Hurricanes, Climate, and Other Interesting Stuff

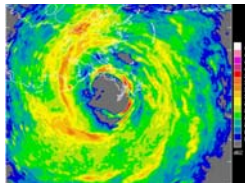
Hydrographic Services Review Panel
Wednesday, November 19, 2008

Briefing Delivered by

Judith Gray

Atlantic Oceanographic & Meteorological Laboratory
National Oceanic & Atmospheric Administration

Physical Processes of Hurricane Intensity Change



Motivation

- Improvements in intensity forecasts lagging behind those of track
- Understanding tropical cyclone intensity is a multi-scale challenge

Tropical Cyclone Intensity Change (surrounding environment)

- *Rapid Intensification*
- Inner Core SST Responses
- *SST & Ocean Heat Content* (Aircraft Buoy Deployments)
- *Saharan Air Layer* (i.e. Saharan dust storms)

Tropical Cyclone Intensity Change (inner core processes)

- Eyewall replacement cycles
- Eye-Eyewall mixing

Rapid Intensity Changes

Greatest forecast challenge for hurricane forecasters
83% of major hurricanes have at least one RI event

<u>Rapid Intensity Predictors</u>

1) Vertical wind shear

2) Upper-level divergence (200 hPa)

3) Intensity trend (previous 24-hr)

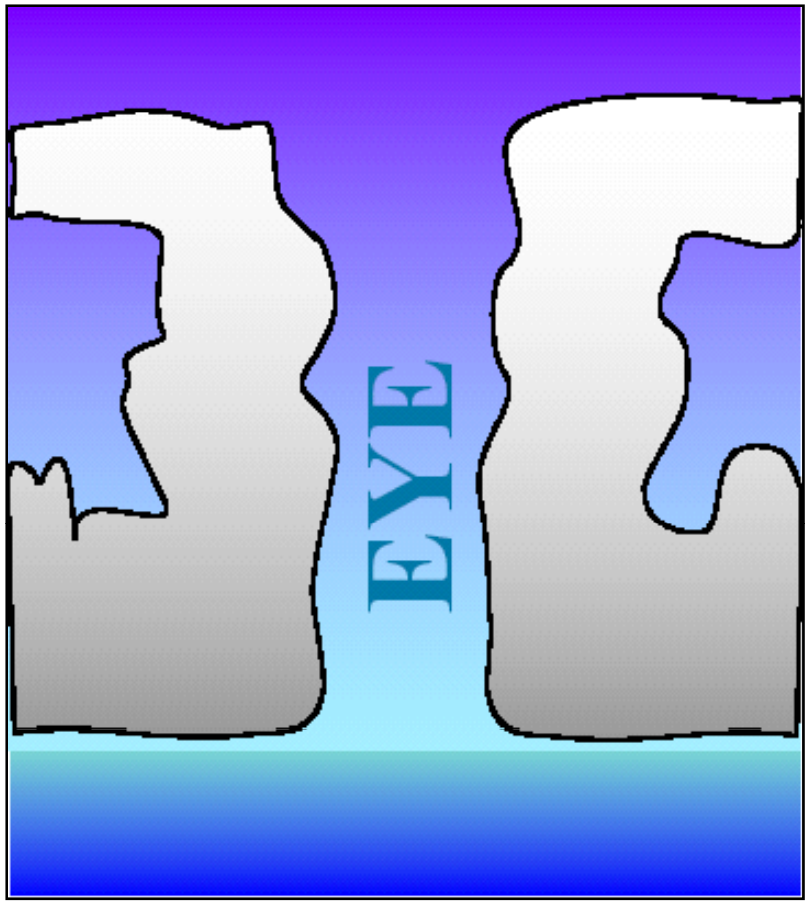
4) Storm Symmetry (GOES satellite)

5) % area with deep convection (GOES satellite)

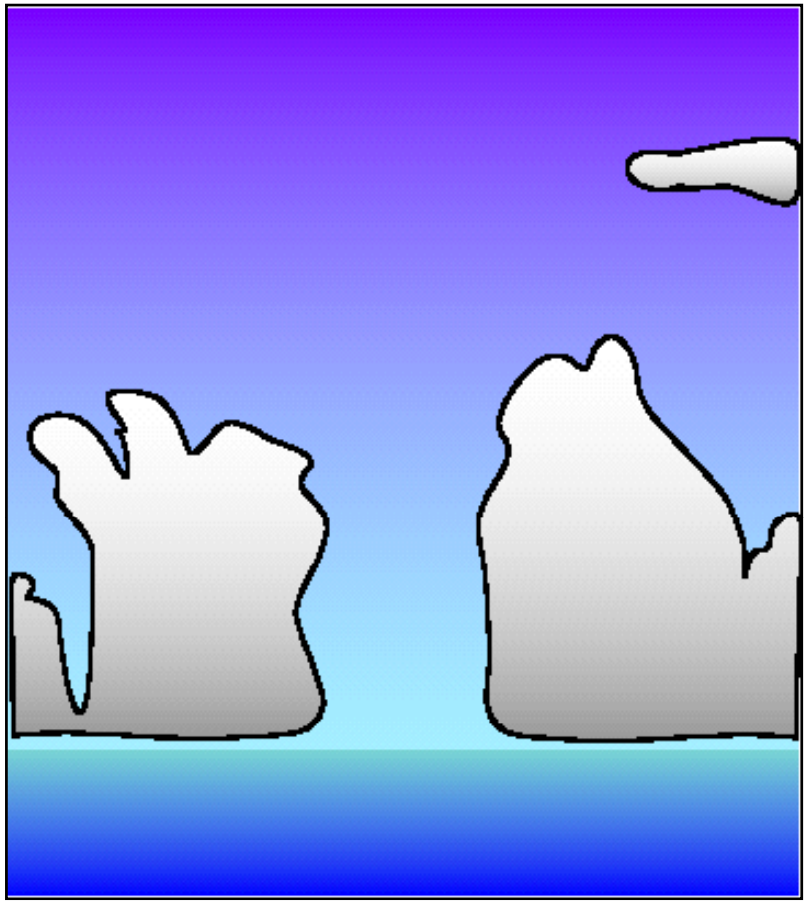
6) Mid-level humidity

7) Potential Intensity (how close to the theoretical max intensity)

Effects of Vertical Wind Shear on Atlantic Hurricanes

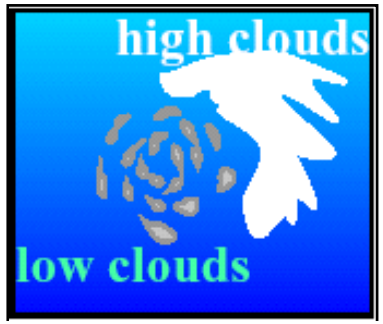


***WEAK* SHEAR => FAVORABLE**



***STRONG* SHEAR => *UN*FAVORABLE**

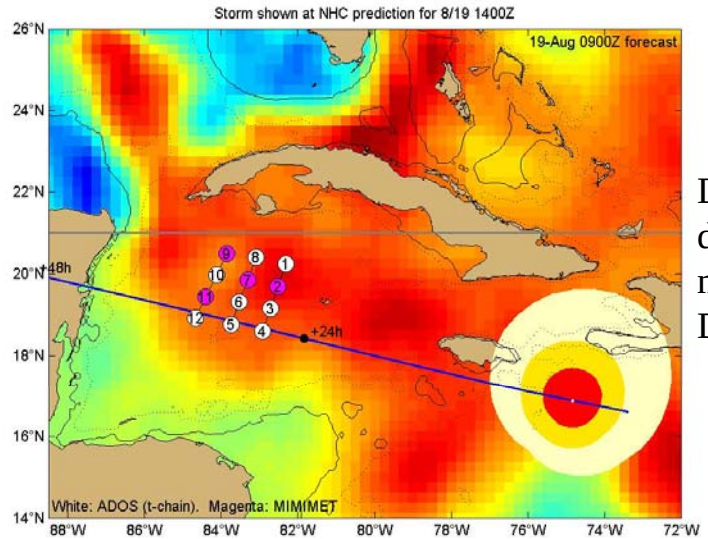
Vertical wind shear either helps a vertically coherent storm vortex to develop or hinders it from doing so, depending on its magnitude.



Deployments of Buoy Drifter Arrays

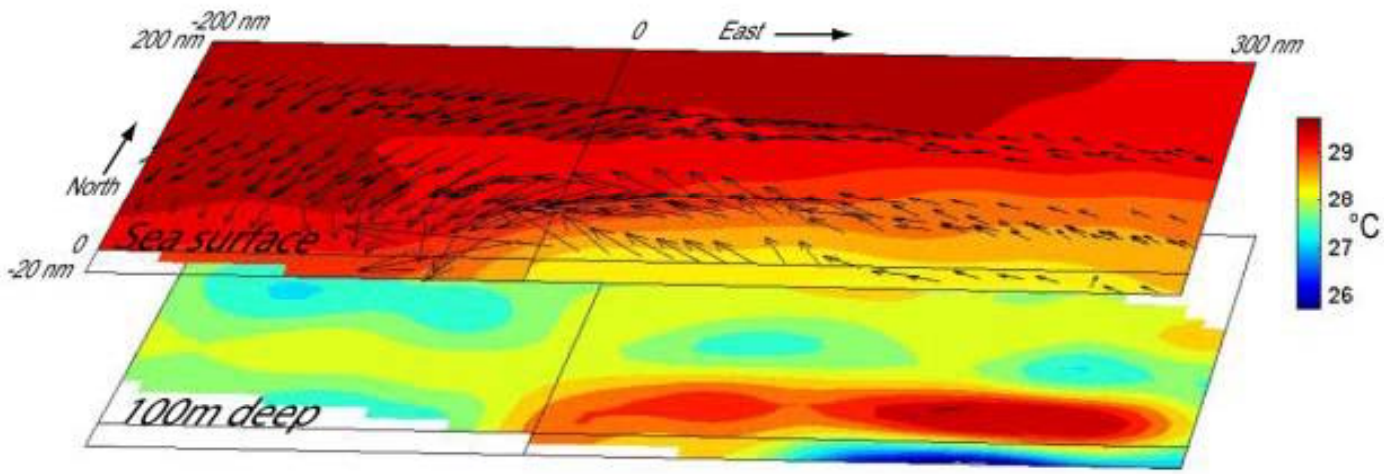
Main Science Objective:

Improve our understanding of the 3-dimensional ocean response to TCs



Drifting buoy array deployed in front of major Hurricane Dean (Aug 2007);

