

2005

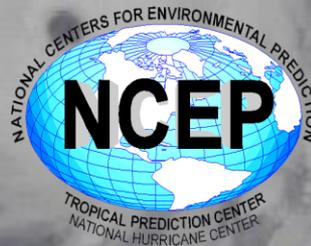
# Hurricanes and Global Warming: What Does the Data Tell Us?

16 May, 2008

Florida Governor's Hurricane Conference

Chris Landsea

National Hurricane Center, Miami



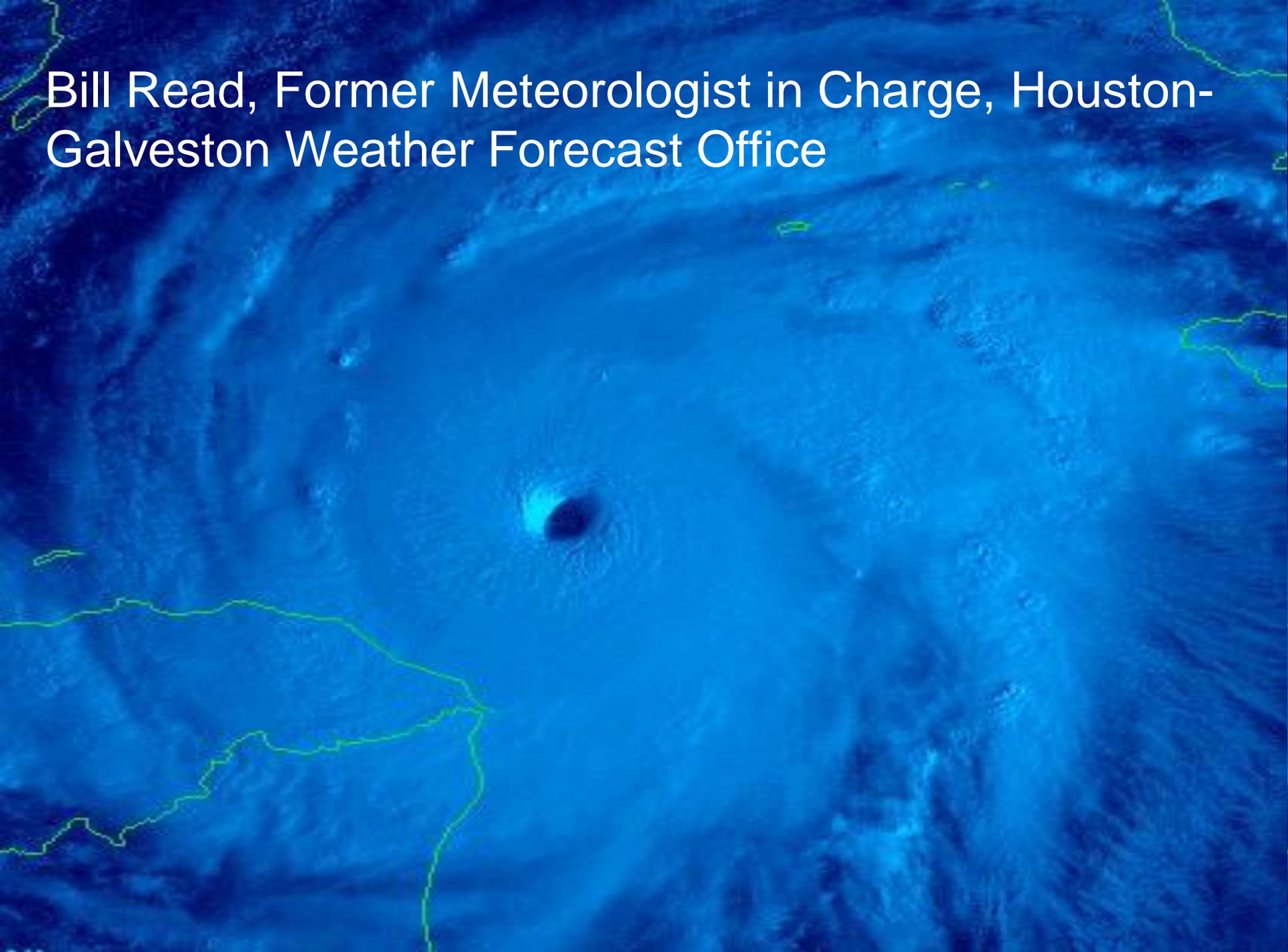
Rita  
23 September

Bertha  
10 July

Katrina  
28 August

Wilma  
21 October

Bill Read, Former Meteorologist in Charge, Houston-Galveston Weather Forecast Office



# Hurricanes and Man-made Climate Change: 2004 Perspective

"This new millennium balances us on the edge of history. If we continue to ignore the issue of global warming, we will most certainly suffer the effects . . . [these] include climate changes that will cause more drastic typhoons, hurricanes and floods, plus the bleaching of coral reefs, the melting of polar ice caps, an increase in insect-borne tropical diseases and much, much more."

Is it **Al Gore?** **Ralph Nader?** **Rachel Carson?**

# Hurricanes and Man-made Climate Change: 2004 Perspective

## Leo goes eco

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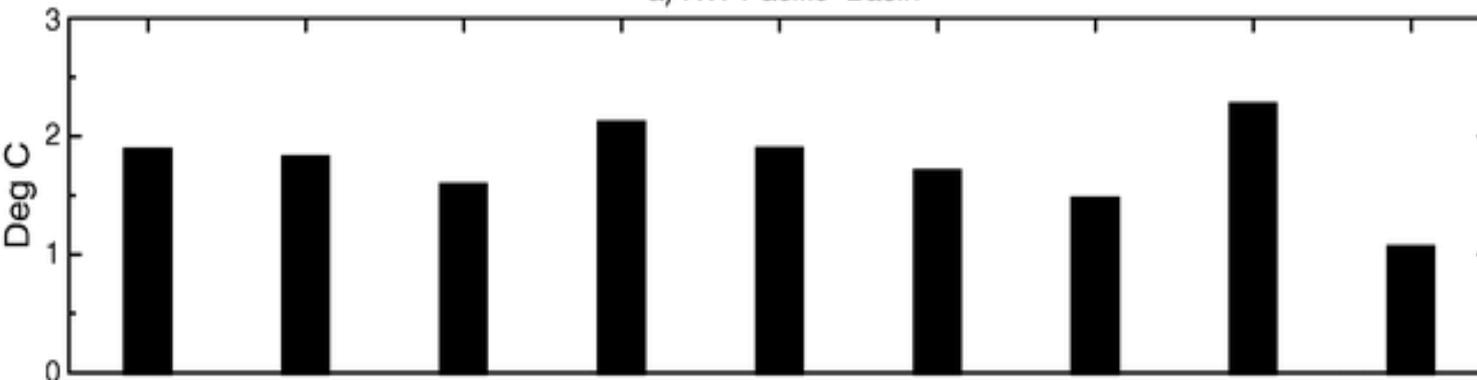


**DICAPRIO**

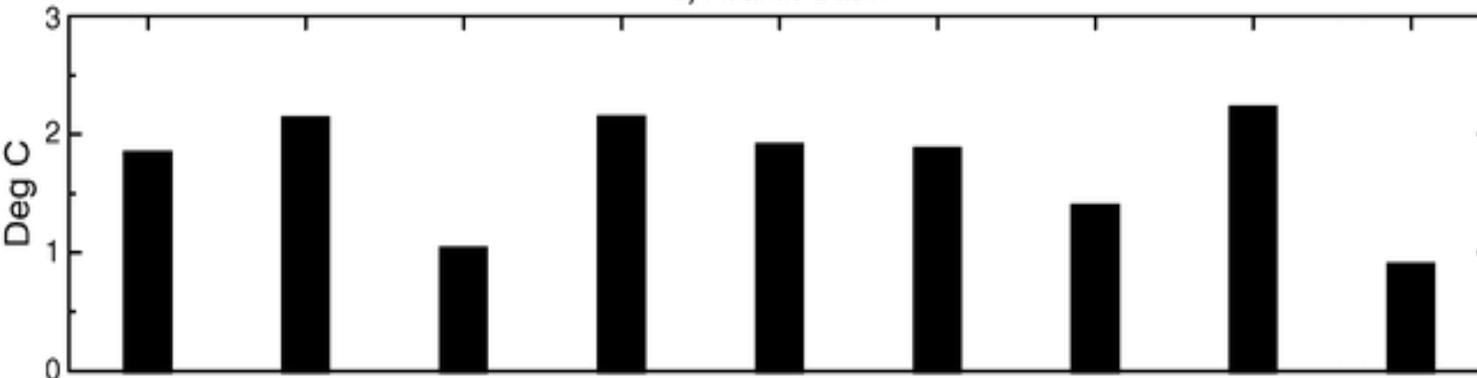
**nardo DiCaprio**, in an essay written for Time magazine, Young Leo is the honorary chairman of Earth Day 2000, and will host a rally in Washington, D.C., calling for clean energy.

# SST Change (High CO<sub>2</sub> - Control)

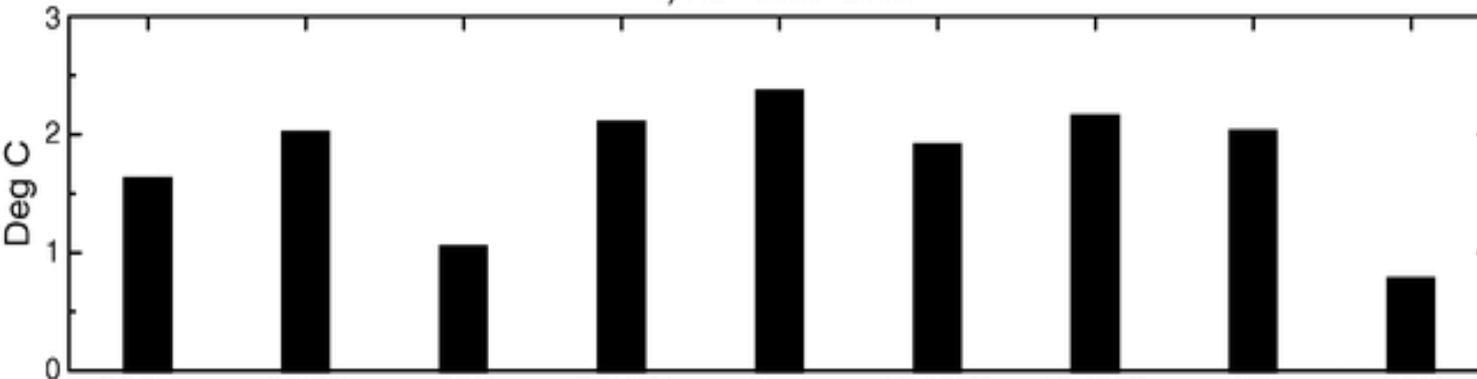
## a) NW Pacific Basin



## b) Atlantic Basin



## c) NE Pacific Basin

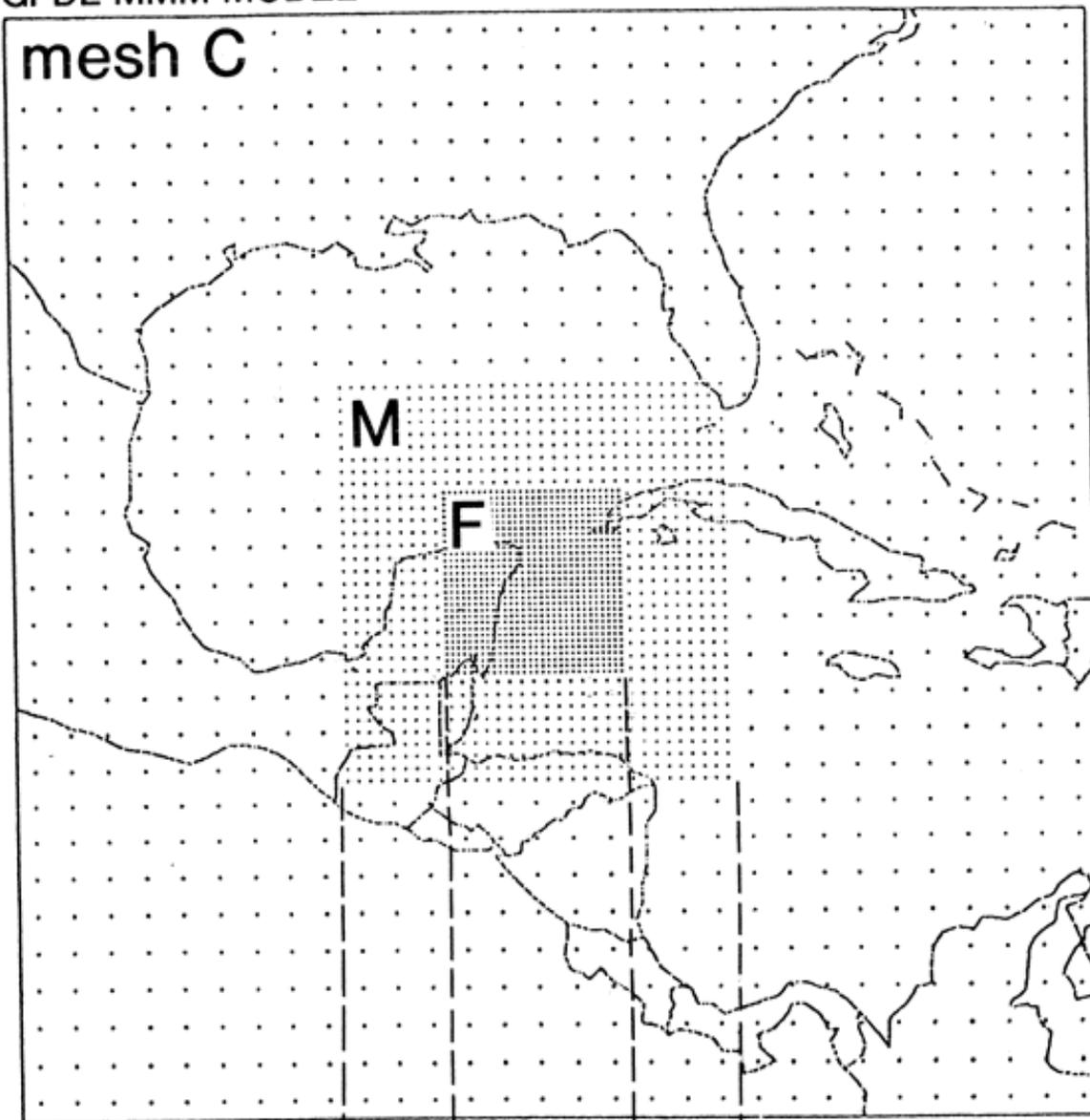


Global Model

SST changes  
2 x CO<sub>2</sub>

Knutson and  
Tuleya (2004)

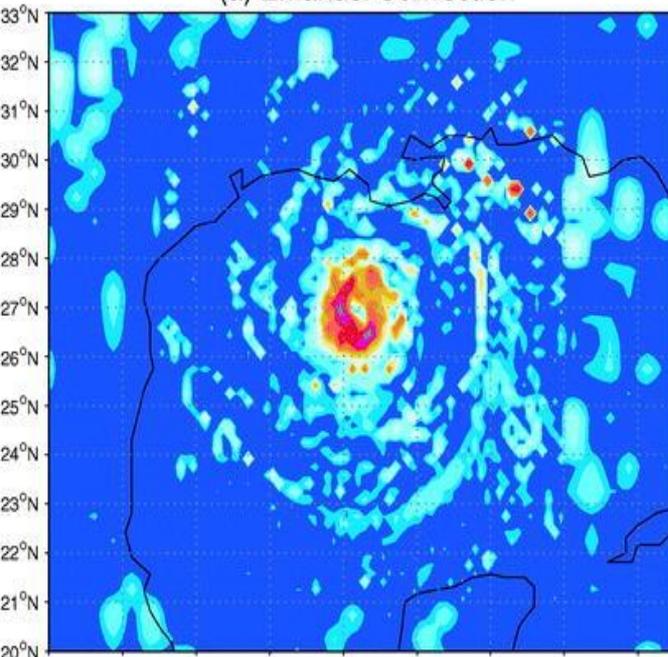
mesh C



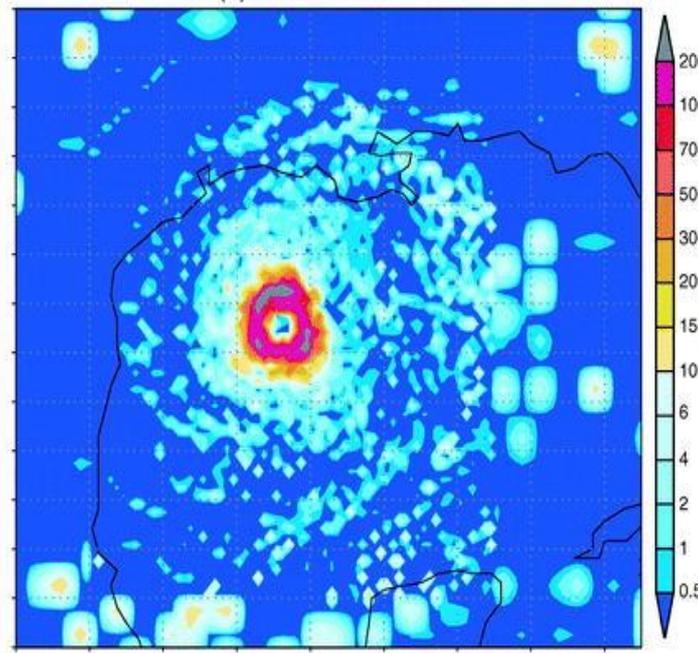
# Tropical Cyclone Intensity Changes from Global Warming – Use of Mesoscale Models

Knutson and Tuleya (2004)

