Climate and the Tropical Atlantic

What drives Tropical Atlantic climate changes and what are their impacts?






Presenter: Rick Lumpkin
AOML Program Review
4-6 March 2014

Climate and the Tropical Atlantic

Why this matters to NOAA and to society:

Climate variability in the Tropical Atlantic drives floods, droughts, hurricane activity, etc., affects the evolution of SST anomalies in other ocean basins, and is a fingerprint for large-scale climate change.

Challenges:

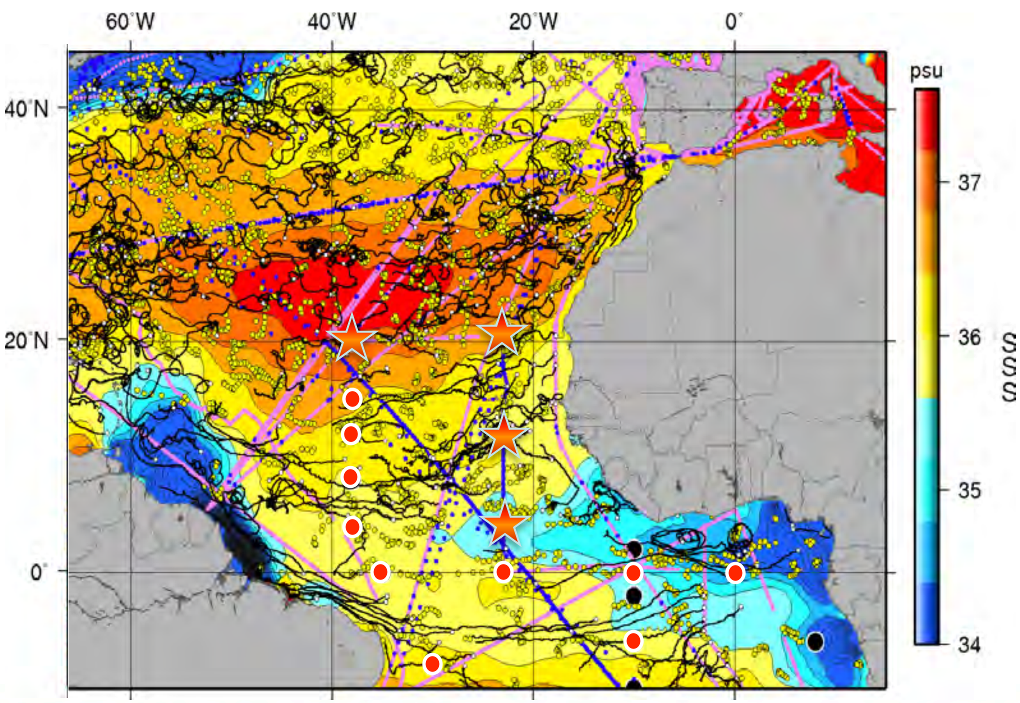
- ***Biases*** in coupled models limiting predictability.
- Intense variability at ***intraseasonal*** to ***seasonal*** scales, modulated at ***interannual*** and longer time scales.
- ***Teleconnections*** to other regions: not just one-way!

Research conducted by a mix of NOAA/AOML and CIMAS investigators, with frequent partnerships with Univ. Miami, NOAA/PMEL and NOAA/NESDIS researchers. Additional partnerships noted in this talk.

Tropical Atlantic sustained observations

AOML has taken the lead in maintaining sustained observations in the region, and have partnered with researchers around the world to better understand climate fluctuations.

★ = *NOAA-maintained PIRATA Northeast Extension (AOML/PMEL partnership)*



Shading: sea surface salinity during spring 2010.
Markers: in-situ ocean observations during spring 2010.

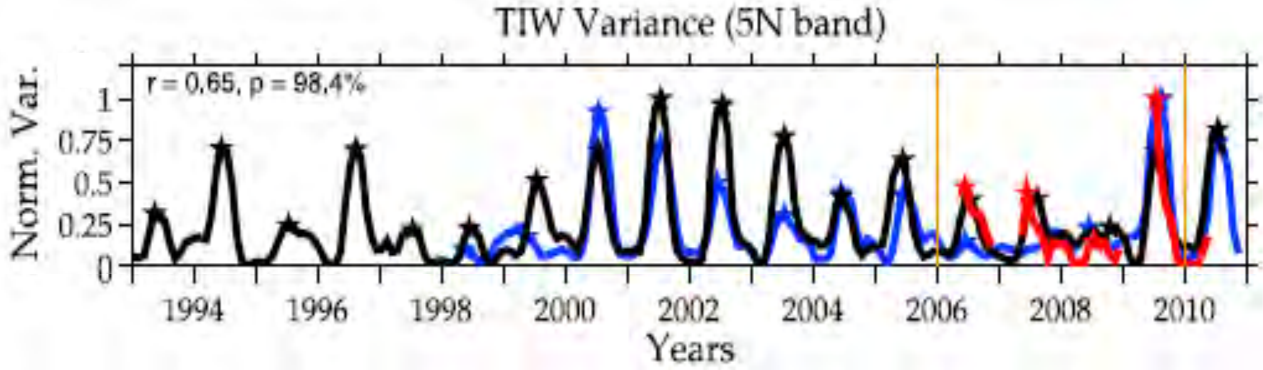
Blue: XBT profiles
Yellow: Argo float profiles
Black: surface drifter trajectories
Purple: TSG transects
Red: PIRATA moorings (upper 500m)

Research results from these data will be highlighted in the following slides.

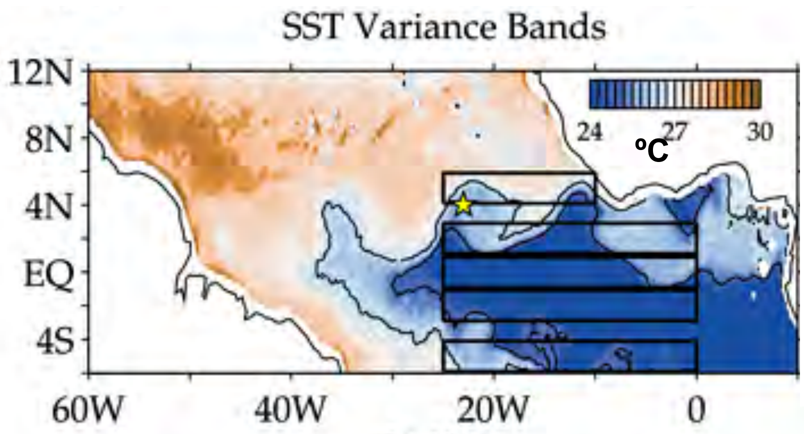
Work in partnership with Brazil, France, and others

OCEAN DYNAMICS AND TROPICAL ATLANTIC CLIMATE

Interannual modulation of Tropical Instability Waves (TIWs)



Normalized variance along 5ºN associated with TIWs, calculated from TMI SST (blue), AVISO SLA (black), and the current meter on the PIRATA mooring 4ºN 23ºW (red). Stars: peak value for each year.



