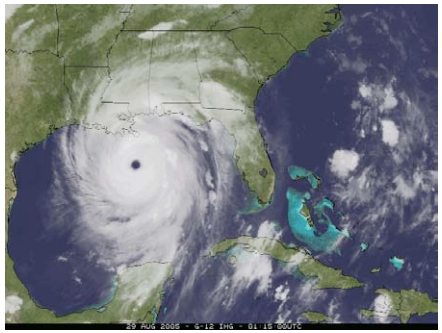
# Walter Orr Roberts Memorial Public Lecture

Aspen Global Change Institute

# Hurricanes and Global Warming: Mixing Science and Politics


## Greg Holland

National Center for Atmospheric Research

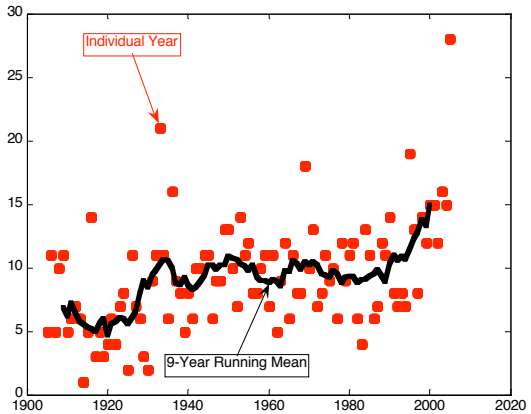
## Summary:

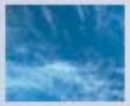
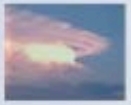
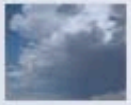
**Politics and Science**

**Climate Impacts on N. Atlantic Hurricanes**

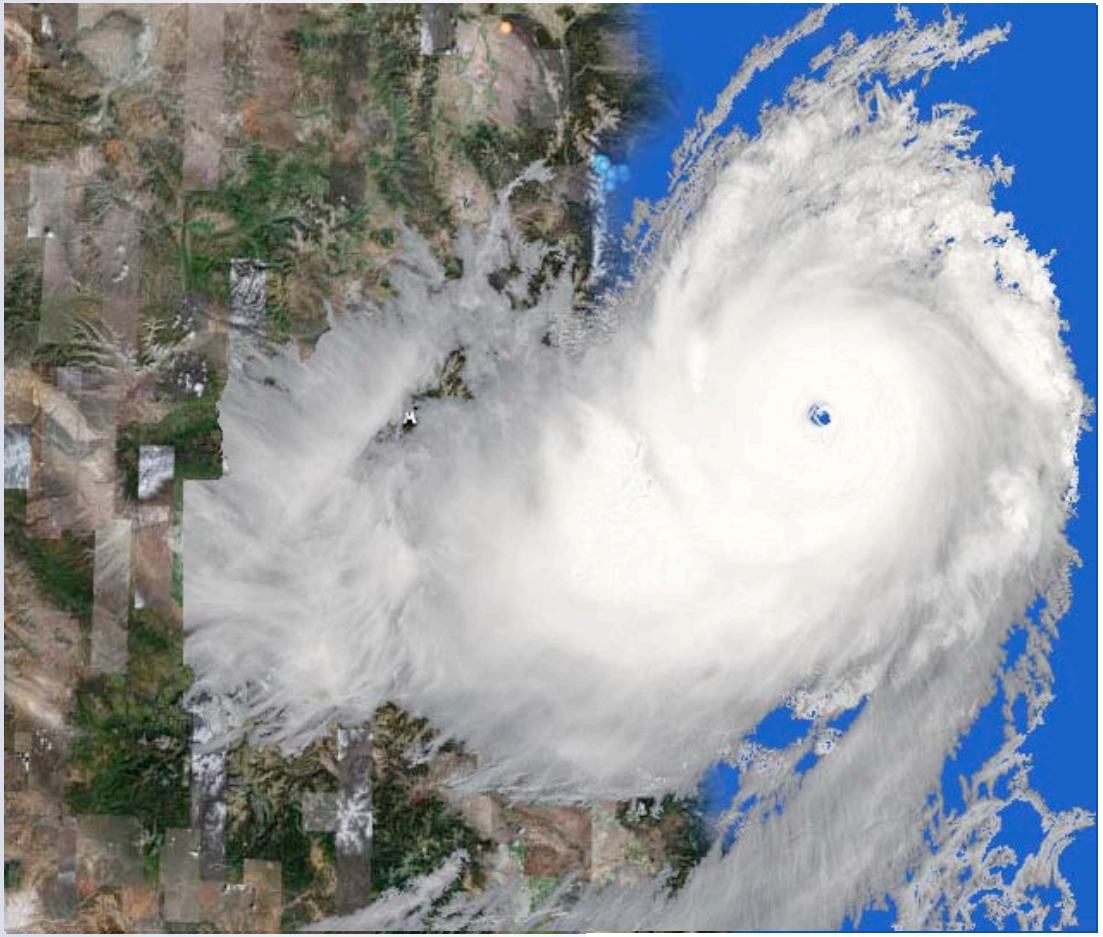
- What is happening
- Attribution

**Some Projections**



# So why talk about Hurricanes in Aspen?



# Politics and Science

# The Calm Before the Storm

- The 2004 Hurricane Season had 4 hurricanes striking Florida, related by Trenberth to global warming;
- Emanuel: Increasing destructiveness of tropical cyclones over the past 30 years. Nature, 436, 686-688; published July 2005;
- Webster, Holland, Curry and Chang: Changes in tropical cyclone number, duration, and intensity in a warming environment. Science, 309, 1844-1846; published August 2005 right between Katrina and Wilma.

# Realization

- **2004 and 2005 brought a sharp public realization that global warming was not some academic exercise, it could result in Katrina-like destruction, and attention shifted to other effects (1000-y drought in SE Australia, ice cap melting)**

**Overtopping of MR GO Levees, New Orleans by Katrina**

# The Political Storm

GLOBAL WARMING INC.
Let's know if there's anything we can do.
HURRICANE
COAL
Pelty

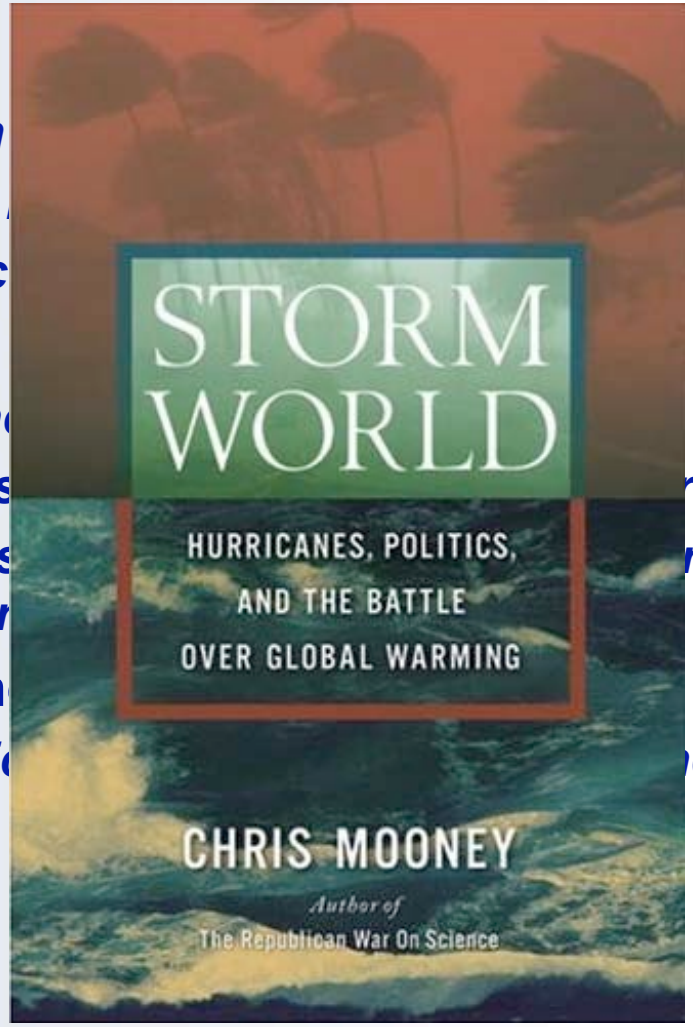
2500 SCIENTISTS SAY WE'VE CAUSED GLOBAL WARMING
TANDBERG
I'D LIKE A SECOND OPINION

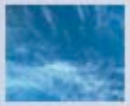
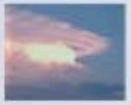
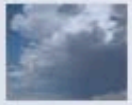
TANDBERG
GLOBAL WARMING CATASTROPHE
I DON'T SUBSCRIBE TO ALARMIST VIEWS

HAIR TONICS
DO YOU HAVE ANYTHING FOR A SHRINKING ICE CAP?
GLOBAL WARMING
BARLING
THE CHRISTIAN SCIENCE MONITOR

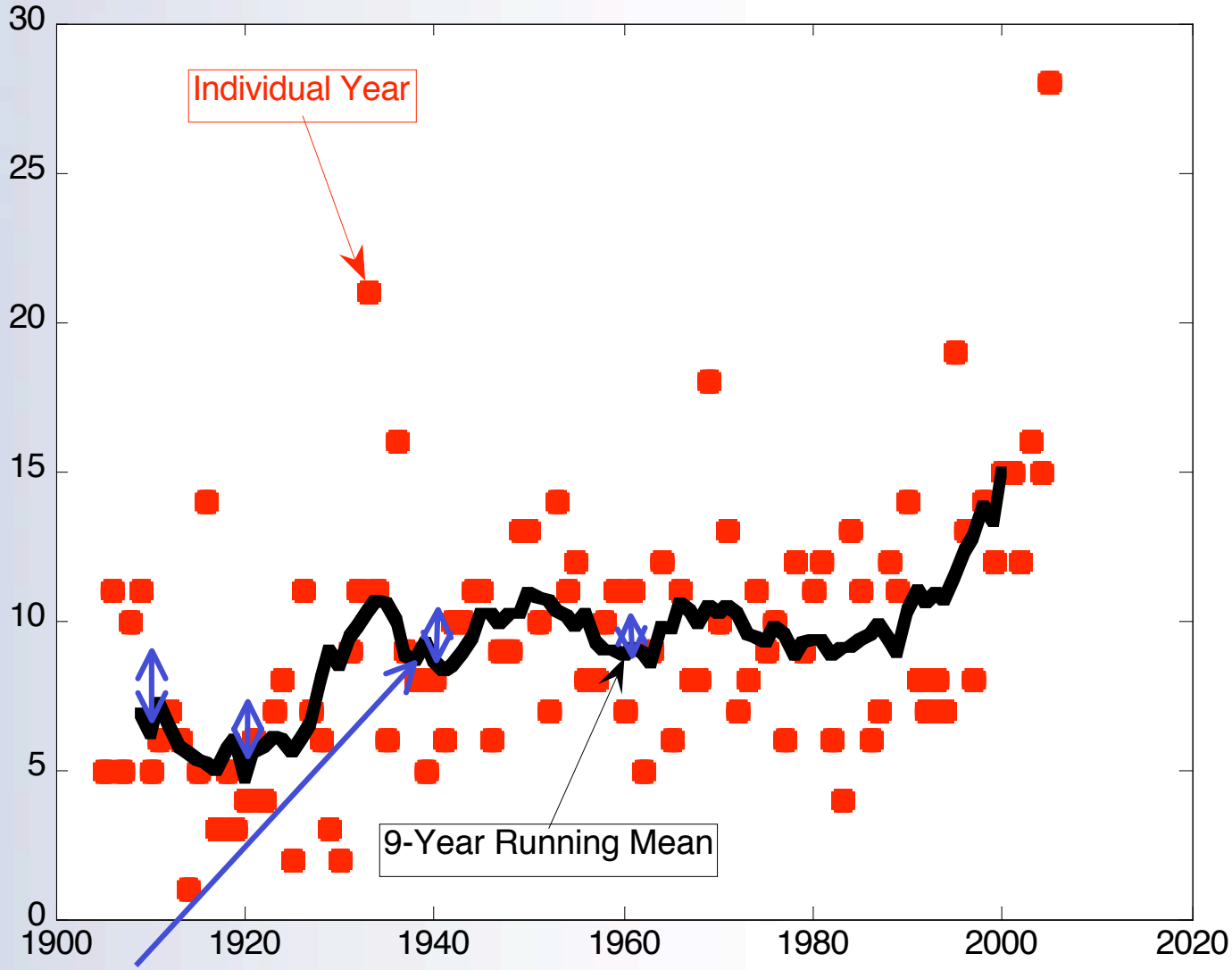
# The Scientific Storm

- **The Downside**
  - *Ad Hominem*
  - *Decisions in*
  - *Tribal Scienc*
- **The Upside**
  - *Enormous In*
  - *Established s* *rricane field*
  - *New students* *ng careers in hurricanes ar*
- **We focus on th** **of the lecture:**
  - *North Atlanti* *d*



