

**22nd Annual Governor's Hurricane
Conference**

Ft. Lauderdale, May 12-16, 2008

The **HOT Debate:
*Is There a Link between
Global Warming
and
Hurricane Activity?***

**Stanley Goldenberg, Research Meteorologist
Hurricane Research Division/AOML/NOAA, Miami, FL**

The Debate on Friday 1030am-Noon

“Global Warming & Hurricanes” WS-G116



Vs.



Dr. Christopher
Landsea



Dr. Kerry Emmanuel
(MIT)

The Battle

Over

Global Warming and Hurricanes

You are committing
Scientific Suicide

You have fossilized brains!

You are a GANG of 5!
Your Science is sloppy!



Global Warming Definitions

- Confusion of terms:
 - AGW (Anthropogenic (man-made) Global Warming)
 - ≠ Global Warming ≠ Climate Change
- Just because the earth has warmed $\sim 0.7^{\circ}\text{C}$ in last 100 years ≠ AGW!
- Just because climate changes happen ≠ AGW!
- Just because weather disasters happen ≠ AGW!
(Burma?)
- "An Inconvenient Truth" and most in media are speaking of
CAGW (CATASTROPHIC Anthropogenic Global Warming)
- FACT -- there are numerous scientists who 1) do not believe that the majority of the warming we have been seeing is anthropogenic and 2) do not believe we will experience CAGW

Global Warming and Hurricane Activity

- We have “observed” a long-term warming trend in tropical oceans.
- I will simply refer to that as “global warming” -- but will not infer it is anthropogenic (AGW). Also, we do NOT know with ANY DEGREE OF CERTAINTY how long the warming will continue and if it does, how much it will continue to increase.
- Future projections are based primarily on GCM (Global Climate Models) results with increased CO₂.
- Historical results here are based on attempted associations between observed historical long-term warming trend (whether it be natural or man-made or a combination of the two).
- Have current levels of activity been affected by GW?

Problems with Using Historical TC Data Base

Non-Homogeneity of Data -1

- **Temporal Non-Homogeneity**
 - **New observational platforms & tools continually added**
 - Prior to **1944**: Only ship (when/how do they measure and report + they AVOID storms if possible!)
 - **Aircraft Reconnaissance Aircraft --- 1944 to present**
 - Shorter period in WPAC (no longer routinely done there)
 - Aircraft equipment and measurement techniques constantly evolving/improving
 - Interpretation of data evolving (Andrew -- upgraded from Cat 4 to Cat 5 10 years later)
 - **Improvements to Land Observations**
Better stations, RAOBS, radar, doppler radar)
 - **Addition of satellite observations**
 - Continual monitoring **1966** onward
 - New satellites, instrumentations and analysis techniques constantly evolving/improving
 - Dvorak technique -- Visible -- early 70's, **IR mid-1980's**

Problems with Using Historical TC Data Base

Non-Homogeneity of Data -2

- **Spatial Non-Homogeneity**
 - Data quality varies tremendously between different basins or different parts of same (Atlantic) basin.
 - Earlier -- depended on ship tracks.
 - Next -- depended on Aircraft recon. flight patterns.
 - Satellite coverage used to be far from uniform
- **Many of the alleged AGW-related increases or trend match changes in data measurements very closely.**
E.g. SSTs increasing as observational coverage increasing
- **Similar trends do not indicate association --**

TROPICAL CYCLONE PARAMETERS: DEFINITIONS

DEPRESSION (DEP): ≤ 38 mph

(with organized convection and closed surface circulation)

TROPICAL STORMS (TS): 39 to <73 mph

HURRICANES (HR): ≥ 74 mph

MAJOR (or “INTENSE”) HURRICANES (MH): ≥ 111 mph

(Saffir/Simpson scale categories 3, 4 & 5)

1. **NS:** # of **TS** & **HR** (**Named **Sto**rms)**

2. **HR:** # of **HR**

3. **MH:** # of **MH**

4. **NSD:** # of **NS** days * *(*) by 6-hr increments)*

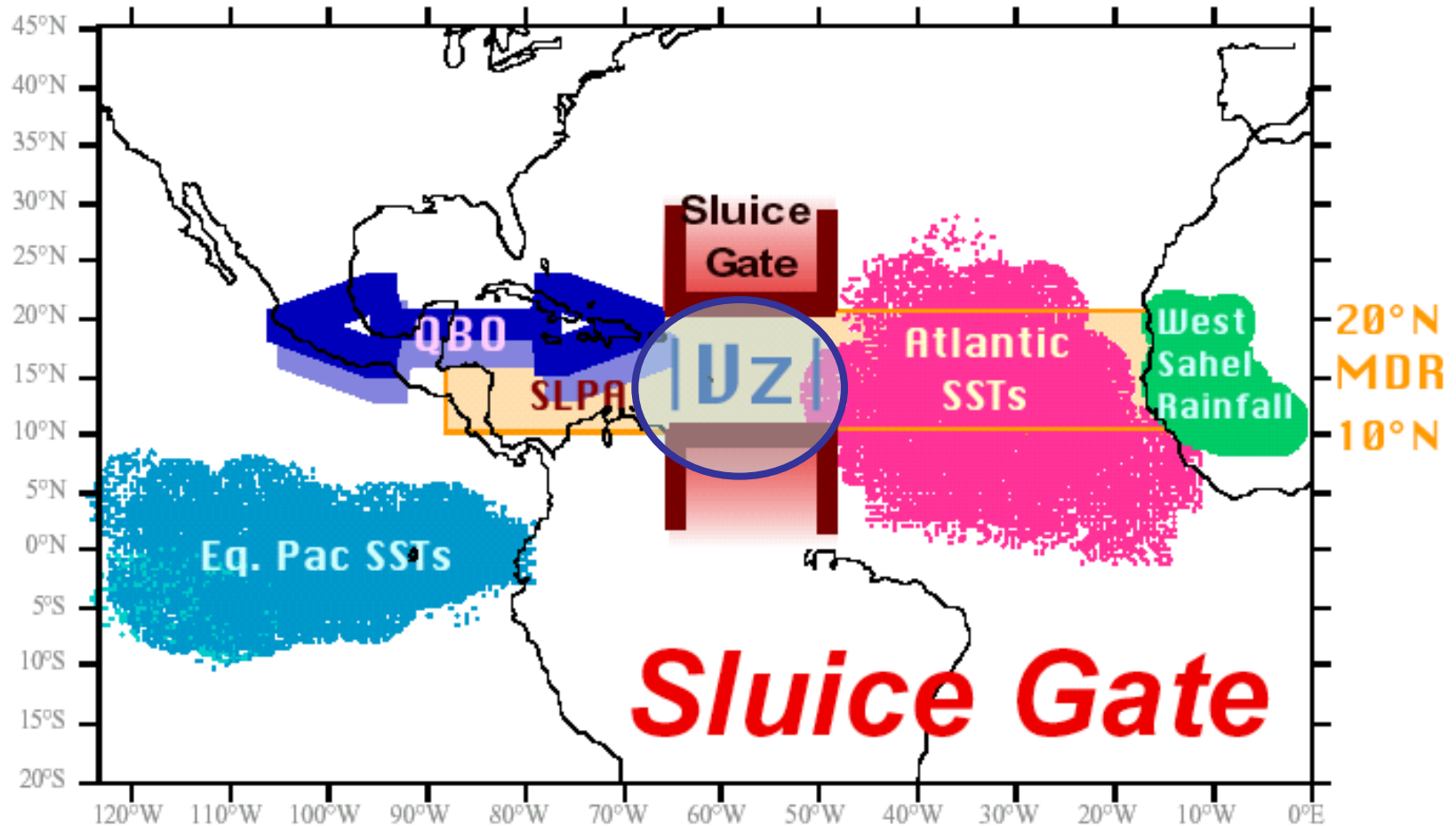
5. **HRD:** # of **HR** days *

6. **MHD:** # of **MH** days *

7. **NTC (Net Tropical Cyclone Activity)** (100% is long-term average)
 $= (\%NS + \%HR + \%MH + \%NSD + \%HRD + \%MHD) / 6$

