

# FUTURE CLIMATE SCENARIOS IN THE CARIBBEAN

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Associate Professor

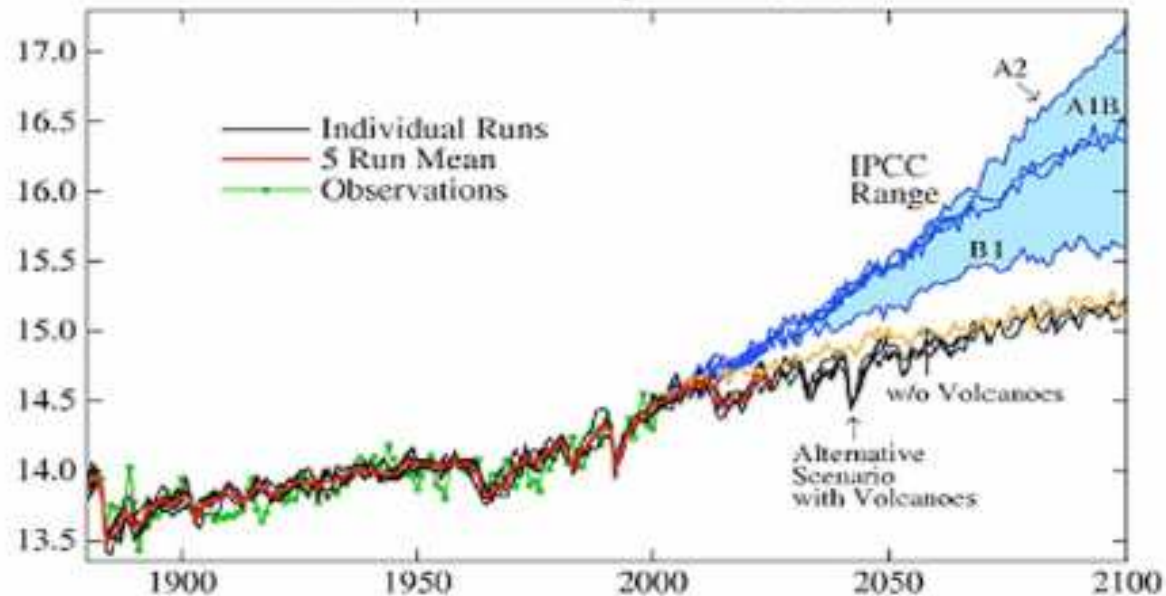
National University, San Diego, USA

# CARIBBEAN CLIMATE SYMPOSIUM (CCS)

- April, 2006
- University of Puerto Rico – Mayaguez
- 100 participants
- <http://cmg.uprm.edu/ccs/>
- Book to be published by Cambridge University Press
- Seeking more material
- Give me your contact details

# 21<sup>st</sup> Century Global Warming

Surface Air Temperature (°C)



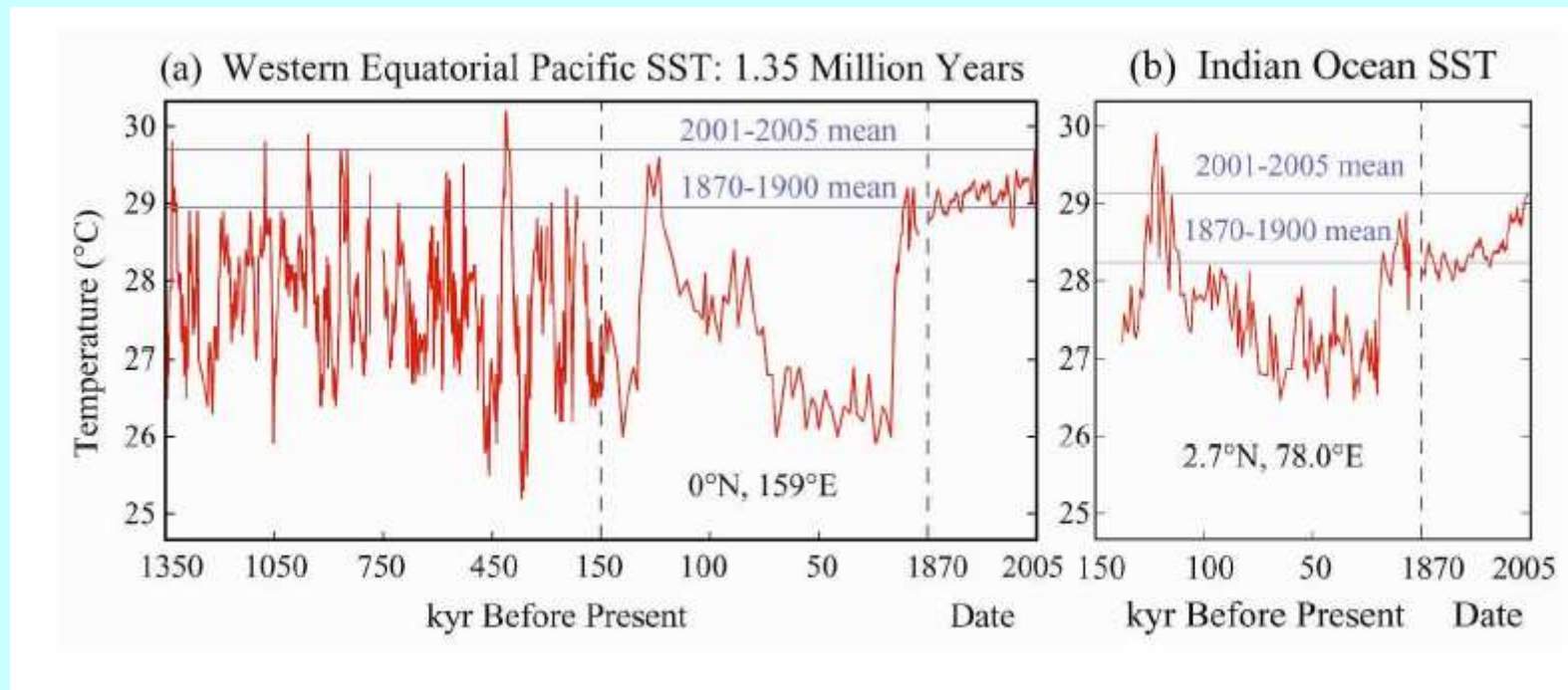
## Climate Simulations for IPCC 2007 Report

- ▶ **Climate Model Sensitivity 2.7-2.9°C for 2xCO<sub>2</sub>**  
(consistent with paleoclimate data & other models)
- ▶ **Simulations Consistent with 1880-2003 Observations**  
(key test = ocean heat storage)
- ▶ **Simulated Global Warming < 1°C in Alternative Scenario**

**Conclusion: Warming < 1°C if additional forcing ~ 1.5 W/m<sup>2</sup>**

Source: Hansen et al., to be submitted to *J. Geophys. Res.*

## SST FOR THE LAST 1,350,000 YEARS



Taken from Jim Hansen WWF talk, November 2006

# HOW WILL THESE CHANGES AFFECT THE CARIBBEAN?

- Increased SSTs?
- Changing wind patterns?
- Changing vertical wind shear?
- Increased Saharan dust?
- Changes in precipitation?
- Changes in surface salinity?
- Changes in stratification – vertical mixing?

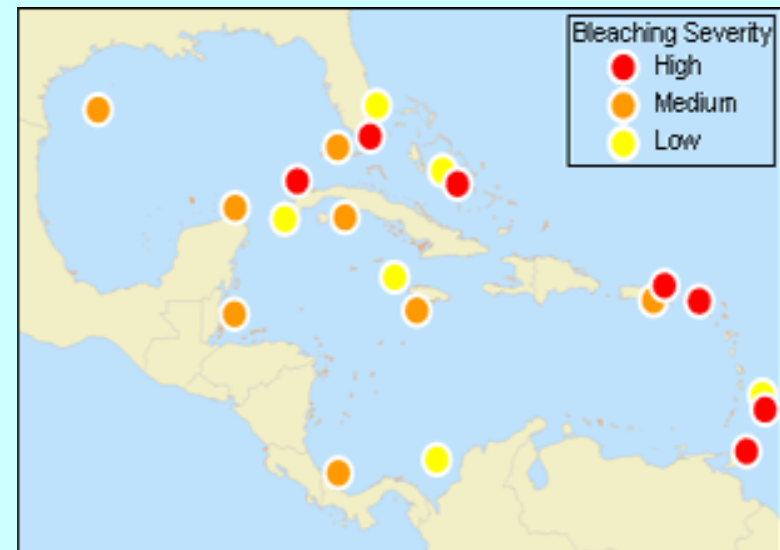
## DEAD AND DYING CORAL



Taken from "Our Changing Planet: The View from Space"  
Contribution by Liu and Strong

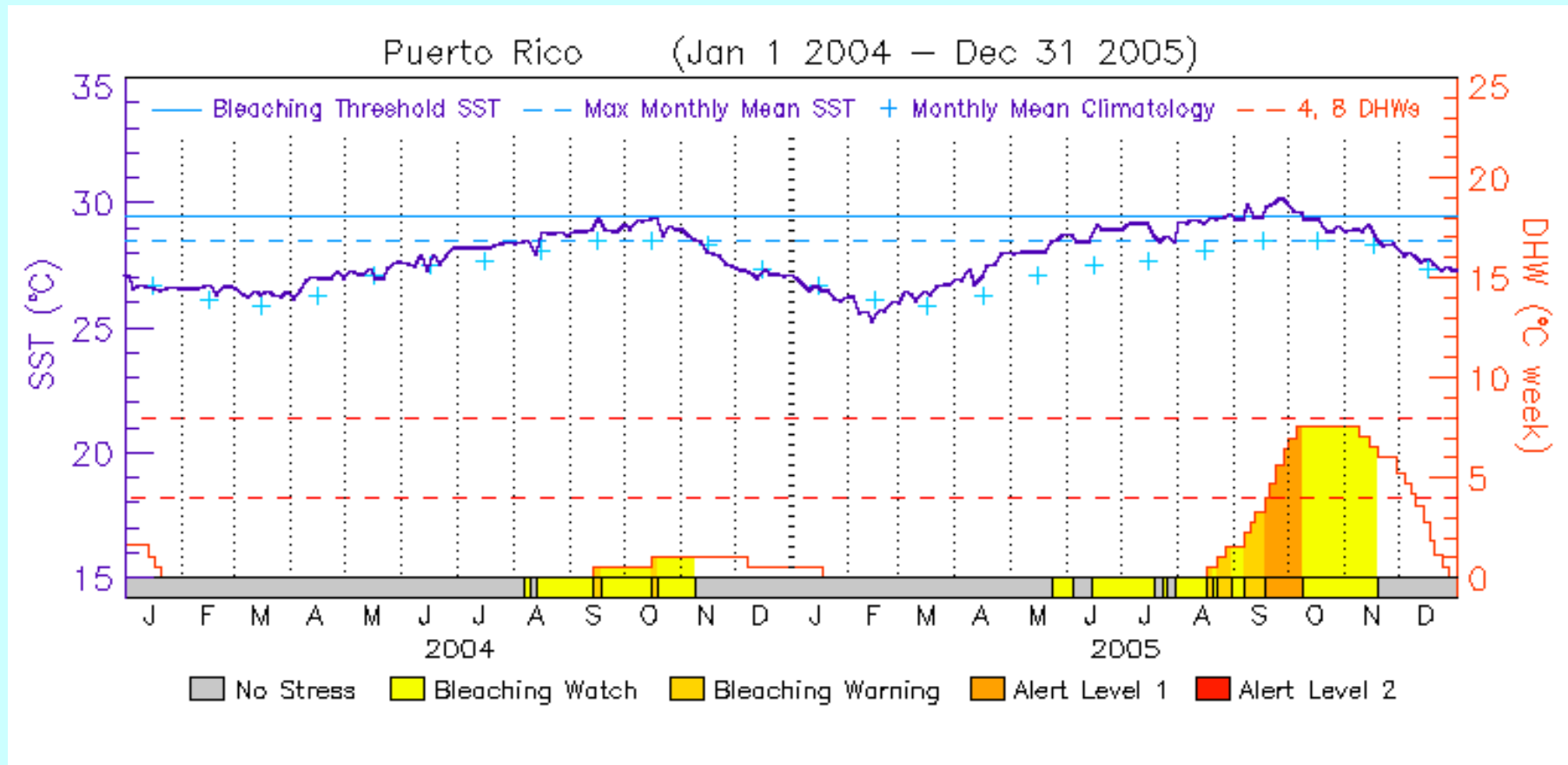
# 2005 Coral Bleaching Across Caribbean Basin

