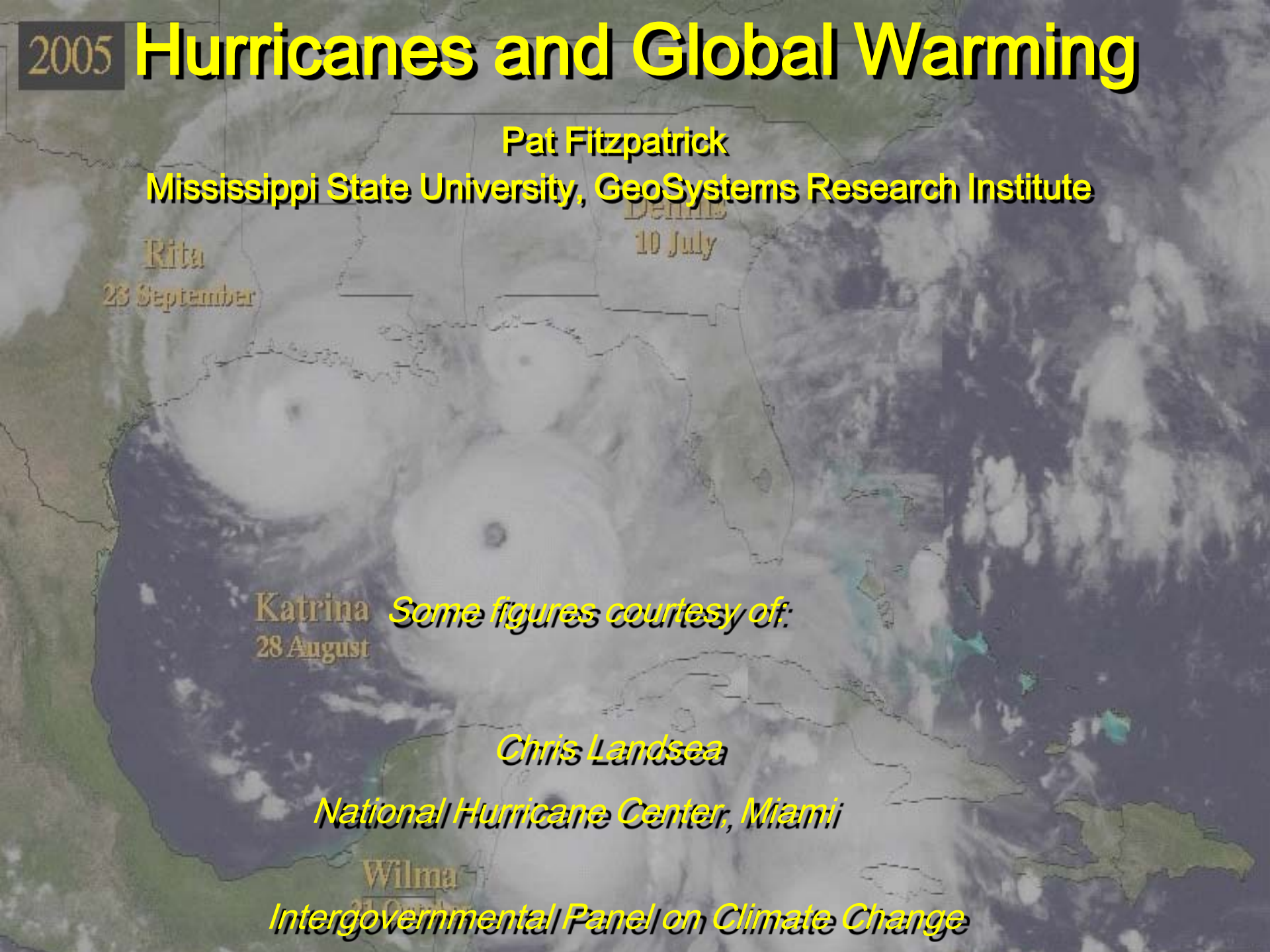


Hurricanes and Global Warming

Pat Fitzpatrick
Mississippi State University, GeoSystems Research Institute

Some figures courtesy of:

Chris Landsea

National Hurricane Center, Miami

Intergovernmental Panel on Climate Change

Outline

- A review of global warming observations
- Is the number of intense hurricanes increasing? The controversy……
- What is the natural variability of hurricane?
- How accurate is the historical record?
- How global warming could impact future hurricane activity
- The consensus statement from the WMO

IPCC statement on global warming

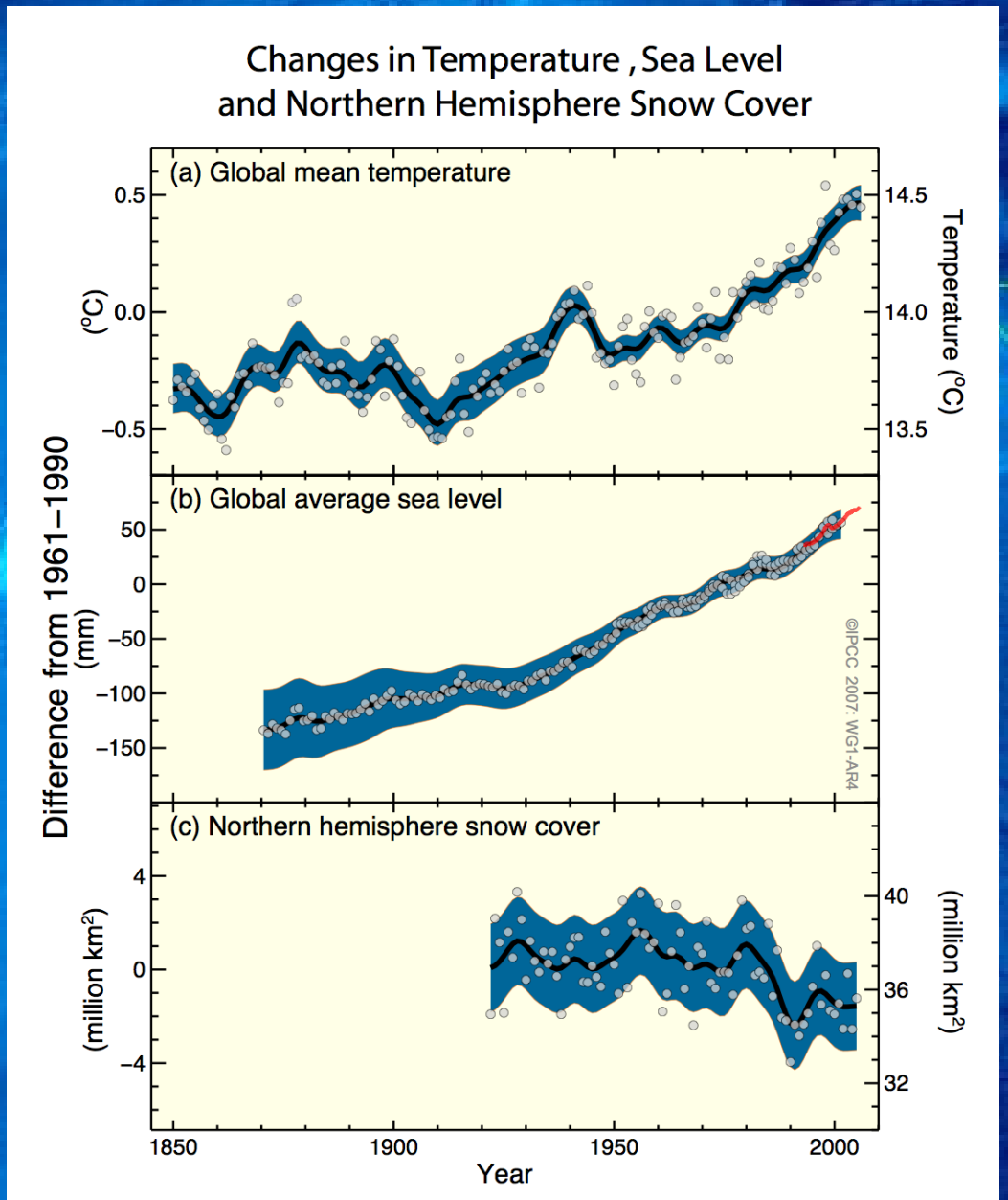
Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level.

Direct Observations of Recent Climate Change

Global mean temperature

Global average sea level

Northern hemisphere Snow cover

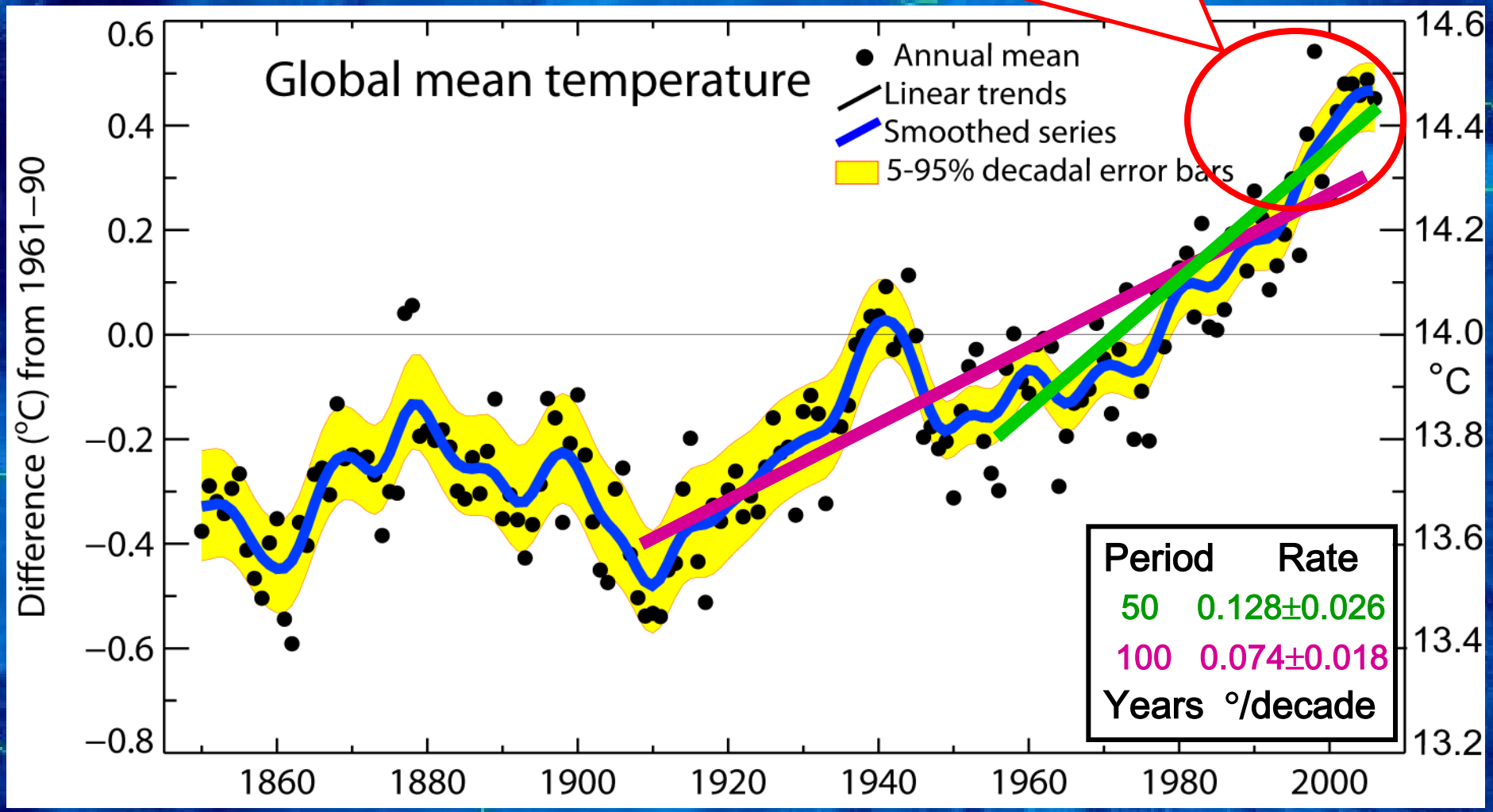


At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed, including:

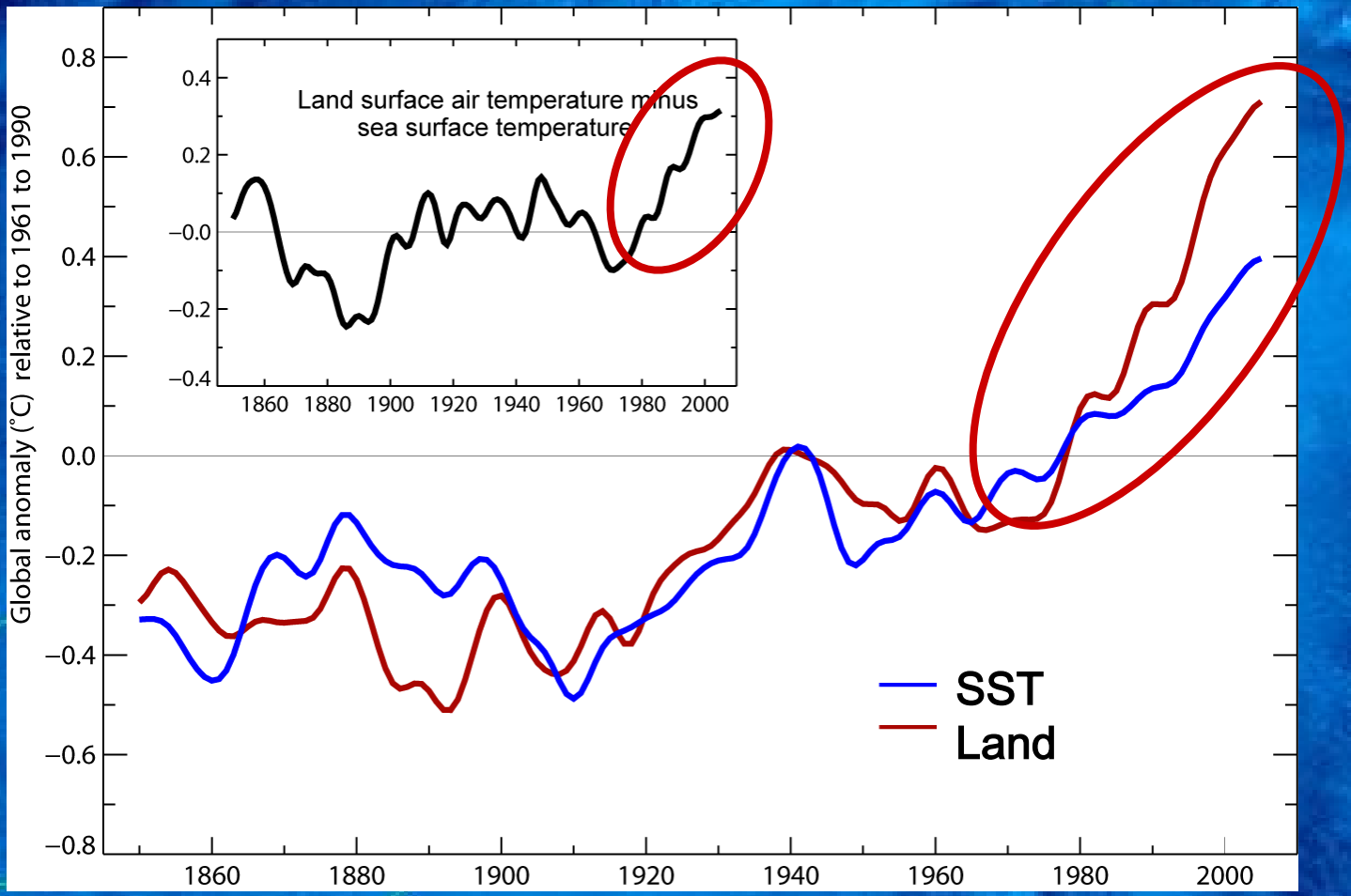
- Average ocean temperature increased to depths of at least 3000 m – ocean has absorbed 80% of heat added
- Changes in Arctic temperature and ice
- Annual average Arctic sea ice extent shrunk by 2.7% per decade, decreases in summer 7.4%
- The maximum area covered by seasonally frozen ground has decreased by about 7%
- Changes in precipitation amounts, ocean salinity, wind patterns
- Increased droughts

Global mean tempera

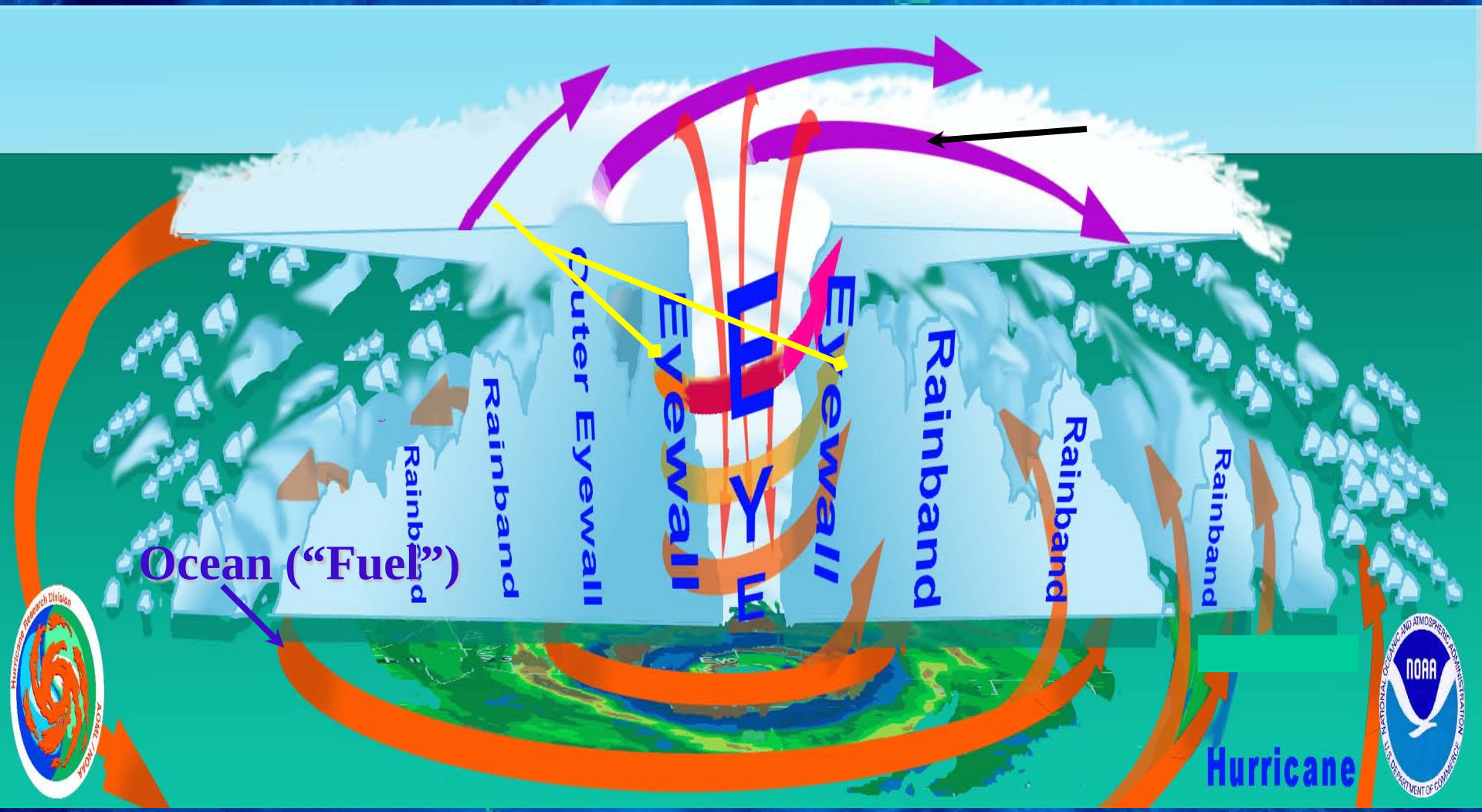
Warmest 12 years:
1998,2005,2003,2002,2004,2006,
2001,1997,1995,1999,1990,2000



