# Seasonal Cycle and Interannual Variability: Implications for Models

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1. Seasonal cycle
2. Interannual variability, zonal mode
3. Impact of zonal mode on ENSO
4. Sensitivity of interannual variability to model formulation

Ding, H., N. S. Keenlyside, and M. Latif (2009), (2010), (2011)

Wahl, S., M. Latif, and N. S. Keenlyside (2009)

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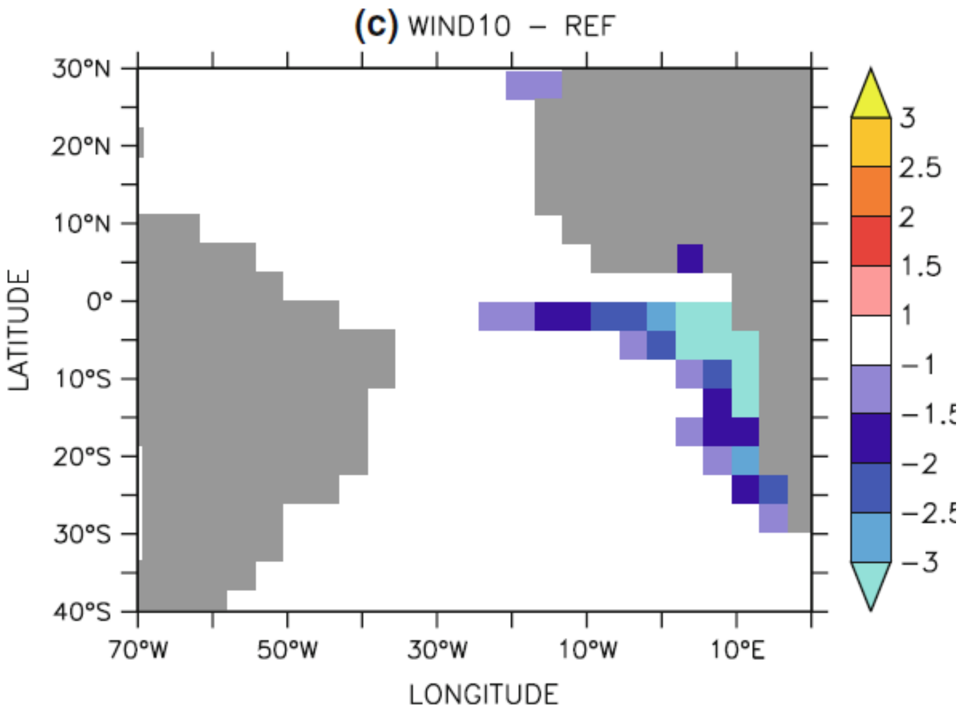
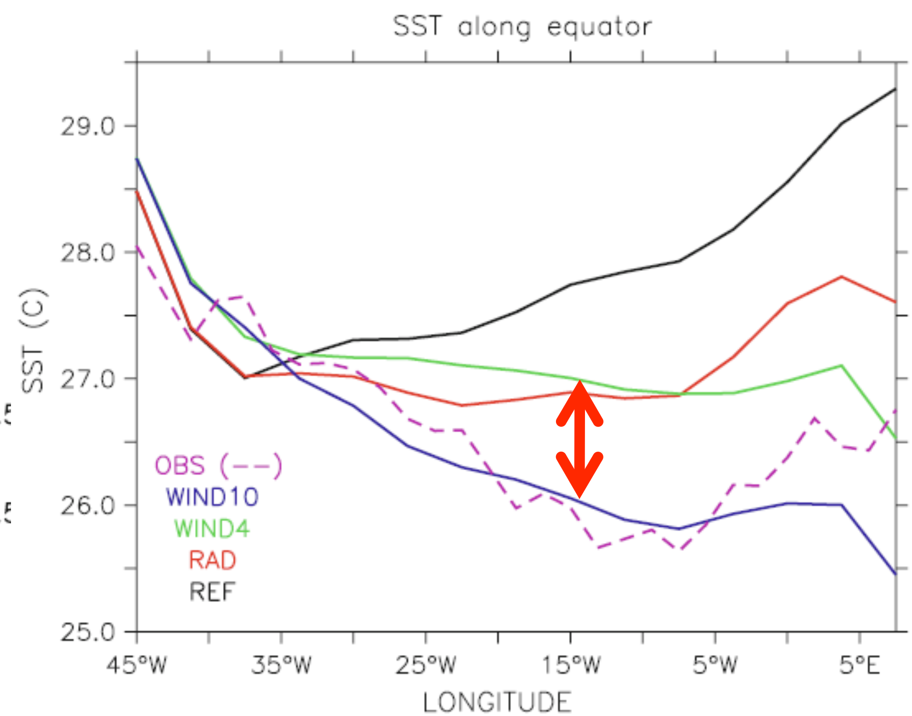
# Effect of prescribing the wind stress in the region 10N-10S and 4N-4S on the warm bias in the Kiel Climate Model