- Caribbean basin experienced major bleaching event mid to late 2005
- Significant bleaching also seen in Bahamas, and Florida Keys
- Remotely sensed signals, visual reef observations, and NOAA's Coral Reef Watch IMN provided early signals of onset of bleaching
- NOAA issued bleaching alert for Florida Keys late August, Puerto Rico and U.S. Virgin Islands early October
- Reports from ReefBase, Global Coral Reef Monitoring Network, and NOAA Coral Health and Monitoring Program being compiled to produce comprehensive report



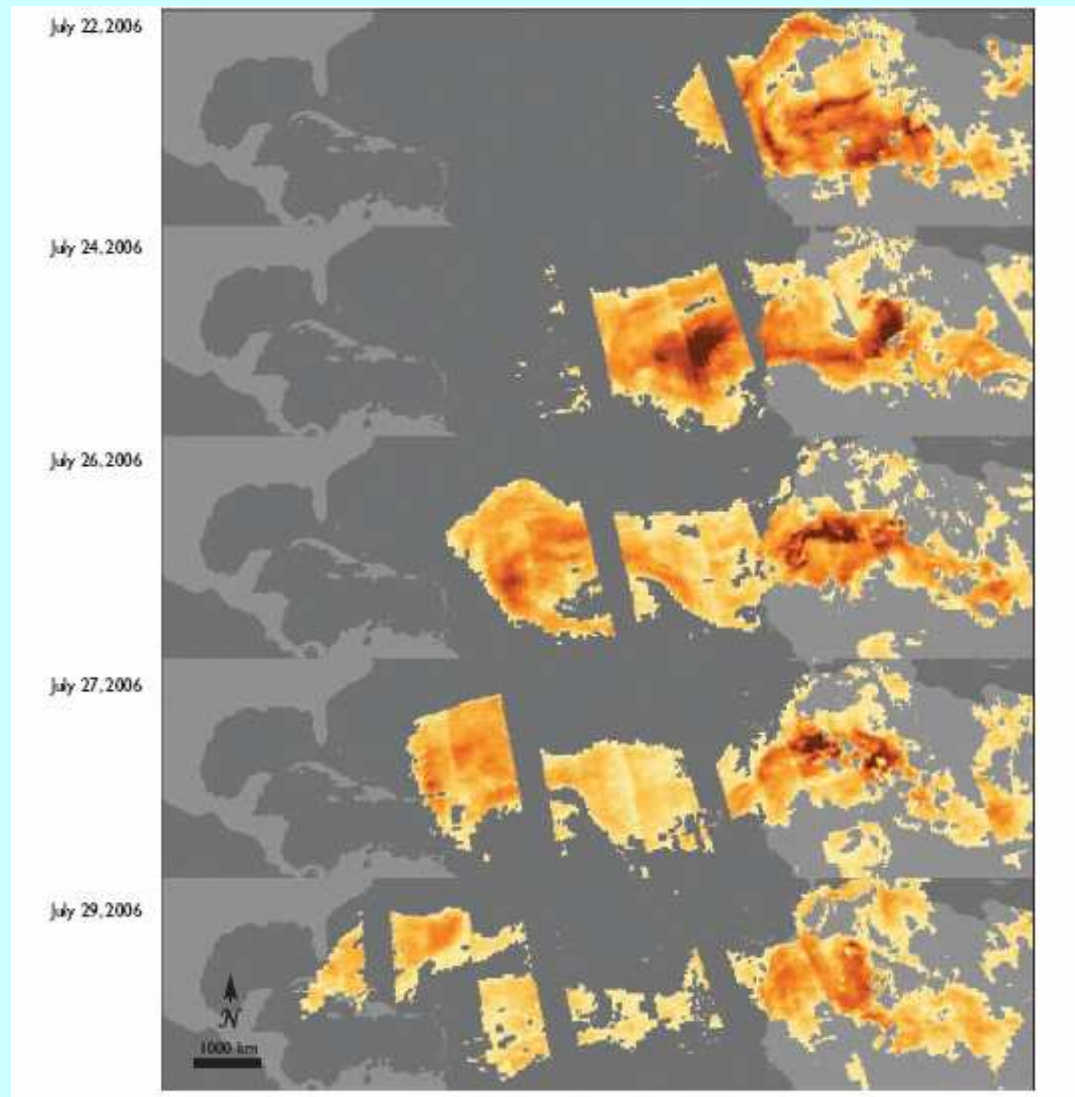
From CCS by Scott Stripling

# NOAA Coral Reef Watch Tropical Ocean Coral Bleaching Indices



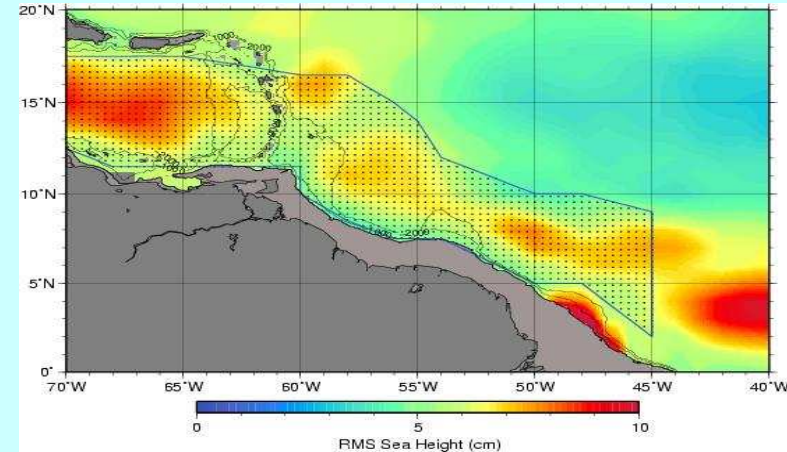
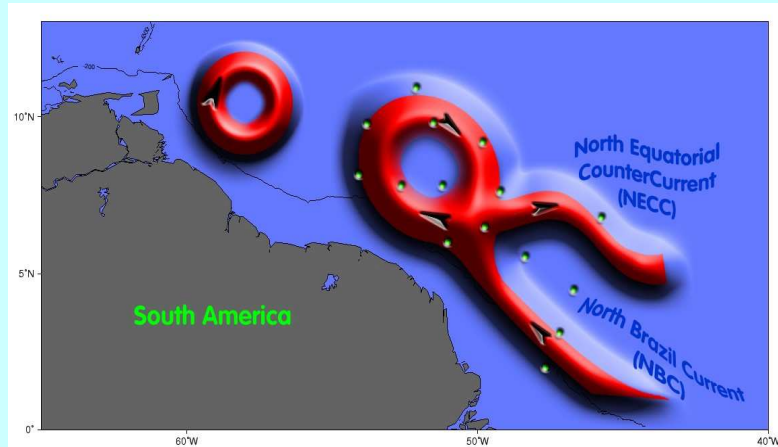
From CCS by Scott Stripling

## SAHARAN DUST IN JULY 2006



Taken from “Our Changing Planet: The View from Space”  
Contribution by Carder, Walsh, and Cannizzaro

# NBC Rings



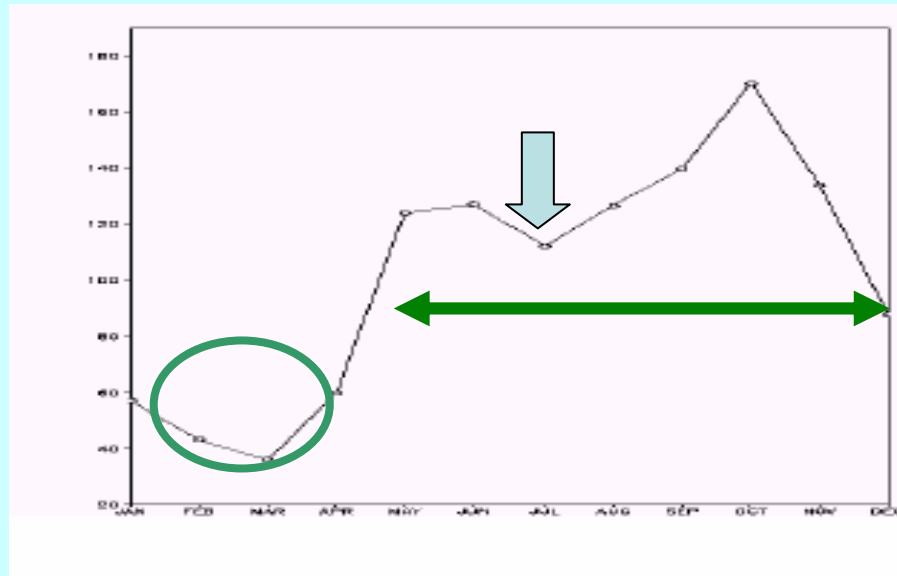
- **Large anticyclones that pinch off from NBC retroflection near 8°N**
- **Translate northwestward along coast of South America toward Caribbean**
- **Ring shedding one of several mechanisms that contribute to transport of South Atlantic upper ocean waters to North Atlantic as part of Atlantic MOC (Johns *et al.*, 1998).**
- **Satellite measurements (TOPEX/Poseidon and Sea-WIFS) suggest that number of rings generated is 5-6 per year with associated 5-6 Sv of northward transport (Goni and Johns, 2001; Fratantoni and Glickson, 2002).**

From CCS by Scott Stripling

# CARIBBEAN CLIMATE

(From CCS by Michael Taylor)