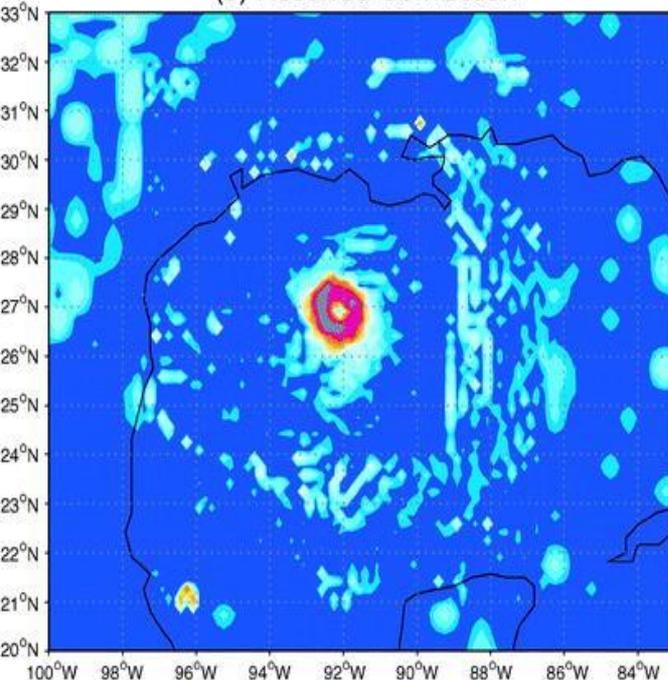
(a) Emanuel Convection



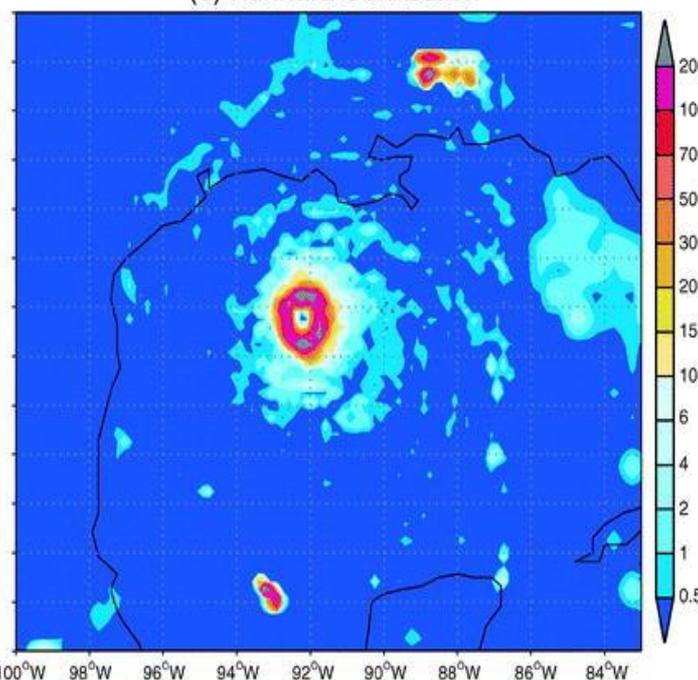
(c) Pan Convection



(b) Resolved Convection

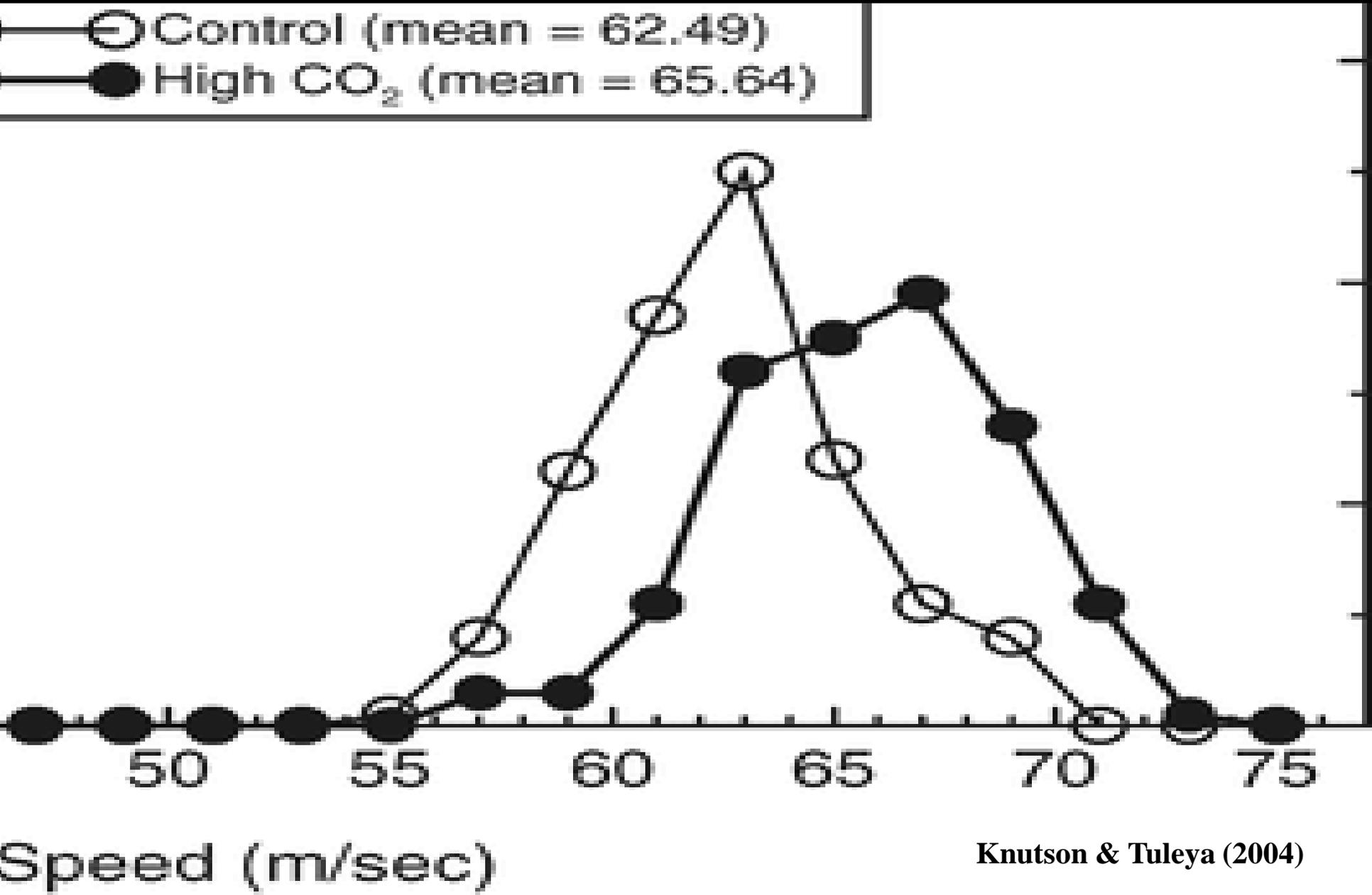


(d) Kurihara Convection



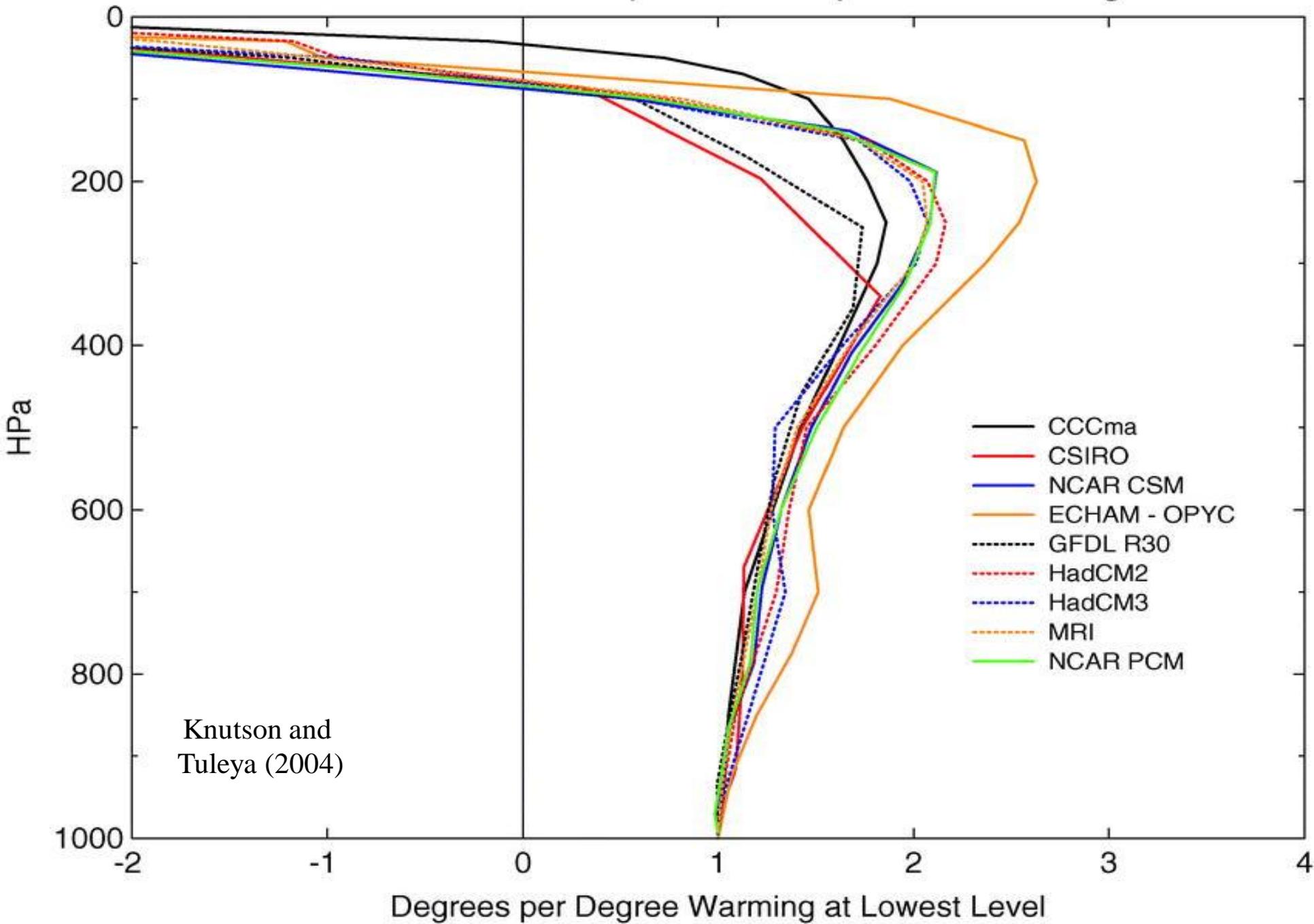
Comparison of  
4 convection  
schemes and  
9 coupled  
global models -  
Knutson and Tuleya (2004)

# Global Warming and Hurricane Winds: Theory and Modeling Work Suggest 5% increase by late 21<sup>st</sup> Century

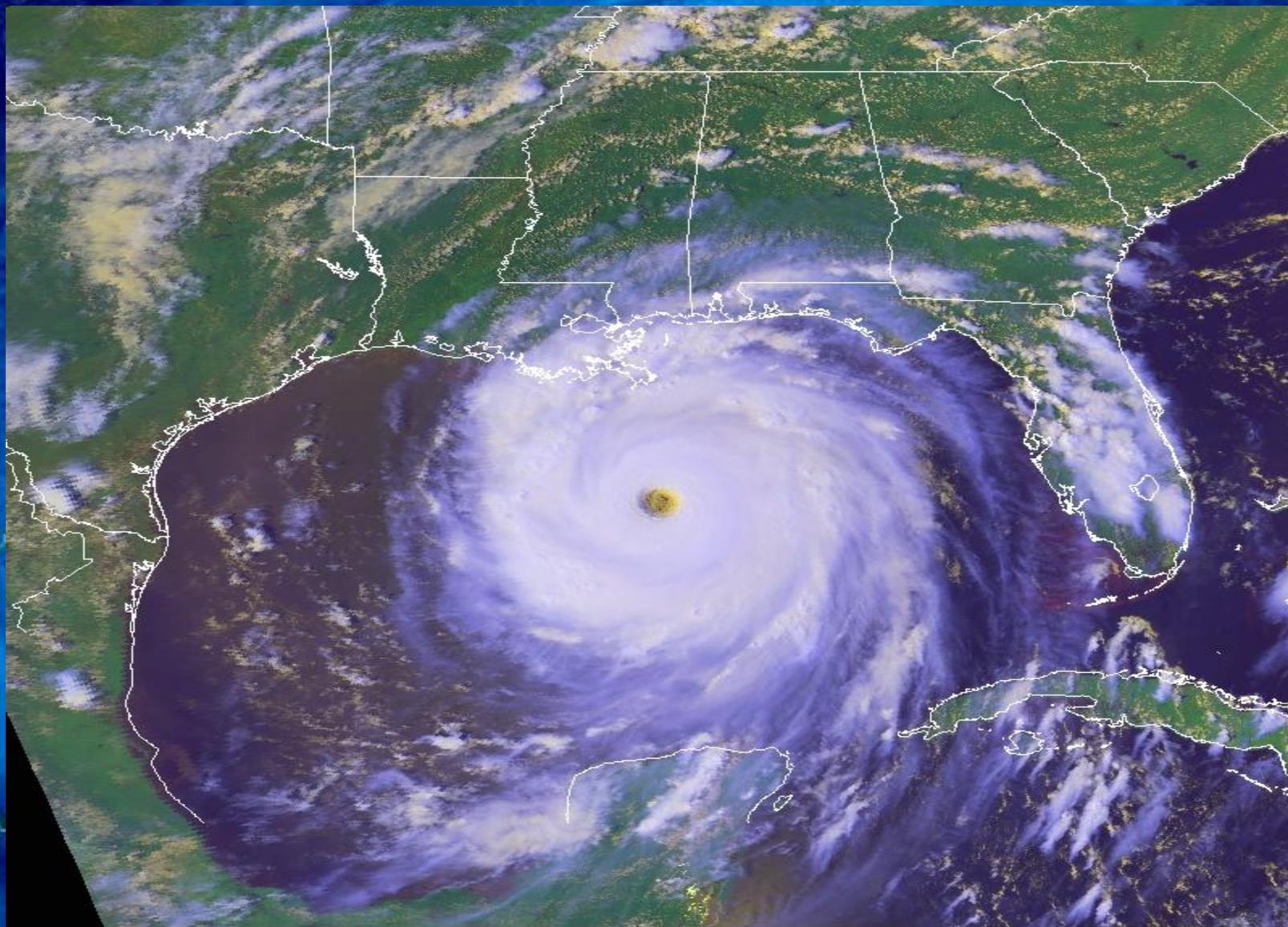


Knutson & Tuleya (2004)

# Normalized Atmospheric Temperature Change



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

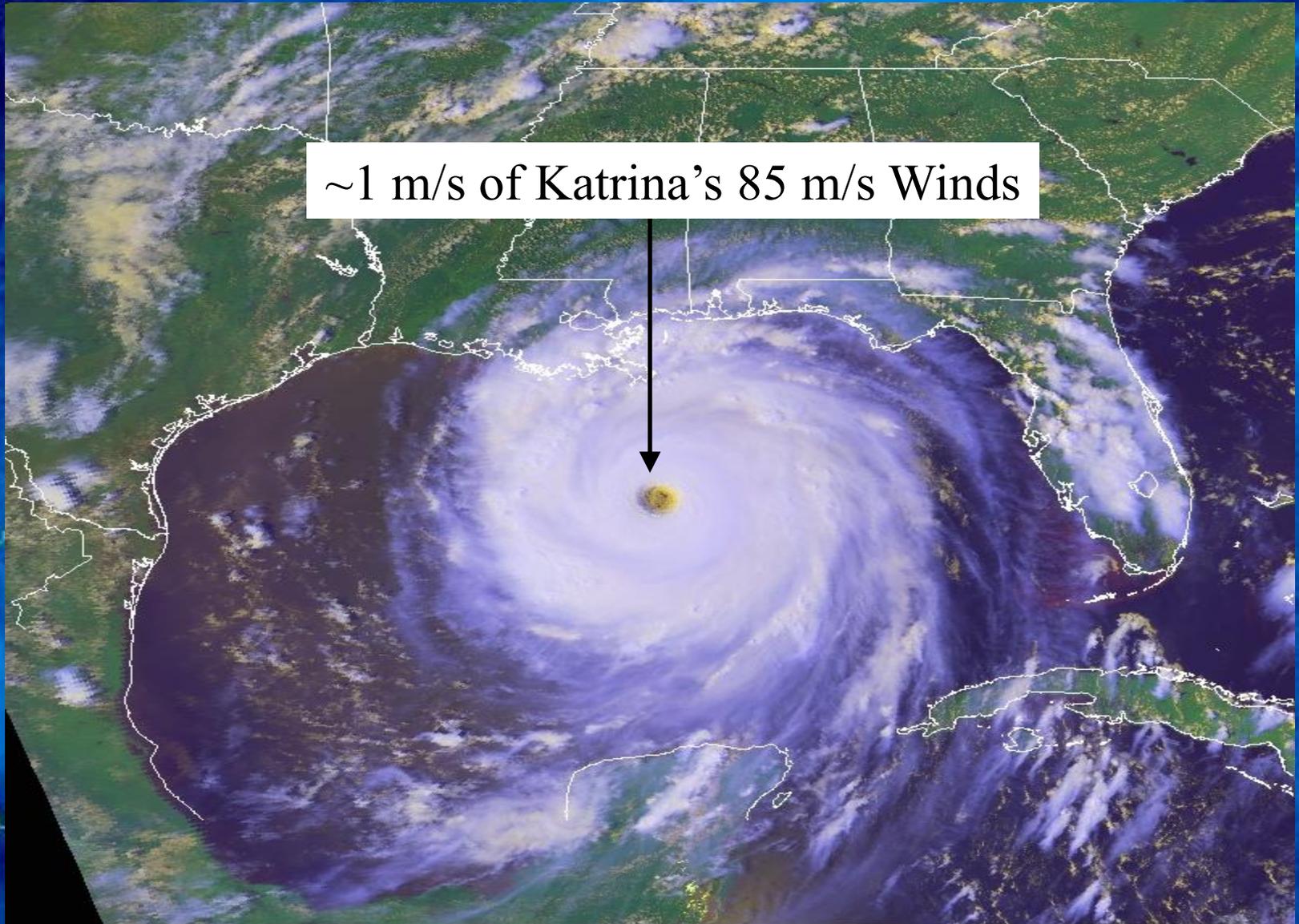


KATRINA NOAA-16 AVHRR 28 AUG 05 20:11 GMT  
UW-MADISON SPACE SCIENCE AND ENGINEERING CENTER

McIDAS

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

~1 m/s of Katrina's 85 m/s Winds

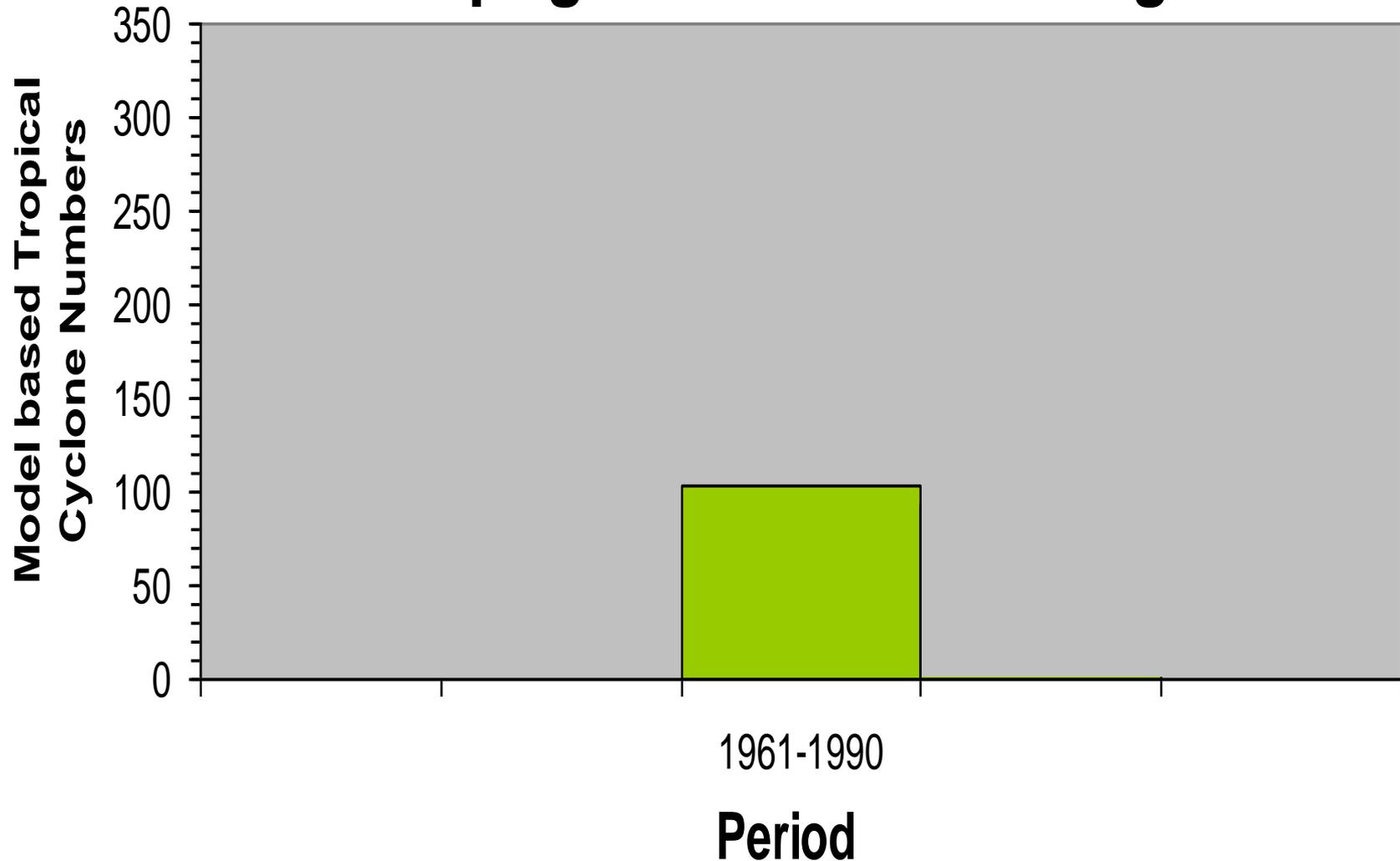


“An important issue is whether and when any CO<sub>2</sub>-induced increase of tropical cyclone intensity is likely to be detectable in the observations. The magnitude of the simulated increase in our experiments is about +6% for maximum tropical cyclone surface winds ... The SST changes observed for the past 50 yr in the Tropics imply that the likely SST-inferred intensity change for the past half century is small, relative to both the limited accuracy of historical records of storm intensity and to the apparently large magnitude of interannual variability of storm intensities in some basins. This further implies that **CO<sub>2</sub>-induced tropical cyclone intensity changes are unlikely to be detectable in historical observations and will probably not be detectable for decades to come.**”

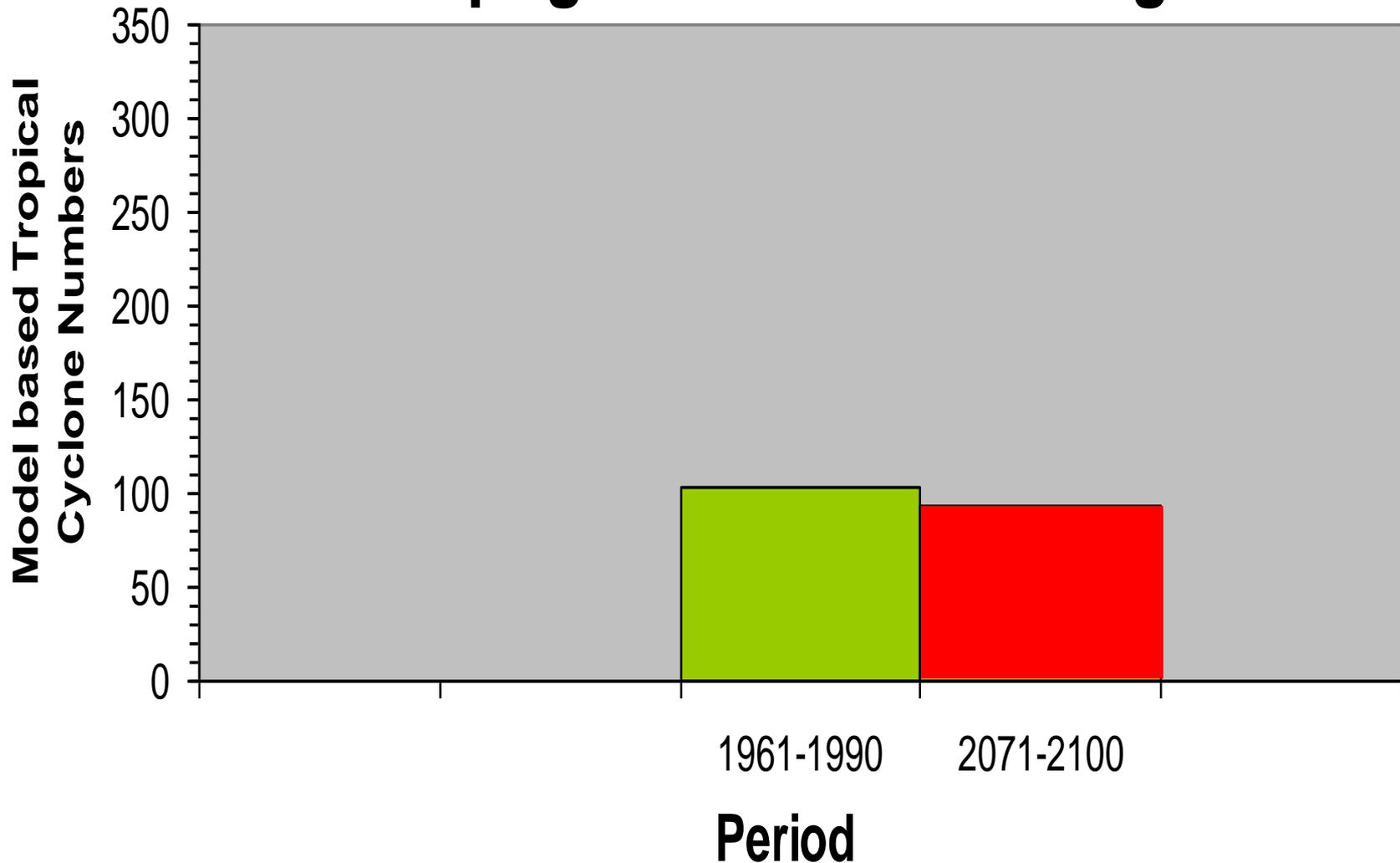
--- Knutson and Tuleya (2004)



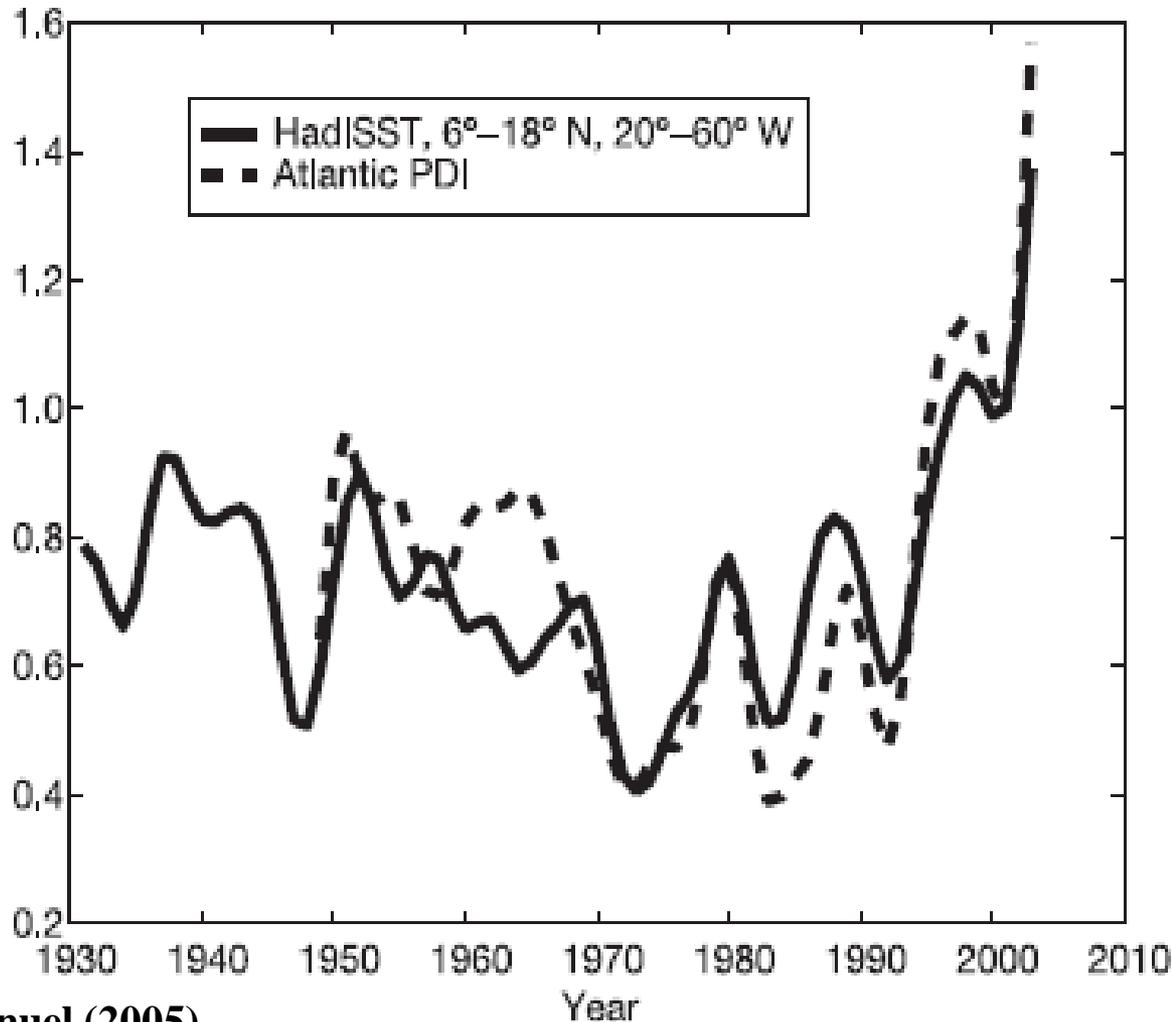
# Frequency of Tropical Cyclones Due to Anthropogenic Climate Change



