

2005

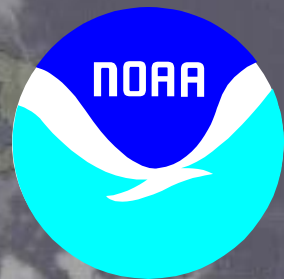
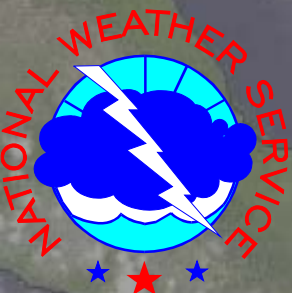
Long Term Hurricane Trends: How are These Storms Changing Over Time?

25 May, 2010

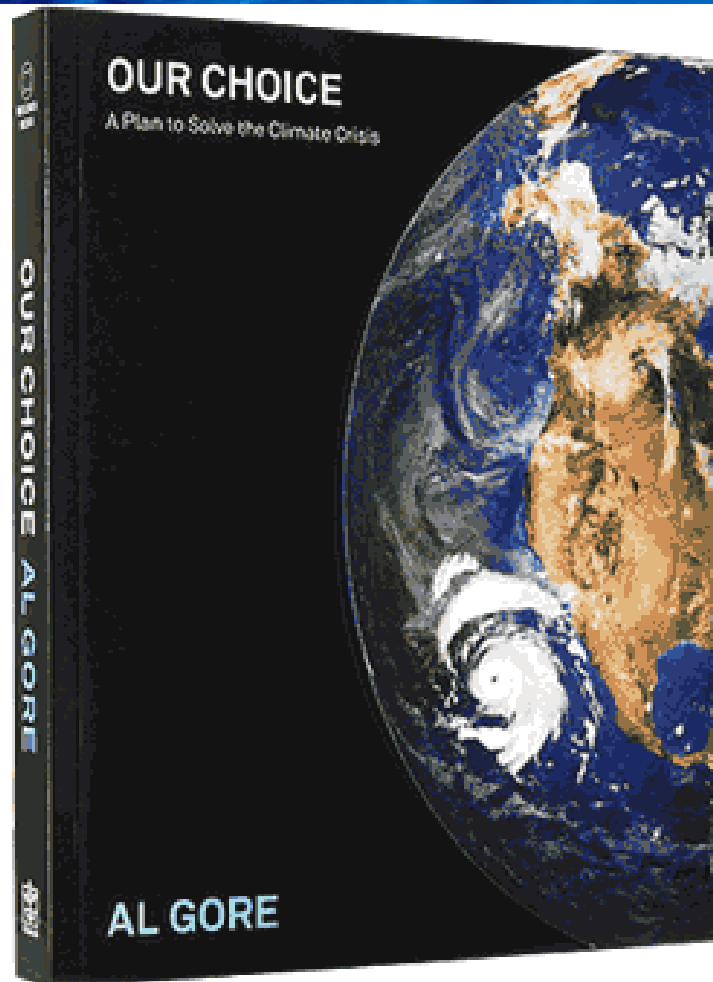
Florida Governor's Hurricane Conference

Chris Landsea, National Hurricane Center, Miami, USA

Chris.Landsea@noaa.gov



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





Before Katrina...

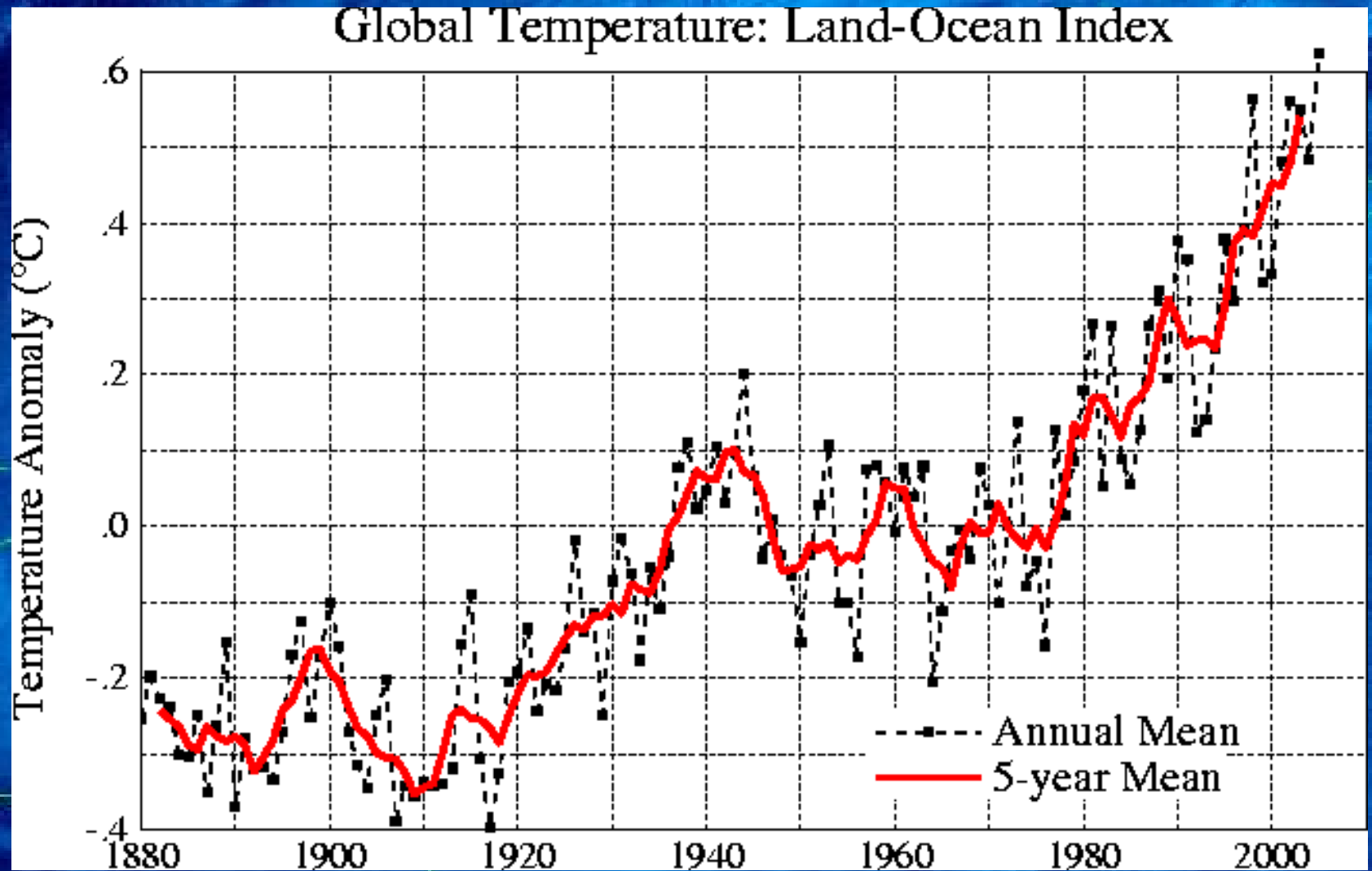
David & Kimberly King
Waveland, MS



...After Katrina

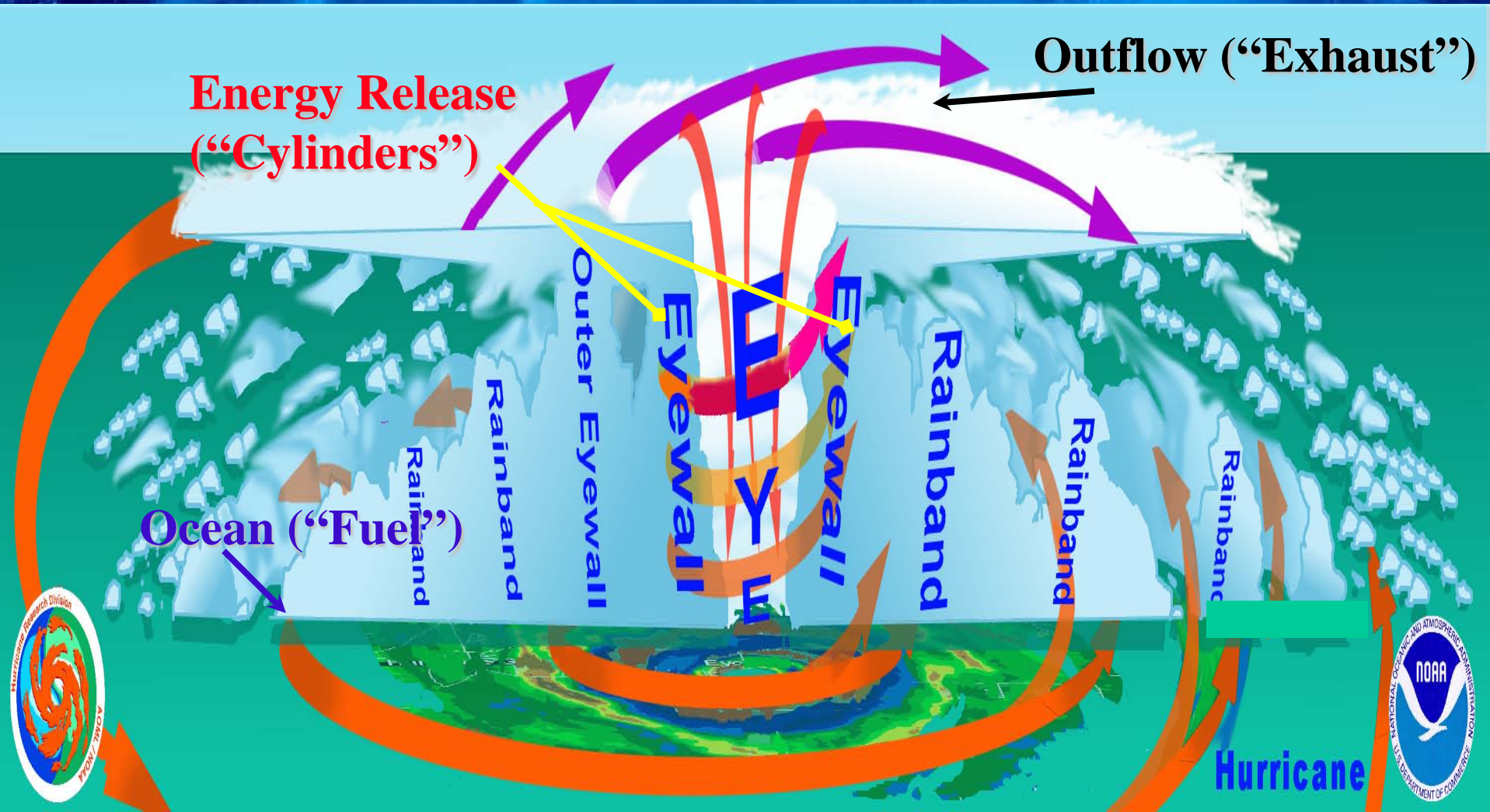
David & Kimberly King
Waveland, MS

Global Warming – Past Temperature Changes

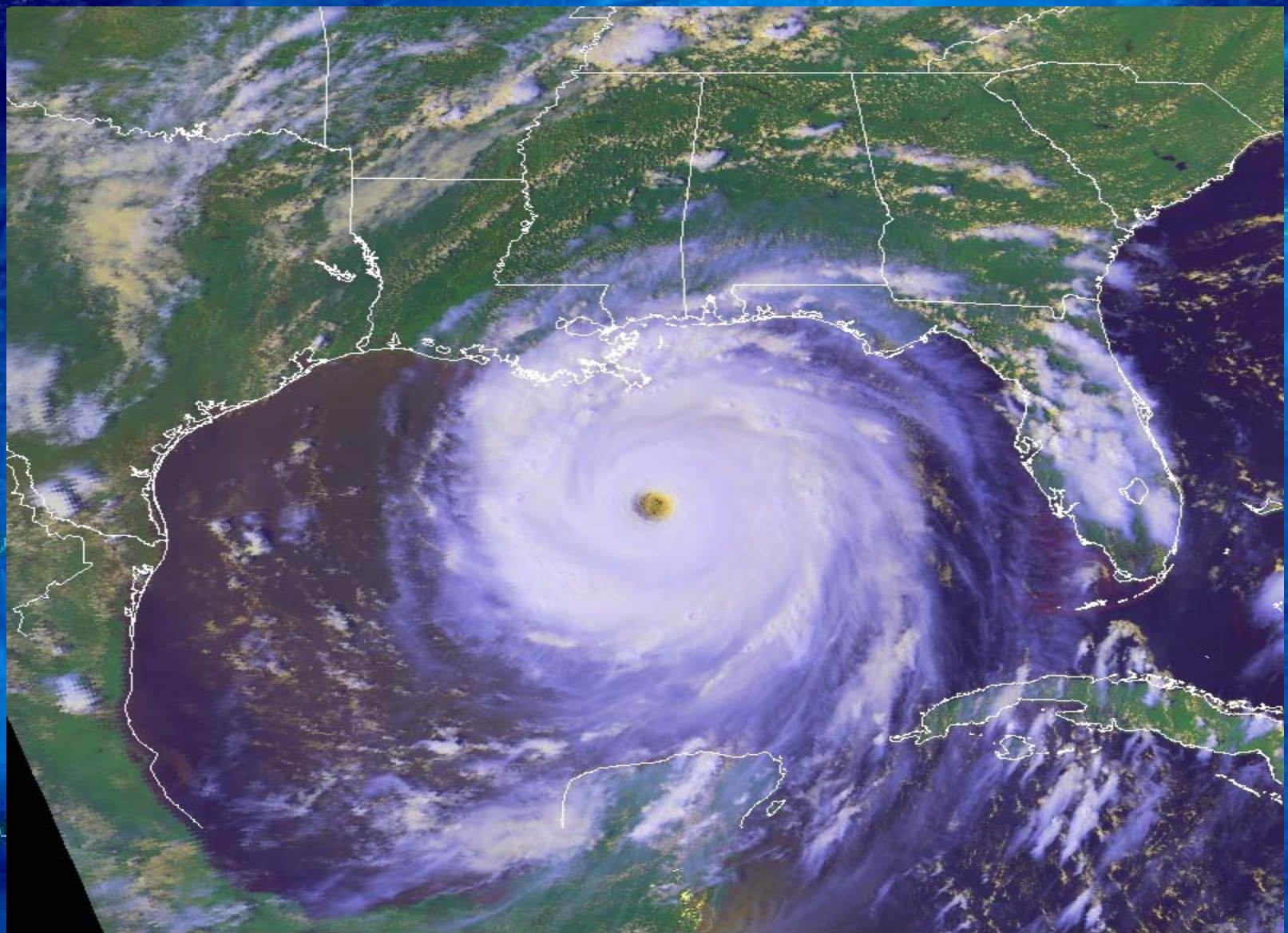


Nature's great heat engine...

The Hurricane



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

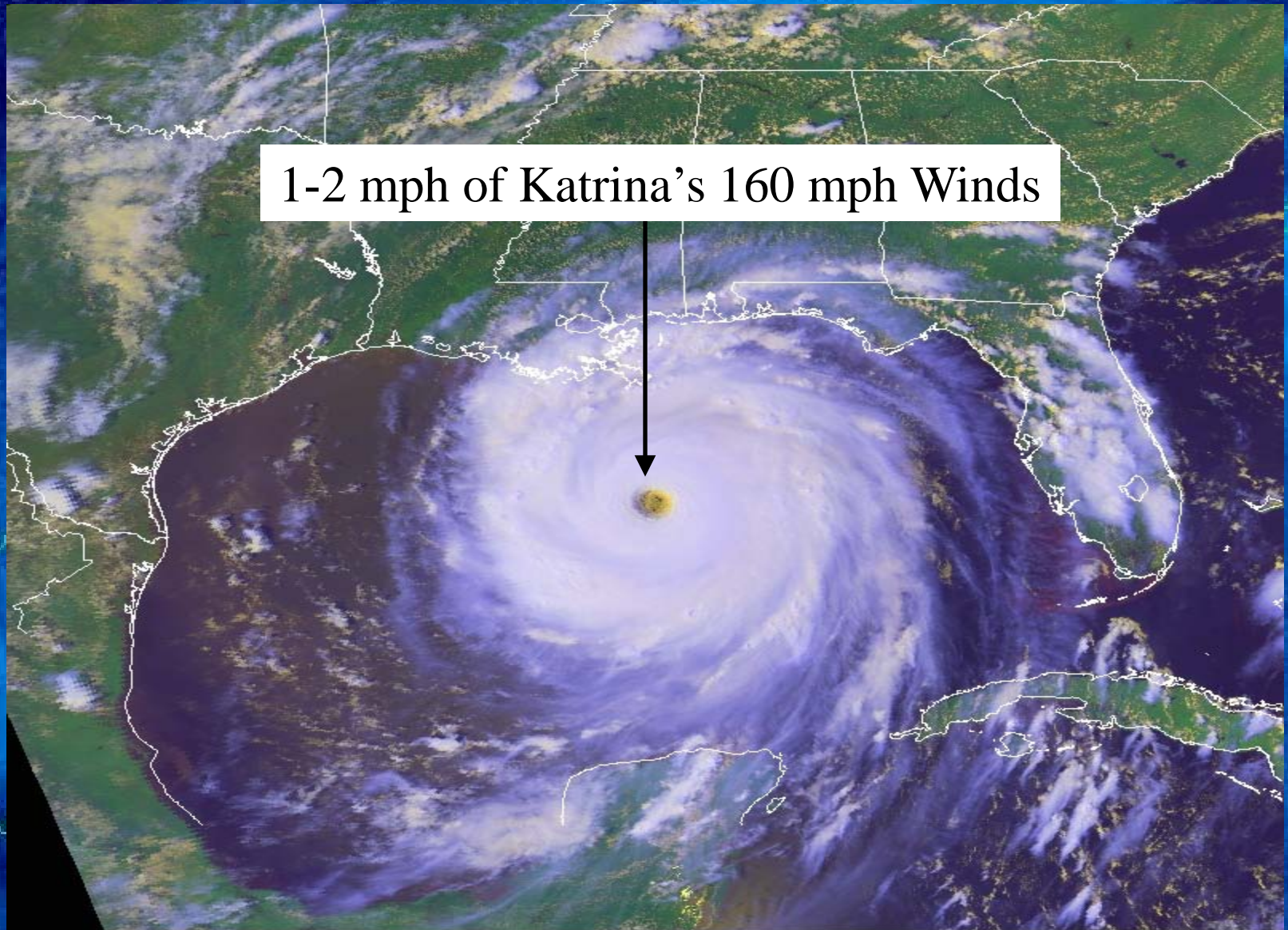


KATRINA NOAA-16 AVHRR 28 AUG 05 20:11 GMT
UW-MADISON SPACE SCIENCE AND ENGINEERING CENTER

McIDAS

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

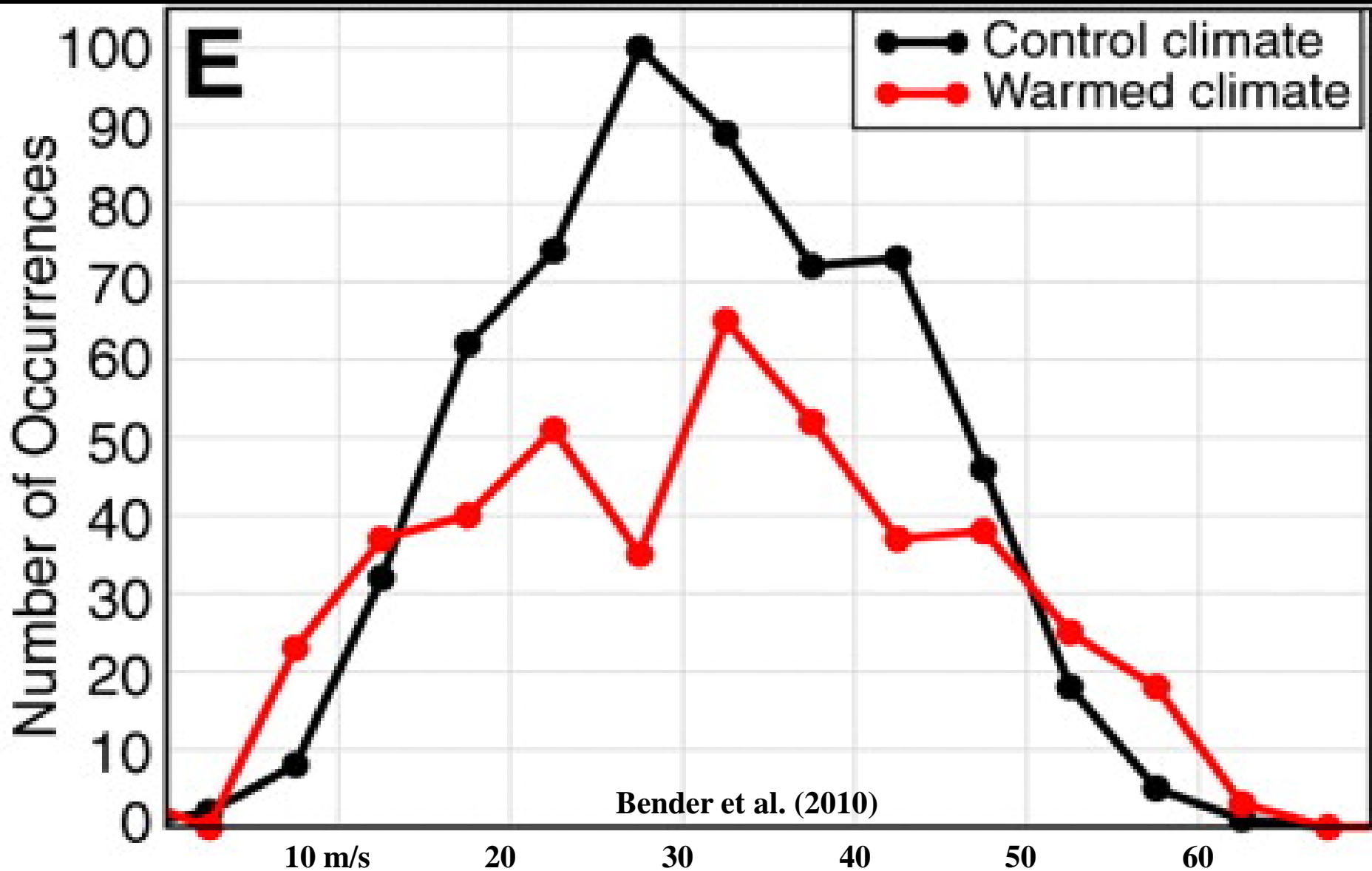
1-2 mph of Katrina's 160 mph Winds



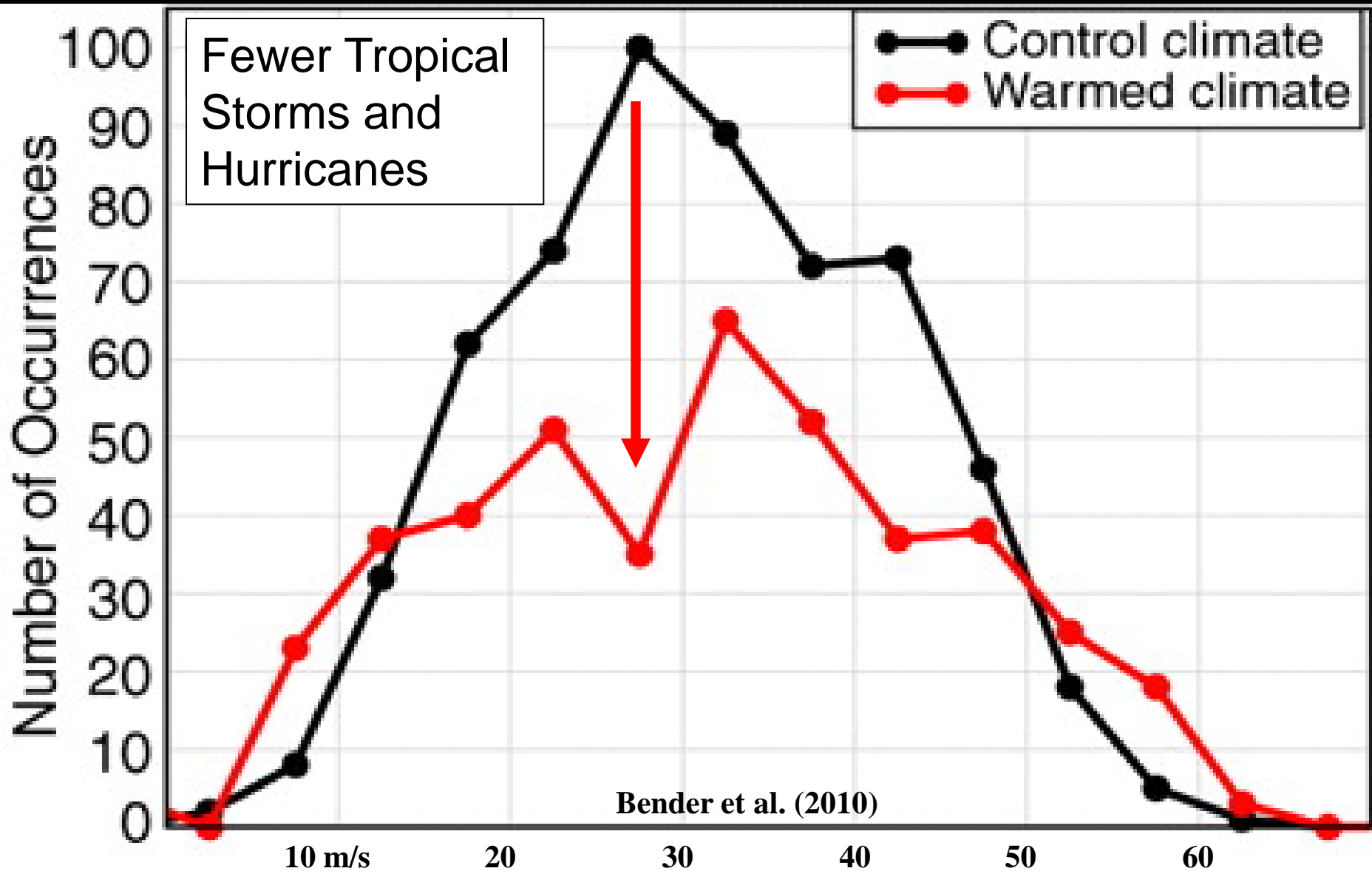
KATRINA NOAA-16 AVHRR 28 AUG 05 20:11 GMT
UW-MADISON SPACE SCIENCE AND ENGINEERING CENTER

McIDAS

Global Warming and Hurricanes:
Theory and Modeling Work Suggest ~3% wind increase with a
DECREASE in frequency by late 21st Century

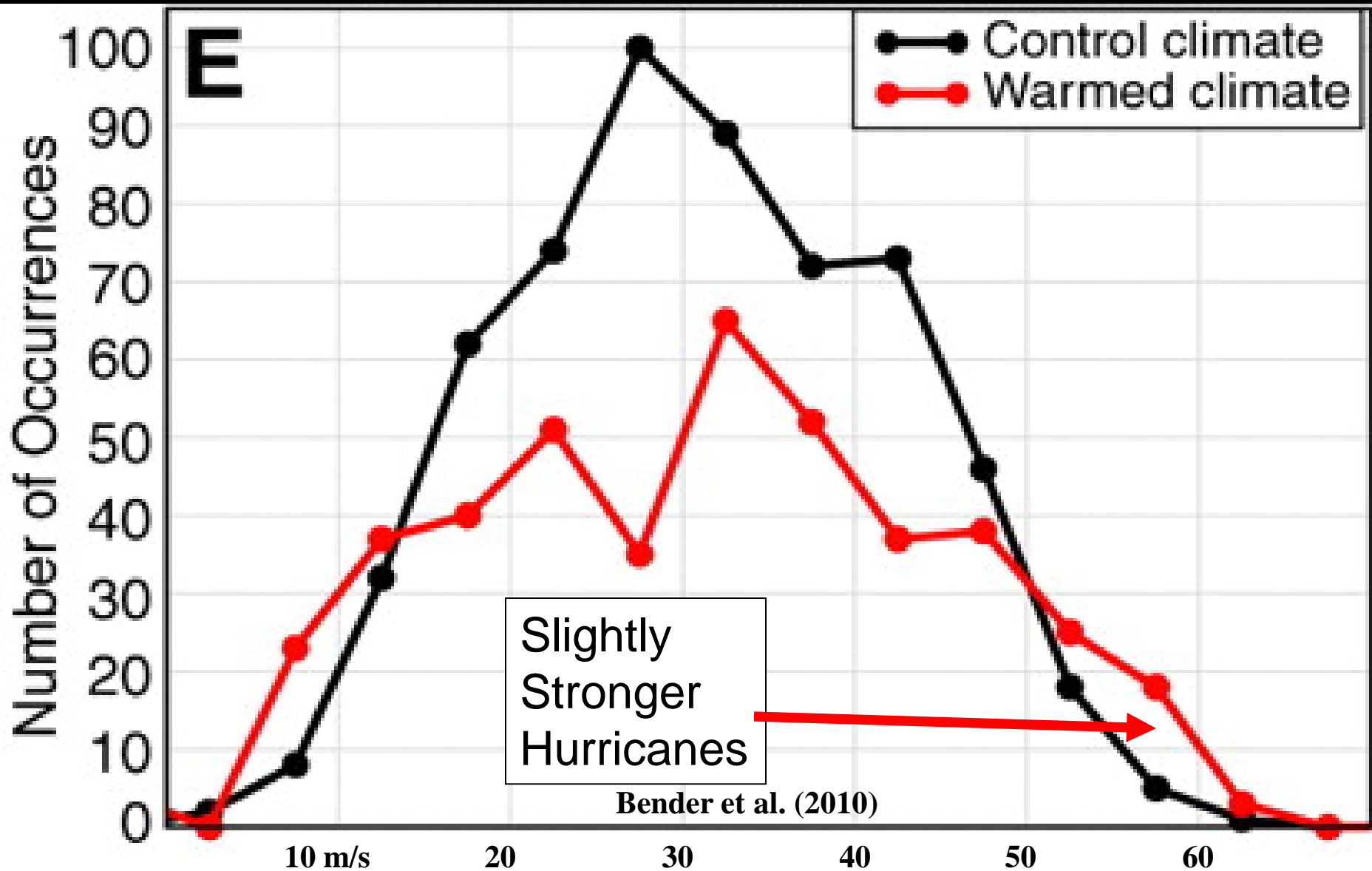


Global Warming and Hurricanes:
Theory and Modeling Work Suggest ~3% wind increase with a
DECREASE in frequency by late 21st Century

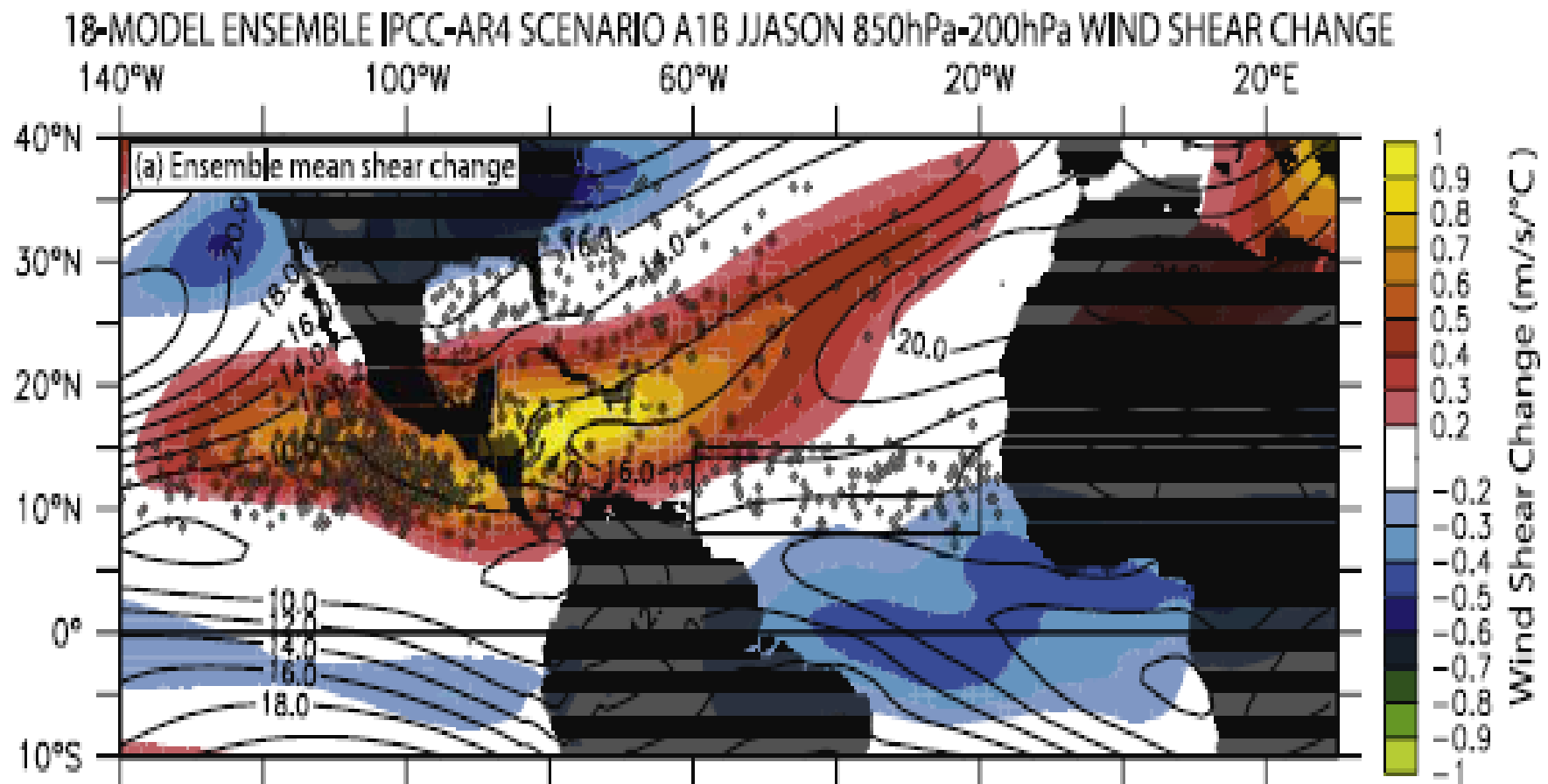


Global Warming and Hurricanes:

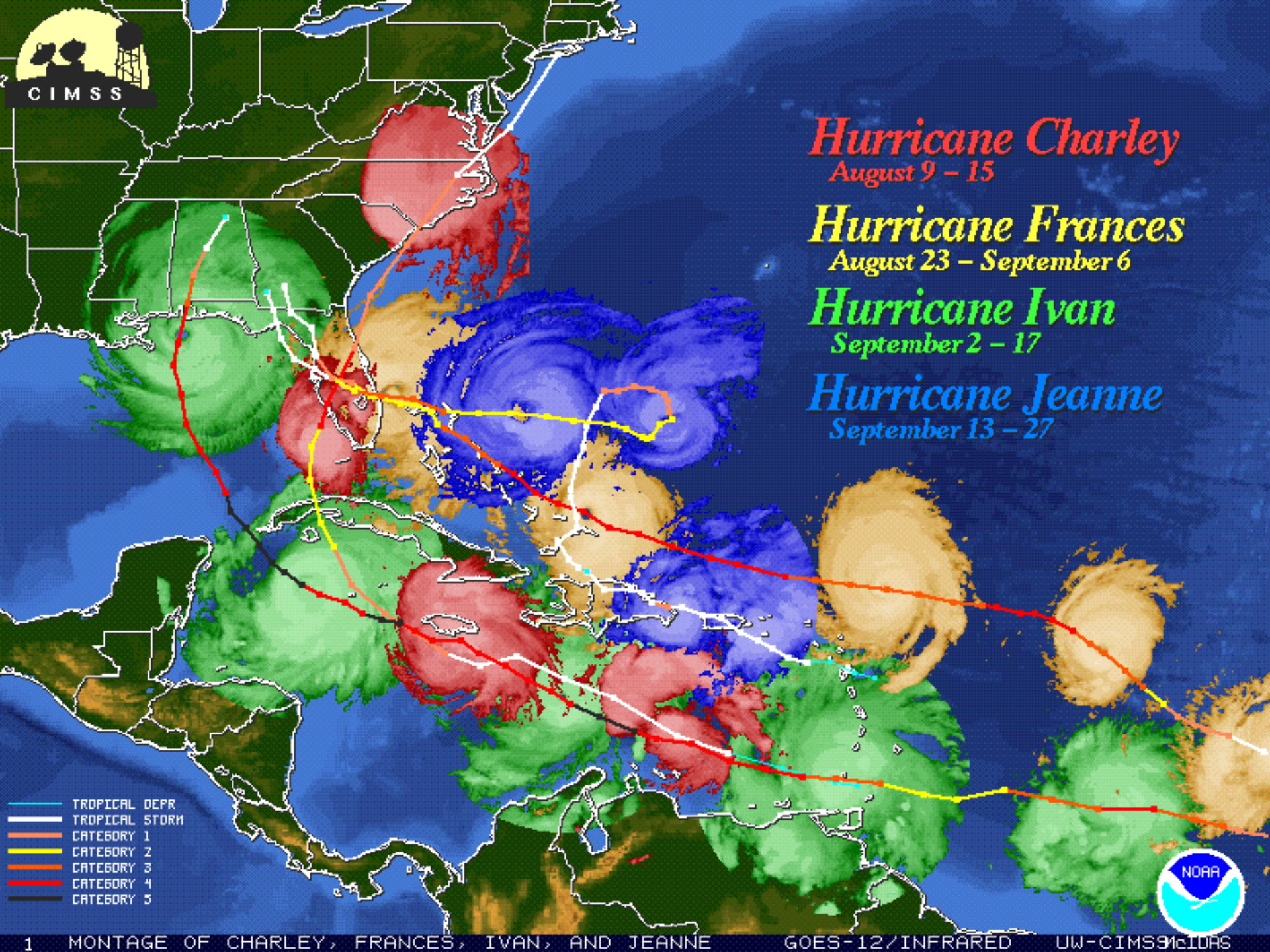
Theory and Modeling Work Suggest ~3% wind increase with a
DECREASE in frequency by late 21st Century



Increased Wind Shear from Global Warming



Vecchi and Soden (2007)



Hurricane Charley
August 9 – 15

Hurricane Frances
August 23 – September 6

Hurricane Ivan
September 2 – 17

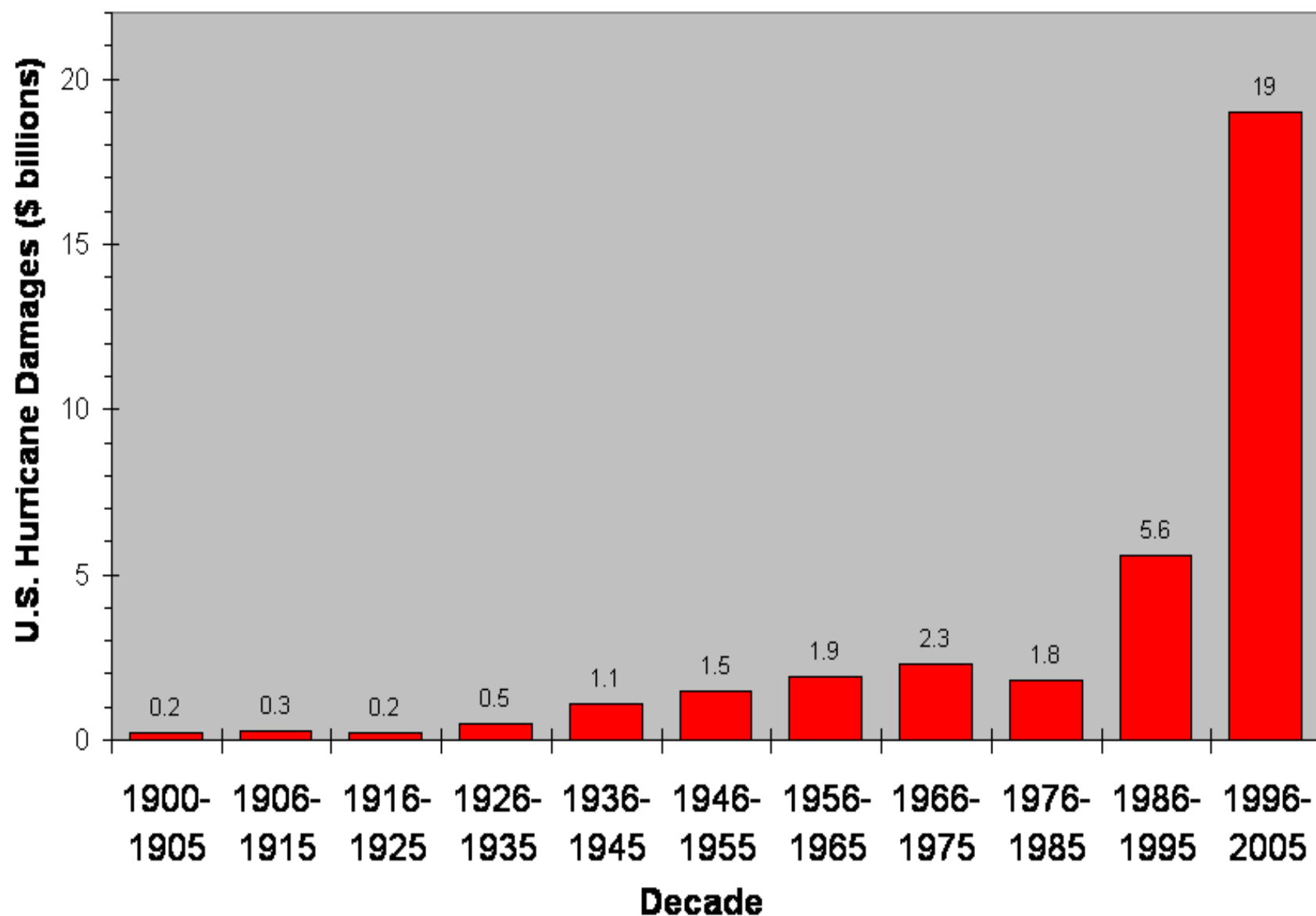
Hurricane Jeanne
September 13 – 27

- TROPICAL DEPR
- TROPICAL STORM
- CATEGORY 1
- CATEGORY 2
- CATEGORY 3
- CATEGORY 4
- CATEGORY 5



U.S. Tropical Storm and Hurricane Damages

\$BILLIONS Annually - Inflation Adjusted

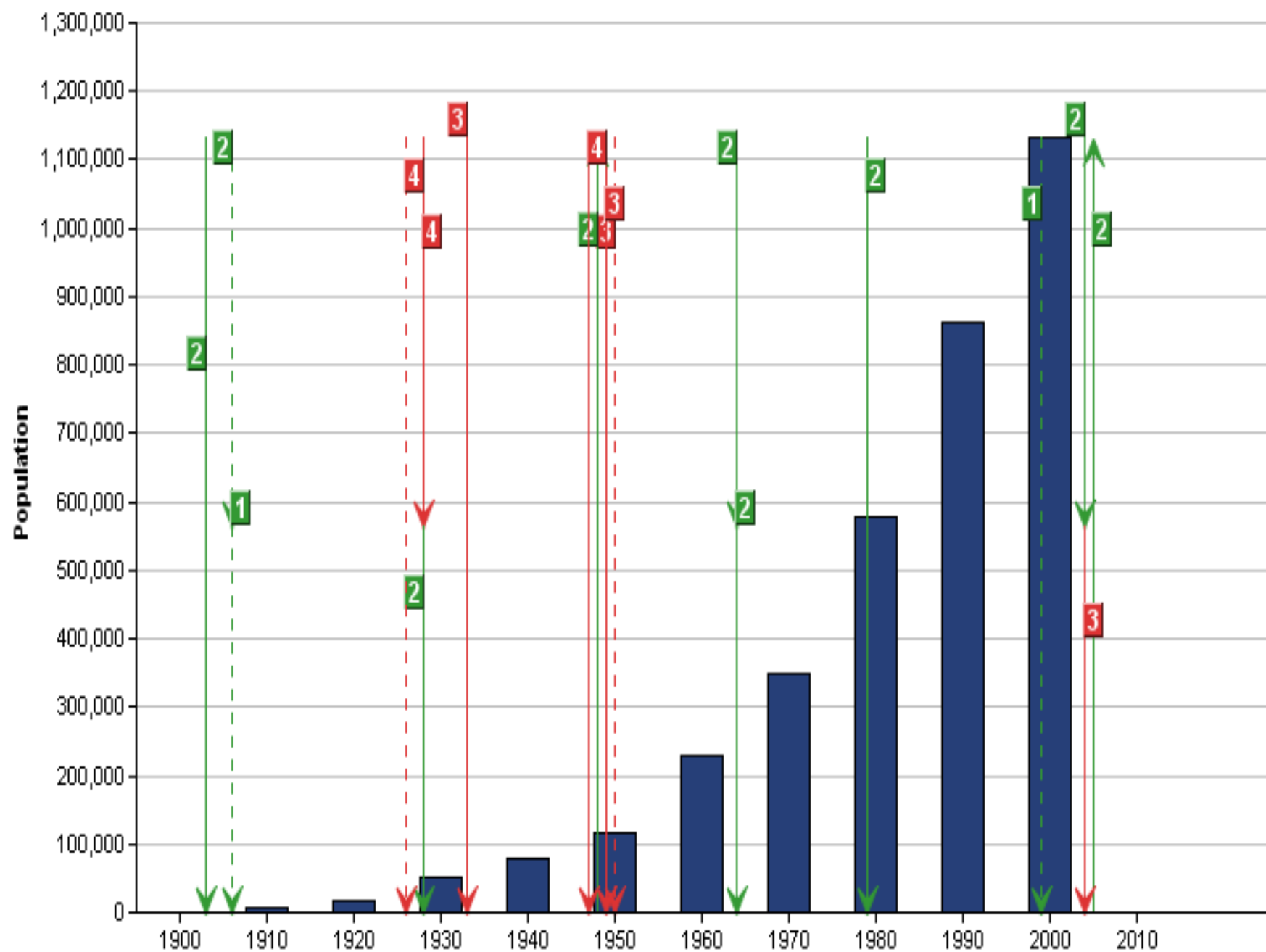


Increases in personal wealth (people have more “stuff”, and larger homes to stow their stuff, etc.) has led to greatly increased damage from hurricanes.





Hurricane Strikes vs Population for Palm Beach, Florida



NORMALIZED DAMAGE...

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

$ND = f(\text{inflation, coastal population, wealth})$

Pielke and Landsea (1998)

$ND = f(\text{inflation, coastal housing, wealth})$

Pielke et al. (2008)

1926 Great Miami Hurricane

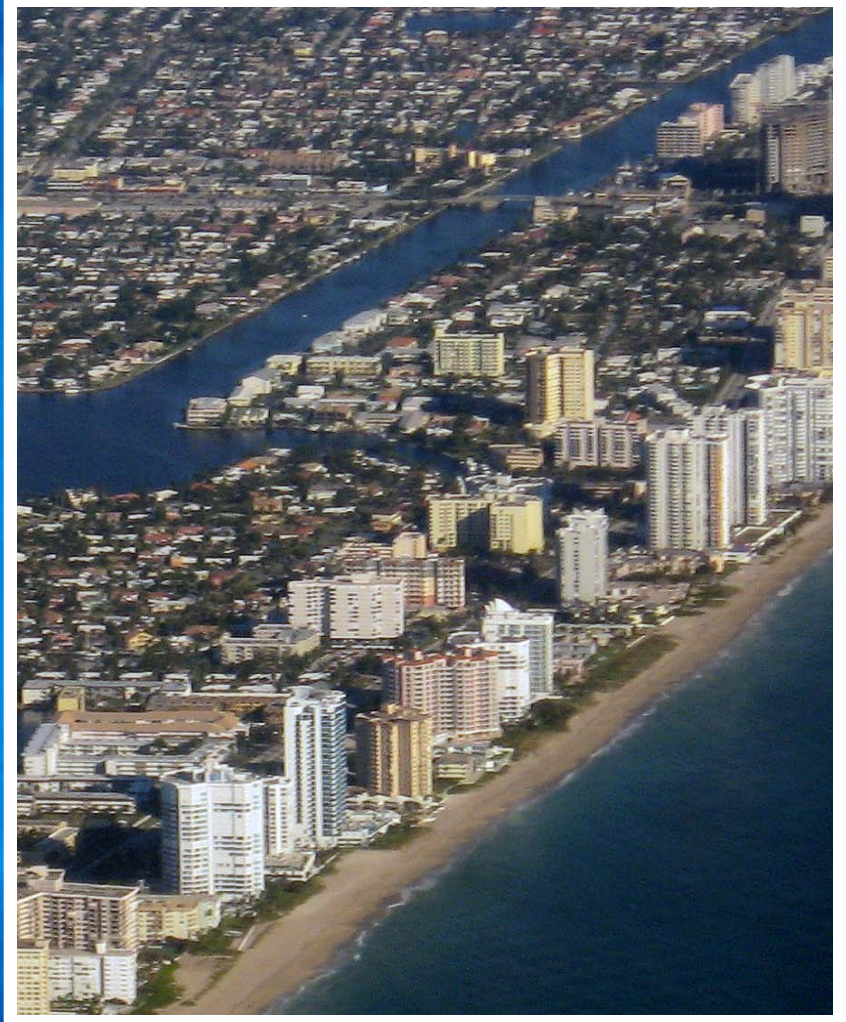
\$140-157 Billion Today

Miami Beach 1926



Wendler Collection

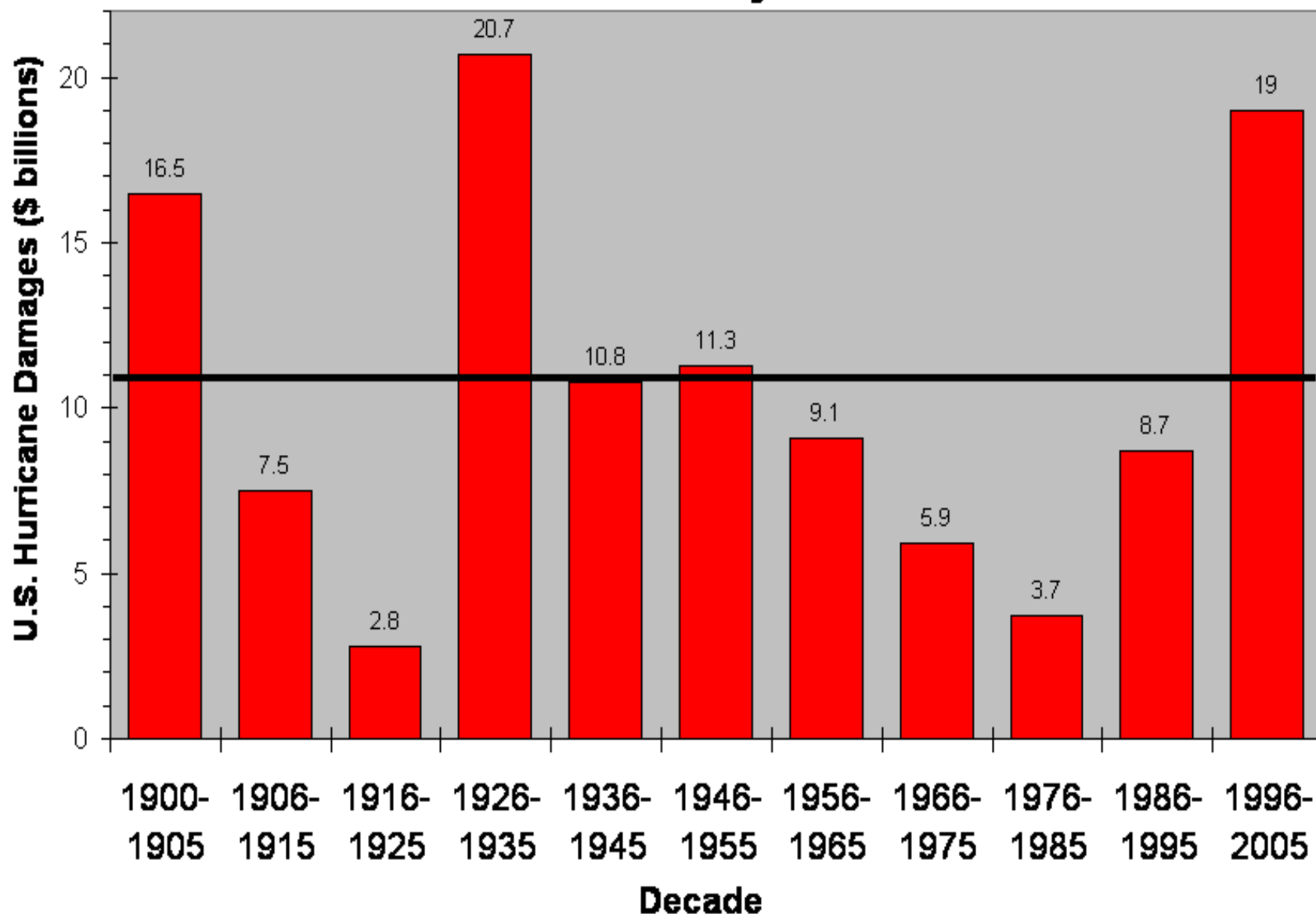
Miami Beach 2006



Joel Gratz © 2006

U.S. Tropical Storm and Hurricane Damages

\$BILLIONS Annually - Normalized

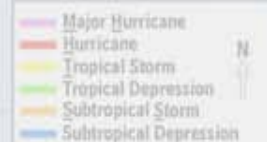


U.S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART

2008

| NUMBER | TYPE | NAME | DATE |
|--------|------|-----------|--------------|
| 1 | T | ARTHUR | MAY 31-JUN 1 |
| 2 | MH | BERTHA | JUL 3-20 |
| 3 | T | CRISTOBAL | JUL 19-23 |
| 4 | H | DOLLY | JUL 20-25 |
| 5 | T | EDOUARD | AUG 3-6 |
| 6 | T | FAY | AUG 15-26 |
| 7 | MH | GUSTAV | AUG 25-SEP 4 |
| 8 | H | HANNA | AUG 28-SEP 7 |
| 9 | MH | IKE | SEP 1-14 |
| 10 | T | JOSEPHINE | SEP 2-6 |
| 11 | H | KYLE | SEP 25-29 |
| 12 | T | LMIRA | SEP 29-OCT 1 |
| 13 | T | MARCO | OCT 6-7 |
| 14 | T | NANA | OCT 12-14 |
| 15 | MH | OMAR | OCT 13-18 |
| 16 | MH | PALOMA | NOV 5-9 |

What does the Atlantic hurricane database (HURDAT) show for changes in time of tropical cyclone frequency and intensity?



“This record [of Atlantic tropical cyclone counts] ... shows a strong, long-term relationship with tropical Atlantic August-October SST...The underlying factor appears to be the influence of (primarily anthropogenic) forced large-scale warming.”

Linking Atlantic storm numbers to ocean temperatures

Eos, Vol. 87, No. 24, 13 June 2006

EOS

EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

Atlantic Hurricane Trends Linked to Climate Change

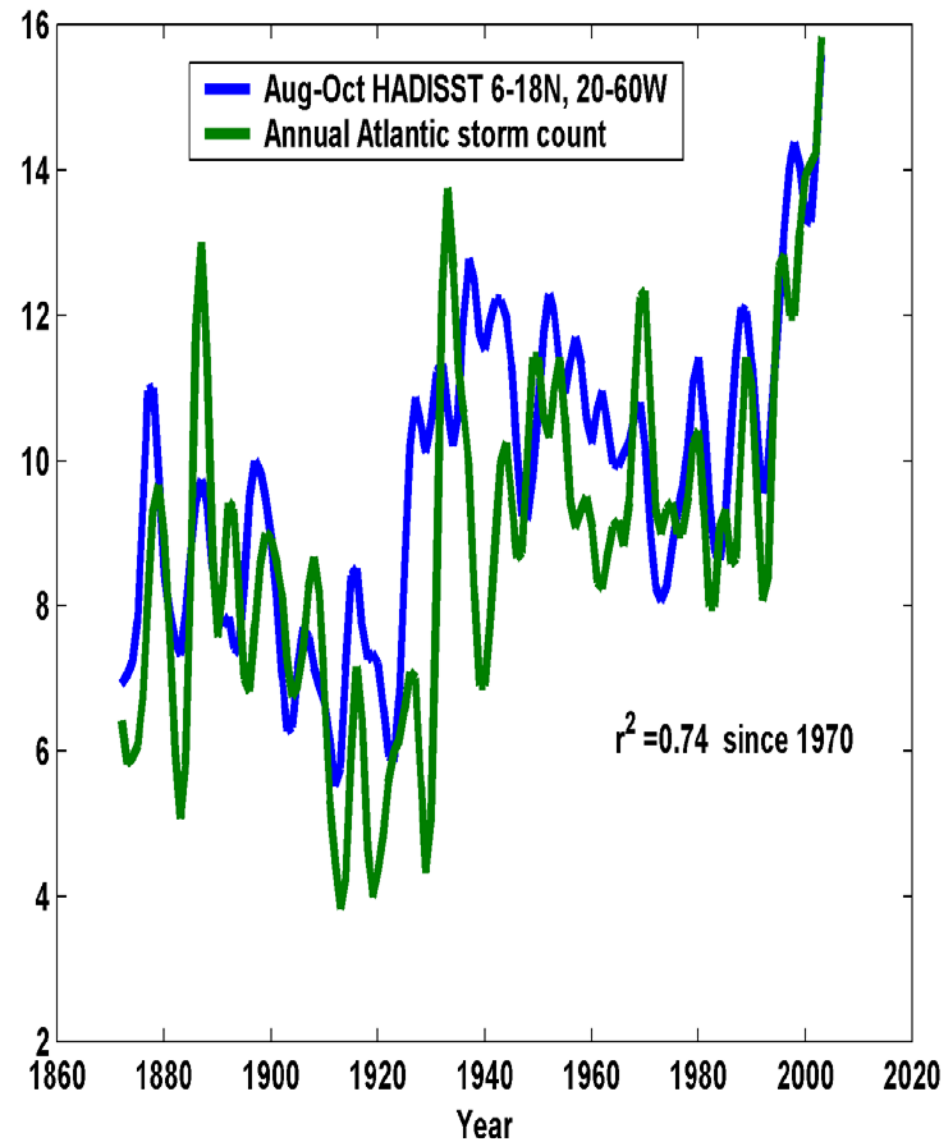
PAGES 233, 238, 241

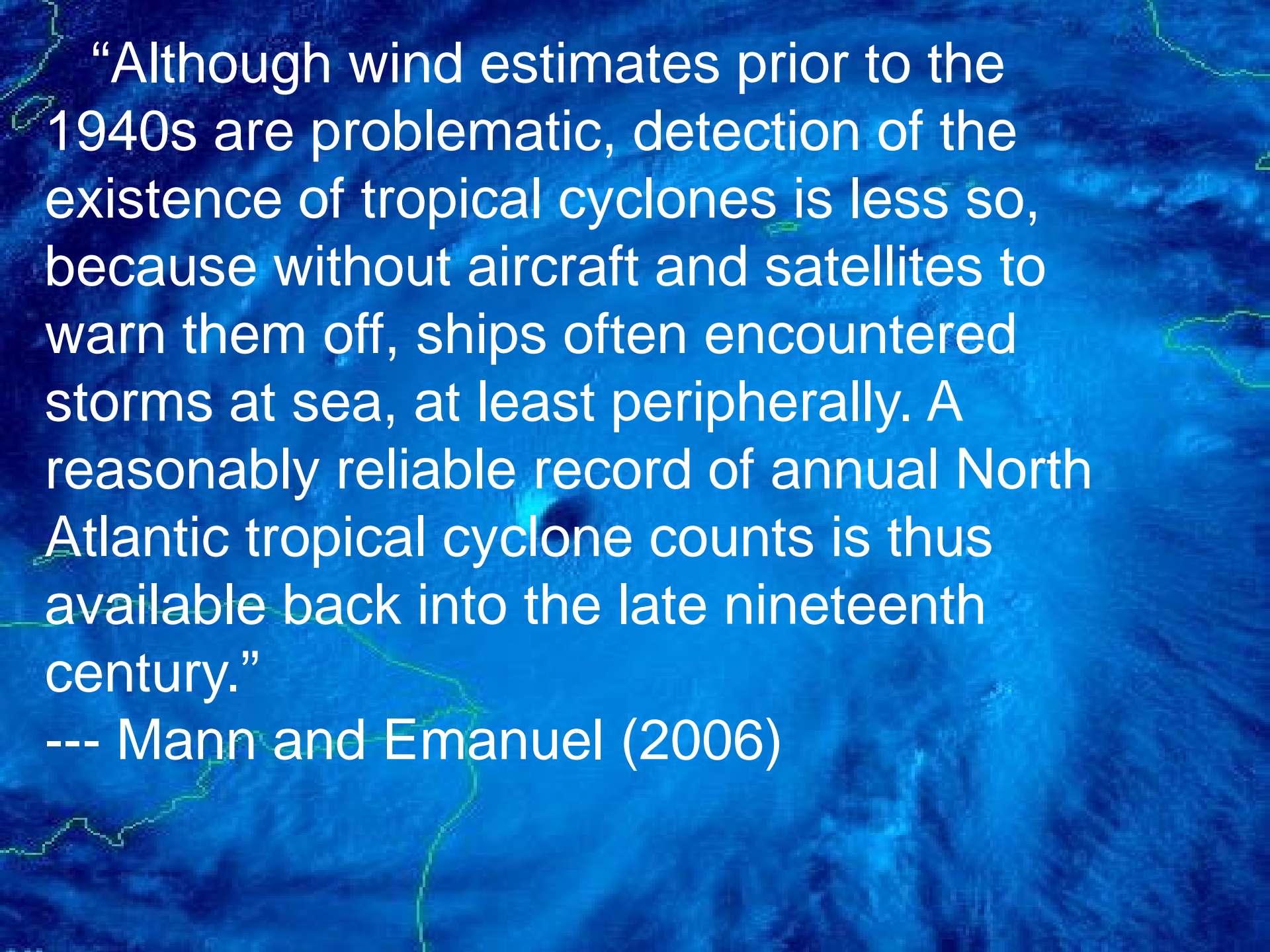
Increases in key measures of Atlantic hurricane activity over recent decades are believed to reflect, in large part, contemporaneous increases in tropical Atlantic warmth [e.g., *Emanuel, 2005*]. Some recent studies [e.g., *Goldenberg et al., 2001*] have attributed these increases to a natural climate cycle

termed the Atlantic Multidecadal Oscillation (AMO), while other studies suggest that climate change may instead be playing the dominant role [Emanuel, 2005; Webster et al., 2005].

Using a formal statistical analysis to separate the estimated influences of anthropogenic climate change from possible natural cyclical influences, this article presents results indicating that anthropogenic factors are likely responsible for long-term trends in tropical Atlantic warmth and tropical cyclone

BY M. E. MANN AND K. A. EMANUEL

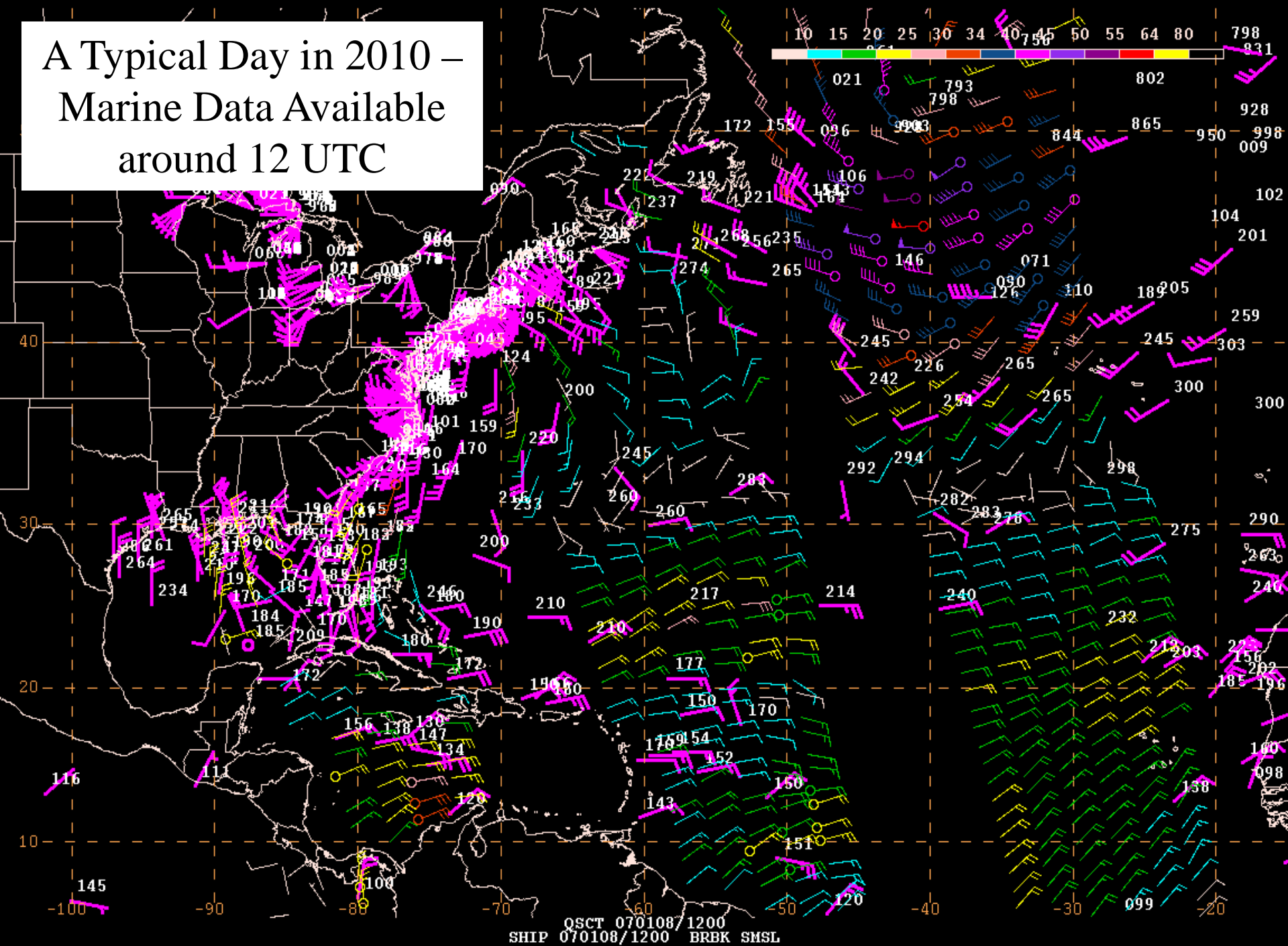




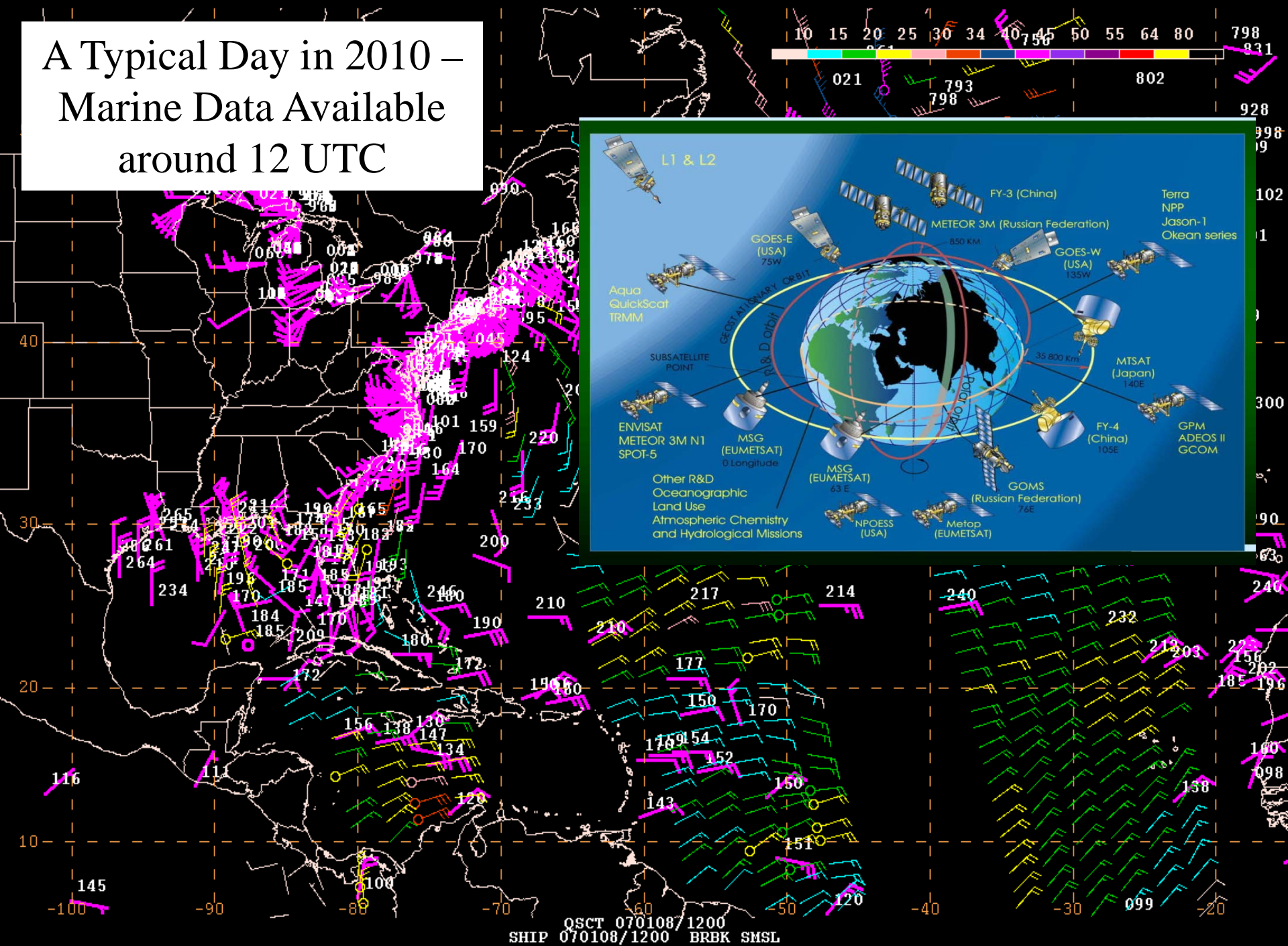
“Although wind estimates prior to the 1940s are problematic, detection of the existence of tropical cyclones is less so, because without aircraft and satellites to warn them off, ships often encountered storms at sea, at least peripherally. A reasonably reliable record of annual North Atlantic tropical cyclone counts is thus available back into the late nineteenth century.”

