloud, and often (but not always) visible as a funnel cloud.

On a local scale, the tornado is the most intense of all atmospheric circulations. Its vortex usually rotates cyclonically (on rare occasions anticyclonically rotating tornadoes have been observed) with wind speeds as low as 30 m/s (108 km/h) to as high as 135 m/s (486 km/h), and is generally < 2 km in diameter. Tornado intensity is often estimated on the basis of wind damage using the Enhanced Fujita Scale; however, this estimate can be refined using other measurements, especially in the absence of damage indicators. Some tornadoes may also contain secondary vortices (also referred to as suction vortices, subvortices, multiple, and satellite vortices).Tornadoes have been observed on all continents except Antarctica but are most common in the United States, where the average number of reported tornadoes is roughly 1000 per year, with the majority of them on the central plains and in the southeastern states (see Tornado Alley). They can occur throughout the year at any time of day. In the central plains of the United States they are most frequent in spring during the late afternoon."

Modified from *Glossary of Meteorology (2000). Section: T (2 ed.). American Meteorological Society. http://glossary.ametsoc.org/wiki/Tornado*

Tornadoes: Basics: What, Where, When

Tornadoes are violently rotating columns of wind that cause intense, although local, destruction.

Tornadoes are relatively narrow, violently rotating air columns that extend between a thunderstorm's cloud base and the ground surface. Because the outer walls of the rotating air column are rather sharply defined, even though tornadoes inflict extreme destruction on everything within their path, the areas immediately adjacent to a tornado's touchdown may be completely unaffected.

Tornado outbreaks appear to be most prevalent in North America, although they are also reported to occur frequently in Australia as well as in parts of South America, southern Russia, and Bangladesh, and also occasionally in Britain. They may occur in other countries too, but are not as well tracked and reported as they are in the U.S.A. where roughly 1,000 tornadoes occur annually, most often (but not exclusively) in the southern and southeastern states in the spring and early summer months.

A tornado touchdown near Tuscaloosa, Alabama, U.S.A. on April 27, 2011, one of a swarm of more than 200 tornadoes that day in the southeastern U.S.A. that caused a total death toll of almost 400.

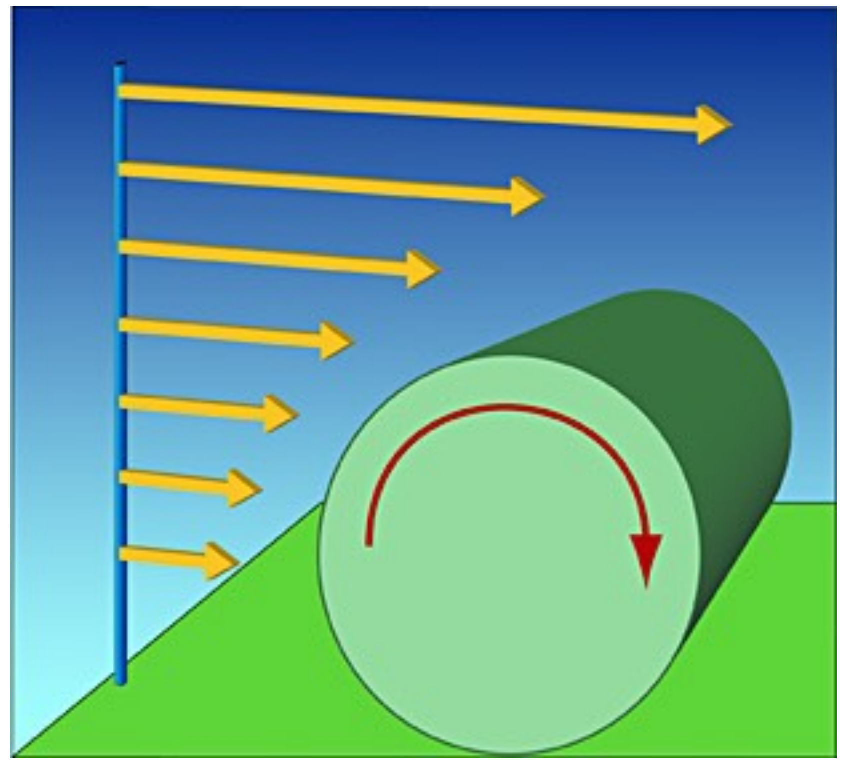
Tornado destruction in Pratt City area of Birmingham, Alabama, U.S.A. on April 27, 2011.