8. **ACE (Accumulated Cyclone Energy):** Sum (Max-wnd)² **\geq TS**

Climatic Controls for *Main Development Region (MDR)*



"Local" Effects

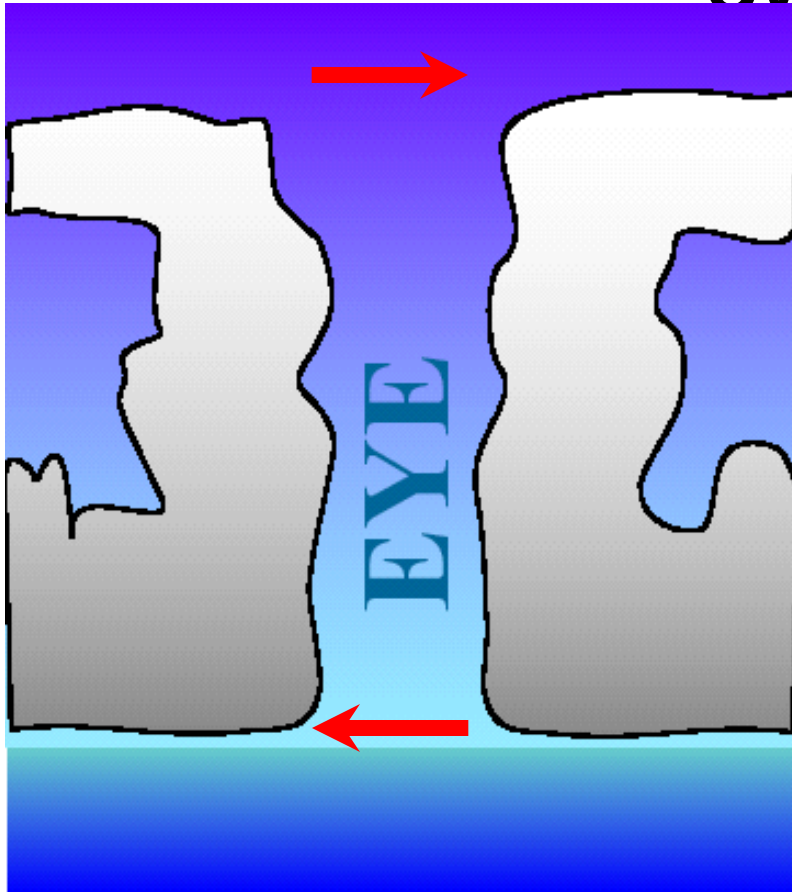
- **Vertical Shear $|Uz|$
- QBO (U30, U50)
- Atlantic SSTs
- SLPA

"Remote" Effects

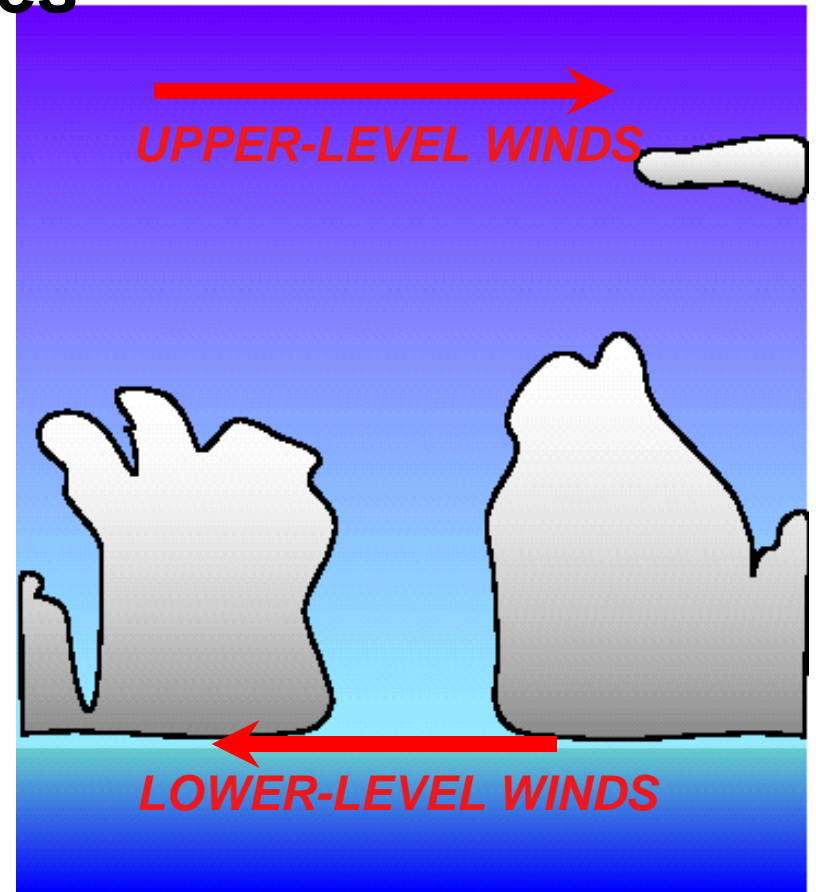
- Eq. Pac SSTs (El Niño/La Niña)
- West Sahel Rainfall

mechanism

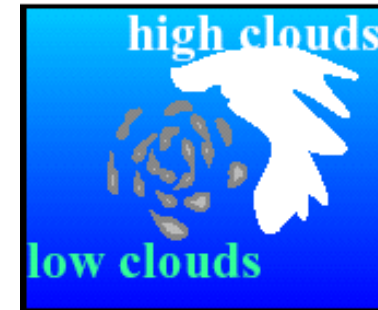
Effects of Vertical Wind Shear (v_z) on Tropical Cyclones