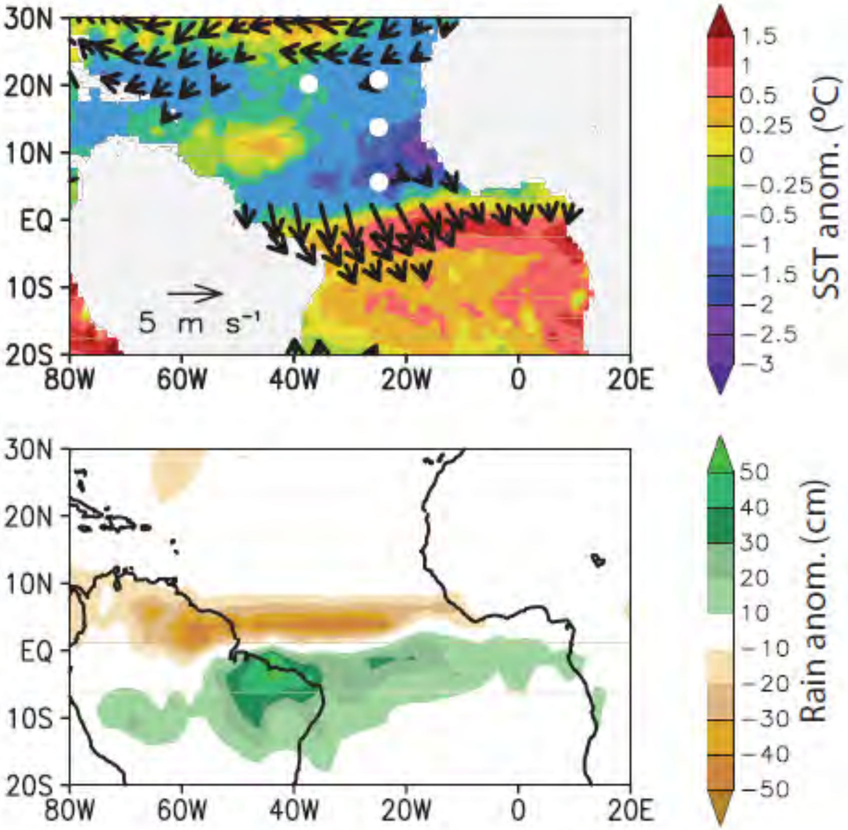
Low (high) TIW seasons are associated with:

- warm (cold) SSTs in the cold tongue region
- weak (strong) wind stress divergence
- weak (strong) zonal current shear in region 2ºN-5ºN
- weak (strong) curl in the region 2ºS-2ºN

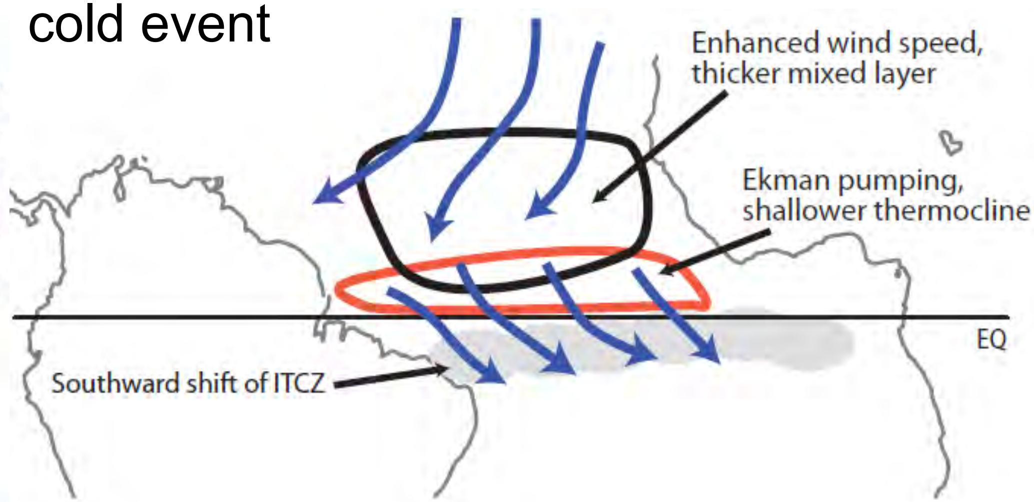
Perez et al. (2012)

The cold event of 2009

Anomalous conditions during Apr-May 2009



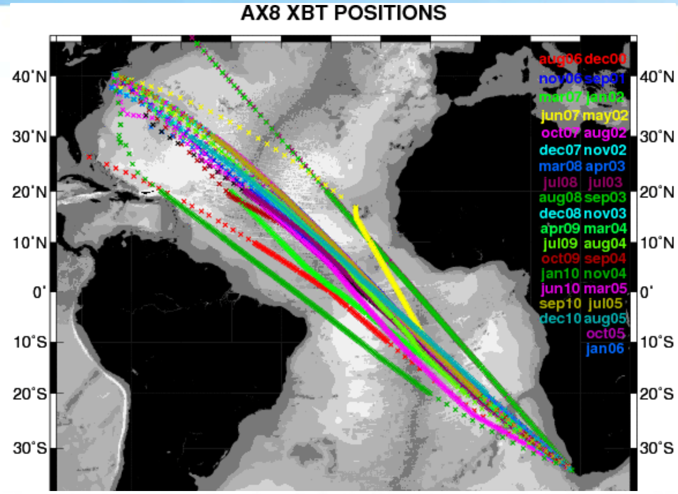
Data from PIRATA and Argo reveal the mechanisms responsible for the 2009 cold event

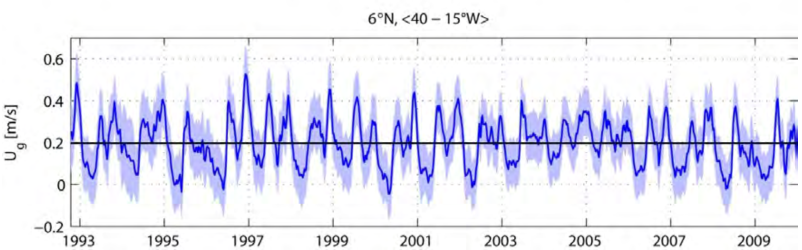


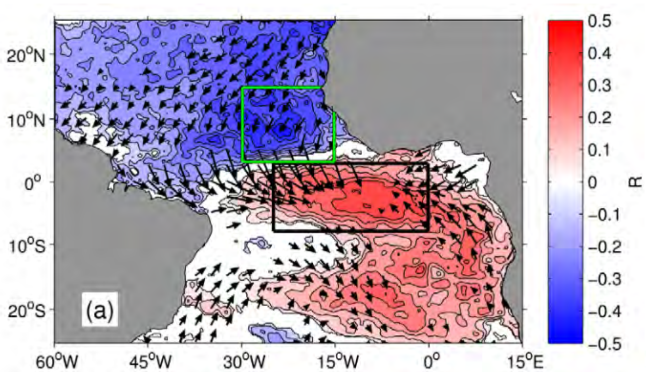
- Initial cooling in northern basin driven by strengthened NE Trades.
- Winds to the south responded to interhemispheric SST gradient.
- Subsequent cooling in central basin driven by wind-induced upwelling, magnifying the SST gradient (positive feedback).