Funnels vs. Tornadoes

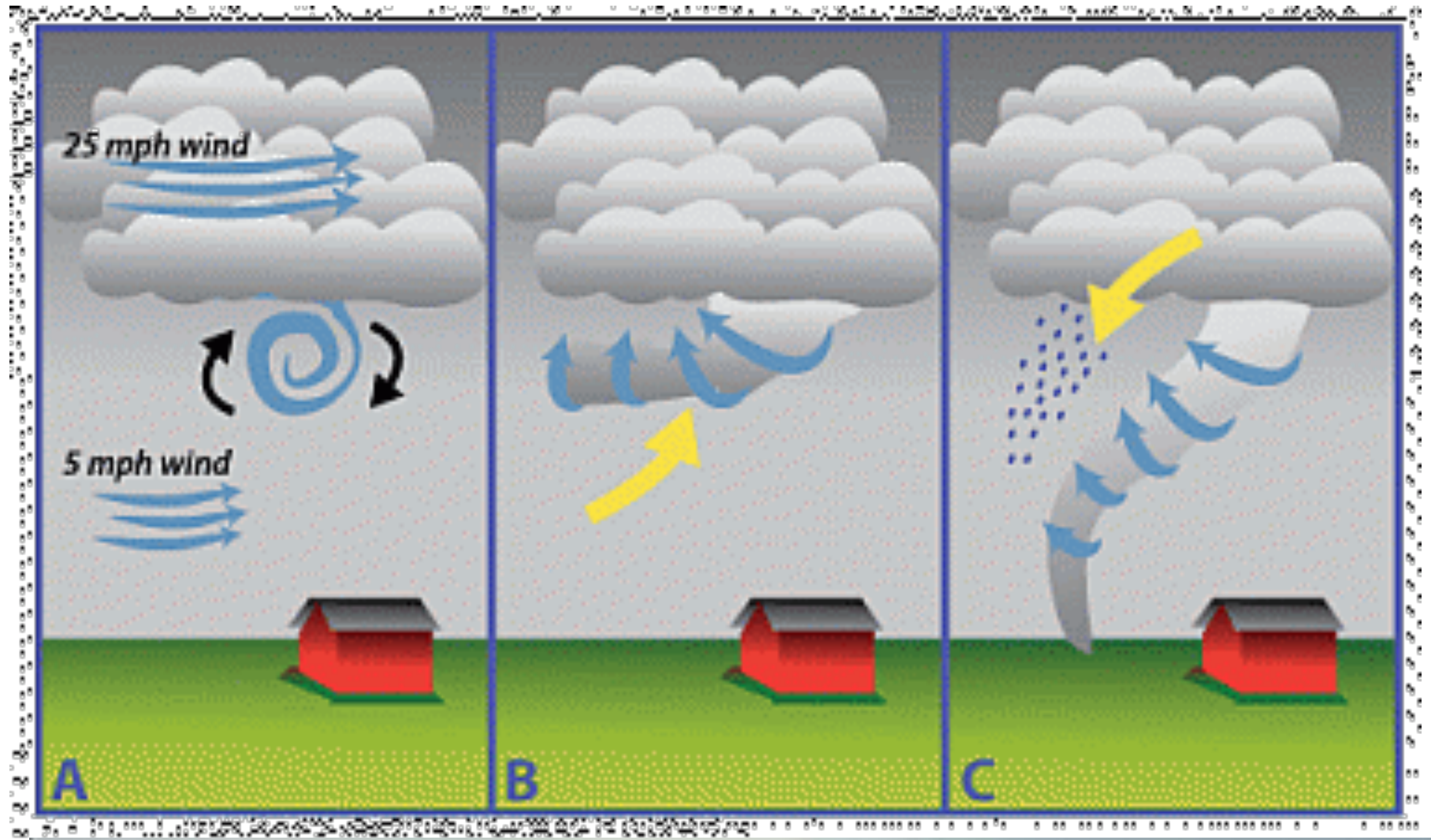
A vortex of rapidly spinning air can form a funnel cloud that may, or may not, become a tornado.

The wind at ground level often blows in a different direction and/or at a different speed than higher level air. This is especially true under thunderstorm conditions when the differential conditions create strong wind shear, which can form a spinning tube of air known as a vortex beneath the cloud base.

Funnel clouds, which do not reach the ground, occur when condensed water vapor is entrained in the vortex and are not in themselves dangerous except to small aircraft that may fly into them (unlikely, as pilots are trained to avoid thunderstorms). However, strong downdrafts, such as occur in supercells, may push one end of the vortex downwards so that makes contact with the ground as a tornado.



Wind direction (left) and speed (right) vary with height above ground.



Left: Differential wind speeds create wind shear. Center: Wind shear and updrafts form a tilted, spinning tube of air, called a vortex, often seen as a funnel cloud. Right: Strong downdrafts with rain and/or hail connect the vortex to the ground as a tornado.