--- Mann and Emanuel (2006)

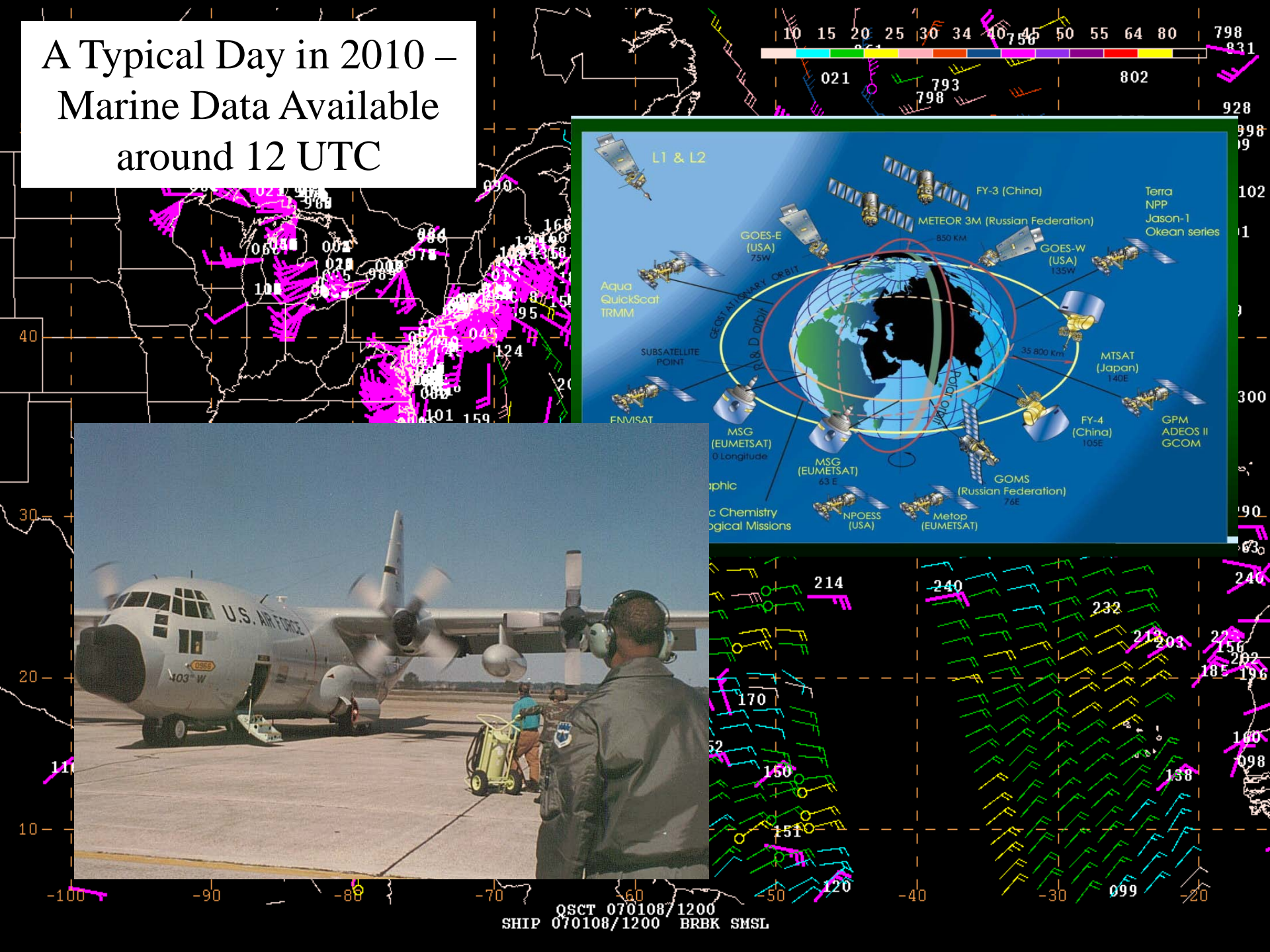
A Typical Day in 2010 – Marine Data Available around 12 UTC



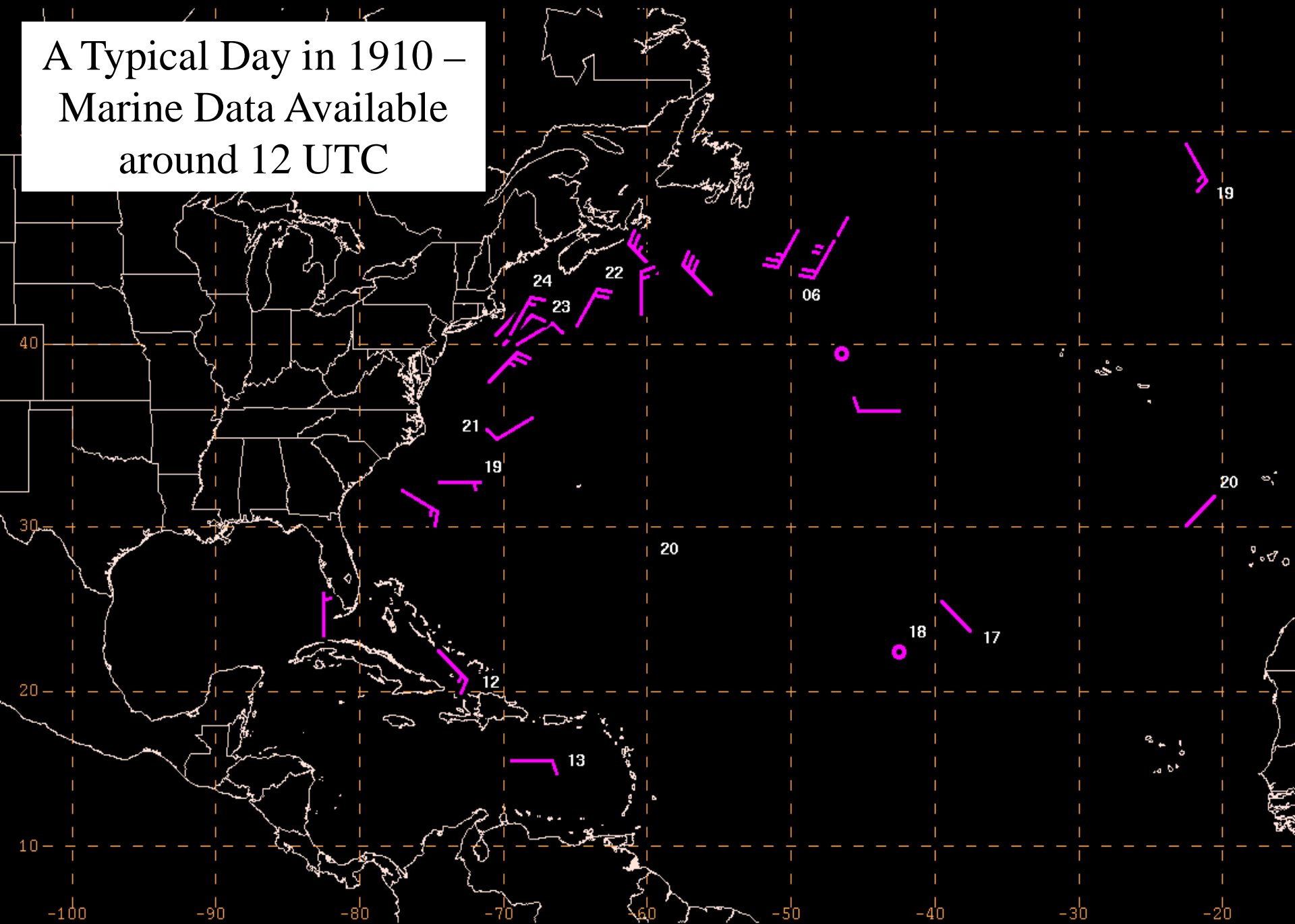
A Typical Day in 2010 – Marine Data Available around 12 UTC



A Typical Day in 2010 – Marine Data Available around 12 UTC



A Typical Day in 1910 –
Marine Data Available
around 12 UTC



A Typical Day in 1010

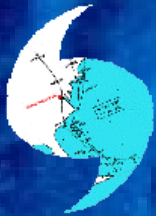
N



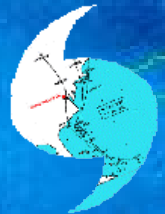
-100 -90 -80 -70 -60 -50 -40 -30 -20

Atlantic Hurricane Database Re-Analysis Project

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



1851 through 1925 changes accepted and officially adopted by NHC. Revisions for 1926 to 1940 are currently being considered. Remainder of 20th Century currently being reanalyzed.

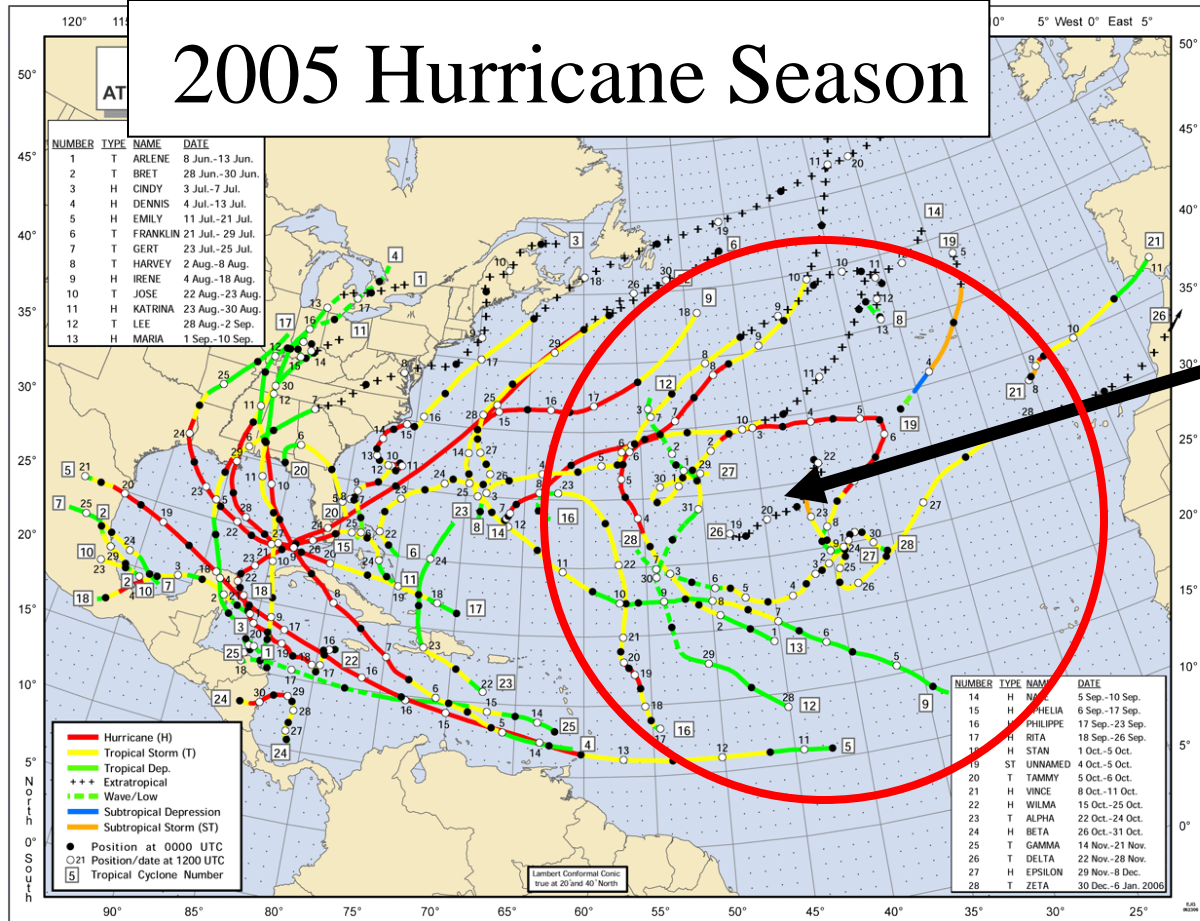


RE-ANALYSES NEED TO BE CONDUCTED GLOBALLY!!!

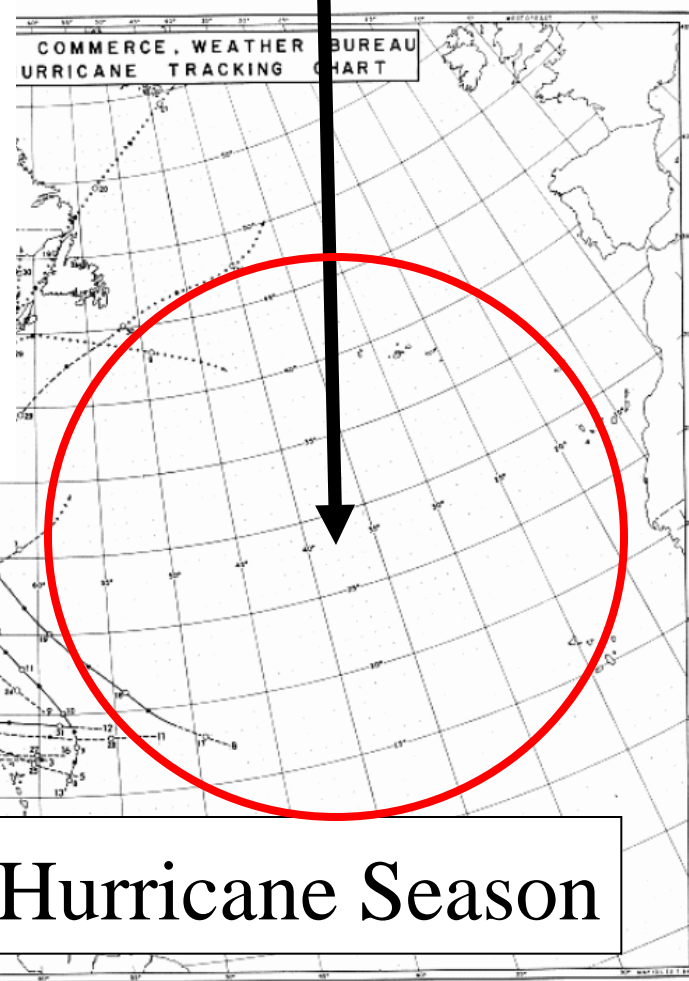


"Florida's Hurricane History"

2005 Hurricane Season

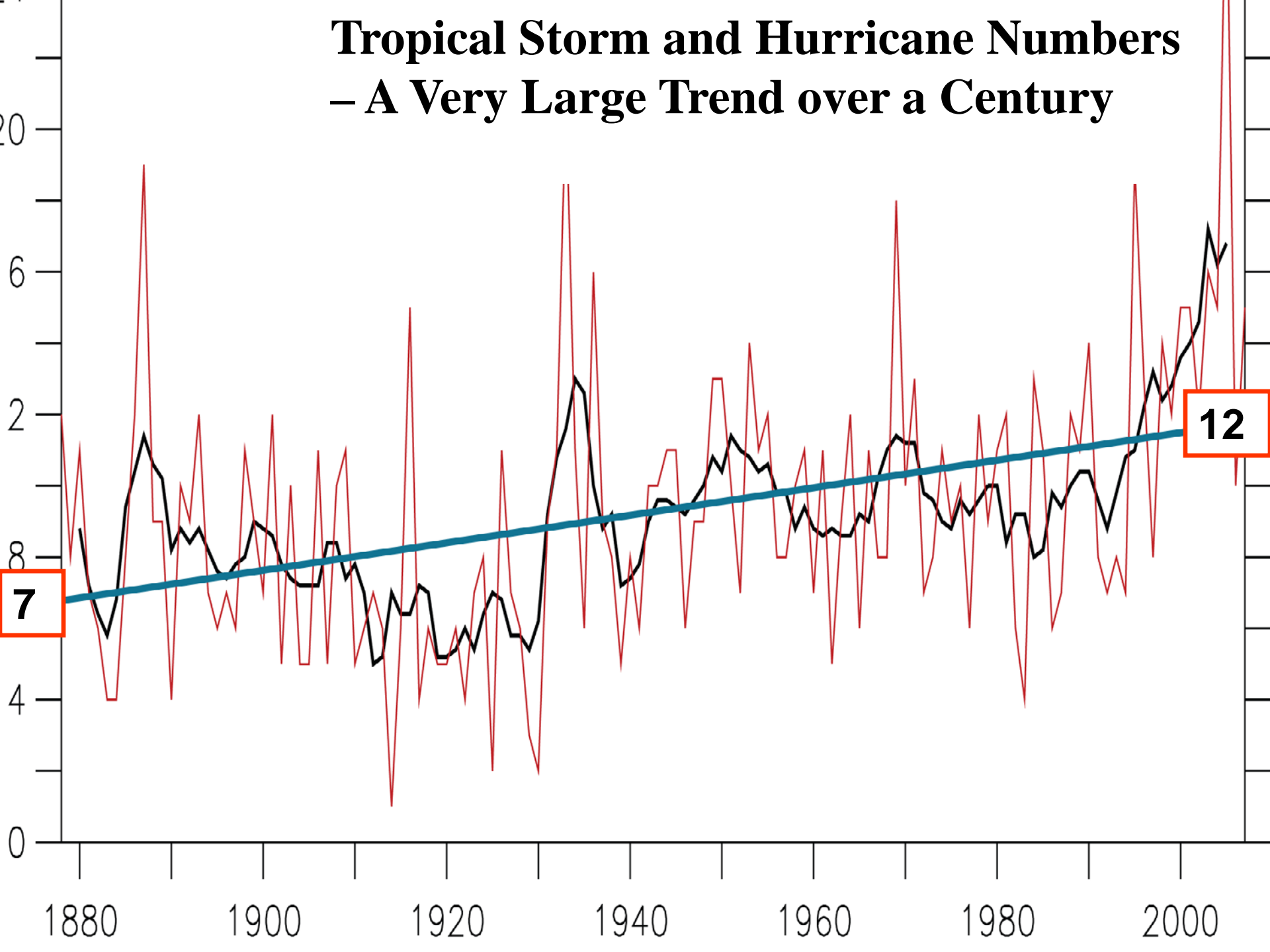


Open Atlantic
Ocean Differences



1933 Hurricane Season

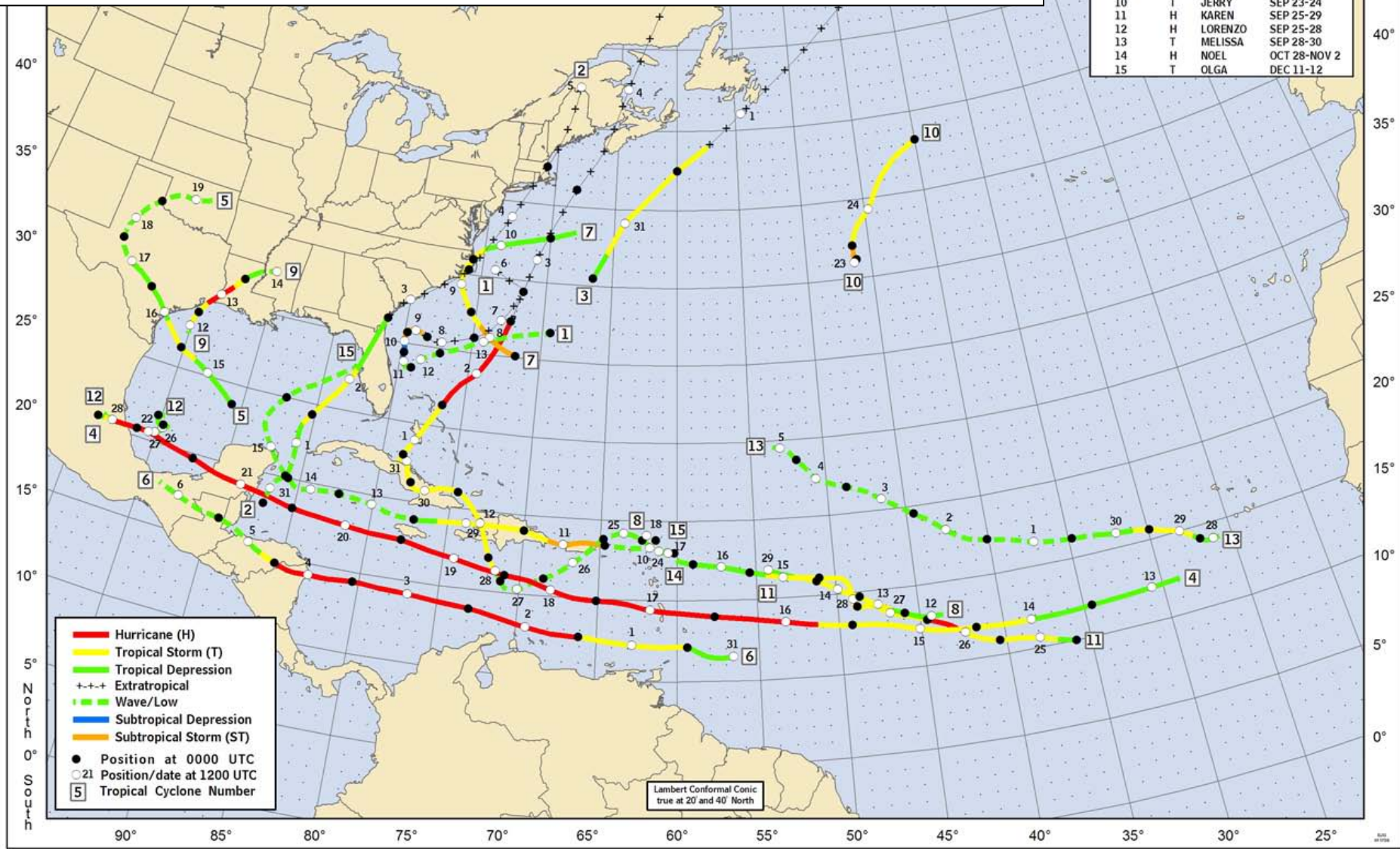
Tropical Storm and Hurricane Numbers – A Very Large Trend over a Century



2007 Hurricane Season -

15 Tropical Storms & Hurricanes...

...9 of which were very short-lived (< 36 hr)

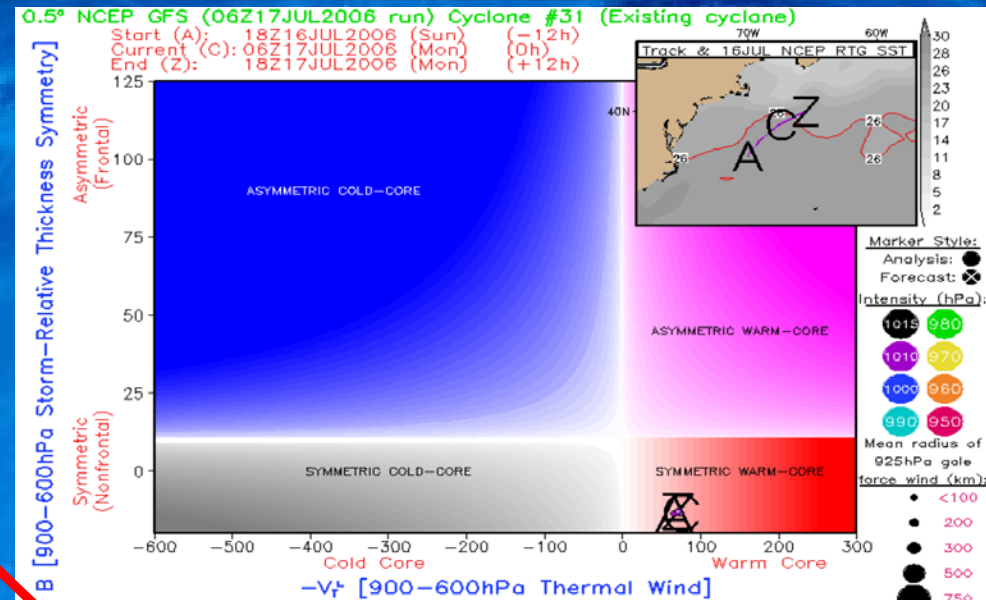


New Tools and Technologies ~ Additional TCs lately?

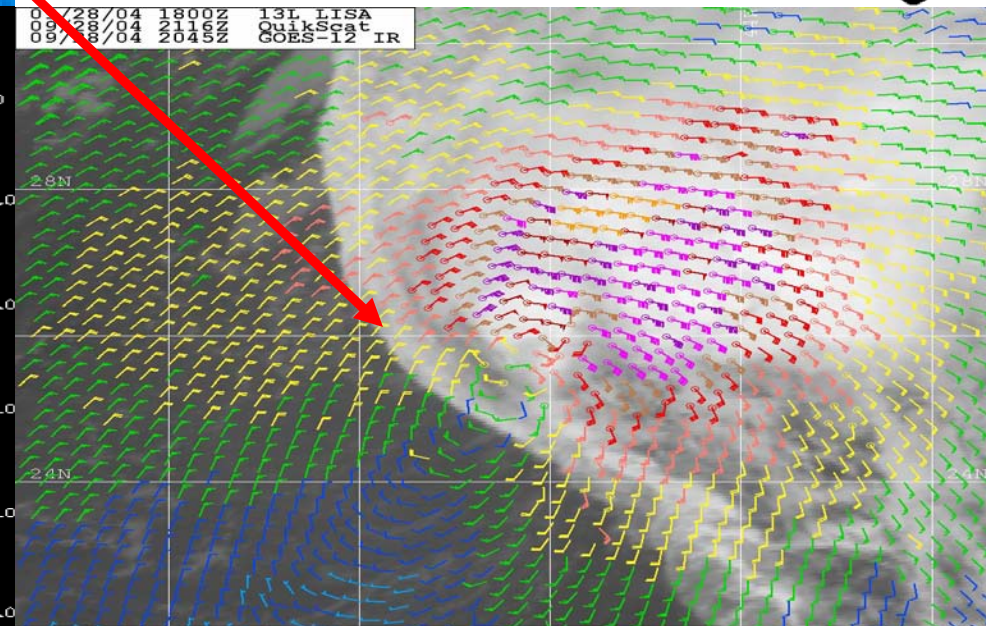
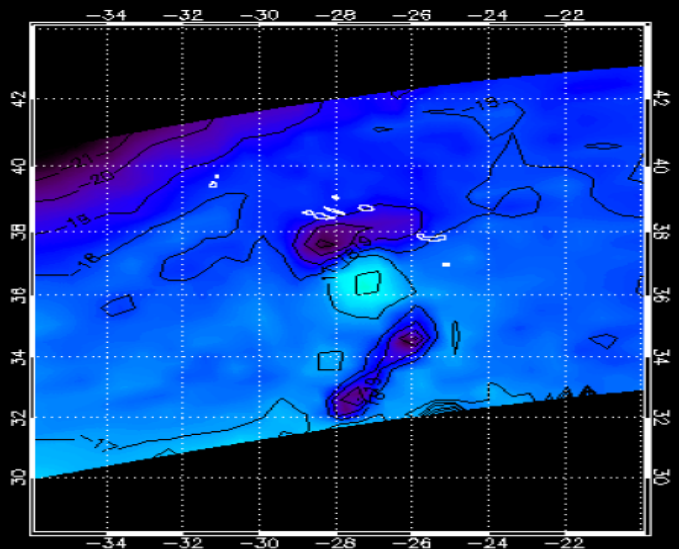
Hart's Cyclone Phase
Space Analyses

Quikscat Surface
Vectors

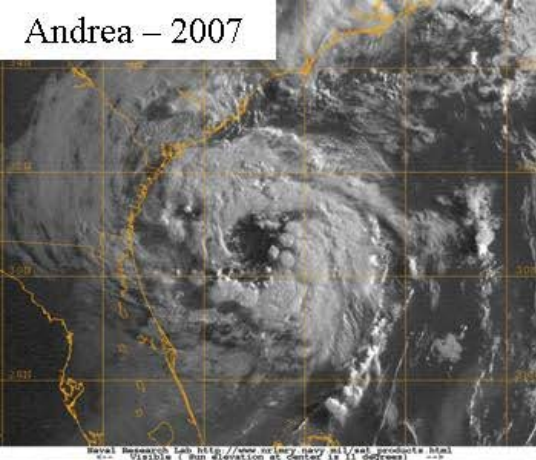
AMSU Tropospheric
Temperatures



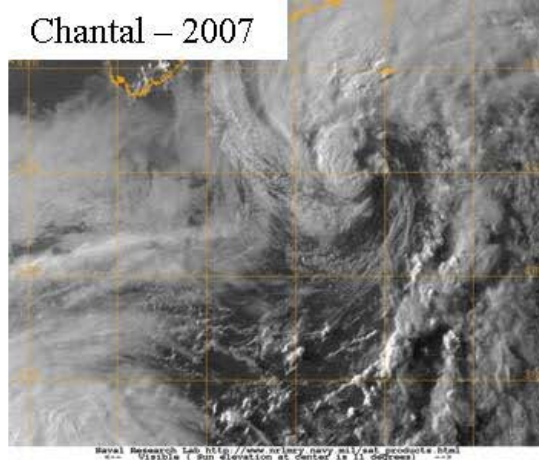
ST 2005
AMSU-A Channel 5 (53.6GHz) Brightness Temperature (C)
04oct05277 Time: 1517 UTC
NDAA-18



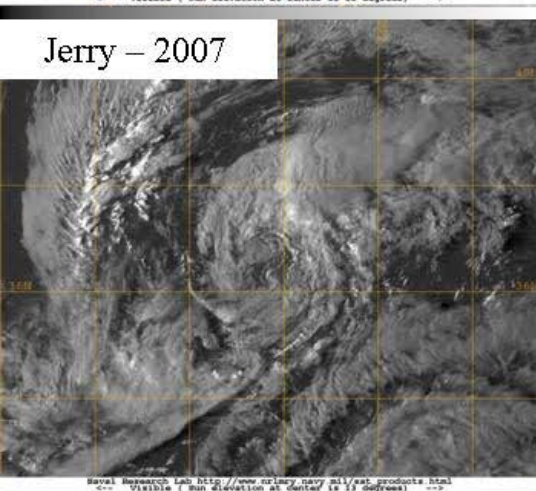
Andrea – 2007



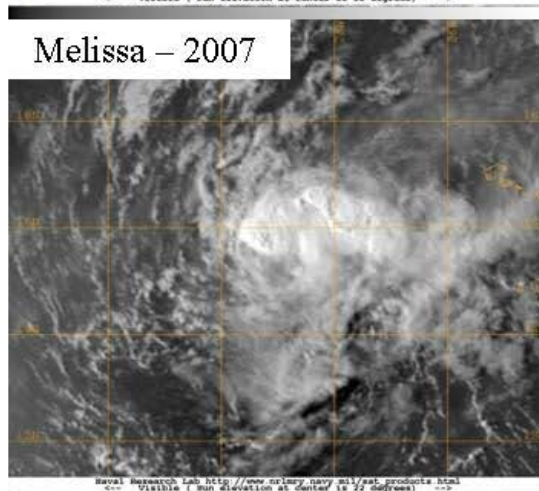
Chantal – 2007



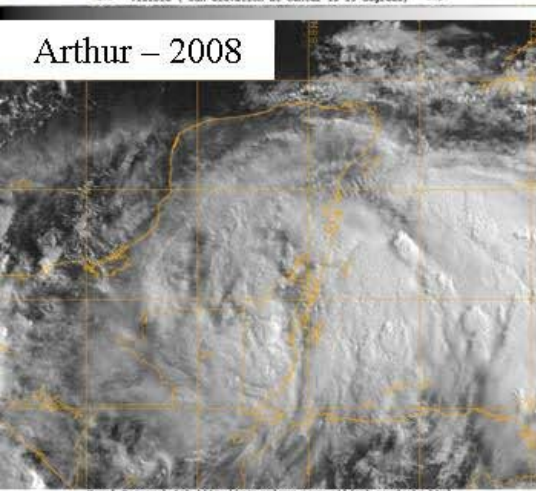
Jerry – 2007



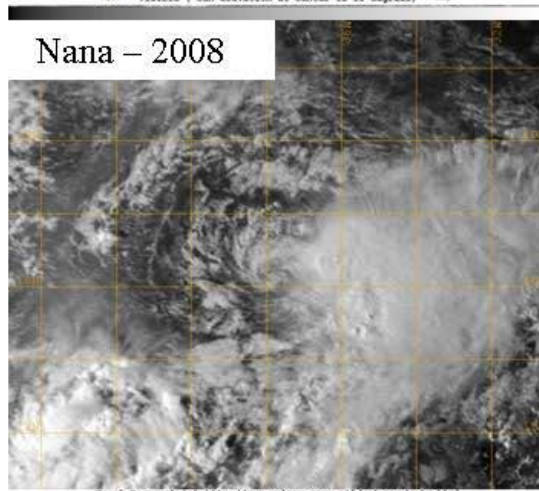
Melissa – 2007



Arthur – 2008



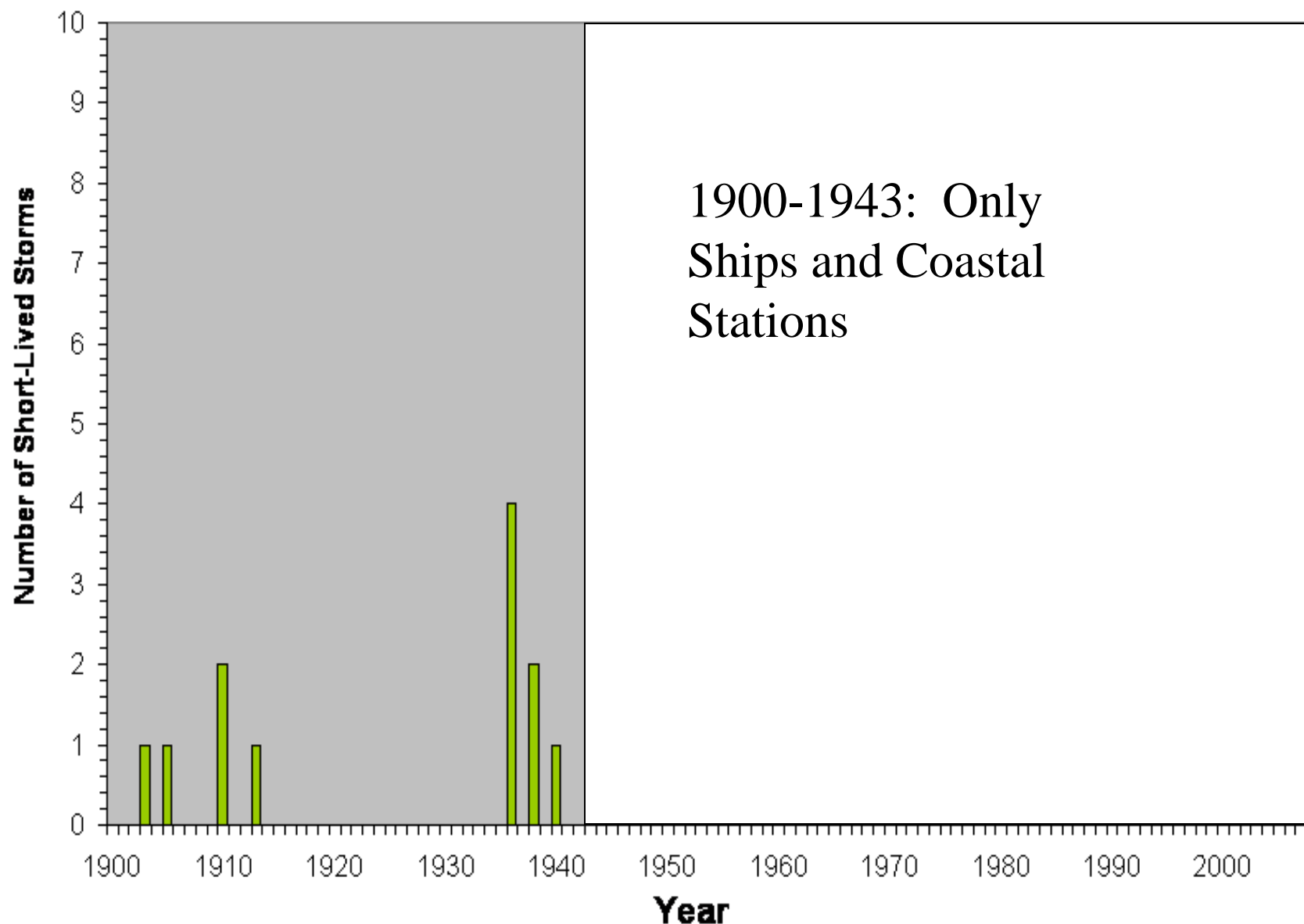
Nana – 2008



Six weak, short-lived storms in recent seasons – Unlikely to have been “named” previously