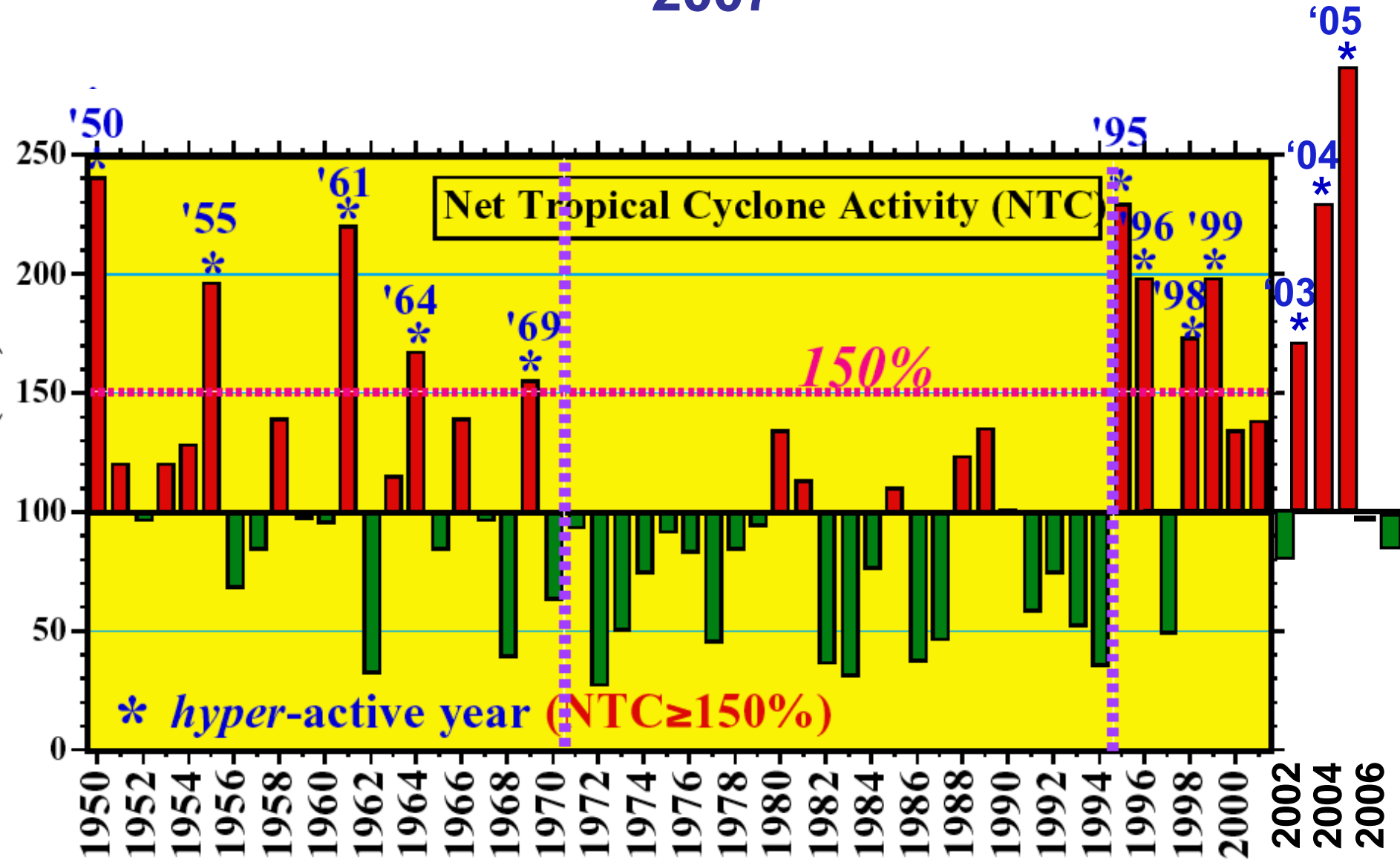
WEAK SHEAR = FAVORABLE



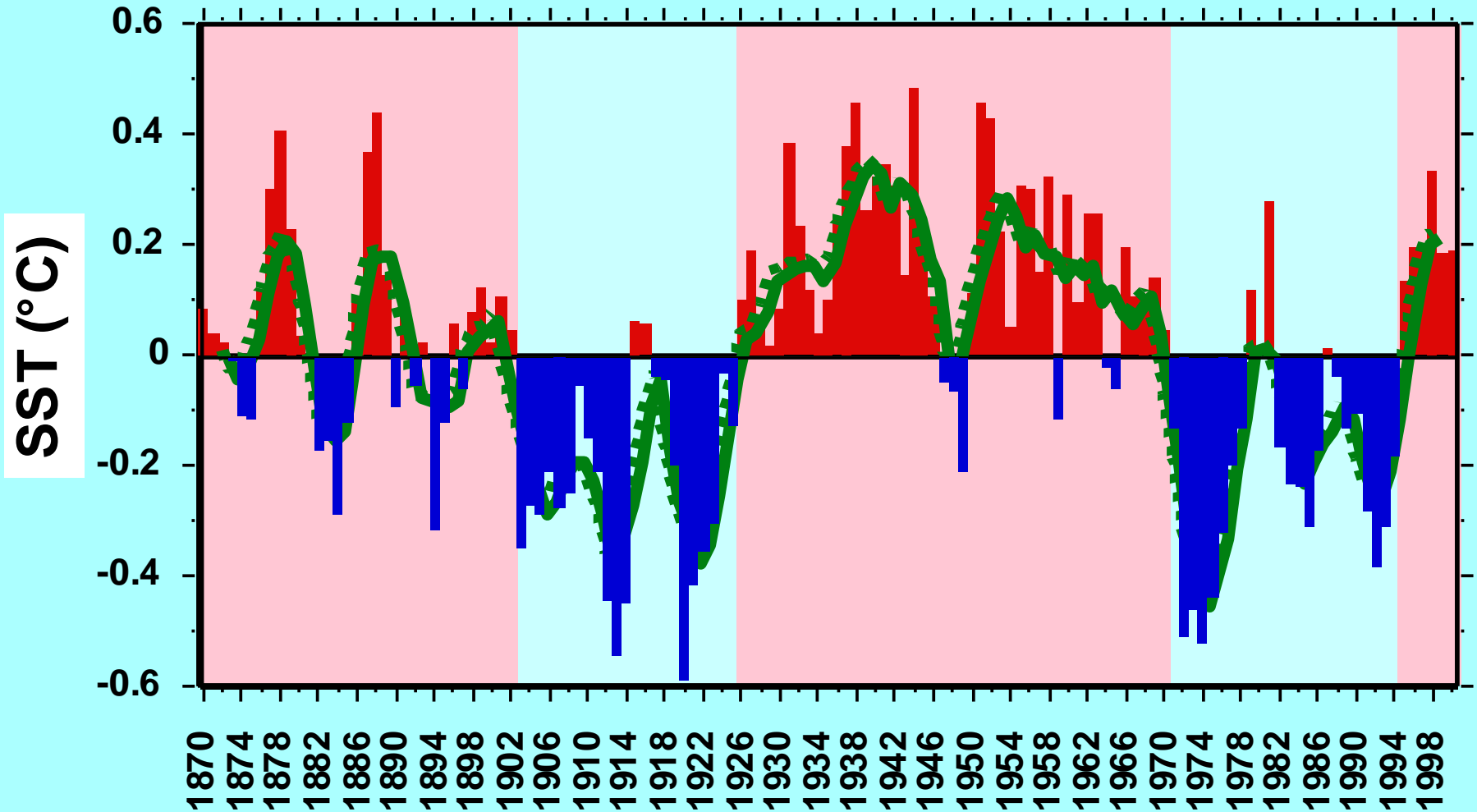
STRONG SHEAR = UNFAVORABLE



Net Tropical Cyclone Activity (NTC %) 1950-2007



Atlantic SST Multidecadal Mode (AMM) (rotated)



Annual means and 5-year RM for N. Atlantic Box

from Goldenberg et al. *Science*, July 20, 2001

NOTE....

*****Increased SSTs don't automatically mean more hurricanes (esp. more MHs) --- it takes changes in atmospheric circulation as well (e.g., lower Vertical Shear).**

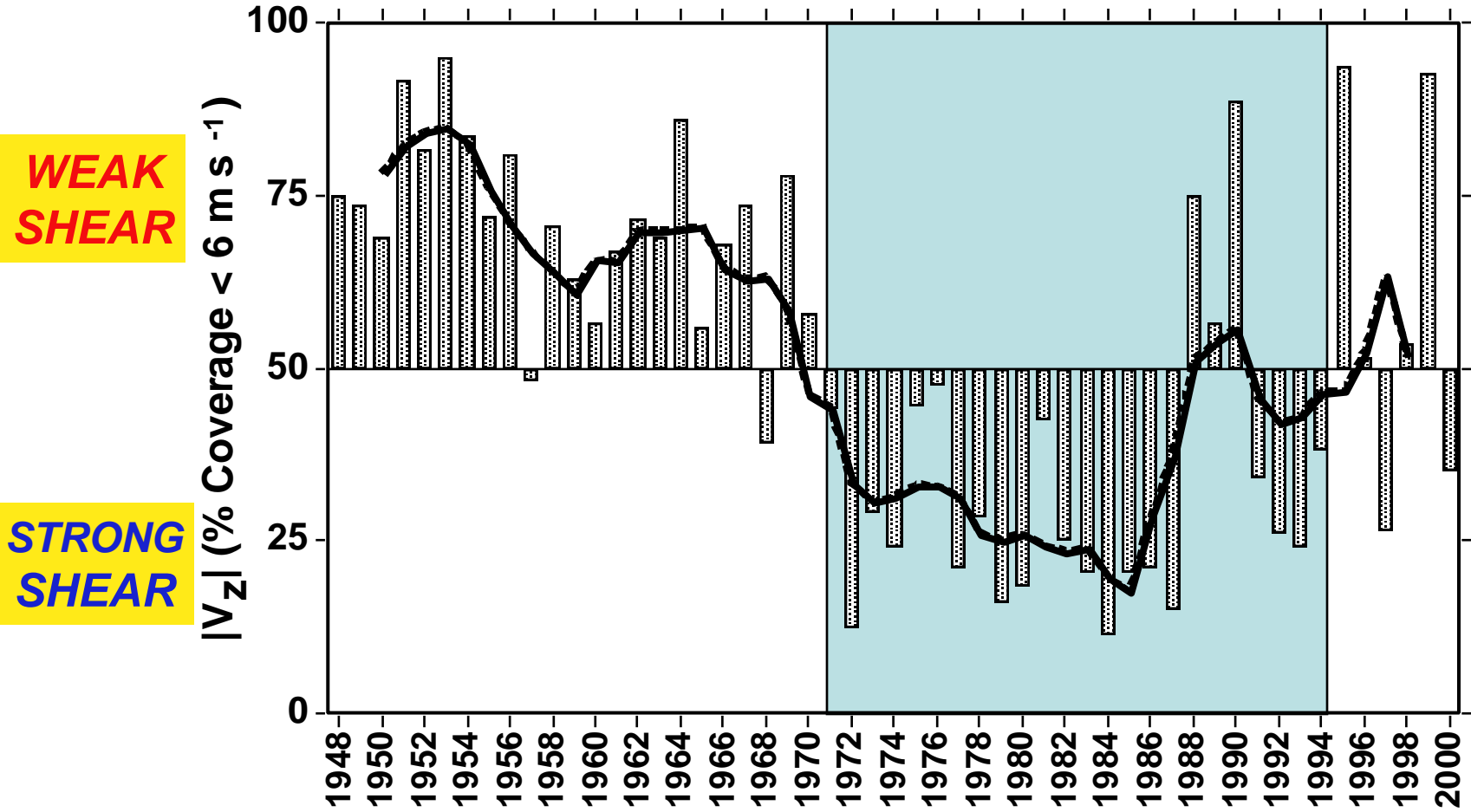
Shapiro & Goldenberg 1998 showed direct (local) effect of SST accounts for only 10% of variance of activity.

E.g., 2006 -- 2nd highest observed SST in main development region (MDR) (almost equal to 2005!) but ACE & NTC only average!

1997 -- MDR SSTs still above average but ACE & NTC < 50%.

The KEY is the change in atmospheric circulation associated with SST changes.