Funnel cloud seen over Oak Brook, near Chicago, Illinois, on June 24, 2014.

Tornadoes: Basics: What, Where, When

This tornado has no funnel cloud; however, the rotating dust cloud indicates that strong winds are occurring at the surface, and thus it is a true tornado.

Tornadoes: Basics: What, Where, When

A **multiple-vortex tornado** has two or more columns of spinning air that rotate about their own axis and at the same time around a common center. A multi-vortex structure is more likely to occur in intense tornadoes.

A **satellite tornado** is a smaller tornado which forms very close to a large, strong tornado contained within the same mesocyclone. The satellite tornado may appear to orbit around the larger tornado and this system may look like a large multi-vortex tornado. However, a satellite tornado is a distinct circulation and is much smaller than the main funnel.

A multiple-vortex tornado outside Dallas, Texas on April 2, 1957.

Tornadoes: Basics: What, Where, When

A **waterspout** is defined as a tornado over water. Fair weather waterspouts are less severe than tornadic waterspouts but far more common. They form at the bases of cumulus congestus clouds over tropical and subtropical waters. They have weak winds, smooth walls, and typically travel very slowly. They are mainly found in the Florida Keys and the northern Adiratic Sea. Tornadic waterspouts are stronger tornadoes over water. They can form over water or are stronger tornadoes which cross over water. They form from severe thunderstorms and can be far more intense, faster, and longer-lived than fair weather waterspouts, and they are more dangerous.

A **landspout**, or dust-tube tornado, is a tornado not associated with a mesocyclone. Waterspouts and landspouts share many defining characteristics, including relative weakness, short lifespan, and a small, smooth condensation funnel which often does not reach the surface. If they make contact with the ground, they create a distinctively laminar cloud of dust. Although they are usually weaker than classic tornadoes, they can produce strong and damaging winds.

A waterspout near the Florida Keys in 1969.

Tornadoes: Basics: What, Where, When

A **gustnado** is a small, vertical swirl associated with a gust front or downburst. They are not connected with a cloud base. They form when fast moving cold, dry outflow air from a thunderstorm s blown through a mass of stationary, warm, moist air near the outflow boundary, resulting in a "rolling" effect. If low level wind shear is strong enough, the rotation can be turned vertically or diagonally and make contact with the ground.

A **dust devil** or whirlwind looks like tornado in that it is a vertical column of swirling air. They form under clear skies when a strong convective updraft is formed near the ground on a hot day. They are comparable to the weakest tornadoes but they can result in major damage. If there is enough low level wind shear, a column of hot, rising air can develop a small cyclonic motion that can be seen near the ground because of the dust.

