The Atlantic Hurricane Database Reanalysis Project - Re-discovering "Missing" Tropical Cyclones***

20 September 2023

HFIP Monthly Seminar

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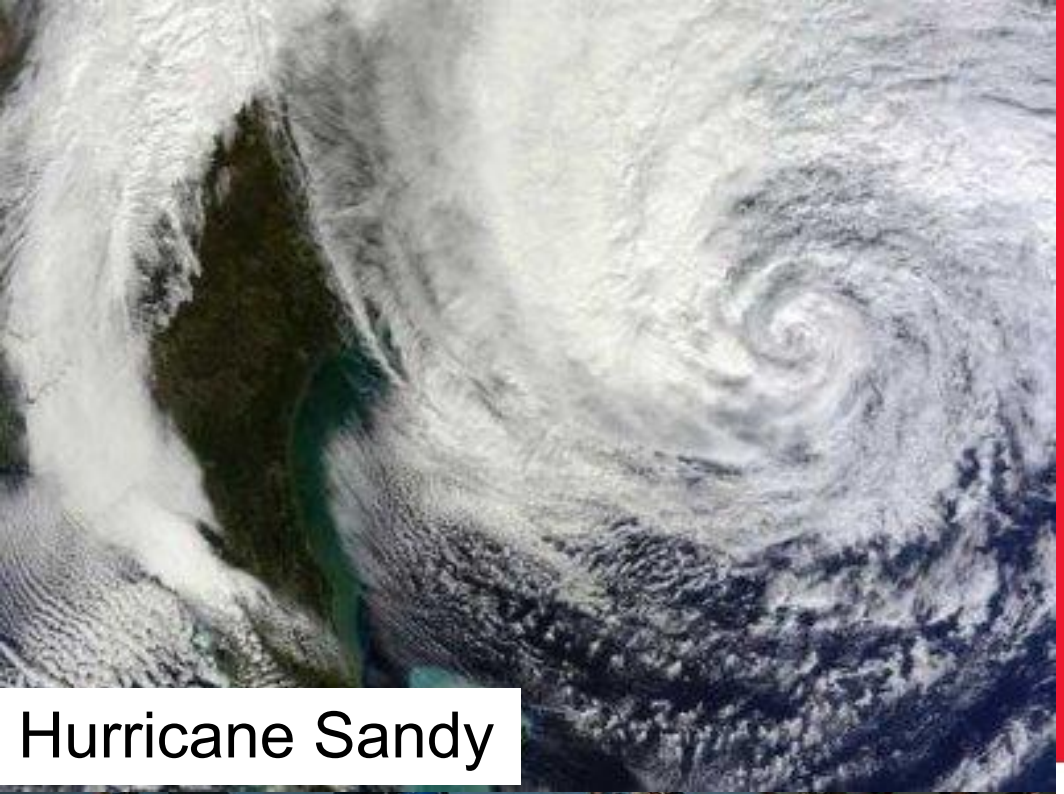
Chris.Landsea@noaa.gov

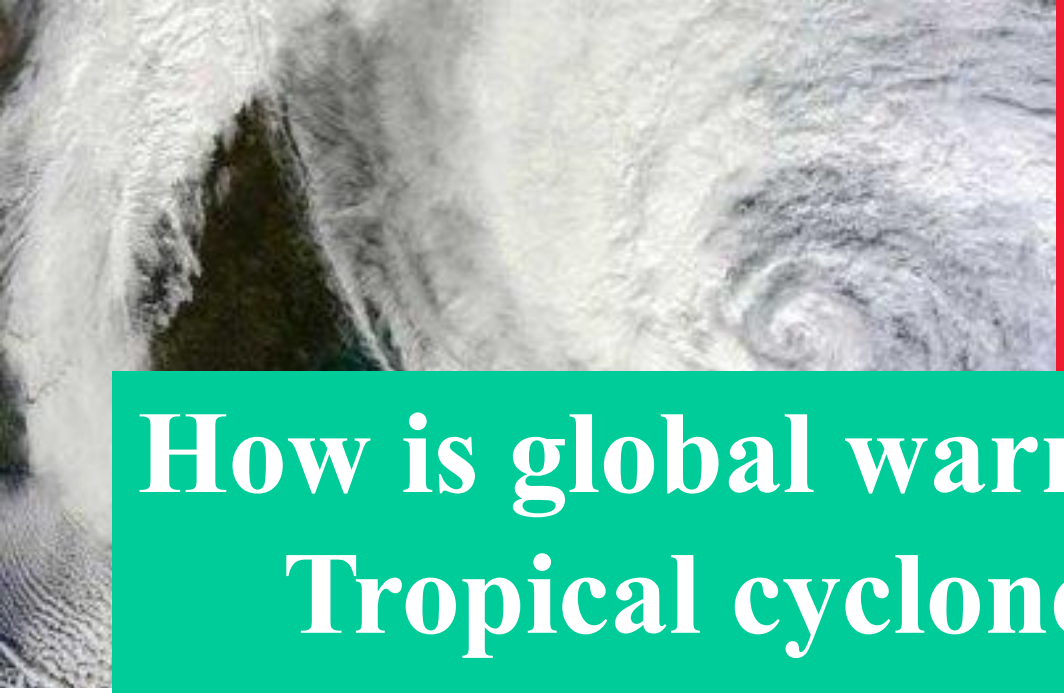
The Atlantic Hurricane Database Reanalysis Project - Re-discovering "Missing" Tropical Cyclones***

*** And What Does This Imply for Understanding Hurricanes and Global Warming?

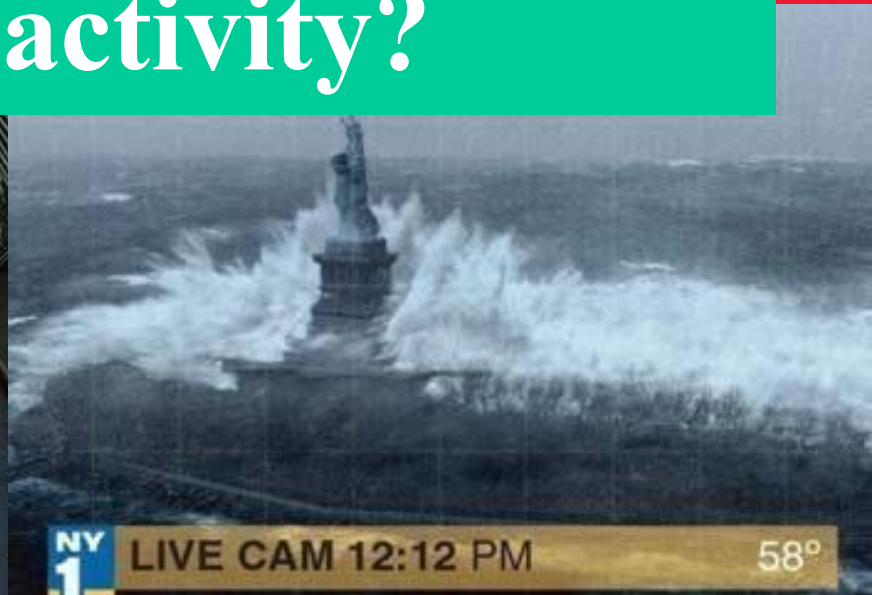
Chris.Landsea@noaa.gov



Hurricane Sandy



How is global warming affecting: Tropical cyclone frequency, intensity, genesis, track, rainfall, and overall activity?



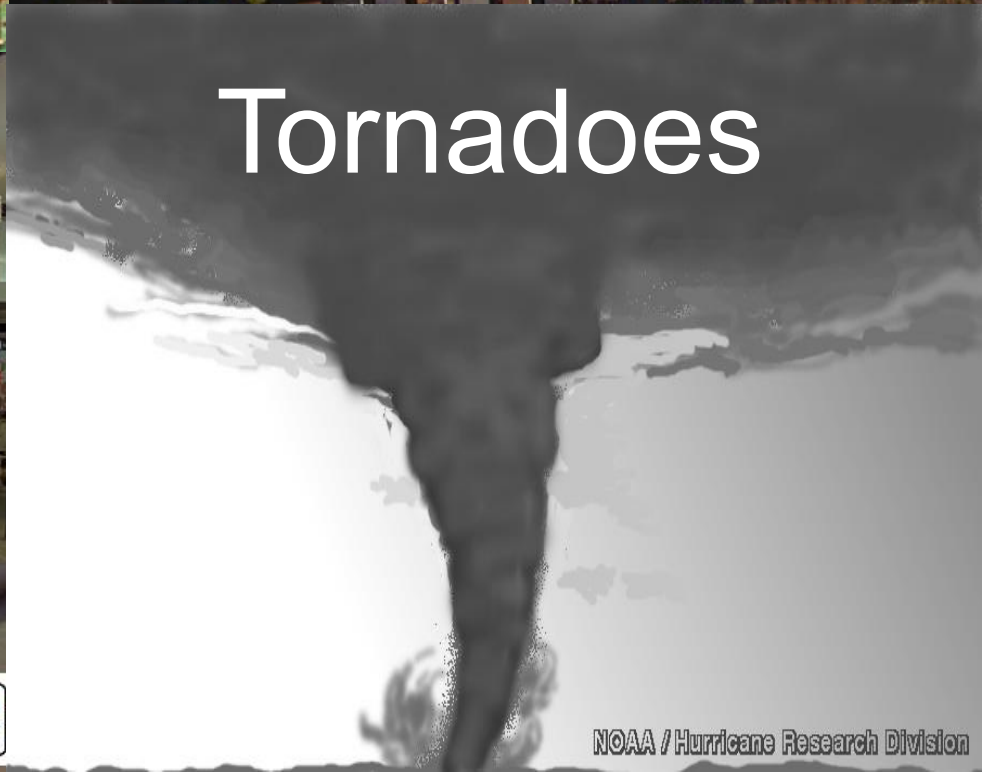
Quiz #1
What are the Most Dangerous Impacts of Hurricanes?

Wind-caused Damage

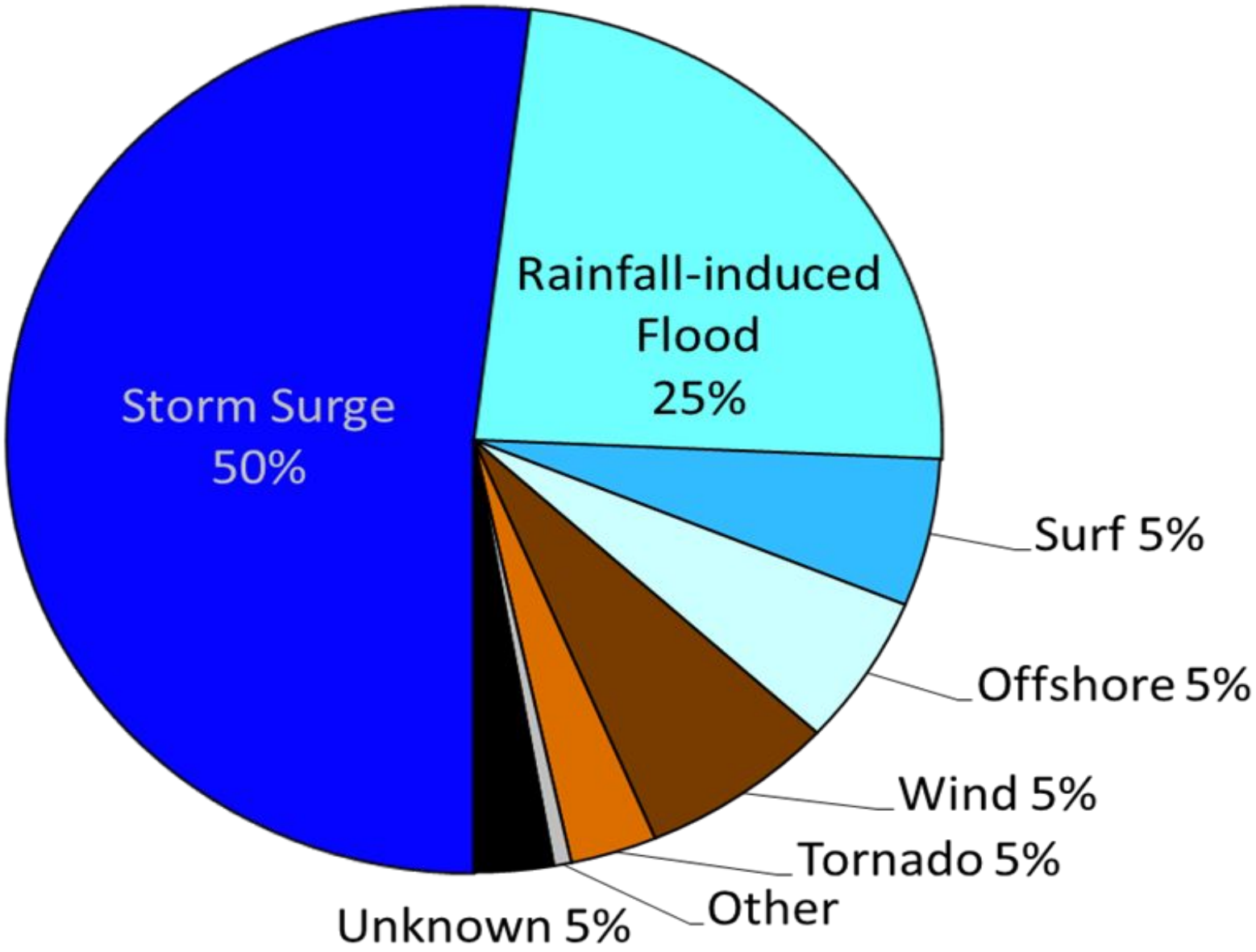
Storm Surge

Inland Flooding

Tornadoes

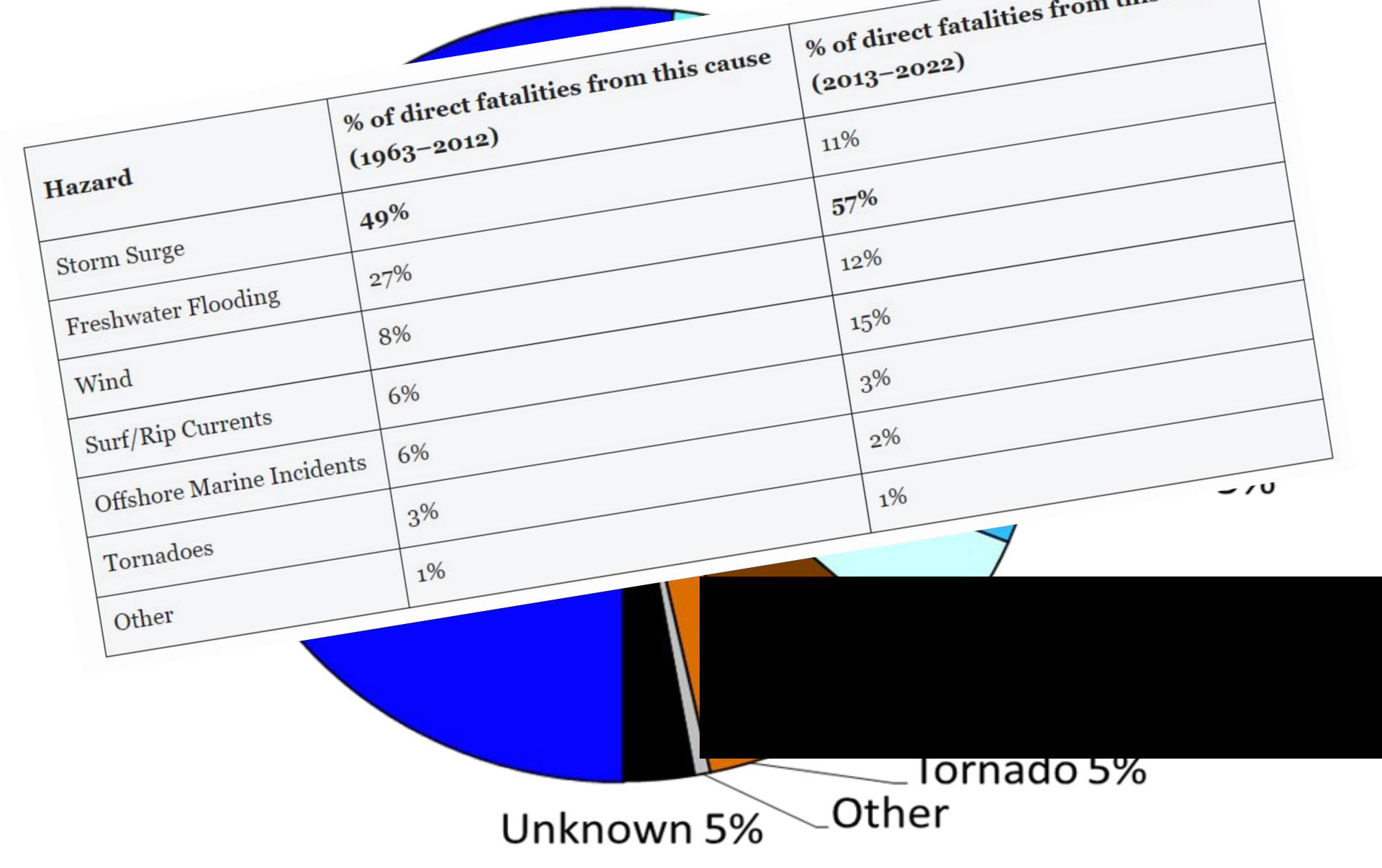


U.S. Atlantic Tropical Cyclone Deaths, 1962-2011



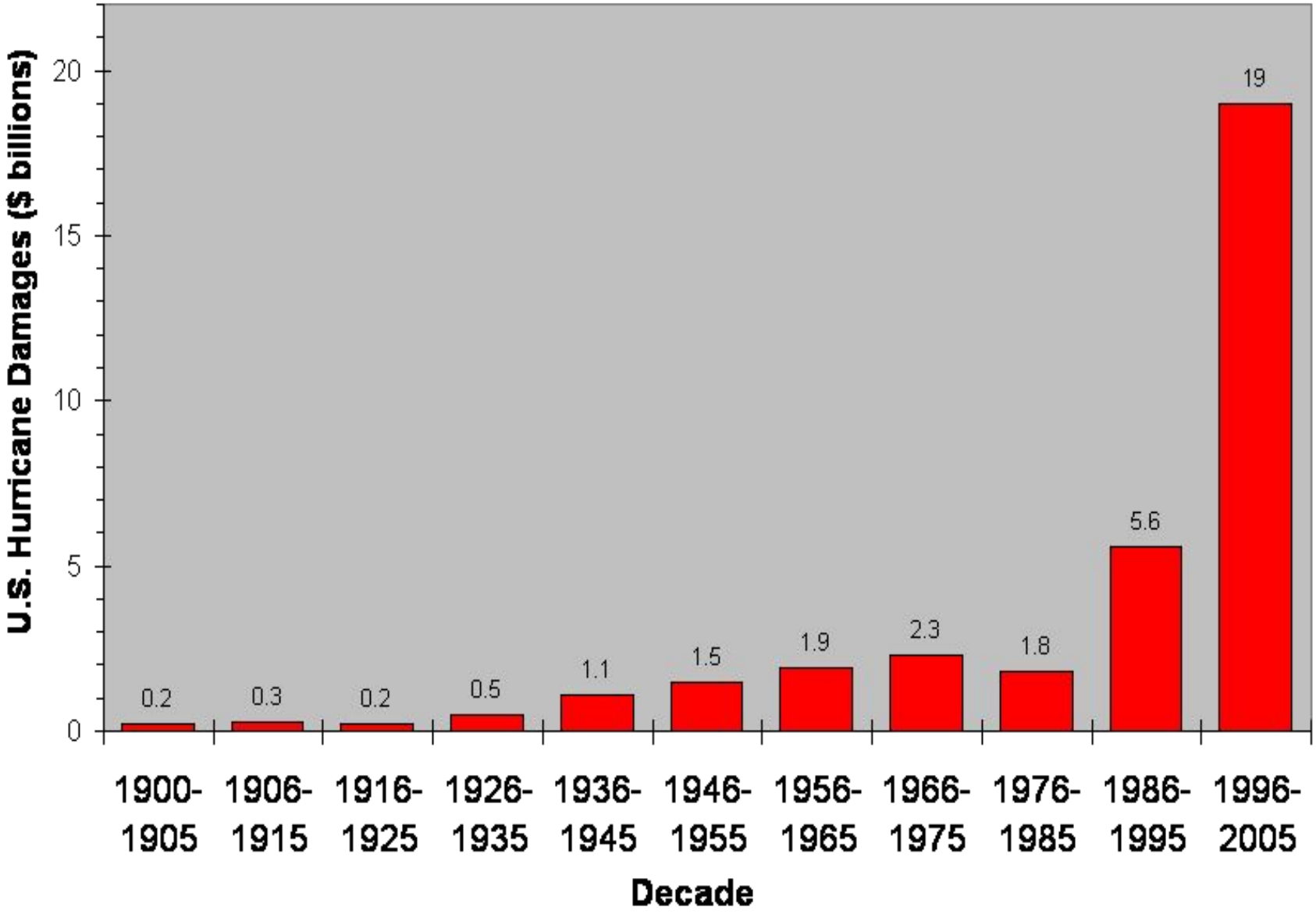
U.S. Atlantic Tropical Cyclone Deaths, 1962-2011

Hazard	% of direct fatalities from this cause (1963–2012)	% of direct fatalities from this cause (2013–2022)
Storm Surge	**49%**	11%
Freshwater Flooding	27%	**57%**
Wind	8%	12%
Surf/Rip Currents	6%	15%
Offshore Marine Incidents	6%	3%
Tornadoes	3%	2%
Other	1%	1%

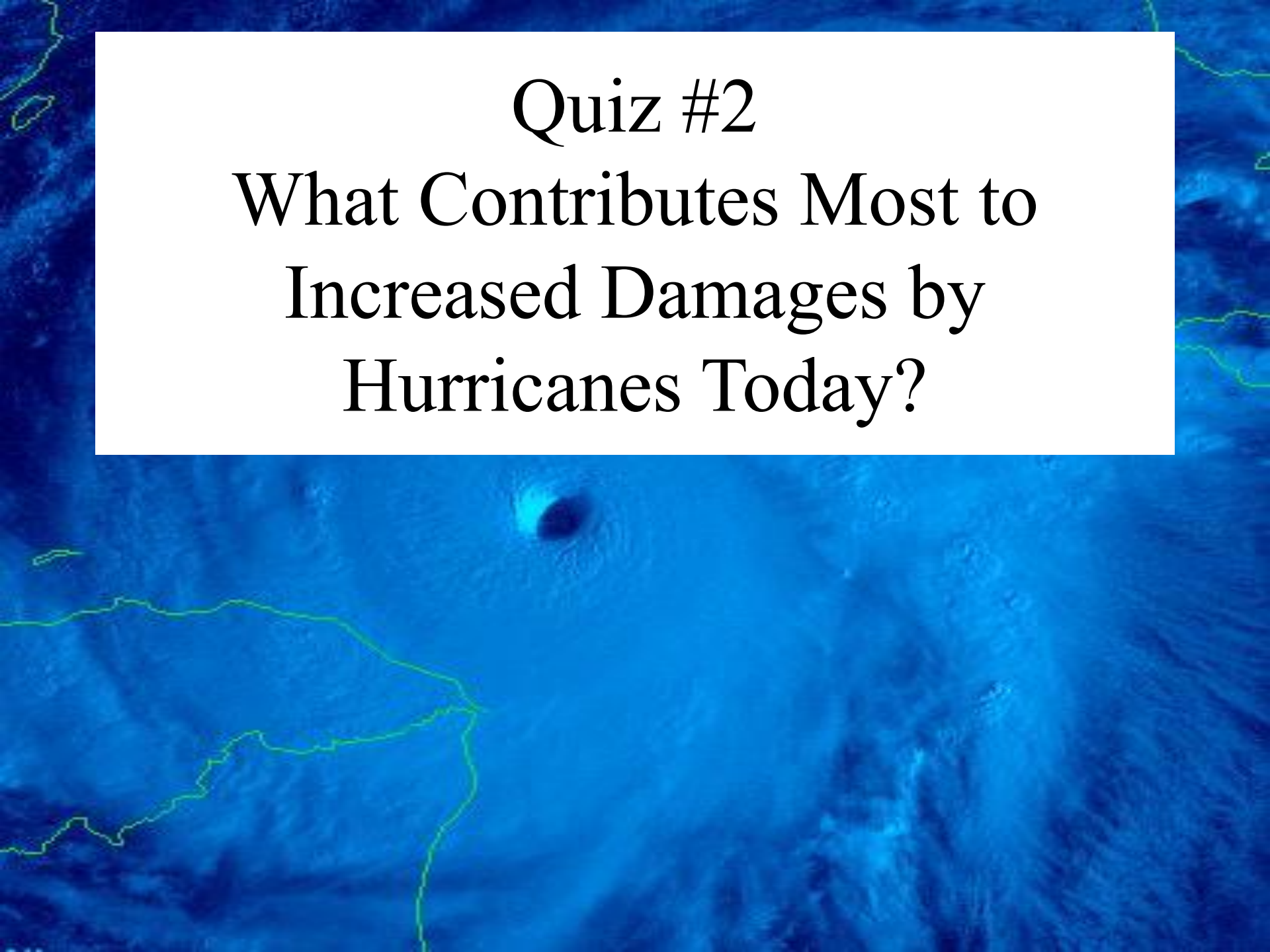


U.S. Tropical Storm and Hurricane Damages

$BILLIONS Annually - Inflation Adjusted



Quiz #2
What Contributes Most to Increased Damages by Hurricanes Today?