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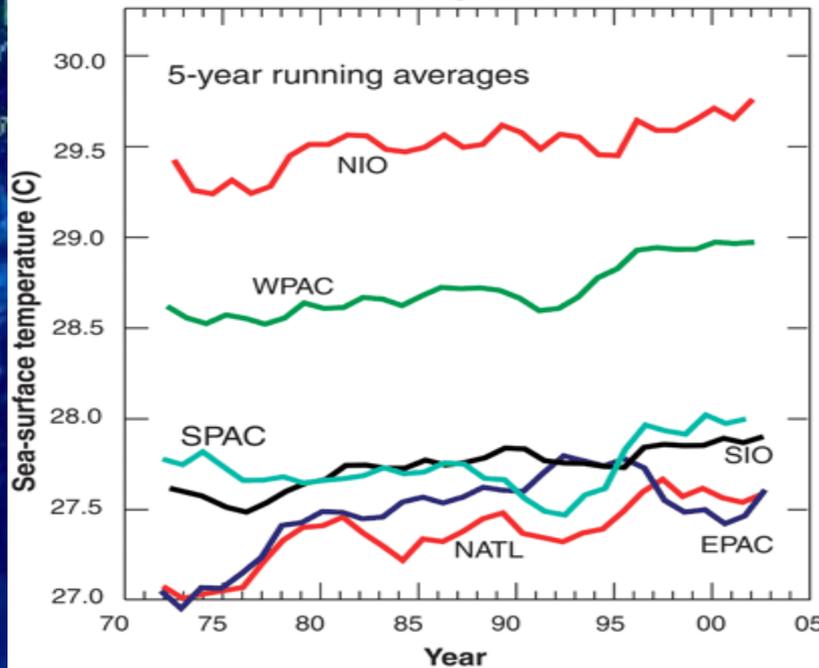


# Emanuel's study: Doubling in Atlantic Hurricane Wind Index – “Unprecedented”

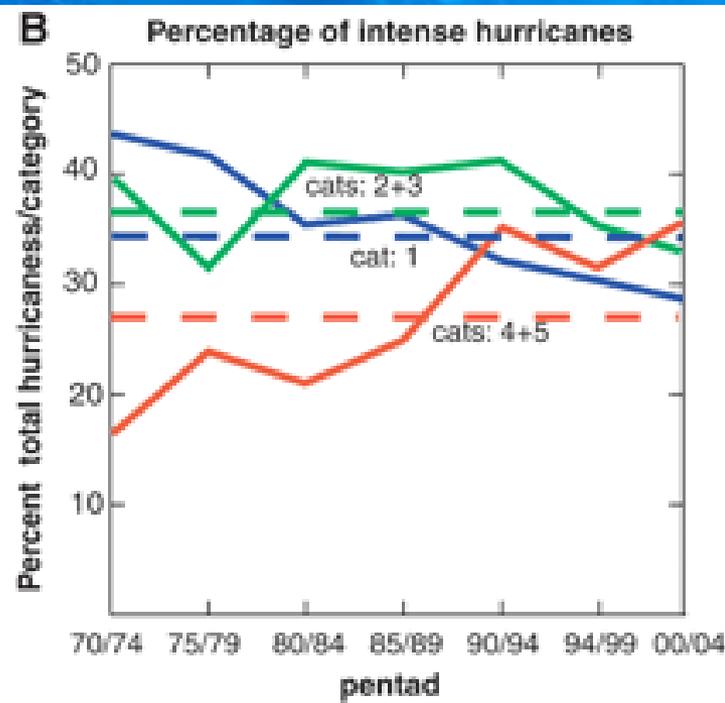
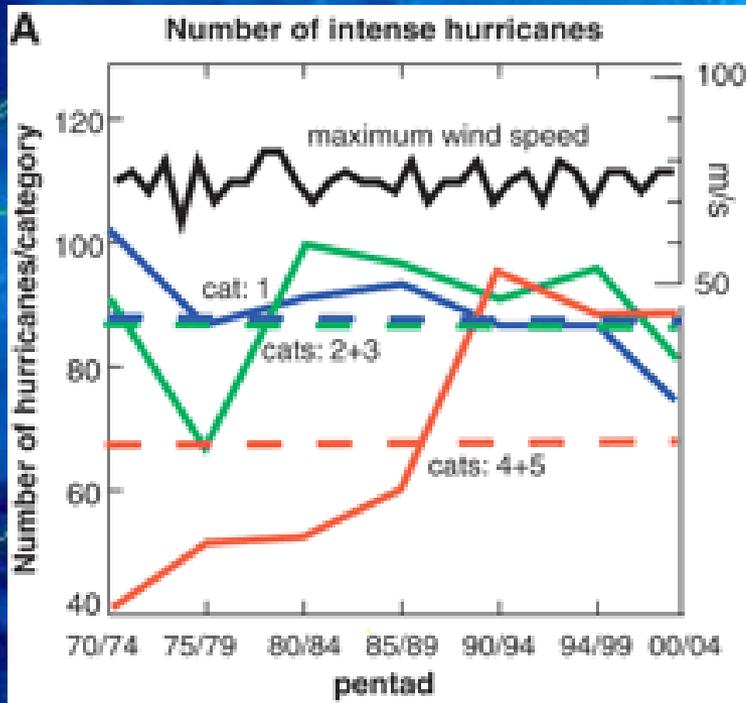


PDI = Power  
Dissipation  
Index (winds  
cubed &  
summed for  
season)

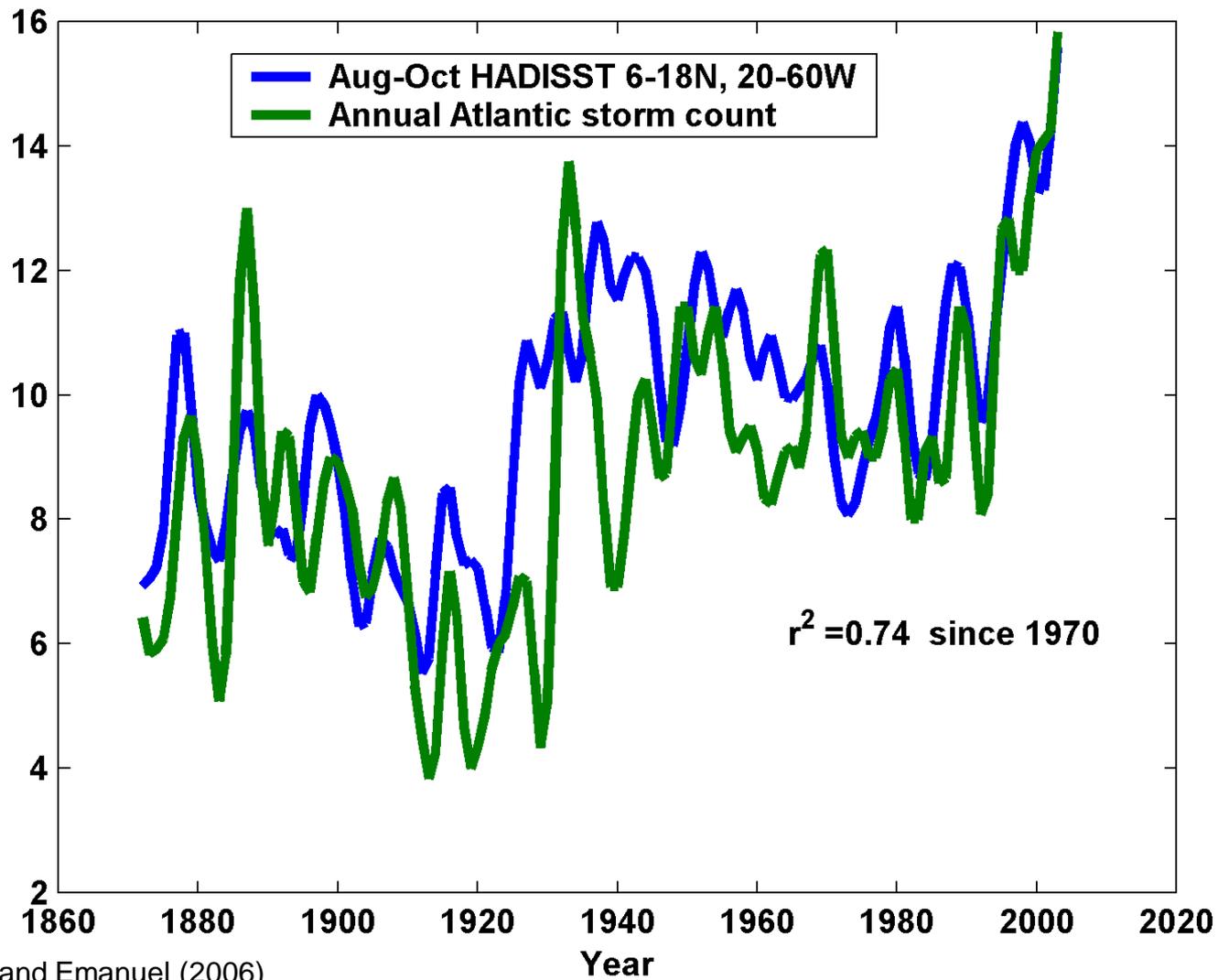
Summer SST by Ocean Basin



“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.” (Authors’ Webpage)



# Linking frequency of Atlantic tropical cyclones to SSTs



Mann and Emanuel (2006)

# Was Leo Right???

## Leo goes eco

"This new millennium balances us on the edge of history. If we continue to ignore the issue of global warming, we will most certainly suffer the effects . . . [these] include climate changes that will cause more drastic typhoons, hurricanes and floods, plus the bleaching of coral reefs, the melting of polar ice caps, an increase in insect-borne tropical diseases and much, much more."

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**DICAPRIO**

**nardo DiCaprio**, in an essay written for Time magazine. Young Leo is the honorary chairman of Earth Day 2000, and will host a rally in Washington, D.C., calling for clean energy.

# 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.

# Effects of Anthropogenic Global Warming On Tropical Cyclones Around 2100

Frequency? 0 to -10%

Maximum intensity? +5%

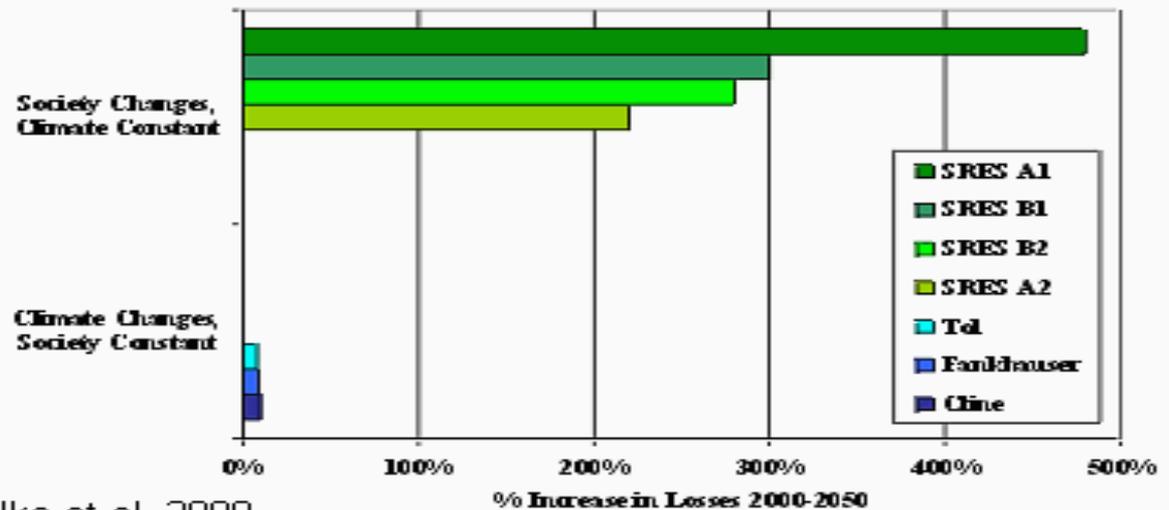
Average intensity? +5%

Rainfall? +5 to +15%

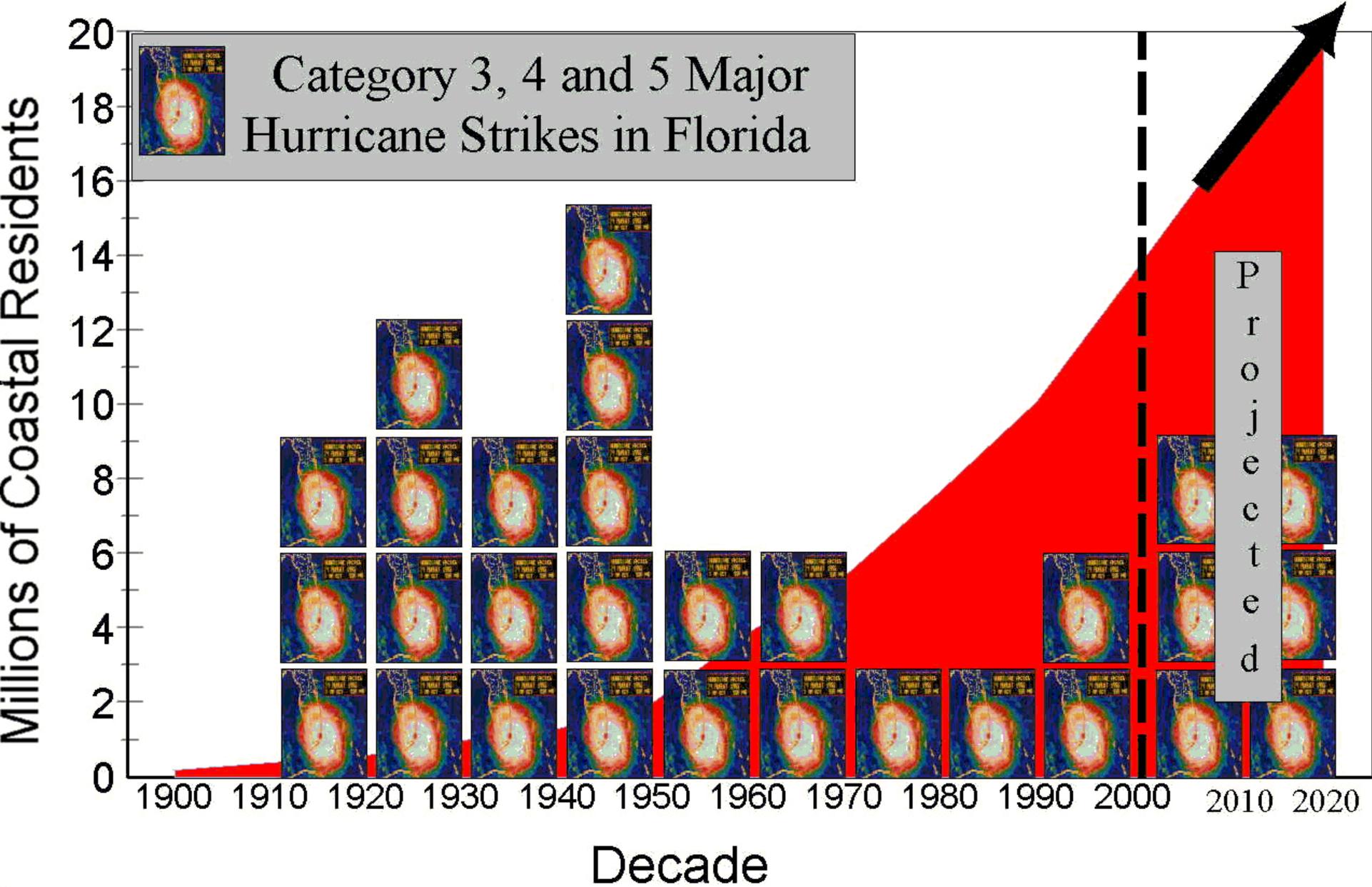
Area of formation/occurrence? No change

However,  
tropical cyclone  
impacts will  
continue to  
dramatically  
increase...

Sensitivity Analysis of 2XCO<sub>2</sub> Worldwide Global Tropical  
Cyclone Loss Estimates for 2050

