Natural Hazards and Disaster

Class 9: Hurricanes, Typhoons, Cyclones

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

Definitions, Scales

“Hurricanes and typhoons are atmospheric circulation systems of tropical origin characterized by low pressure at the center and near surface winds spiraling inward around this center, typically storm size ranges from 10 to 80 km for the radius to maximum wind speeds with cloud cover extending from about 150 to 1,500 km. In meteorological terms, hurricanes and typhoons are low pressure, warm-core cyclones, originating in warm waters with closed surface winds rotating about an eye.”

From Resio, D., Kay, S., 2015. Hurricanes and Typhoons. In "Encyclopedia of Marine Geosciences", pages 1-8, Springer, https://link.springer.com/referenceworkentry/10.1007/978-94-007-6644-0_180-1.

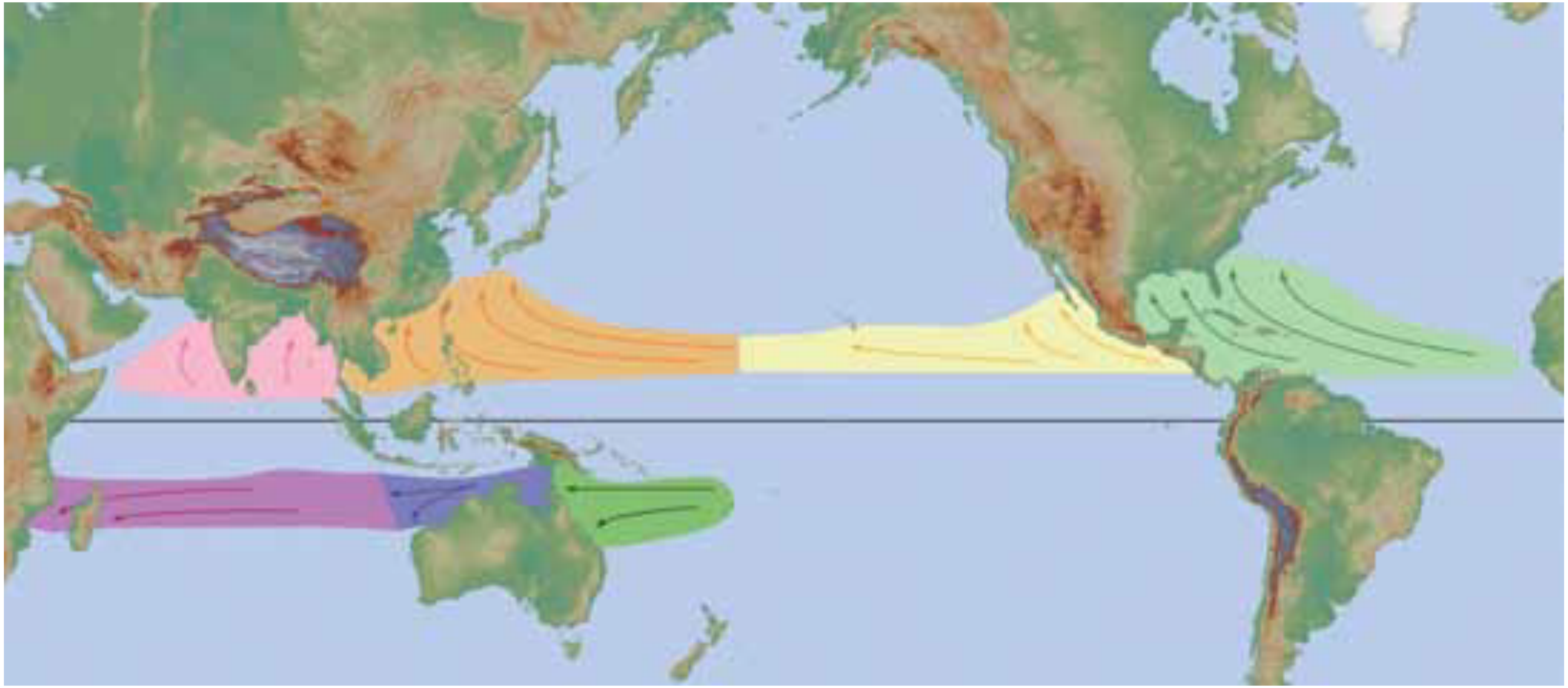
A tropical cyclone is a rotating, organized system of clouds and thunderstorms that originates over tropical or subtropical waters and has a closed low-level circulation. Tropical cyclones rotate counterclockwise in the Northern Hemisphere. They are classified as follows:

- **Tropical Depression**: A tropical cyclone with maximum sustained winds of 38 mph (33 knots) or less.
- **Tropical Storm**: A tropical cyclone with maximum sustained winds of 39 to 73 mph (34 to 63 knots).
- **Hurricane**: A tropical cyclone with maximum sustained winds of 74 mph (64 knots) or higher. In the western North Pacific, hurricanes are called **typhoons**; similar storms in the Indian Ocean and South Pacific Ocean are called **cyclones**.
- **Major Hurricane**: A tropical cyclone with maximum sustained winds of 111 mph (96 knots) or higher, corresponding to a Category 3, 4 or 5 on the Saffir-Simpson Hurricane Wind Scale.

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

Definitions, Scales

Tropical cyclones forming between 5 and 30 degrees North latitude typically move toward the west. Sometimes the winds in the middle and upper levels of the atmosphere change and steer the cyclone toward the north and northwest. When tropical cyclones reach latitudes near 30 degrees North, they often move northeast.



Tropical Cyclone formation regions with mean tracks
From http://www.nhc.noaa.gov/climo/

Definitions, Scales

Strength of event

(km/h)

119-153

154-177

178-209

210-249

>249

Strength of event

Table 1. The Saffir/Simpson Hurricane Wind Scale, modifed from Simpson (1974).

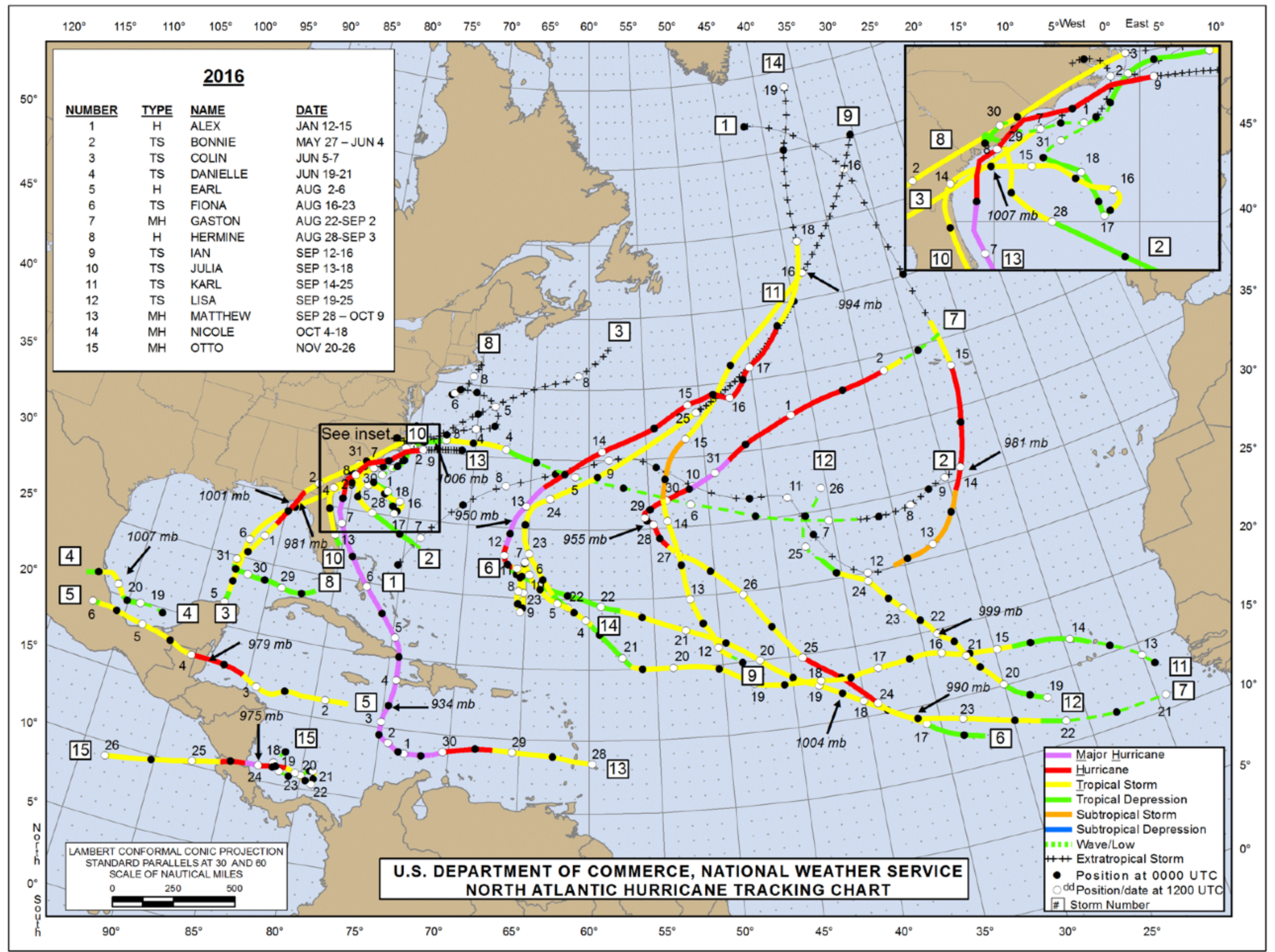
Scale Number (Category)	Winds Maximum 1-min (mph)	(km/h)
1	74-95	119-153
2	96-110	154-177
3	111-130	178-209
4	131-155	210-249
5	> 155	>249

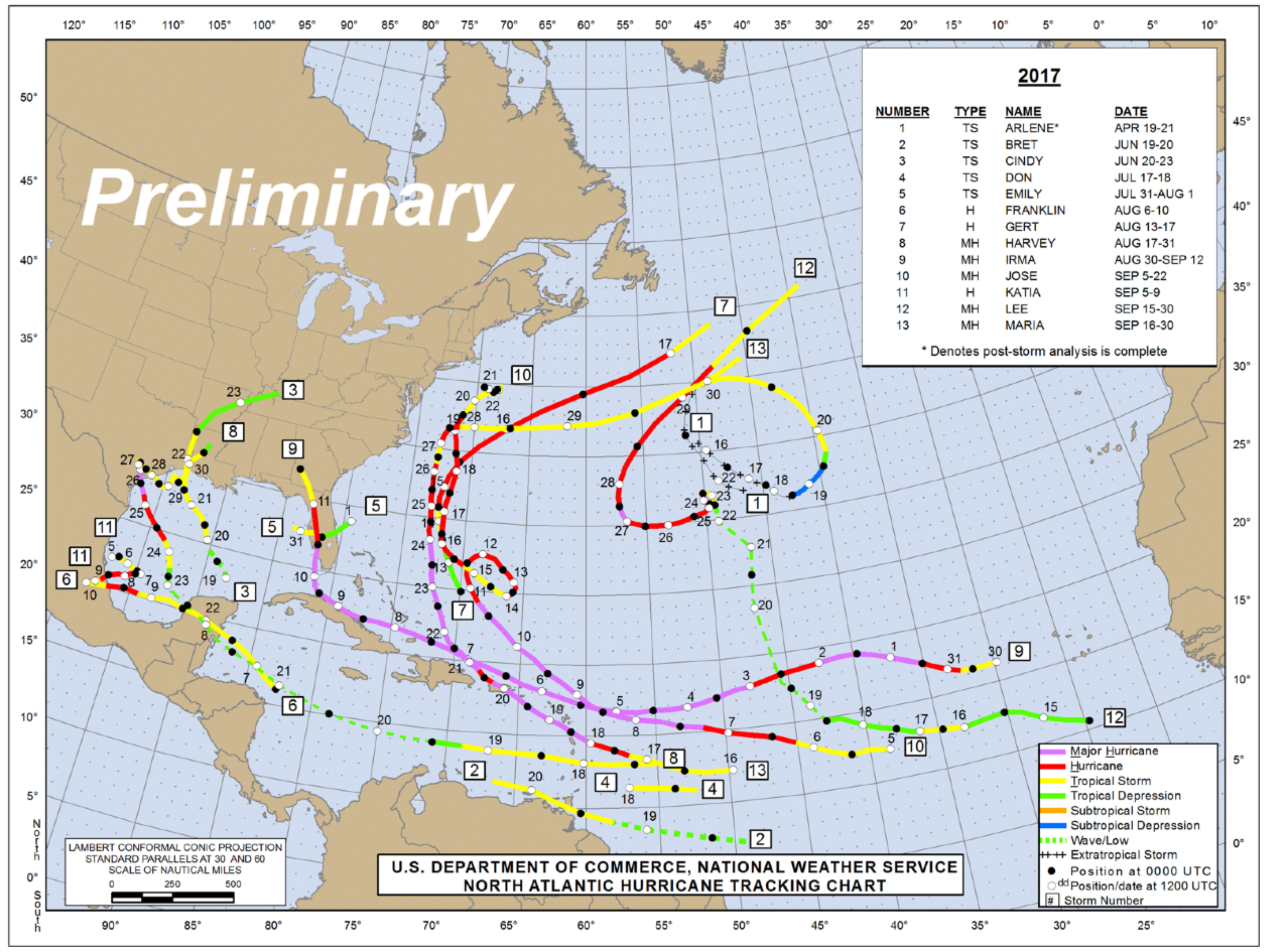
http://www.nhc.noaa.gov/pdf/nws-nhc-6.pdf

Damage

1 Minimal
2 Moderate
3 Extensive
4 Extreme
5 Catastrophic

Definitions, Scales





- Why do Hurricanes form?
- Why do Hurricanes spin?
- Why do they wander about?
- Why do they rotate so fast?
- What causes a storm surge?
- Can we improve forecasts?
- Are things getting worse?
- Is global warming at fault?

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Recap: Climate vs Weather - a matter of time scale!

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- **Weather is short term**!! - hours, days, weeks…
- **Climate is long term** - at least 30 yr average - and influences a broad region of Earth

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- **Weather is short term**!! - hours, days, weeks…
- **Climate is long term** - at least 30 yr average - and influences a broad region of Earth

- **Climate change** can be "long term" (thousands to millions of years), or short term (years to decades)
- Influenced by El Niño, La Niña, volcanic eruptions, or other changes in Earth's system

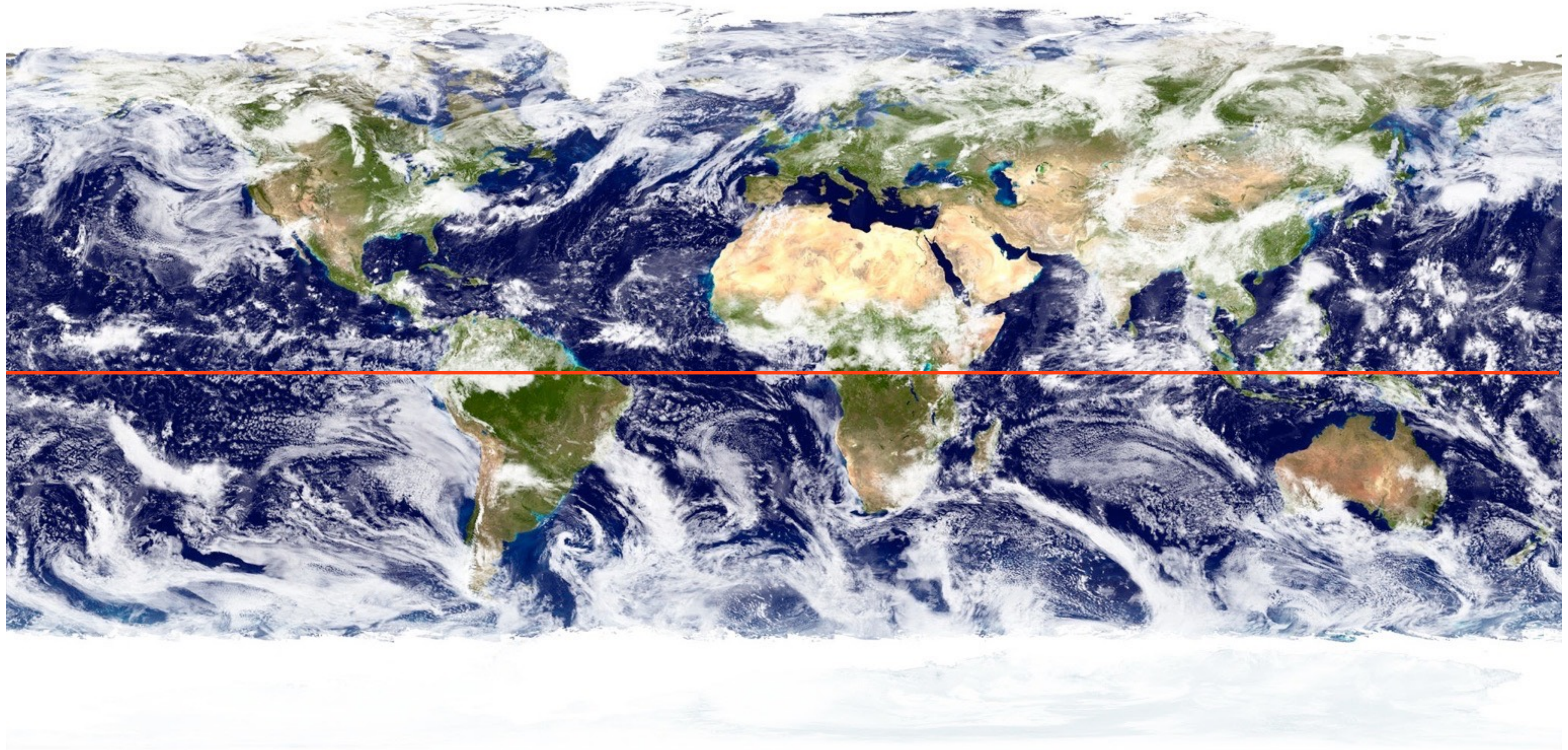
Basics

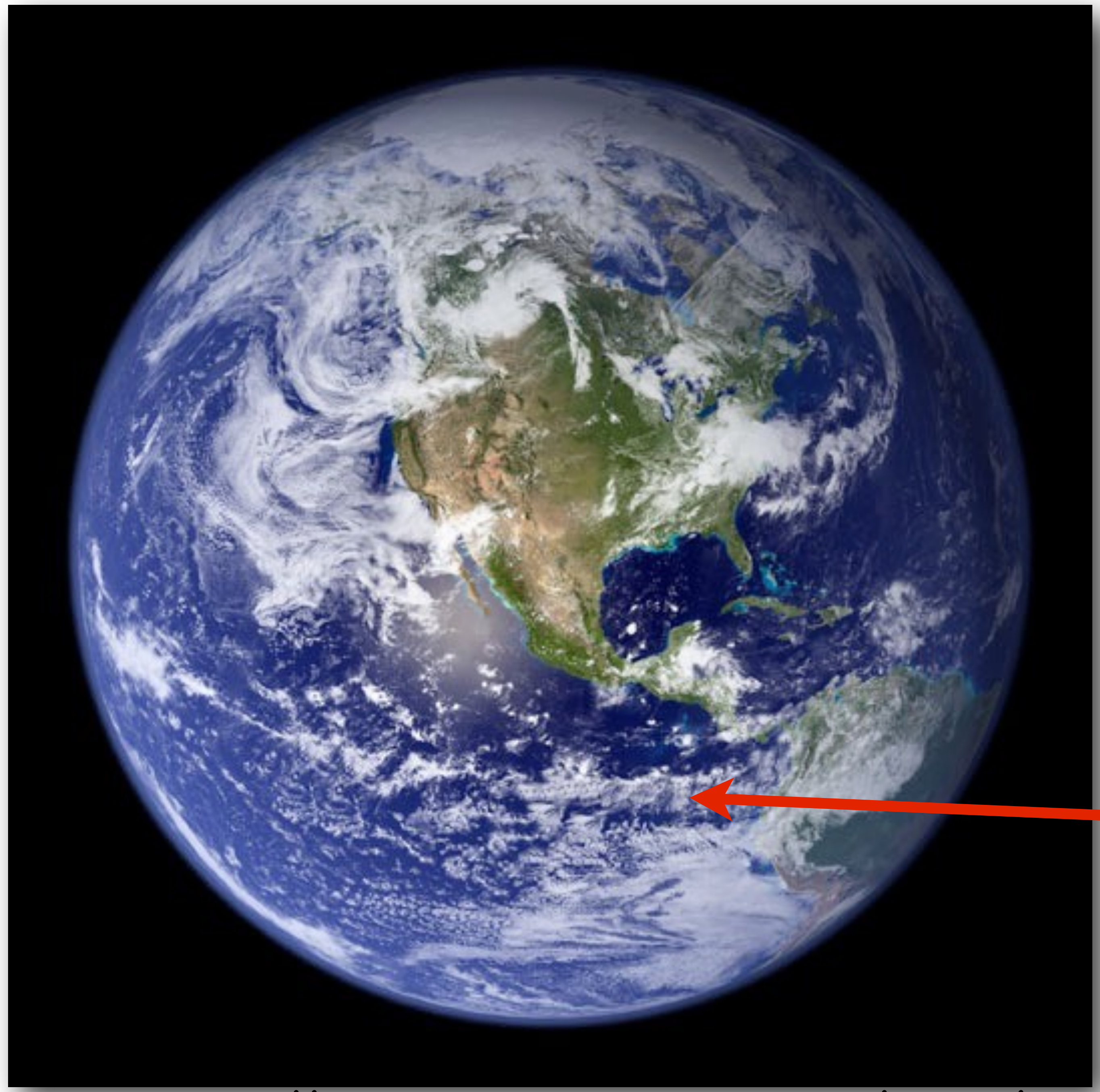
Hadley cells together with Coriolis Force (more later on this) influence prevailing wind direction

prevailing winds NE to SW

equatorial “doldrums”

prevailing winds SE to NW



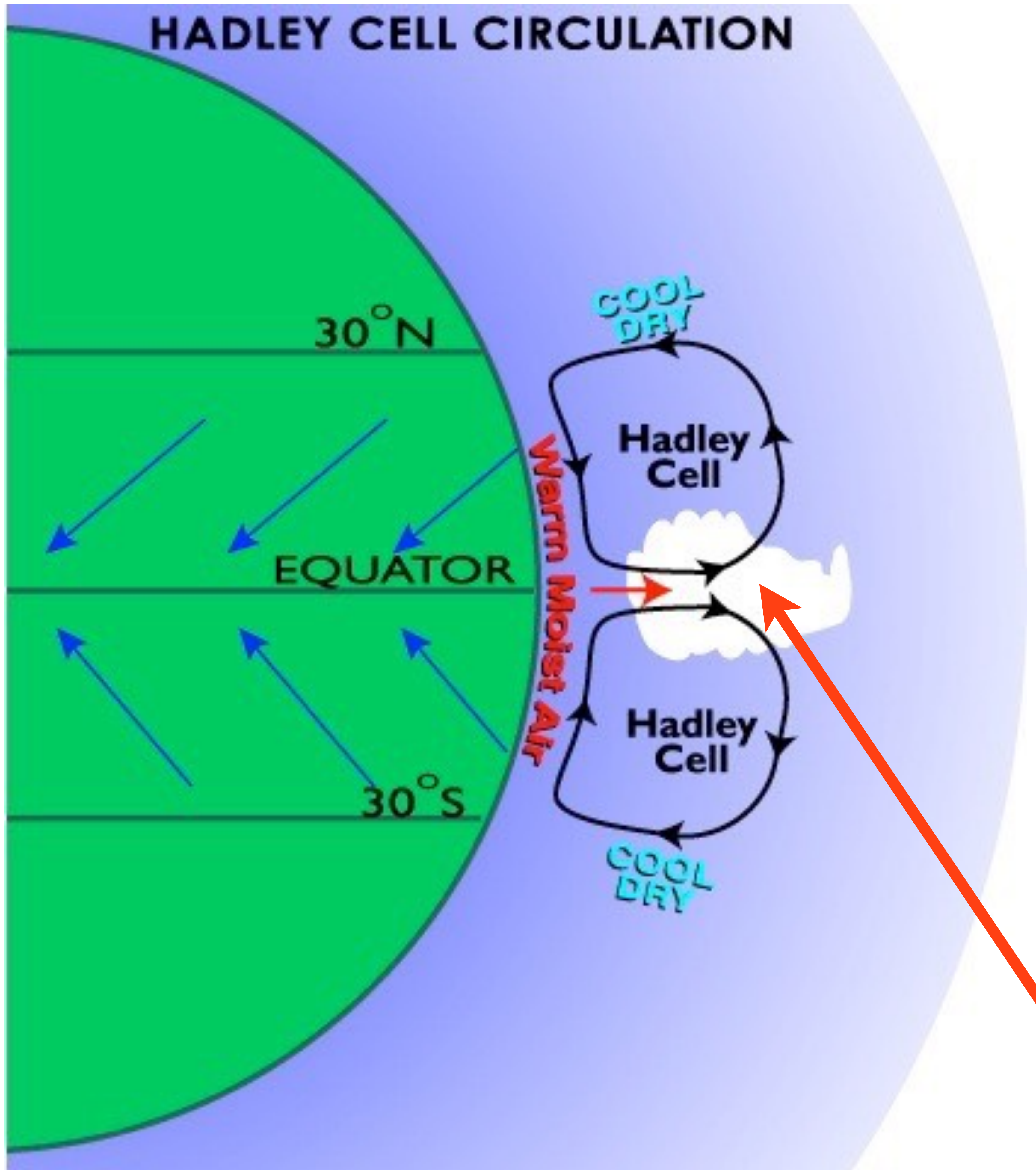


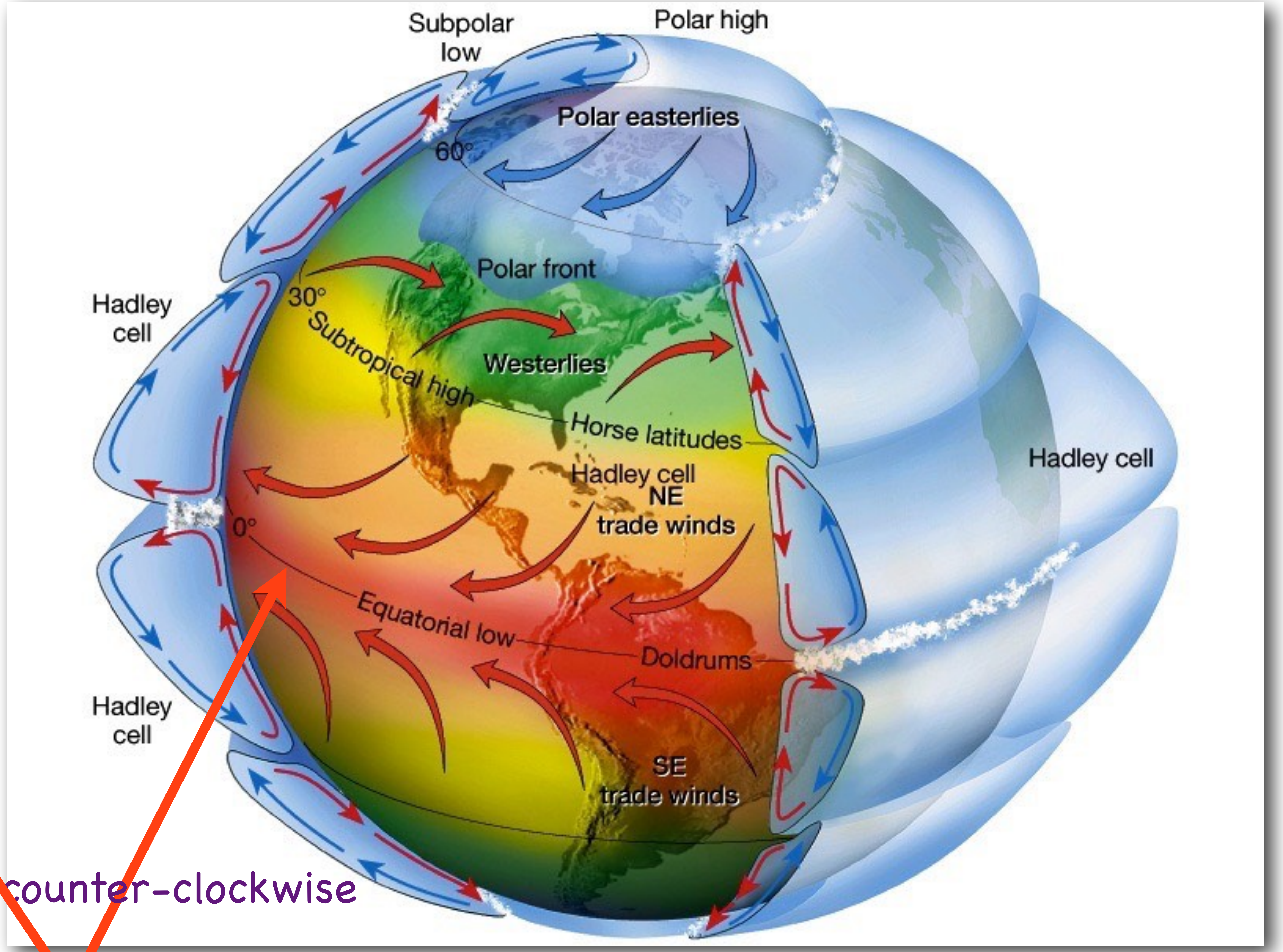
equatorial “doldrums”

http://veimages.gsfc.nasa.gov/2429/globe_west_540.jpg

Basics

Hadley cells in tropical zones influence predominant wind direction across entire planet

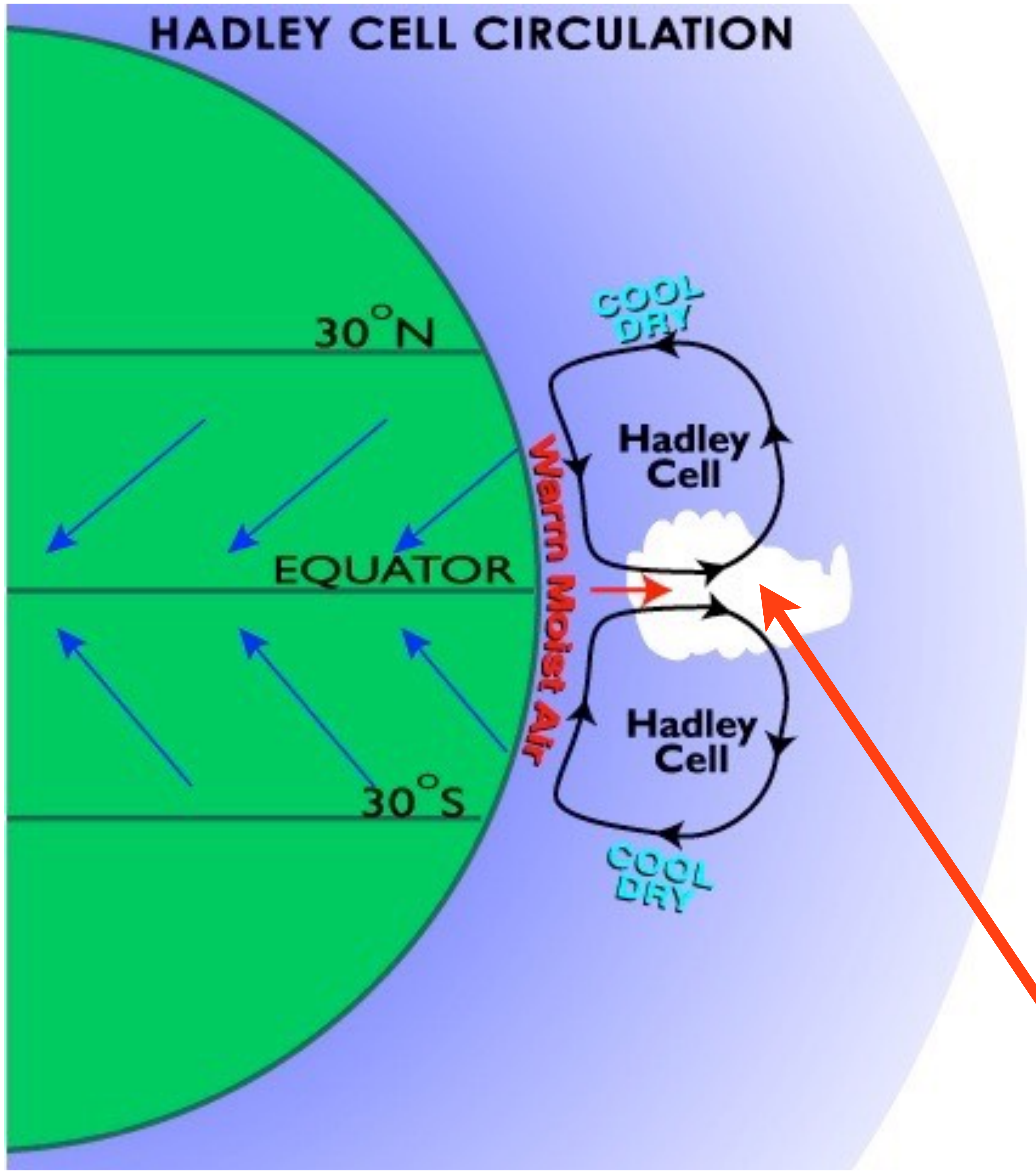


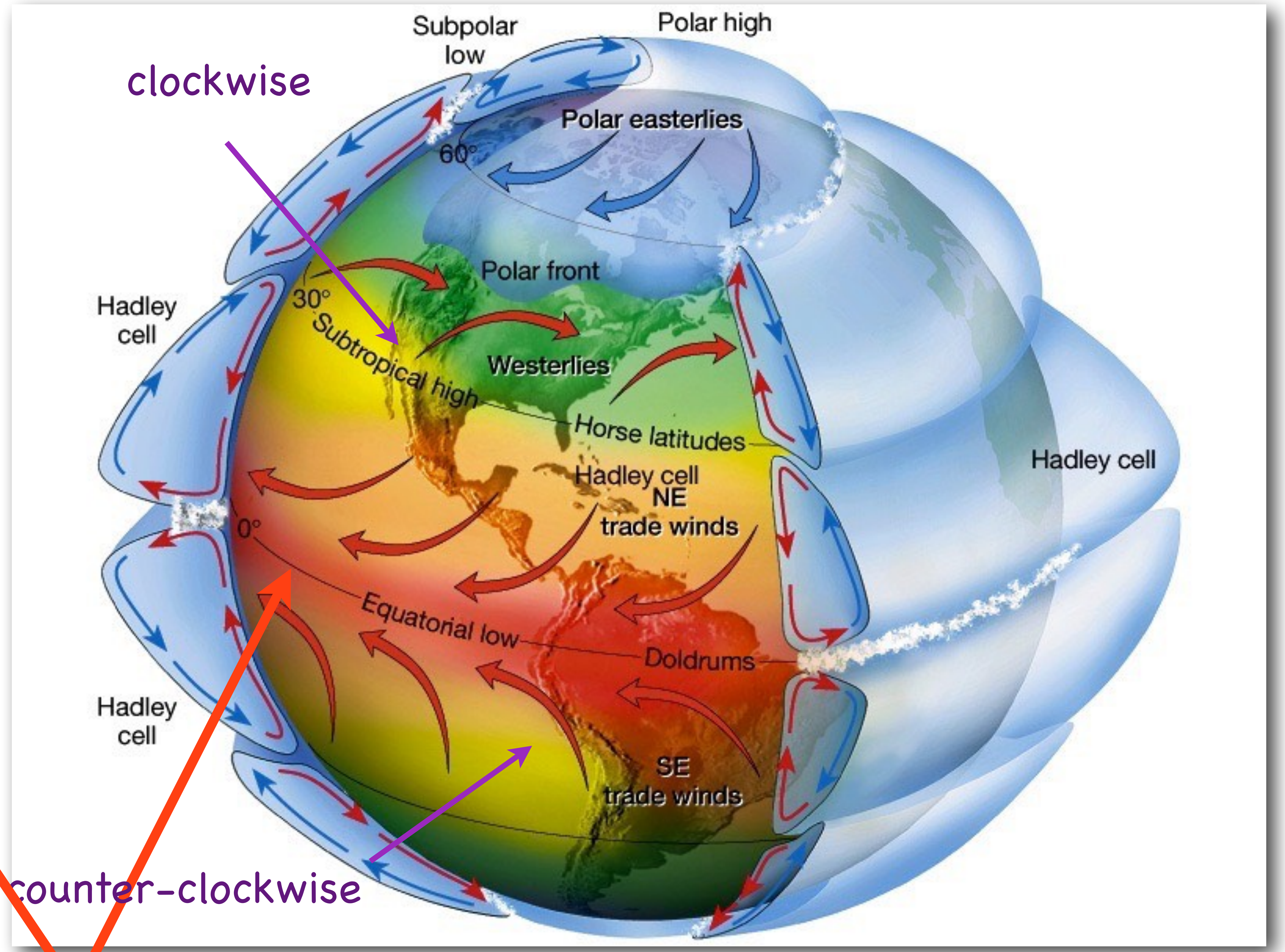


equatorial “doldrums”
- where warm, moist air rises

http://www.geology.um.maine.edu/ges121/lectures/20-monsoons/hadley.jpg

Hadley cells in tropical zones influence predominant wind direction across entire planet





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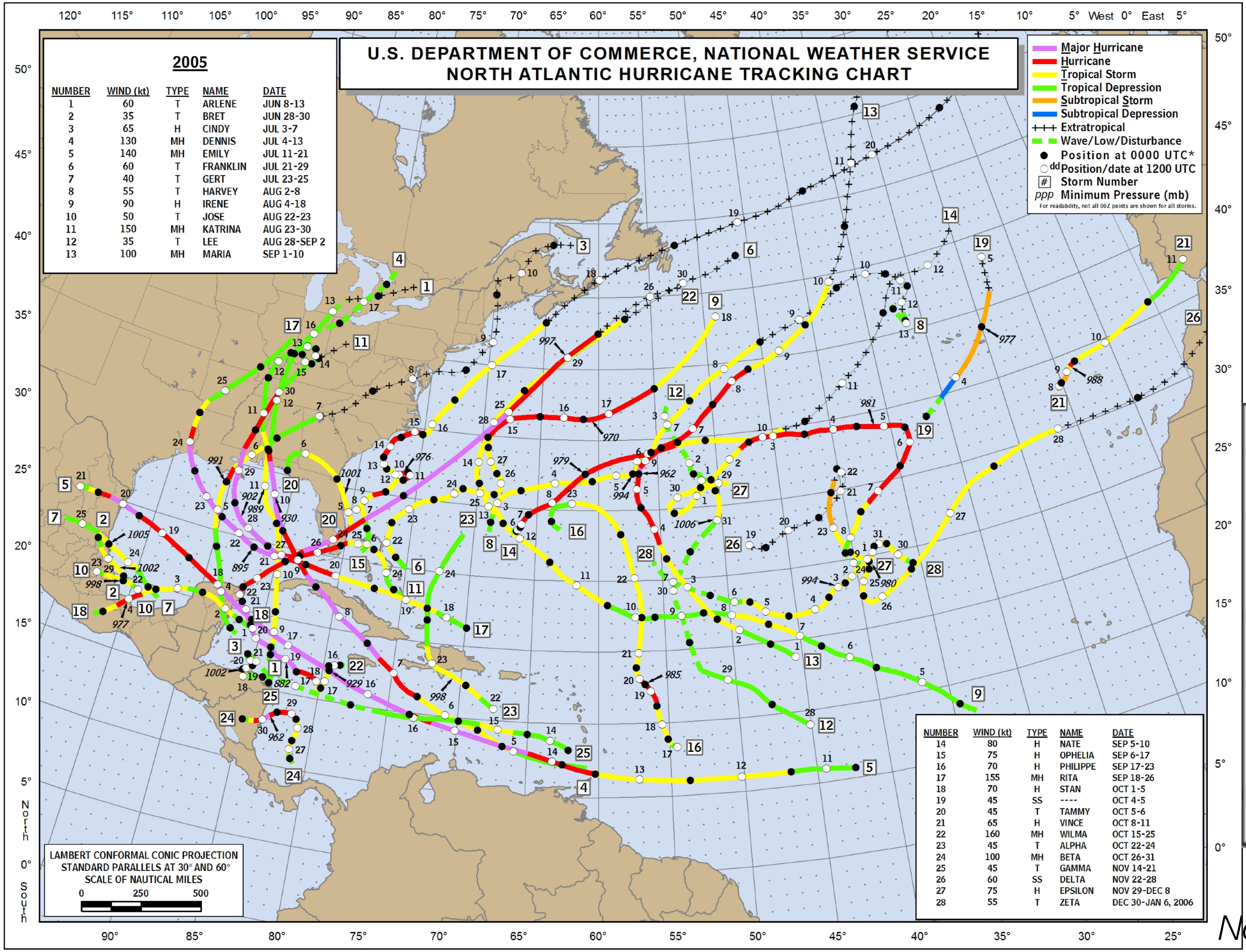
Basics



2005

NUMBER	WIND (kt)	TYPE	NAME	DATE
1	60	T	ARLENE	JUN 8-13
2	35	T	BRET	JUN 28-30
3	65	H	CINDY	JUL 3-7
4	130	MH	DENNIS	JUL 4-13
5	140	MH	EMILY	JUL 11-21
6	60	T	FRANKLIN	JUL 21-29
7	40	T	GERT	JUL 23-25
8	55	T	HARVEY	AUG 2-8
9	90	H	IRENE	AUG 4-18
10	50	T	JOSE	AUG 22-23
11	150	MH	KATRINA	AUG 23-30
12	35	T	LEE	AUG 28-SEP 2
13	100	MH	MARIA	SEP 1-10

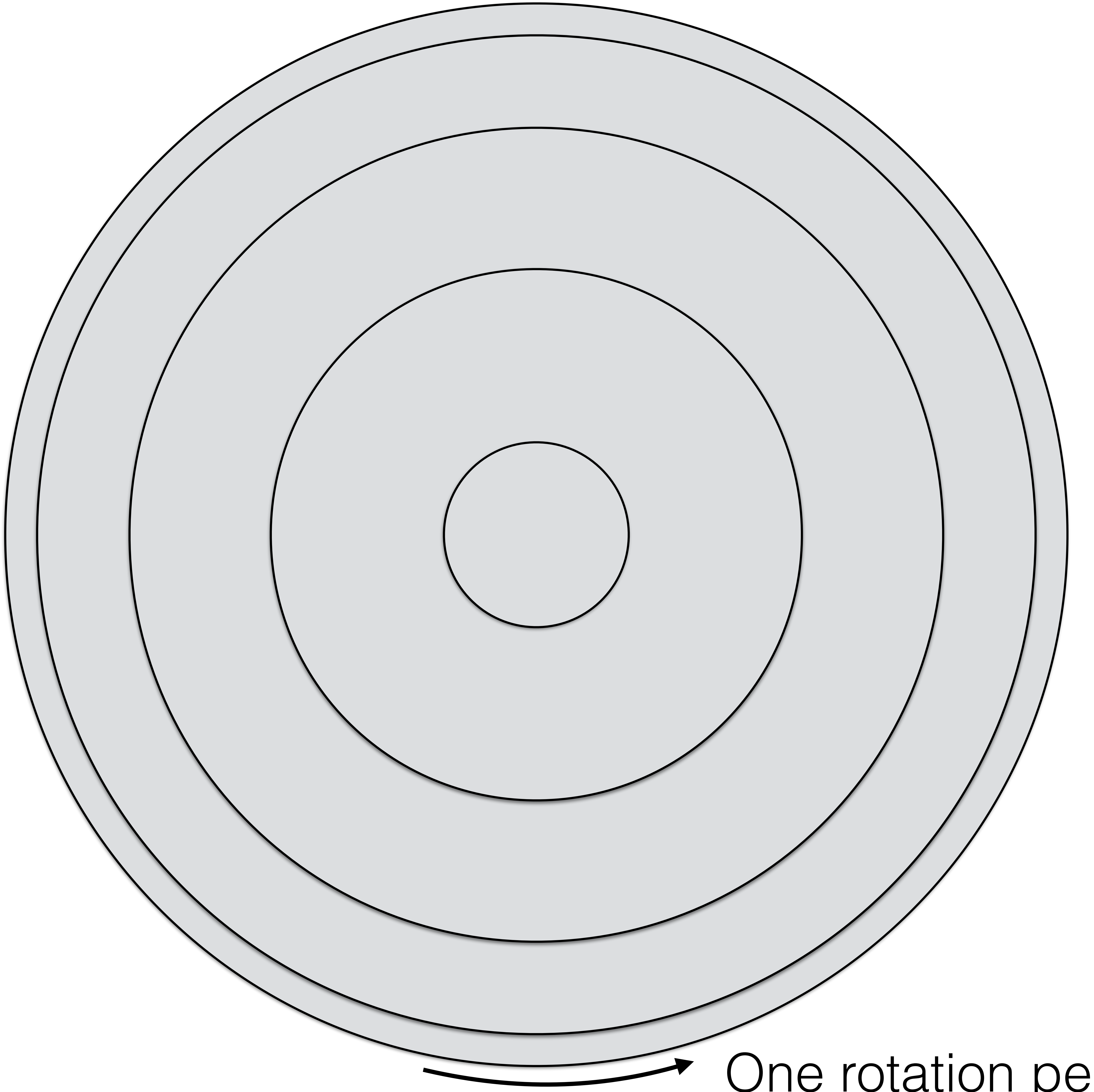
NUMBER	WIND (kt)	TYPE	NAME	DATE
14	80	H	NATE	SEP 5-10
15	75	H	OPHELIA	SEP 6-17
16	70	H	PHILIPPE	SEP 17-23
17	155	MH	RITA	SEP 18-26
18	70	H	STAN	OCT 1-5
19	45	SS	----	OCT 4-5
20	45	T	TAMMY	OCT 5-6
21	65	H	VINCE	OCT 8-11
22	160	MH	WILMA	OCT 15-25
23	45	T	ALPHA	OCT 22-24
24	100	MH	BETA	OCT 26-31
25	45	T	GAMMA	NOV 14-21
26	60	SS	DELTA	NOV 22-28
27	75	H	EPSILON	NOV 29-DEC 8
28	55	T	ZETA	DEC 30-JAN 6, 2006

Note clockwise deflection of storm paths!