Upper Ocean Heat Content



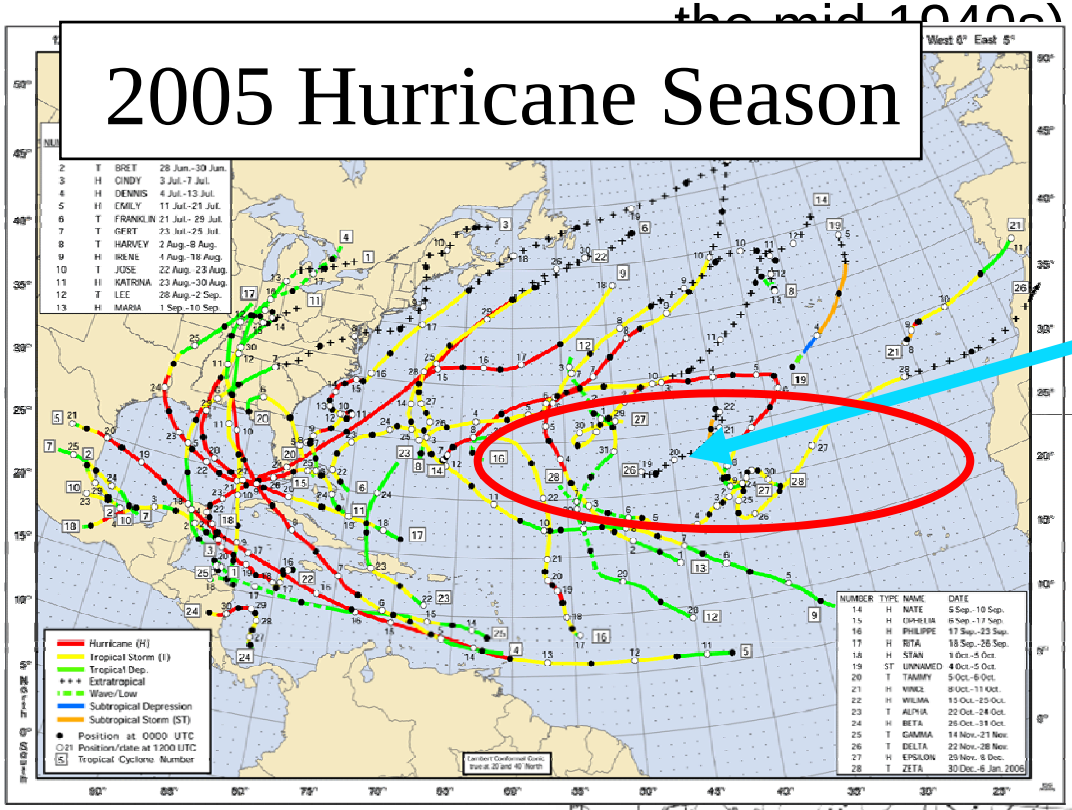
Top: Sea surface temperature (shading, °C) and winds (arrows) measured by the hurricane drifter array at top. Bottom: subsurface temperatures at a depth of 100m.

The Saharan Air Layer (Saharan Dust Storms)

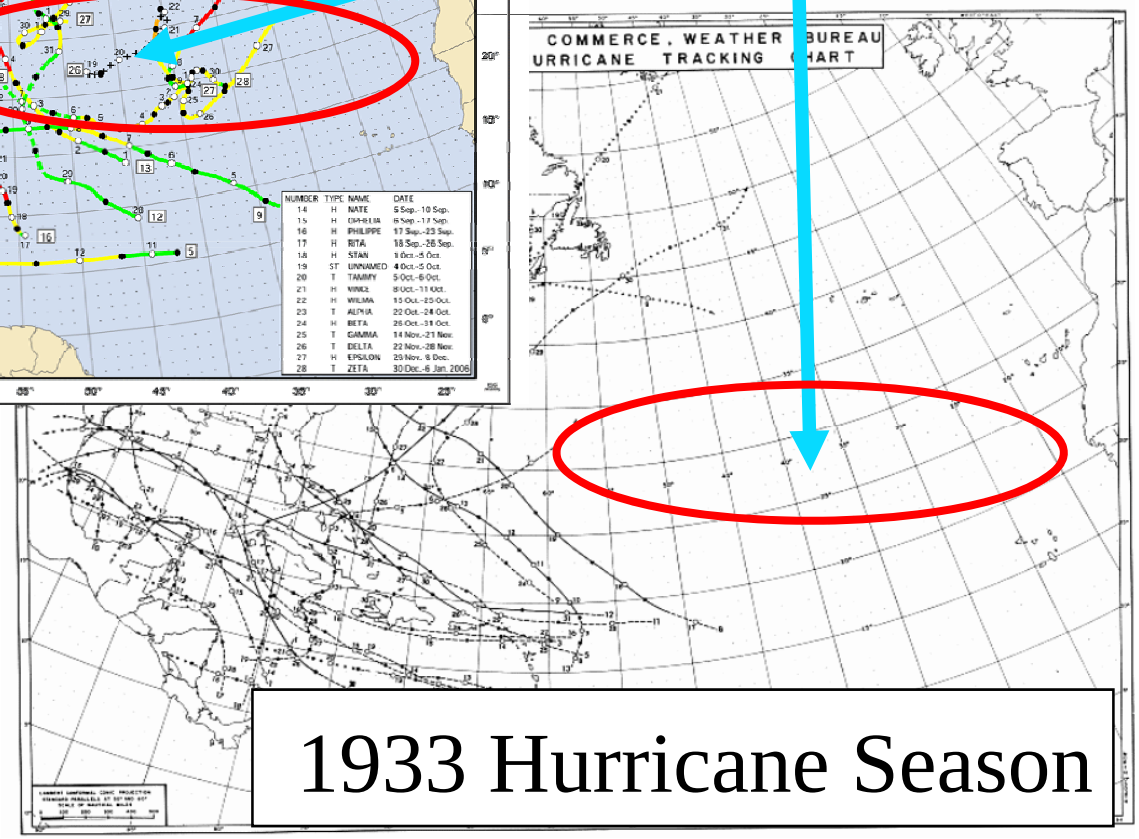
Main Science Objectives:

Improve our understanding *of how the SAL's* ***dry air***, ***mid-level easterly jet***, *and* ***suspended mineral dust*** *affect TC intensity change*

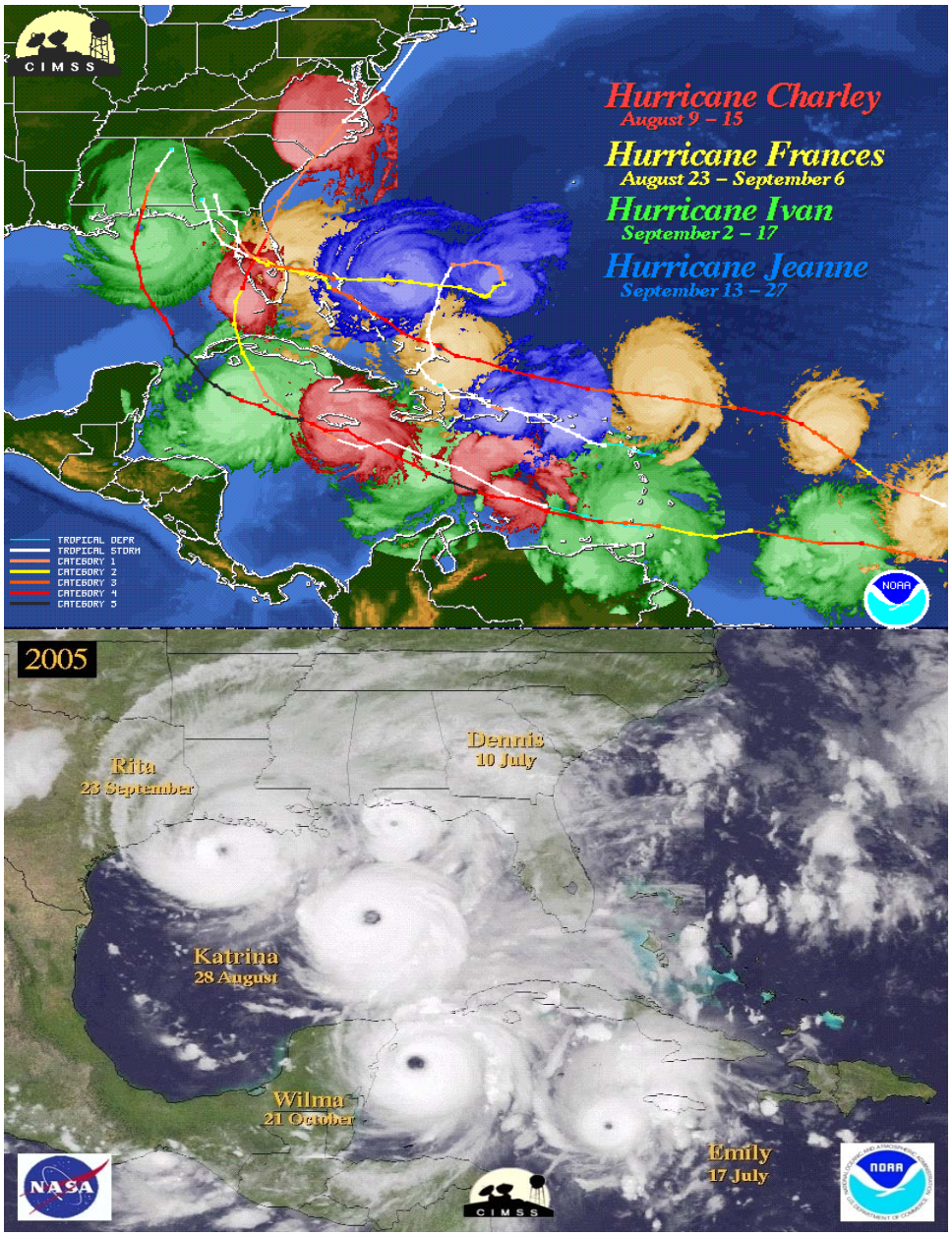
Hurricane data problem: Hurricanes were hardly detected over the open ocean before the era of satellite technology (around the mid-1960s) & aircraft reconnaissance (around the mid-1940s)



Open Atlantic Ocean Differences



Climate and Atlantic Hurricane Activity



GLOBAL WARMING

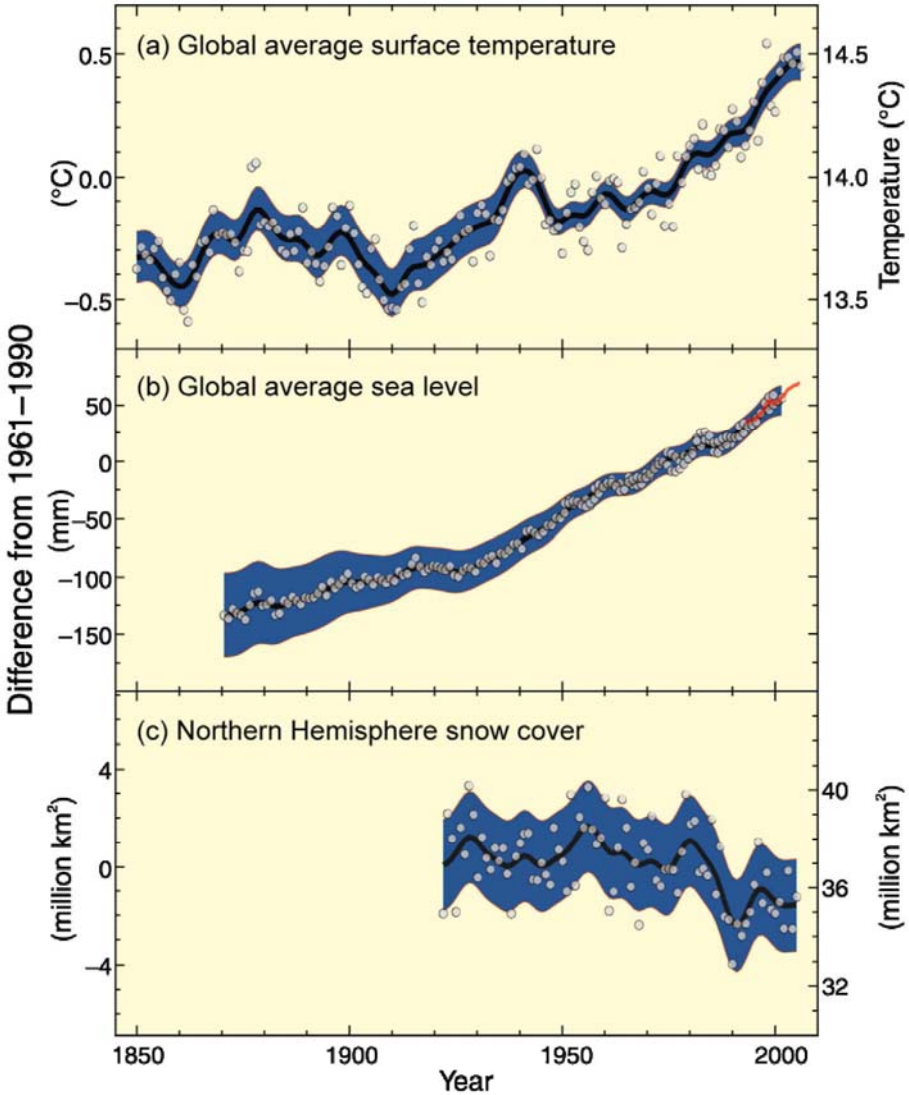
2004 & 2005 - record number of hurricanes and record number of U.S. landfalls