# Rainfall Climatology



## 1. Dry Season

*December - April*

## 2. Rainfall Season

*May - November*

*Peaks in*

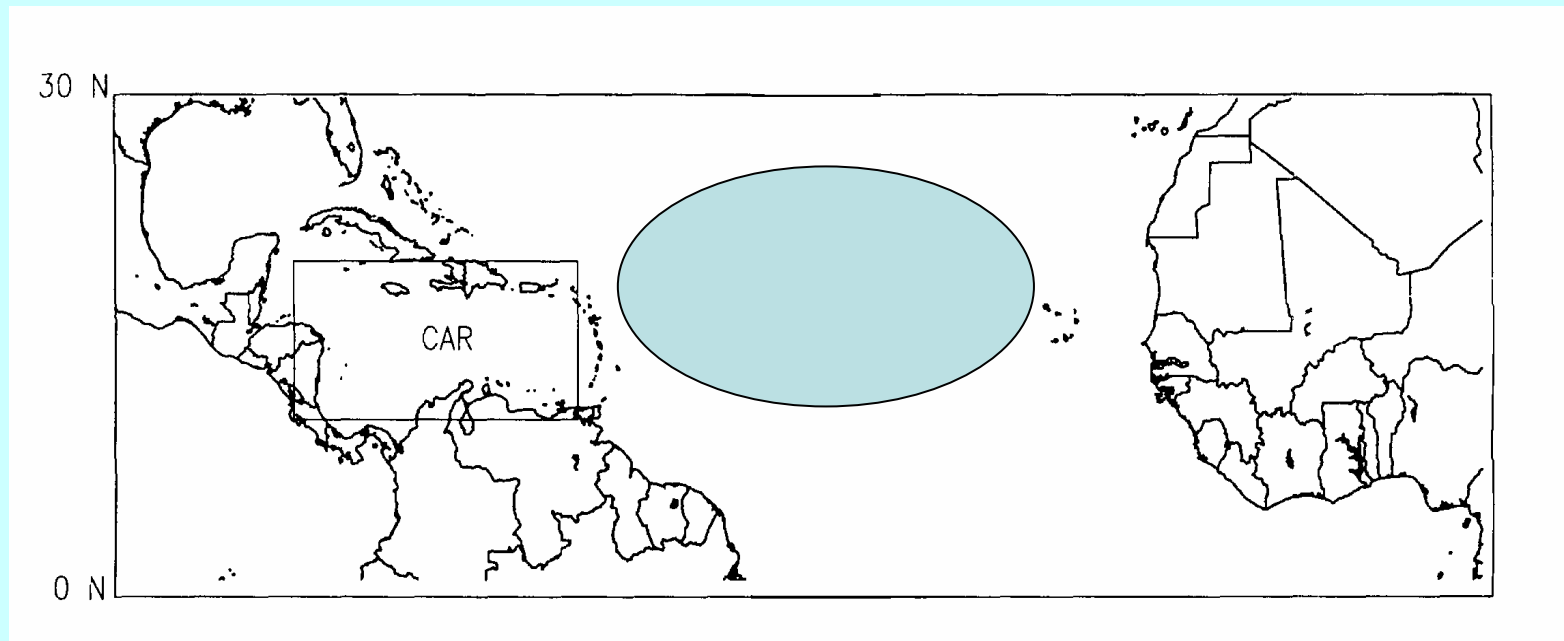
*September/October*

## 3. Bimodal - MSD

*Early season - May-July*

*Late Season - August - November*

# 1. Subtropical High



Semi-permanent feature

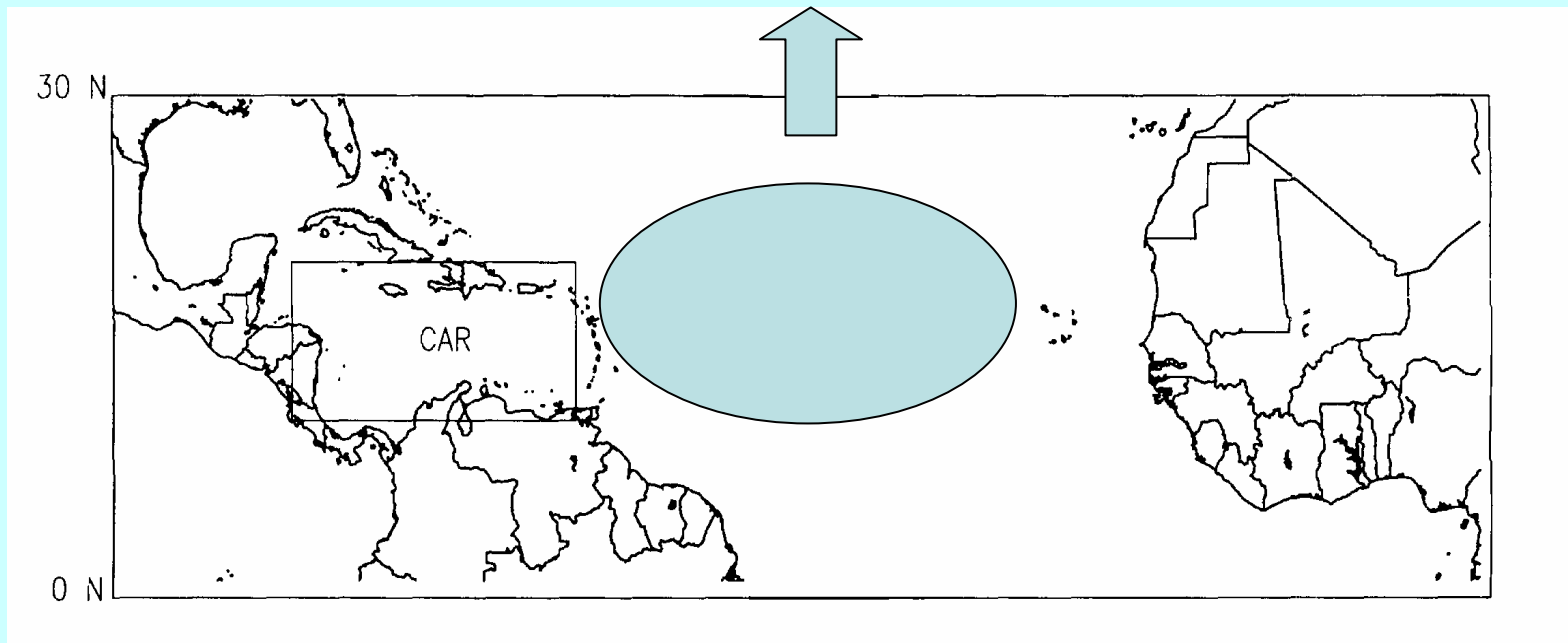
Subsidence

Strong meridional gradient in pressure

Strong easterlies, i.e., trades

Keeps Caribbean dry – winter months

# 1. Subtropical High



Migrates northward: April - November

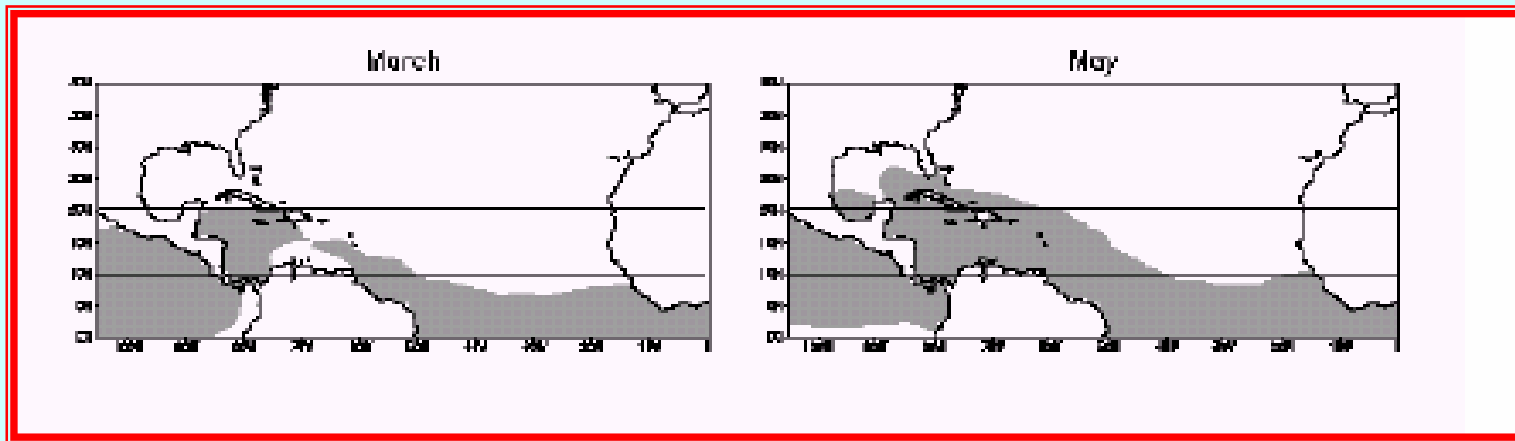
Weakened meridional pressure gradient

Weakened trades

Convergence over Caribbean

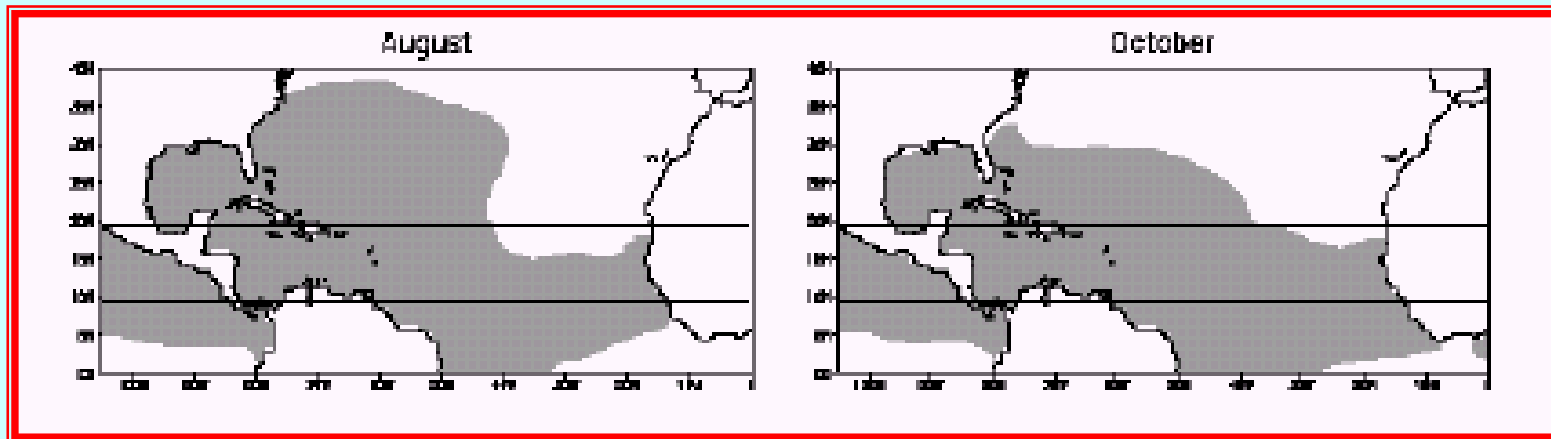
Brief southward retrogression July - Caribbean dry

## 2. SSTs



Warm SSTs support convection  
27°C threshold  
Warm Pool appears early March  
Begins eastward trek.

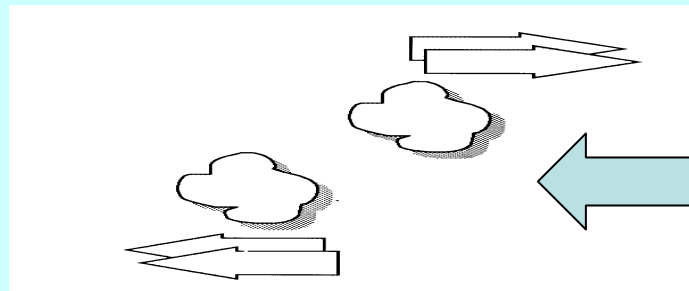
## 2. SSTs



Warm pool covers much of Atlantic by October

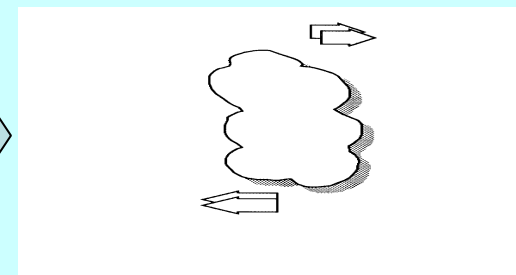
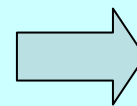
# 3. Vertical Shear

- \* Concurrent with weaker surface easterlies is a weakening of the upper level westerlies.
  - \* Implies weaker vertical shear



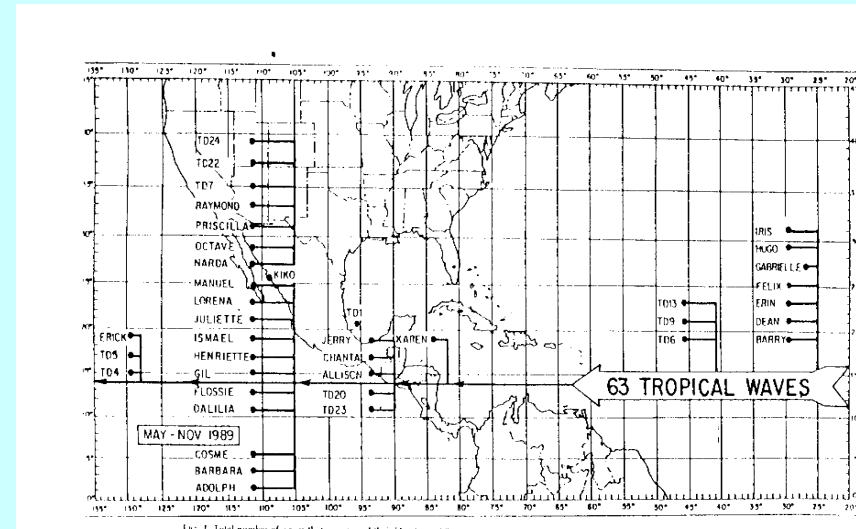
Strong Shear  
Cloud formation  
restricted

Weak shear Vertical  
development possible



# 4. Easterly Waves

Disturbances which leave African coast and move westward through the Caribbean.