Basics

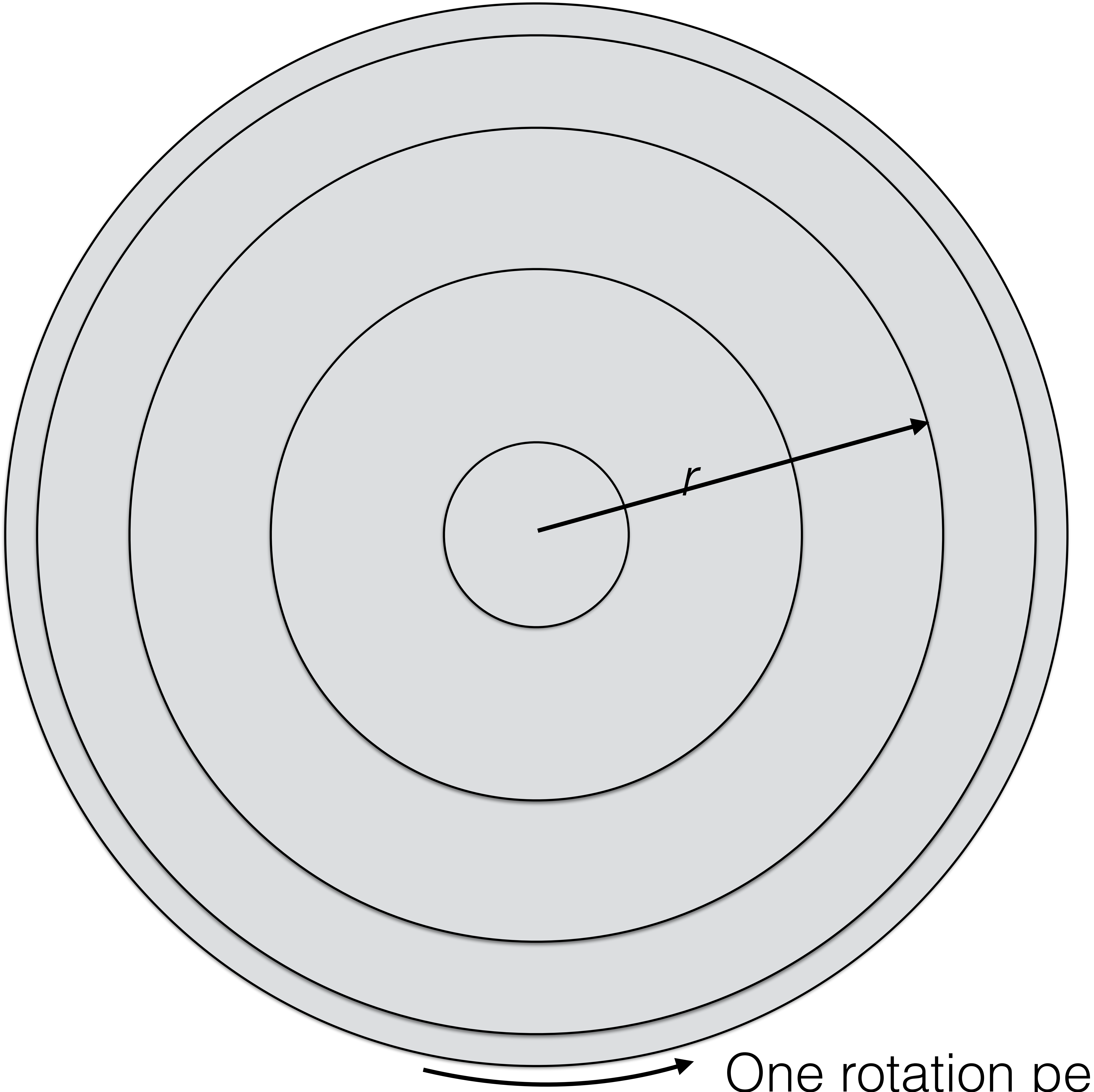
Basics

Speed is distance traveled divided by time used to travel the distance



One rotation per day, T = 24 h

Speed is distance traveled divided by time used to travel the distance



$C = 2\pi r$

$v = C/T = 2\pi r/T$

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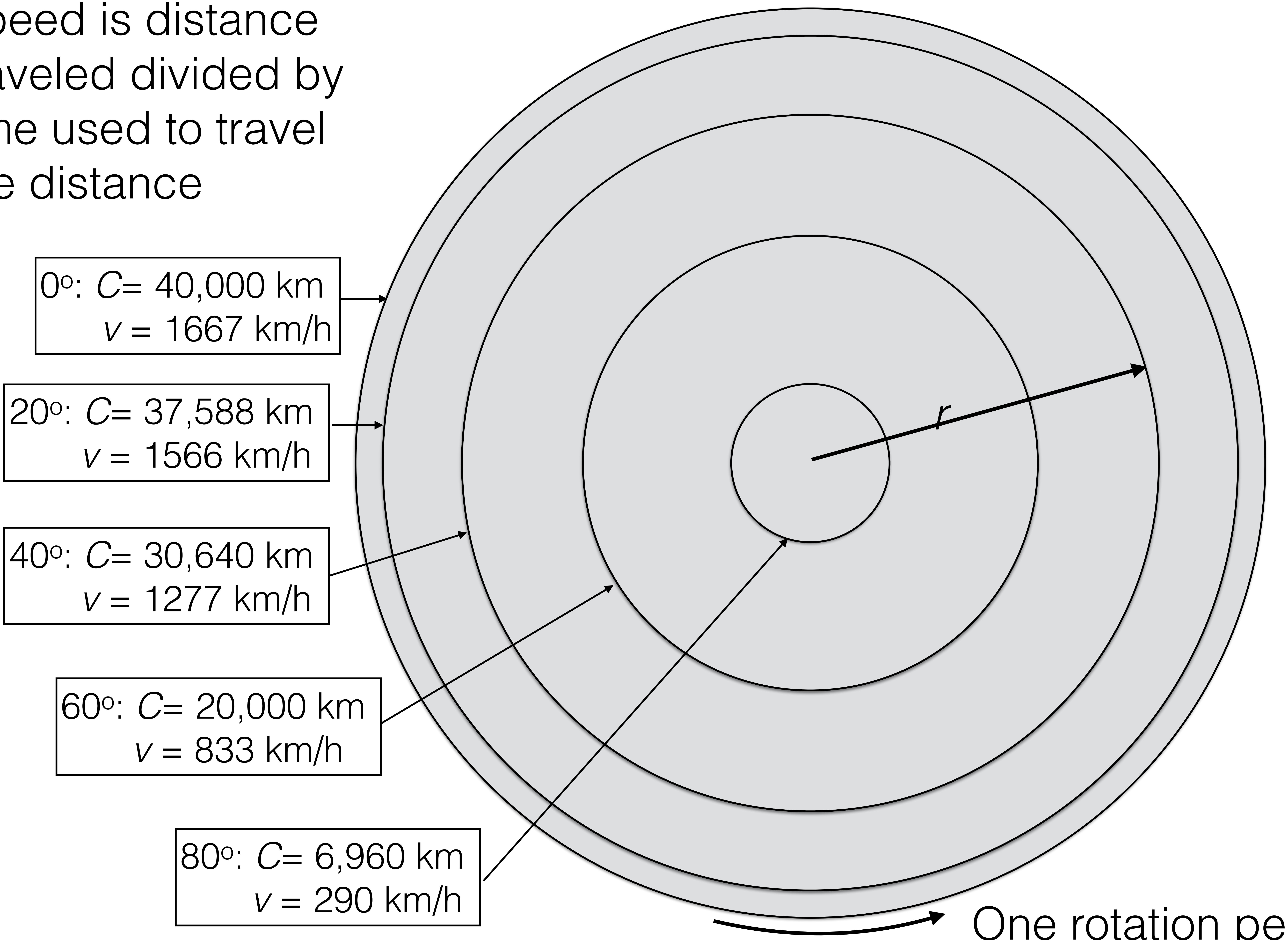

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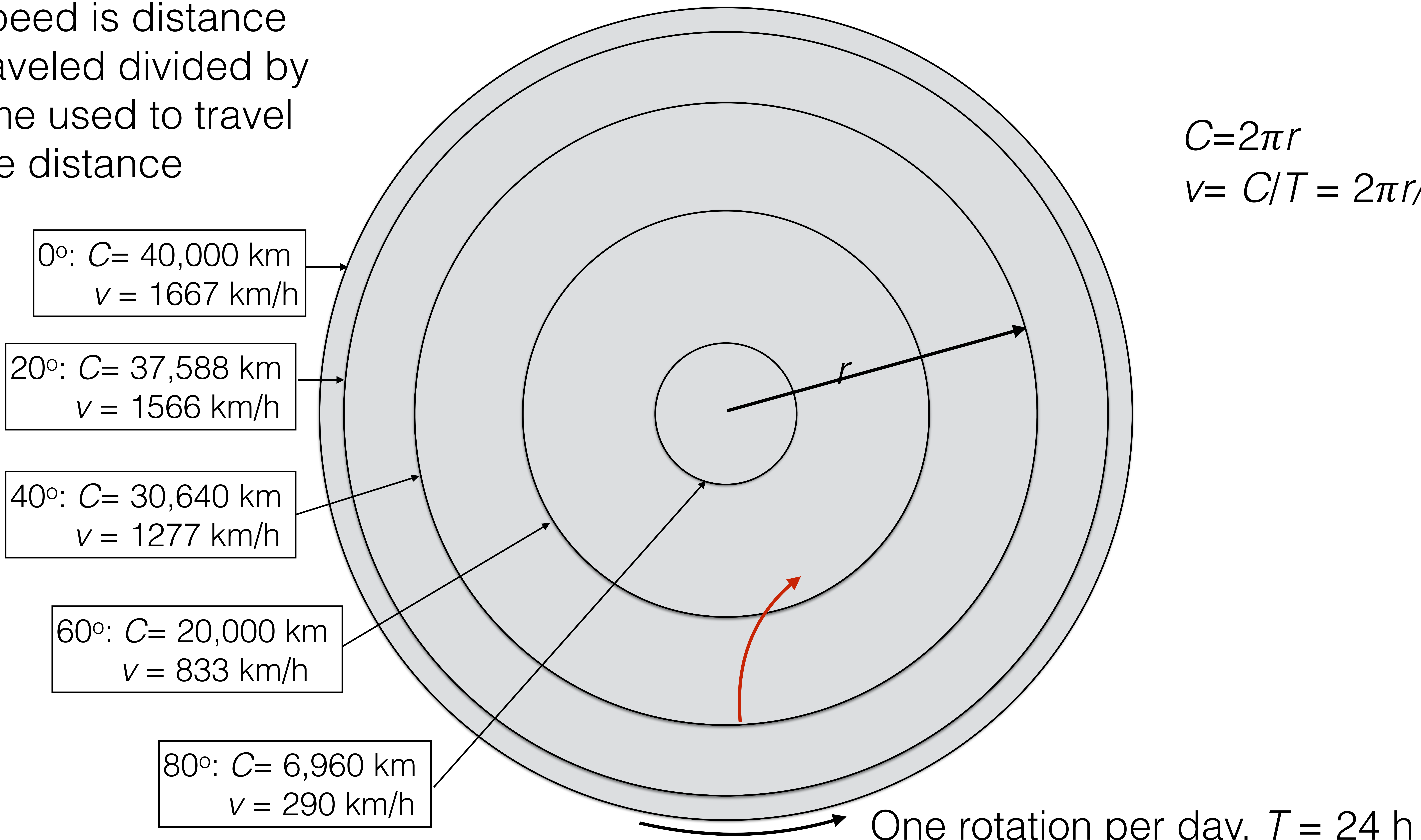
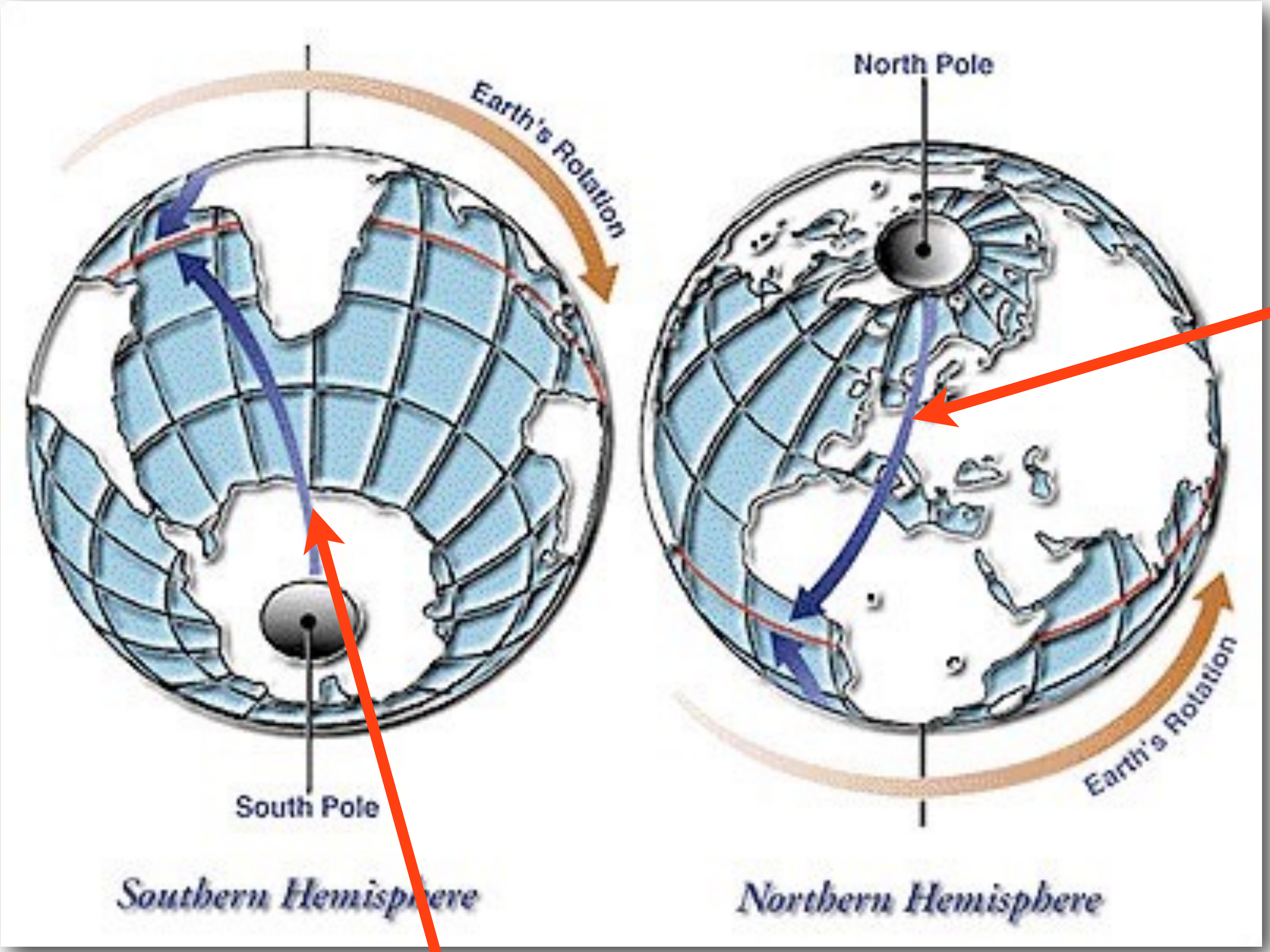
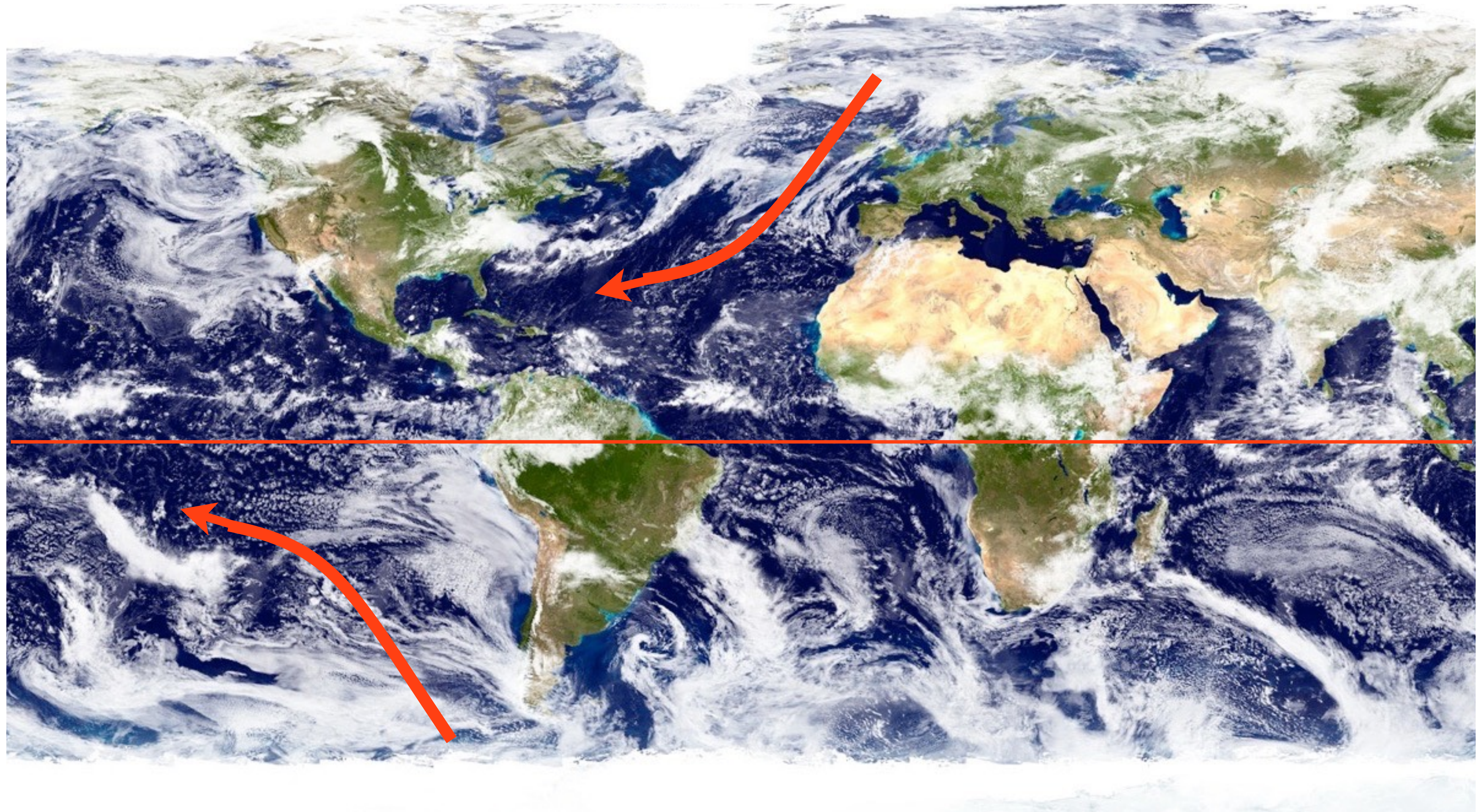


Coriolis Effect - Earth's rotation deflects winds



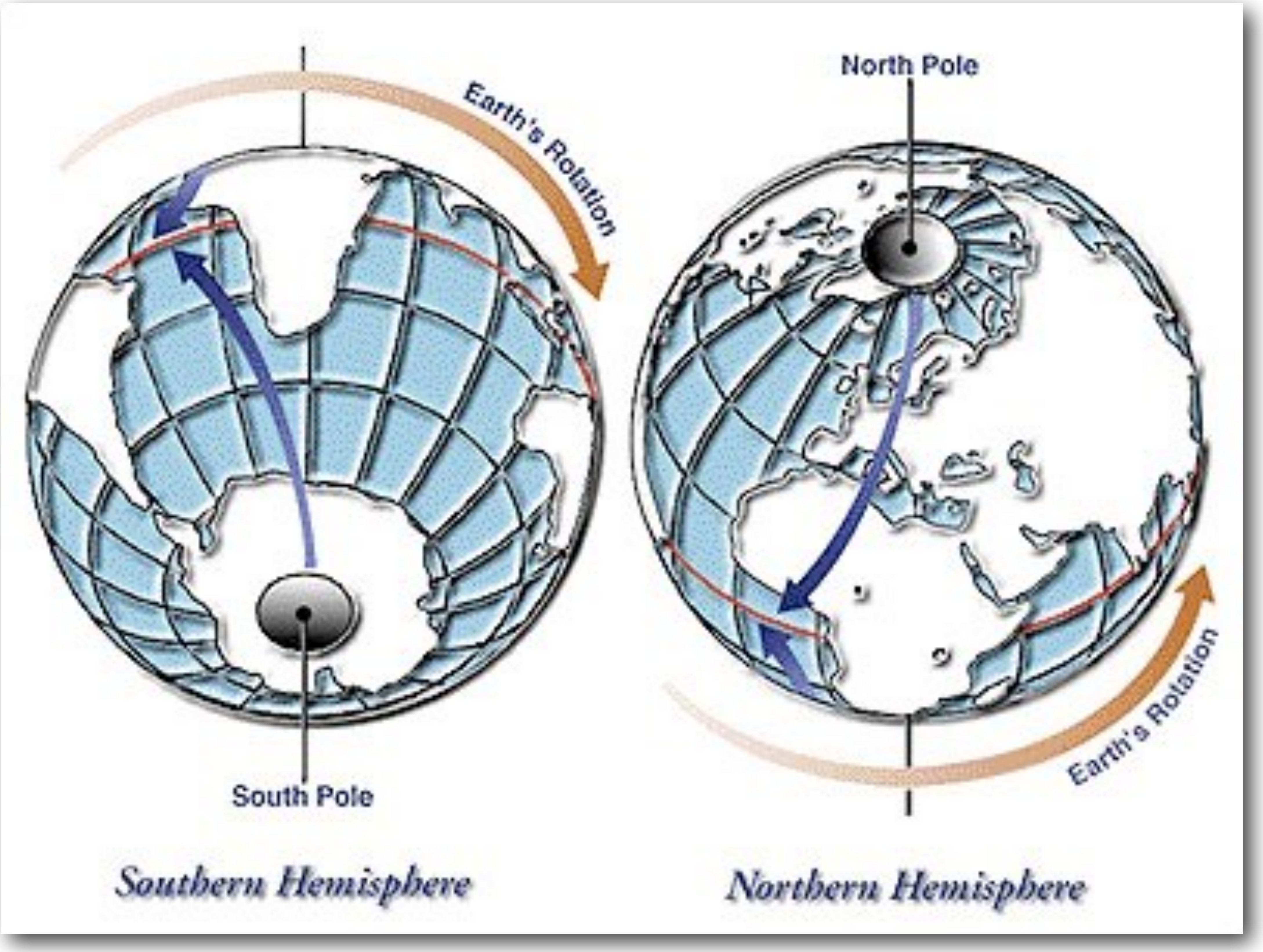
www.uwsp.edu/.../coriolis-force_NASA_JPL.jpg

"Clockwise" (to the right) on northern hemisphere



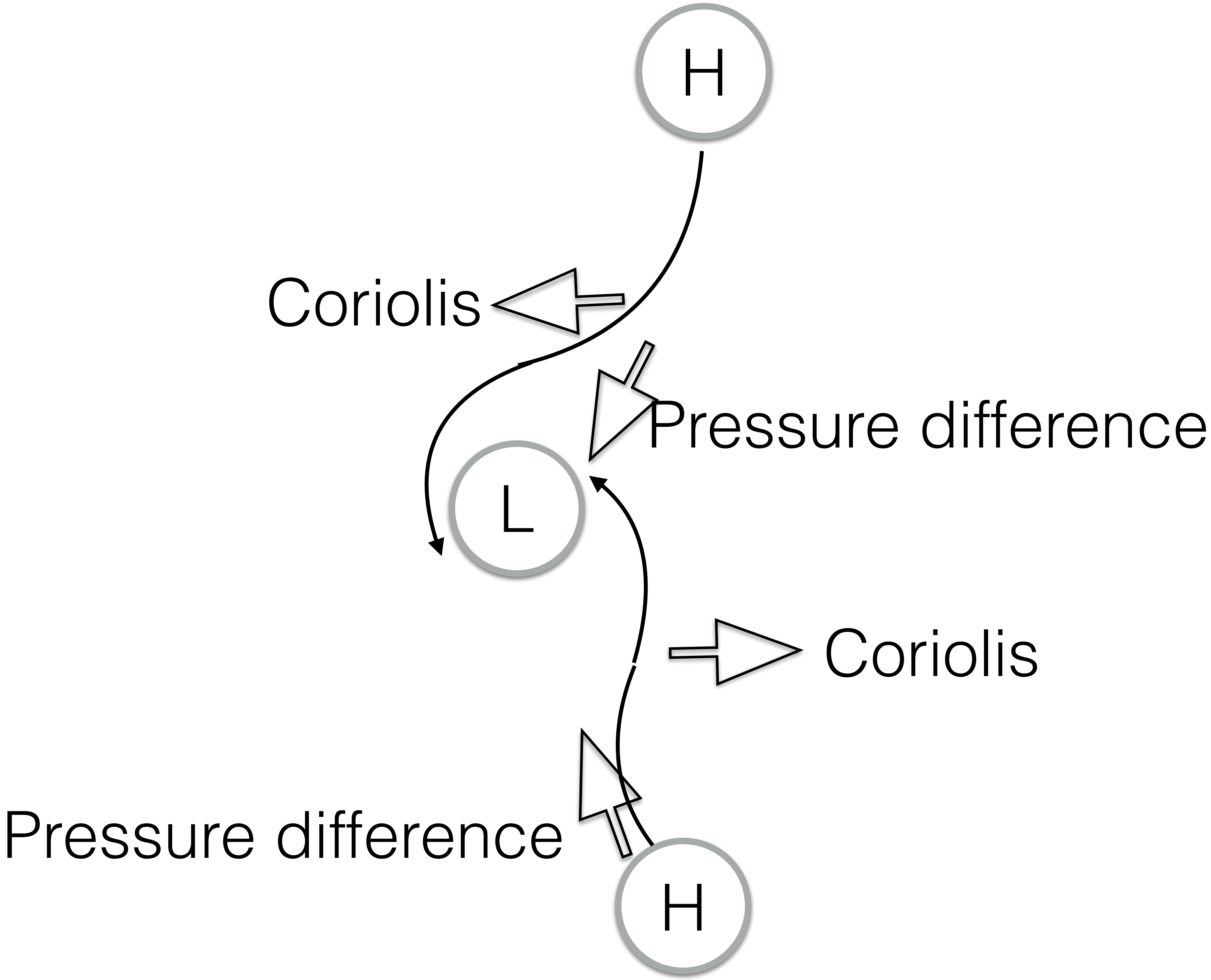
"Counter- clockwise" (to the left) on southern hemisphere

Coriolis Effect - Earth's rotation also impacts rotation of cyclones

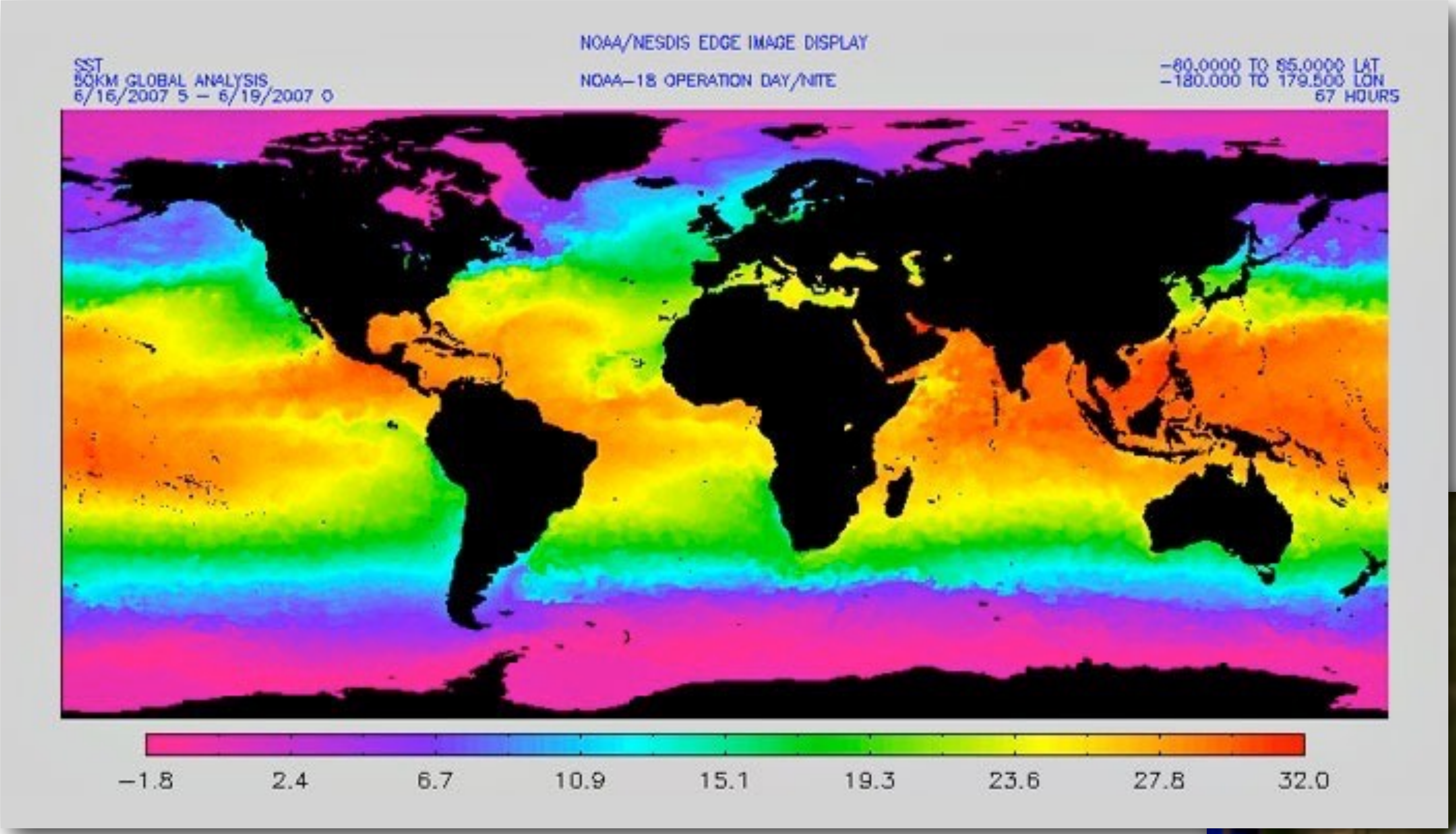


www.uwsp.edu/…/coriolis-force_NASA_JPL.jpg

On northern Hemisphere:



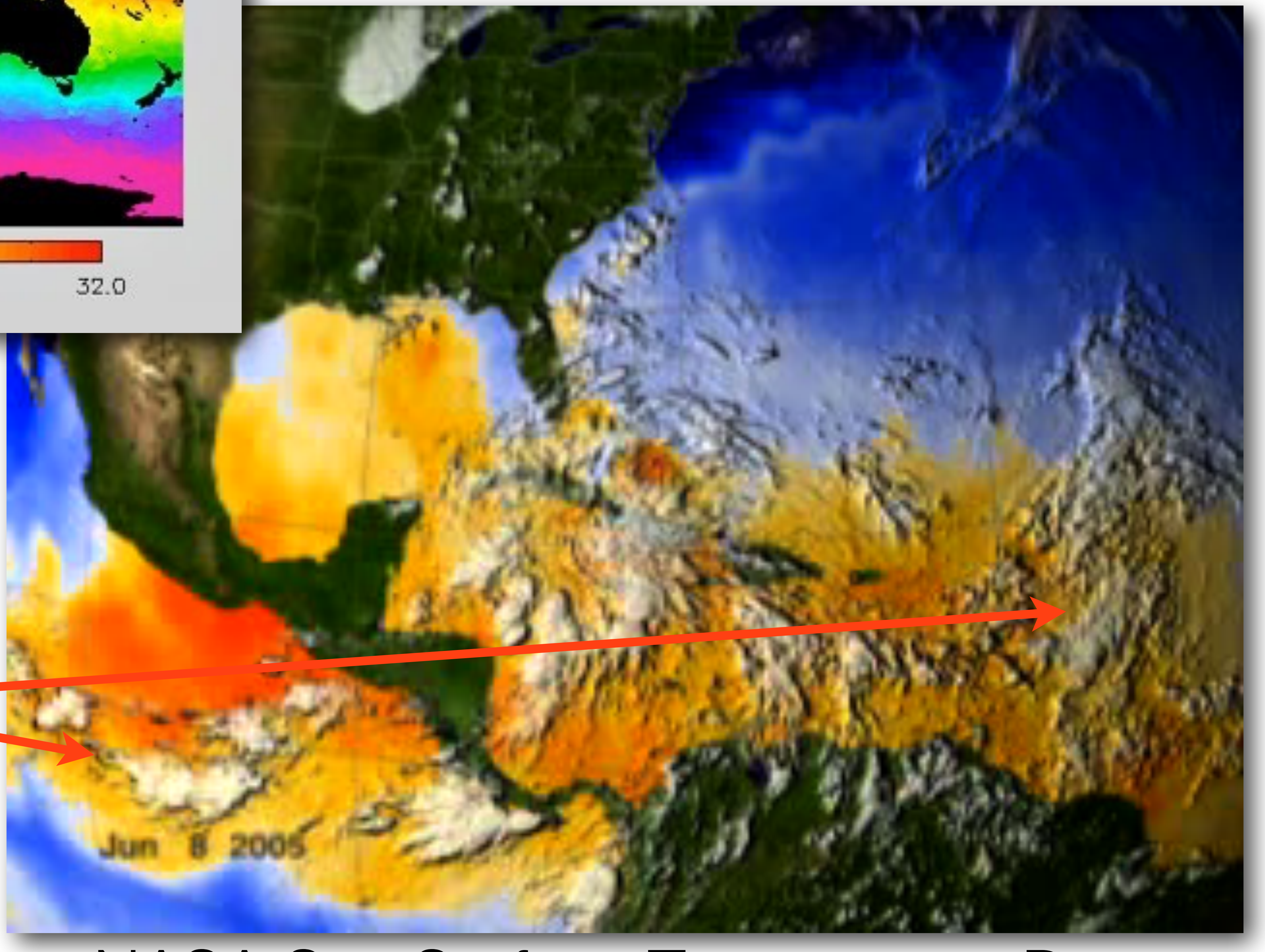
Hurricanes are fed by warm surface ocean waters (>26°C)



warmer waters in equatorial regions

http://www.learner.org/courses/envsci/visual/img_lrg/sea_surface_temperature.jpg

storm cells initiate in warm waters



NASA Sea Surface Temperature Data

www.nasa.gov/vision/earth/lookingatearth/hurricane_record.html

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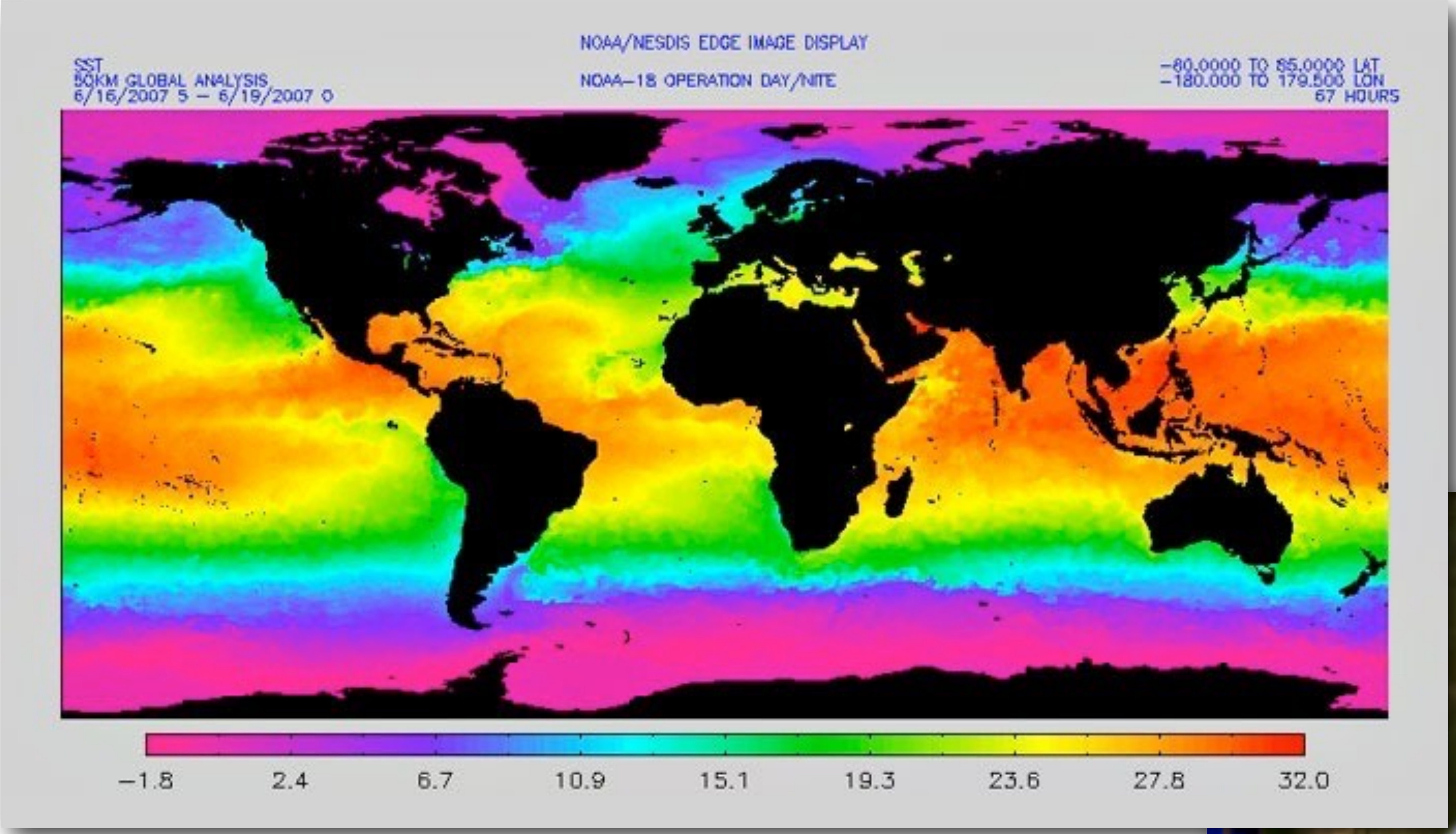

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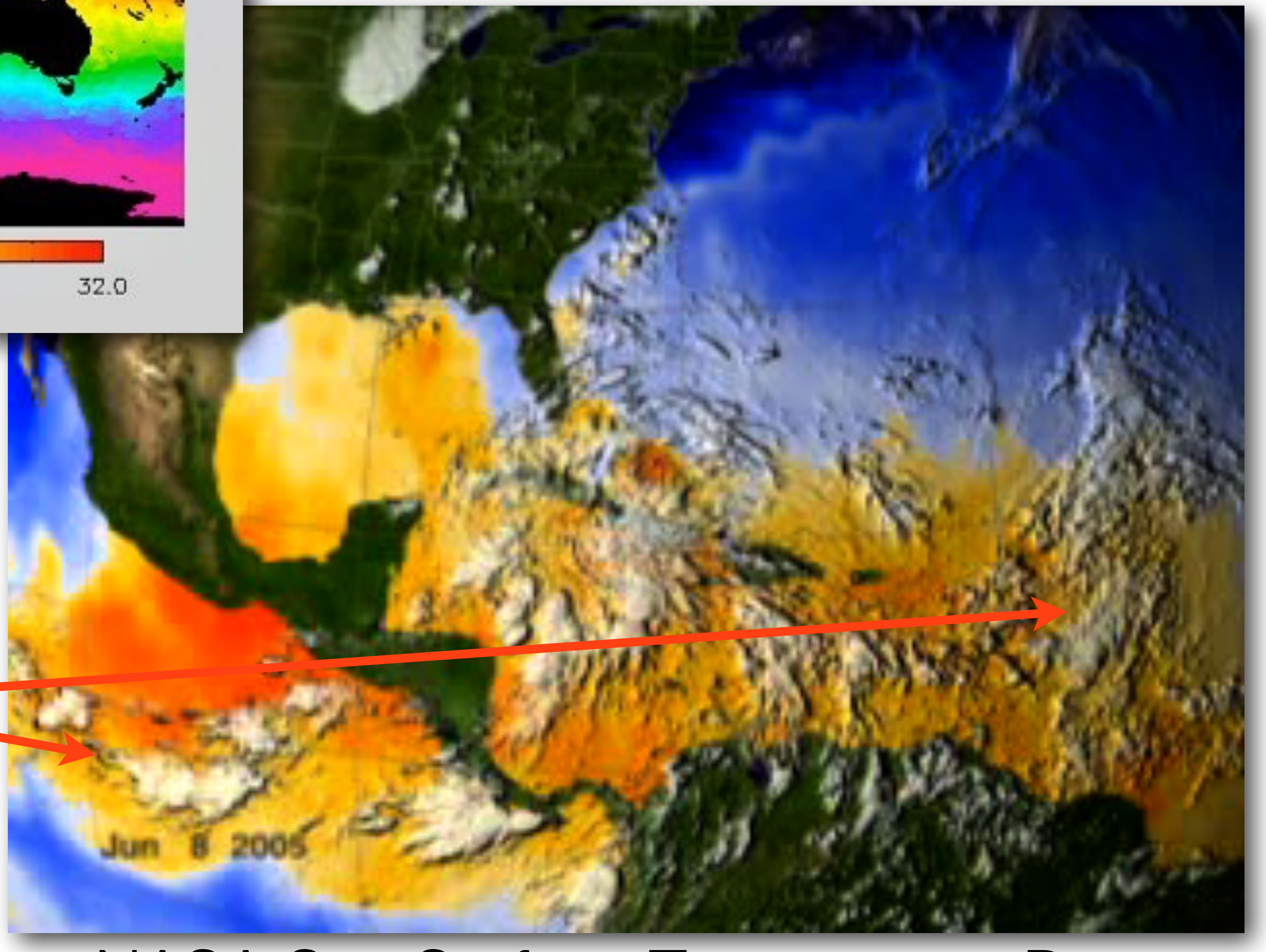
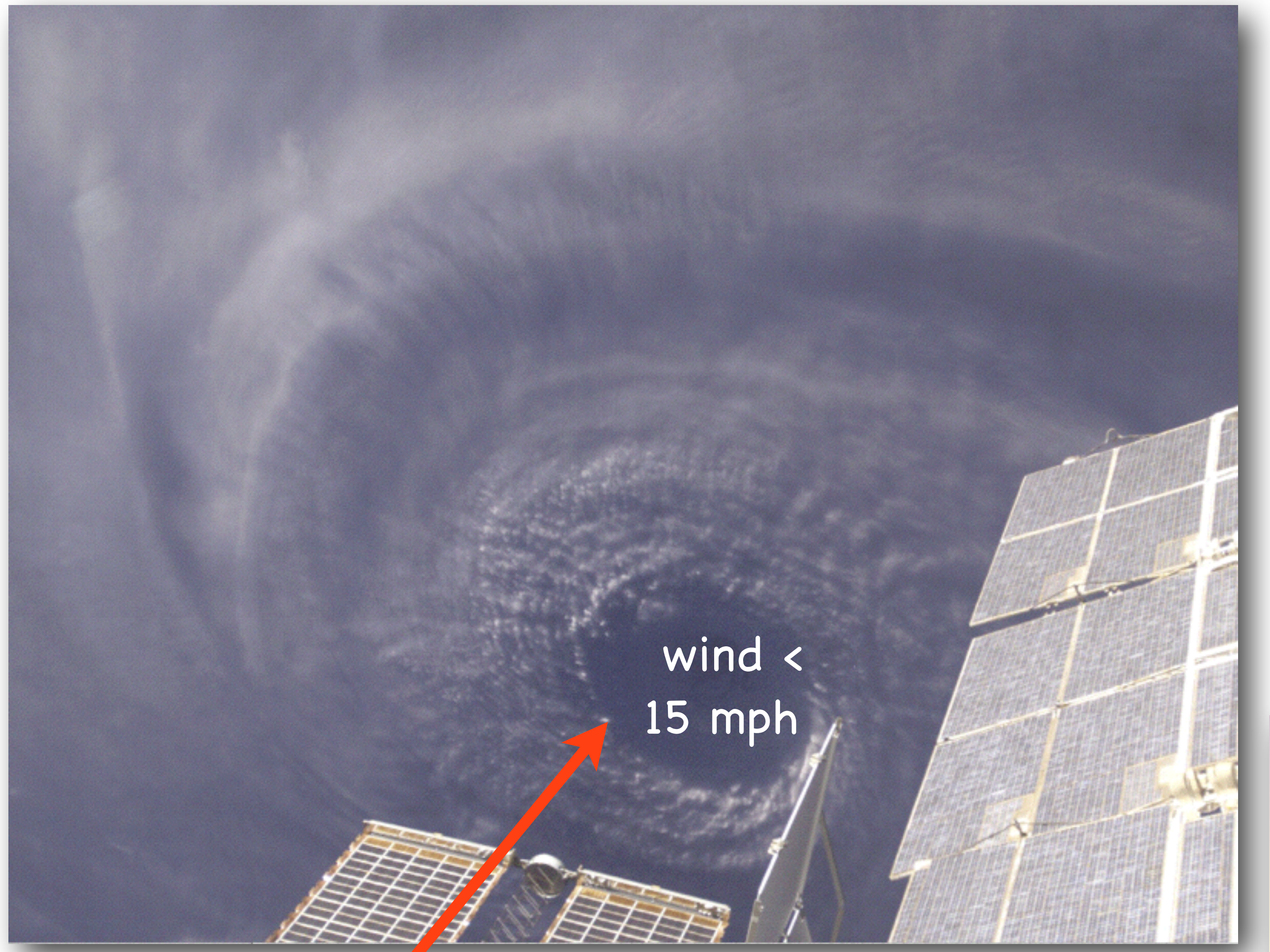