Many scientists and The media linked the Increase to global Warming

However…

2006 & 2007 - were relatively quiet years

Sea surface temperature and sea level changes

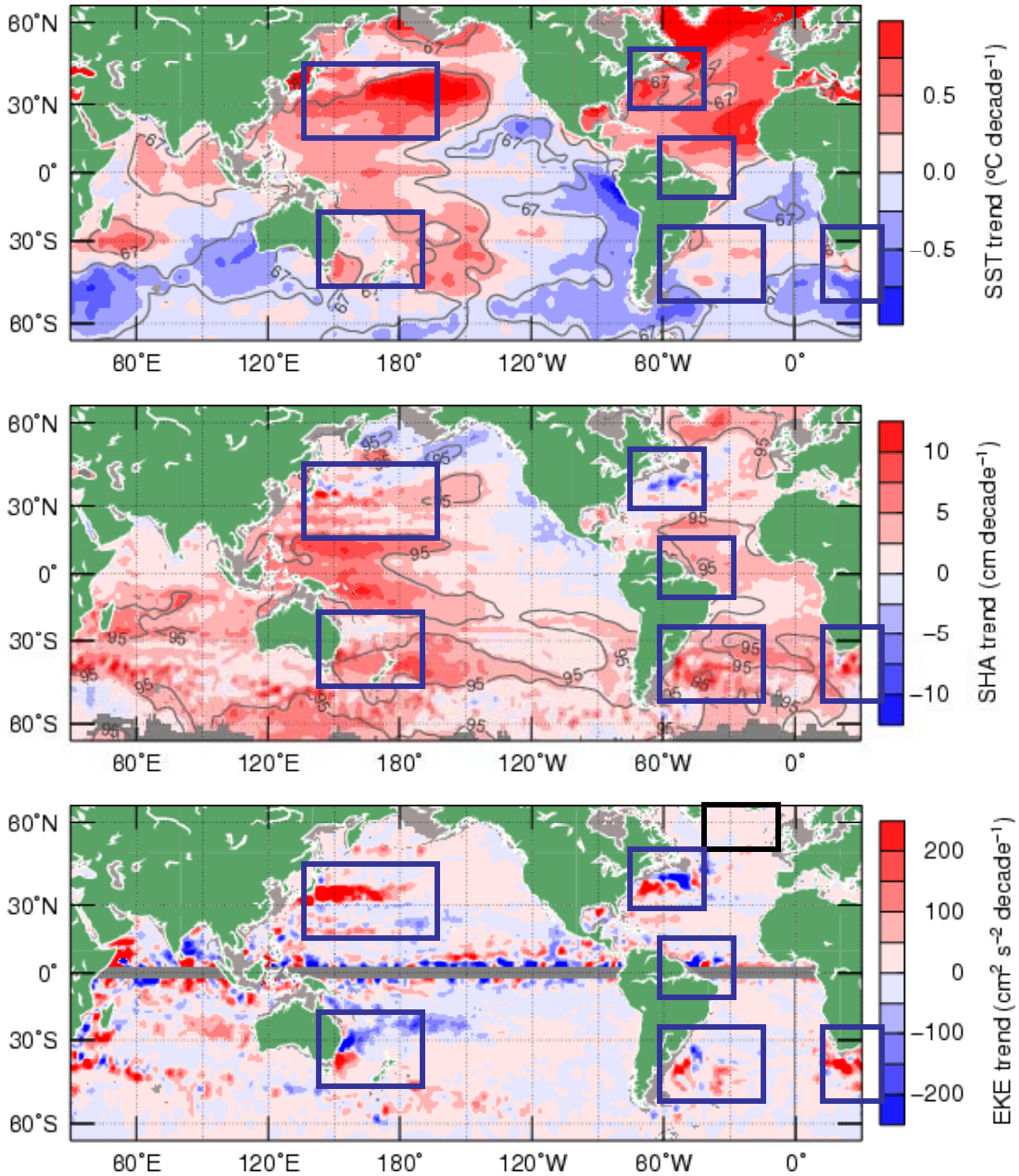


	1901-2005	1979-2005
Sea surface temperature trend (°C/decade)	0.067±0.018	0.133±0.057

	1961-2003	1993-2003
Sea level trend (mm/year)	1.8	3.1

Source: IPCC Report

Global ocean trends 1993-2006



Sea surface temperature

NH = 2.3°C/dec
SH = -0.04°C/dec
Global = 0.14°C/dec

Sea height

NH = 0.6mm/yr
SH = 2.3mm/yr
Global = 1.6mm/yr

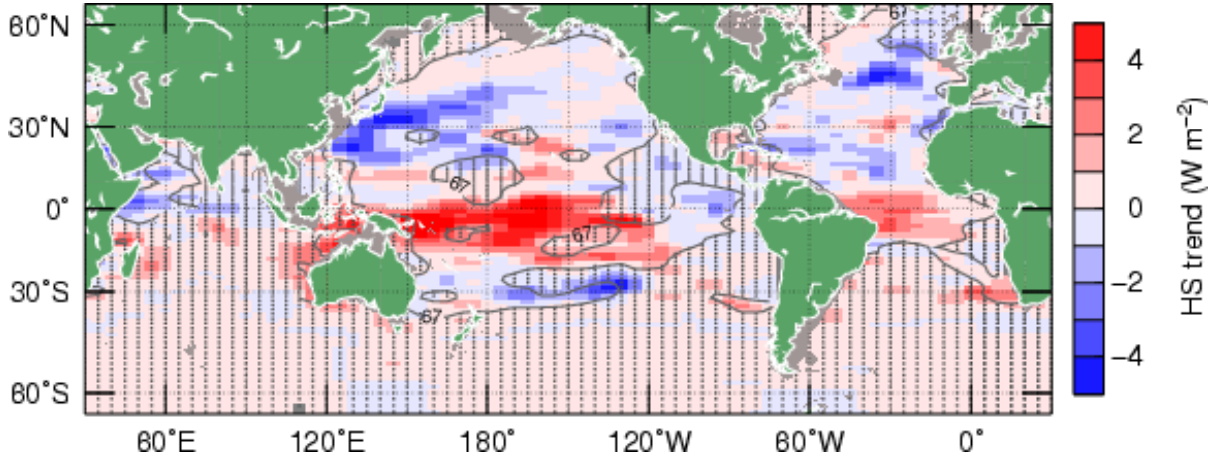
Eddy kinetic energy

NH = 0.82 cm^2s^{-2}/yr
SH = 0.66 cm^2s^{-2}/yr
Global = 0.74 cm^2s^{-2}/yr

Goni et al, 2008

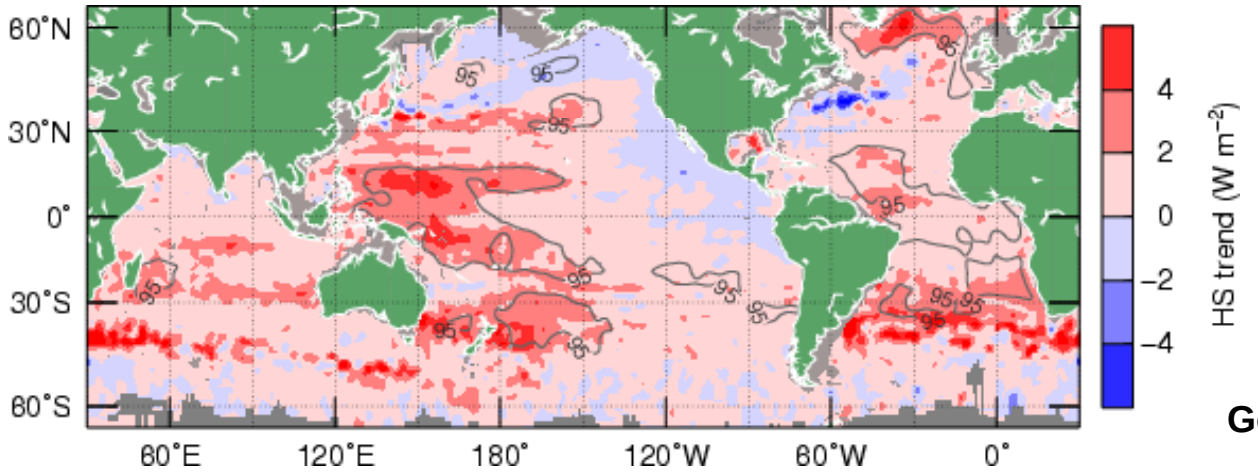
Global ocean trends 1993-2006

Heat storage mixed layer depth (XBTs + Argo)



NH = -0.4 w/m^2
SH = 1.9 w/m^2
Tot = 0.8 w/m^2

Heat Storage top 750m (Altimetry + XBTs + Argo)