% Coverage of Favorable (< 6 m/s) Vertical Shear (S. Central MDR: 20°-70°W, 10°-14°N)



Summary of main increases since 1995

- LARGE increases!
- Since 1995 not since 2004 or 2005
- Overall activity (NTC): 2X
- Number of Major Hurricanes: 2.5X (Not stronger storms , but more of the stronger storms)
- Caribbean hurricanes: 5X !!
- October/November Major hurricanes: ~10X !! (up from once every 10 years to almost once per year)

Science

20 July 2001

Vol. 293 No. 5529
Pages 381-560 \$9

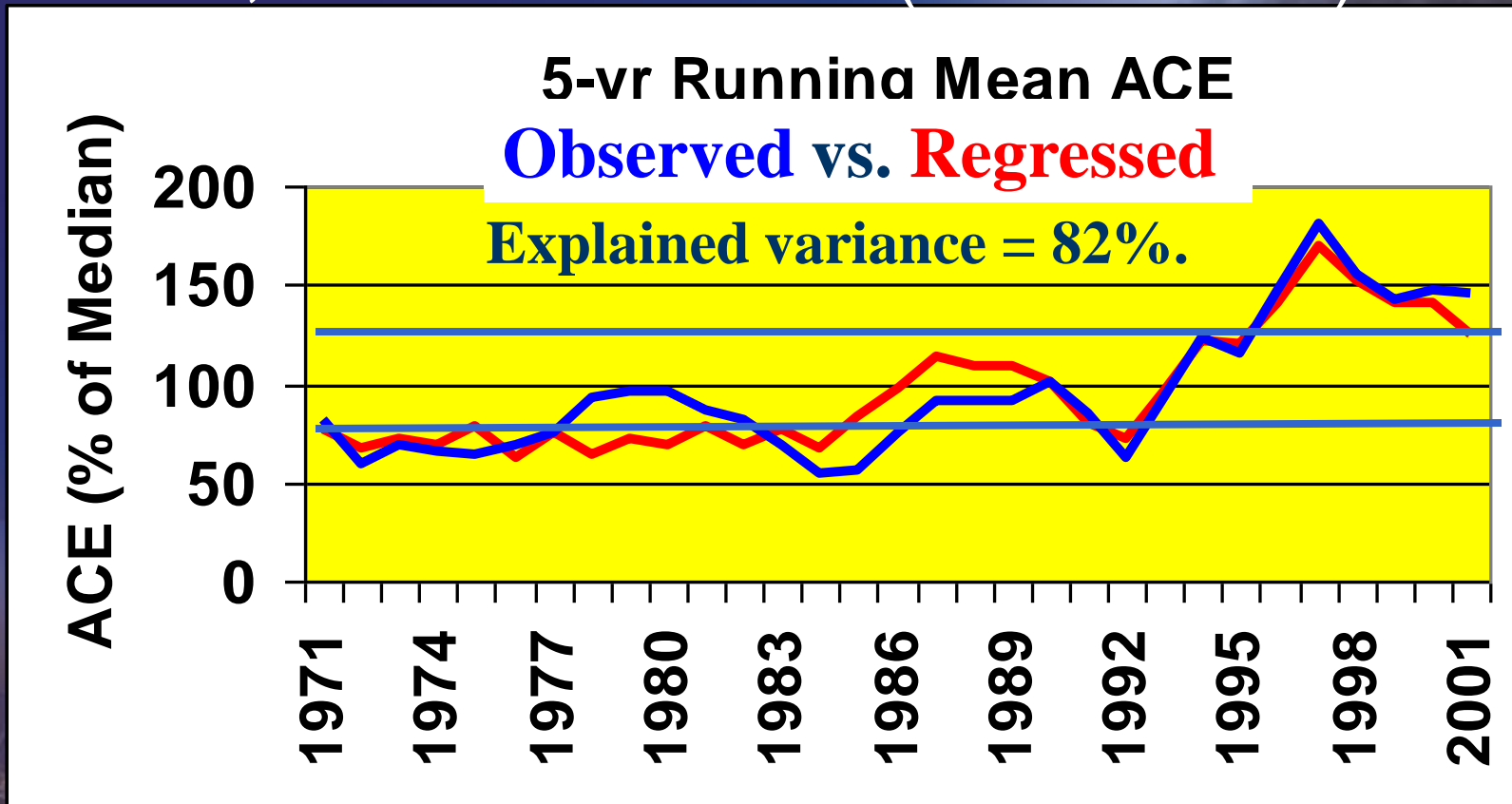


AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

**S. Goldenberg,
C. Landsea,
A. Mestas-
Nuñez & W.
Gray
*Science***

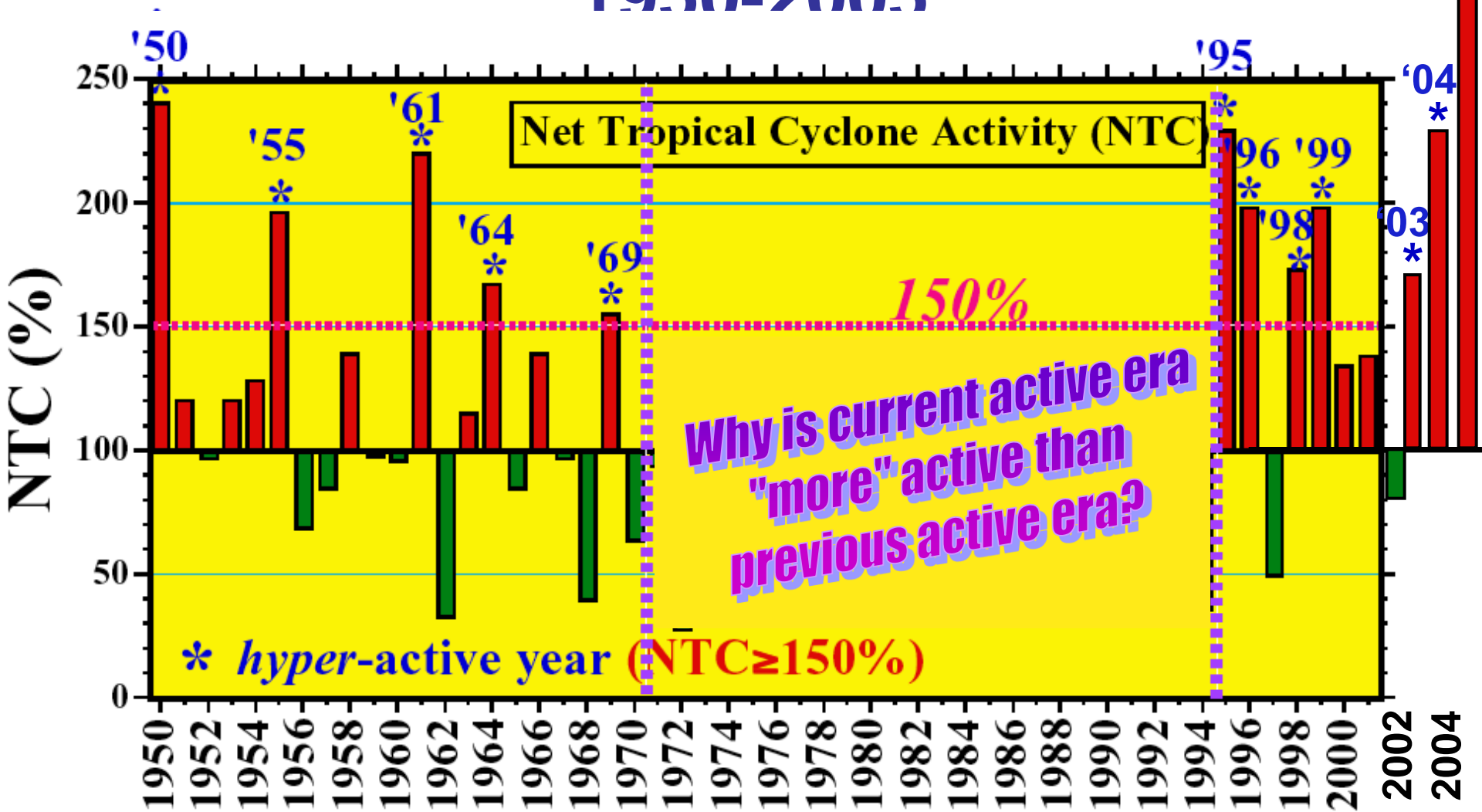
TROPICAL MULTIDECADAL MODE

Bell, G. D. & M. Cheliah (NOAA's CPC)



Current active Atlantic hurricane era associated with phase change in tropical multi-decadal signal. Low Frequency variability in all KEY circulation features strongly related to leading tropical multi-decadal modes. (Used for NOAA Hurr. Outlook)

Net Tropical Cyclone Activity (NTC) 1950-2005



Ending of Science Article (Goldenberg et al. 2001)

- Tropical North Atlantic SST has exhibited a warming trend of $\sim 0.3^{\circ}\text{C}$ over the last 100 years; whereas **Atlantic hurricane activity has not exhibited trend-like variability, but rather distinct multidecadal cycles as documented here and elsewhere...**
- The **possibility** exists that the unprecedented activity since 1995 is the result of a **combination** of the **multidecadal-scale changes in Atlantic SSTs (and vertical shear)** along with the **additional increase in SSTs resulting from the long-term warming trend.**
- It is, however, **equally possible** that the current active period (1995-2000) **only appears more active** than the previous active period (1926-70) **due to the better observational network now in place.** During the previous active period, only 1966-70 had continual satellite coverage. Further study is essential to separate any actual increase from an apparent one due to more complete observations.
- *Note: RECENT DISASTERS HAVE NOT BEEN A*