NASA Sea Surface Temperature Data

www.nasa.gov/vision/earth/lookingatearth/hurricane_record.html

Basics

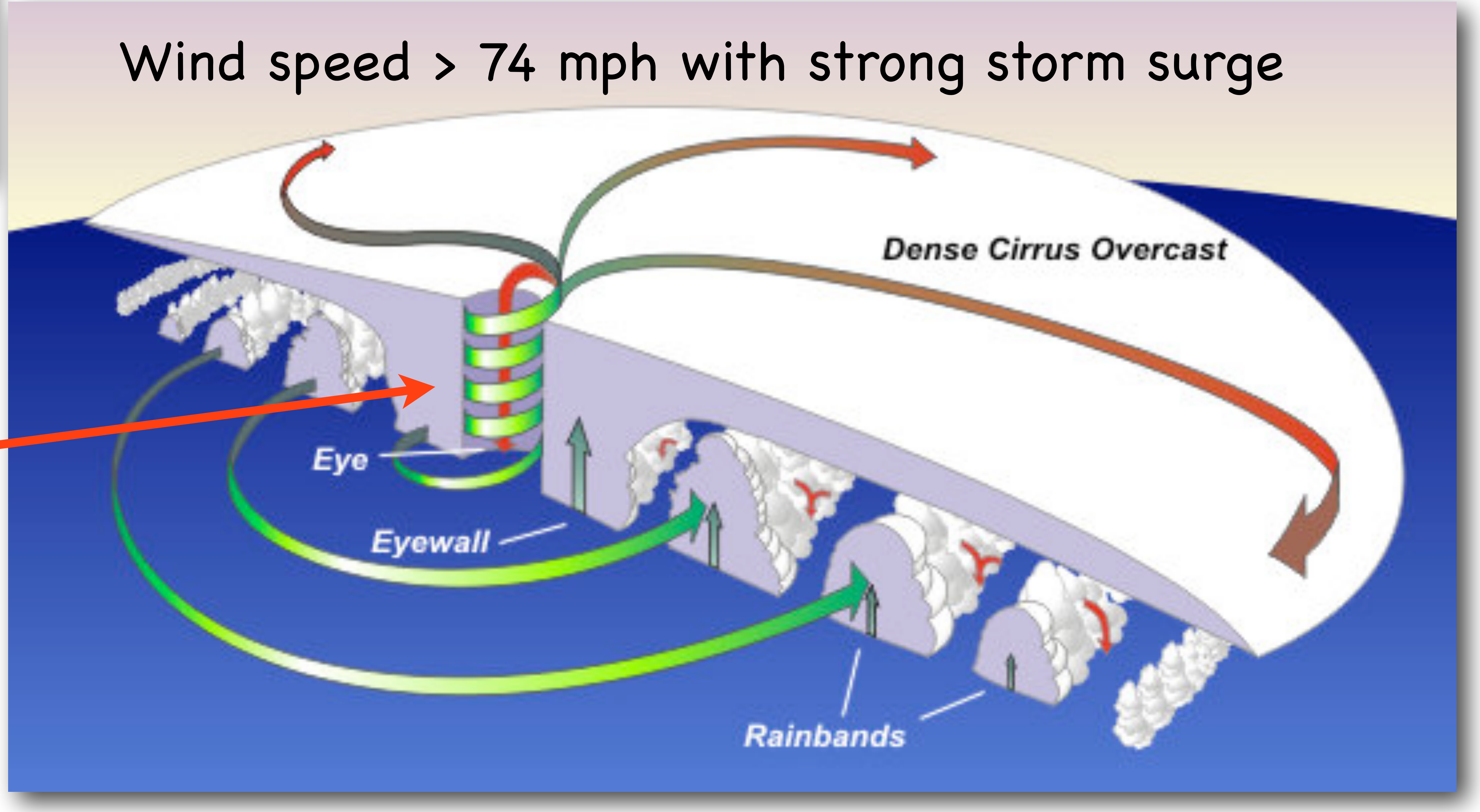
Structure of Hurricanes



Eye wall
~50 km diameter
winds < 15 mph

Saffir-Simpson Scale of Hurricane Strength

1 Minimal
2 Moderate
3 Extensive
4 Extreme
5 Catastrophic



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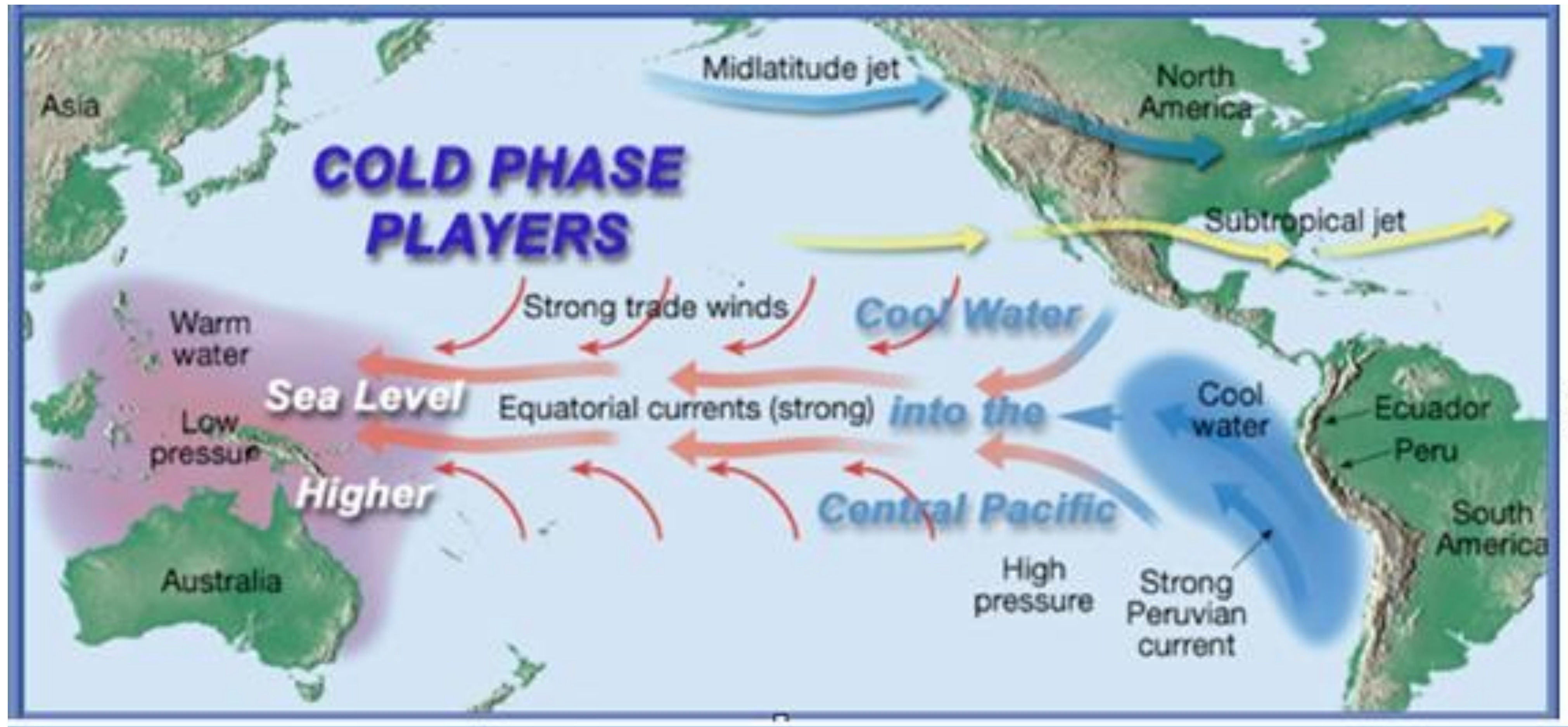
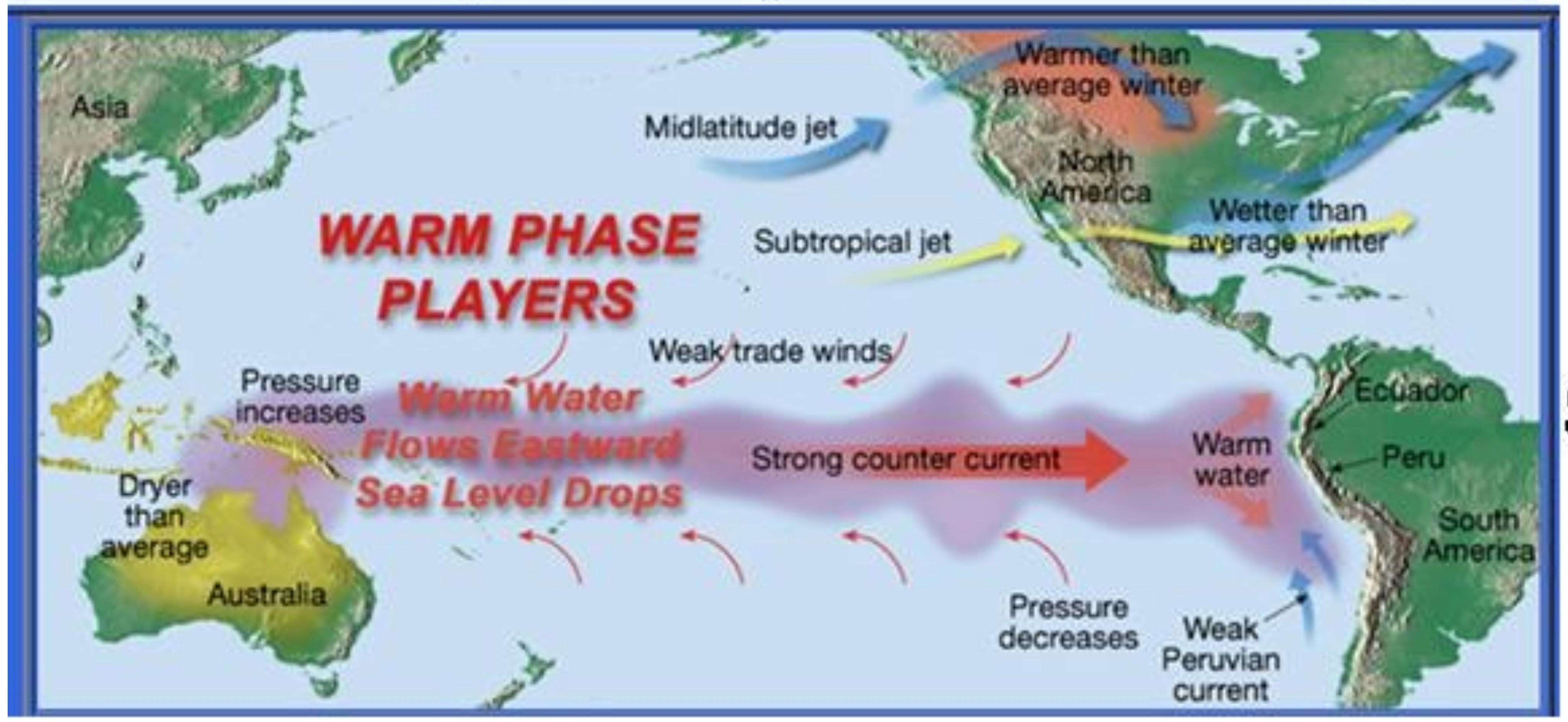
El Niño - La Niña

- Alternating seasons of warm and cold ocean temperatures in central Pacific Ocean, off the coast of Ecuador
- Entire cycle is called **ENSO** - the El Niño Southern Oscillation

El Niño - La Niña



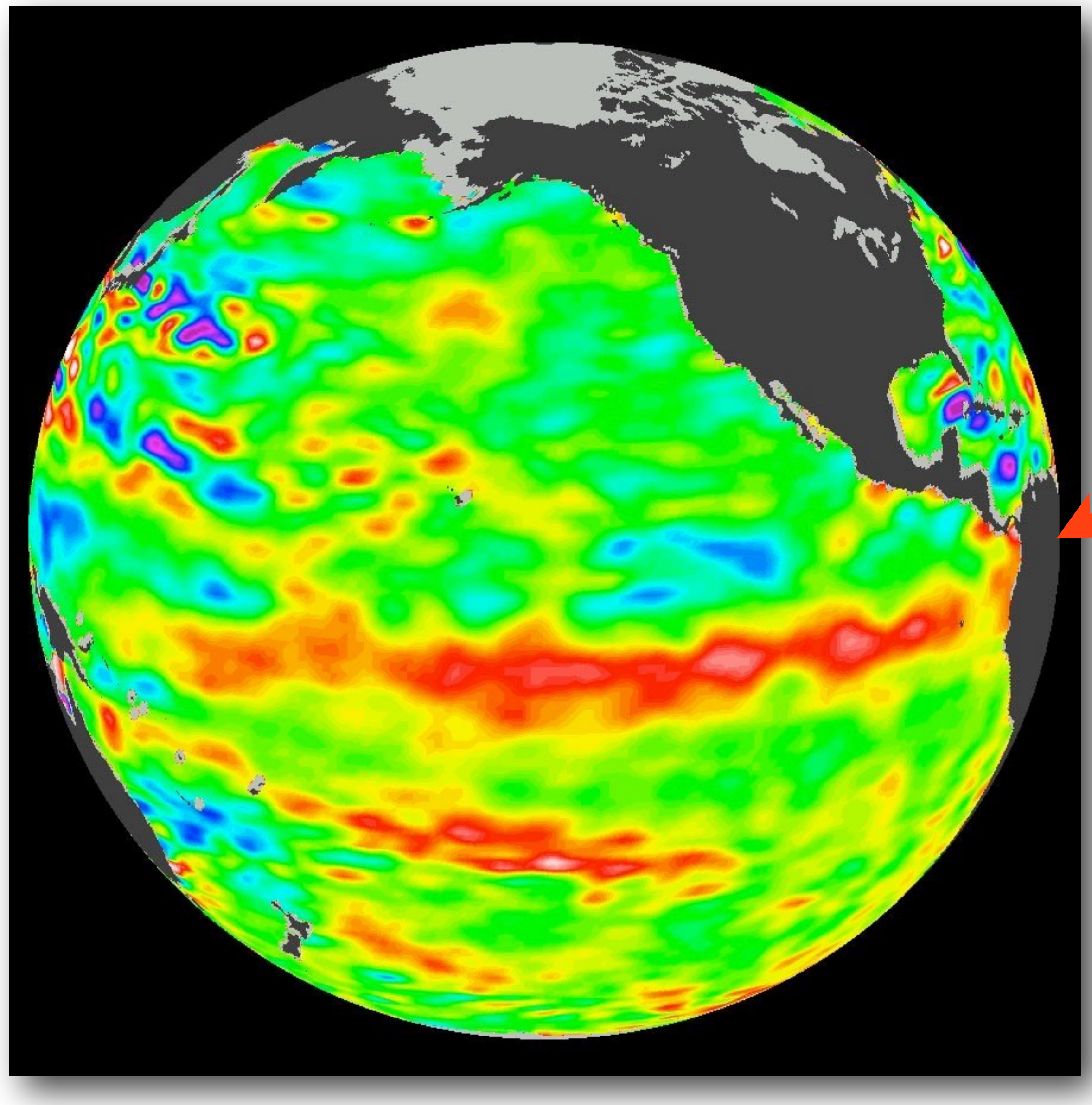
Normal Situation



El Nino Situation

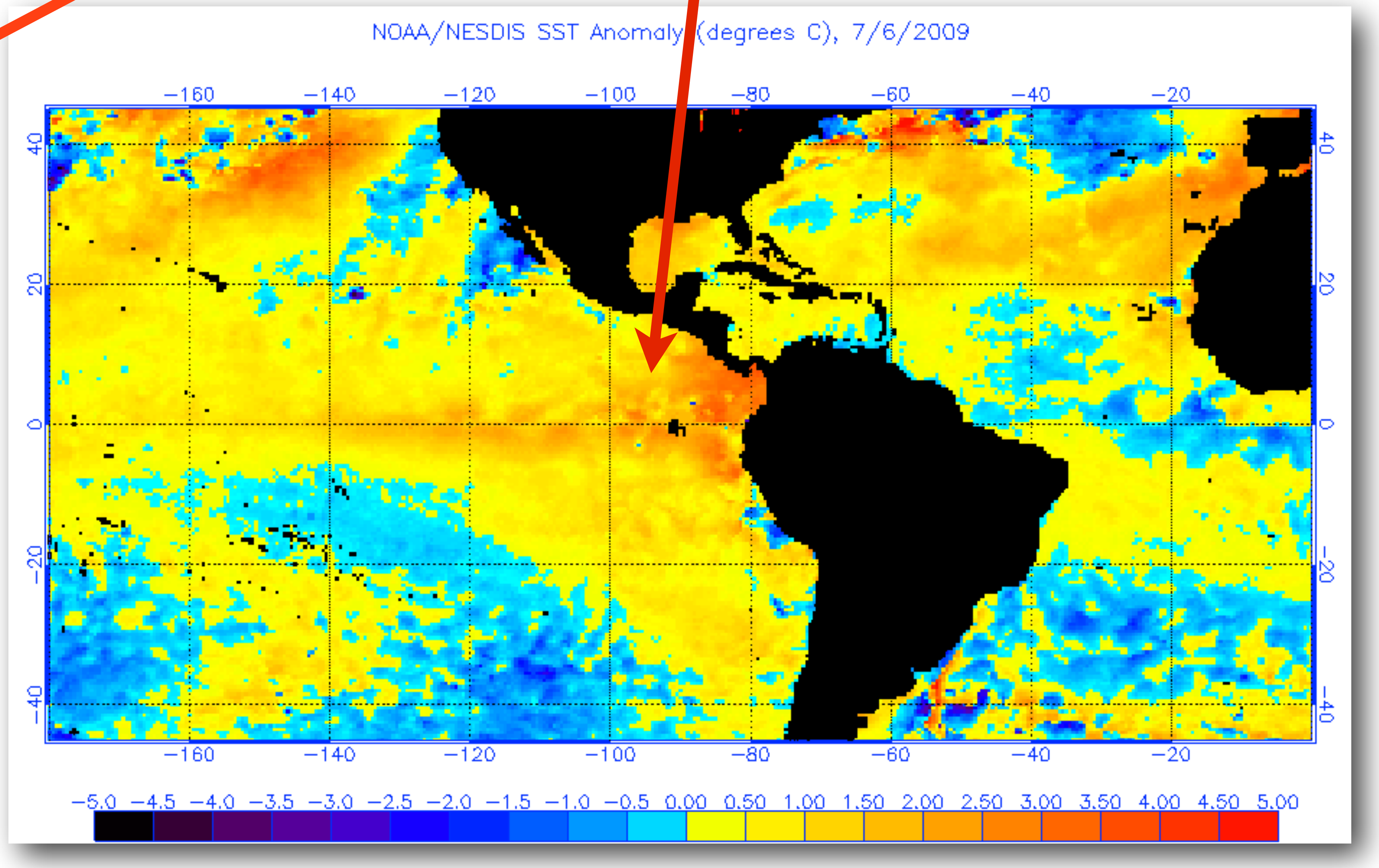
El Niño - La Niña

El Niño



http://earthobservatory.nasa.gov/images/imagerecords/7000/7001/ElNino_JAS_20060905_lrg.jpg

exceptionally warm surface waters off coast of Ecuador in December/ January



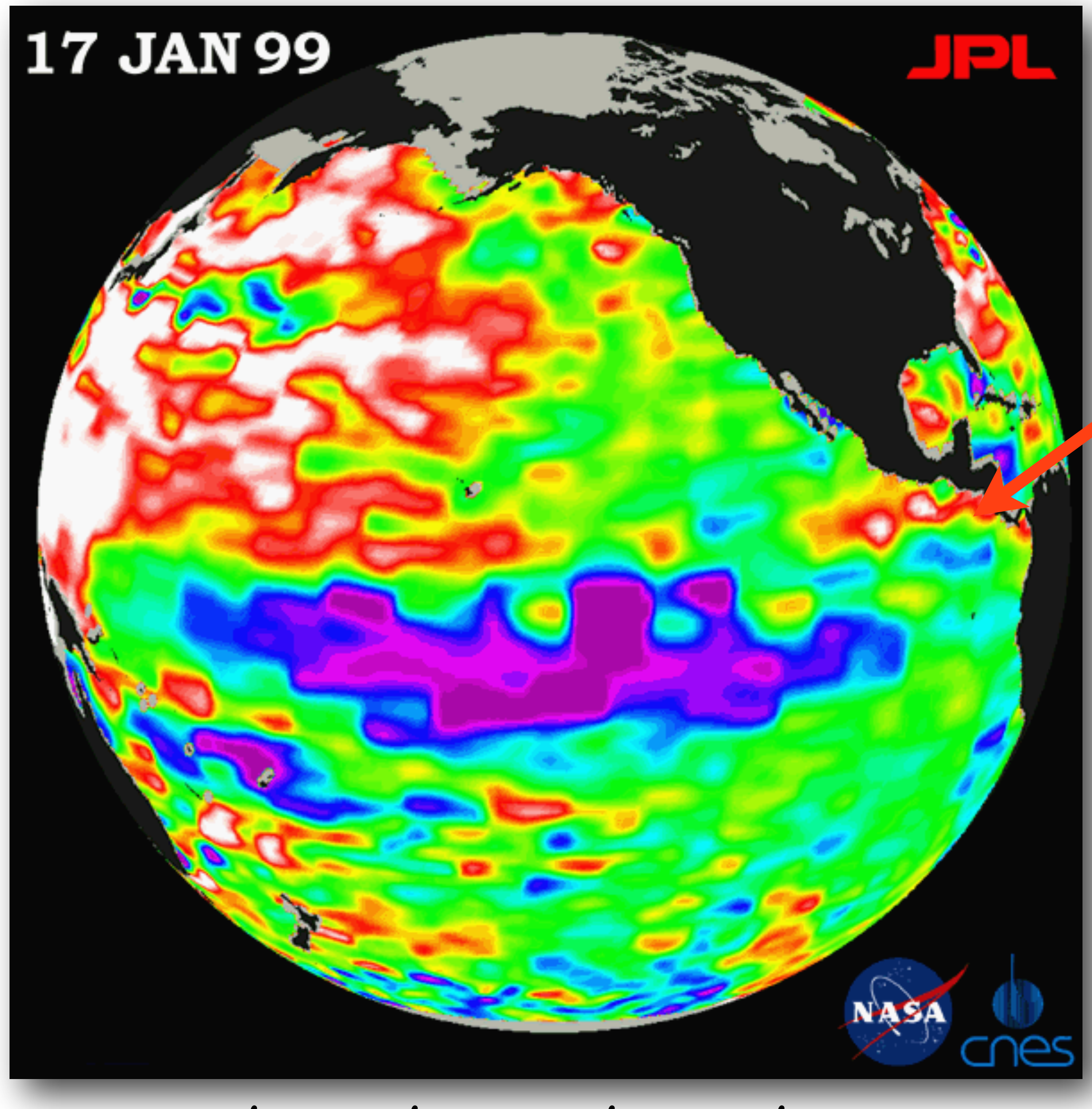
http://www.osdpd.noaa.gov/data/sst/anomaly/2009/anomw.7.6.2009.gif

trade winds in central and western Pacific lessen

thermocline in the western Pacific is elevated

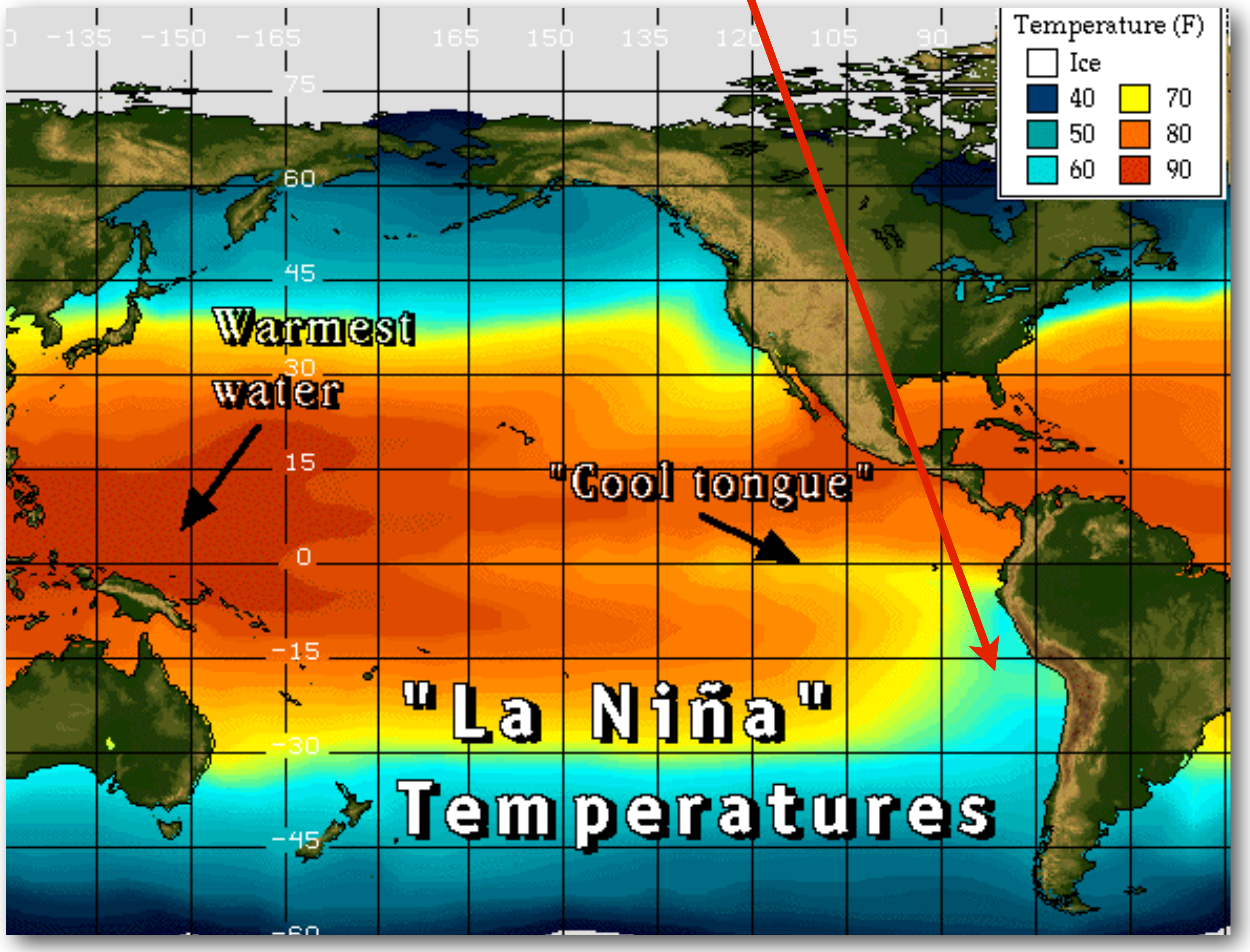
El Niño - La Niña

La Niña



http://apod.nasa.gov/apod/image/9902/lanina2_topex_big.gif

unusually cold surface waters off coast of Ecuador in December/January



http://media.mgnetwork.com/scp/blog/postimg/fjohnson/LaNina.gif

In USA:

- warmer winters in Southeast
- cooler winters in the Northwest

La Niña correlates with more severe hurricanes in USA

El Niño - La Niña

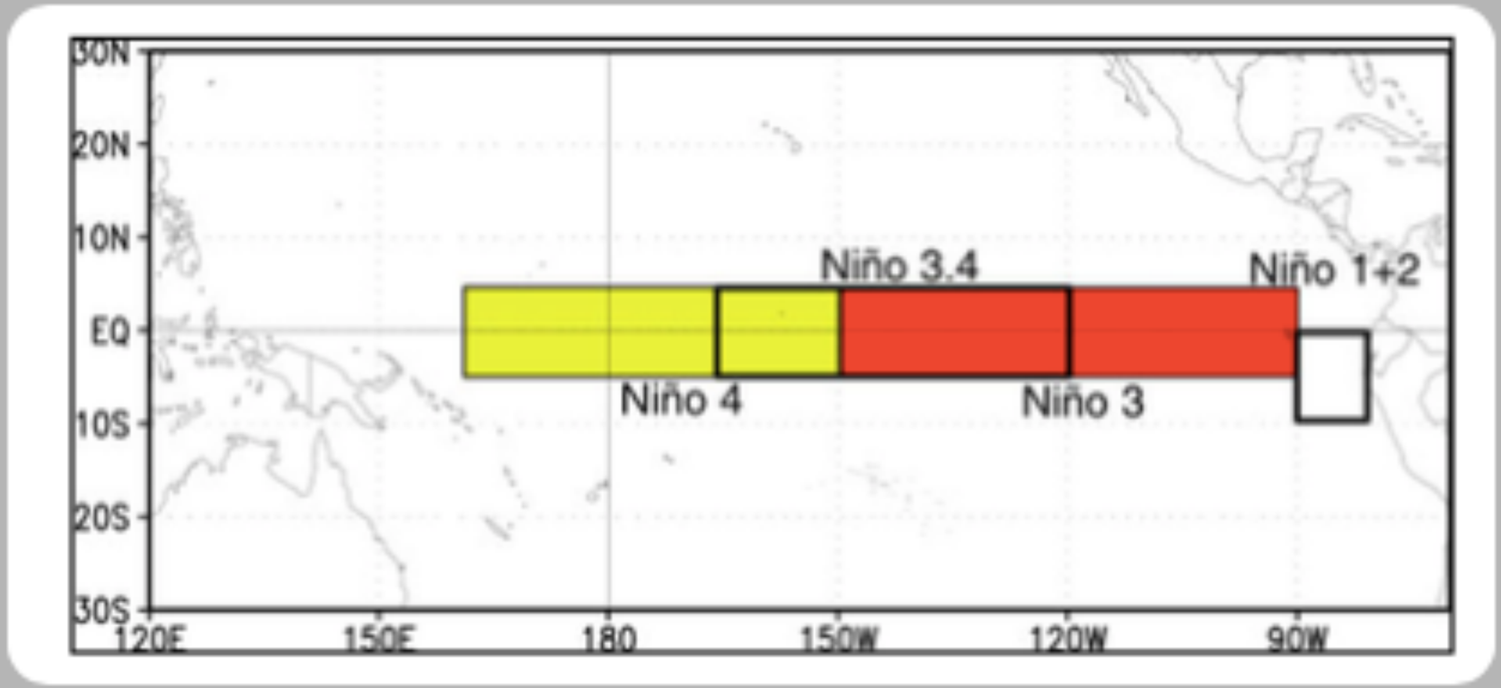
- El Niño does not mean no hurricanes - can still have some very damaging ones - avg. damage per storm ca. $800 million
- May change as a result of ocean warming
- the 2017-2018 winter was an El Niño
- La Niña does mean more of them and more severe damage - avg. damage per storm ca. $1,600 million

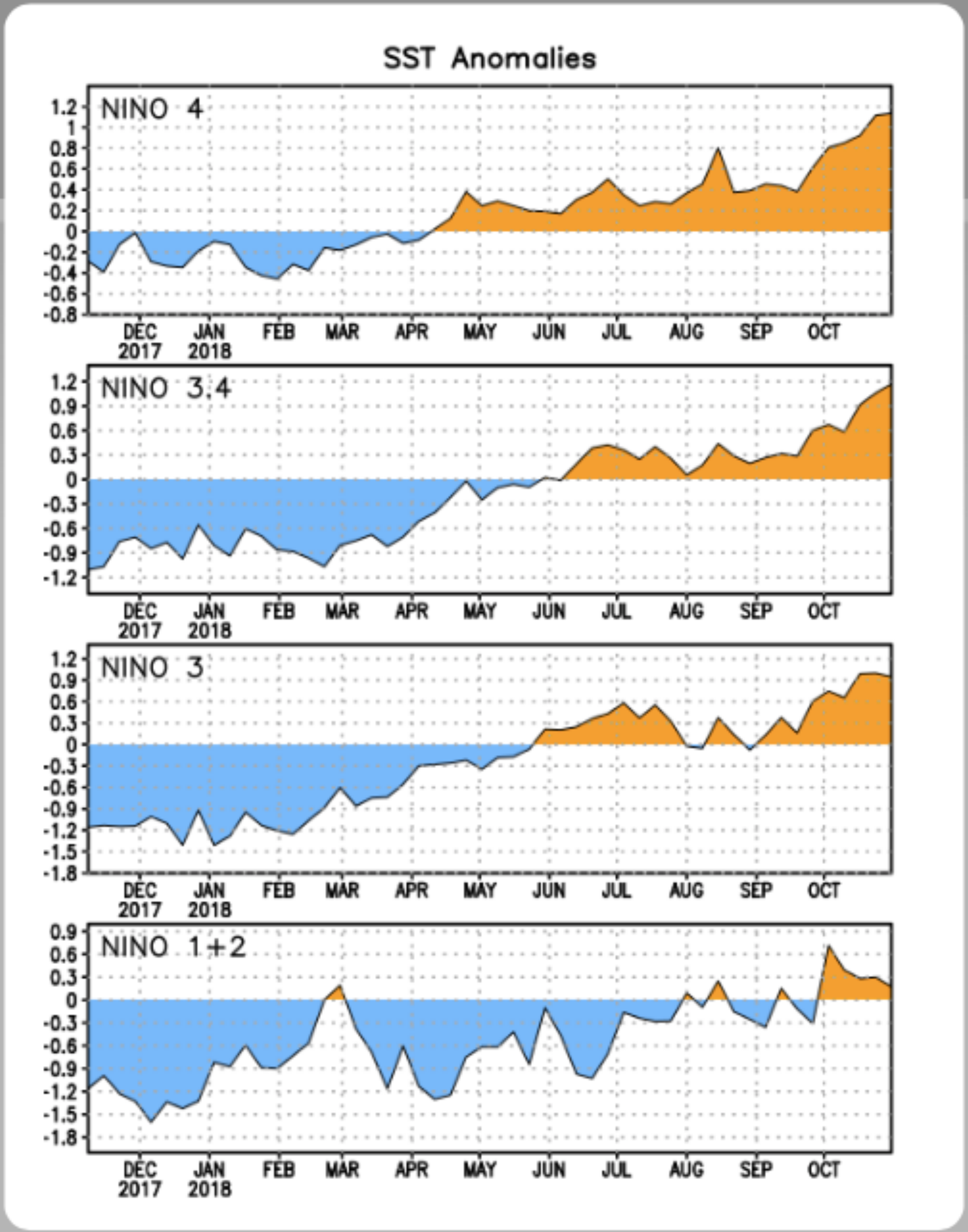
El Niño - La Niña

Niño Region SST Departures (ºC) Recent Evolution

The latest weekly SST departures are:

Niño 4	1.1ºC
Niño 3.4	1.2ºC
Niño 3	0.9ºC
Niño 1+2	0.2ºC



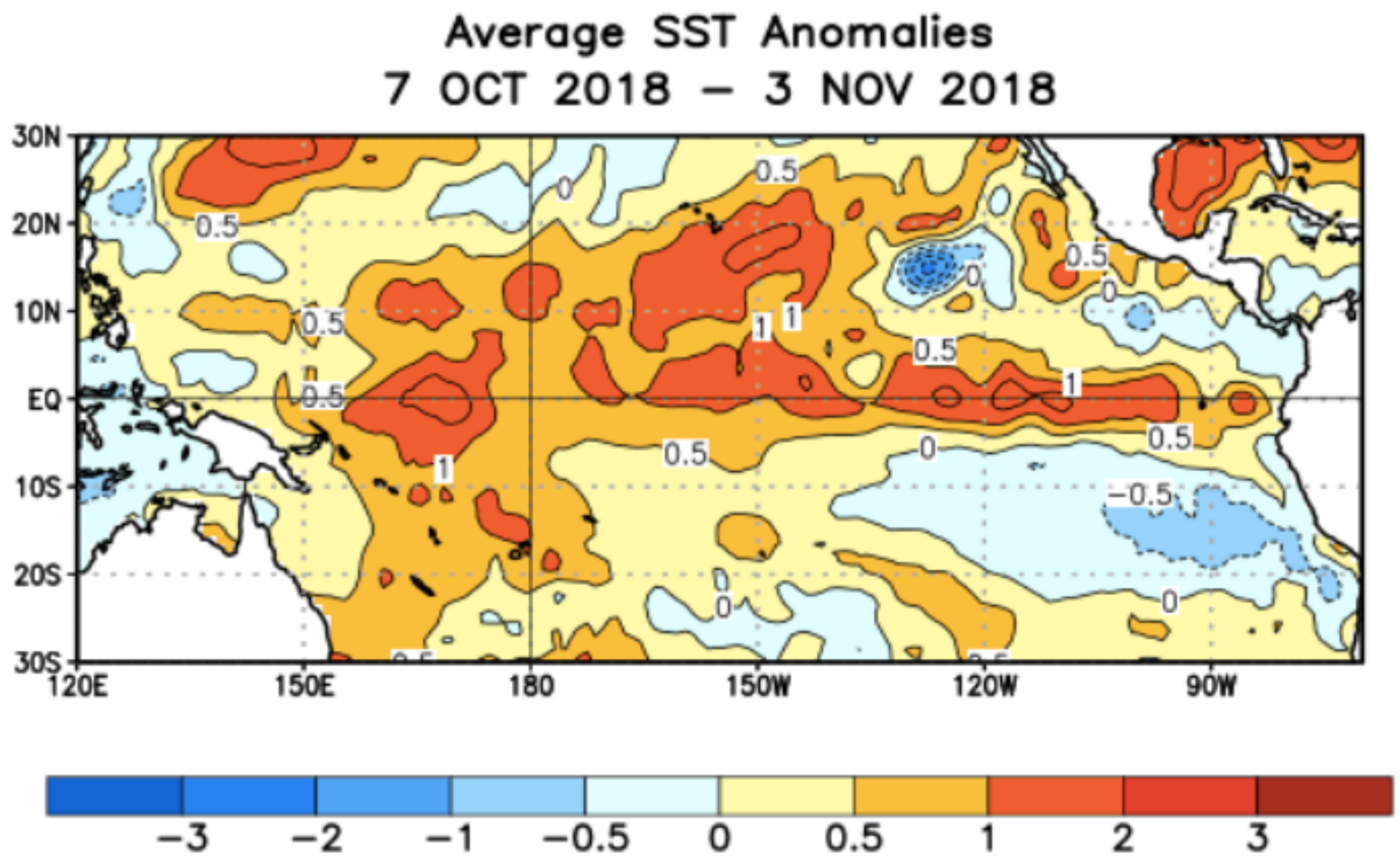


http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf

El Niño - La Niña

SST Departures (ºC) in the Tropical Pacific During the Last Four Weeks

During the last four weeks, equatorial SSTs were above average across the Pacific Ocean.



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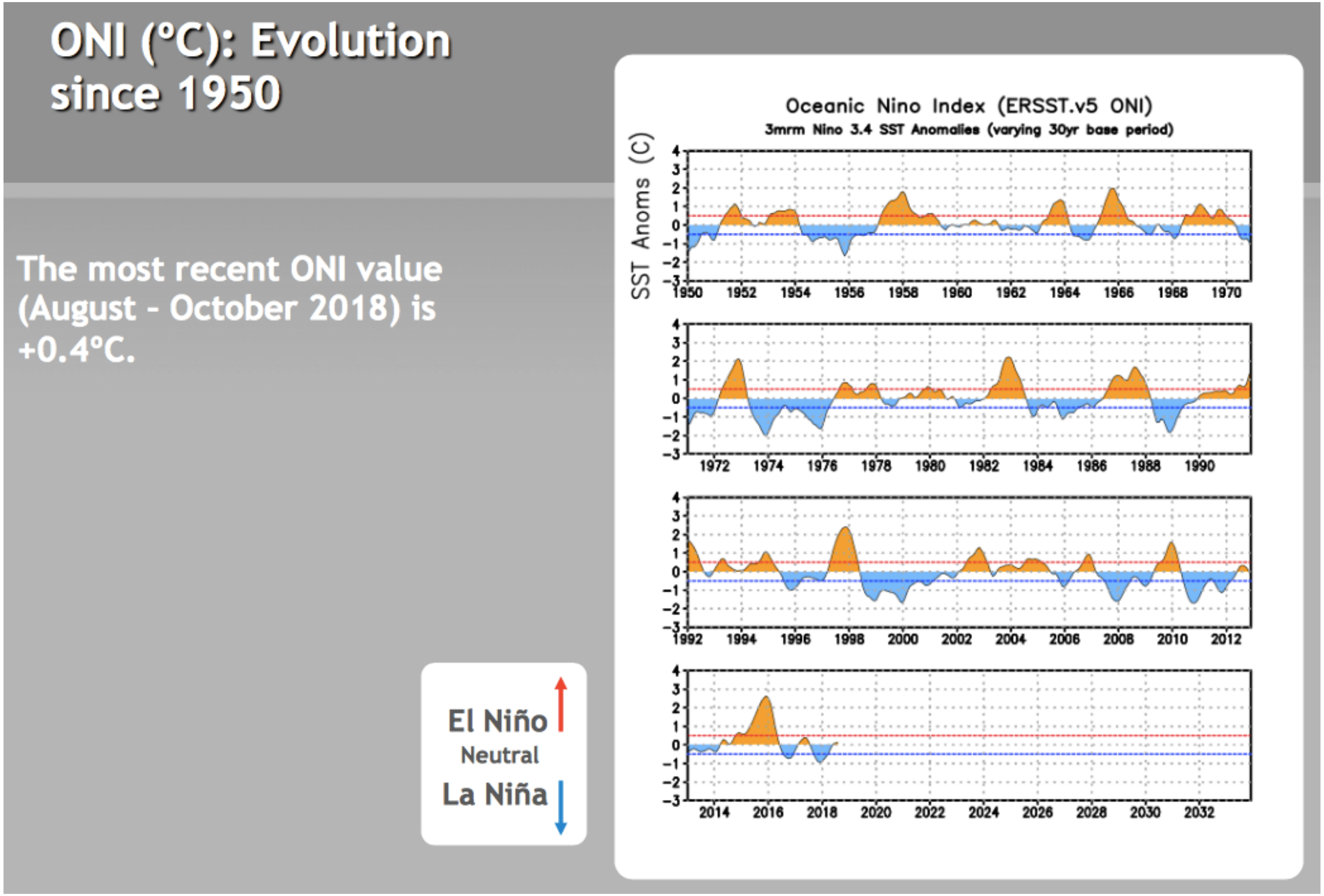

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OLD DOMINION UNIVERSITY

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Data Sources

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2005 Atlantic Hurricane Season

1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017

The National Hurricane Center's Tropical Cyclone Reports contain comprehensive information on each tropical cyclone, including synoptic history, meteorological statistics, casualties and damages, and the post-analysis best track (six-hourly positions and intensities). Tropical cyclones include depressions, storms and hurricanes. Tropical depressions listed below are those that did not reach tropical storm strength.

XML index of all Tropical Cyclone Reports

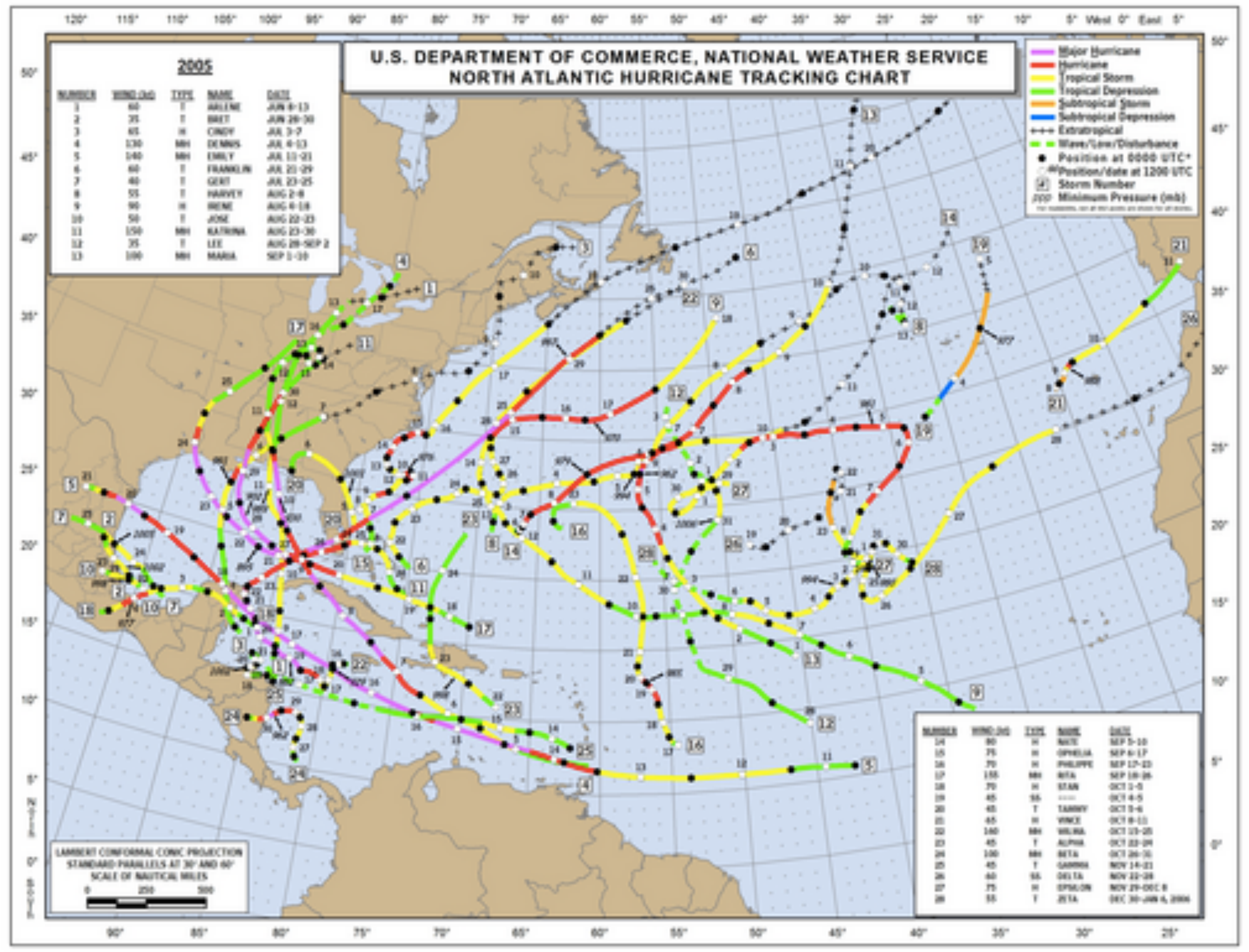
Atlantic | Eastern Pacific

- **Tropical Storm Arlene – PDF**
- **Tropical Storm Bret – PDF**
- **Hurricane Cindy[1] – PDF**
- **Hurricane Dennis[2] – PDF**
- **Hurricane Emily – PDF**
- **Tropical Storm Franklin – PDF**
- **Tropical Storm Gert – PDF**
- **Tropical Storm Harvey – PDF**
- **Hurricane Irene – PDF**
- **Tropical Depression Ten – PDF**
- **Tropical Storm Jose – PDF**
- **Hurricane Katrina[3] – PDF**
- **Tropical Storm Lee – PDF**
- **Hurricane Maria – PDF**
- **Hurricane Nate – PDF**
- **Hurricane Ophelia[4] – PDF**
- **Hurricane Philippe – PDF**
- **Hurricane Rita[5] – PDF**
- **Tropical Depression Nineteen – PDF**
- **Hurricane Stan – PDF**
- **Subtropical Storm (Unnamed)[6] – PDF**
- **Tropical Storm Tammy – PDF**
- **Subtropical Depression Twenty-Two – PDF**
- **Hurricane Vince – PDF**
- **Hurricane Wilma[7] – PDF**
- **Tropical Storm Alpha – PDF**
- **Hurricane Beta – PDF**
- **Tropical Storm Gamma – PDF**
- **Tropical Storm Delta – PDF**
- **Hurricane Epsilon – PDF**
- **Tropical Storm Zeta – PDF**

1. Cindy was redesignated as a hurricane in the post-season re-analysis
2. Dennis updated 09 September 2014
3. Katrina updated 15 September 2011
4. Ophelia updated 14 June 2006
5. Rita updated 15 September 2011
6. This unnamed subtropical cyclone was identified during NHC's post-season re-analysis
7. Wilma updated 09 September 2014

http://www.nhc.noaa.gov/data/tcr/index.php?season=2005&basin=atl

Atlantic Tropical Cyclone Tracks



2005 North Atlantic Hurricane Season Track Map (click to enlarge)

Data Sources

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- **Tropical Depression Nineteen** – PDF
- **Hurricane Stan** – PDF
- **Subtropical Storm (Unnamed)**[6] – PDF
- **Tropical Storm Tammy** – PDF
- **Subtropical Depression Twenty-Two** – PDF
- **Hurricane Vince** – PDF
- **Hurricane Wilma**[7] – PDF
- **Tropical Storm Alpha** – PDF
- **Hurricane Beta** – PDF
- **Tropical Storm Gamma** – PDF
- **Tropical Storm Delta** – PDF
- **Hurricane Epsilon** – PDF
- **Tropical Storm Zeta** – PDF

1. Cindy was redesignated as a hurricane in the post-season re-analysis
2. Dennis updated 09 September 2014
3. Katrina updated 15 September 2011
4. Ophelia updated 14 June 2006
5. Rita updated 15 September 2011
6. This unnamed subtropical cyclone was identified during NHC's post-season re-analysis
7. Wilma updated 09 September 2014

http://www.nhc.noaa.gov/data/tcr/index.php?season=2005&basin=atl

http://www.nhc.noaa.gov/data/tcr/AL122005_Katrina.pdf

Tropical Cyclone Report
Hurricane Katrina
23-30 August 2005

Richard D. Knabb, Jamie R. Rhome, and Daniel P. Brown
National Hurricane Center
20 December 2005

Updated 14 September 2011 to include damage estimates from the National Flood Insurance Program and to revise the total damage estimate

Updated 10 August 2006 for tropical wave history, storm surge, tornadoes, surface observations, fatalities, and damage cost estimates

Katrina was an extraordinarily powerful and deadly hurricane that carved a wide swath of catastrophic damage and inflicted large loss of life. It was the costliest and one of the five deadliest hurricanes to ever strike the United States. Katrina first caused fatalities and damage in southern Florida as a Category 1 hurricane on the Saffir-Simpson Hurricane Scale. After reaching Category 5 intensity over the central Gulf of Mexico, Katrina weakened to Category 3 before making landfall on the northern Gulf coast. Even so, the damage and loss of life inflicted by this massive hurricane in Louisiana and Mississippi were staggering, with significant effects extending into the Florida panhandle, Georgia, and Alabama. Considering the scope of its impacts, Katrina was one of the most devastating natural disasters in United States history.

a. Synoptic History

The complex genesis of Katrina involved the interaction of a tropical wave, the middle tropospheric remnants of Tropical Depression Ten, and an upper tropospheric trough. This trough, located over the western Atlantic and the Bahamas, produced strong westerly shear across Tropical Depression Ten, causing it to degenerate on 14 August approximately 825 n mi east of Barbados. The low-level circulation gradually weakened while continuing westward, and it eventually dissipated on 21 August in the vicinity of Cuba. Meanwhile, a middle tropospheric circulation originating from Tropical Depression Ten lagged behind and passed north of the Leeward Islands on 18-19 August. A tropical wave, which departed the west coast of Africa on 11 August, moved through the Leeward Islands and merged with the middle tropospheric remnants of Tropical Depression Ten on 19 August and produced a large area of showers and thunderstorms north of Puerto Rico. This activity continued to move slowly northwestward, passing north of Hispaniola and then consolidating just east of the Turks and

Data Sources

Home Mobile Site Text Version RSS Local Forecast Enter City,St or ZIP code Go

NATIONAL HURRICANE CENTER

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

ANALYSES & FORECASTS ▾ DATA & TOOLS ▾ EDUCATIONAL RESOURCES ▾ ARCHIVES ▾ ABOUT NHC ▾ SEARCH ▾

2005 Eastern Pacific Hurricane Season

1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017

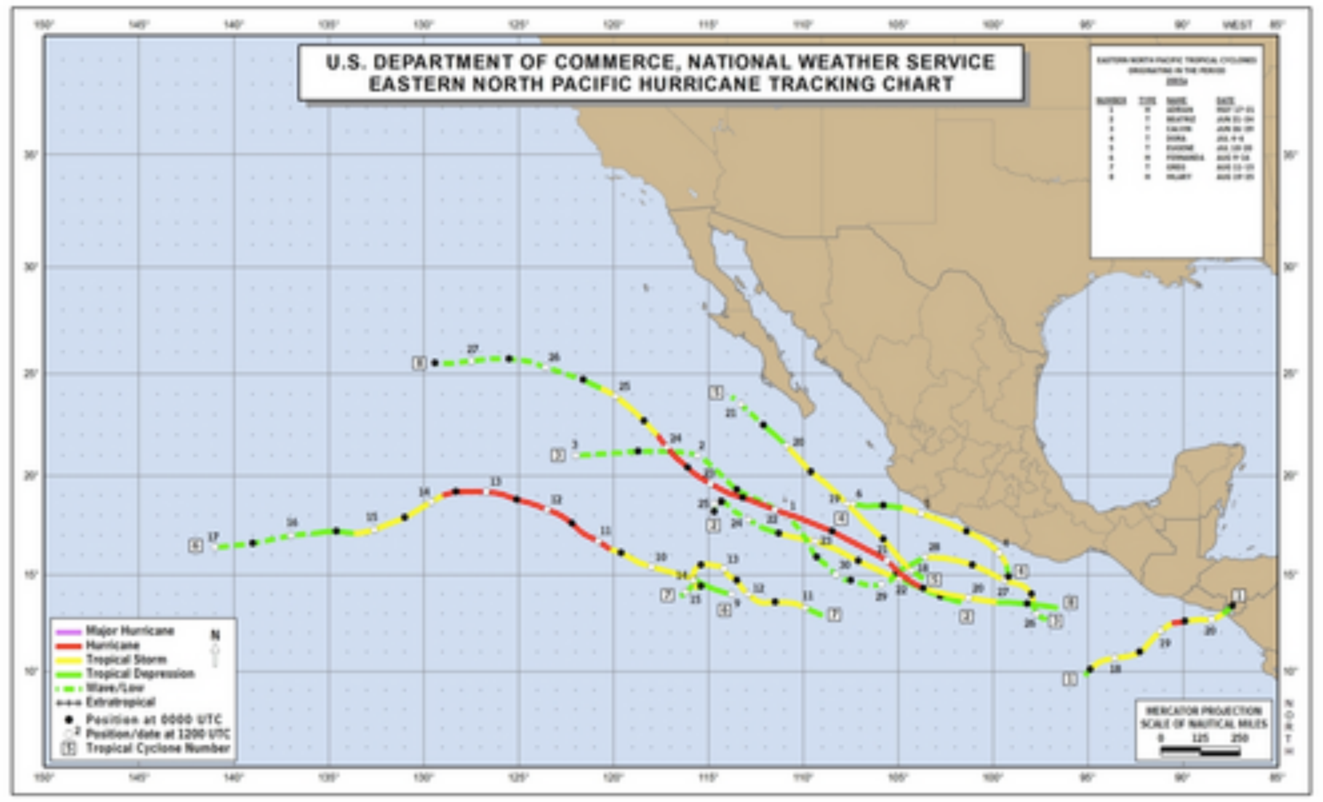
The National Hurricane Center's Tropical Cyclone Reports contain comprehensive information on each tropical cyclone, including synoptic history, meteorological statistics, casualties and damages, and the post-analysis best track (six-hourly positions and intensities). Tropical cyclones include depressions, storms and hurricanes. Tropical depressions listed below are those that did not reach tropical storm strength.