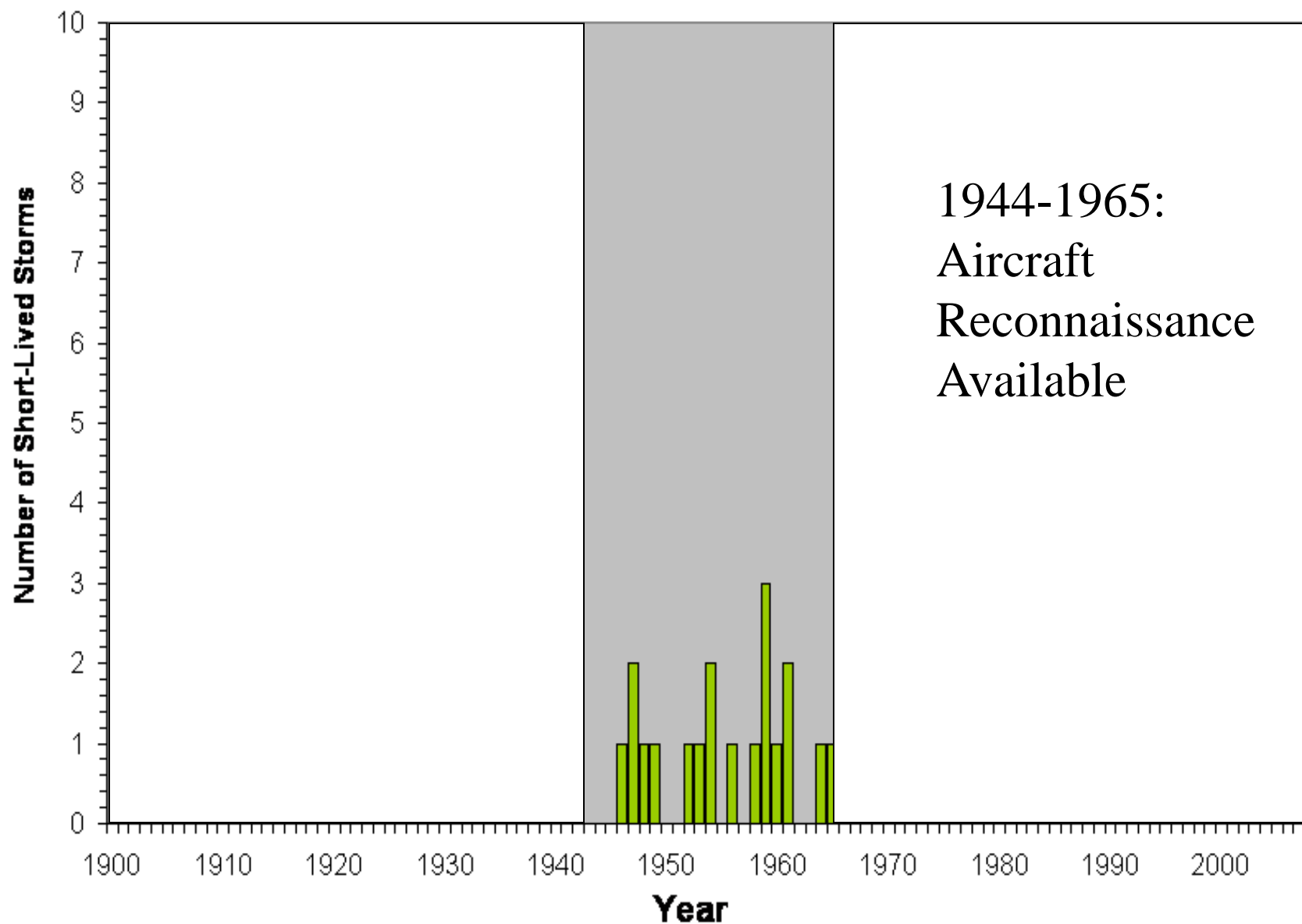
Short-Lived Atlantic Tropical Cyclones

1900-2007 1.5 Days or Less as Named Storm



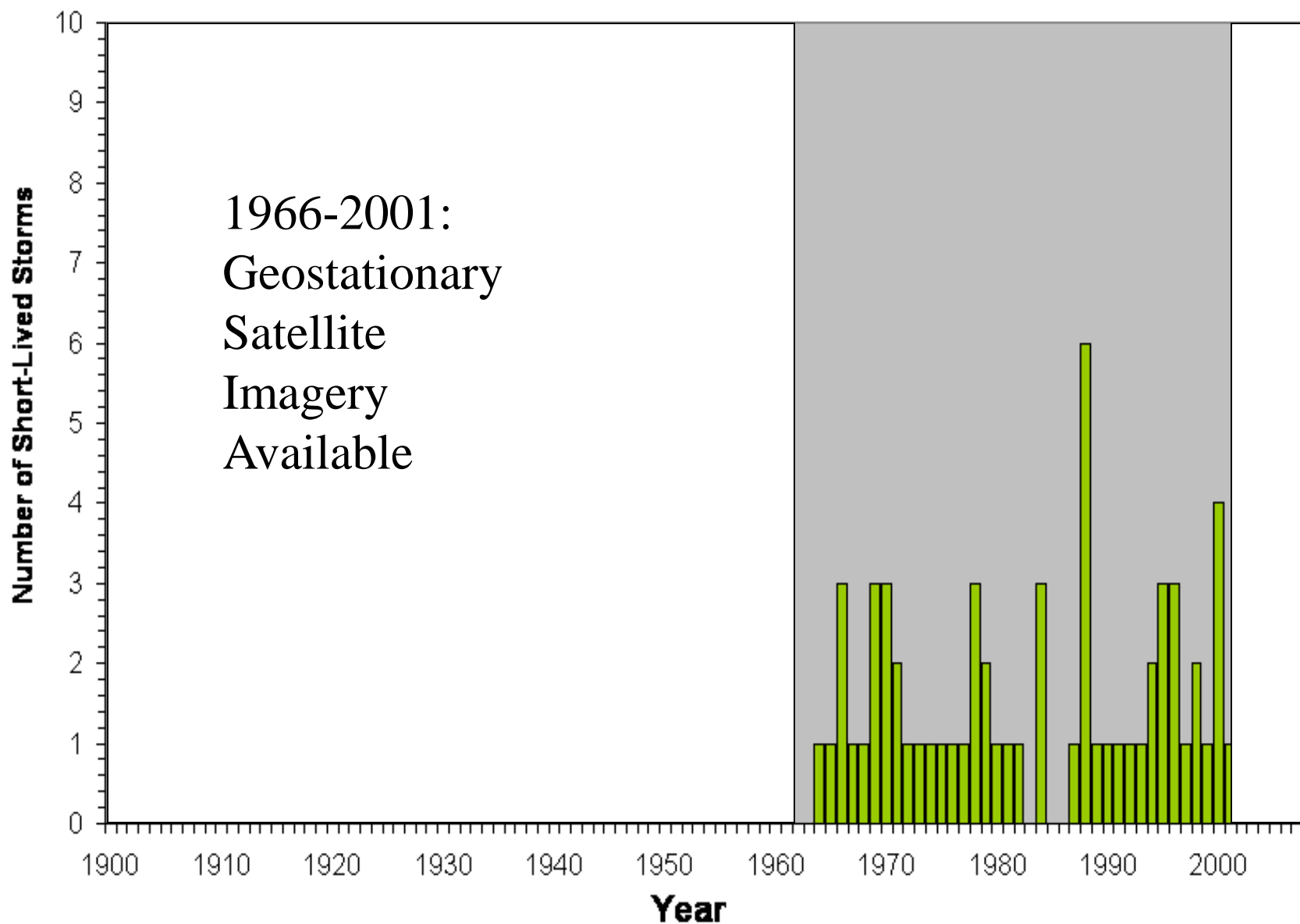
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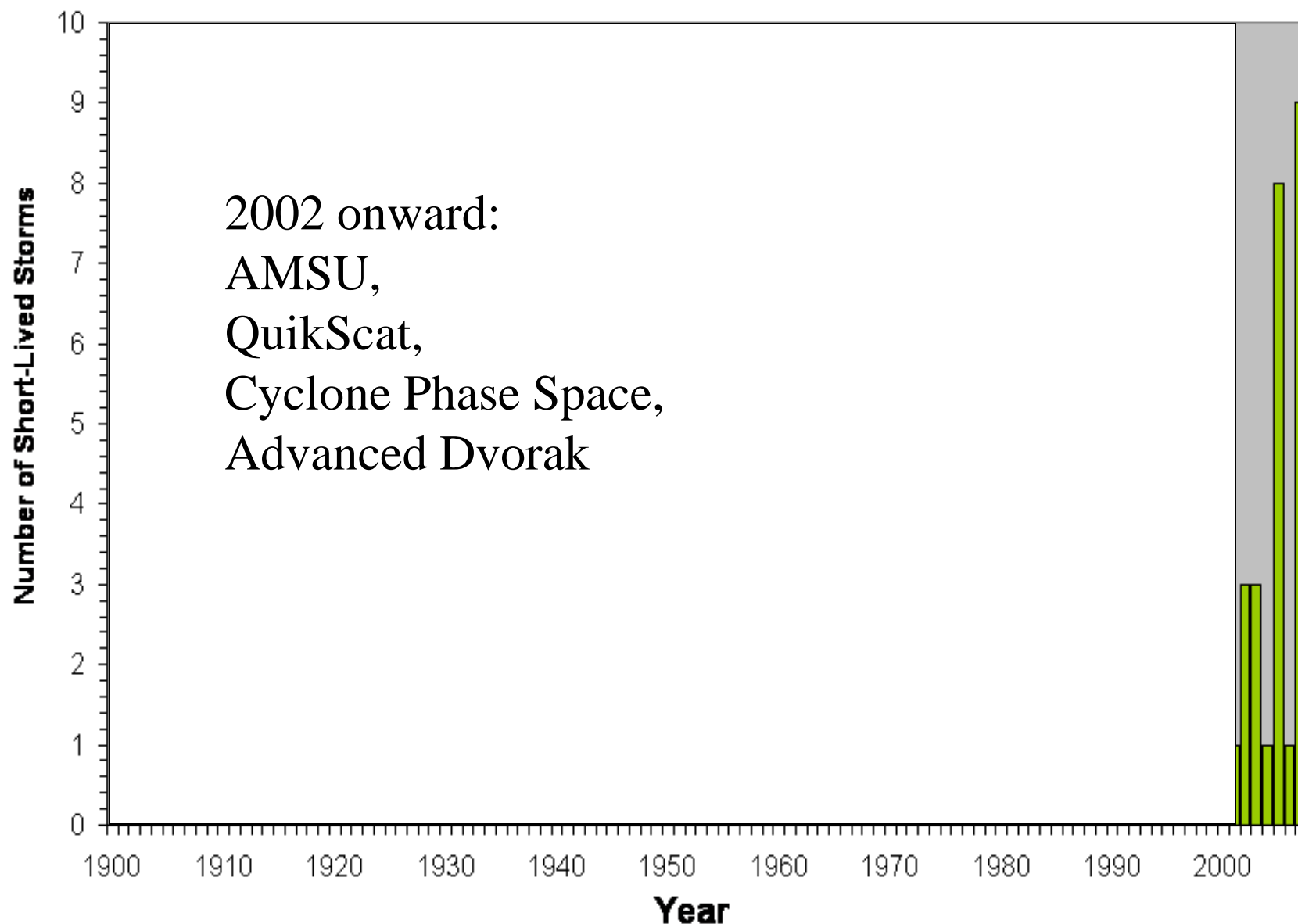
Short-Lived Atlantic Tropical Cyclones

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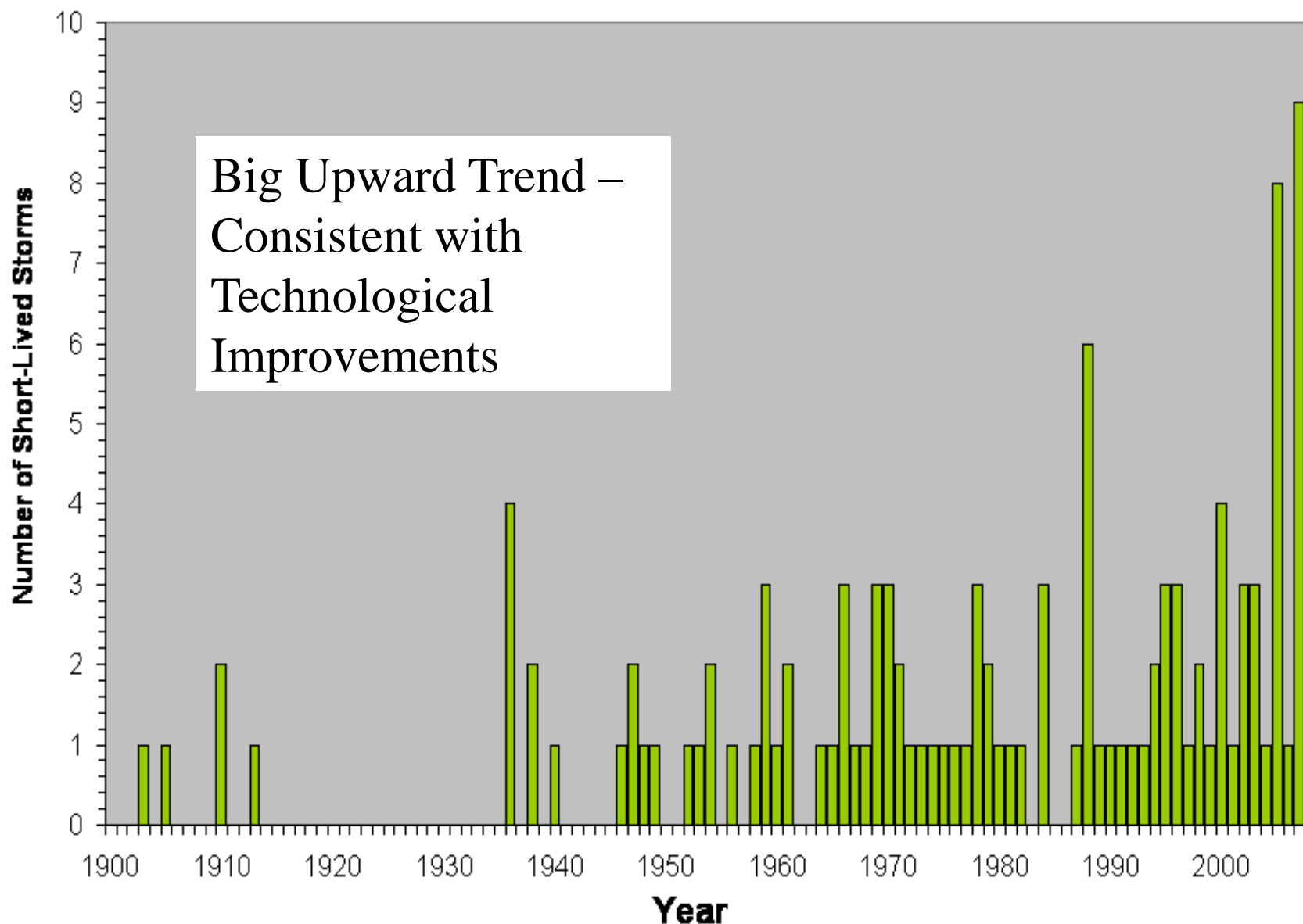
Short-Lived Atlantic Tropical Cyclones

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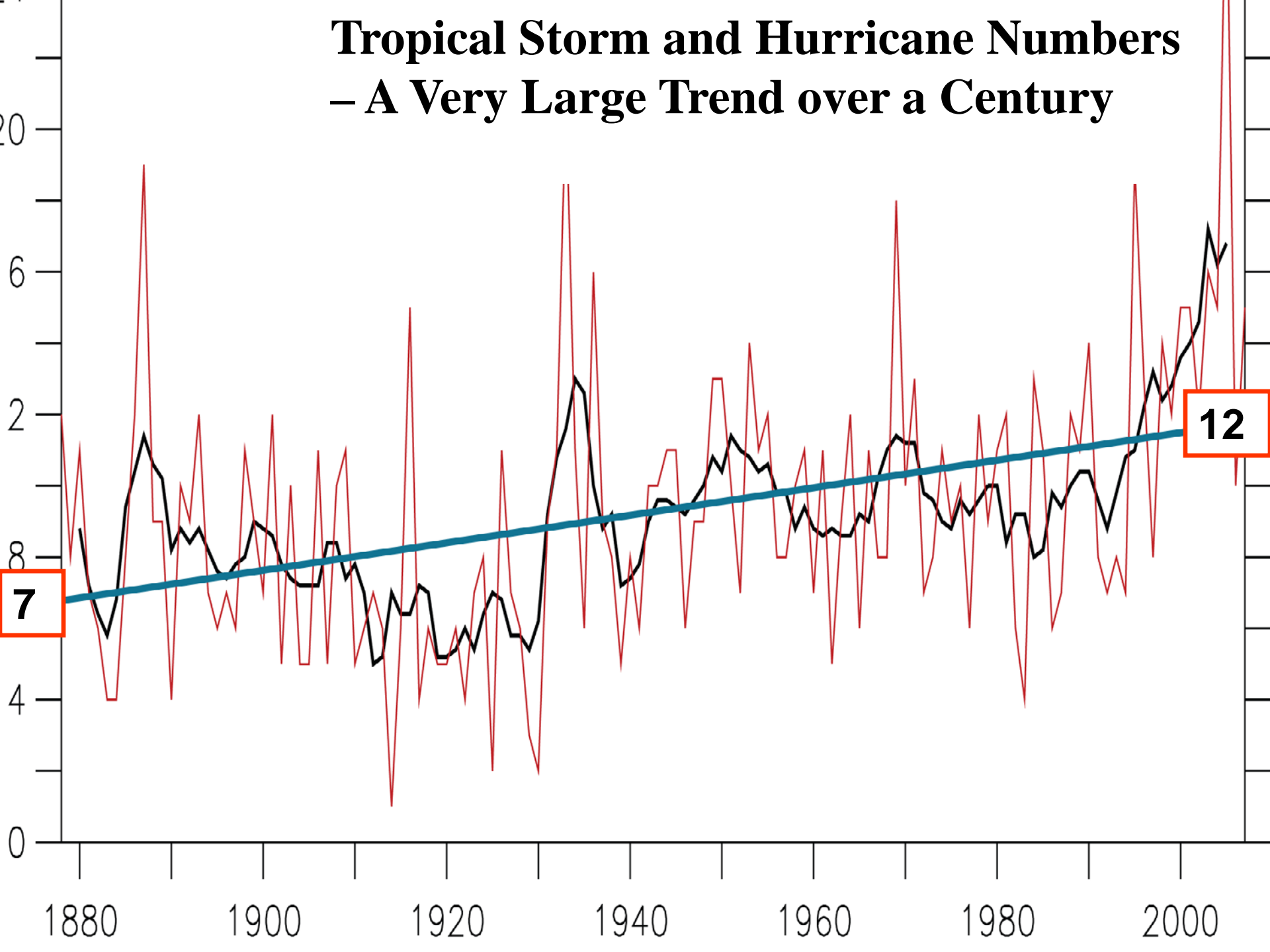


Short-Lived Atlantic Tropical Cyclones

1900-2007 1.5 Days or Less as Named Storm

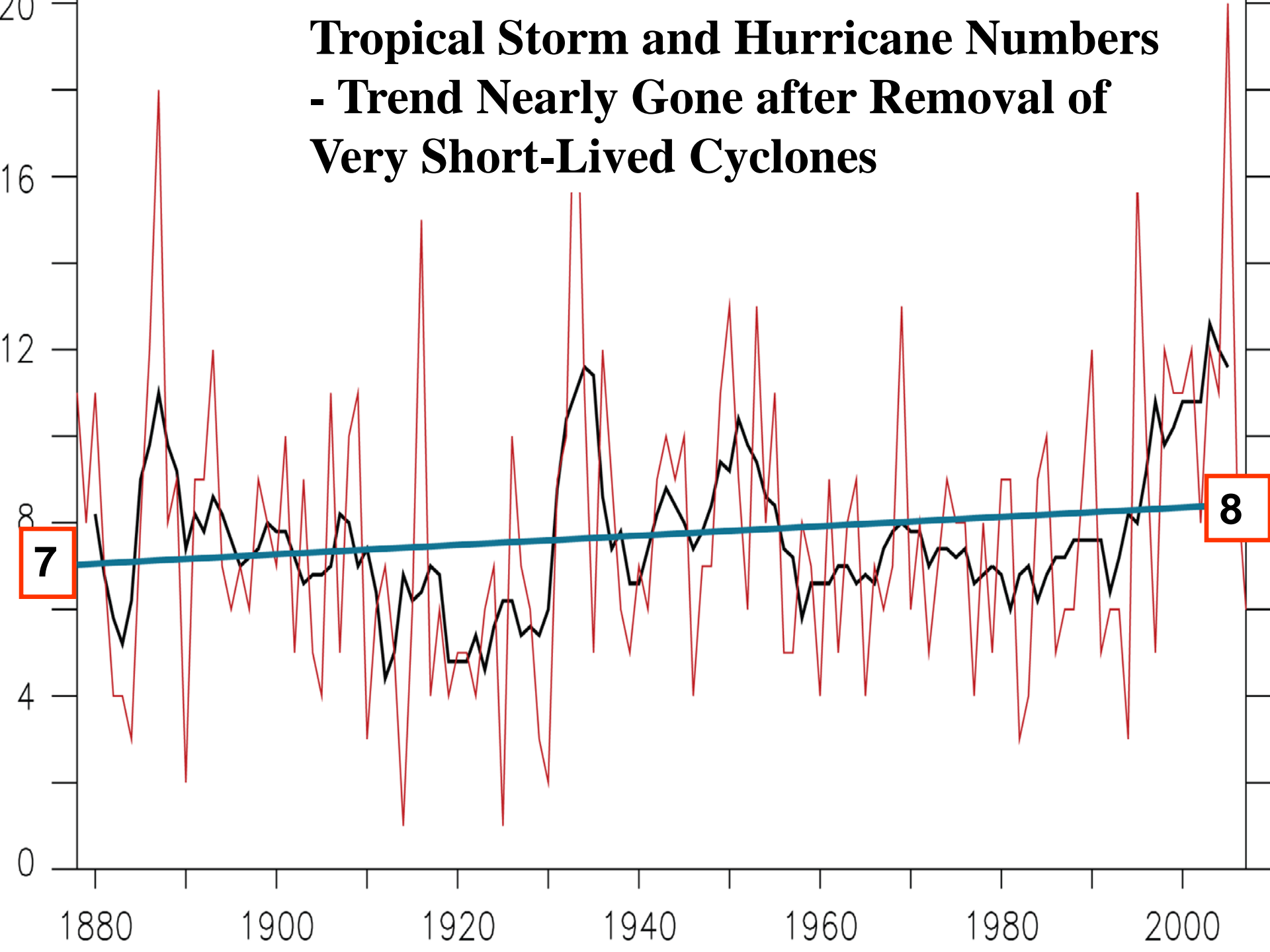


Tropical Storm and Hurricane Numbers – A Very Large Trend over a Century



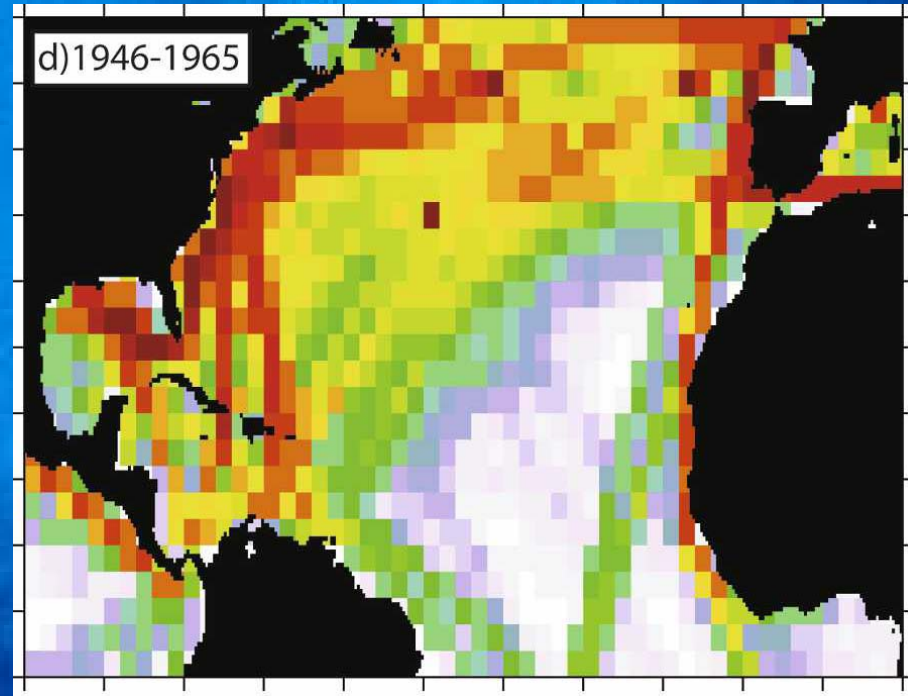
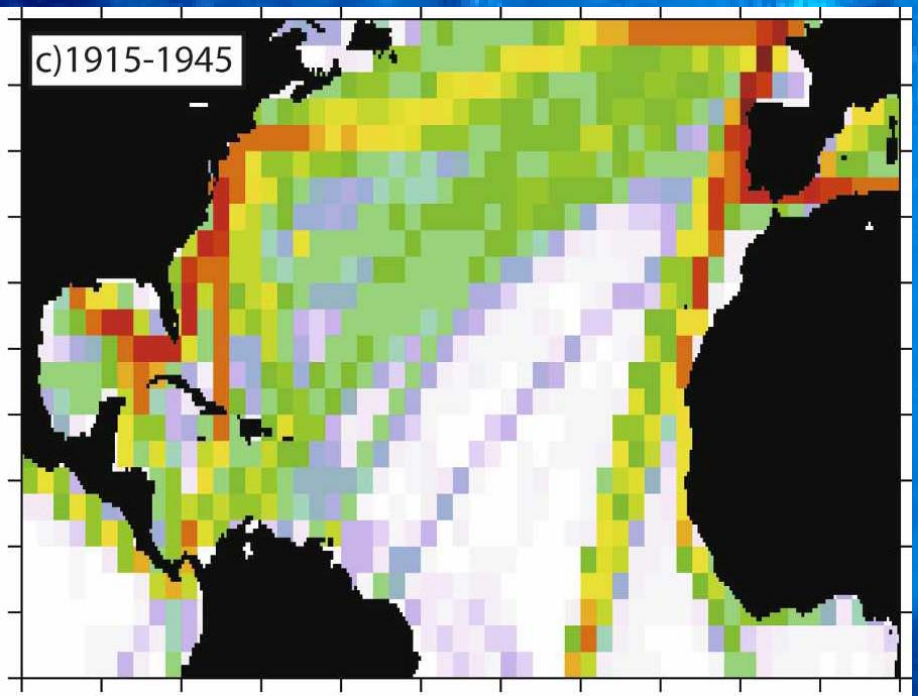
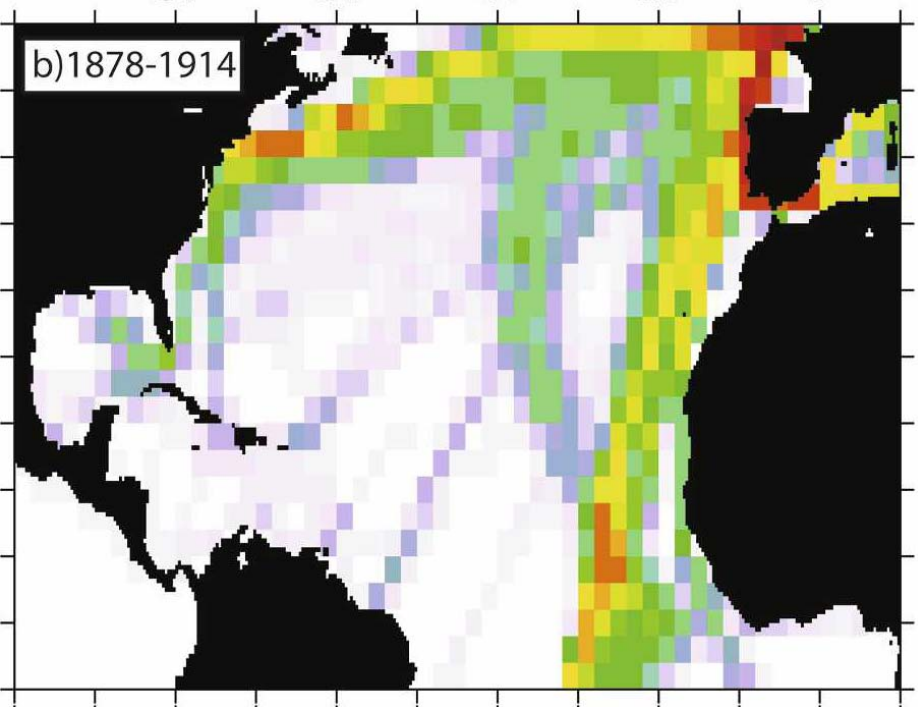
Tropical Storm and Hurricane Numbers

- Trend Nearly Gone after Removal of Very Short-Lived Cyclones



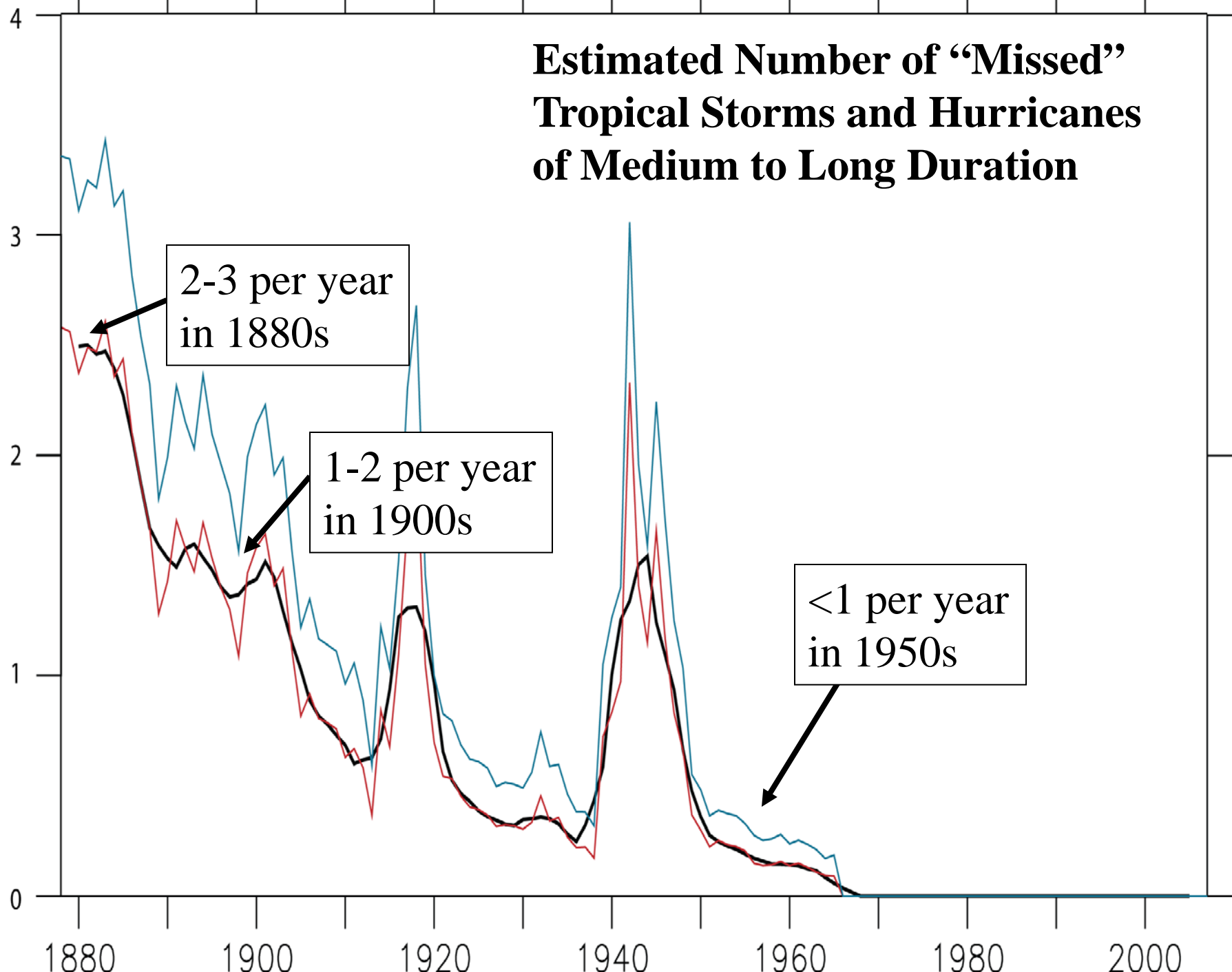
Atlantic ship traffic changes

Vecchi and Knutson (2008)



Vecchi and Knutson (2008) Adjustment to
North Atlantic Tropical Cyclone Counts.