A large dust devil on June 10. Credit: NASA

https://www.nasa.gov/vision/universe/solarsystem/2005_dust_devil.html

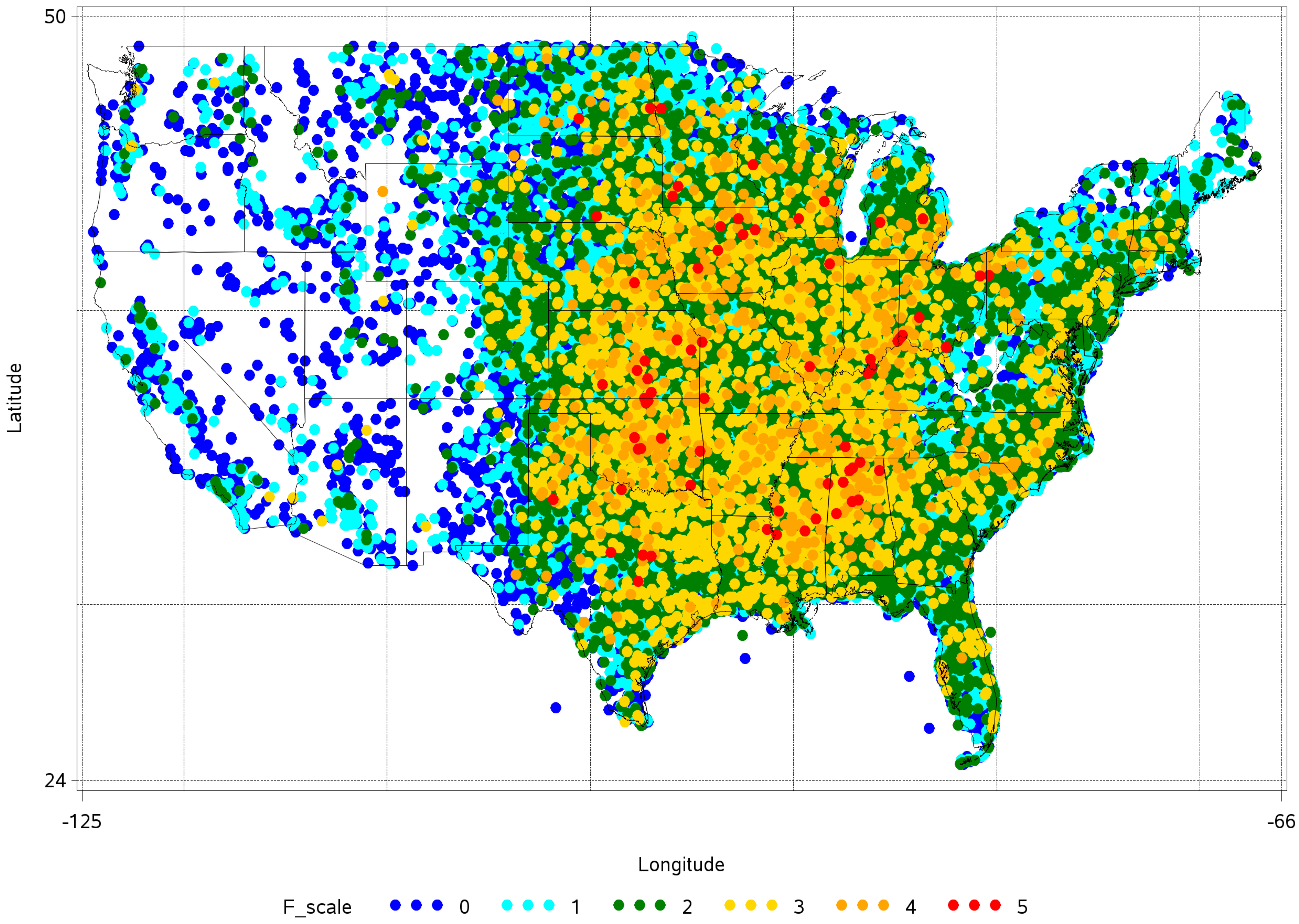
Tornadoes: Basics: What, Where, When

Small-scale circulations can occur near any intense surface heat source.

Fire whirls occur near intense wildfires. They are not considered tornadoes unless in the rare case where they connect to a pyrocumulus or other cumuliform cloud above. Fire whirls usually are not weaker than tornadoes associated with thunderstorms but they can produce significant damage.

A **steam devil** is a rotating updraft between 50 m and 200 m wide that involves steam or smoke. They do not have high wind speeds and only complete a few rotations per minute. Steam devils are very rare and most often form from smoke issuing from a power plant's smokestack. Hot springs and deserts may also be suitable locations for a tighter, faster-rotating steam devil to form. Steam devils can occur over water, when cold arctic air passes over relatively warm water.

Tornadoes: Basics: What, Where, When



All tornadoes in the US, 1950–2013, plotted by midpoint, highest F-scale on top, Alaska and Hawaii negligible, source NOAA Storm Prediction Center.

Natural Hazards and Disaster

Lab in Class 20: Hurricanes, Typhoons, Cyclones

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Tornadoes: Strength

Tornadoes are rated according to the damage they cause, using an Enhanced Fujita Scale (EF-Scale).

The strength of a tornado is estimated by the amount of property damage caused by its winds. The Fujita scale (F-scale) was introduced by Dr. T. Theodore Fujita in 1971. The Enhanced Fujita Scale (EF scale) was introduced in the U.S. , in 2007 and in Canada in 2013. For the EF, damage to various types of buildings has been calibrated by engineers and meteorologists. Like the original scale, the EF scale runs from EF0 (very little damage; wind speeds of under 30 m/s) to a maximum of EF5 (wind speeds over 116 m/s). Most damage is caused by EF3 and EF4 tornadoes. The most violent EF5 tornadoes destroy weather instruments, therefore no accurate measurements have yet been made of the strongest wind speeds within tornadoes. The highest near-surface tornado wind speeds measured to date were over 480 km/h in Oklahoma on May 3, 1999, using remote Doppler radar instruments.

Enhanced Fujita (EF) Tornado Intensity Scale

EF Scale	Class	Wind Speed			Description
		mph	km h^{-1}	m s^{-1}	
EF0	weak	65-85	105-137	29-38	Gale
EF1	weak	86-110	138-177	38-49	Moderate
EF2	strong	111-135	178-217	50-60	Significant
EF3	strong	136-165	218-266	61-74	Severe
EF4	violent	166-200	267-322	74-89	Devastating
EF5	violent	> 200	> 322	> 89	Incredible

Enhanced Fujita (EF) Scale estimates wind speeds from damage to buildings of various structural strengths, using a strongly-built wooden frame house as baseline. Original F-scale correlated building damage with wind strength, but did not allow for variations in the structural strength of buildings.