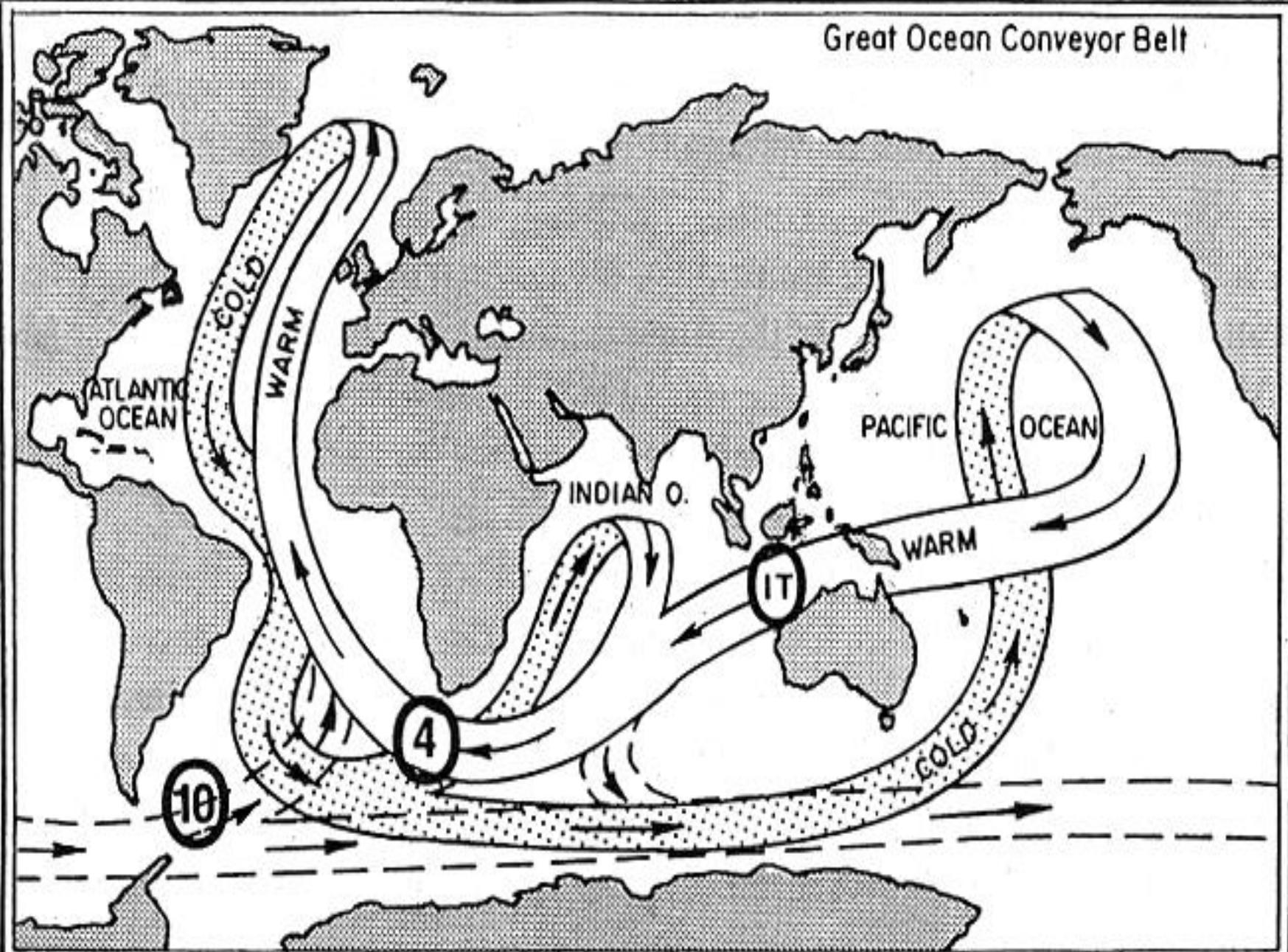


# Florida Population and Major Hurricanes

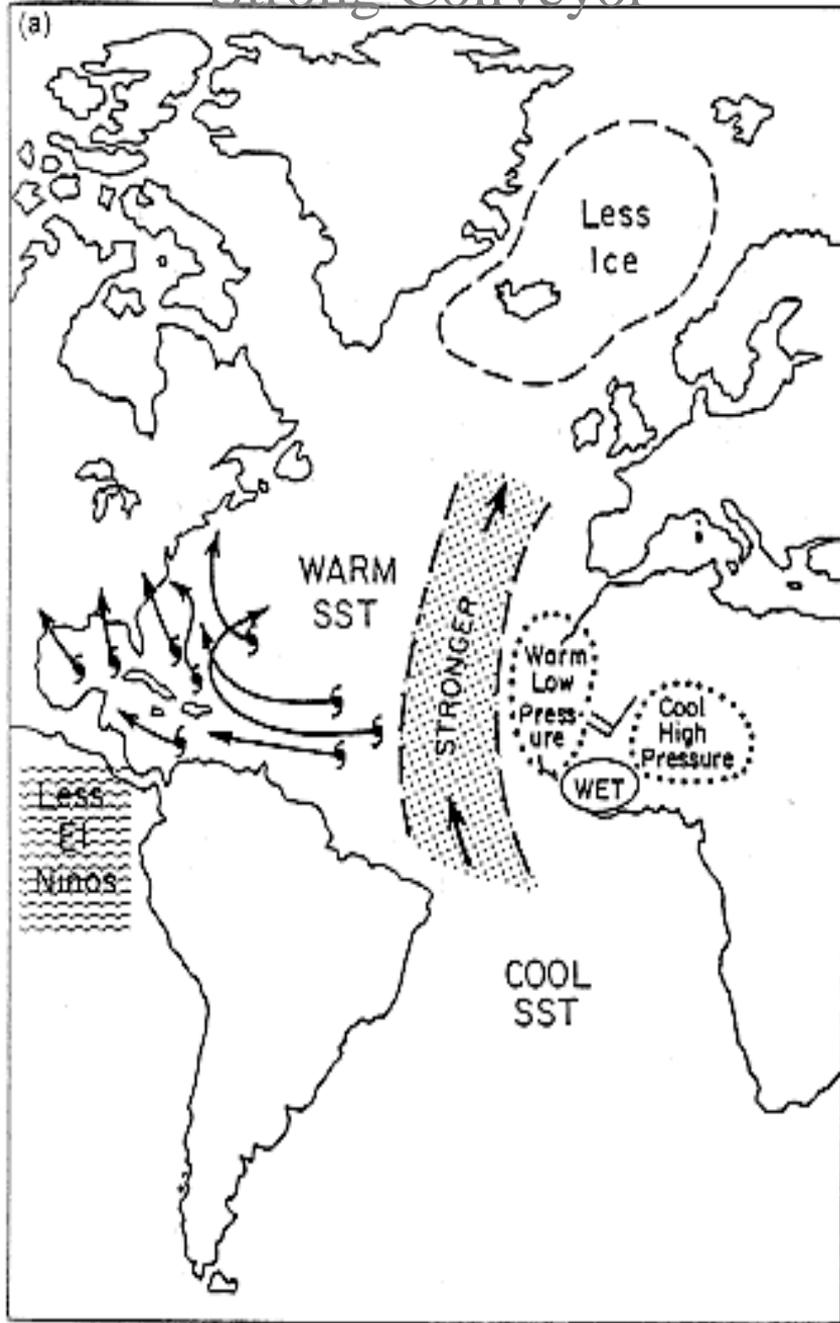




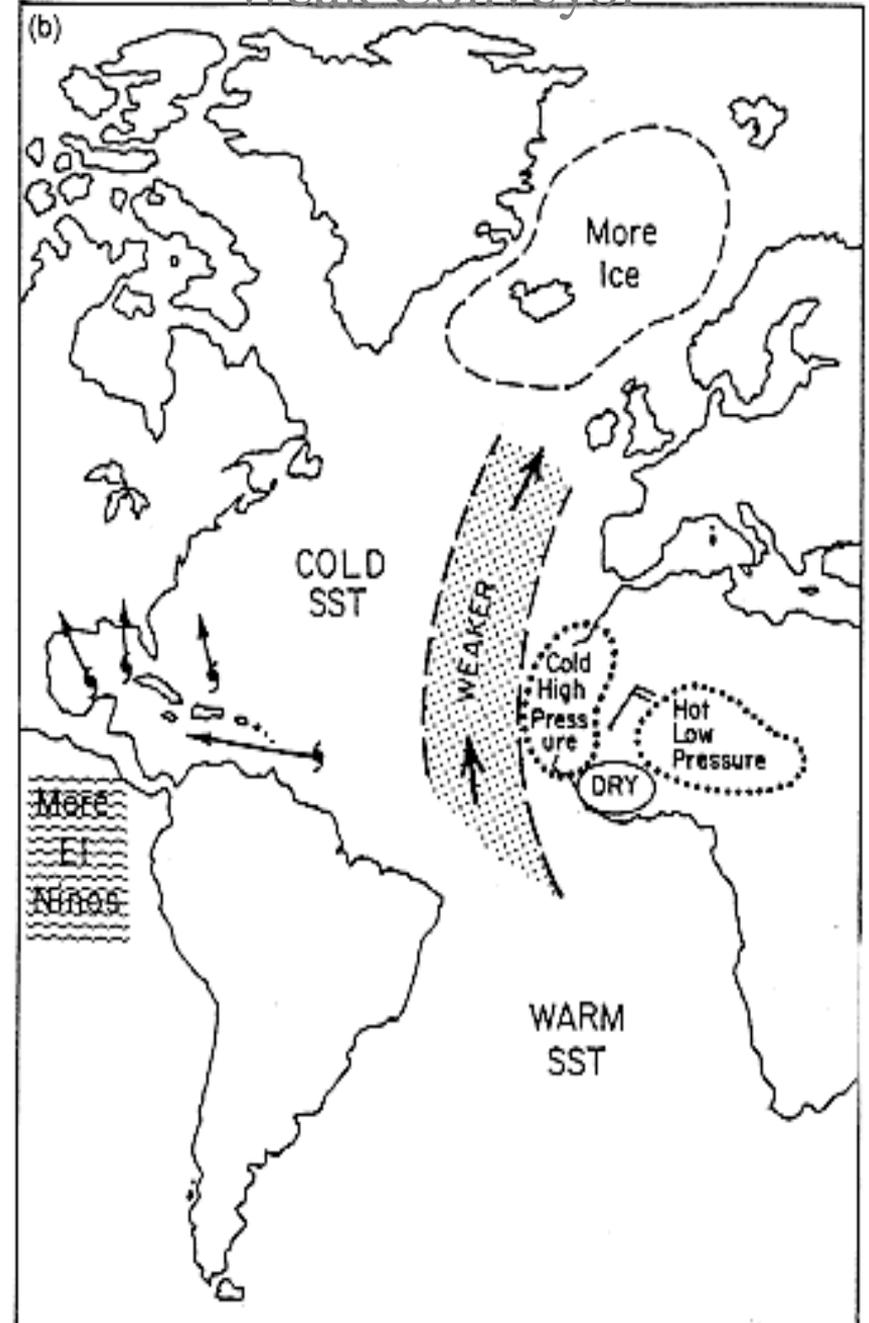
Great Ocean Conveyor Belt



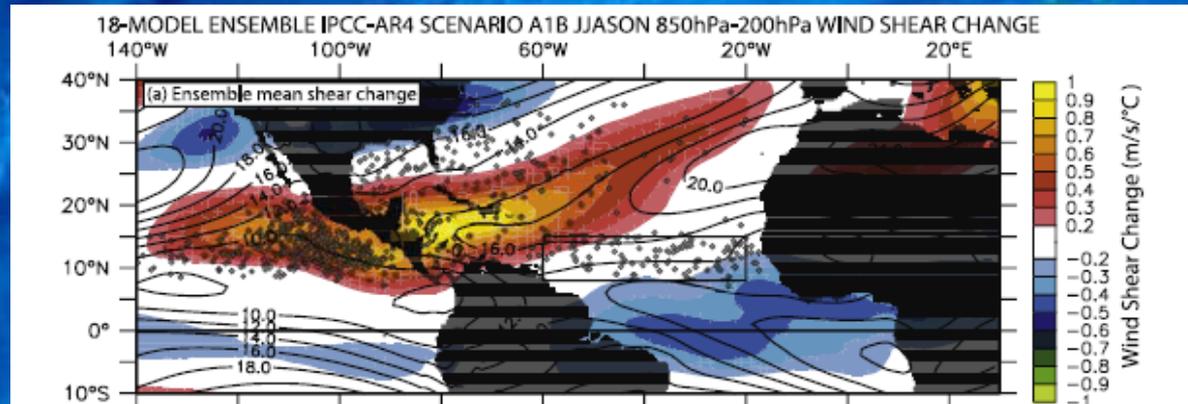
# Strong Conveyor

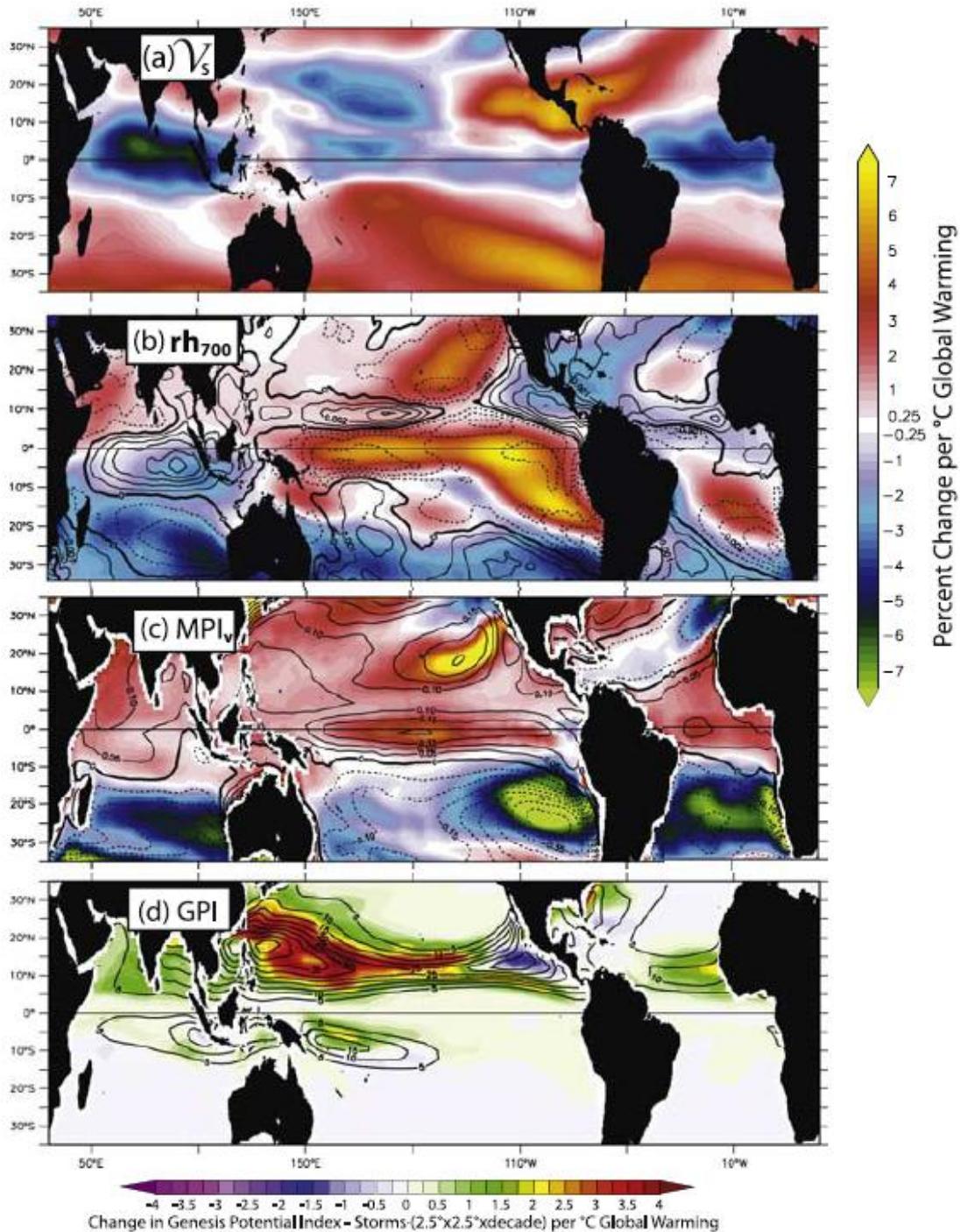


# Weak Conveyor



# Vecchi and Soden paper

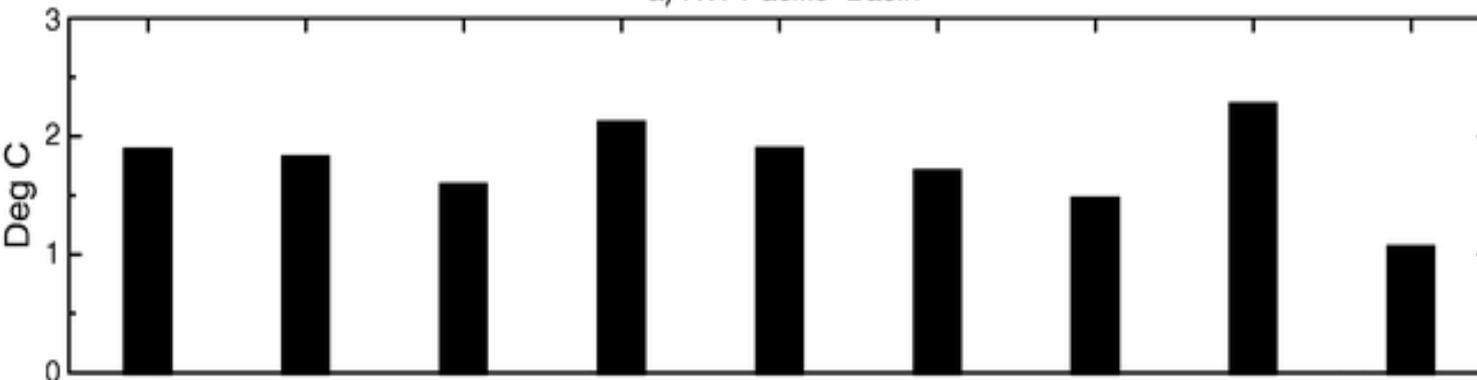




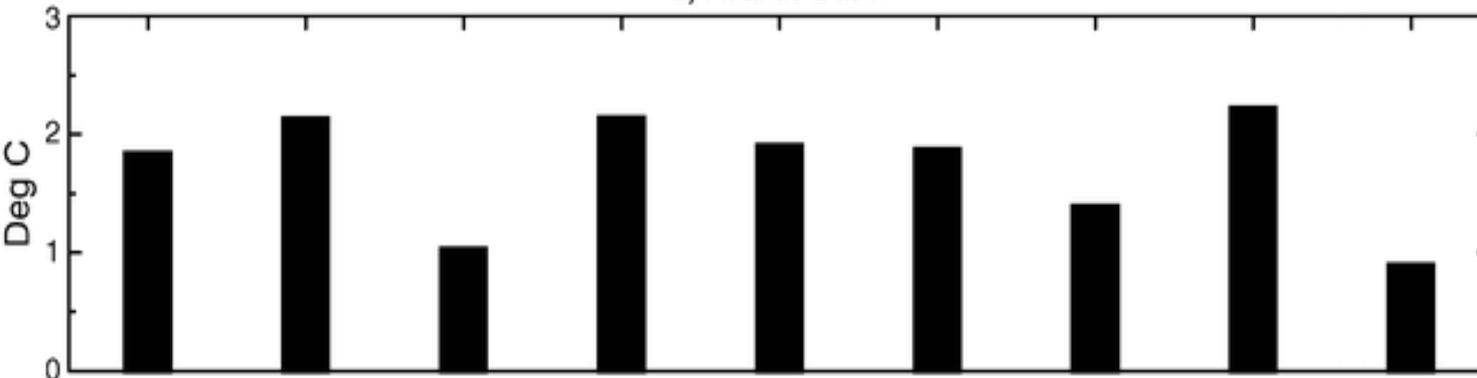
Vecchi and Soden  
paper

# SST Change (High CO<sub>2</sub> - Control)

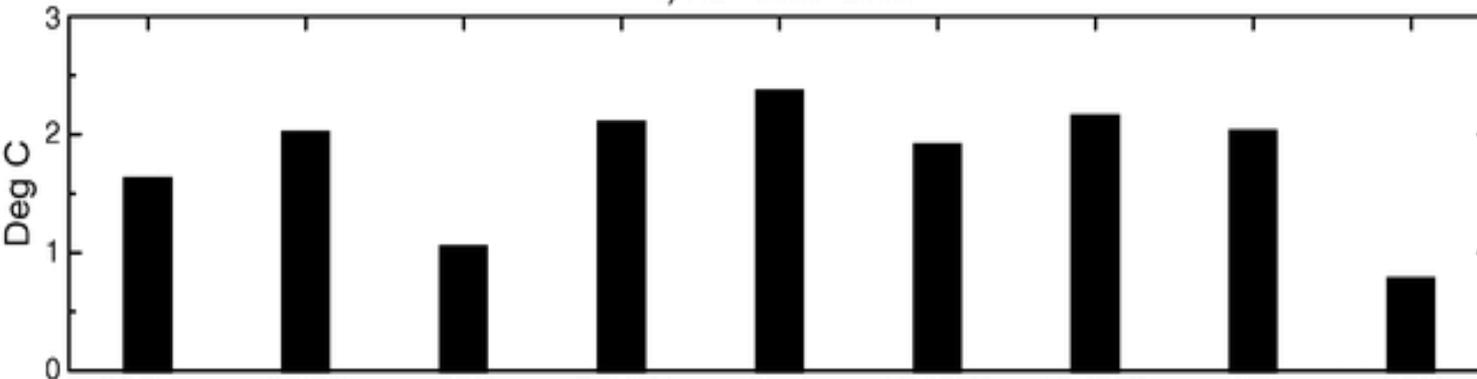
## a) NW Pacific Basin



## b) Atlantic Basin



## c) NE Pacific Basin

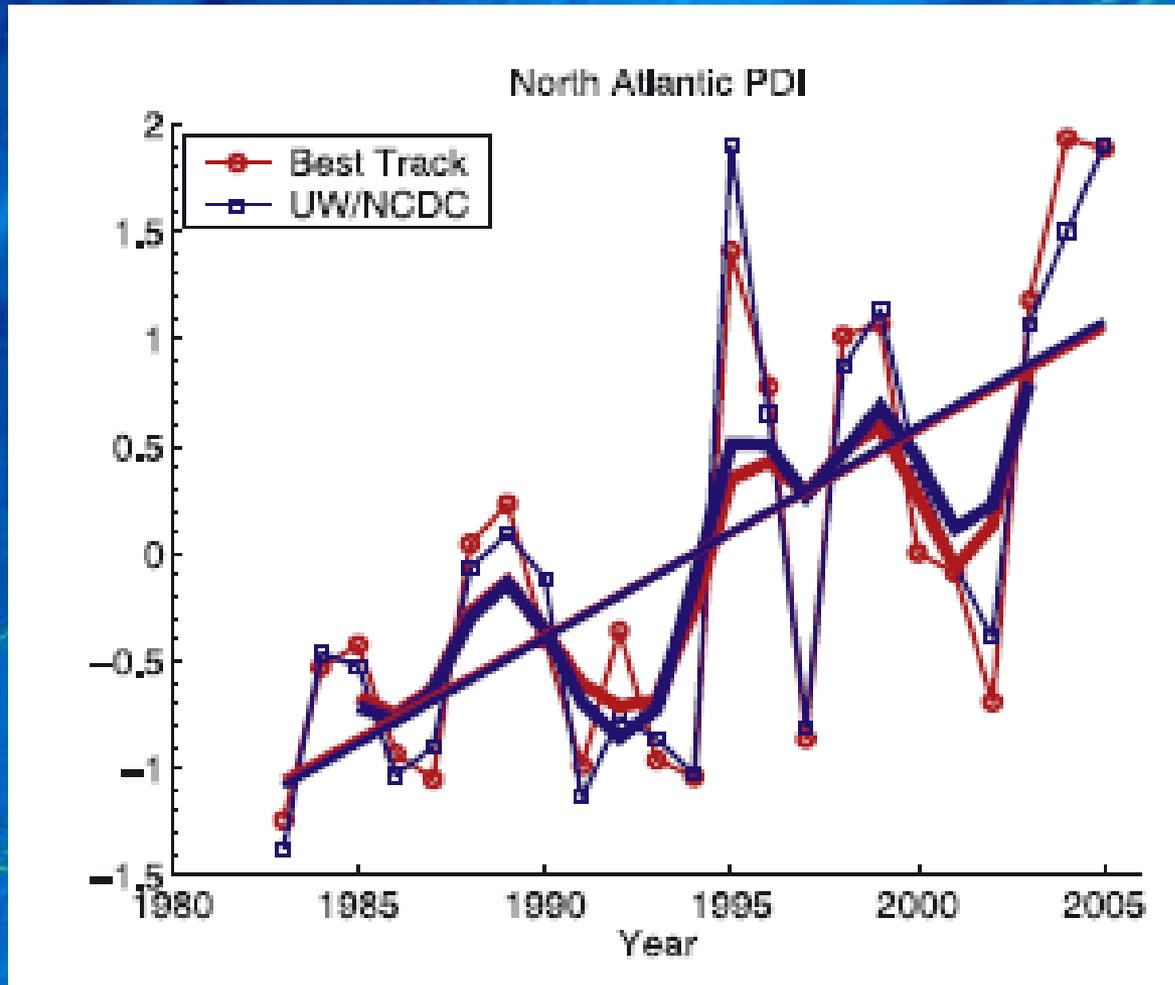


Global Model

SST changes  
2 x CO<sub>2</sub>

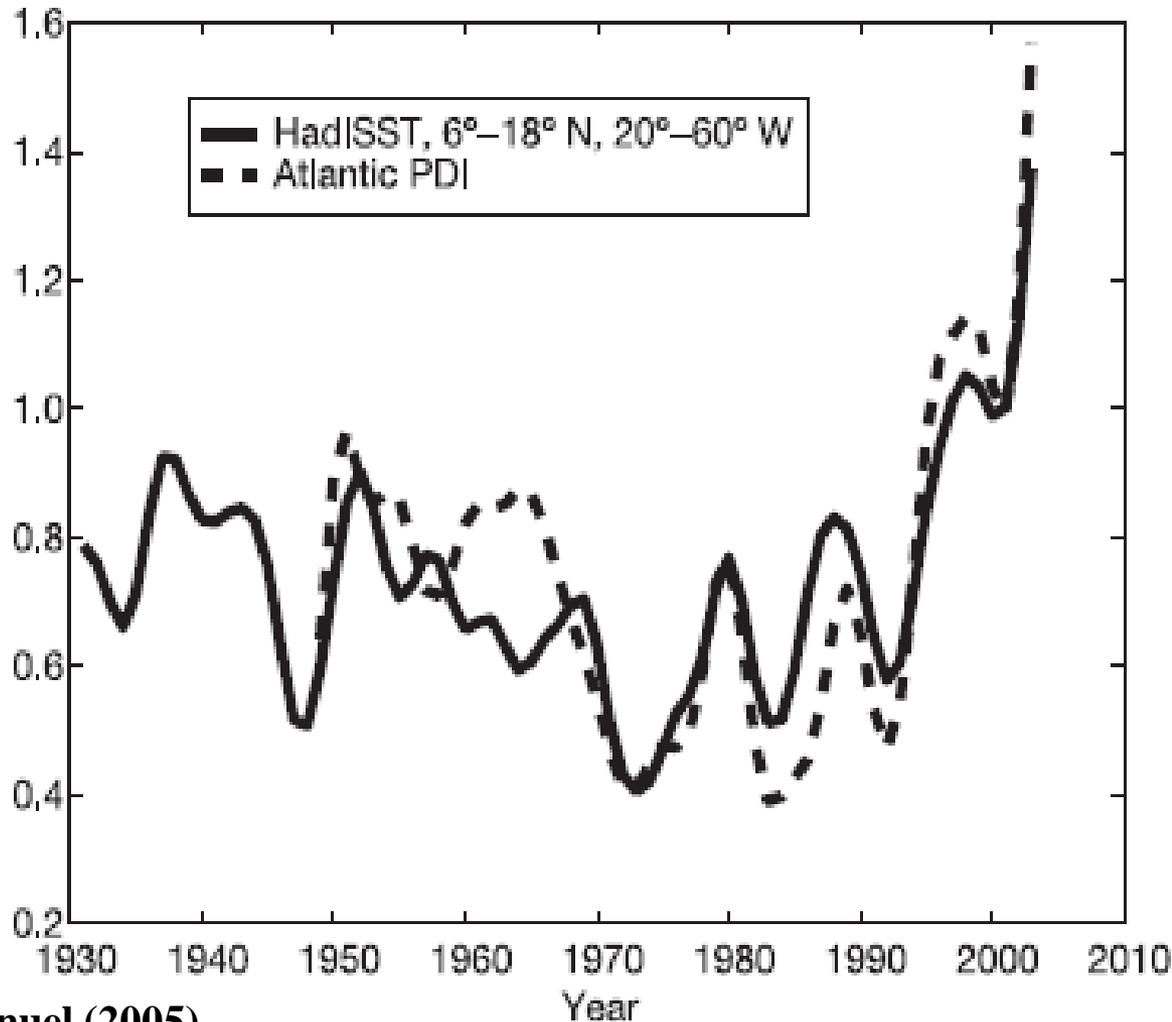
Knutson and  
Tuleya (2004)

# A globally consistent satellite-based reanalysis of hurricane intensity trends confirms that the Atlantic has been busy since 1995...



Kossin et al. (2007)

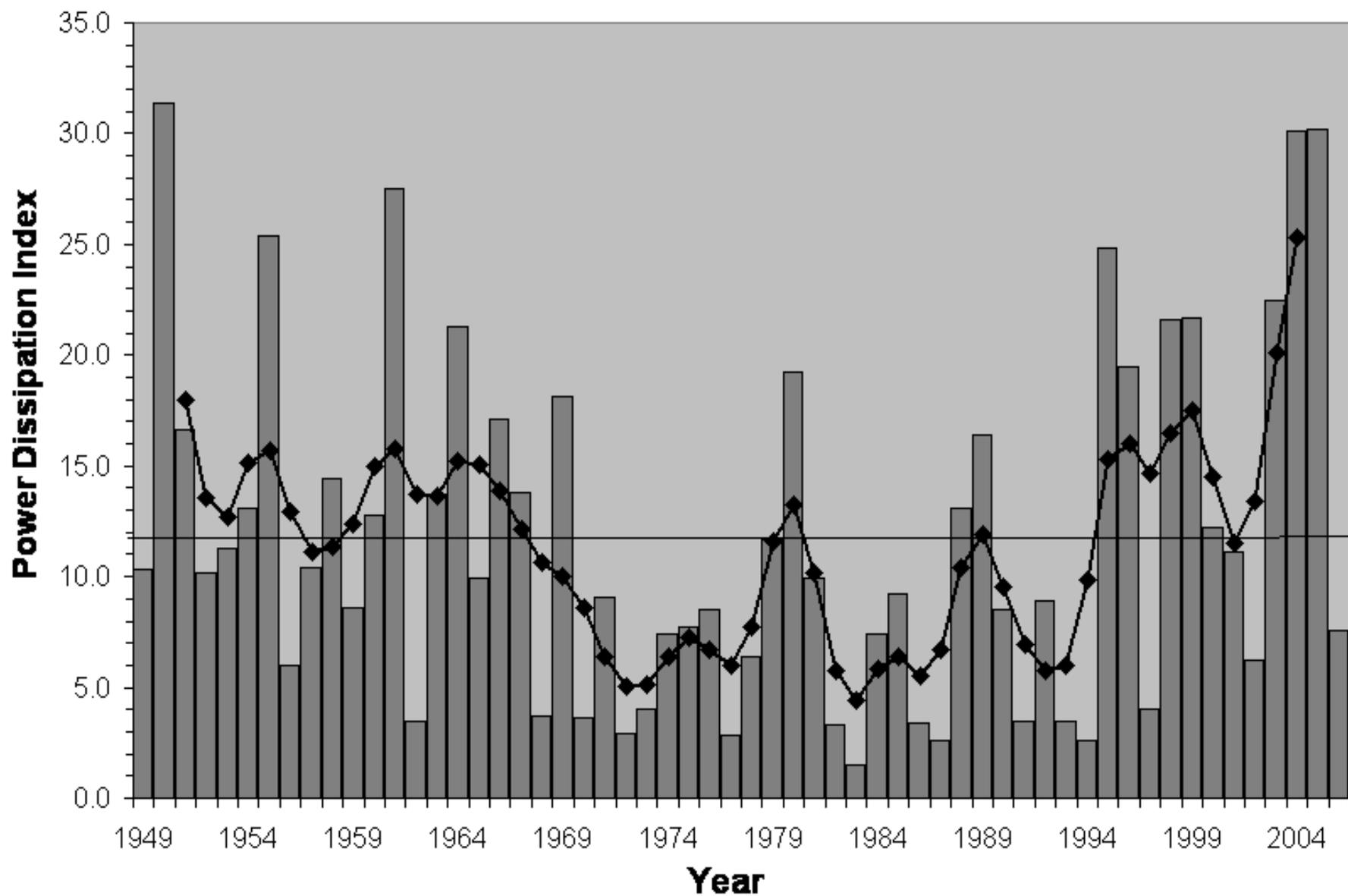
# Emanuel's study: Doubling in Atlantic Hurricane Wind Index – “Unprecedented”