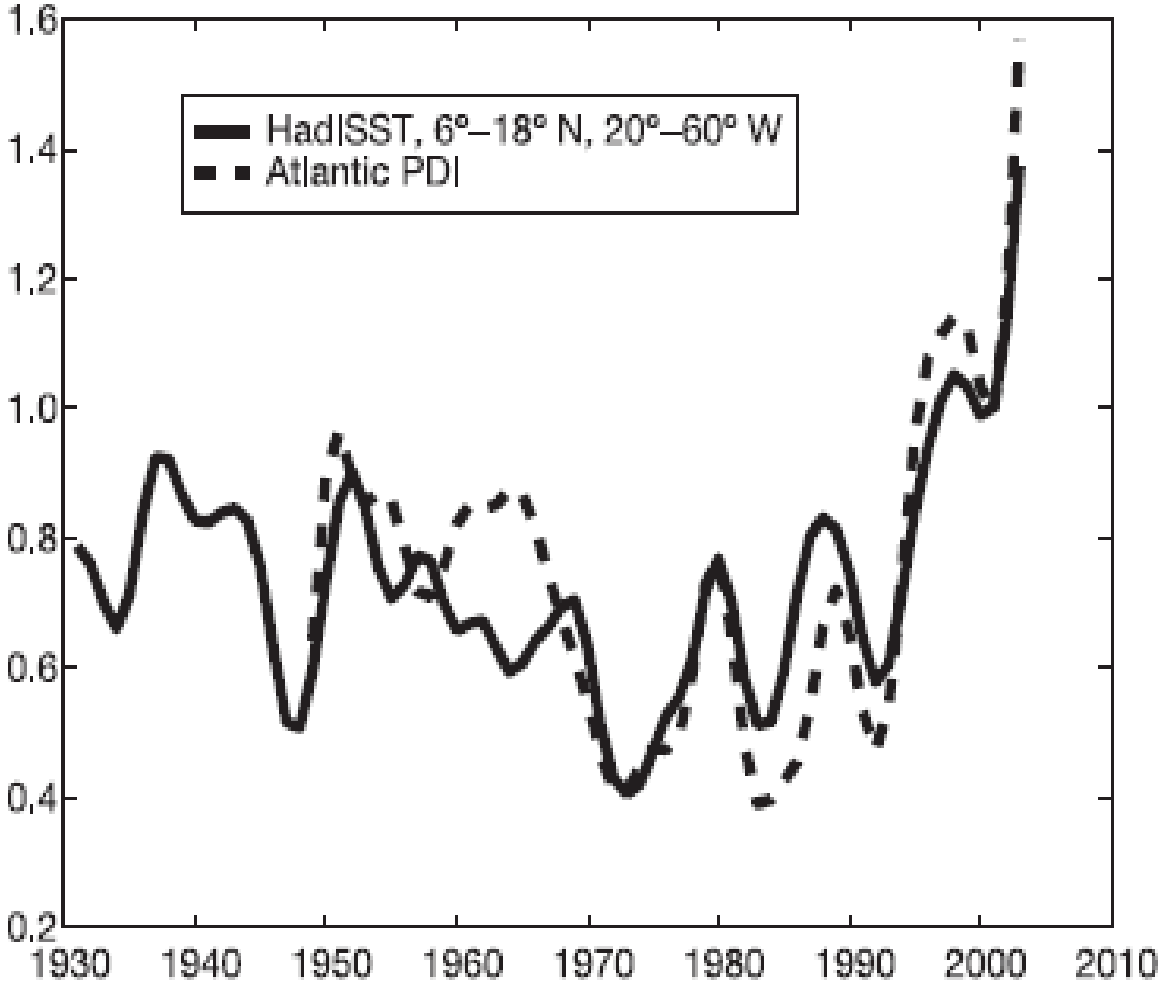
Land surface temperatures are rising faster than SSTs



What about hurricanes?

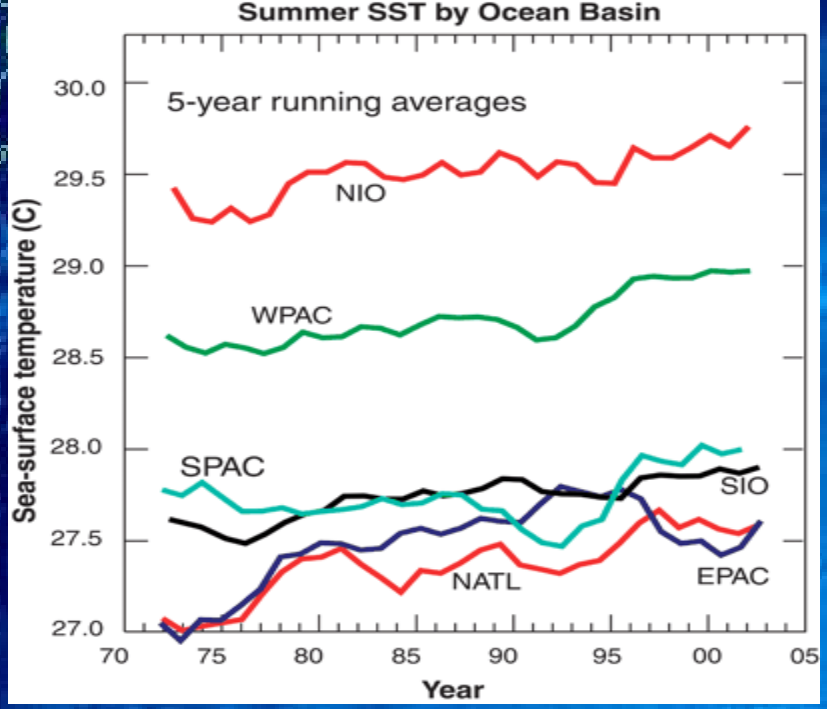


Emanuel's study:
Doubling in Atlantic Hurricane Wind Index – "Unprecedented"

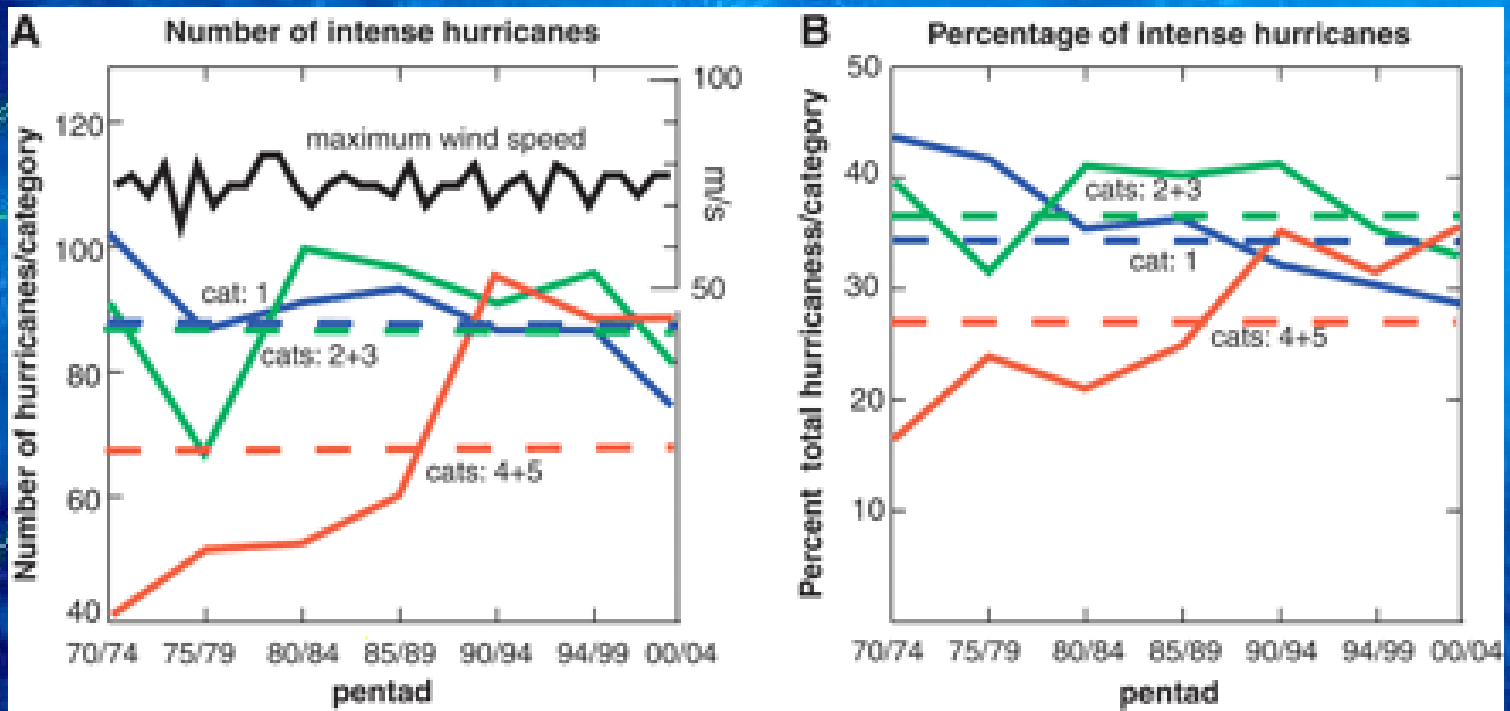


Emanuel (2005)

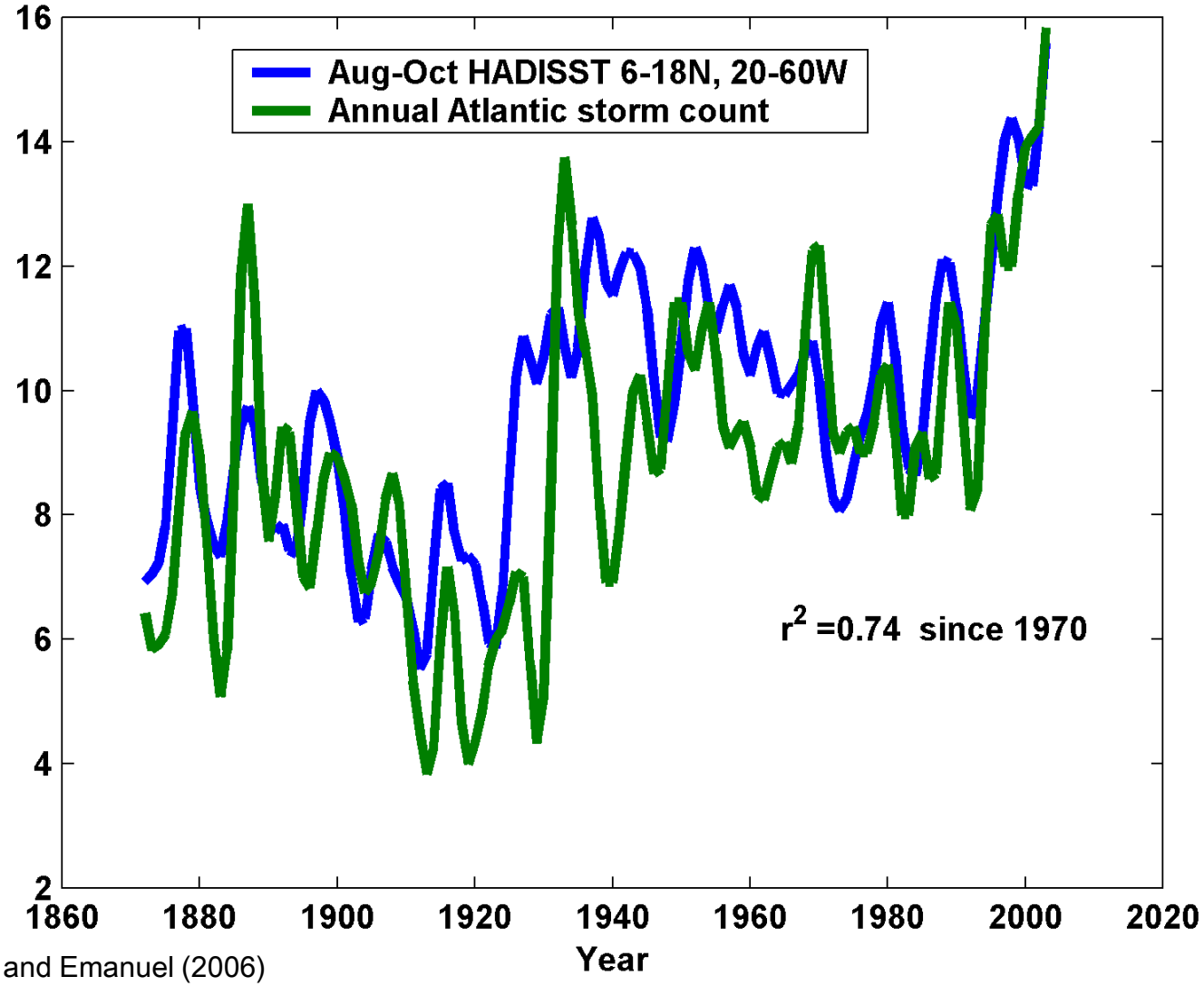
PDI = Power Dissipation Index (winds cubed & summed for season)



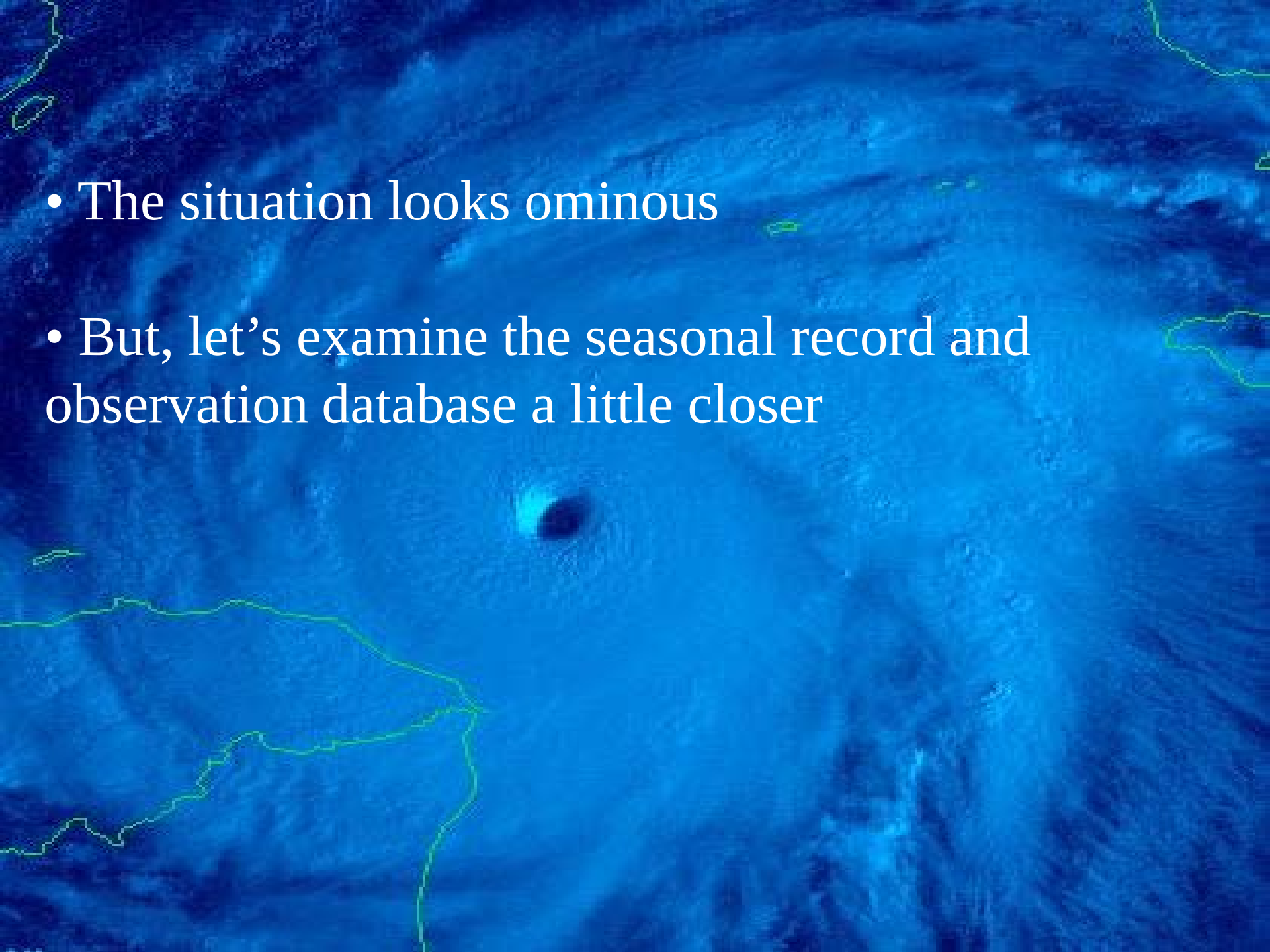
"P. Webster (EAS, GT), Greg Holland (NCAR), Judy Curry (EAS, GT) and Hai-Ru Chang (EAS, GT) reports in *Science* that the number of Category 4 and 5 hurricanes has nearly doubled over the past 35 years."



