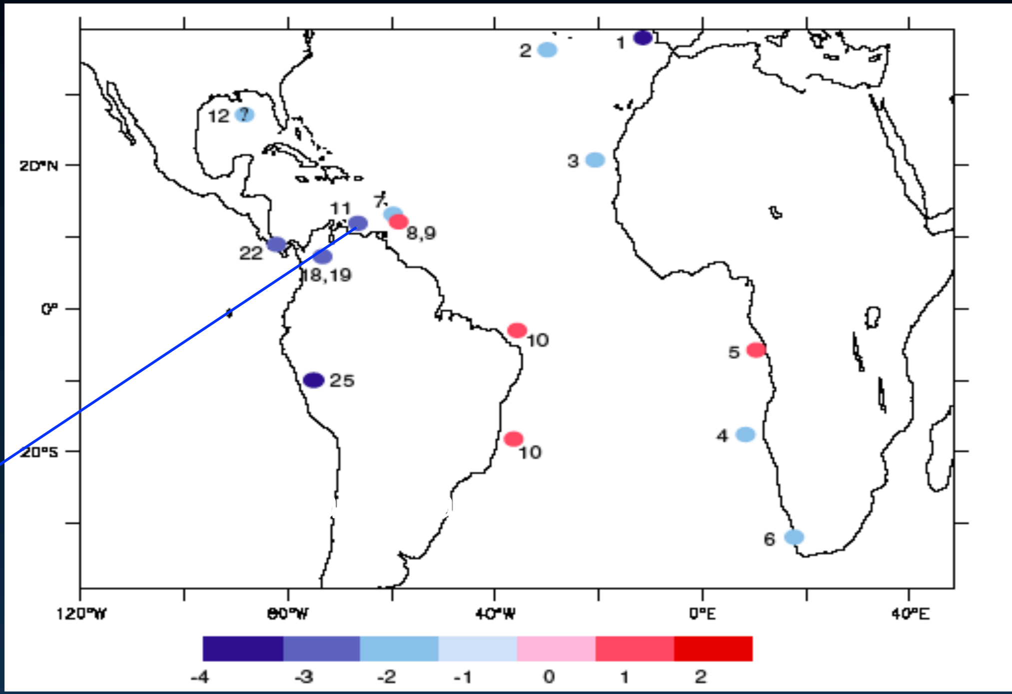
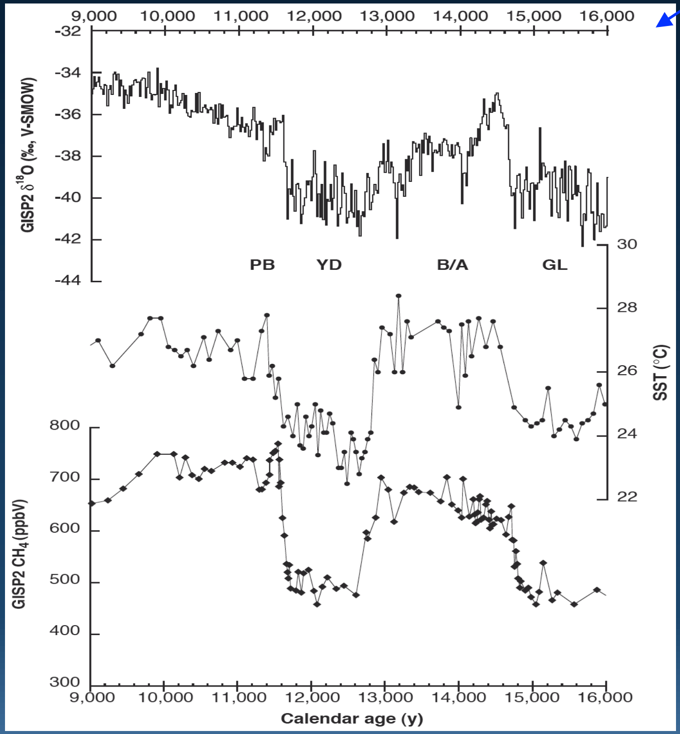
Outline

- The tropical Atlantic interacts with other oceanic and atmospheric regions
- Use a regional modeling approach for mechanistic experiments
  - *Play with oceanic and atmospheric lateral boundary conditions*
- *Oceanic interaction*: STC interaction with AMOC
  - Wen et al. (2011), J. Climate
- *Atmospheric interaction*: AMM interaction with ENSO
  - Patricola et al. (2014), J. Climate

Paleo proxies indicate that during YD events, AMOC weakens substantially, causing surface cooling in the north Atantic and warming in tropical South Atlantic

Paleo-SST reconstruction during YD



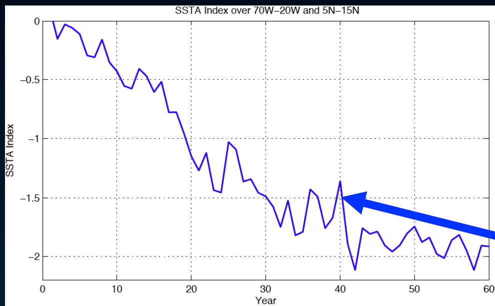


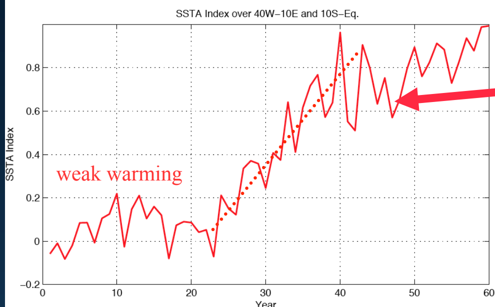
Lea et al. (2003)

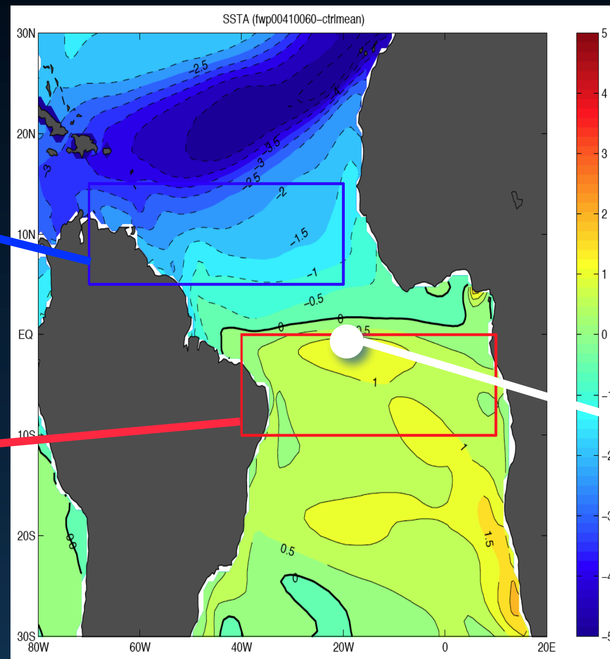
Question 1

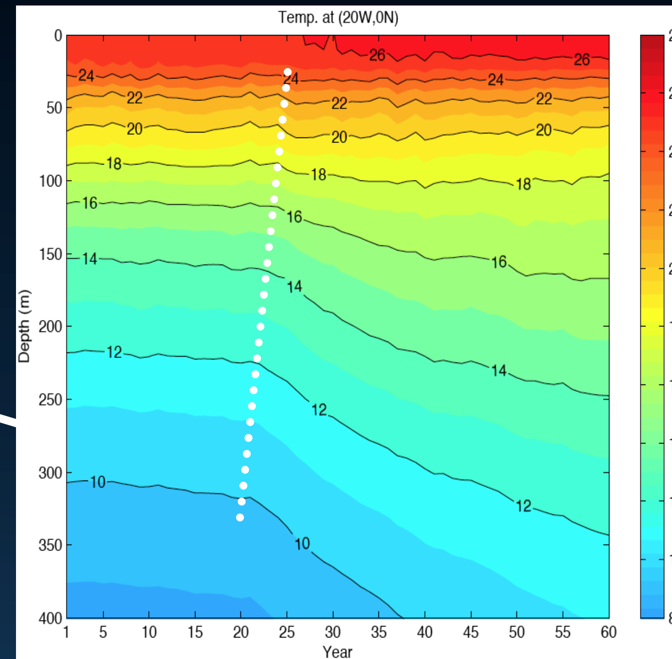
- What are the factors that affect the Tropical Atlantic response to AMOC slowdown?
  - How does the AMOC interact with the wind-driven subtropical cell (STC)?
  - What is the role of atmosphere-ocean interaction?

GFDL Coupled Model Response to Water Hosing

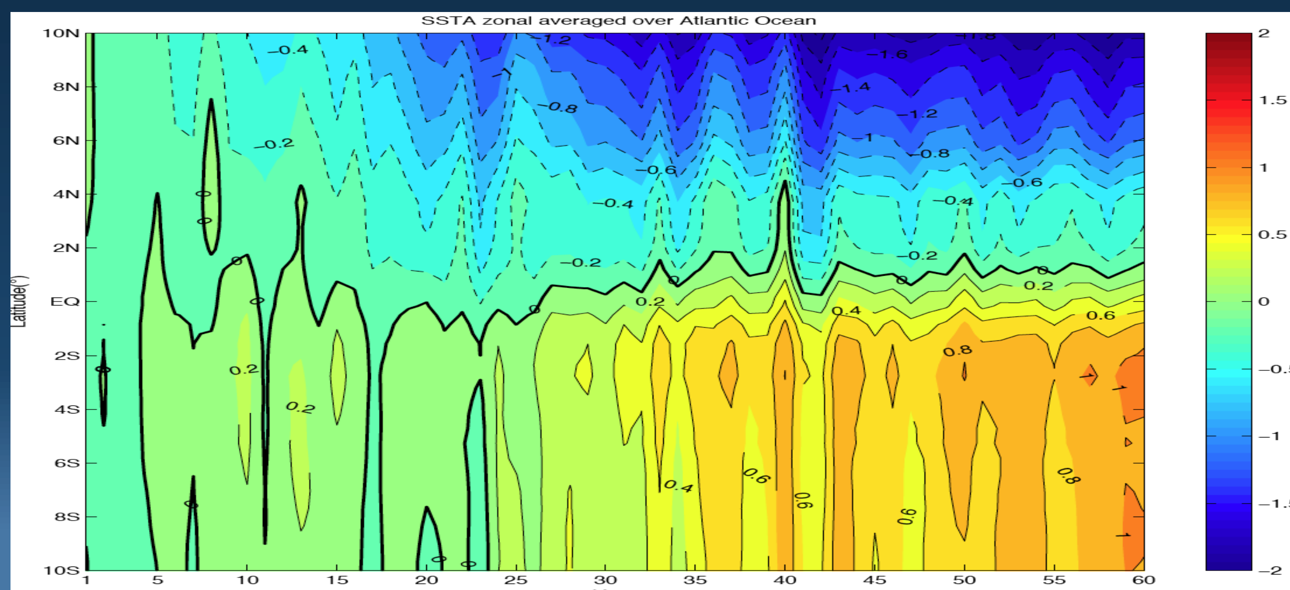






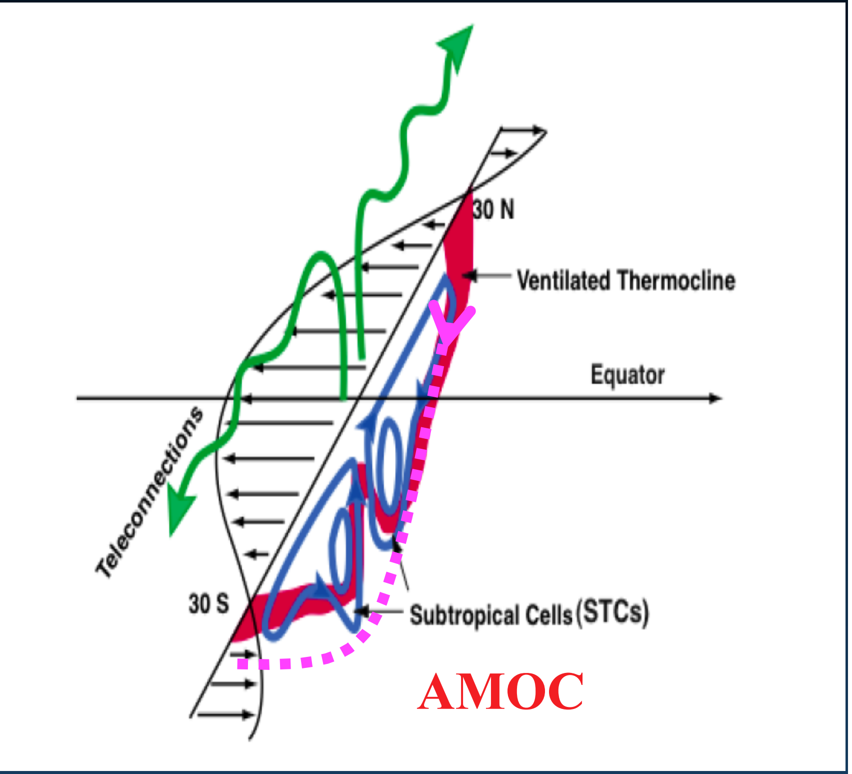


- A weak warming in SH occurs within a decade, but major warming lags the NH cooling by 25 years.
- Subsurface warming leads the surface warming.
- The delayed response hints that the adjustment is oceanic.