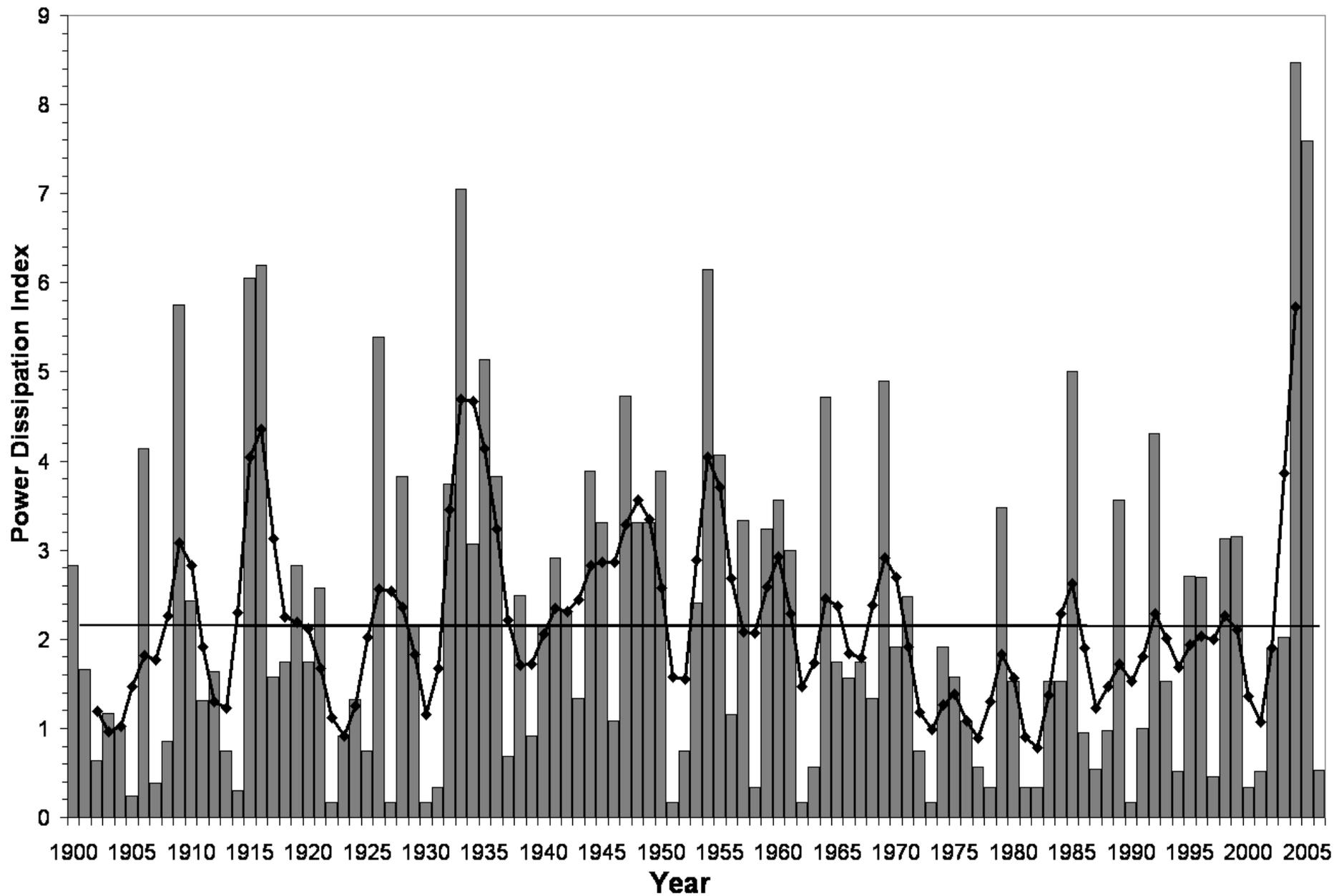
PDI = Power  
Dissipation  
Index (winds  
cubed &  
summed for  
season)

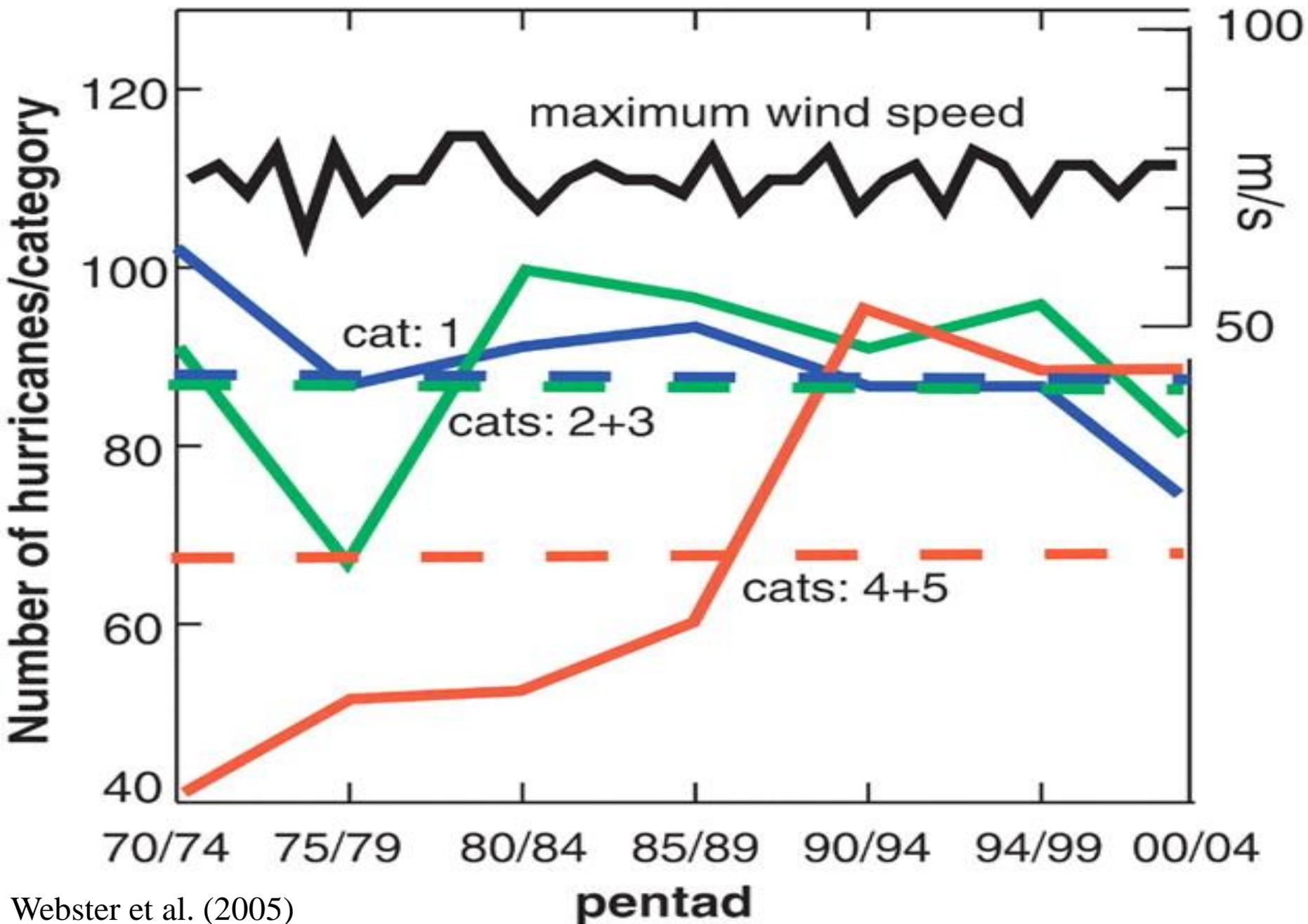
# Atlantic Power Dissipation Index

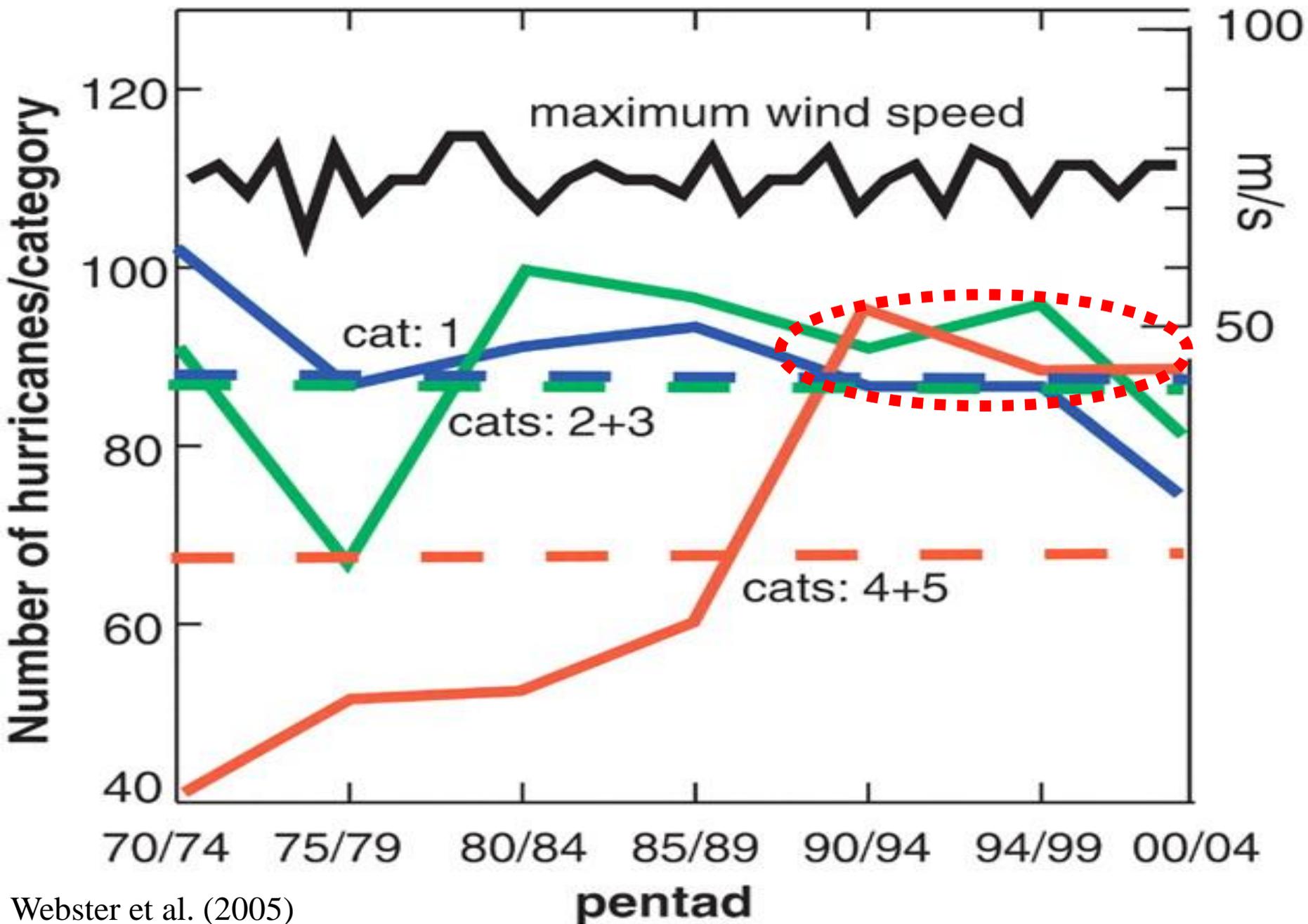
Original Data - 1949 to 2006



# United States Power Dissipation Index 1900 to 2006



**A****Number of intense hurricanes**

**A****Number of intense hurricanes**

# Hurricane Hunters – Only in the Atlantic



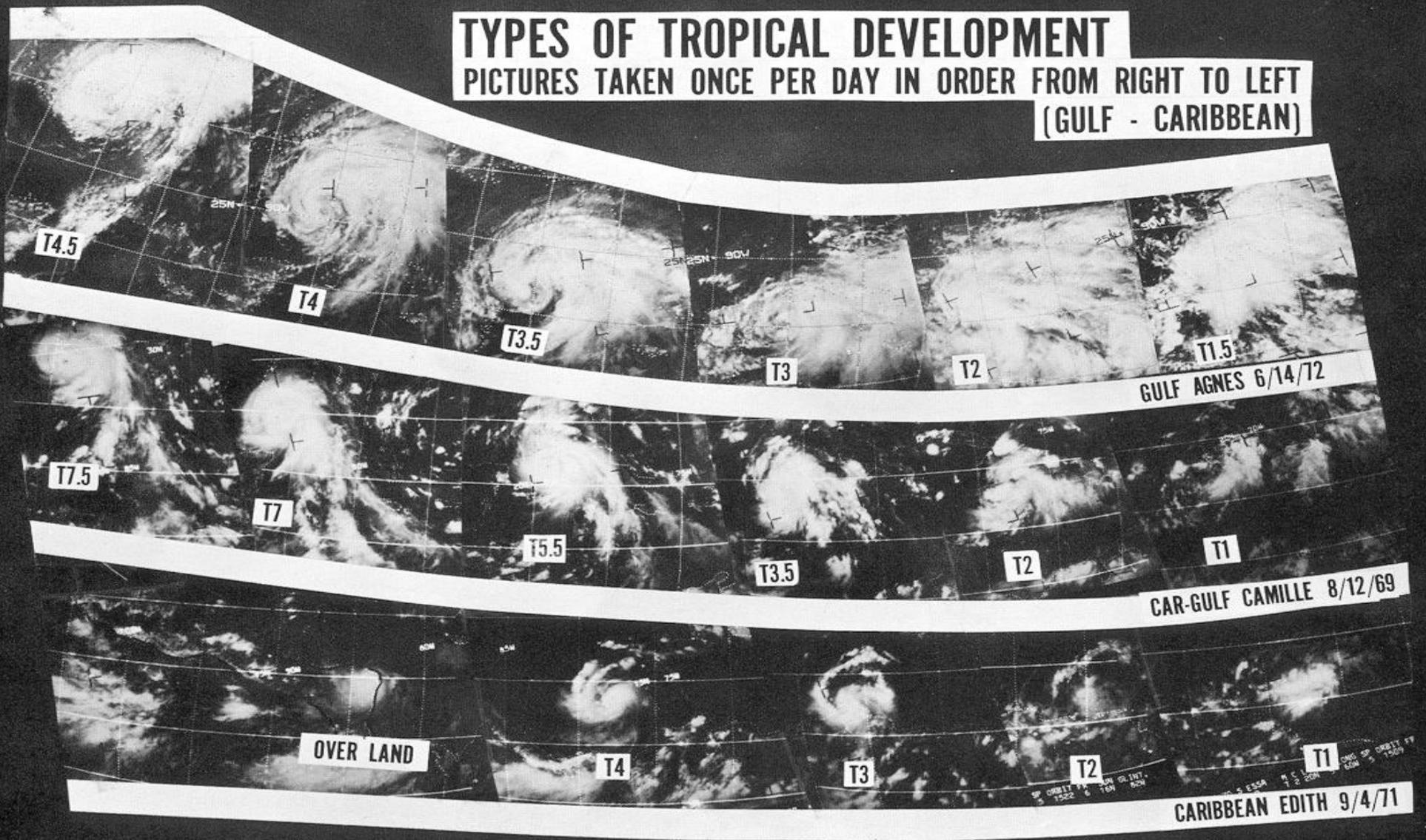
Lower-fuselage  
radar



# The Dvorak Technique (1972)

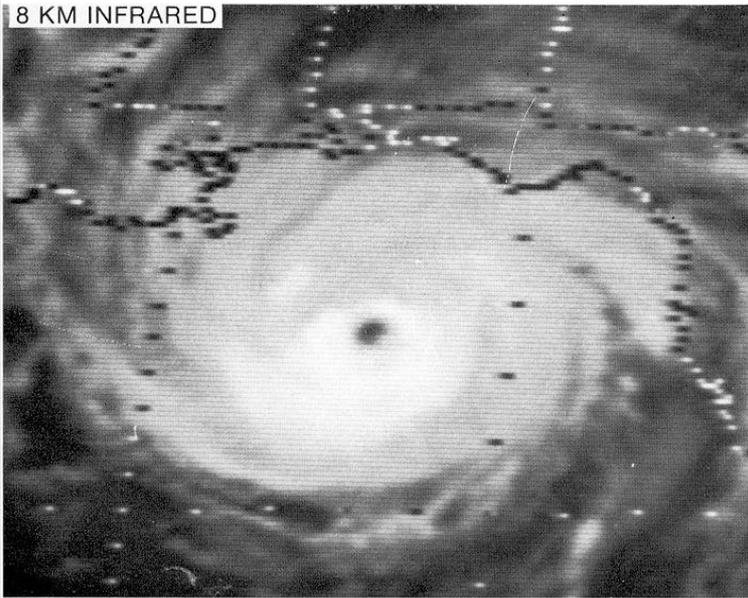
## TYPES OF TROPICAL DEVELOPMENT

PICTURES TAKEN ONCE PER DAY IN ORDER FROM RIGHT TO LEFT  
(GULF - CARIBBEAN)

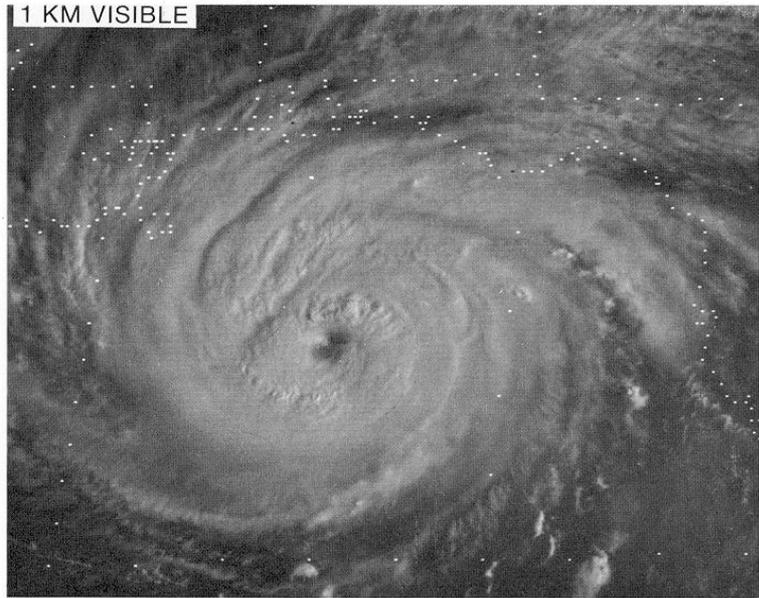


# Infrared Version of Dvorak (1984)

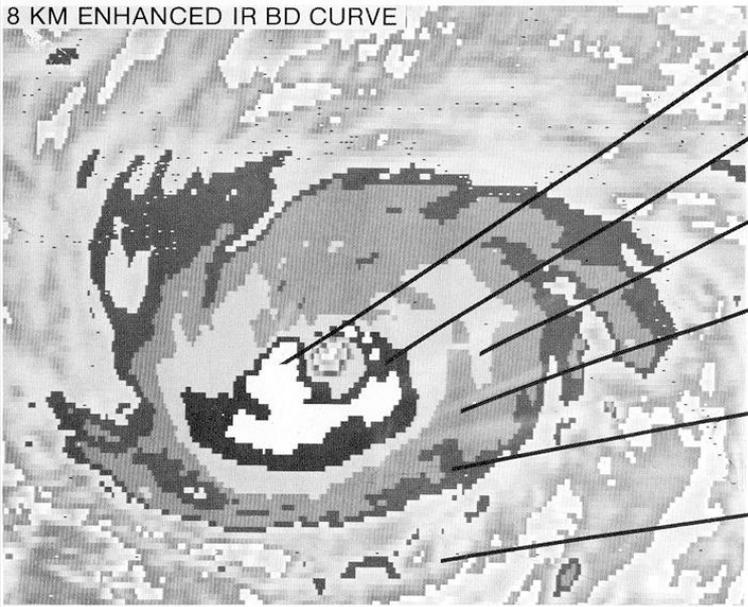
8 KM INFRARED



1 KM VISIBLE



8 KM ENHANCED IR BD CURVE



WHITE  
( $-70^{\circ}\text{C}$  to  $-75^{\circ}\text{C}$ )

BLACK  
( $-64^{\circ}\text{C}$  to  $-69^{\circ}\text{C}$ )

LIGHT GRAY  
( $-54^{\circ}\text{C}$  to  $-63^{\circ}\text{C}$ )

MED GRAY  
( $-42^{\circ}\text{C}$  to  $-53^{\circ}\text{C}$ )

DARK GRAY  
( $-30^{\circ}\text{C}$  to  $-41^{\circ}\text{C}$ )

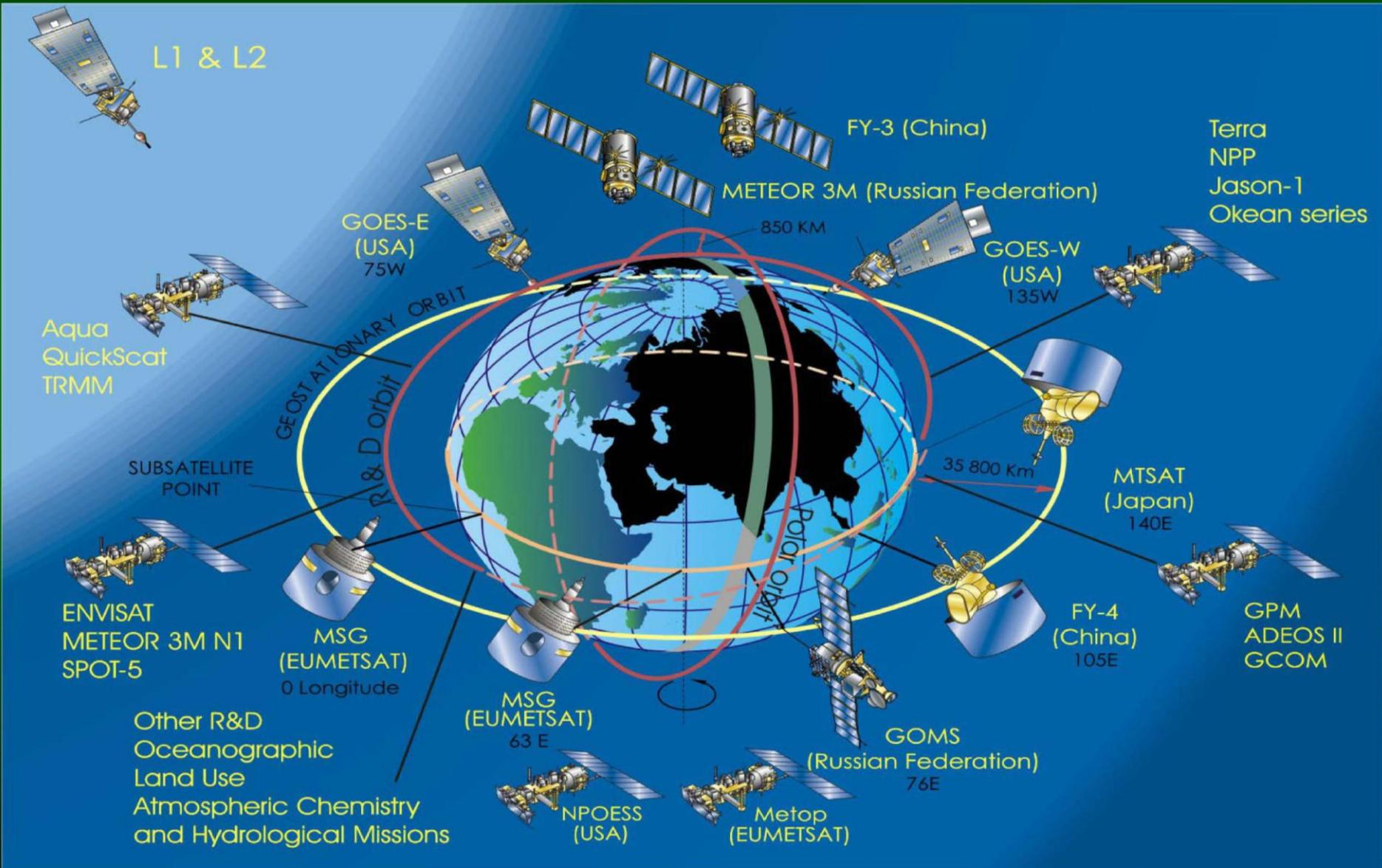
OFF WHITE  
( $2^{\circ}\text{C}$  to  $-29^{\circ}\text{C}$ )