# North Atlantic Trends and Variability

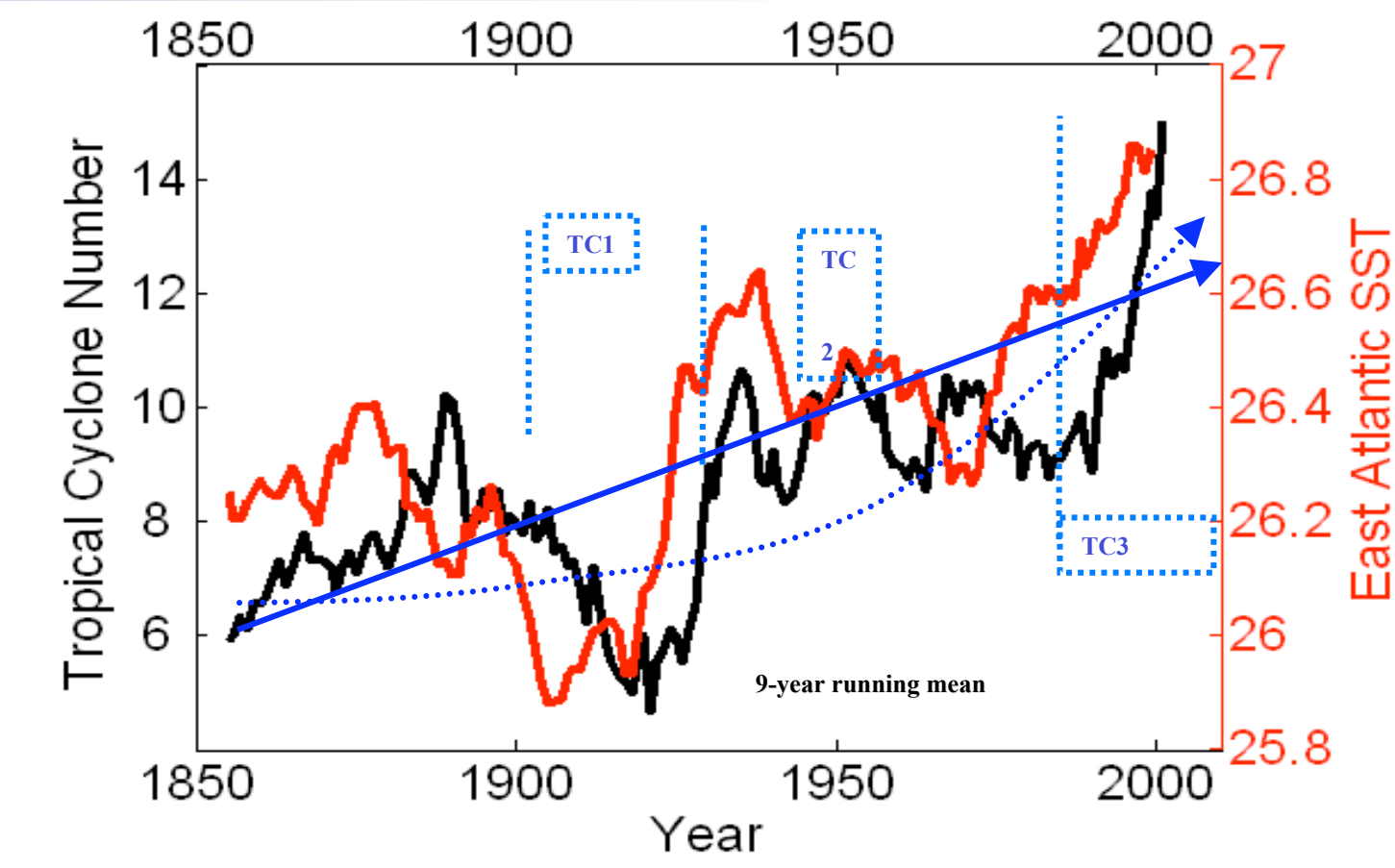



**Error Estimate**

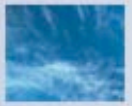
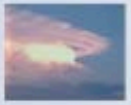
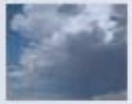


ESSL NCAR

# The Trend




**Based on the archived data an accelerating upward trend is one logical choice, though a series of steps is a more logical choice (both TCs and SSTs)**

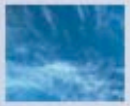
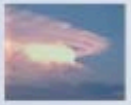
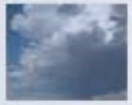
# Climate Regime Statistics

| Regime | Period | Tropical Cyclones | | | Hurricane Proportion | | | East NATL SST Anomaly | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Dev. | Min/Max | Mean | Std. Dev. | Min/Max | Mean | Std. Dev. | Min/ Max |
| TC1 | 1905-1930 | 6.0 | 3.2 | 1/14 | 0.58 | 0.25 | 0/1 | -0.38 | 0.29 | -0.7 +0.3 |
| TC2 | 1931-1994 | 9.7 | 3.1 | 4/21 | 0.53 | 0.16 | 0.13/0.86 | 0.06 | 0.25 | -0.5 +0.7 |
| TC3 | 1995-2005 | 15.2 | 5.1 | 8/28 | 0.55 | 0.12 | 0.33/0.71 | 0.42 | 0.28 | -0.1 +0.8 |

**Note that the regimes are quite distinct from each other. For example, the annual minima from the next regime barely overlap with the mean from the previous one. Note also the remarkably constant proportion of hurricanes.**

**1 TC for each 0.1°C increase in SST**

**1 Hurricane for each 0.2°C increase in SST**

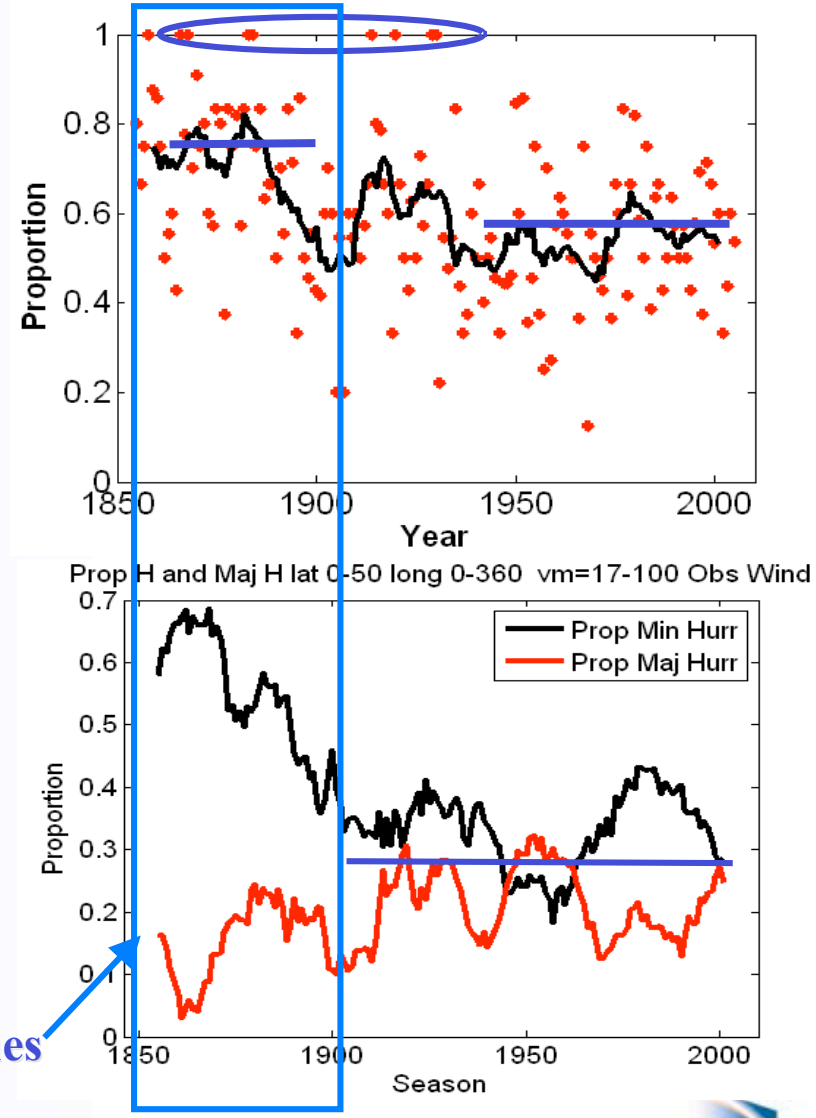




# Hurricane Intensity and Proportions

# Past Hurricane Proportions

- **Stable proportions of hurricanes to all tropical cyclones over the past 50-100 years (the higher earlier proportions are considered due to analysis errors);**

- **Stable major hurricane proportions but with a marked, multi-decadal oscillation (peaks associated with equatorial developments and expansion of the warm pool).**




Data Issues

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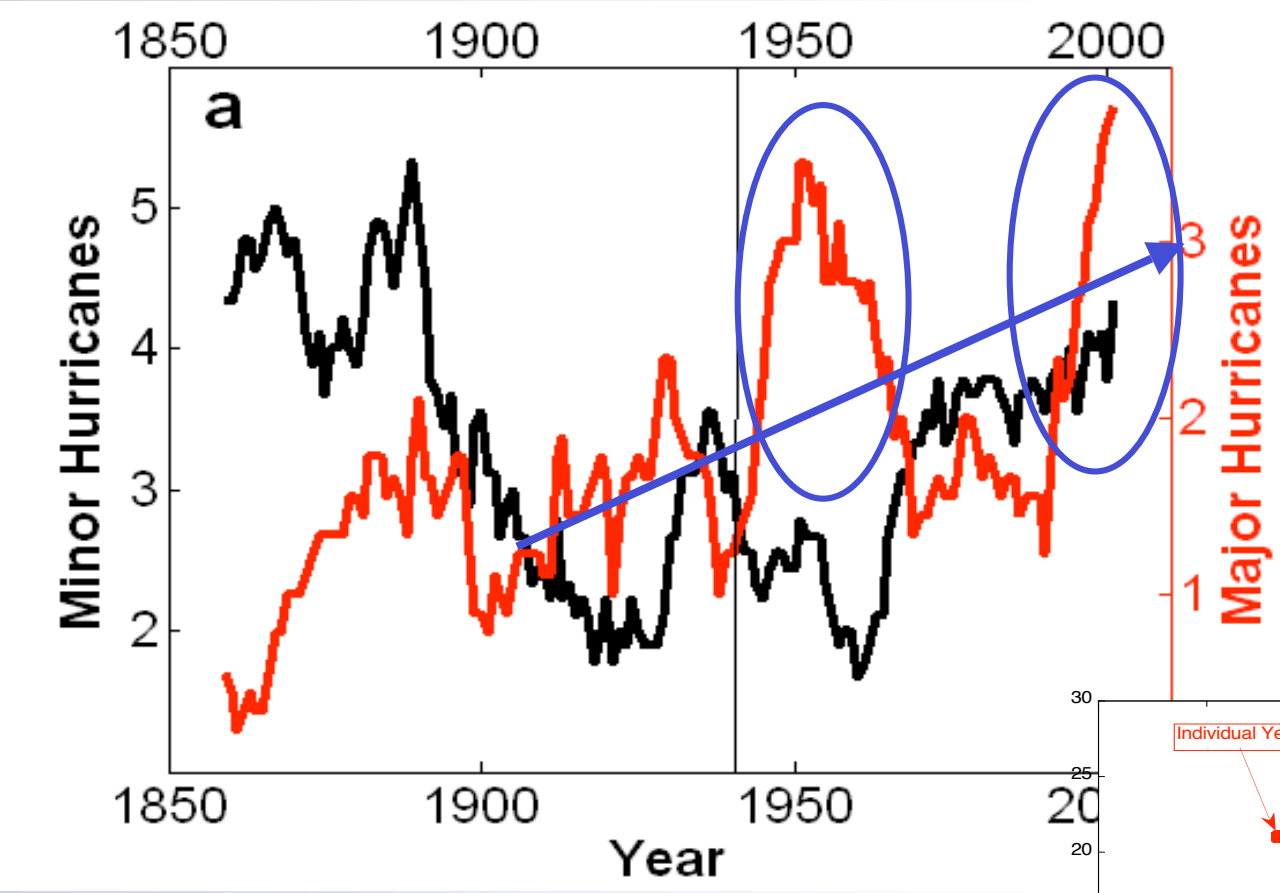
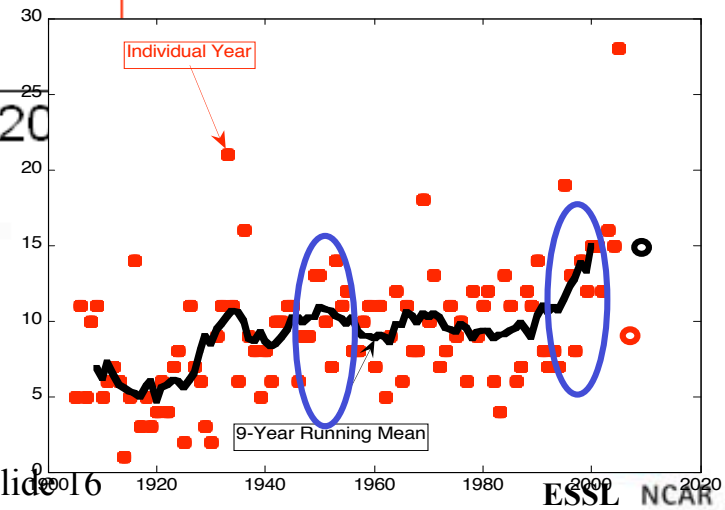
# Past Hurricane Numbers




(Holland and Webster 2007)