Quiz #2
What Contributes Most to Increased Damages by Hurricanes Today?

a. Increasing Per Capita Wealth
b. Increasing Coastal Population
c. Increasing Numbers/Intensities of Hurricanes

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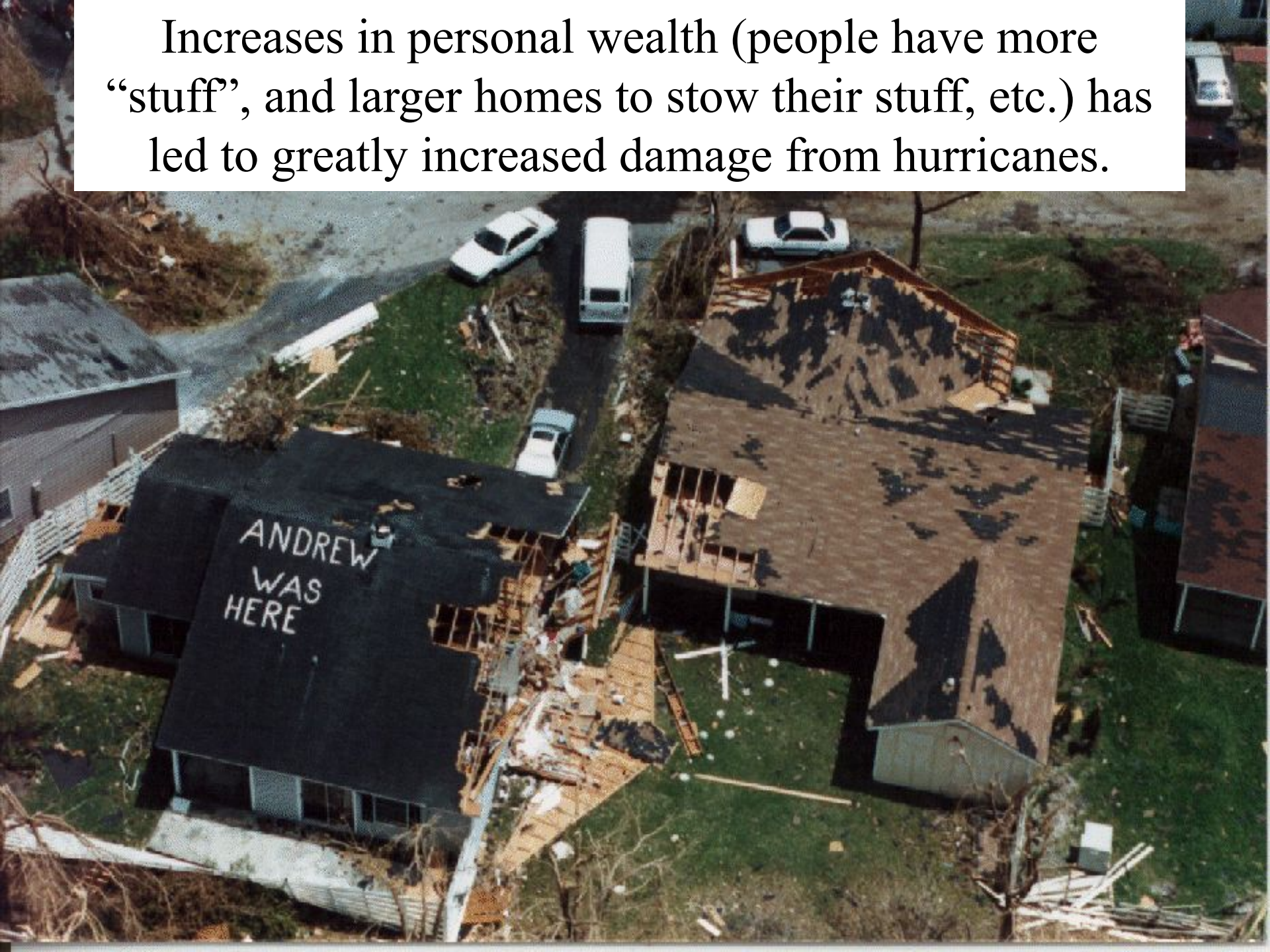
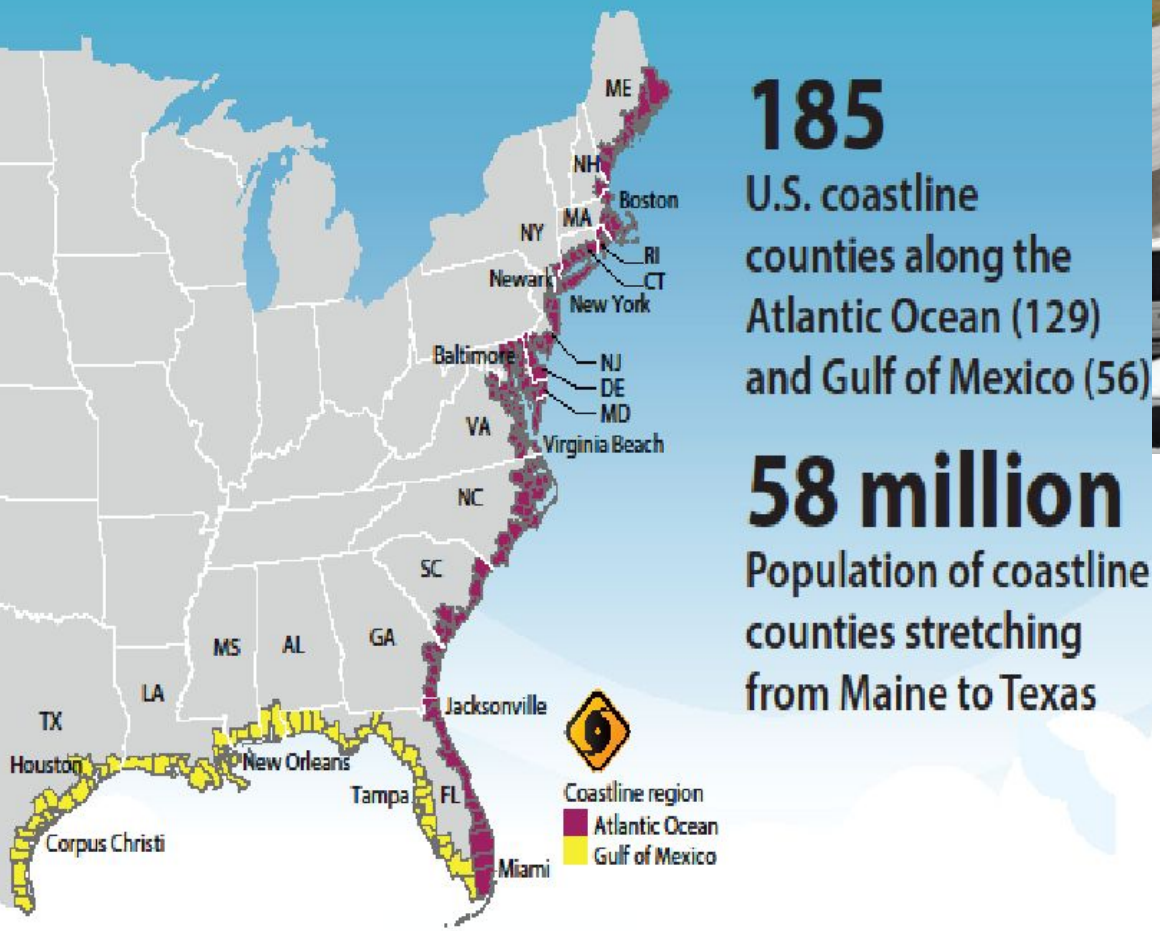
c. Increasing Numbers/Intensities of Hurricanes

Increases in personal wealth (people have more "stuff", and larger homes to stow their stuff, etc.) has led to greatly increased damage from hurricanes.



Emergency Planning

Census Bureau Statistics Can Help Community Leaders Prepare for Hurricanes

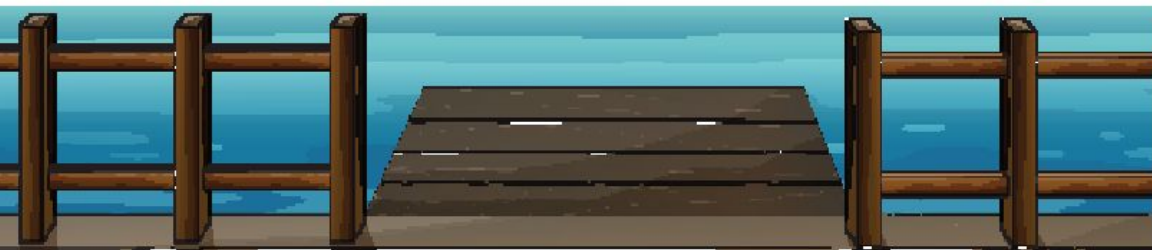


185

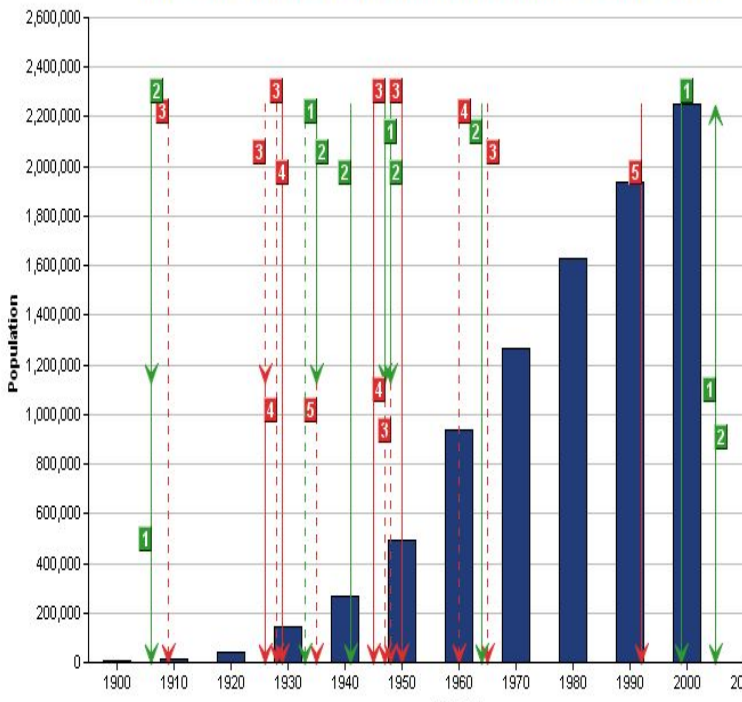
U.S. coastline counties along the Atlantic Ocean (129) and Gulf of Mexico (56)

58 million

Population of coastline counties stretching from Maine to Texas



Hurricane Strikes vs Population for Miami-Dade, Florida



NORMALIZED DAMAGE…

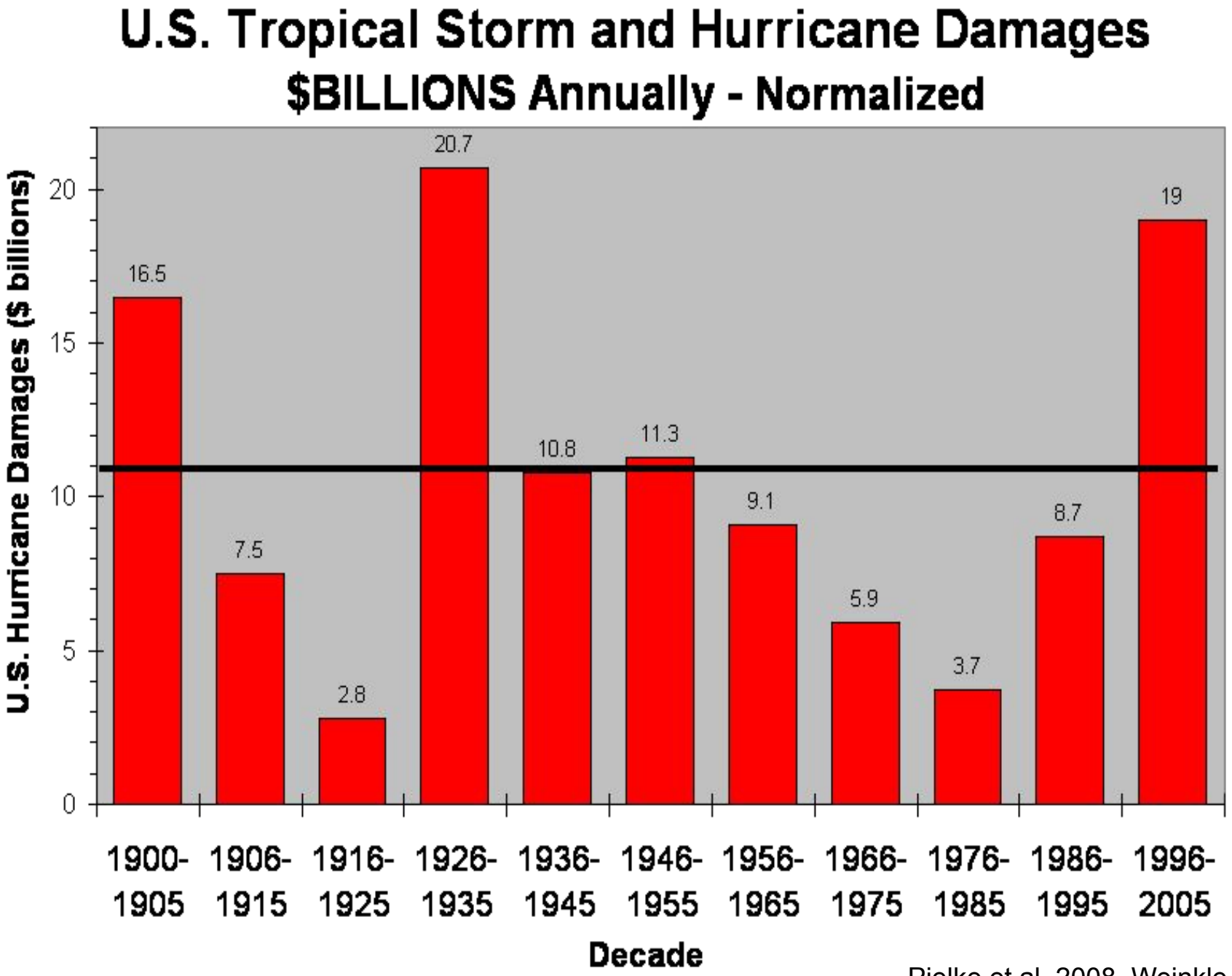
Estimated direct damage if past storms made landfall with present-day societal conditions

ND = f(inflation, coastal population, wealth)

Pielke and Landsea (1998)

ND = f(inflation, coastal housing, wealth)

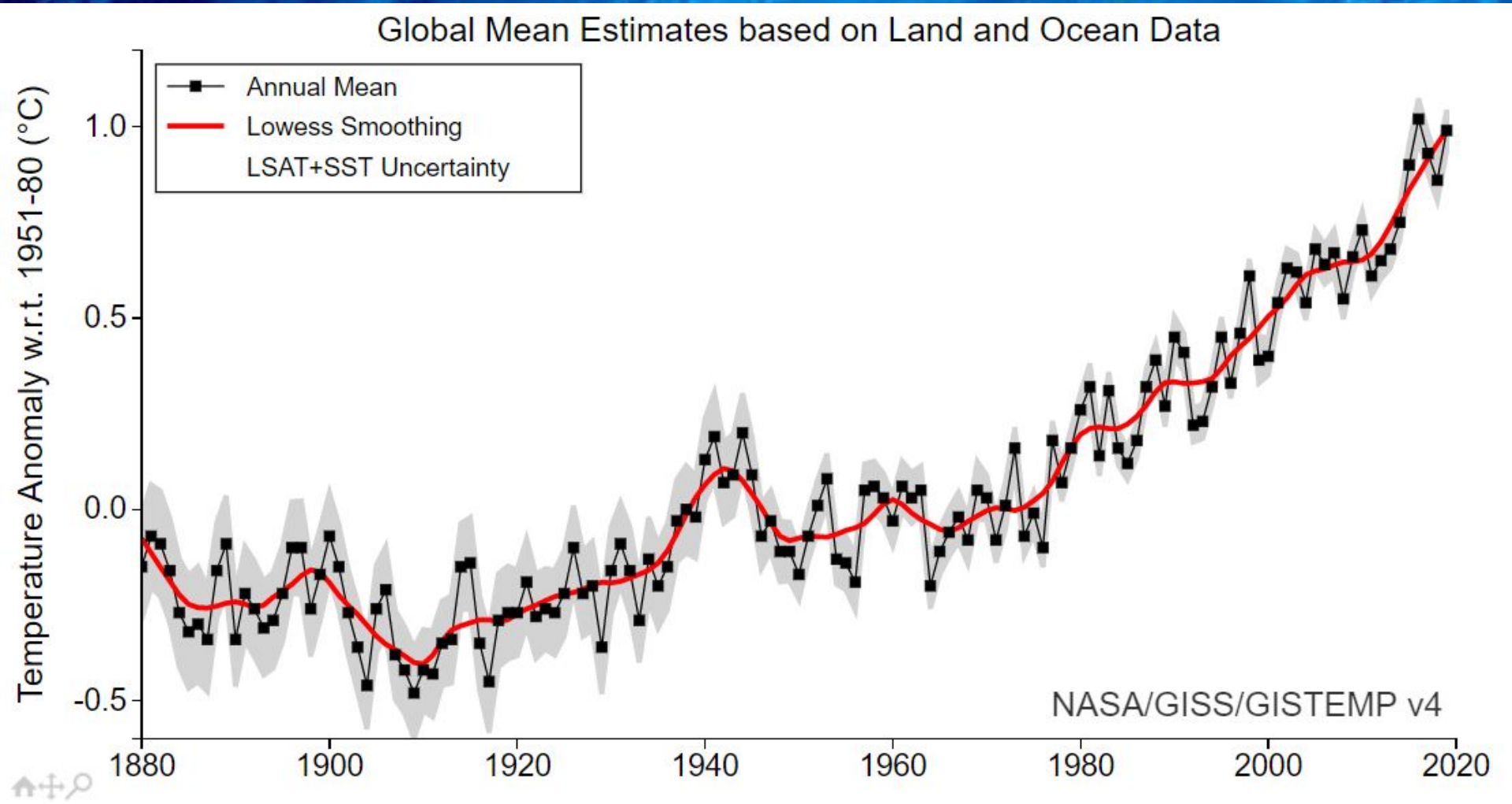
Pielke et al. (2008), Weinkle et al. (2018)



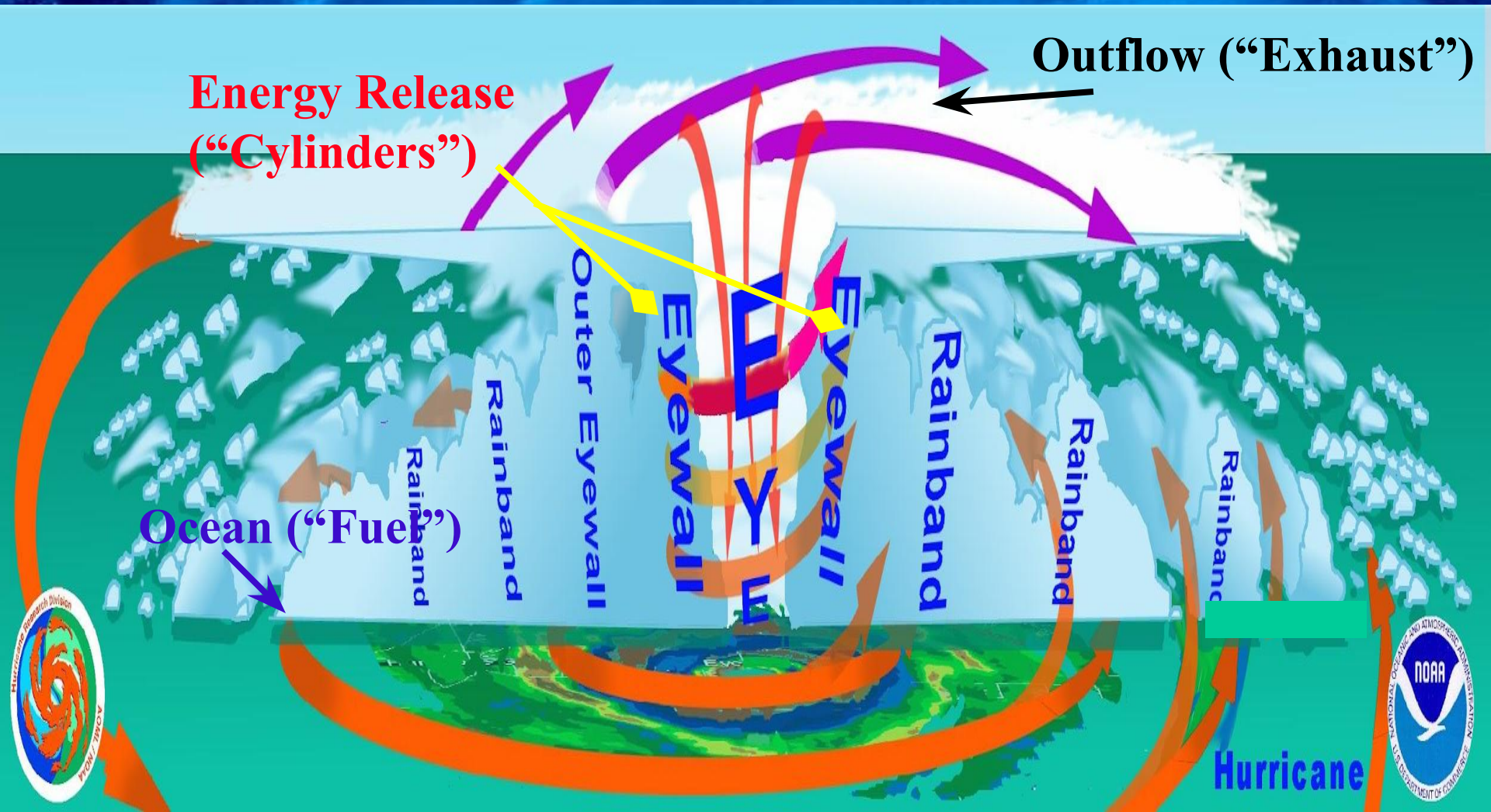
Pielke et al. 2008, Weinkle et al. 2018

Quiz #3
How will Global Warming Impact Hurricane Intensity (Maximum Winds)?

Global Warming – Past Temperature Changes



Nature's great heat engine...
The Hurricane



Quiz #3
How will Global Warming Impact Hurricane Intensity (Maximum Winds)?

A. 100% Stronger

B. 50% Stronger

C. 25% Stronger

D. 5% Stronger

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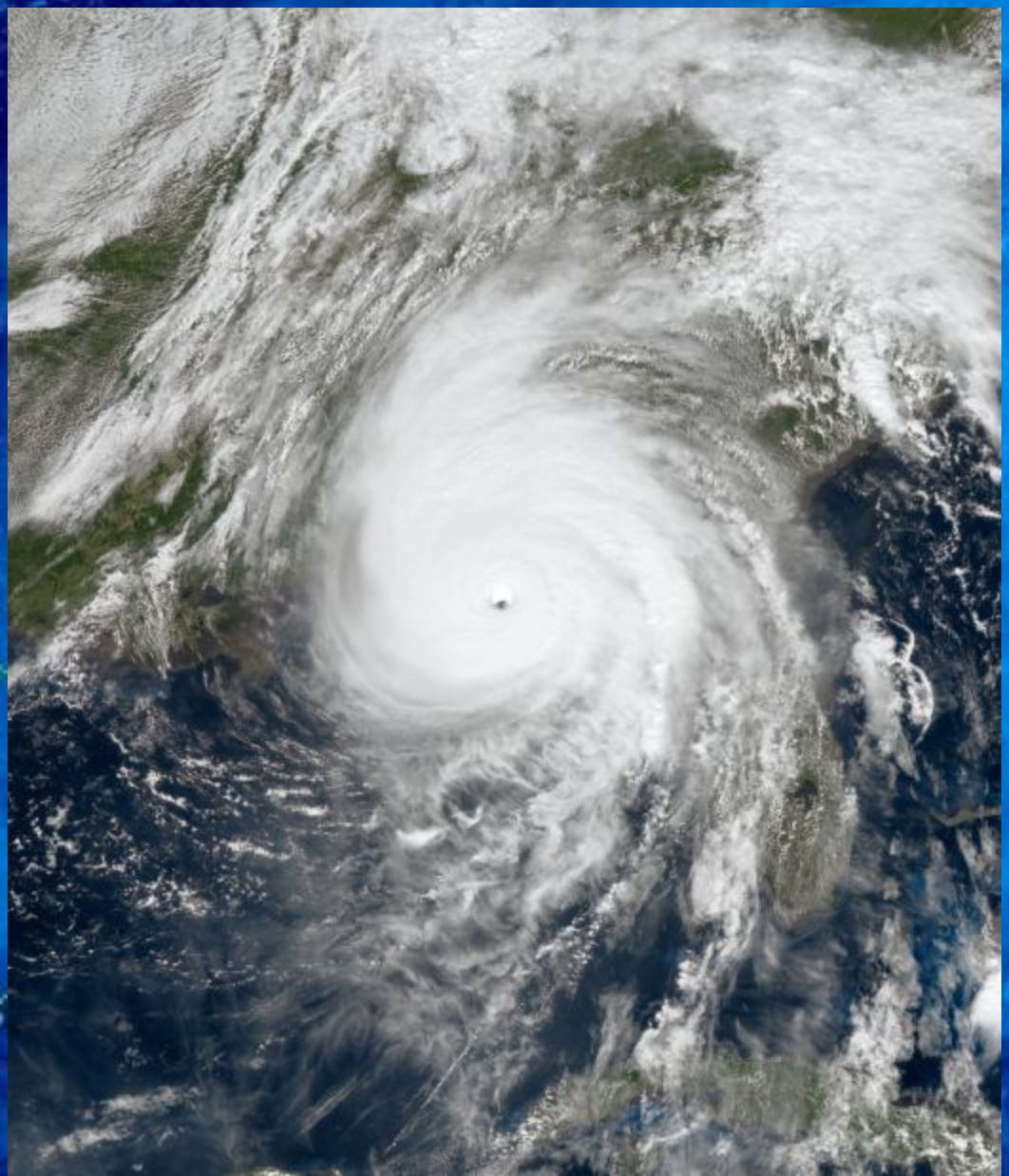
Global Warming and Hurricane Winds:
Theory and Modeling Work Suggest ~1% Increase Today