Estimated Number of “Missed” Tropical Storms and Hurricanes of Medium to Long Duration



North Atlantic Tropical Cyclone Counts

Tropical Storm and Hurricane Numbers – Upward Trend Gone After Adding in “Missed” and Removing Very Short-Lived Cyclones

Duration greater than 2.0 days (VK08 Adjusted)

9

8

1880

1900

1920

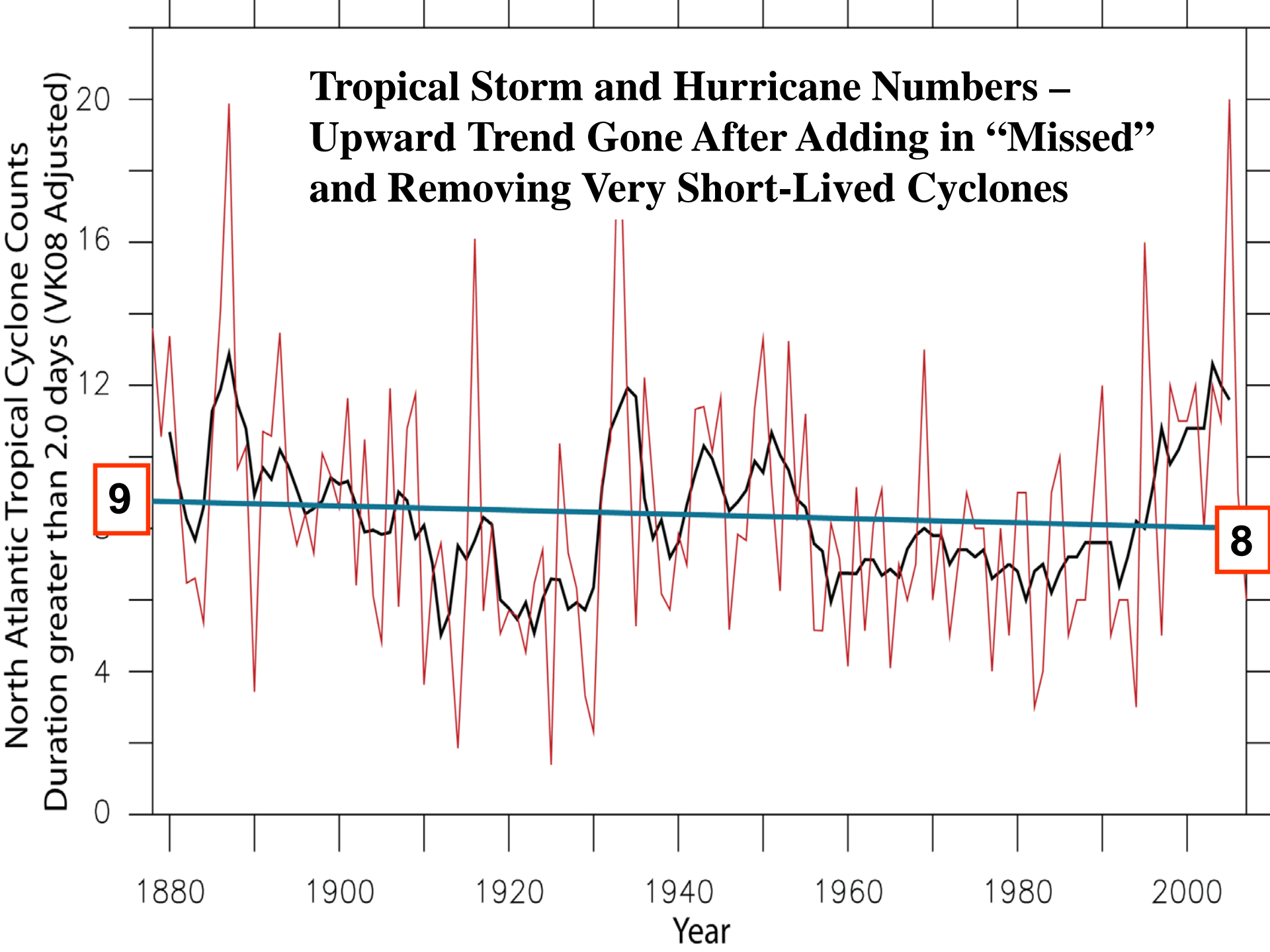
1940

1960

1980

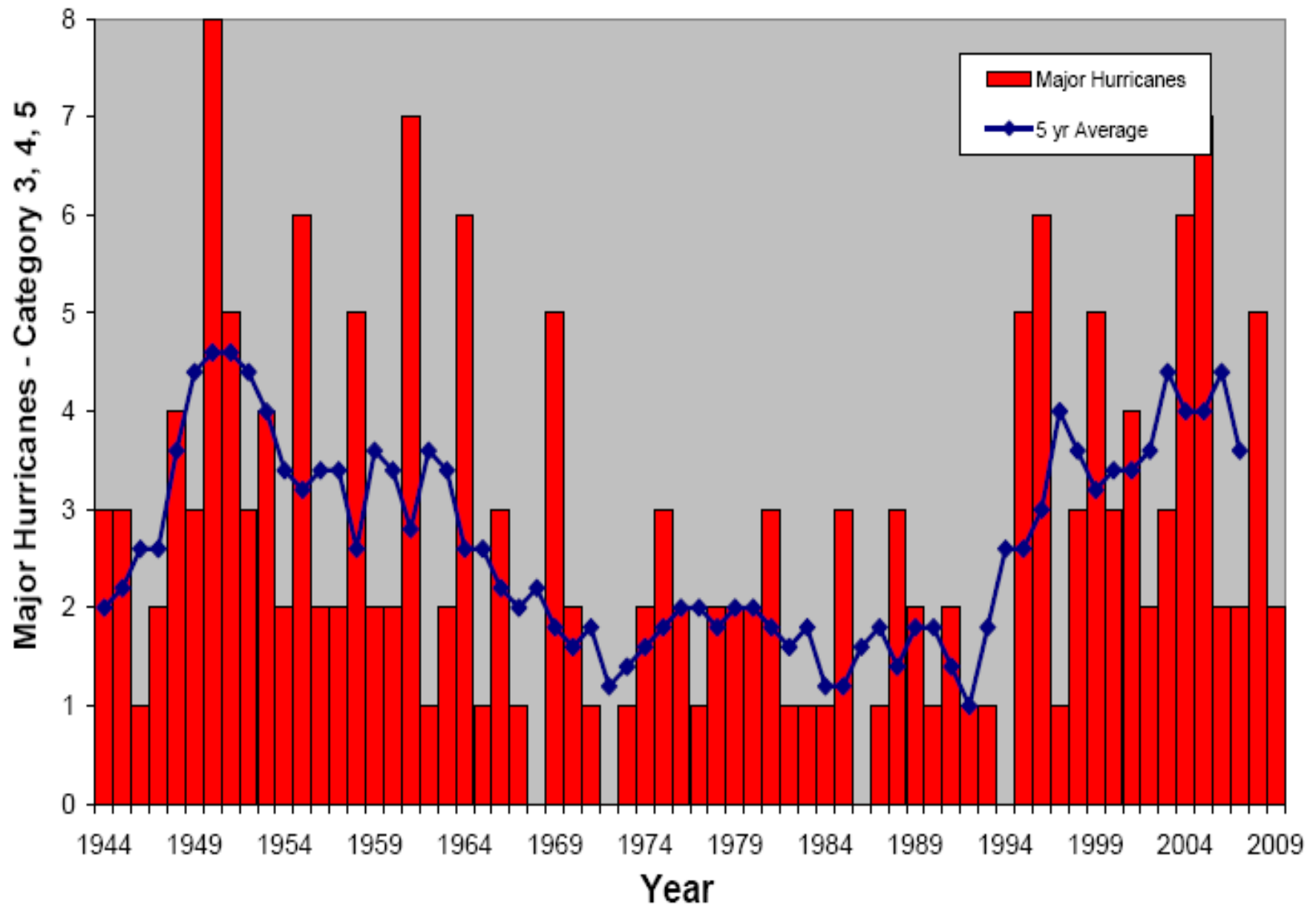
2000

Year



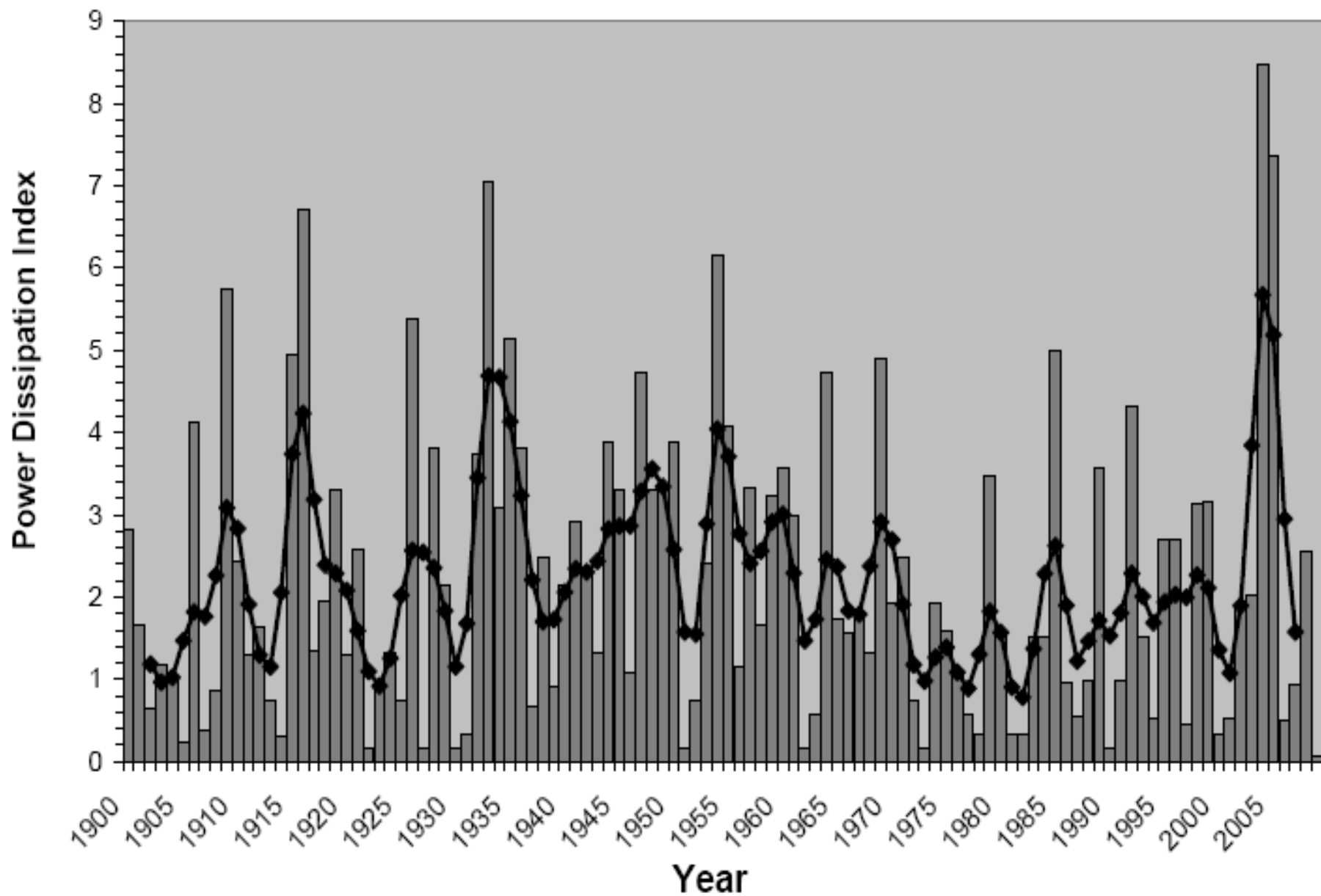
Atlantic Major Hurricanes

1944 to 2009

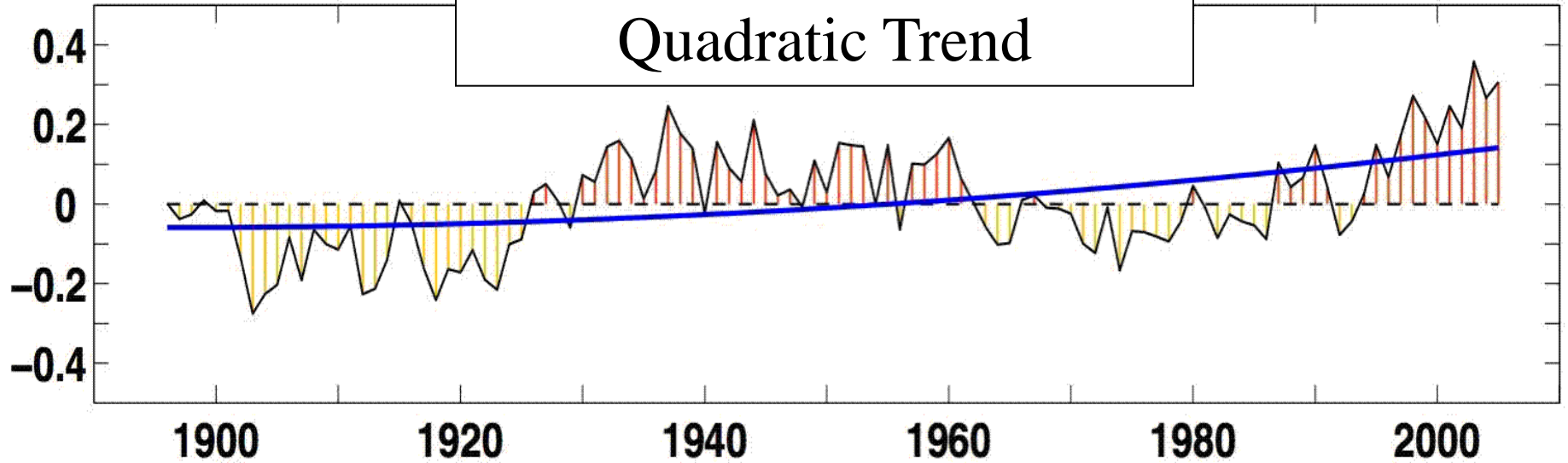


United States Power Dissipation Index

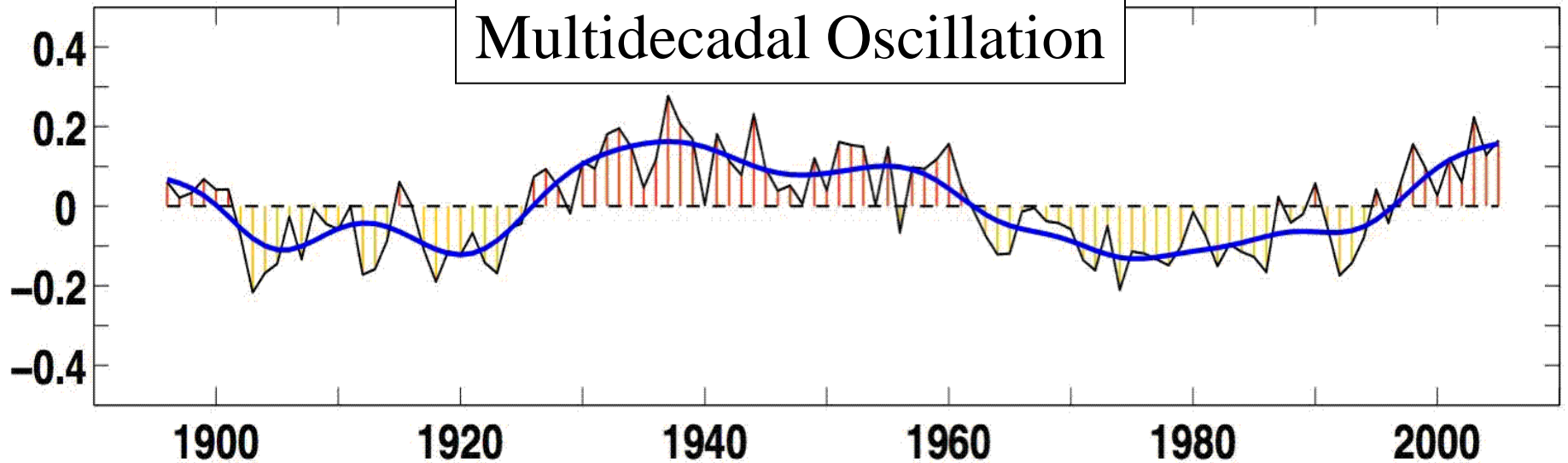
1900 to 2009



North Atlantic SSTs and Quadratic Trend



Residual Atlantic Multidecadal Oscillation

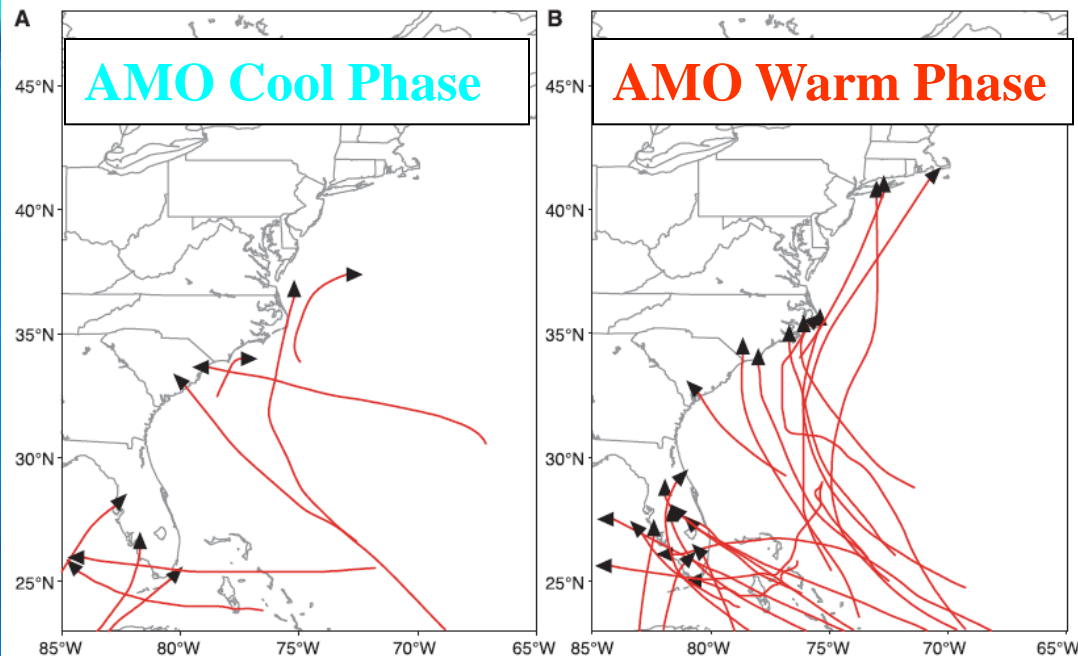


The Recent Increase in Atlantic Hurricane Activity: Causes and Implications

Stanley B. Goldenberg,^{1*} Christopher W. Landsea,¹
Alberto M. Mestas-Nuñez,² William M. Gray³

The years 1995 to 2000 experienced the highest level of North Atlantic hurricane activity in the reliable record. Compared with the generally low activity of the previous 24 years (1971 to 1994), the past 6 years have seen a doubling of overall activity for the whole basin, a 2.5-fold increase in major hurricanes (≥ 50 meters per second), and a fivefold increase in hurricanes affecting the Caribbean. The greater activity results from simultaneous increases in North Atlantic sea-surface temperatures and decreases in vertical wind shear. Because these changes exhibit a multidecadal time scale, the present high level of hurricane activity is likely to persist for an additional ~ 10 to 40 years. The shift in climate calls for a reevaluation of preparedness and mitigation strategies.

20 JULY 2001 VOL 293 SCIENCE



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

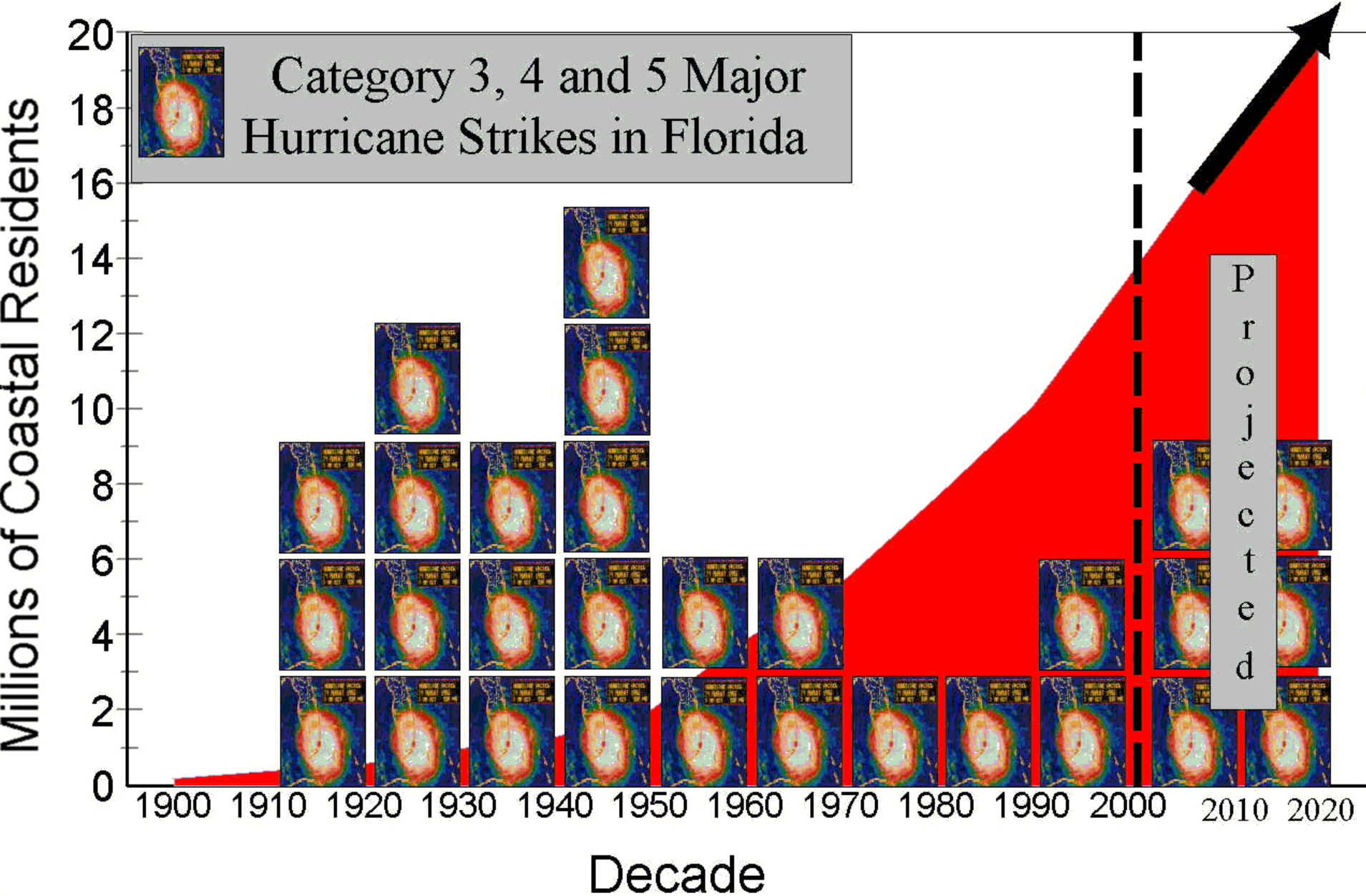
Frequency: Numbers may see a moderate decrease (~25%)

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 cyclone (~10% within 200 mi of storm), but reduced frequency may offset increases

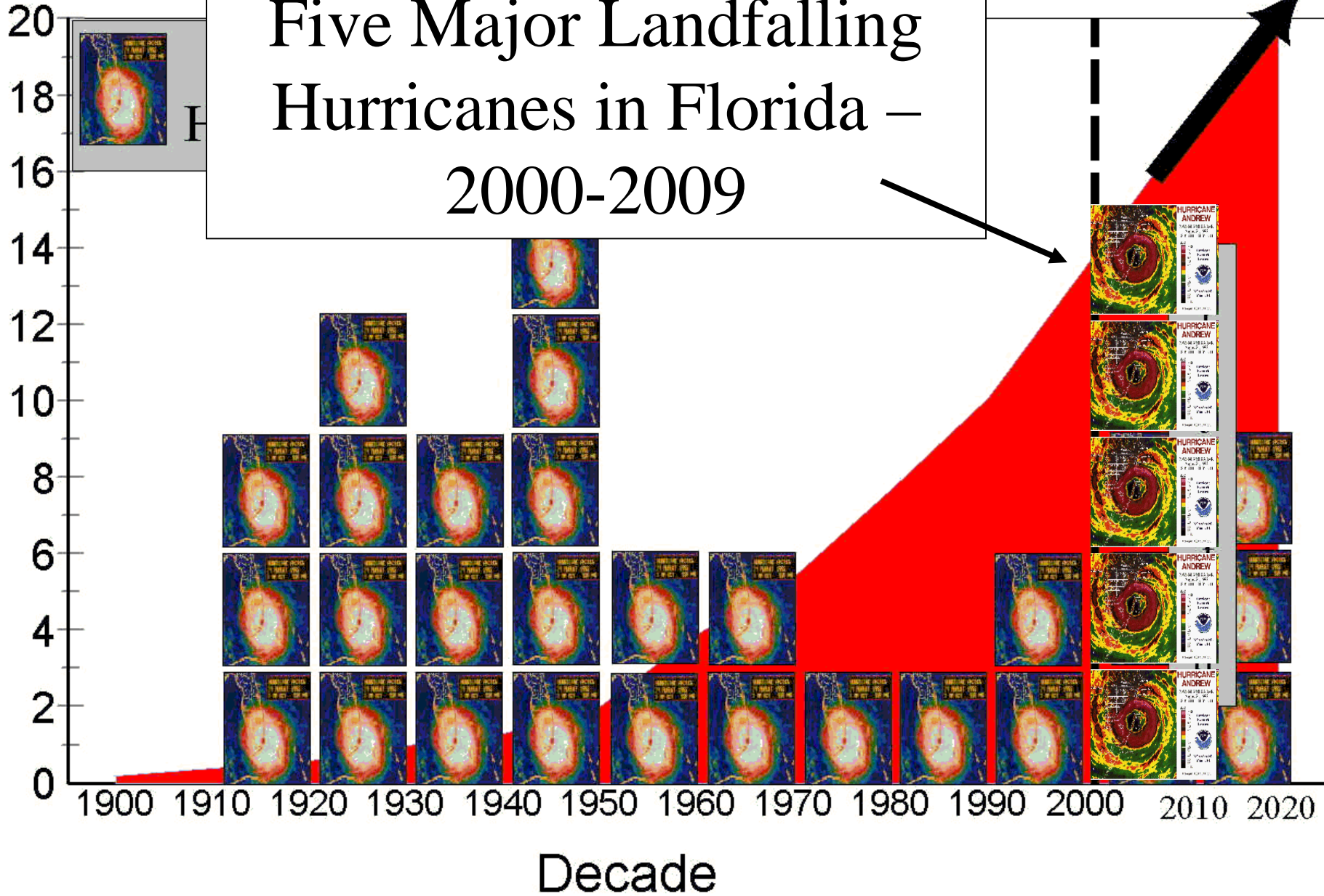
Florida Population and Major Hurricanes



Florida Population and Major Hurricanes

Five Major Landfalling
Hurricanes in Florida –
2000-2009

Millions of Coastal Residents





2005

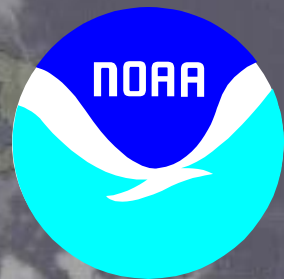
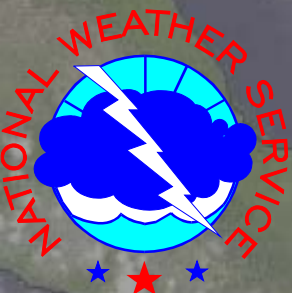
Long Term Hurricane Trends: How are These Storms Changing Over Time?

25 May, 2010

Florida Governor's Hurricane Conference

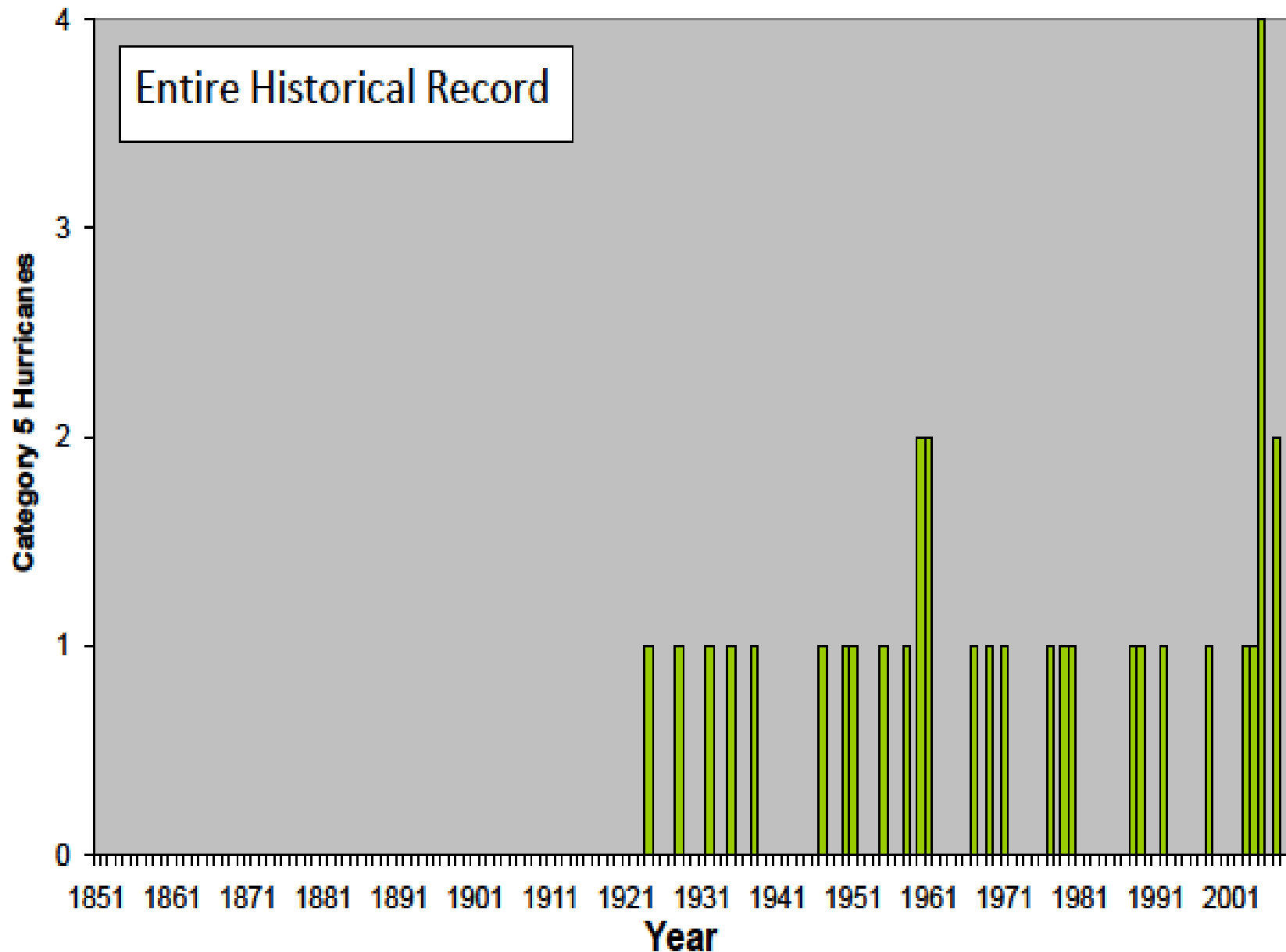
Chris Landsea, National Hurricane Center, Miami, USA

Chris.Landsea@noaa.gov



Atlantic Basin Category 5 Hurricanes

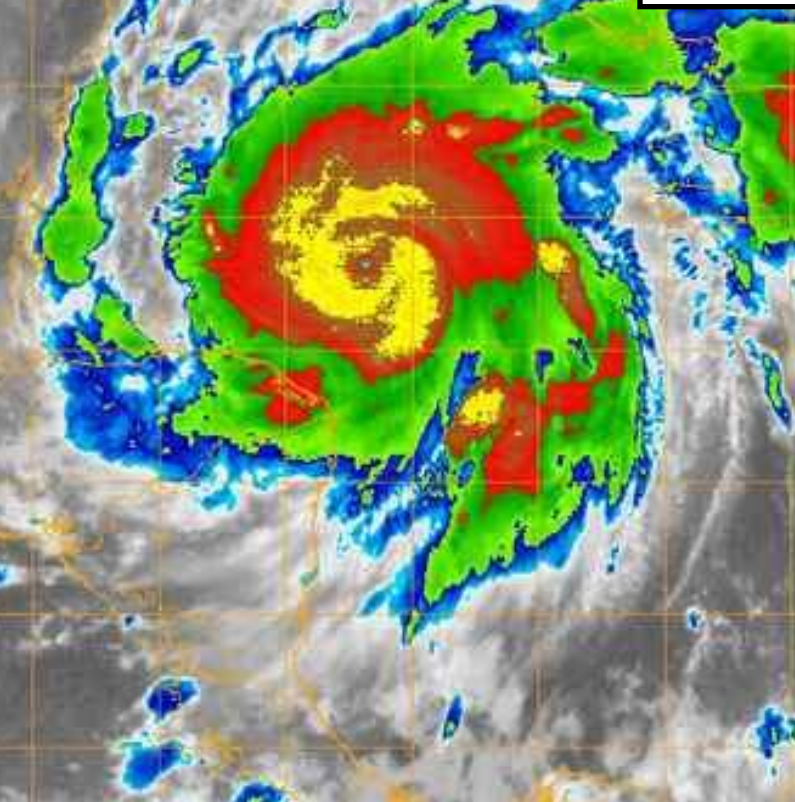
1851-2009 - Current HURDAT



0600Z 24L WILMA
1215Z GOES-12 IR

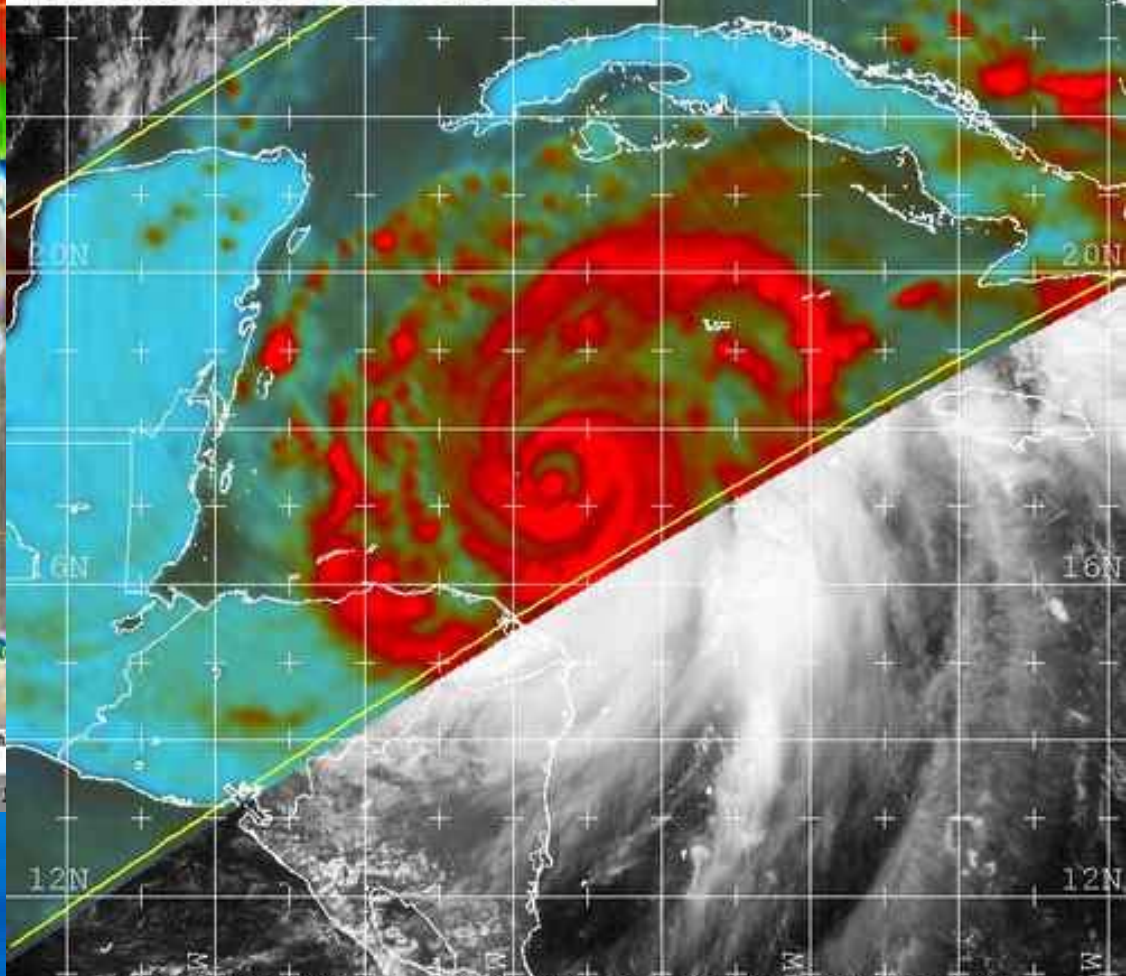
2005's Hurricane Wilma

Strongest Hurricane Ever Observed with 882 mb Central Pressure...