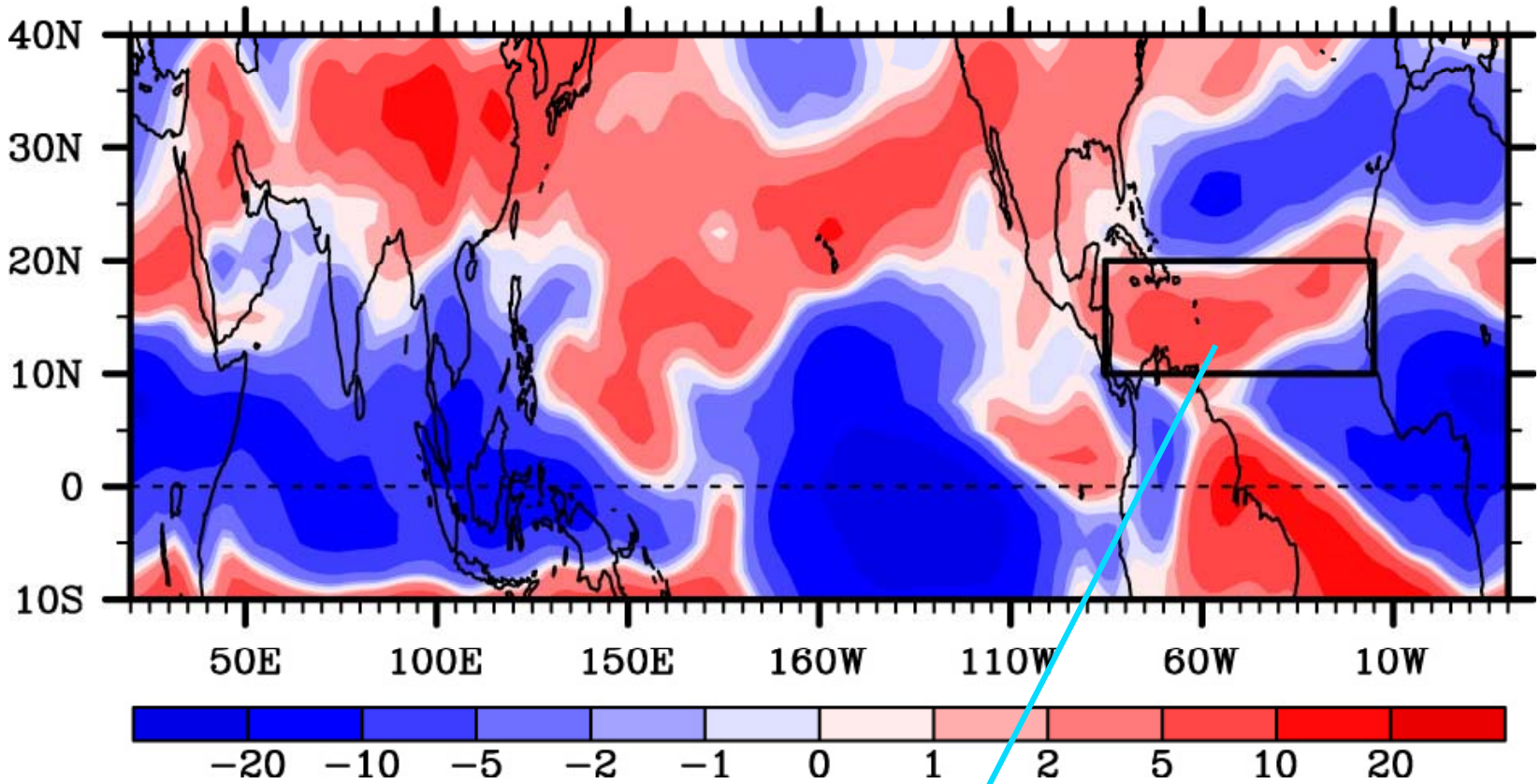


NH = 1.0 w/m^2
SH = 1.4 w/m^2
Tot = 1.2 w/m^2

Goni et al, 2008

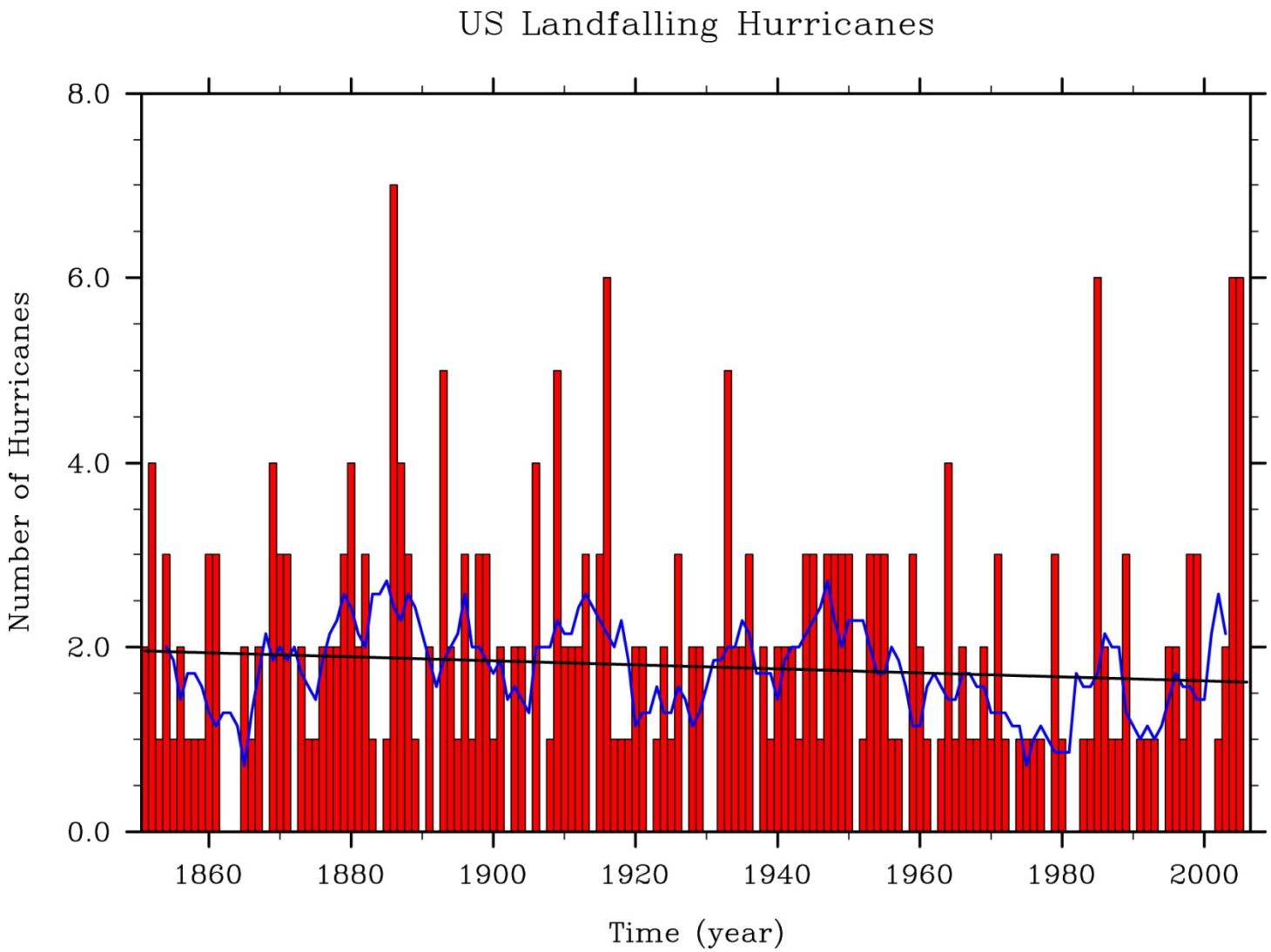
As the global ocean is warmed up, the vertical wind shear in the hurricane Main Development Region is increased.

Regression of vertical wind shear (June-November) onto global warming index



Global Ocean Warming refers to an average over the whole globe, not locally. Three tropical oceans compete with one another for affecting Atlantic hurricanes: Atlantic, Pacific, and Indian Oceans

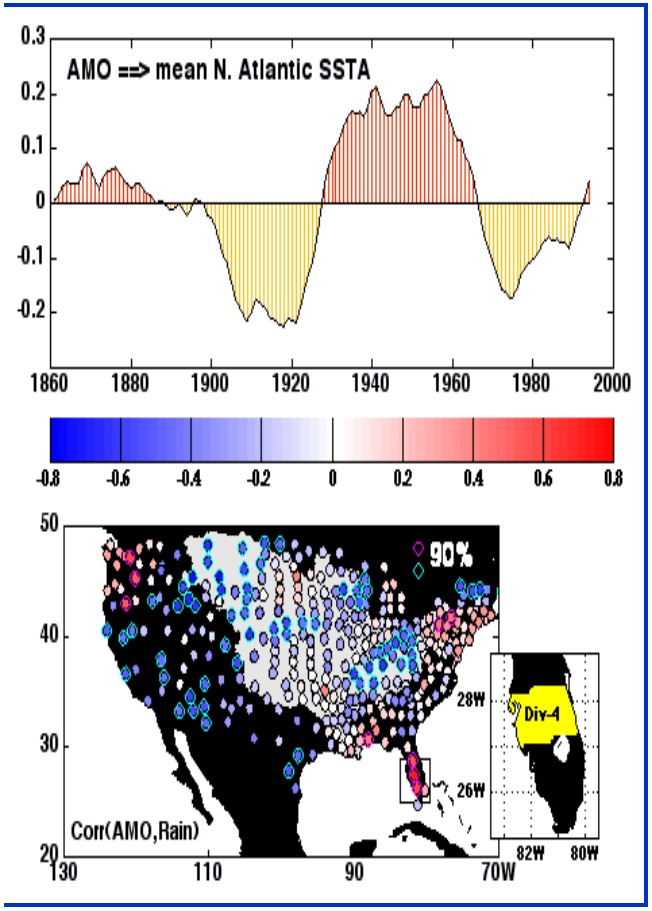
Given hurricane data problem, the most reliable hurricane measurement over the long term is U.S. landfalling hurricanes.

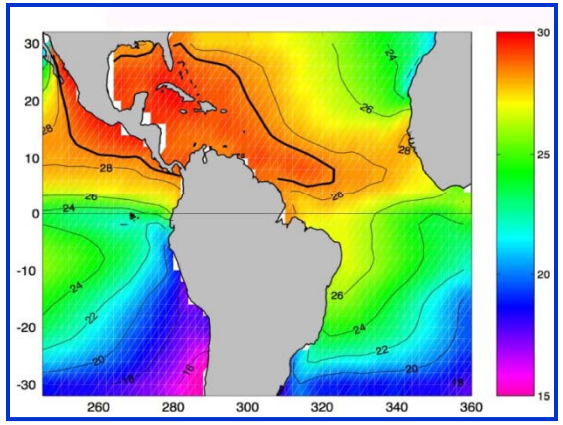


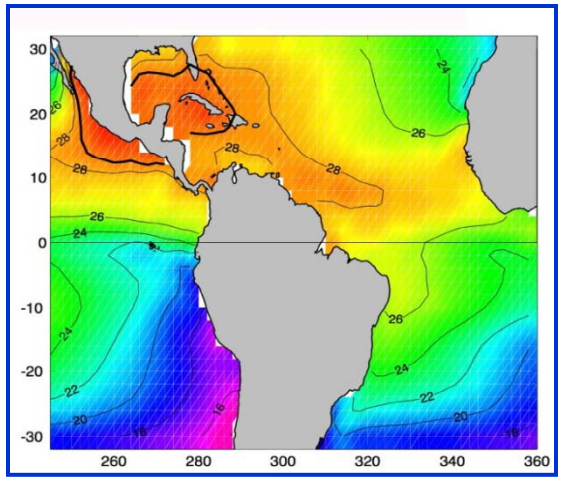
NOAA Atlantic Oceanographic & Meteorological Laboratory

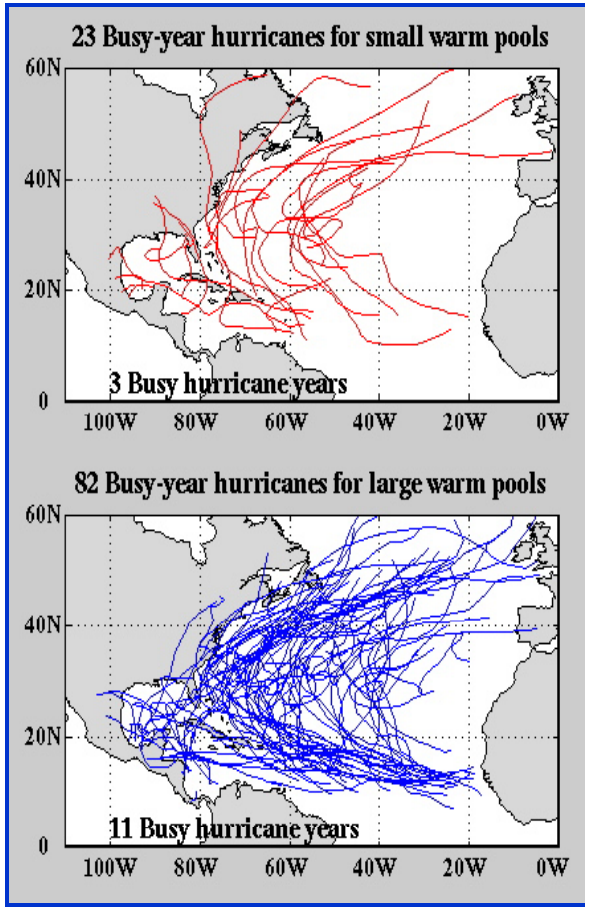
- It shows a weak downward trend.
- However, trend is robust because it is independent of the beginning of linear fit as long as the fitted data cover at least a full cycle of AMO.
- It shows an upward trend from the 1970s because the period of 1970-2006 is from cool (1970-90) to warm (1995-2006) AMO phases.