Foltz et al. (2012)

Relationships between ocean currents and the climate modes



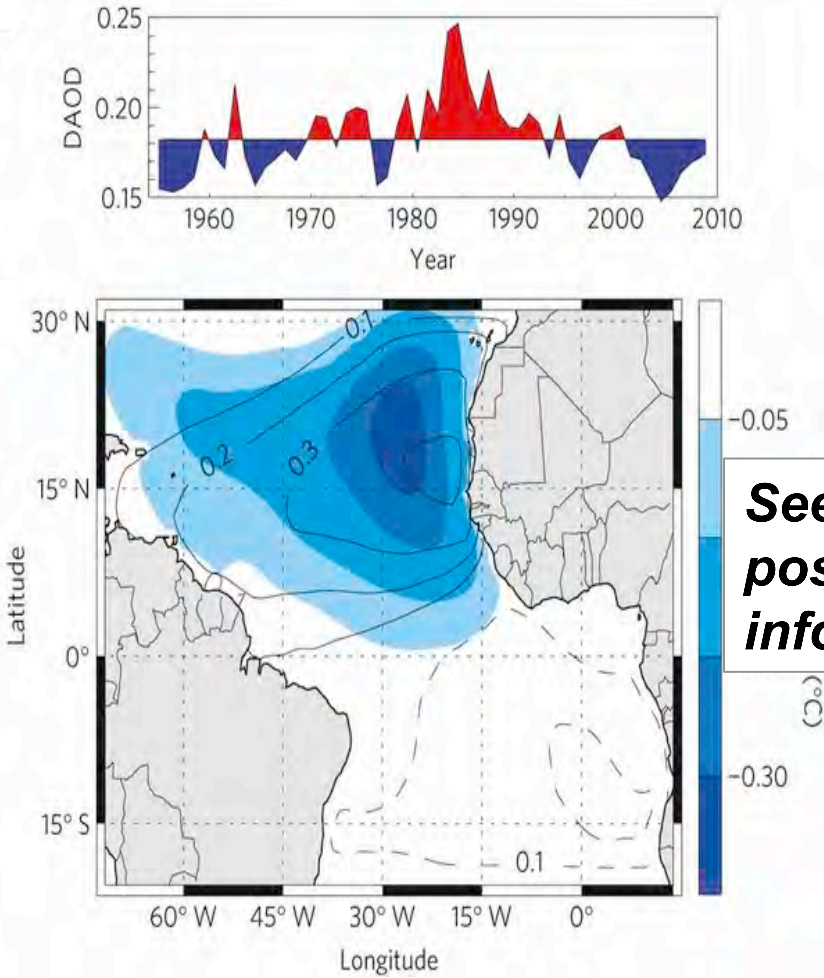




- Interannual variations of the surface North Equatorial Countercurrent and subsurface North Equatorial Undercurrent calculated from XBT, surface drifter, Argo float and satellite wind and altimetry observations.
- Changes in strength and position correlated with SST and wind anomalies, related to the zonal and meridional climate modes of variability.
- These results support a link between the two modes and highlight the potential role of ocean dynamics in their evolution.

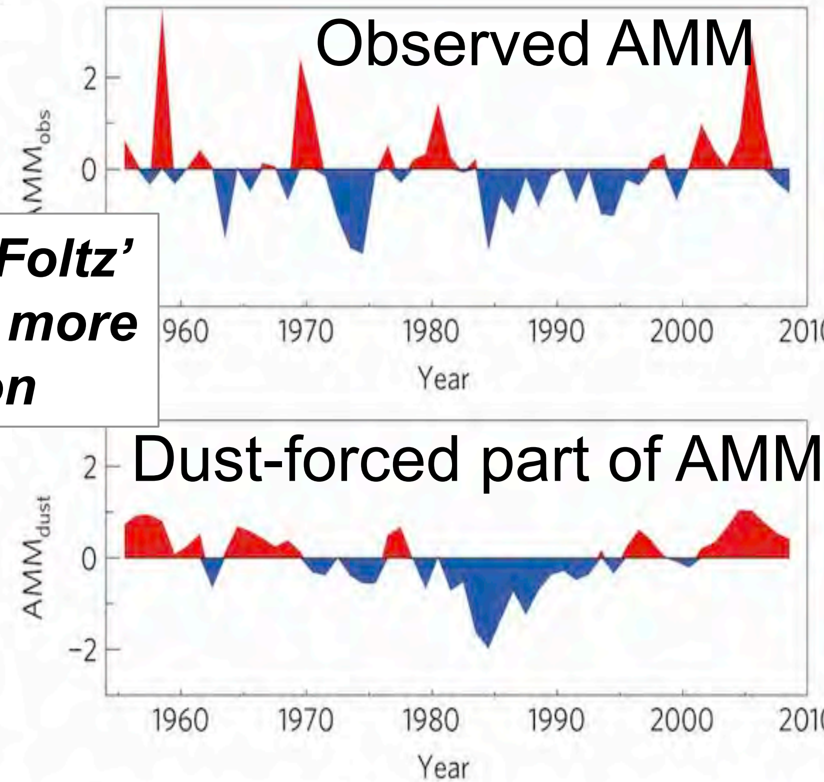
Hormann et al. (2012); Goes et al. (2013)