**Correction of off-equatorial wind stress helps to improve the equatorial SST gradient**

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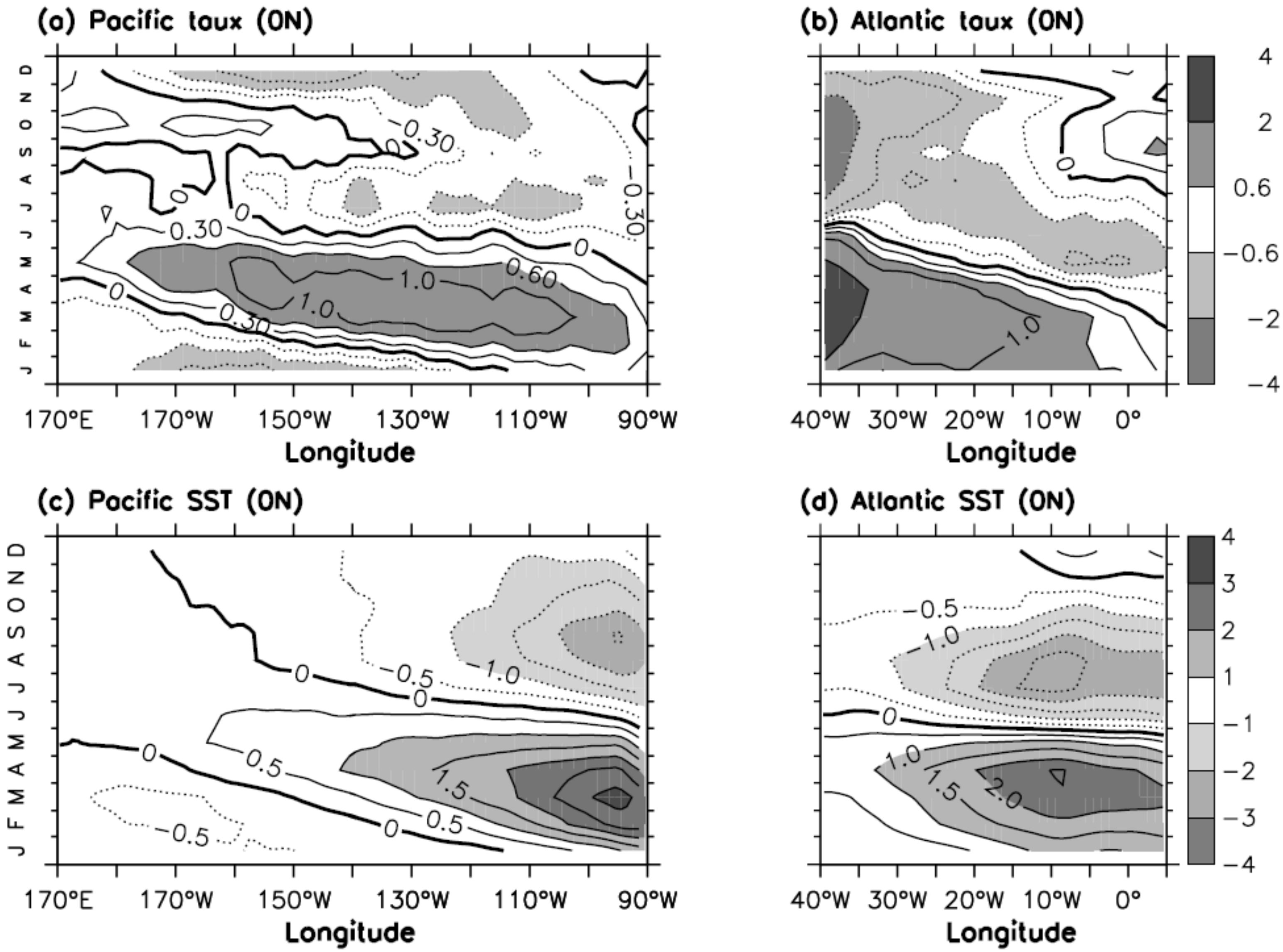
# 1. Seasonal cycle

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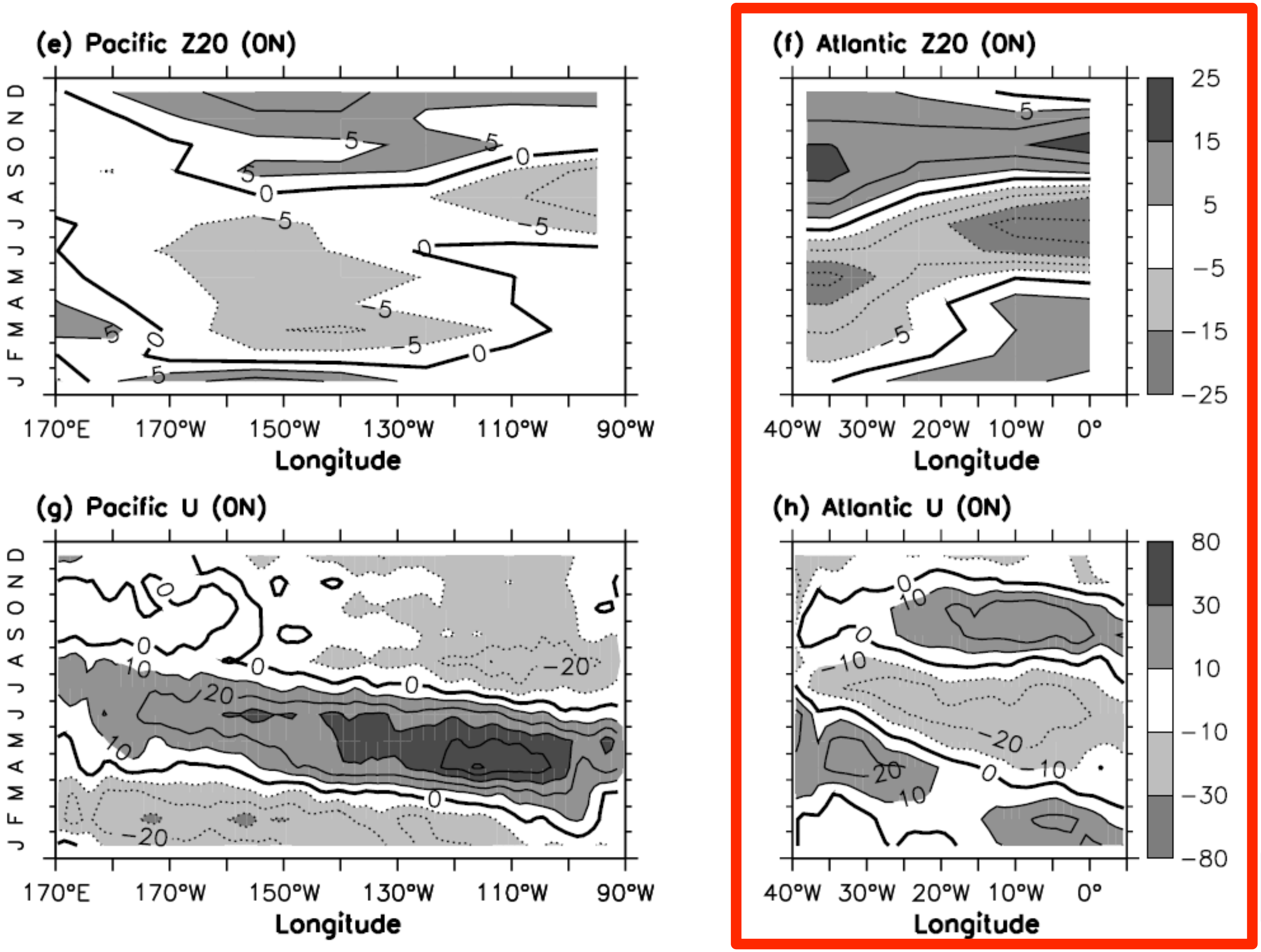
# There is a strong thermocline depth signal and semi-annual cycle in the Atlantic