Linking frequency of Atlantic tropical cyclones to SSTs



Mann and Emanuel (2006)

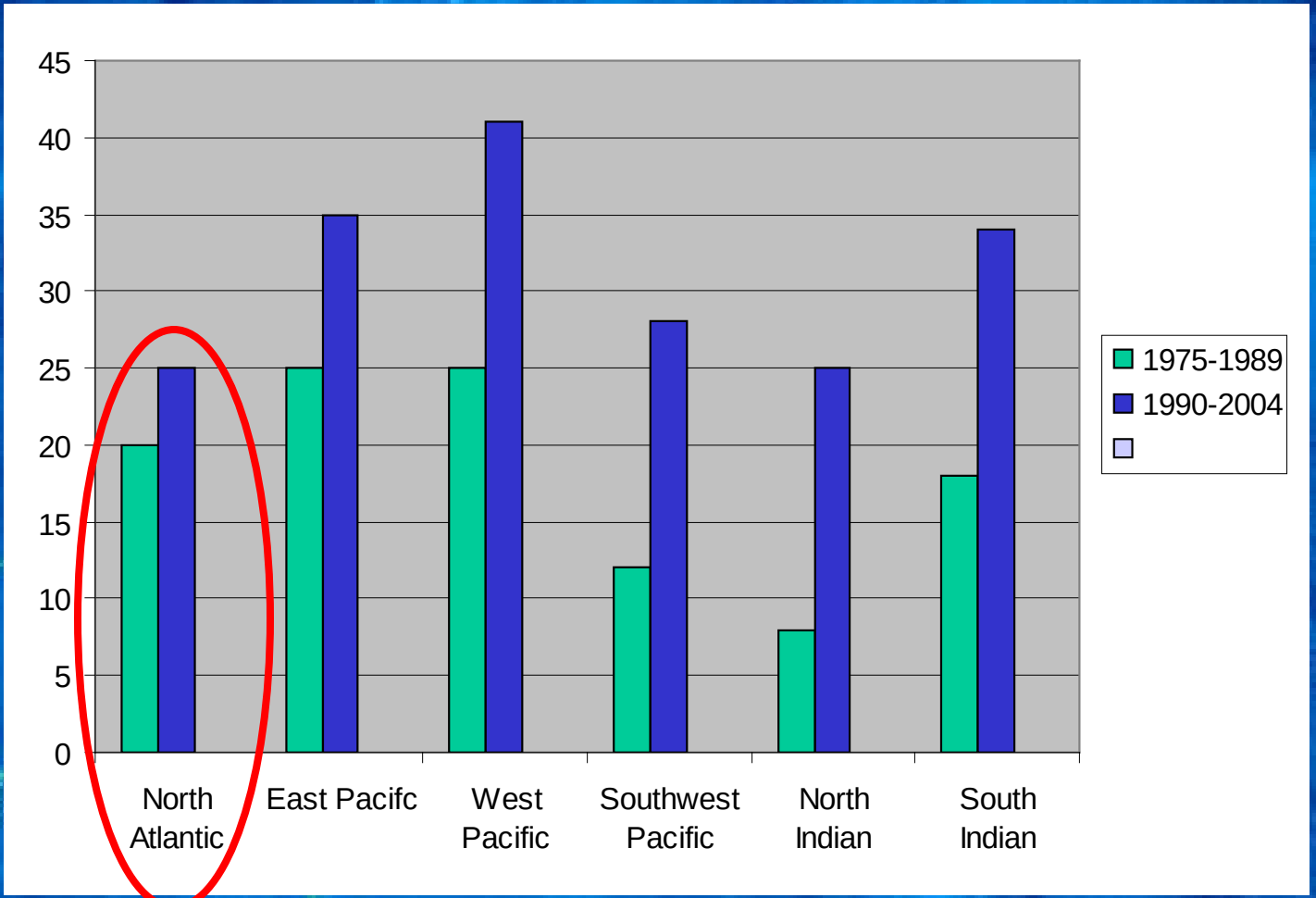


- The situation looks ominous

- But, let’s examine the seasonal record and observation database a little closer

Seasonal hurricane cycle issues

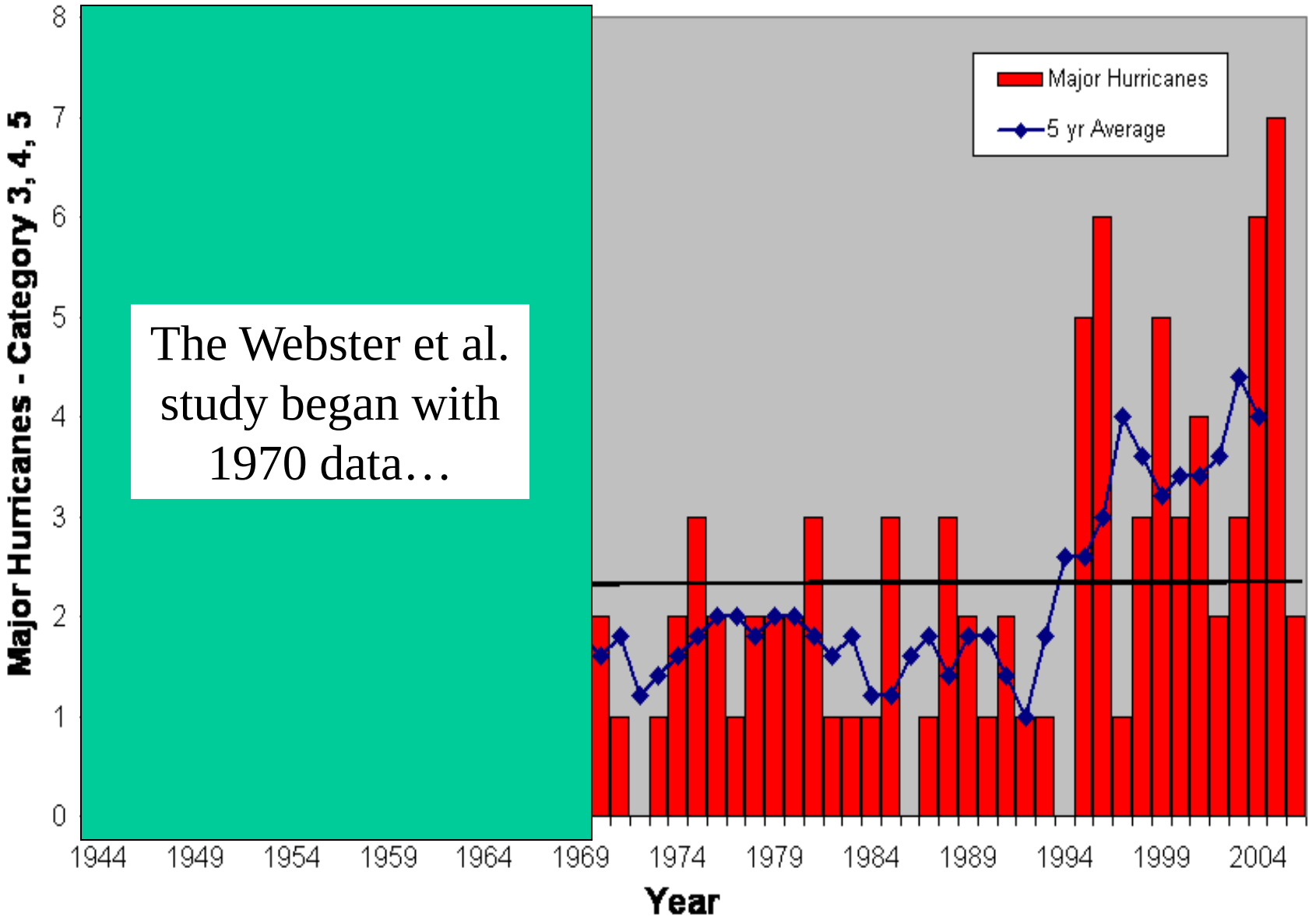
Webster et al.: The percentage of hurricanes which reach Category 4-5 has increased in all basins, comparing two recent 15-year periods…



Source: Adapted from Webster et al., *Science,* Sept. 2005.

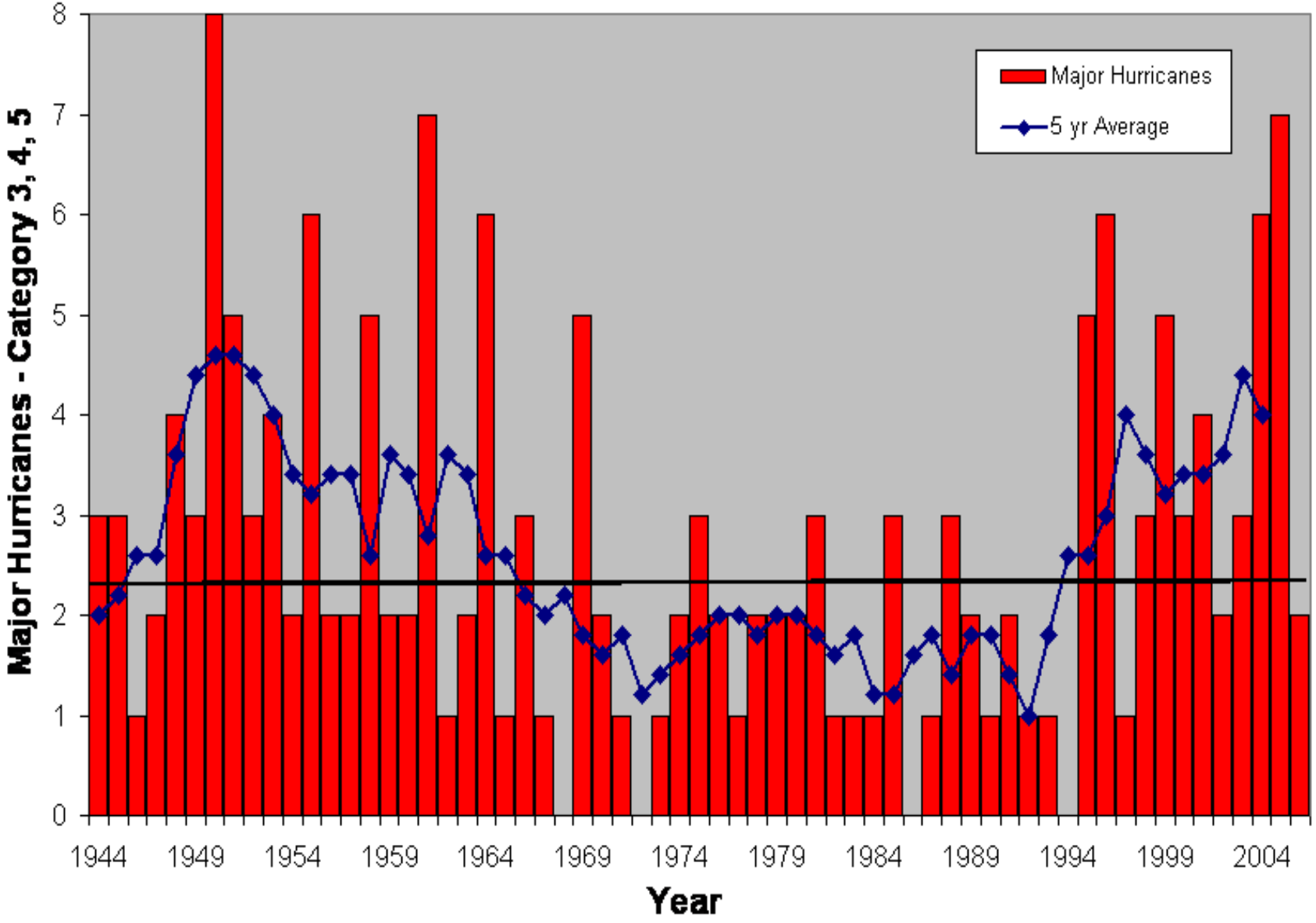
Atlantic Major Hurricanes

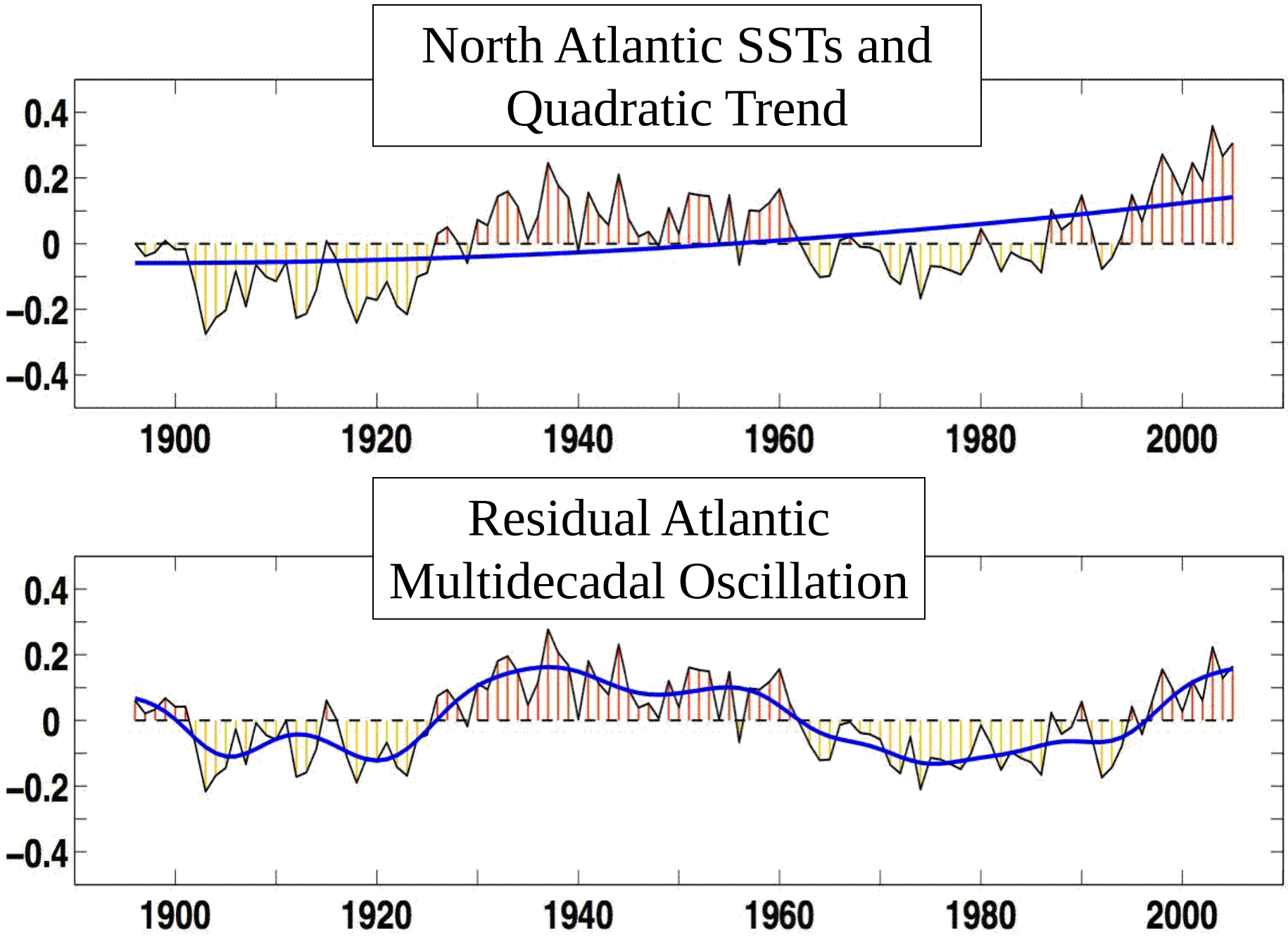
1944 to 2006



The Webster et al. study began with 1970 data…

Note 20-year decadal cycle in major Atlantic hurricanes

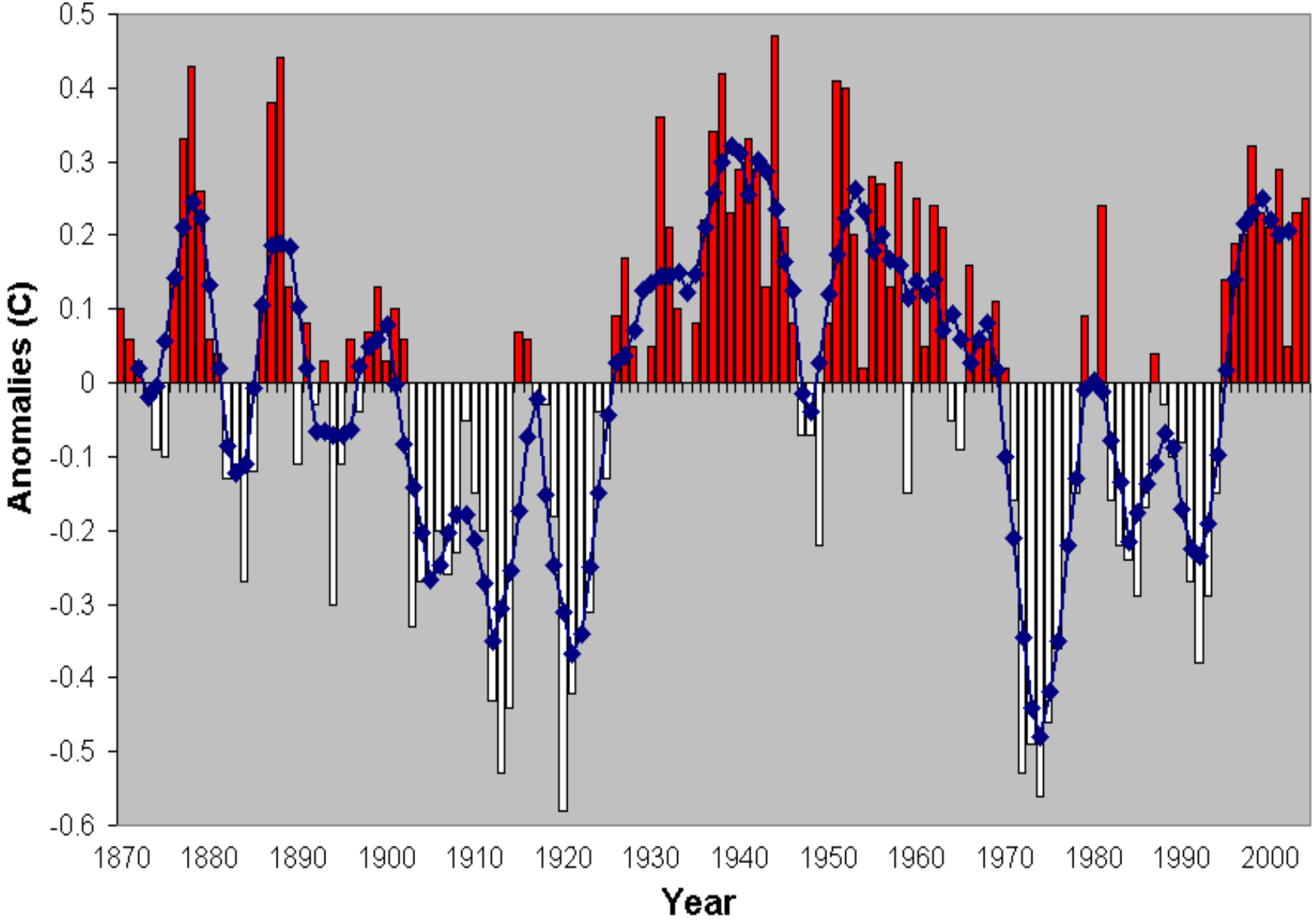




Enfield and Cid (2007)