Tropical Atlantic SST forced by dust



AMM=Atlantic Meridional Mode of SST variability

See Greg Foltz' poster for more information

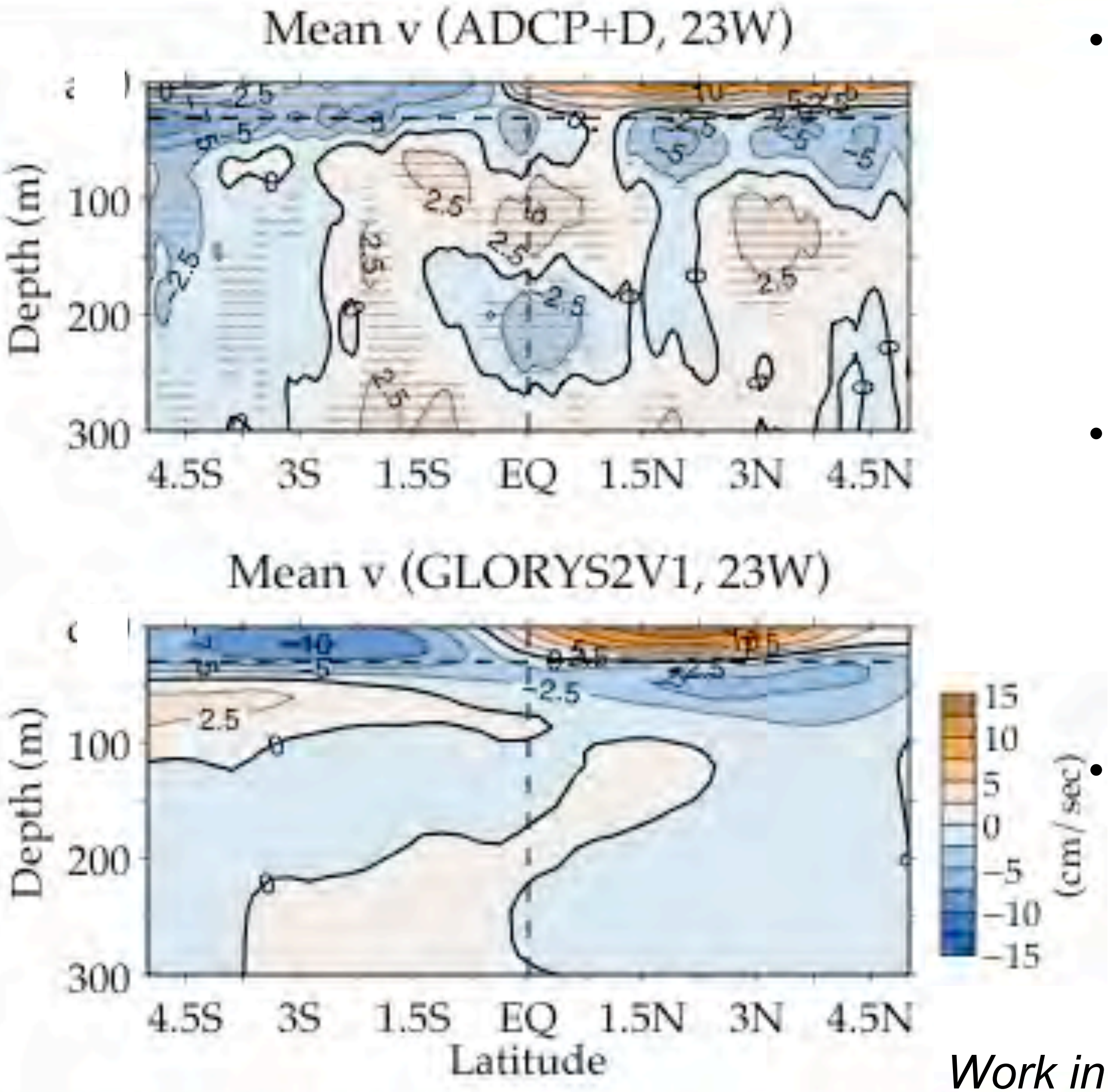


SST-induced dust shading in MIT OGCM
AMM: contours

Work in partnership with Univ. Virginia

Evan et al., 2011; Foltz et al., 2013

Structure of the Tropical Cells in observations and in assimilating models

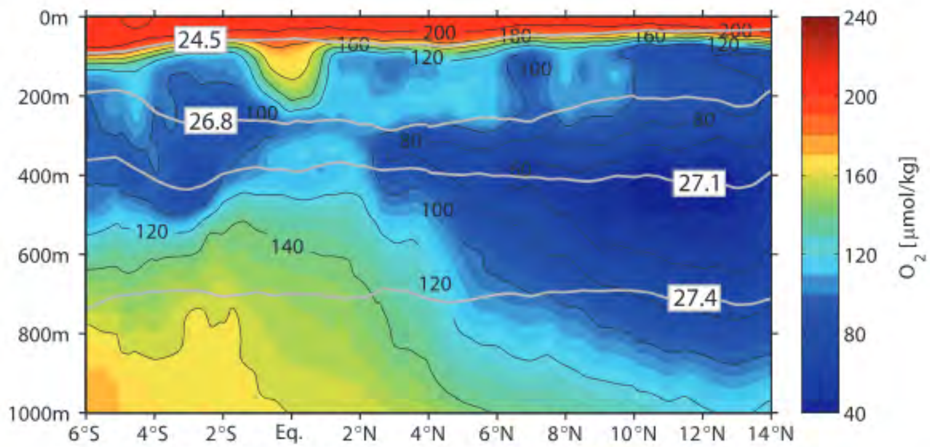


- First calculation of time-mean meridional currents at two key longitudes (23 & 10ºW) in the eastern and central TA, from ADCP, drifter and Argo float observations.
- Surface poleward currents: faster, shallower on northern side. Transition south of the equator. Subsurface equatorward flow also resolved.
- Consistent results simulated in GLORYS assimilating model at surface, but significant differences at depth.

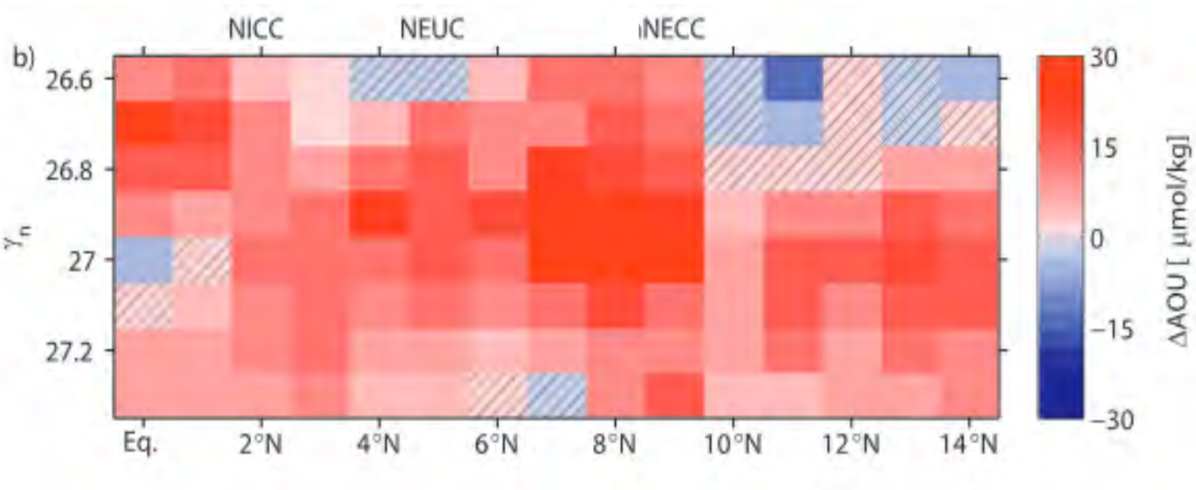
Work in partnership with GEOMAR and IRD

Perez et al. (2013)

Decreasing oxygen in the Atlantic Oxygen Minimum Zone (OMZ)



Oxygen along 23ºW averaged over 18 research cruises (US, German and French)