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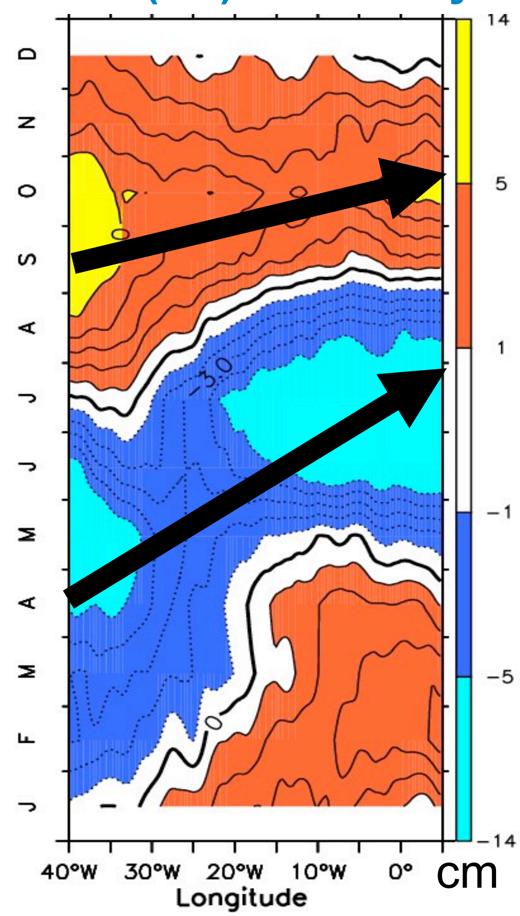
# What is the role of equatorial waves?

- **Regarding the seasonal variations in SSH, there exist two "contradicting" views on the role of equatorial waves**
  - **Equatorial waves play an important role (Schouten et al, 2005)**
  - **Propagation from April to July is too slow compared to single Kelvin wave (Bunge and Clarke, 2008)**