# Attribution of Changes

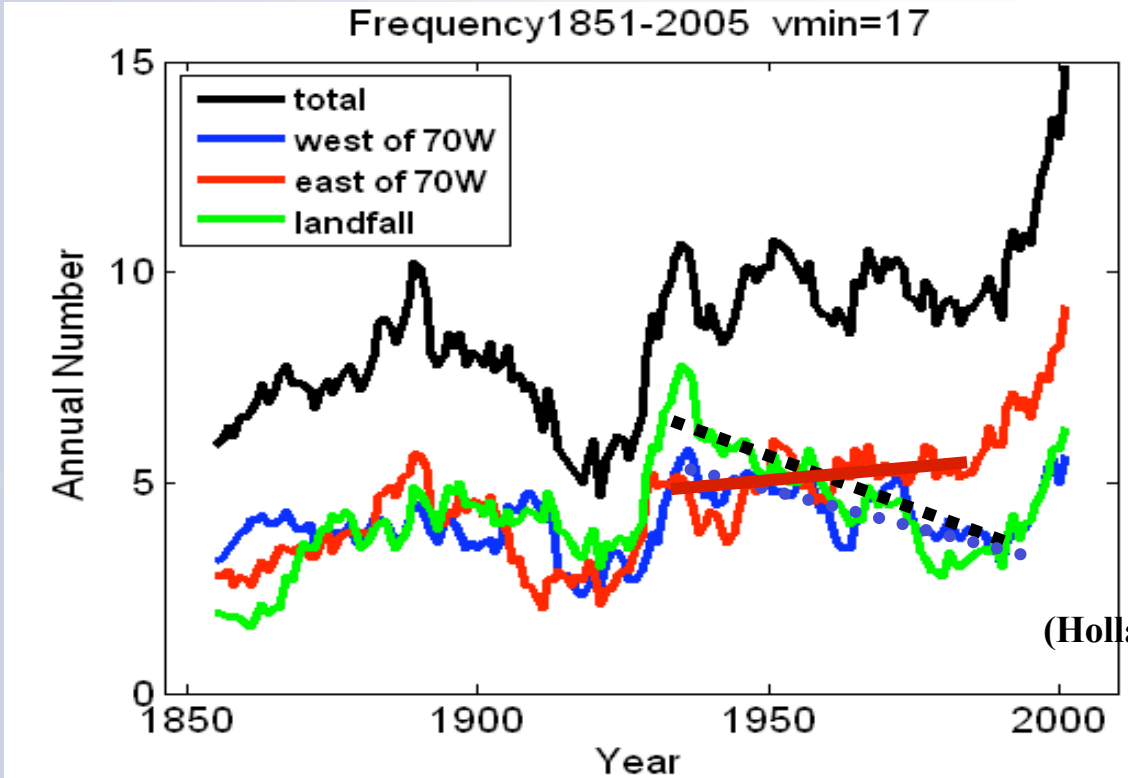
# Attribution by Peak Bodies

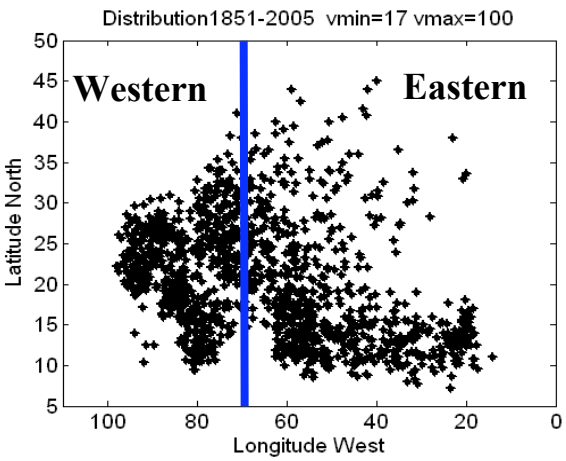
- **WMO IWTC-VI:**
  - **Though there is evidence both for and against the existence of a detectable anthropogenic signal in the tropical cyclone climate record to date, no firm conclusion can be made on this point.**
- **IPCC:**
  - **Likely that increases have occurred in some regions since 1970;**
  - **More likely than not a human contribution to the observed trend;**
  - **Likely that there will be future increasing trends in tropical cyclone intensity and heavy precipitation associated with ongoing increases of tropical SSTs.**

# Attribution to Poor Data in Early Years

- **There is no doubt that cyclones were missed early on, the question is how many?**
  - ***Landsea (2004, 2007) 4-6 < 1900, 2 <1960***
  - ***Neumann (1999) 1 in early years***
  - ***Holland and Webster (2007) 1-2 early -- 0 by 1950***
  - ***Vecci and Knutson (2007) 2.5 < 1900 -- 0 by 1960***
  - ***Holland (2007) 2 <1900 -- 0 by 1950***
- **One issue has been the lack of any trend in landfall in the western Caribbean, Central and North American Regions…..**

# Eastern vs Western Genesis and Landfall



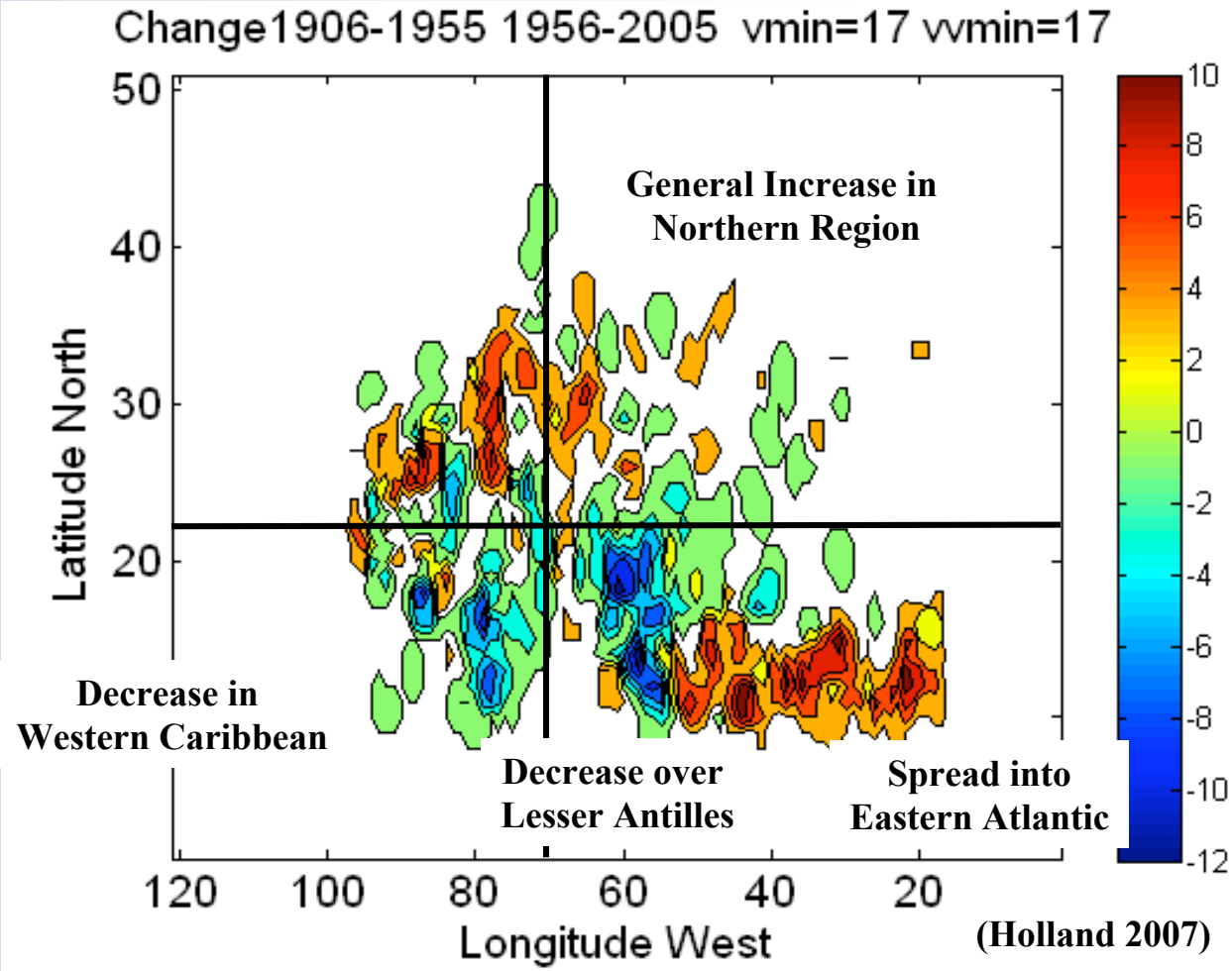




(Holland 2007)

**Note that the step changes in numbers are due equally to western and eastern region genesis!**

**Changing landfall numbers is due largely to decreasing western region genesis!**

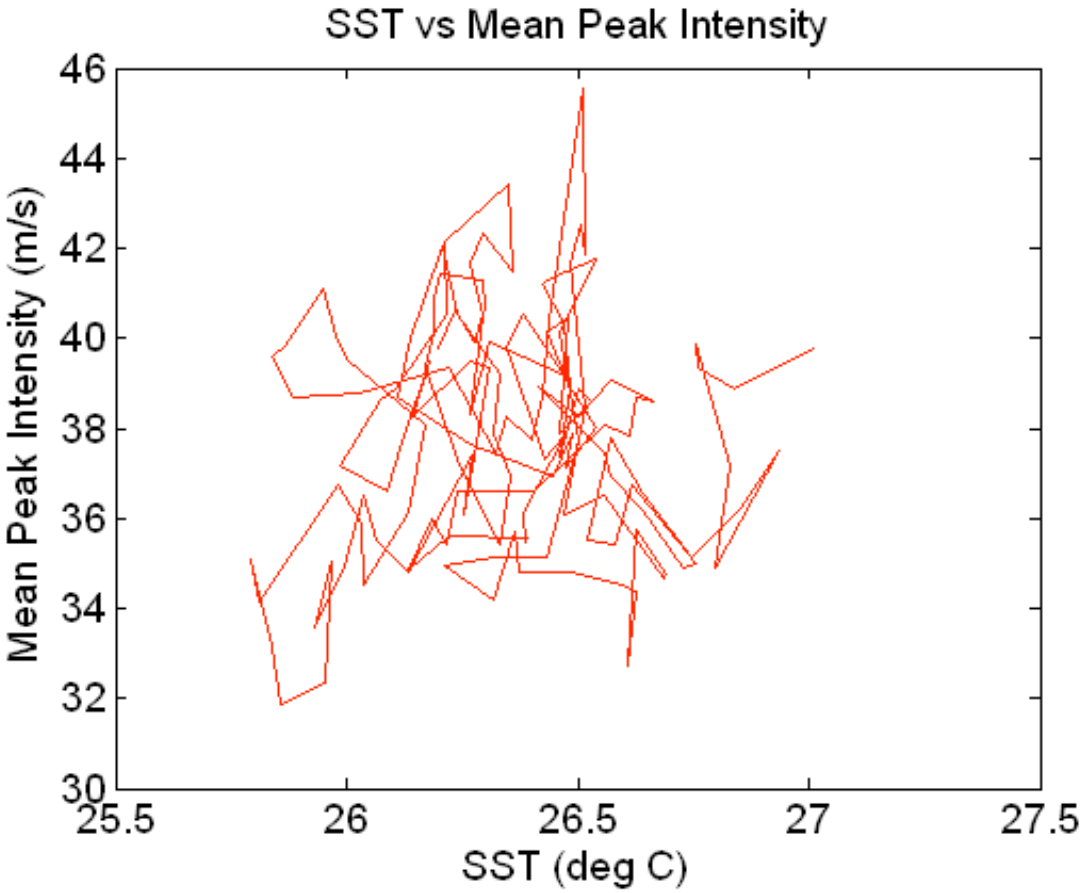
# Changing Formation Regions: 1906-1955 to 1956-2005




(Holland 2007)

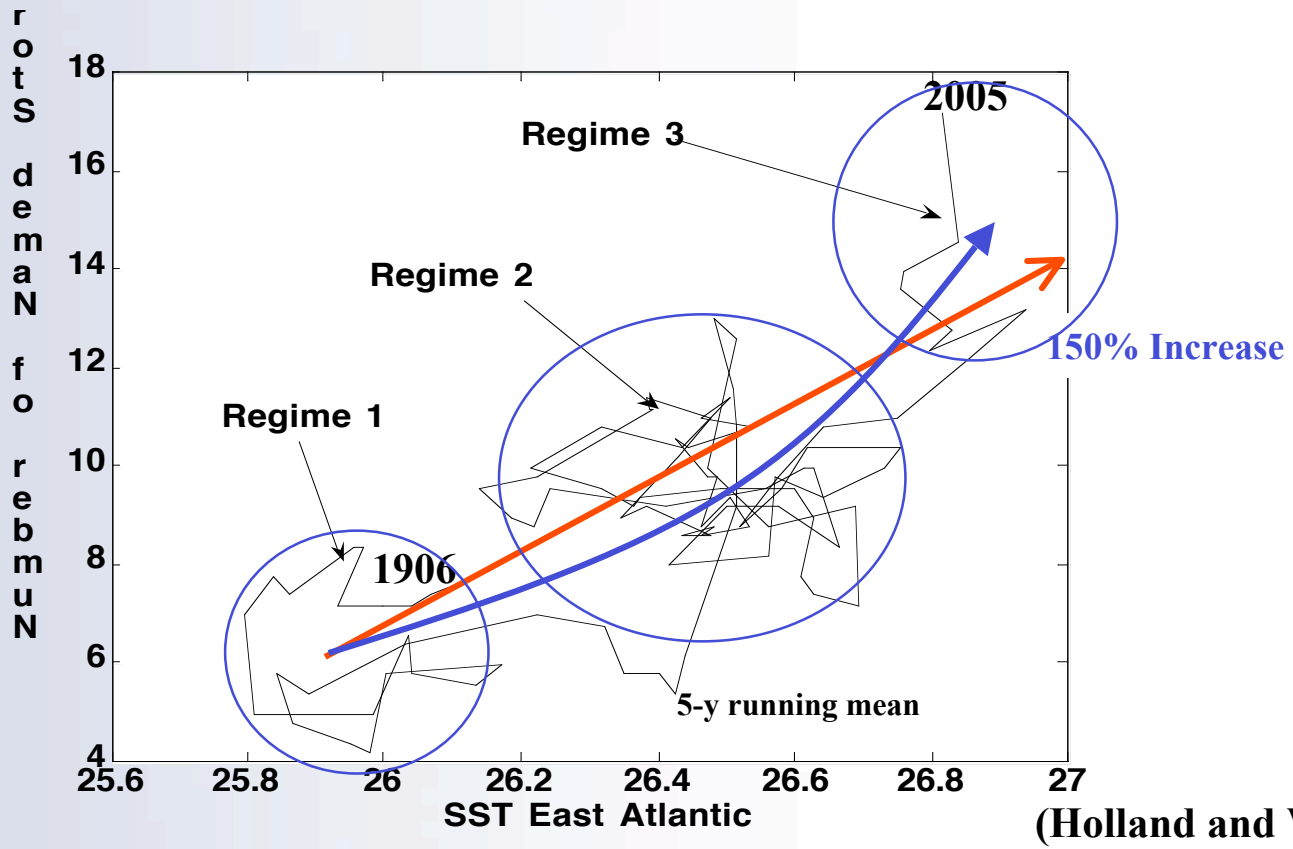
# Relationship to SST

# Mean Peak Intensity




**No real change in peak intensity since 1906 as SST has increased, as predicted by earlier studies (e.g. Henderson-Sellers et al 1997)**