XML index of all Tropical Cyclone Reports

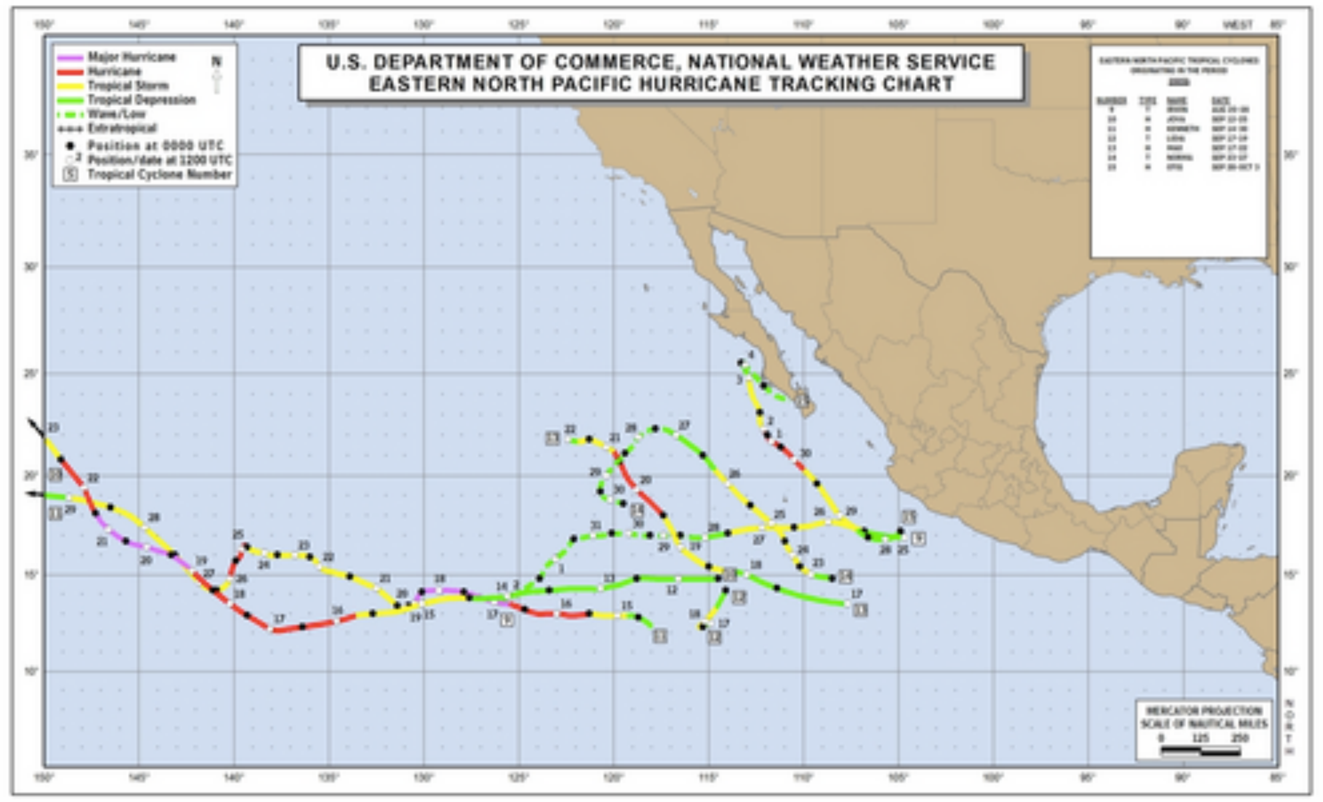
Atlantic | Eastern Pacific

- **Hurricane Adrian – PDF**
- **Tropical Storm Beatriz – PDF**
- **Tropical Storm Calvin – PDF**
- **Tropical Storm Dora – PDF**
- **Tropical Storm Eugene – PDF**
- **Hurricane Fernanda – PDF**
- **Tropical Storm Greg – PDF**
- **Hurricane Hilary – PDF**
- **Tropical Storm Irwin – PDF**
- **Hurricane Jova – PDF**
- **Hurricane Kenneth – PDF**
- **Tropical Storm Lidia – PDF**
- **Hurricane Max – PDF**
- **Tropical Storm Norma – PDF**
- **Hurricane Otis – PDF**
- **Tropical Depression Sixteen-E – PDF**

Eastern North Pacific Tropical Cyclone Tracks

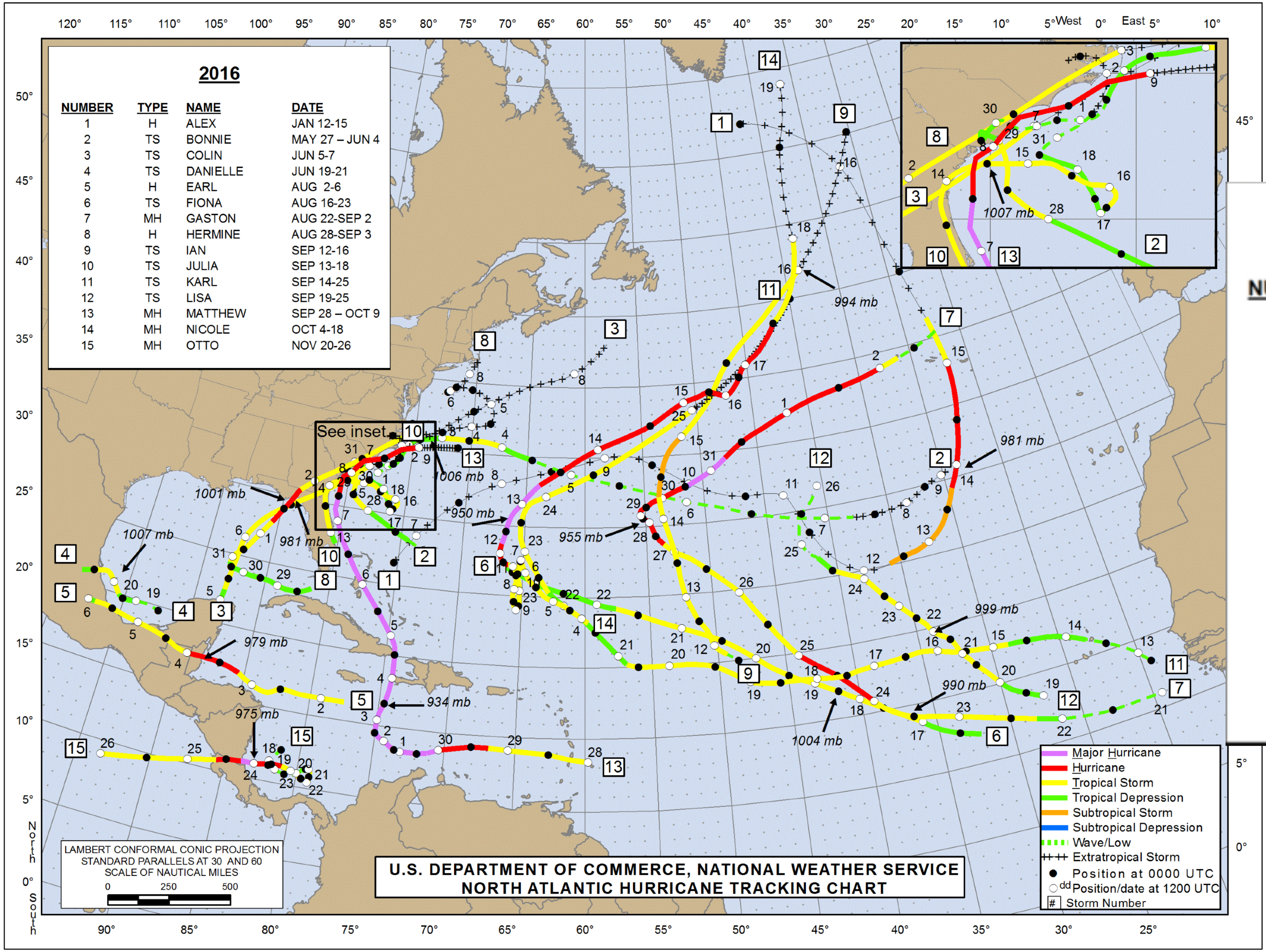


2005 Eastern North Pacific Hurricane Season Track Map (click to enlarge)



2005 Eastern North Pacific Hurricane Season Track Map Part b (click to enlarge)

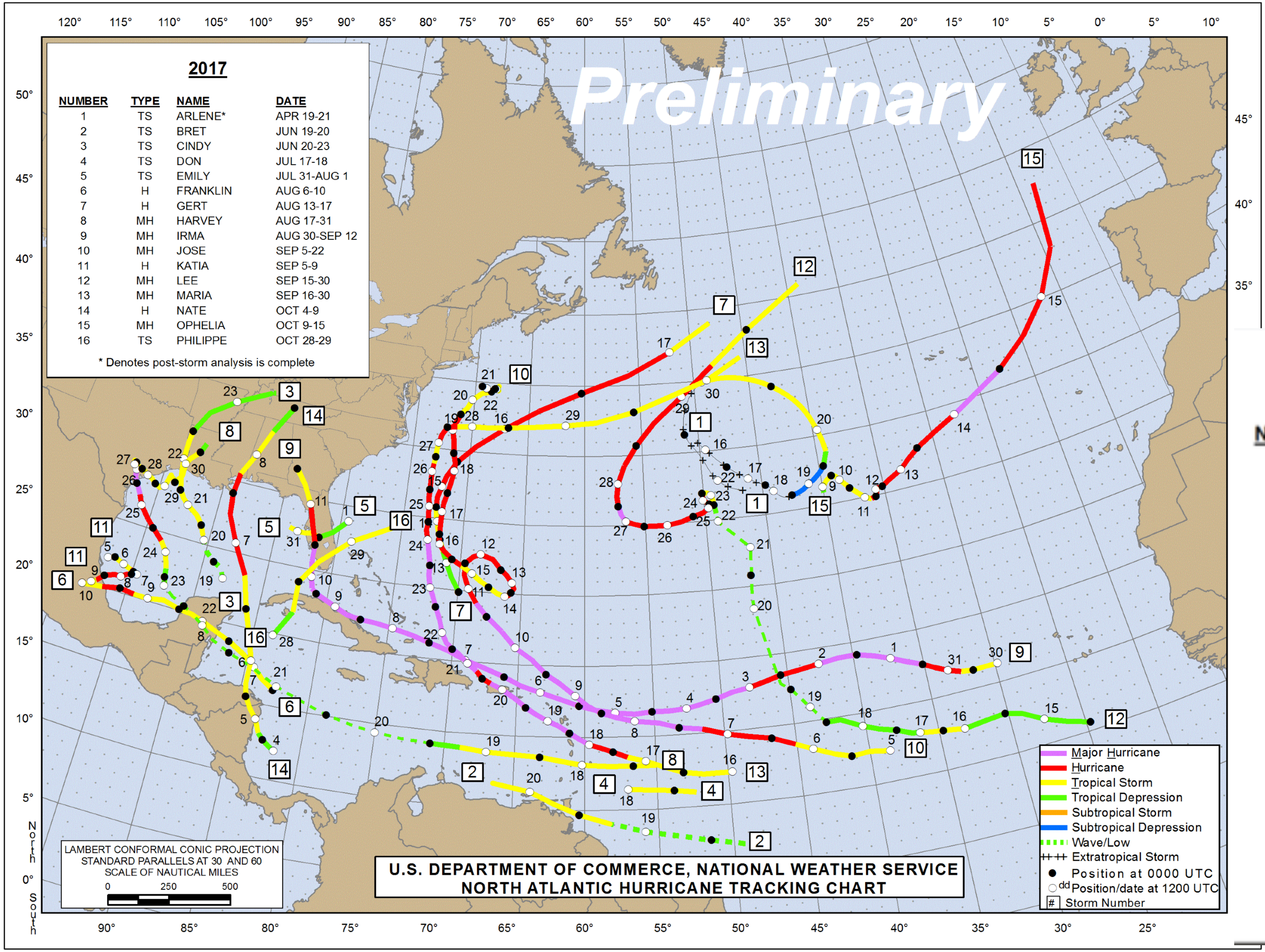
Data Sources



2016

NUMBER	TYPE	NAME	DATE
1	H	ALEX	JAN 12-15
2	TS	BONNIE	MAY 27 – JUN 4
3	TS	COLIN	JUN 5-7
4	TS	DANIELLE	JUN 19-21
5	H	EARL	AUG 2-6
6	TS	FIONA	AUG 16-23
7	MH	GASTON	AUG 22-SEP 2
8	H	HERMINE	AUG 28-SEP 3
9	TS	IAN	SEP 12-16
10	TS	JULIA	SEP 13-18
11	TS	KARL	SEP 14-25
12	TS	LISA	SEP 19-25
13	MH	MATTHEW	SEP 28 – OCT 9
14	MH	NICOLE	OCT 4-18
15	MH	OTTO	NOV 20-26

Data Sources

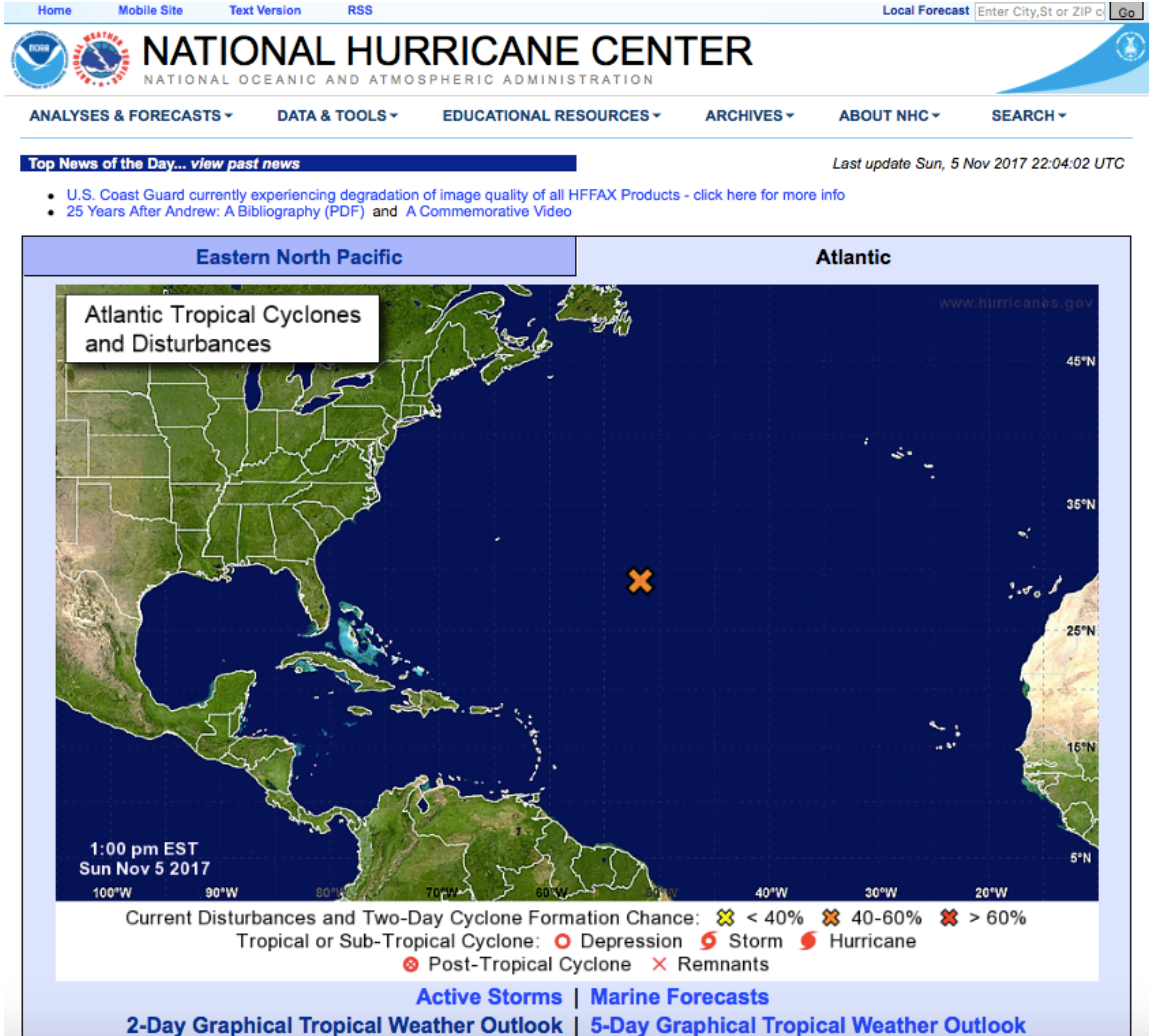


2017

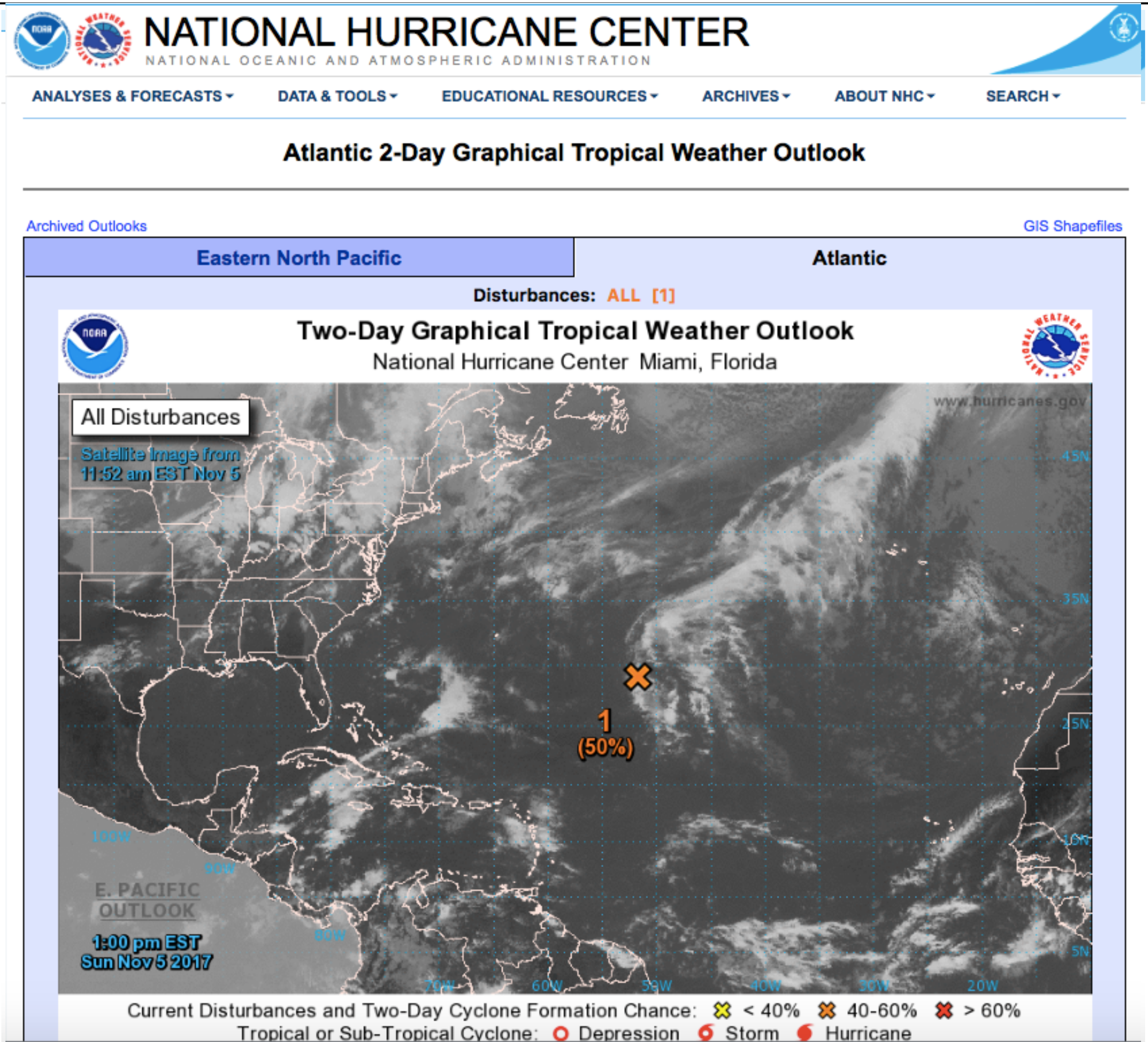
NUMBER	TYPE	NAME	DATE
1	TS	ARLENE*	APR 19-21
2	TS	BRET	JUN 19-20
3	TS	CINDY	JUN 20-23
4	TS	DON	JUL 17-18
5	TS	EMILY	JUL 31-AUG 1
6	H	FRANKLIN	AUG 6-10
7	H	GERT	AUG 13-17
8	MH	HARVEY	AUG 17-31
9	MH	IRMA	AUG 30-SEP 12
10	MH	JOSE	SEP 5-22
11	H	KATIA	SEP 5-9
12	MH	LEE	SEP 15-30
13	MH	MARIA	SEP 16-30
14	H	NATE	OCT 4-9
15	MH	OPHELIA	OCT 9-15
16	TS	PHILIPPE	OCT 28-29

* Denotes post-storm analysis is complete

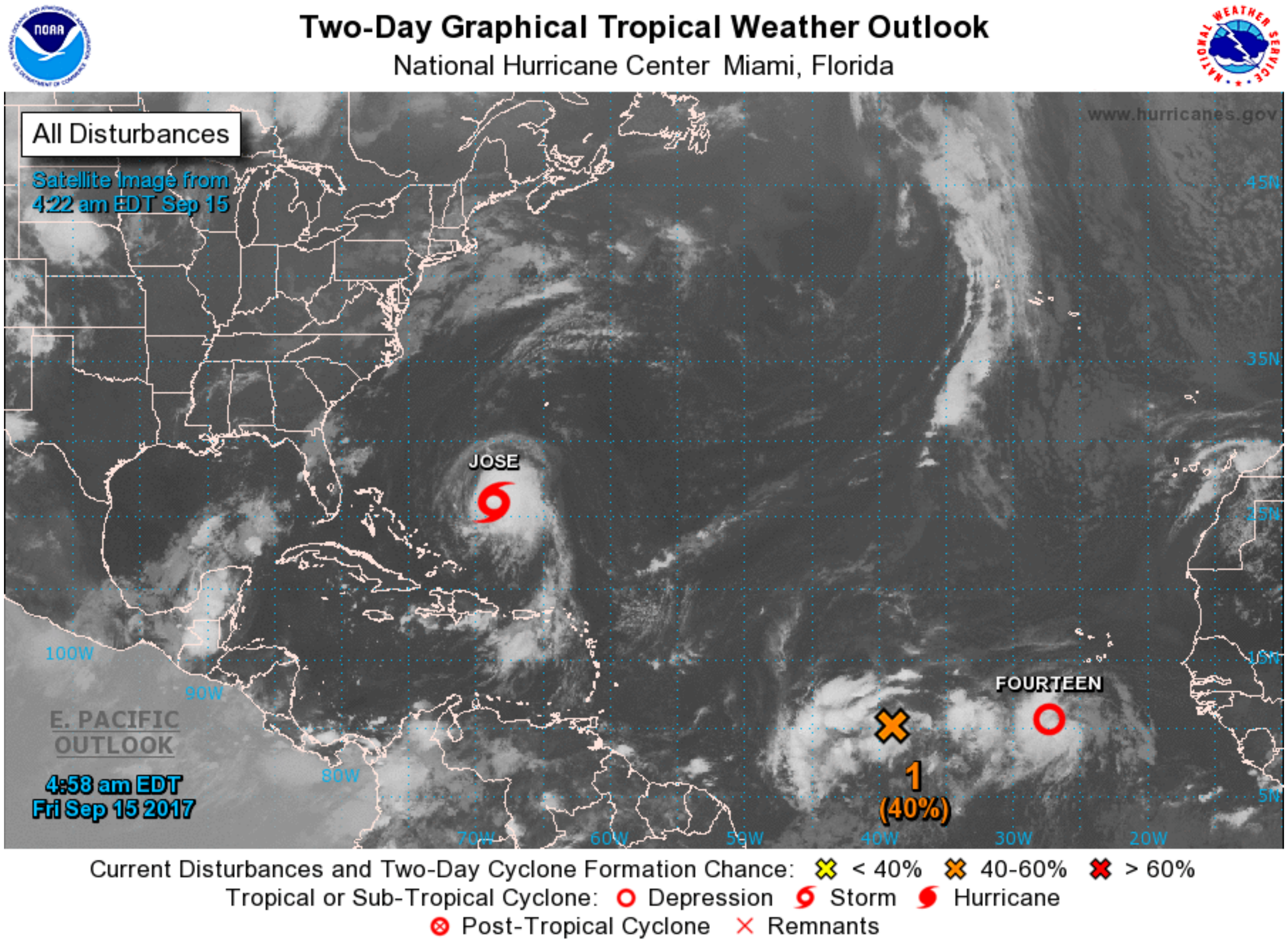
Data Sources



Data Sources



Data Sources



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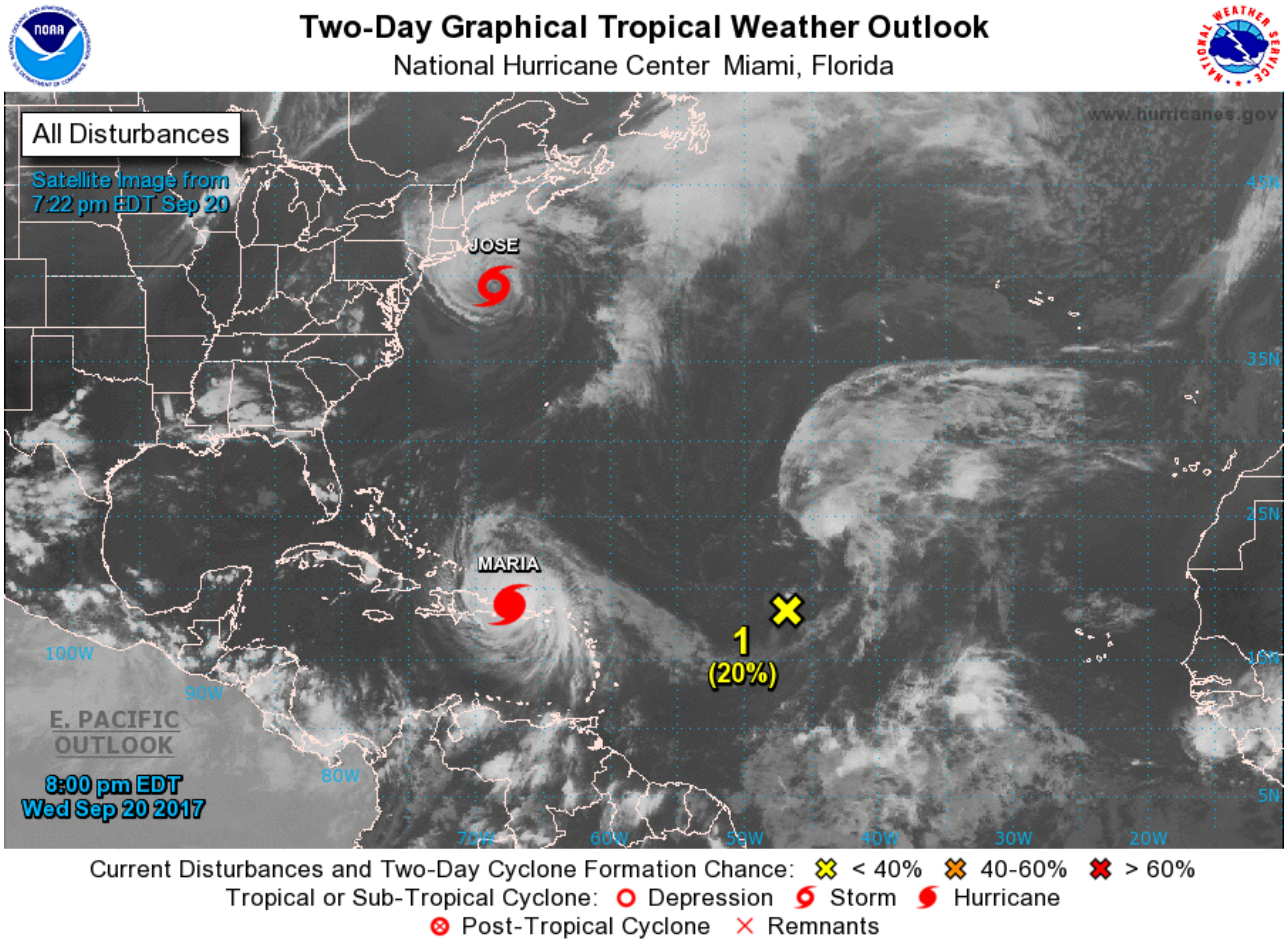

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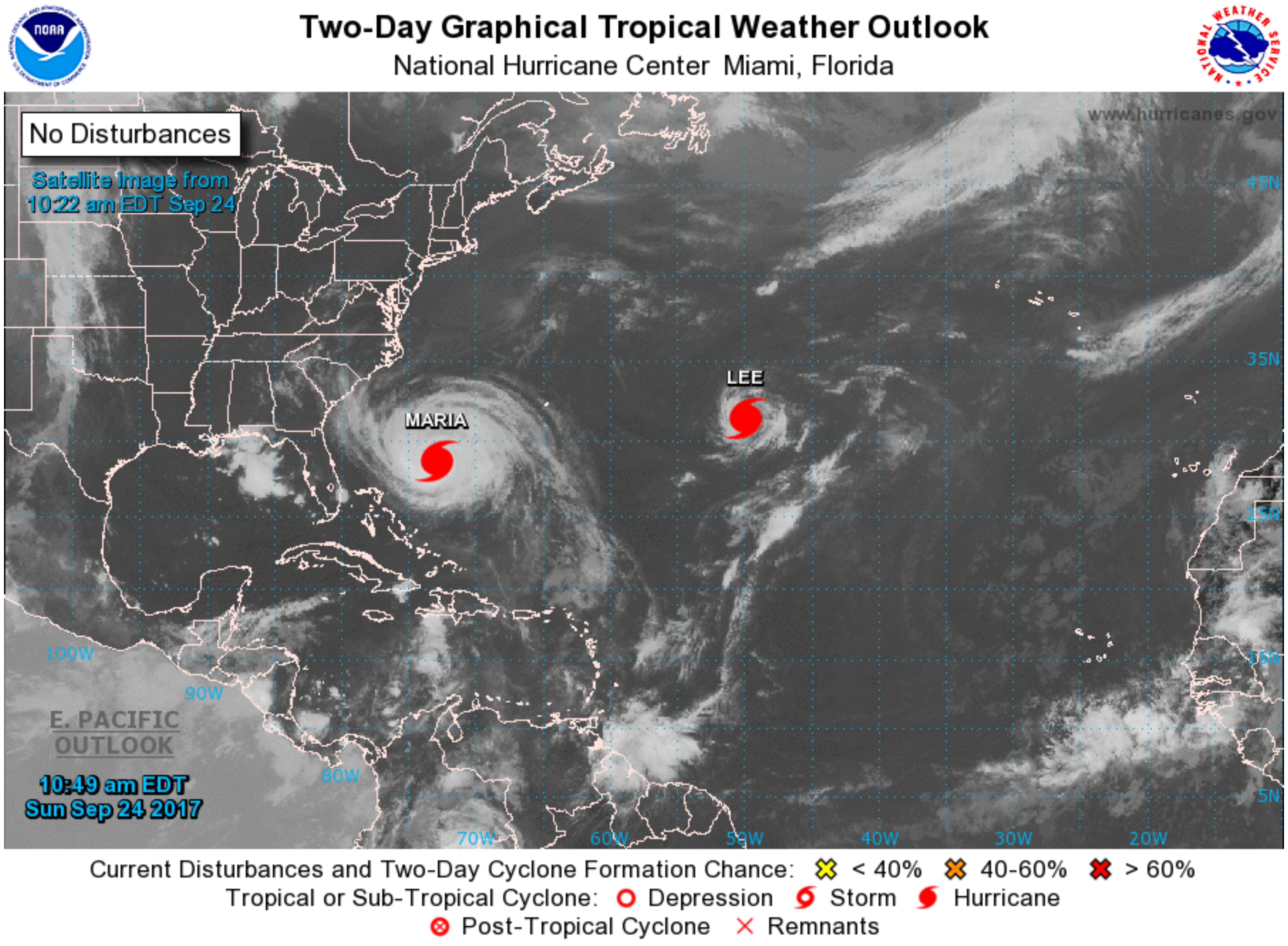
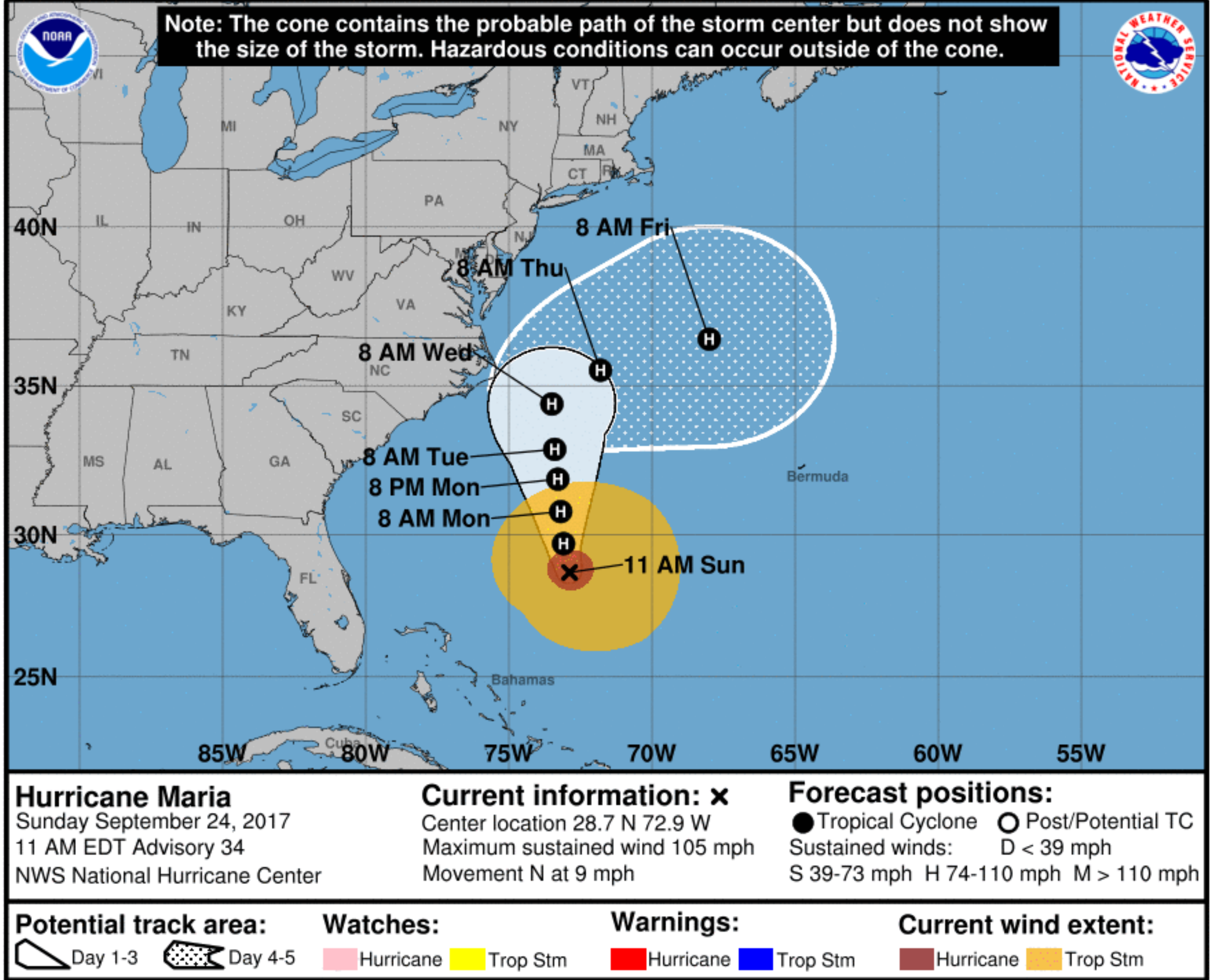
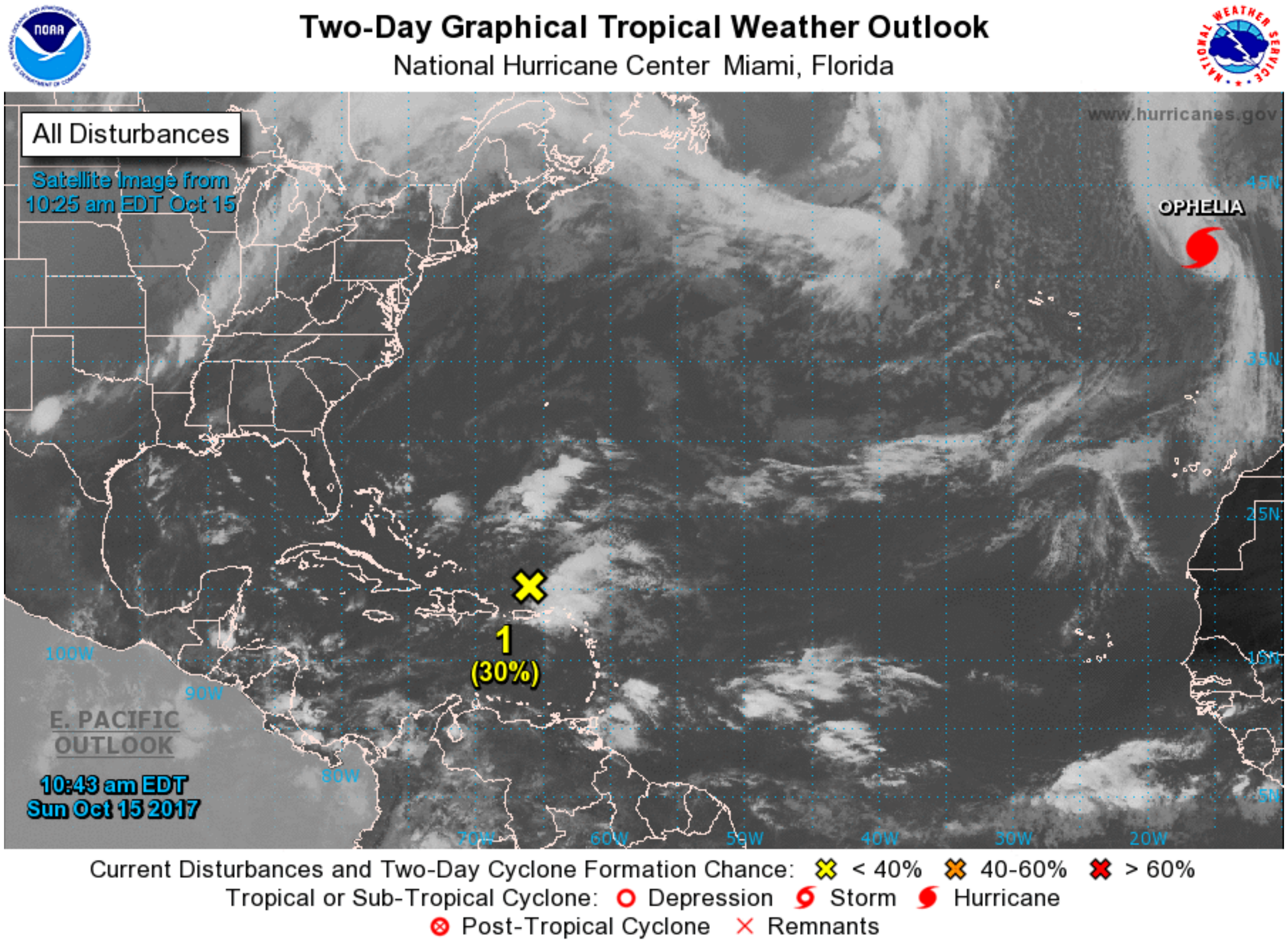


Data Source


Note: The cone contains the probable path of the storm center but does not show the size of the storm. Hazardous conditions can occur outside of the cone.
8 AM Fri
8 AM Thu
8 AM Wed
8 AM Tue
8 PM Mon
8 AM Mon
11 AM Sun
Bermuda
Bahamas
Cuba
40N
35N
30N
25N
85W
80W
75W
70W
65W
60W
55W
Hurricane Maria
Sunday September 24, 2017
11 AM EDT Advisory 34
NWS National Hurricane Center
Current information: ×
Center location 28.7 N 72.9 W
Maximum sustained wind 105 mph
Movement N at 9 mph
Forecast positions:
Tropical Cyclone
Post/Potential TC
Sustained winds: D < 39 mph
S 39-73 mph H 74-110 mph M > 110 mph
Potential track area:
Day 1-3
Day 4-5
Watches:
Hurricane
Trop Stm
Warnings:
Hurricane
Trop Stm
Current wind extent:
Hurricane
Trop Stm

Data Sources



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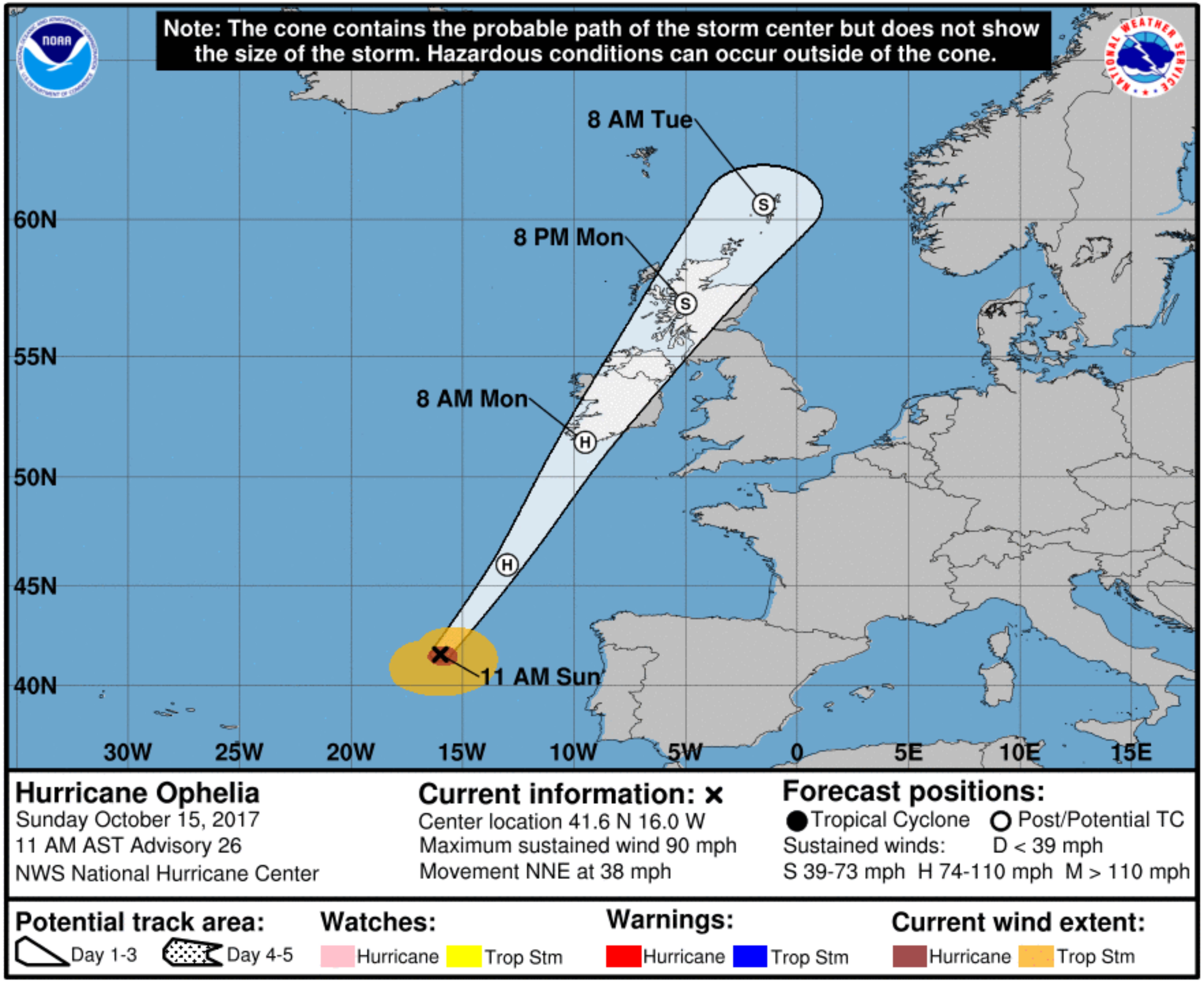