**<u>Analysis of SSH 1993-2008</u>**

**H. Ding, N. S. Keenlyside, and M. Latif (2009): Seasonal cycle in the upper equatorial Atlantic Ocean, JGR, Oceans.**

**SSH (0N) - altimetry**

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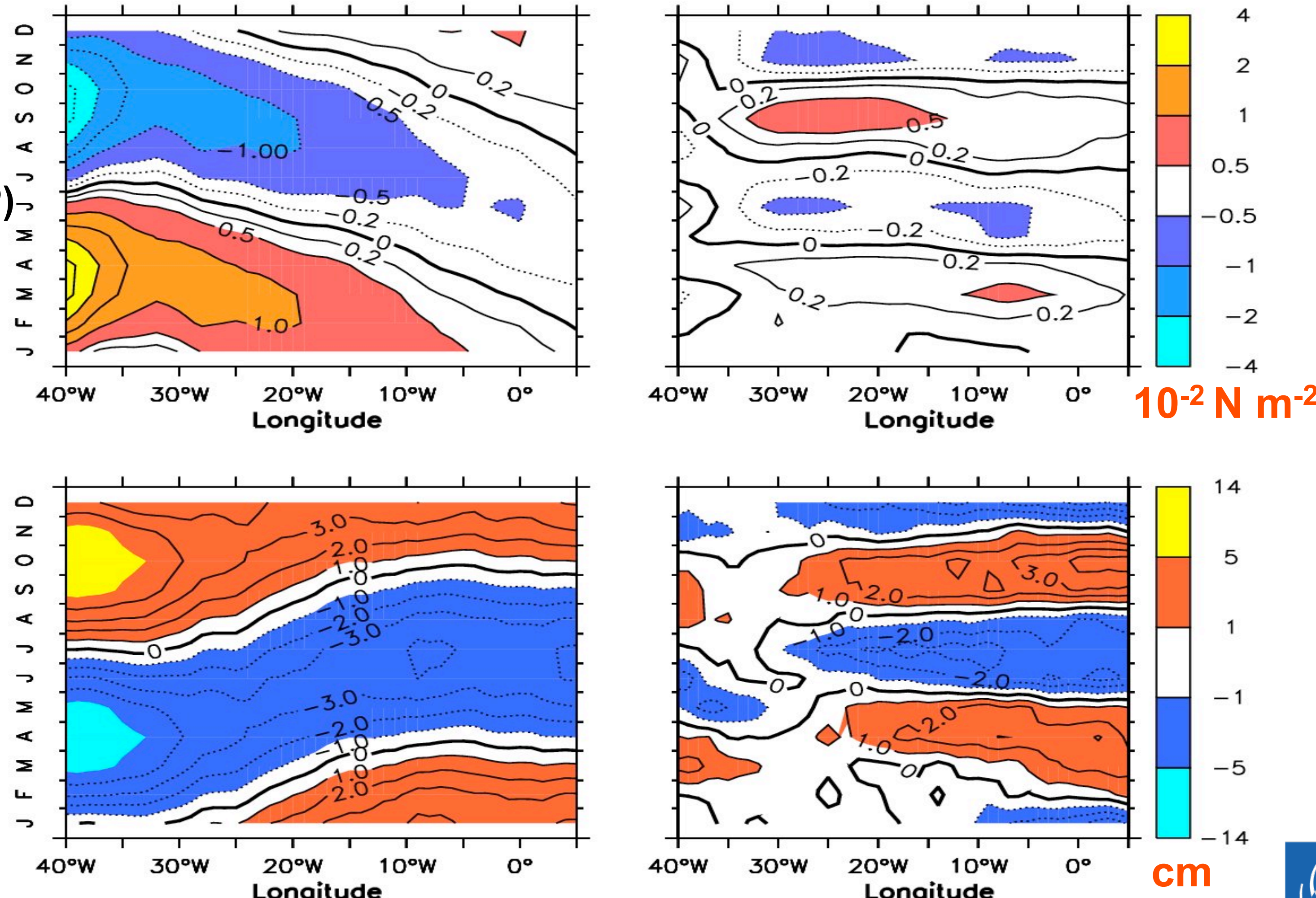
# Zonal wind stress has a weak semi-annual harmonic, but drives a prominent semi-annual harmonic in SSH, why?

**Annual harmonic** | **Semi-annual harmonic**

**Zonal wind stress (NCEP)**

**SSH (atimetry)**

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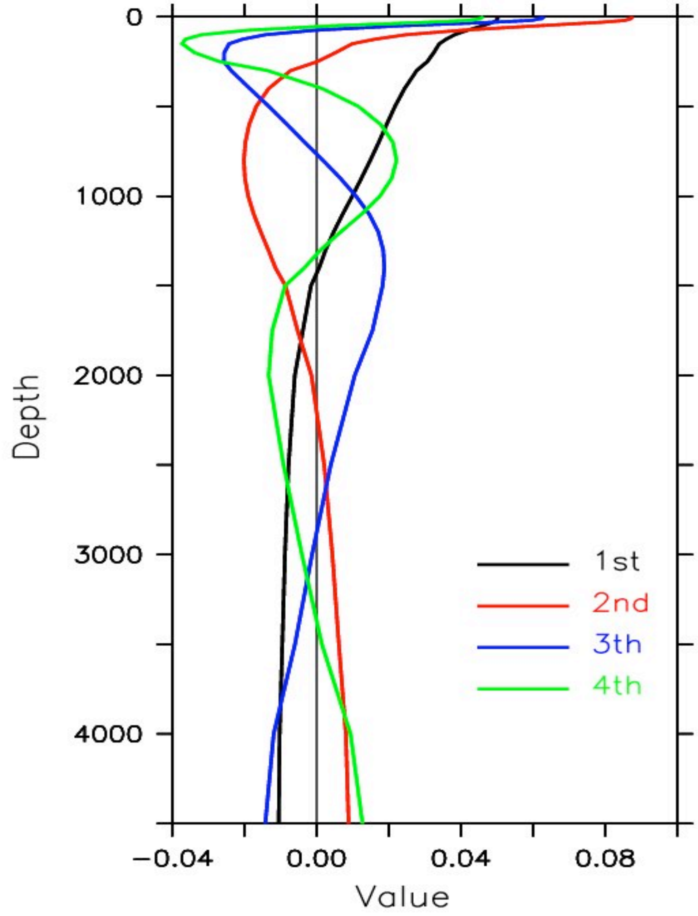
# Linear Equatorial Wave Model

- **Gill and Clarke, 1974**
  - In the vertical direction, the model decomposes the governing equations using the first four gravest baroclinic modes yielding a set of equations for each mode
  - Solving for Kelvin wave and the first meridional mode Rossby wave for each baroclinic mode
  - The model is driven by zonal wind stress (NCEP)