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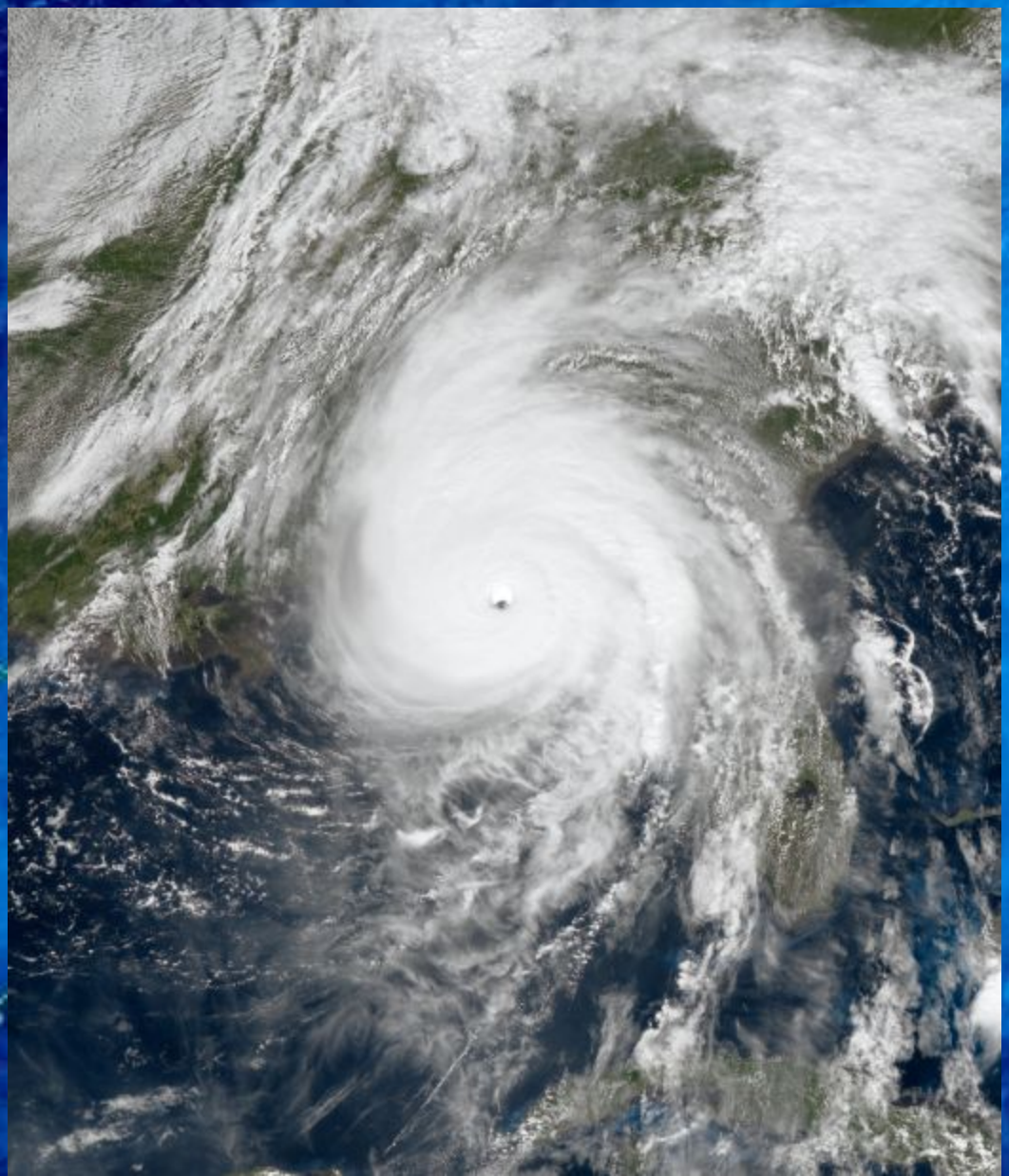
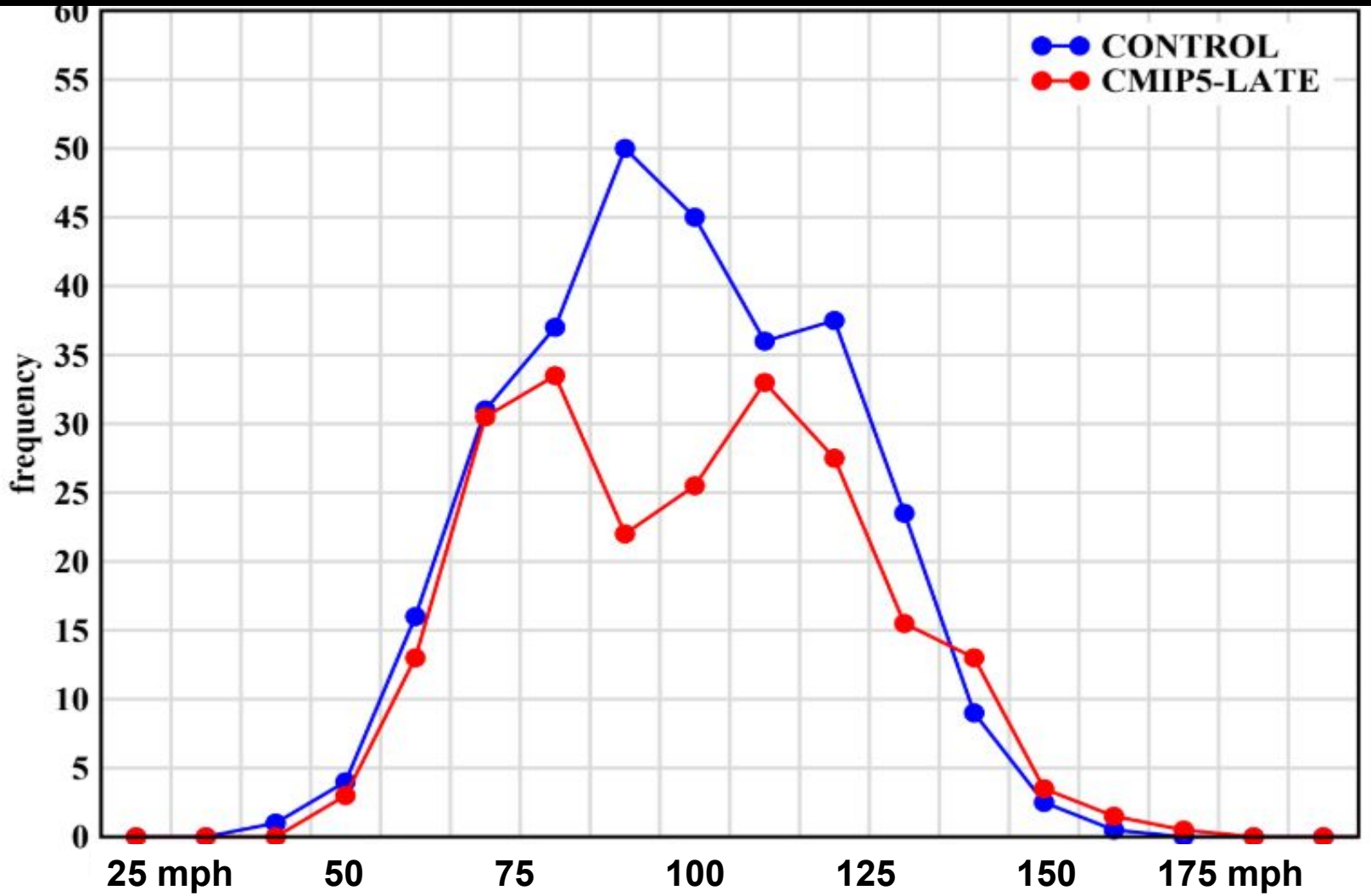


1-2 mph of Hurricane Michael's 160 mph Winds

Global Warming and Hurricanes:
Theory and Modeling Work Suggest ~3-5% wind increase by late 21st Century



Knutson et al. (2013)

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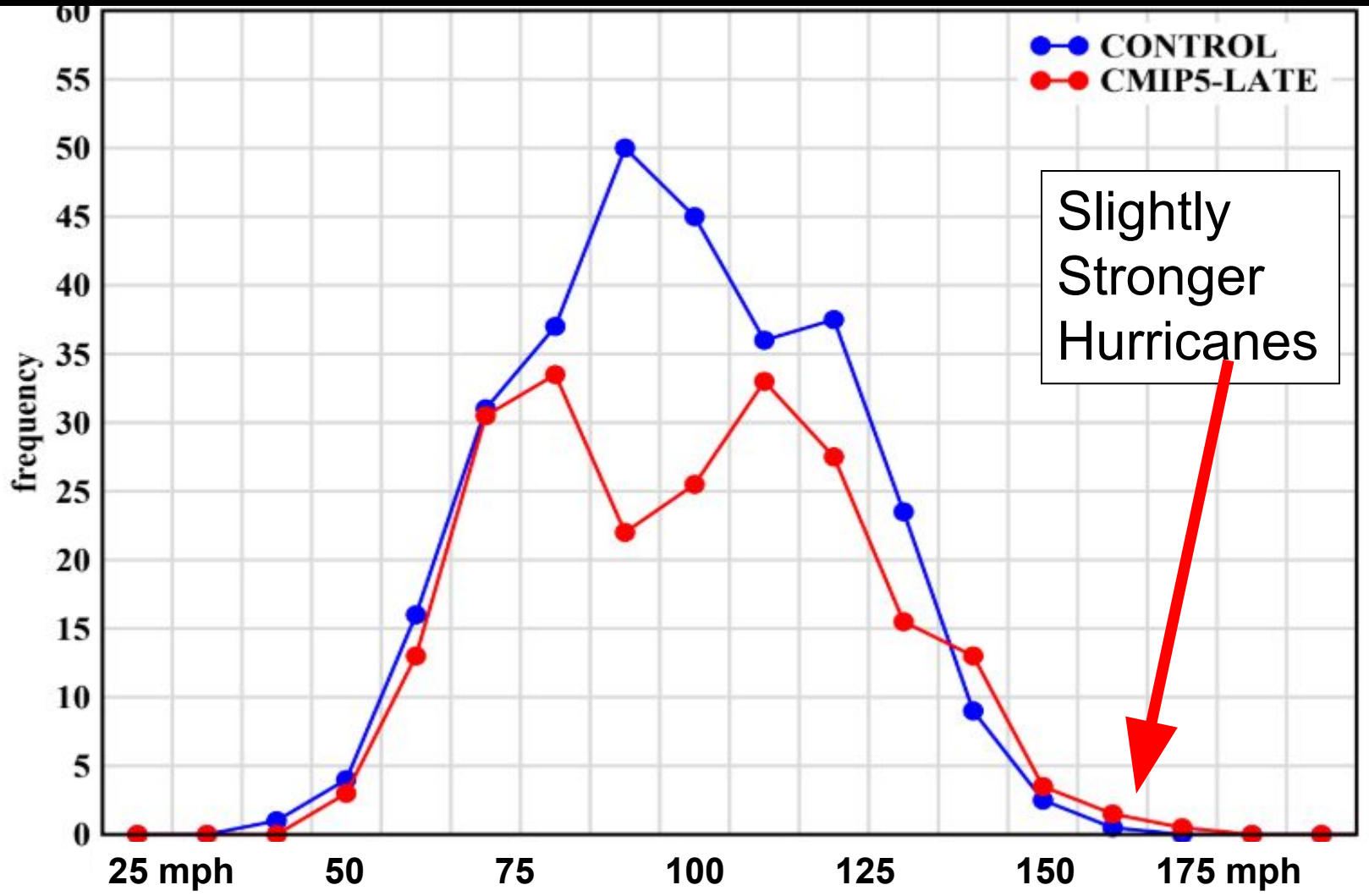

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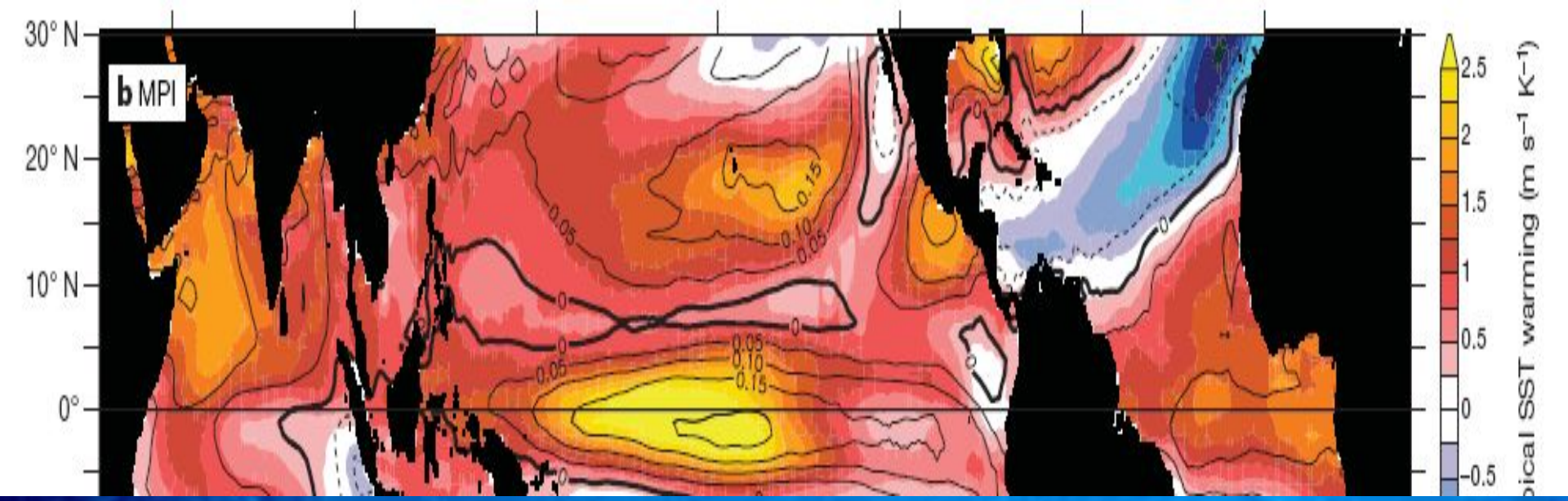
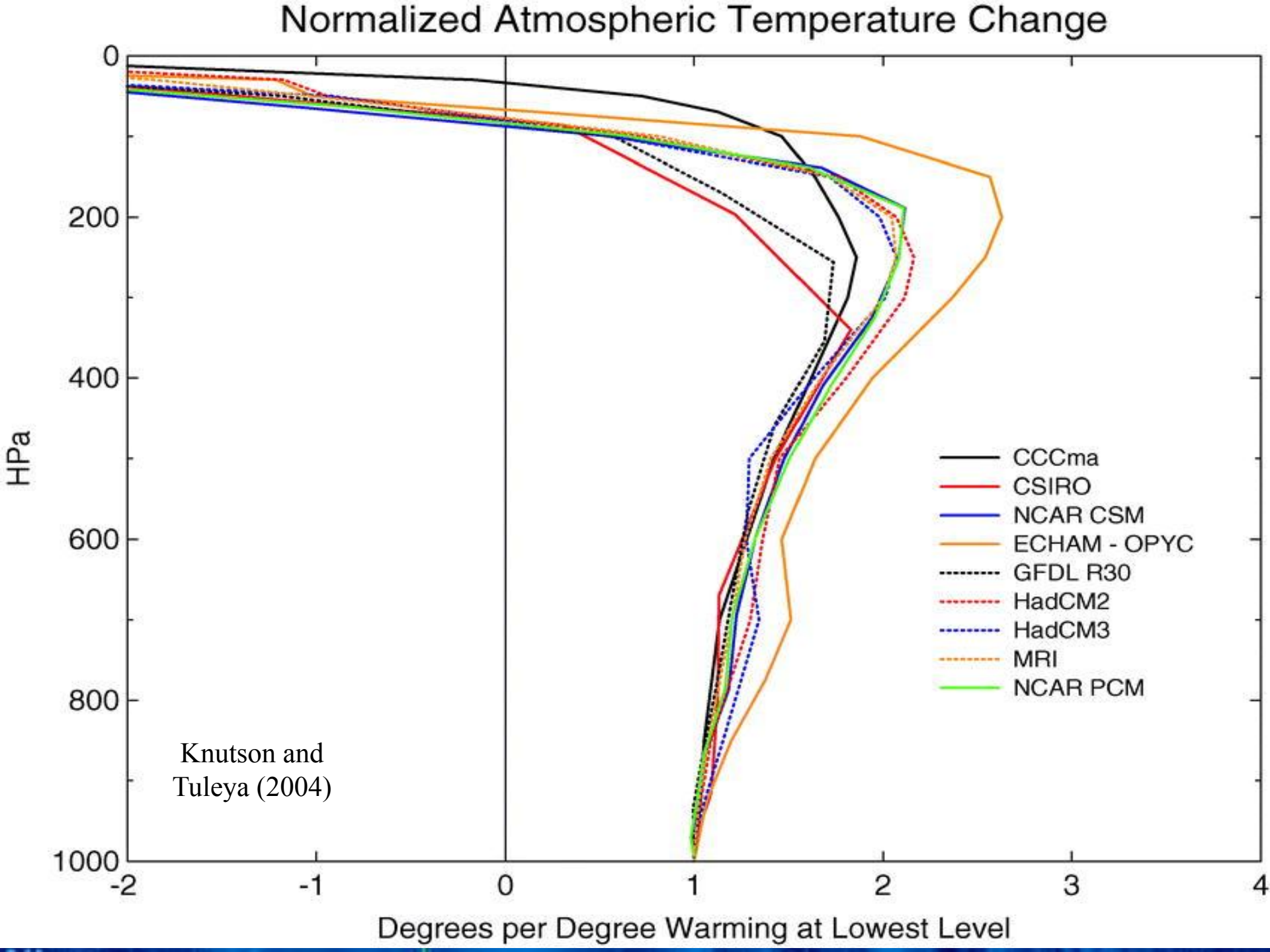
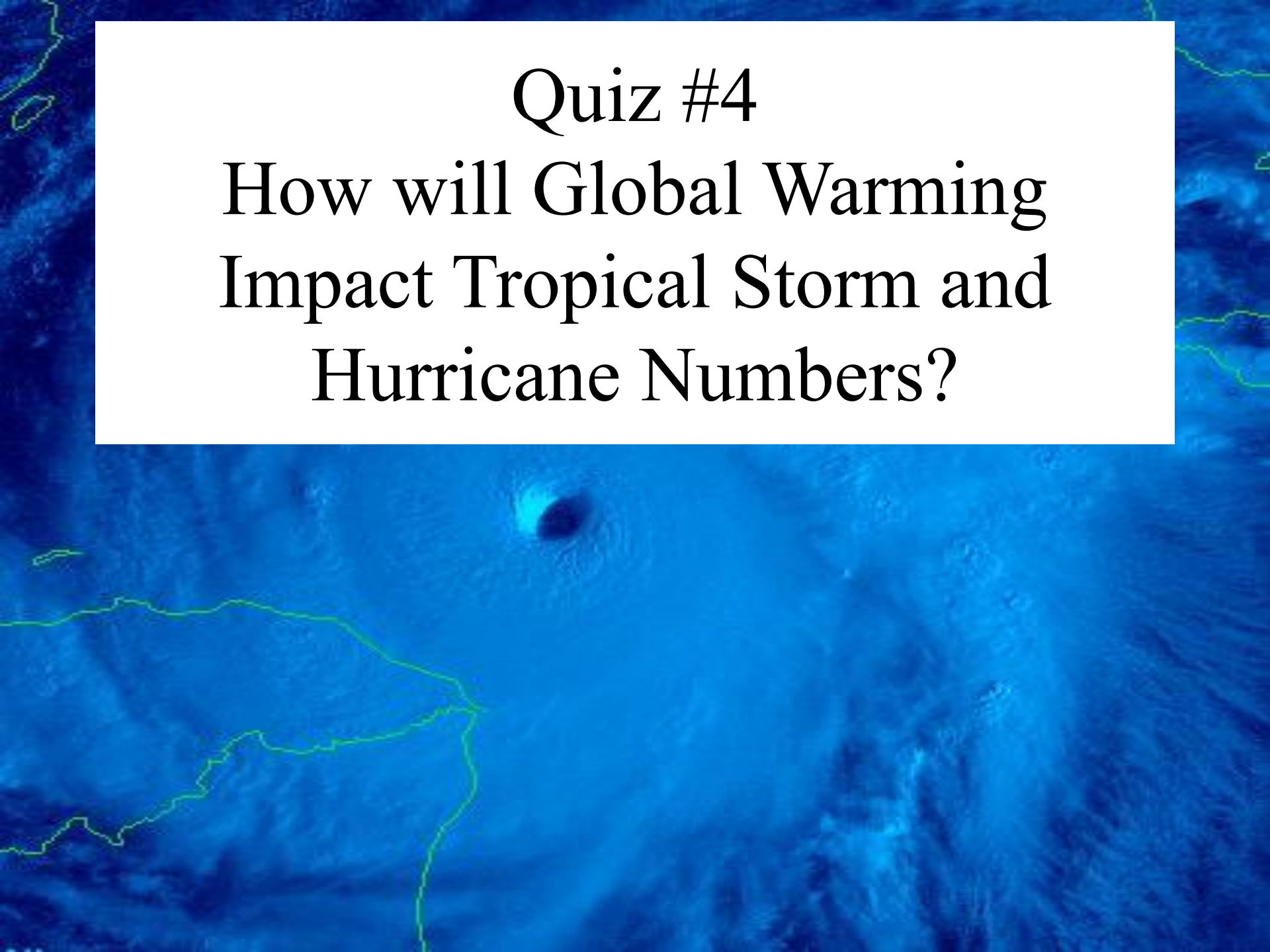


Maximum Potential Intensity Change
Atlantic Basin: +1% stronger per ºC SST change
Vecchi and Soden (2007)


Normalized Atmospheric Temperature Change
HPa
0
200
400
600
800
1000
-2
-1
0
1
2
3
4
Degrees per Degree Warming at Lowest Level
CCCma
CSIRO
NCAR CSM
ECHAM - OPYC
GFDL R30
HadCM2
HadCM3
MRI
NCAR PCM
Knutson and
Tuleya (2004)

Quiz #4
How will Global Warming Impact Tropical Storm and Hurricane Numbers?



Quiz #4
How will Global Warming Impact Tropical Storm and Hurricane Numbers?

A. 50% More
B. 25% More
C. No change
D. 25% Fewer

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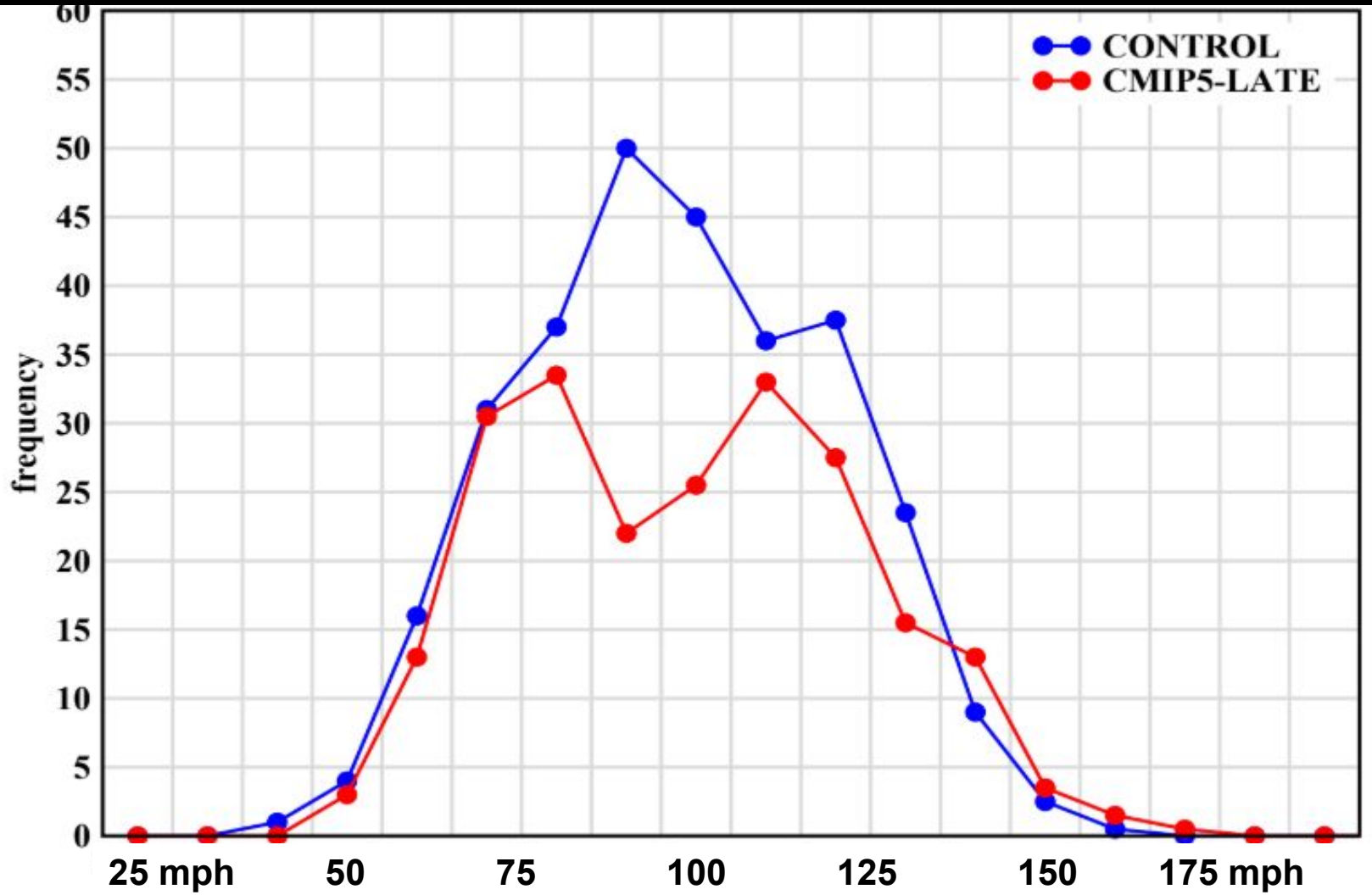
Global Warming and Hurricanes:
Theory and Modeling Work Suggest a sizable DECREASE in frequency by late 21st Century