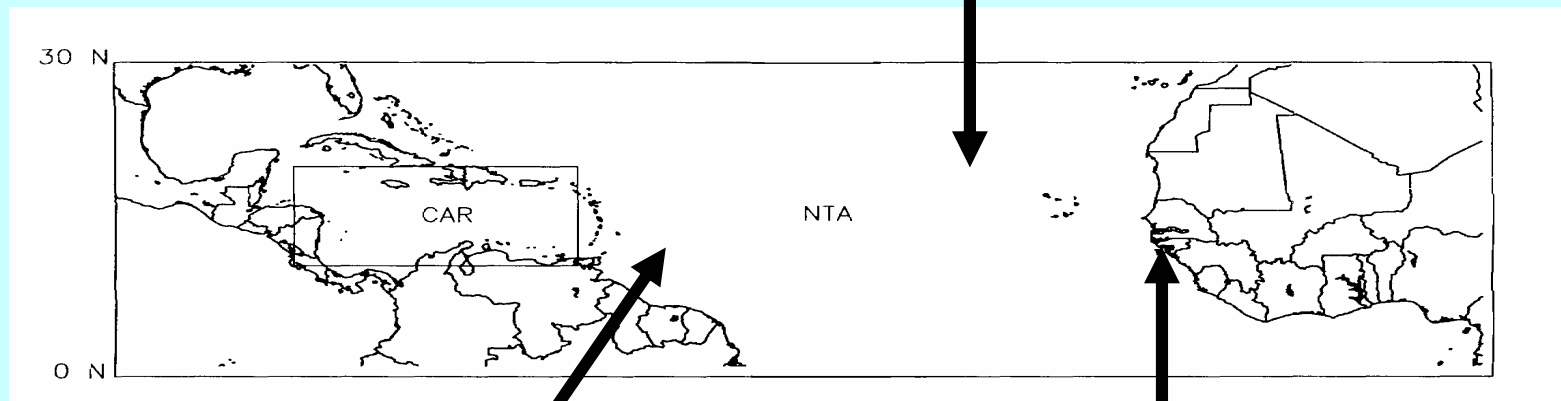


- May-October
- One every 3-5 days
- Strengthen : Wave -> Disturbance -> Depression -> Storm -> Hurricane

# Mechanisms

## Movement of North Atlantic High (NAH)

- April - November
- Reduced vertical shear



## SST Increase

- April-October (peak)
- >27°C

## Easterly/Tropical Waves

- Late May-November
- 3-5 days
- Strengthen

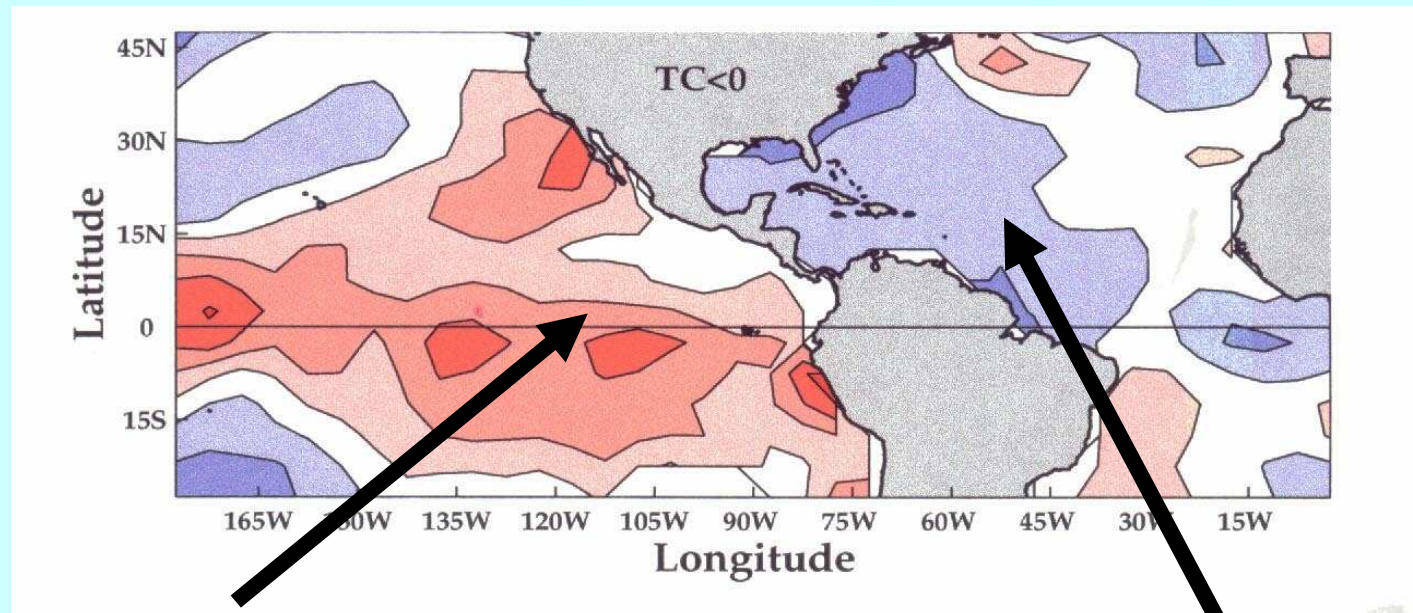
# The Dry Season

- Strong Hadley Circulation
- Subsidence (descending arm) over the Caribbean

**BUT...**

- Cold fronts: December – January
- Rain over northern Caribbean isles

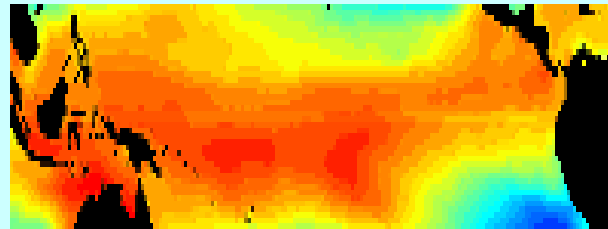
# Influence of global climatic fluctuations on the mechanisms



Influence of the  
tropical Pacific

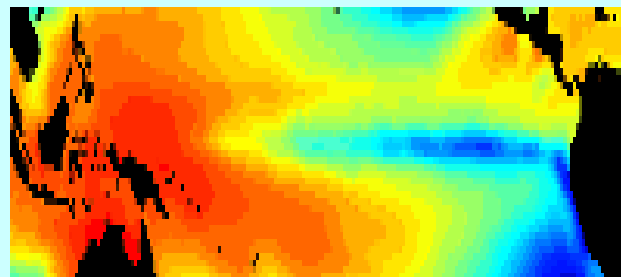
Influence of the  
tropical Atlantic

# 1. ENSO



Niño

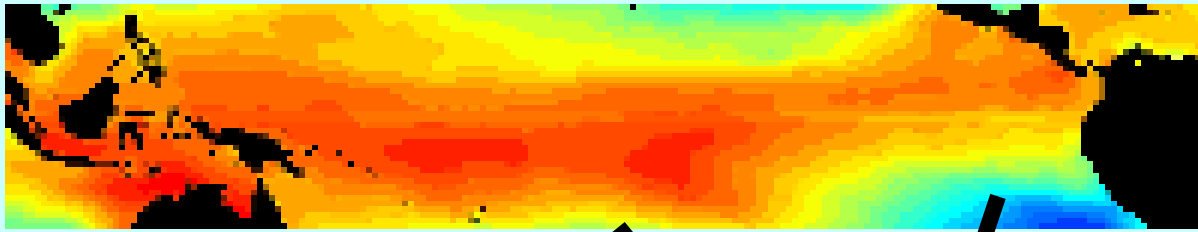
Abnormal warming (Niño) or cooling (Niña) of the equatorial Pacific.



Niña

Causes changes in climate across the globe.