Vertical structure

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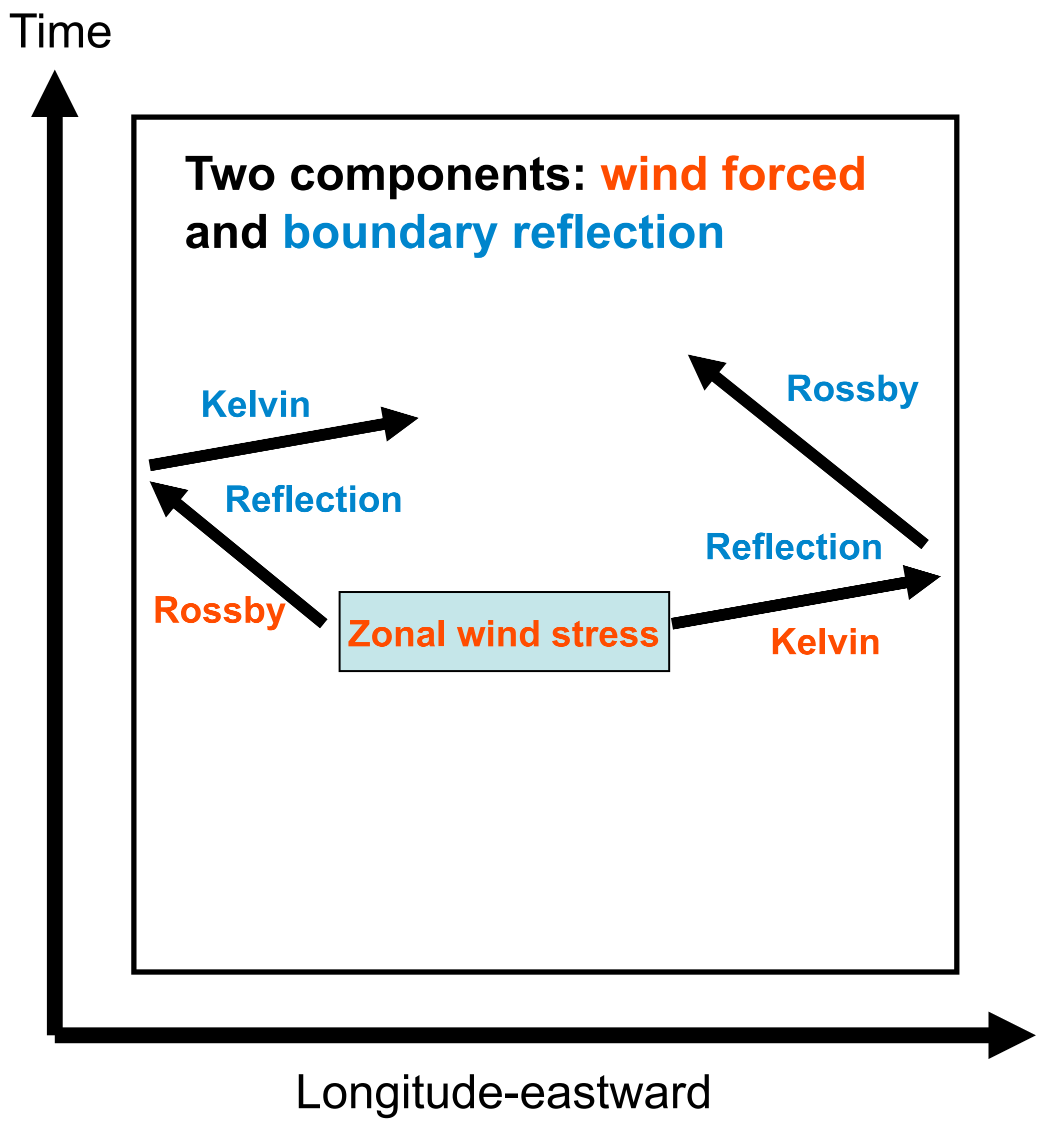
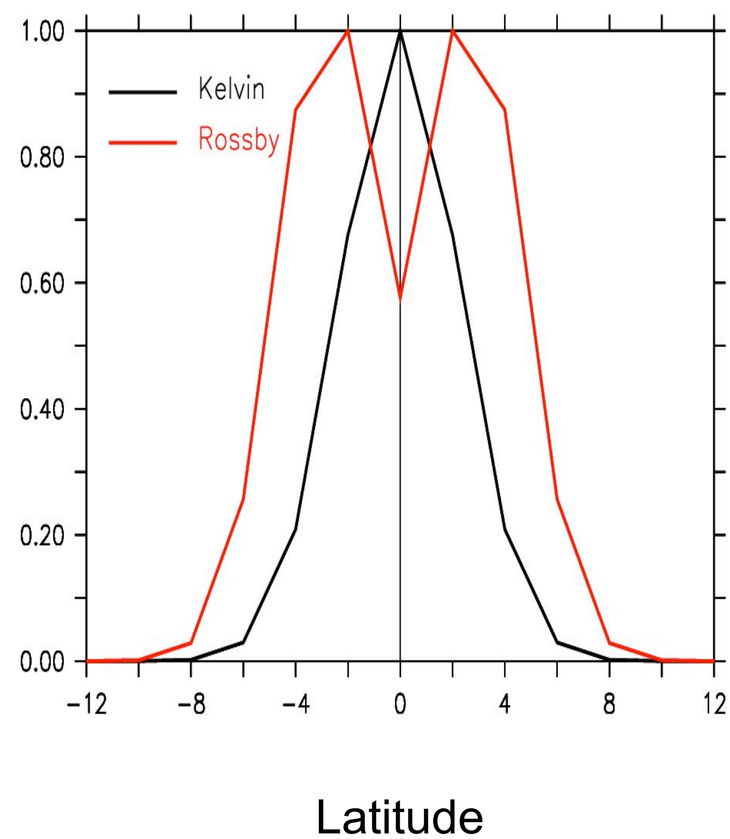
# Equatorial Kelvin and Rossby waves