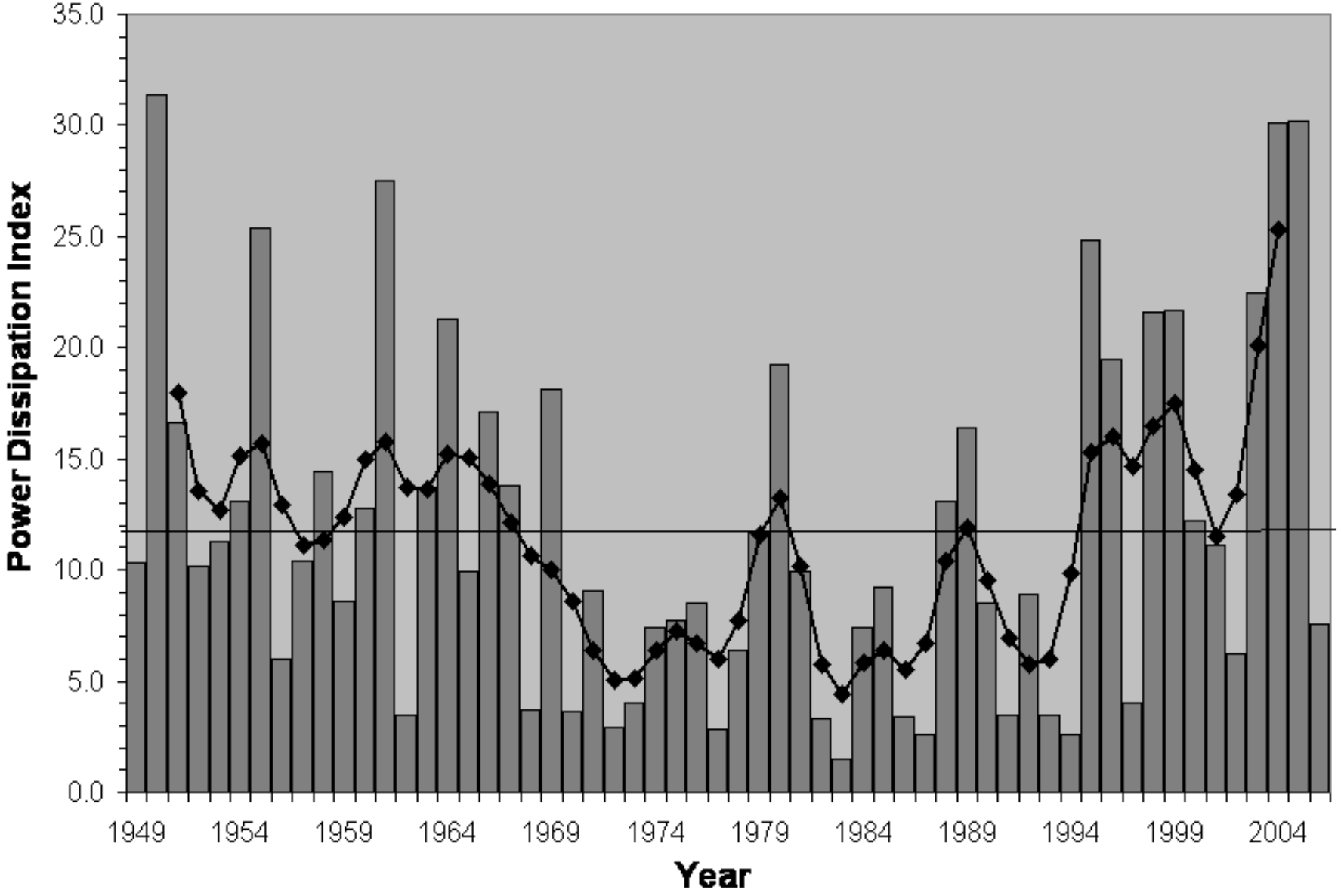
Atlantic SST Multidecadal Mode

1870-2006

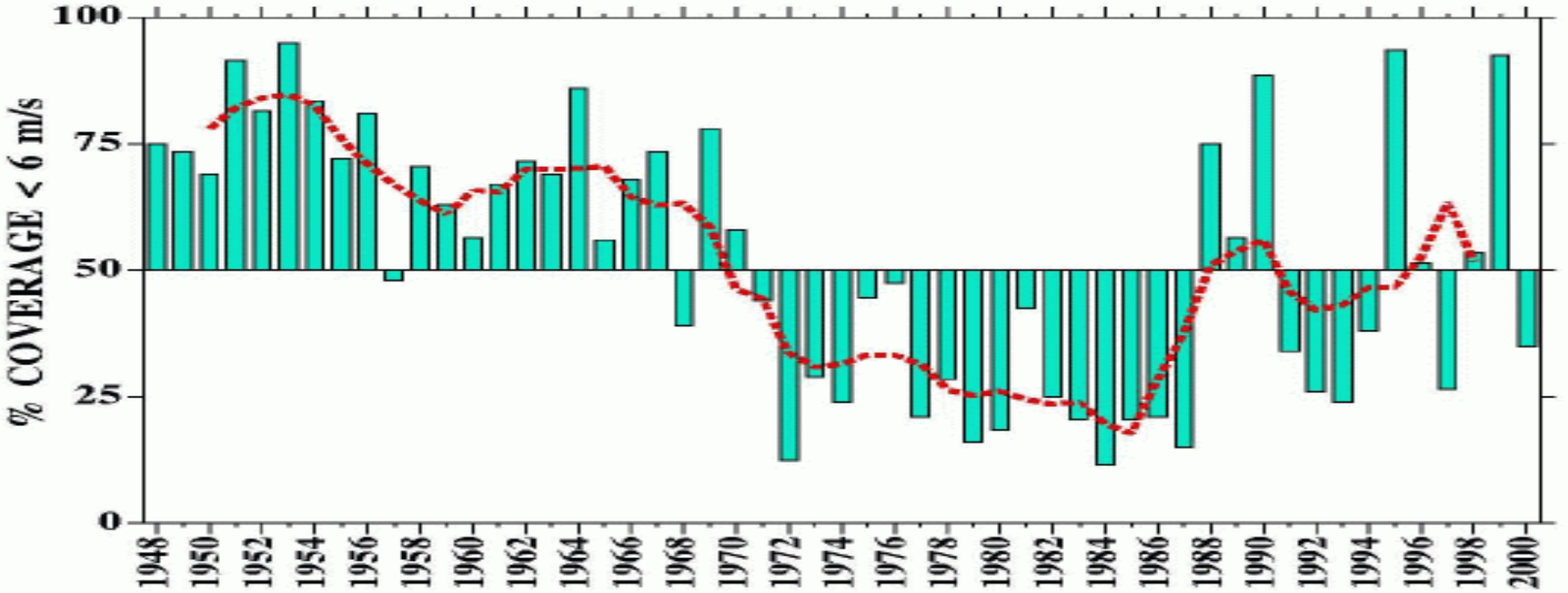


Atlantic Power Dissipation Index

Original Data - 1949 to 2006



Coverage of Low Tropospheric Vertical Wind Shear



Atlantic tropical cyclones with 11-yr running mean

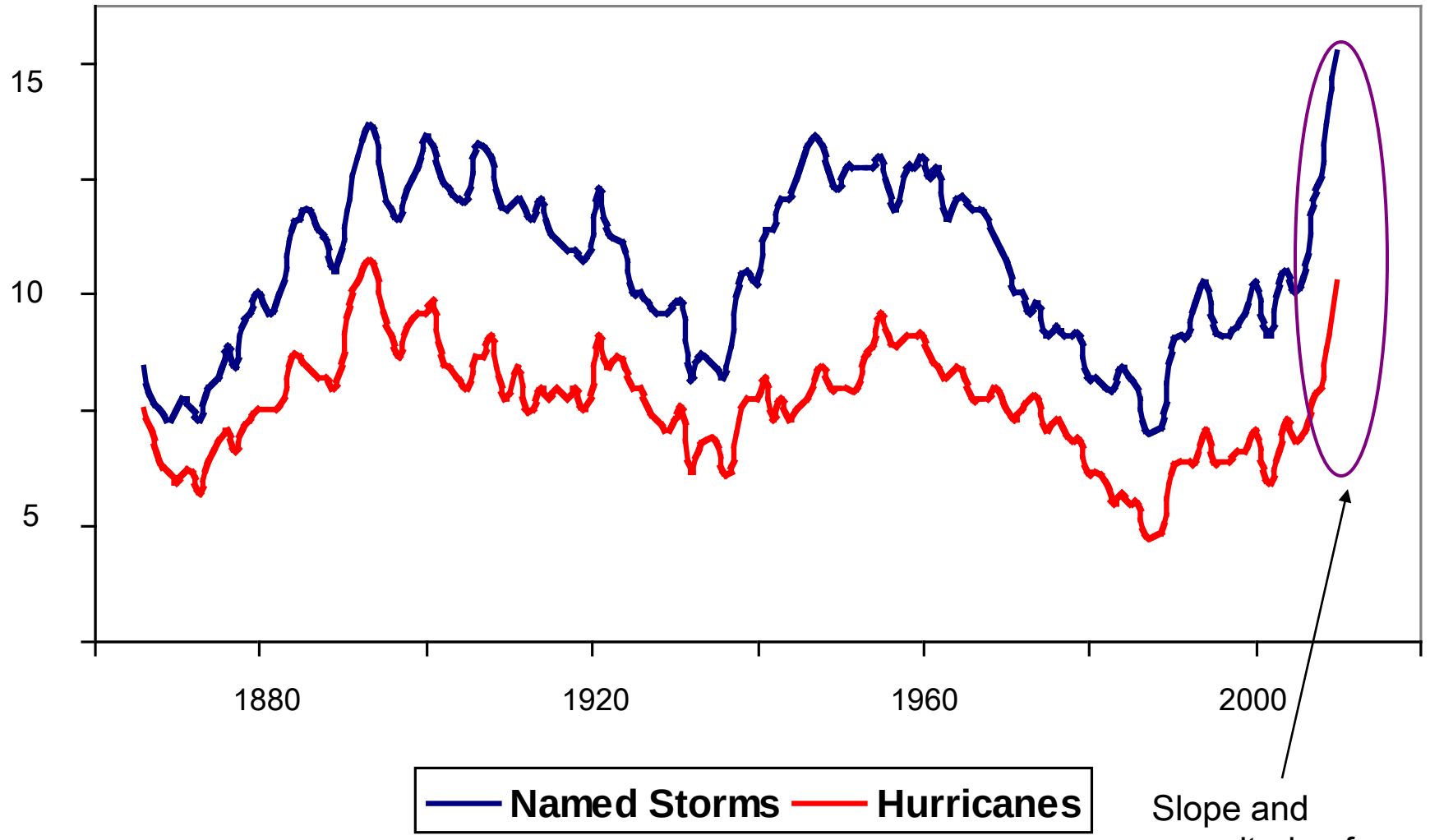
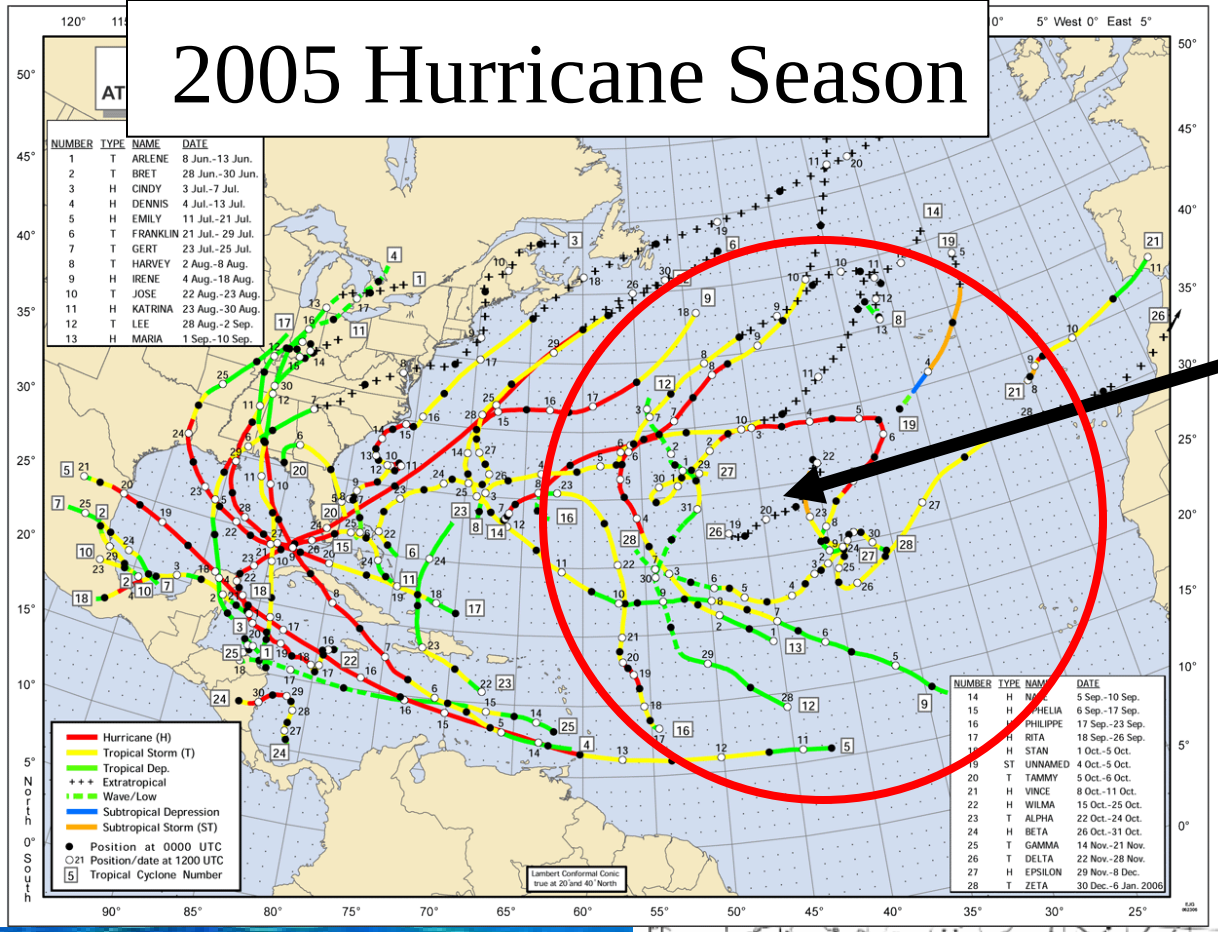