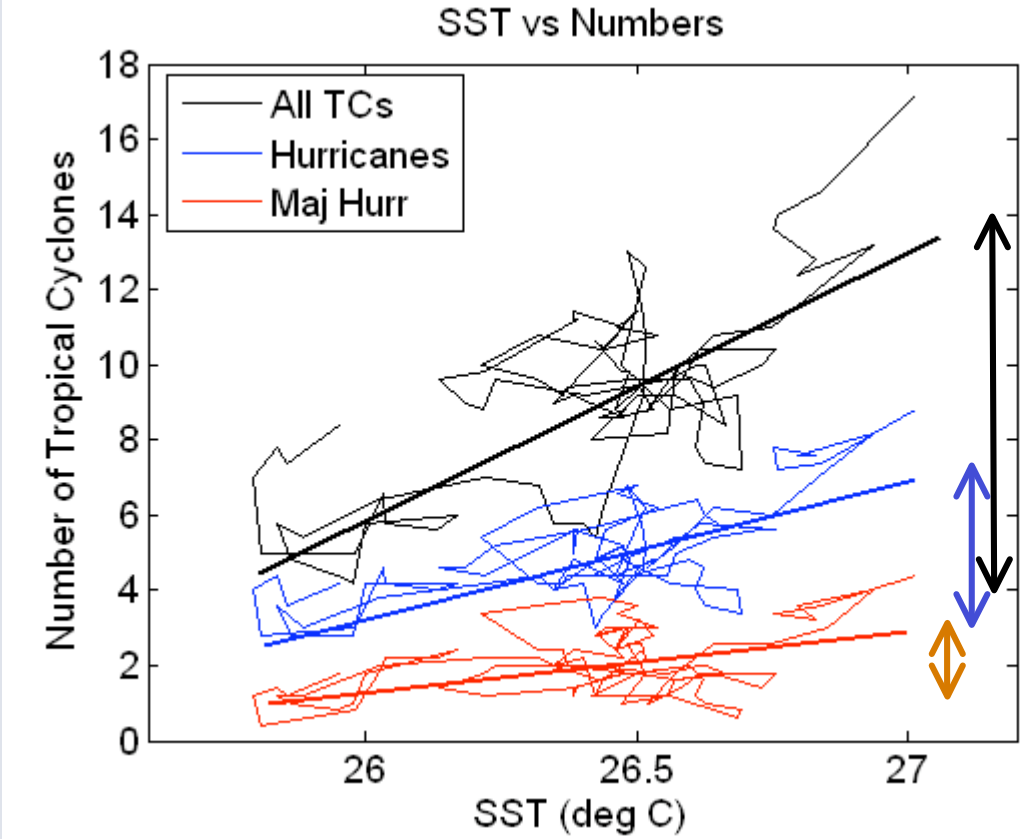
# The SST/Tropical Cyclone Relationship




(Holland and Webster 2007)

***We emphasize that the SST-TC relationship is not entirely direct, but also arises from related atmospheric environmental changes (e.g. Goldenberg et al 2001; Delworth 2006; Kossin and Vimont 2007; Holland and Webster 2007b).***

# The SST/TC, Hurr, Maj Hurr Relationship

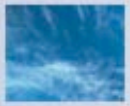
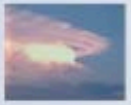
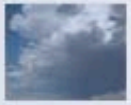



**9-10 TCs**

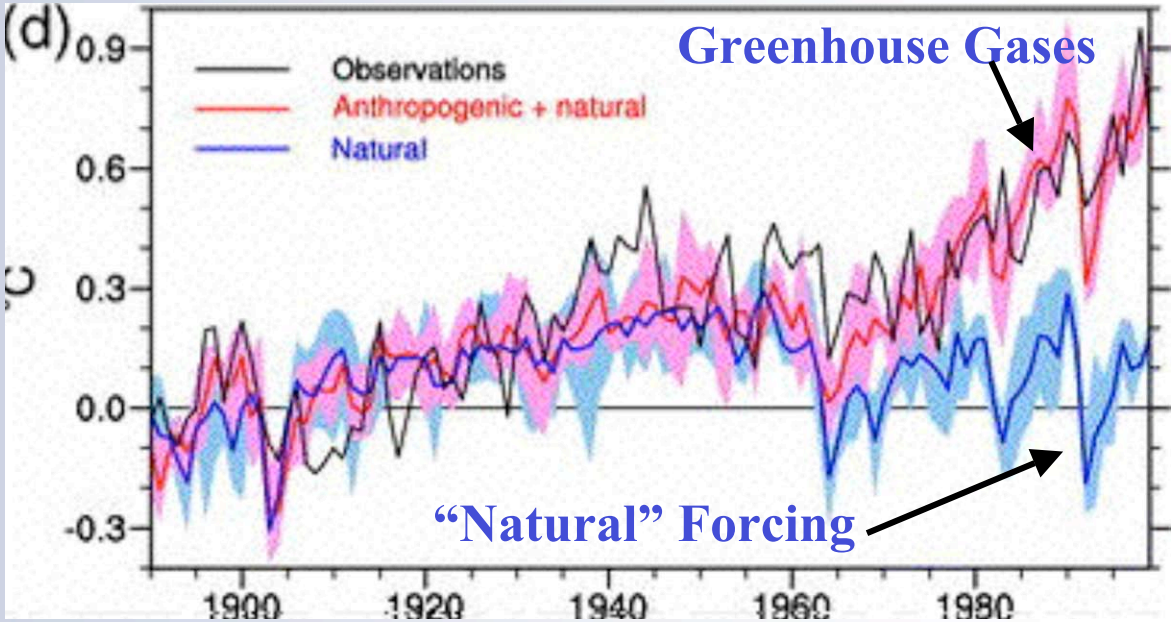
**4 Hurricanes**

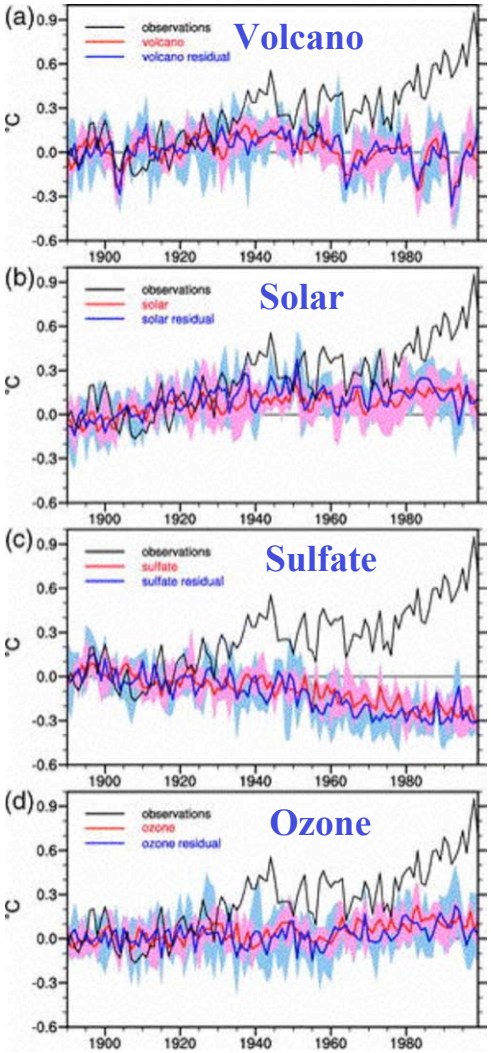
**2 Maj Hurr**

**1 TC for each 0.1°C increase in SST**
**1 Hurricane for each 0.2°C increase in SST**
**1 Major Hurricane for each 0.3°C increase in SST**

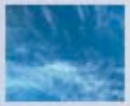
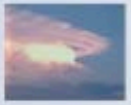
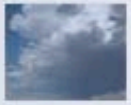
# Global Surface Temperature Variability



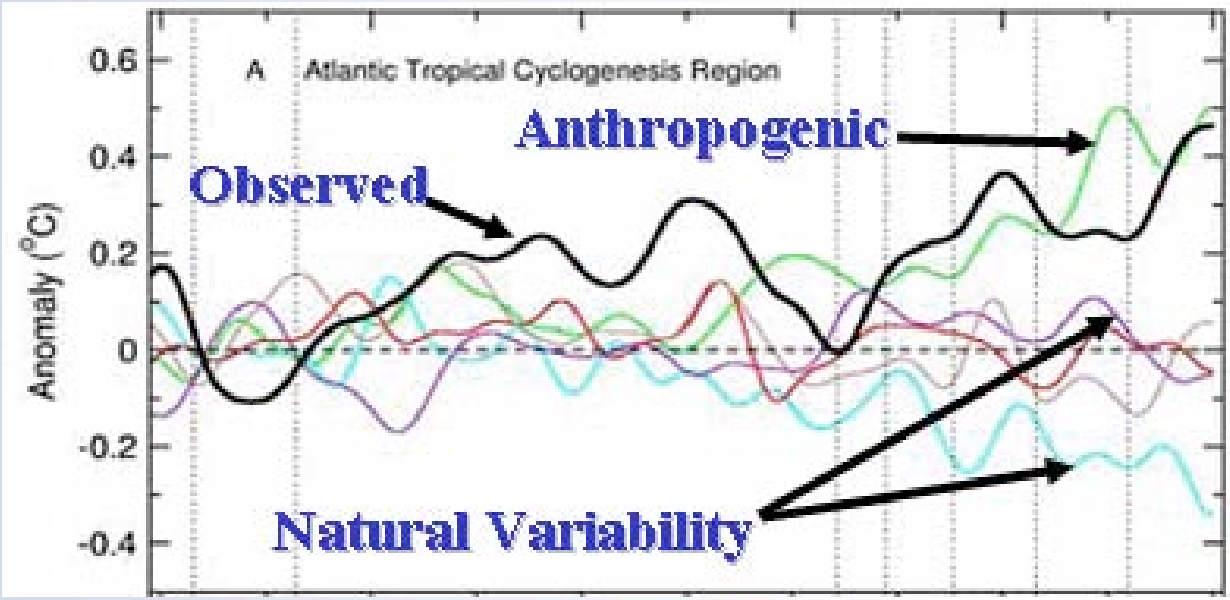




**There is no known natural forcing mechanism that can explain the surface temperature increases since 1960 (Meehl et al 2004, 2006).**

**IPCC concluded that it was virtually certain that the SST increases are substantially due to anthropogenic causes.**

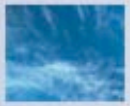
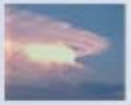
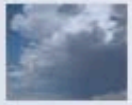