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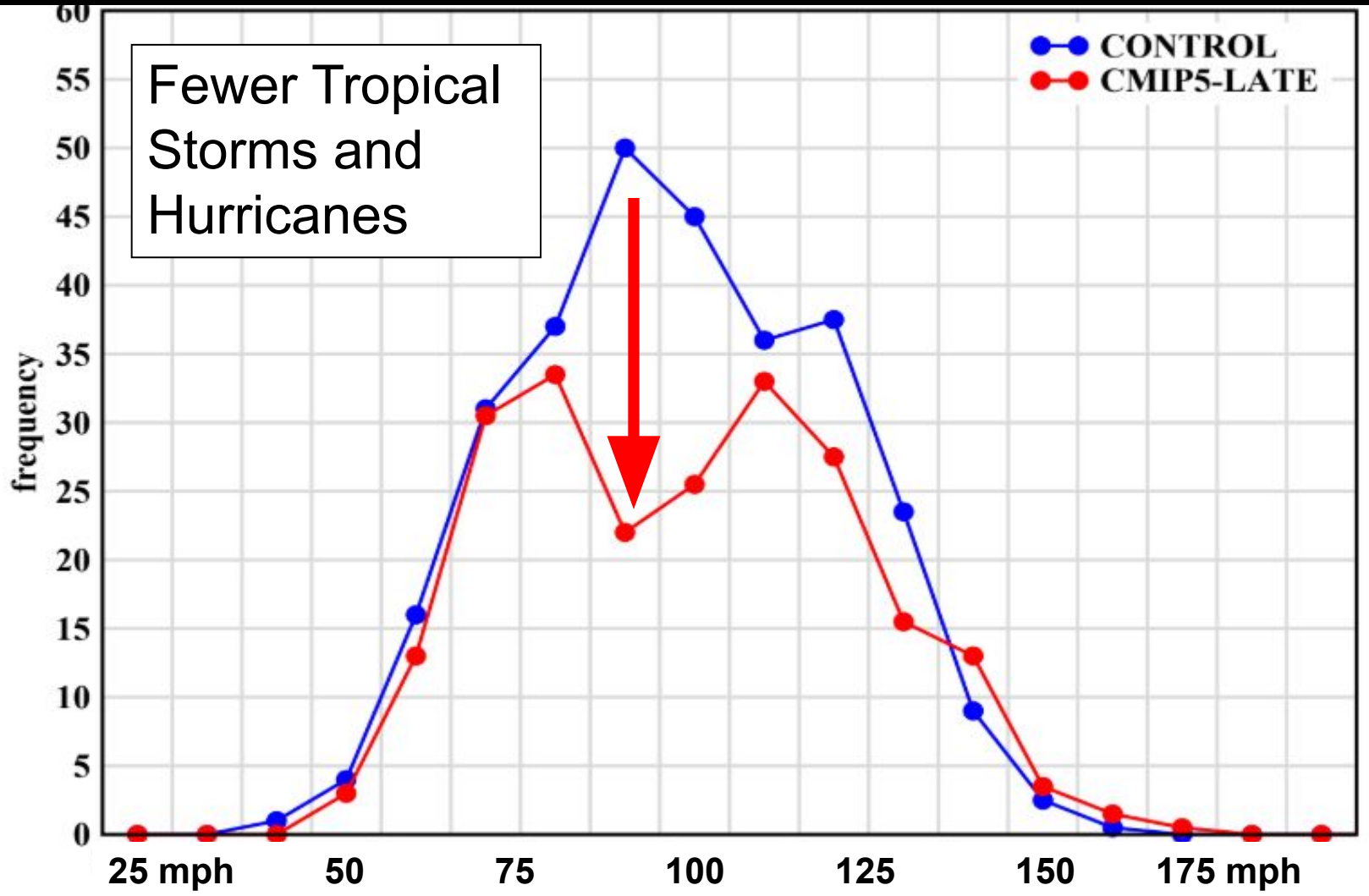
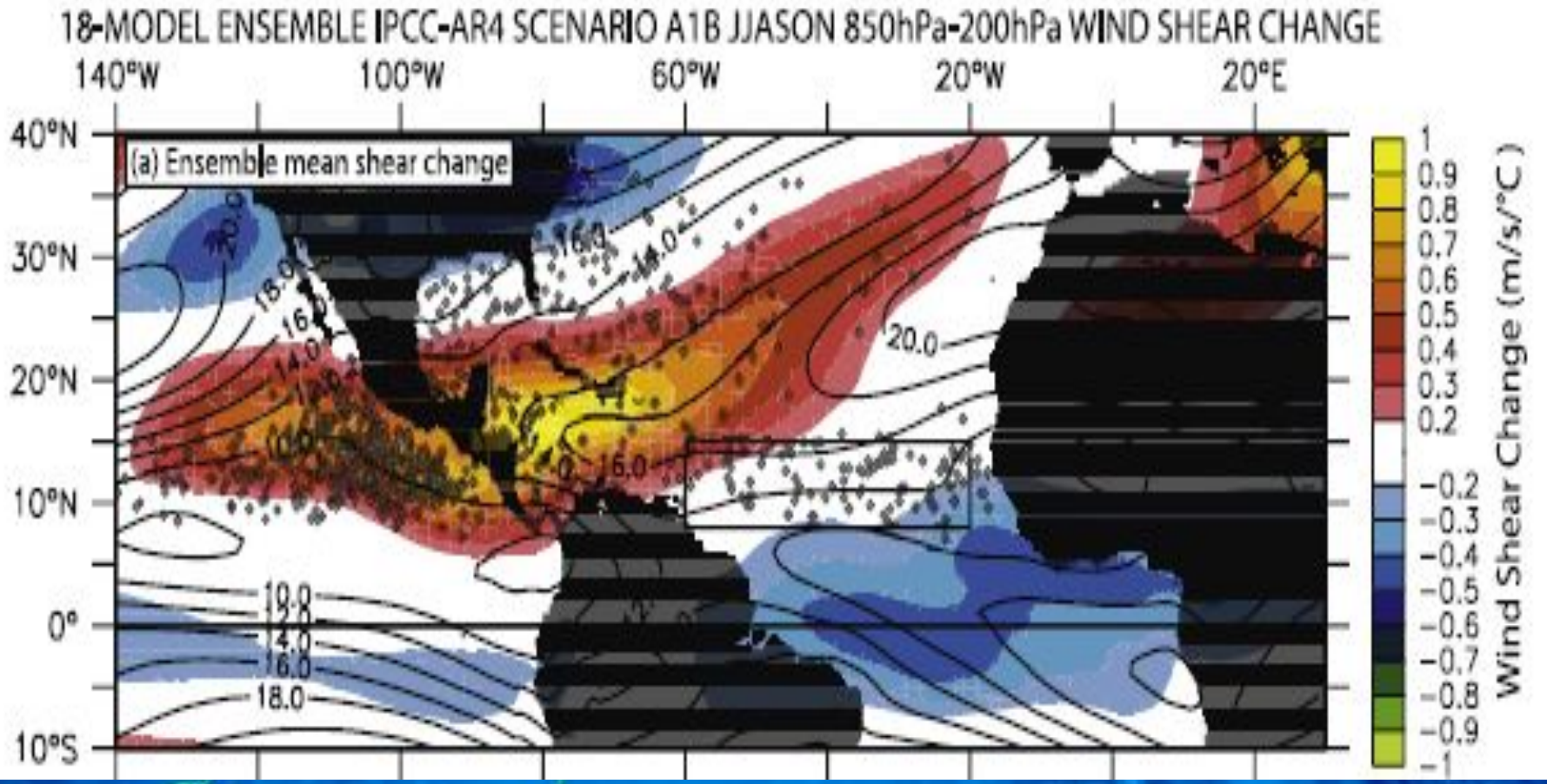
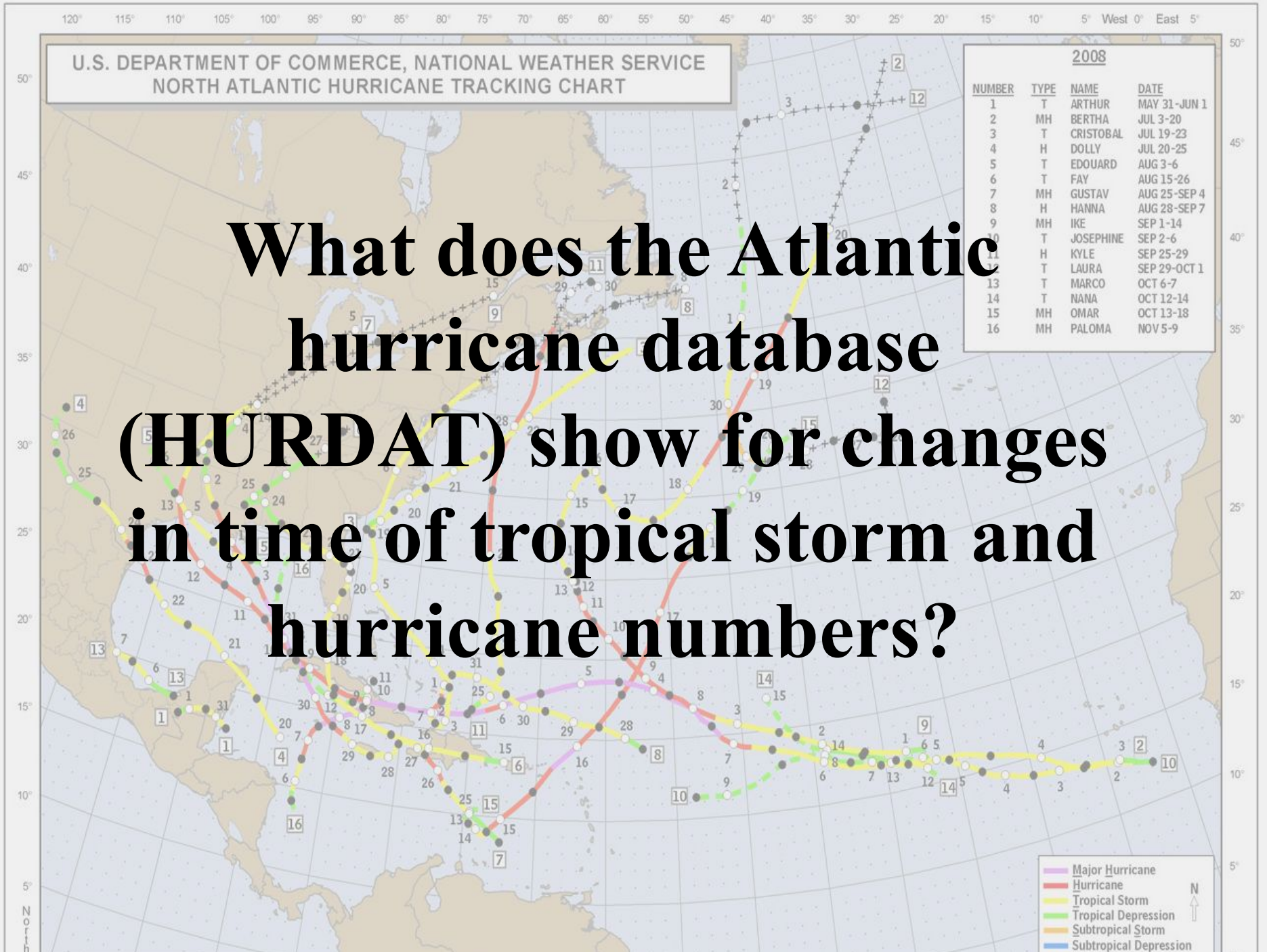


Knutson et al. (2013)

Increased Wind Shear and More Stable Mid-Level Atmosphere from Global Warming



Vecchi and Soden (2007)



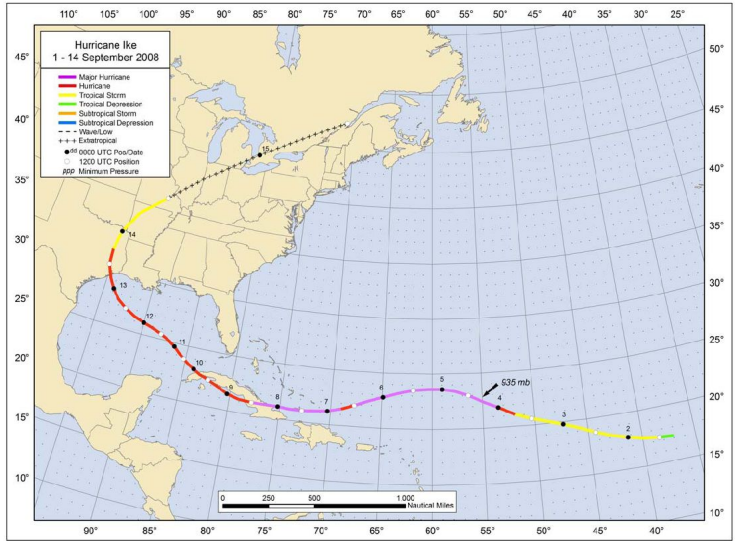
What does the Atlantic hurricane database (HURDAT) show for changes in time of tropical storm and hurricane numbers?

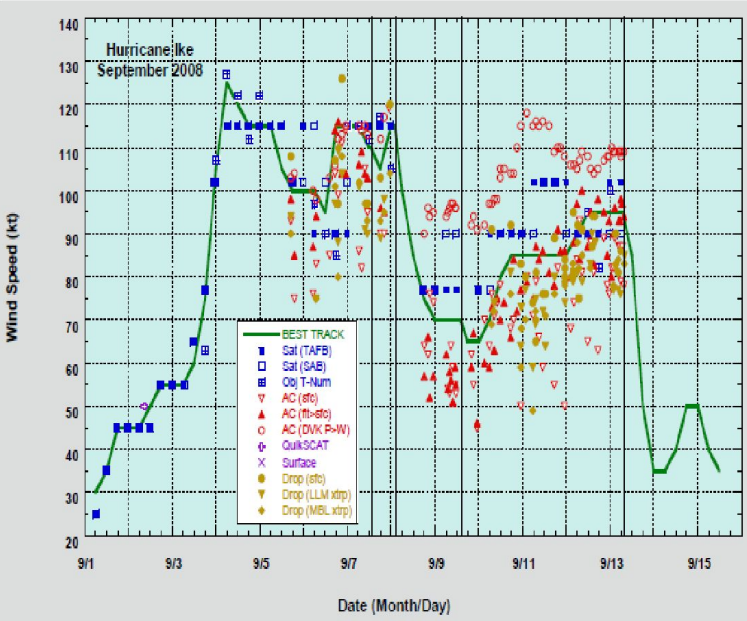
HURDAT

The National Hurricane Center maintains and updates annually the North Atlantic Basin's Hurricane Database (HURDAT)

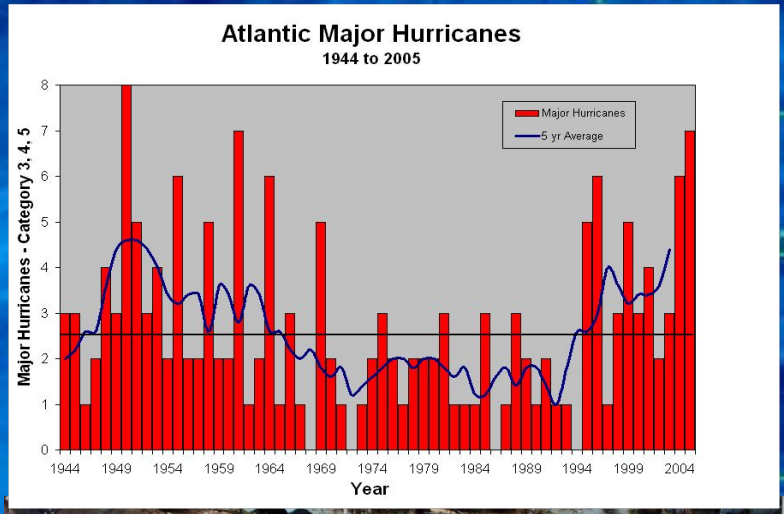
HURDAT provides from 1851 to 2022 for all tropical storms, subtropical storms, and hurricanes every 6 hours (metadata):

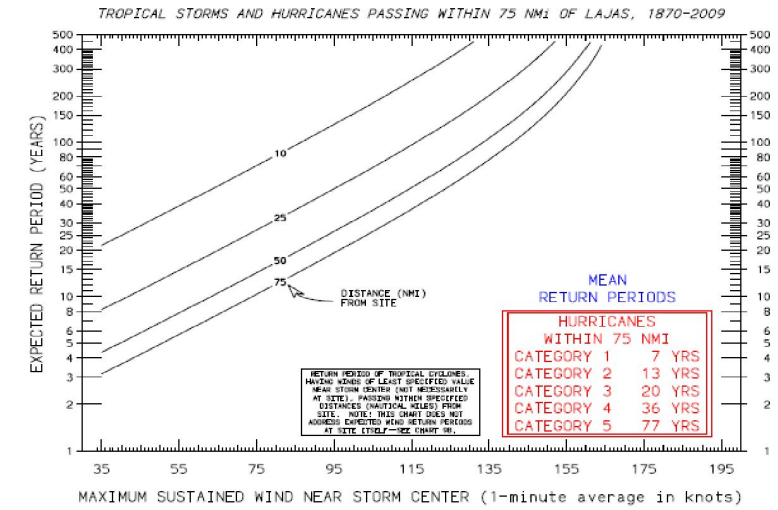
- **Positions** (to nearest 0.1 degree latitude/longitude)
- **Intensity** (1 min surface winds to nearest 10 kt from 1851-1885, 5 kt from 1886 onward)
- **Central pressure** (to nearest 1 mb, when observed)
- **34, 50, and 64 kt wind radii maximum extent** since 2004 (by quadrant, to nearest 10 nmi)
- **Radius of Maximum Wind (RMW)** since 2021 (to nearest 5 nmi)



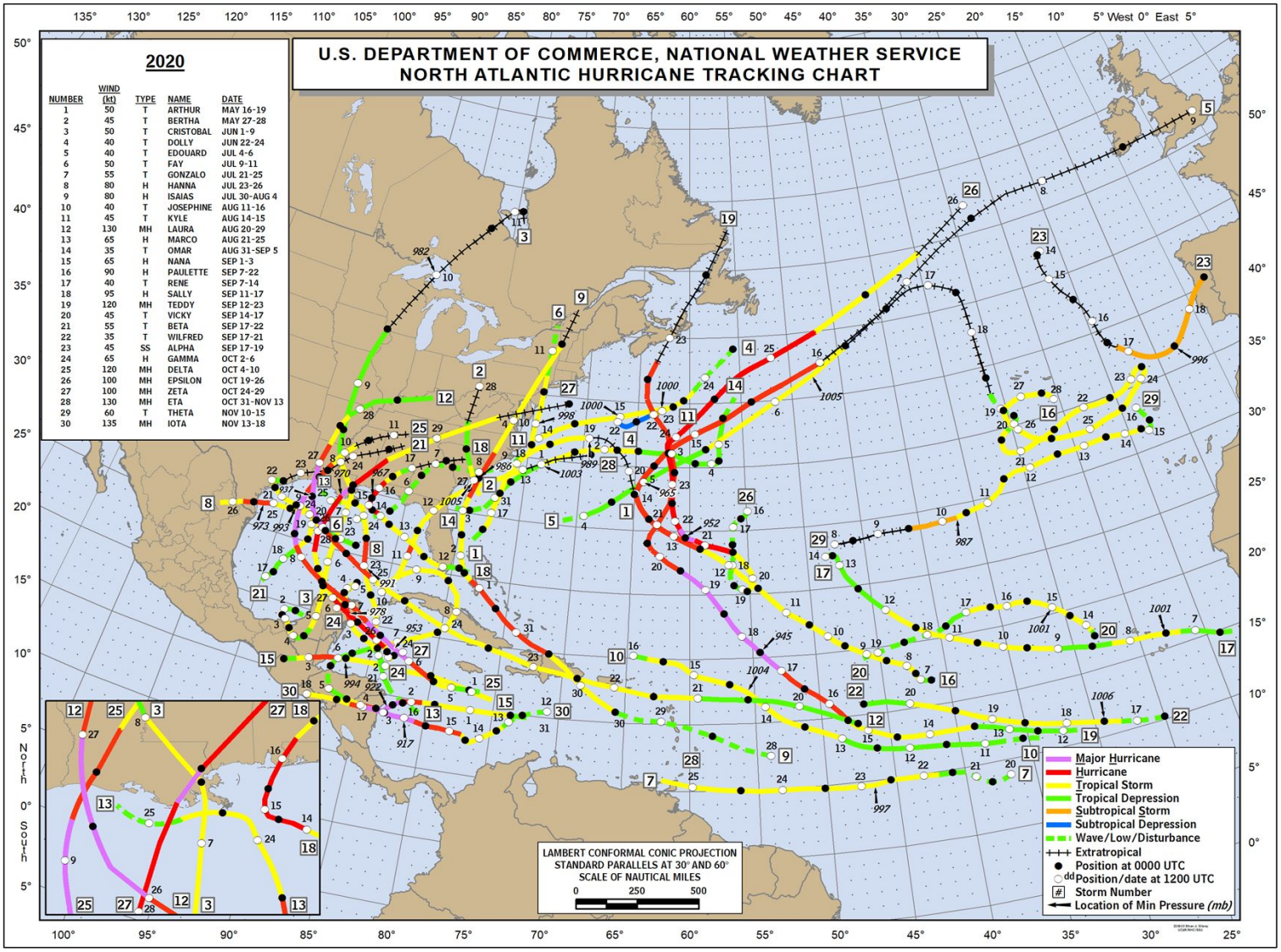


- HURDAT applications:
  - Validation of official and model predictions
  - Climate trend assessment – long term trends, seasonal forecasts, etc.
  - Building code standards and insurance rates for coastal communities
  - Risk assessment for emergency managers (recurrence intervals)