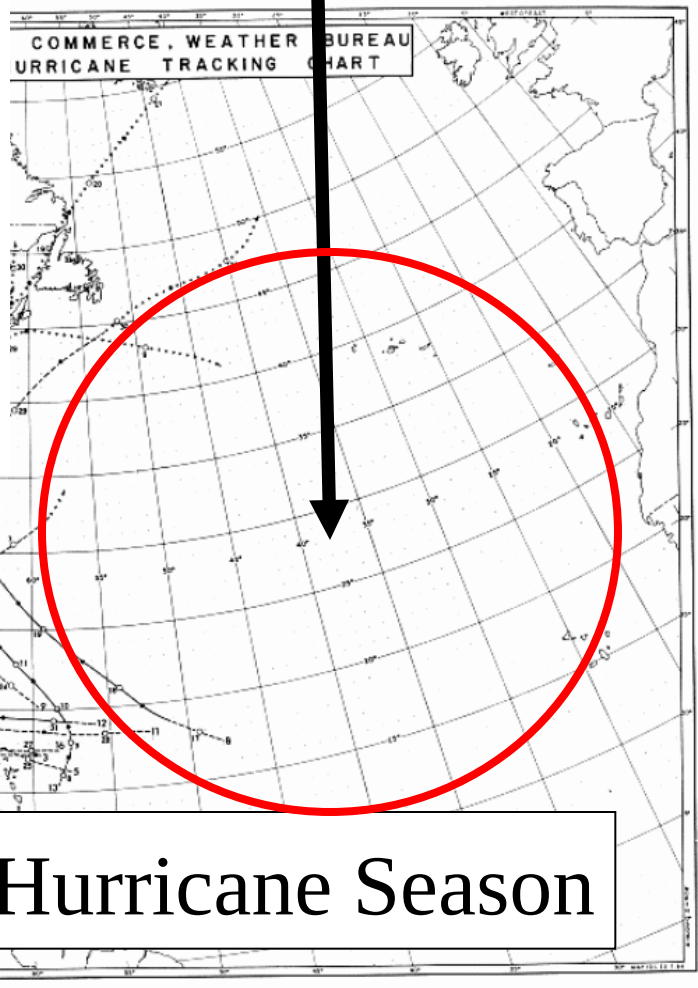
Figure courtesy of Judith Curry

Historical data issues Atlantic Ocean

2005 Hurricane Season

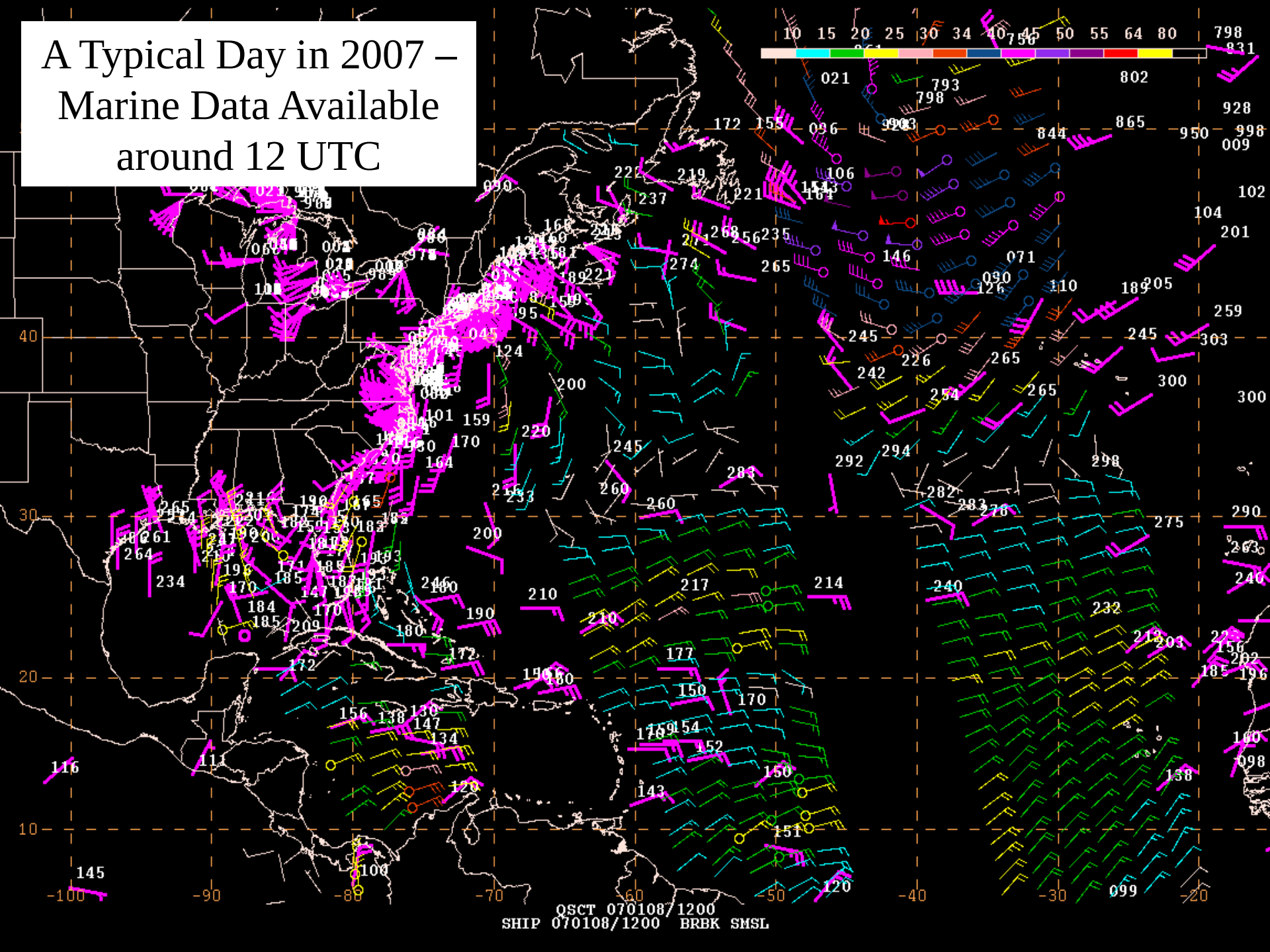


Open Atlantic Ocean Differences



Landsea (2007)
1 May issue of EOS

1933 Hurricane Season

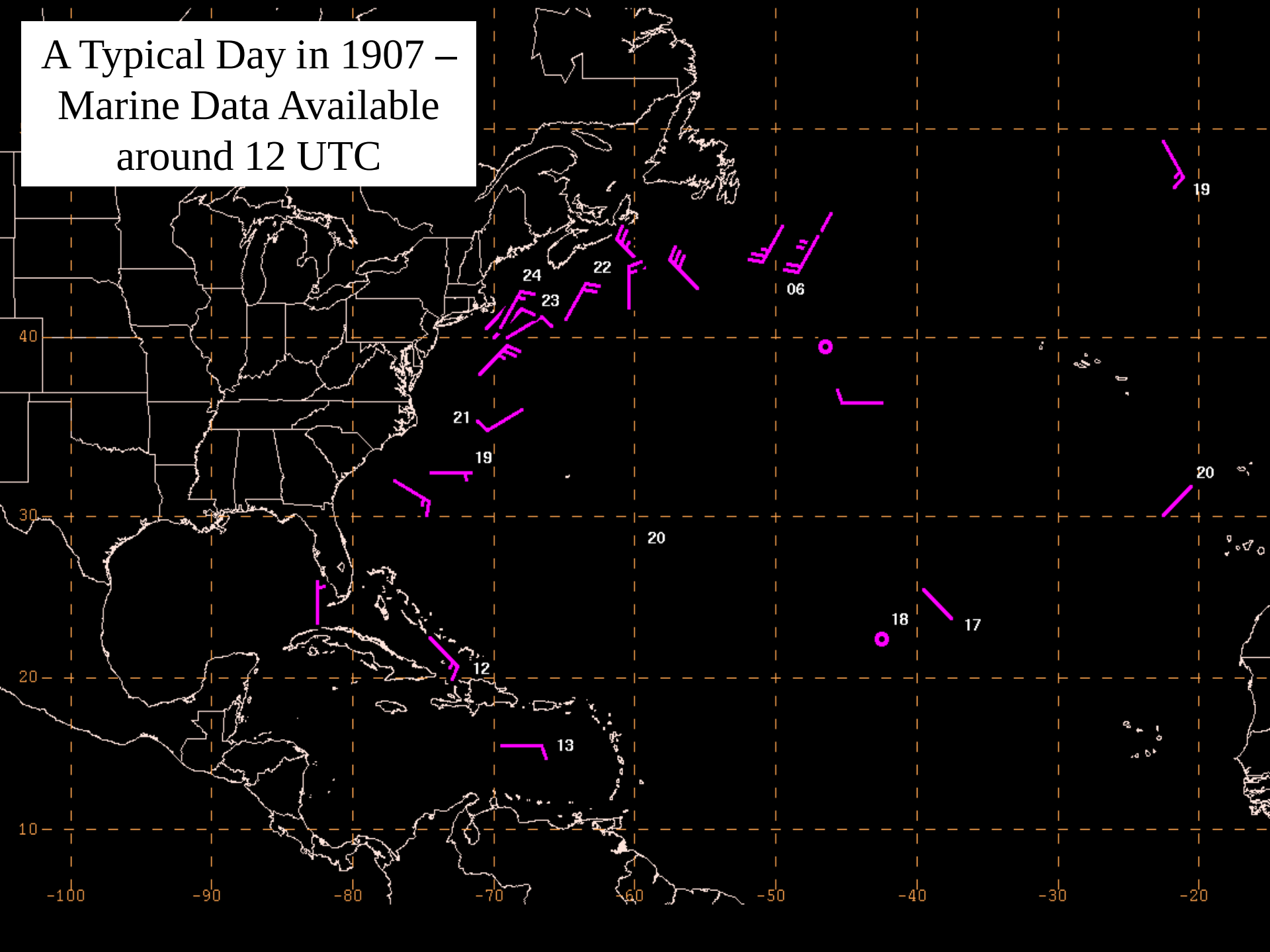

A Typical Day in 2007 – Marine Data Available around 12 UTC
10 15 20 25 30 34 40 45 50 55 64 80
QSCT 070108/1200
SHIP 070108/1200 BRBK SMSL

A Typical Day in 2007 – Marine Data Available around 12 UTC

QSCT 070108/1200
SHIP 070108/1200 BRBK SMSL

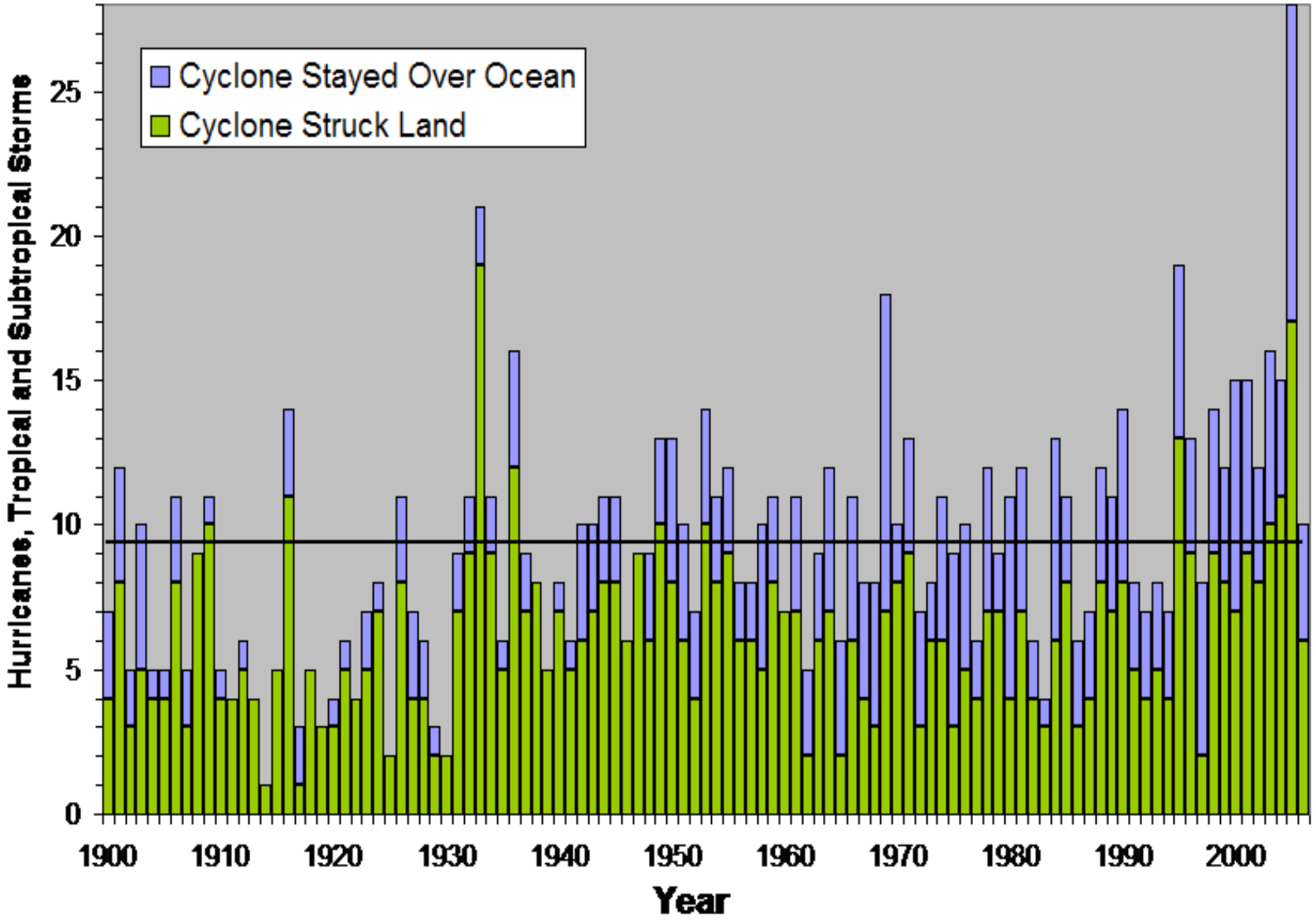
A Typical Day in 2007 – Marine Data Available around 12 UTC

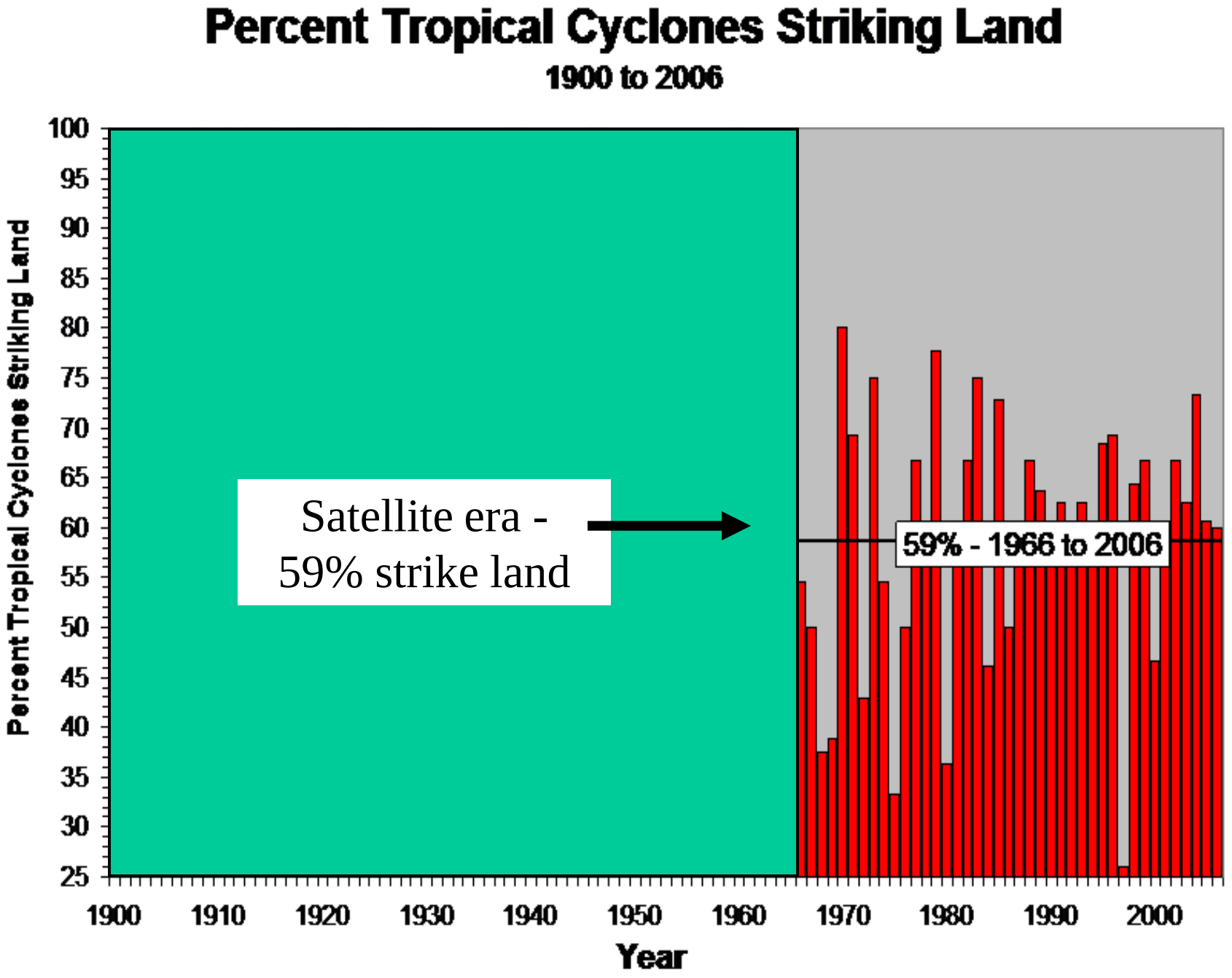
QSCT 070108/1200
SHIP 070108/1200 BRBK SMSL

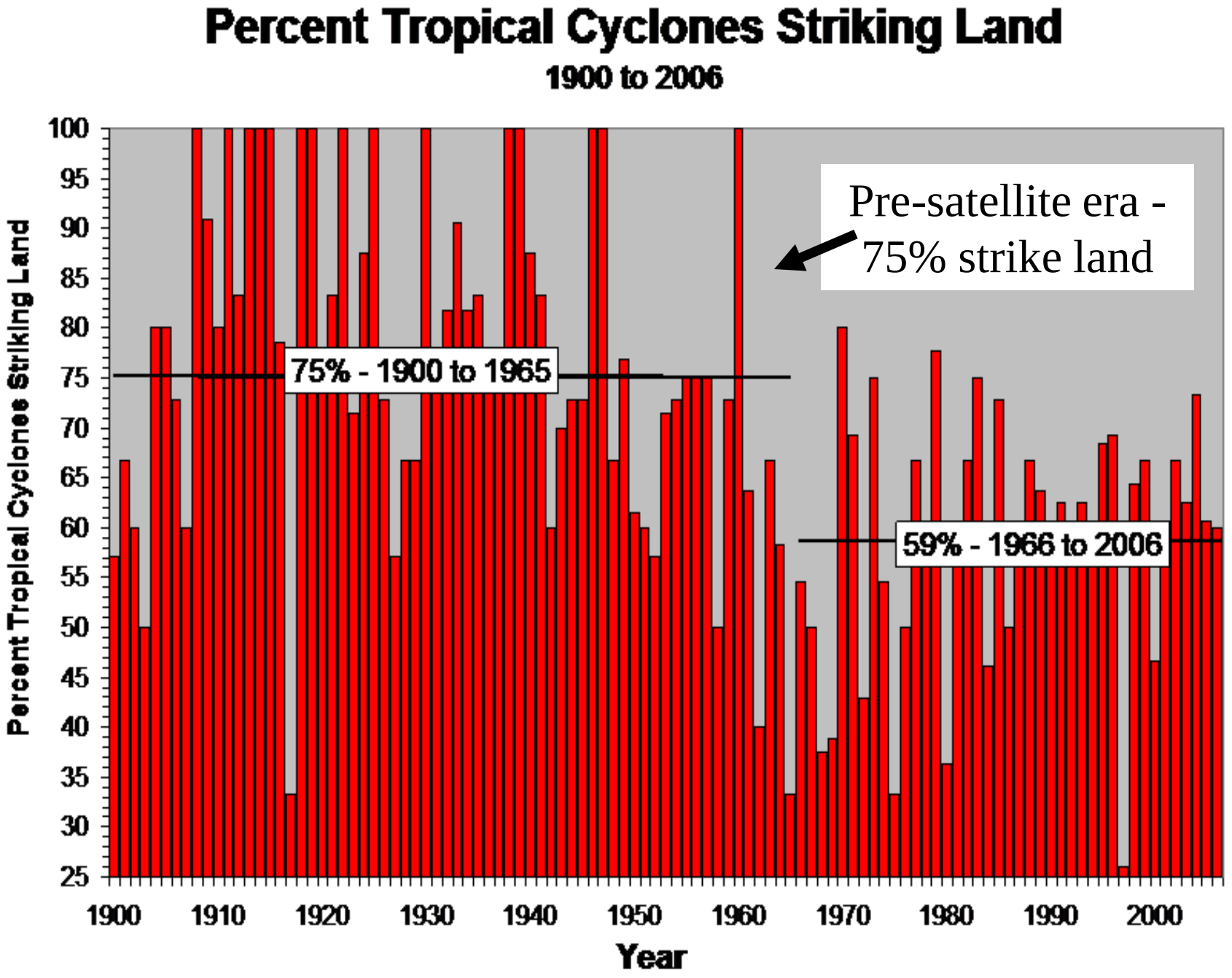

A Typical Day in 1907 – Marine Data Available around 12 UTC
19
24
22
23
06
40
21
19
20
30
20
18
17
12
13
10
-100
-90
-80
-70
-60
-50
-40
-30
-20