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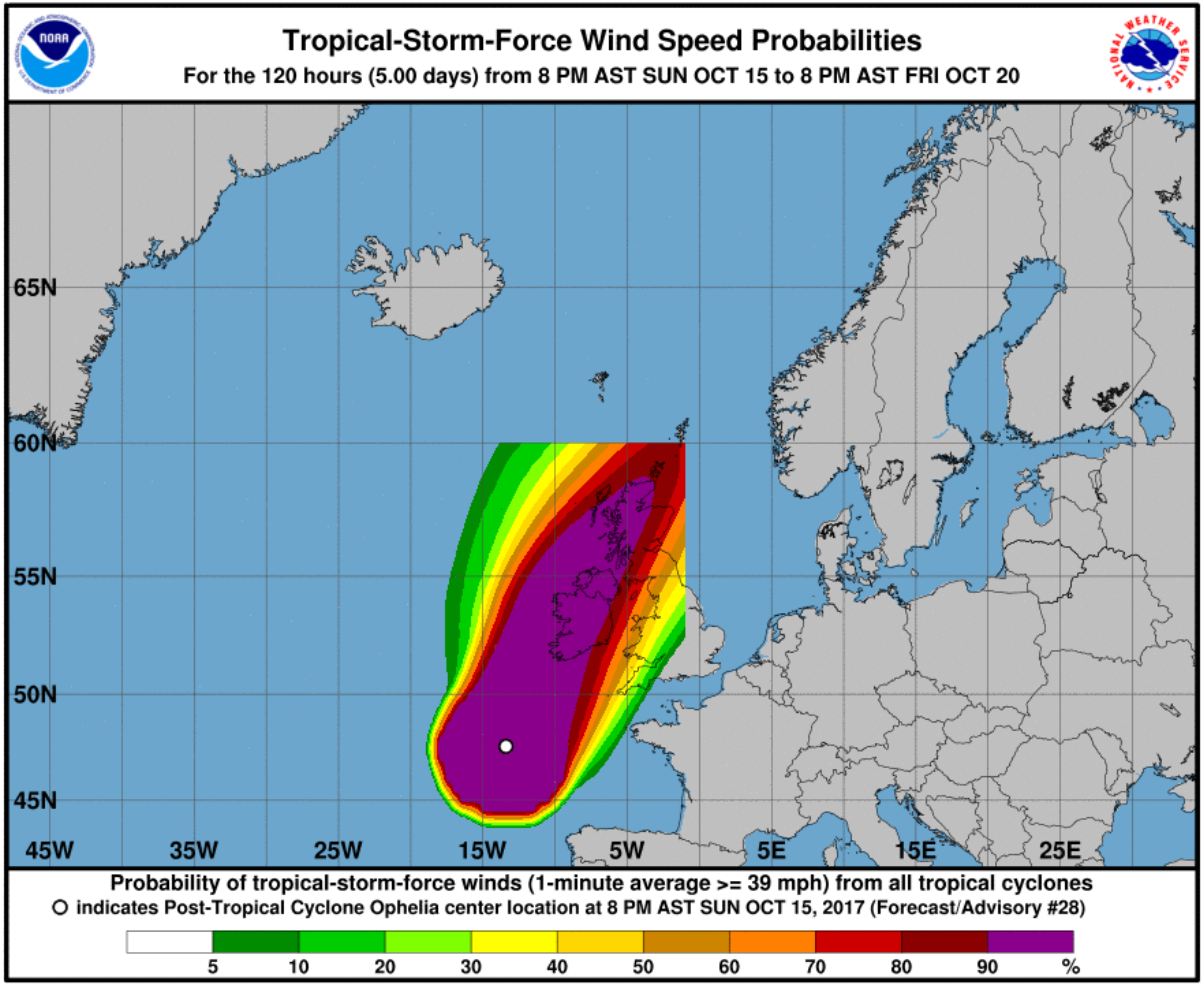
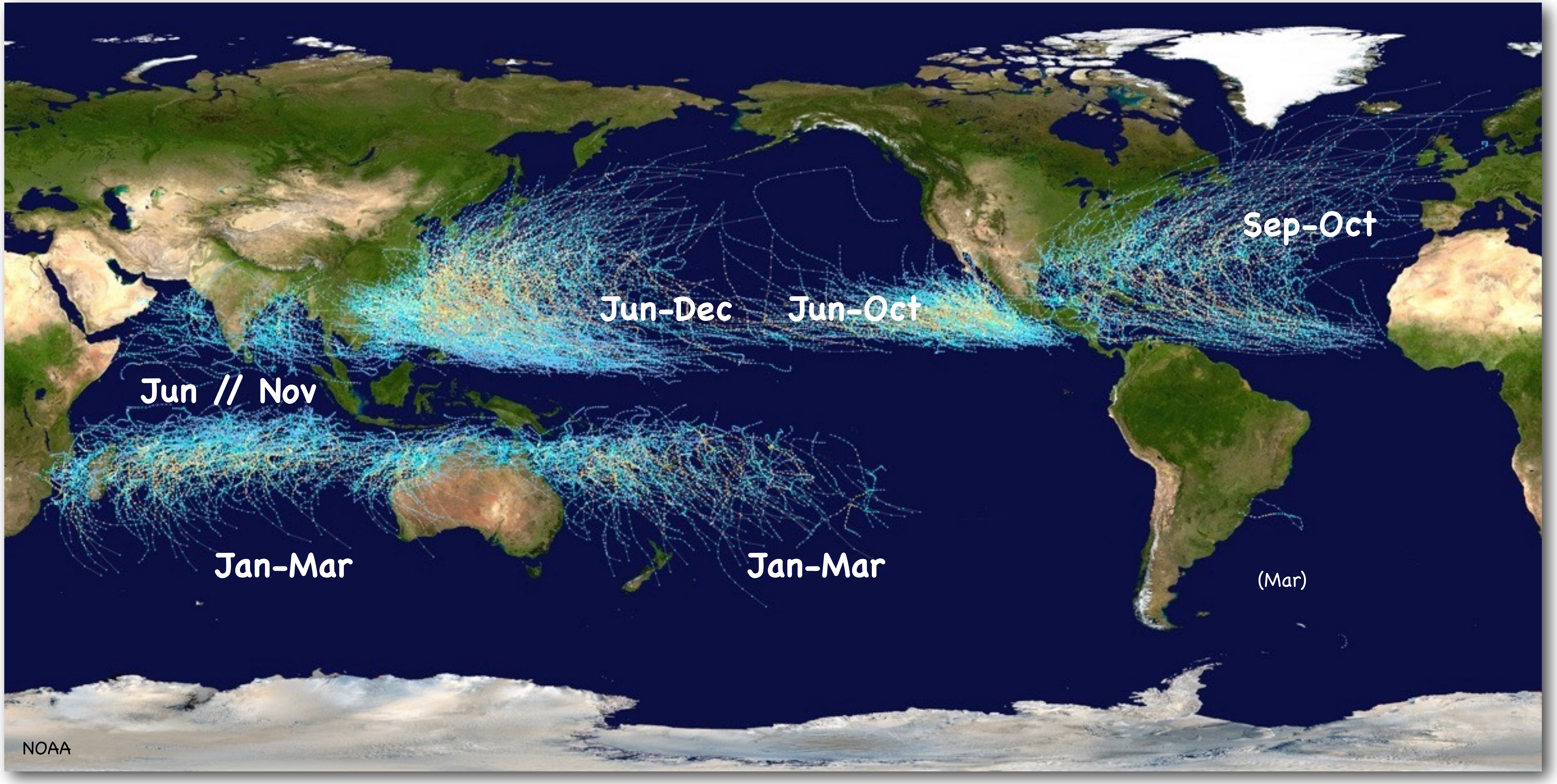


Natural Hazards and Disaster

Class 9: Hurricanes, Typhoons, Cyclones

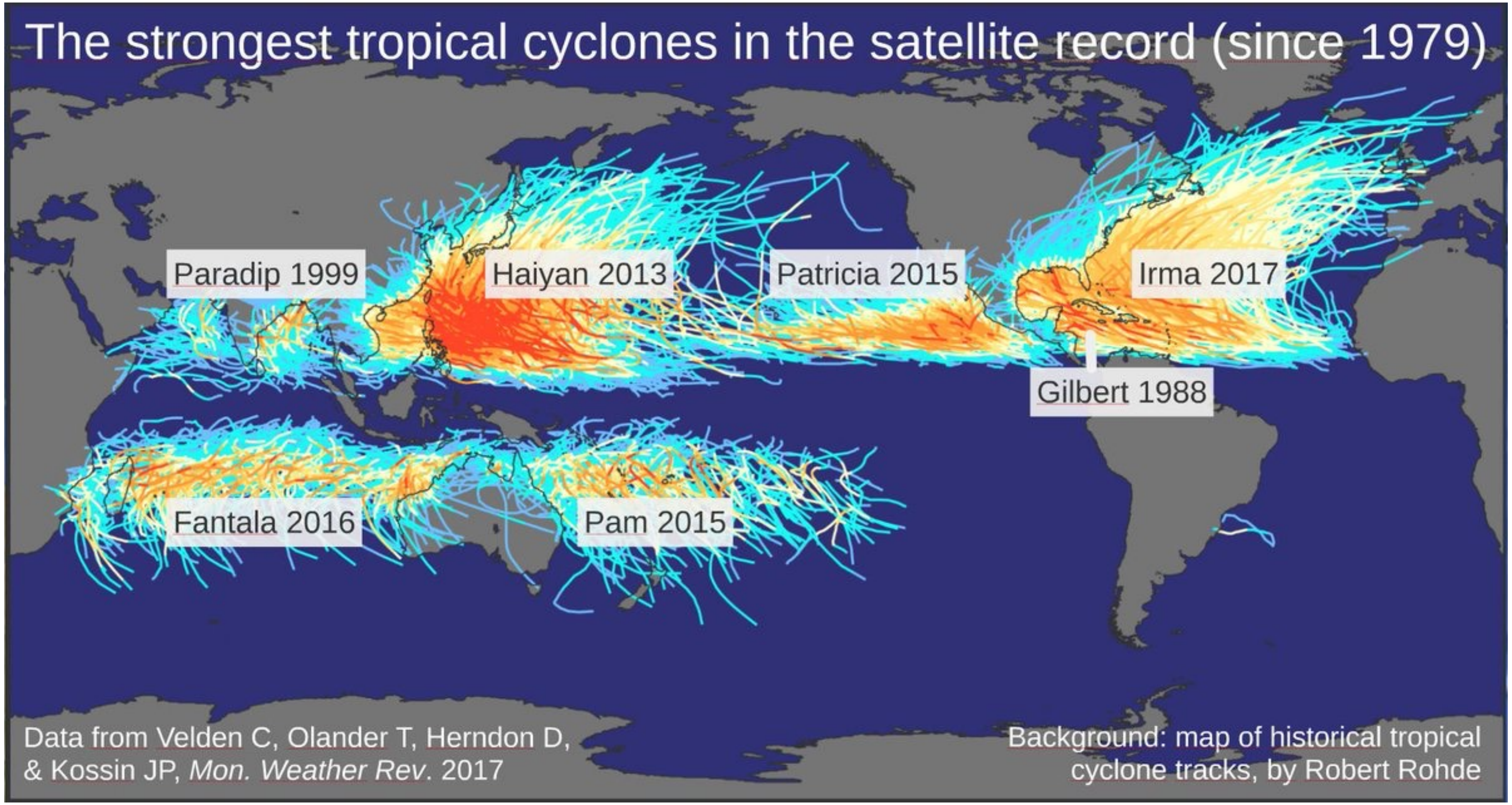
- Definitions, Scales
- Basics
- El Niño - La Niña
- Data Sources
- Where, When, Why
- Cases
- Climate Change Impacts

Where, When, Why



Hurricanes get their energy from warm ocean water

Where, When, Why

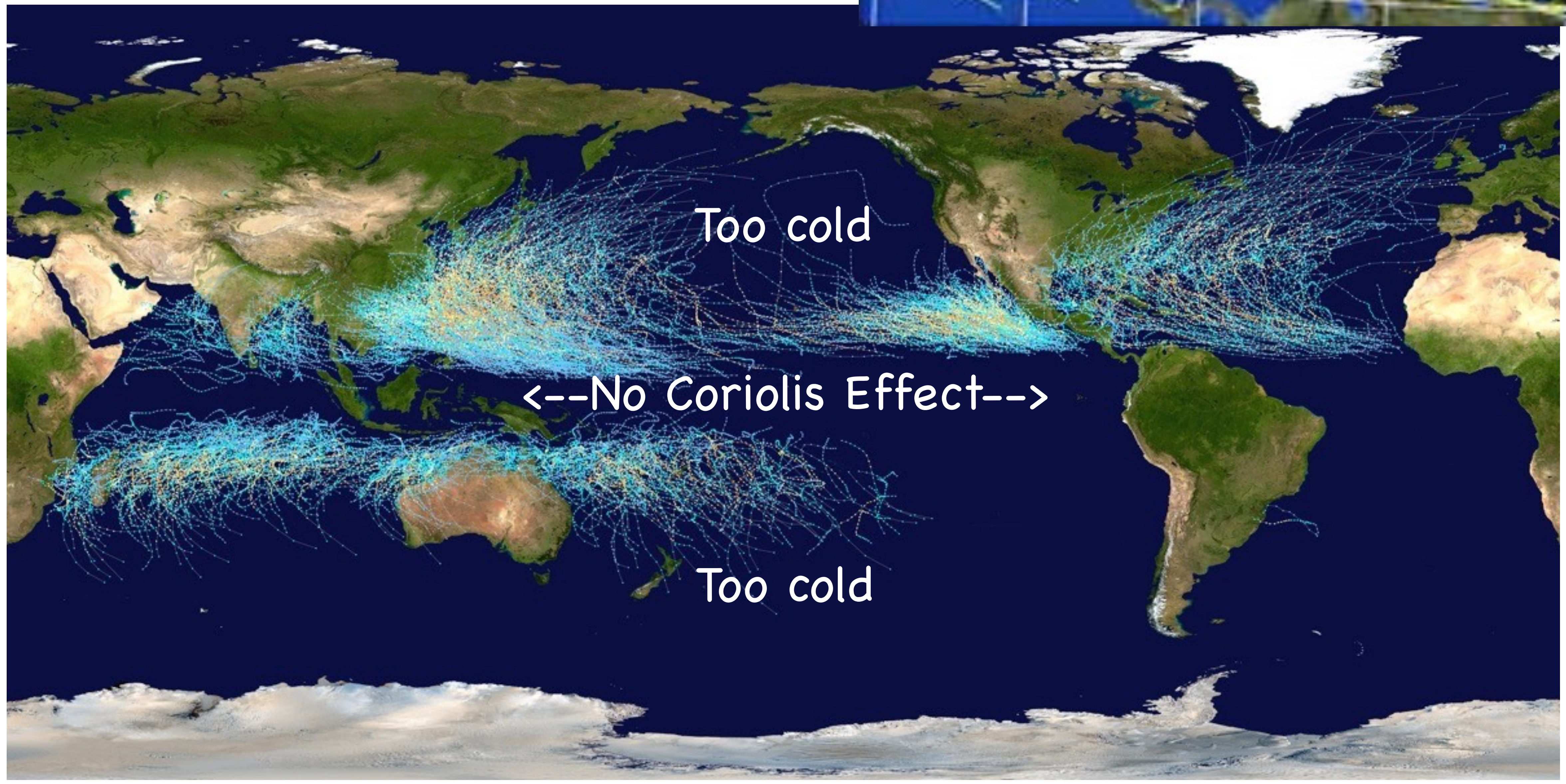


Hurricanes get their energy from warm ocean water

Where, When, Why

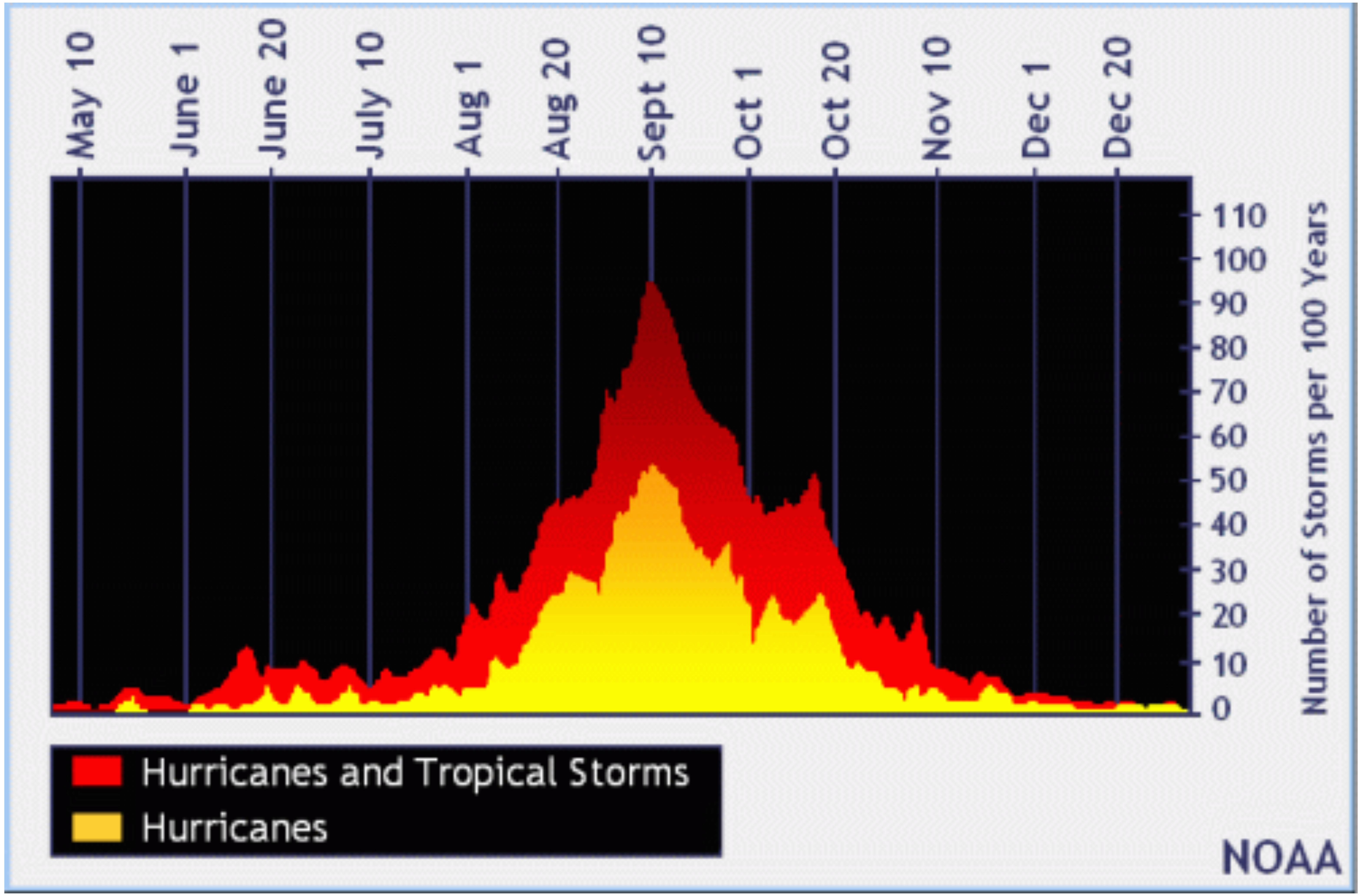
Why does path change?

Coriolis effect
again!



varies with latitude

Where, When, Why



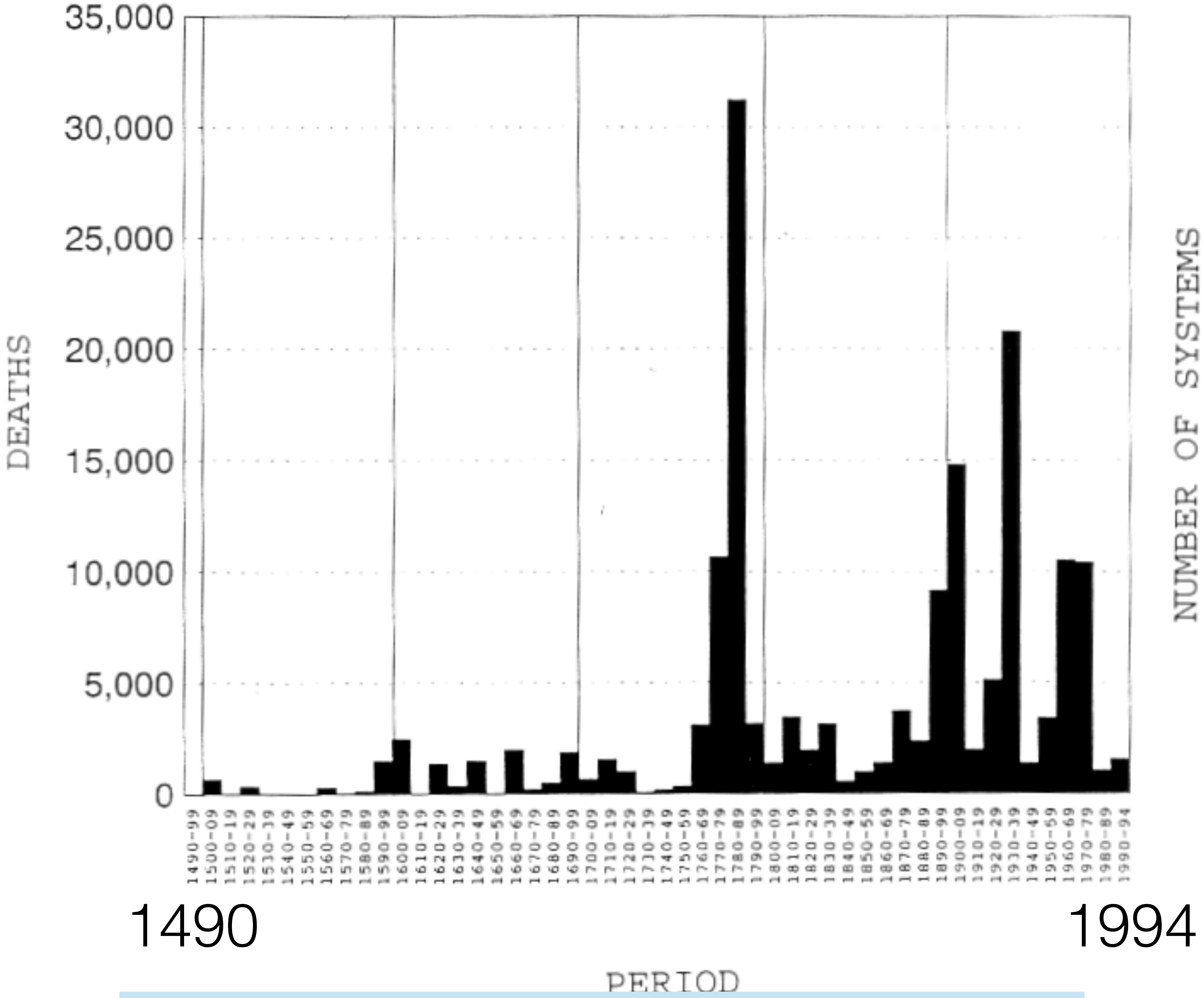
Number of Tropical Cyclones per 100 Years for the Atlantic Basin (the Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico). The official hurricane season for the Atlantic Basin is from 1 June to 30 November. As seen in the graph above, the peak of the season is from mid-August to late October. However, deadly hurricanes can occur anytime in the hurricane season.

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

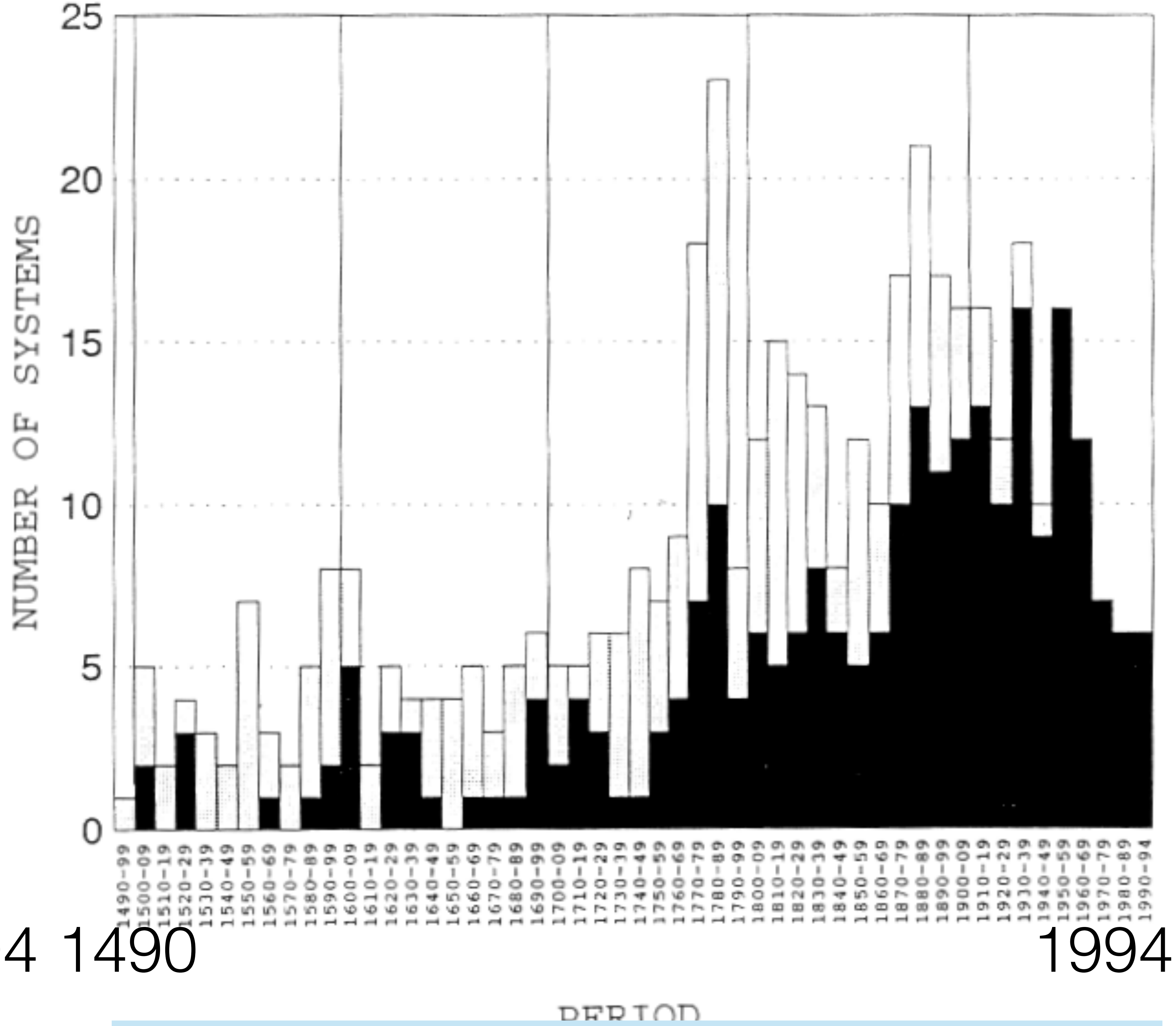
Where, When, Why

http://www.nhc.noaa.gov/pastdeadly4.shtml

1 Appendix 1: Cyclones with 25+ deaths
2 Appendix 2: Cyclones that may have 25+ deaths



Atlantic tropical cyclone deaths based on Appendix 1 and shown in 10-year periods (except for 1990-1994).

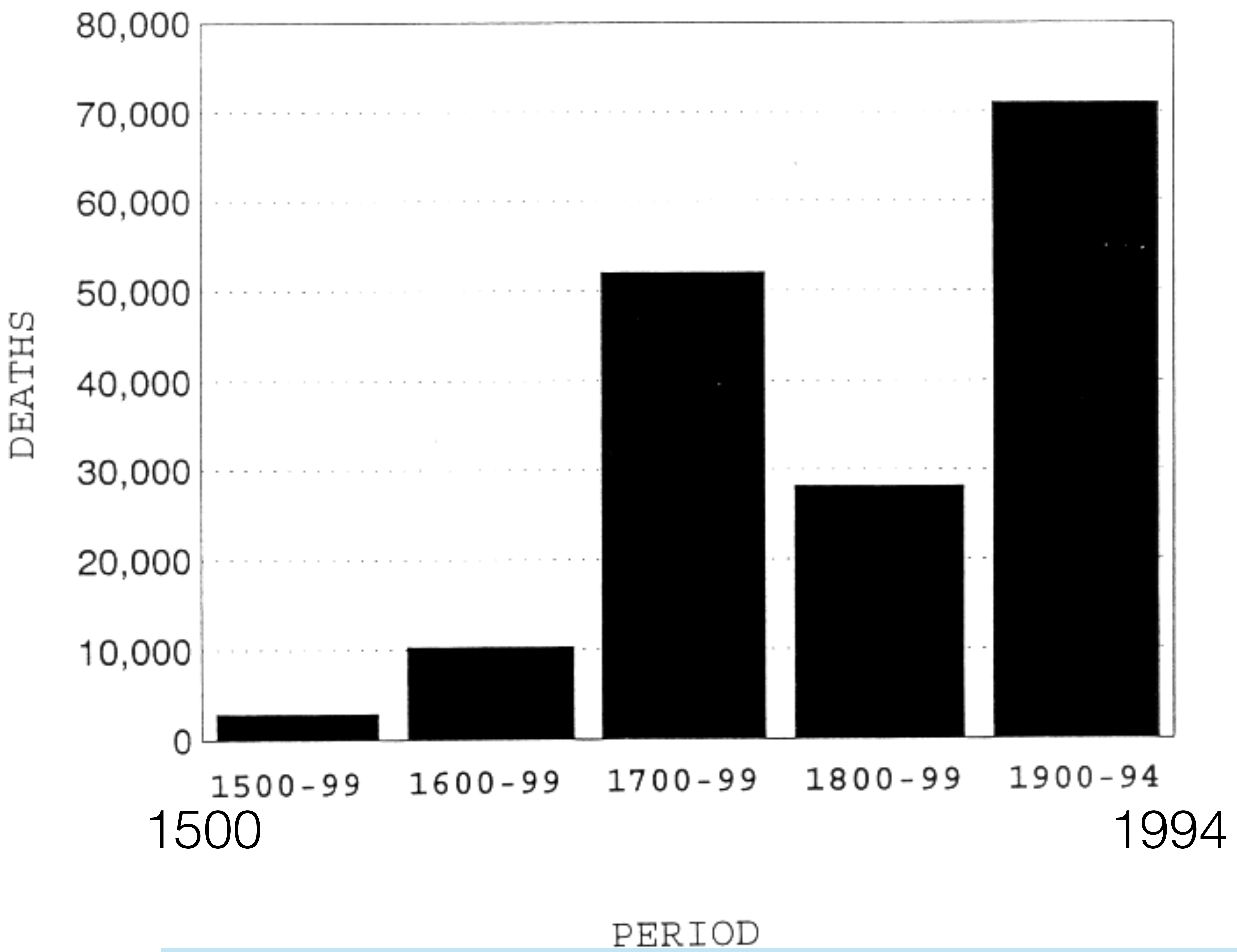


Number of Atlantic tropical cyclones listed in Appendix 1 (dark shading) and Appendix 2 (light shading), shown in 10-year periods (except for 1990-1994).

Where, When, Why

http://www.nhc.noaa.gov/pastdeadly4.shtml

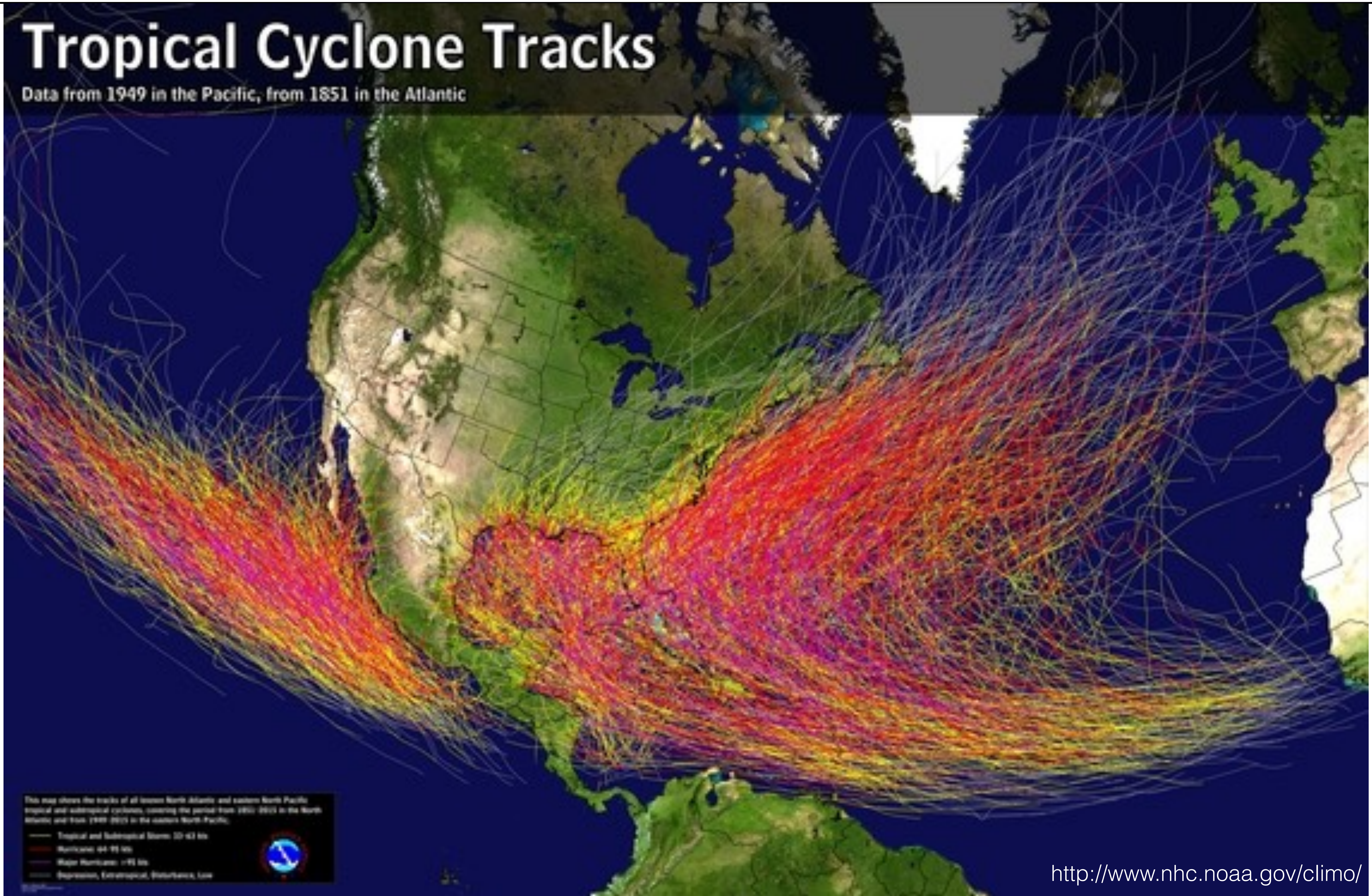
1 Appendix 1: Cyclones with 25+ deaths
2 Appendix 2: Cyclones that may have 25+ deaths



Atlantic tropical cyclones deaths based on Appendix 1 and shown in 100-year periods (except for 1990-1994).

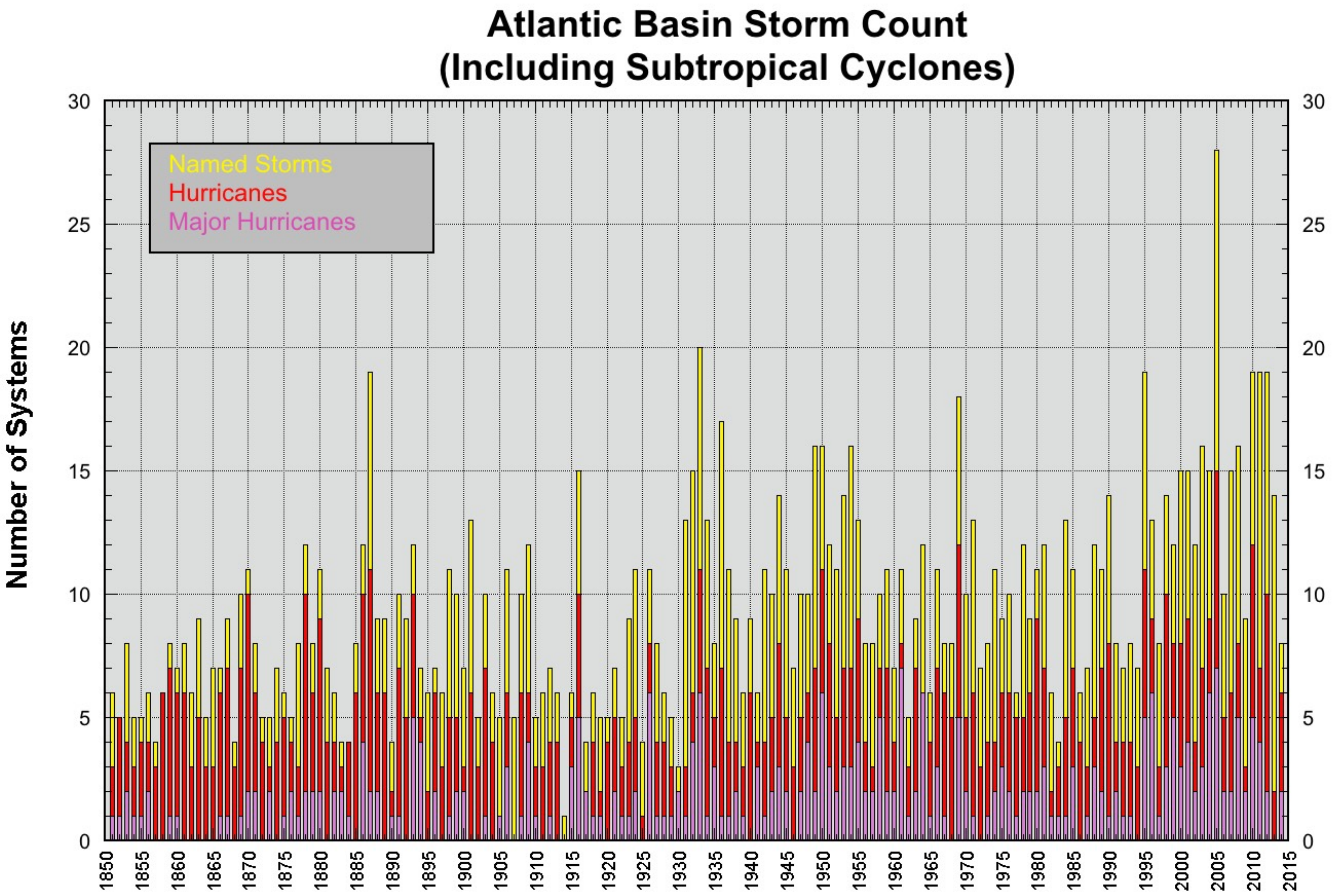
http://www.nhc.noaa.gov/pastdeadly4.shtml?

Where, When, Why



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

Where, When, Why



1850 2015

Bars depict number of named systems (yellow), hurricanes (red), and category 3 or greater (purple), 1850-2014

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

Where, When, Why

Table 2. Mainland U.S. tropical cyclones causing 25 or greater deaths 1851-2010.

RANK	HURRICANE	YEAR	CATEGORY	DEATHS
1	TX (Galveston)	1900	4	8000 [a]
2	FL (SE/Lake Okeechobee)	1928	4	2500 [b]
3	*KATRINA* (SE LA/MS)	2005	3	1200
4	LA (Cheniere Caminanda)	1893	4	1100-1400 [c]
5	SC/GA (Sea Islands)	1893	3	1000-2000 [d]
6	GA/SC	1881	2	700
7	*AUDREY* (SW LA/N TX)	1957	4	416 [h]
8	FL (Keys)	1935	5	408
9	LA (Last Island)	1856	4	400
10	FL (Miami)/MS/AL/Pensacola	1926	4	372
11	LA (Grand Isle)	1909	3	350
12	FL (Keys)/S TX	1919	4	287 [e]
13	LA (New Orleans)	1915	3	275 [j]
13	TX (Galveston)	1915	4	275
15	New England	1938	3	256 [e]
15	*CAMILLE* (MS/SE LA/VA)	1969	5	256
17	*DIANE* (NE U.S.)	1955	1	184
18	GA, SC, NC	1898	4	179
19	TX	1875	3	176
20	SE FL	1906	3	164
21	TX (Indianola)	1886	4	150
22	MS/AL/Pensacola	1906	2	134
23	FL, GA, SC	1896	3	130
24	*AGNES* (FL/NE U.S.)	1972	1	122 [f]
25	*HAZEL* (SC/NC)	1954	4	95
26	*BETSY* (SE FL/SE LA)	1965	3	75
27	Northeast U.S.	1944	3	64 [g]
28	*CAROL* (NE U.S.)	1954	3	60
29	*FLOYD* (Mid Atlantic & NE U.S.)	1999	2	56
30	NC	1883	2	53
31	SE FL/SE LA/MS	1947	4	51
32	NC, SC	1899	3	50 [h,i]
32	GA/SC/NC	1940	2	50
32	*DONNA* (FL/Eastern U.S.)	1960	4	50
35	LA	1860	2	47 [h]
36	NC, VA	1879	3	46 [h,j]
36	*CARLA* (N & Central TX)	1961	4	46
38	TX (Velasco)	1909	3	41
38	*ALLISON* (SE TX)	2001	TS [k]	41
40	Mid-Atlantic	1889	TS [l]	40 [h,j]
40	TX (Freeport)	1932	4	40
40	S TX	1933	3	40
43	*HILDA* (LA)	1964	3	38
44	SW LA/Upper TX	1918	3	34
45	SW FL	1910	3	30
45	*ALBERTO* (NW FL, GA, AL)	1994	TS [k]	30
47	SC, FL	1893	3	28 [m]
48	New England	1878	2	27 [h,n]
48	Texas	1886	2	27 [h]
50	*ANDREW* (S FL, LA)	1992	5	26
50	*FRAN* (NC)	1996	3	26
52	LA	1926	3	25
52	*CONNIE* (NC)	1955	3	25
52	*IVAN* (NW FL, AL)	2004	3	25

ADDENDUM (Not Atlantic/Gulf Coast)

RANK	HURRICANE	YEAR	CATEGORY	DEATHS
2	Puerto Rico (San Ciriaco)	1899	3	3369 [i]
6	P.R., USVI (San Narcico)	1867	3	811 [f,j]
6	Puerto Rico (San Lorenzo)	1852	1	800 [f,o]
12	Puerto Rico (San Felipe)	1928	5	312
17	USVI, P.R. (San Ciprian)	1932	2	225
25	*DONNA* (St. Thomas, VI)	1960	4	107
25	Puerto Rico (San Gil)	1888	1	100 [h]
38	Southern California	1939	TS [k]	45
38	*ELOISE* (Puerto Rico)	1975	TS [k]	44
48	USVI (Santa Juana")	1871	3	27 [h]
52	Puerto Rico (San Liborio)	1926	2	25

Notes:

a	Could be as high as 12,000
b	Could be as high as 3000
c	Total including offshore losses near 2000
d	August
e	Total including offshore losses is 600
f	No more than
g	Total including offshore losses is 390
h	At least
i	Puerto Rico 1899 and NC, SC 1899 are the same storm
j	Could include some offshore losses
k	Only of Tropical Storm intensity.
l	Remained offshore
m	Mid-October
n	Four deaths at shoreline or just offshore
o	Possibly a total from two hurricanes

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

Where, Wher

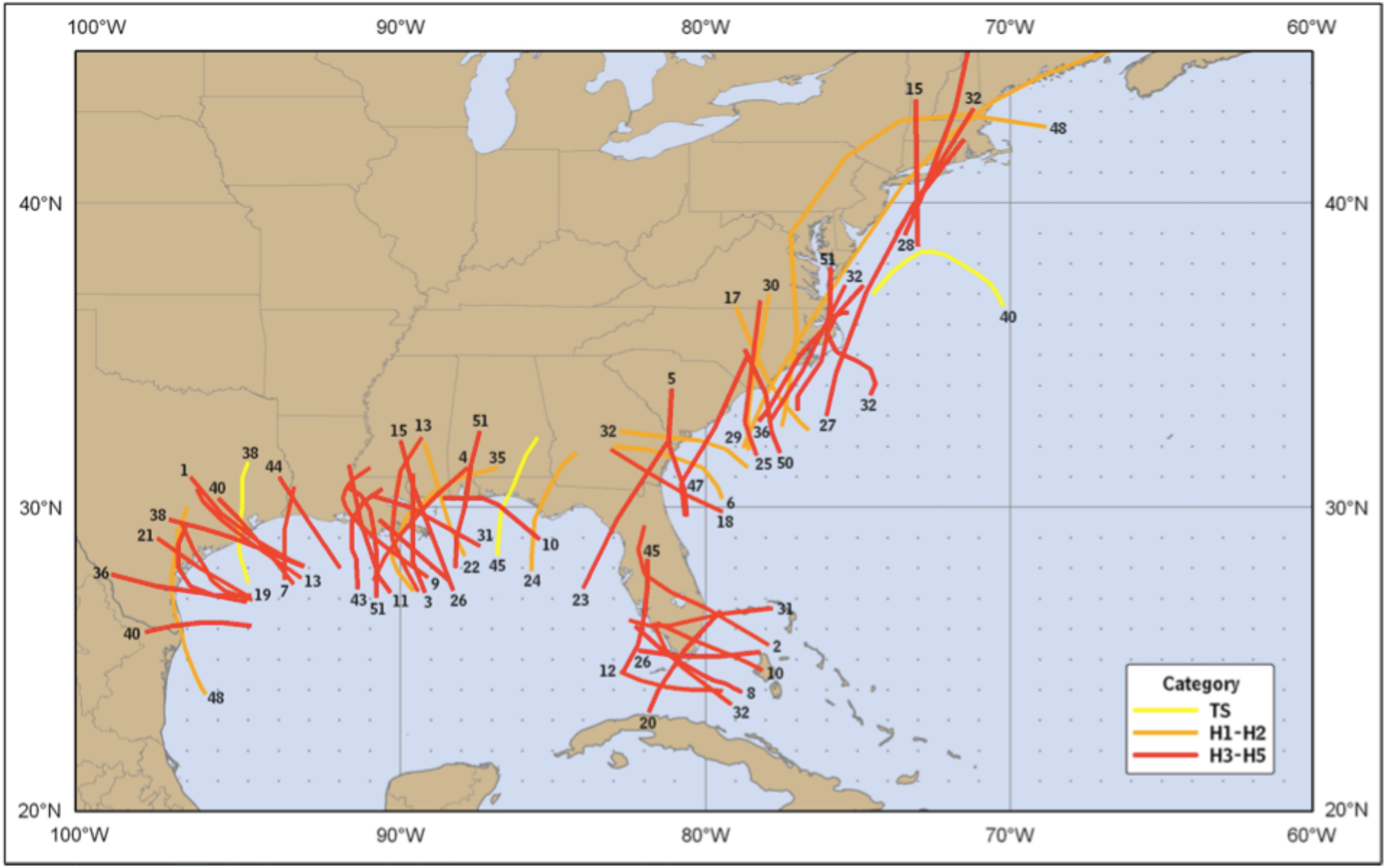


Figure 1. Mainland United States tropical cyclones causing 25 or more deaths, 1851-2010. The black numbers are the ranks of a given storm on Table 2 (e.g. 1 is the deadliest all-time). The colors are the intensity of the tropical cyclone at its maximum impact on the United States.