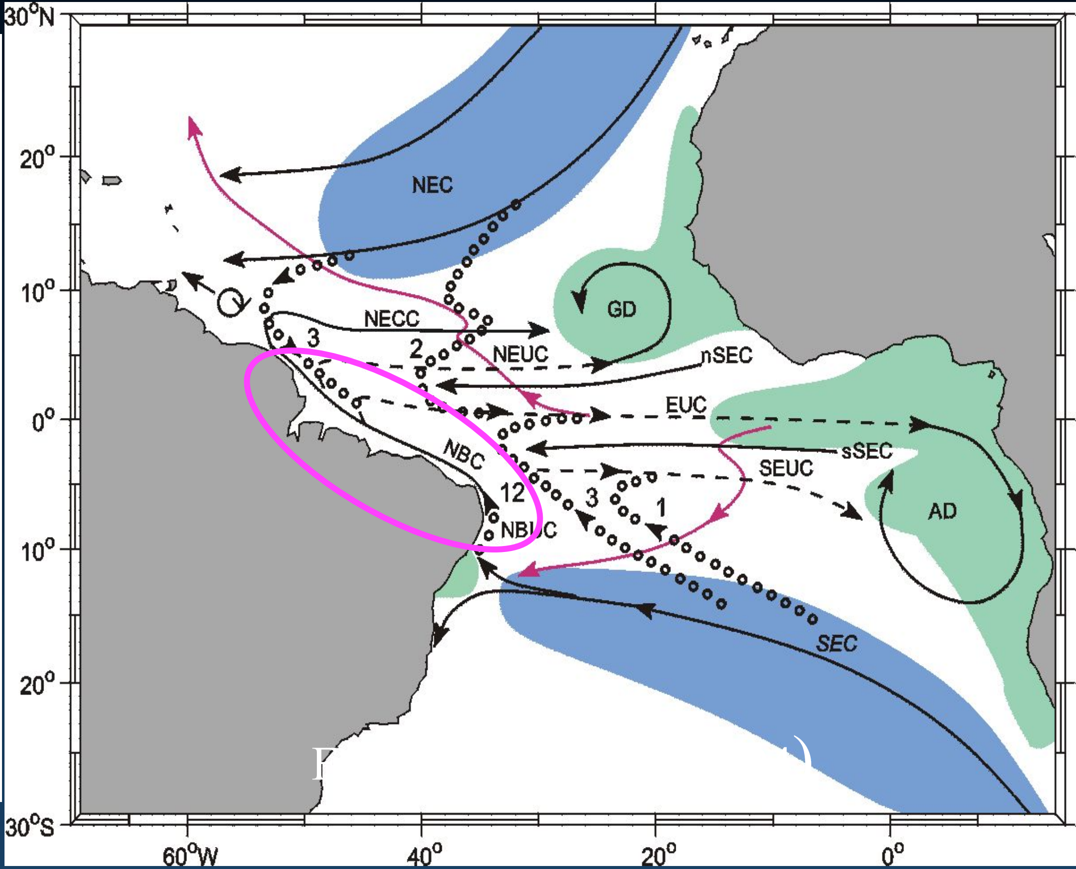


Upper Circulation of Tropical Atlantic Ocean

Schematic Atlantic STC



Horizontal Structure



- ASTC is highly asymmetric about the equator
- The pathway of the northern STC to the equatorial zone is blocked by the AMOC return flow along the western boundary (Zhang et al. 2004; Schott 1998; Fratantoni 2000).

Regional Coupled Model (RCM)

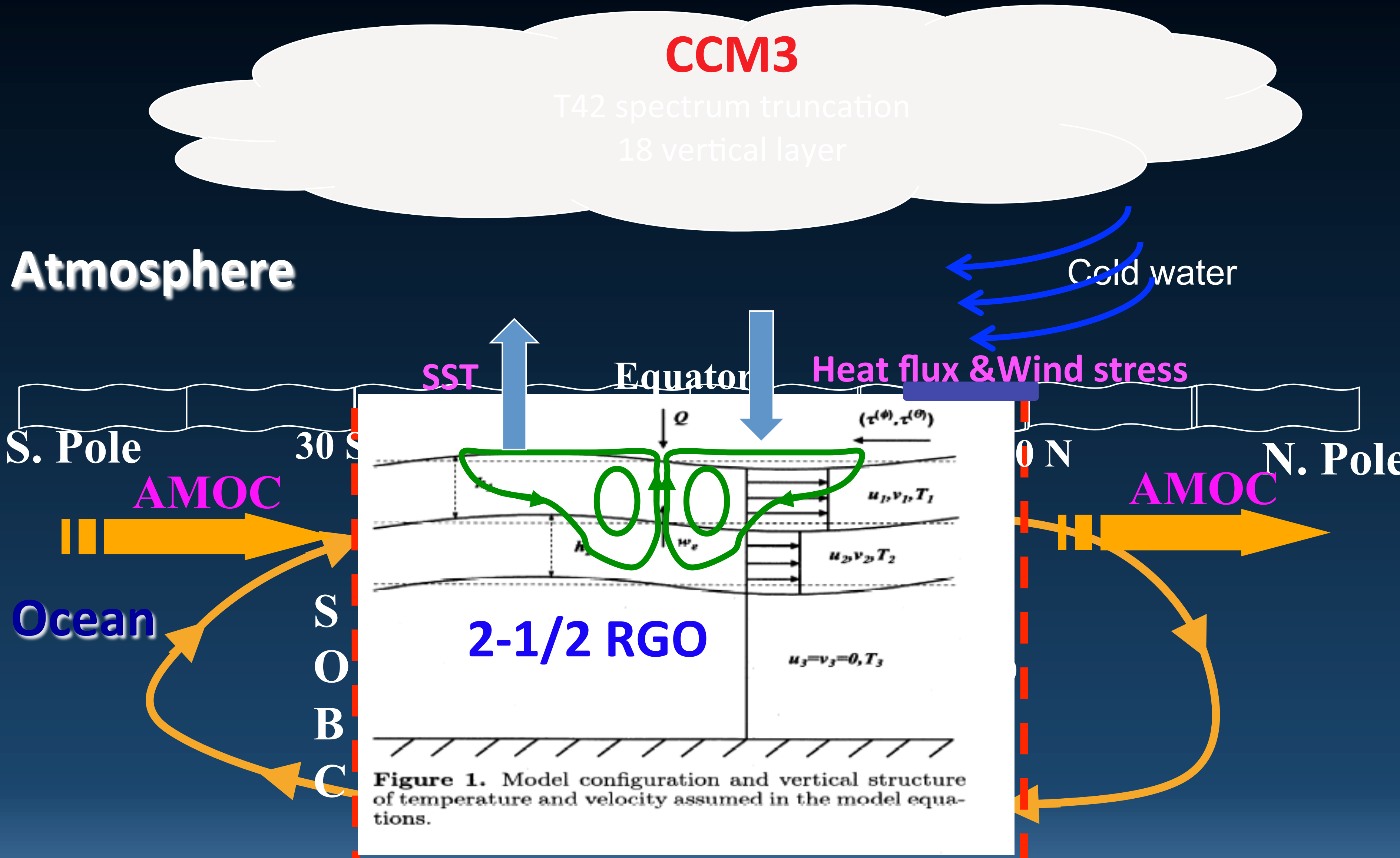
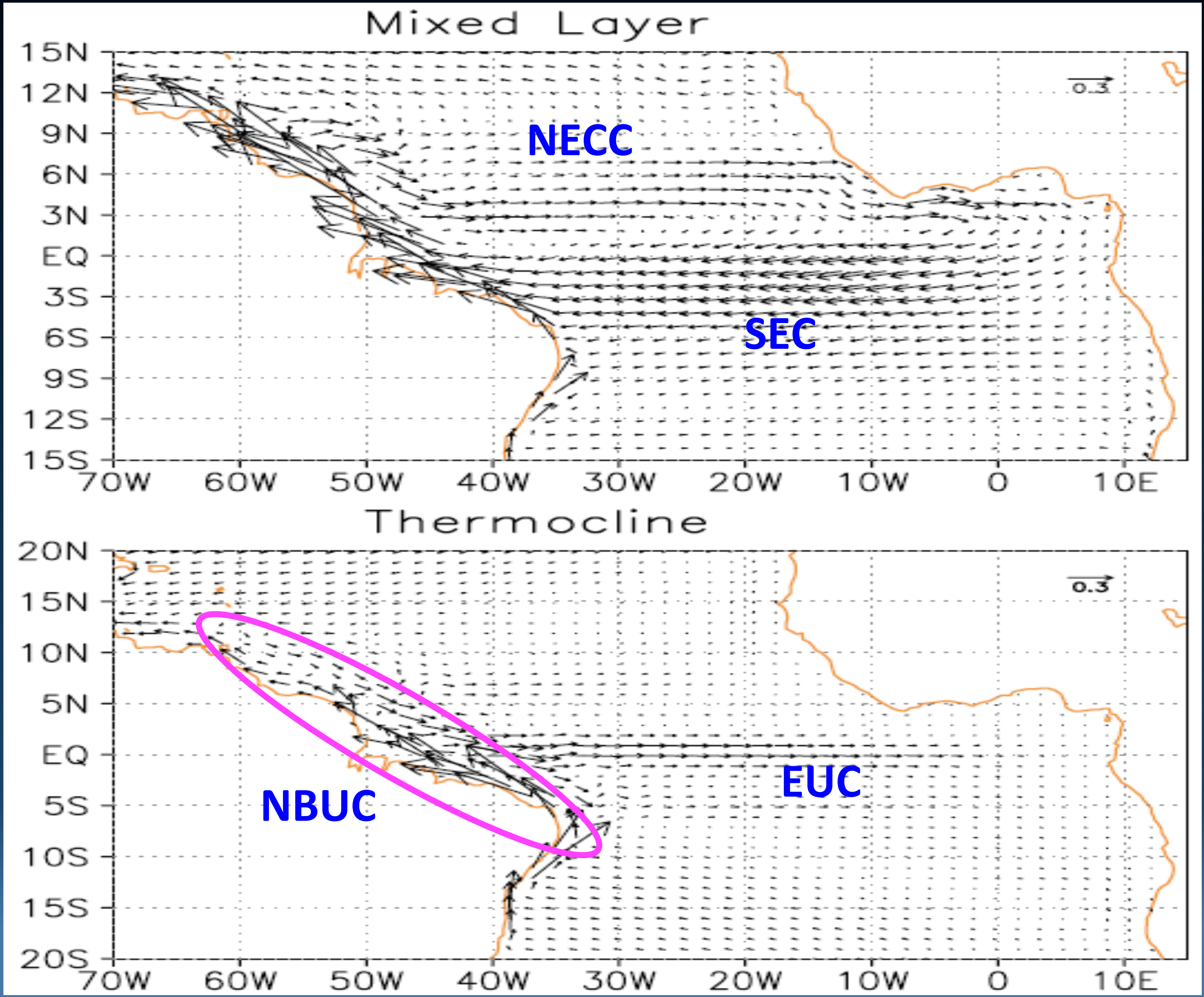


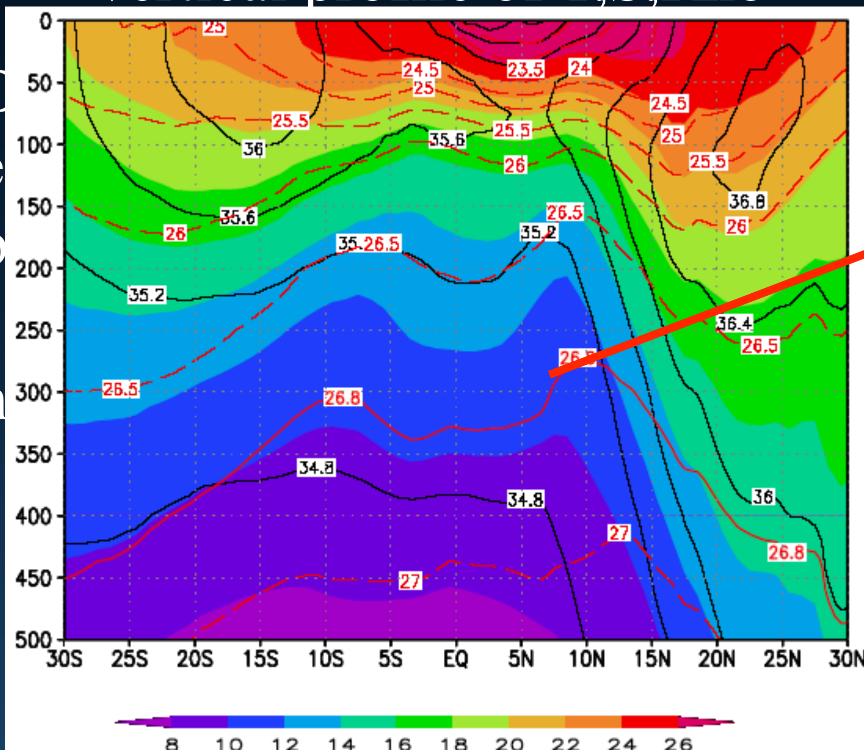
Figure 1. Model configuration and vertical structure of temperature and velocity assumed in the model equations.