Naval Research Lab http://www.nrlmry.navy.mil/sat_products.htm
IR Temperature (Celsius)

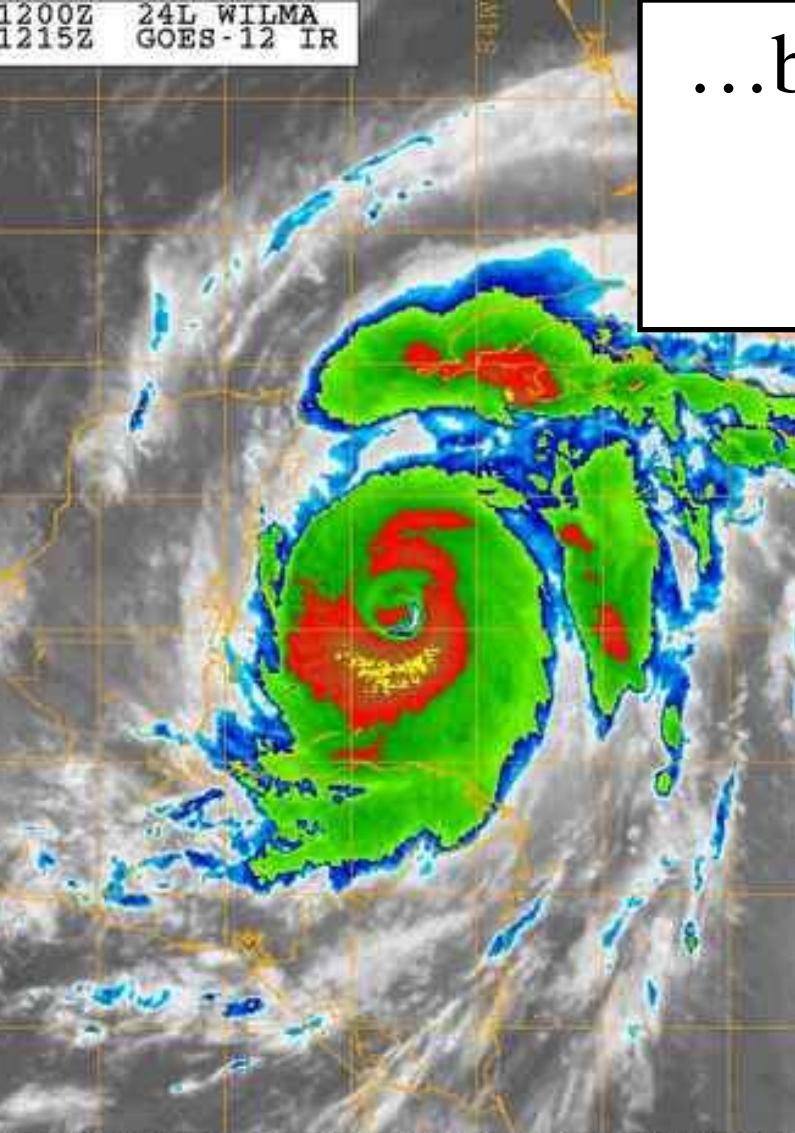
10/19/05 1800Z 24L WILMA
10/19/05 1740Z TRMM COMPOSITE
10/19/05 1615Z GOES-12 VIS



Naval Research Lab www.nrlmry.navy.mil/sat_products.htm
Red=85PCT Green=85H Blue=85V

1200Z 24L WILMA
1215Z GOES-12 IR

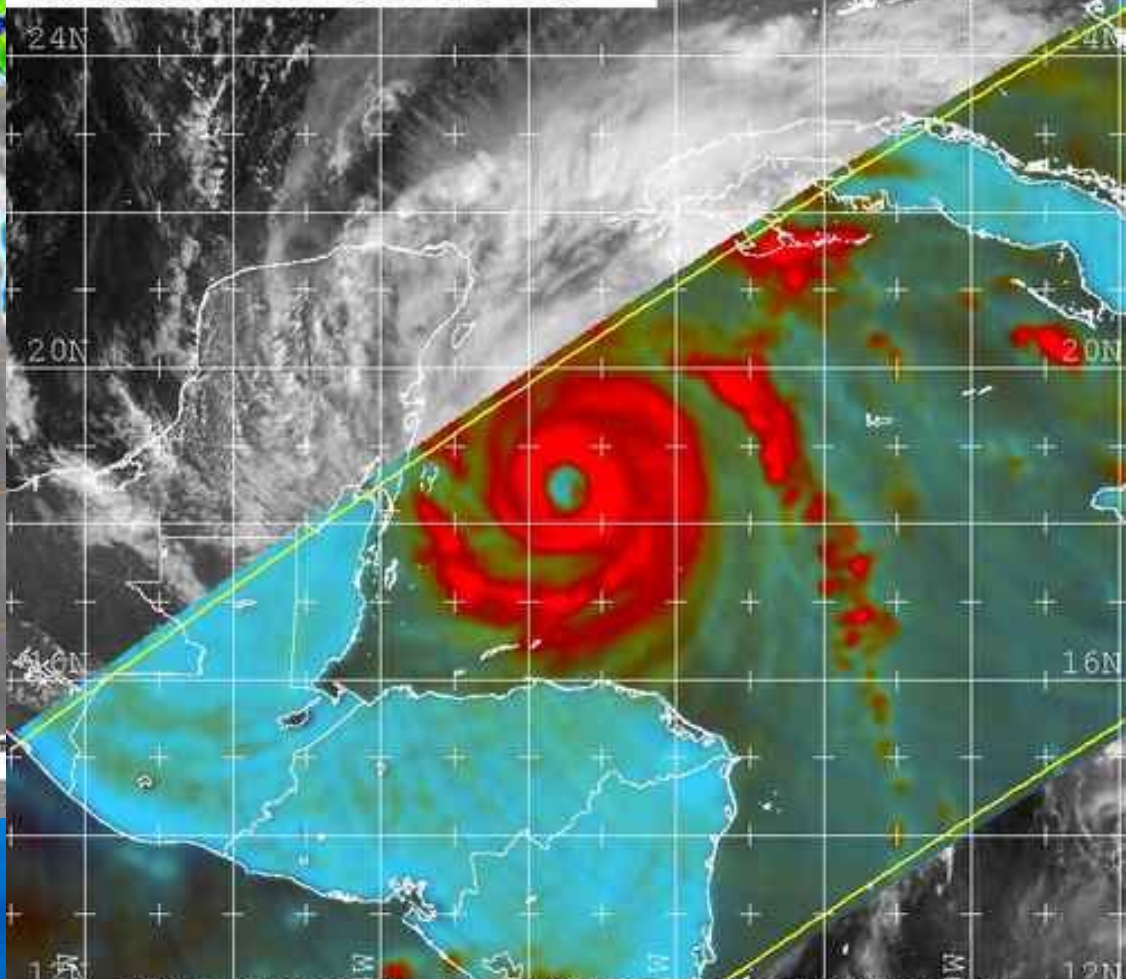
...but only a Category 5 (> 135 kt)
for 18 hours over
the open Caribbean Sea



Naval Research Lab http://www.nrlmry.navy.mil/sat_products.html
IR Temperature (Celsius)

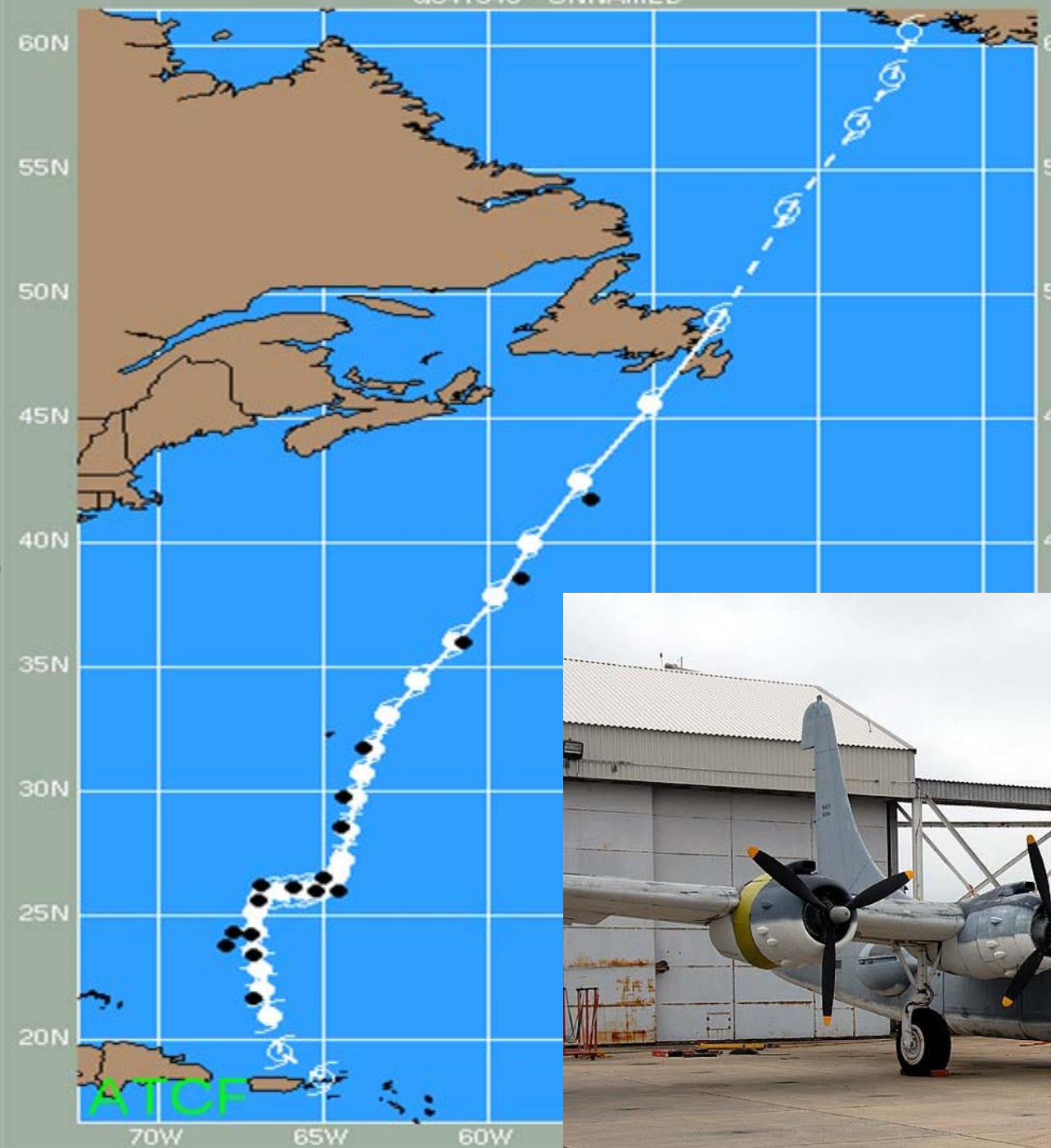


10/20/05 1800Z 24L WILMA
10/20/05 1645Z TRMM COMPOSITE
10/20/05 1515Z GOES-12 VIS



Naval Research Lab www.nrlmry.navy.mil/sat_products.html
Red=85PCT Green=85H Blue=85V

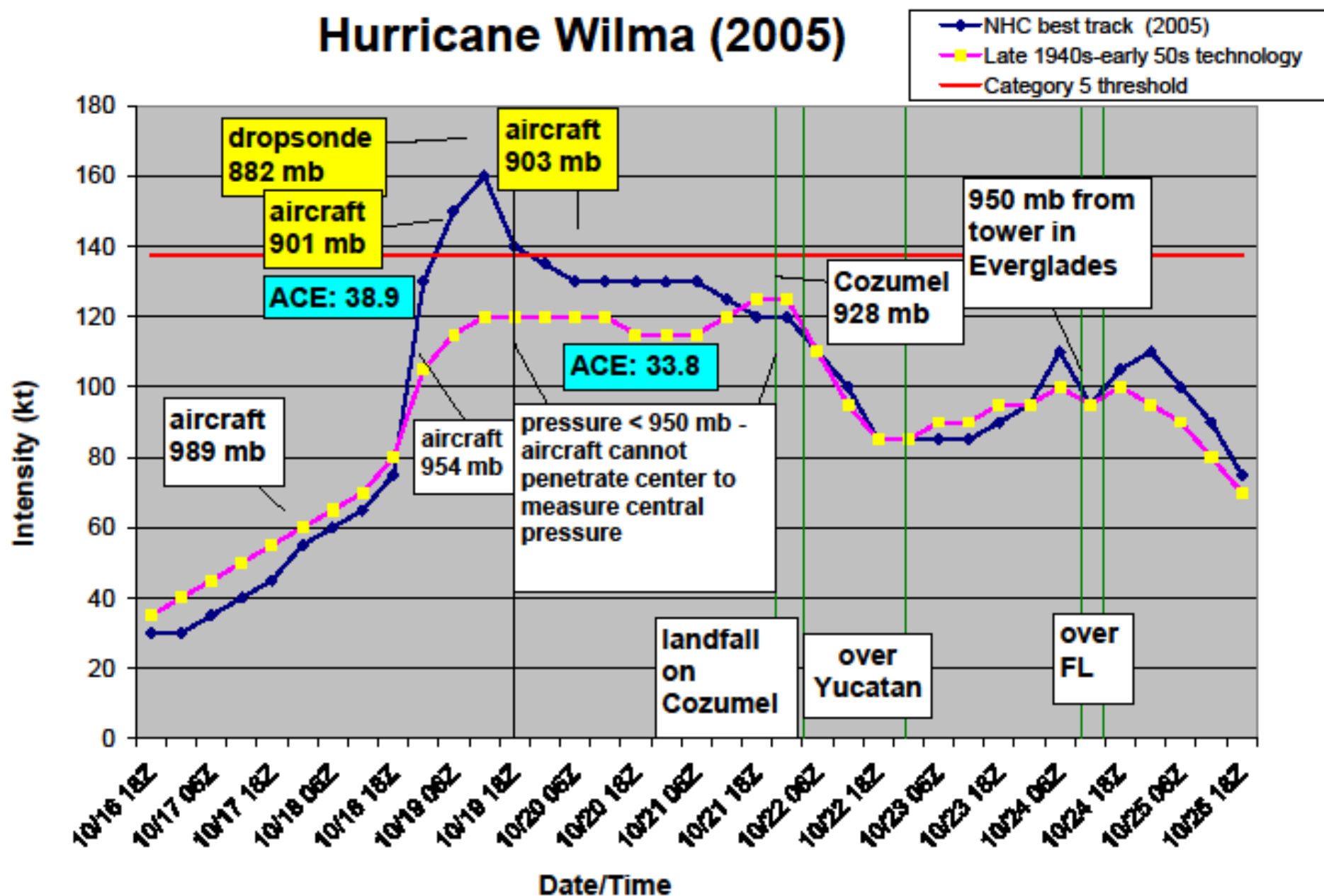
041949 - UNNAMED



Hurricane
Aircraft
Reconnaissance
in 1940s and
early 1950s:
U.S. Navy's
PB4Y2

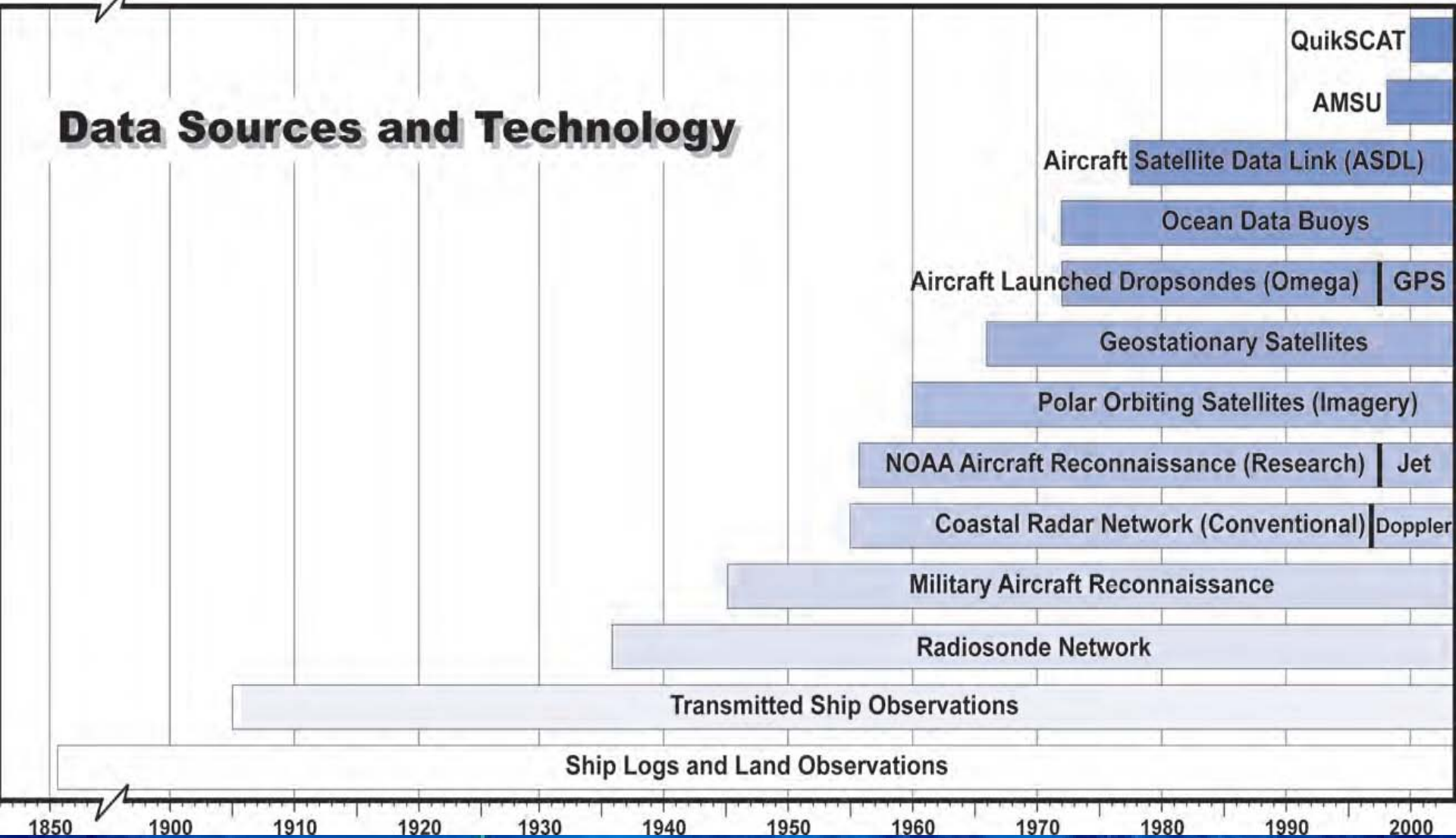


Hurricane Wilma (2005)



Observation Capabilities: Huge Improvements over Time

Data Sources and Technology

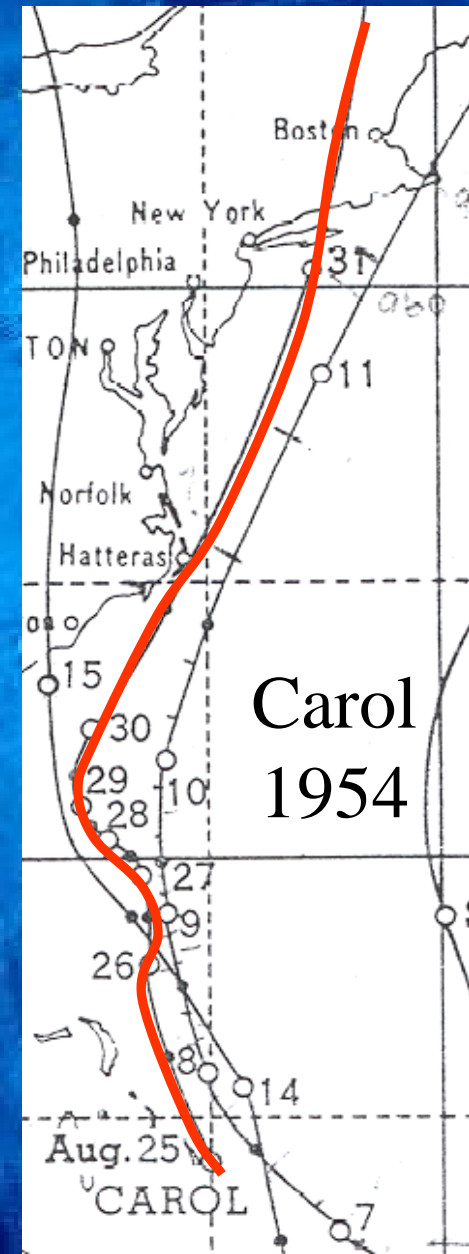


Galveston 1900

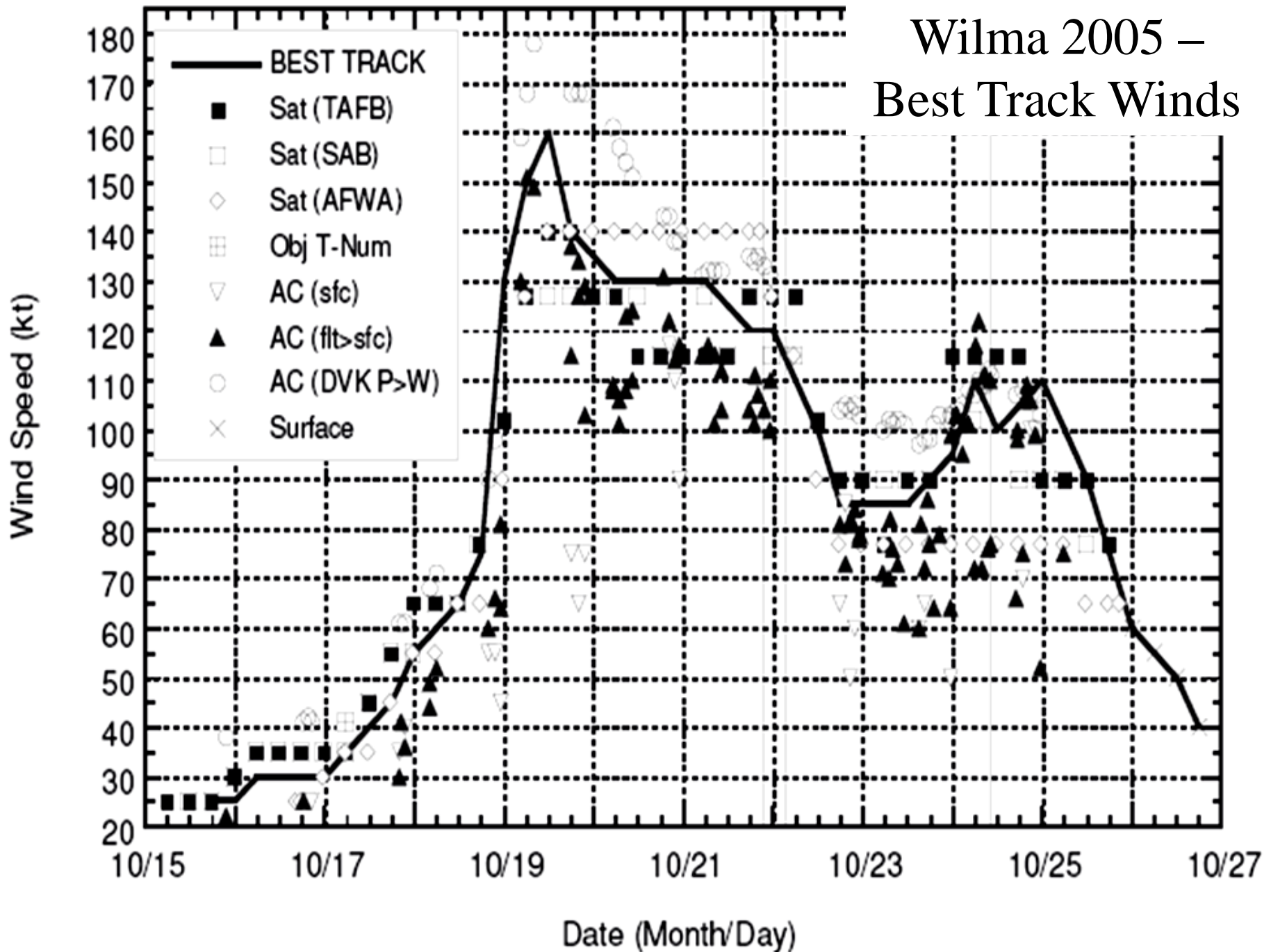


Wilma

How many
direct
measurements/
estimates of
strongest
winds and/or
central
pressure?



Wilma 2005 – Best Track Winds

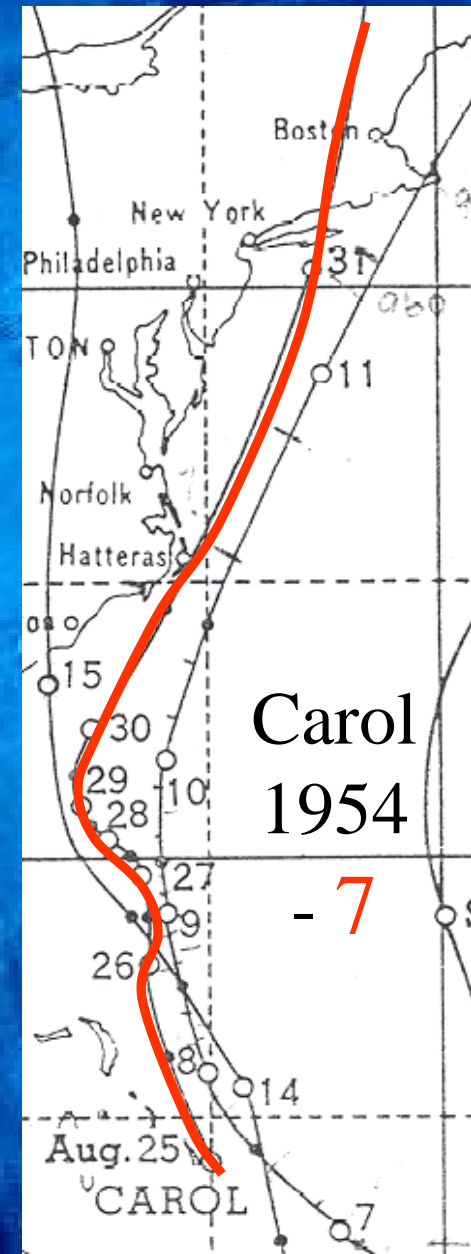


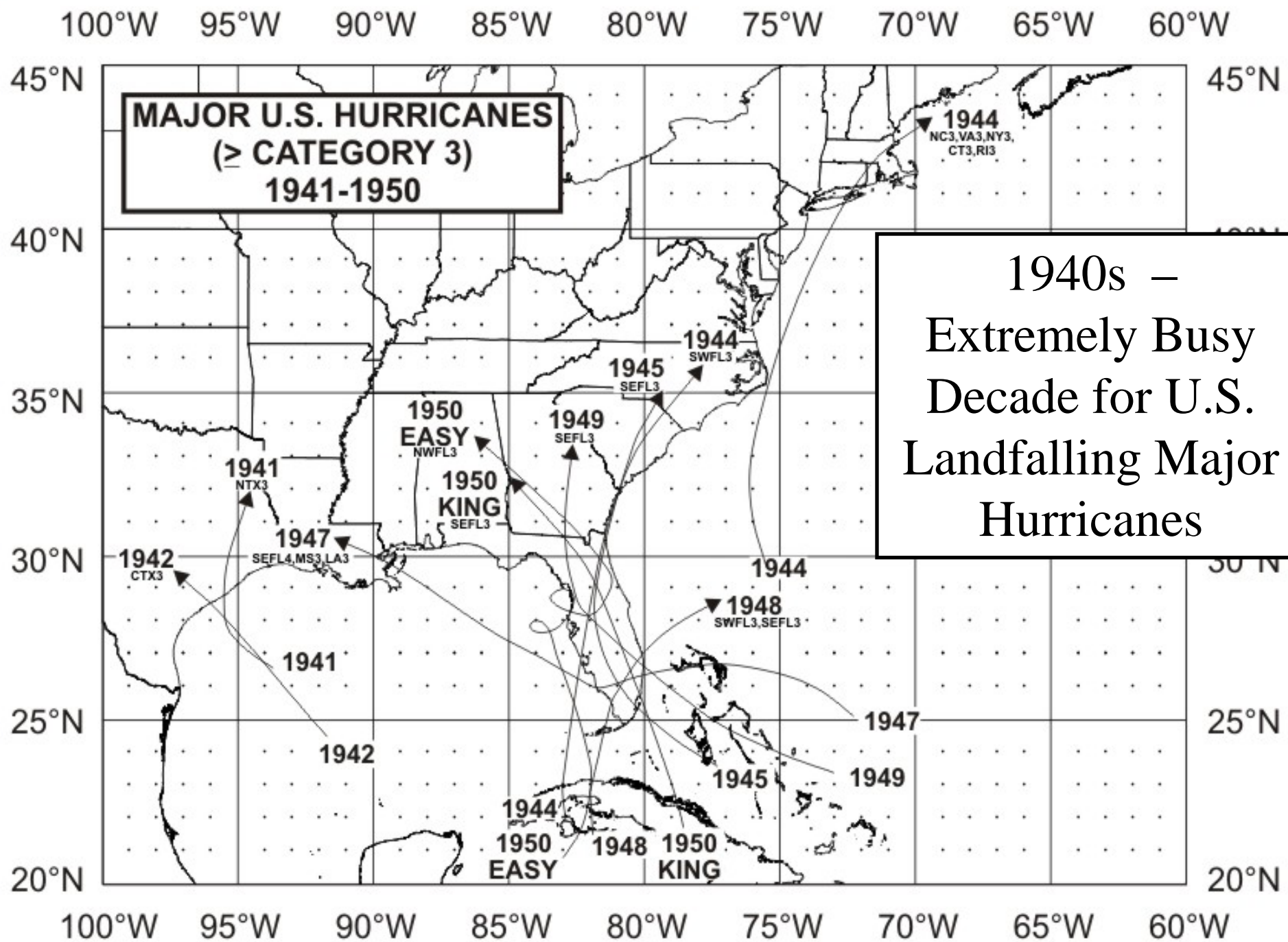
Galveston 1900 - 1



Wilma - 280

How many
direct
measurements/
estimates of
strongest
winds and/or
central
pressure?