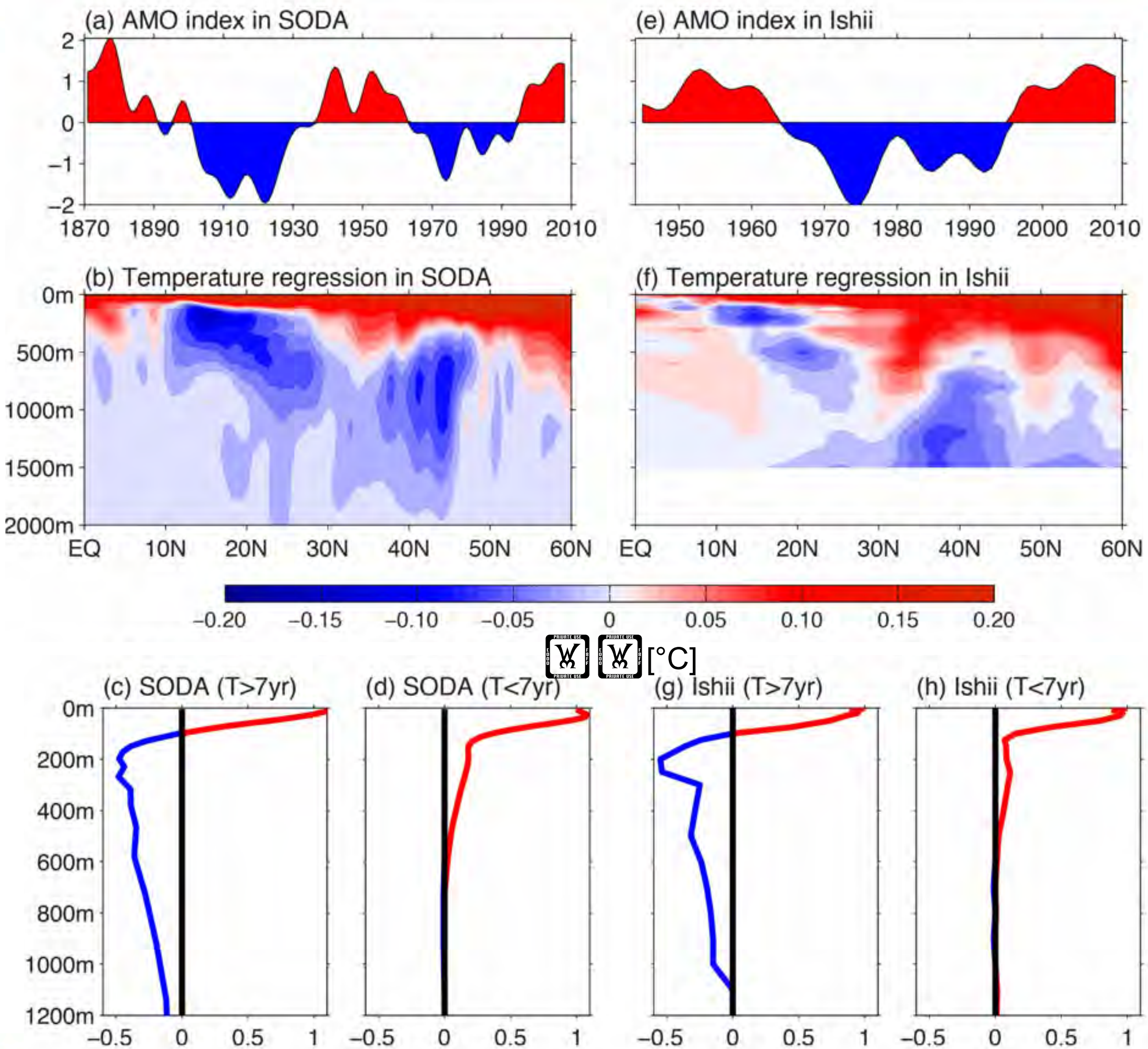
('99-'08) -('72-'85) Apparent Oxygen Utilization (AOU): significant decrease in O_2 of ~15 μmol/kg

Oxygen decrease and salinity increase attributed to weakening of zonal jets that ventilate the OMZ.

Work in partnership with GEOMAR

CONNECTIONS TO LARGER-SCALE CLIMATE CHANGES

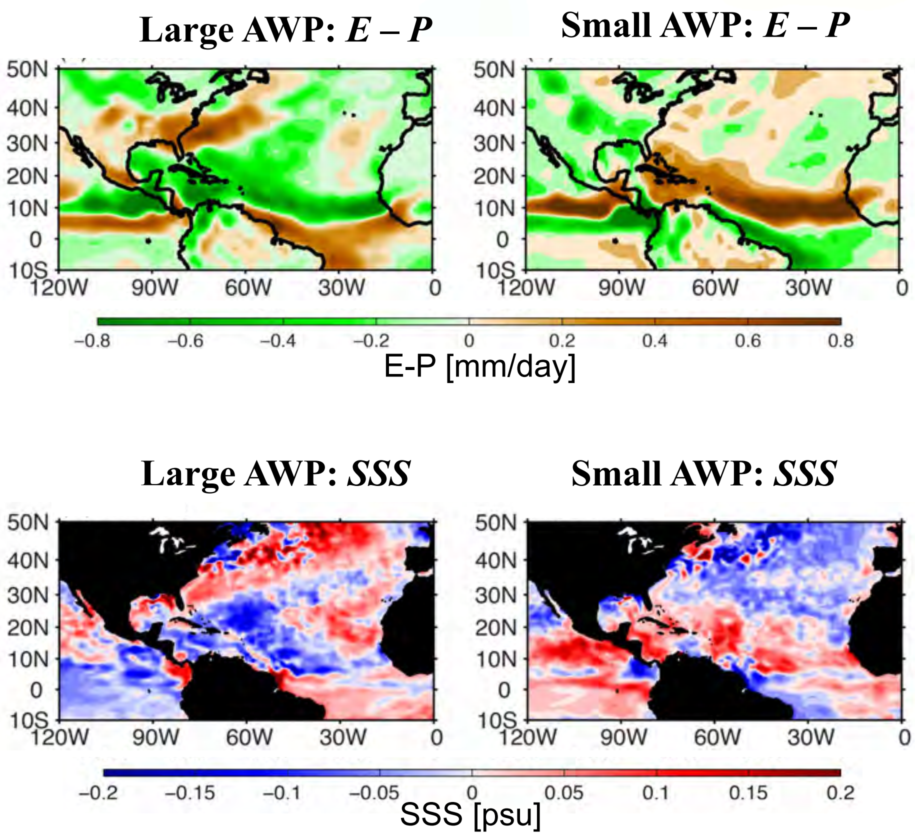
Variation of TNA ocean temperature as a fingerprint for the AMOC



- AMO warm (cold) phase: warm (cold) SST over the entire North Atlantic, in observations and most CMIP5 models.
- However, it is also associated with subsurface cooling (warming) in the TNA.
- This is because the warm phase of the AMO corresponds to a strengthening of the AMOC, and a cold phase corresponds to a weakening of the AMOC.
- The out-of-phase relationship between TNA surface and subsurface temperature occurs only on multidecadal timescale (not on interannual timescale).

Wang et al. (2010), Wang and Zhang (2013)