Model Evaluation: Annual Mean Currents

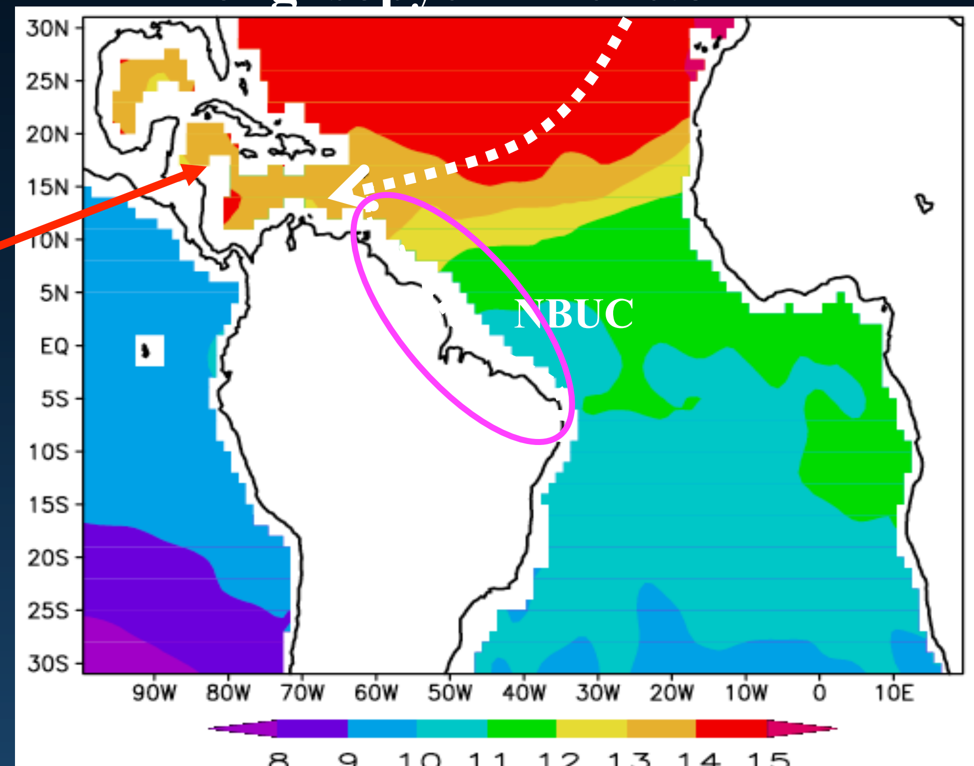


Teleconnection Mechanisms: Oceanic Processes

Vertical profile of T,S,Rho



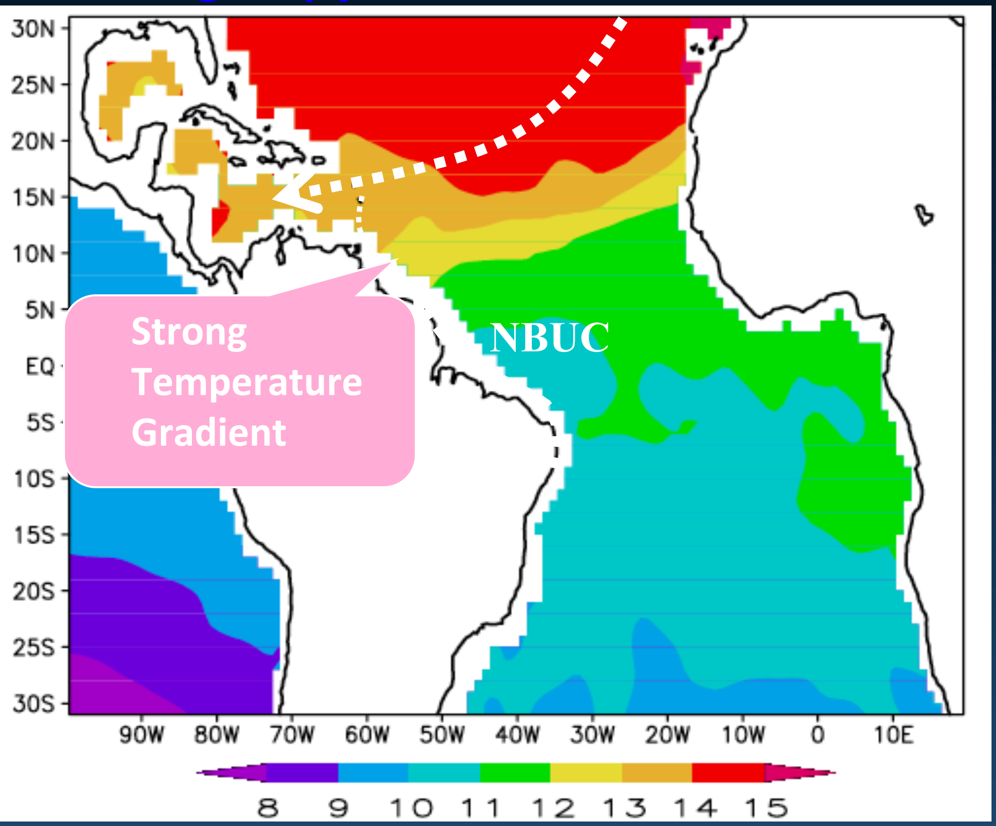
T along isopycnal 1026.8



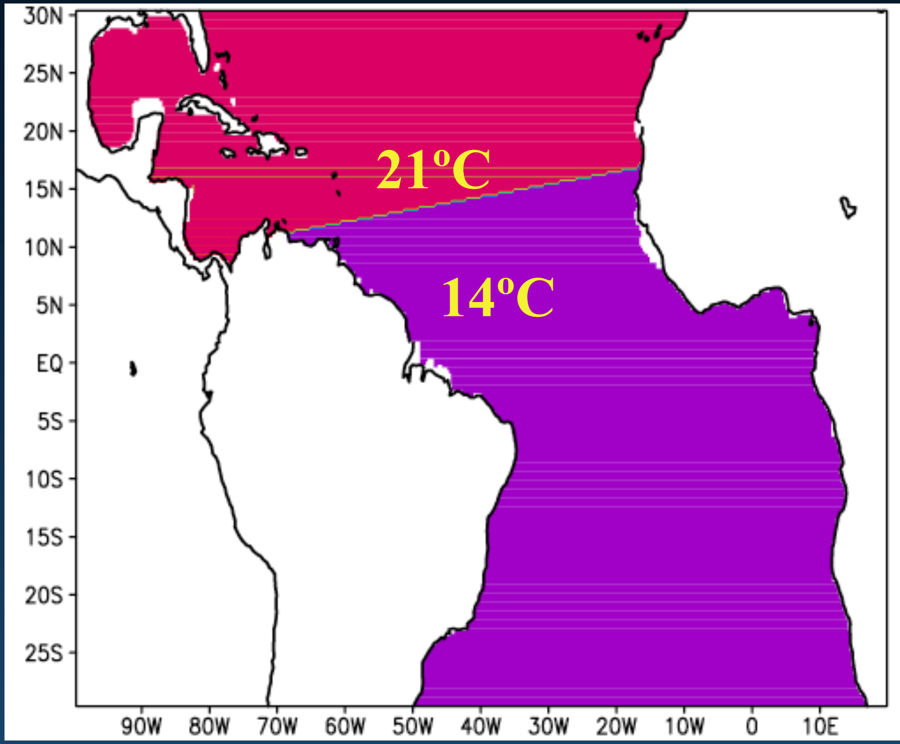
Levitus Data

Hypothesis: AMOC modulates equatorial SST by modifying pathways of STCs (Chang et al.2008)

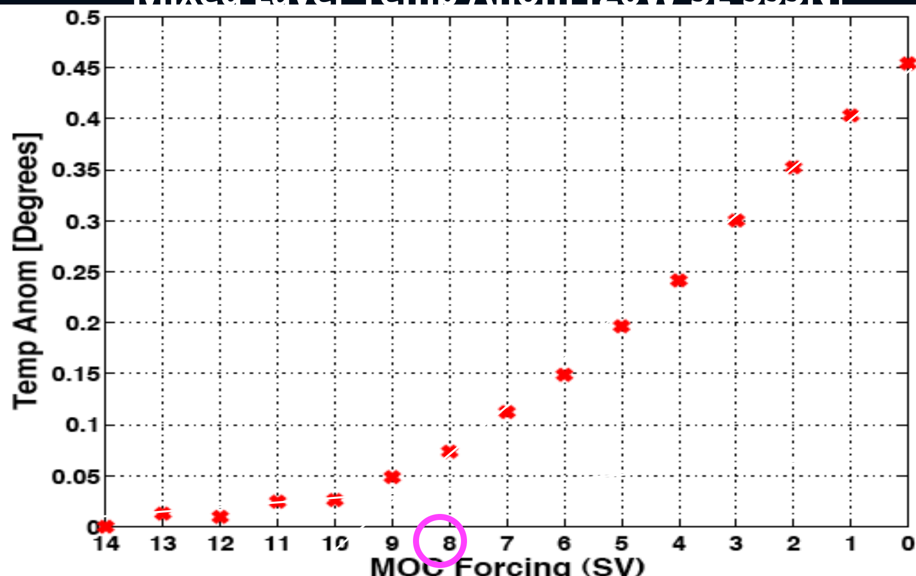
T along isopycnal 1026.8 Levitus

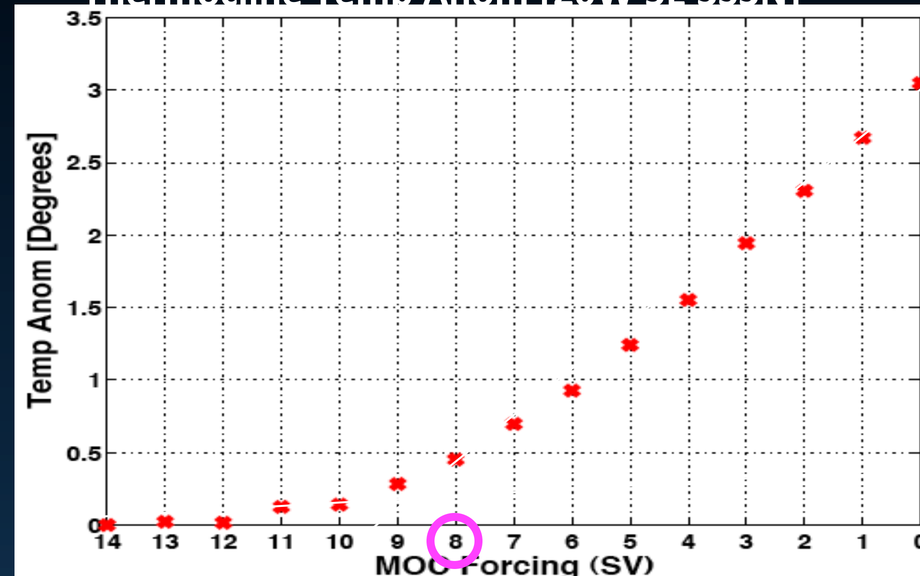


Idealized "OBS" Subsurface Temp

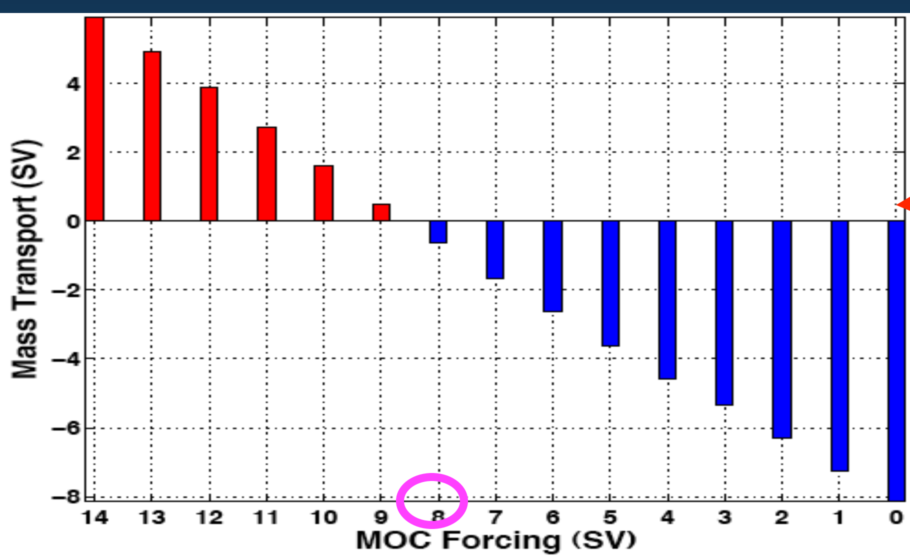


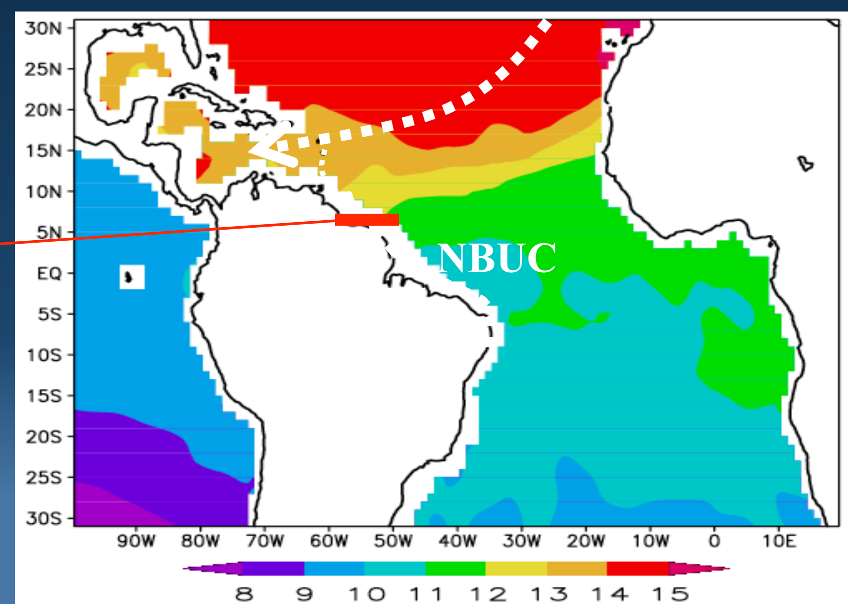
Sensitivity of SST response to changes in AMOC