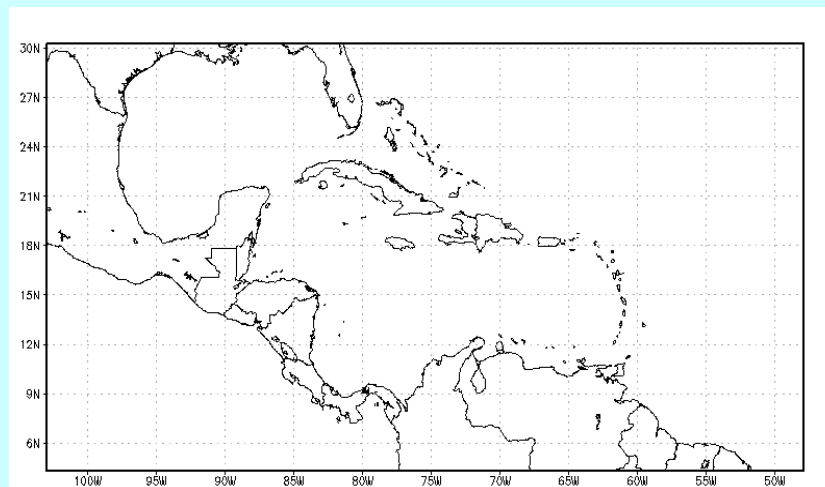
# El Niño



Late Wet Season

Early Wet Season

Dry Season



# Late Wet Season

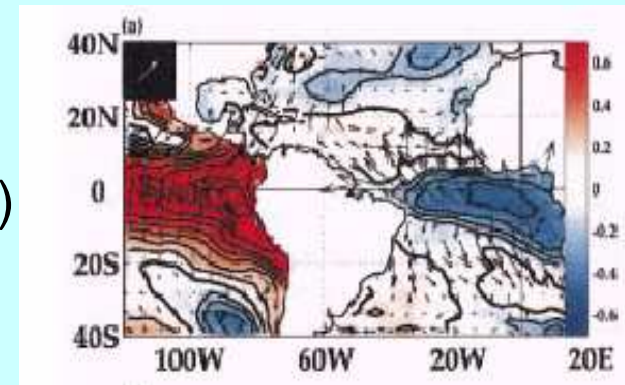
Most well documented teleconnection

1. Stronger upper level winds => Strong shear (*Gray 1968, Arkin 1982*)

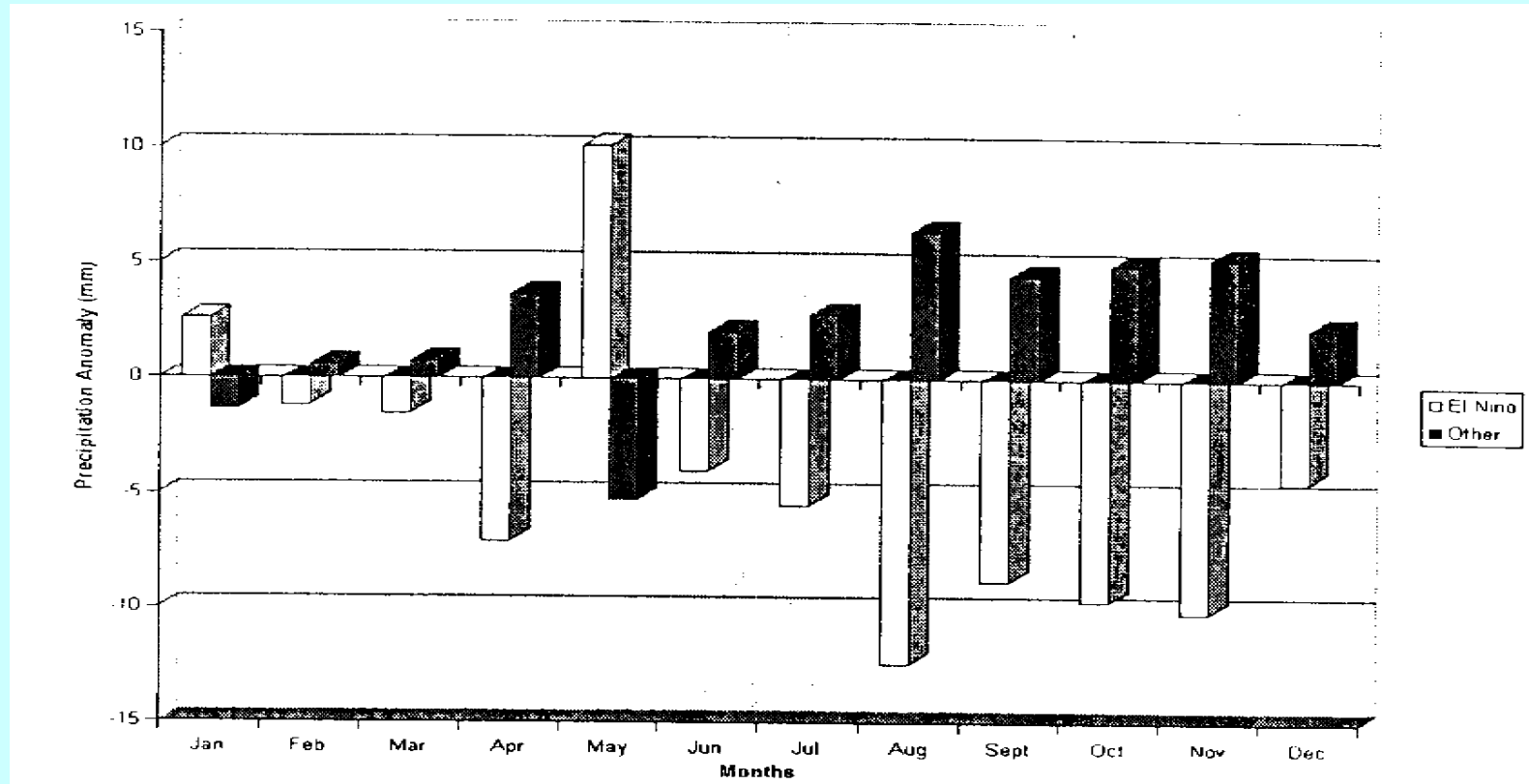
2. Strong zonal SST gradient with tropical Atlantic (directed to Pacific)  
=> strong easterlies

Net effect = strong shear

**Caribbean is dry** ☁

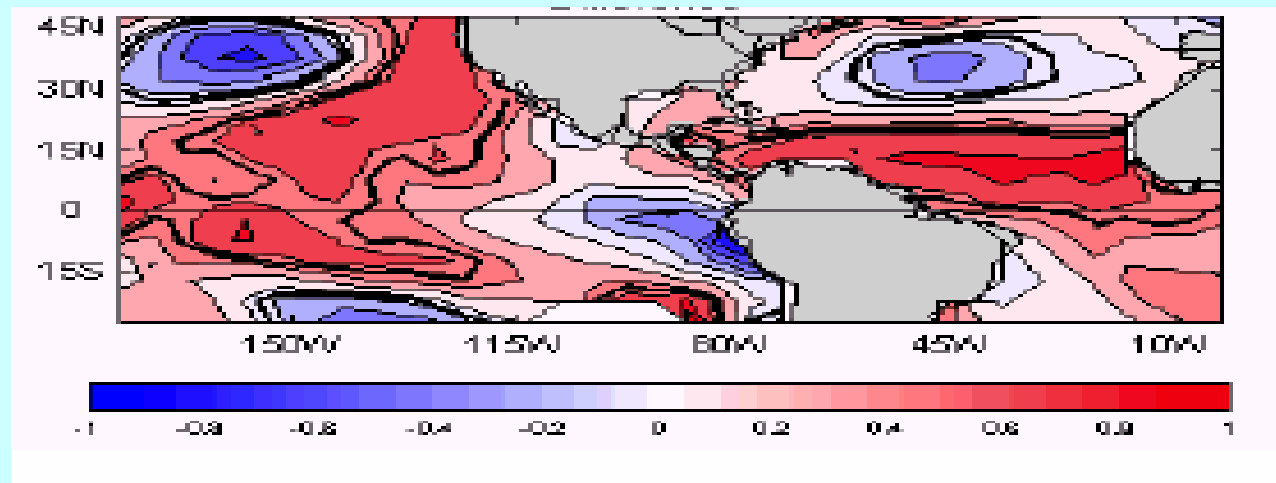


# Late Wet Season



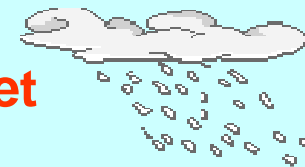
# Early Wet Season (+1)

Tropical north Atlantic SST lags tropical Pacific by 6-8 months

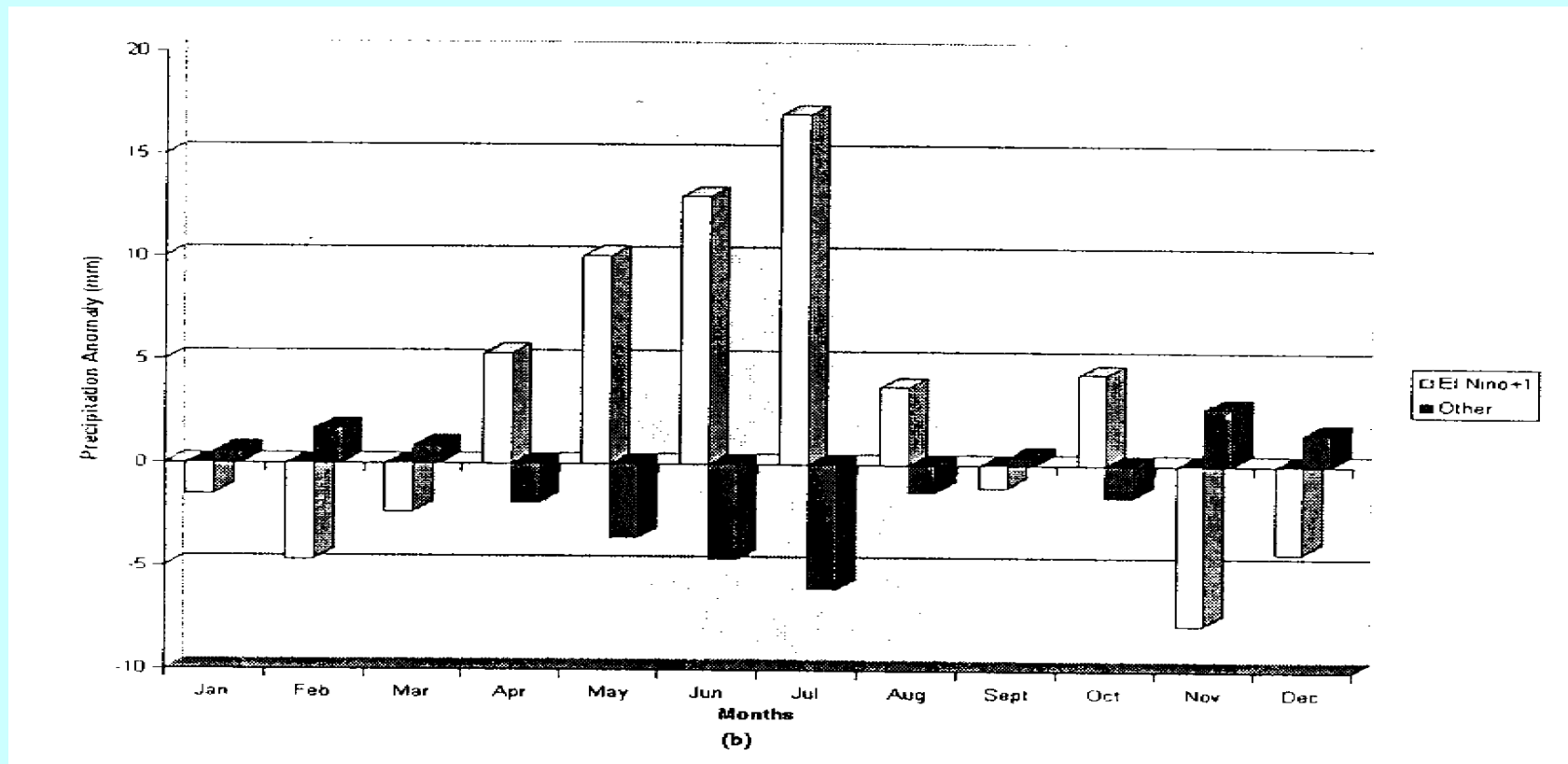


Therefore, warm SSTs during April-June after El Nino events  
*(Nobre and Shukla 1996, Enfield and Mayer 1997)*

**Caribbean is wet**

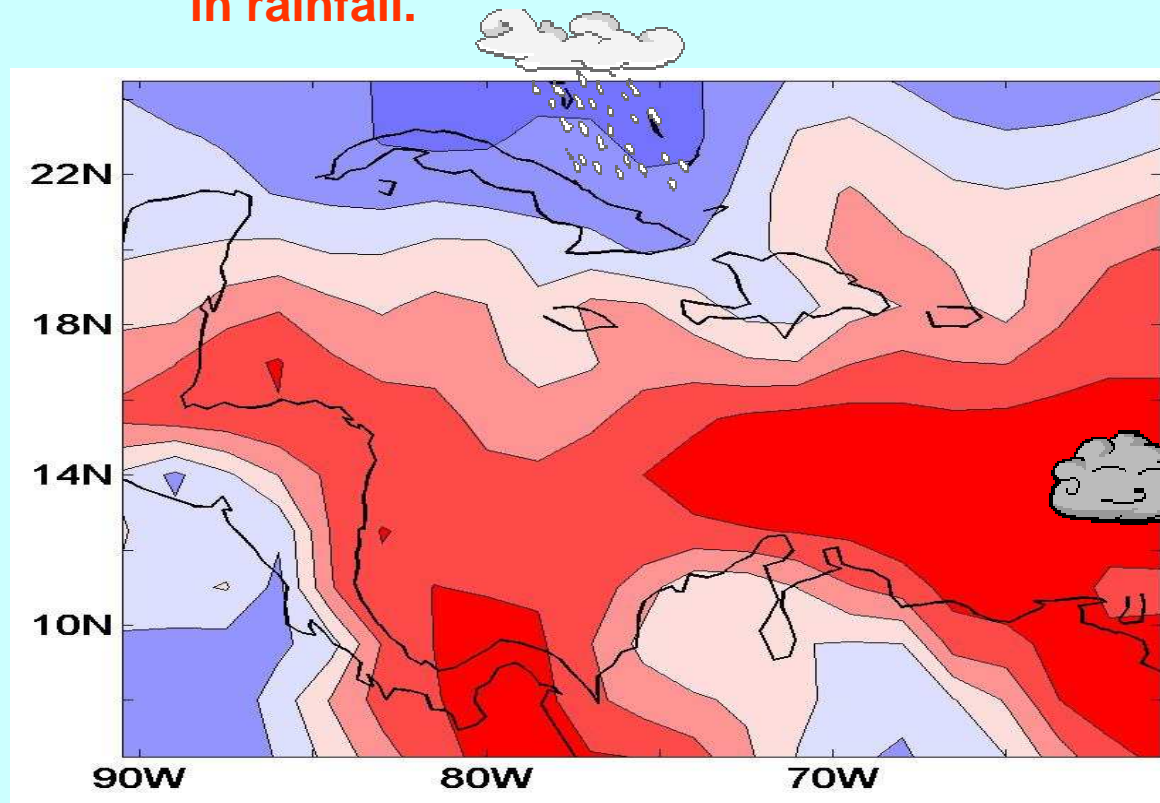


# Early Wet Season (+1)



# Dry Season

Oppositely signed. North-south gradient  
in rainfall.