Atlantic Named Storms

1900 to 2006

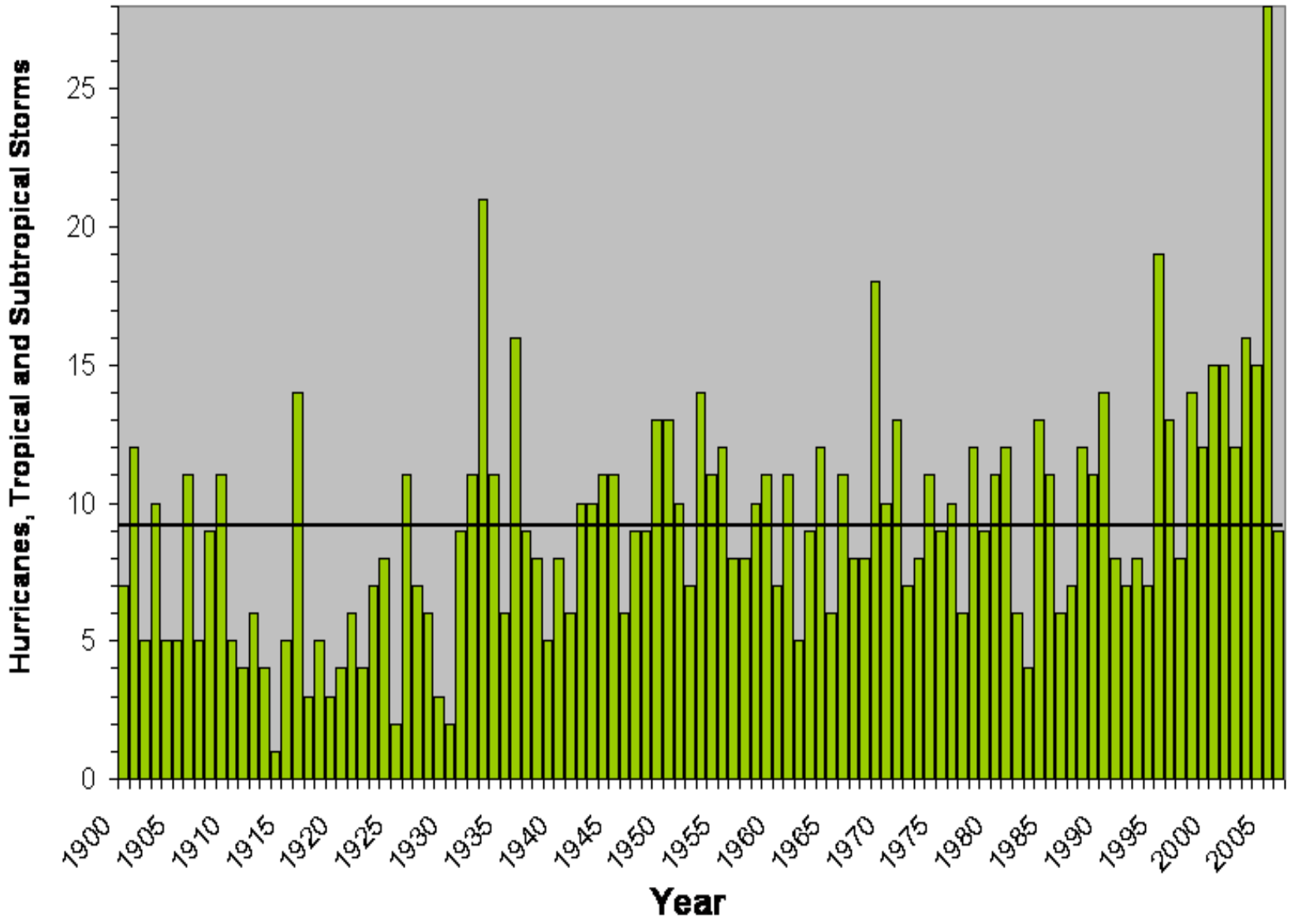



Percent Tropical Cyclones Striking Land
1900 to 2006
Percent Tropical Cyclones Striking Land
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year
Satellite era -
59% strike land
59% - 1966 to 2006


Percent Tropical Cyclones Striking Land
1900 to 2006
Percent Tropical Cyclones Striking Land
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year
Pre-satellite era -
75% strike land
75% - 1900 to 1965
59% - 1966 to 2006