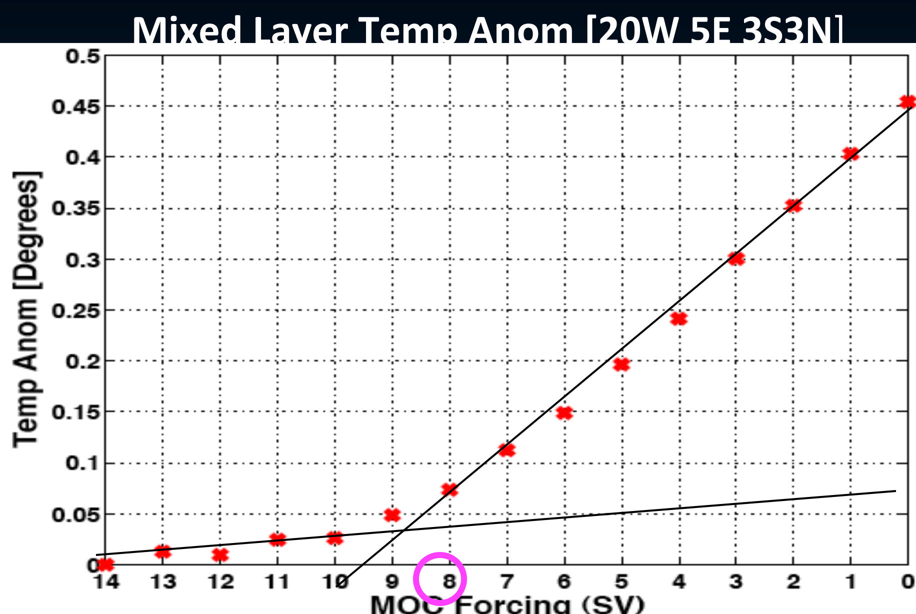


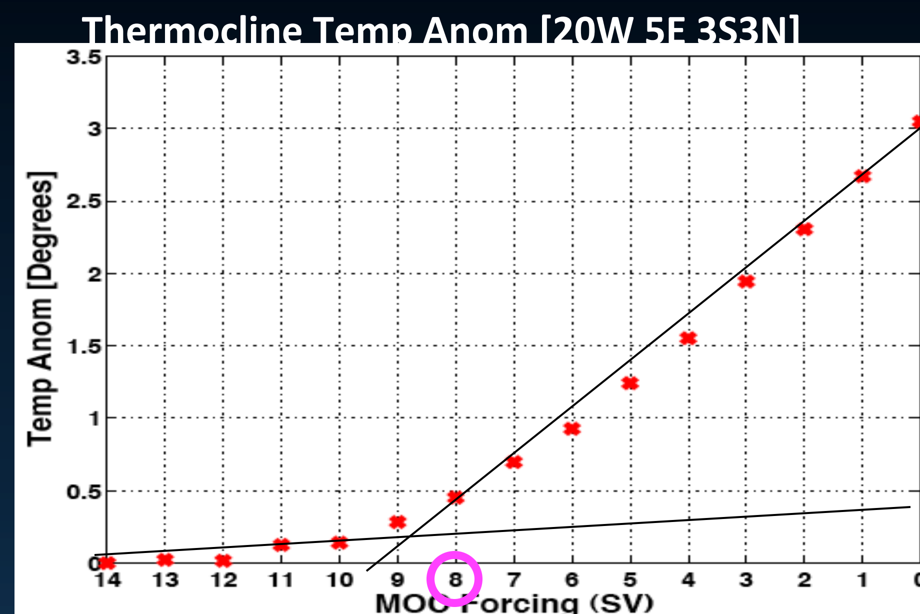
Reversal of western boundary current



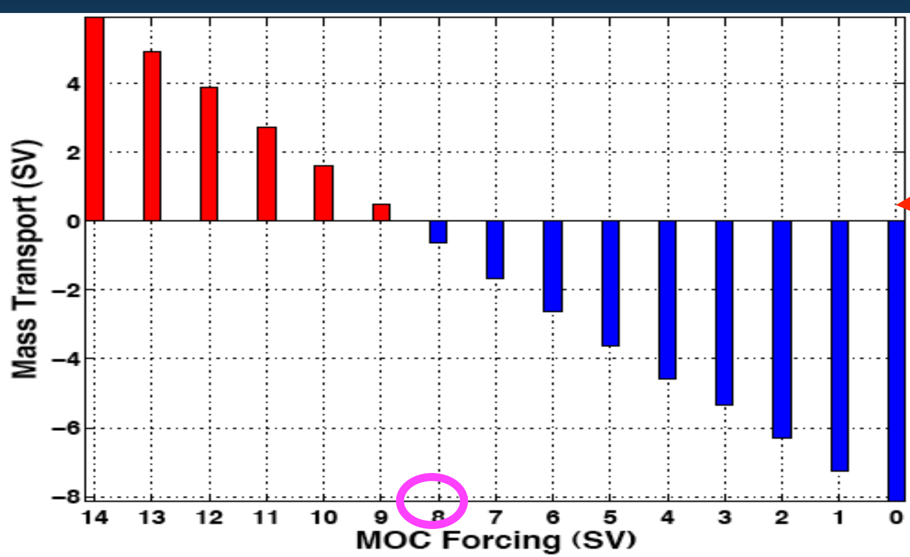


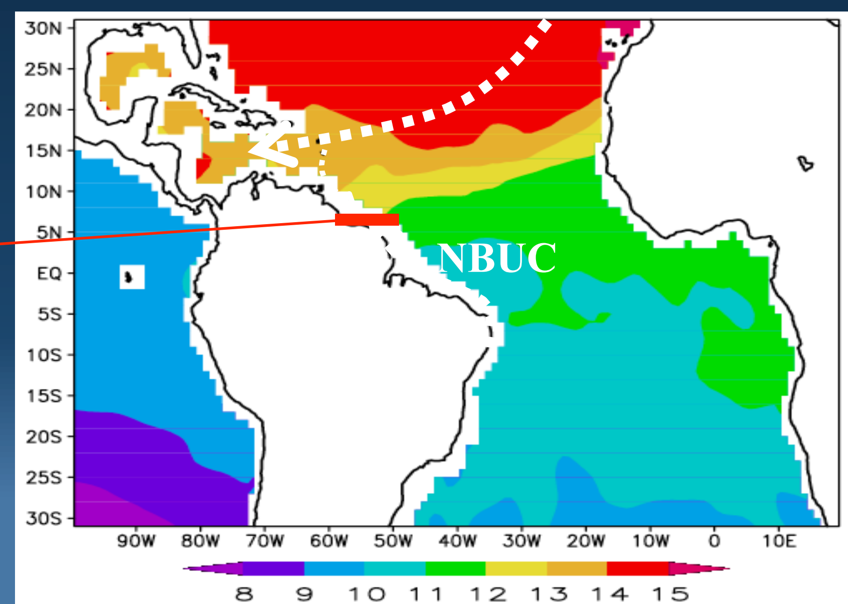
Sensitivity of SST response to changes in AMOC



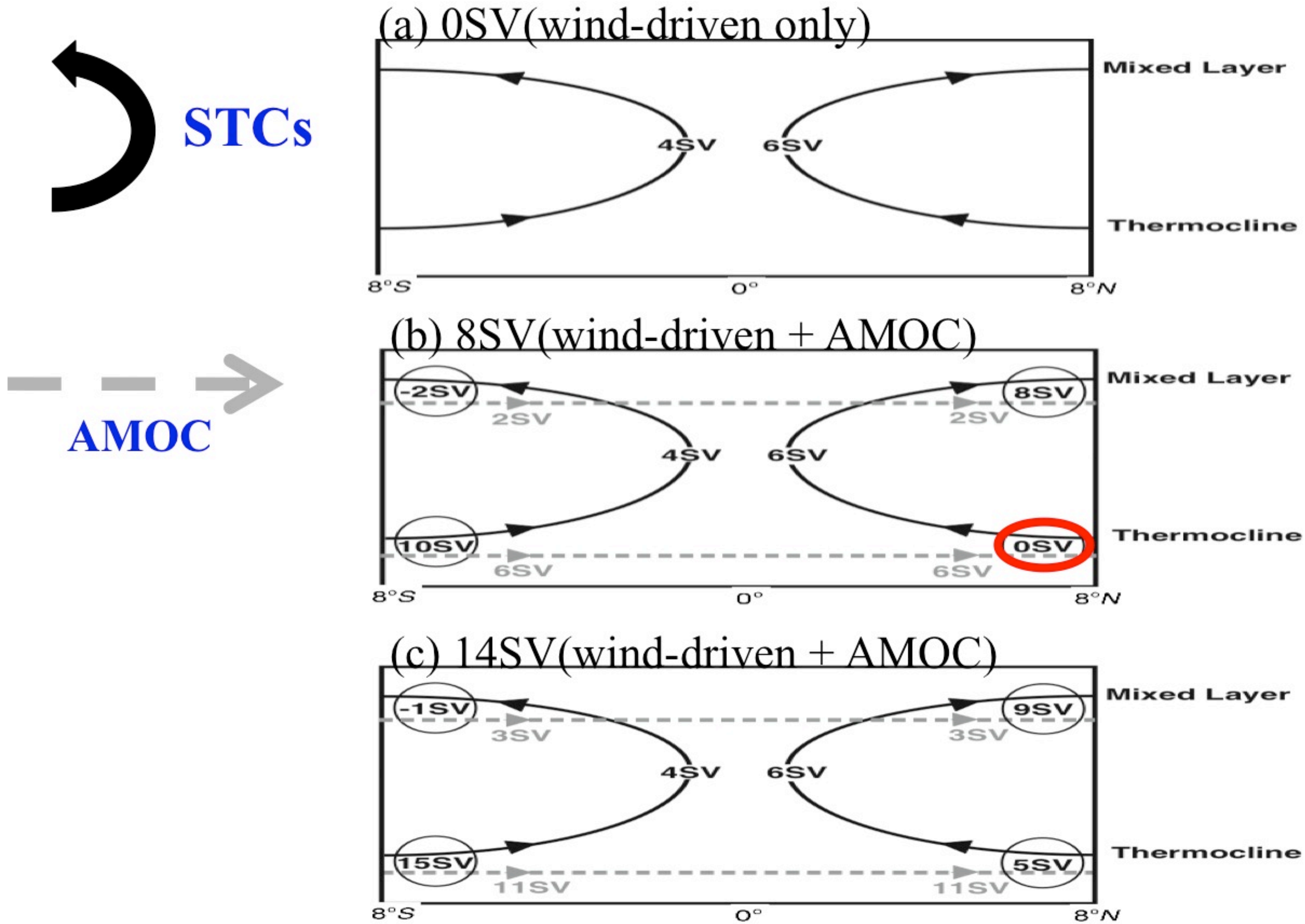


Reversal of western boundary current





Zonally integrated mass transport

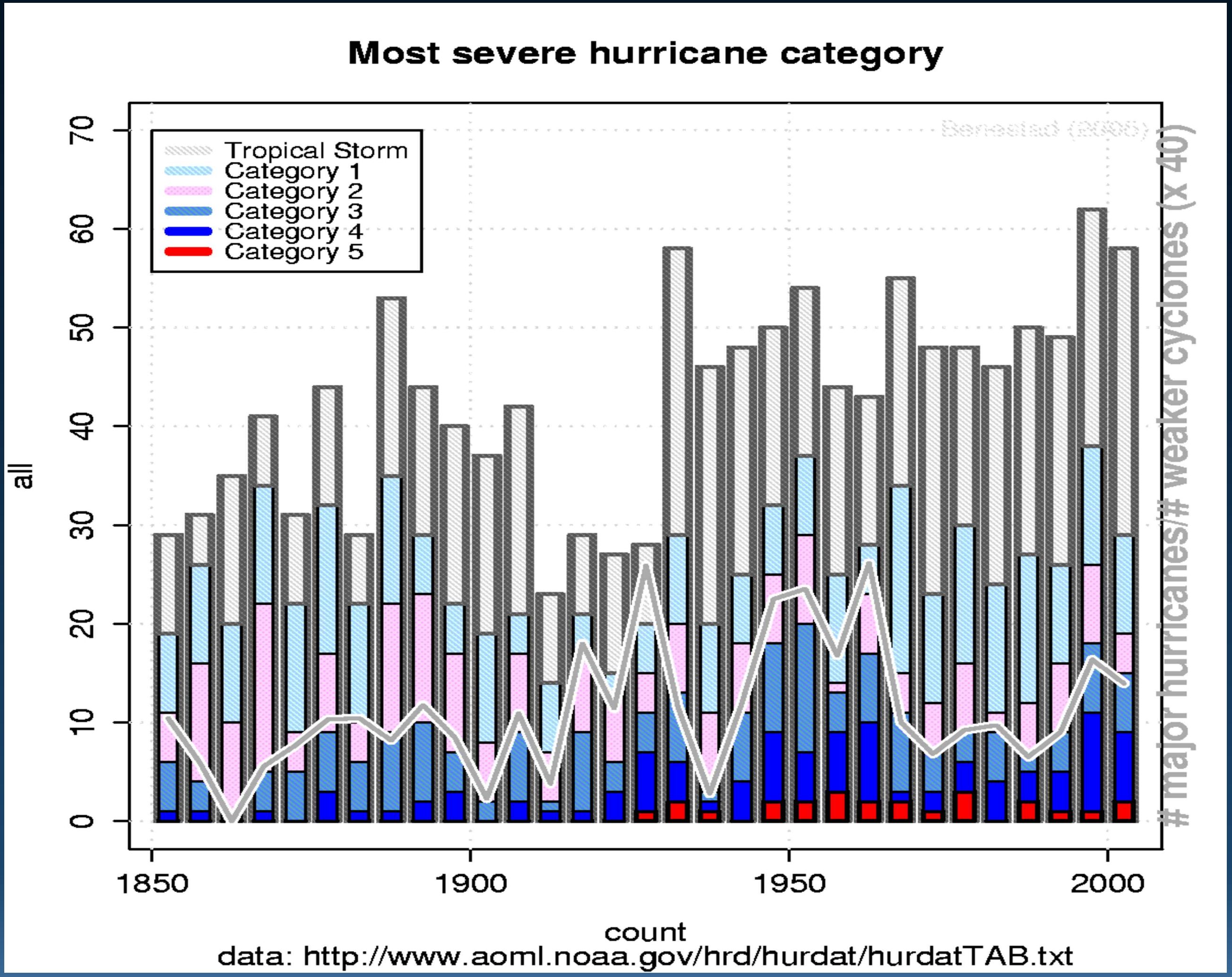


Conclusions: Part I

- Dynamics of the Western Boundary Current in the Tropical Atlantic plays an important role in Atlantic climate change
  - *Affects position of ITCZ and Nordeste rainfall*

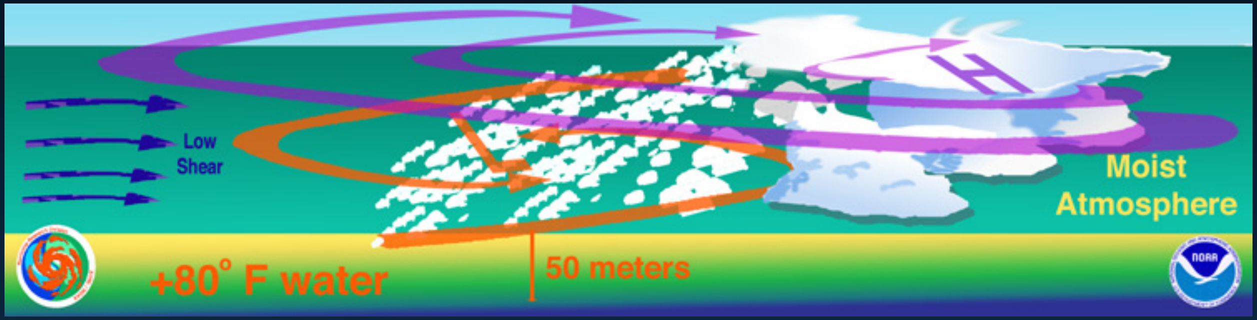
- Competition between AMOC and the STC in the NH thermocline
  - *Can explain nonlinear response to AMOC slowdown (Chang et al., 2008; Wen et al., 2010, 2011)*

Variability in Atlantic Tropical Storm numbers



Environmental precursors for hurricane genesis

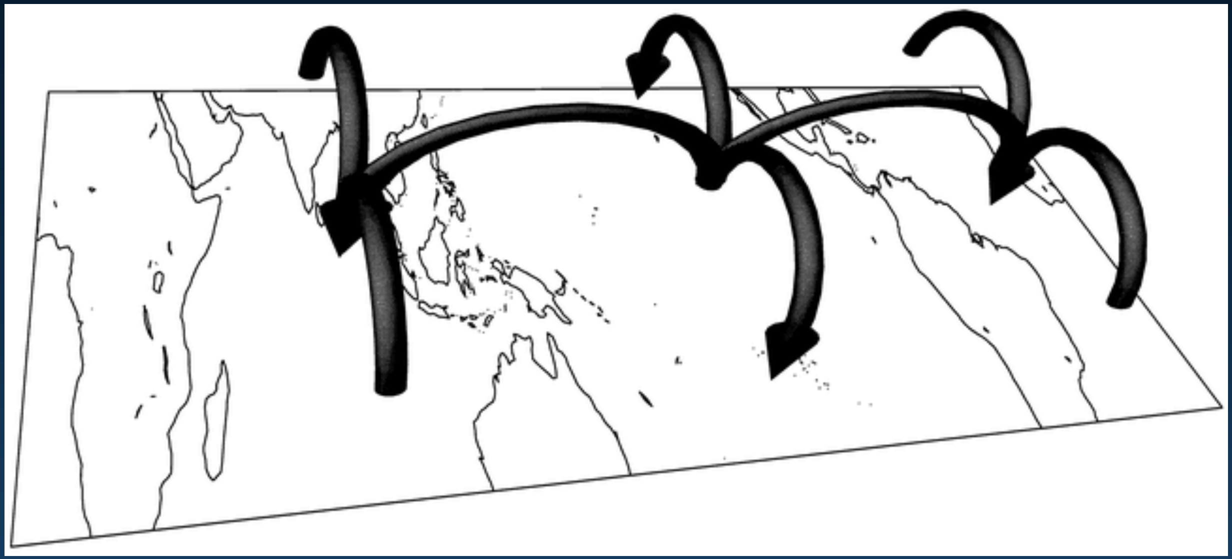
Gray (1968, 1979)