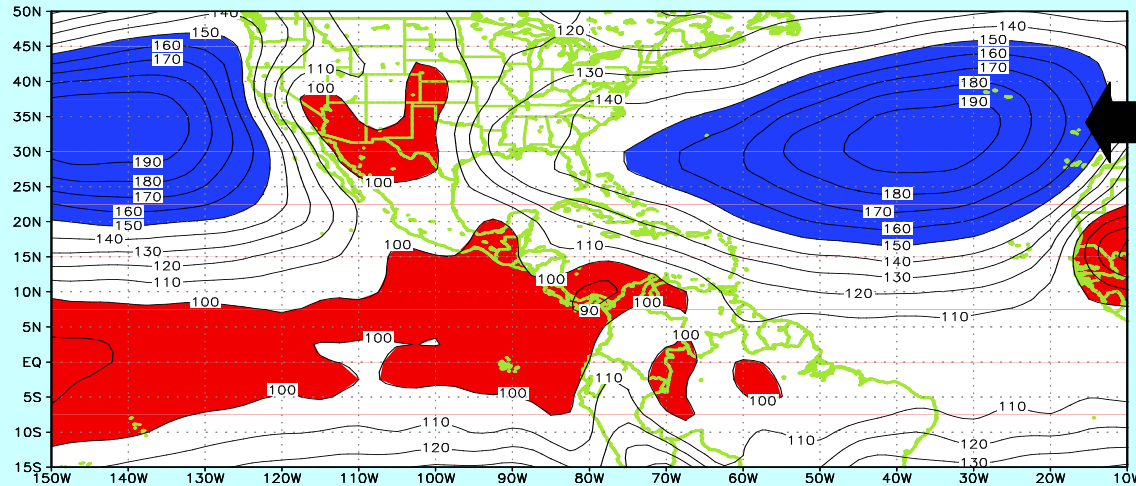
PNA Pattern+  
Weaker Hadley  
circulation

**Wet north  
Caribbean**


Altered east-west  
Circulation

**Dry south  
Caribbean**

## 2. NAO



Affects the strength of the north Atlantic High in winter months

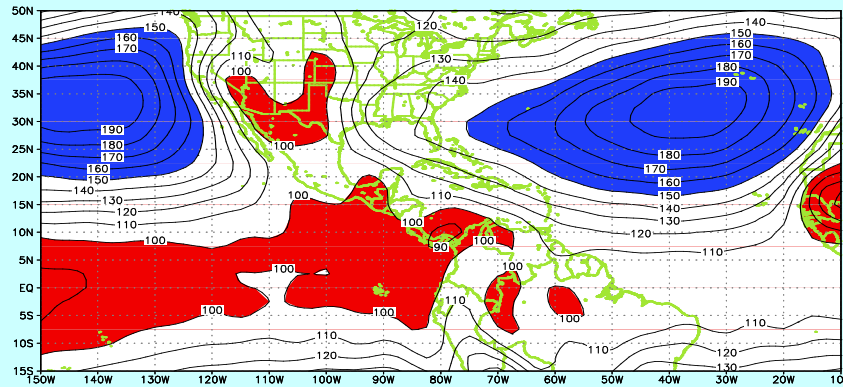
Direct effect  subsidence  
when NAO is in +ve phase

# 2. NAO

## Indirect Effect

Stronger NAO implies cooler SSTs in the subtropical North Atlantic.

Cooler SSTs persist from winter to early rainfall season



Cooler SSTs  
impact negatively  
on early season  
Caribbean rainfall

# IMPORTANT POINTS

- Principal factors that enhance Caribbean rainfall and hurricane development are:
  - Low surface pressure
  - Low VWS (850 – 200 mb)
  - Low convective stability
  - Warmer SST
- ENSO and NAO affect Caribbean climate
- Climate change will affect ENSO and NAO

# MODELING CARIBBEAN CLIMATE

- NASA funded 5-year program
- “Caribbean Climate Studies”
- GCM model of the Caribbean
- Grad student – Moises Angeles
- Published in the Int. J. of Climatology
- Angeles, Gonzalez, Erickson, and hernandez

“PIECE DE RESISTANCE”

# MODELING DETAILS

- Parallel Climate Model (PCM)
- NCEP Reanalysis Data
- Xie-Arkin Precipitation Data
- Reynolds-Smith SSTs
- Future Climatology 2041-2058

# METHODOLOGY

- Model validated with current climatology
- Model run from 1996 to 2098
- Future climatology defined from 2041 to 2058
- Three periods:
  - Dry season (DS): Dec to April
  - Early rainfall season (ERS): May to July
  - Late rainfall season (LRS): Aug to Nov

# OBSERVED CLIMATOLOGIES

DS

ERS

LRS

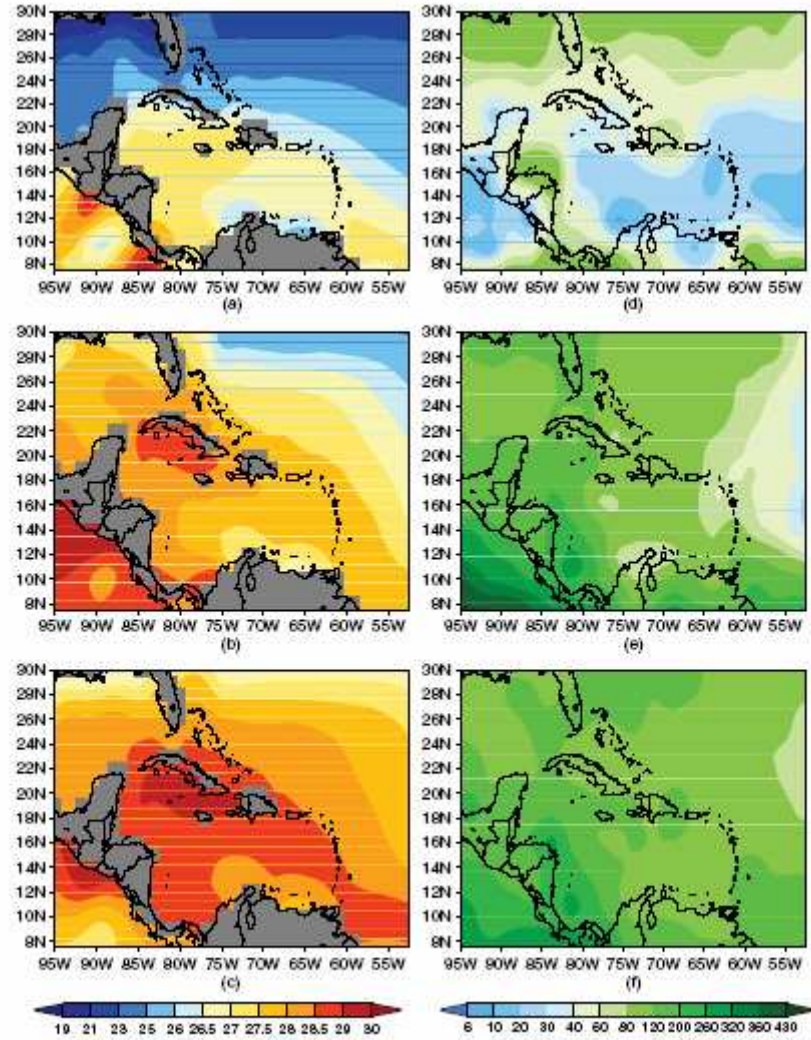


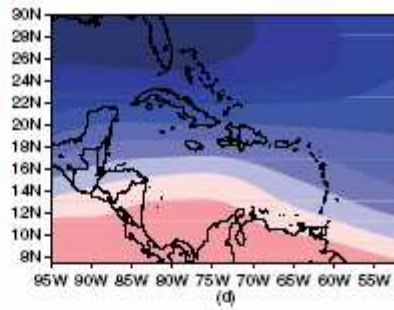
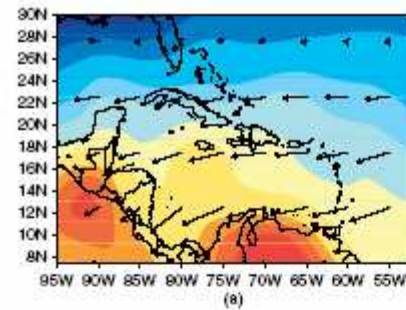
Figure 1. Observed climatological SSTs from Reynolds–Smith for (a) DS, (b) ERS, and (c) LRS. The blue color depicts SST < 26.5 °C, while the red color SST > 26.5 °C. Observed climatological accumulated precipitation from CPC-merged analysis for (d) DS, (e) ERS, and (f) LRS

SST

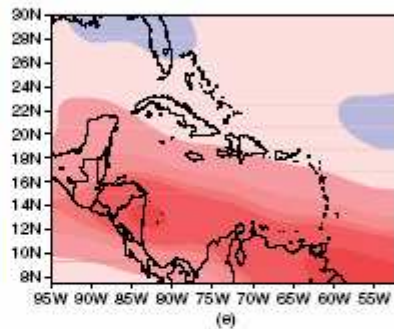
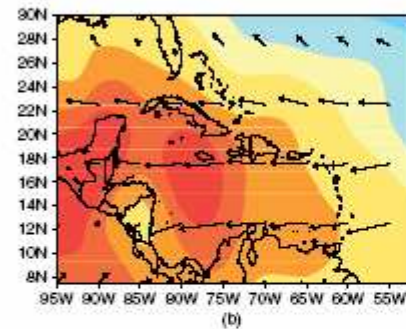
PRECIP

# OBSERVED CLIMATOLOGIES

DS



ERS



LRS

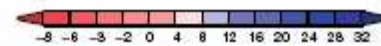
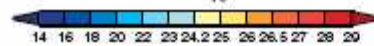
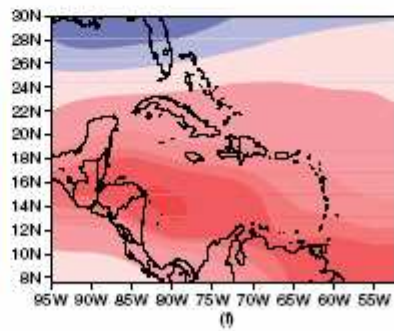
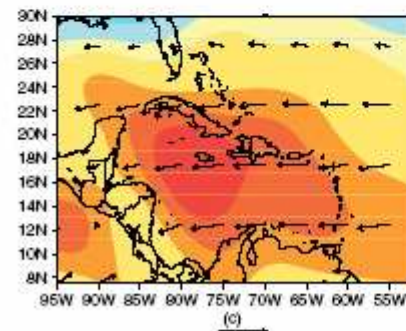