Meridional structure

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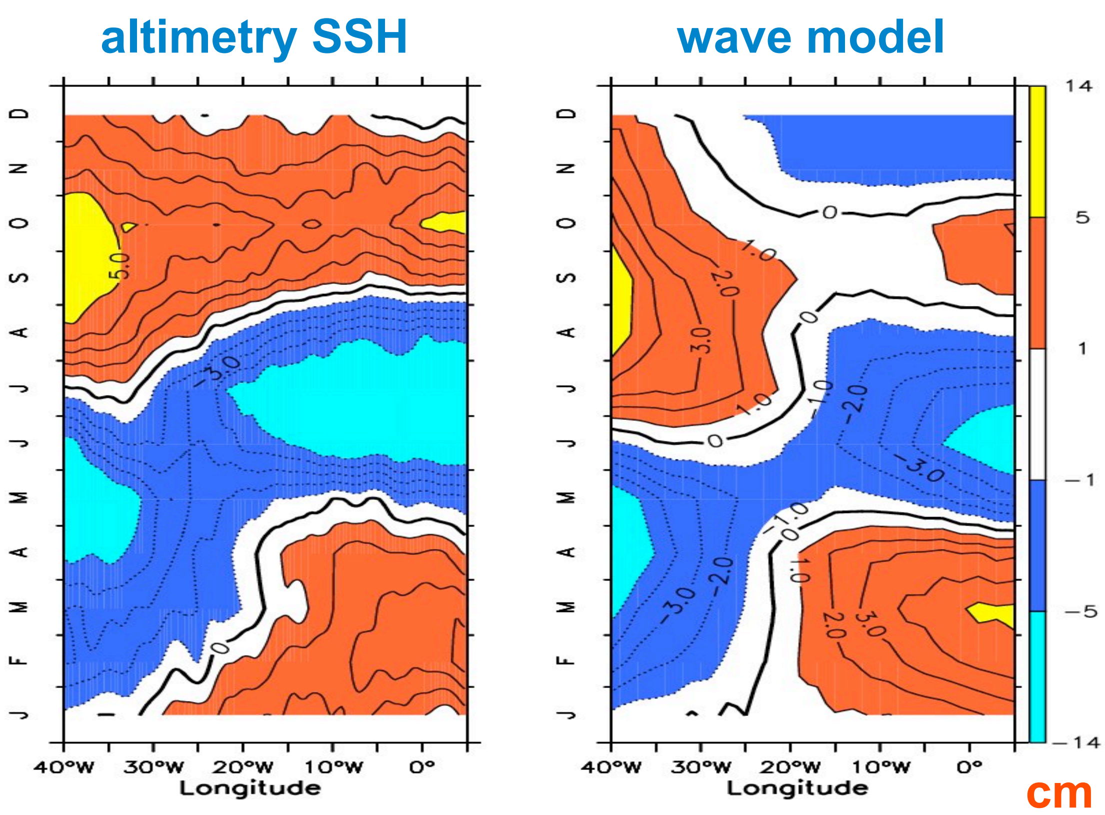
# Sea surface height seasonal cycle at the equator from observations and wave model




**Kelvin and Rossby waves can capture the basic pattern seen in satellite-altimetry sea surface height**

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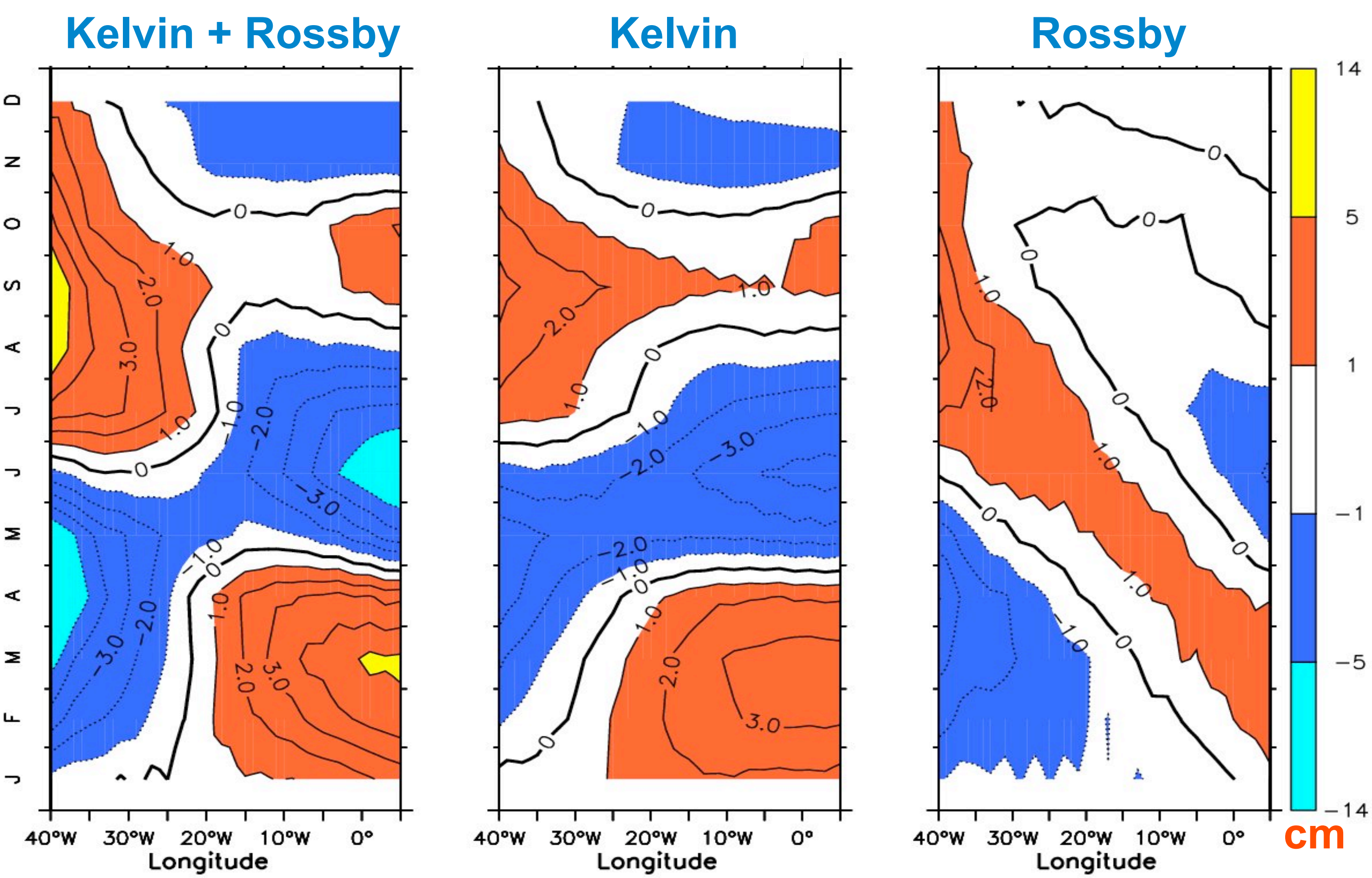
# Kelvin and Rossby wave contributions to SSH in the wave model at the equator