Damage caused by an EF4 tornado in Washington, Illinois, U.S.A. on November 17, 2013.

Tornadoes: Strength

Scale	Wind speed (Estimated)[5]			Relative frequency	Potential damage	Example of damage
	mph	km/h	m/s			
EF0	65–85	105–137	29–37	56.88%	Minor or no damage. Peels surface off some roofs; some damage to gutters or siding; branches broken off trees; shallow-rooted trees pushed over. Confirmed tornadoes with no reported damage (i.e., those that remain in open fields) are always rated EF0.	
EF1	86–110	138–177	38–49	31.07%	Moderate damage. Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken.	
EF2	111–135	178–217	50–60	8.80%	Considerable damage. Roofs torn off well-constructed houses; foundations of frame homes shifted; mobile homes completely destroyed; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.	
EF3	136–165	218–266	61–73	2.51%	Severe damage. Entire stories of well-constructed houses destroyed; severe damage to large buildings such as shopping malls; trains overturned; trees debarked; heavy cars lifted off the ground and thrown; structures with weak foundations are badly damaged.	
EF4	166–200	267–322	74–90	0.66%	Extreme damage. Well-constructed and whole frame houses completely leveled; cars and other large objects thrown and small missiles generated.	
EF5	>200	>322	>90	0.08%	Total destruction of buildings. Strong-framed, well-built houses leveled off foundations are swept away; steel-reinforced concrete structures are critically damaged; tall buildings collapse or have severe structural deformations; some cars, trucks and train cars can be thrown approximately 1 mile (1.6 kilometres).	

Tornado rating classifications

<table>
<tr><th>EF0</th><th>EF1</th><th>EF2</th><th>EF3</th><th>EF4</th><th>EF5</th></tr>
<tr><td colspan="2">Weak</td><td colspan="2">Strong</td><td colspan="2">Violent</td></tr>
<tr><td colspan="2"></td><td colspan="4">Significant</td></tr>
<tr><td colspan="3"></td><td colspan="3">Intense</td></tr>
</table>

https://en.wikipedia.org/wiki/Enhanced_Fujita_scale

Tornadoes: Strength

DI No.	Damage Indicator (DI)	Degrees of Damage (DOD)
1	Small Barns or Farm Outbuildings (SBO)	8
2	One- or Two-Family Residences (FR12)	10
3	Manufactured Home – Single Wide (MHSW)	9
4	Manufactured Home – Double Wide (MHDW)	12
5	Apartments, Condos, Townhouses [3 stories or less] (ACT)	6
6	Motel (M)	10
7	Masonry Apartment or Motel Building (MAM)	7
8	Small Retail Building [Fast Food Restaurants] (SRB)	8
9	Small Professional Building [Doctor's Office, Branch Banks] (SPB)	9
10	Strip Mall (SM)	9
11	Large Shopping Mall (LSM)	9
12	Large, Isolated Retail Building [K-Mart, Wal-Mart] (LIRB)	7
13	Automobile Showroom (ASR)	8
14	Automobile Service Building (ASB)	8
15	Elementary School [Single Story; Interior or Exterior Hallways] (ES)	10
16	Junior or Senior High School (JHSH)	11
17	Low-Rise Building [1–4 Stories] (LRB)	7
18	Mid-Rise Building [5–20 Stories] (MRB)	10
19	High-Rise Building [More than 20 Stories] (HRB)	10
20	Institutional Building [Hospital, Government or University Building] (IB)	11
21	Metal Building System (MBS)	8
22	Service Station Canopy (SSC)	6
23	Warehouse Building [Tilt-up Walls or Heavy-Timber Construction] (WHB)	7
24	Electrical Transmission Lines (ETL)	6
25	Free-Standing Towers (FST)	3
26	Free-Standing Light Poles, Luminary Poles, Flag Poles (FSP)	3
27	Trees: Hardwood (TH)	5
28	Trees: Softwood (TS)	5

The EF scale currently has 28 damage indicators (DI), or types of structures and vegetation, each with a varying number of degrees of damage (DoD). Larger degrees of damage done to the damage indicators correspond to higher wind speeds. The links in the right column of the table describe the degrees of damage for the damage indicators listed in each row.

https://en.wikipedia.org/wiki/Enhanced_Fujita_scale