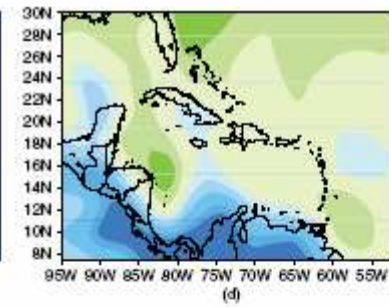
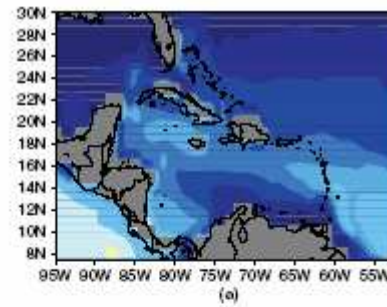
Figure 2. Observed climatological air temperature at 1000 mb level from NCEP and easterly winds to see the warm/cold advection for (a) DS, (b) ERS, and (c) LRS. Observed climatological VWS for (d) DS, (e) ERS, and (f) LRS

AIR TEMP AND WINDS

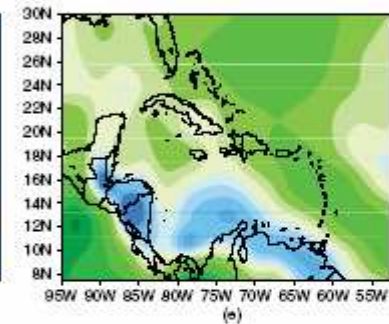
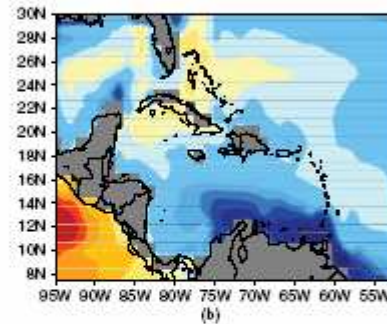
VWS

# MODEL CLIMATOLOGIES

DS



ERS



LRS

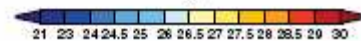
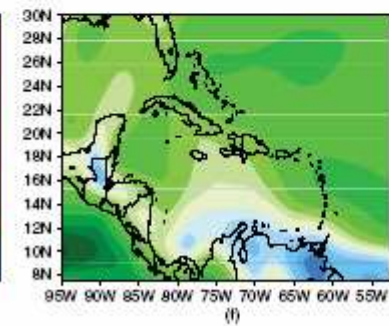
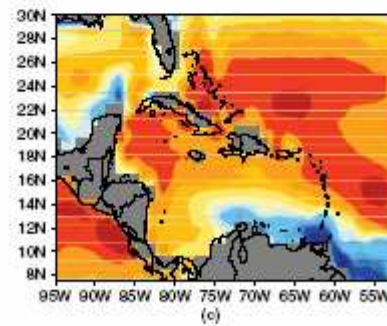


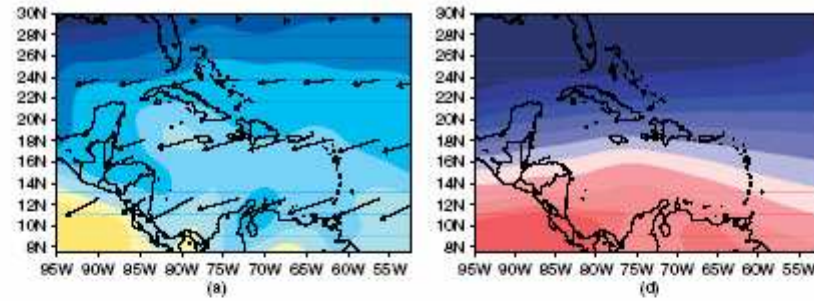
Figure 3. Current climatological SSTs from PCM (1996–2010) for (a) DS, (b) ERS, and (c) LRS. The blue color depicts SST < 26.5°C, while the red color SST > 26.5°C. Climatological accumulated precipitation from PCM is calculated for (d) DS, (e) ERS, and (f) LRS

SST

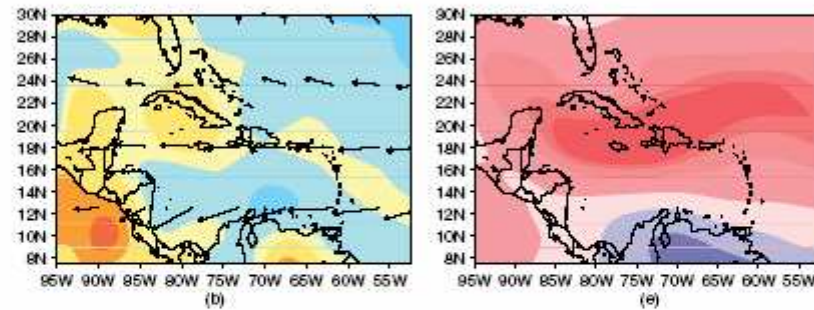
PRECIP

# MODEL CLIMATOLOGIES

DS



ERS



LRS

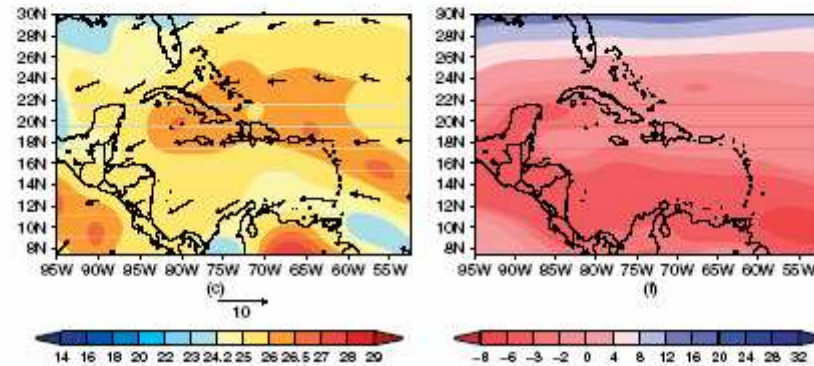


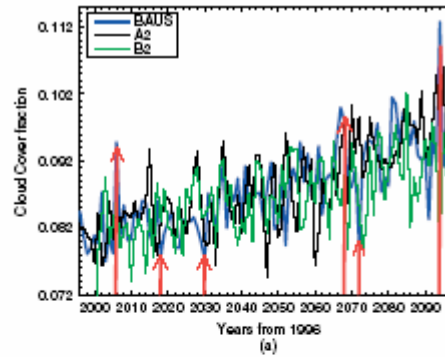
Figure 4. Current Caribbean climatology (1996–2010) predicted by PCM for the air temperature at 1000 mb level and easterlies to see the warm/cold advection for (a) DS, (b) ERS, and (c) LRS, the VWS for (d) DS, (e) ERS, and (f) LRS. The blue color depicts air temperature <math>< 24.2^{\circ}\text{C}</math> that corresponds to SST =

AIR TEMP AND WINDS

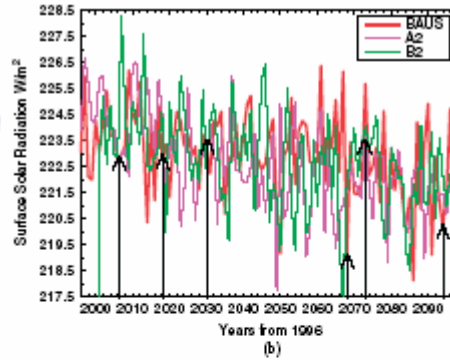
VWS

# MODEL PREDICTIONS 1996 TO 2098 – BASIN AVERAGES

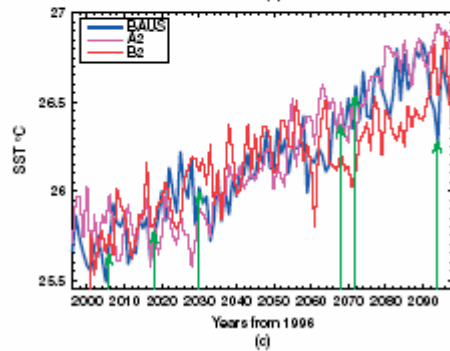
CLOUD  
COVER



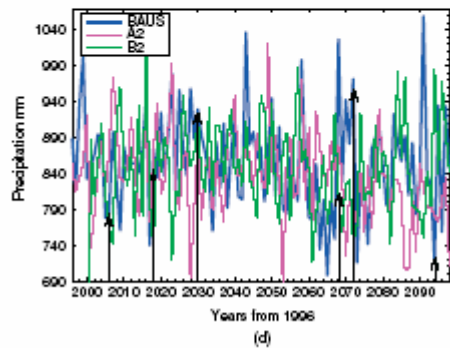
(a)



(b)



(c)



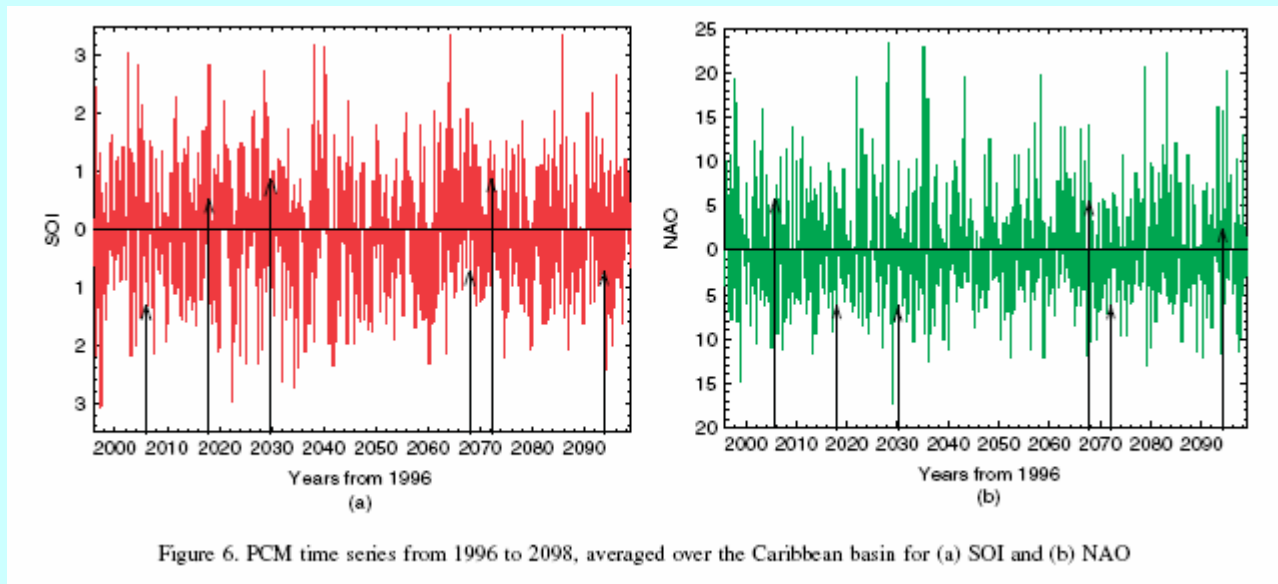
(d)

Figure 5. PCM time series from 1996 to 2098, averaged over the Caribbean basin for (a) Cloud Cover, (b) Solar flux at the surface, (c) SSTs, and (d) Accumulated precipitation