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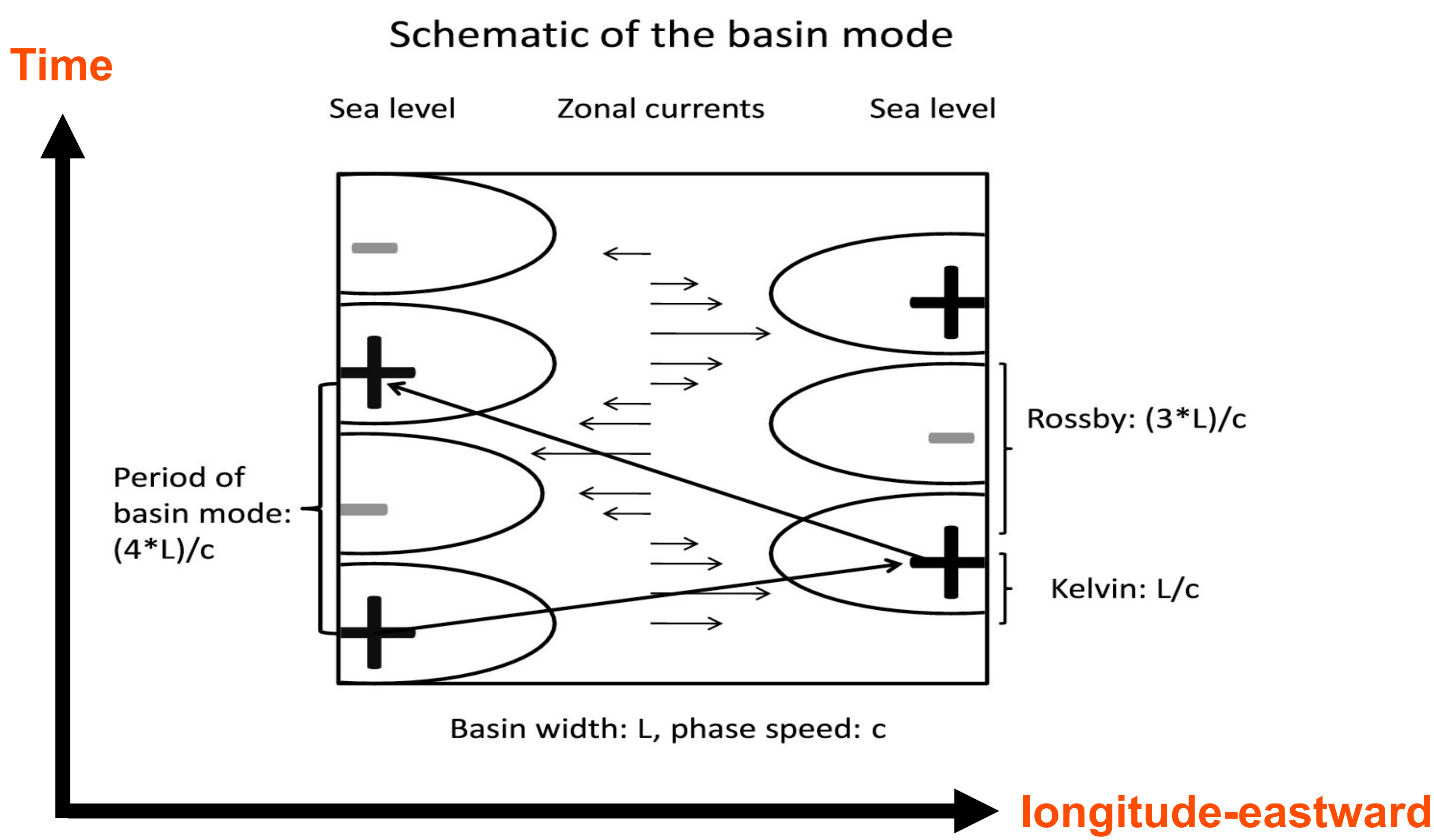
# Resonant basin mode (Cane and Moore, 1981) explains the existence of the semi-annual cycle in SSH




- **Second baroclinic mode is dominant**
- **Its period is close to semi-annual**

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## Summary: Seasonal cycle

**Are equatorial waves important for sea surface height?**

**Yes, Kelvin and Rossby waves explain eastward and westward propagation at and off the Equator, respectively.**

**Zonal wind stress has a weak semi-annual harmonic, but drives a prominent semi-annual harmonic in sea surface height, why?**

**Because the semi-annual harmonic in zonal wind stress excites a resonant oscillation (basin mode).**

**It appears that the dynamics of the seasonal cycle are rather different between the equatorial Pacific (surface layer) and equatorial Atlantic (subsurface)**