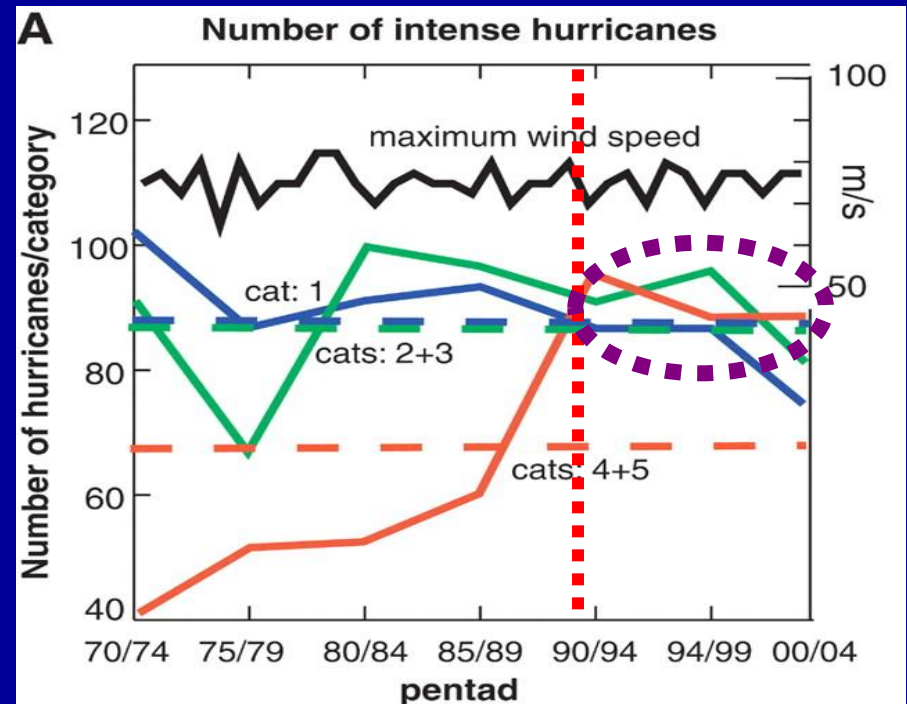
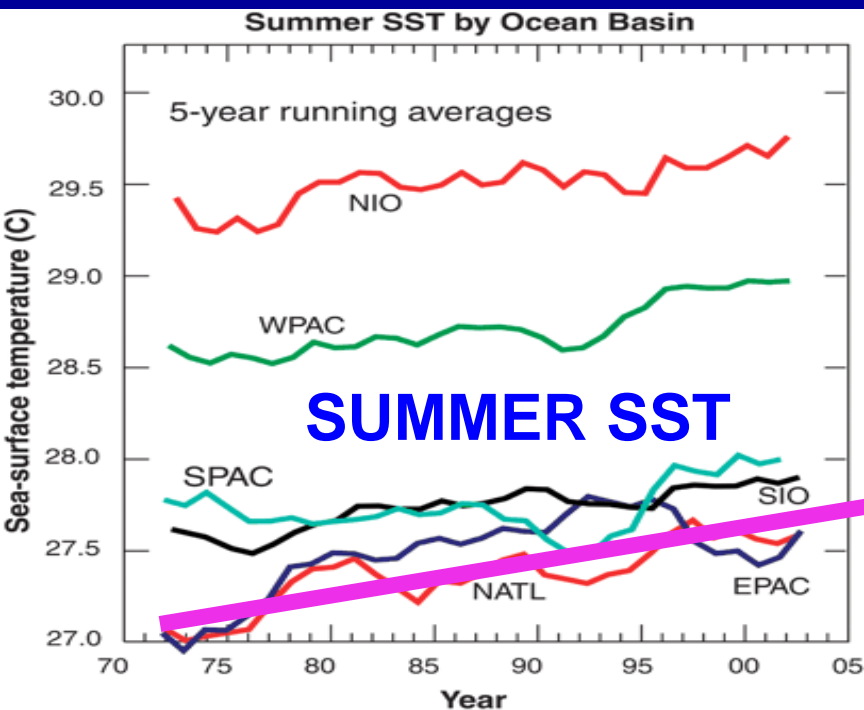
Then came the debate...

- 1) Claims that various types of increases in TC activity are being *caused* by long-term trends (increases) in SSTs (esp. in tropics) (aka AGW),
- The focus not just on increased activity (in NATL) since 1995, but **increased U.S. landfalls (esp. MHs) since 2004.**
- **Tendency** of some in media, gvt. & certain scientific circles **to attribute almost ANY increase in natural disasters to AGW.** *“If it’s bad -- it must be AGW!” (Burma cyclone)*
- The push **by a few prominent scientists** (started in 2004) to announce that the horrible landfalls were from AGW (press conference -- not based on any published articles)!
- 2 published articles (2005) in *Nature* & *Science* attributing so-called trends in activity with AGW --

Webster et al. [Science (9/2005)]

Analyzed Global # of Category 4+5 TC's showing that they nearly DOUBLED in past 35 years."

(Note -- no increase in any other parameter!)
#'s of Cat 4&5 has stayed level in last 15 years (since advent of Dvorak IR technique/)



Responses to Webster et al. (2005)

- Note: Just because it is published in the refereed scientific literature doesn't make it **true!** (Even **Science** or **Nature**)
- **Results challenged by “peer discussion” & peer-reviewed “Comments”**
- Started in 1970 (to use Satellite data) but **AVAILABILITY, QUALITY & ANALYSIS** of satellite data have evolved greatly!
(Dvorak IR technique only used globally since late 1980's)
- Ignored **NATURAL VARIABILITY**:
NATL and WPAC both had higher activity before 1970.
(Started at low point in multi-decadal cycle)
- **Increased SSTs don't automatically mean more hurricanes** (esp. more MHs) --- **it takes changes in atmospheric circulation as well** (e.g., **lower Vertical Shear**).
- **PROBLEMS w/use of data in most of the TC basins!**

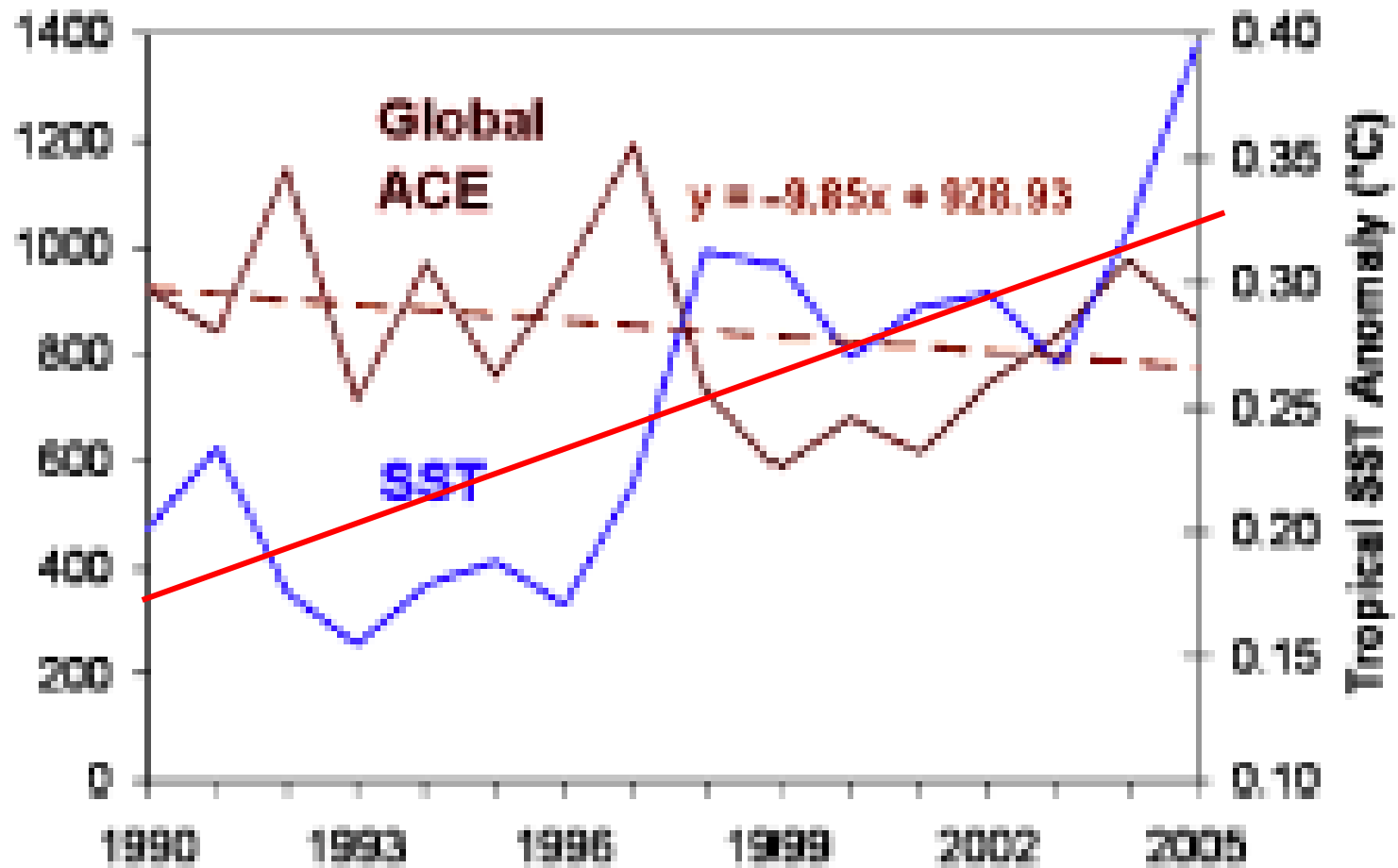
Problems with East Pacific Basin (EPAC)

- EPAC TCs handled by Redwood City, WSFO till 1987, when taken over by NHC.
- 1970-1987, they reported only 2 TCs > 125 kts.
- 1988-2005, NHC reported 20 TCs > 125 kts.
- Note that EPAC is usually MUCH more active when NATL has a slow year. 1970-1987 was an EXTREMELY slow period for NATL! Therefore -- the biases here are even worse than they look!