Climate, ocean variability and its influence on the climate and weather of the surrounding continents









Global warming and U.S. landfalling hurricanes.

Atlantic warm pool (AWP) and Atlantic hurricane activity.

Atlantic Ocean Variability Important to Summer Weather in Eastern U.S. Including Hurricanes

- ENSO impacts climate mainly in winter; we need a value-added paradigm for summer climate prediction, especially for rainfall in the eastern US, and for Atlantic hurricanes

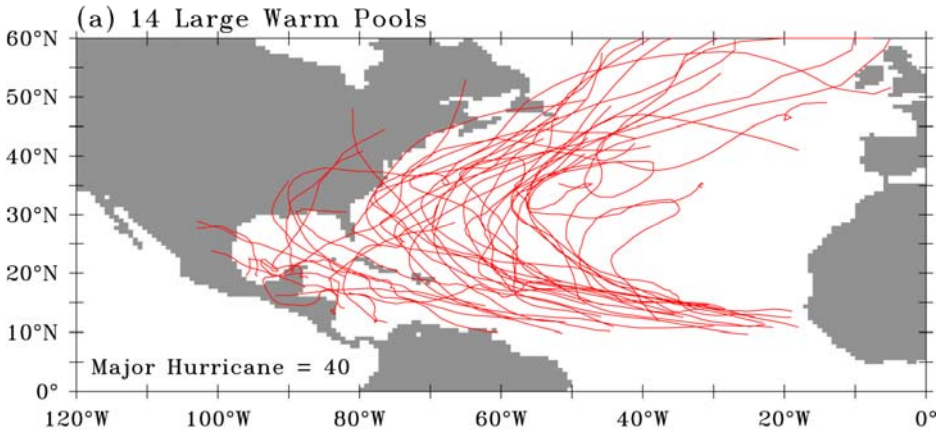
- The Indo-Pacific and Atlantic compete with each other and the atmosphere responds to inter-basin anomalies. We can no longer afford to make projections based only on the Pacific

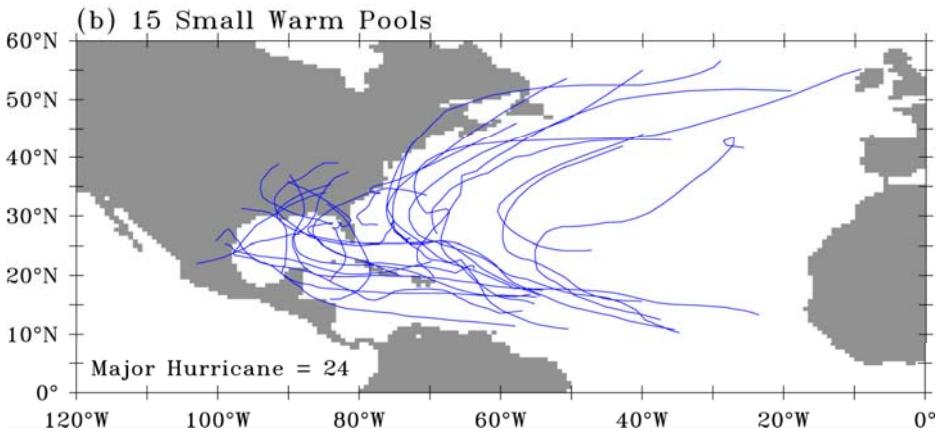
- Warm pool size is an expression of SST anomalies, but weighted toward regions of maximum SST > 28°C where deep convective heating occurs -- also a good match for tropical cyclogenesis

- Applicability to summer precipitation and hurricanes

Atlantic Warm Pool (AWP) and Atlantic Hurricanes

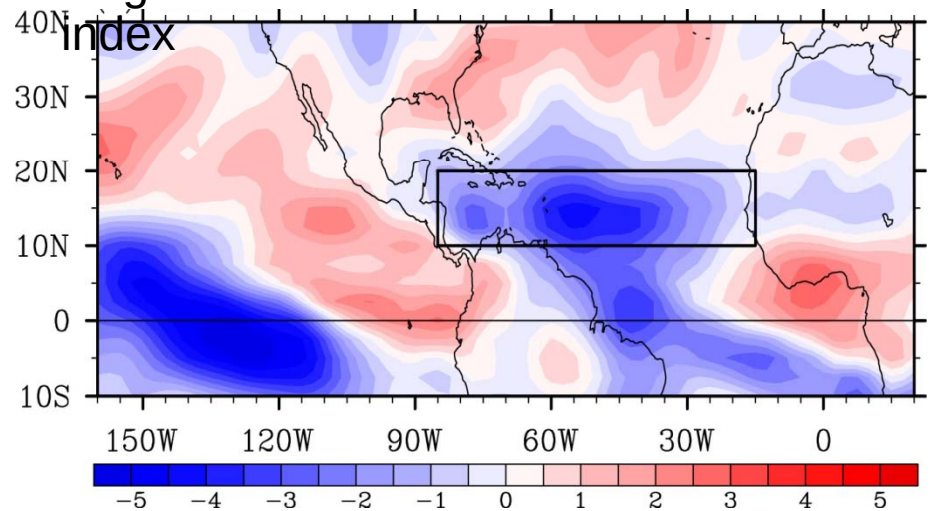
Hurricane composites for large & small AWPs





Why does the AWP affect hurricanes?

Regression of wind shear onto AWP index



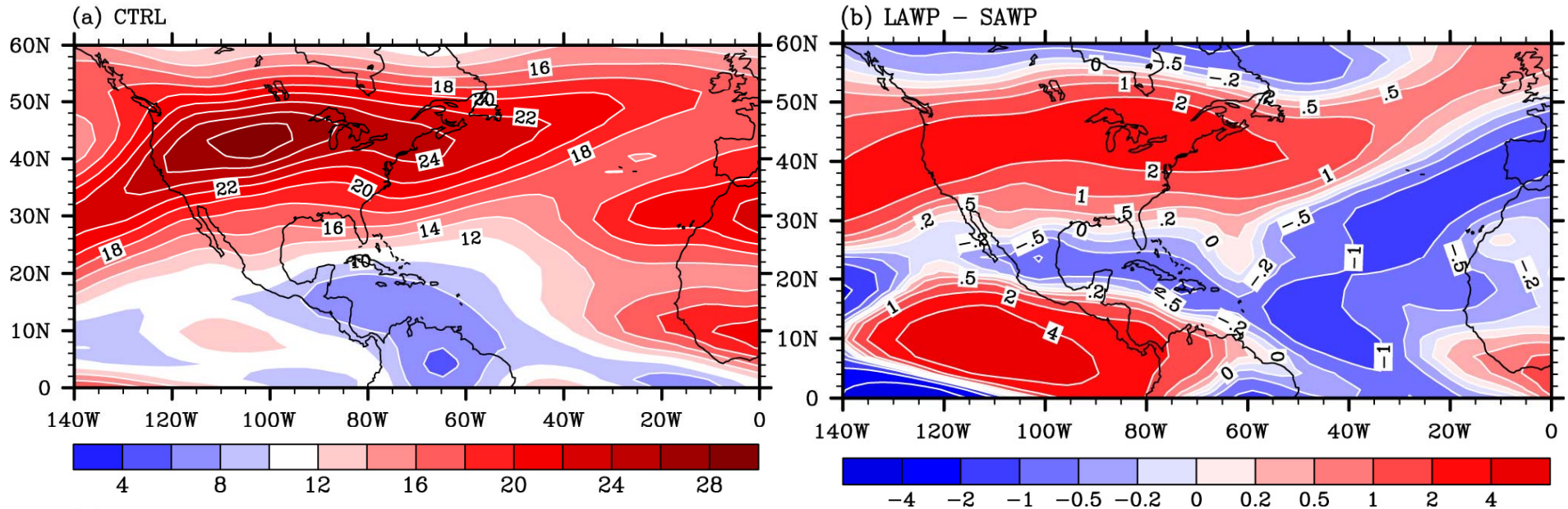
AWP acts as a link between AMO & TCs:

- About 80%, large (small) AWPs occur during warm (cool) phases of AMO.
- Climate response to North Atlantic SST is primarily forced at low latitudes.
- AWP is the path of or a birthplace for TCs.

Large (small) AWPs => Low (high) shear => More (less) hurricanes.