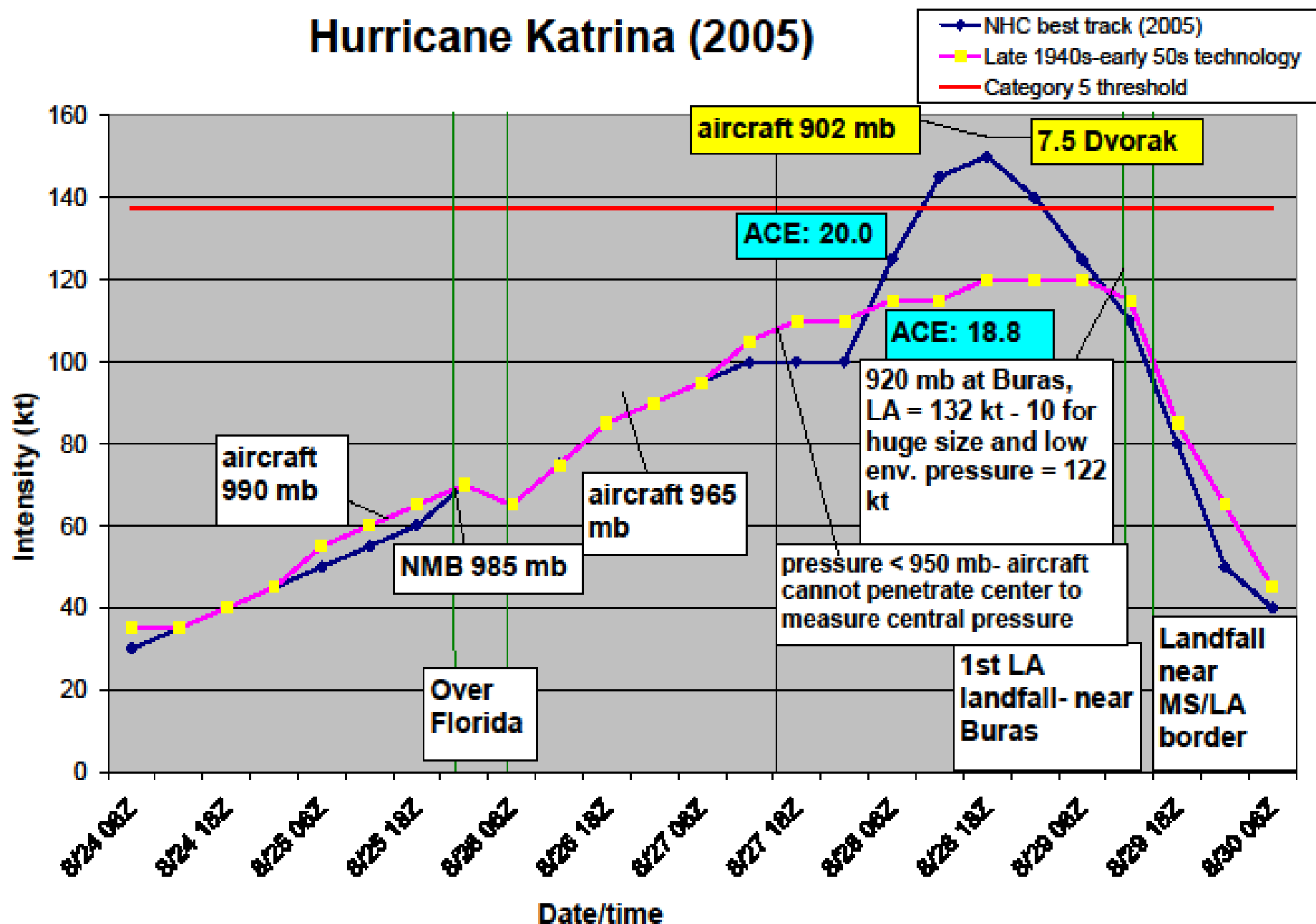




Ten Most Recent Atlantic Basin Category 5 Hurricanes



Hurricane Katrina (2005)



Recent Category 5 Hurricanes:

Today's Monitoring versus 1940s

| Recent Category 5 Hurricane | Best Track Peak (kt) | Duration as Cat 5 (days) | 1940s Peak (kt) | Best Track ACE (10^4 kt^2) | 1940s ACE (10^4 kt^2) |
|-----------------------------|----------------------|--------------------------|----------------------|--|-----------------------------------|
| Andrew - 1992 | 150 | 0.62 | 145 – Cat 5 | 28 | 25 |
| Mitch – 1998 | 155 | 1.75 | 140 – Cat 5 | 36 | 34 |
| Isabel – 2003 | 145 | 1.75 | 115 – Cat 4 | 63 | 41 |
| Ivan – 2004 | 145 | 2.50 | 135 – Cat 4 | 70 | 64 |
| Emily – 2005 | 140 | 0.25 | 125 – Cat 4 | 33 | 30 |
| Katrina - 2005 | 150 | 0.75 | 120 – Cat 4 | 20 | 19 |
| Rita – 2005 | 155 | 1.00 | 135 – Cat 4 | 25 | 25 |
| Wilma – 2005 | 160 | 0.75 | 125 – Cat 4 | 39 | 34 |
| Dean – 2007 | 150 | 1.00 | 130 – Cat 4 | 35 | 35 |
| Felix - 2007 | 150 | 1.00 | 130 – Cat 4 | 18 | 16 |
| Average | 150.0 | 1.37 | 130.0 – Cat 4 | 36.7 | 32.3 |

Recent Category 5 Hurricanes: Today's Monitoring versus 1940s

- Raw Category 5 hurricane records show dramatic long-term trend and recent “unprecedented” increase
- Monitoring abilities in 1940s, however, had extreme difficulty in detecting Category 5 hurricanes
- Of the **10** most recent Category 5's, only **2** (both landfallers) would have been identified as Category 5 in 1940s
- Substantial undercount (~20%) to integrated measures of activity (ACE, PDI) in 1940s
- Because accurate detection of these extreme hurricanes has increased substantially over last few decades, **TRENDS IN CATEGORY 5 HURRICANES ARE UNRELIABLE**

“Florida’s Coming Hurricane Calamities”

Miami Herald

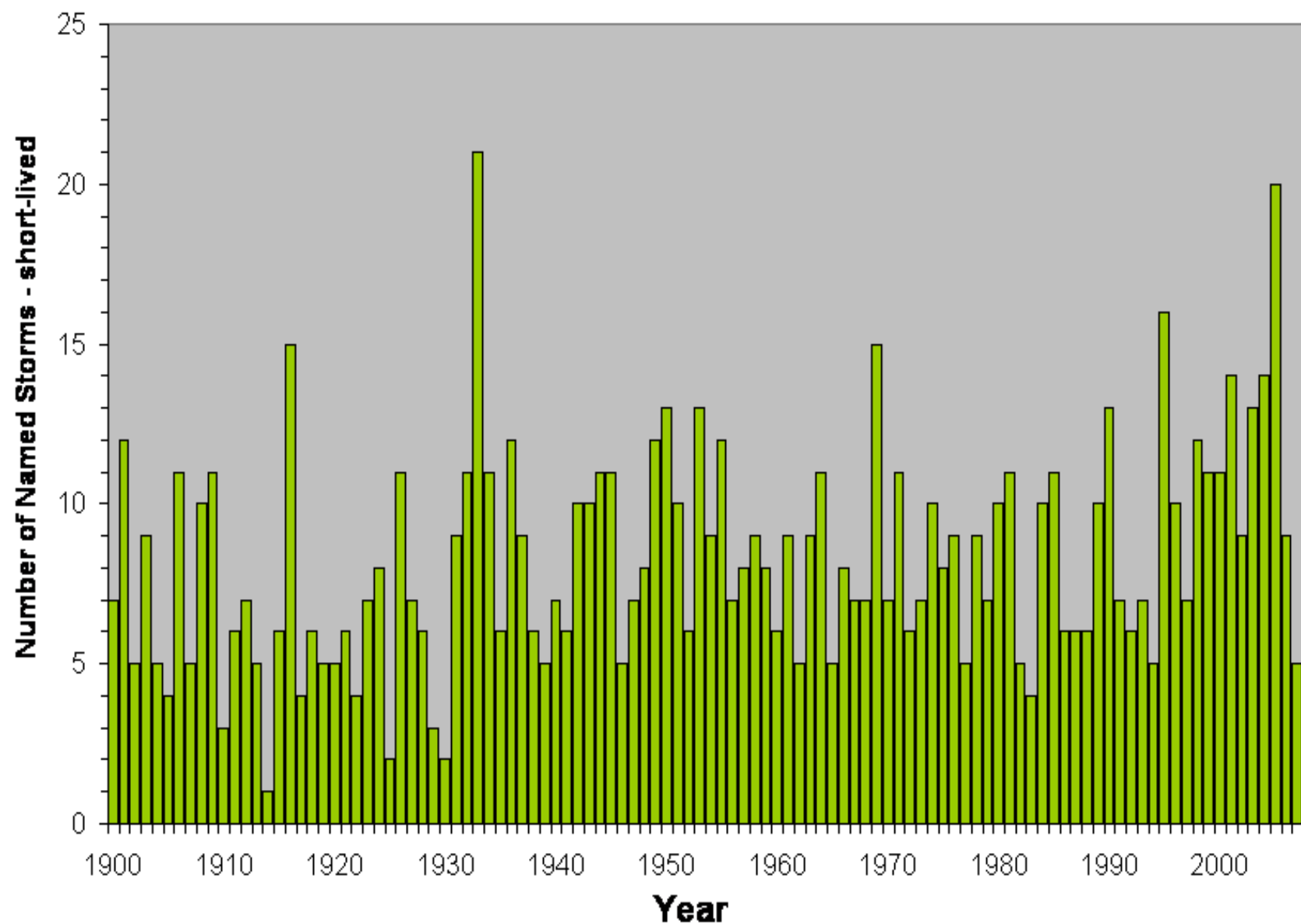
Chris Landsea & Bill Gray

22 July, 2002

“This works out to about **three major hurricanes making landfall in Florida per decade in the active era** versus one and a half major hurricane per decade in the quiet era - a doubling in the major hurricane landfalls expected...The combined effect in the next few decades of more landfalling major hurricanes in Florida with very large and increasing coastal populations with much more property at risk leads to a recipe for disaster...We anticipate that the rate of **economic loss in the state of Florida due to hurricane landfalls will be about SIX TO EIGHT TIMES the rate that occurred during the 1970s, 1980s and 1990s** ...In addition to impacts financially, concerns loom about the possibility of a large number of fatalities from a major hurricane making landfall. If an incomplete evacuation occurs due to either an unanticipated rapid intensification of a hurricane at landfall or due to apathetic residents choosing foolishly not to evacuate until too late on congested roadways, then **hundreds or even thousands of Florida residents could drown in a hurricane's storm surge.** “

Atlantic Tropical Cyclones - Short-Lived

1900-2007 Named Storms

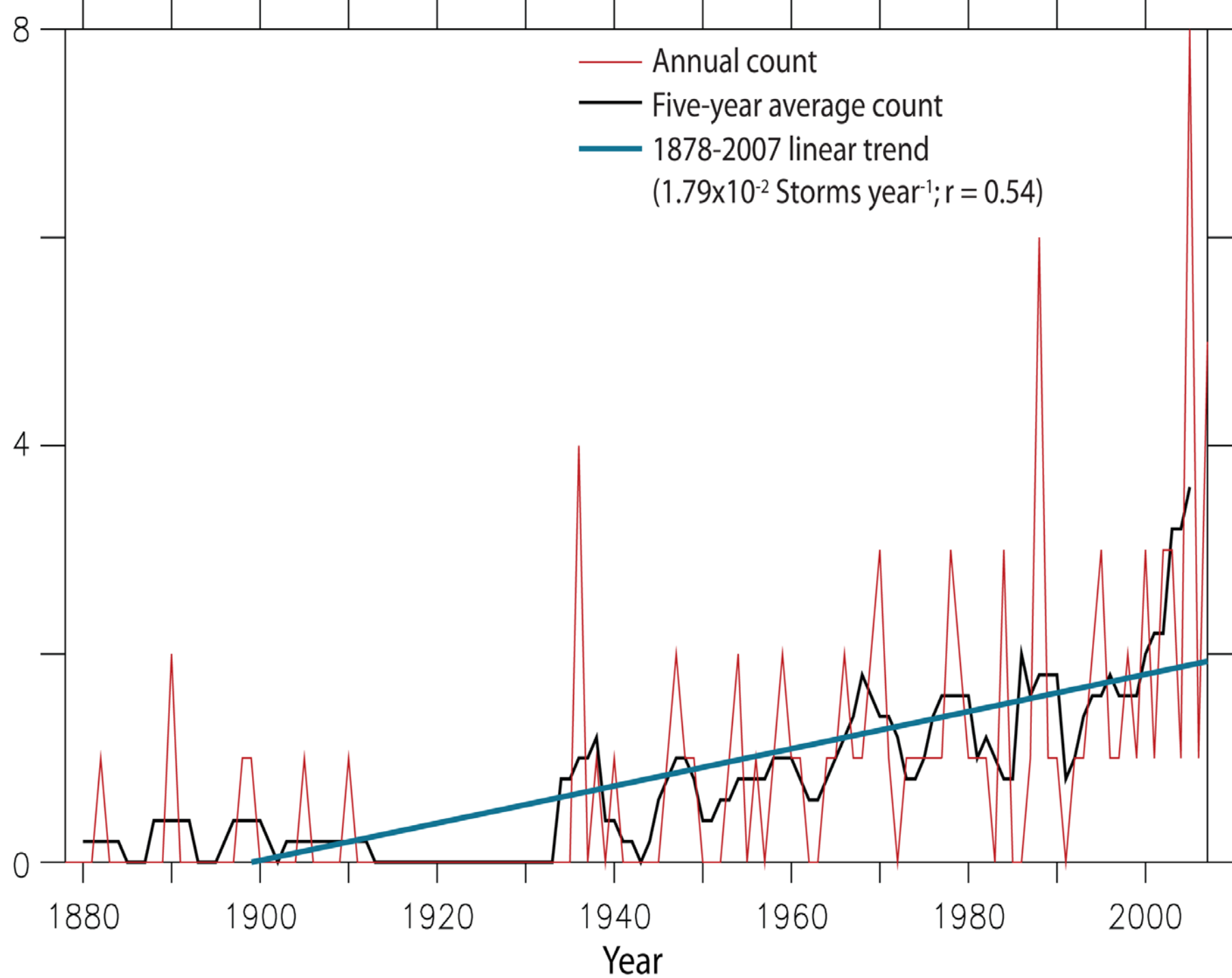


Changes in “Naming” Criteria

““[The National Hurricane Center] seems to be naming a lot more than they used to. This year, I would put four storms in the very questionable category, and maybe even six. In the past, we would have waited to see if another observation supported naming the system. We would have been a little more conservative.”

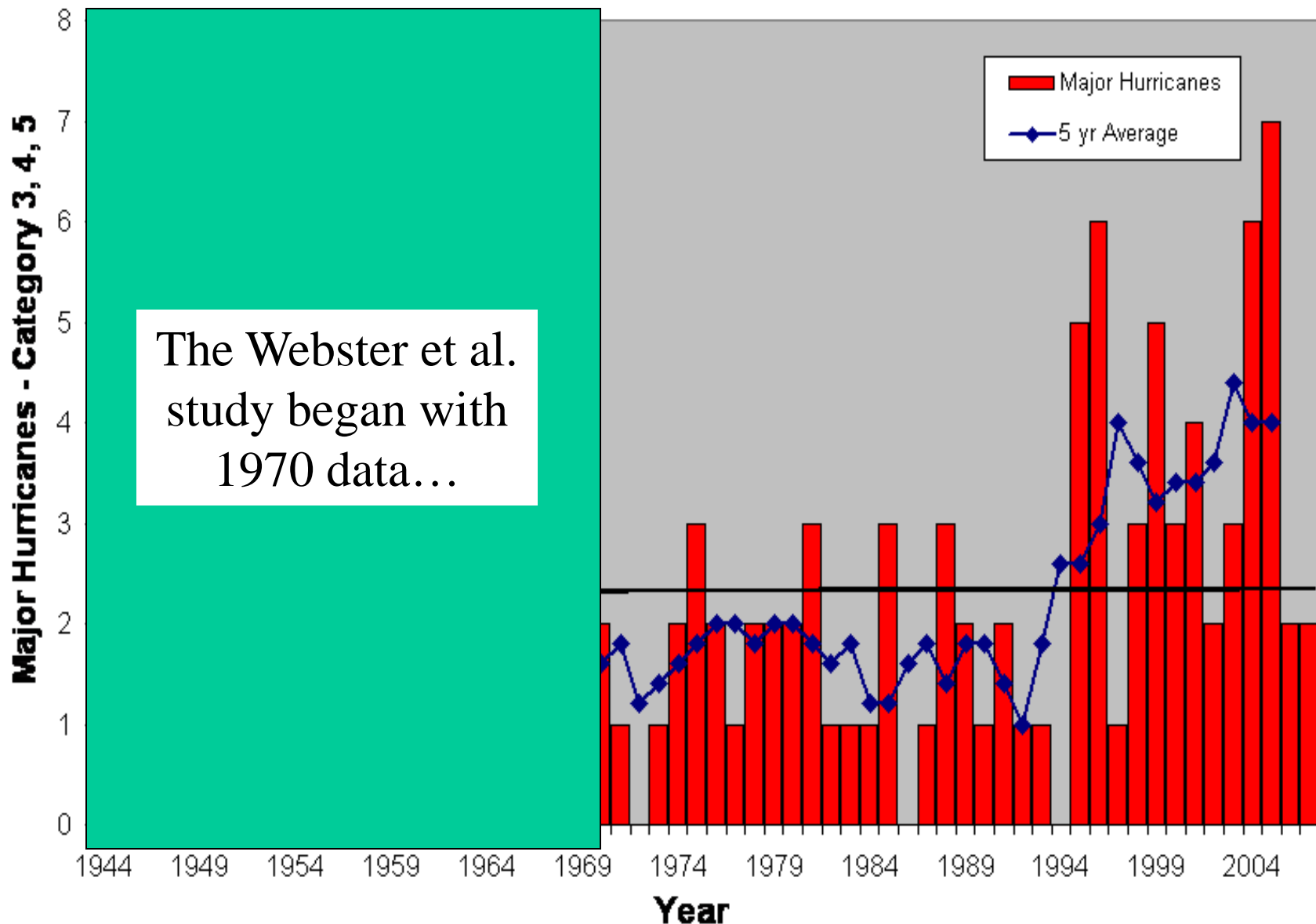
Neil Frank, National Hurricane Center Director, 1974-1987

North Atlantic Tropical Cyclone Counts
Duration 1.5 days or less (HURDAT)