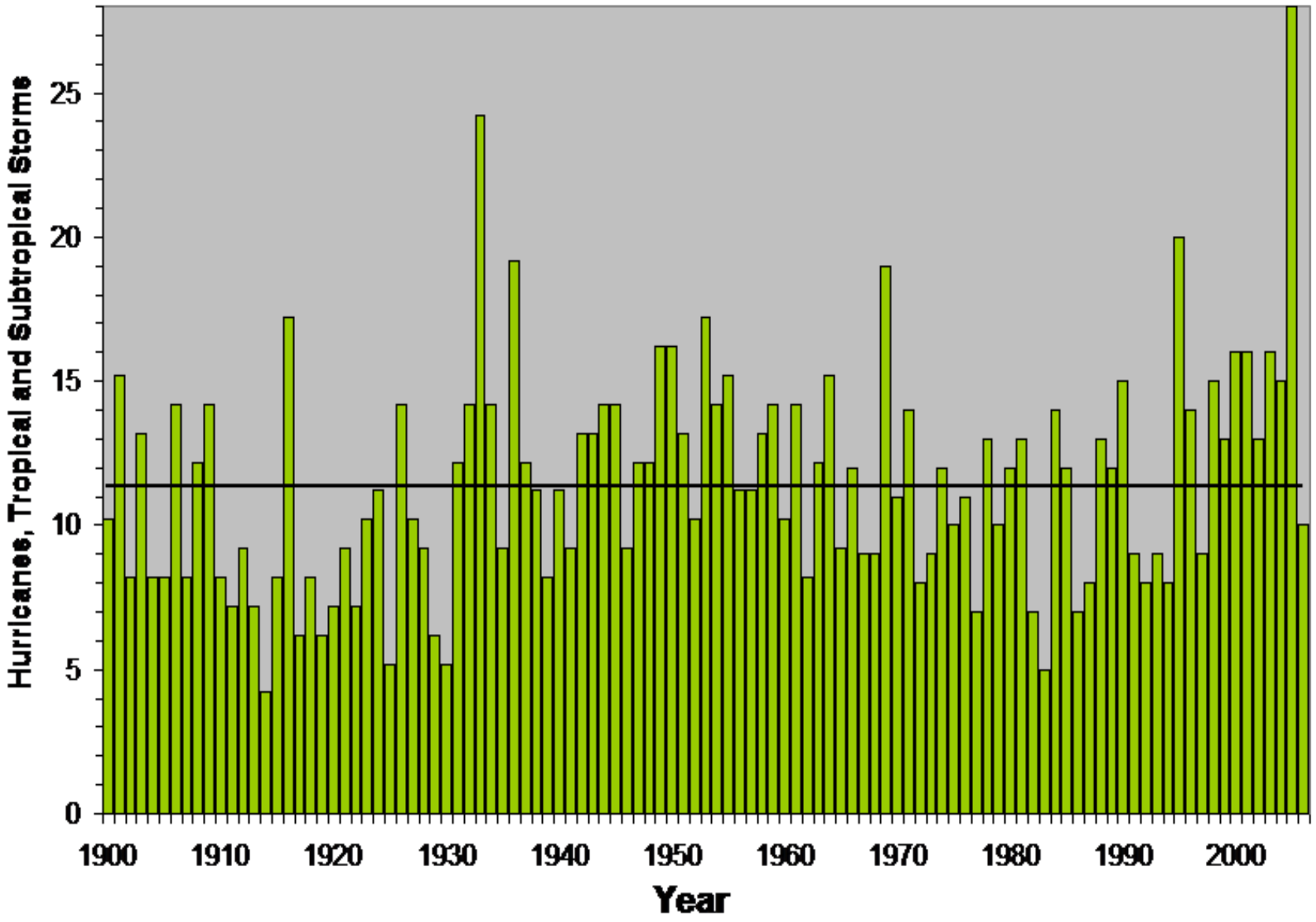
Atlantic Named Storms

1900 to 2006



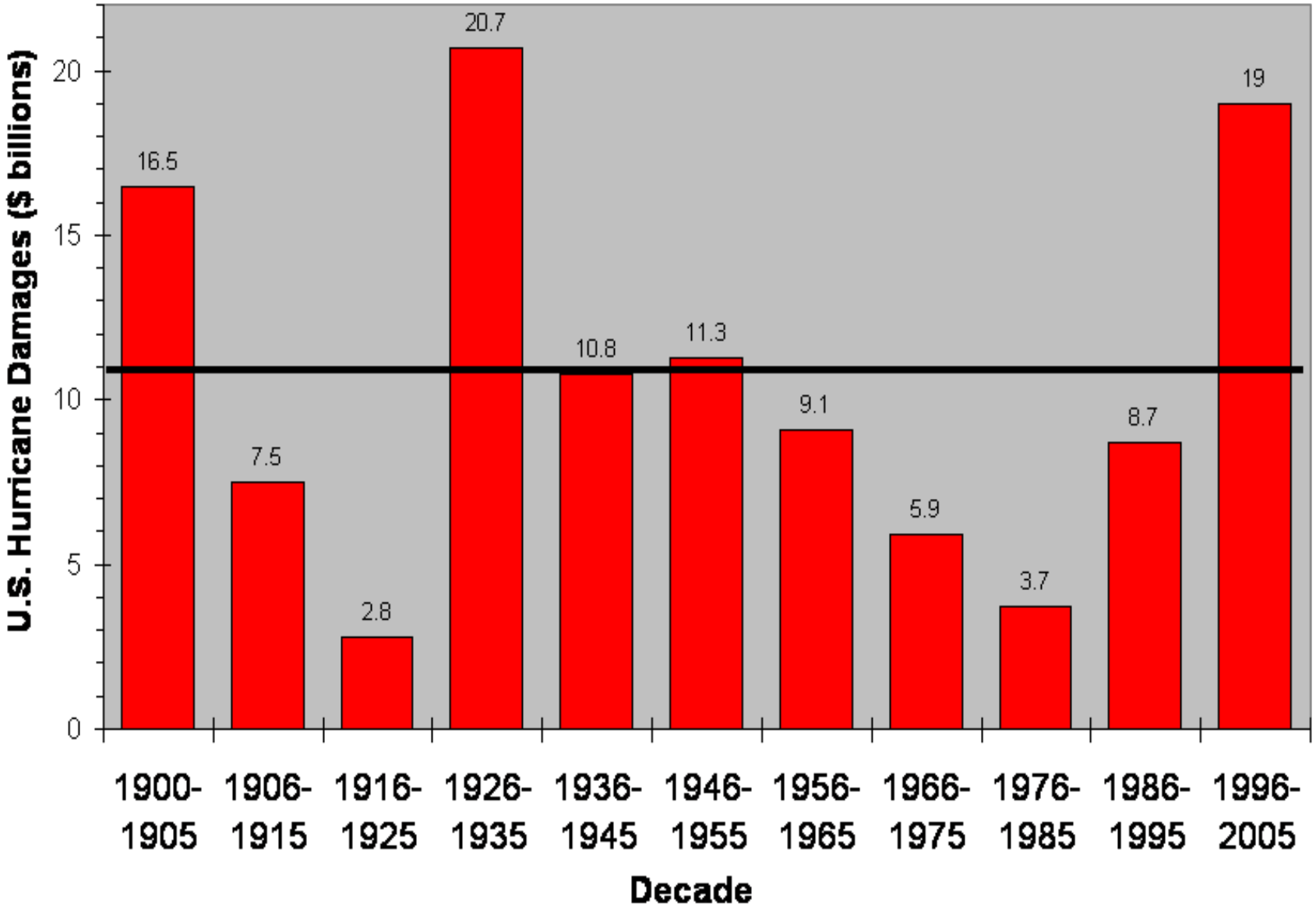
Adjusted Atlantic Named Storms

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



U.S. Tropical Storm and Hurricane Damages

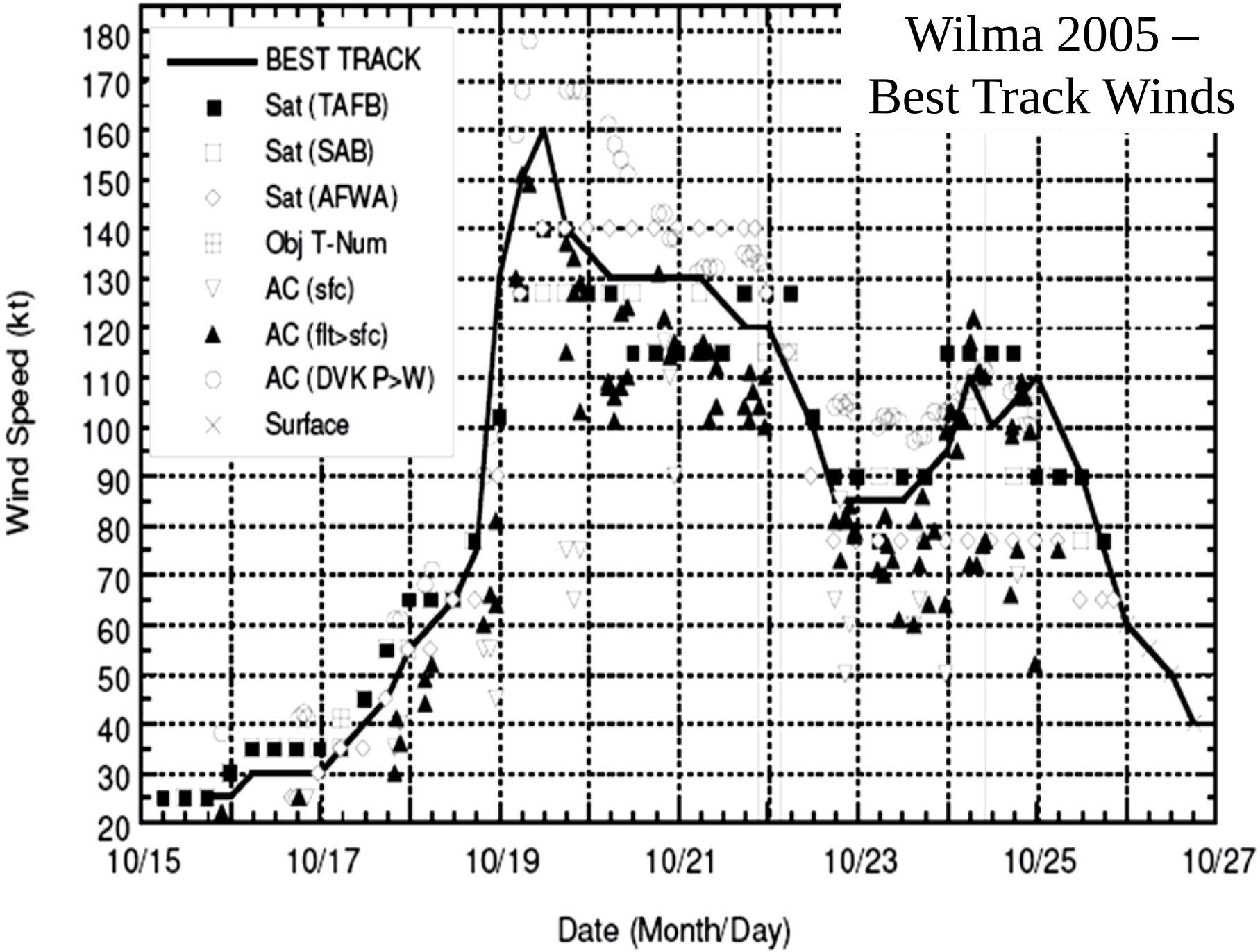
$BILLIONS Annually - Normalized



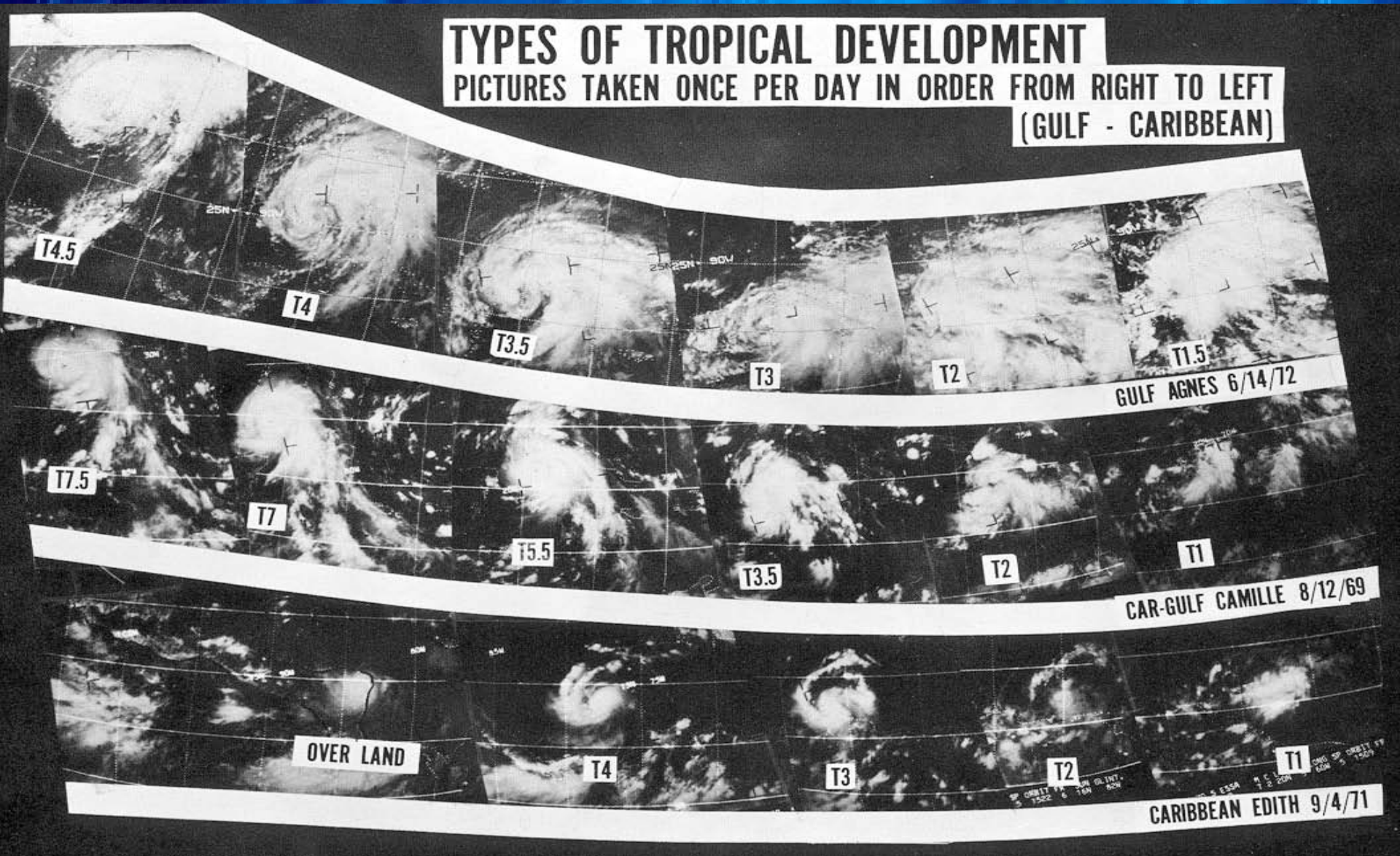
Historical data issues
Other Oceans

Hurricane Hunters – Only in the Atlantic

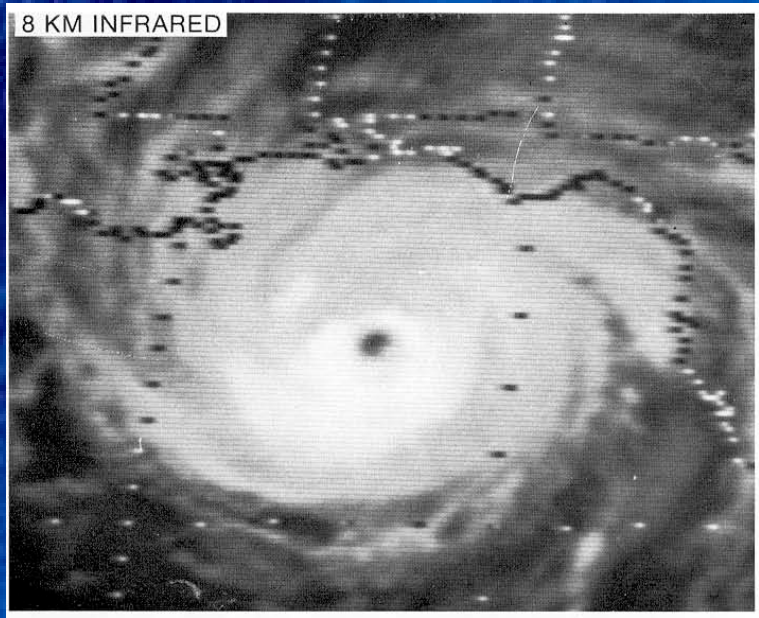
Wilma 2005 – Best Track Winds

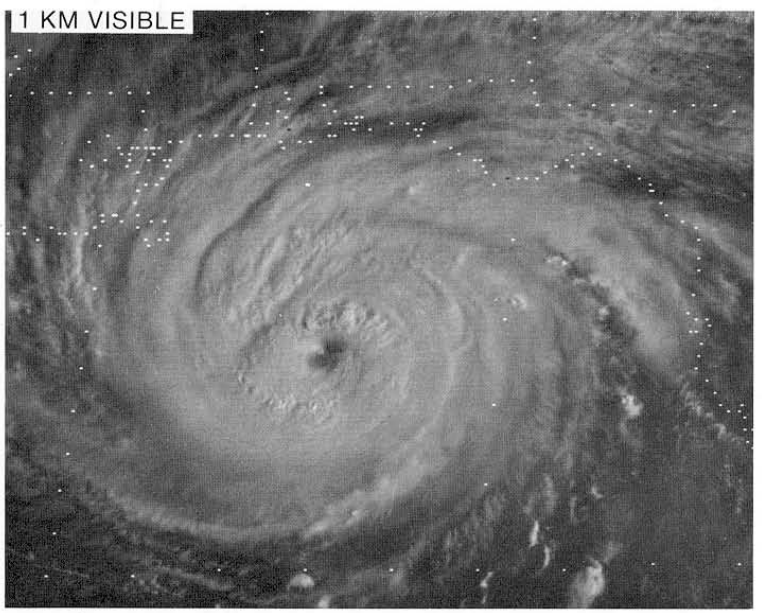


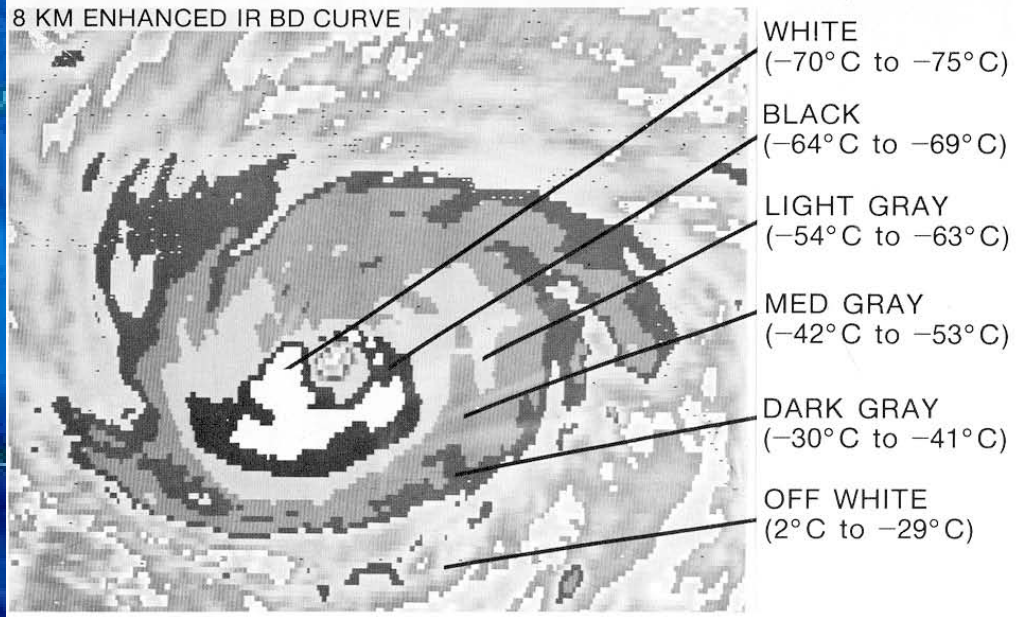
The Dvorak Technique (1972)



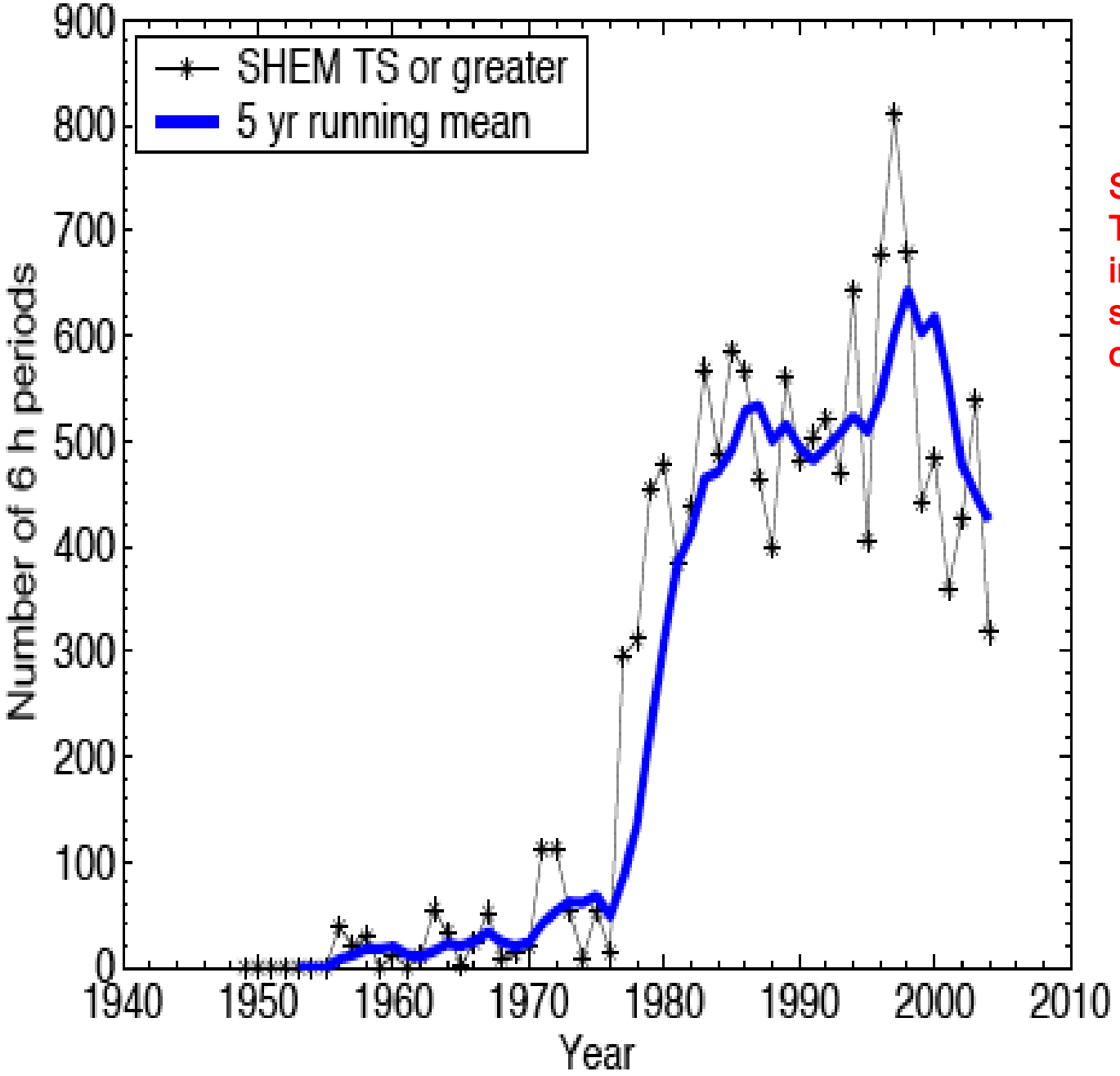
Infrared Version of Dvorak (1984)





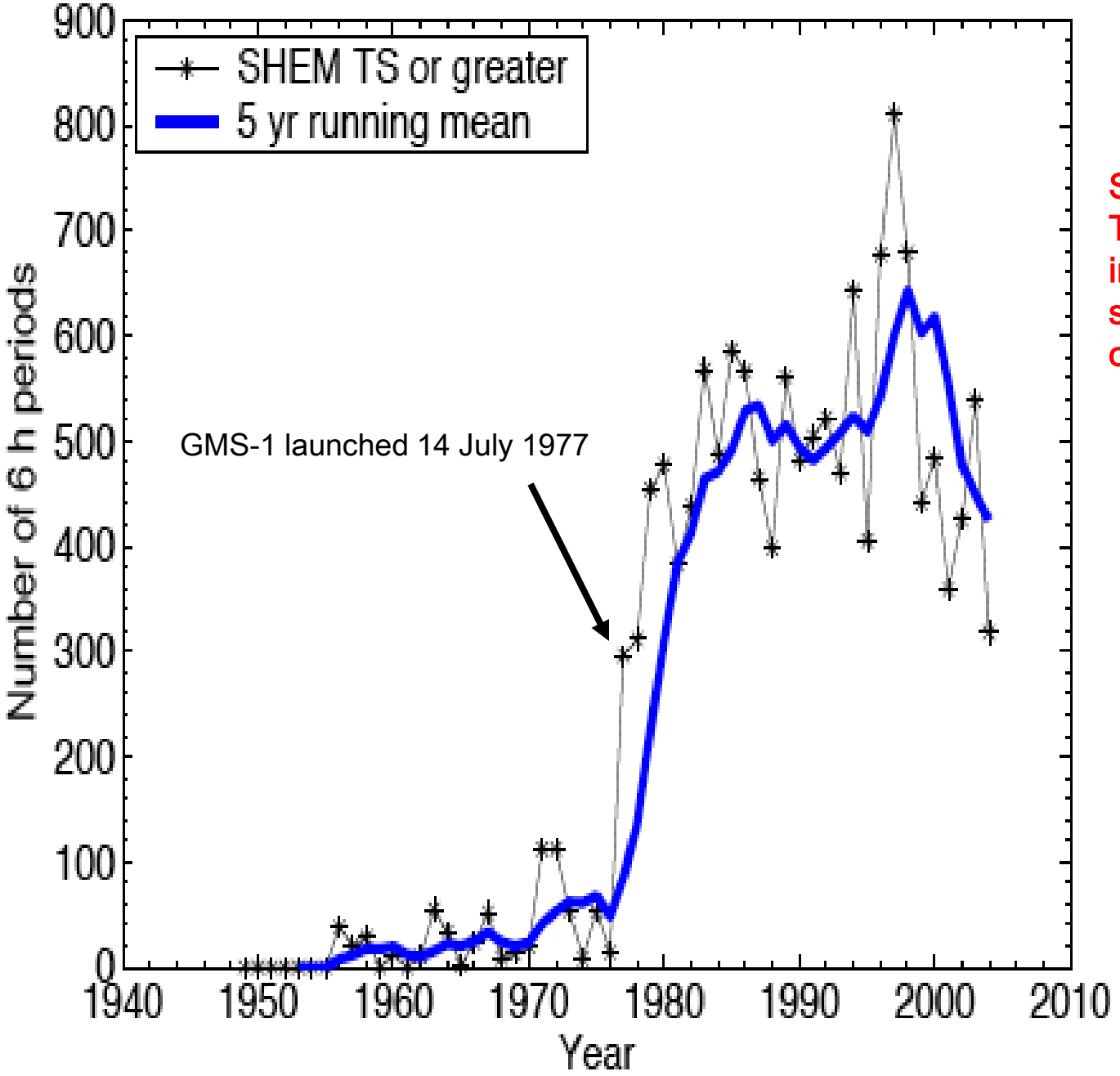


TROPICAL CYCLONE ANALYSIS
SATELLITE DATA
COMPARISON EXERCISE
HURRICANE FREDERIC
1331 GMT 12 September 1979



Simple example of Best Track inconsistencies introducing a potentially spurious trend in measure of TS-days

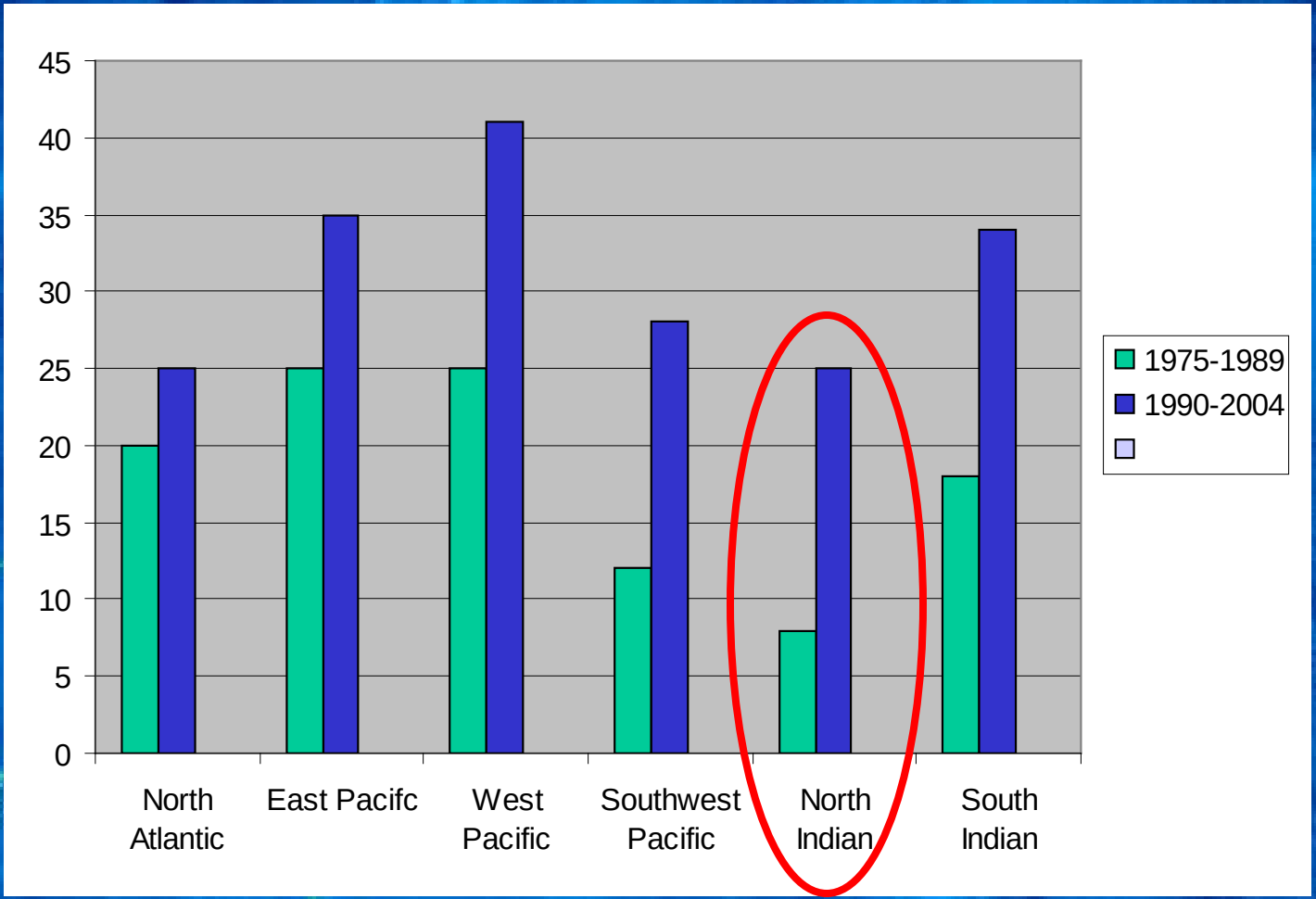
Kossin, et al. (2007)



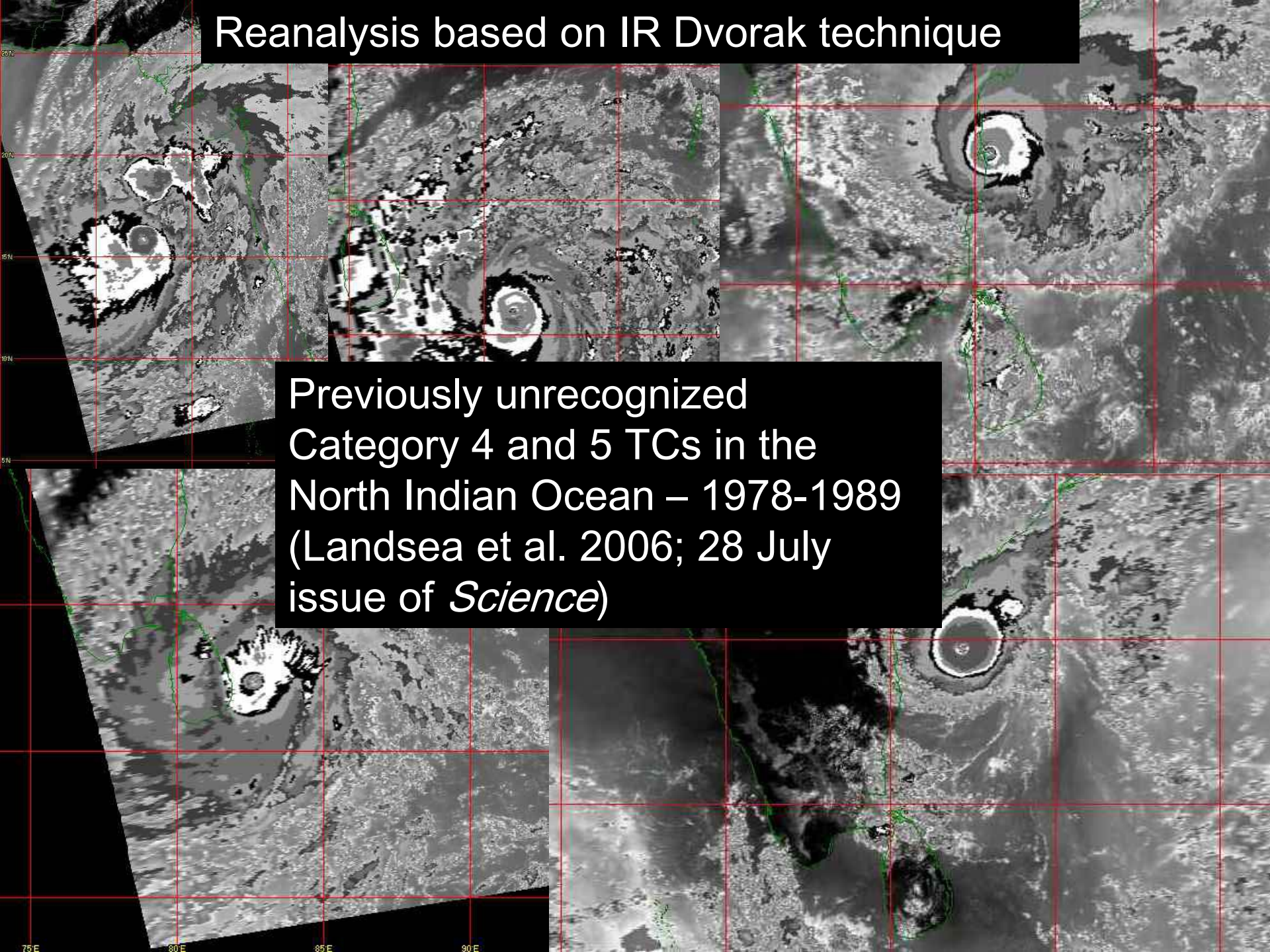
Simple example of Best Track inconsistencies introducing a potentially spurious trend in measure of TS-days