# SST Changes in the eastern North Atlantic

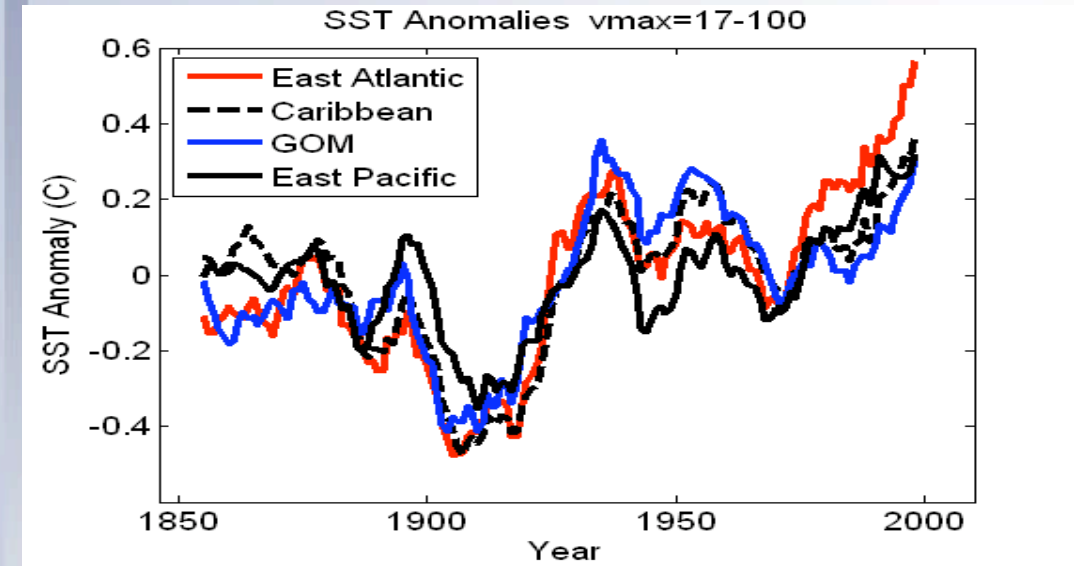


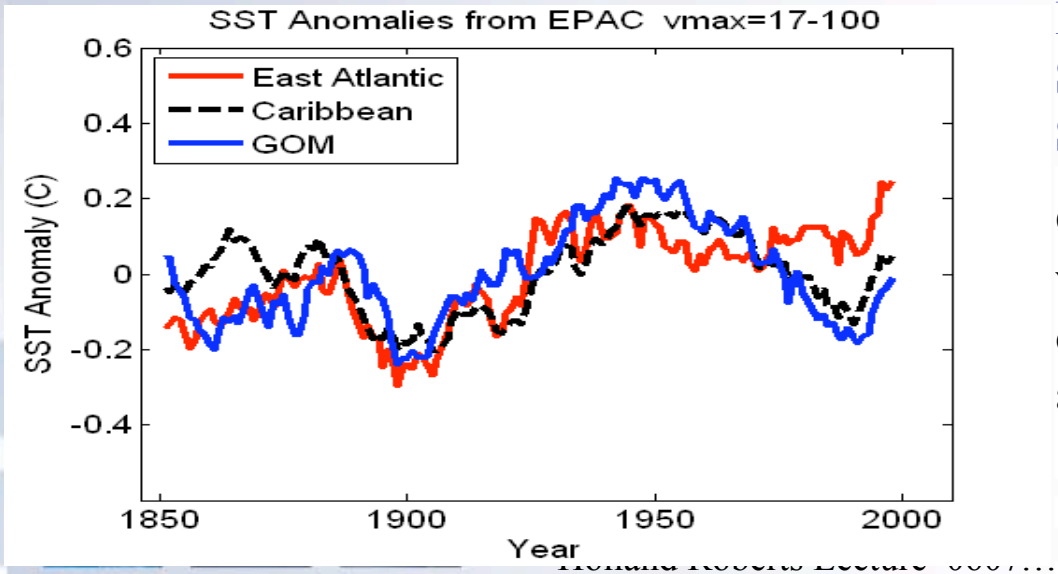

**Santer et al (2006) clearly confirmed that the Meehl et al (2006) results for the globe are also applicable to the cyclone development regions.**

**The bulk of the warming since 1970 is due to anthropogenic effects.**

# Atlantic SST and Atmospheric Modes of Variation




**Several studies claim a domination by natural variability (Bell and Chelliah 2005, Goldenberg et al 2001)**

**BUT**

**Others disagree (Mann and Emanuel 2006, Trenberth and Shea 2005, Bryden et al 2005, Santer et al. 2006).**

**Conclude definite internal variability but the major trend contribution has been anthropogenic.**

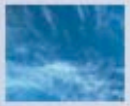
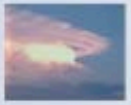
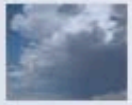
# THUS

**North Atlantic hurricane variations and trends are closely associated with Sea Surface Temperatures…..**

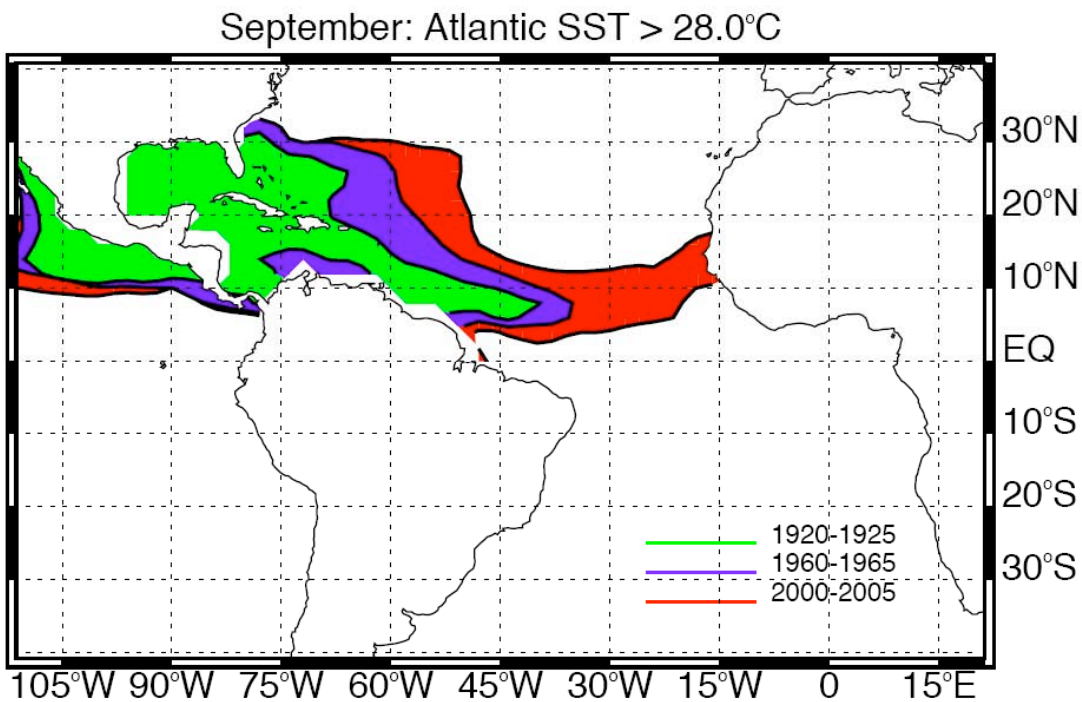
**North Atlantic SSTs have likely increased due to anthropogenic effects….**

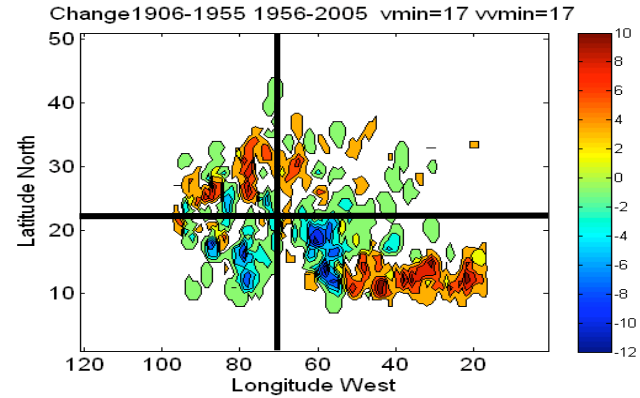
**The balance of evidence indicates that, while there is undoubted intra-regional variability in North Atlantic hurricane activity, there has been a substantial anthropogenic contribution to tropical cyclone frequency associated with the warming of the oceans**

**But what of the physical connections?**

# Why the Eastward Expansion?

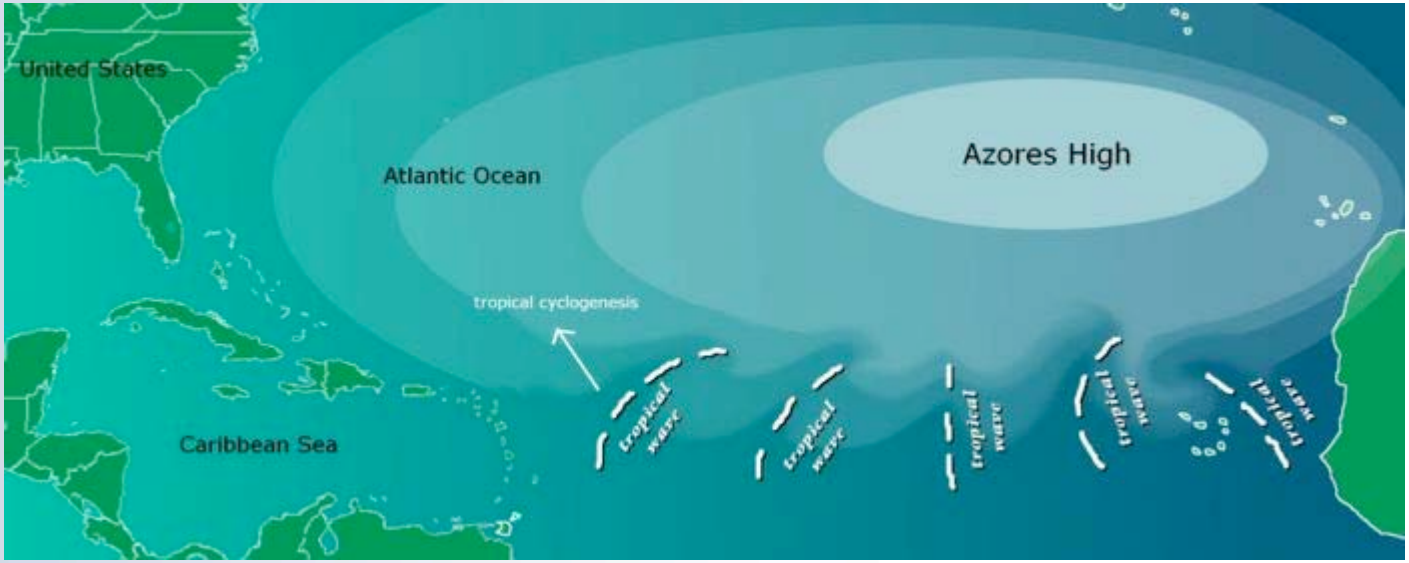



- **East Atlantic formations are consistent with the expansion of the North Atlantic Warm Pool.**

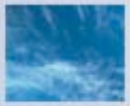
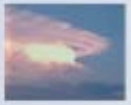
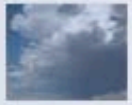
**Hoyos and Webster (2007)**

# African Easterly Waves (AEW) and Hurricane Formation

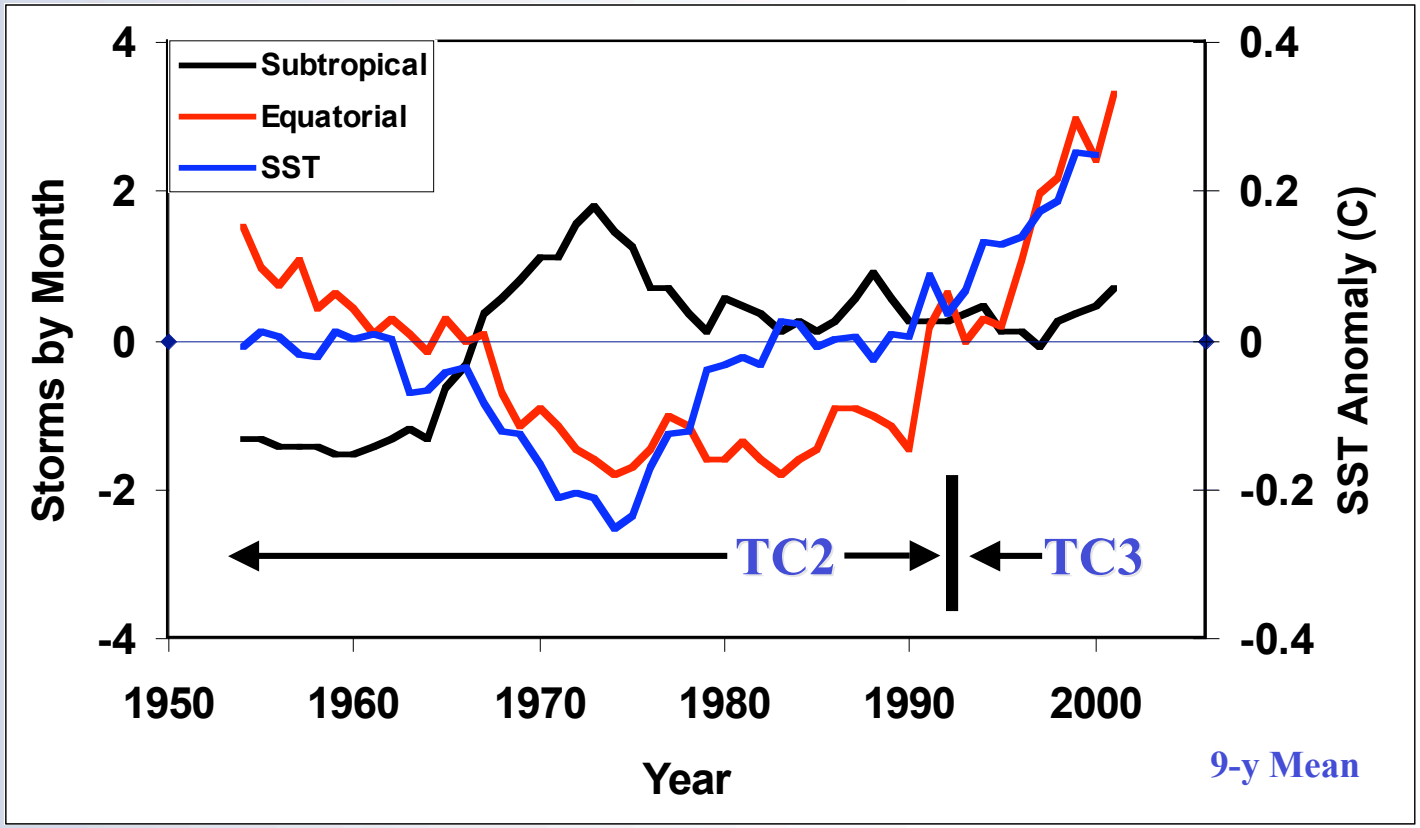



Wikipedia

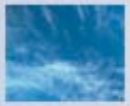
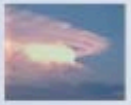
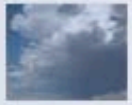
- **African Easterly Waves**
  - *Form over Africa and move eastward across the equatorial Atlantic and into the Pacific*
  - *Historically 10% have generated tropical cyclones*
  - *Generate ~60% of Atlantic tropical cyclones, 85% of major hurricanes and most of those in the equatorial North Atlantic*
- **Thus the eastward extension of tropical cyclone formation must have an association with easterly wave developments.**