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

Table 3a. The 30 costliest mainland United States tropical cyclones, 1900-2010, (not adjusted for inflation).

RANK	TROPICAL CYCLONE	YEAR	CATEGORY	DAMAGE (U.S.)
1	*KATRINA* (SE FL, LA, MS)	2005	3	$108,000,000,000
2	*IKE (TX, LA)*	2008	2	29,520,000,000
3	*ANDREW* (SE FL/LA)	1992	5	26,500,000,000
4	*WILMA* (S FL)	2005	3	21,007,000,000
5	*IVAN* (AL/NW FL)	2004	3	18,820,000,000
6	*CHARLEY* (SW FL)	2004	4	15,113,000,000
7	*RITA* (SW LA, N TX)	2005	3	12,037,000,000
8	*FRANCES* (FL)	2004	2	9,507,000,000
9	*ALLISON* (N TX)	2001	TS	9,000,000,000
10	*JEANNE* (FL)	2004	3	7,660,000,000
11	*HUGO* (SC)	1989	4	7,000,000,000
12	*FLOYD* (Mid-Atlantic & NE U.S.)	1999	2	6,900,000,000
13	*ISABEL* (Mid-Atlantic)	2003	2	5,370,000,000
14	*OPAL* (NW FL/AL)	1995	3	5,142,000,000
15	*GUSTAV* (LA)	2008	2	4,618,000,000
16	*FRAN* (NC)	1996	3	4,160,000,000
17	*GEORGES* (FL Keys, MS, AL)	1998	2	2,765,000,000
18	*DENNIS (NW FL)*	2005	3	2,545,000,000
19	*FREDERIC (AL/MS)*	1979	3	2,300,000,000
20	*AGNES (FL/NE U.S.)*	1972	1	2,100,000,000
21	*ALICIA (N TX)*	1983	3	2,000,000,000
22	*BOB (NC, NE U.S)*	1991	2	1,500,000,000
22	*JUAN (LA)*	1985	1	1,500,000,000
24	*CAMILLE (MS/SE LA/VA)*	1969	5	1,420,700,000
25	*BETSY (SE FL/SE LA)*	1965	3	1,420,500,000
26	*ELENA (MS/AL/NW FL)*	1985	3	1,250,000,000
27	*DOLLY* (S TX)	2008	1	1,050,000,000
28	*CELIA (S TX)*	1970	3	930,000,000
29	*LILI* (SC LA)	2002	1	925,000,000
30	*GLORIA* (Eastern U.S.)	1985	3	900,000,000

ADDENDUM (Rank is independent of other events in group)

17	*GEORGES* (USVI,PR)	1998	3	3,600,000,000
22	*INIKI* (Kauai, HI)	1992	3	1,800,000,000
22	*MARILYN* (USVI, PR)	1995	2	1,500,000,000
28	*HUGO* (USVI, PR)	1989	4	1,000,000,000

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

Where, When, Why

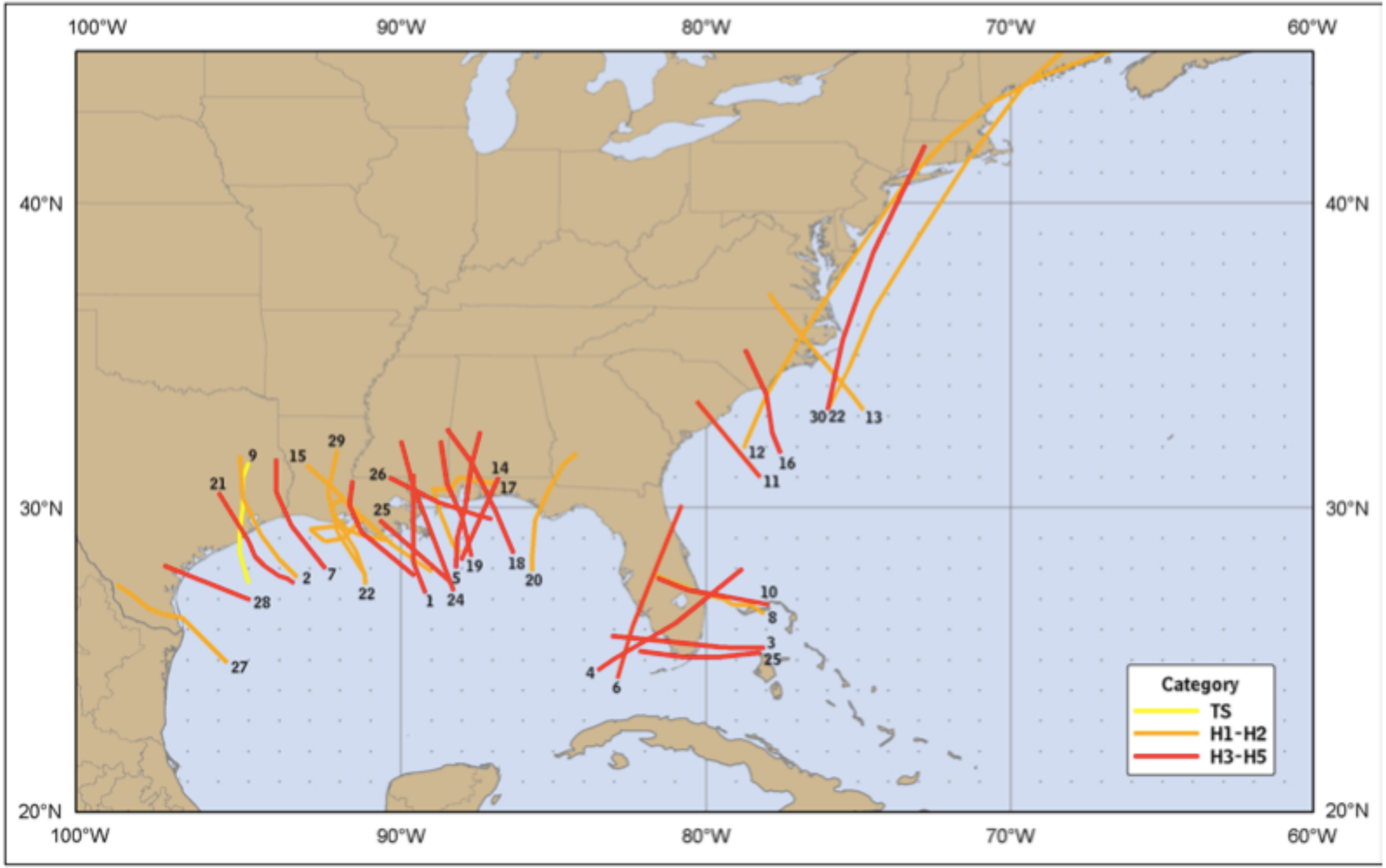


Figure 2. The 30 costliest tropical cyclones to strike the United States, 1900-2010. The black numbers are the ranks of a given storm on Table 3a (e.g. 1 is the costliest all-time). The colors are the intensity of the tropical cyclone at its maximum impact on the United States.

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

Where, When, Why

Table 3b. The 30 costliest mainland United States tropical cyclones, 1900-2010.

Ranked Using 2010 Deflator[*]

RANK	TROPICAL CYCLONE	YEAR	Category	Damage (Millions)[*]
1	*KATRINA* (LA/MS/FL)	2005	3	$105,840
2	*ANDREW* (SE FL/SE LA)	1992	5	45,561
3	*IKE (Upper TX/SW LA)*	2008	2	27,790
4	*WILMA* (SW/SE FL)	2005	3	20,587
5	*IVAN* (NW FL/AL)	2004	3	19,832
6	*CHARLEY* (SW FL)	2004	4	15,820
7	*HUGO* (SC)	1989	4	12,775
8	*RITA* (LA/TX/FL)	2005	3	11,797
9	*AGNES* (FL/NE U.S.)	1972	1	11,760
10	*BETSY* (SE FL/SE LA)	1965	3	11,227
11	*ALLISON* (N TX)	2001	TS	10,998
12	*FRANCES* (SE FL)	2004	2	10,018
13	*CAMILLE* (MS/SE LA/VA)	1969	5	9,282
14	*FLOYD* (Mid Atlc & NE U.S.)	1999	2	9,225
15	*JEANNE* (SE FL)	2004	3	8,072
16	*OPAL* (NW FL/AL)	1995	3	7,729
17	*DIANE* (NE U.S.)	1955	1	7,408
18	*FREDERIC* (AL/MS)	1979	3	6,571
19	New England	1938	3	6,325
20	*FRAN* (NC)	1996	3	6,140
21	*ISABEL* (NC/VA)	2003	2	6,112
22	CELIA (S TX)	1970	3	5,918
23	NE U.S.	1944	3	5,706
24	*ALICIA* (N TX)	1983	3	4,569
25	*GUSTAV (LA)*	2008	2	4,347
26	*CAROL* (NE U.S.)	1954	3	4,175
27	*GEORGES (FL, LA, MS)*	1998	2	3,860
28	*JUAN* (LA)	1985	1	3,238
29	*DONNA* (FL/Eastern U.S.)	1960	4	3,215
30	*BOB* (NC, NE U.S)	1991	2	2,703
ADDENDUM				
30	*INIKI* (Kauai, HI)	1992	4	3,095
30+	*GEORGES* (USVI,PR)	1998	3	2,513
30+	*MARILYN* (USVI,E. PR)	1995	2	2,255
30+	*HUGO* (USVI, PR)	1989	4	1,825
30+	San Felipe (PR)	1928	5	1,757

Ranked Using 2010 Inflation, Population and Wealth Normalization[L]

RANK	TROPICAL CYCLONE	YEAR	Category	Damage (Millions)[L]
1	SE Florida/Alabama	1926	4	$164,839
2	KATRINA (SE LA, MS, AL)	2005	3	113,400
3	N Texas (Galveston)	1900	4	104,330
4	N Texas (Galveston)	1915	4	71,397 [†]
5	ANDREW (SE FL/LA)	1992	5	58,555
6	New England	1938	3	41,122
7	SW Florida	1944	3	40,621
8	SE Florida/Lake Okeechobee	1928	4	35,298
9	IKE (N TX/SW LA)	2008	2	29,520
10	DONNA (FL/Eastern U.S.)	1960	4	28,159
11	CAMILLE (MS/LA/VA)	1969	5	22,286
12	WILMA (S FL)	2005	3	22,057
13	IVAN (NW FL, AL)	2004	3	21,575
14	BETSY (SE FL/LA)	1965	3	18,749
15	DIANE (NE U.S.)	1955	1	18,073
16	AGNES (NW FL, NE U.S.)	1972	1	18,052
17	HAZEL (SC/NC)	1954	4	17,339
18	CHARLEY (SW FL)	2004	4	17,210
19	CAROL (NE U.S.)	1954	3	16,940
20	HUGO (SC)	1989	4	16,088
21	SE Florida	1949	3	15,398
22	CARLA (N & Central TX)	1961	4	14,920
23	SE Florida/Louisiana/Alabama	1947	4	14,406
24	NE U.S.	1944	3	13,881
25	SE FL/S TX	1919	4	13,847
26	SE Florida	1945	3	12,956
27	RITA (SW LA/N TX)	2005	3	12,639
28	ALLISON (N TX)	2001	TS	12,523
29	CELIA (S TX)	1970	3	12,104
30	FRANCES (SE FL)	2004	2	10,899

notes

[*] based on U.S. Census Bureau Price Deflator (Fisher) for Construction.

[†] Damage estimate in 1915 reference is considered too high

[L] 'Normalization reflects inflation, changes in personal wealth and coastal county population to 2005, (Pielke et al. 2007) then including an estimate to 2010 dollars.

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

Where, Whe

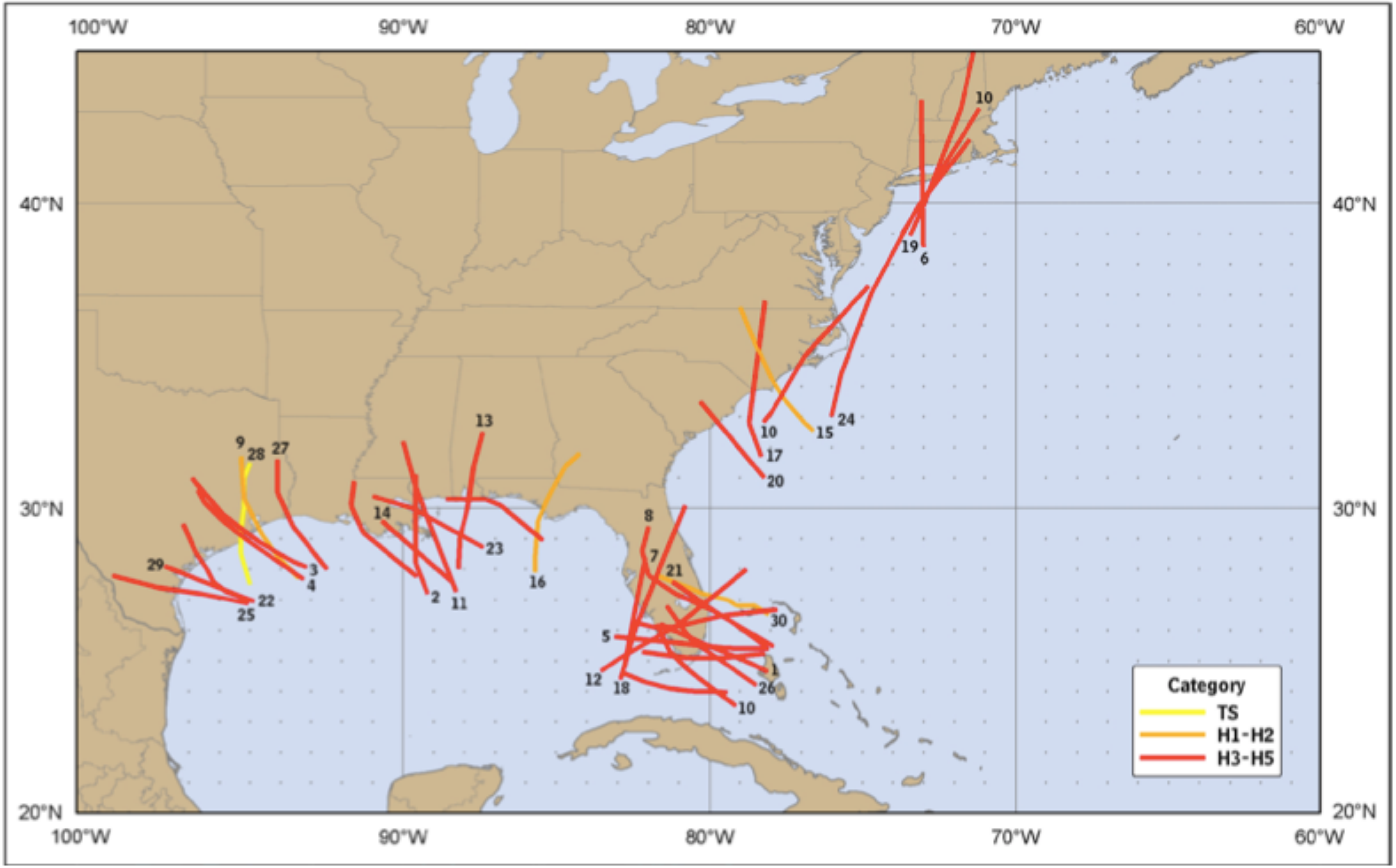


Figure 3. The 30 costliest United States tropical cyclones, ranked by normalization for inflation, population and wealth, 1900-2010. The black numbers are the ranks of a given storm on the right side of Table 3b.The colors are the intensity of the cyclone at its impact on the U.S. Coast.

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

Where, Wher

Table 4. The most intense mainland United States hurricanes ranked by pressure, 1851-2010 (includes only major hurricanes at their most intense landfall).

RANK	HURRICANE	YEAR	CATEGORY (at landfall)	MINIMUM PRESSURE Millibars	MINIMUM PRESSURE Inches
1	FL (Keys)	1935	5	892	26.35
2	*CAMILLE (MS/SE LA/VA)*	1969	5	909	26.84
3	*KATRINA (SE LA, MS)*	2005	3	920	27.17
4	*ANDREW (SE FL/SE LA)*	1992	5	922	27.23
5	*TX (Indianola)*	1886	4	925	27.31
6	FL (Keys)/S TX	1919	4	927	27.37
7	FL (Lake Okeechobee)	1928	4	929	27.43
8	*DONNA (FL/Eastern U.S.)*	1960	4	930	27.46
8	FL (Miami)/MS/AL/Pensacola	1926	4	930	27.46
10	*CARLA (N & Central TX)*	1961	4	931	27.49
11	S TX	1916	4	932	27.52
12	LA (Last Island)	1856	4	934	27.58
12	*HUGO (SC)*	1989	4	934	27.58
14	TX (Galveston)	1900	4	936	27.64
15	*RITA (SW LA/N TX)*	2005	3	937	27.67
16	GA/FL (Brunswick)	1898	4	938	27.70
16	*HAZEL (SC/NC)*	1954	4	938	27.70
18	SE FL/SE LA/MS	1947	4	940	27.76
18	TX (Galveston)	1915	4	940	27.76
20	N TX	1932	4	941	27.79
20	*CHARLEY (SW FL)*	2004	4	941	27.79
22	*GLORIA (Eastern U.S.)*	1985	3	942	27.82
22	*OPAL (NW FL/AL)*	1995	3	942	27.82
24	LA (New Orleans)	1915	3	944	27.88
25	FL (Central)	1888	3	945	27.91
25	E NC	1899	3	945	27.91
25	*AUDREY (SW LA/N TX)*	1957	4	945	27.91
25	*CELIA (S TX)*	1970	3	945	27.91
25	*ALLEN (S TX)*	1980	3	945	27.91
30	New England	1938	3	946	27.94
30	*FREDERIC (AL/MS)*	1979	3	946	27.94
30	*IVAN (AL, NW FL)*	2004	3	946	27.94
30	*DENNIS (NW FL)*	2005	3	946	27.94
34	NE U.S.	1944	3	947	27.97
35	LA (Chenier Caminanda)	1893	4	948	27.99
35	*BETSY (SE FL/SE LA)*	1965	3	948	27.99

RANK	ADDENDUM	YEAR	CATEGORY (at landfall)	MINIMUM PRESSURE Millibars	MINIMUM PRESSURE Inches
5	*DAVID* (S of PR)	1979	4	924	27.29
10	San Felipe (PR)	1928	5	931	27.49
18	*HUGO* (USVI & PR)	1989	4	940	27.76
43	*INIKI* (KAUAI, HI)	1992	3	950	27.91
65	*DOT* (KAUAI, HI)	1959	3	955	28.11

RANK	HURRICANE	YEAR	CATEGORY (at landfall)	MINIMUM PRESSURE Millibars	MINIMUM PRESSURE Inches
35	SE FL/NW FL	1929	3	948	27.99
35	SE FL	1933	3	948	27.99
39	NW FL	1917	3	949	28.02
39	NW FL	1882	3	949	28.02
39	*DIANA (NC)*	1984	3	949	28.02
39	S TX	1933	3	949	28.02
43	MS/AL	1916	3	950	28.05
43	GA/SC	1854	3	950	28.05
43	LA/MS	1855	3	950	28.05
43	LA/MS/AL	1860	3	950	28.05
43	LA	1879	3	950	28.05
43	*BEULAH (S TX)*	1967	3	950	28.05
43	*HILDA (Central LA)*	1964	3	950	28.05
43	*GRACIE (SC)*	1959	3	950	28.05
43	TX (Central)	1942	3	950	28.05
43	*JEANNE (FL)*	2004	3	950	28.05
43	*WILMA (S FL)*	2005	3	950	28.05
54	SE FL	1945	3	951	28.08
54	*BRET (S TX)*	1999	3	951	28.08
56	LA (Grand Isle)	1909	3	952	28.11
56	FL (Tampa Bay)	1921	3	952	28.11
56	*CARMEN (Central LA)*	1974	3	952	28.11
59	SC/NC	1885	3	953	28.14
59	S FL	1906	3	953	28.14
61	GA/SC	1893	3	954	28.17
61	*EDNA (New England)*	1954	3	954	28.17
61	SE FL	1949	3	954	28.17
61	*FRAN (NC)*	1996	3	954	28.17
65	SE FL	1871	3	955	28.20
65	LA/TX	1886	3	955	28.20
65	SC/NC	1893	3	955	28.20
65	NW FL	1894	3	955	28.20
65	*ELOISE (NW FL)*	1975	3	955	28.20
65	*KING (SE FL)*	1950	3	955	28.20
65	Central LA	1926	3	955	28.20
65	SW LA	1918	3	955	28.20

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Where, When,

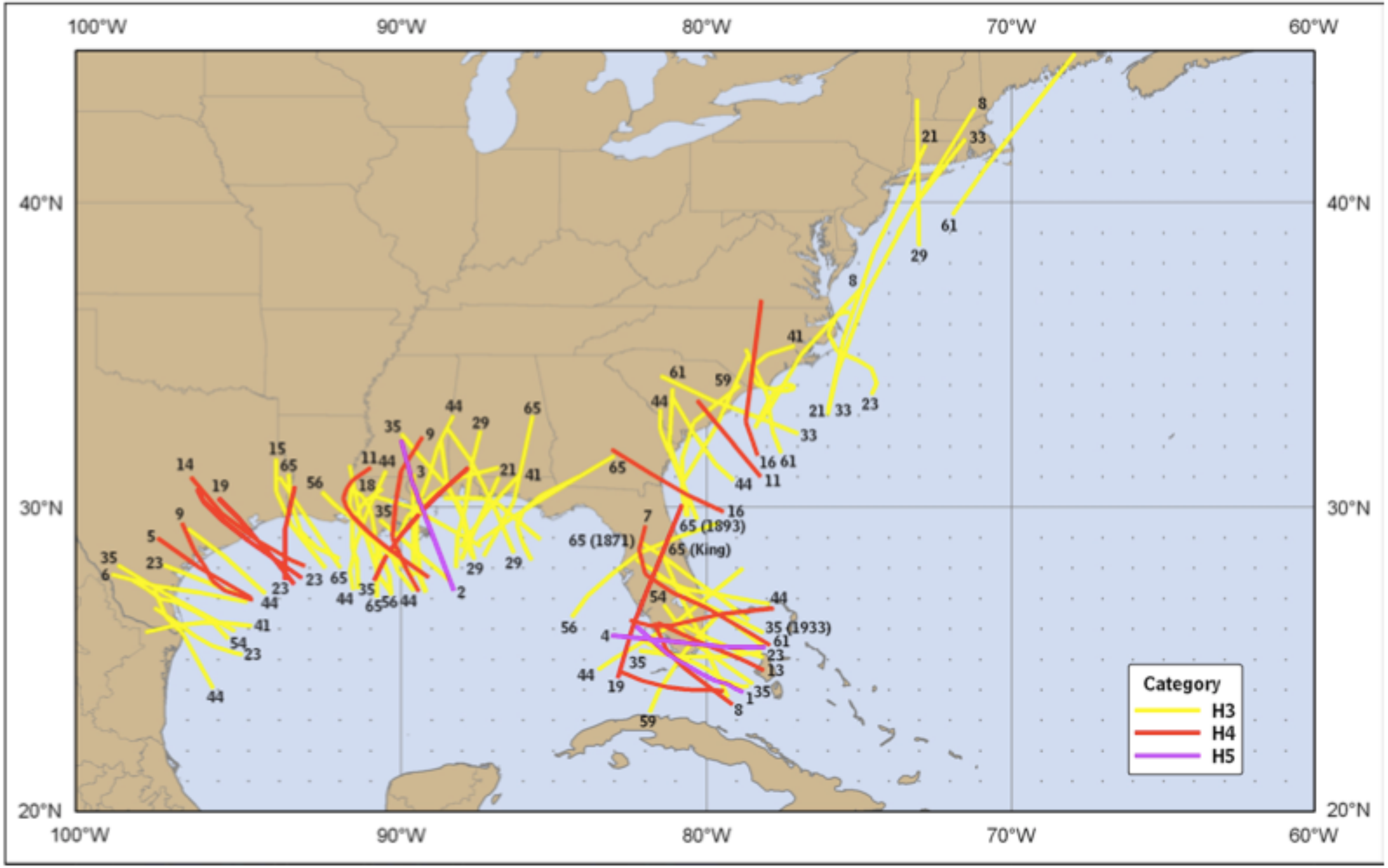

Figure 4. The most intense United States major hurricanes, ranked by pressure at landfall, 1851-2010. The black numbers are the ranks of a given storm on Table 4 (e.g. 1 has the lowest pressure all-time). The colors are the intensity of the tropical cyclone at its maximum impact on the United States.

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Where, When, Why

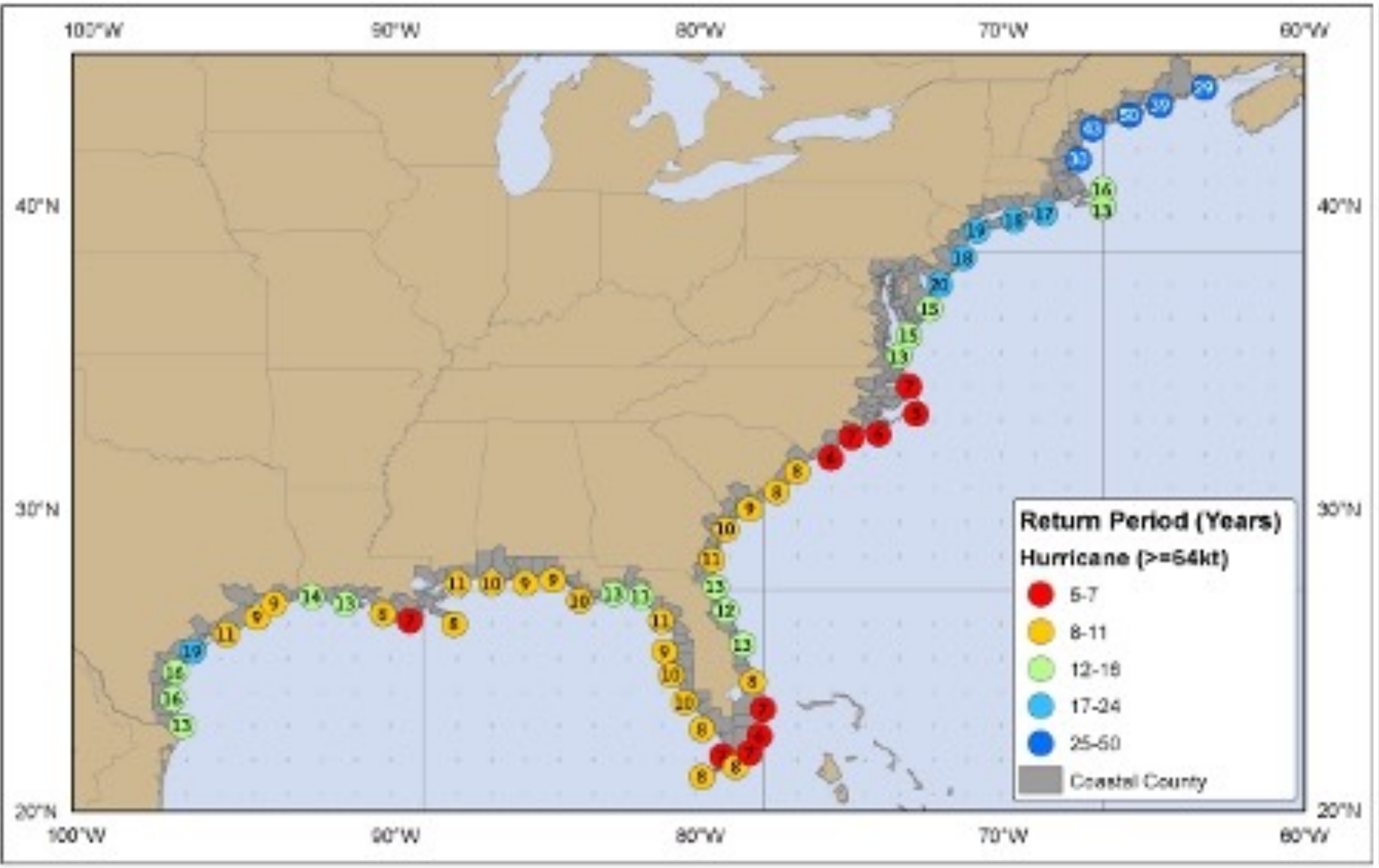
Table 14. Deadliest & Costliest Tropical Cyclones (1900-2010) for Hawaii, Puerto Rico and the U.S. Virgin Islands.

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

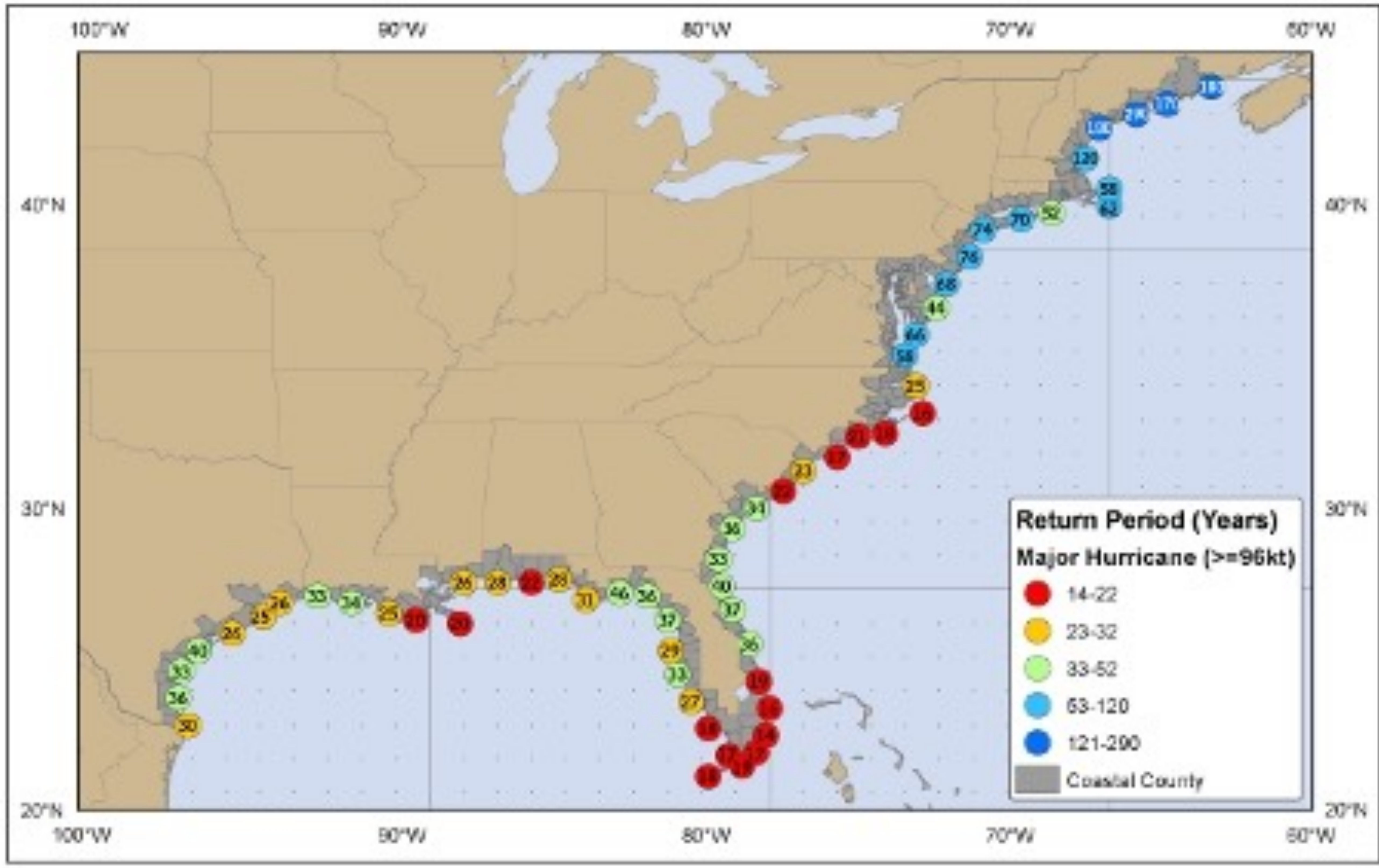
[1] Effects continued into the following day. [2] Damage and Casualties from David and Frederic are combined.
[3] Adjusted to 2010 dollars based on U.S. Census Bureau Price Deflator (Fisher) Index for Construction

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/

Where, When, Why

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

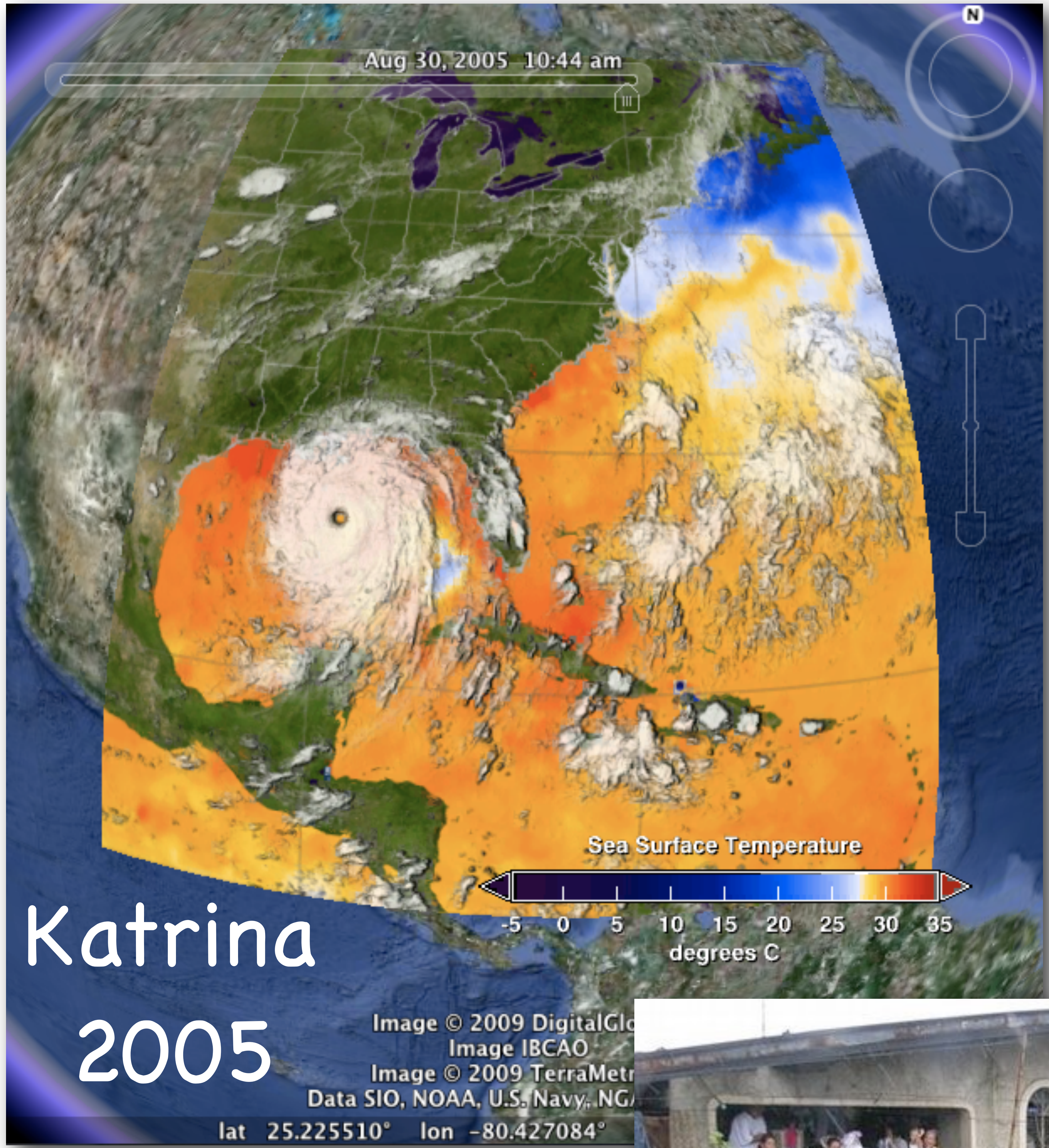
http://www.nhc.noaa.gov/pdf/nws-nhc-6.pdf

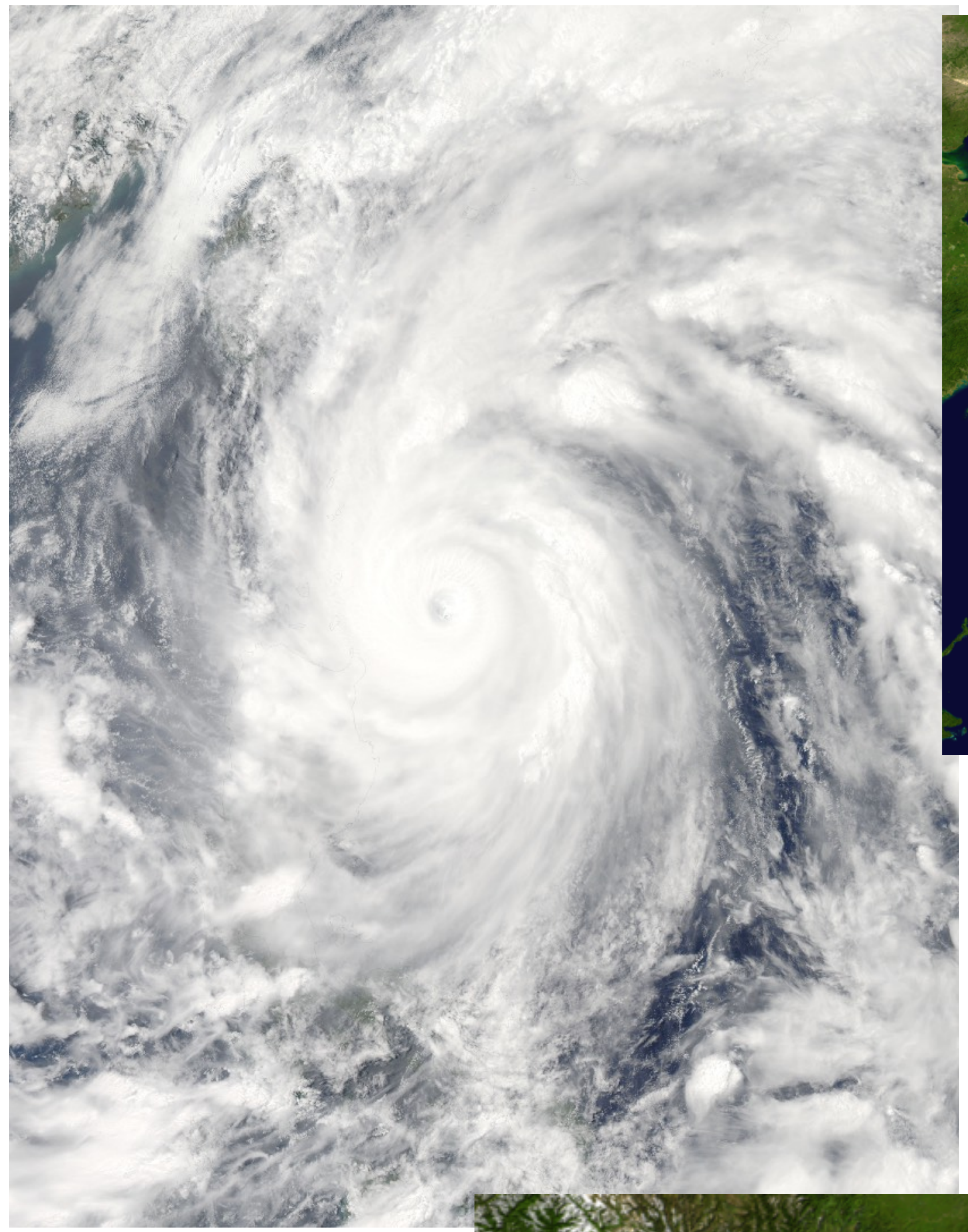
Natural Hazards and Disaster

Class 9: Hurricanes, Typhoons, Cyclones

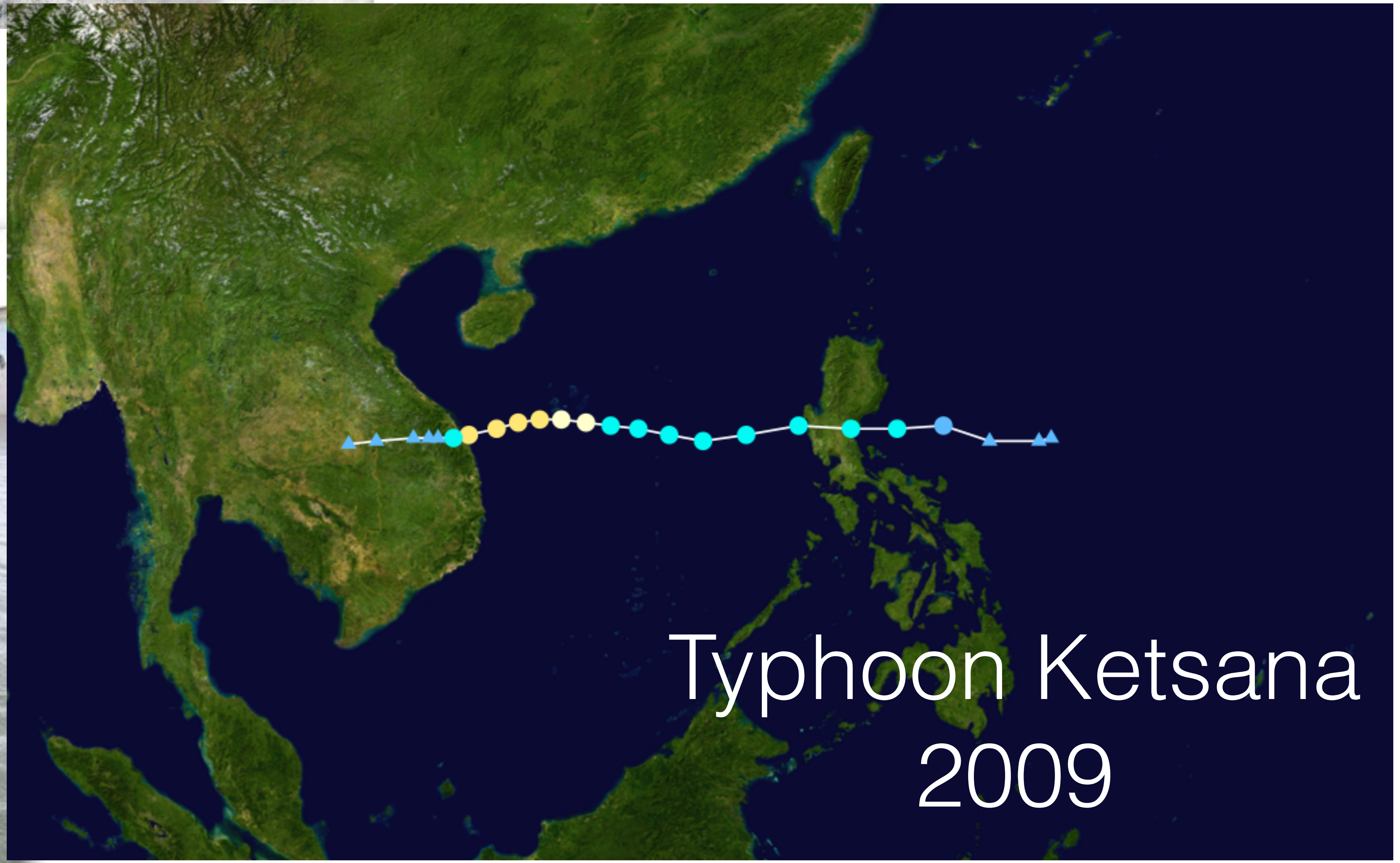
- Definitions, Scales
- Basics
- El Niño - La Niña
- Data Sources
- Where, When, Why
- Cases
- Climate Change Impacts

Cases



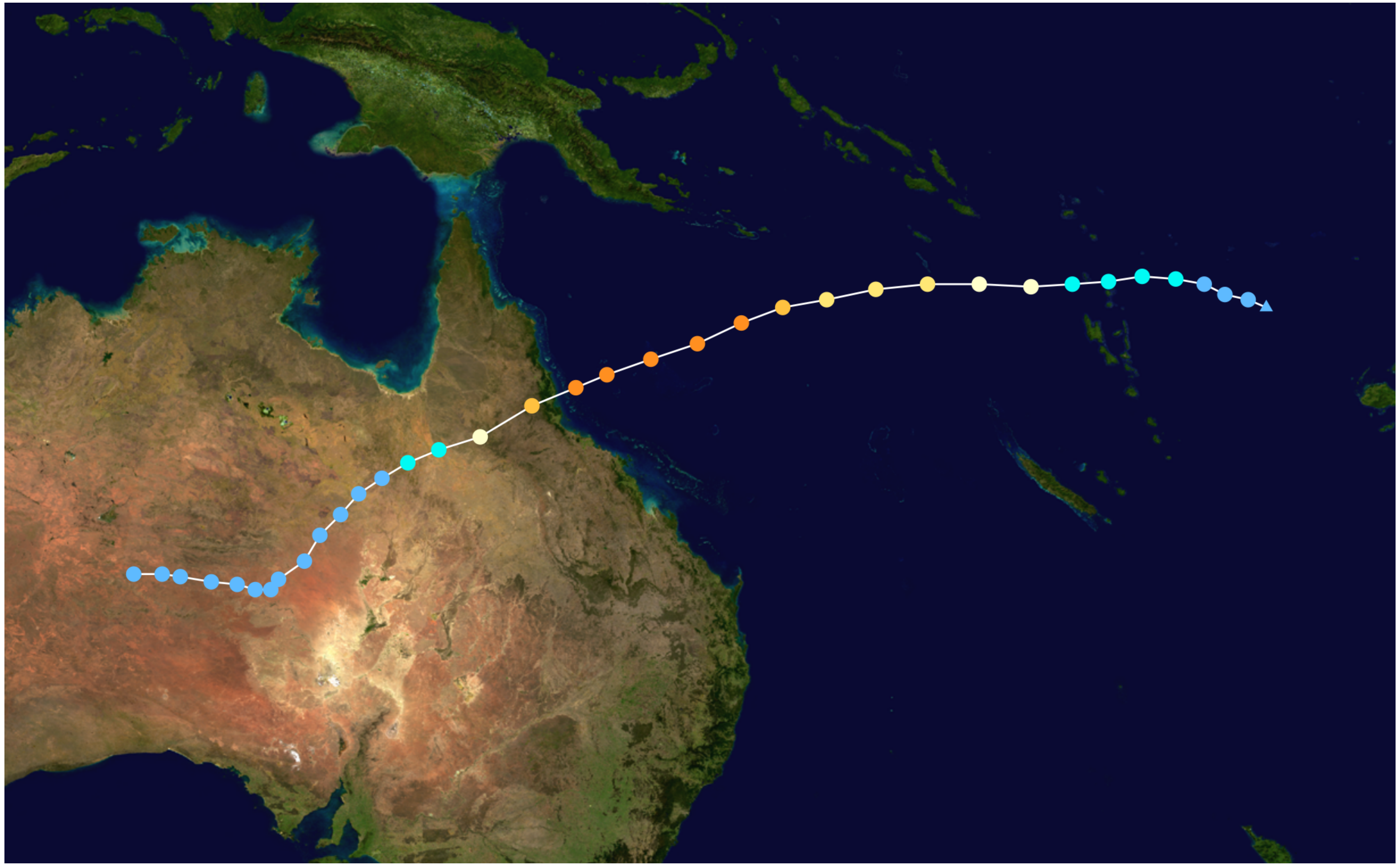


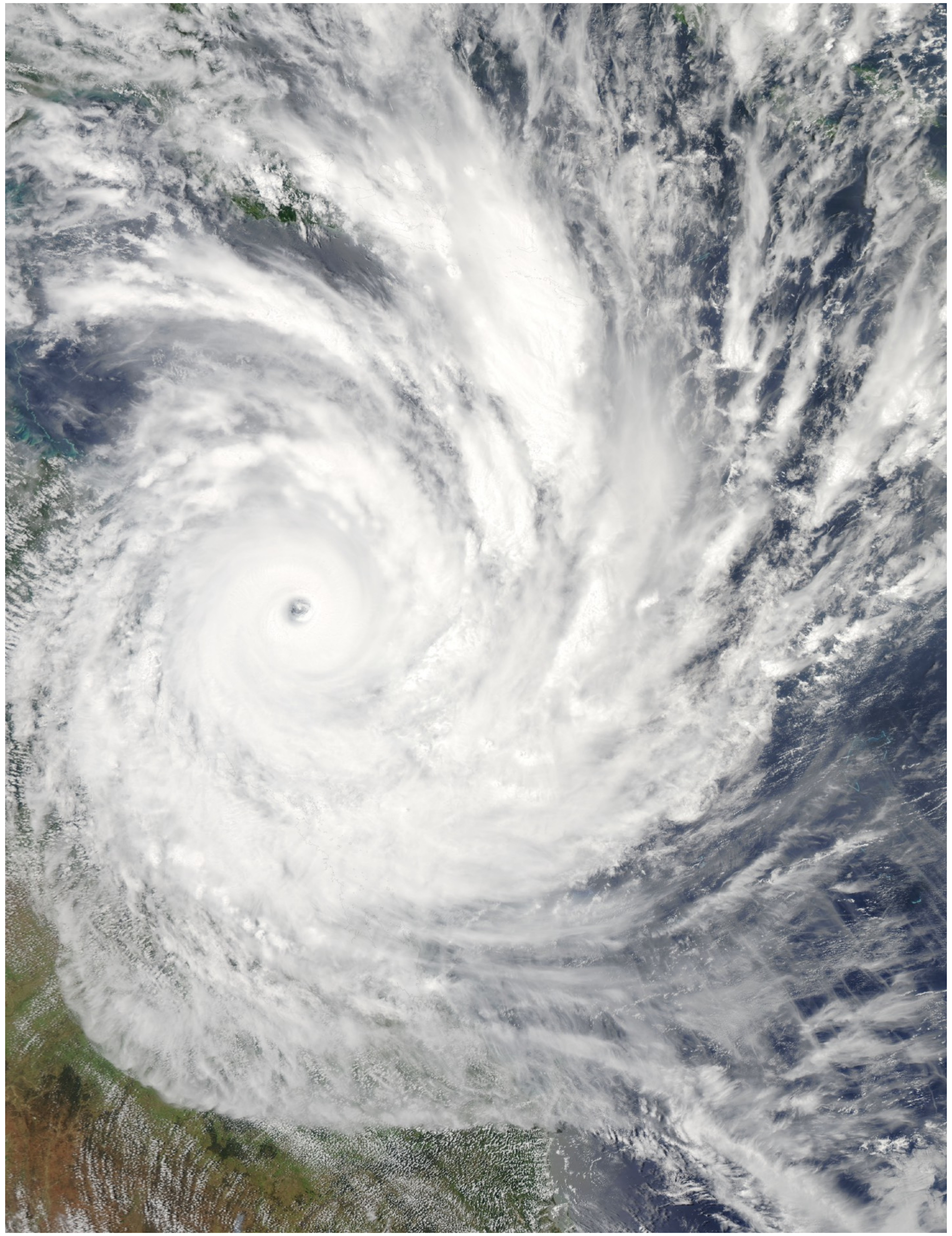
Typhoon Songda "Chedeng": Public Storm Warning Signal Number One areas in yellow, Signal Number Two areas in pink.