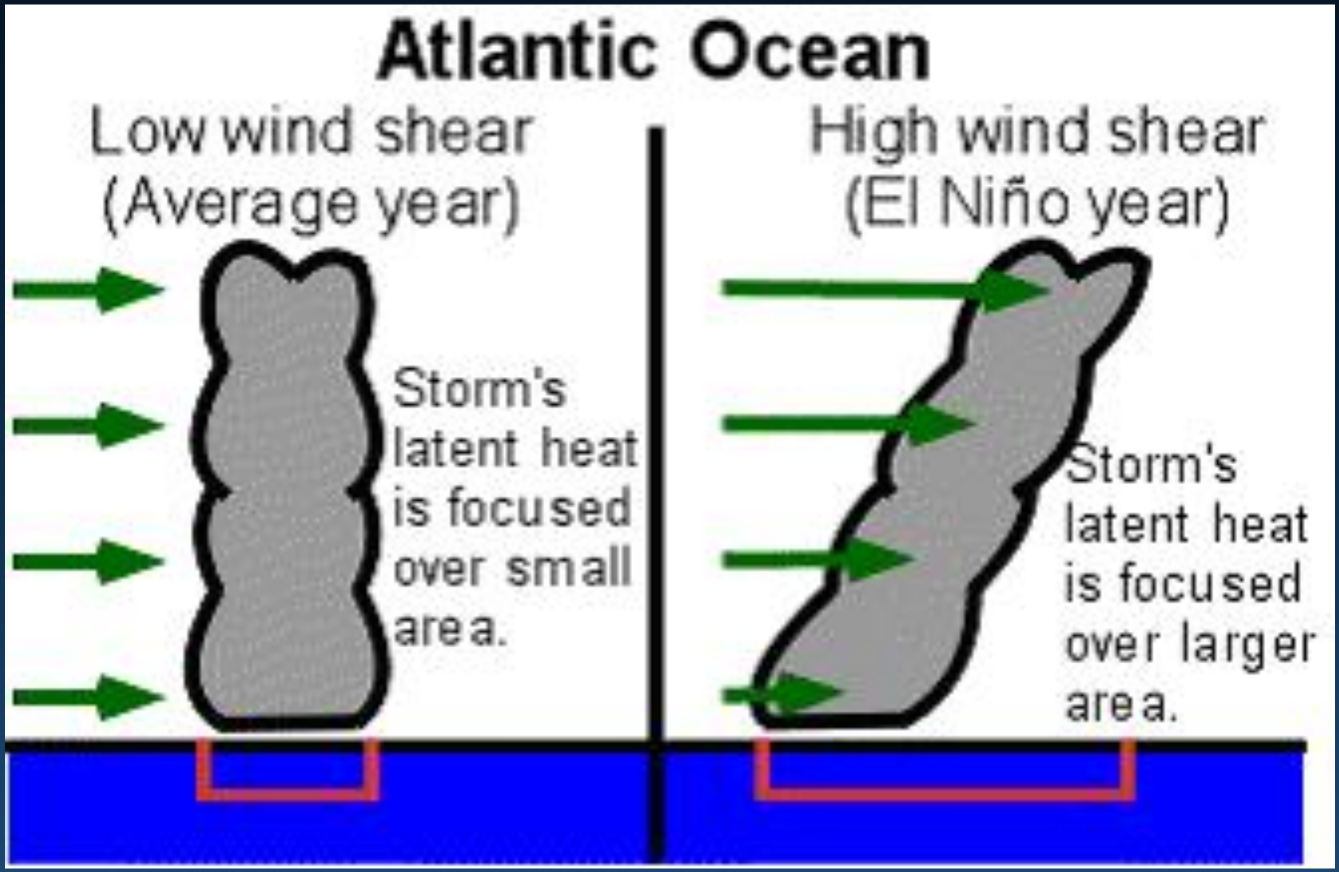
- **Sea surface temperatures > 26 degrees C**
  - **Sufficiently deep mixed layer (> 50m)**
- **Deep conditional instability**
  - **Cooling with height, mid-tropospheric moisture**
- **Low values (< 10 m/s) of vertical shear between 850 hPa and 200 hPa**
- **Sufficiently removed from equator for Coriolis effect**
- **Pre-existing disturbance with cyclonic vorticity**

Tropical Atmospheric Bridge

(Klein et al, 1999)



Vertical shear and hurricanes



Observed relationships between Atlantic TCs and ENSO

	eastern Equatorial Pacific SST anomaly	**Tropical Atlantic vertical wind shear**	**Tropical Atlantic static stability**	**Atlantic TC season**
El Niño	warm	increase	increase	inactive
La Niña	cool	decrease	decrease	active

[Gray 1984; Shapiro 1987; Gray and Sheaffer 1991; Gray et al. 1993; Goldenberg and Shapiro 1996; Richards and O'Brien 1996; Knaff 1997; Tang and Neelin 2004; Camargo et al. 2007; others]

Atlantic Meridional Mode (AMM)

Positive AMM:
- warm northern tropical Atlantic SST
- cool southern tropical Atlantic SST
- ITCZ shifted northward

Negative AMM:
- cool northern tropical Atlantic SST
- warm southern tropical Atlantic SST
- ITCZ shifted southward

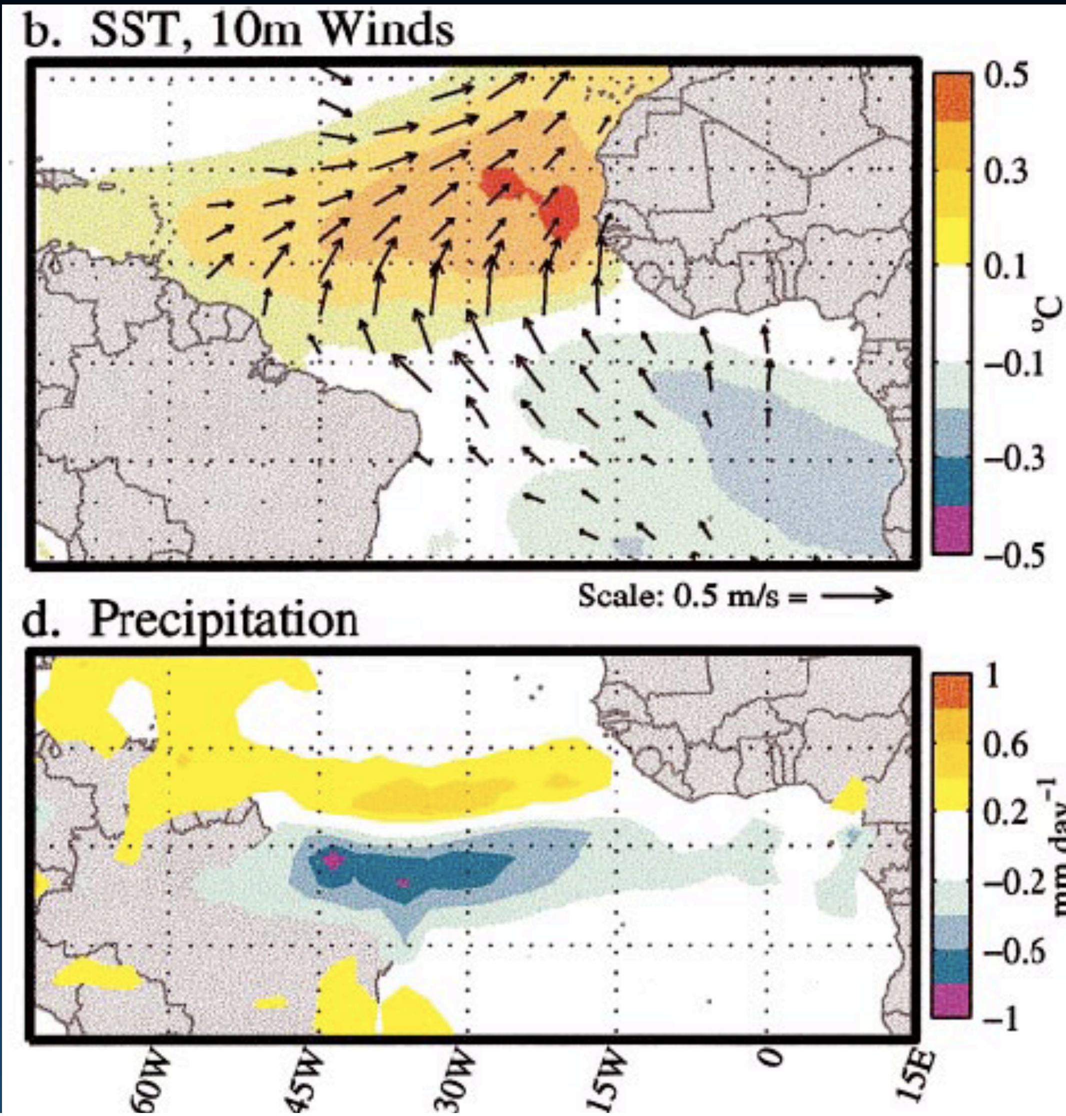


Figure: Chiang and Vimont, 2004

Top: Regression maps of the Maximum Covariance Analysis leading mode sea surface temperature (SST) normalized expansion coefficients on SST and 10-m wind vectors. Wind vectors are plotted where the geometric sum of their correlation coefficients exceeds the 95% confidence level. Middle: Same as top, but for precipitation (mm/day). In general, shaded regions in all panels exceed the 95% confidence level.

Observed relationships between Atlantic TCs and AMM, AMO, MDR SST

Correlations between Atlantic hurricane activity and climatic indices

	MDR SST	AMM	AMO	Nino 3.4
unfiltered	0.45	0.64	0.44	-0.31
Low-pass filtered (decadal)	0.79	0.75	0.80	~~-0.03~~
High-pass filtered (interannual)	~~0.21~~	0.49	~~0.01~~	-0.44

(significant at 95% level, unless stricken out)

[from Vimont and Kossin, 2007]

Observed relationships between Atlantic TCs and AMM

	tropical Atlantic SST anomaly		Tropical Atlantic vertical wind shear	Tropical Atlantic static stability	Atlantic TC season
	northern	southern			
positive	warm	cool	decrease	decrease	active
negative	cool	warm	increase	increase	inactive

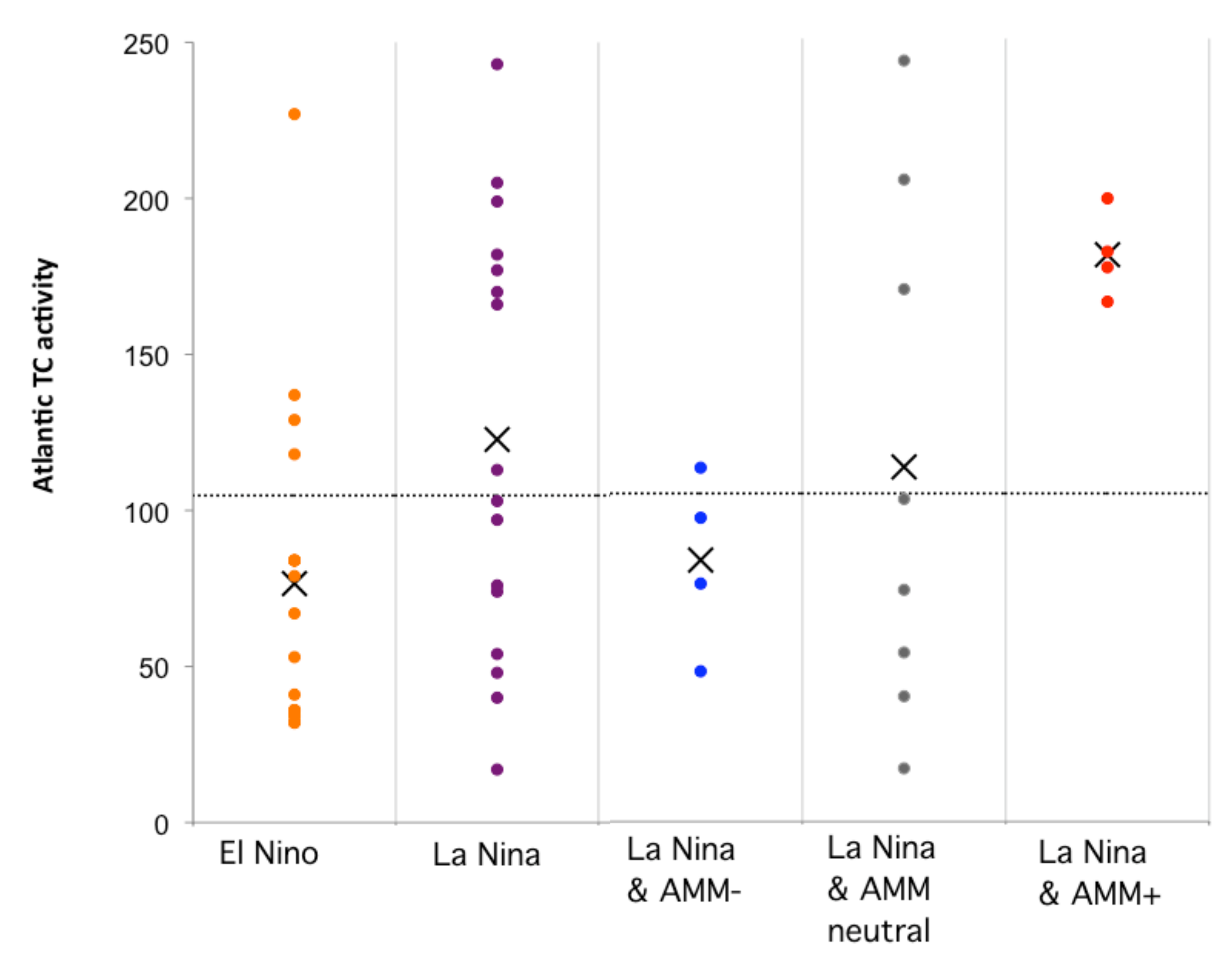
[Kossin and Vimont, 2007; Vimont and Kossin, 2007]

Atlantic TCs and Atlantic SST: Landsea et al. 1999; Goldenberg et al. 2001; Vitart and Anderson (2001); Emanuel (2005); Trenberth (2005); Webster (2005); Holland and Webster (2007); Knutson et al (2007); others