Impact of the AWP on Atlantic Hurricanes: via Wind Shear

Vertical Wind Shear (JJASON): $VWS = \sqrt{(U_{200} - U_{850})^2 + (V_{200} - V_{850})^2}$

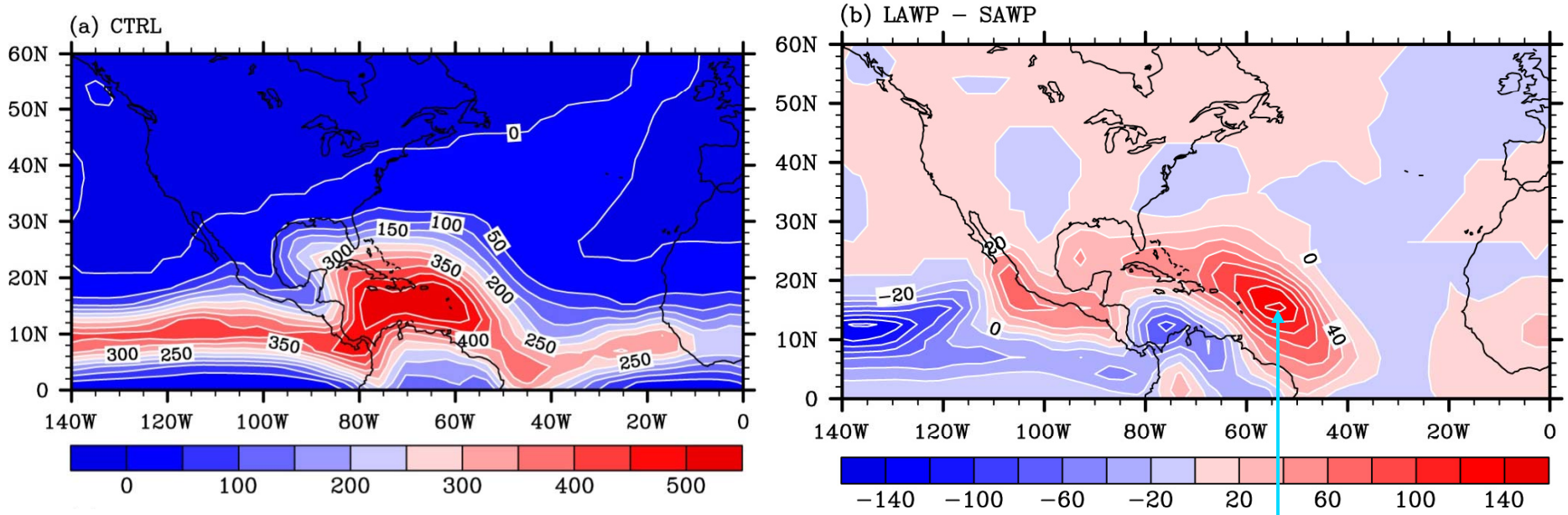


The AWP reduces lower tropospheric easterly flow and upper tropospheric westerly flow, resulting in a reduction of the vertical wind shear in the MDR that favors Atlantic hurricanes. This is because the atmospheric response to the AWP's heating is baroclinic (Gill 1980).

Impact of the AWP on Atlantic Hurricanes: via Atmos. Instability

Convective Available Potential Energy (CAPE)

he higher the CAPE value, the more energy available to foster storm growt



The orientation lies along the track of historical hurricanes.

A large AWP tends to increase CAPE due to the increased near-surface air temperature and water vapor content, which provides the fuel for moist convection and thus increases Atlantic hurricane activity.

Summary

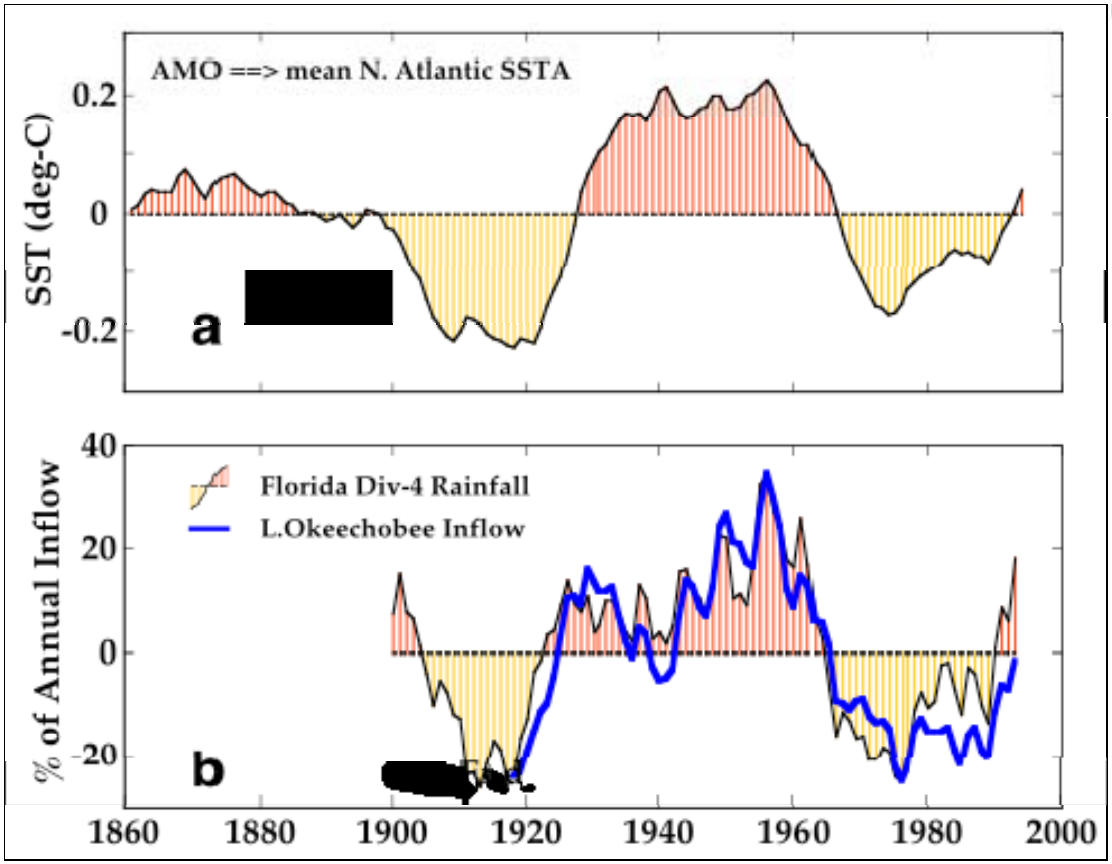
- Global warming is associated with a secular increase of vertical wind shear in the MDR which coincides with a downward trend in U.S. landfalling hurricanes.
- Whether future global warming increases Atlantic hurricane activity will depend on relative warming role of the three tropical oceans.
- The AWP acts as a link between the AMO and hurricanes/climate response.
- Large (small) AWP reduces (enhances) vertical wind shear in the MDR and increases (decreases) the moist static instability of the troposphere, both of which favor (disfavor) Atlantic TC activity.
- Saharan air layer can act to suppress TC intensity.