Kossin, et al. (2007)

Webster et al.: The percentage of hurricanes which reach Category 4-5 has increased in all basins, comparing two recent 15-year periods…



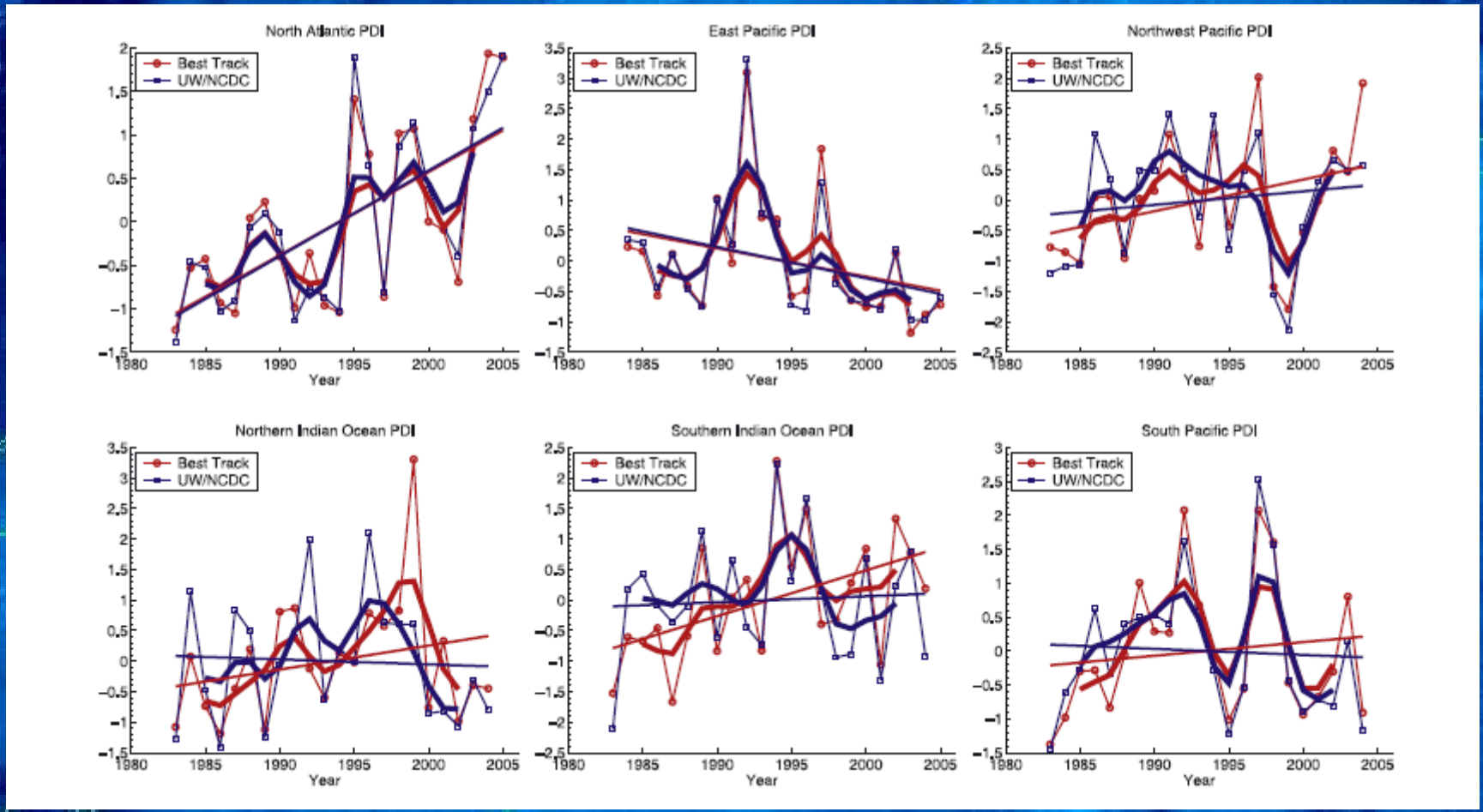
Source: Adapted from Webster et al., *Science,* Sept. 2005.


Reanalysis based on IR Dvorak technique
Previously unrecognized Category 4 and 5 TCs in the North Indian Ocean – 1978-1989 (Landsea et al. 2006; 28 July issue of *Science*)

Landsea 2006, 2007 concludes:

- The increase of tropical cyclone counts is due to improved monitoring techniques
- Many short-term and open ocean tropical cyclones would have been missed
- Category 3, 4, and 5 hurricanes are more readily identified
- In addition to improved satellite coverage and resolution, new technologies (such as Quikscat) and techniques (phase space analysis) identifies tropical cyclones that would have been dismissed as extratropical (Ana 2003, Otto 2004, unnamed subtropical storm of 2005, unnamed tropical storm of 2006)
- Former NHC directors Neil Frank and Bob Sheets have also stated that more tropical systems are being named than in the past.

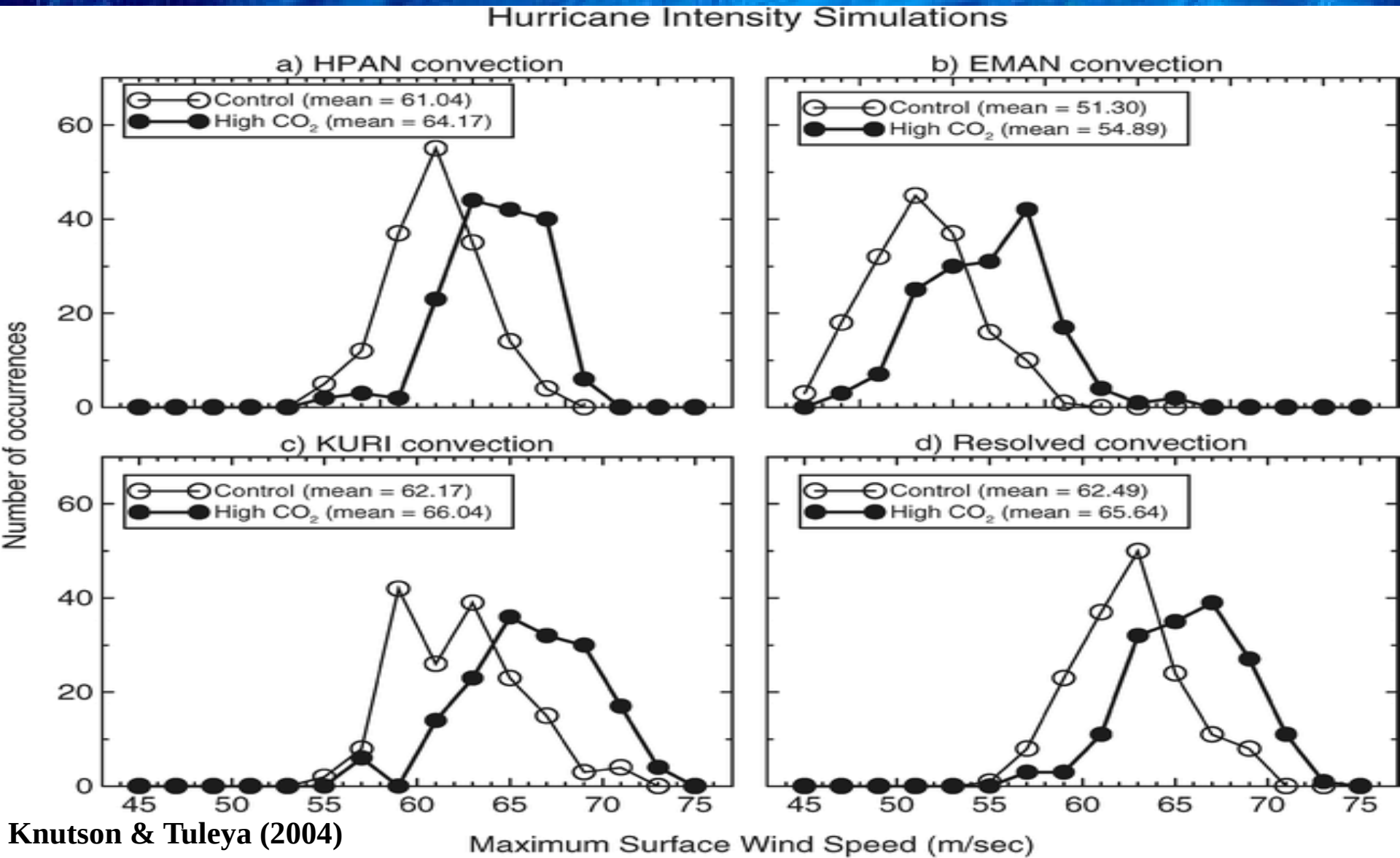
Kossin et al. 2007: A global intensity reanalysis using geostationary satellites based on EOFs of tropical cyclone eye, eyewall, and size features (*Geo. Res. Letters*)



Increase of PDI in N. Atlantic due to increased lifetime and frequency, not increase in intensity.
Increase of PDI in W. Pacific due to increase of intensity (Wu et al. 2007).

If global warming is real, how could hurricane activity be affected in the future?

Global Warming and Hurricane Winds:
Theory and Modeling Work Suggest 5% increase by late 21st Century



Knutson & Tuleya (2004)

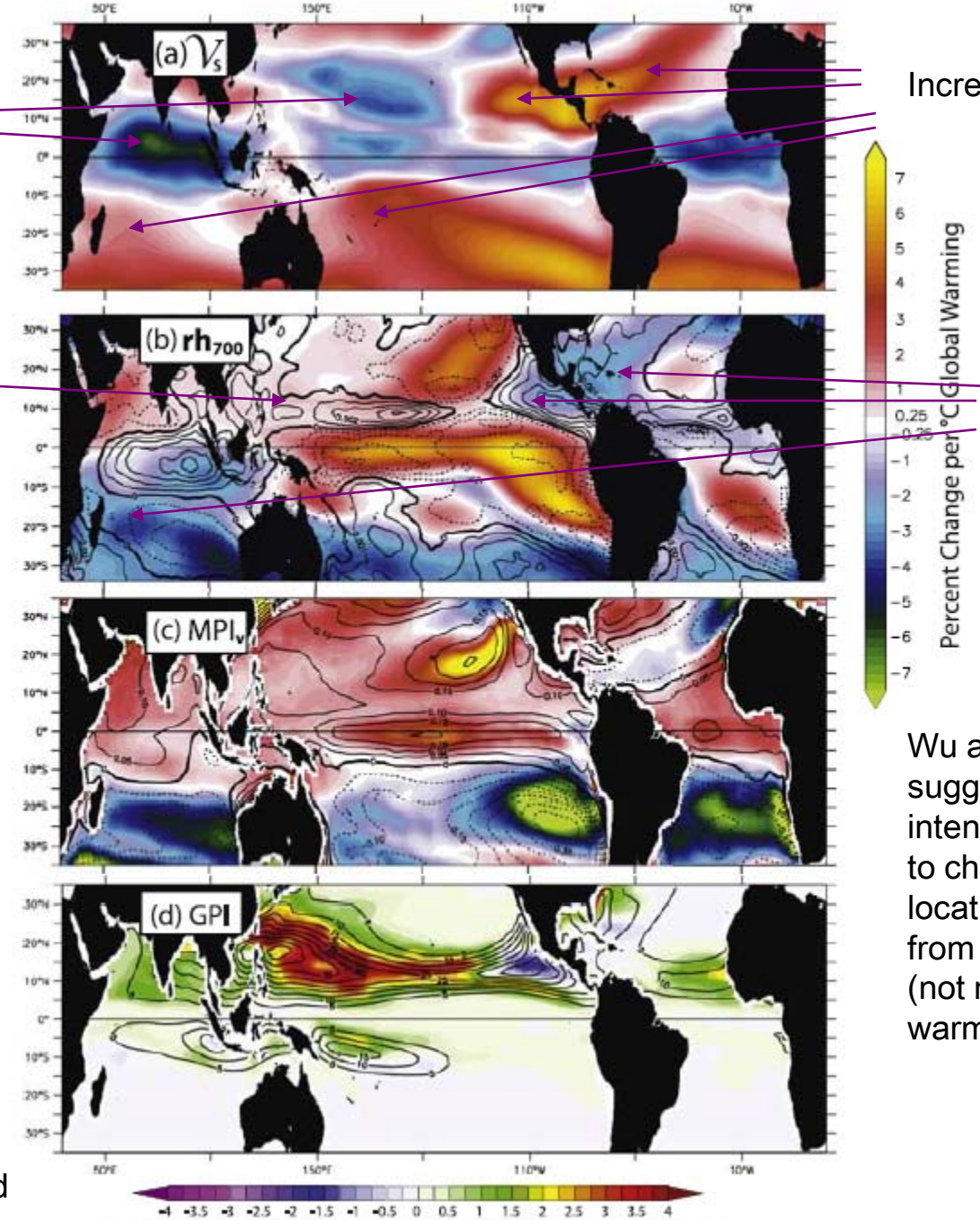
Ensemble of 18 global climate models (Vecchi and Soden 2007)

Less shear

Increased shear

Increased moisture

Drier



These results suggest the West Pacific would see an increase, while most areas would have a decrease.

Stowasser, Wang, and Hamilton (2007) reach same conclusions

Moral: SST not directly correlated to hurricane activity. All factors need

Wu and Wang (2007) also suggest recent changes in intense hurricanes are due to changes in formation locations and track changes from environmental factors (not necessarily global warming).

Yikes! Lots of conflicting information!

Has an impartial group of scientists tried to reach a consensus?

Fortunately, yes.

Statement on Tropical Cyclones and Climate Change

WMO International Workshop on Tropical Cyclones – Nov/Dec 2006

1. Though there is evidence both for and against the existence of a detectable anthropogenic signal in the tropical cyclone climate record to date, no firm conclusion can be made on this point.
2. No individual tropical cyclone can be directly attributed to climate change.
3. The recent increase in societal impact from tropical cyclones has largely been caused by rising concentrations of population and infrastructure in coastal regions.
4. Tropical cyclone wind-speed monitoring has changed dramatically over the last few decades, leading to difficulties in determining accurate trends.
5. There is an observed multi-decadal variability of tropical cyclones in some regions whose causes, whether natural, anthropogenic or a combination, are currently being debated. This variability makes detecting any long-term trends in tropical cyclone activity difficult.
6. It is likely that some increase in tropical cyclone peak wind-speed and rainfall will occur if the climate continues to warm. Model studies and theory project a 3-5% increase in wind-speed per degree Celsius increase of tropical sea surface temperatures.
7. There is an inconsistency between the small changes in wind-speed projected by theory and modeling versus large changes reported by some observational studies.
8. Although recent climate model simulations project a decrease or no change in global tropical cyclone numbers in a warmer climate, there is low confidence in this projection. In addition, it is unknown how tropical cyclone tracks or areas of impact will change in the future.
9. Large regional variations exist in methods used to monitor tropical cyclones. Also, most regions have no measurements by instrumented aircraft. These significant limitations will continue to make detection of trends difficult.
10. If the projected rise in sea level due to global warming occurs, then the vulnerability to tropical cyclone storm surge flooding would increase.

It should be noted that the IPCC has issued a stronger statement that hurricane intensity has already increased due to global warming.

Holland and Webster (2007) conclude ("with confidence"), however

The recent upsurge in…frequency… is due in part to global warming and this is most likely the dominant effect. Earlier variations, such as the sharp increase in the 1930's, wer also probably impacted by greenhouse warming.

We have noted with some concern the contradictory conclusions…..which describe the data as being of high quality sufficient to determine "natural variability" ….but…. insufficient ….to determine trends.

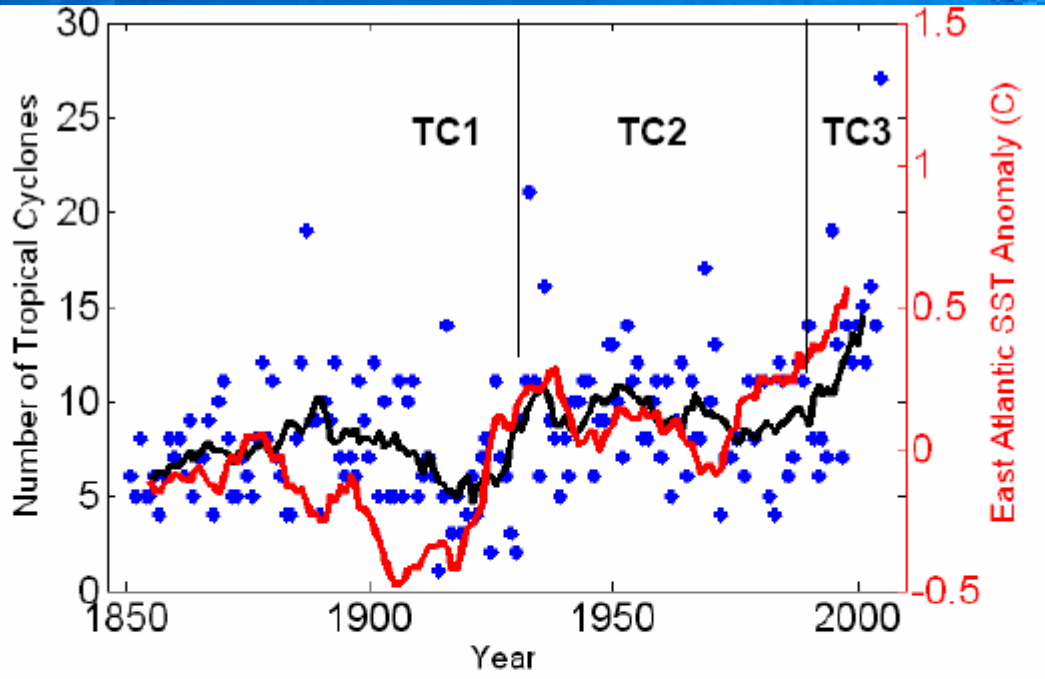


Figure 1. Tropical cyclone occurrence (blue points indicate annual totals and the black line is a 9-y running mean) in the North Atlantic together with East Atlantic SST anomalies for the hurricane season (red line) from 1855-2005. TC1, 2 and 3 refer to climate regimes discussed in the text.