2020 – Record-breaking hurricane season

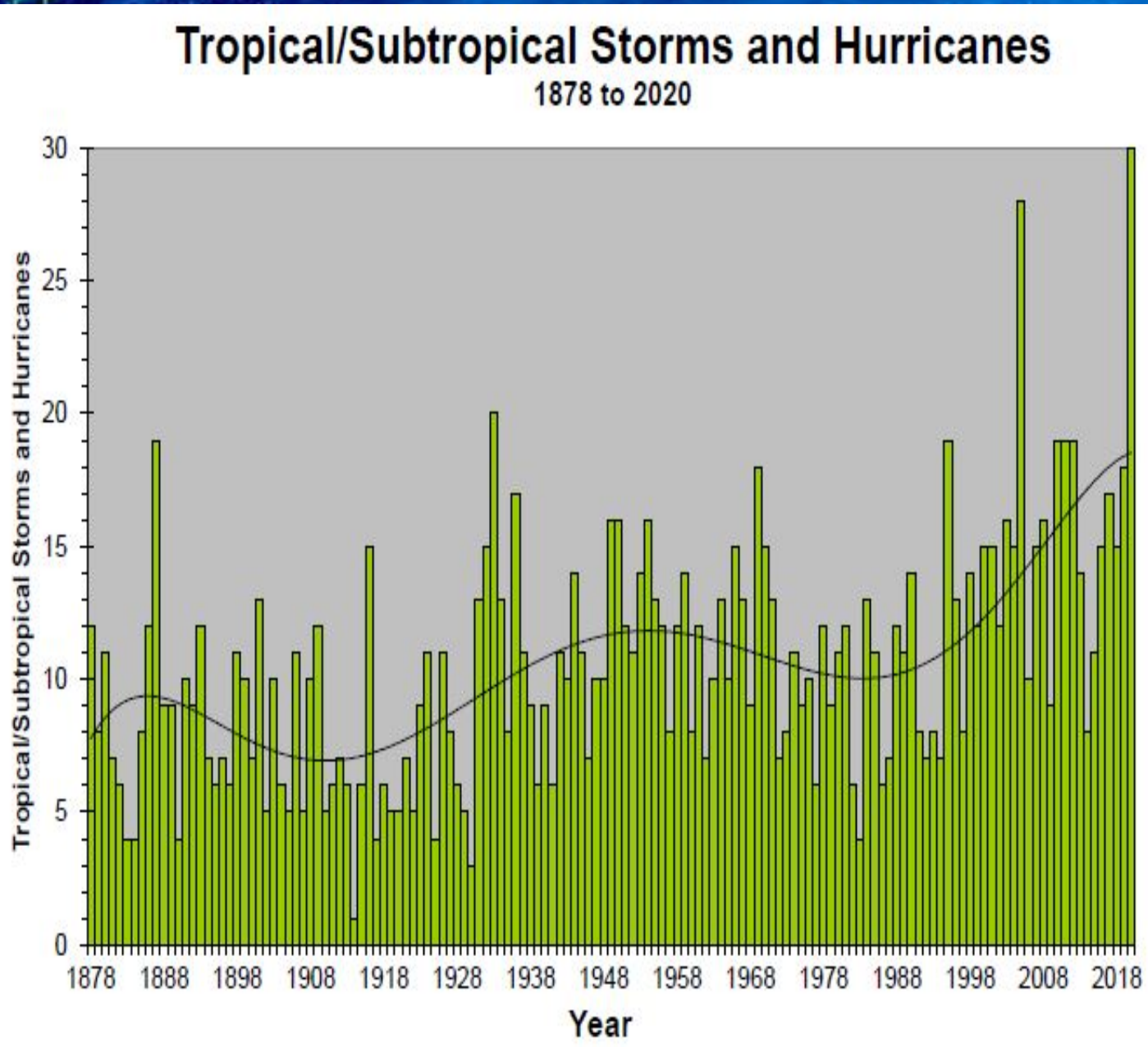


Record **30** **"Named" Storms**

Record **13 U.S. named storms**

Record yearly total of **7** **billion-dollar tropical cyclone damage events**

Named Storms

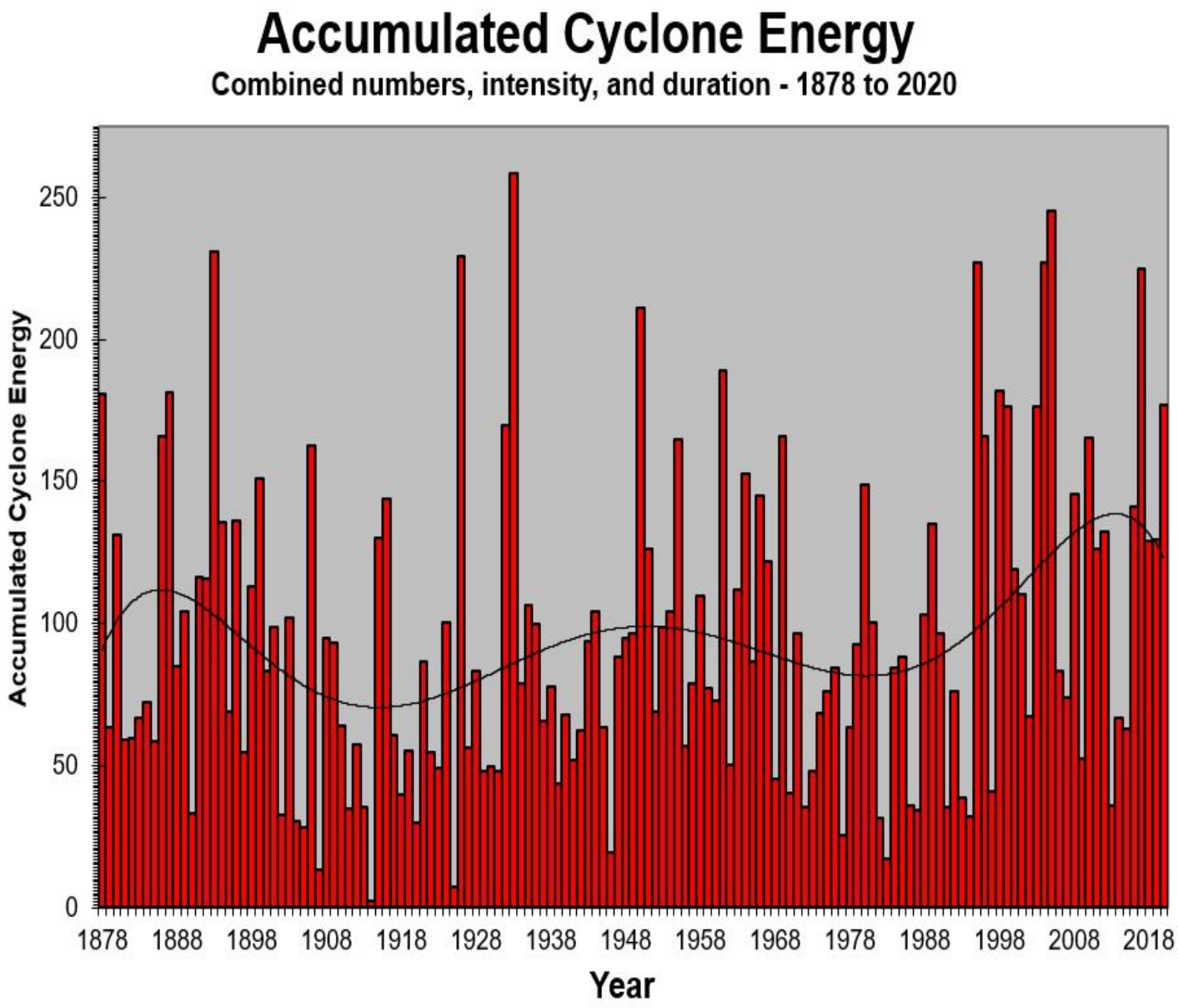


30 Named Storms

-

Busiest on record

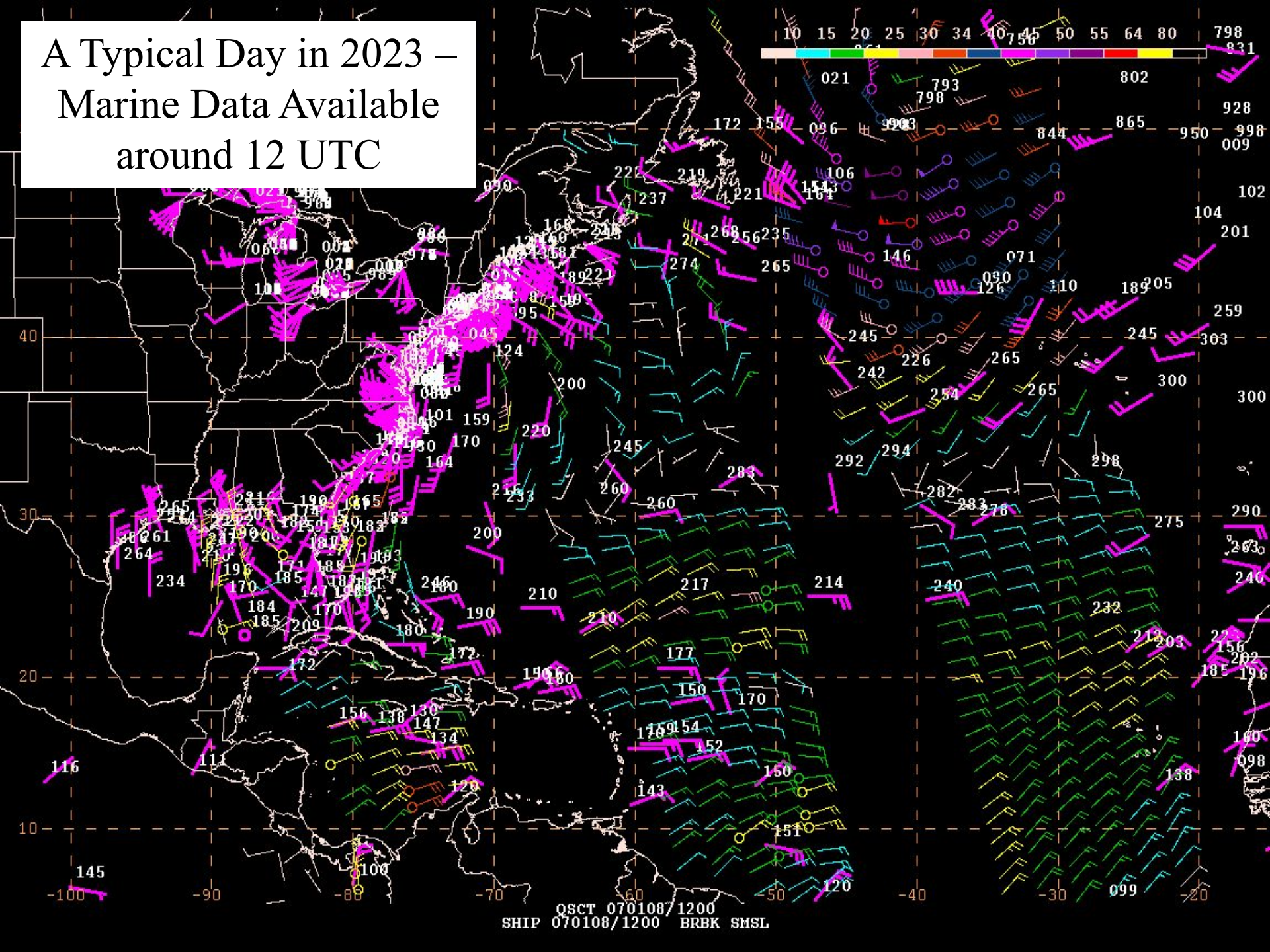
Accumulated Cyclone Energy



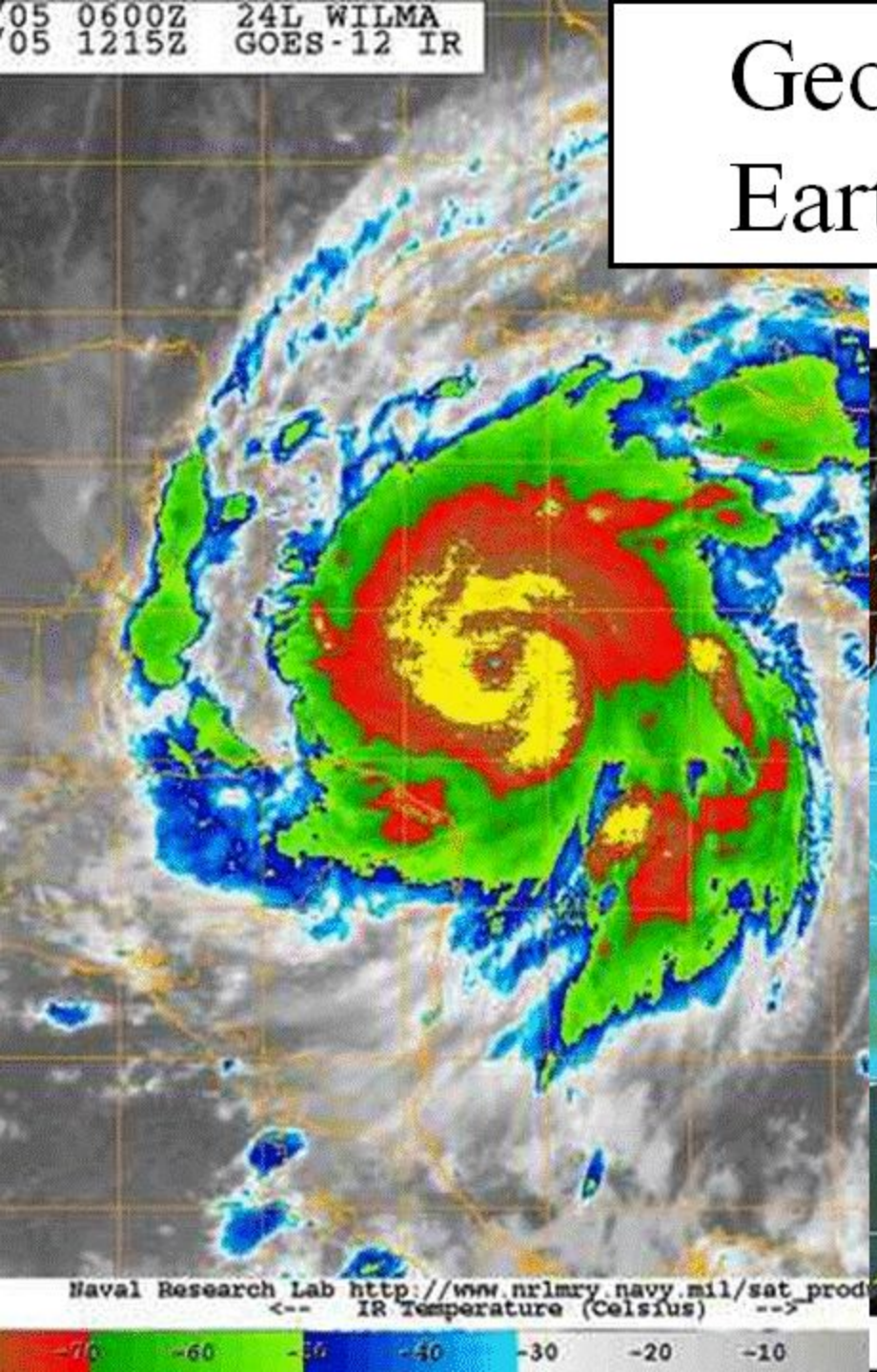
180 ACE

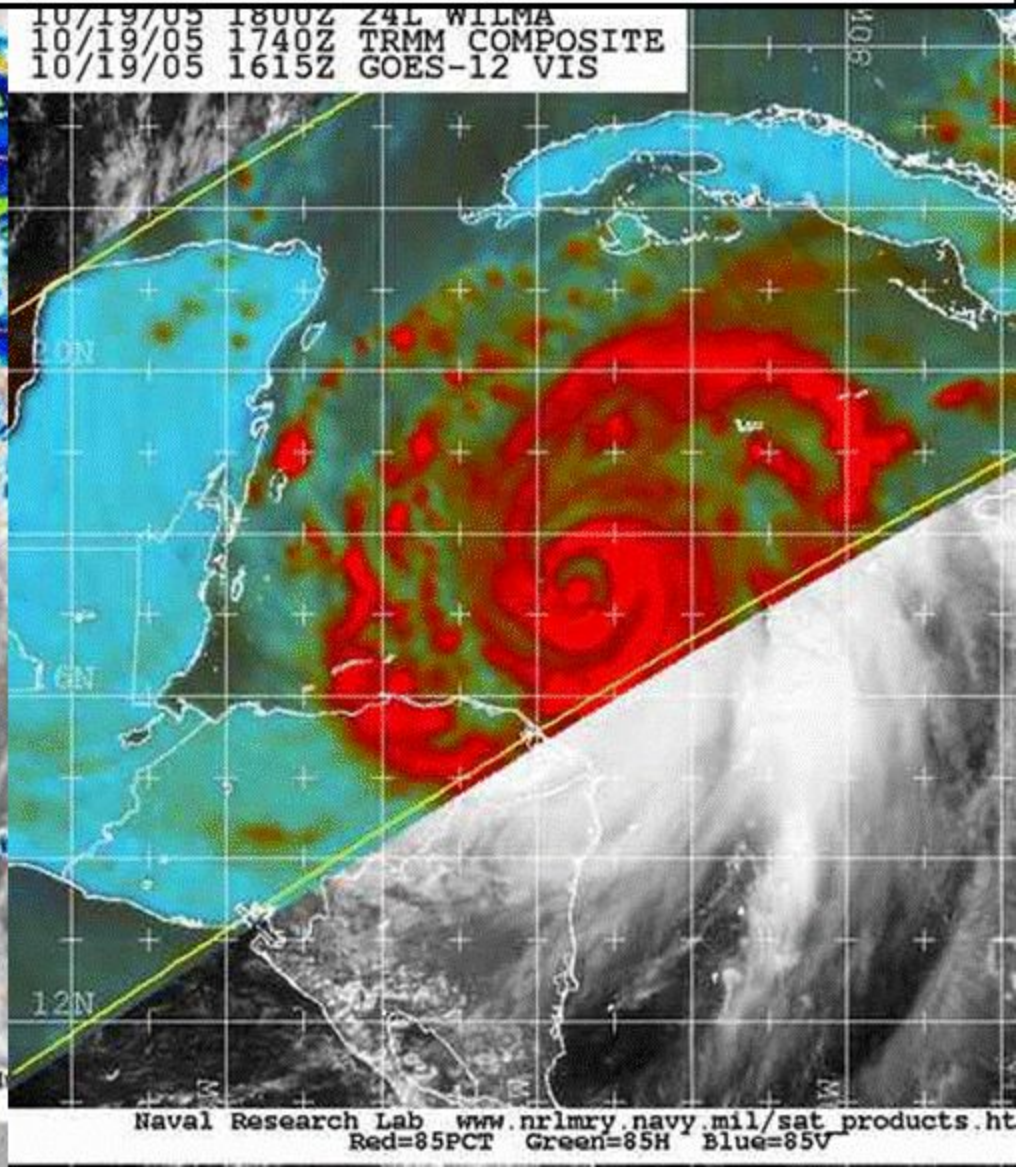
-

13th busiest on record

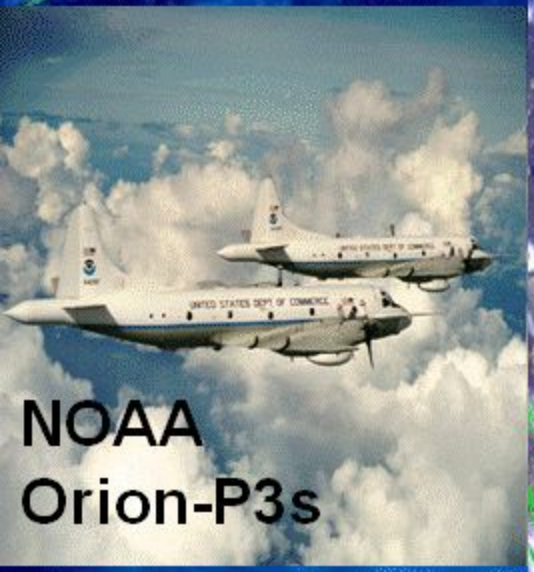

A Typical Day in 2023 – Marine Data Available around 12 UTC
10 15 20 25 30 34 40 45 50 55 64 80
QSCT 070108/1200
SHIP 070108/1200 BRBK SMSL

Geostationary and Low-Earth Orbiting Satellites



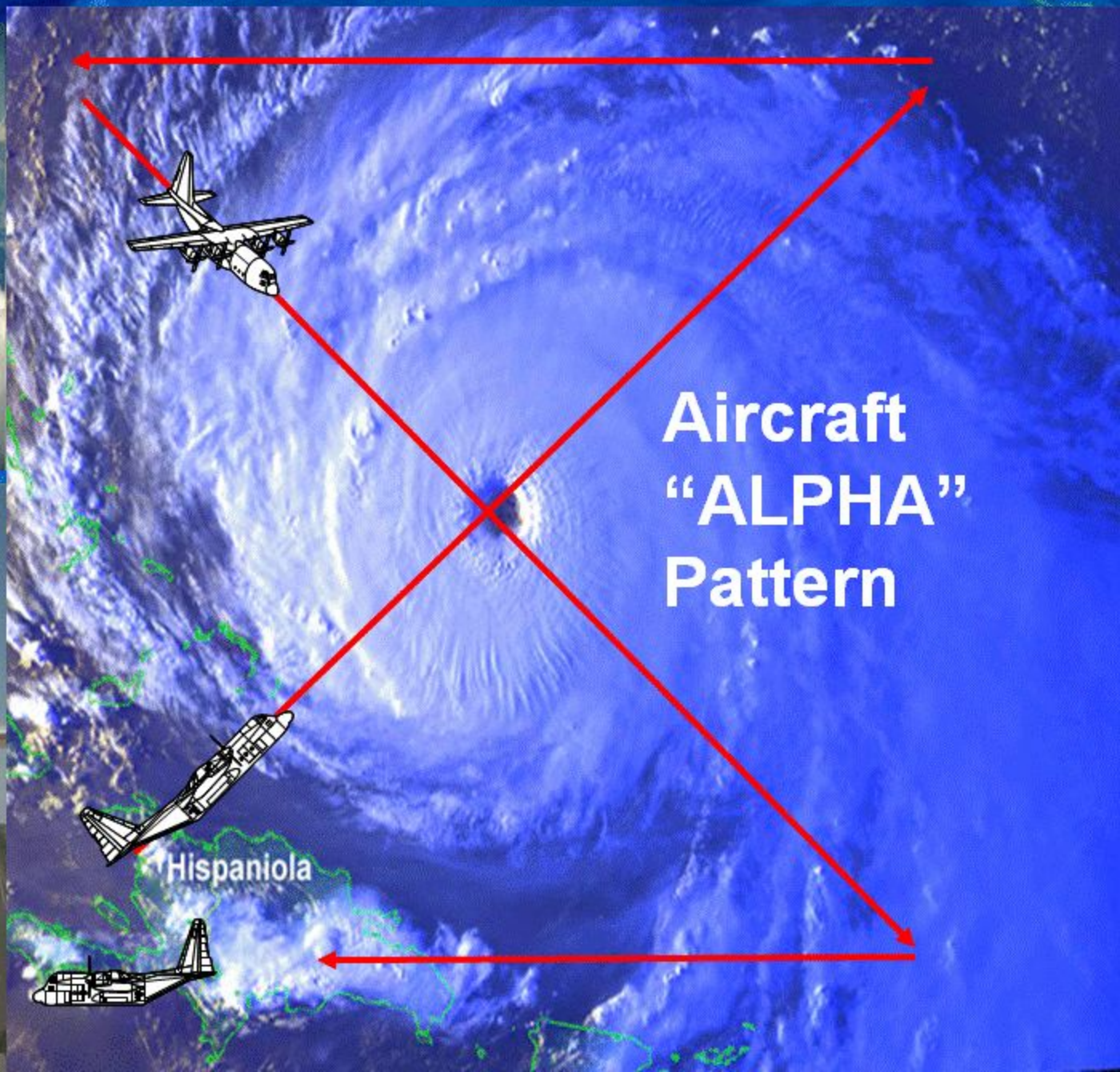


RECONNAISSANCE FLIGHT PATH

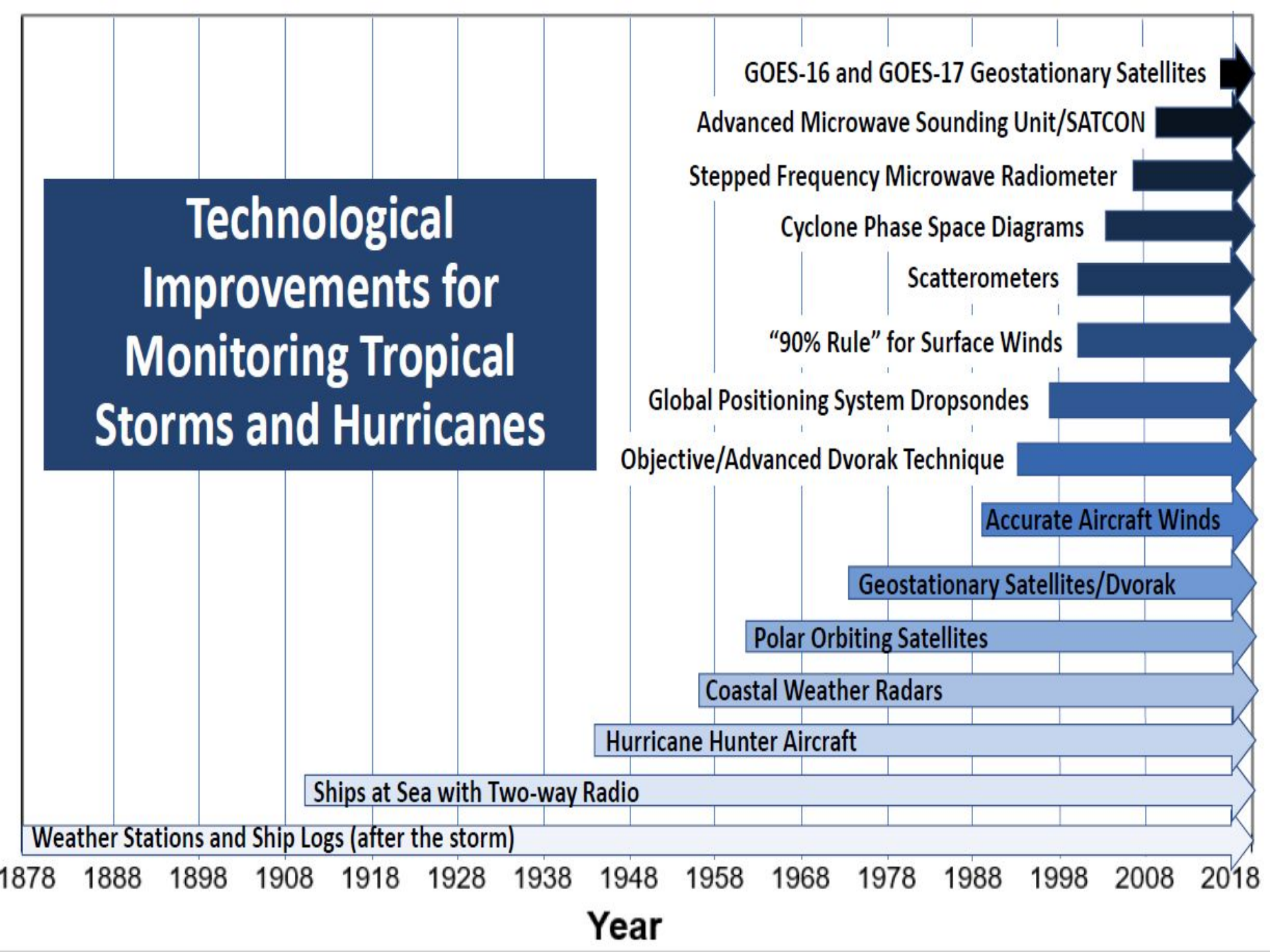


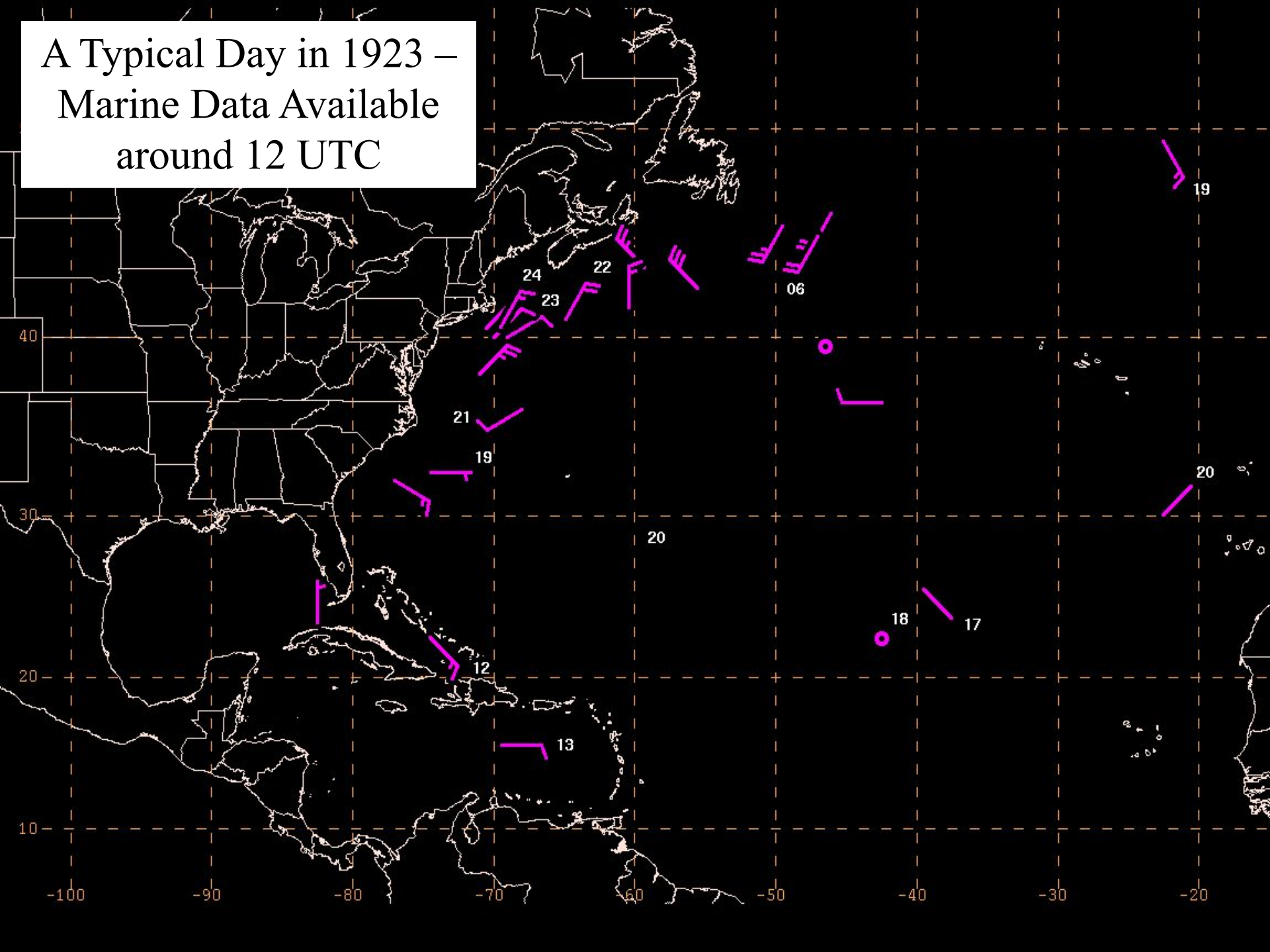
NOAA
Orion-P3s

Air Force
C-130s



Aircraft
"ALPHA"
Pattern

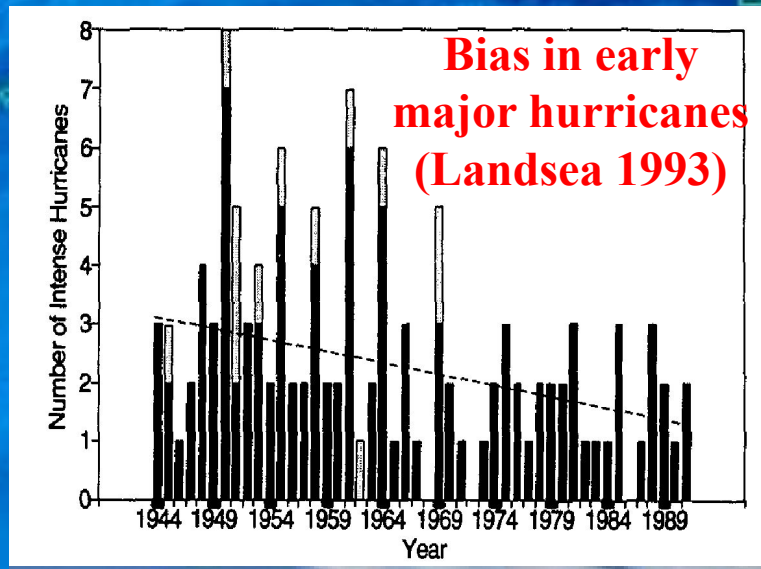

Technological Improvements for Monitoring Tropical Storms and Hurricanes
GOES-16 and GOES-17 Geostationary Satellites
Advanced Microwave Sounding Unit/SATCON
Stepped Frequency Microwave Radiometer
Cyclone Phase Space Diagrams
Scatterometers
"90% Rule" for Surface Winds
Global Positioning System Dropsondes
Objective/Advanced Dvorak Technique
Accurate Aircraft Winds
Geostationary Satellites/Dvorak
Polar Orbiting Satellites
Coastal Weather Radars
Hurricane Hunter Aircraft
Ships at Sea with Two-way Radio
Weather Stations and Ship Logs (after the storm)
1878 1888 1898 1908 1918 1928 1938 1948 1958 1968 1978 1988 1998 2008 2018
Year


A Typical Day in 1923 – Marine Data Available around 12 UTC
19
24
22
23
06
40
21
19
20
30
20
18
17
12
13
20
10
-100
-90
-80
-70
-60
-50
-40
-30
-20

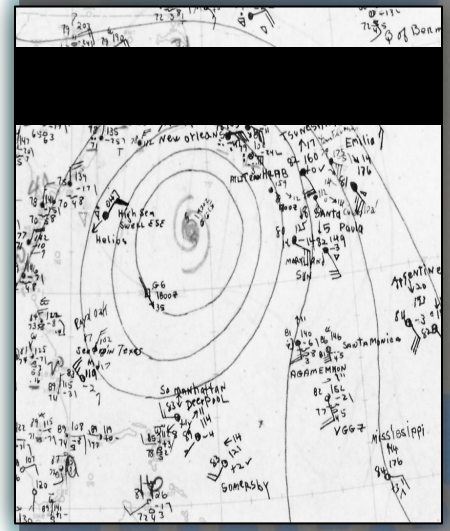
A Typical Day in 1923
M

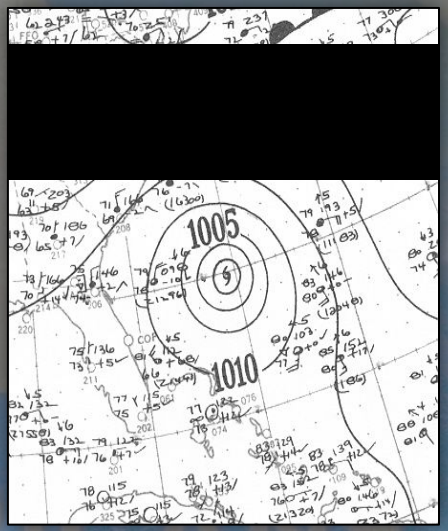
Why revise HURDAT?