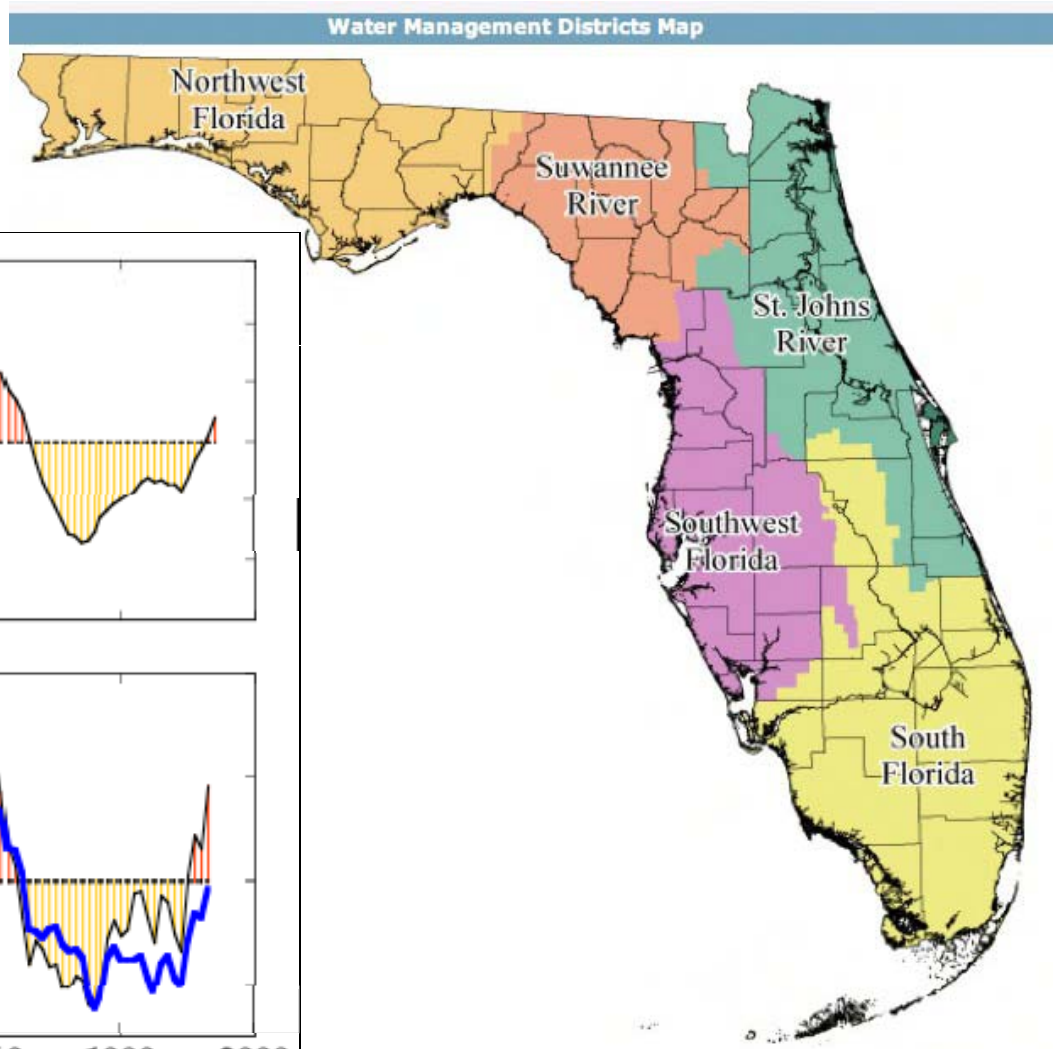
Florida Water Management Districts

AOML research is influencing water planning

Statute-mandated 20-year water plans every 5 years

Lake Okeechobee inflow vs. AMO

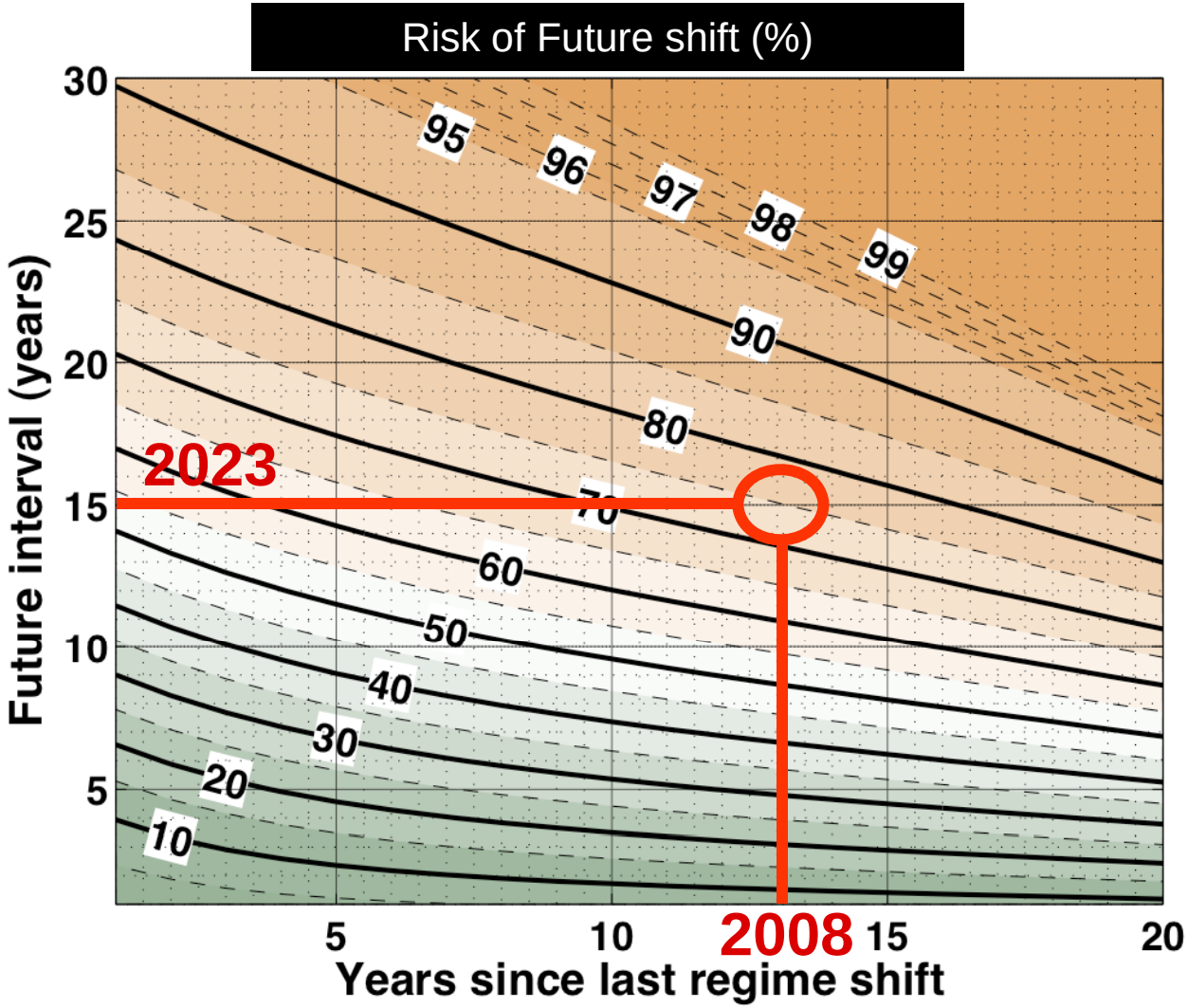




A decision support tool for long-term planning

Let t_1 = years since last shift; t_2 = years until the next shift

We now compute the conditional probability for t_2 given t_1



Questions?

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Atlantic Oceanographic & Meteorological Laboratory

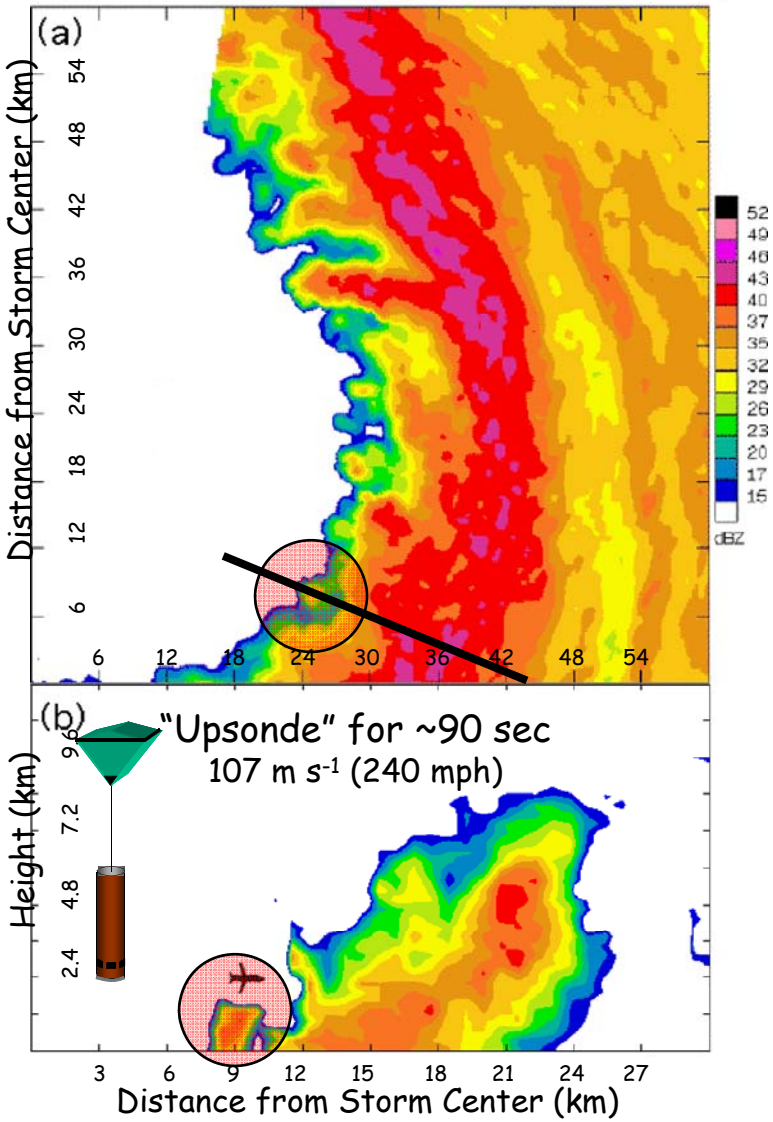
National Oceanic & Atmospheric Administration

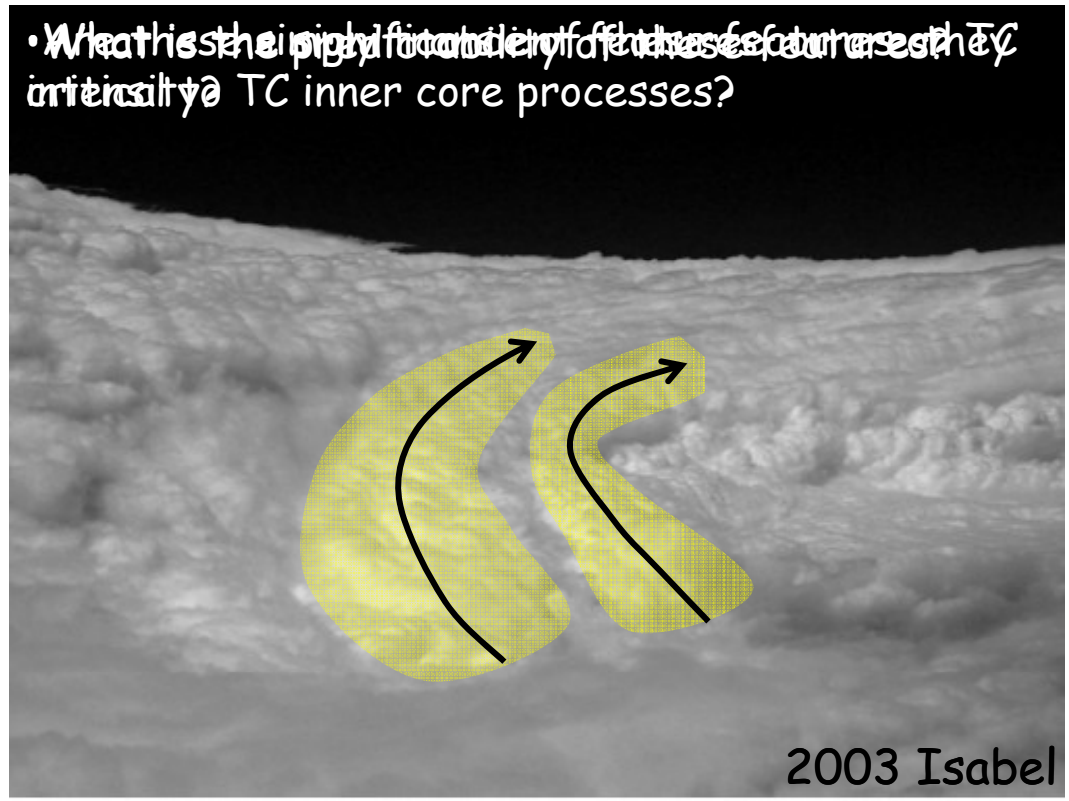
Background Slides

Eye-Eyewall Mixing Processes

Main Science Objective:

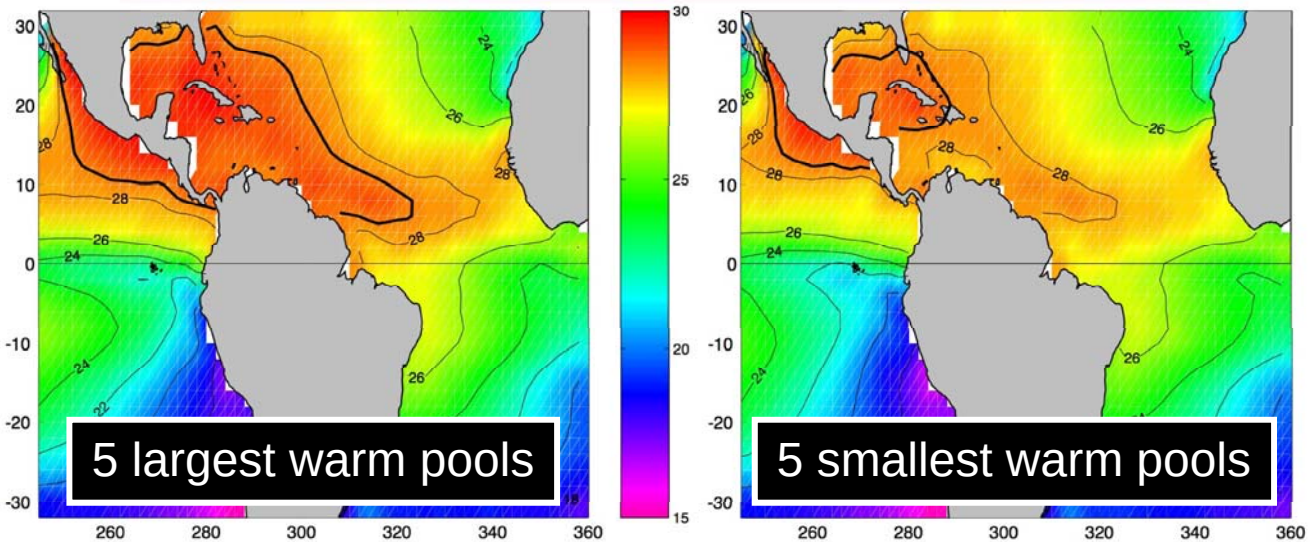
Understand and describe the small-scale features found in tropical cyclone eyewalls and their effect on intensity & landfall impacts





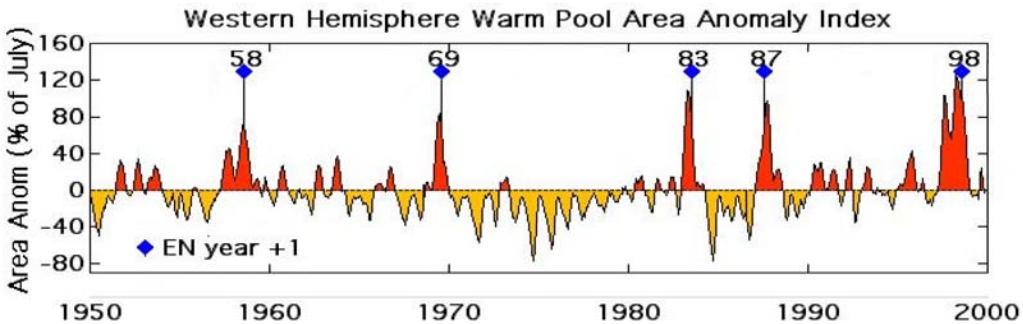
Possible mixing of warmer/moister air from the eye into the surrounding eyewall (on very short time scales: ~1.5 hr);