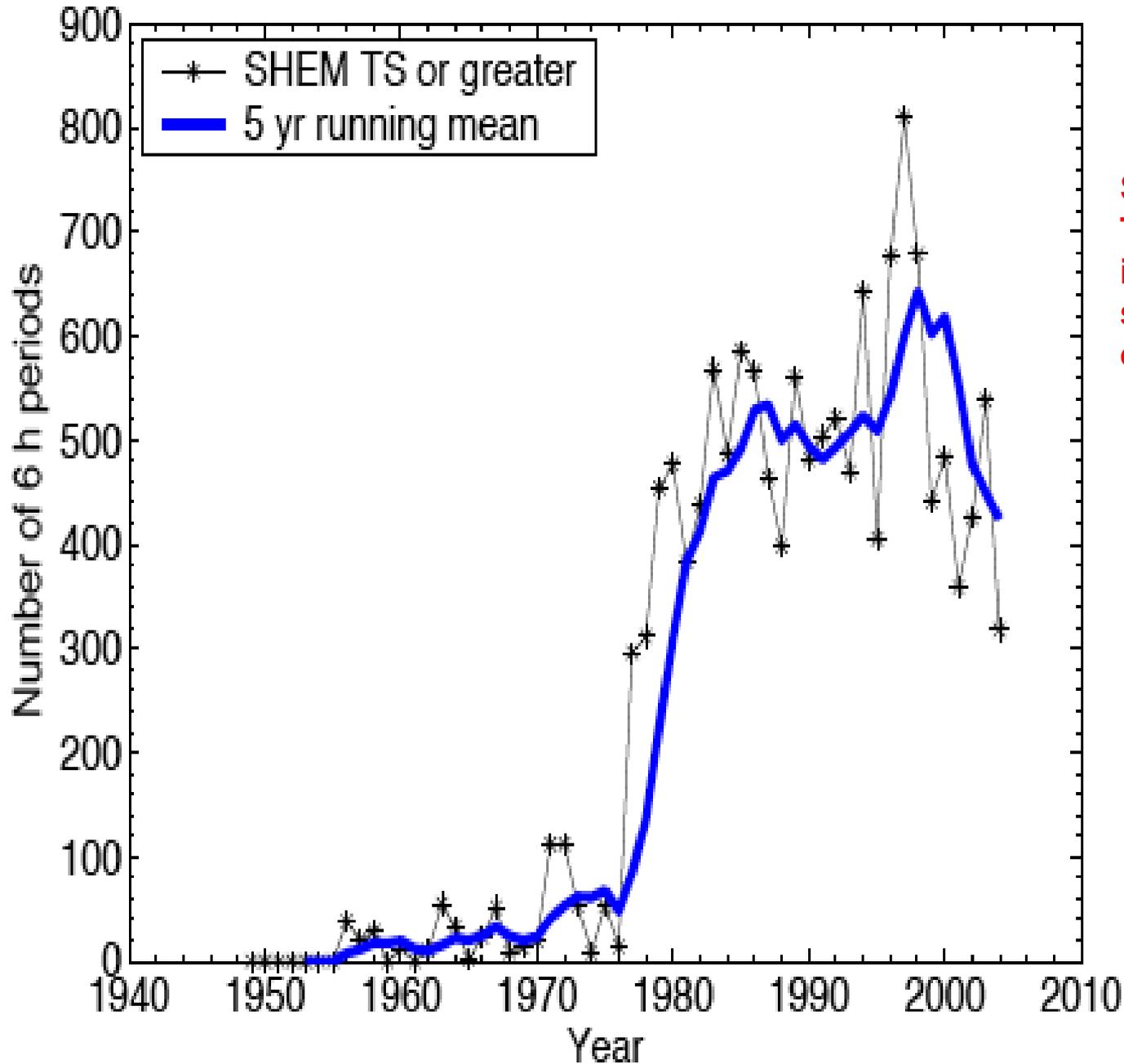
TROPICAL CYCLONE ANALYSIS  
**SATELLITE DATA**

**COMPARISON EXERCISE**  
**HURRICANE FREDERIC**

1331 GMT 12 September 1979

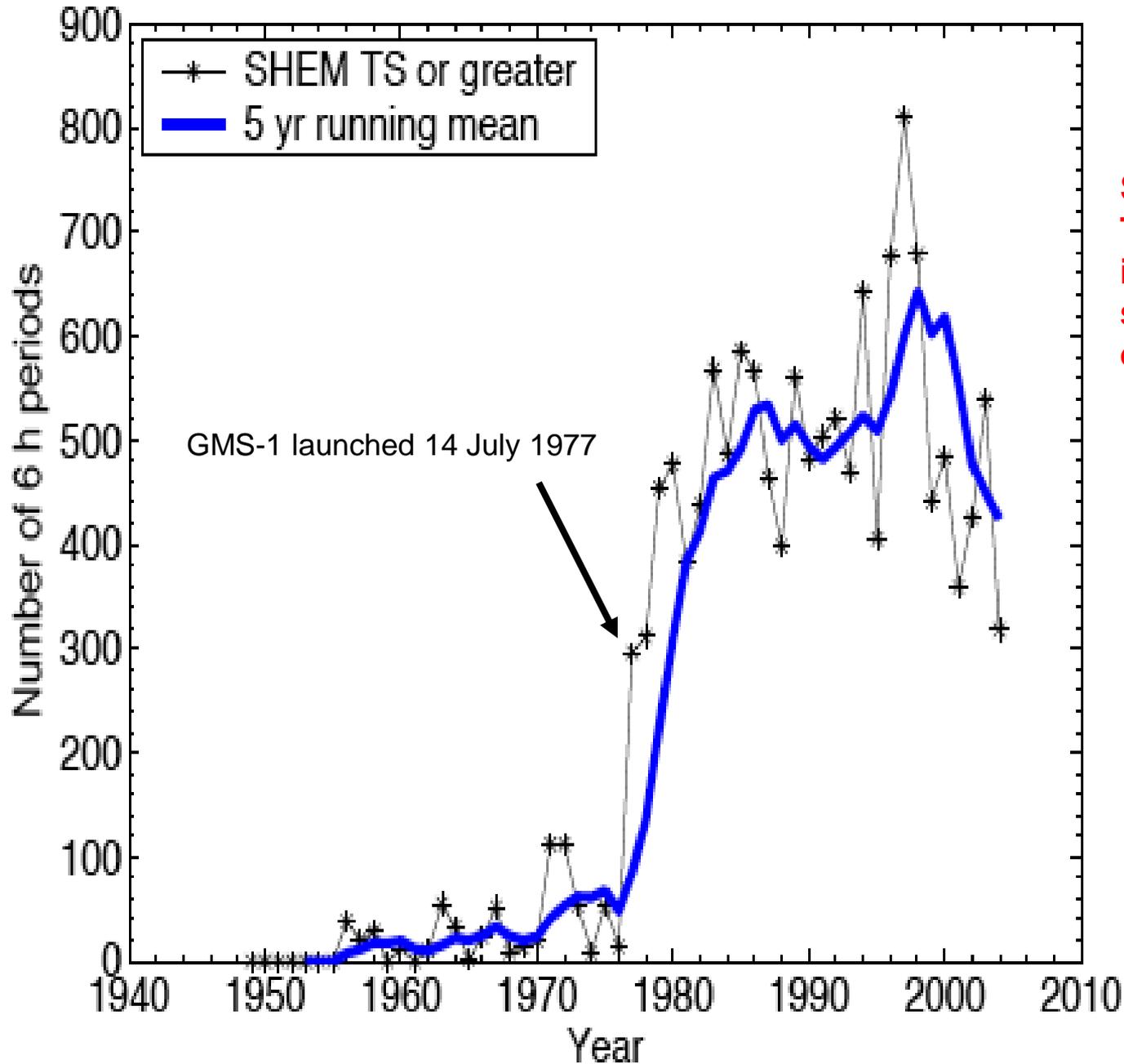
# Coverage Today of Meteorological/Oceanographic Satellites





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

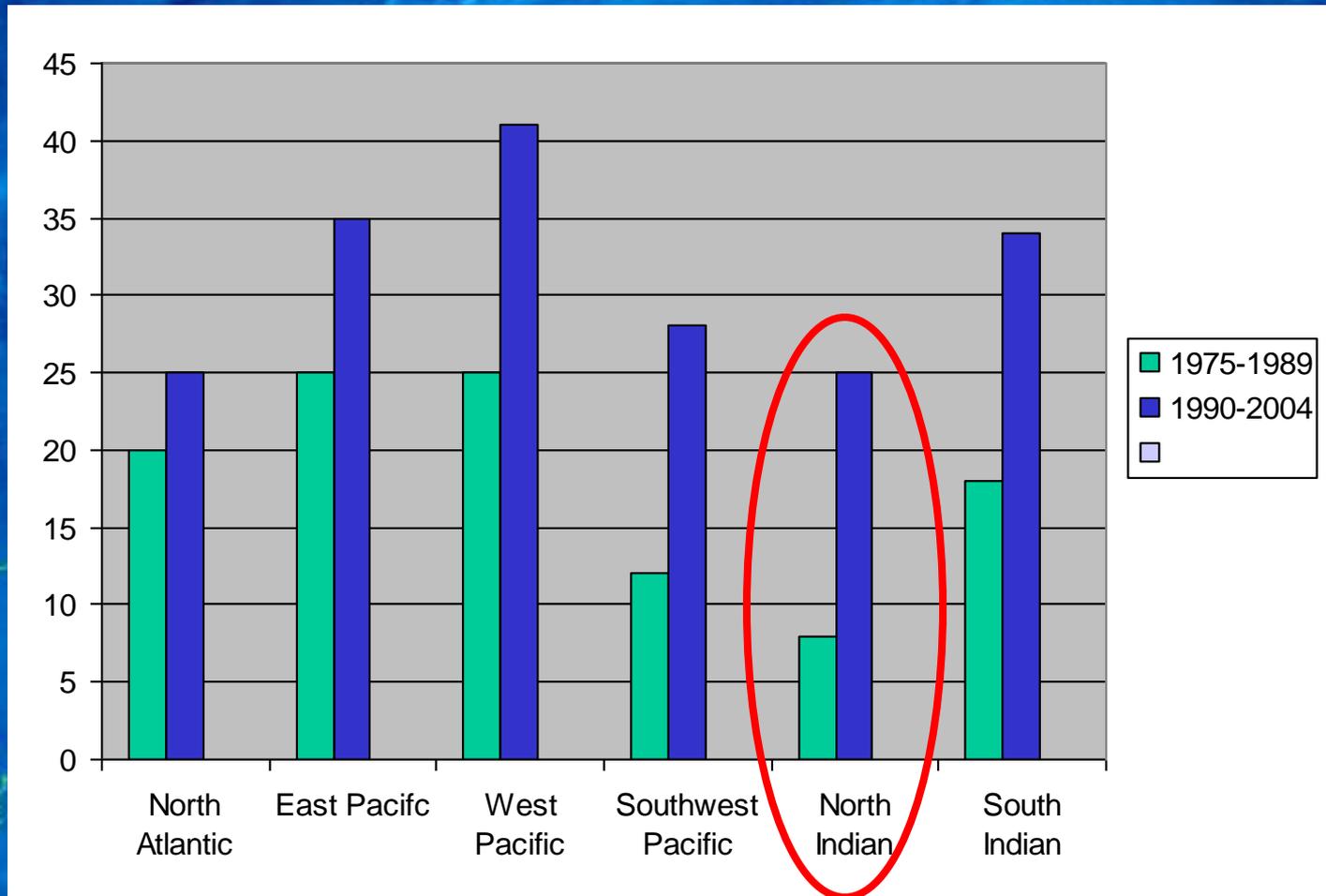
Kossin (Per. Comm., 2006)



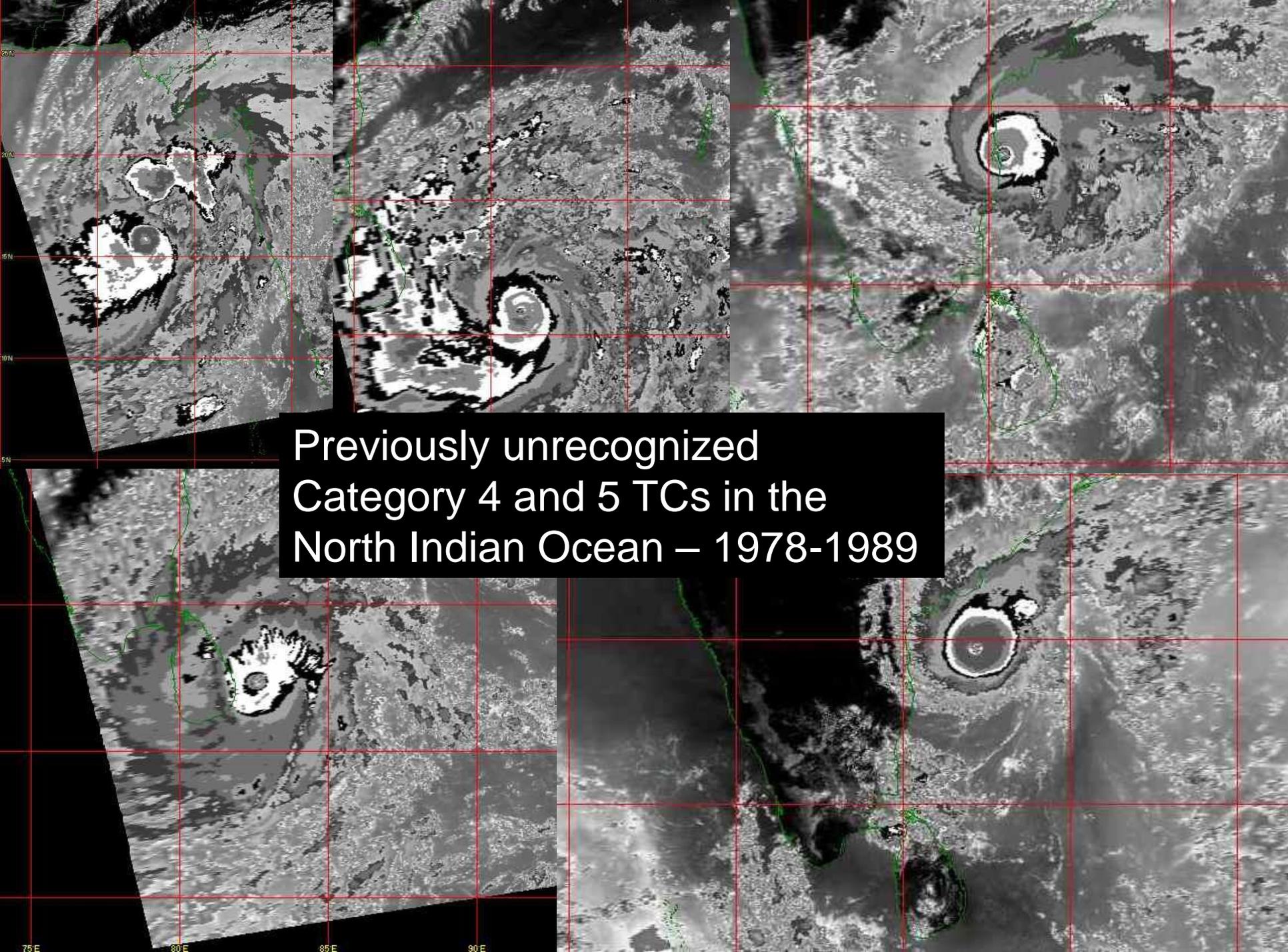
**Simple example of Best Track inconsistencies introducing a potentially spurious trend in measure of TS-days**

Kossin (Per. Comm., 2006)

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



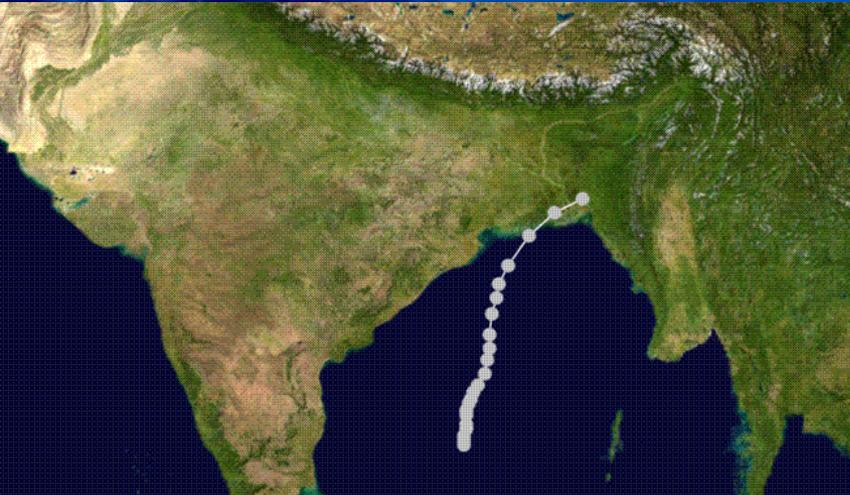
Source: Adapted from Webster et al., *Science*, Sept. 2005.



Previously unrecognized  
Category 4 and 5 TCs in the  
North Indian Ocean – 1978-1989

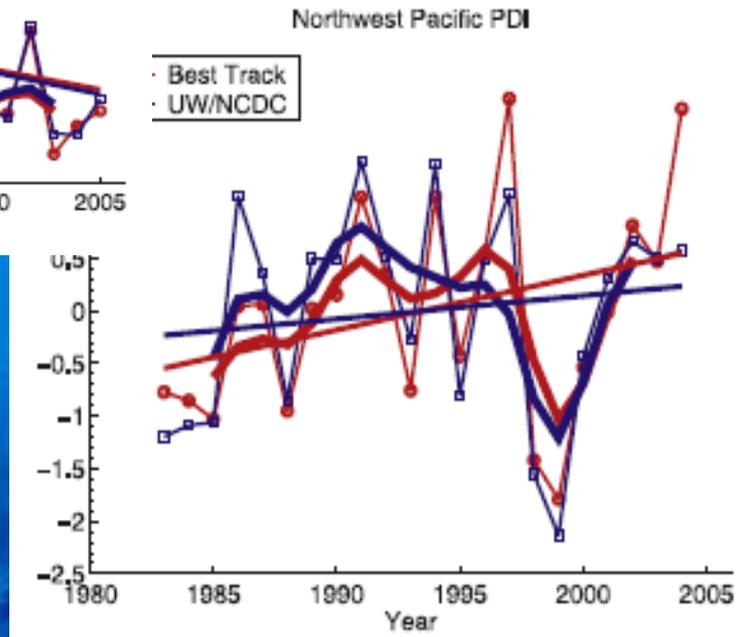
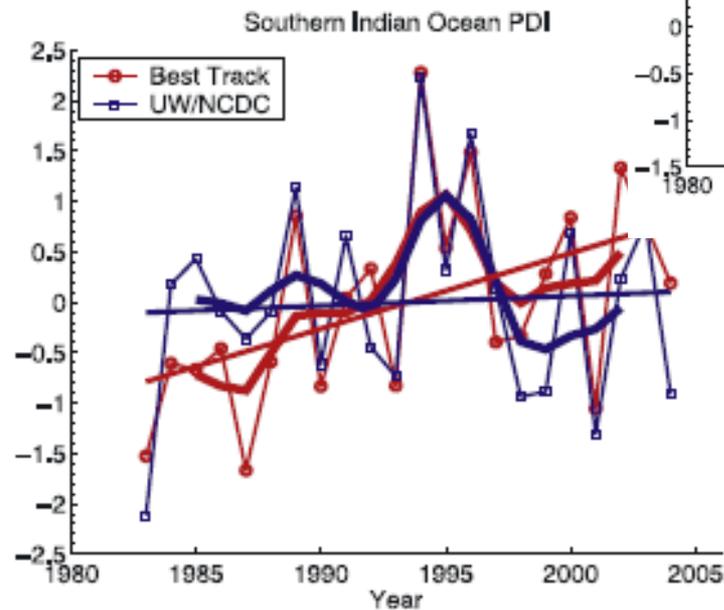
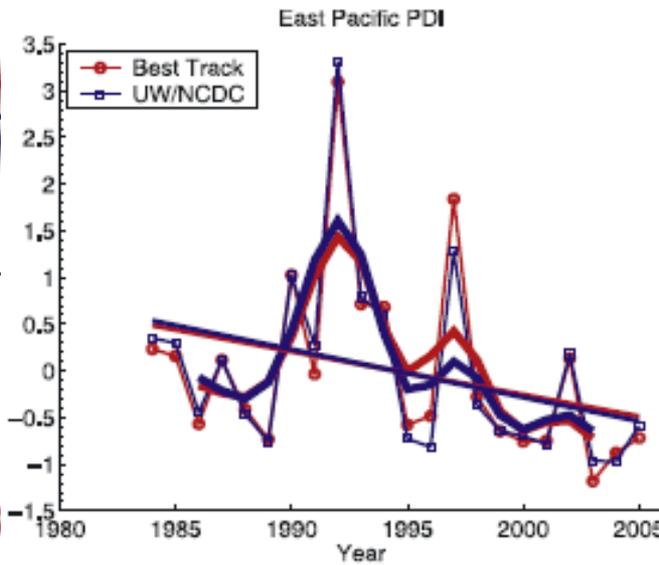
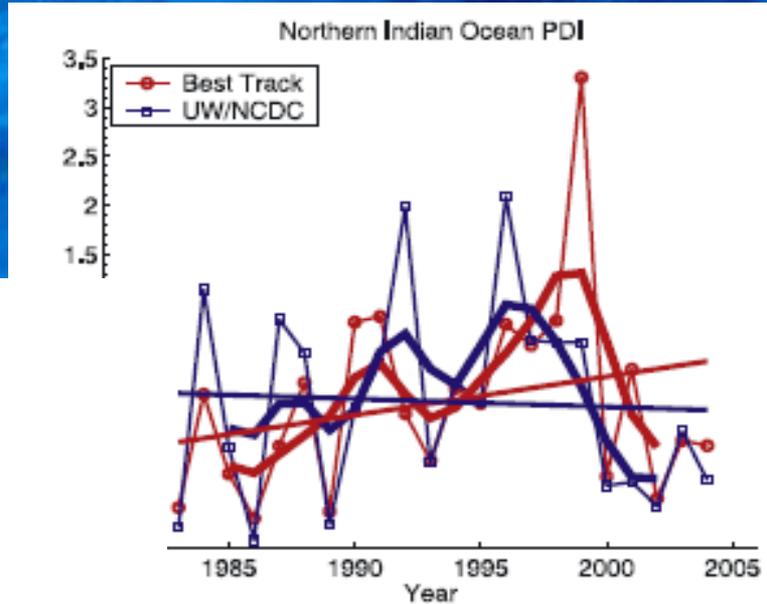
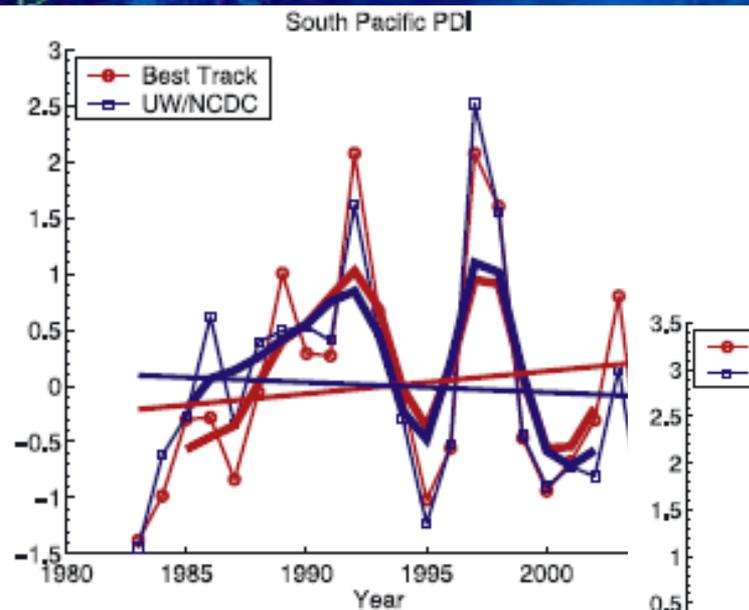
# 1970 Bangladesh Cyclone