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





Cases

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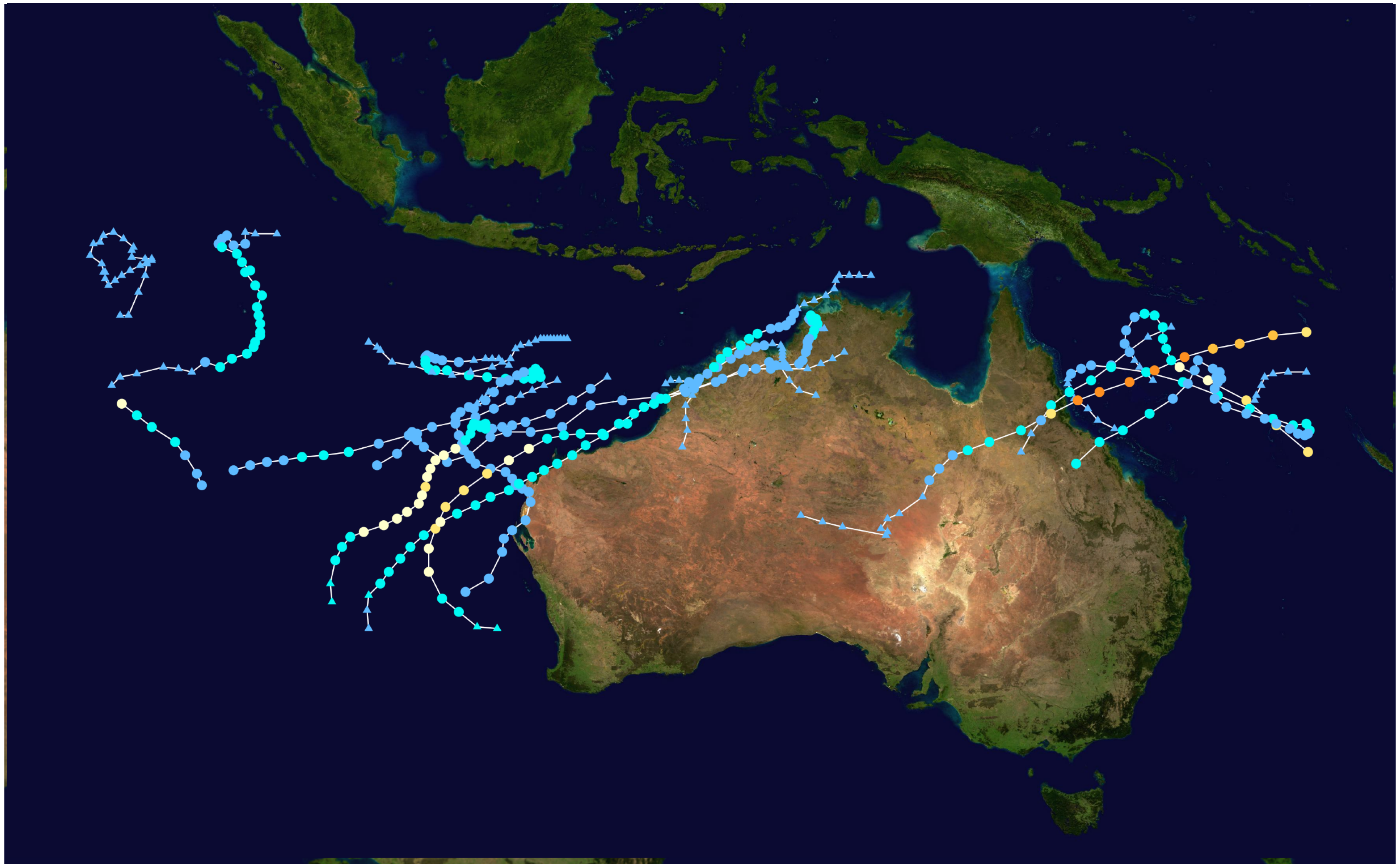
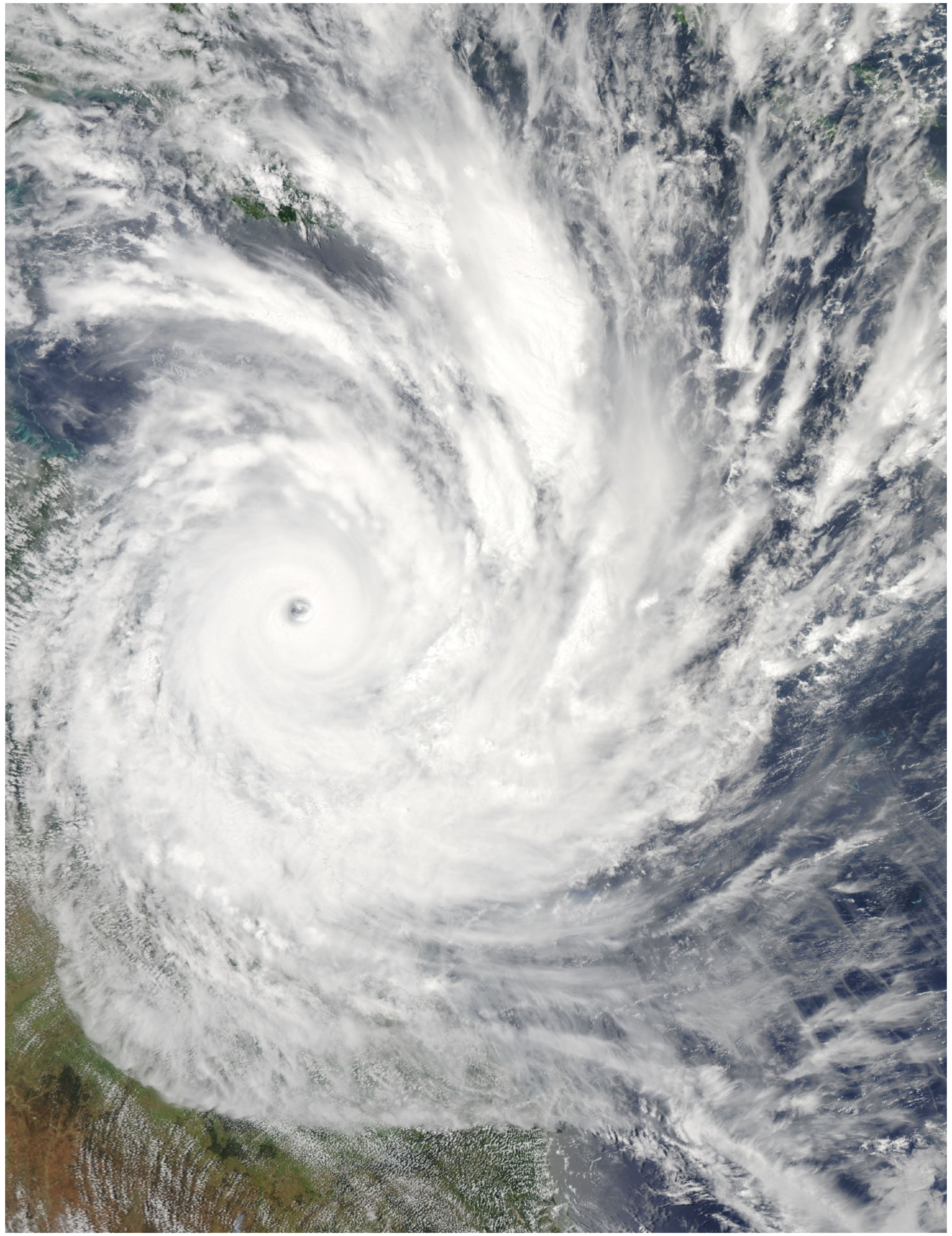
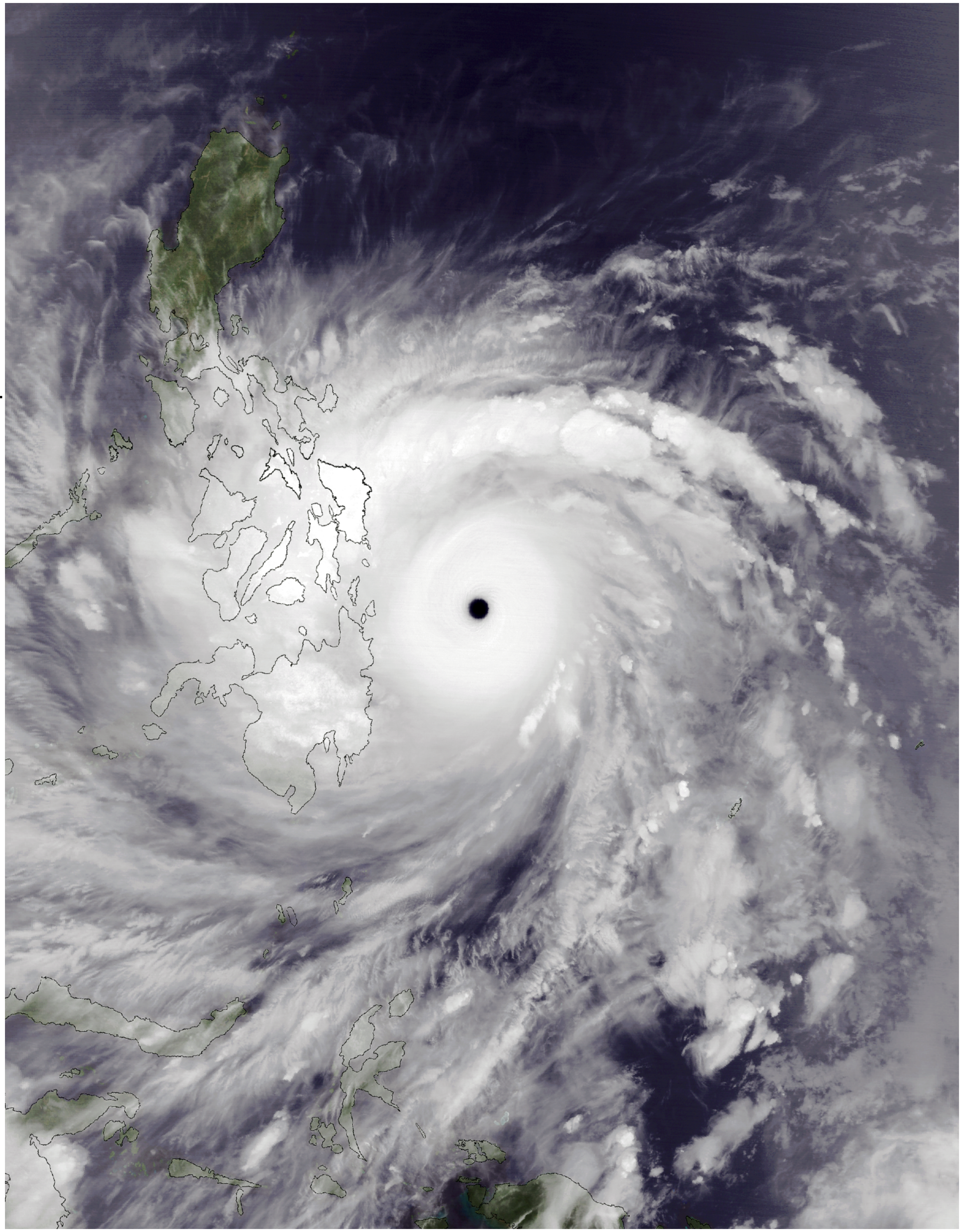




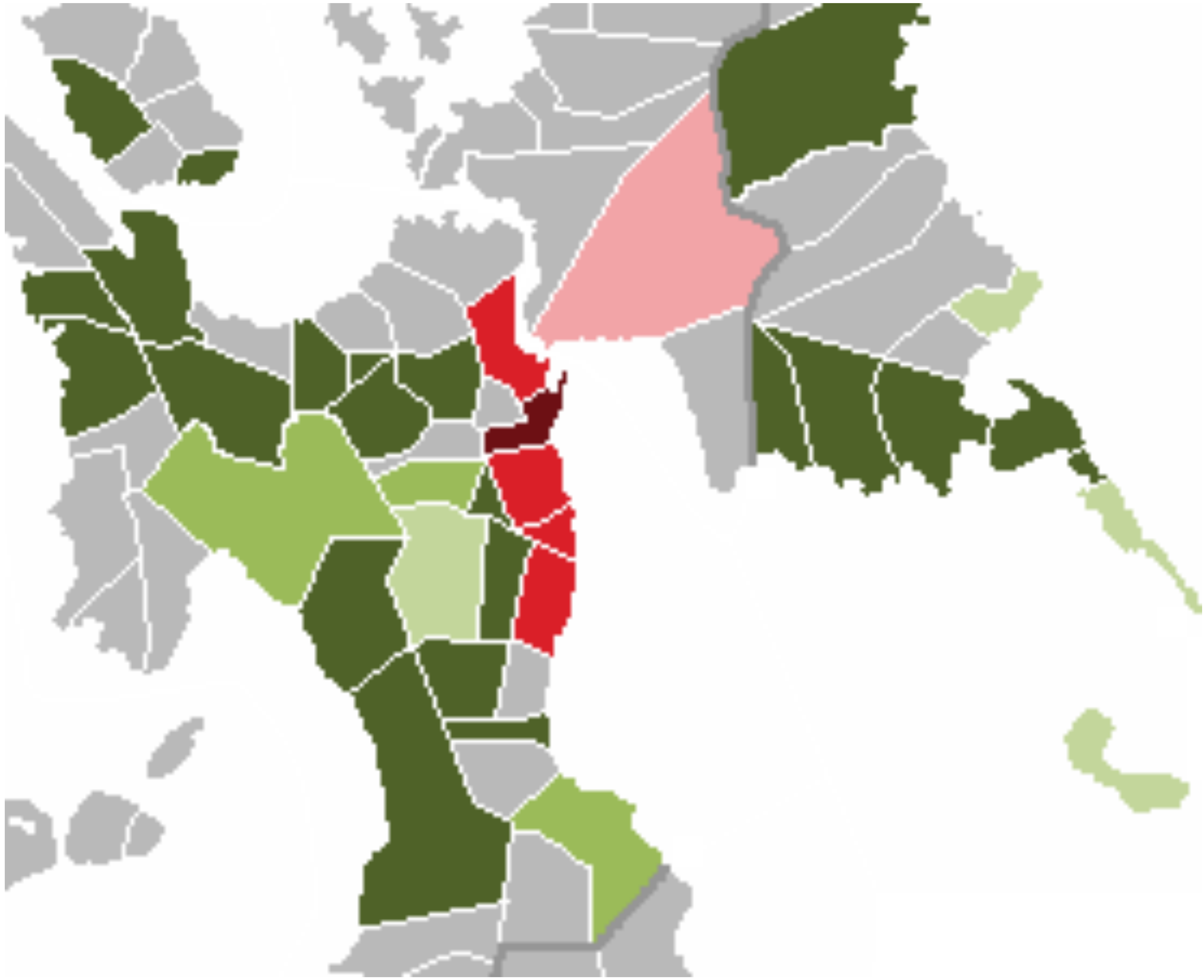
Cases

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

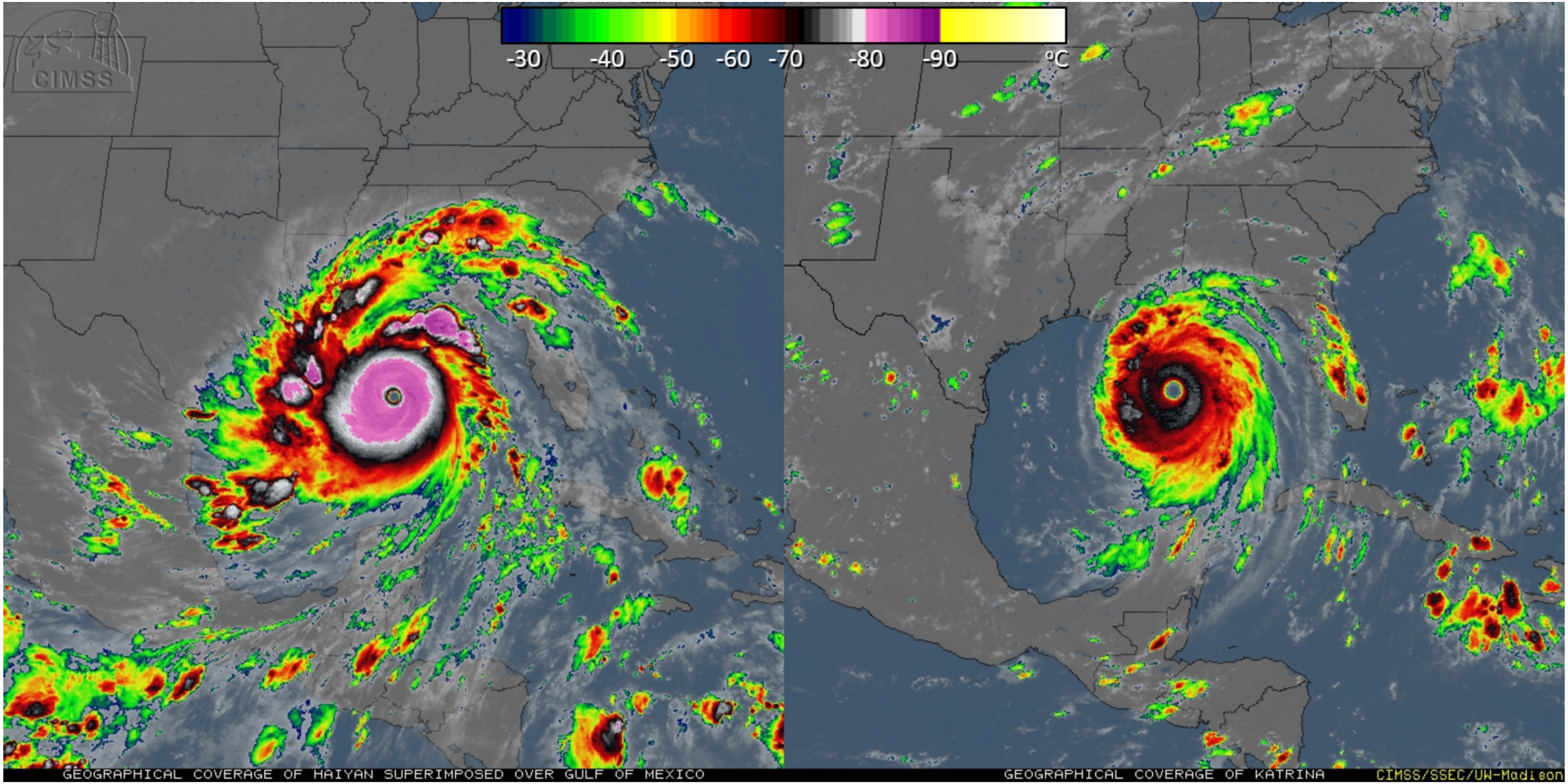


Cases

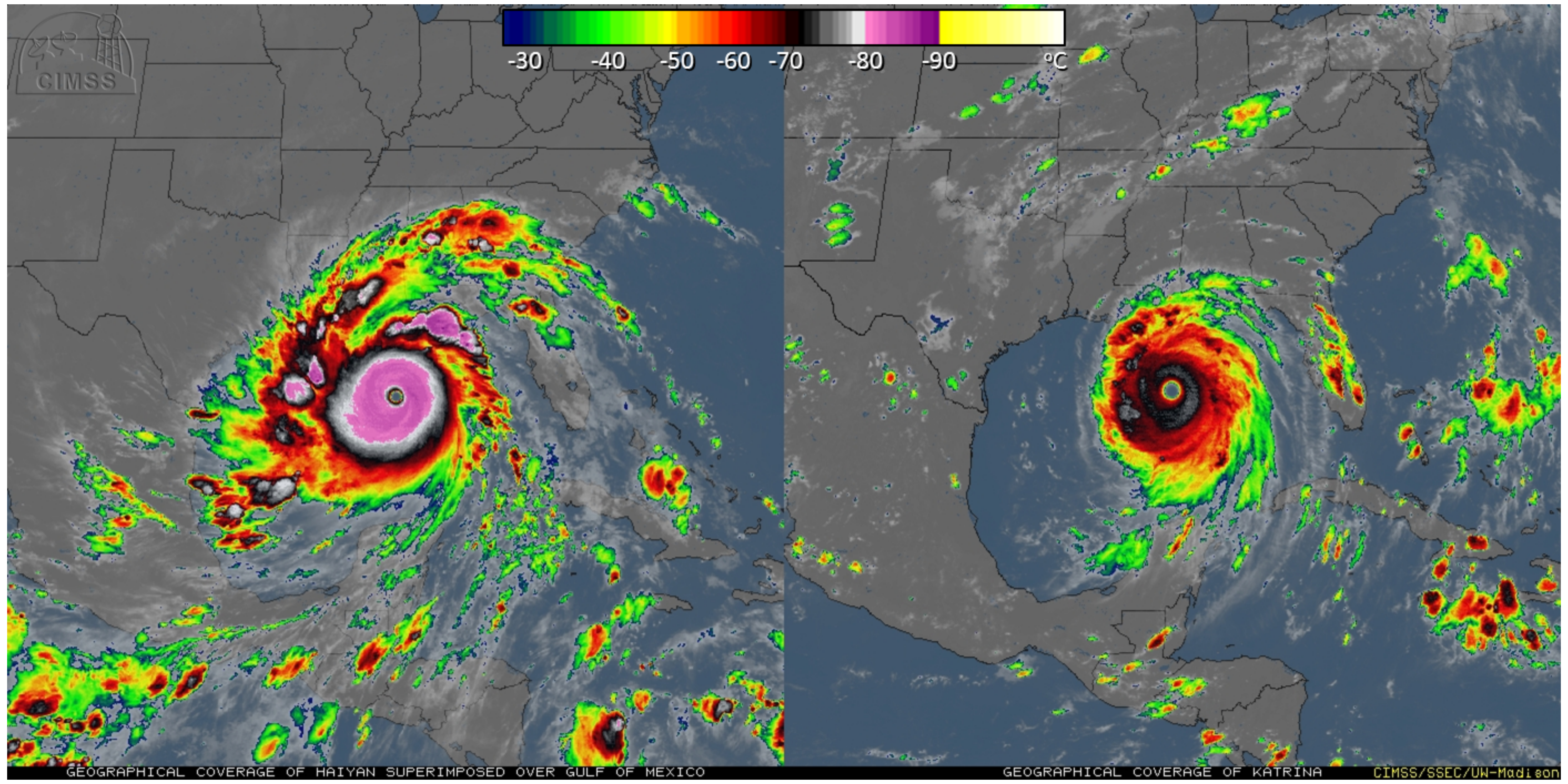


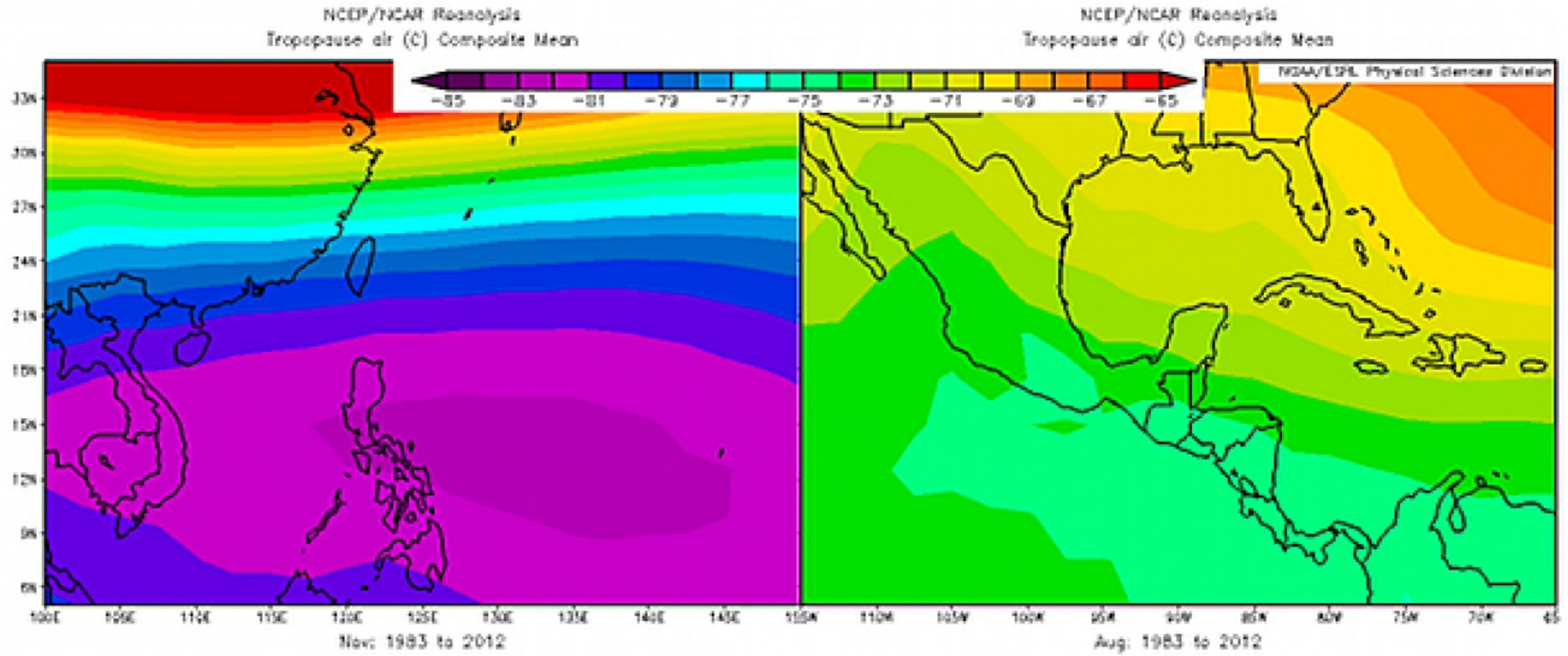
Color coded map of Eastern Visayas showing the number of deaths caused by Typhoon Haiyan. More than 1,000 500-999 100-499 50-99 25-49 1-24 0

Comparison of Katrina and Haiyan



Comparison of Katrina and Haiyan

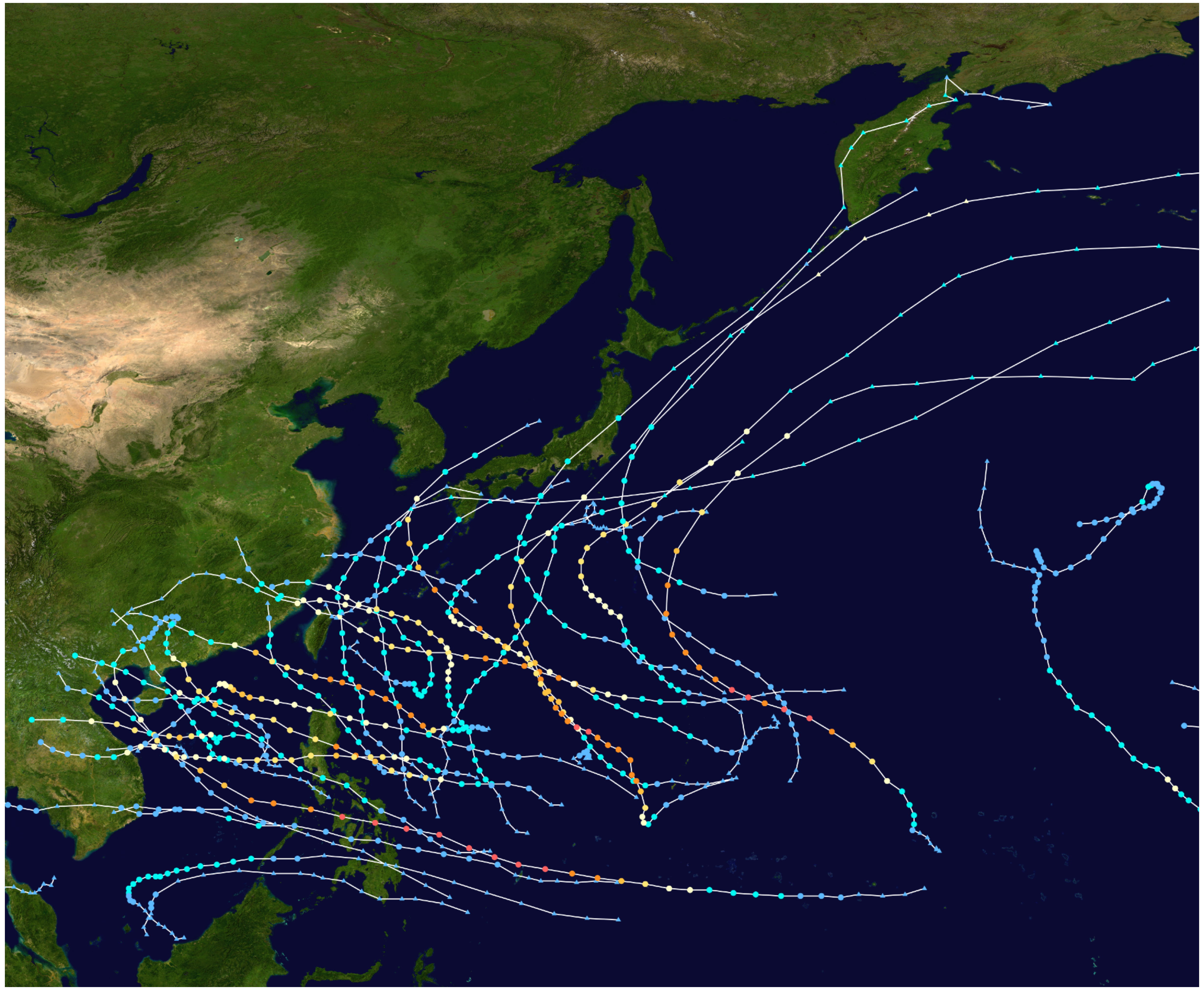


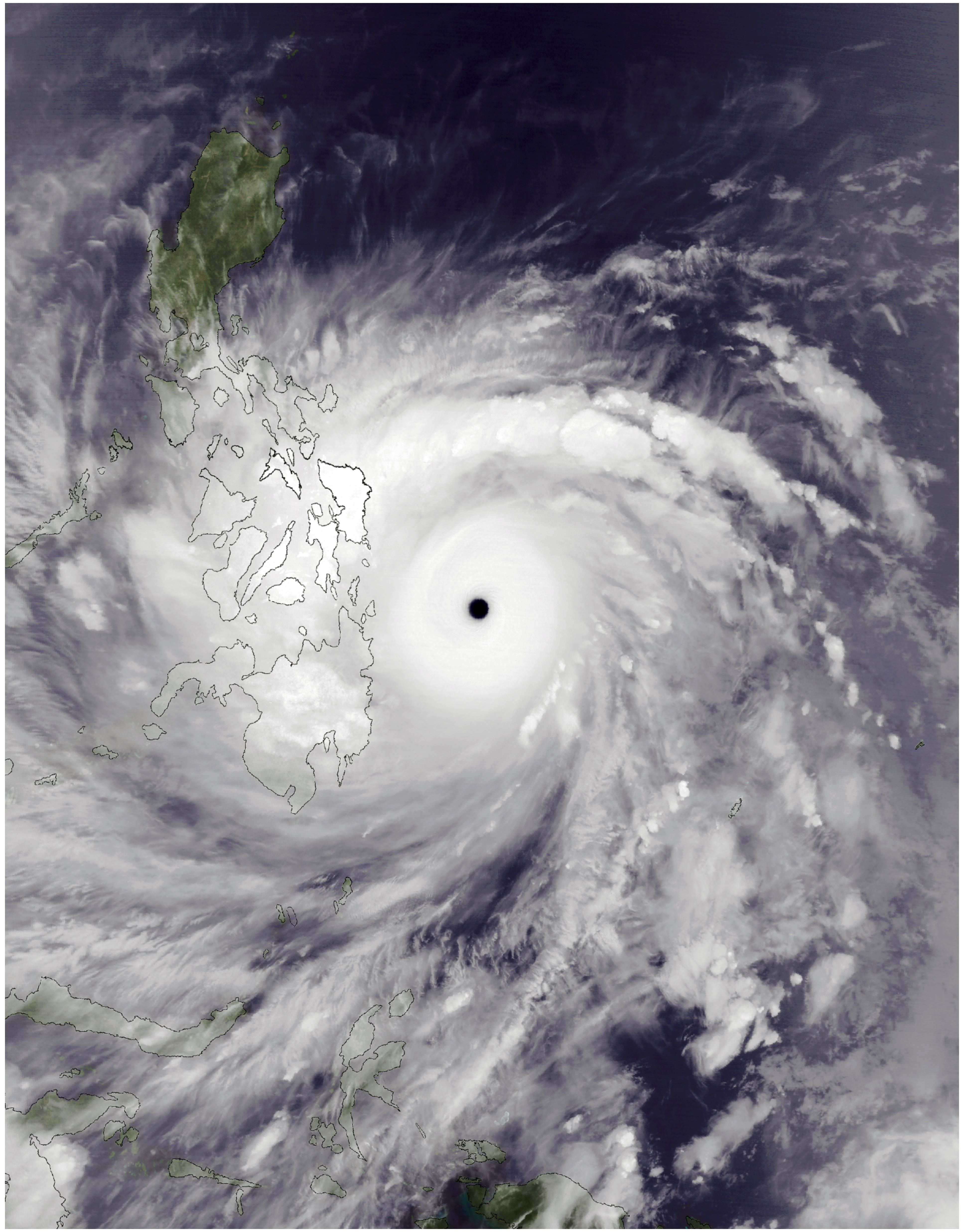


Haiyan (left) was more intense than Katrina (right) at its peak. The ring of clouds over the eyewall is much colder and thicker in Haiyan. While both storms were over very warm water – around 30°C, the tropopause is higher and colder in the western tropical Pacific than it is in the tropical Atlantic,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

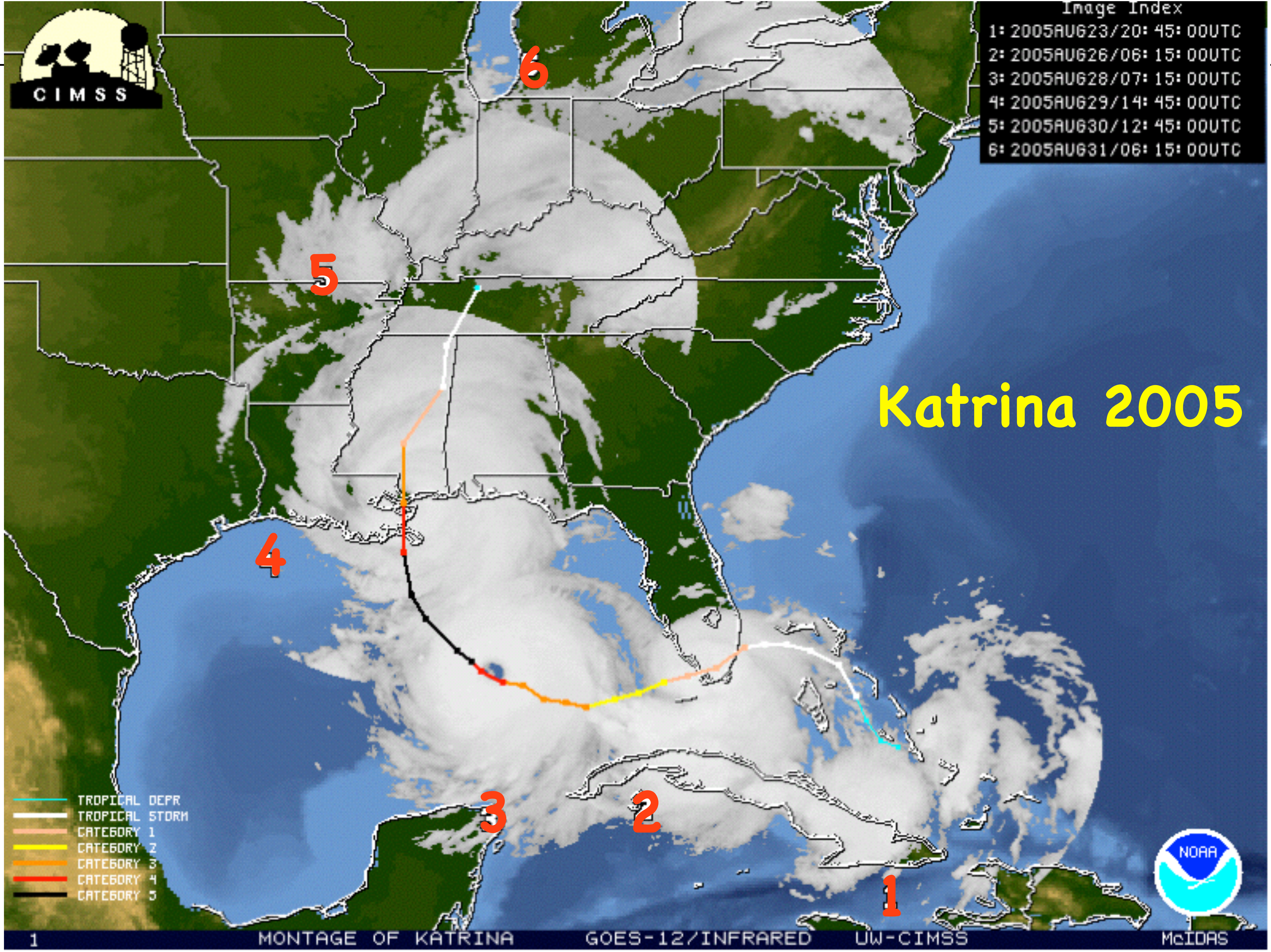
Cases

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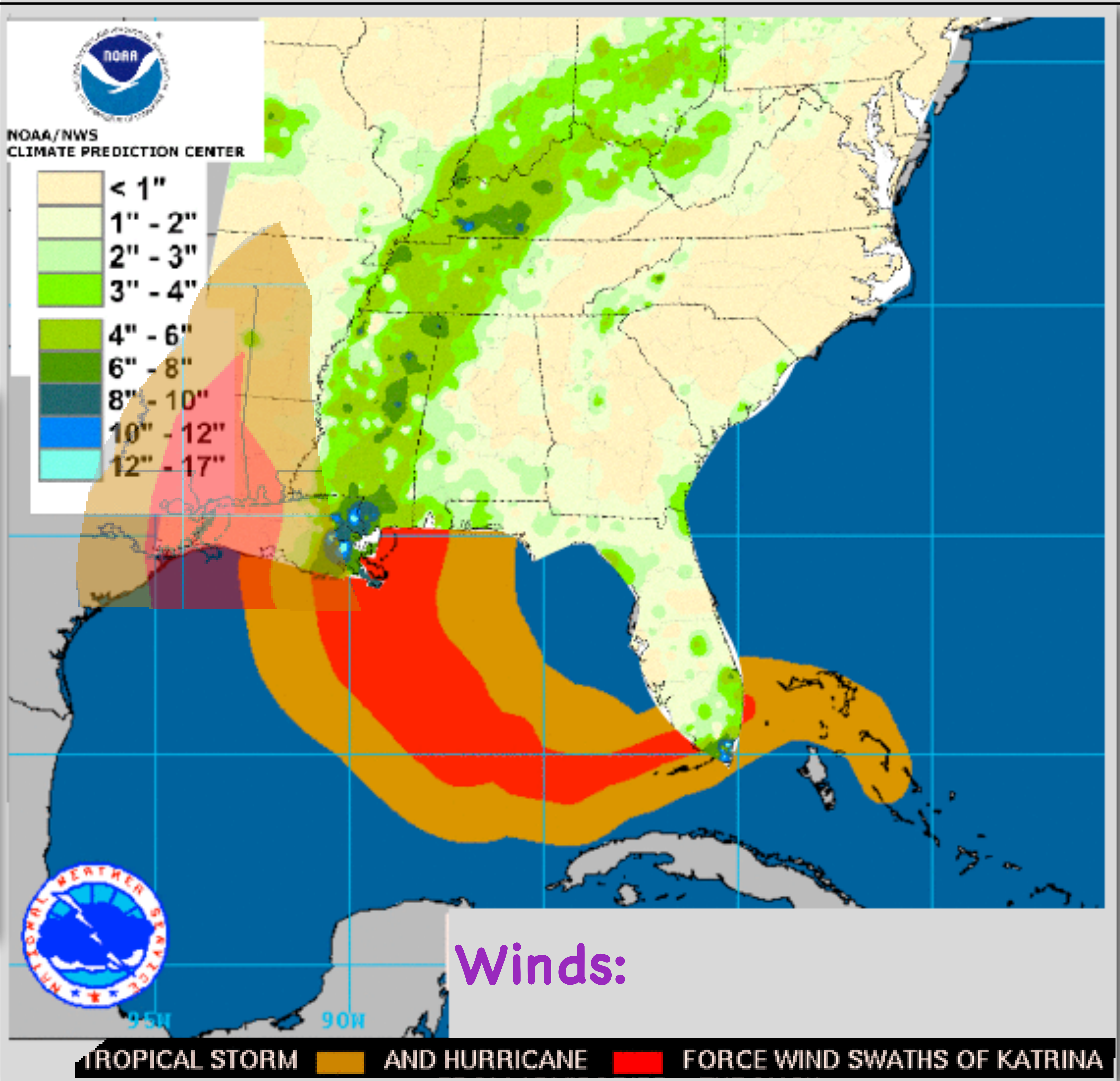
1 MONTAGE OF KATRINA GOES-12/INFRARED UW-CIMSS McIDAS

Cases

Rain:



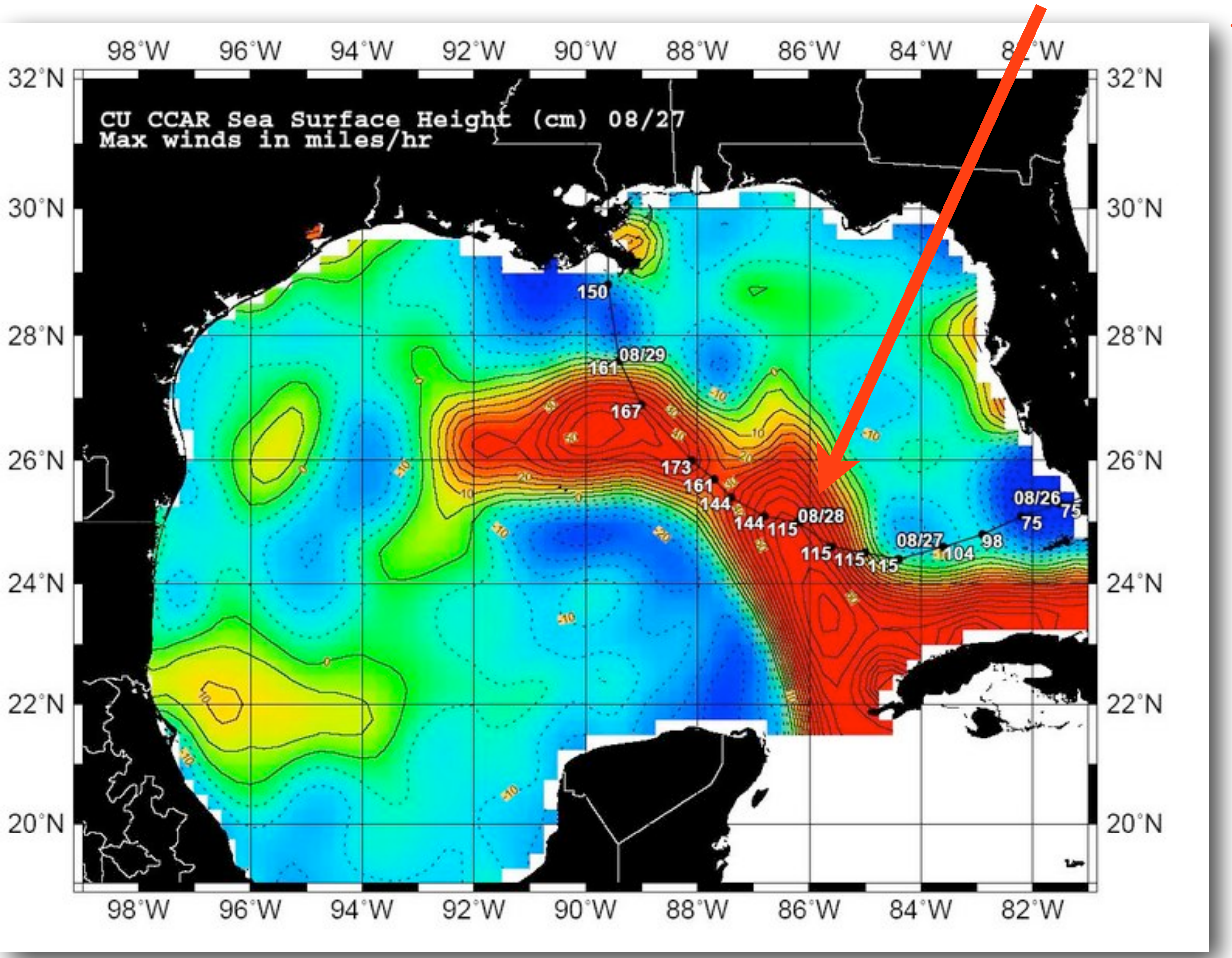
Winds:

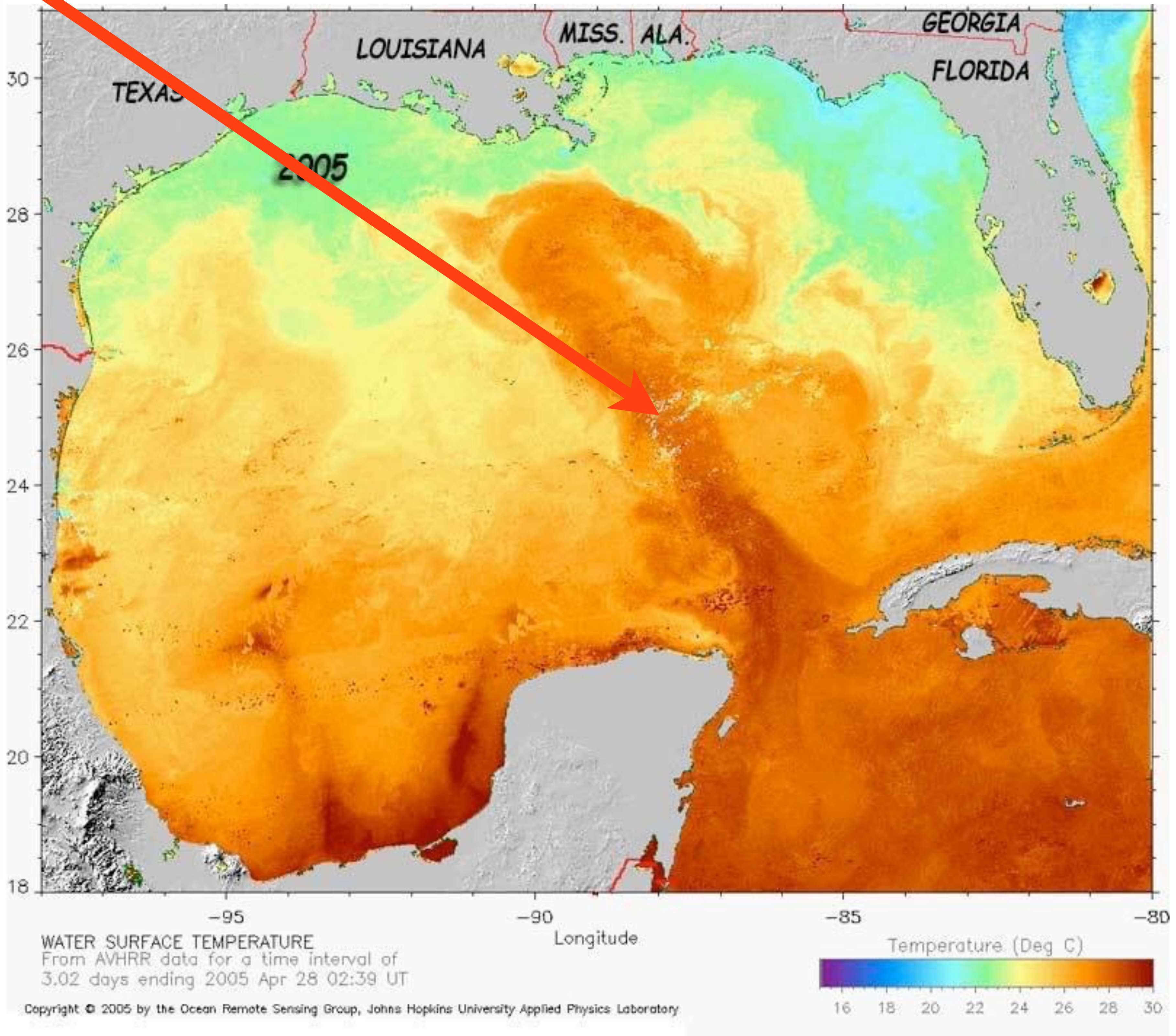
Storm surge:

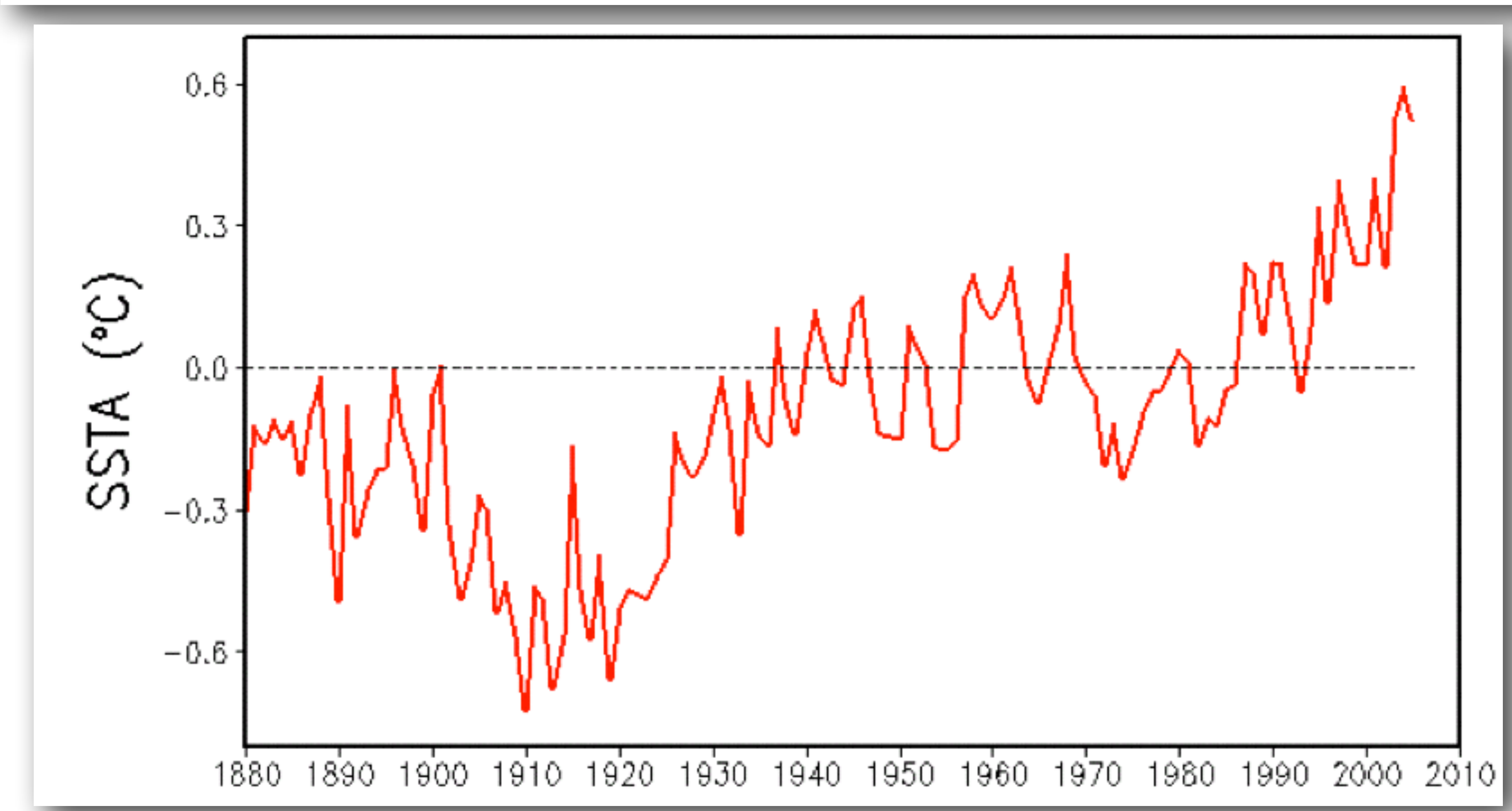
usace/army.mil

Cases

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

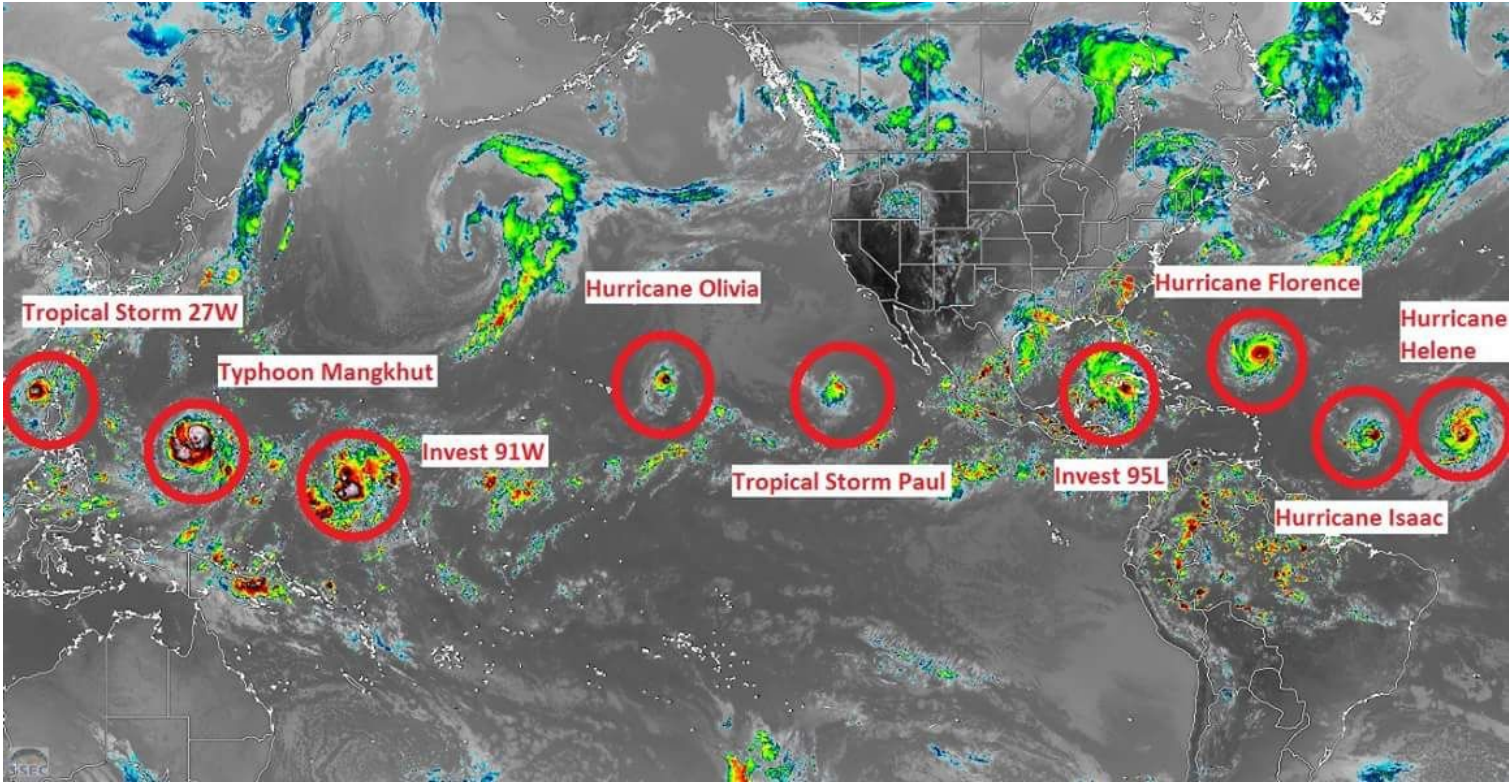






...and Gulf water is getting warmer!

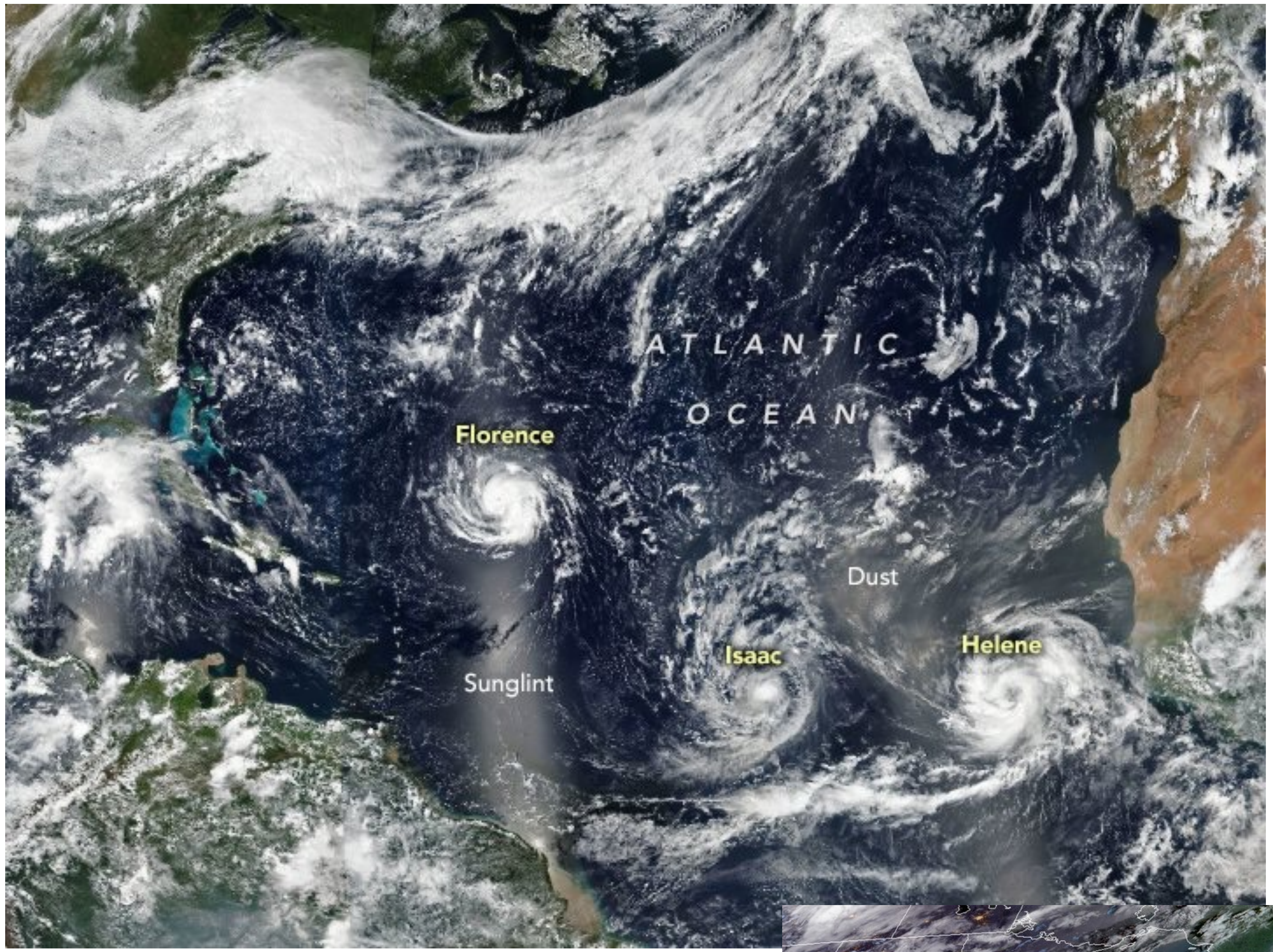
Cases

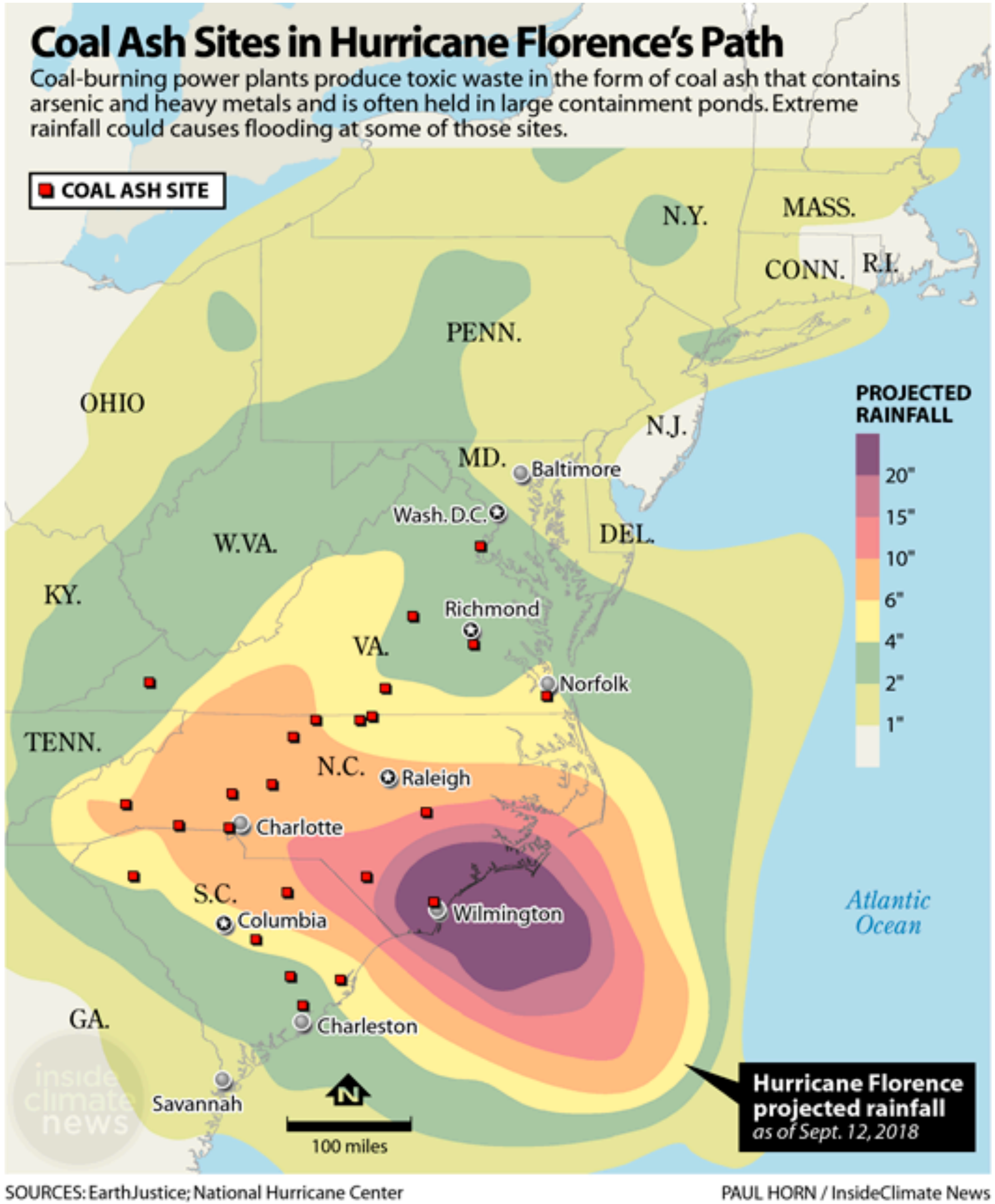

Tropical Storm 27W
Typhoon Mangkhut
Invest 91W
Hurricane Olivia
Tropical Storm Paul
Invest 95L
Hurricane Florence
Hurricane Helene
Hurricane Isaac

Cases


TROPICAL SATELLITE
AccuWeather
50% CHANCE
HURRICANE FLORENCE
TROPICAL DEPRESSION PAUL
70% CHANCE
HURRICANE HELENE
TROPICAL STORM OLIVIA
30% CHANCE
TROPICAL STORM ISAAC

Cases


ATLANTIC
OCEAN
Florence
Dust
Isaac
Helene
Sunglint


Coal Ash Sites in Hurricane Florence's Path
Coal-burning power plants produce toxic waste in the form of coal ash that contains arsenic and heavy metals and is often held in large containment ponds. Extreme rainfall could causes flooding at some of those sites.
COAL ASH SITE
N.Y.
MASS.
CONN.
R.I.
PENN.
OHIO
N.J.
MD.
Baltimore
Wash. D.C.
DEL.
W.VA.
KY.
Richmond
VA.
Norfolk
TENN.
N.C.
Raleigh
Charlotte
S.C.
Columbia
Wilmington
GA.
Charleston
Savannah
100 miles
N
PROJECTED RAINFALL
20"
15"
10"
6"
4"
2"
1"
Atlantic Ocean
Hurricane Florence projected rainfall
as of Sept. 12, 2018
SOURCES: EarthJustice; National Hurricane Center
PAUL HORN / InsideClimate News

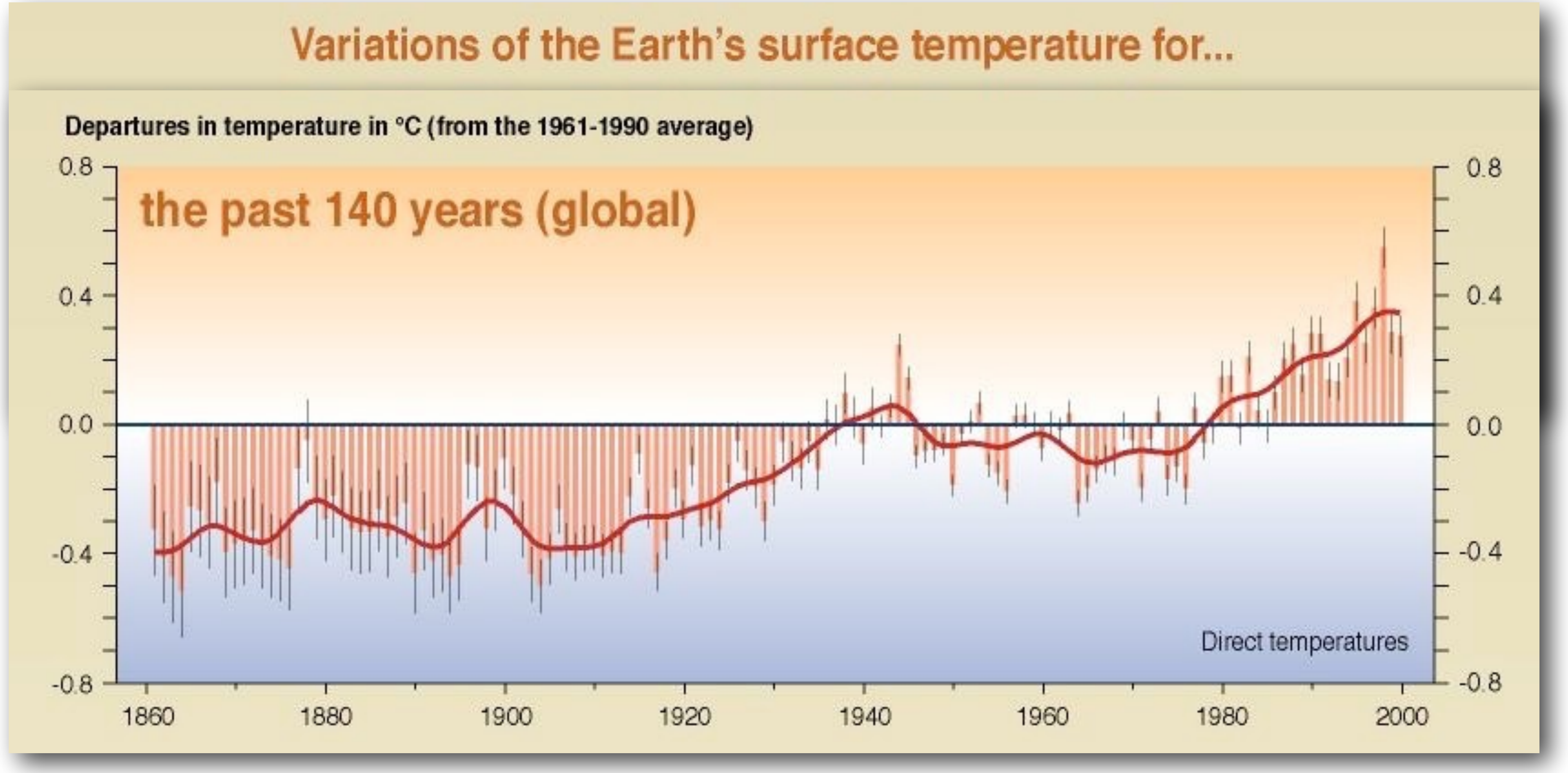
Natural Hazards and Disaster

Class 9: Hurricanes, Typhoons, Cyclones

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

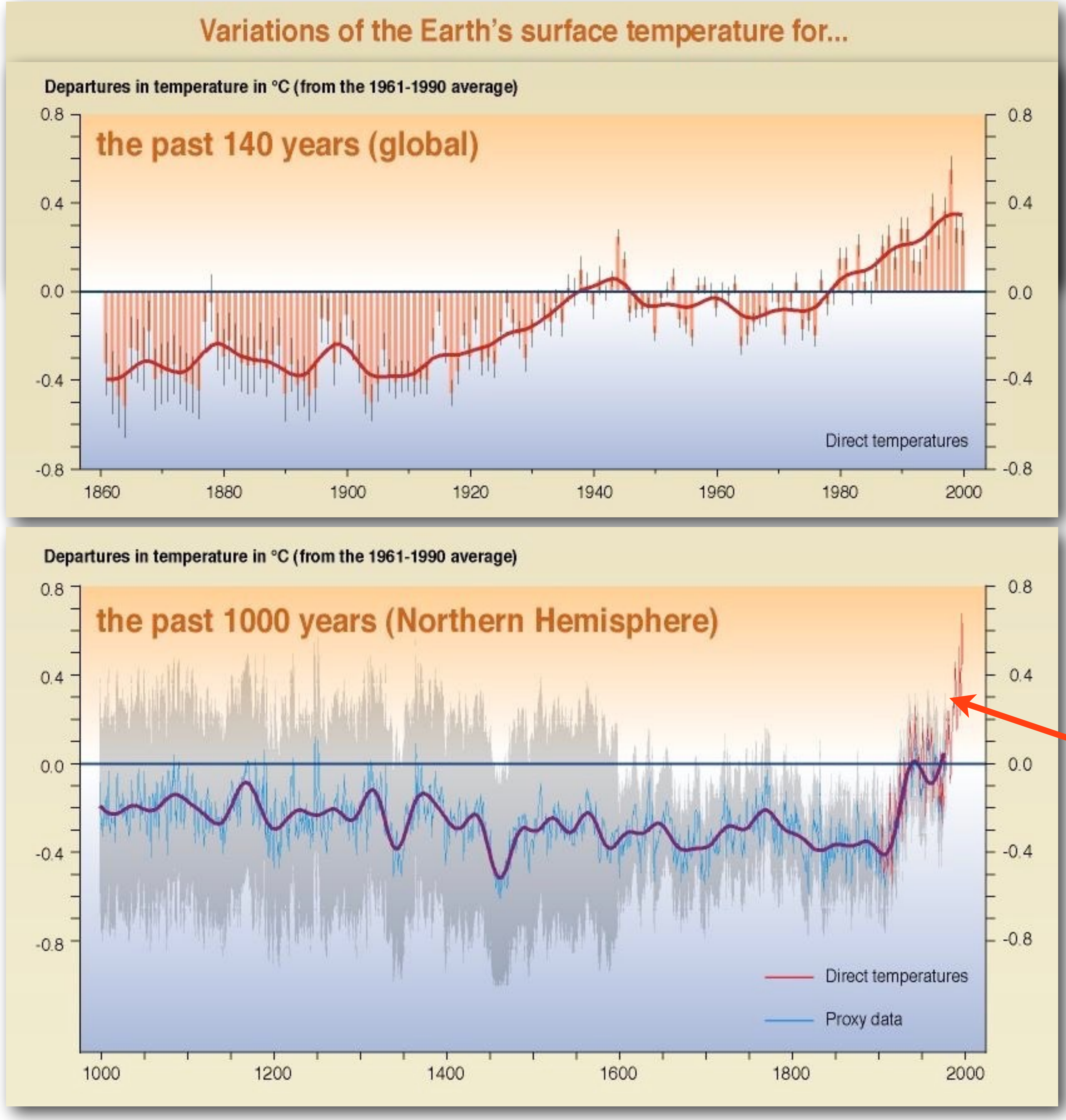
Climate Change Impacts

Is it all getting worse?



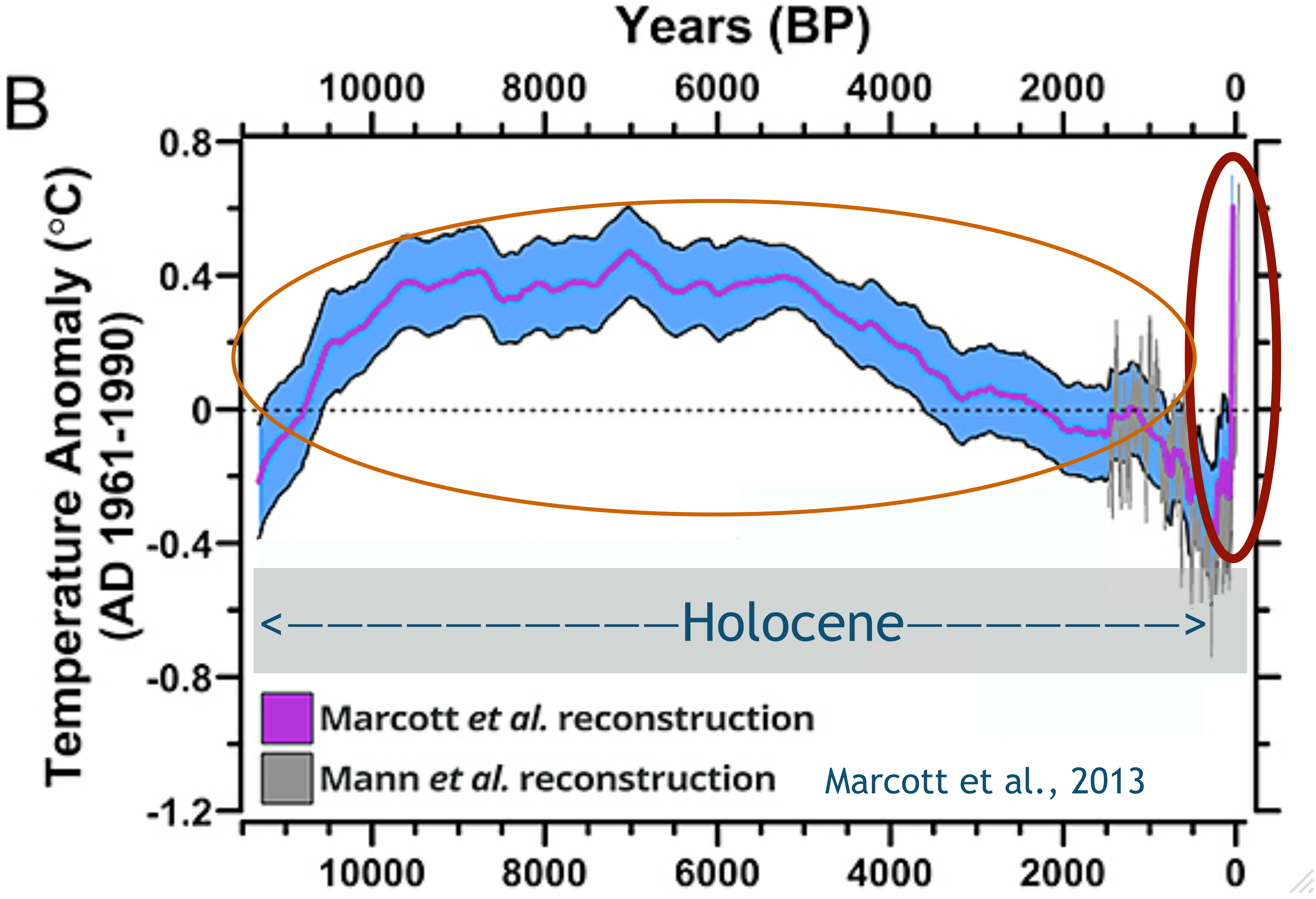
Climate Change Impacts

Is it all getting worse?



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

Is it all getting worse?

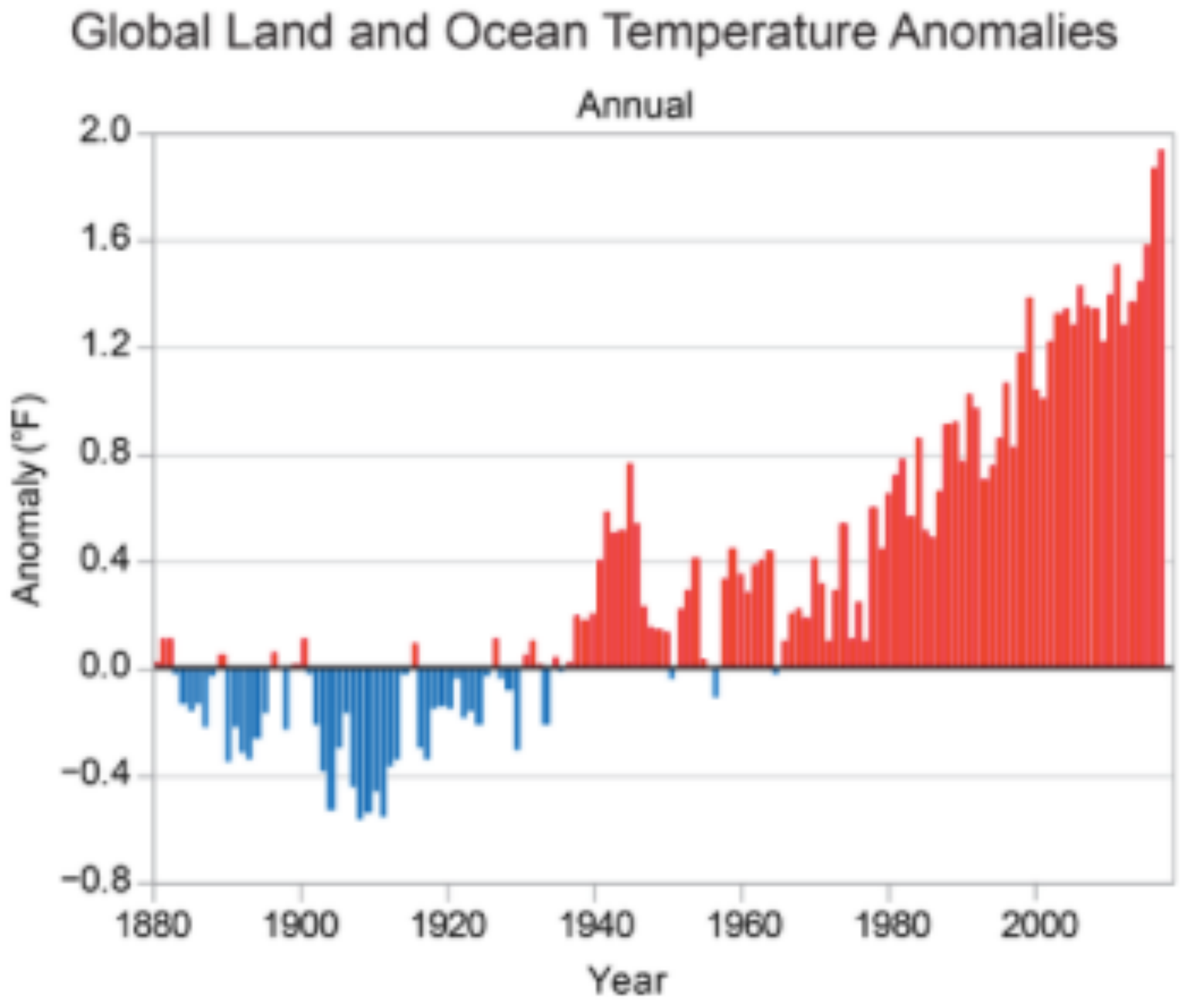


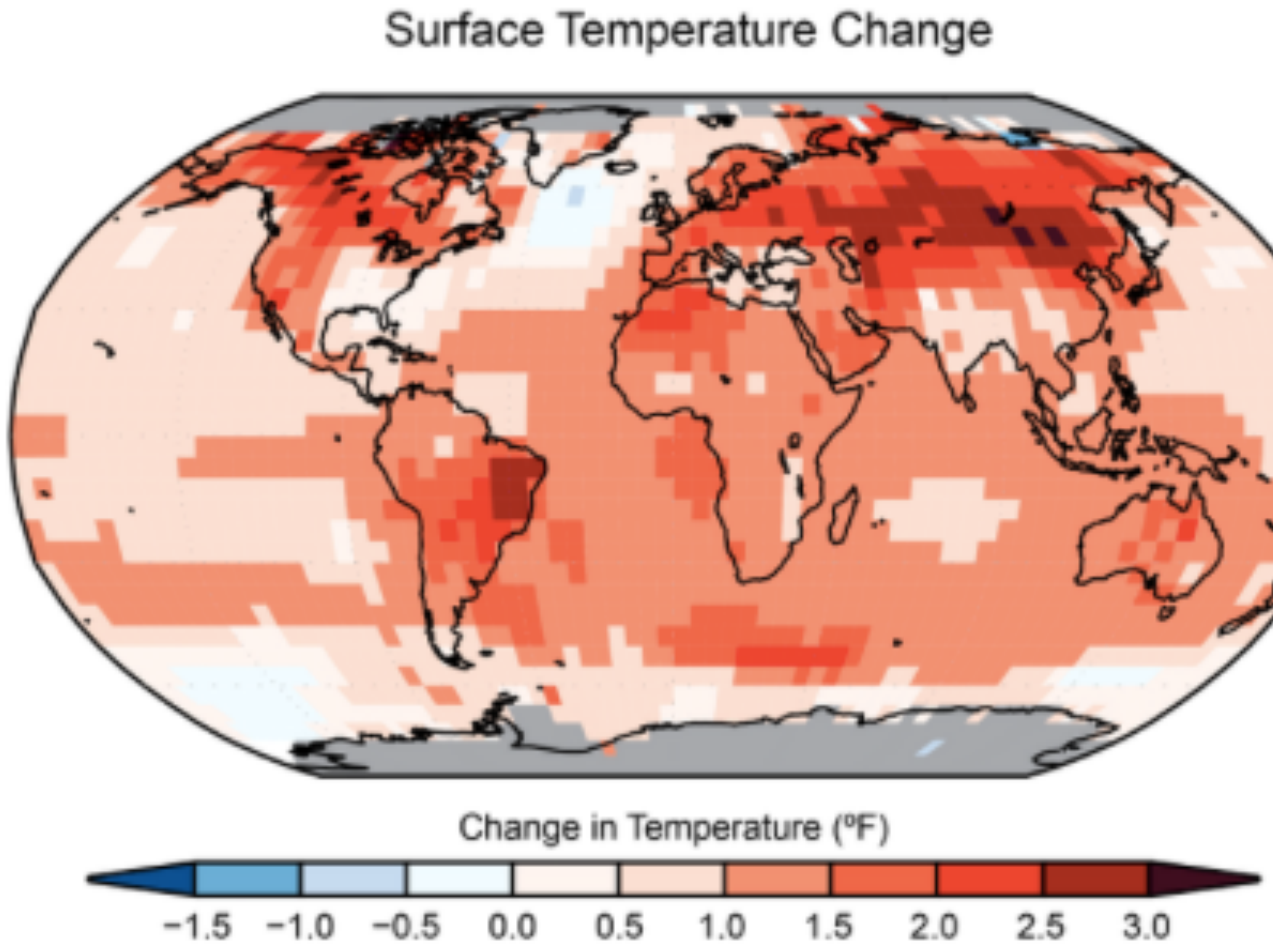
Climate Change Impacts

Is it all getting worse?

Climate Change Impacts

Is it all getting worse?





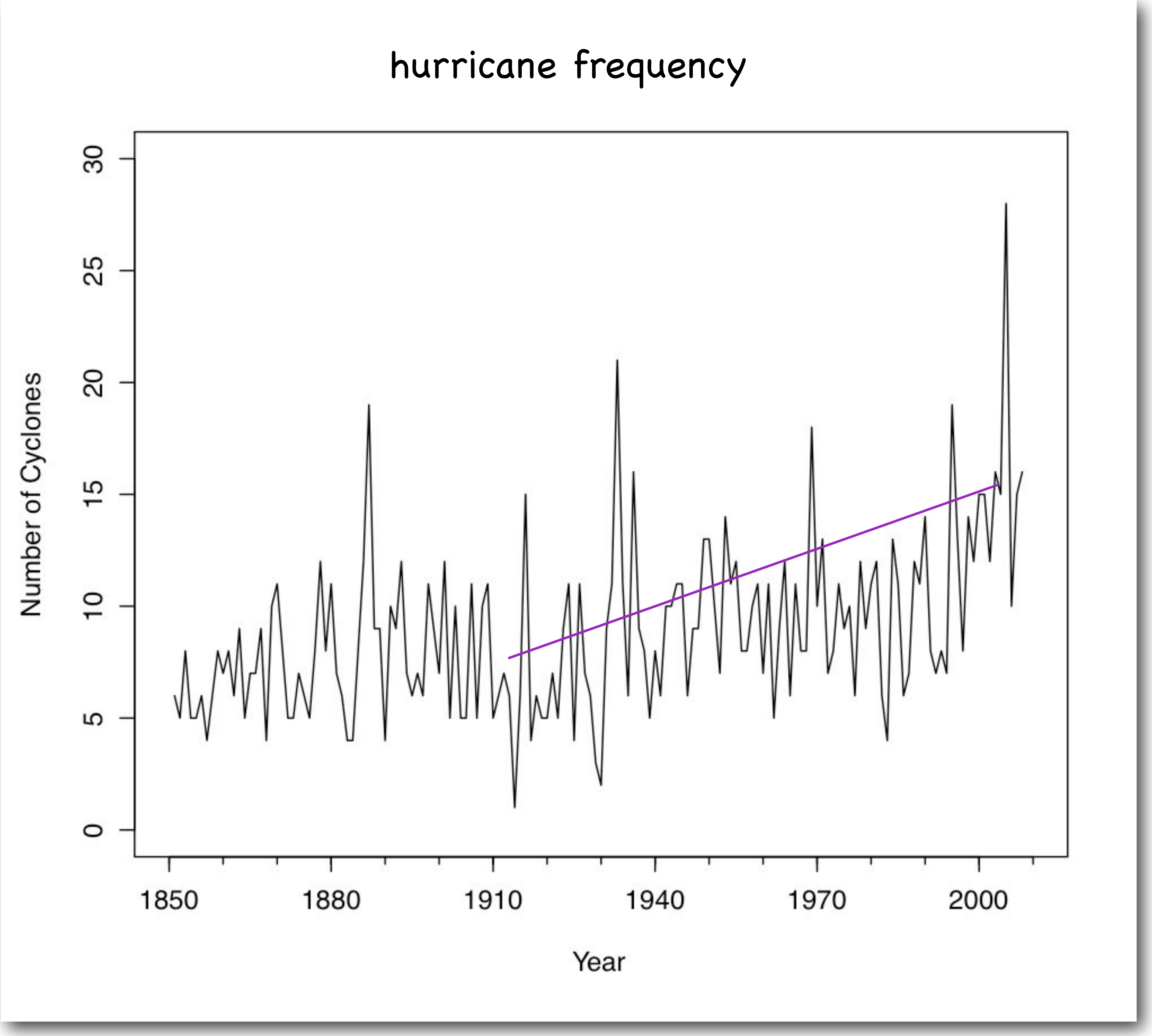
(left) Global annual average temperature has increased by more than 1.2°F (0.7°C) for the period 1986–2016 relative to 1901–1960. Red bars show temperatures that were above the 1901–1960 average, and blue bars indicate temperatures below the average. (right) Surface temperature change (in °F) for the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

Climate Change Impacts

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	2	1879,1886,1915, 1916,1926,1944, 1950,1955,1985
4	1869,1880,1887, 1888,1906,1915, 1916,1926,1964		

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

Climate Change Impacts

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	-

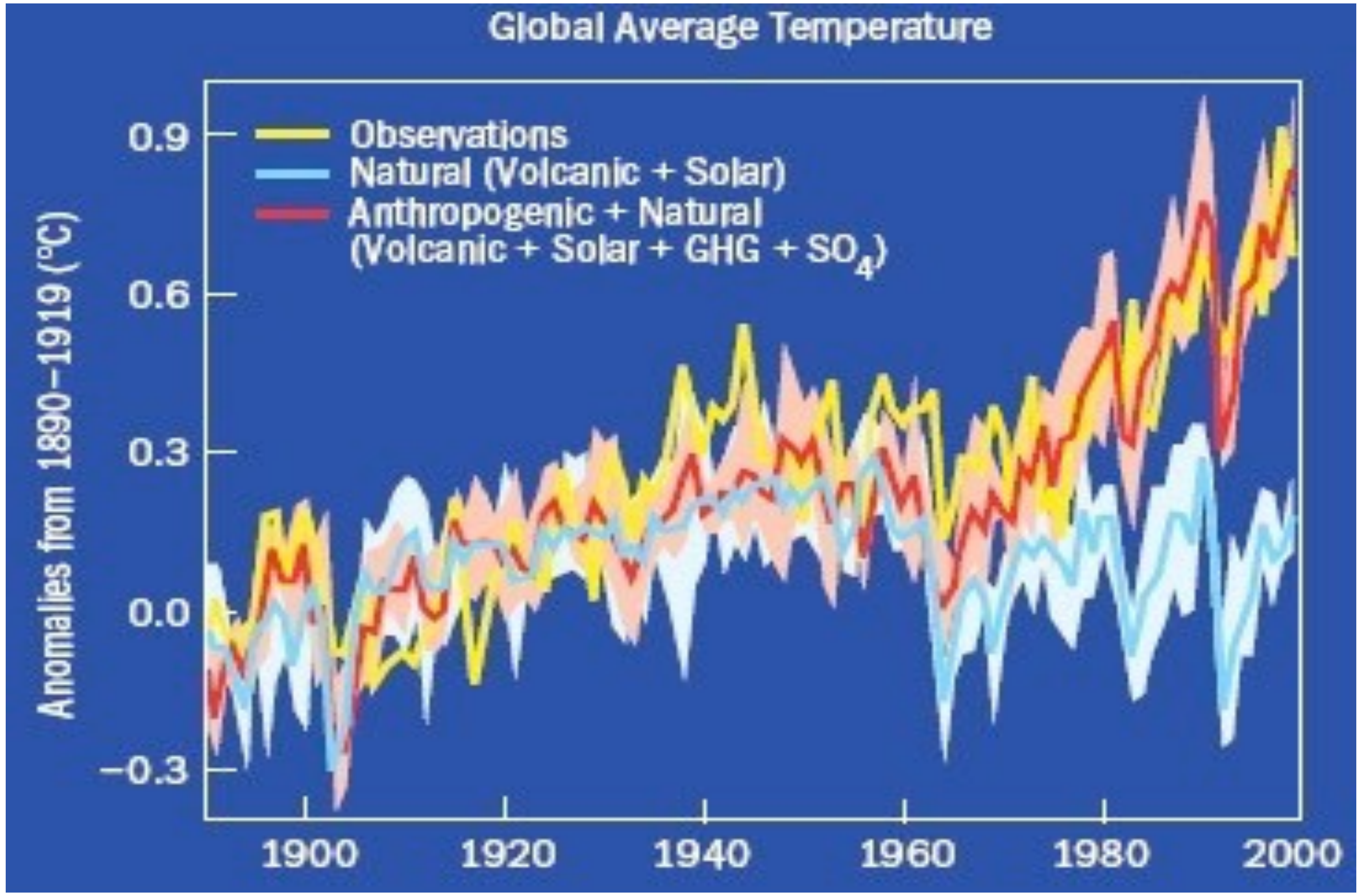
[1] Includes subtropical storms after 1967. See McAdie et al. (2009) for details.

* 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