Western Hemisphere Warm Pool



All tied together:

- Atlantic Warm Pool
- AMO
- Rainfall
- Hurricanes



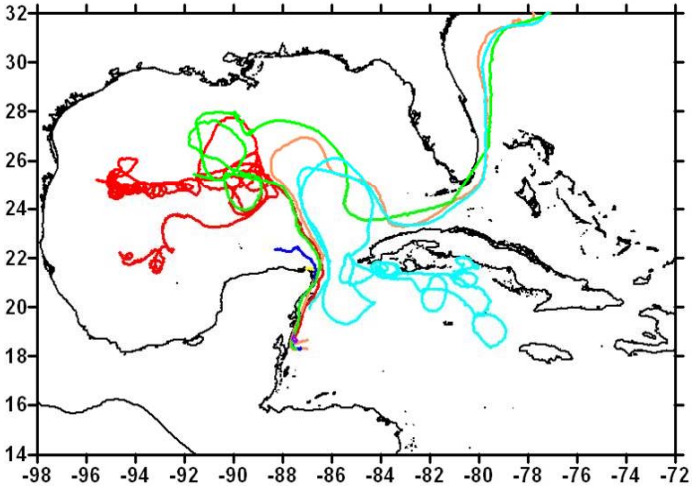
ECOSYSTEM CONNECTIVITY

Elizabeth Johns

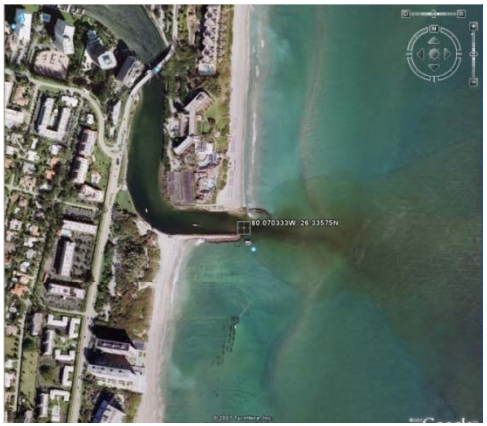
Scientists from AOML are working collaboratively with scientists from SEFSC to determine the degree of physical and biological connectivity of the coral reefs of NOAA's Florida Keys National Marine Sanctuary (FKNMS) with upstream coral reef ecosystems

- The FKNMS is strongly linked by ocean currents to waters of the Yucatan Peninsula
- Eddies and gyres are important in establishing the time and length scales of the physical connectivity
- This physical connectivity between geographically separated spawning grounds may have an important influence on the degree of biological connectivity between larval reef species populations
- The project supports NOAA's 5-year Ecosystem Mission Goal to Protect, Restore and Manage Use of Coastal and Ocean Resources.

Drifter Trajectories from the Gordon Gunter Cruise, March 2006

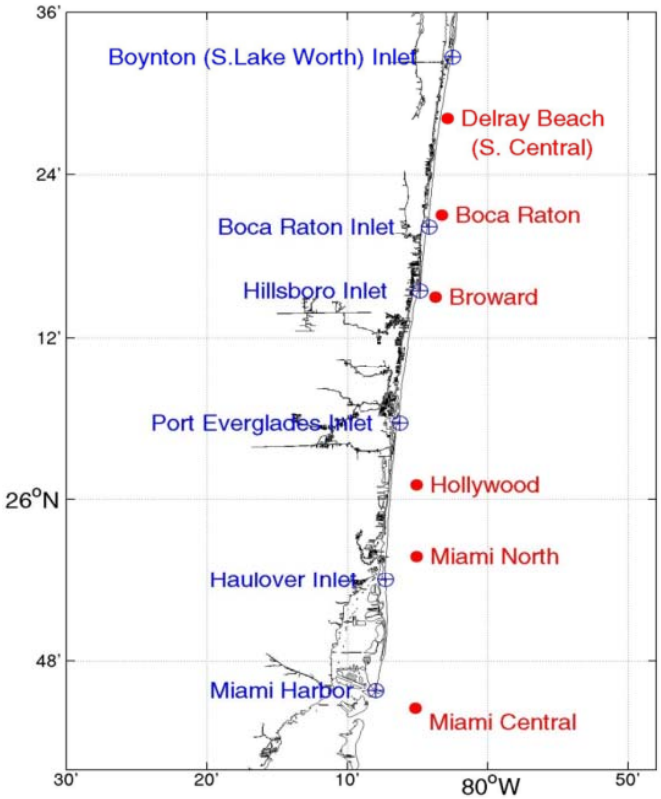


The Florida Area Coastal Environment (FACE) Program



Boca Raton Inlet
(GoogleEarth)

Boca Raton WWTP outfall boil
October, 2006



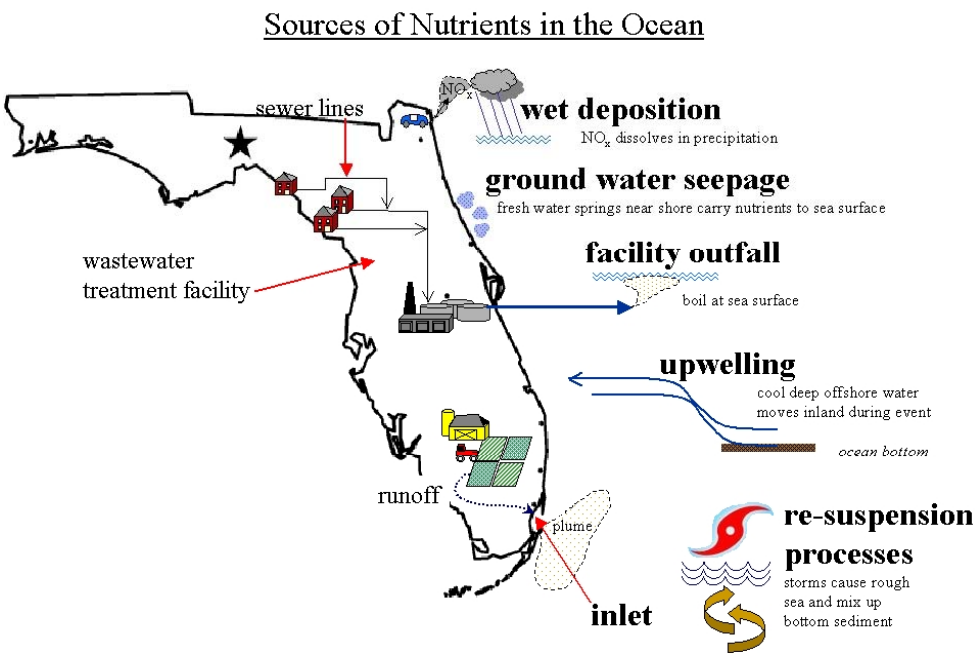
Inlets and TWWP Outfalls in SE Florida

FACE

FACE Mission

FACE is a multi-agency program including federal, state, local governments, and water and sewer authorities.

- **Provide scientific information for management decision-making**
- **Develop a multi-decadal database on coastal environmental parameters**
- **Communicate results to the general public.**



FACE Approach

- **Quantify nutrient and microbiological sources**
- **Determine natural (background) concentrations**
- **Determine potential effects of the anthropogenic substances**

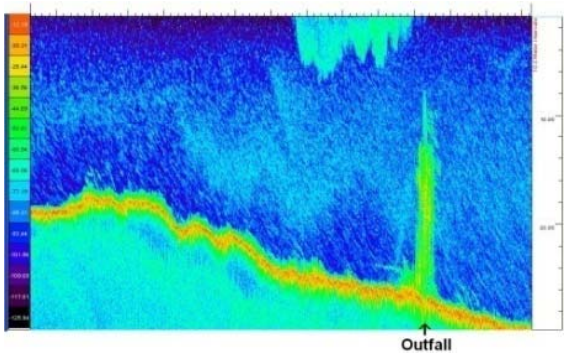
NOAA R/V Nancy Foster

NOAA R/V Cable

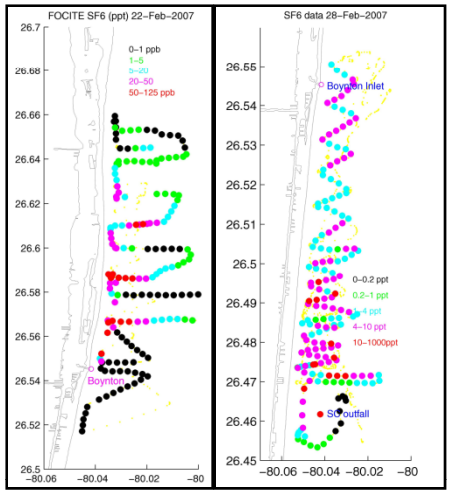
FACE-2

Field Program

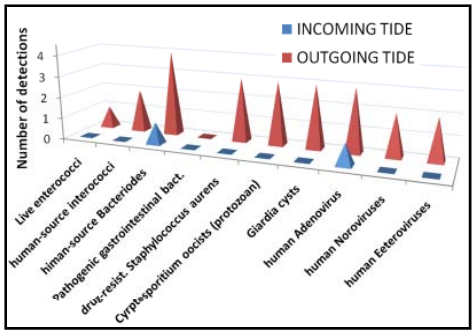
- **Tracer Experiments at Inlets and Outfalls**
- **Water quality monitoring programs**
- **Inlet Characterization**
- **Ocean Current measurements**
- **Microbiology investigations**
- **Acoustic backscatter profiles**
- **Stable isotope studies (^{15}N, ^{13}C)**



Acoustic backscatter image of SC plume

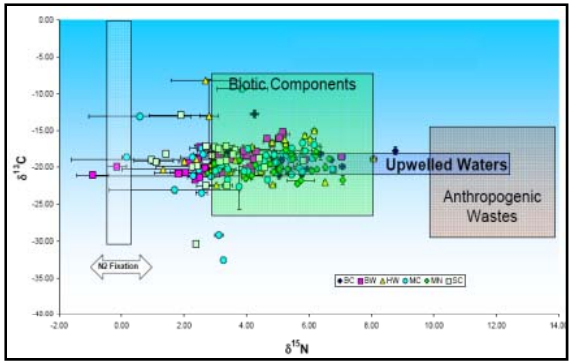


SF_6 concentrations at Boynton Inlet (L) and S.C. outfall plume (R), Feb. 2007



Microbiology of Boynton Inlet

Stable Isotope analysis of TWWP plume water



Publications

- P. Swart and C. Drayer, FACE 1st Year Report, Sampling of Nitrogen Compounds for Determination of Isotopic Values in Benthic Macroalgae, Sediment Organics, and Seawater, 2008.
- J. Proni et al., Brevard County Near Shore Ocean Nutrification Analysis, NOAA Technical Report OAR-AOML-37, July, 2005.
- R. Wanninkhof et al., Farfield Tracing of a Point Source Discharge Plume in the Coastal Ocean Using Sulfur Hexafluoride, Environ. Sci. Technol. 39, 8883-8890, 2005.
- J. Proni and R. Williams, Acoustic Measurement of Currents and Effluent Plume Dilutions in the Western Edge of the Florida Current, in Acoustic Remote Sensing Applications, p. 537-550, 1997.
- SEFLOE Final Report, Hazen and Sawyer, 1994.