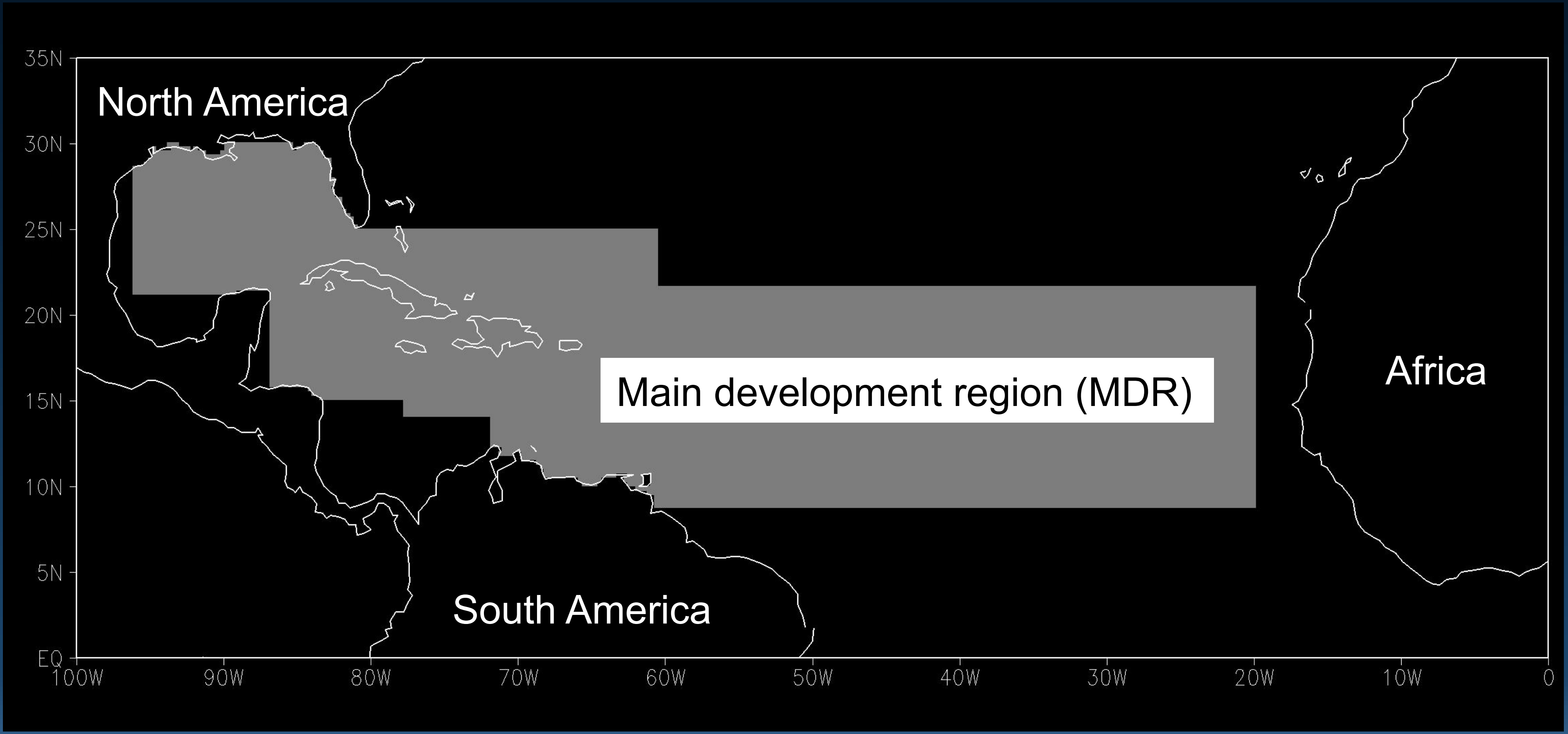
Question 2

- What is the impact of *concurrent* modes of tropical Pacific (ENSO) and Atlantic (AMM) climate variability on seasonal Atlantic tropical cyclone activity?
    - How do ENSO and AMM constrain the upper and lower limits of seasonal Atlantic TC activity?

Remote (ENSO) vs. local (AMM) influences on Atlantic TC activity



Main development region (MDR)

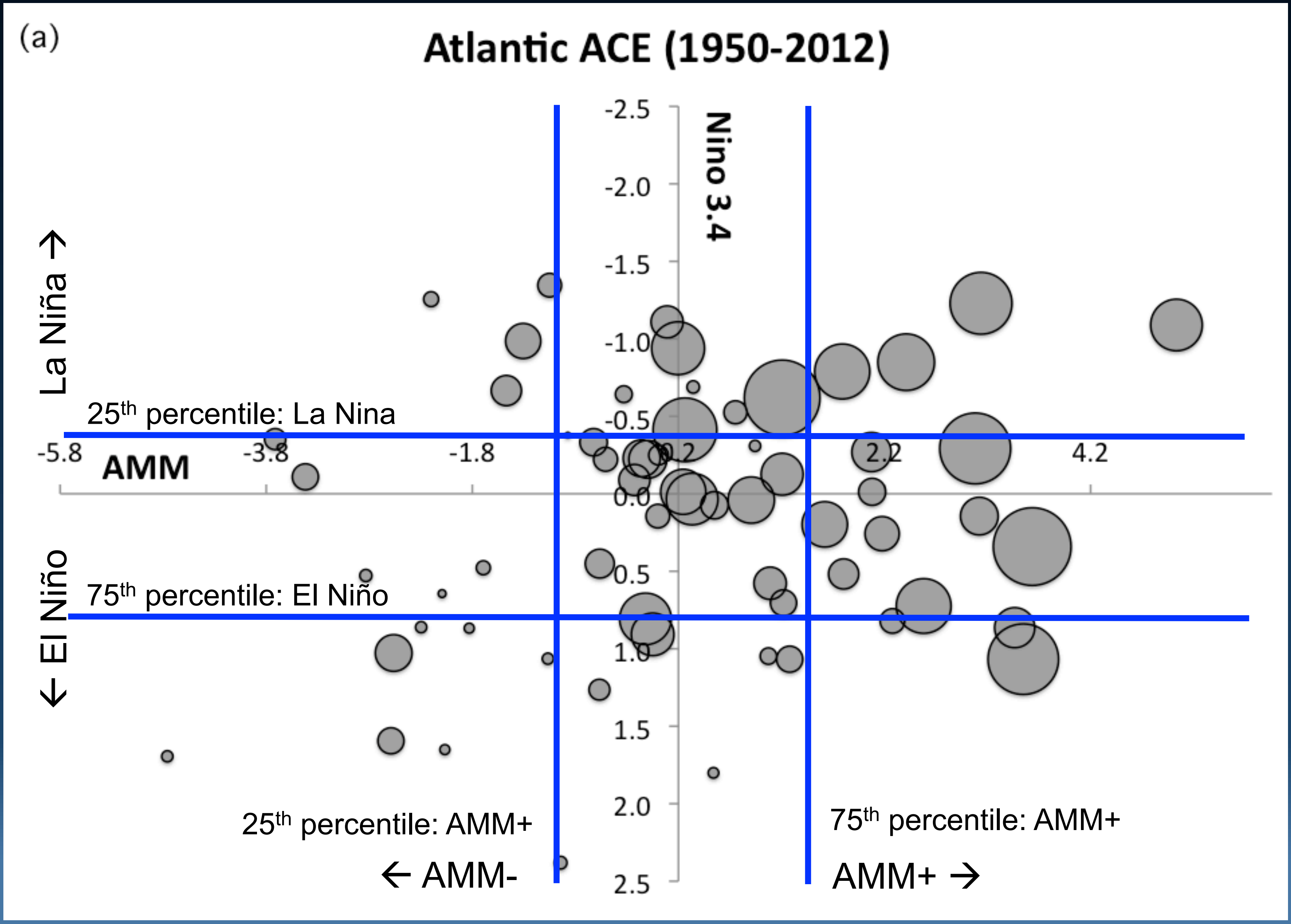


Observational analysis

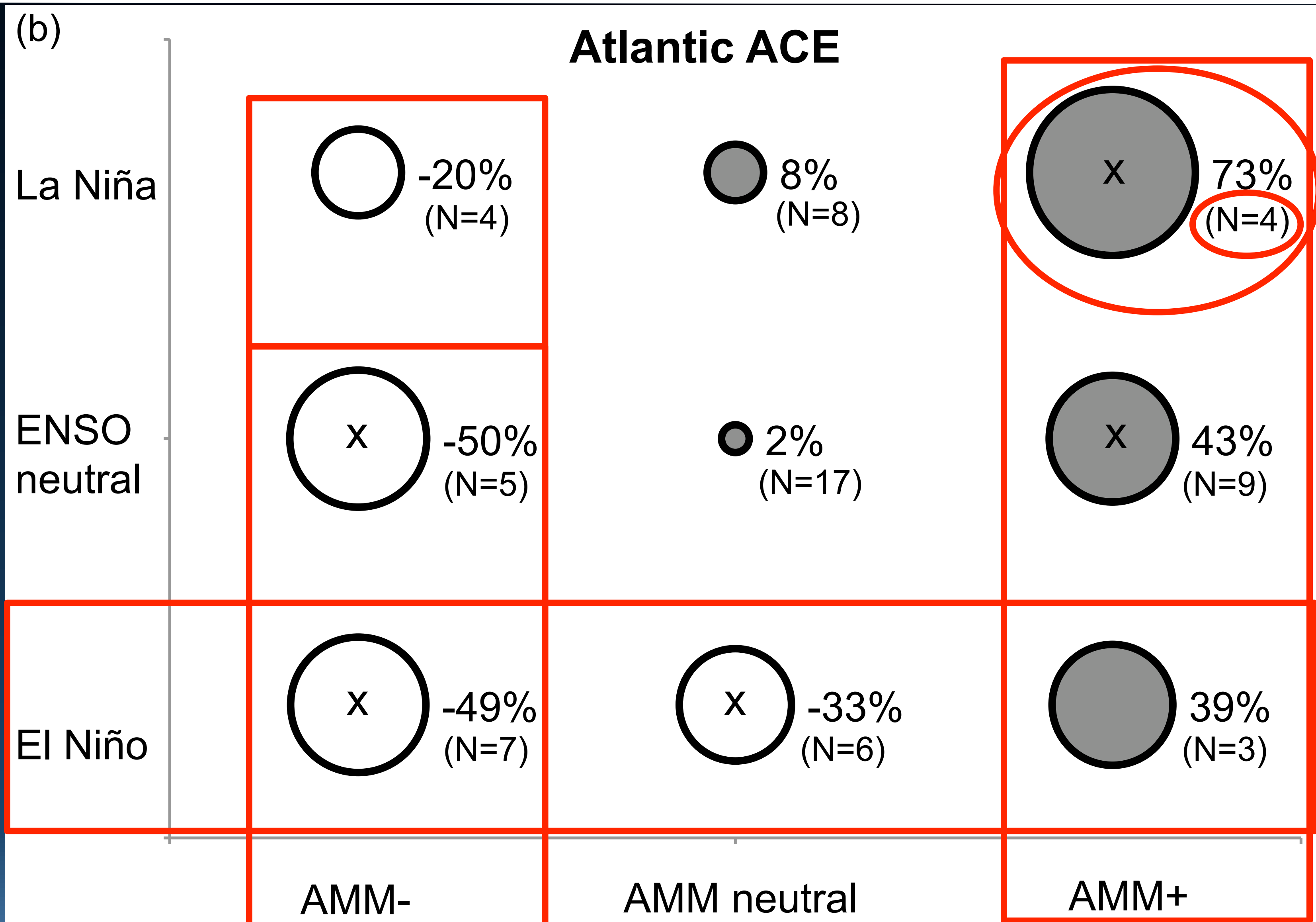
Influence of concurrent AMM and ENSO on Atlantic TC activity

Observations from HURDAT [Landsea et al. 2004]

Observed Atlantic ACE: ENSO and AMM



Observed Atlantic ACE: Composites by ENSO and AMM



Average deviation from 1950-2012 mean in seasonal Atlantic ACE (%) from HURDAT according to Aug-Oct averaged AMM and ENSO. Phases defined by the 0-25th and 75-100th percentiles.