300,000 to 500,000 fatalities

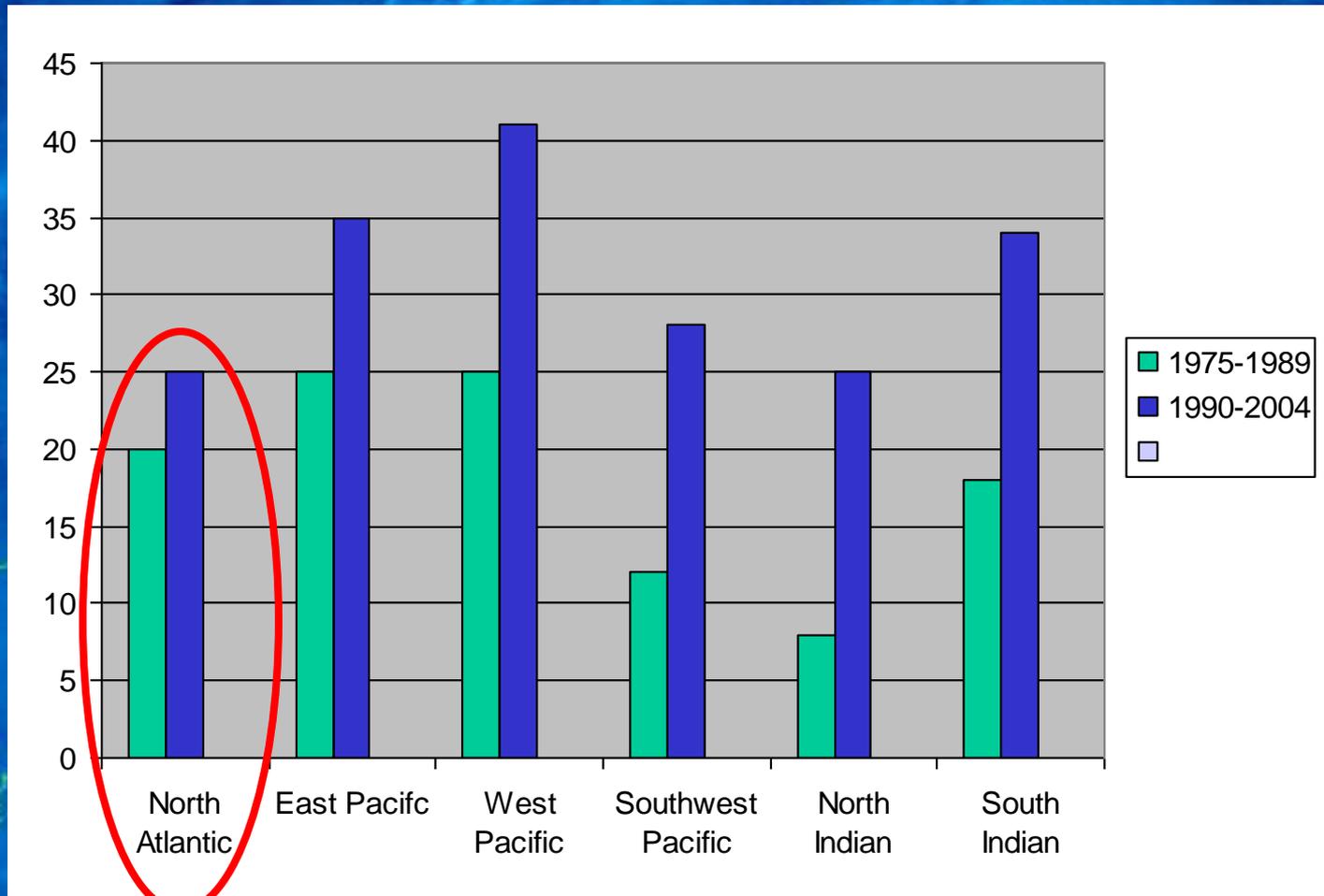


# Actual global changes: either steady or weakening hurricanes since early 1980s

Kossin et al. (2007)



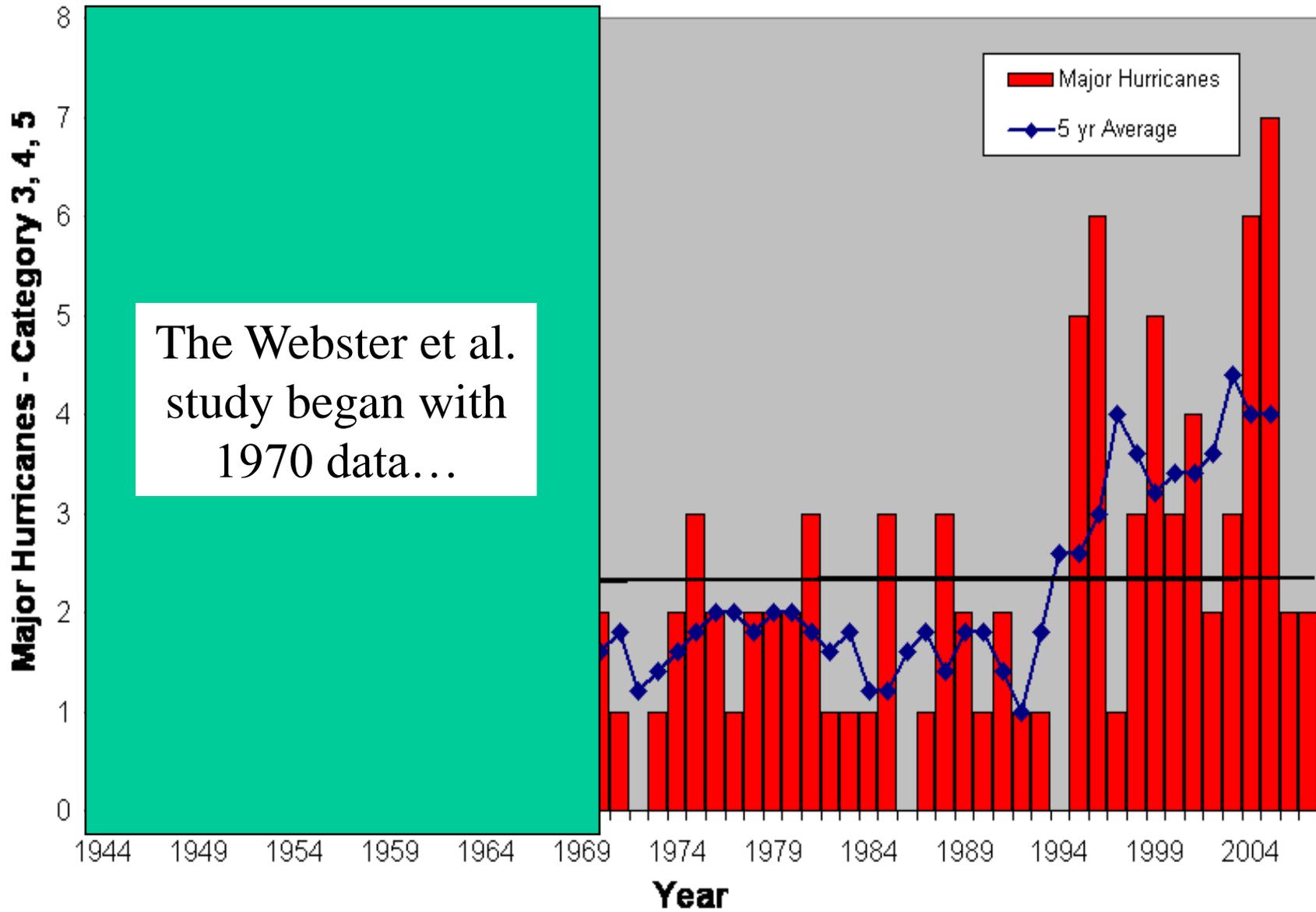
Webster et al.: The percentage of hurricanes which reach Category 4-5 has increased in all basins, comparing two recent 15-year periods...



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

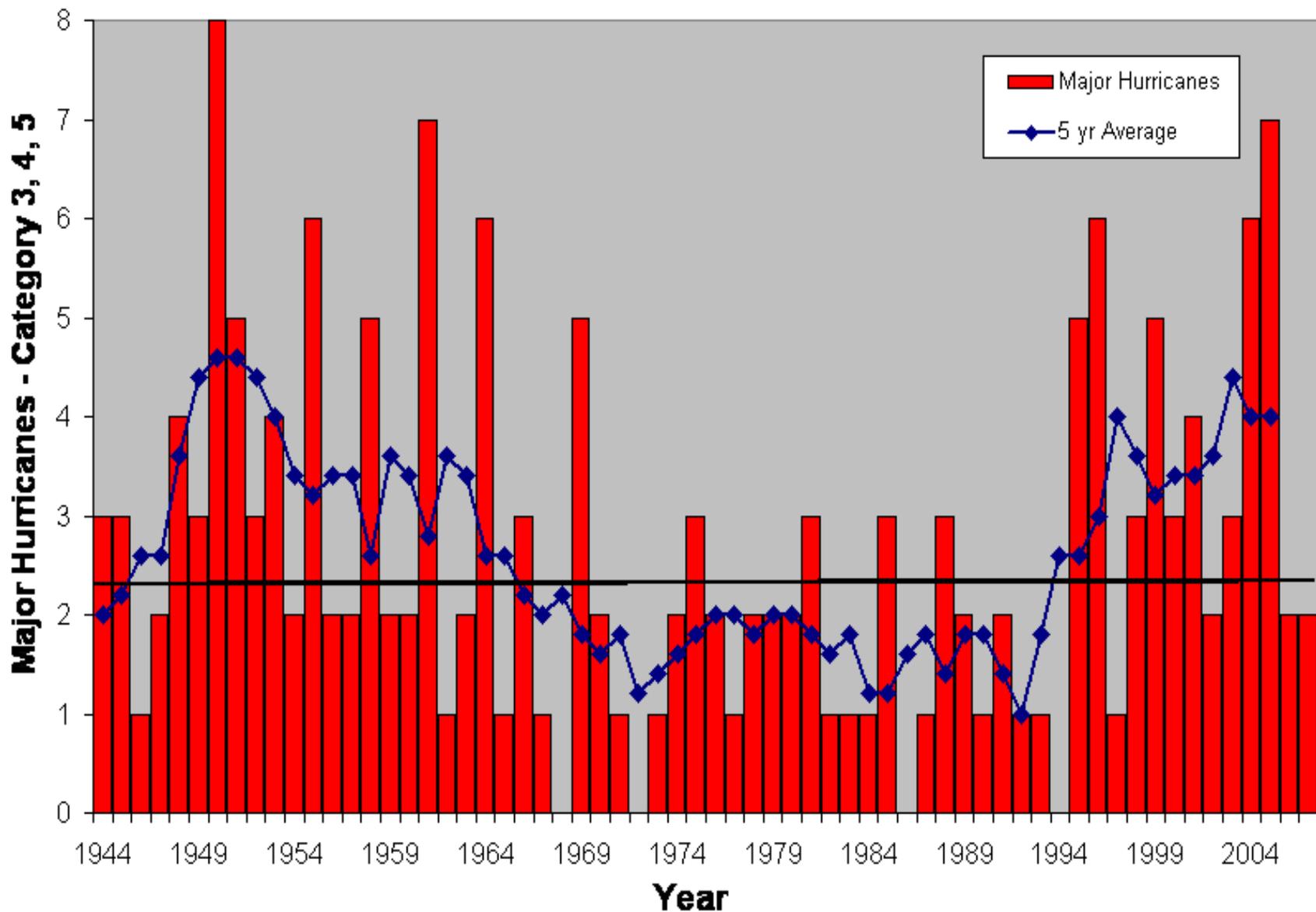
# Atlantic Major Hurricanes

1944 to 2007

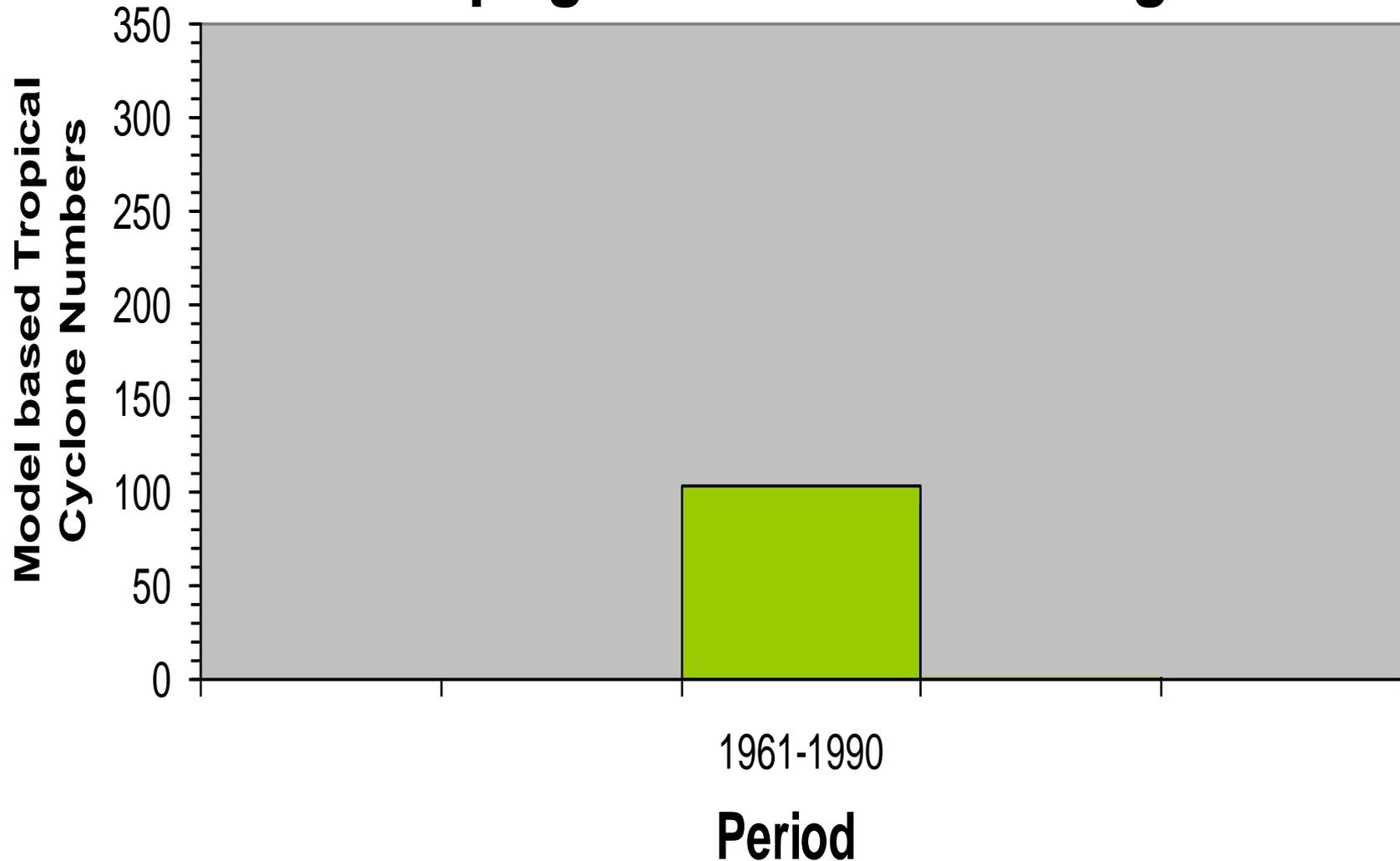


# Atlantic Major Hurricanes

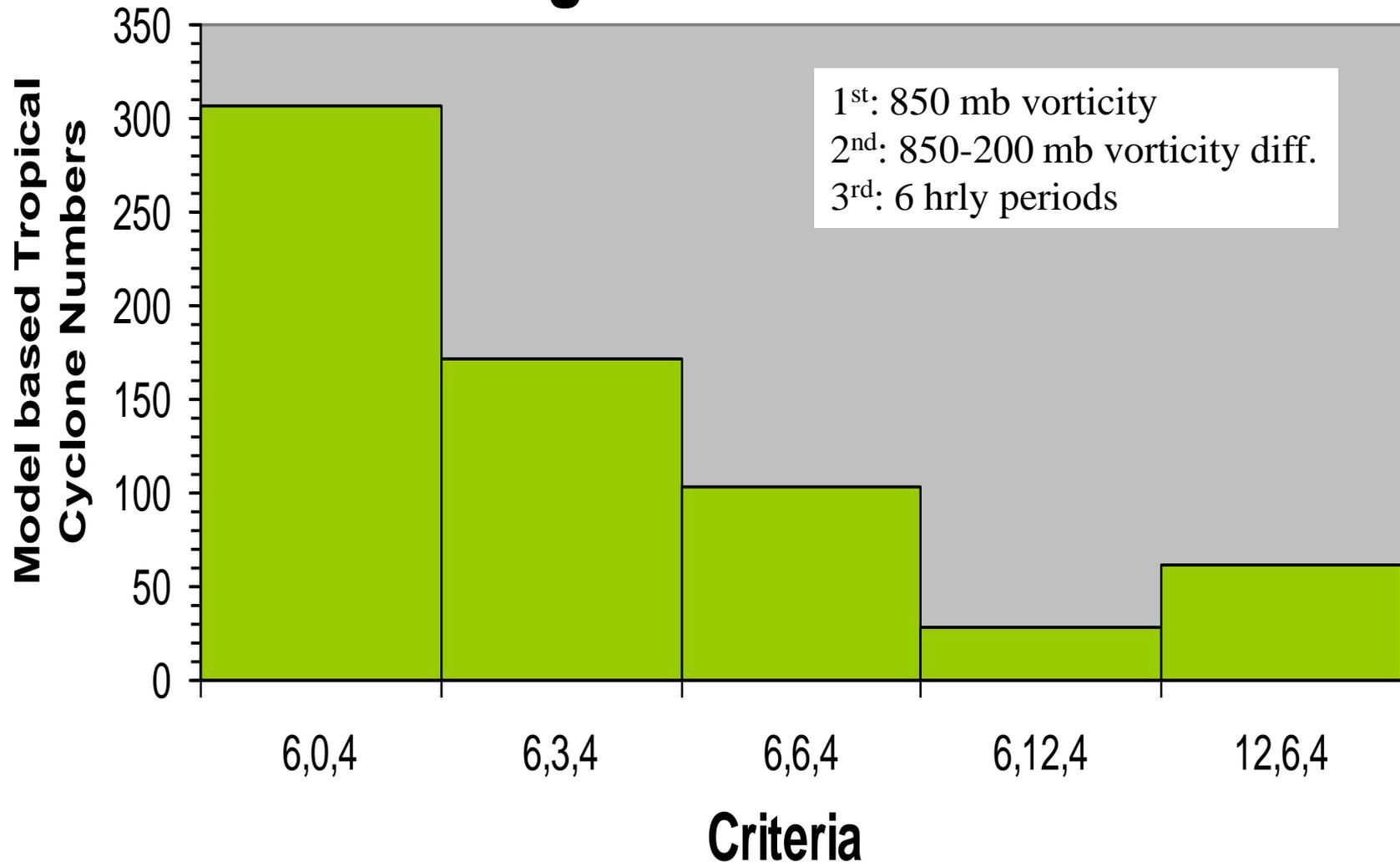
1944 to 2007



# Frequency of Tropical Cyclones Due to Anthropogenic Climate Change



# Frequency of Tropical Cyclones Using Differing Threshold Criteria

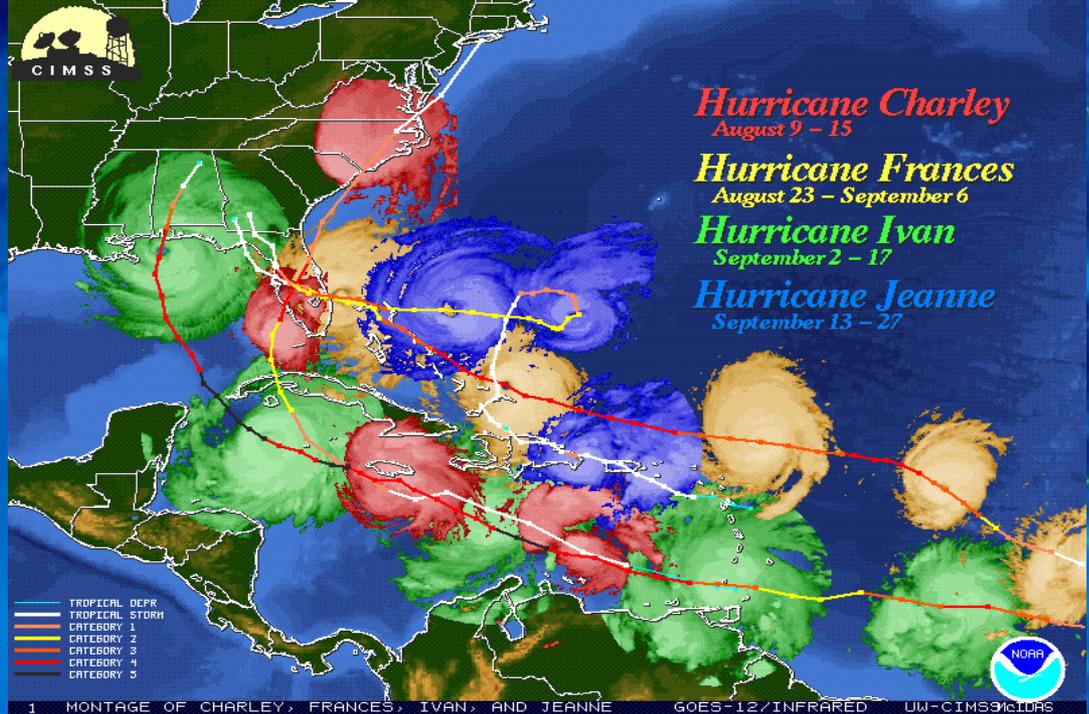


"This **broad consistency** between observations, models, and theory is a powerful indicator that we are likely already experiencing more intense tropical cyclones as a result of global warming."

--- Anthes, Correll, Holland, Hurrell, MacCracken, Trenberth  
--- Bulletin of the American Meteorological Society, 2006

"There is **an inconsistency** between the small changes in wind-speed projected by theory and modeling versus large changes reported by some observational studies."