- HURDAT contains many systematic and random errors
  - 1938 Hurricane: Cat 3 at landfall, but 85kts at last offshore position
- "Missing storms"
- Lack of exact hurricane landfall parameters
- Advances in the understanding of hurricanes and analysis techniques

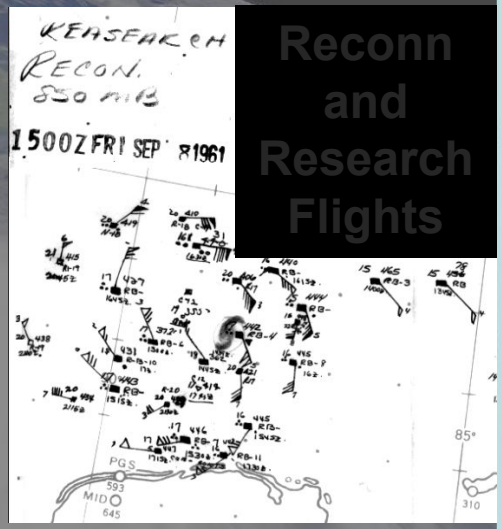


Data Sources





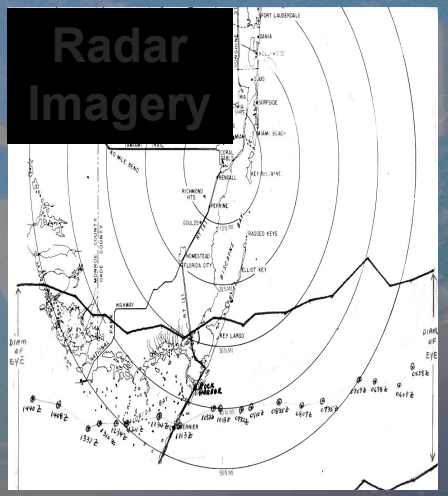
Comprehensive Ocean-Atmosphere Data Set

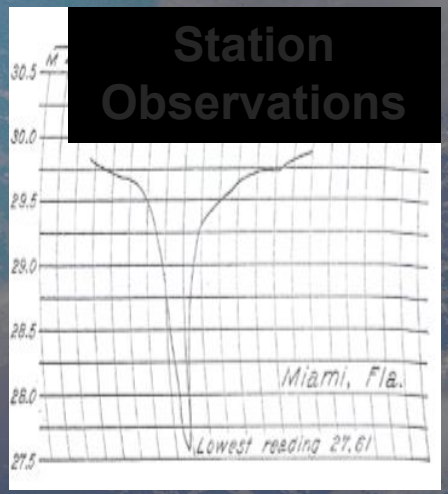


Reconn and Research Flights

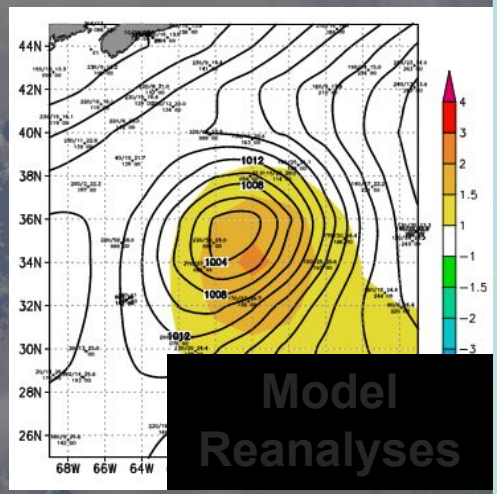
Satellite Imagery

Radar Imagery



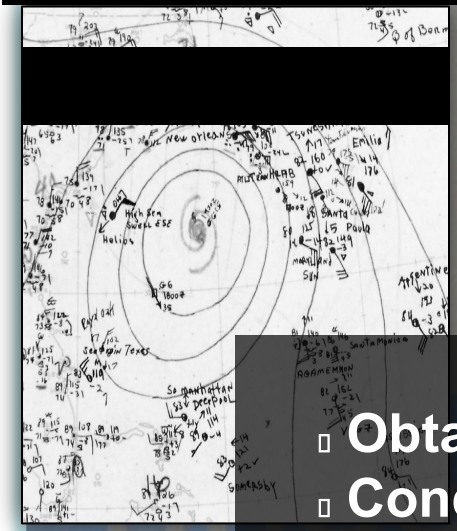


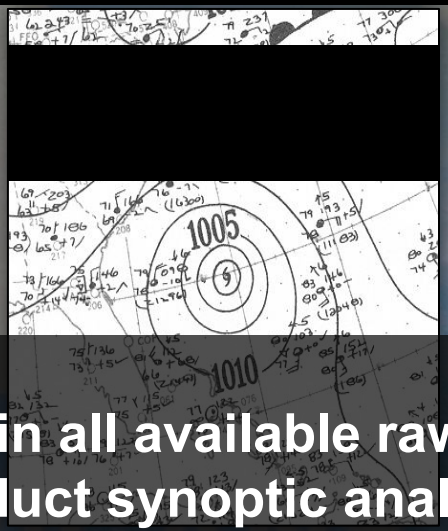
Station Observations



Model Reanalyses

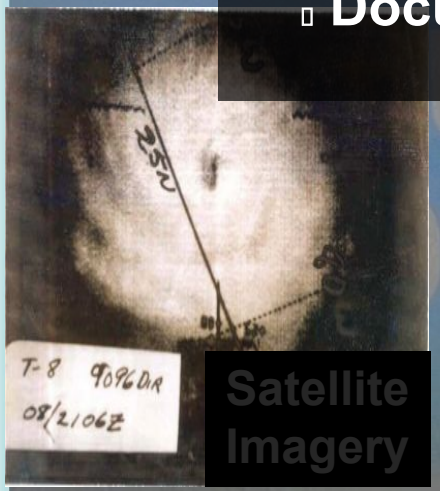
How is the reanalysis conducted?



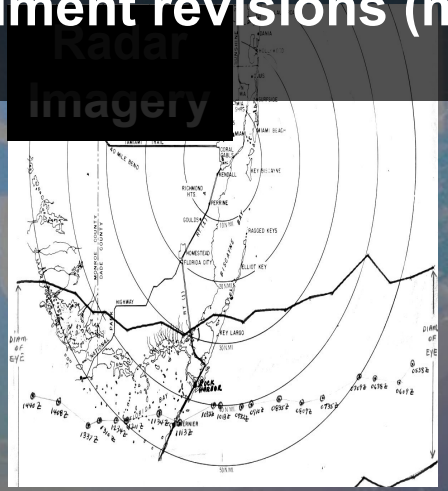


Reconn and Research Flights

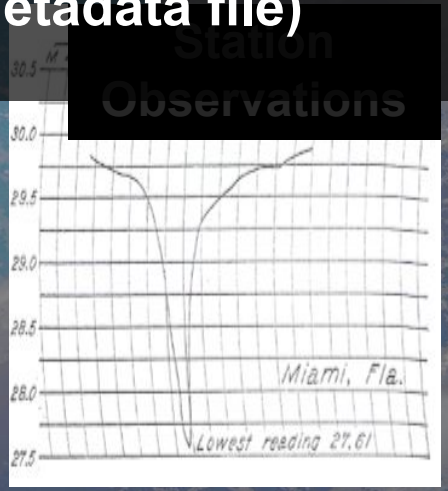
- Obtain all available raw data into a single database
- Conduct synoptic analysis four times daily
- Determine track, intensity, structure, genesis/dissipation
- Document revisions (metadata file)



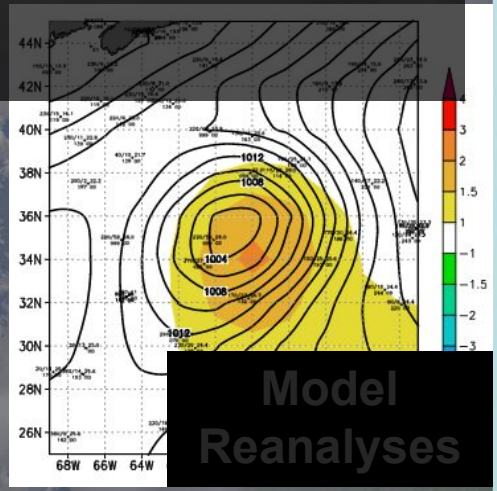
Satellite Imagery



Radar Imagery



Station Observations



Model Reanalyses

U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART

ORIGINAL

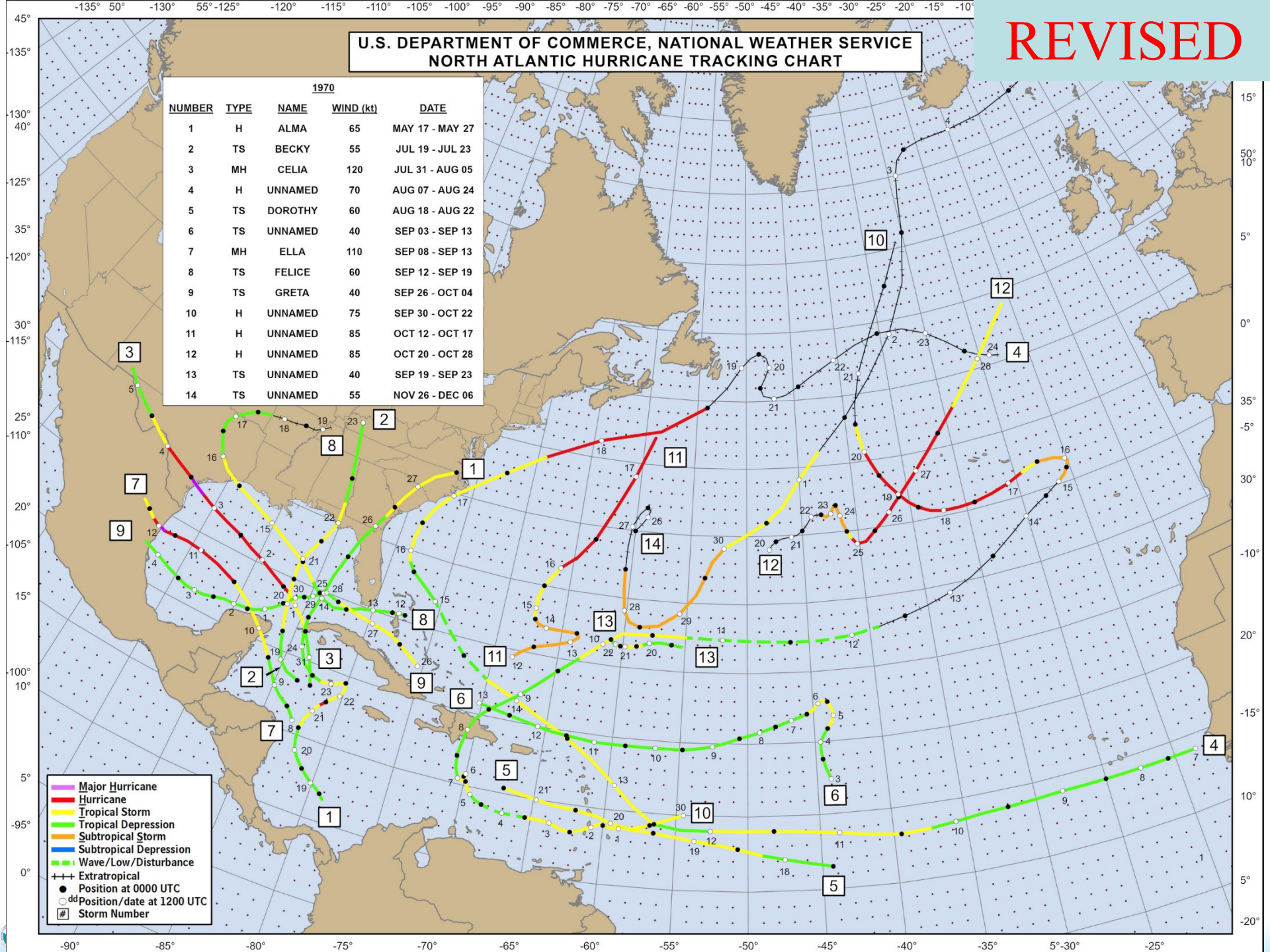
NORTH ATLANTIC TROPICAL STORMS ORIGINATING IN THE PERIOD 1970

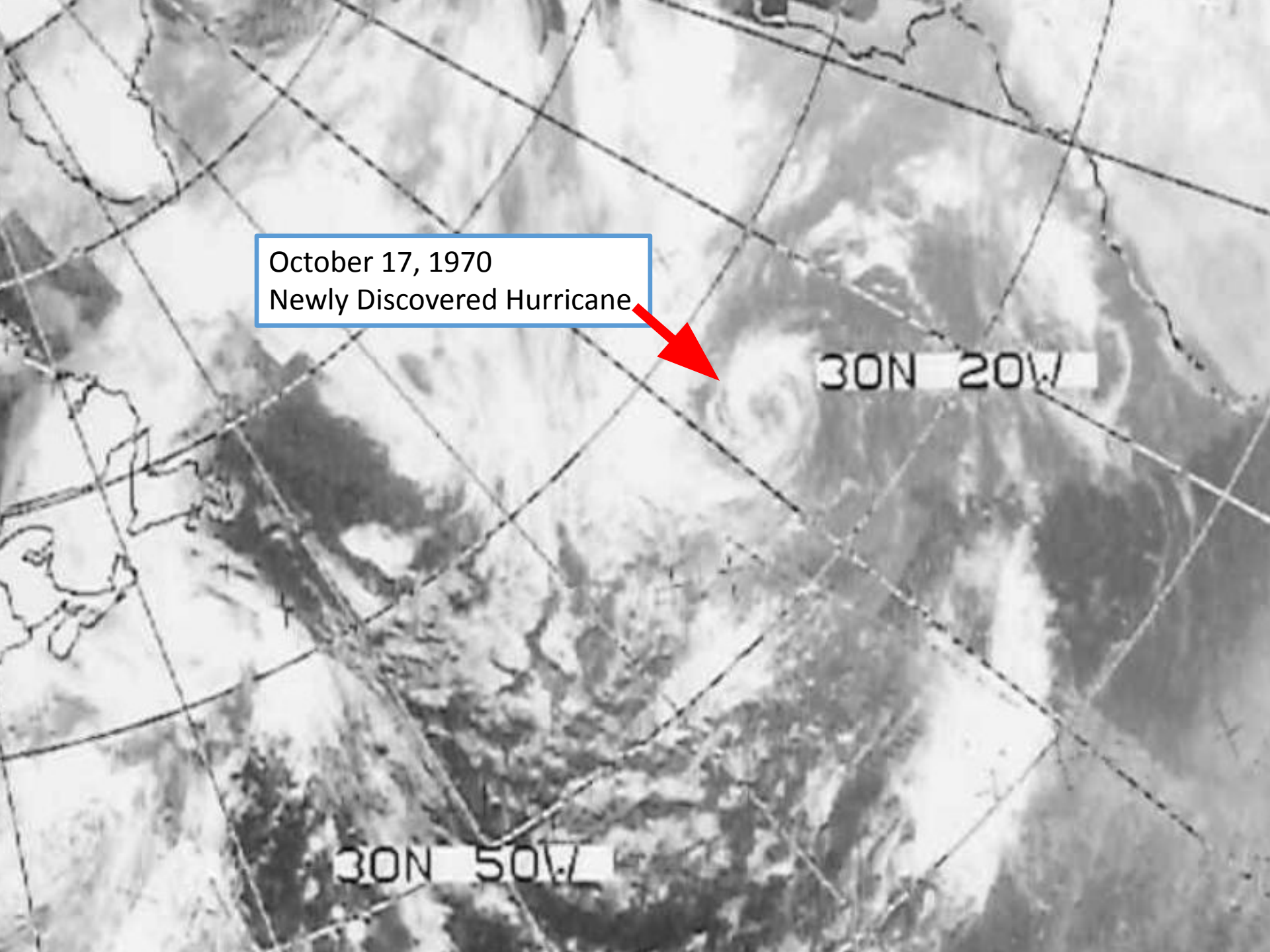
NUMBER	TYPE	NAME	WIND (kt)	DATE (UTC)
1	H	ALMA	70	MAY 17 - MAY 27
2	T	BECKY	55	JUL 19 - JUL 23
3	MH	CELIA	110	JUL 31 - AUG 5
4	T	----	60	AUG 15 - AUG 19
5	T	DOROTHY	60	AUG 17 - AUG 23
6	MH	ELLA	110	SEP 8 - SEP 13
7	T	FELICE	60	SEP 12 - SEP 17
8	T	GRETA	45	SEP 26 - OCT 5
9	H	----	90	OCT 12 - OCT 18
10	H	----	65	OCT 20 - OCT 28

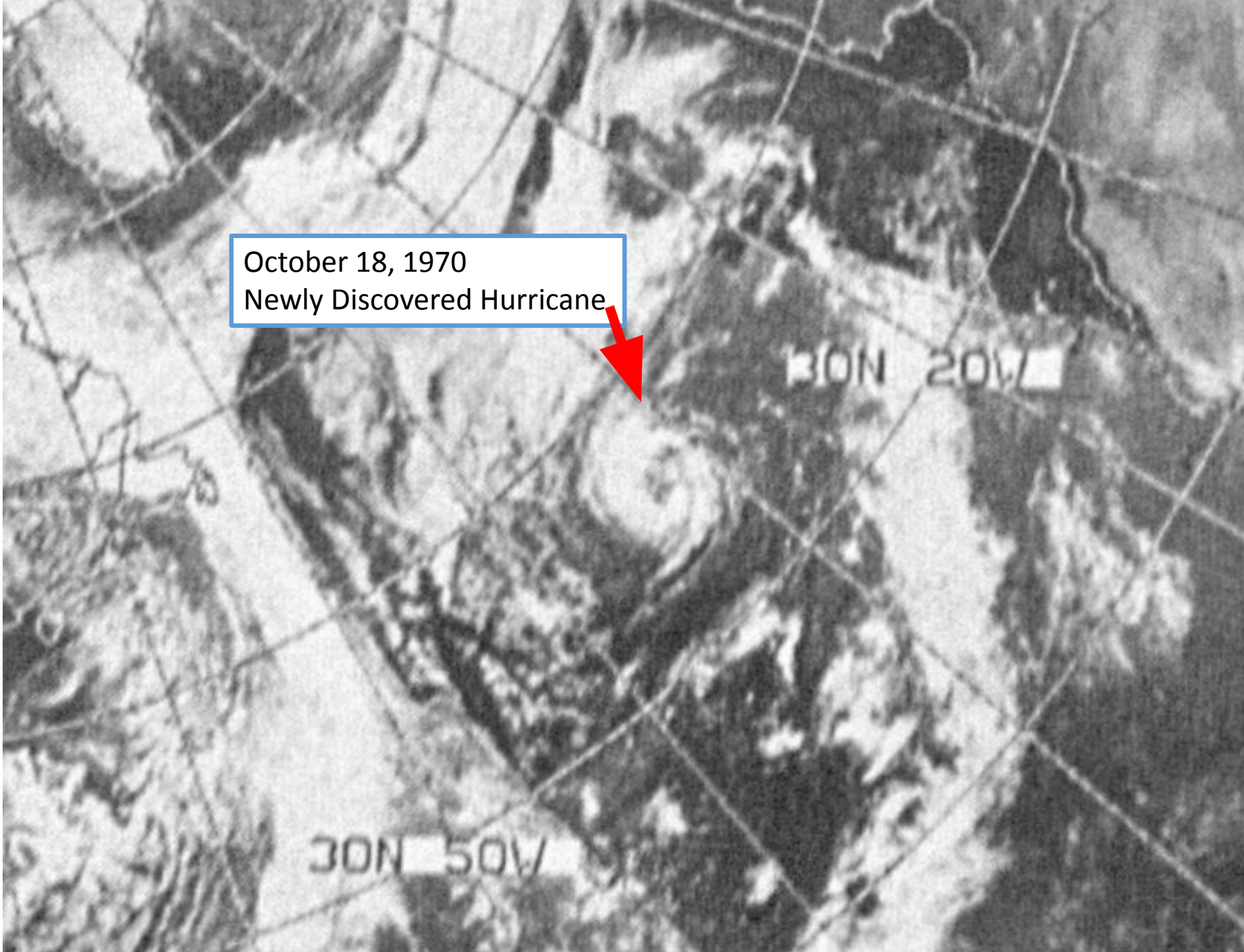
Major Hurricane: Category 3 or higher.
Hurricane: Reached hurricane intensity.
Tropical Storm
Tropical Depression
Extratropical Stage
Wave
Subtropical Depression (winds less than 34 kt)
Subtropical Storm (winds 34 kt or higher)
5 Position/date at 7:00 am E.S.T.
Position at 7:00 pm E.S.T.
4 Tropical Cyclone Number

LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30° AND 60°
SCALE OF NAUTICAL MILES
0 250 500

JED_07


U.S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
REVISED
1970
NUMBER TYPE NAME WIND (kt) DATE
1 H ALMA 65 MAY 17 - MAY 27
2 TS BECKY 55 JUL 19 - JUL 23
3 MH CELIA 120 JUL 31 - AUG 05
4 H UNNAMED 70 AUG 07 - AUG 24
5 TS DOROTHY 60 AUG 18 - AUG 22
6 TS UNNAMED 40 SEP 03 - SEP 13
7 MH ELLA 110 SEP 08 - SEP 13
8 TS FELICE 60 SEP 12 - SEP 19
9 TS GRETA 40 SEP 26 - OCT 04
10 H UNNAMED 75 SEP 30 - OCT 22
11 H UNNAMED 85 OCT 12 - OCT 17
12 H UNNAMED 85 OCT 20 - OCT 28
13 TS UNNAMED 40 SEP 19 - SEP 23
14 TS UNNAMED 55 NOV 26 - DEC 06
Major Hurricane
Hurricane
Tropical Storm
Tropical Depression
Subtropical Storm
Subtropical Depression
Wave/Low/Disturbance
Extratropical
Position at 0000 UTC
dd Position/date at 1200 UTC
Storm Number


October 17, 1970
Newly Discovered Hurricane
30N 20W
30N 50W


October 18, 1970
Newly Discovered Hurricane
30N 20W
30N 50W

Highlights of Changes

- 14 new tropical storms were discovered during these five hurricane seasons and added to the database
- Additionally, two new hurricanes were diagnosed, which previously were only considered to be a tropical depression (AL151970) and a tropical storm (AL081970).
- On the flip side, two major hurricanes (Francelia - AL131969 and Inga - AL201969) were downgraded to a Saffir-Simpson Hurricane Scale category 2 hurricane
- U.S. hurricanes were reduced from 7 to 6, due to Gerda's downgrade to tropical storm impact
- U.S. major hurricanes were increased from 3 to 4, due to Alma's upgrade to Category 3

	TS+H	H	MH	ACE
Original	11.0	6.8	2.2	103.6
Revised	13.8	7.2	1.8	105.6

Year	Storm	State	Max Cat	Cat Change	Max Wind (kt)	Wind Change
1966	Alma	FL	3 (2)	+1	100 (110)	-10
1966	Inez	FL	2 (1)	+1	85 (75)	+10
1967	Beulah	TX	3	no change	100	N/A
1968	Gladys	FL	2	no change	85 (70)	+15
1969	Camille	MS	5	no change	150 (165)	-15
1969	Gerda	ME	TS (1)	-1	70* (95)	-25
1970	Celia	TX	4 (3)	+1	120 (110)	+10

Atlantic Hurricane Database Re-Analysis Project

http://www.aoml.noaa.gov/hrd/data_sub/re_anal.html

Publications

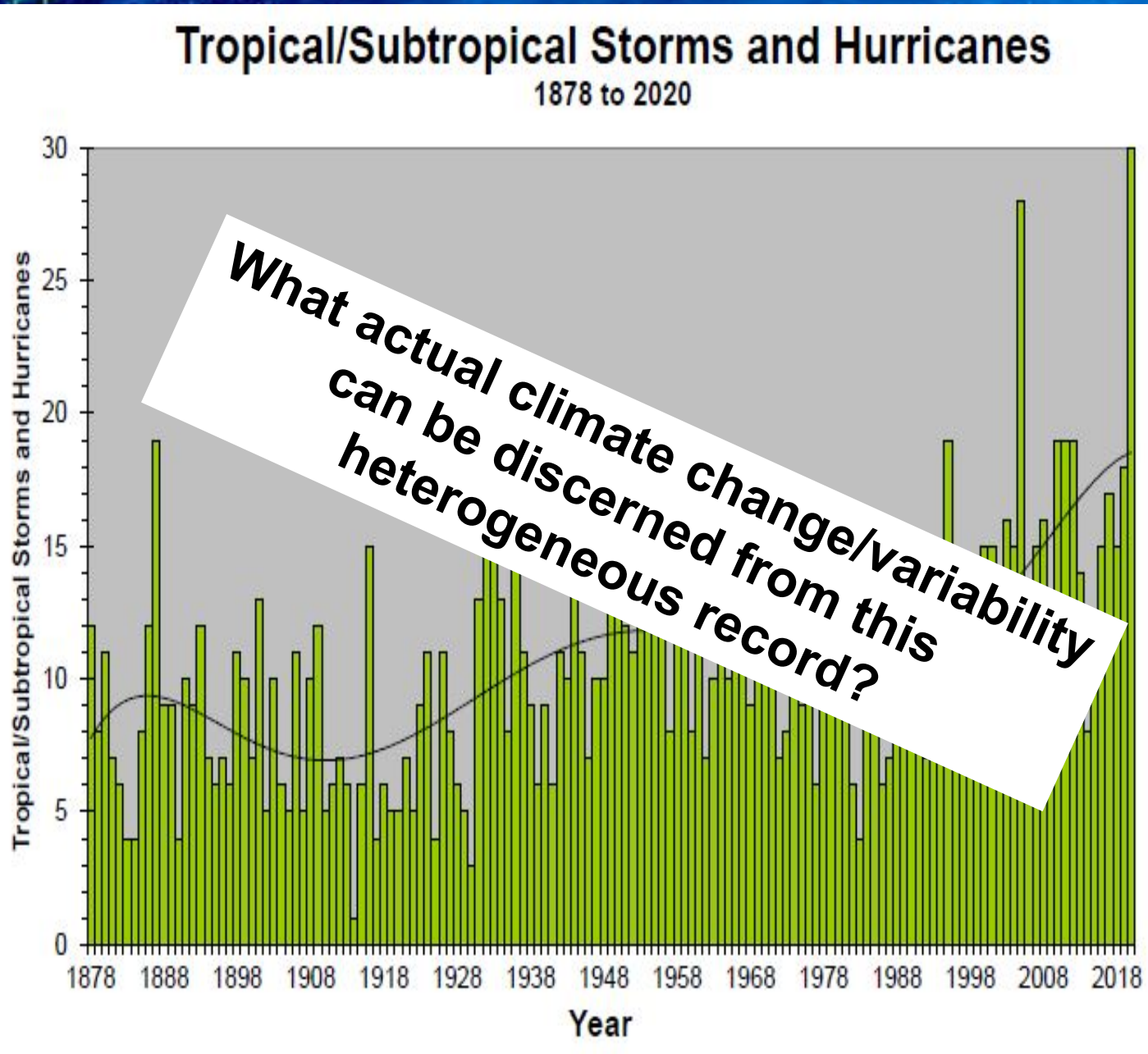
1) 1851 through 1970 (plus 1992's Andrew) changes accepted and officially adopted by NHC Best Track Change Committee

2) 1971-1972 have been preliminarily reanalyzed

3) Remainder of 20th Century will be reanalyzed

RE-ANALYSES NEED TO BE CONDUCTED GLOBALLY!!!