Problems with West Pacific Basin (WPAC) (From William Gray Comment about Webster et al. on Web)

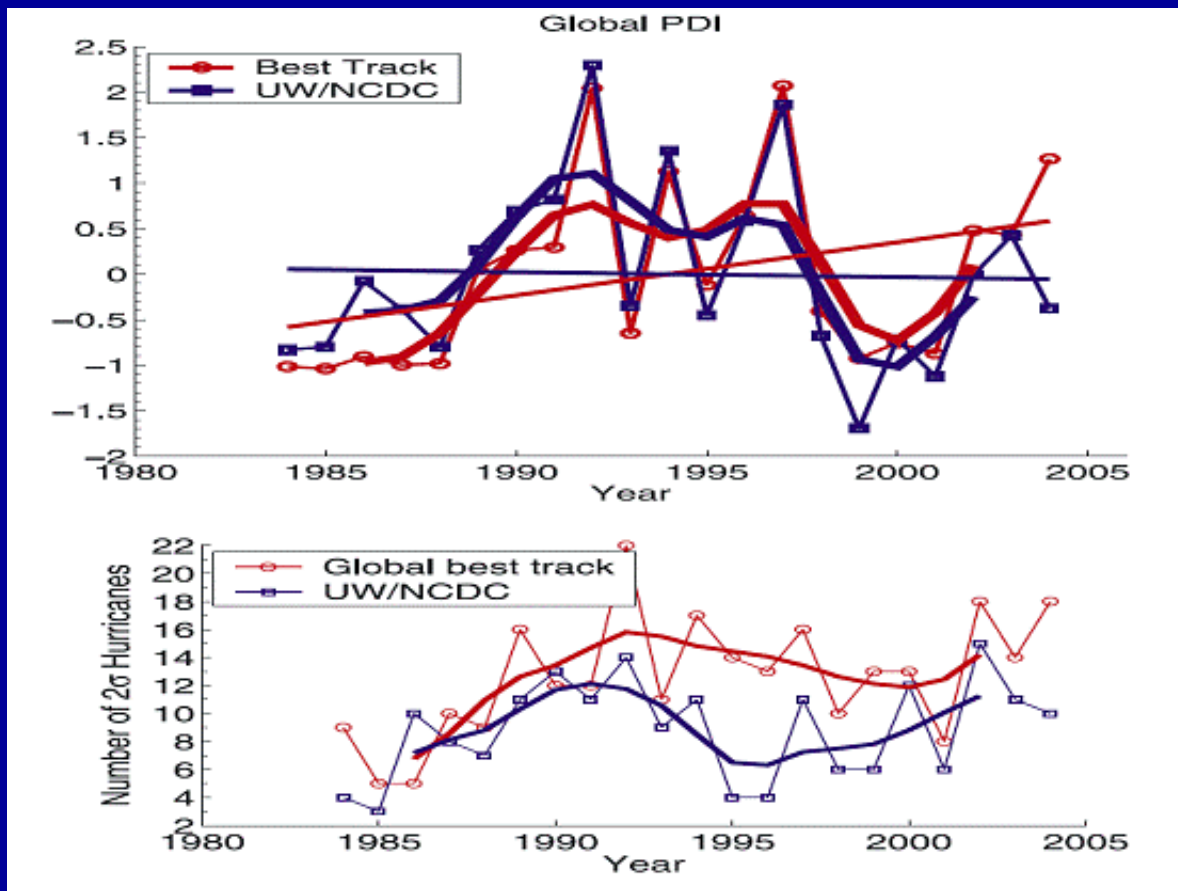
- Last two 10-year period for WPAC show almost no difference in Cat 4+5 numbers: 85-94 (70); 95-04 (65)
- For three eras -- for all Cat 3-4-5 (annual averages), **decadal-scale fluctuations** are evident:
 - 50-72 -- 5.3 (SSTs=28.93°C)
 - 73-86 -- 2.3 (SSTs = 28.92°C)
(Atkinson-Holiday intensity scheme, maybe low)
 - 87-04 -- 4.9 (SSTs = 29.22°C)
- Webster et al. analysis started at low activity point in multidecadal cycle
- WPAC data use also challenged by Chen (2006)

Analysis by *Klotzbach (2006)* shows a downward trend in Global ACE since 1990 even though global SSTs are warming



A globally consistent reanalysis of hurricane variability and trends:

J. P. Kossin, K. R. Knapp, D. J. Vimont, R. J. Murnane, and B. A. Harpe (2007)



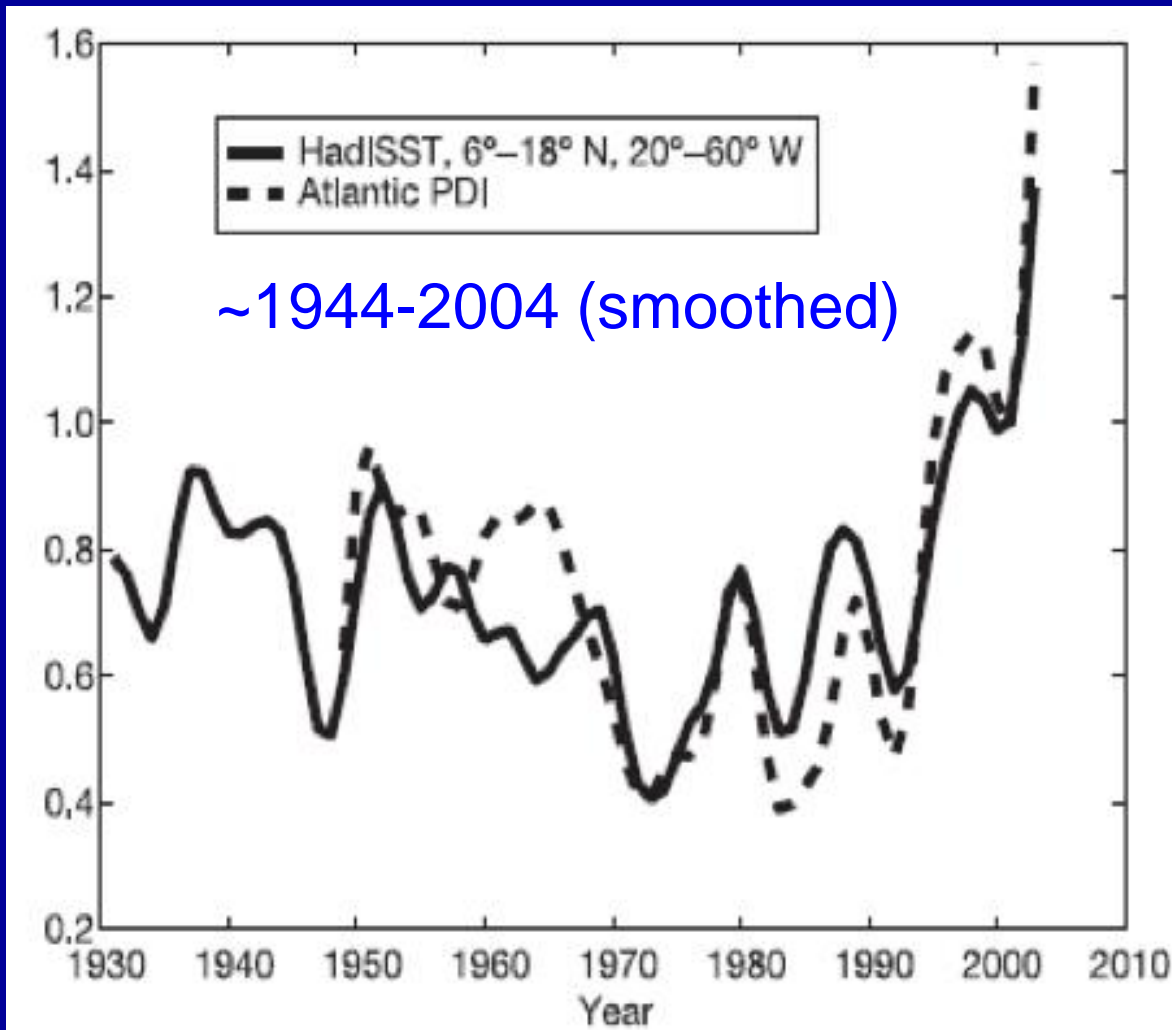
REANALYZED
Satellite data
(1983-2005) by
“degrading” newer
data to match
quality of older
data
(homogeneity)

Upward trend in measures of activity -- PDI (Power Dissipation index -- cube of wind speed) & number of stronger storms -- disappear in homogeneous data sample!