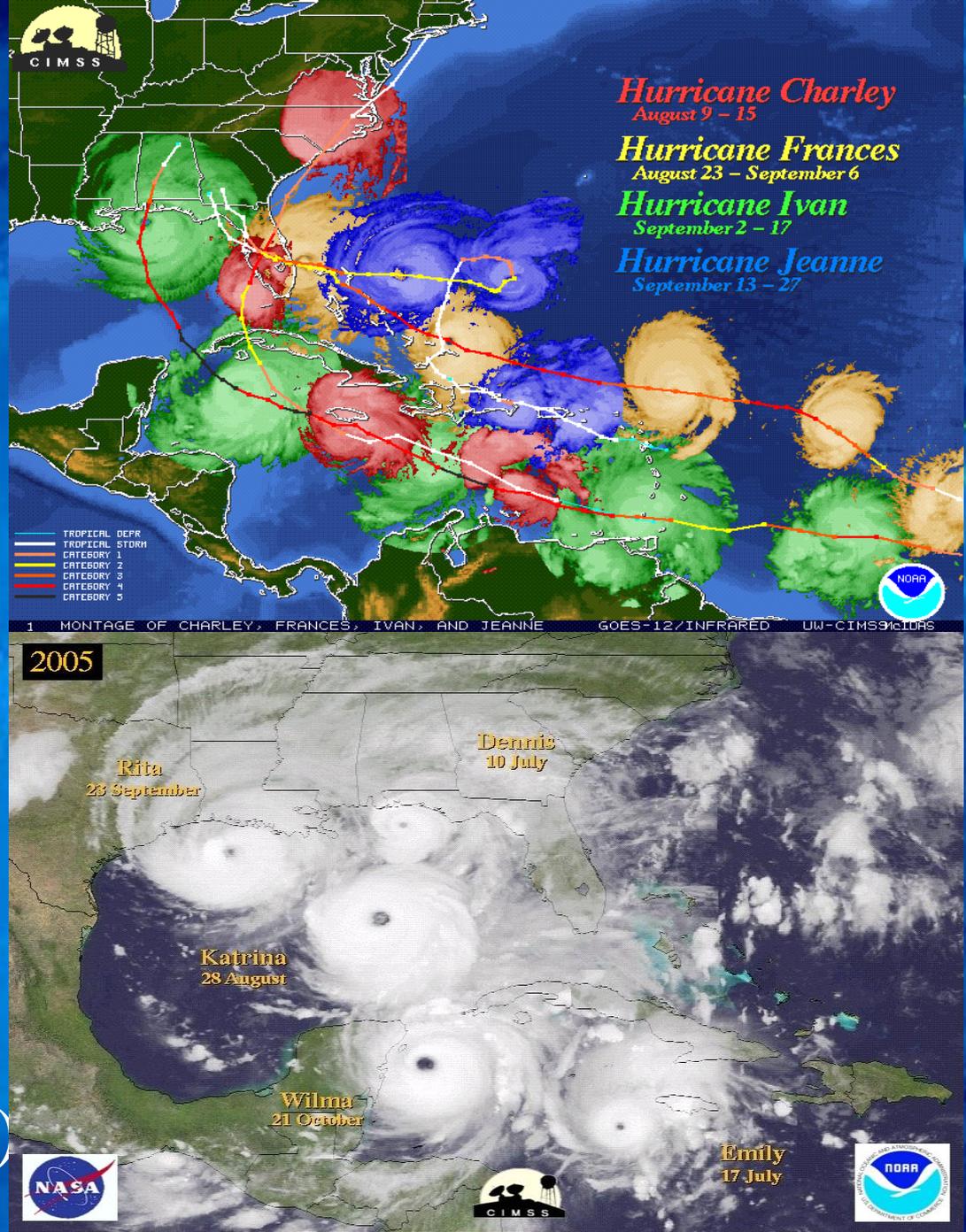
--- Statement on Tropical Cyclones and Climate Change  
--- International Workshop on Tropical Cyclones, 2006

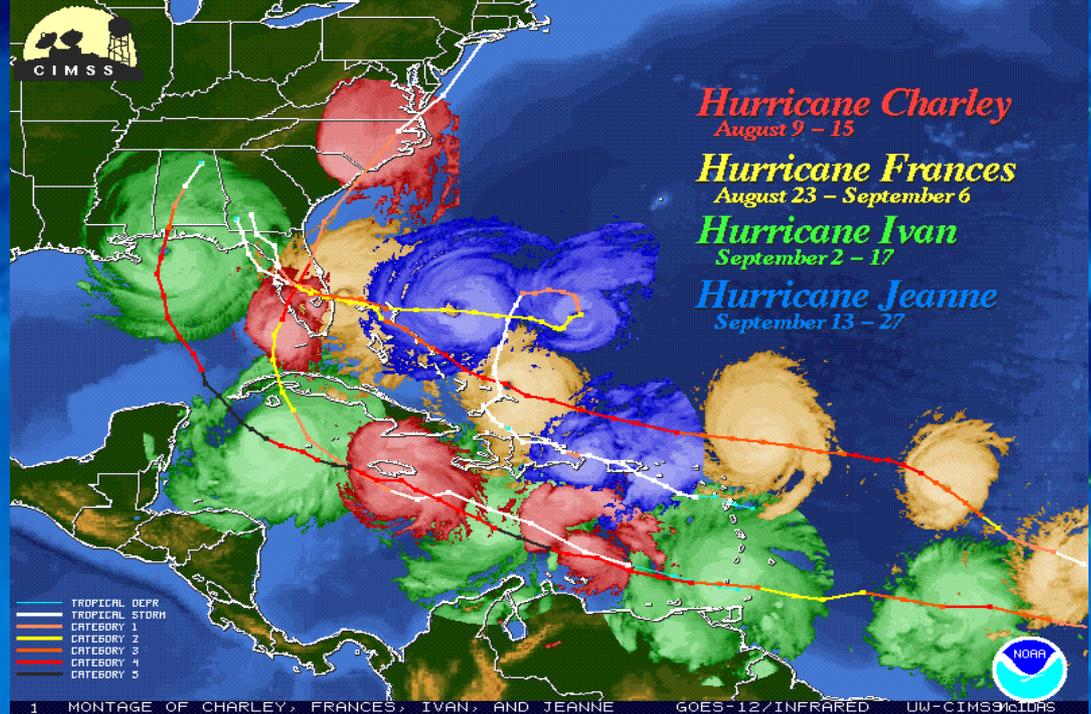


1 MONTAGE OF CHARLEY, FRANCES, IVAN, AND JEANNE GOES-12/INFRARED UW-CIMSS/ILLAS

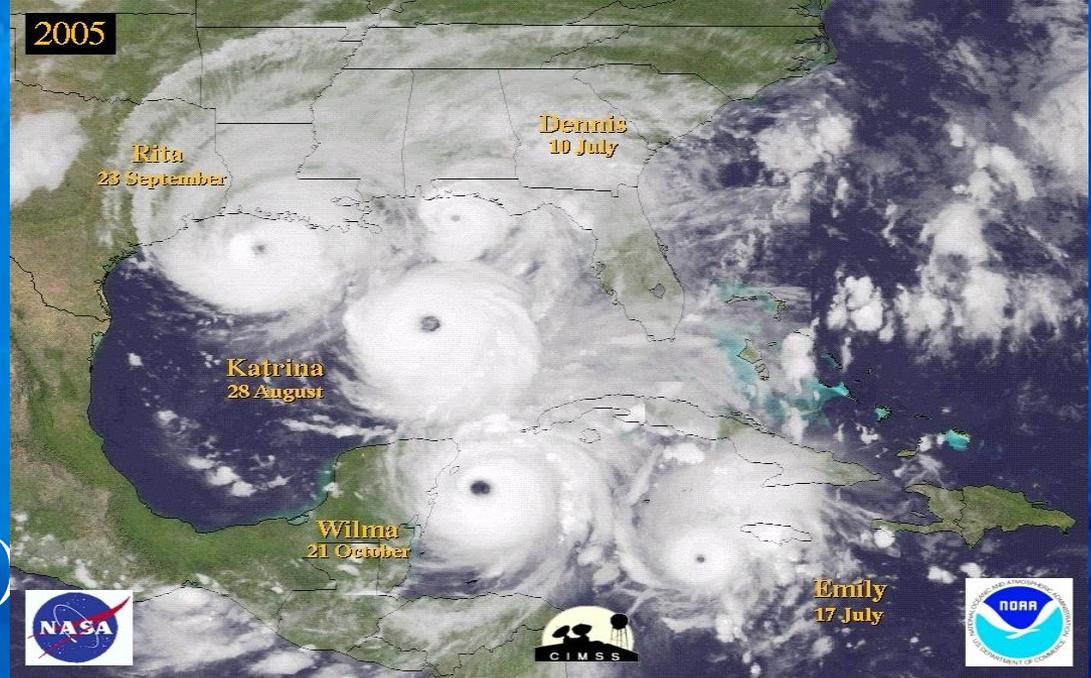


Emanuel (2005)  
Webster et al. (2005)  
Mann/Emanuel (2006)



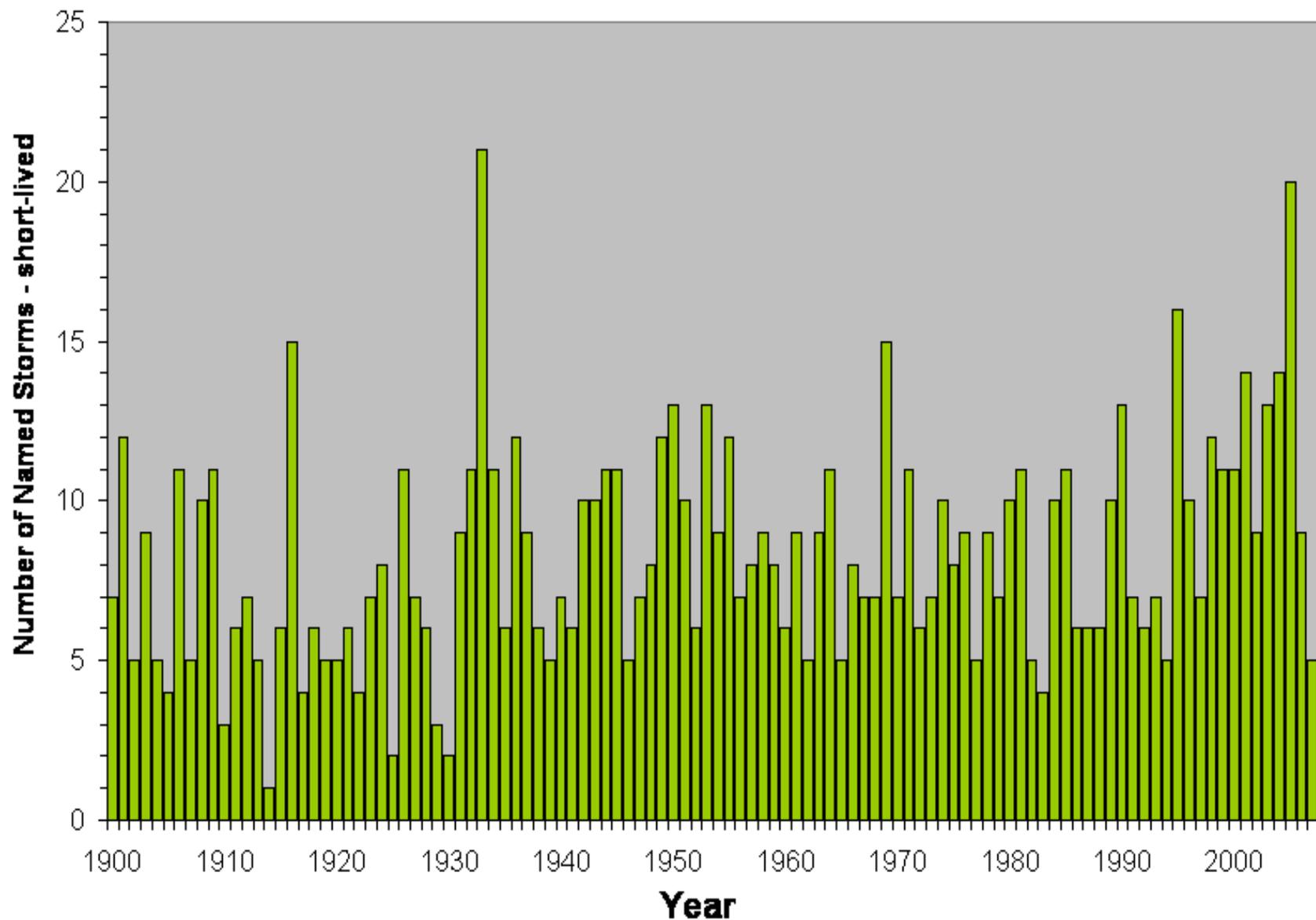


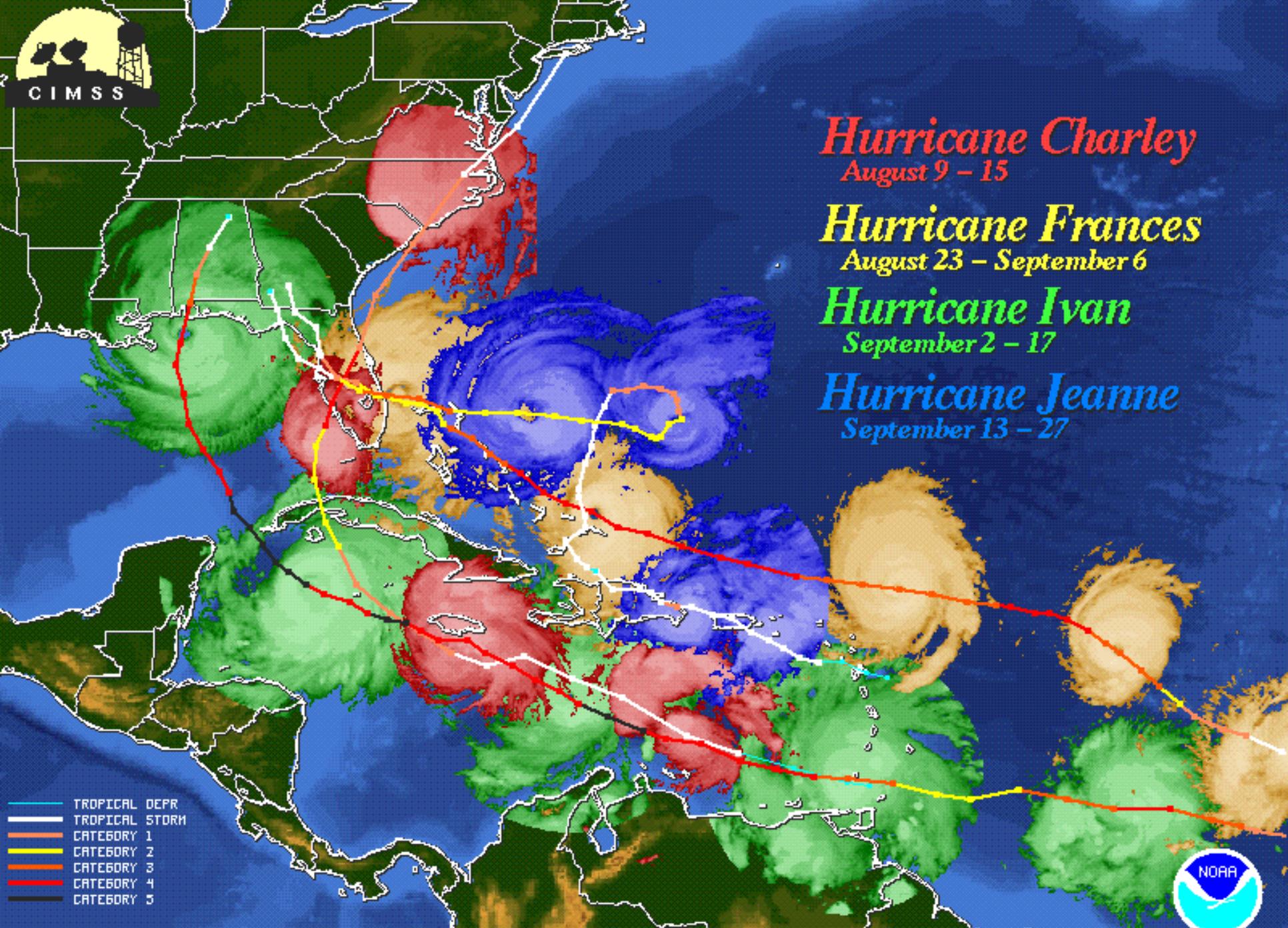
Emanuel (2005)  
Webster et al. (2005)  
Mann/Emanuel (2006)



# Atlantic Tropical Cyclones - Short-Lived

## 1900-2007 Named Storms





*Hurricane Charley*  
August 9 - 15

*Hurricane Frances*  
August 23 - September 6

*Hurricane Ivan*  
September 2 - 17

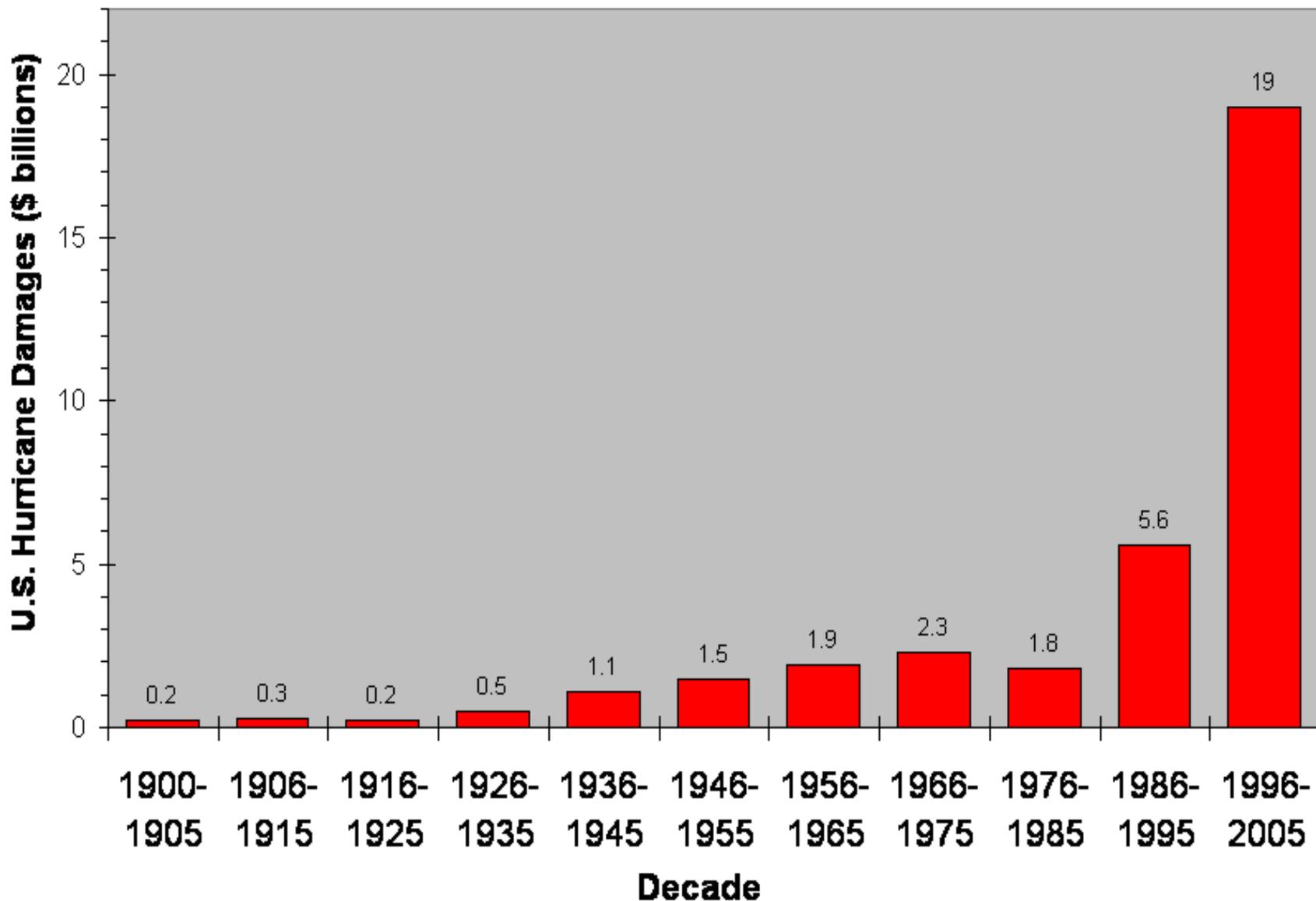
*Hurricane Jeanne*  
September 13 - 27

- 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

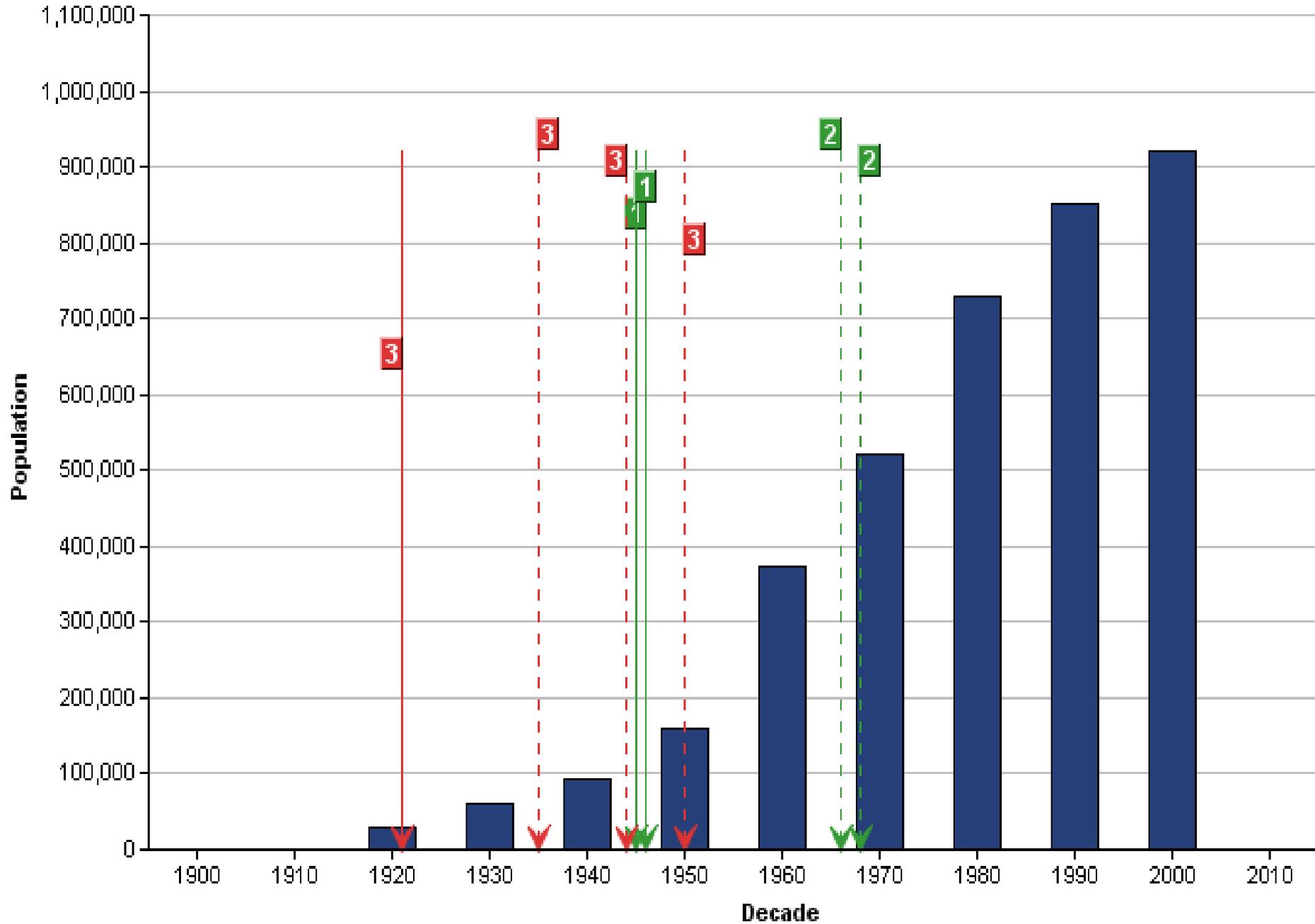


Increases in personal wealth (people have more “stuff”, and larger homes to stow their stuff, etc.) has led to greatly increased damage from hurricanes.





# Hurricane Strikes vs Population for Pinellas, 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)

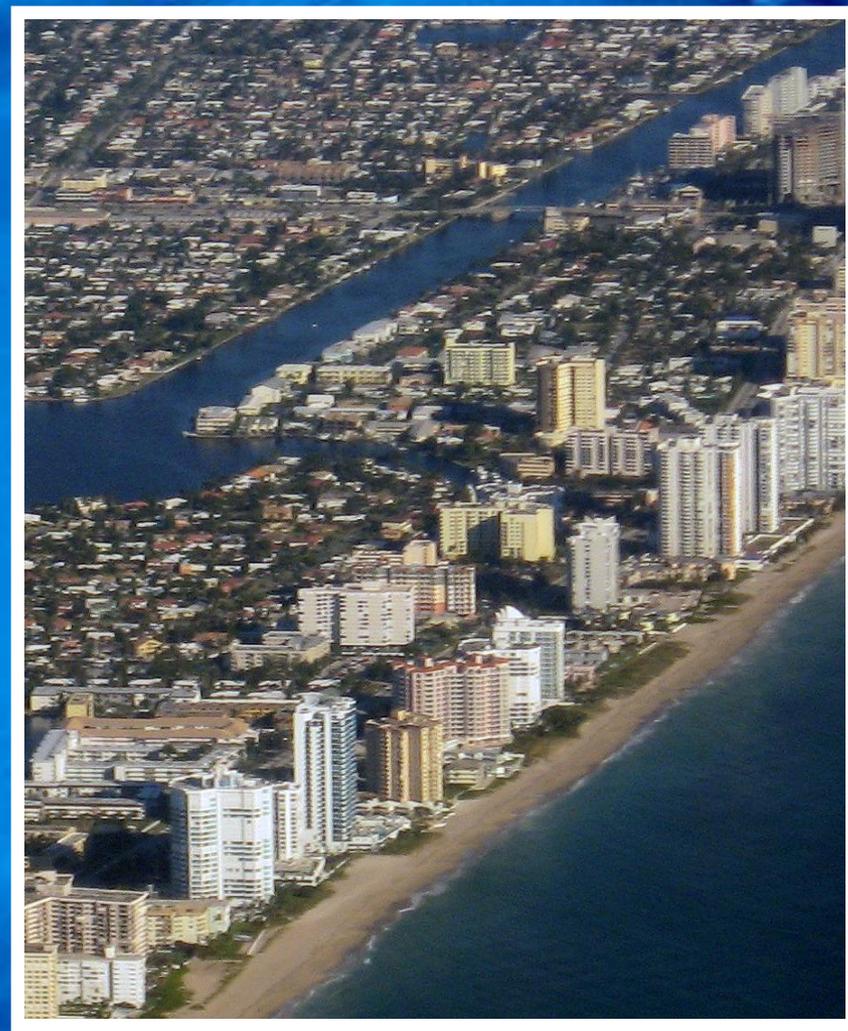
# 1926 GREAT MIAMI HURRICANE

\$140-157 BILLION TODAY

Miami Beach 1926



Miami Beach 2006



# U.S. Tropical Storm and Hurricane Damages

## \$BILLIONS Annually - Normalized