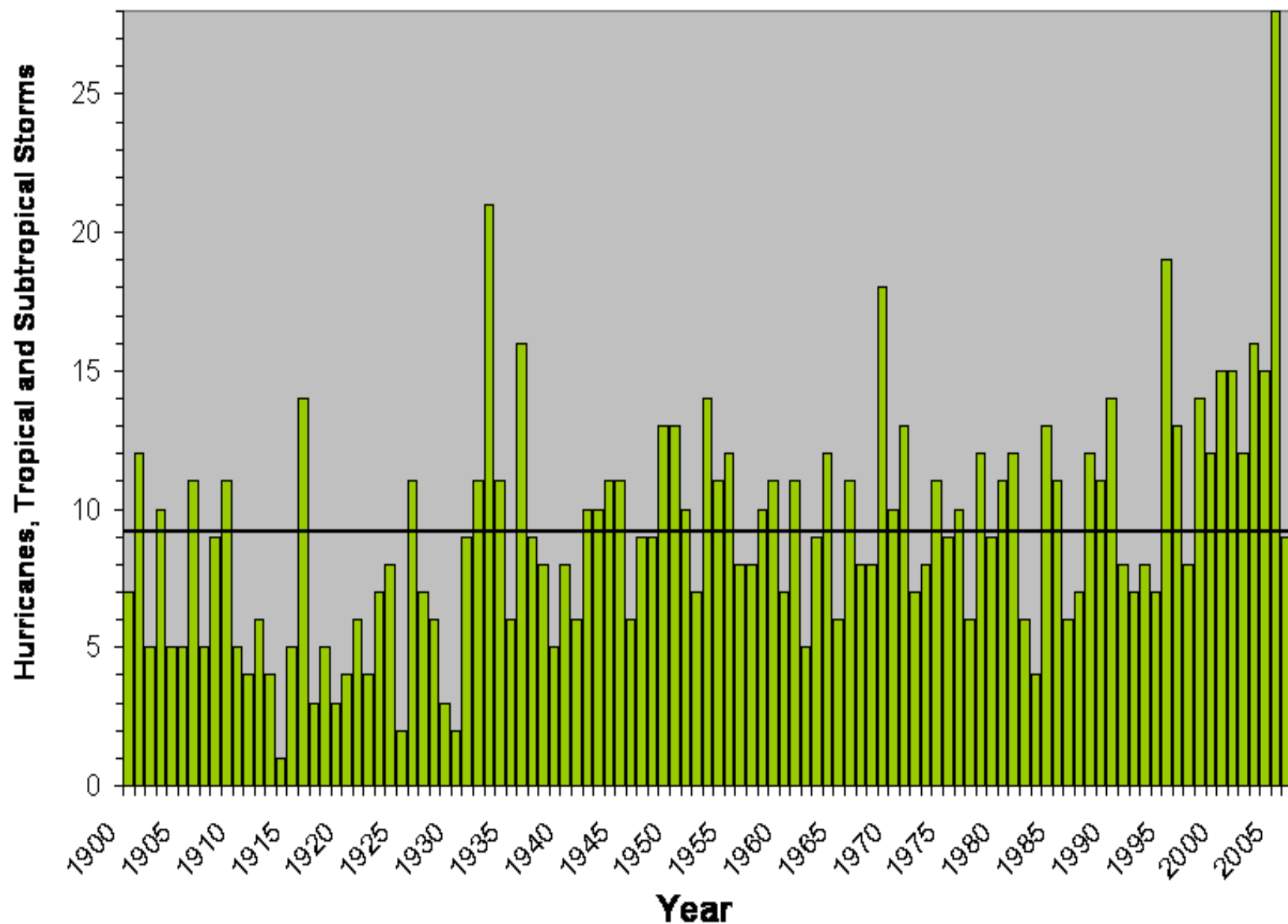
Atlantic Major Hurricanes

1944 to 2007



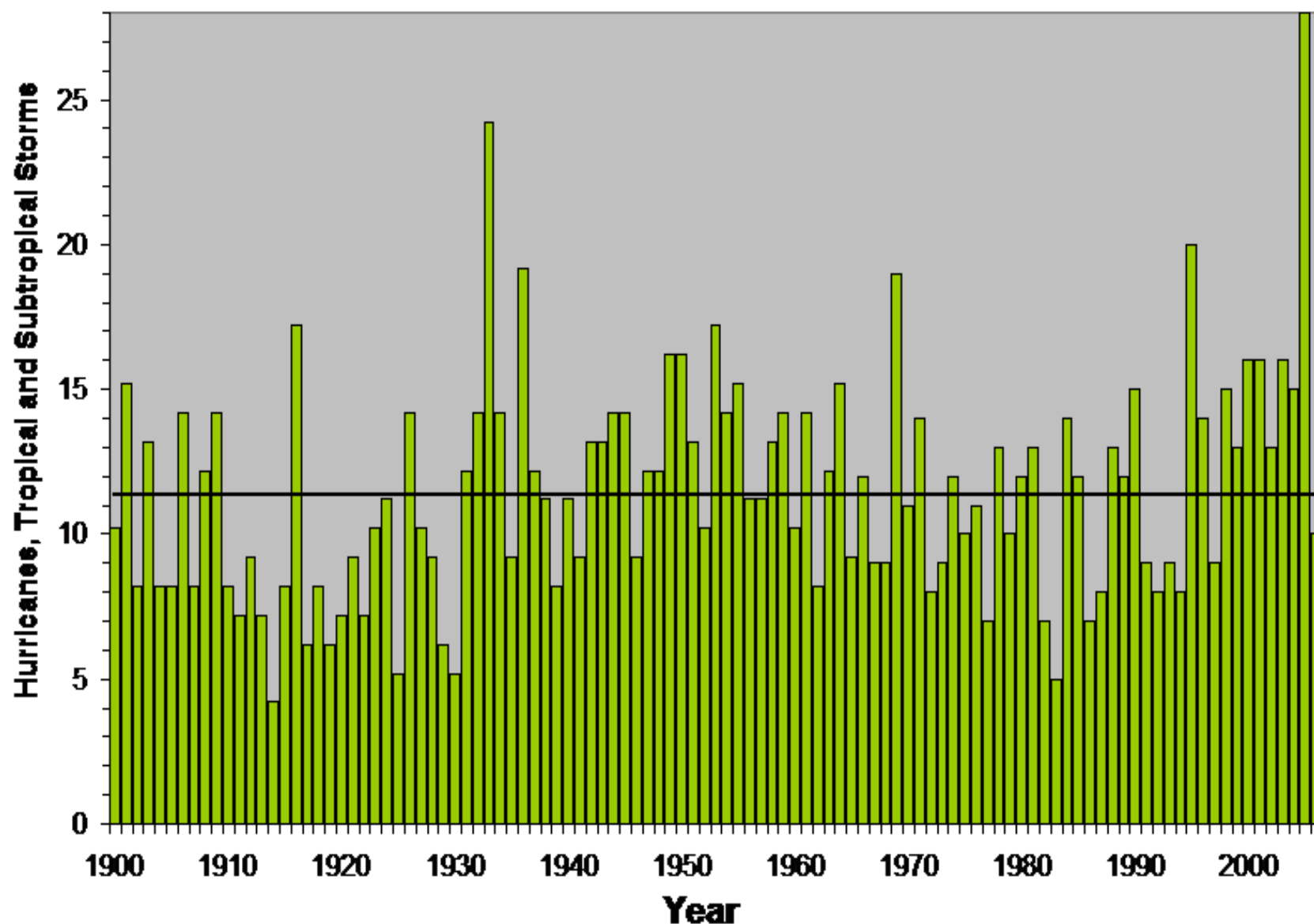
Atlantic Named Storms

1900 to 2006



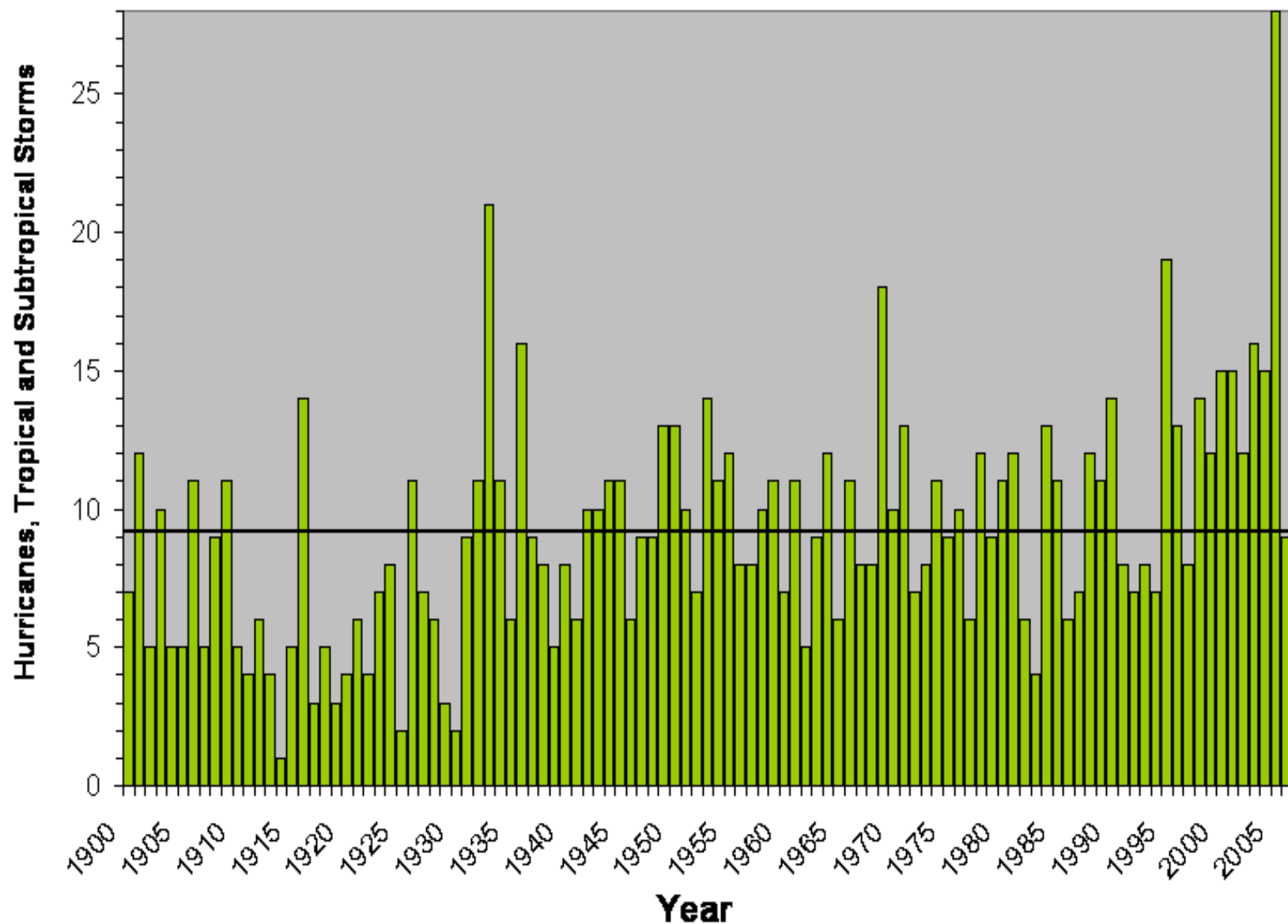
Adjusted Atlantic Named Storms

1900 to 2006 - Additional 3.2 for 1900-65, 1.0 for 1966-2002



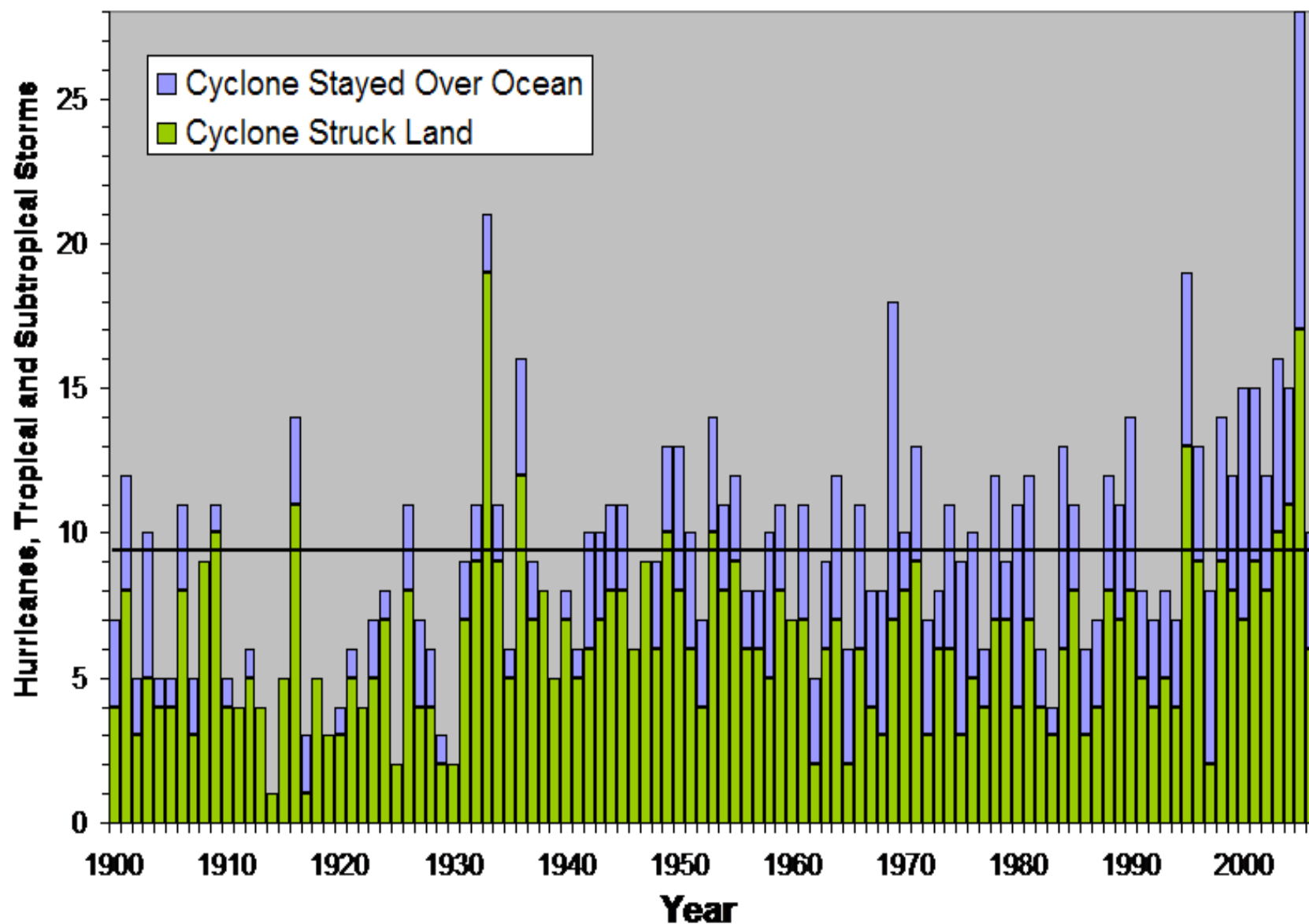
Atlantic Named Storms

1900 to 2006



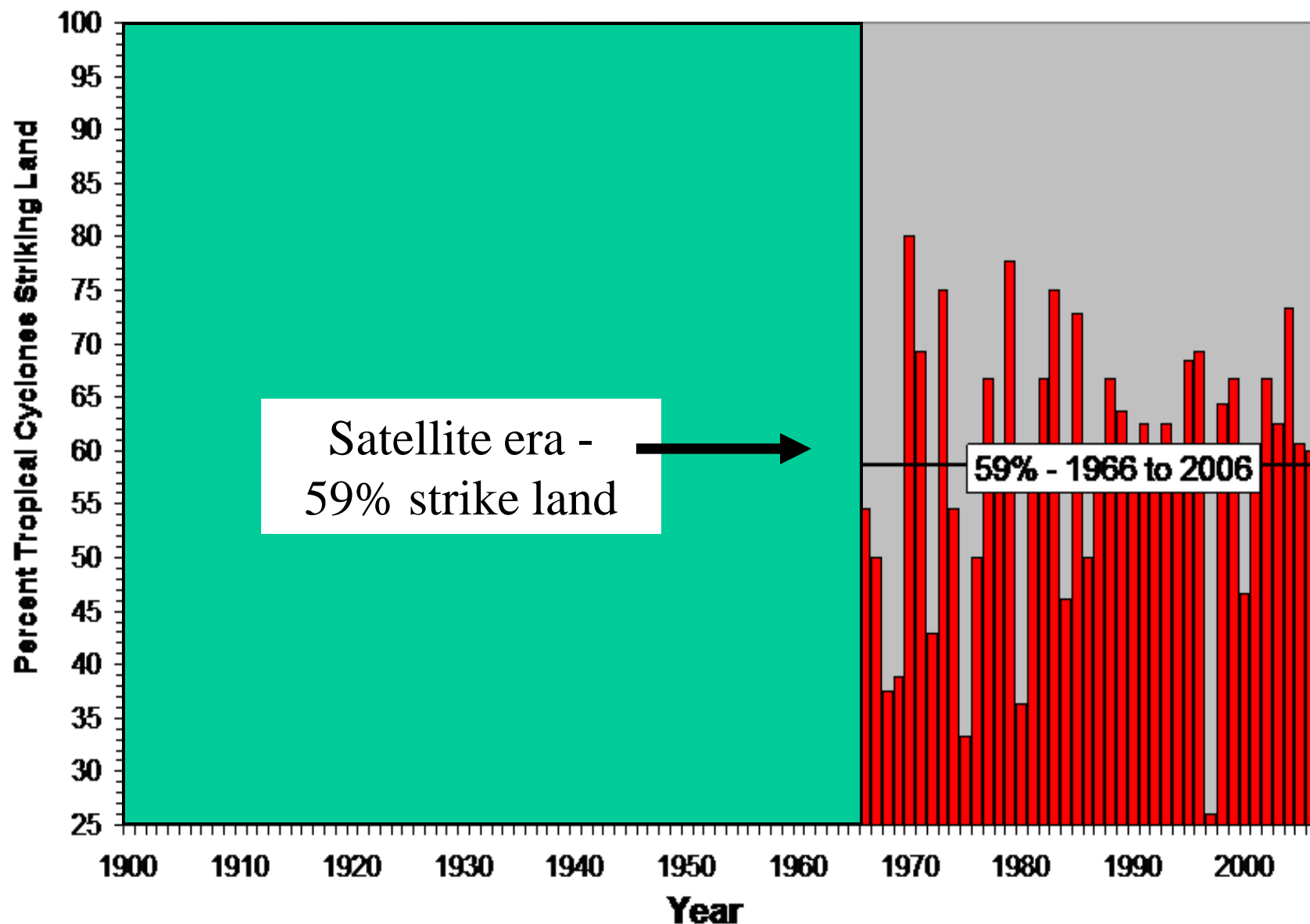
Atlantic Named Storms

1900 to 2006



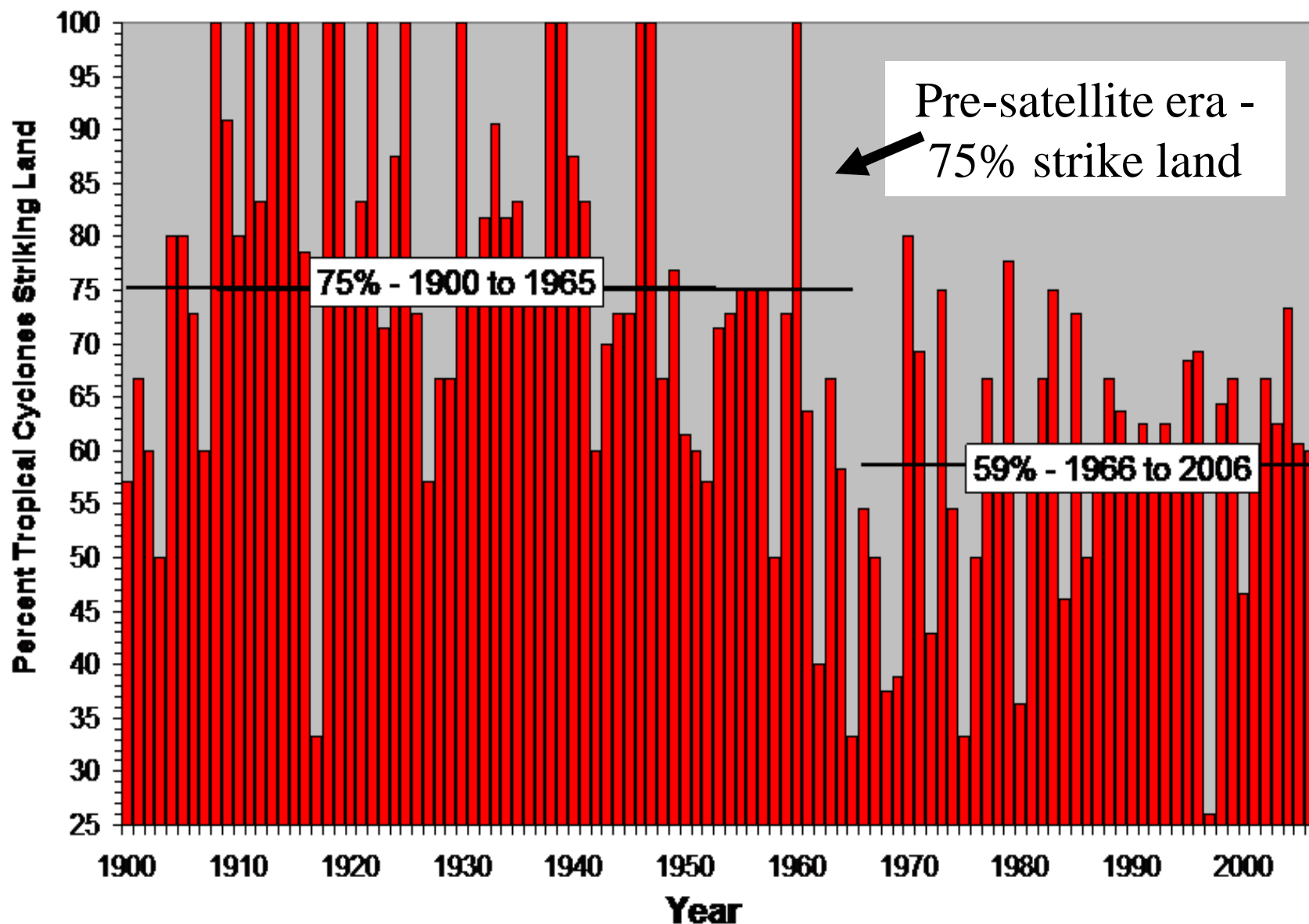
Percent Tropical Cyclones Striking Land

1900 to 2006

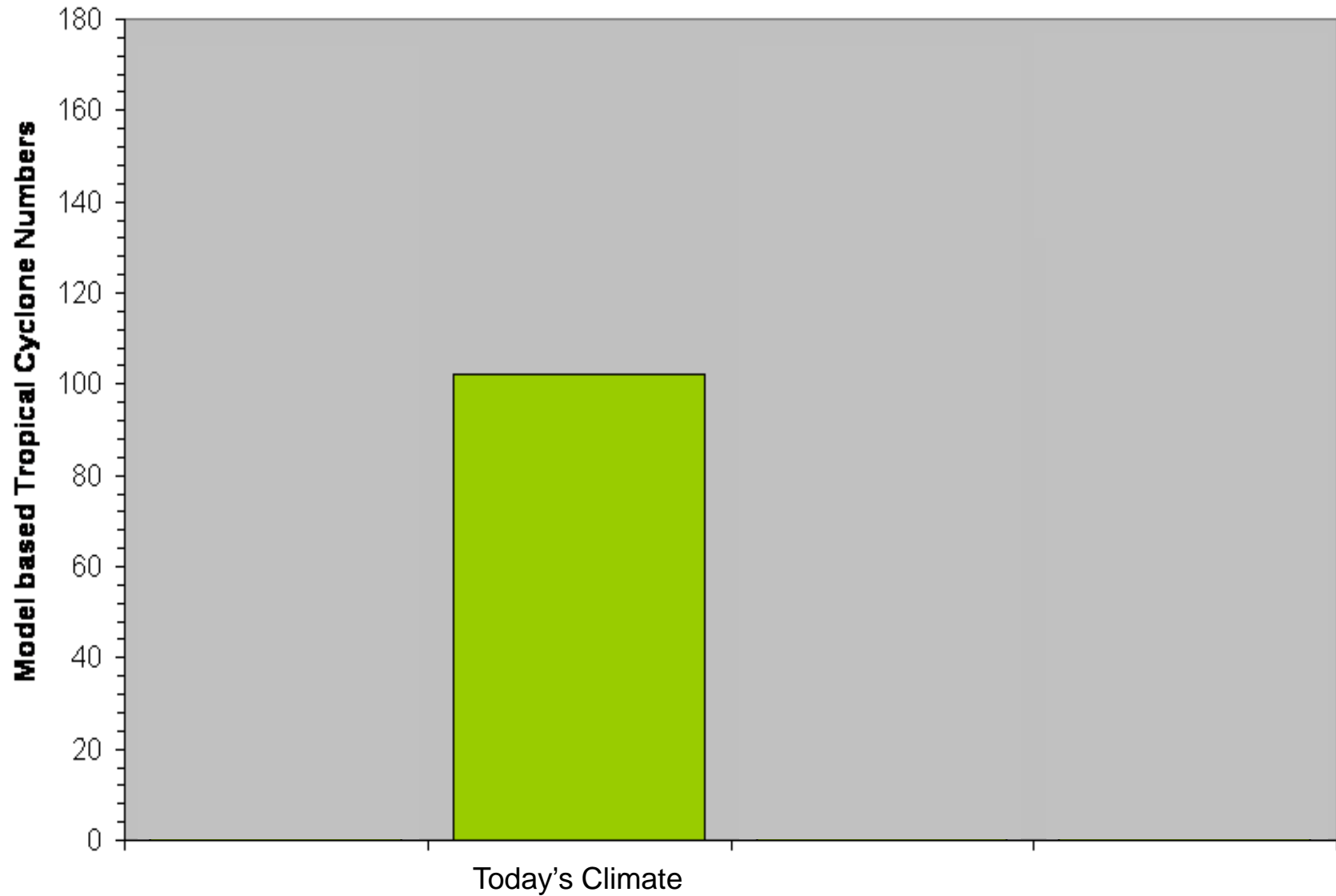


Percent Tropical Cyclones Striking Land

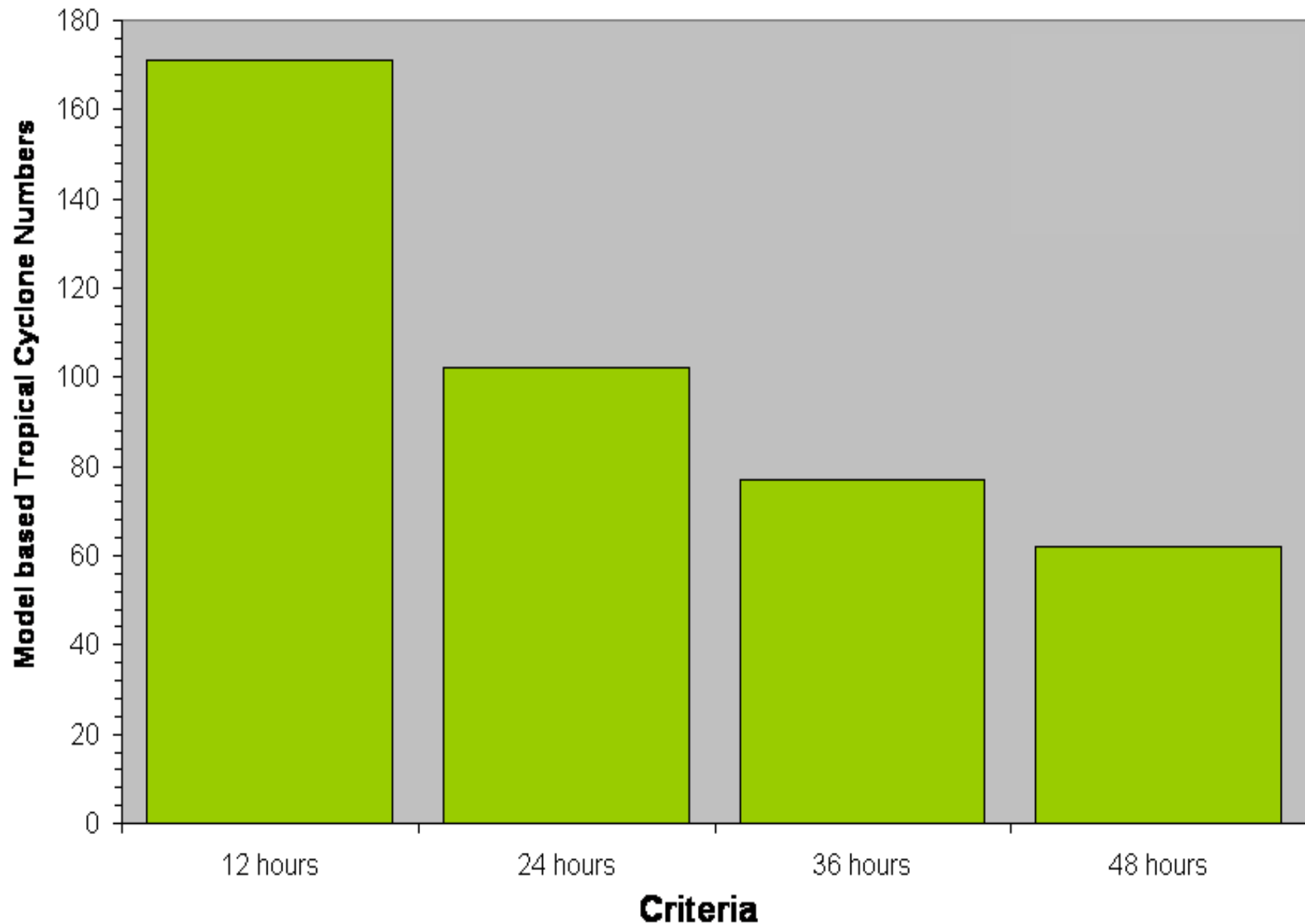
1900 to 2006



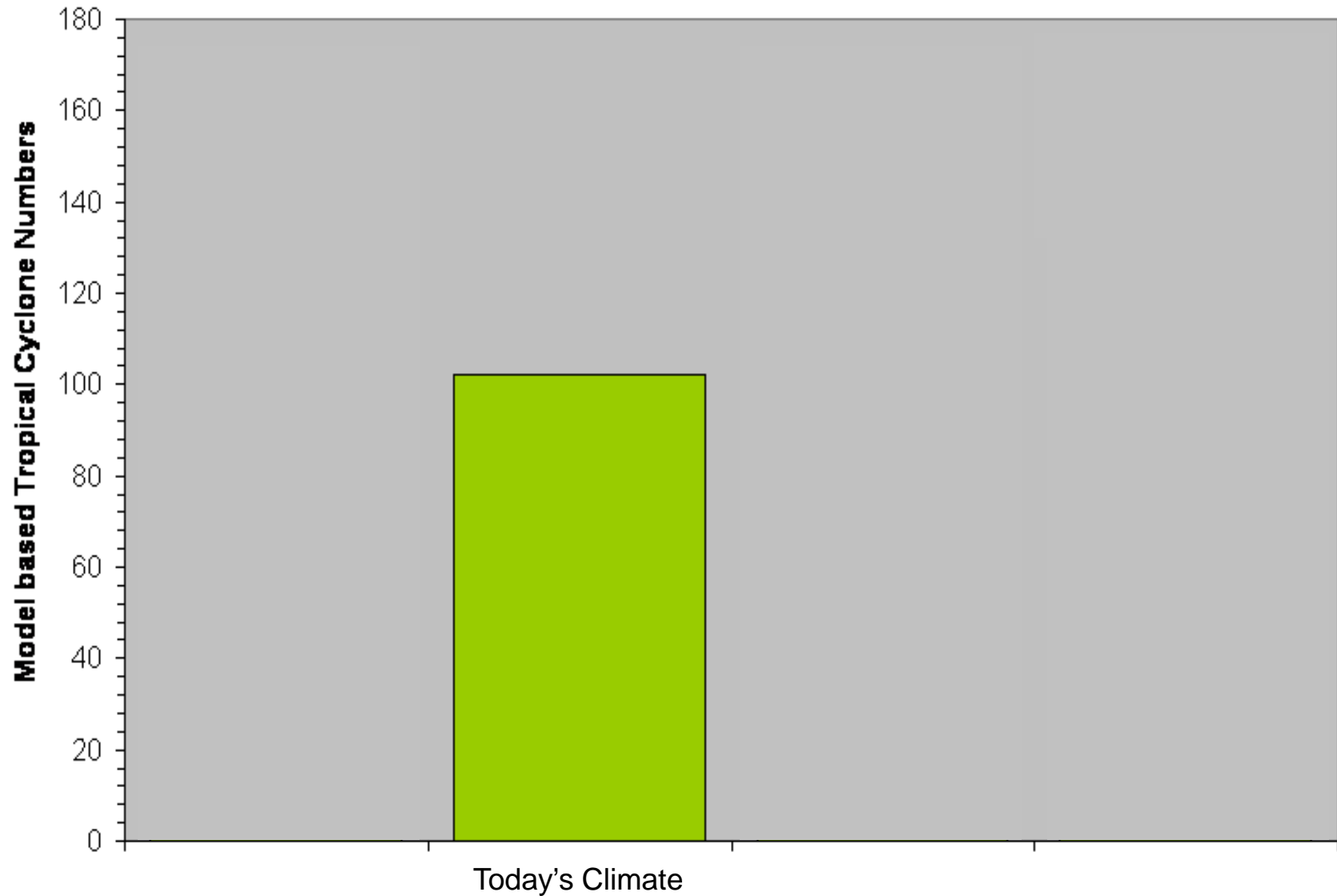
Frequency of Tropical Cyclones in Today's Climate



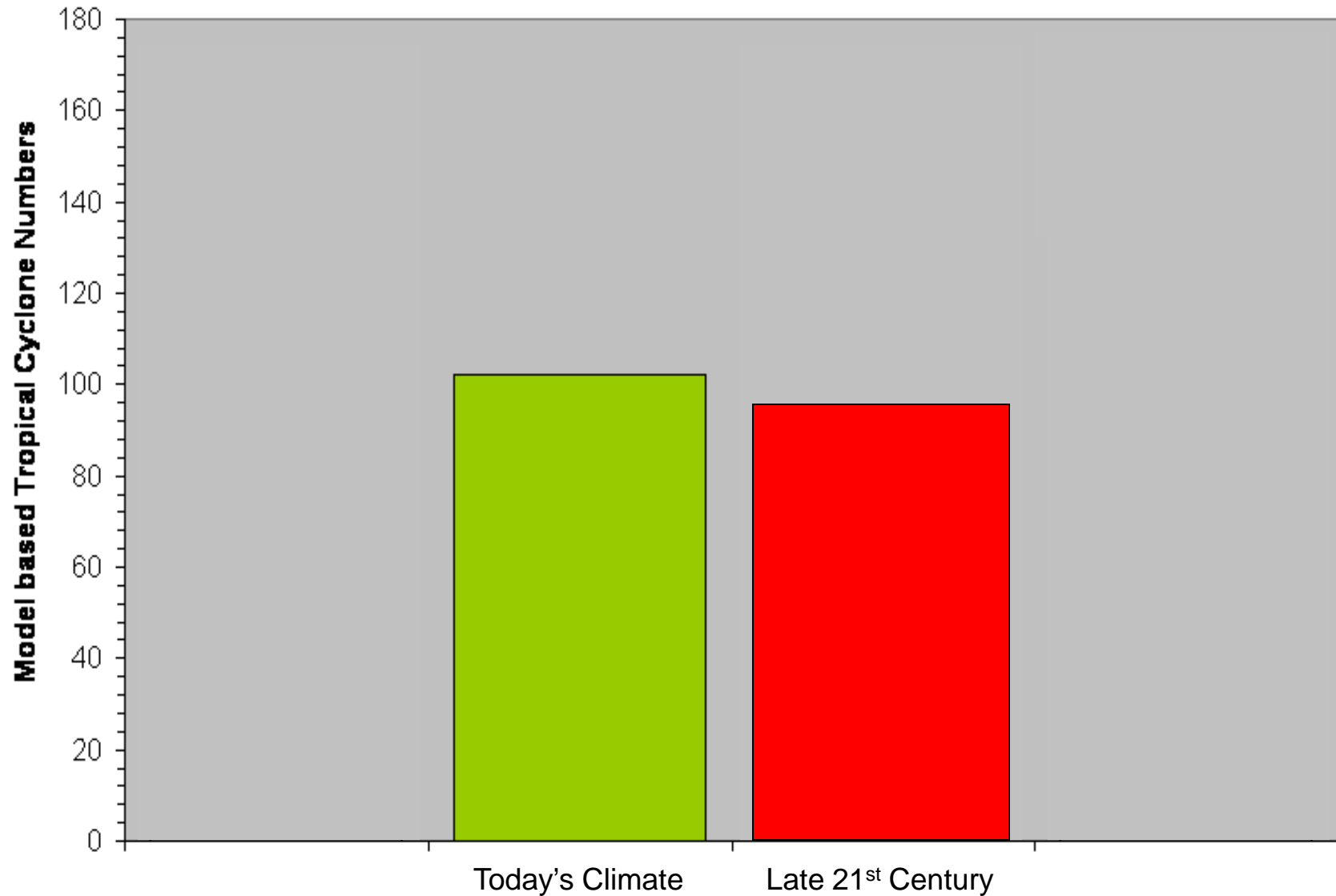
Frequency of Tropical Cyclones in Today's Climate ...Based upon Differing Thresholds of Duration



Frequency of Tropical Cyclones in Today's Climate



Frequency of Tropical Cyclones in Today's Climate Versus Global Warming Climate



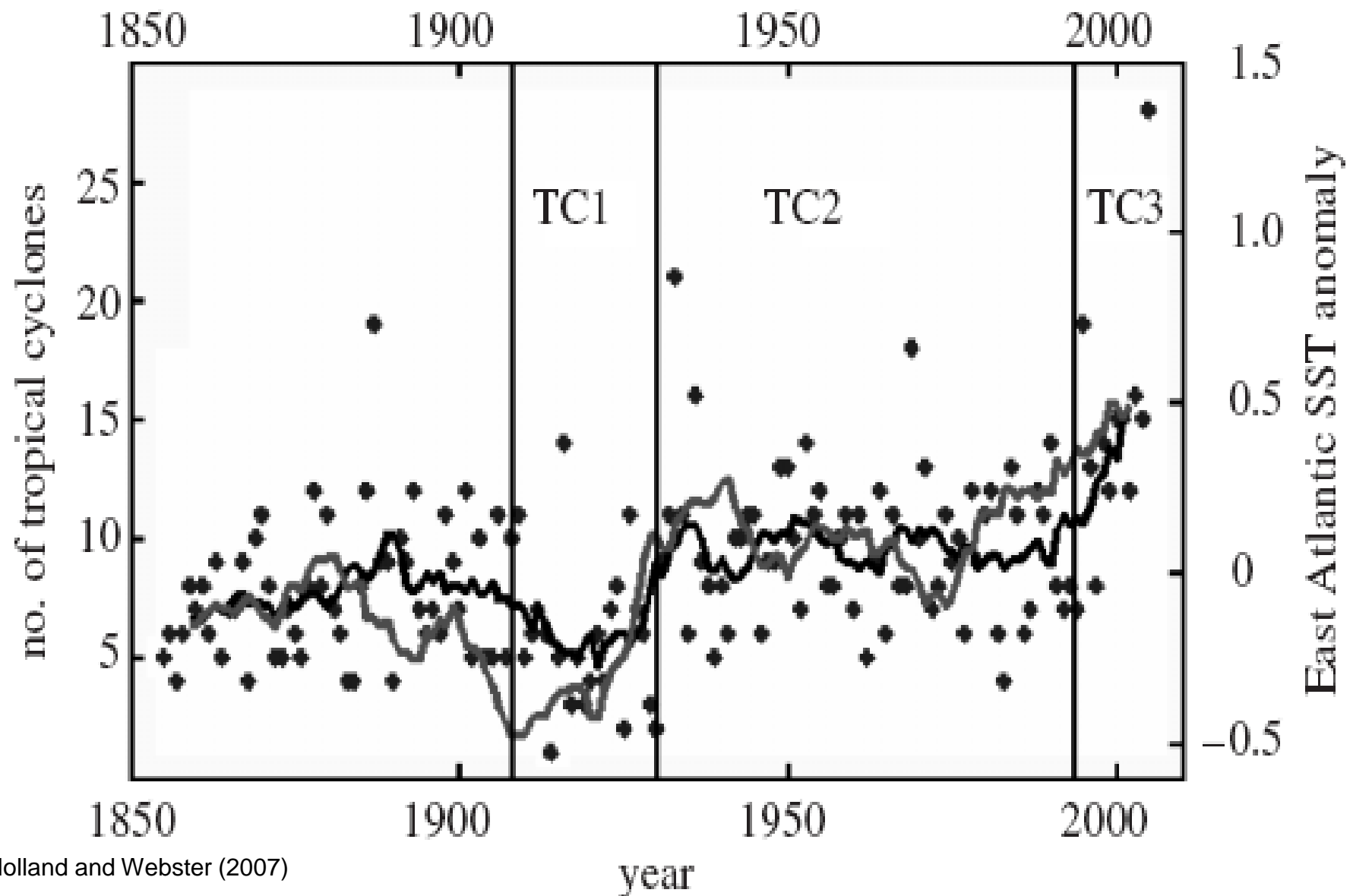
Bengtsson et al. (2007)

Changes in “Naming” Criteria

“If it was quite marginal as to whether or not a storm would be upgraded to tropical storm status or equivalent, that decision would likely be influenced by proximity to possible impacts on land within the next 48 hours or so. That is, I suspect that the margin of acceptable error for most of us would be a little larger over the open sea as compared to potential landfall for such storms that are not all that strong anyway.”

Bob Sheets, National Hurricane Center Director, 1987-1995

Linking frequency of Atlantic tropical cyclones to SSTs



“Questions have been raised over the quality of the NATL data even for such a broad brush accounting. We have carefully examined the data record and considered as yet unpublished analyses by other investigators. Our conclusion is that the number of earlier missed storms most likely lies between 1 and 3 per year prior to 1900, less than 2 in the early nineteenth century [sic] and dropping off to essentially zero by 1960.”

-- Holland and Webster (2007)

“This record [of Atlantic tropical cyclone counts] ... shows a strong, long-term relationship with tropical Atlantic August-October SST...The underlying factor appears to be the influence of (primarily anthropogenic) forced large-scale warming.”

Eos, Vol. 87, No. 24, 13 June 2006

EOS

EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

Atlantic Hurricane Trends Linked to Climate Change

PAGES 233, 238, 241

Increases in key measures of Atlantic hurricane activity over recent decades are believed to reflect, in large part, contemporaneous increases in tropical Atlantic warmth [e.g., Emanuel, 2005]. Some recent studies [e.g., Goldenberg *et al.*, 2001] have attributed these increases to a natural climate cycle

By M. E. MANN AND K. A. EMANUEL

termed the Atlantic Multidecadal Oscillation (AMO), while other studies suggest that climate change may instead be playing the dominant role [Emanuel, 2005; Webster *et al.*, 2005].

Using a formal statistical analysis to separate the estimated influences of anthropogenic climate change from possible natural cyclical influences, this article presents results indicating that anthropogenic factors are likely responsible for long-term trends in tropical Atlantic warmth and tropical cyclone

“Overall, there appears to have been a substantial 100-year trend leading to related increases of over 0.78C in SST and over 100% in tropical cyclone and hurricane numbers. It is concluded that the overall trend in SSTs, and tropical cyclone and hurricane numbers is substantially influenced by greenhouse warming.”

PHILOSOPHICAL
TRANSACTIONS
— OF —
THE ROYAL
SOCIETY

A

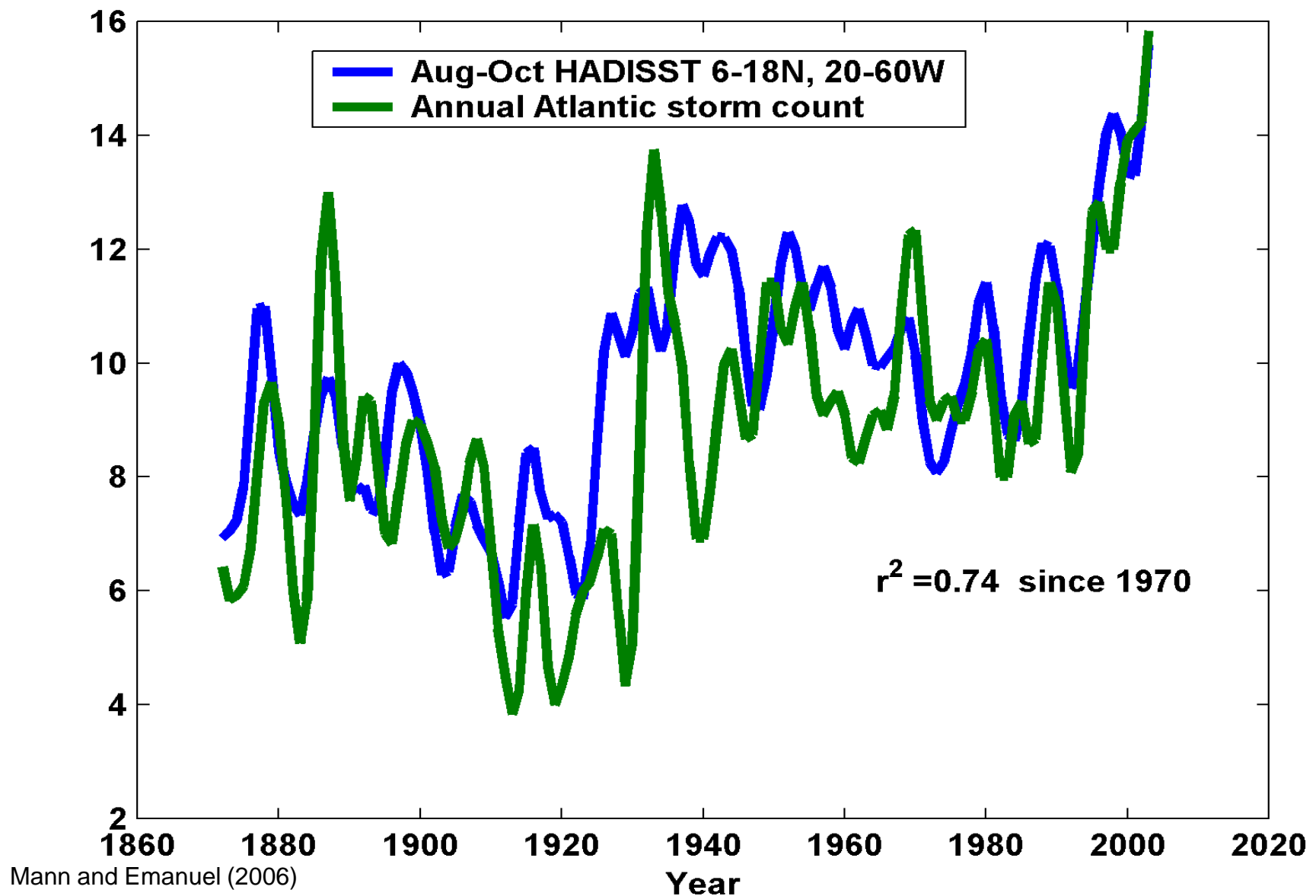


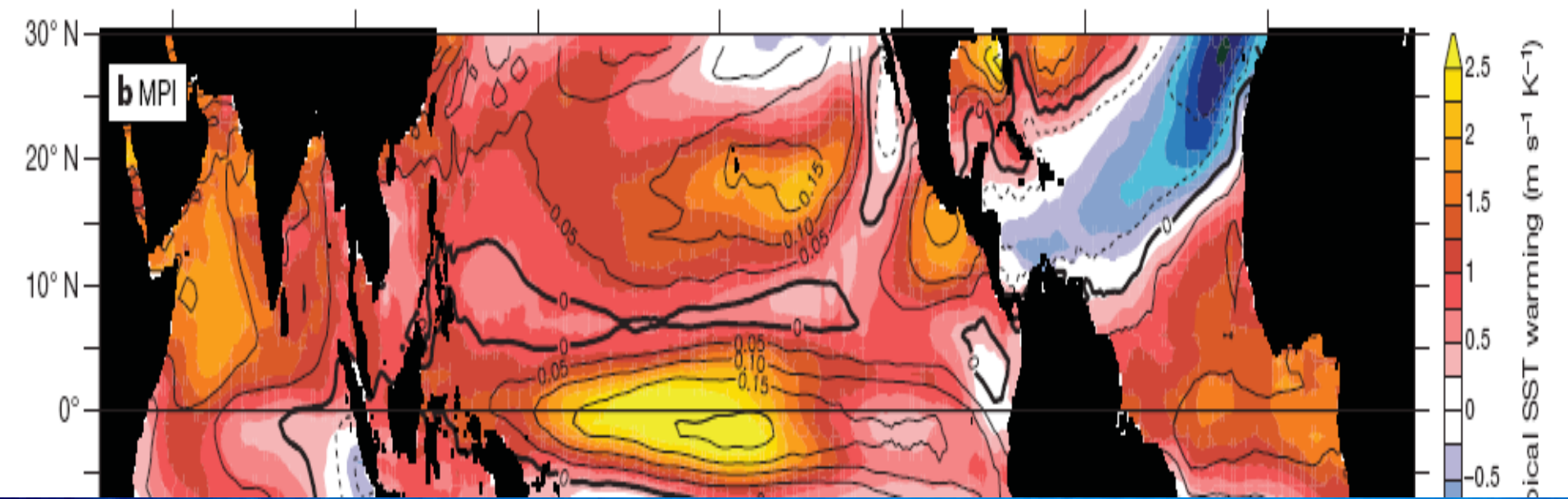
Phil. Trans. R. Soc. A
doi:10.1098/rsta.2007.2083
Published online

Heightened tropical cyclone activity in the North Atlantic: natural variability or climate trend?

By GREG J. HOLLAND¹ AND PETER J. WEBSTER^{2,*}

Linking frequency of Atlantic tropical cyclones to SSTs





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

Normalized Atmospheric Temperature Change

HPa