Sounds great -- BUT.....

- Kossin et al. Press Release stated: ***New evidence that global warming fuels stronger Atlantic hurricanes:***
“Atmospheric scientists have uncovered fresh evidence to support the **hotly debated theory** that global warming has contributed to the emergence of stronger hurricanes in the Atlantic Ocean. **The unsettling trend is confined to the Atlantic,** however, and does not hold up in any of the world's other oceans, researchers have also found.”
- Of course -- they started study during LOW era (1983) and ended in HIGH era (2005)! AGW-associated trend or part of a cycle?
- They admitted that there USED TO BE a multidecadal cycle in Atlantic activity, but that, according to work by **Mann* & Emanuel (2006)**, the AMO (Atlantic Multidecadal Mode) is simply driven (at least recently) by AGW! Therefore -- the recent upswing is REALLY from AGW! -- I.e., they say AMO is not really a natural cycle.
- BUT, the **Mann & Emanuel (2006)**, has been challenged by Knight et al. (2006) and a by soon-to-be published study by

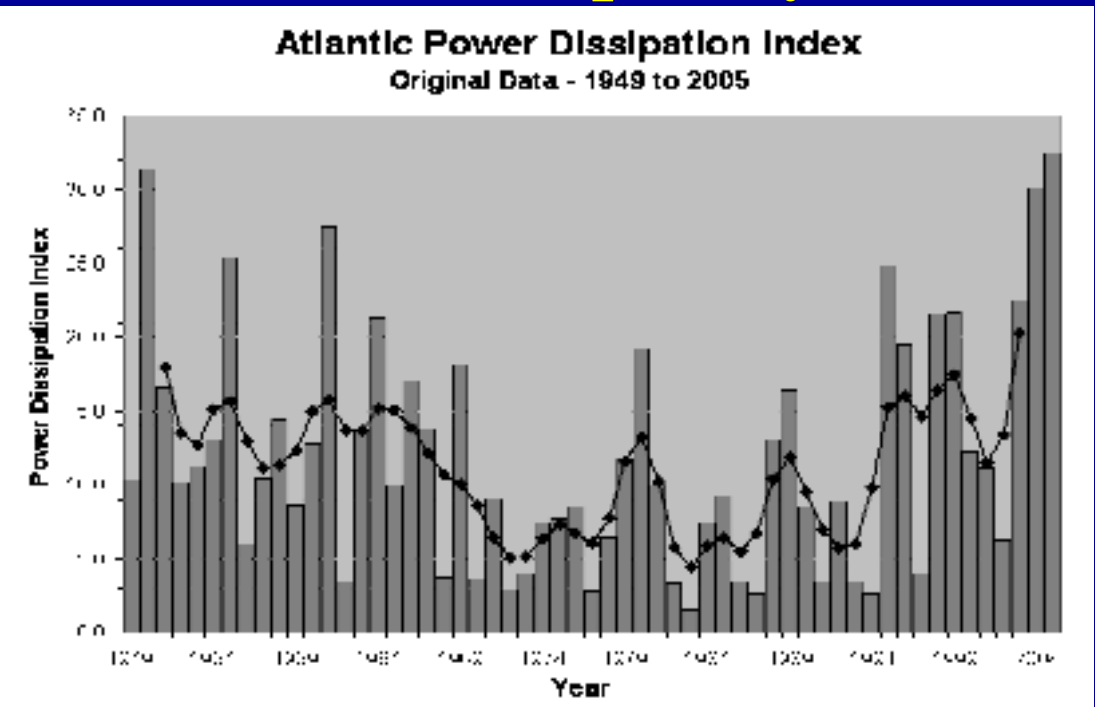
Emanuel's study (Nature 2005): Doubling in Atlantic Hurricane Wind Index – “Unprecedented”



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

Emanuel (2005) challenged by Landsea (2005)

- Stated Emanuel didn't filter end-pts. properly
- Also, Emanuel artificially suppressed previous active era data. (reduced values and then cubed results to get PDI)
- Emanuel study assumes previous active era observed as completely as current one.



Landsea's
Revised
PDI
(Trend
disappears)

Work by Knutson & Colleagues

- Tom Knutson Geophysical Fluid Dynamics Laboratory
 - Have Humans Affected Atlantic Hurricane Climate?
- Threshold temp. changes to 28.5 degrees. (from 26.5)
- Uses findings (Vecchi & Knutson 2007) that GW will INCREASE vertical shear in MDR.
- Overall numbers of storms decrease but slight increase in stronger storms.
- Problems:
 - Storms in his models (GCM) often don't develop in MDR
 - Problems with certain years. These are GCM results!
- They stated that, based on current state of models and ongoing data concerns it is NOT appropriate at this time to attribute PAST changes in activity to

Holland & Webster(2007)

- Showed 100% (doubling) in Atlantic TS and HR frequency during past 100 years (while SSTs have risen $\sim 0.7^{\circ}\text{C}$)
So has AGW DOUBLED Atlantic activity?
- Also claimed regime shifts (significant upward increases in activity and in SSTs)
- The strong increases in the study happened to coincide with known (Goldenberg et al. 2001) shifts between low and high activity eras. (And some of this is being challenged in an upcoming manuscript.)
- No one really knowledgeable in Atlantic data would use overall numbers (of TS, HR or MH) for last 100 years. (Overall data before recon and satellite is NOT reliable.)
- The only indicator of Atlantic activity widely accepted to be somewhat homogeneous for 100 years is IIS

Percent Tropical Cyclones Striking Land

b

1900 to 2006

100%

Percent Tropical Cyclones Striking Land

Landsea 2007
1900-2006

75% -- 1900 to 1965

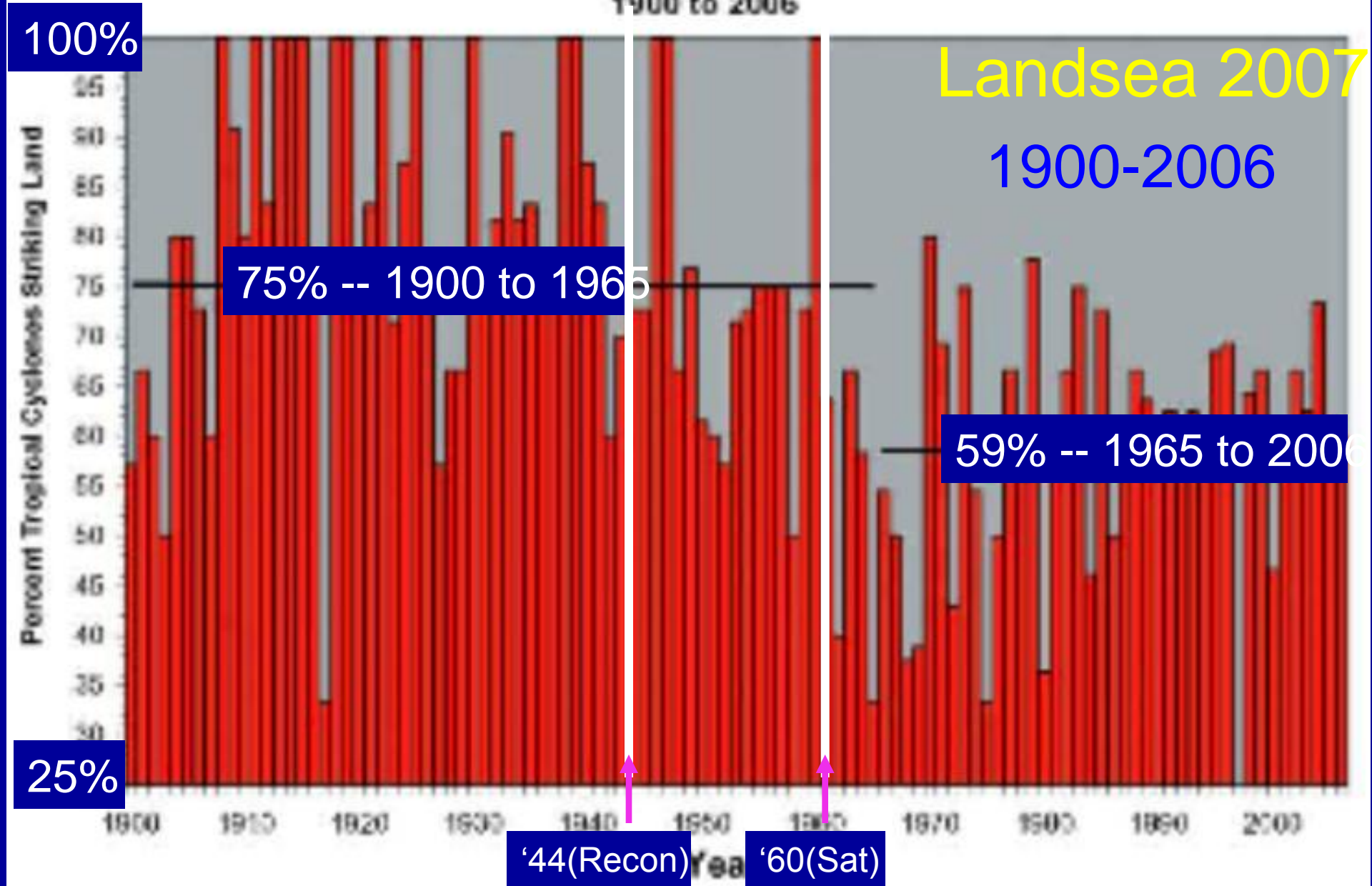
59% -- 1965 to 2006

25%

'44(Recon)