# North Atlantic TC Location Changes

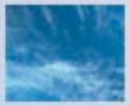
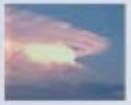
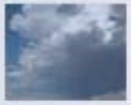



**East Atlantic SST variations explain 69% of the variance in equatorial (AEW) developments.**

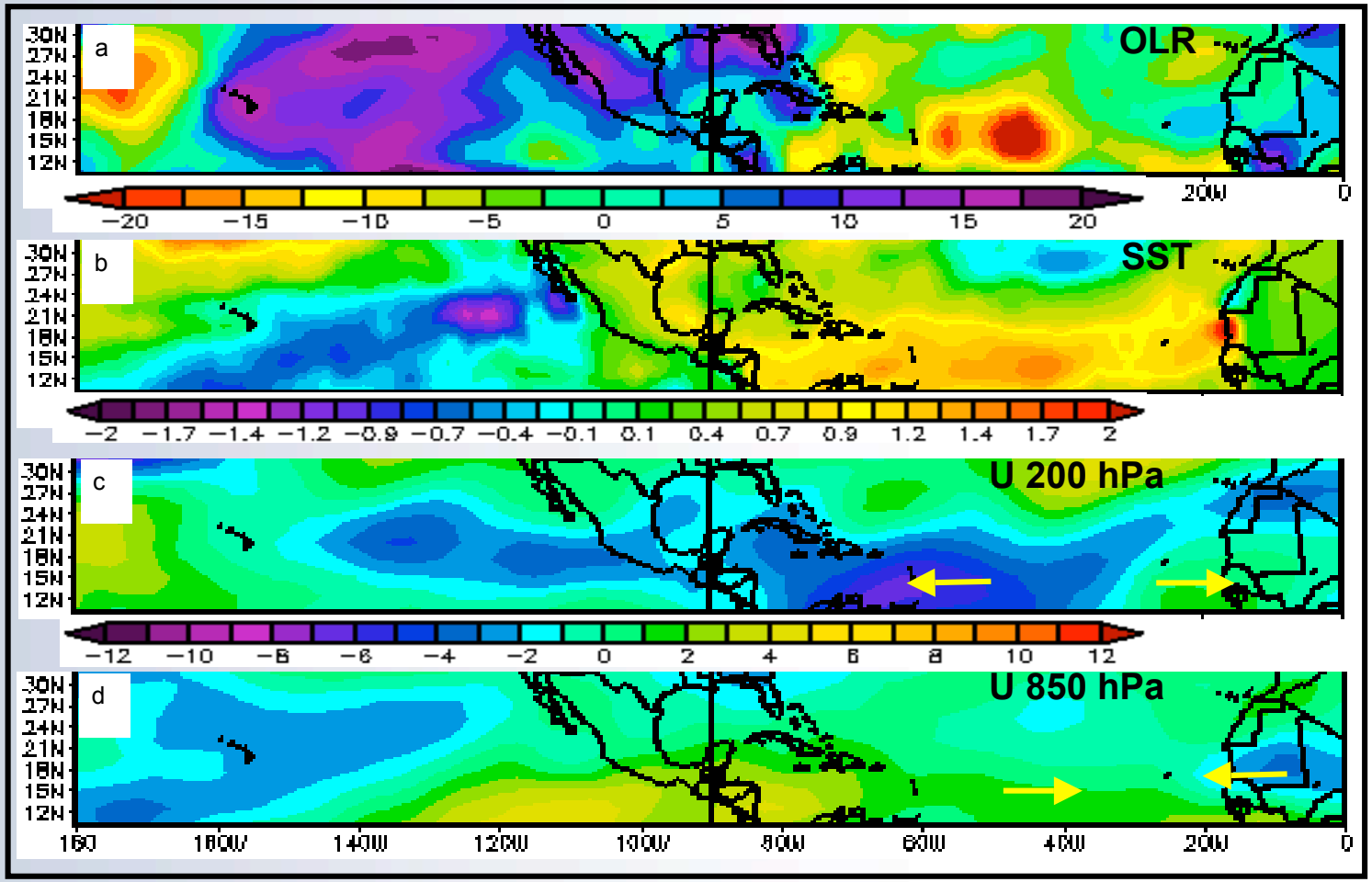




# Compare 2005 with 1991-1993

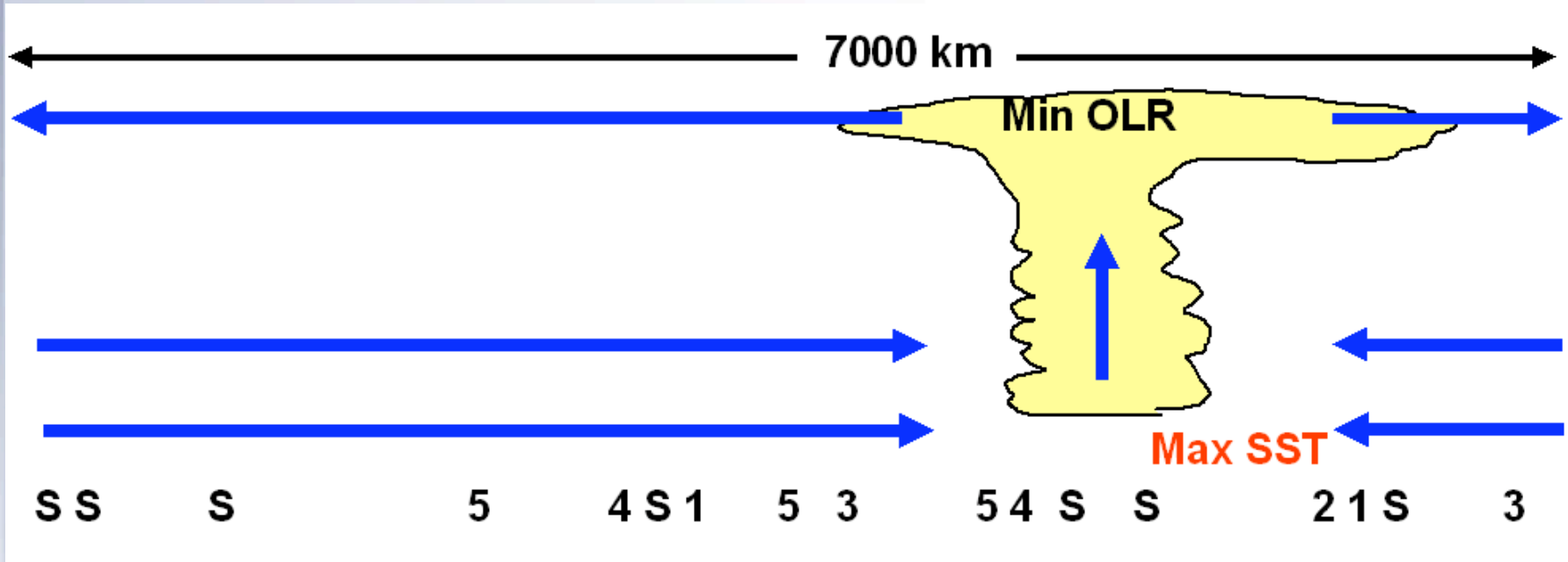
- **2005:**
  - ***Record 30% of AEWs spawned tropical cyclones and 10% became hurricanes (Avila pers. Corresp);***
  - ***AEW developments provided 10 of the 14 hurricanes in 2005, all category 3-5 hurricanes, all tropical cyclones in July and August, and 8 of the 11 tropical cyclones in September and October;***
  - ***Two AEWs also generated two tropical cyclones each, a rare event that last occurred in 1988;***
- **1991-1993:**
  - ***Representative of a 20-year period of weakened equatorial cyclogenesis;***
  - ***No tropical cyclones formed in July, only 1 in October, and only one hurricane developed from AEWs.***

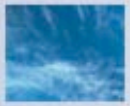
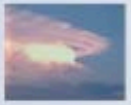
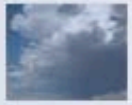
# Difference Fields 2005 to 1991-1993



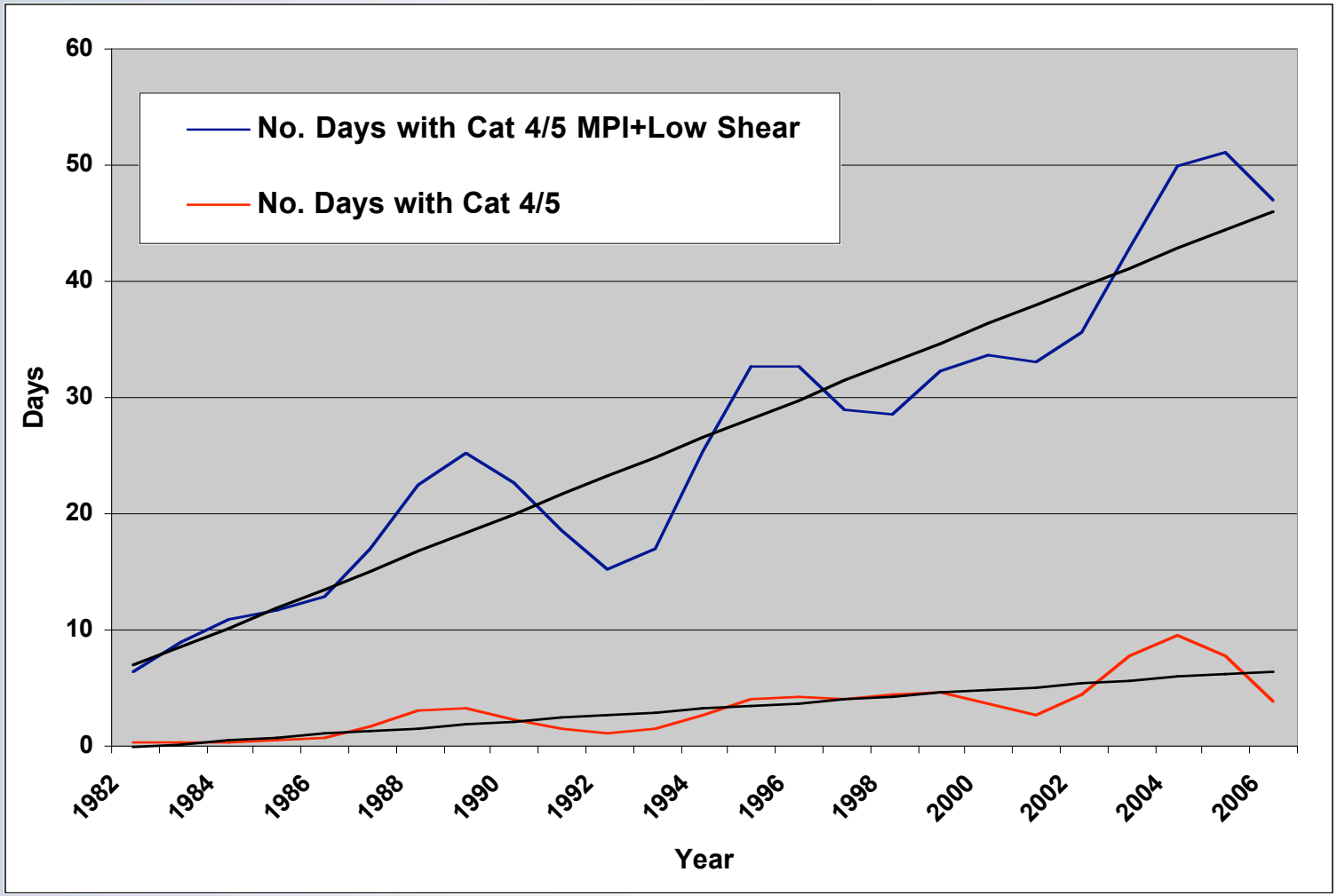
# Cyclogenesis Relative to OLR/SST Max




**Most tropical cyclones and all but one of the major hurricanes formed west of the maximum OLR/SST anomaly, in decreased (more easterly) vertical wind shear and weaker lower easterly winds**