The Atlantic warm pool (AWP): freshwater, salinity and the AMOC

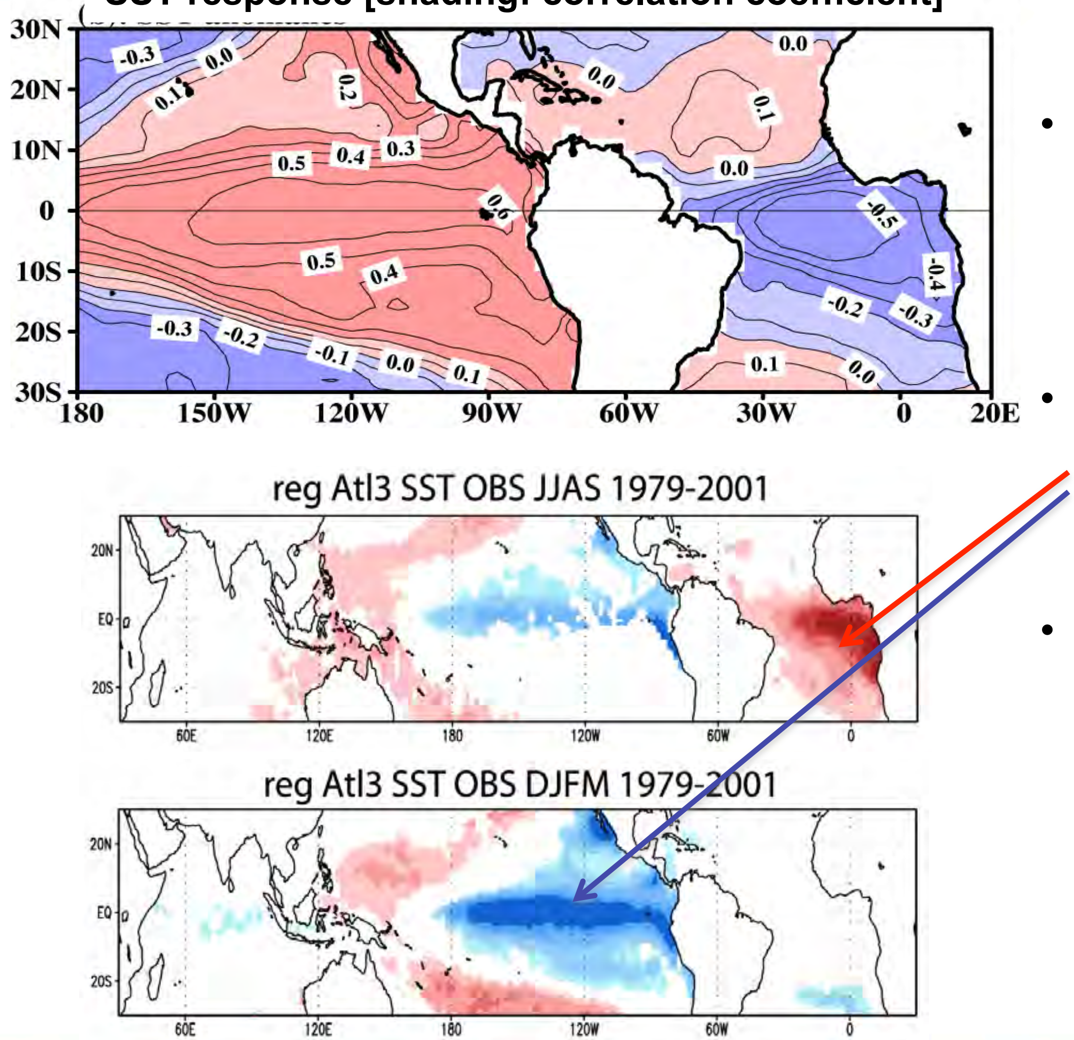


- **AWP**: surface of the Tropical North Atlantic with SST>28.5ºC.
- A large (small) AWP is associated with local freshwater gain (loss) to the ocean
- Both of these induce a local low (high) sea surface salinity (SSS).
- The AWP-induced freshwater flux and salinity anomalies are advected northward to the deep-water formation region and thus affects the strength of the AMOC.
- Thus, AWP variability plays a negative feedback role that acts to recover the AMOC after it is weakened or shut down. This was confirmed by model experiments performed at AOML.

Wang et al. (2013); Zhang et al. (2014)

Tropical Atlantic SST affecting the Pacific and Indian Oceans

SST response [shading: correlation coefficient]



- Both observations and model experiments show that SST anomalies in the equatorial Atlantic can remotely affect the tropical Pacific and Indian Oceans.
- A warm (cold) equatorial Atlantic in summer can help develop a Pacific La Niña (El Niño) condition in the next spring.
- A warm (cold) equatorial Atlantic also weakens (strengthens) the Indian monsoon circulation and increases (decreases) SST in the western Indian Ocean.

Wang et al. (2009)

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Conclusions

- Work at AOML has helped us better understand Tropical Atlantic climate fluctuations and their connections to broader-scale variability. We partner regularly with PMEL, NOAA/NESDIS, Univ. Miami, and many other national and international institutes and organizations.
- Ocean and atmosphere observations are transmitted in near-real time to improve weather forecasting and ocean state estimation efforts for NOAA/NWS and other agencies worldwide.
- Sustained ocean observations (PIRATA, drifters, XBTs, Argo, etc.) are critical to continue improving our understanding of tropical Atlantic climate variability, reduce biases in coupled models, allow seasonal climate forecasts of the region, and anticipate regional impacts of global warming.
- Studies combining observations and models have leveraged the strengths of both, and will become increasingly valuable as the observation record lengthens and the models improve.

Climate and the Tropical Atlantic: the future

- Continue to investigate the causes of climate fluctuations and extreme climate events, and their impacts both locally and globally
- Explore intraseasonal to seasonal surface salinity variability and its impacts on the subtropical salinity maximum and the AMOC
- Collect and analyze new observations, such as upper ocean velocity shear, to better understand process affecting Tropical Atlantic climate variations
- ***Vision for the future***: over the next decade, advances in understanding both the atmospheric and oceanic causes of biases in coupled models will allow us to improve these models and will permit the first skillful seasonal forecasts of Atlantic climate variations. These may improve forecasts elsewhere, such as for the intensity of ENSO events. We will also learn how the modes of variability will change in a warming world, and what the impacts will be on rainfall and drought patterns and the intensity of Atlantic hurricane seasons . As the coupled models grow in their realism, we will more confidently use them to test hypotheses, and better understand observations of dramatic events and their impacts.

Thank you very much!

Questions?






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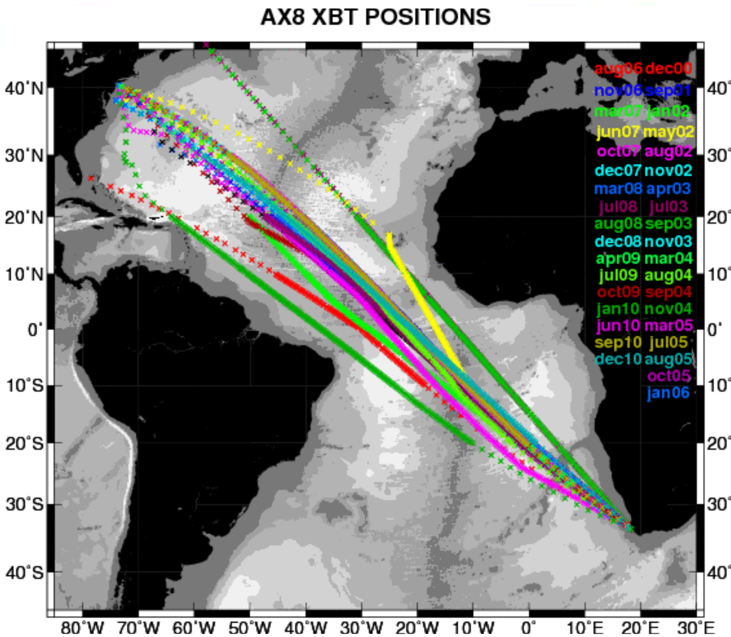
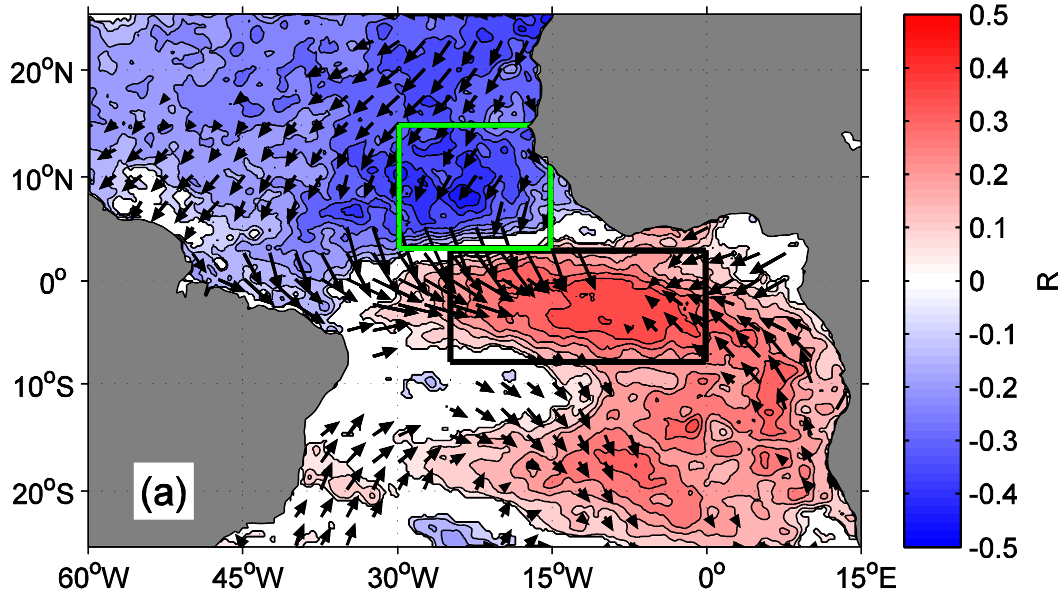
SUPPLEMENTARY SLIDES