Named Storms

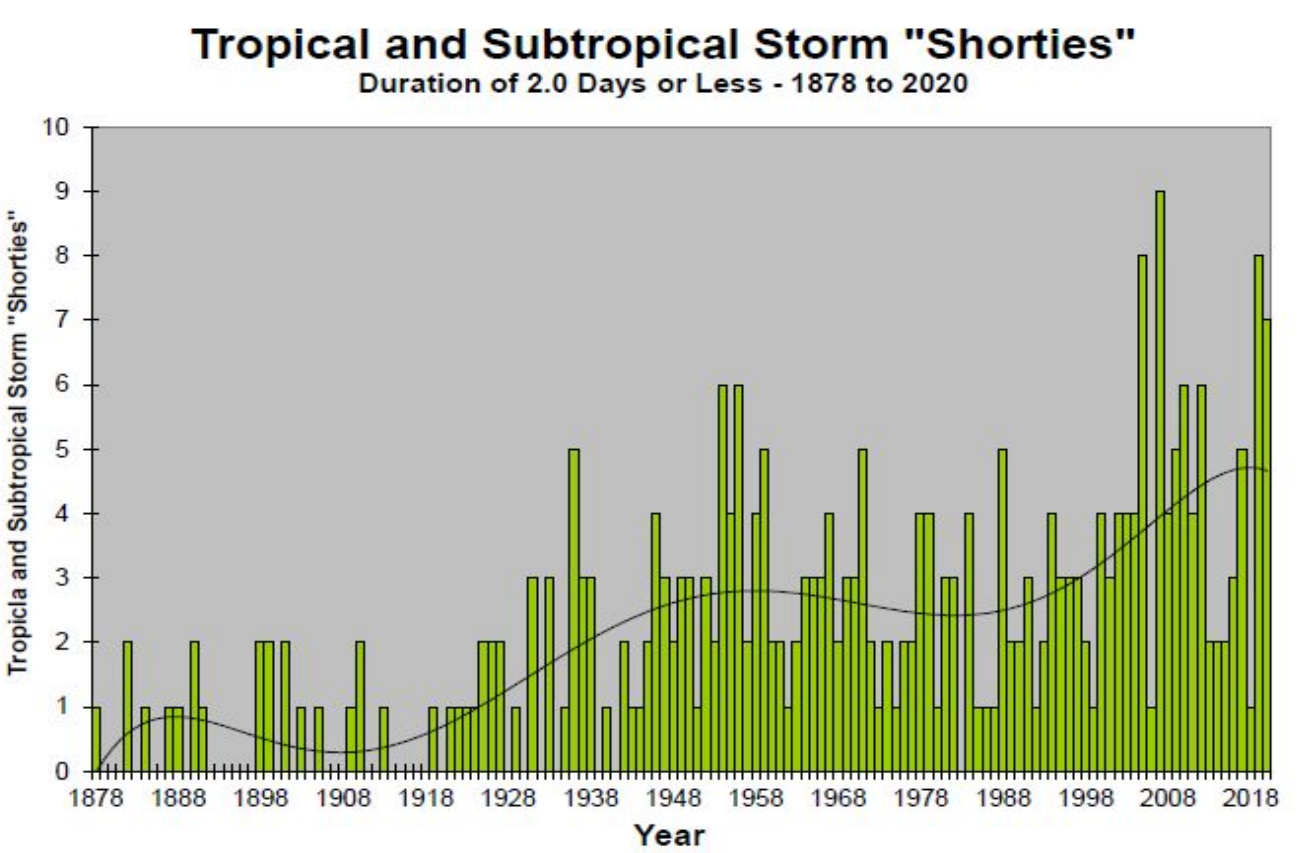


30 Named Storms

-

Busiest on record

Short-lived tropical and subtropical storms



Impact of Duration Thresholds on Atlantic Tropical Cyclone Counts*

CHRISTOPHER W. LANDSEA
NOAA/NWS/National Hurricane Center, Miami, Florida

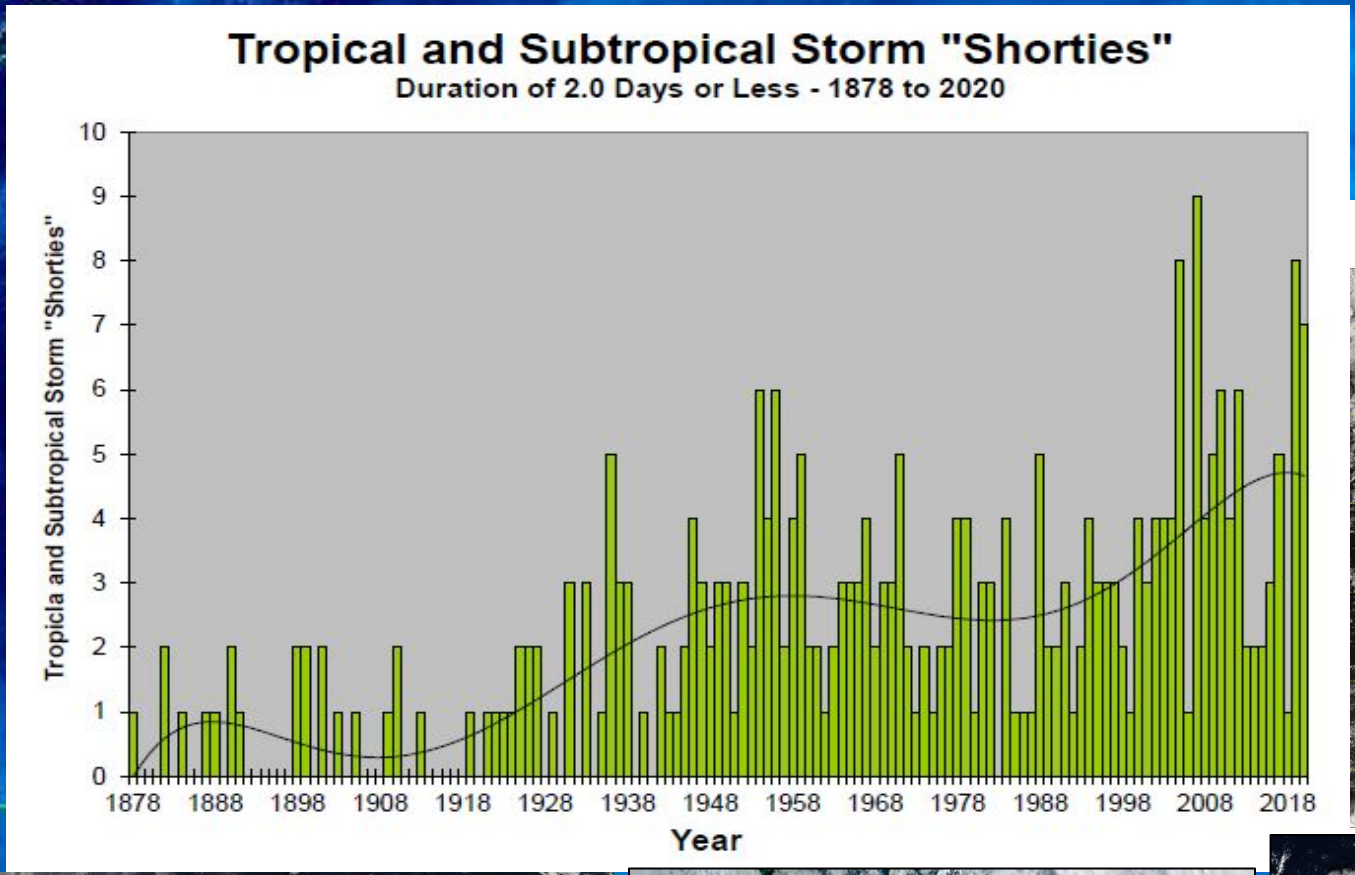
GABRIEL A. VECCHI
NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey

LENNART BENGTSSON
Environmental Systems Science Centre, University of Reading, Reading, United Kingdom

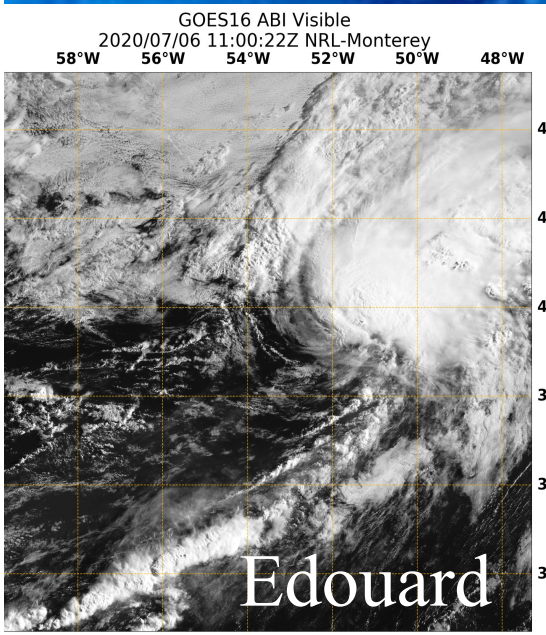
THOMAS R. KNUTSON
NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey

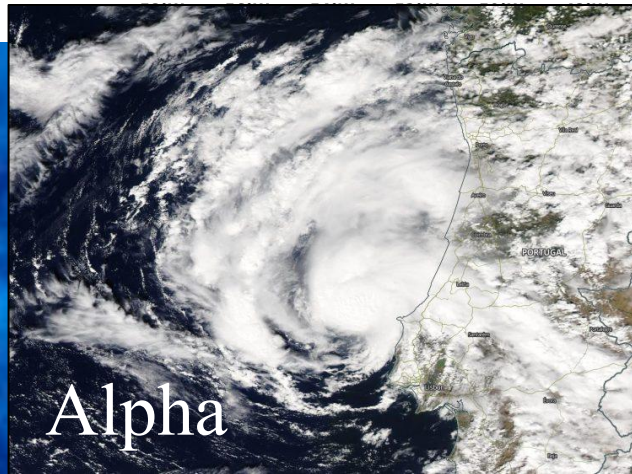
(Manuscript received 15 January 2009, in final form 20 October 2009)

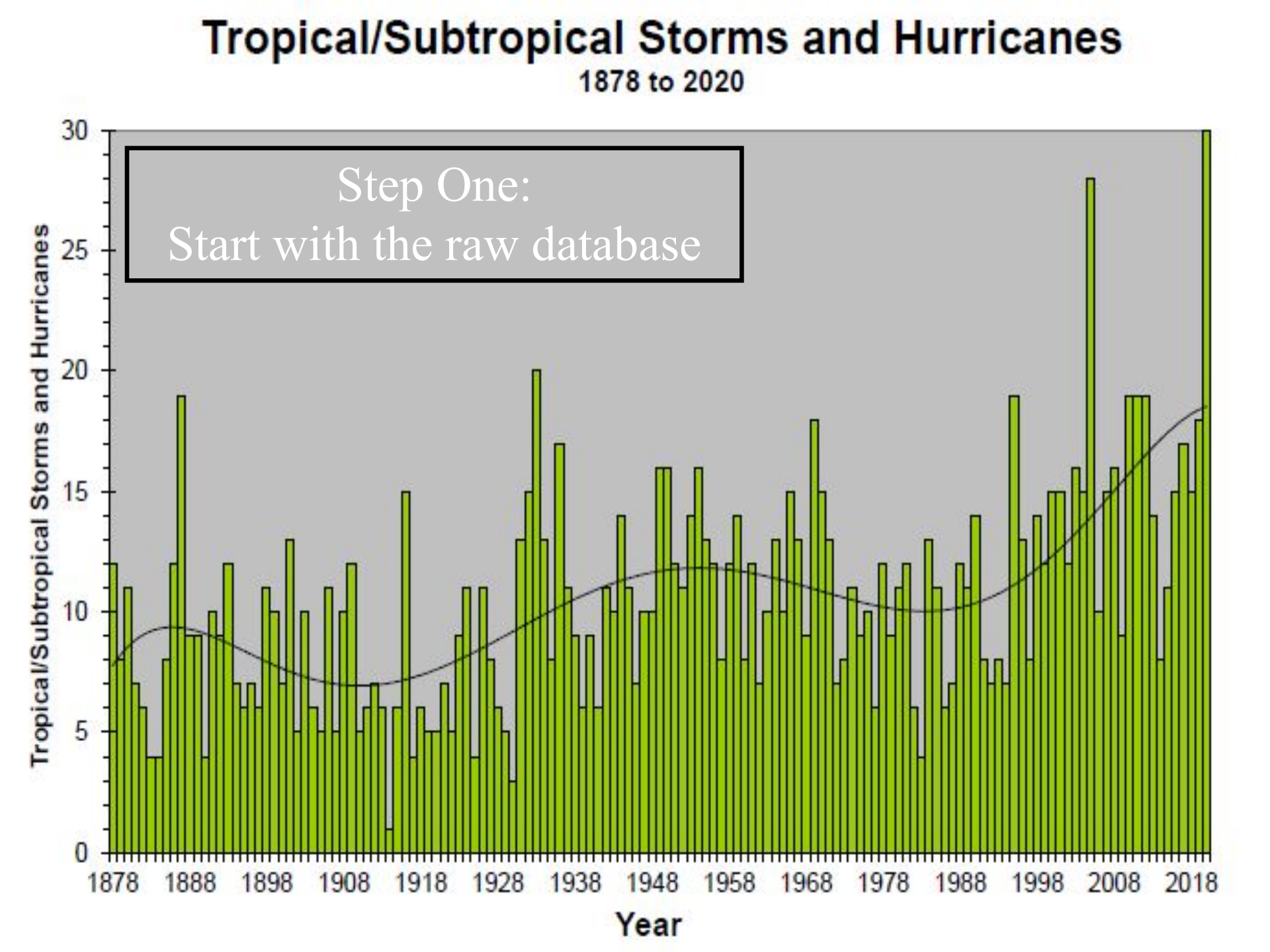
Short-lived tropical and subtropical storms

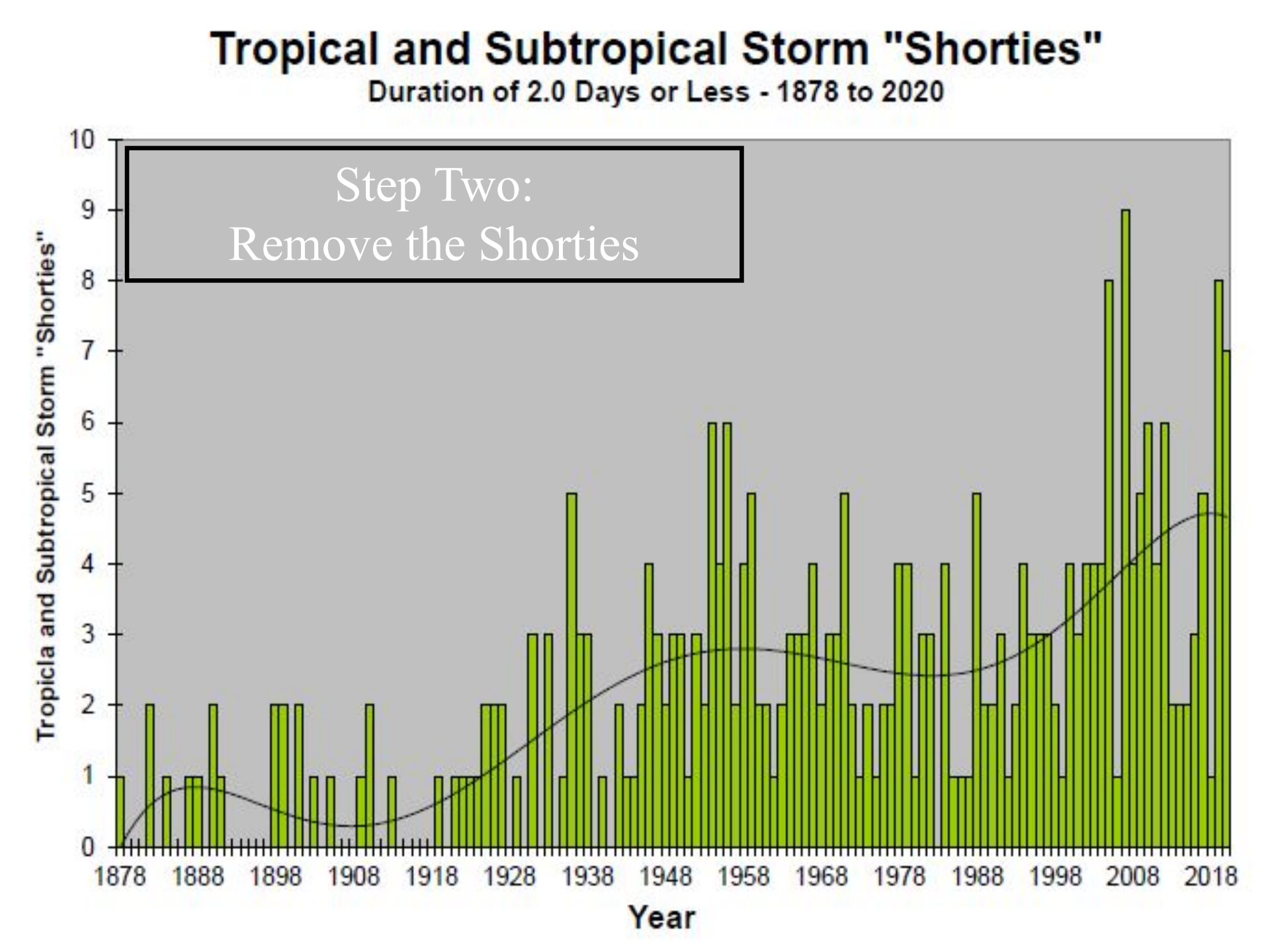


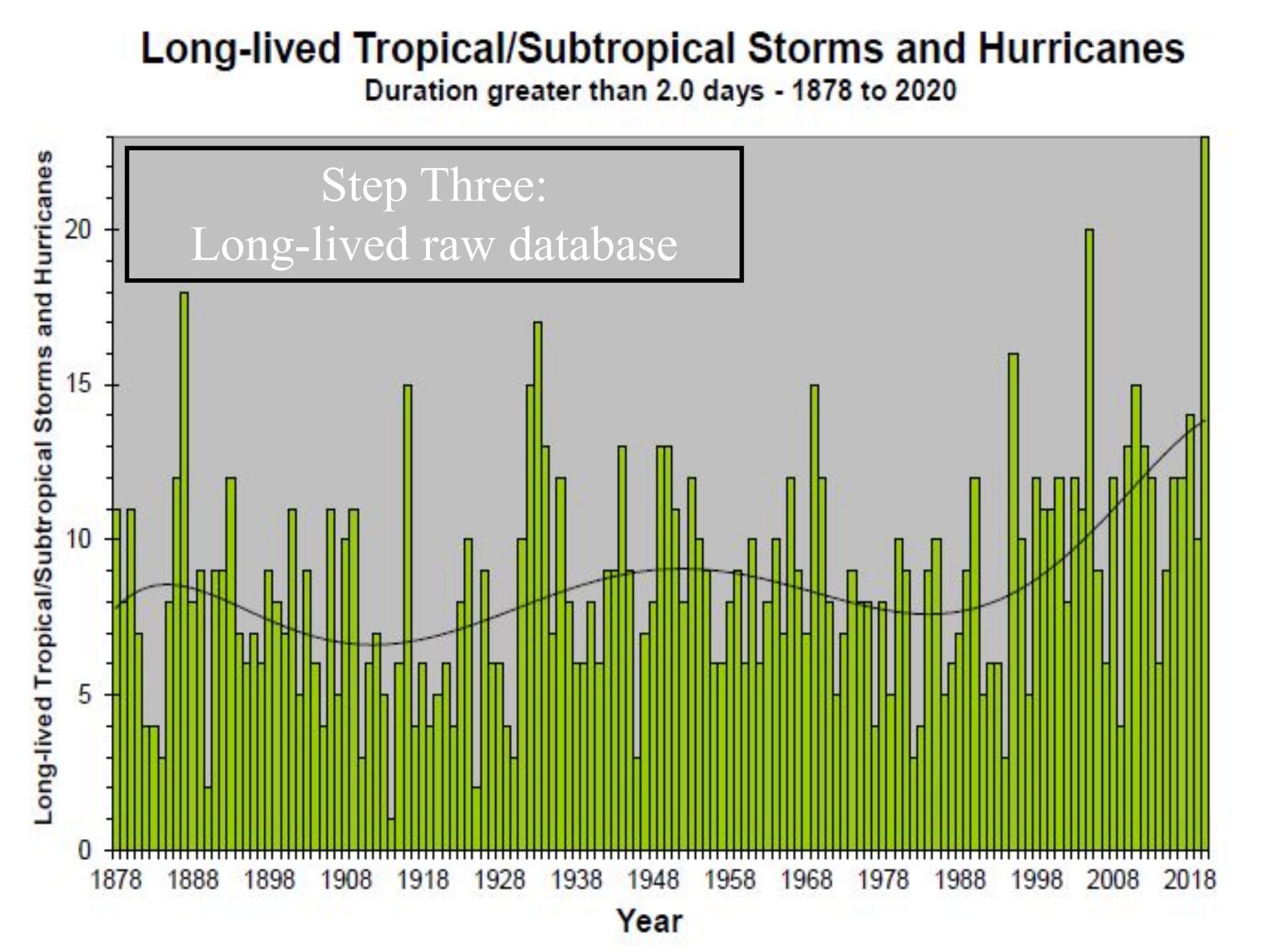
Very unlikely to have been designated as named storms in the past

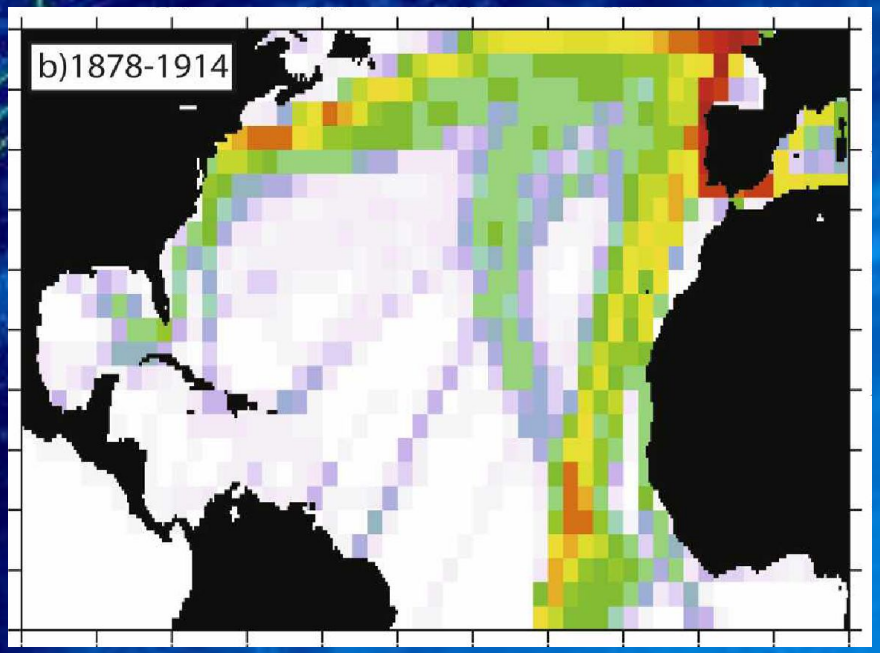





Tropical/Subtropical Storms and Hurricanes
1878 to 2020
Step One:
Start with the raw database
Tropical/Subtropical Storms and Hurricanes
0
5
10
15
20
25
30
1878
1888
1898
1908
1918
1928
1938
1948
1958
1968
1978
1988
1998
2008
2018
Year

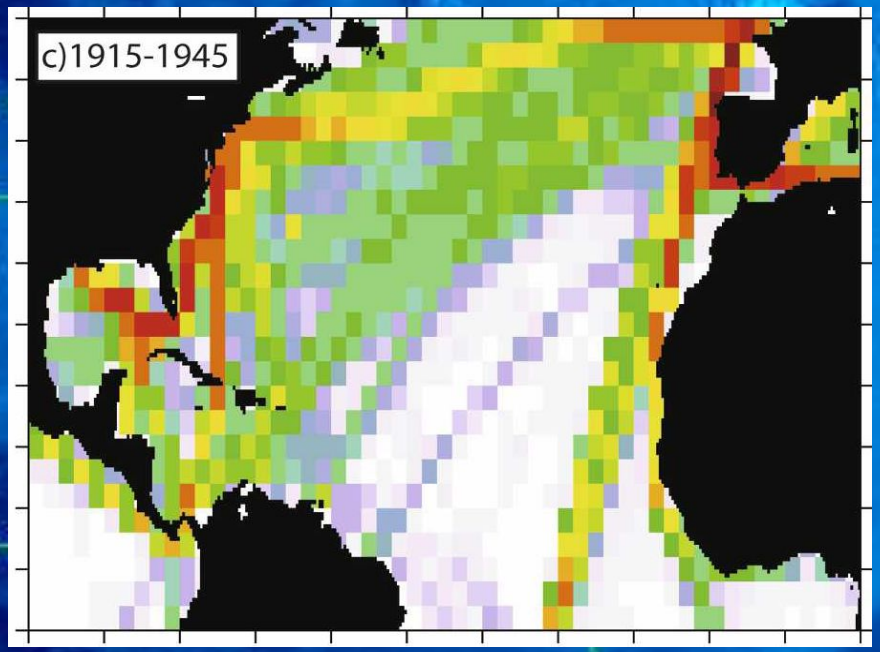

Tropical and Subtropical Storm "Shorties"
Duration of 2.0 Days or Less - 1878 to 2020
Step Two:
Remove the Shorties
Tropicla and Subtropical Storm "Shorties"
0
1
2
3
4
5
6
7
8
9
10
1878
1888
1898
1908
1918
1928
1938
1948
1958
1968
1978
1988
1998
2008
2018
Year