'60(Sat)

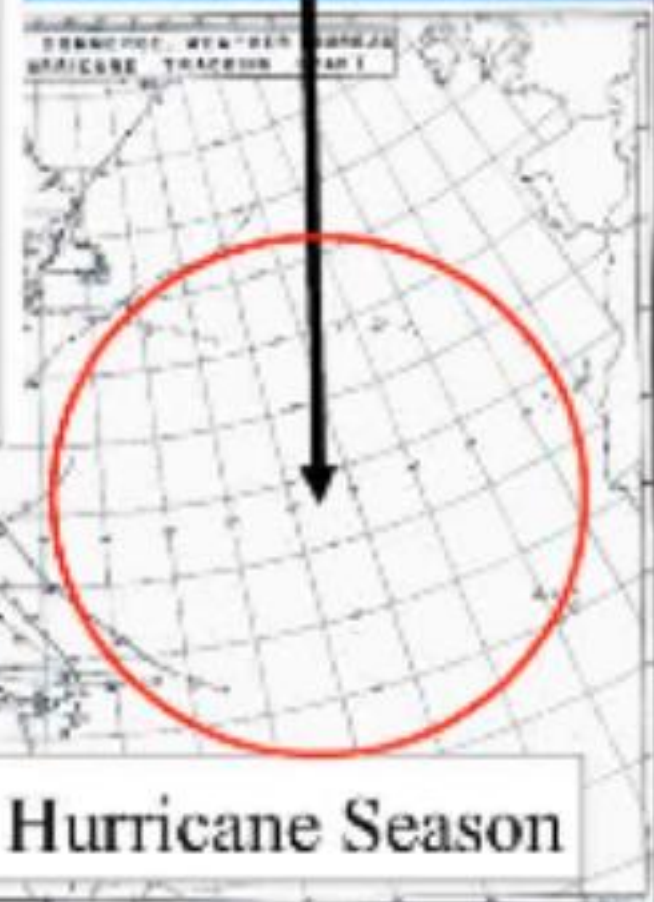
Year



2005 Hurricane Season



Open Atlantic
Ocean Differences



Landsea 2007

1933 Hurricane Season

But Landsea's EOS results (2007) were challenged by Holland's EOS paper (2007)

- Holland (2007) paper: “Misuse of landfall as a proxy for Atlantic tropical cyclone activity.”
- Stated that one of the reasons for smaller percent of storms making landfall in recent years is because the area of development has shifted further east!
- Now Holland is trying to show how we are seeing huge increases in Cat. 5 hurricanes in recent years. (Sounds like Cat 4+5 study....)
- **Brings up important point: Can we ever absolutely prove what activity was missed?**
- We can adjust data by various assumptions, but it can never be fully proved.
- Must use **reasonable assumptions** & some **common sense**.

The first 3 EOF modes of SST (Wang & Lee 2008, Wang et al.

GW Mode
(AGW?)

Increased Vert.
Shear!

Slight **DOWNSWARD**

Trend in **U.S.**

(**Hand falls**)

Three tropical
oceans compete
with each other for
affecting Atlantic
hurricanes.)

Atl. Multidecadal
Mode (AMO)

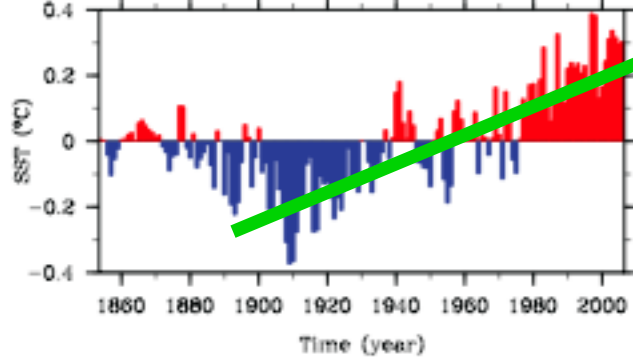
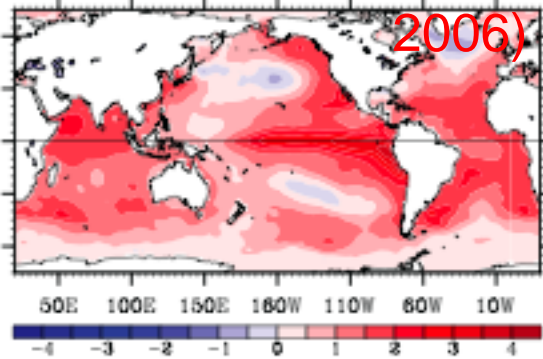
Decreased
Vert. Shear!

Spatial Pattern

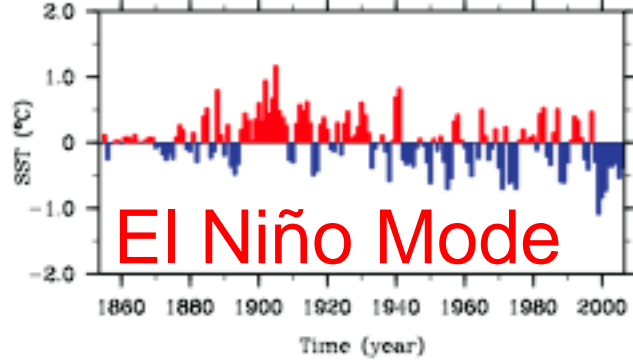
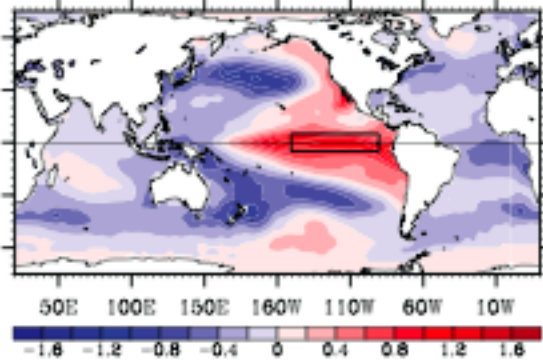
Temporal Variation

SSTs (1854-
2006)

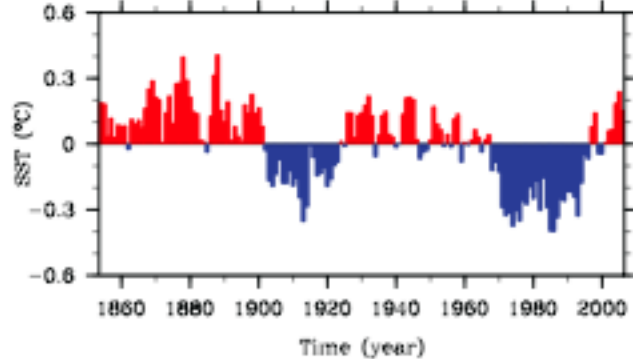
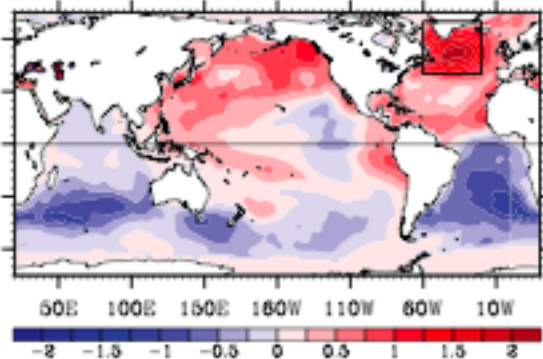
(a) Global Warming Mode



(b) ENSO-like Mode



(c) Atlantic Multidecadal Oscillation



LARGE or SMALL Changes?

- Starting at low-point in activity cycle is like looking at Jan-July St. Louis temps (trend or part of cycle?) -- would indicate HUGE trend! ($\sim 30^{\circ}\text{C}/\text{year}$)
- Looking at changes over several cycles of temporally homogenous data would be like looking at mean July (or mean annual) St. Louis temps for 100 years -- might show small ($\sim 0.7^{\circ}\text{C}/100$ years) increase.

SUMMARY --- DEBATE RAGES ON

- **Historical studies** that carefully use reliable parts of the historical record find **no discernible trend** in any measurement of TC (hurricane) activity in any basin or globally!
- **Future “MODEL” projections** have mixed results **INCREASED VERT. SHEAR => fewer NATL TCs**
But maybe some slightly stronger storms.
(But will this really verify???)
- **How does it matter to YOU? (AGW vs. Natural Var.)**
What would you do differently?
- **Most focus needs to be on understanding the hurricane threat (public awareness) & preparedness!**

The 5 P's of Preparedness

- *P*rotection
- *P*rovisions
- *P*lans
- *P*redictions
- *P*ray!