Variations of the North Equatorial Undercurrent (NEUC)

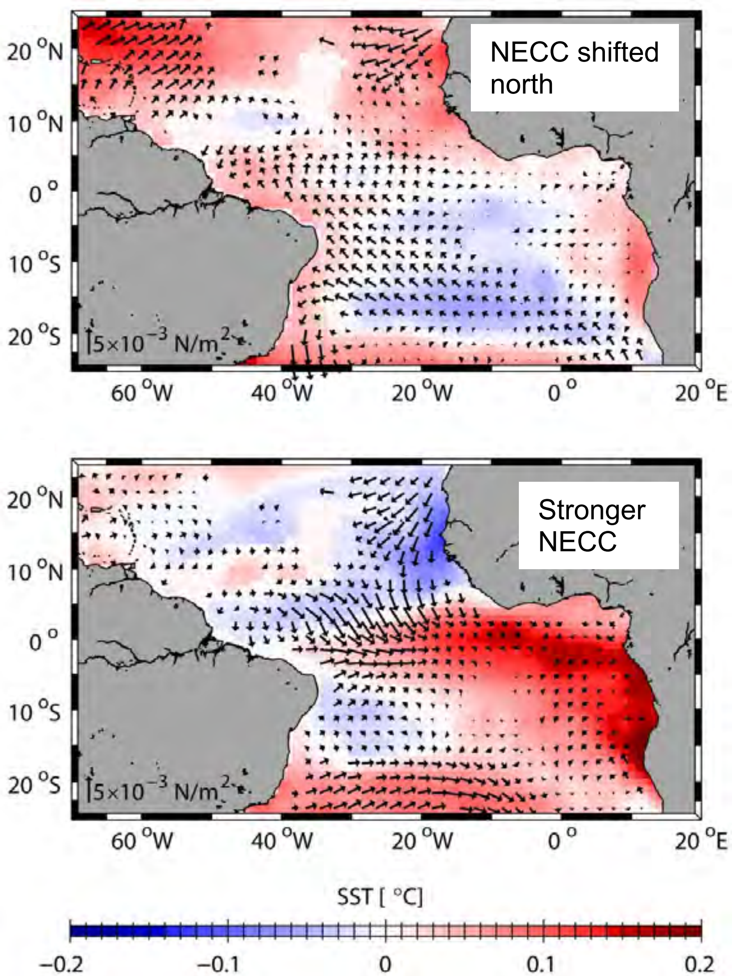


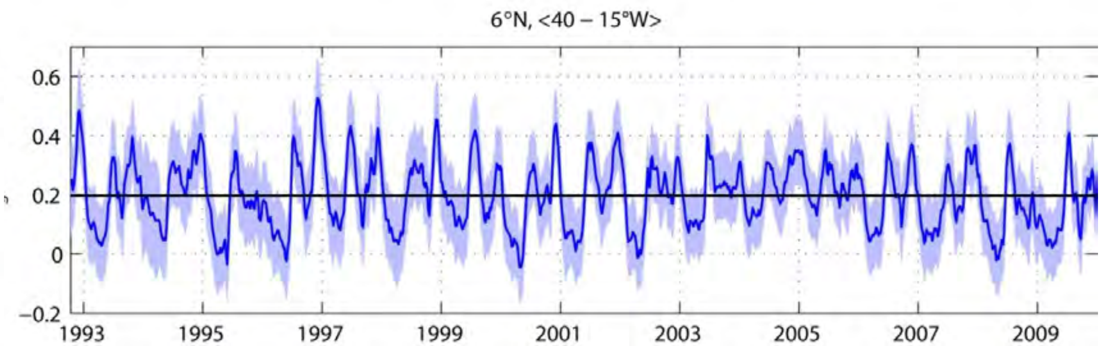


- Transport variations of the subsurface NEUC calculated from XBT, Argo and altimetry observations.
- Decreased NEUC transport correlated with warming in the Gulf of Guinea, cooling in the equatorial and southeastern Atlantic, and strengthening of the southern Trades.
- These transport anomalies could affect the evolution of climate fluctuations.

Goes et al. (2013)

Variations of the North Equatorial Countercurrent (NECC)





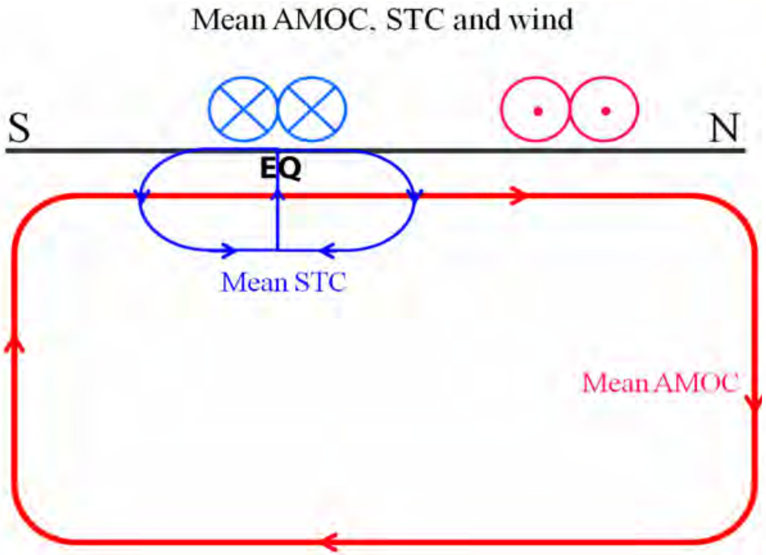
Variations in the NECC derived from drifters, altimetry and wind. CEOF analysis reveals Rossby wave characteristics of anomalies driven by wind events in the northeast TA.

Positive meridional mode: NECC shifts north
Negative zonal mode: NECC strengthens

Supports a link between the meridional and zonal climate modes.