# Potential for and actual Cat 4/5




**(DeMaria 2006 Pers Comm)**



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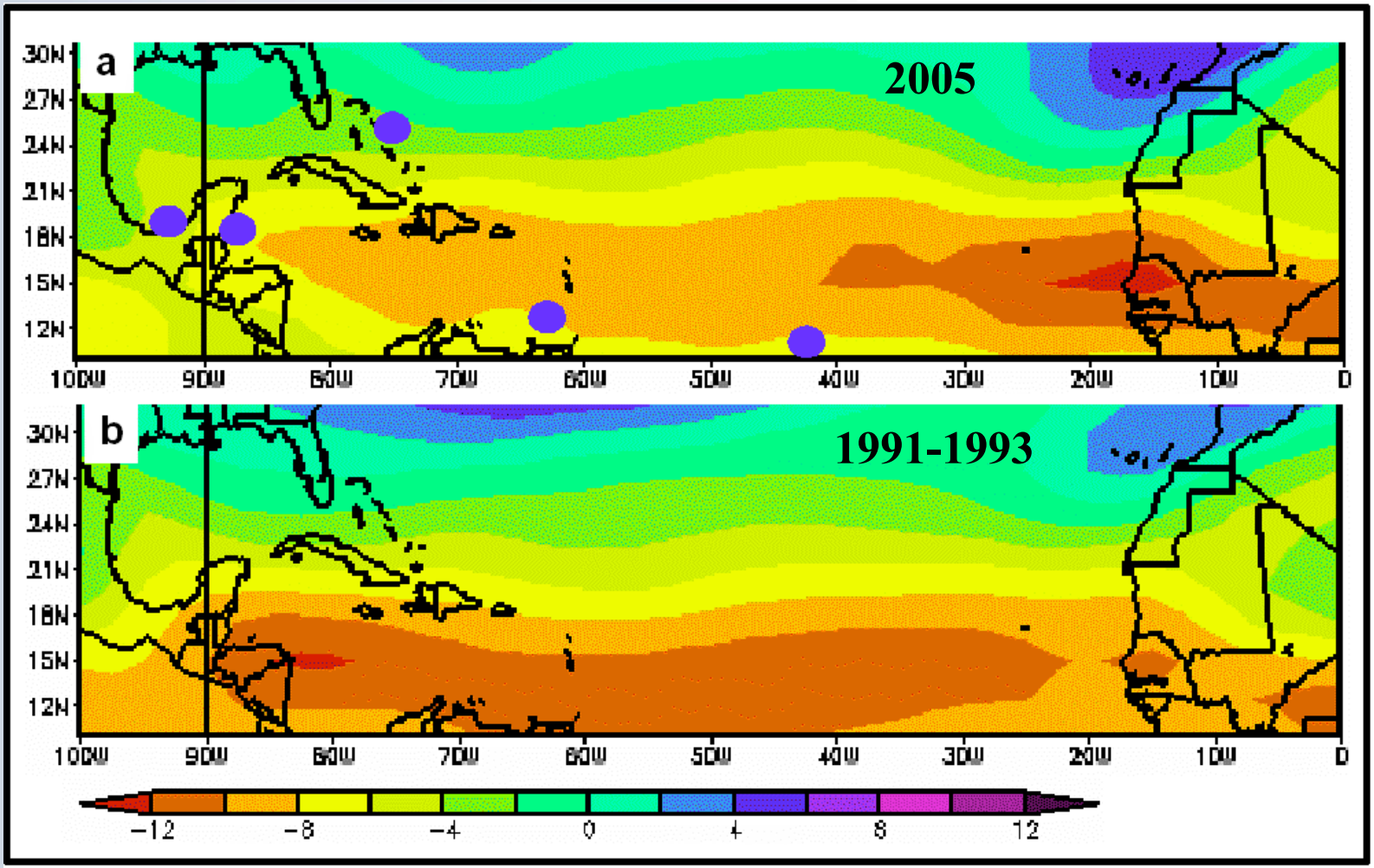
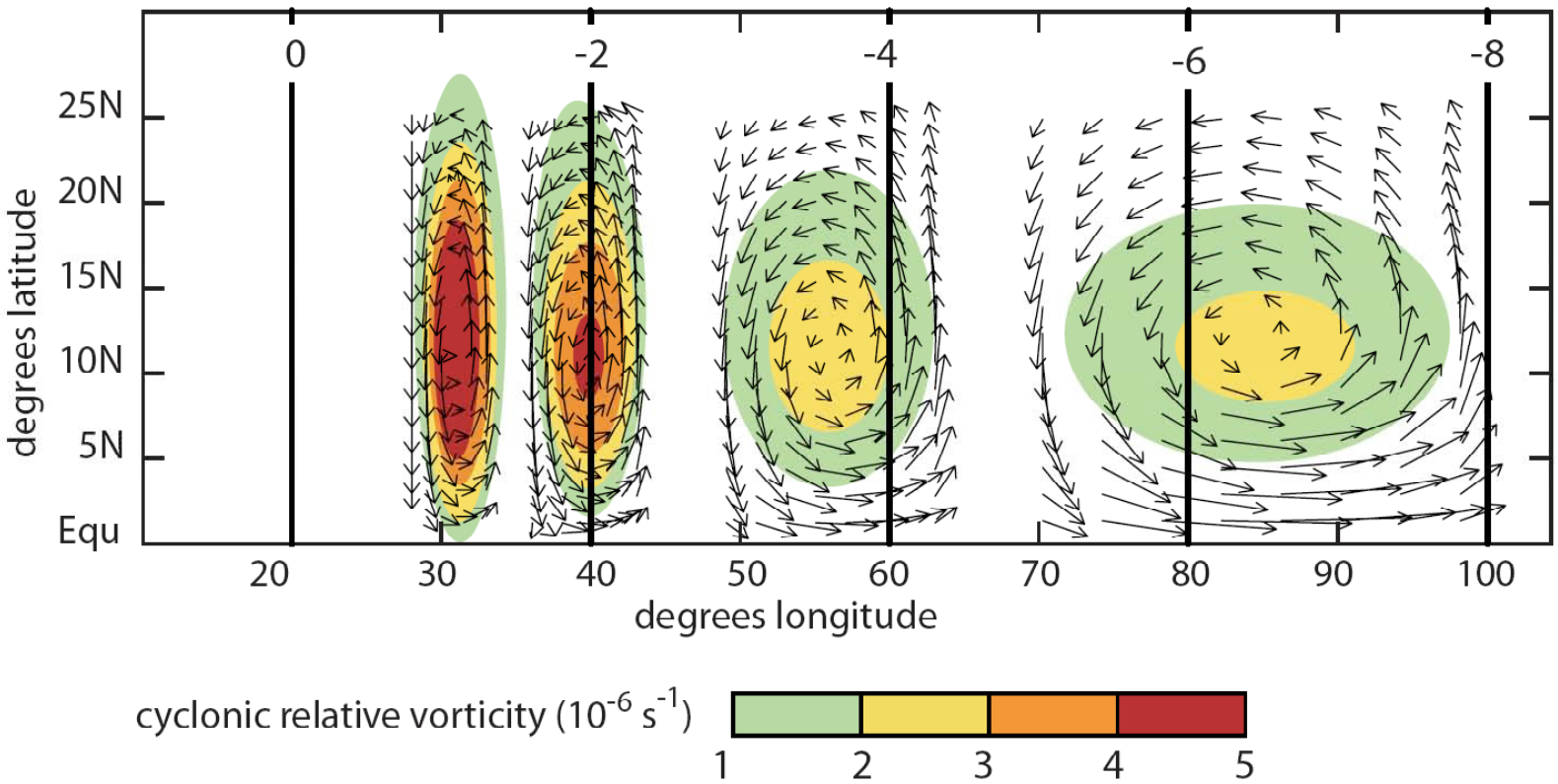
# Compare July Conditions

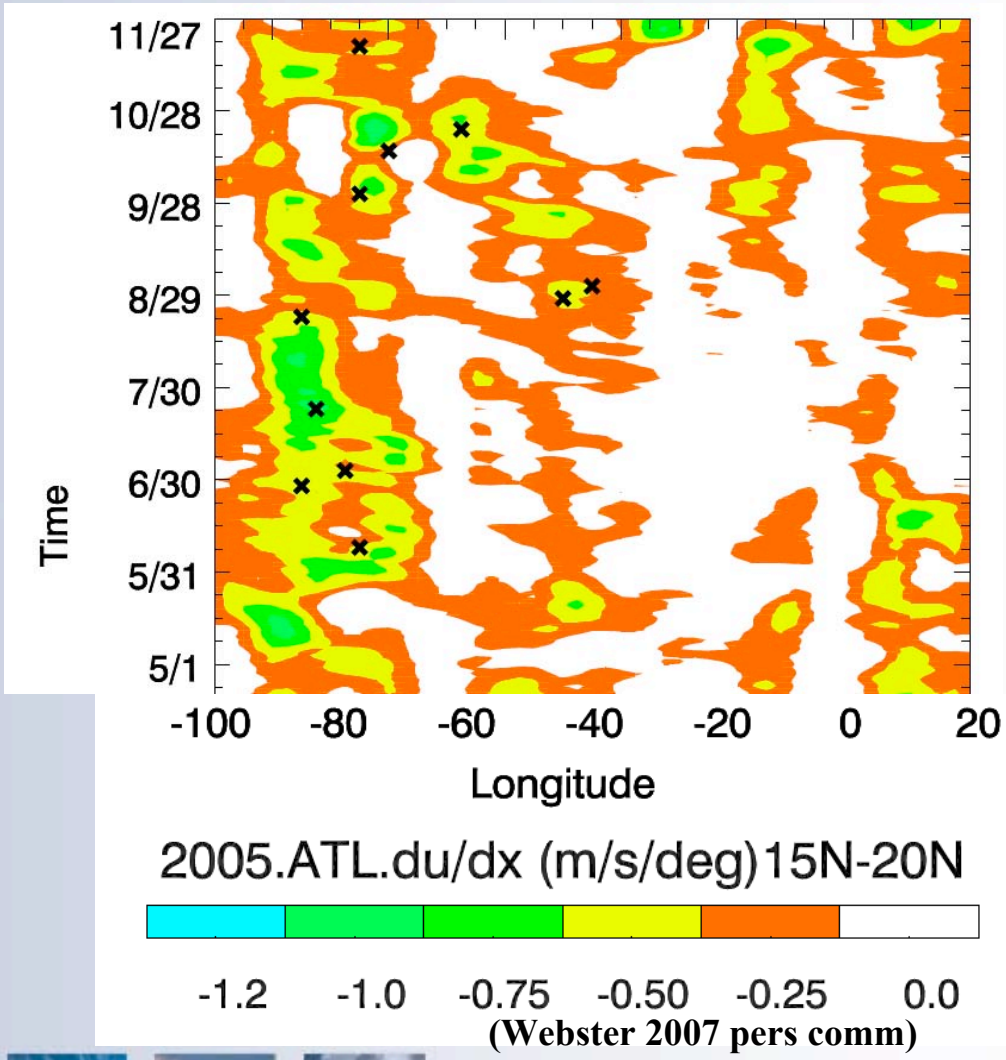


# Equatorial Rossby Wave in July 2005 Conditions




**(Webster 2007 Pers. Comm.)**

# 2005 Equatorial Tropical Cyclones

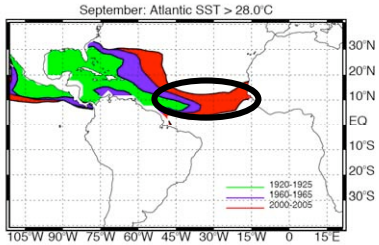


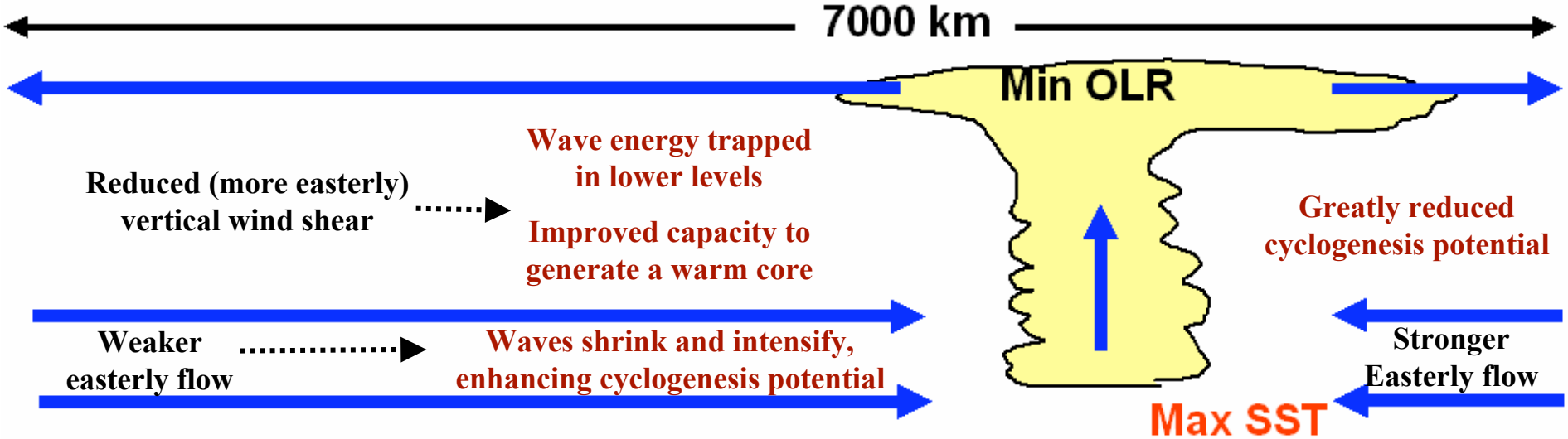

(Webster 2007 pers comm)