Influence of concurrent AMM and ENSO on Atlantic TC activity

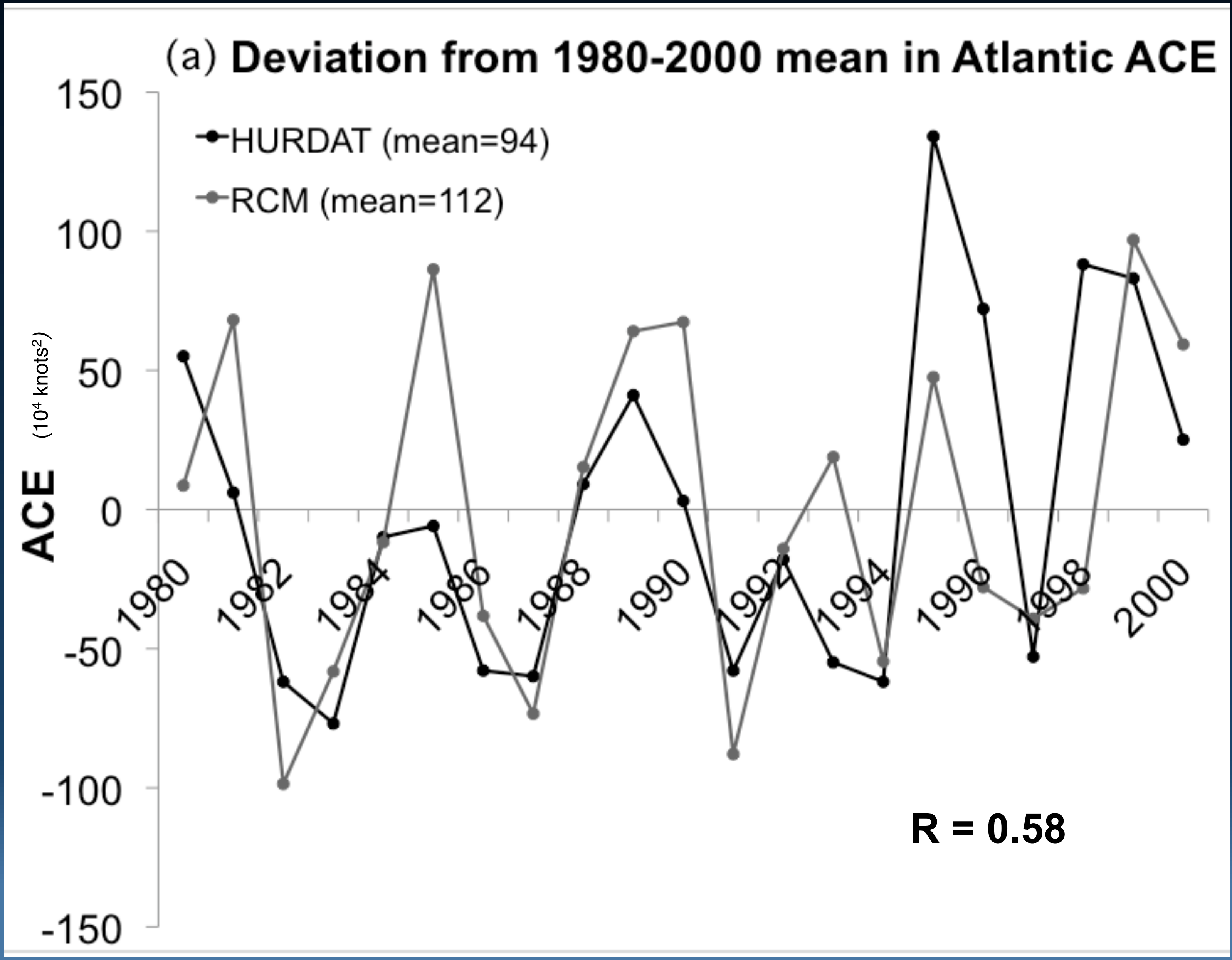
Model simulations

Regional climate model

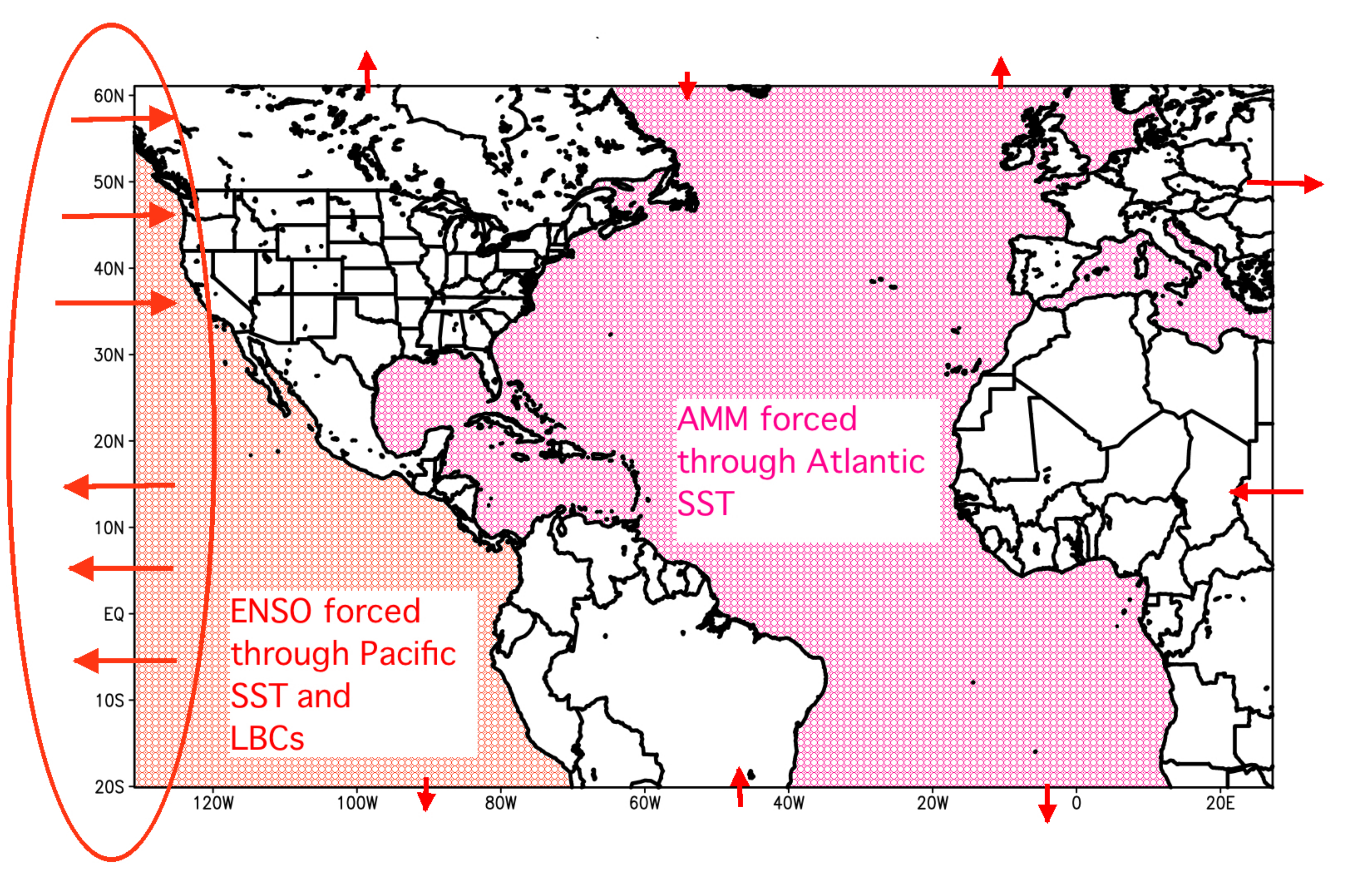
- Weather Research and Forecasting Model (WRF)
- 27 km resolution, 28 levels in vertical
- Lateral boundary conditions: 6-hourly NCEP-II reanalysis
- SST and sea ice: monthly HadISST

- control simulation: 15 January 1980 – 31 December 2000

Regional climate model: control simulation



Regional climate model: experimental design



Regional climate model: experiments

ENSO forcings (observed case of Pacific SST and LBCs)		
El Niño	1987	95^{th} percentile Niño 3.4
La Niña	1999	15^{th} percentile Niño 3.4

AMM forcings (observed case of Atlantic SST)		
Positive	2005	95^{th} percentile AMM index
Negative	1984	5^{th} percentile AMM index
Neutral	1987	60^{th} percentile AMM index
Moderately positive	1999	80^{th} percentile AMM index

<u>Simulations (3- or 4-member ensembles):</u>

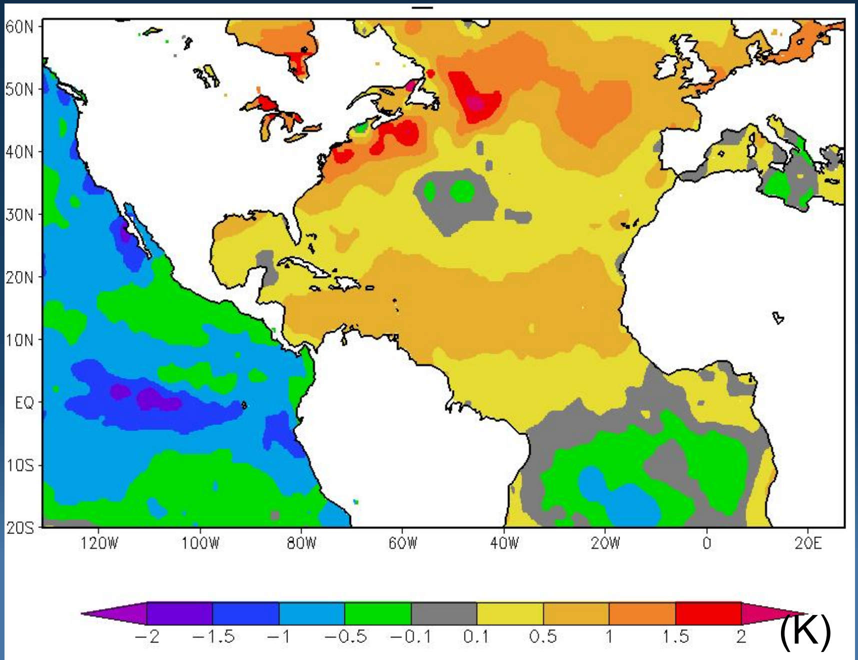
- El Niño &
  - AMM- (strong)
  - AMM neutral
  - AMM+ (strong)
- La Niña &
  - AMM- (strong)
  - AMM + (moderate)
  - AMM+ (strong)

Regional climate model: experiments

ENSO forcings (observed case of Pacific SST and LBCs)		
El Niño	1987	95th percentile Niño 3.4
La Niña	1999	15th percentile Niño 3.4

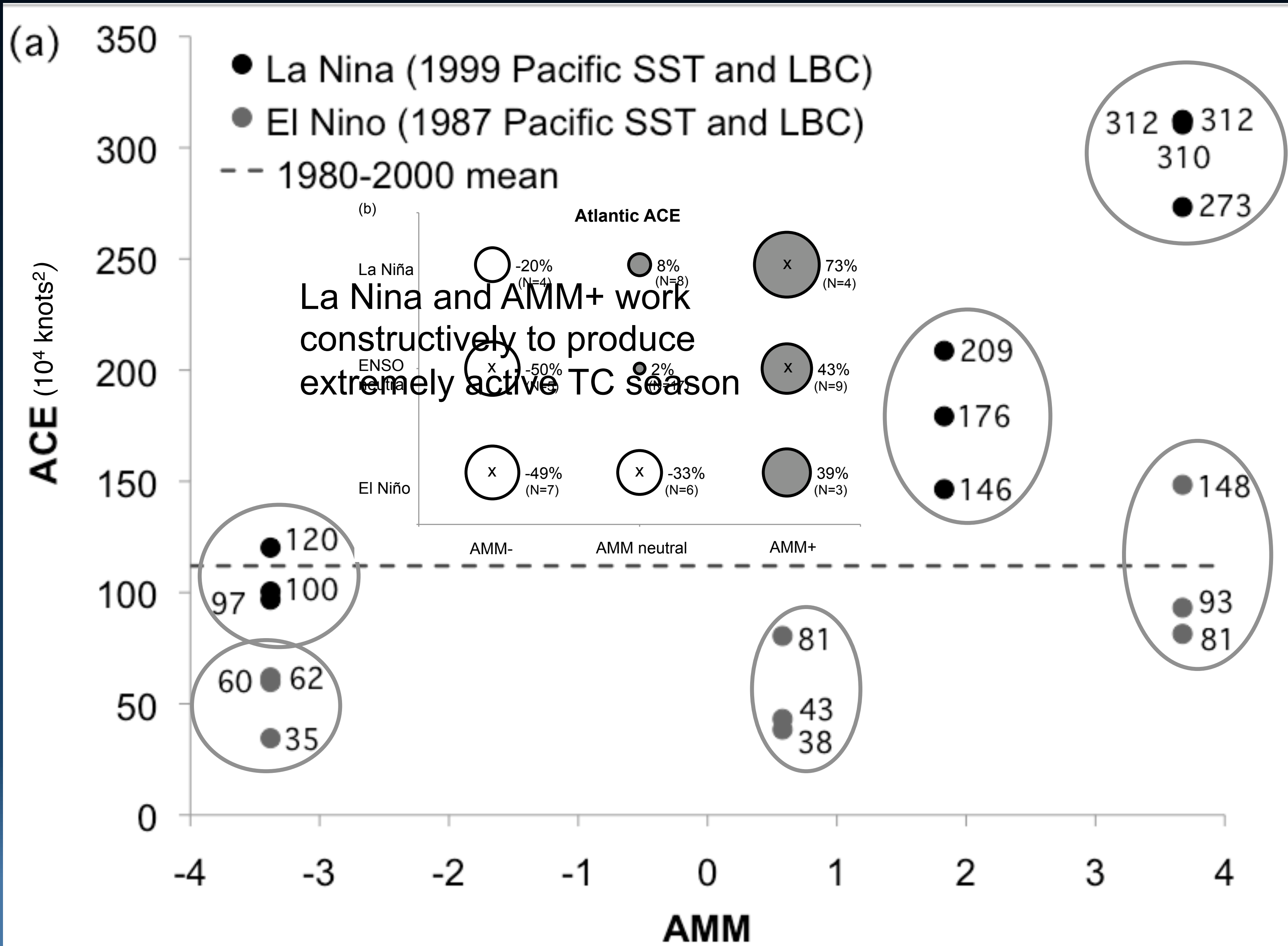
AMM forcings (observed case of Atlantic SST)		
Positive	2005	95th percentile AMM index
Negative	1984	5th percentile AMM index
Neutral	1987	60th percentile AMM index
Moderately positive	1999	80th percentile AMM index

La Niña & AMM+



Allows us to understand TC activity response to combinations of extreme phases of ENSO and AMM for which we do not yet have observations

Atlantic TCs response to AMM and ENSO



La Nina and AMM+ work constructively to produce extremely active TC season

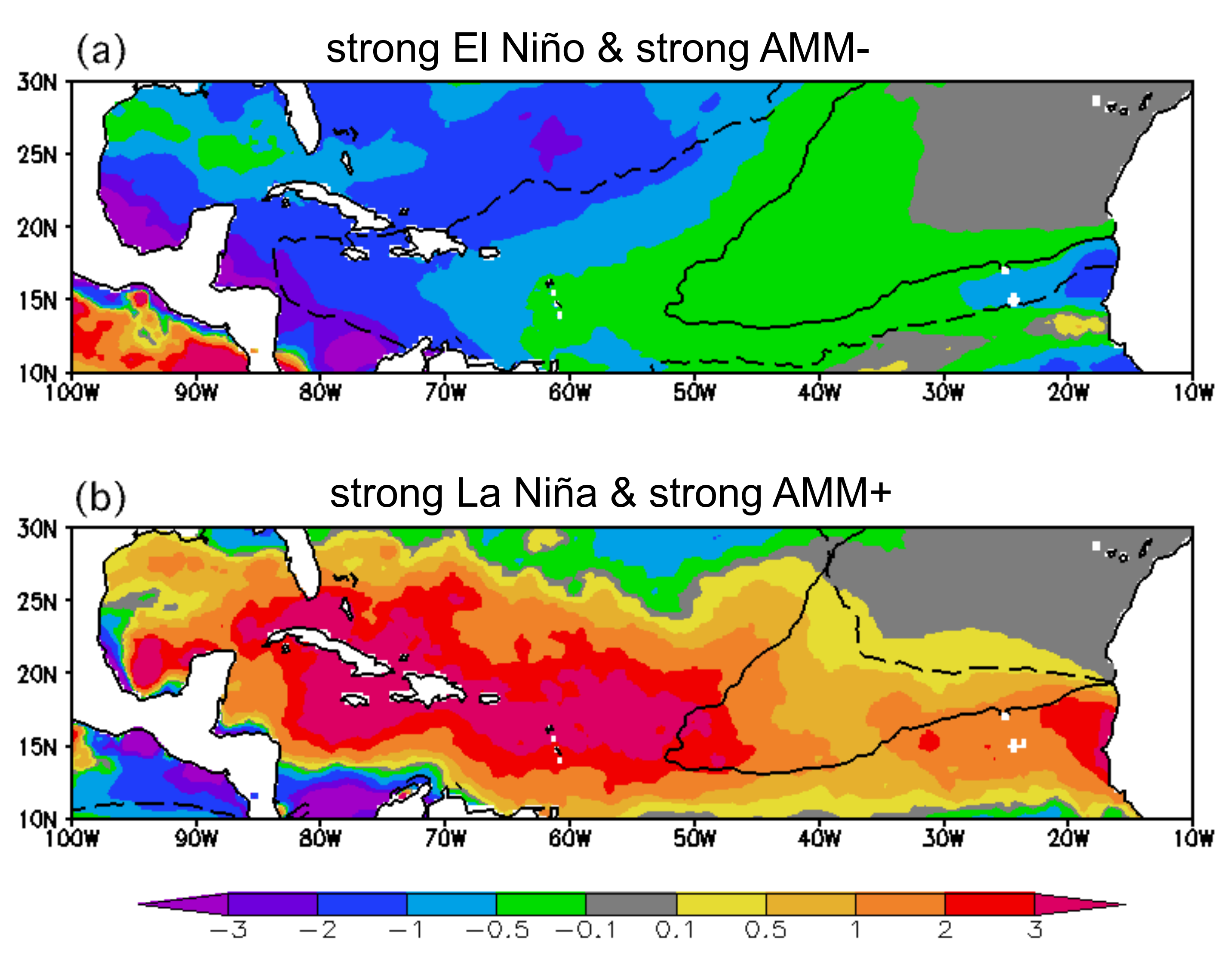
Genesis Potential Index (GPI)

$$GPI = \left|10^5 \eta\right|^{3/2} \left(\frac{H}{50}\right)^3 \left(\frac{V_{pot}}{70}\right)^3 \left(1 + 0.1 V_{shear}\right)^{-2}$$