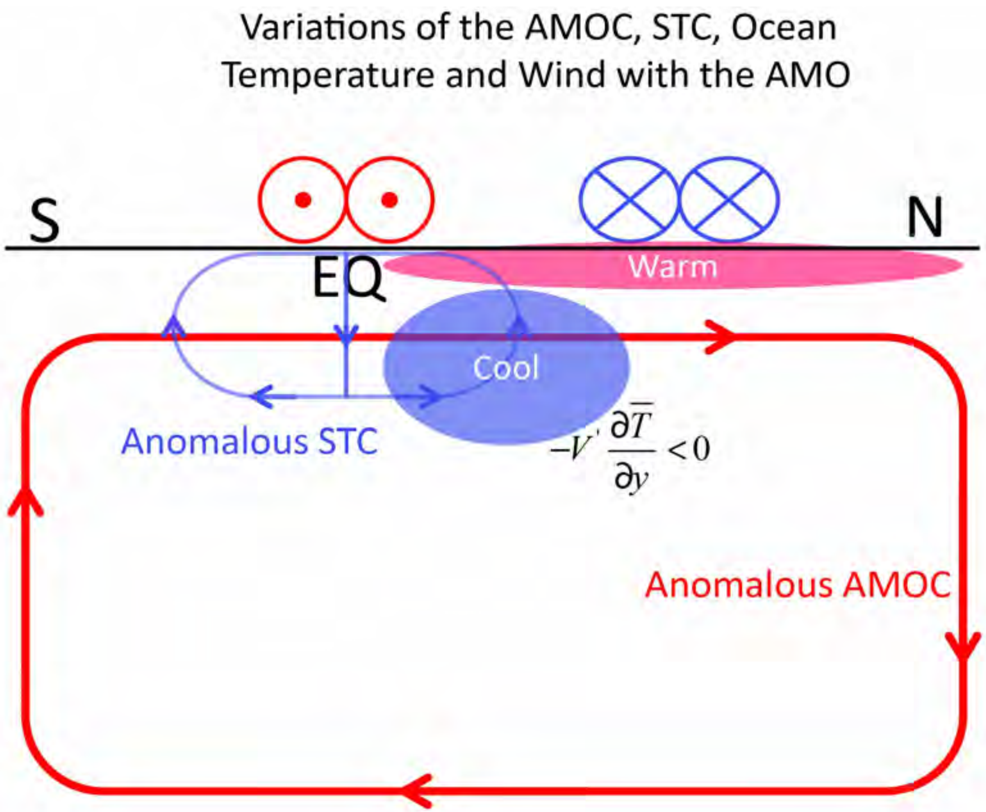
Hormann et al. (2012)

TNA subsurface cooling during the AMO warm phase: importance of the AMOC



Mean States

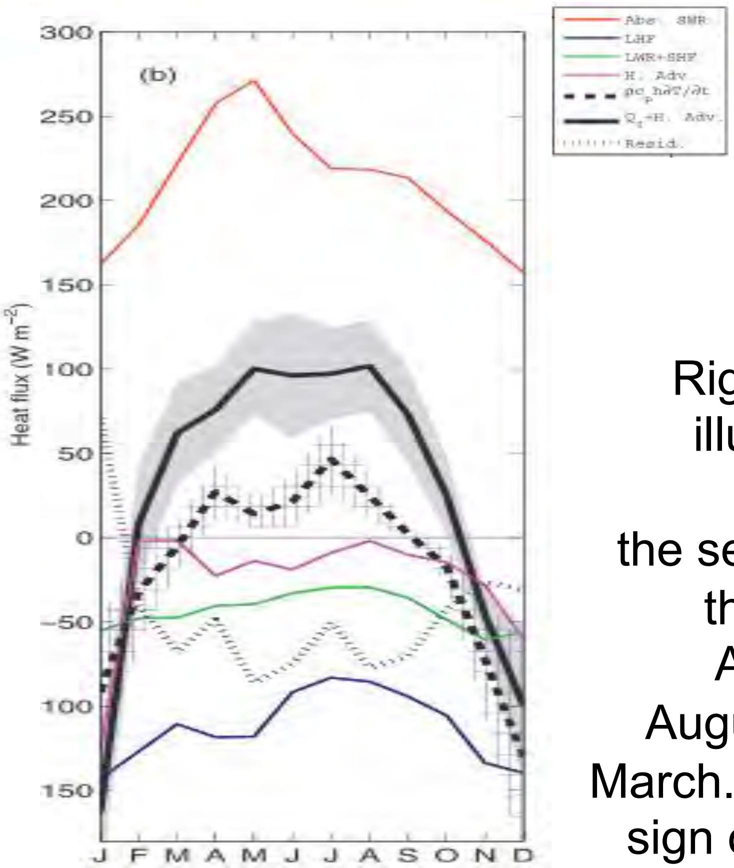
Variations associated with AMO warm phase



The opposite is true during the cold phase of the AMO

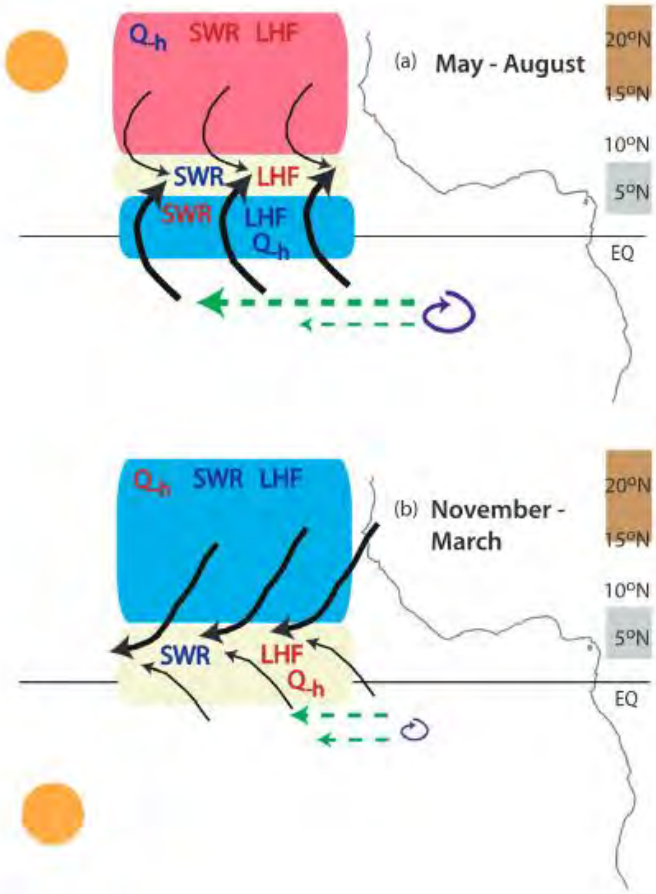
Wang and Zhang (2013)

Heat and salt budgets



Left: Terms in the mixed layer heat at the 20.5N, 23W PIRATA mooring.

Right: Schematic diagram illustrating the processes driving
the seasonal cycle of SST in the northeastern tropical Atlantic during (a) May–August and (b) November–March. Shading indicates the sign of the rate of change of SST: strong warming (red), strong cooling (blue), and weaker warming or cooling (yellow)



Foltz et al. (2013)