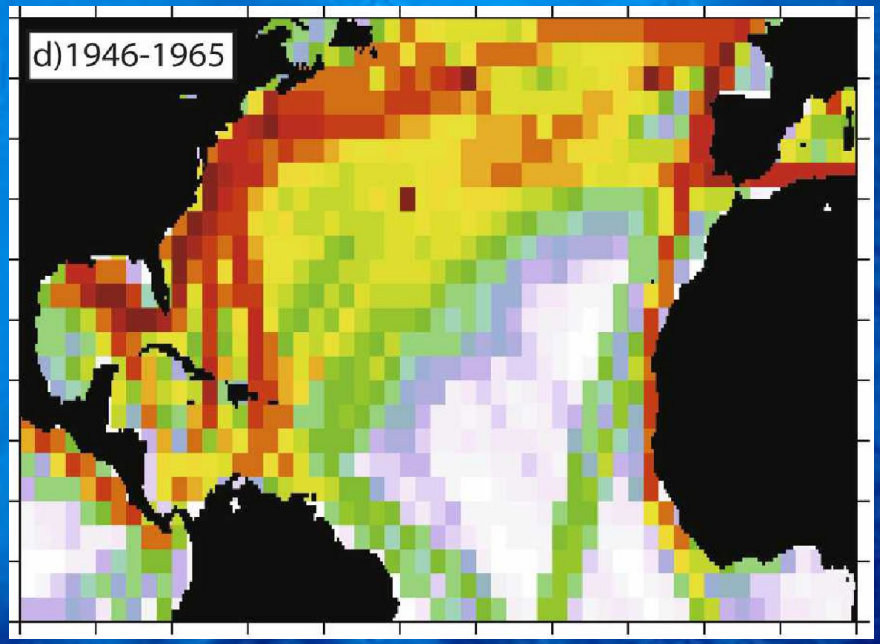

Long-lived Tropical/Subtropical Storms and Hurricanes
Duration greater than 2.0 days - 1878 to 2020
Step Three:
Long-lived raw database
Long-lived Tropical/Subtropical Storms and Hurricanes
0
5
10
15
20
1878
1888
1898
1908
1918
1928
1938
1948
1958
1968
1978
1988
1998
2008
2018
Year

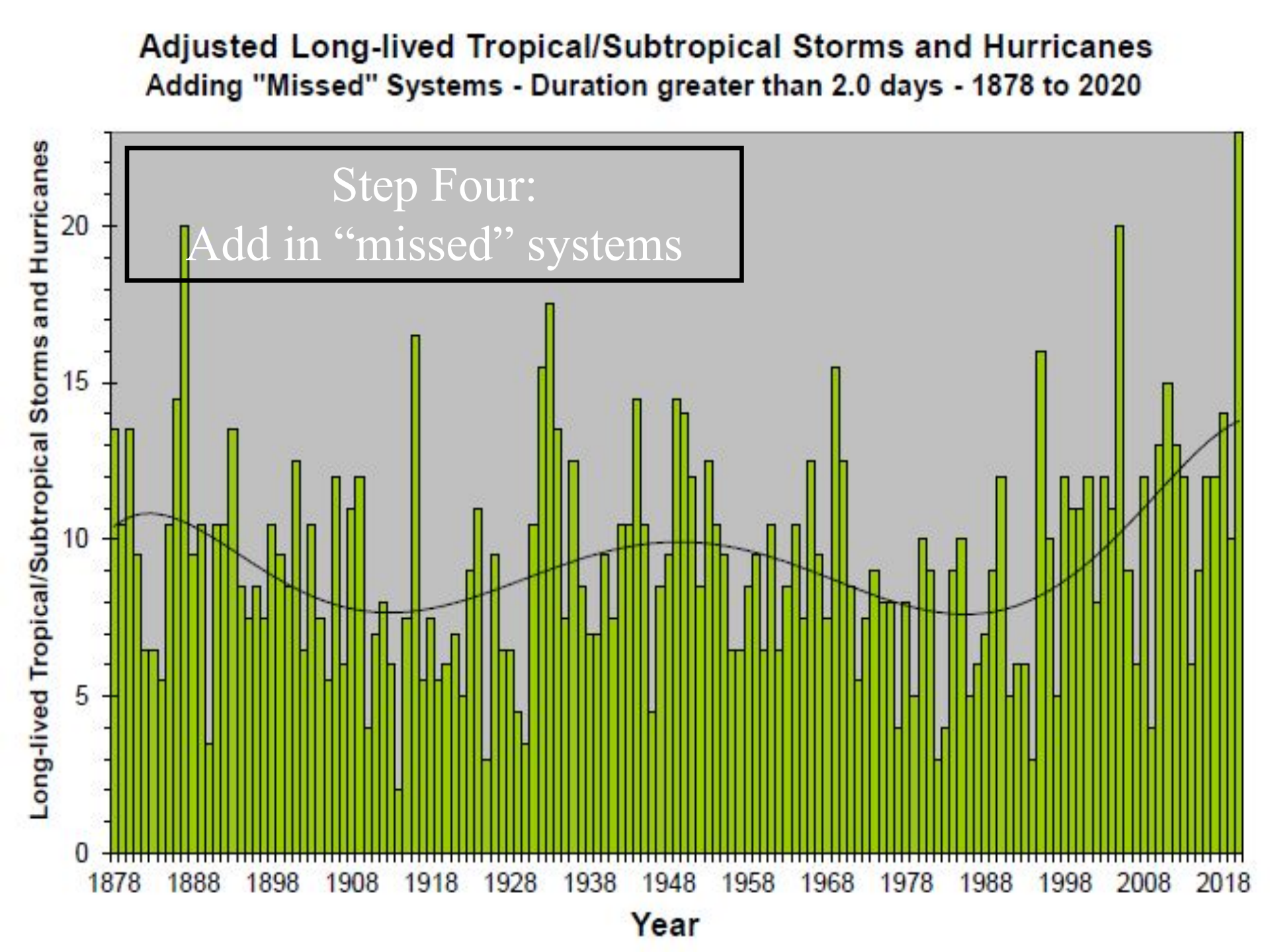


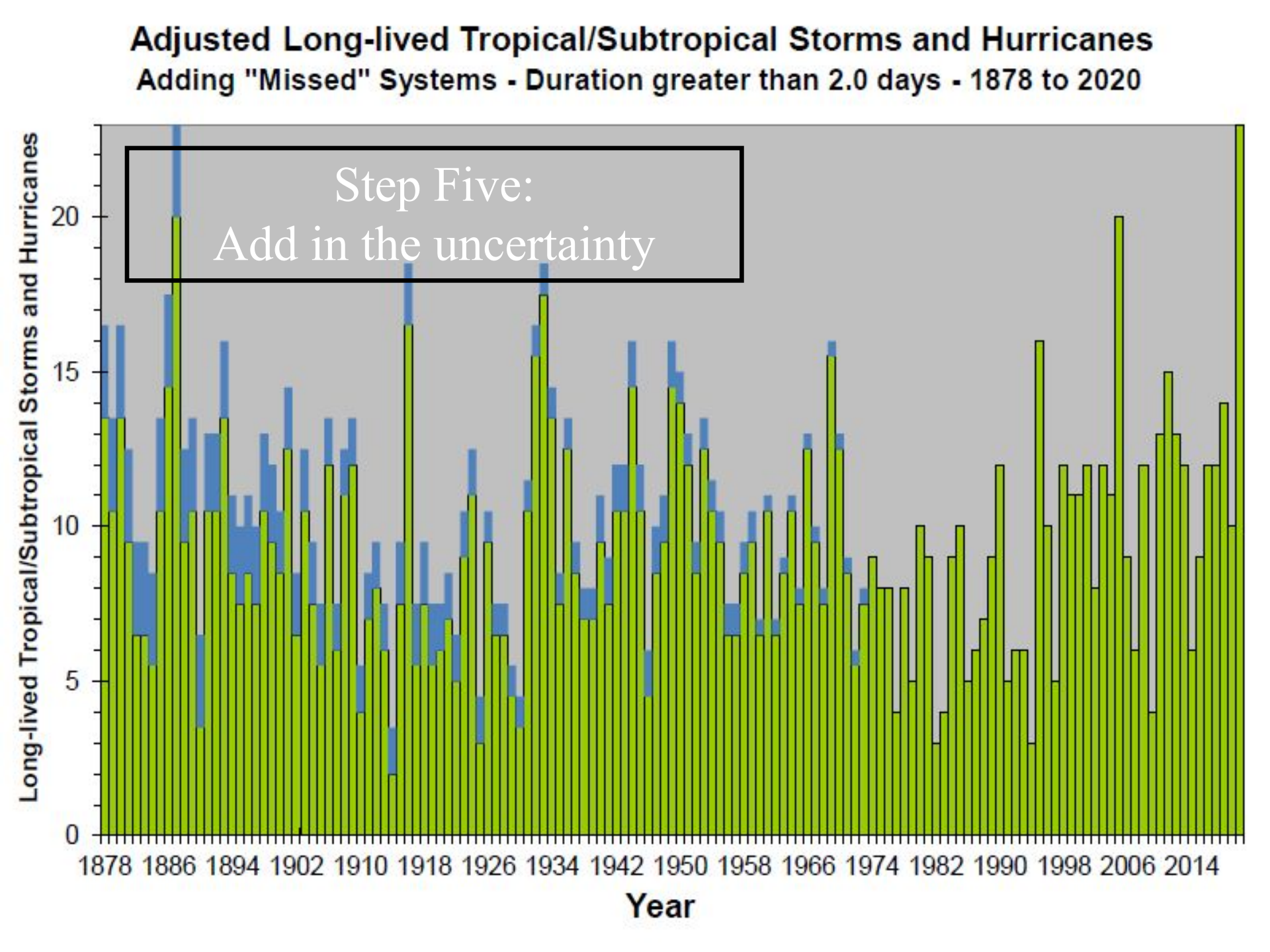
Ship Traffic Over the Atlantic during the 19th and 20th Centuries

Vecchi and Knutson (2008)






Adjusted Long-lived Tropical/Subtropical Storms and Hurricanes
Adding "Missed" Systems - Duration greater than 2.0 days - 1878 to 2020
Step Four:
Add in "missed" systems
Long-lived Tropical/Subtropical Storms and Hurricanes
0
5
10
15
20
1878
1888
1898
1908
1918
1928
1938
1948
1958
1968
1978
1988
1998
2008
2018
Year


Adjusted Long-lived Tropical/Subtropical Storms and Hurricanes
Adding "Missed" Systems - Duration greater than 2.0 days - 1878 to 2020
Step Five:
Add in the uncertainty
Long-lived Tropical/Subtropical Storms and Hurricanes
0
5
10
15
20
1878 1886 1894 1902 1910 1918 1926 1934 1942 1950 1958 1966 1974 1982 1990 1998 2006 2014
Year

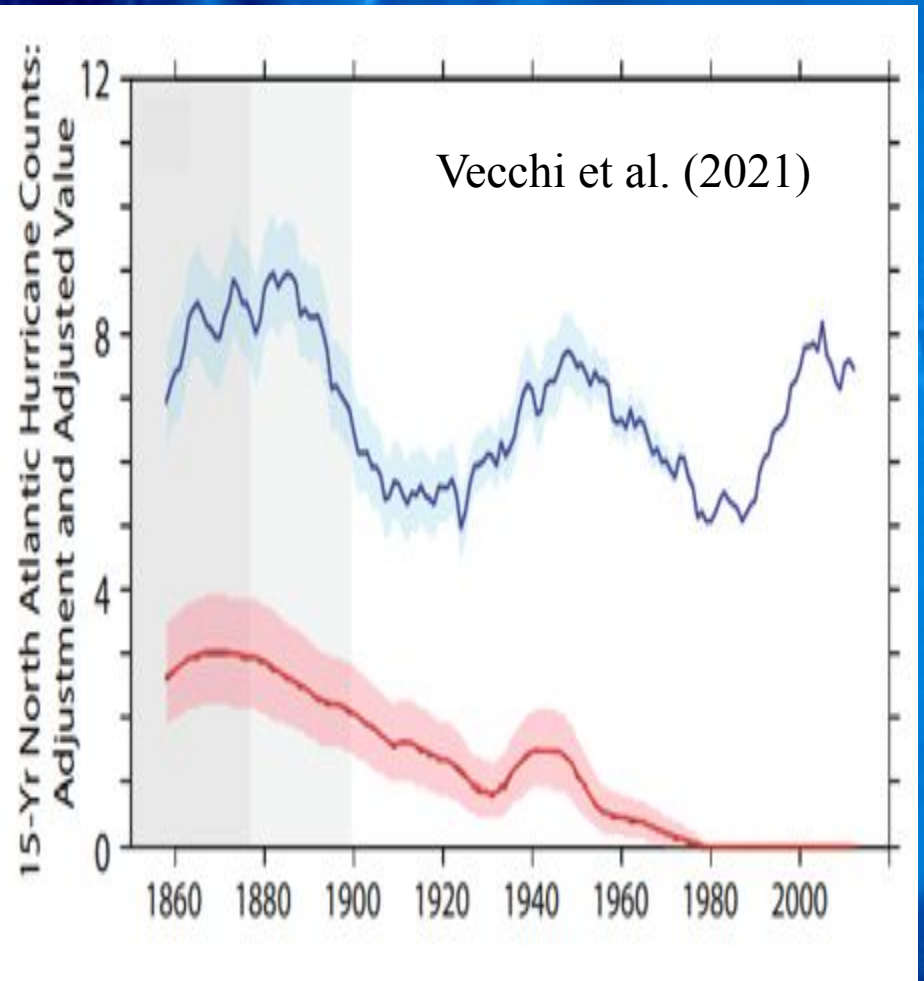
"Was 2020 a Record-Breaking Hurricane Season? Yes, but…"

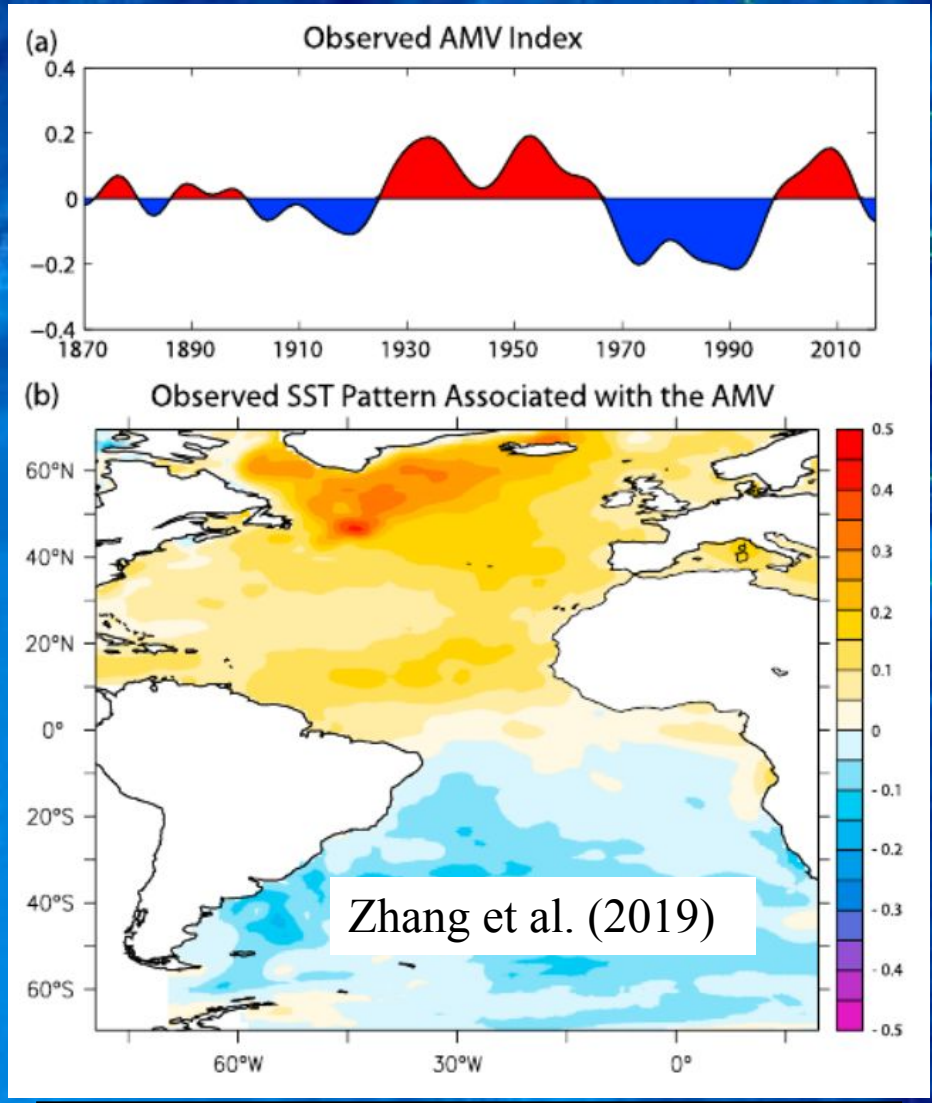
- Doubling in the number of named storms over a century:
  - Technology change, not natural or man-made climate change

- 2020 did set a record for number of named storms:
  - Other years - such as 1887 – may have been as active
  - Other metrics – like "ACE" – not even close to a record

- NHC "Inside the Eye" Blog report:
  - https://noaanhc.wordpress.com/2021/06/30/was-2020-a-record-breaking-hurricane-season-yes-but/

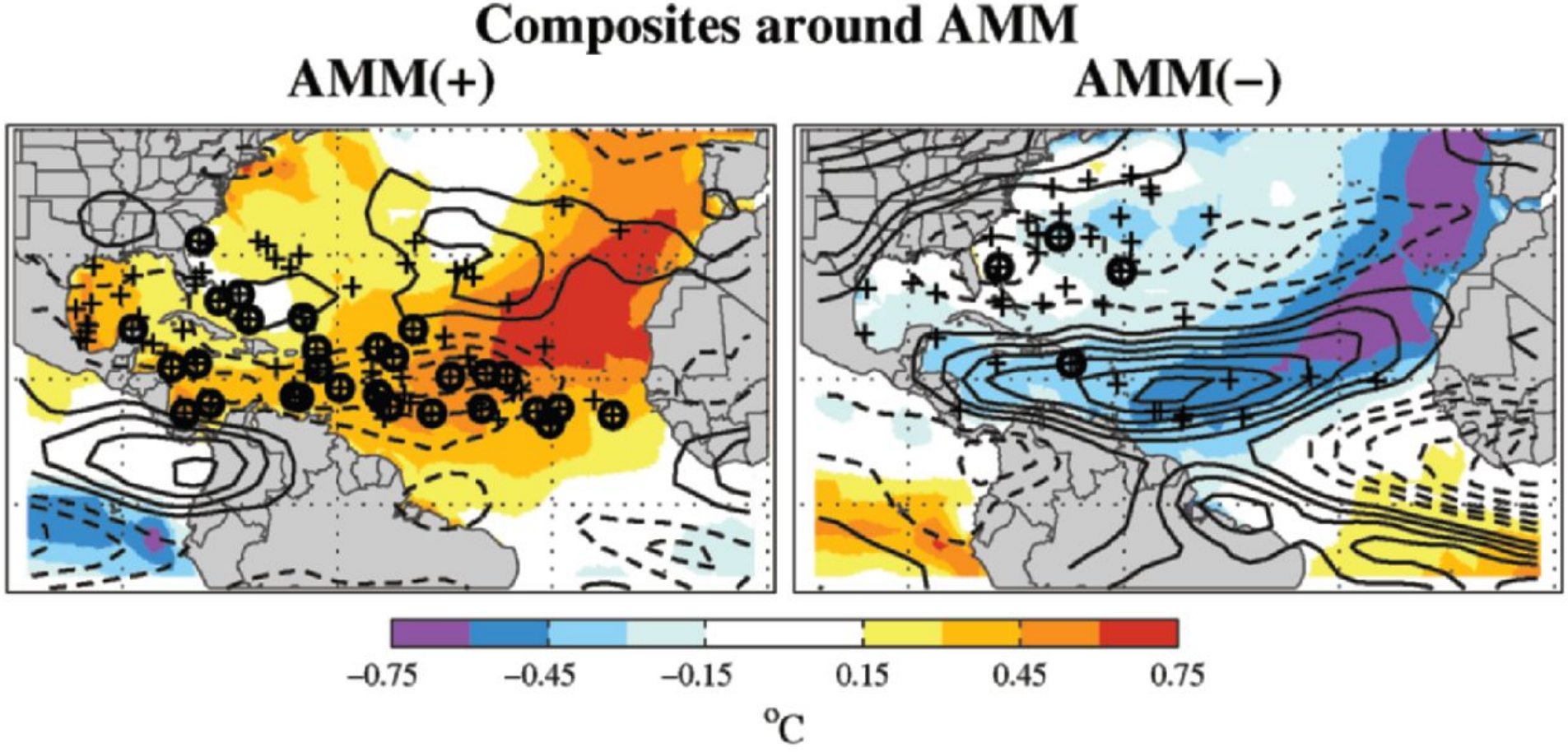
Reconstructed Hurricane Counts





Atlantic Multidecadal Variability

Atlantic Multidecadal Oscillation - SSTs, Vertical Shear and Cyclogenesis



Kossin and Vimont (2007)

Overall Tropical Storm and Hurricane Changes Due to Global Warming by 2100

Frequency: Numbers may see a **moderate decrease** (~25%)

Wind Intensity: **Small increase** (~3% stronger)

Storm Surge: **Small increase** (~3% higher) produced by the hurricane (must also add on additional amount from general sea level rise)

Rainfall: **Moderate increase** per tropical storm and hurricane (~10% within 200 mi of storm), but reduced frequency may offset increases

Genesis: Tropical storms and hurricanes to form **slightly farther away** from North America

Track: Tropical storms and hurricanes to **recurve slightly more often over water** and remain away from land

Overall Tropical Storm and Hurricane Changes Due to Global Warming by 2100

Fre … **oderate decrease** (~25%)

Win … % stronger)

Stor … igher) produced by the hurrica … rise)

Rainfa … storm and hurricane (~10% within 2 … ncy may offset increases

Genesis … form **slightly farther away** from No…

Track: Tro… and hurricane … **over water** and remain away f…

[redacted]

State of the Science FACT SHEET

Atlantic Hurricanes and Climate Change

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION • UNITED STATES DEPARTMENT OF COMMERCE

Summary

Here, we address three important and societally relevant questions about Atlantic hurricane activity and climate: 1) Has there been a change in the number of Atlantic hurricanes? 2) Has human-caused climate change had any detectable influence on hurricanes and their impacts? 3) What changes do we expect going forward with continued global warming?

Several Atlantic hurricane activity metrics show pronounced increases since 1980. However, evidence for any significant trends is much weaker considering trends beginning from the early 20th century, partly due to observed data limitations. Decreases in aerosol forcing since the 1970s and multidecadal ocean circulation changes are thought to be contributing to the increased Atlantic hurricane activity since 1980, though their relative contributions are still uncertain and with no scientific consensus. While greenhouse gas-induced warming may have also affected Atlantic hurricane activity, a detectable greenhouse gas influence on hurricane activity has not been identified with high confidence. This is partly due to the masking of any century-scale trends by pronounced multidecadal variability due to aerosols and/or internal variability. Determining the relative contributions of aerosols, internal variability, and other factors to the recent multidecadal variations in Atlantic hurricane activity has important implications for predictions for the coming decades.

Future projections include increased risk of coastal inundation during storms due to sea level rise, likely increased hurricane rain rates and wind intensities, and possible increased numbers of Category 4-5 hurricanes, along with decreased numbers of tropical storms and hurricanes (all categories combined).

Observed Atlantic Hurricane Changes

Several measures of historical Atlantic hurricane activity, including annual numbers of tropical storms, hurricanes, and major hurricanes, as well as hurricane intensities, power dissipation index (PDI), and rapid intensification occurrence, all show pronounced increases since around 1980. Since the 1940s and 50s, major hurricane annual counts and related measures have shown pronounced multidecadal variations, including a major hurricane 'drought' lasting from the 1970s through the mid-1990s. An increase in stalling near-coastal U.S. tropical cyclones and increases in accumulated rainfall during such stalls has been observed since about 1950. On the century time scale (e.g., since 1900) there has been no significant trend in annual numbers of U.S. landfalling tropical storms, hurricanes, or major hurricanes (Fig. 1). A decreasing trend since 1900 in the propagation speed of tropical storms and hurricanes over the continental U.S. has been reported. Basin-wide annual counts of tropical storms, hurricanes, and major hurricanes since the late 1800s show strong rising trends, but after taking into account changes in observing capabilities, studies suggest no strong evidence for a significant upward trend in any of these basin-wide storm count metrics (Fig. 1).

In terms of important environmental factors related to hurricanes, observed tropical Atlantic and Gulf of Mexico sea surface temperatures show pronounced warming since 1900 as well as multidecadal variability. Since 1950, tropical Atlantic vertical wind shear, sea surface temperatures, and inferred Atlantic Ocean Meridional Overturning Circulation all show pronounced multi-decadal variations that are well-correlated to Atlantic major hurricane counts. Economic damage in the U.S. from hurricanes has increased remarkably over the past century, as has the population and value of built infrastructure in hurricane-prone regions. Prehistoric geologic proxy records of hurricane activity covering thousands of years in some locations offer a complementary source of information on the potential for centennial-scale Atlantic hurricane variability originating from natural causes.

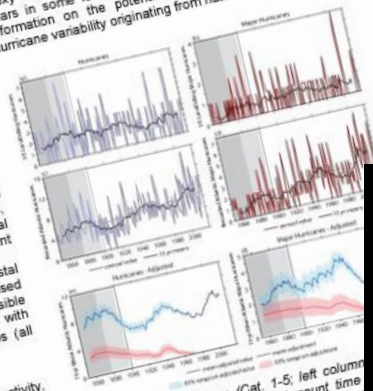


Fig. 1. Atlantic hurricane (Cat. 1-5; left column) and major hurricane (Cat. 3-5; right column) count time series since 1851. Darker gray shading in earlier decades indicates lower confidence due to more limited observing capabilities. Top row: U.S. landfalling counts; middle row: raw Atlantic basin-wide counts; bottom row: Atlantic adjusted basin-wide counts (blue line) including estimated adjustments (red line) for likely missing storms. Red and blue shading: 95% confidence ranges on adjusted values. Source: Vecchi et al., Nat. Comm. 2021.

Attribution of Observed Atlantic Hurricane Changes

For global mean temperature, the Intergovernmental Panel on Climate Change Sixth Assessment Report made highly confident attribution statements linking global warming to anthropogenic increases in greenhouse gases. The observed global warming trend since the late 1800s stands out from multidecadal variations in the record. This warming trend is consistent with climate model simulations that include anthropogenic increases in greenhouse gases, changes in anthropogenic aerosol forcing and natural volcanic emissions. In contrast, for Atlantic hurricane activity, the attribution of

May 2023 | NOAA.gov

[climate.gov blogs:
Can we detect a change in Atlantic hurricanes today due to human-caused climate change?
Can we expect Atlantic hurricanes to

The Atlantic Hurricane Database Reanalysis Project - Re-discovering "Missing" Tropical Cyclones… …And What Does This Imply for Understanding Hurricanes and Global Warming?

1. The HURDAT reanalysis project is improving, but will not make complete, the Atlantic hurricane database
2. Relatively minor manmade hurricane changes decades into the future (except for sea level rise)
3. Huge decadal scale hurricane variations occurring today
4. Huge vulnerability issues today, which will get increasingly severe as population grows
5. Need to address vulnerability issues now (no need to invoke possible minor changes decades from now):
   a. Improved hurricane observational network
   b. Improved hurricane modeling/forecasting
   c. Improved building codes/land use
   d. Improved evacuation/shelter plans