**All formed in regions of wave accumulation (-dU/dx).**

**See also Holland (1995), Maloney and Hartmann (2000, 2001)**

# Summary

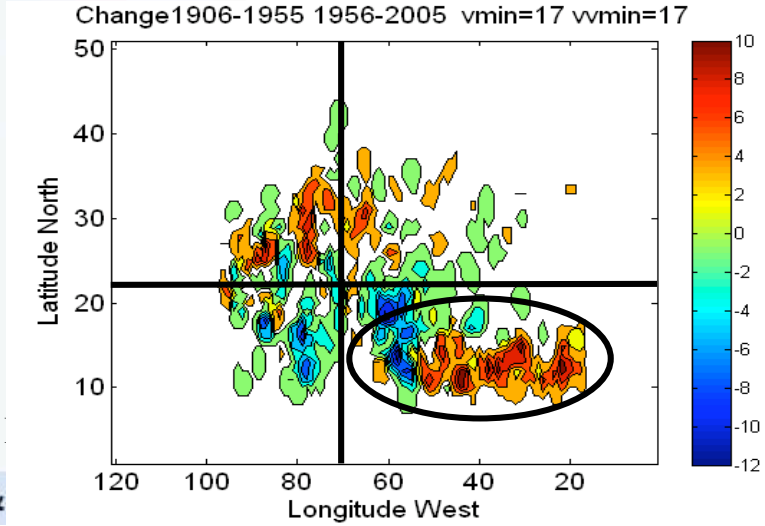



Warmer ocean heat source enhances cyclogenesis and subsequent development

**Some speculation:**

**Cyclones cool the western ocean, potentially enhancing the above and locking into a stable regime**




Holland Roberts



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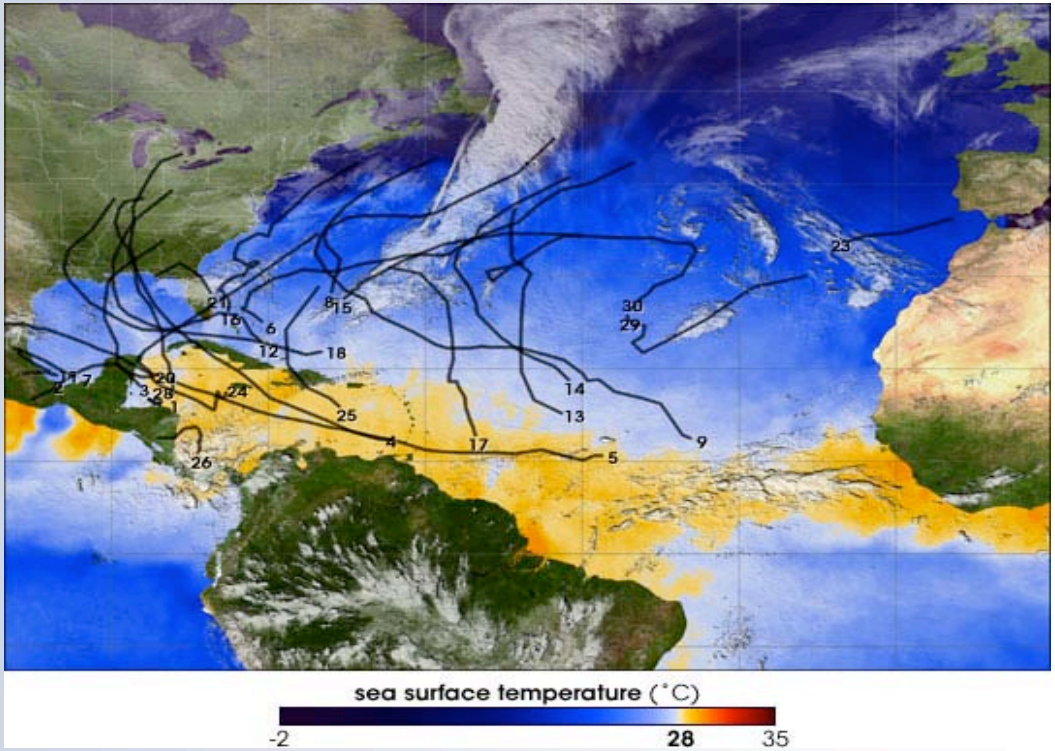
# Impact on Caribbean and US



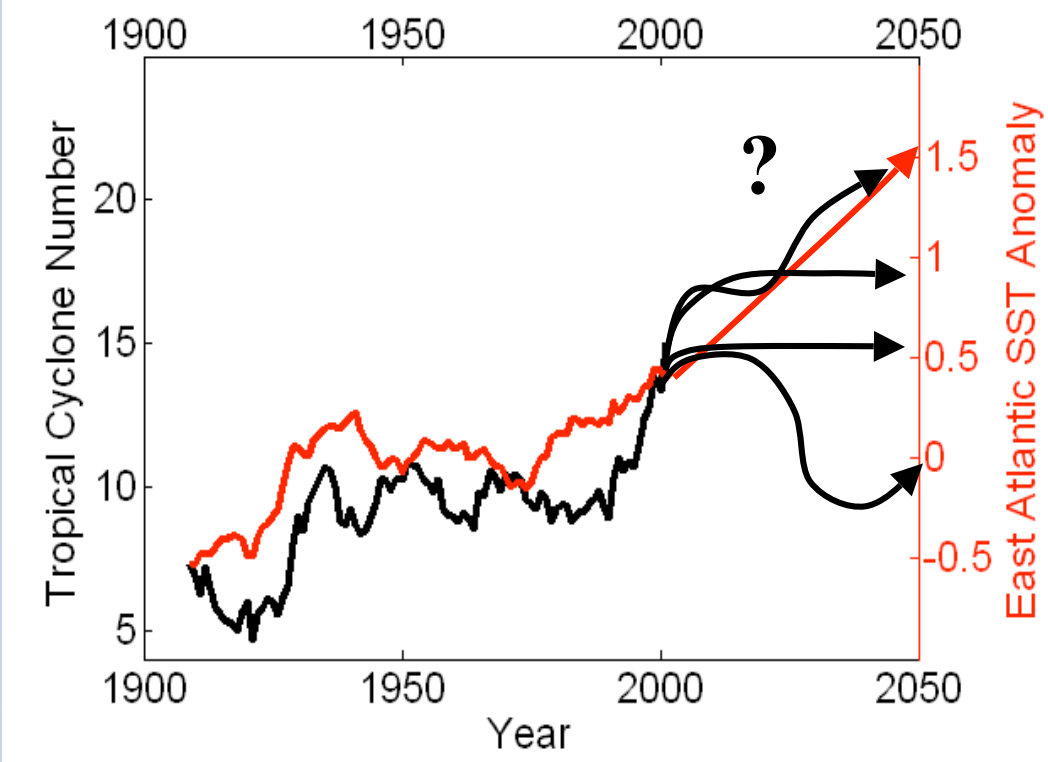

**Increasing eastern equatorial development:**

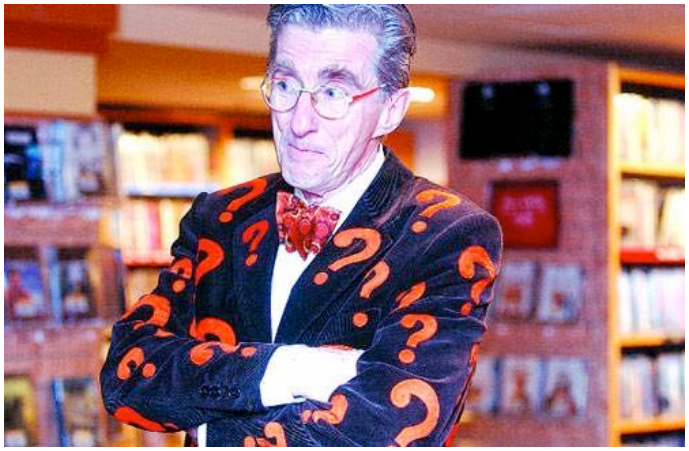
**Explains the decrease in landfall on mainland USA until recently;**

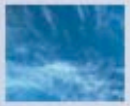
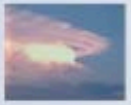
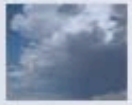
**Results in a higher proportion of major hurricanes that may strike the Caribbean, Central and North American States**

# “The future comes apace”

William Shakespeare

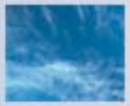
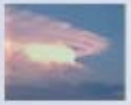
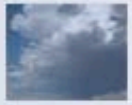


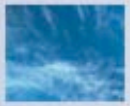
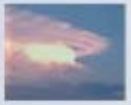
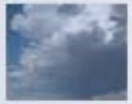
# Climate Model Uses and Limitations

- **The Good (the best tool that we have):**
  - ***Able to provide good projections of broad environmental responses to anthropogenic gas emissions (greenhouse and non-greenhouse), including the broad atmospheric flow regimes and surface temperatures;***
- **The Bad:**
  - ***Unable at present to resolve the hurricane core or overall genesis characteristics, so intensity and frequency must be inferred;***
  - ***Have trouble with generating all tropical modes of variability;***
  - ***Do not necessarily contain adequate capacity to simulate the hurricane feedbacks on climate (ocean cooling, poleward and vertical heat exchanges);***
- **The Ugly:**
  - ***May miss climate shifts (e.g. Atlantic hurricane-circulation feedback, El Nino cycles).***

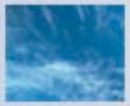
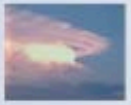
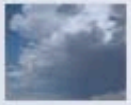
# A Personal Atlantic Projection: Based on Balance of Evidence

- **5-10 Years:**
  - ***Intensity:*** ***small net increase, occurring as a higher proportion of major hurricanes;***
  - ***Frequency:*** ***Increasing or similar to current decade;***
  - ***Landfall:*** ***Higher in Caribbean and more intense…about the same in US, but possibly more intense;***
    - **(Historical projection, AMO is still in warming phase).**
- **30-50 Years:**
  - ***Intensity:*** ***continued small increases, by 5-10%, occurring as higher proportion of major hurricanes;***
  - ***Frequency:*** ***about the same or slightly higher;***
  - ***Landfall:*** ***Continuation of 5-10 year projection;***
    - **(Recent climate model simulations)**

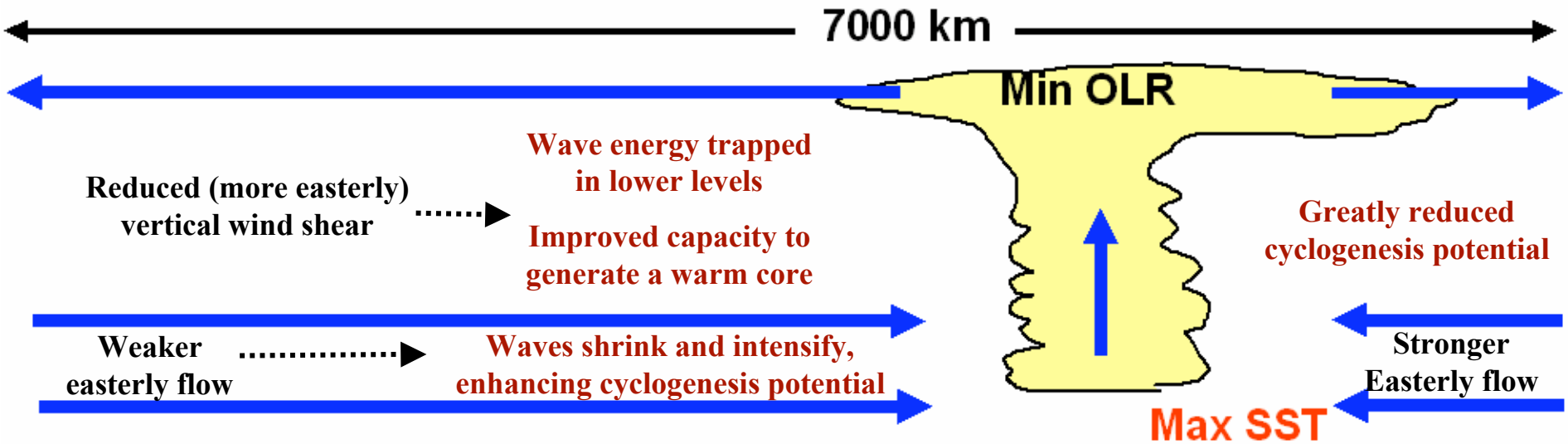




# Other Factors

- **It is too late for preventive emission actions to have an effect for decades yet;**
- **Sea Level Rise will substantially amplify impacts;**
- **Overland Damage from Flooding, Tornadoes and Local Wind Bursts is a complete unknown;**
- **Demographic and Commercial Activity Changes will ensure a continued rise in impacts and societal disruption.**
  - ***Our lemming-like march to the sea***

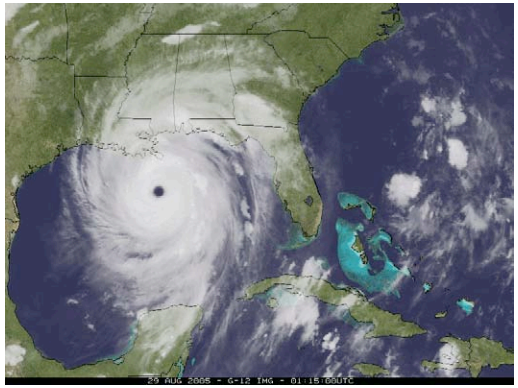




# Thank You




Warmer ocean heat source enhances cyclogenesis and subsequent development

Cyclones cool the western ocean, potentially enhancing the above and locking into a stable regime



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