(Emanuel and Nolan, 2004)

η = absolute vorticity at 850 hPa
H = relative humidity at 600 hPa
V_{shear} = vertical wind shear between 850 hPa and 200 hPa
V_{pot} = potential intensity (function of SST and vertical profiles of atmospheric temperature and moisture)

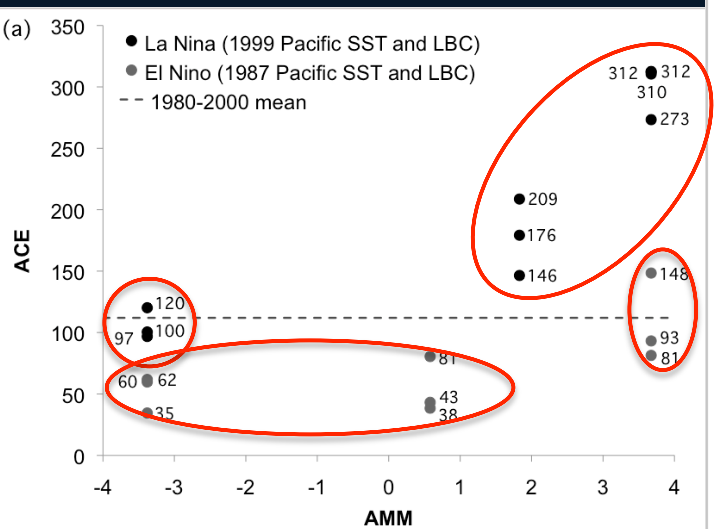
Environmental response to AMM and ENSO: Genesis Potential Index



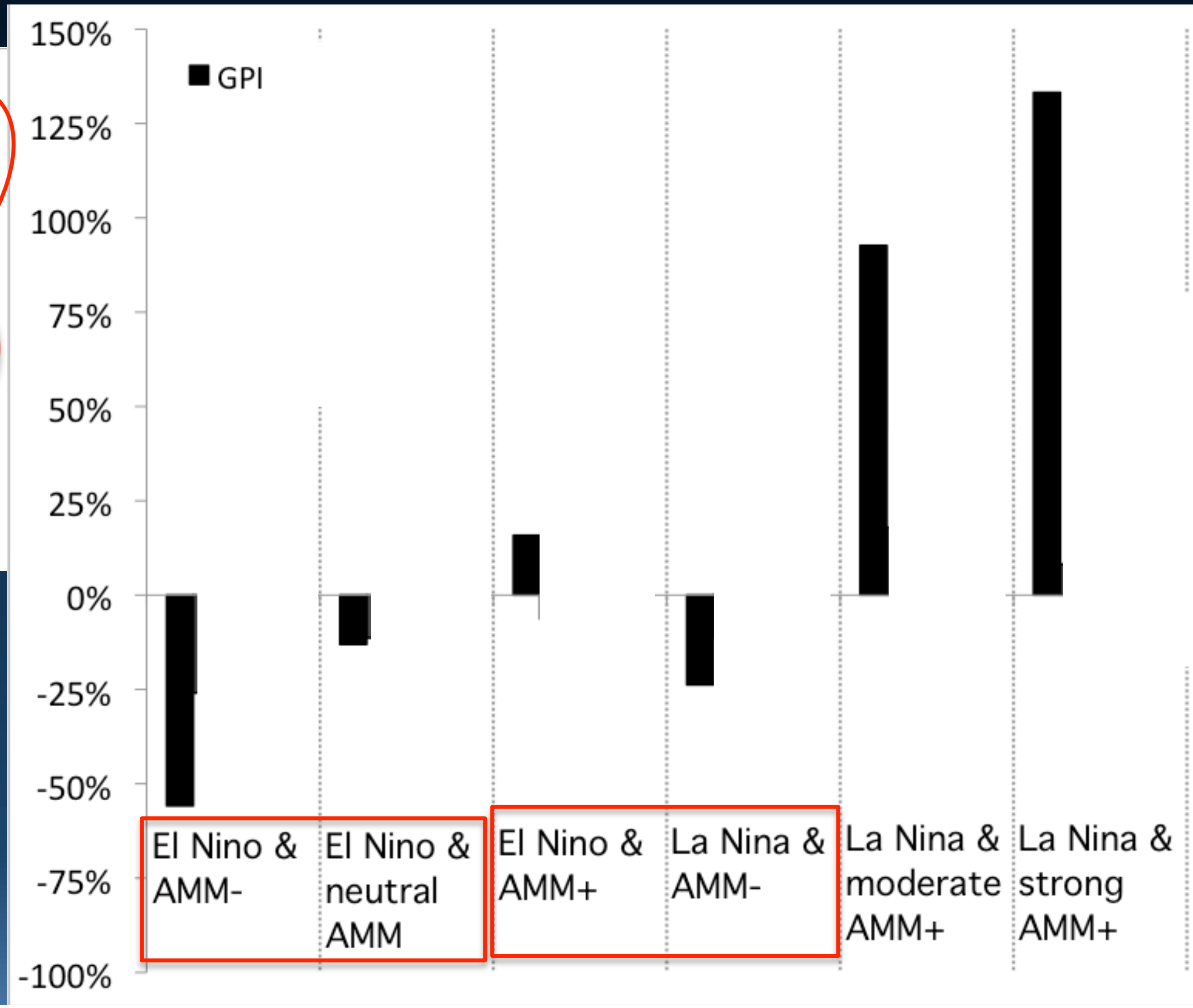
Contour: GPI of 0.5 in climatology (solid) and experiment (dash)

Environmental response to AMM and ENSO: Genesis Potential Index

$$GPI = \left|10^5 \eta\right|^{3/2} \left(\frac{H}{50}\right)^3 \left(\frac{V_{pot}}{70}\right)^3 \left(1 + 0.1 V_{shear}\right)^{-2}$$



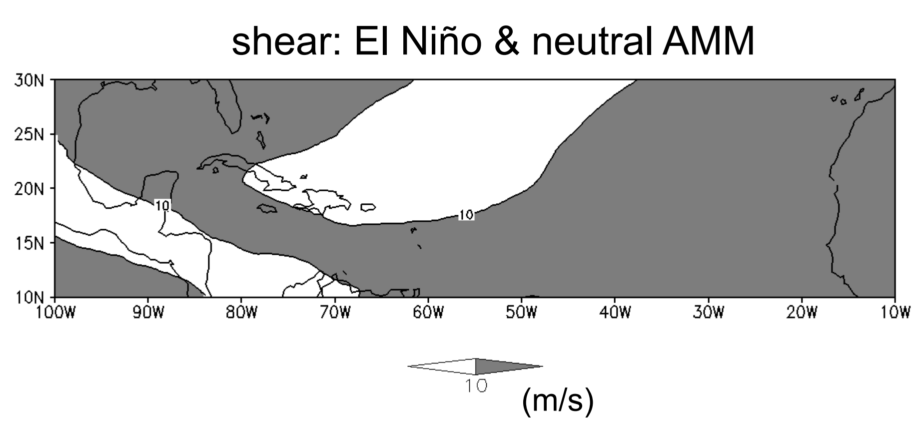
Why are reductions in ACE similar for El Nino and AMM- vs. El Nino and neutral AMM, despite environmental conditions which are more unfavorable for the former?

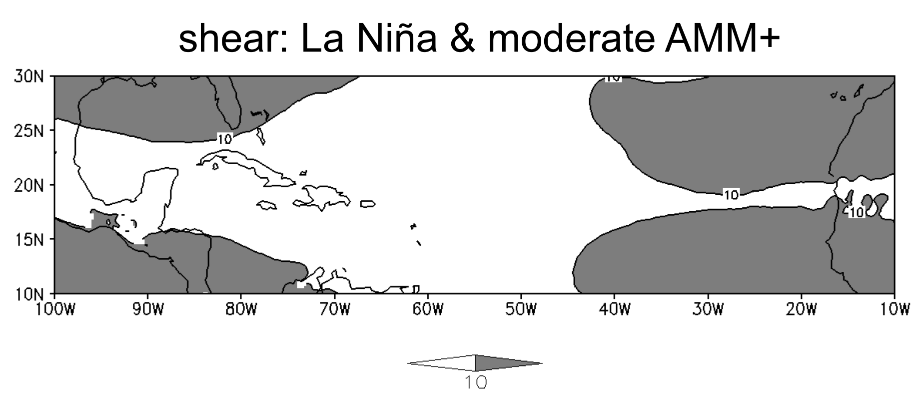


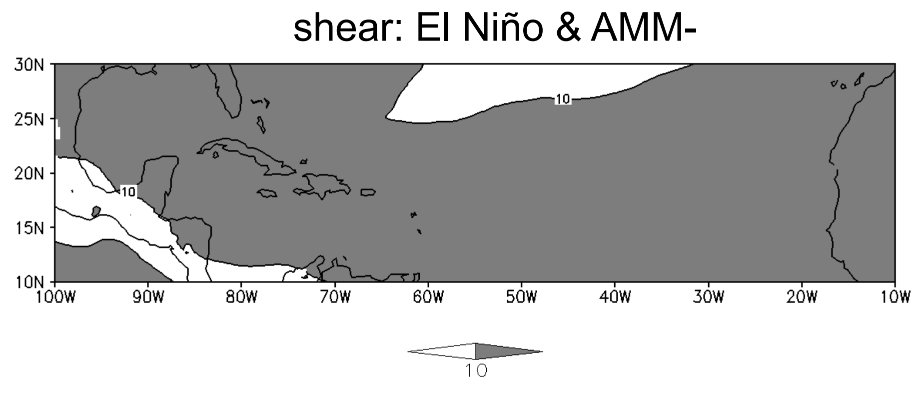
Deviation from ASO 1980-2000 mean (%) in GPI over the development region from model simulations (black); The same, calculated by varying each term while keeping others to climatology (grey).

Response in vertical wind shear to AMM and ENSO

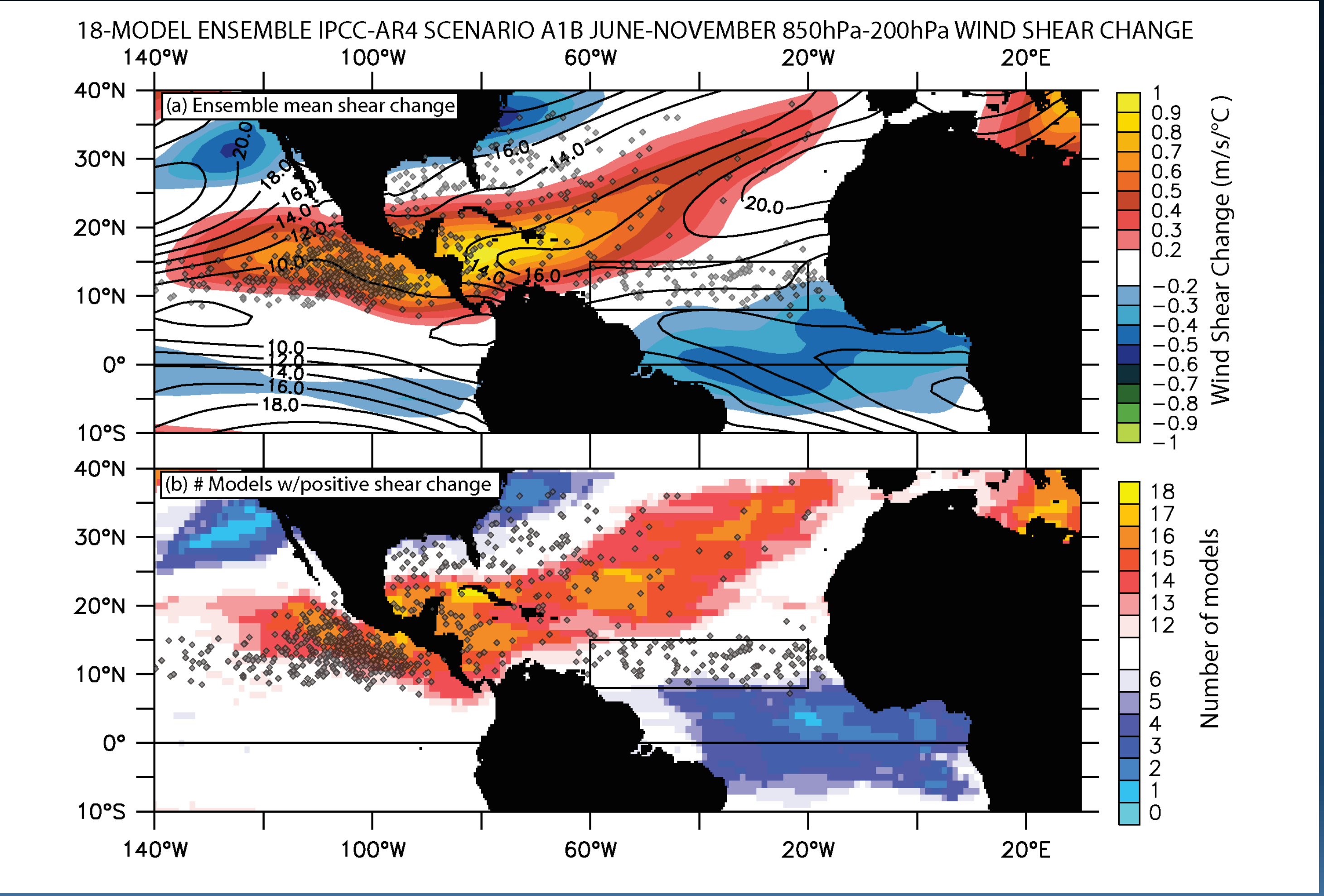
TCs are largely inhibited for shear over a threshold of about 7.5 – 10 m/s
[Zehr 1992; DeMaria et al. 1993]







CMIP3: Projected change in vertical shear



Conclusions: Part II

Observations and simulations demonstrate importance of AMM and ENSO together in determining seasonal Atlantic TC activity.

- ENSO alone is not a good predictor of Atlantic TC activity.

- Combination of unfavorable ENSO and AMM conditions not necessary to suppress Atlantic TC activity
    - Saturation effect for vertical wind shear values exceeding ~10m/s
    - El Niño is not required for lower limit of TC activity.

- Concurrent strong ENSO and AMM phases that separately <u>oppose each other</u> in their influence on Atlantic TC activity produce <u>near-average</u> seasons.

- La Niña and positive AMM <u>work together</u> constructively to support extremely <u>active</u> Atlantic TC seasons largely through mid-tropospheric moisture.
    - Atlantic TC activity response is non-linear to increasing AMM, most strongly during La Niña conditions.

- Implications for hurricanes in past and future climates?