SOLAR FLUX

PRECIP

## MODEL ENSO AND NAO 1996 TO 2098



ENSO

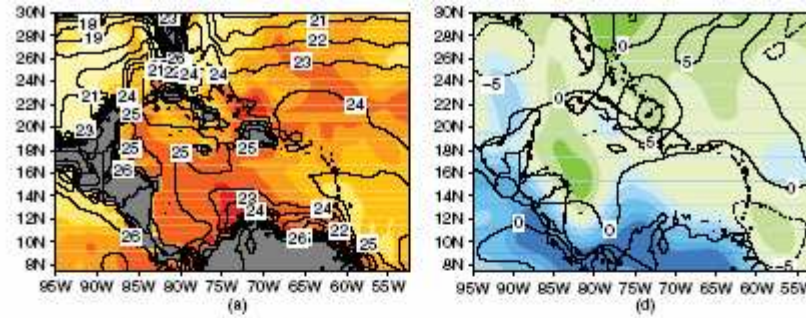
NAO

# EFFECTS OF ENSO AND NAO

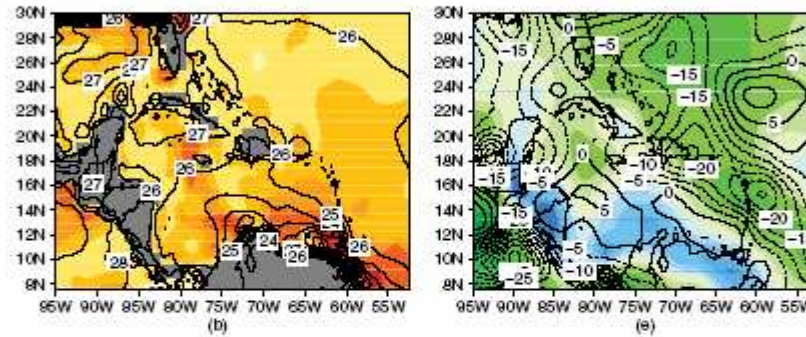
- El Nino => Dry LRS (Stronger VWS)
- El Nino + 1 => Wet ERS (warmer SSTs)
- El Nino => N-S gradient in rainfall in DS
- NAO governs NAH mainly
- NAO neg. correlated with Carib. Rainfall
- ENSO and NAO in phase => dry conditions

# FUTURE CLIMATOLOGIES, 2041-2055 AVERAGE

DS



ERS



LRS

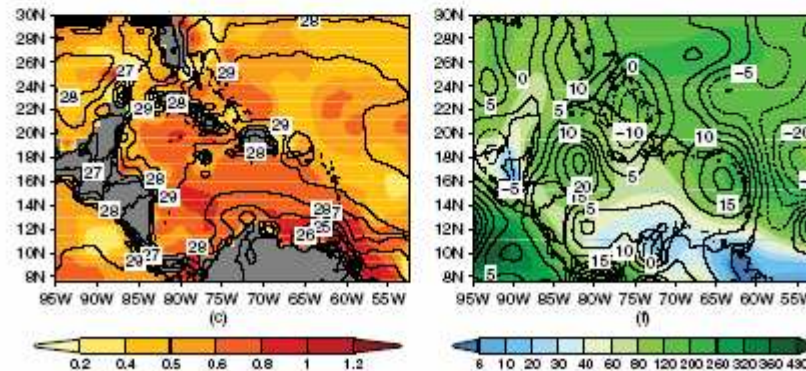


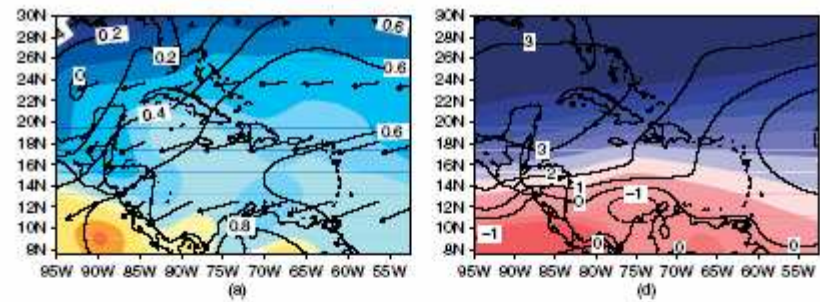
Figure 7. Future Caribbean climatology (2041–2055) predicted by PCM for the SSTs for (a) DS, (b) ERS, and (c) LRS. The contour lines represent the SST in the future climate and the color background the difference between predicted future and present climates. Climatologically accumulated precipitation predicted by PCM for (d) DS, (e) ERS, and (f) LRS. The contour lines represent the differences between the future and current climate

SST

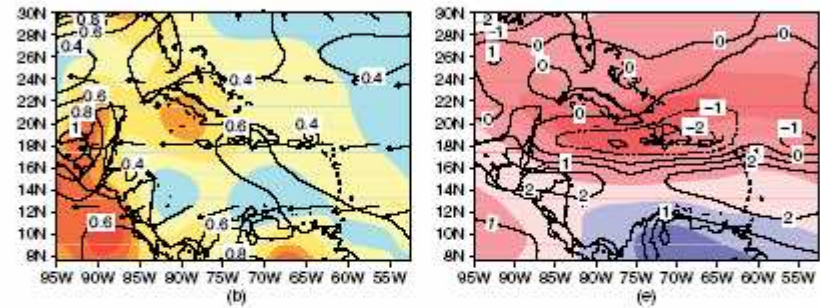
PRECIP

# FUTURE CLIMATOLOGIES, 2041-2055 AVERAGE

DS



ERS



LRS

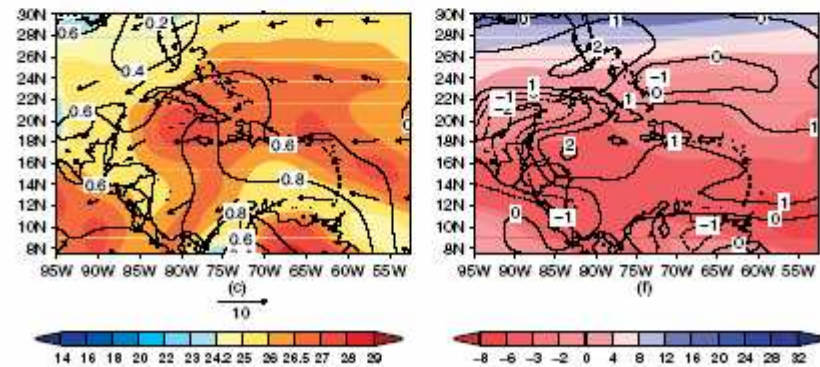


Figure 8. Future Caribbean climatology (2041–2055) predicted by PCM for the air temperature at 1000 mb level and easterlies to see the warm/cold advection for (a) DS, (b) ERS, (c) LRS, VWS for (d) DS, (e) ERS, and (f) LRS. The pink color depicts weak VWS (less than 8 m/s), while the purple color stronger VWS. The contour lines represent the difference of the VWS absolute values between future and current climatology. Positive differences imply a stronger future VWS, while negative values a weaker VWS

AIR TEMP AND WIND

VWS

## FUTURE CLIMATOLOGY, CARIBBEAN AVERAGE

vws  
vapor  
precip  
sst

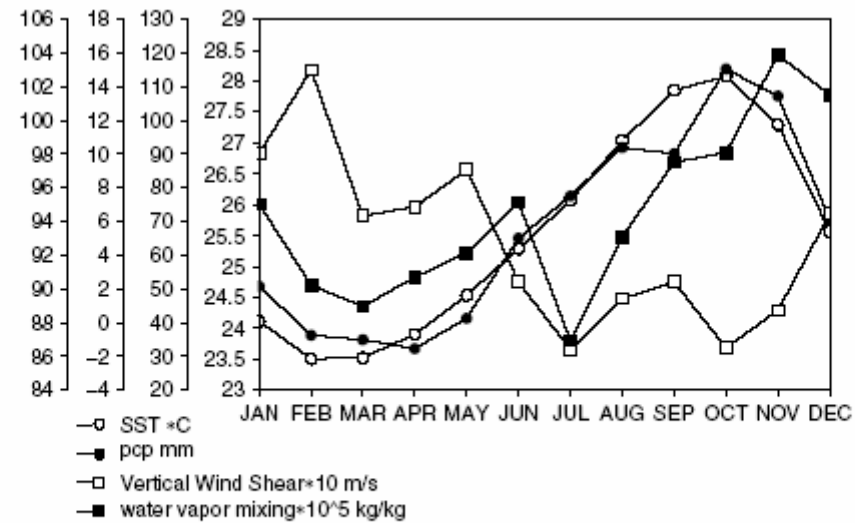
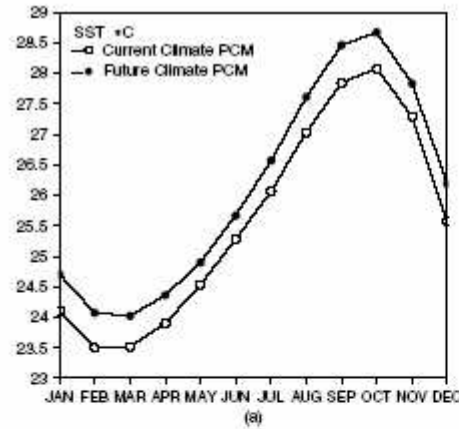


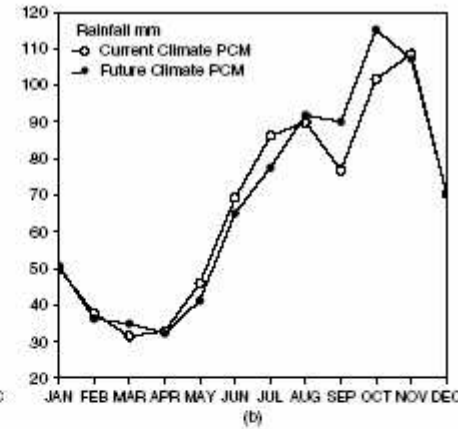
Figure 10. Monthly variability of the PCM atmospheric and oceanic variables for the future climatology. The values are arranged following the legend next to the figure

# COMPARISON OF PRESENT AND FUTURE CLIMATOLOGIES

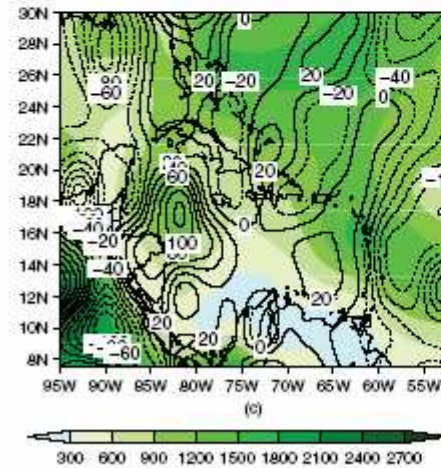
SST



PRECIP



PRECIP



SOLAR FLUX

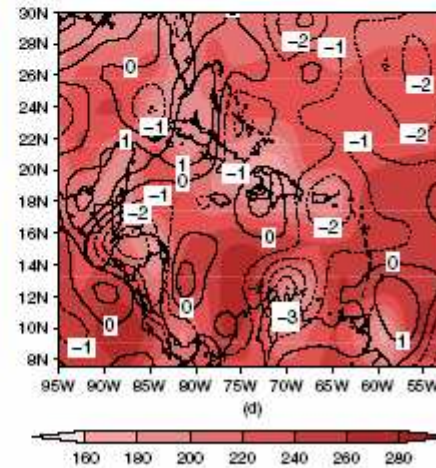


Figure 11. Comparison of the atmospheric and oceanic variables between the future and present PCM climatologies for (a) the SSTs and (b) Accumulated rainfall. The future climatology is shown for annual (c) Accumulated rainfall and (d) Surface solar flux. The contour lines depict the rainfall difference between the future and present climatologies, while the solar flux has a contour interval of  $1 \text{ W/m}^2$ .

# SUMMARY AND CONCLUSIONS

- ENSO and NAO drive rainfall variability
- Model (PCM) underpredicts SSTs
- Business-as-usual scenario (BAUS) used to predict future climate (2041-2058)
- Warmer air temps
- Warmer SSTs (1 degree C)
- Wetter Caribbean
- Wind speed increases but VWS stays below 8 m/s
- **CONDITIONS FAVOR MORE INTENSE TROPICAL STORMS**

# IPCC STATEMENT

“Small islands have a high vulnerability and a low adaptive capacity, and are therefore likely to be the most seriously impacted pieces of land by global climate change”