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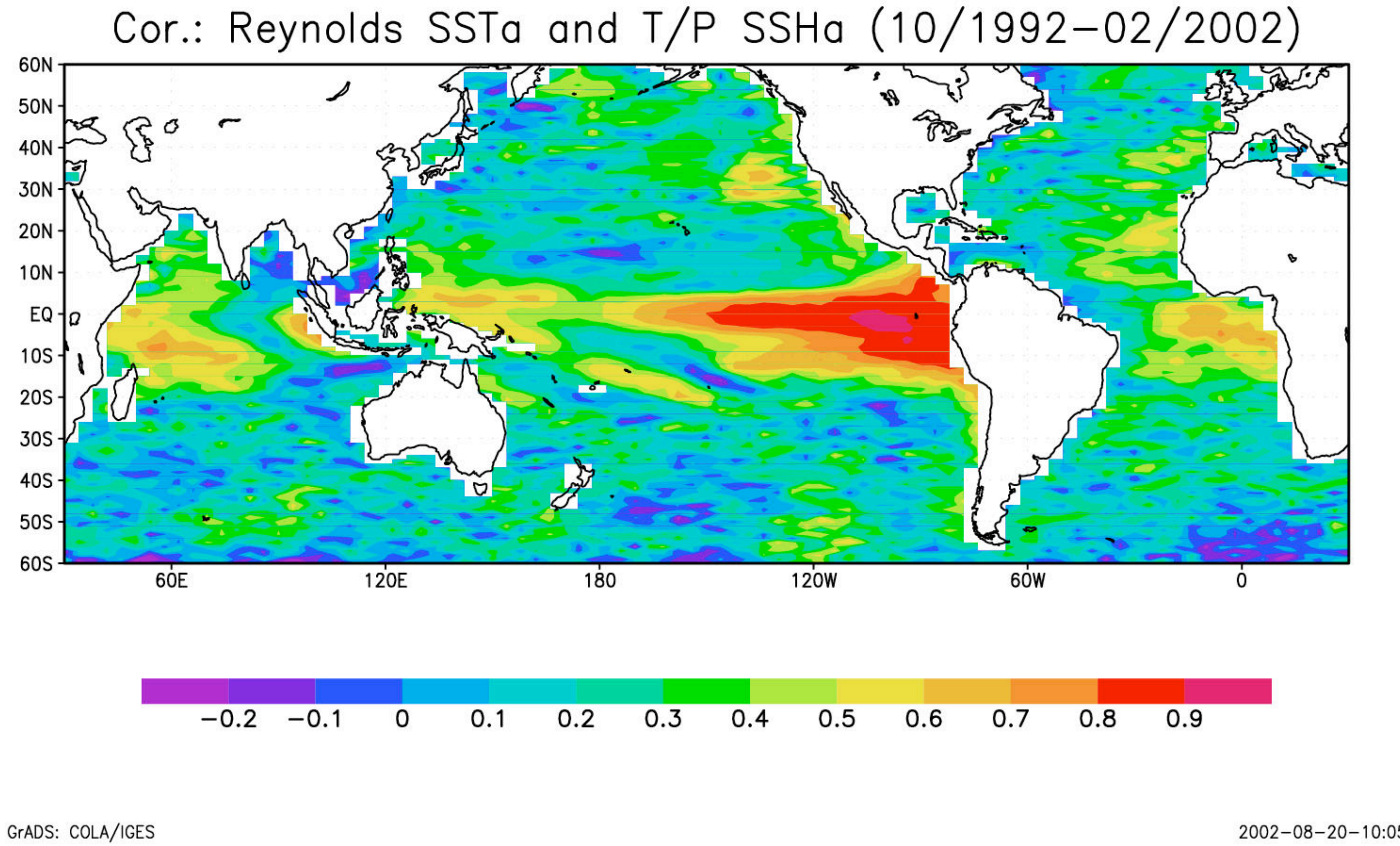
# 2. Interannual variabilty, zonal mode




**Ding, H., N. S. Keenlyside, and M. Latif (2010): Equatorial Atlantic interannual variability: the role of heat content. JGR, Oceans.**

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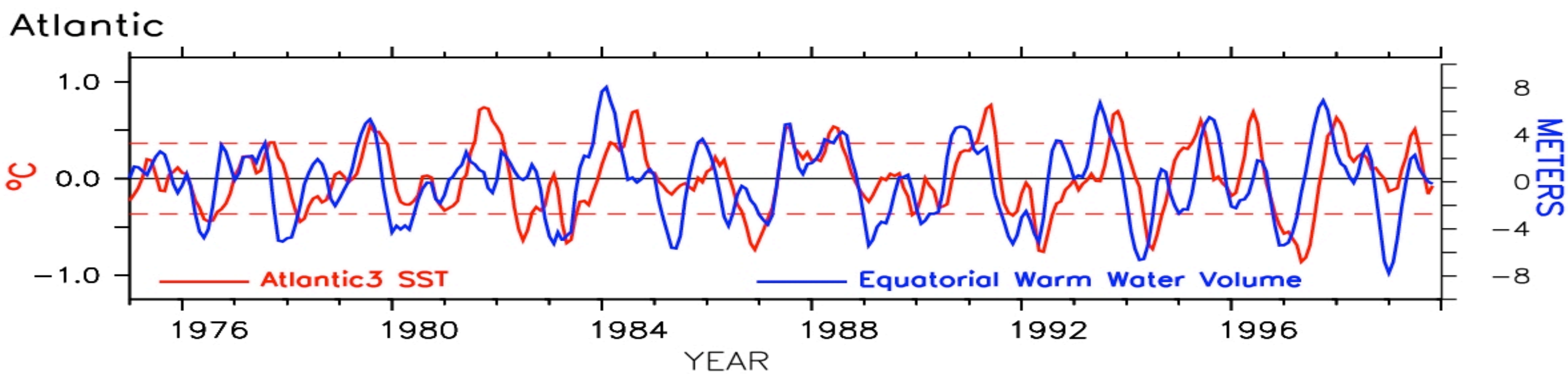
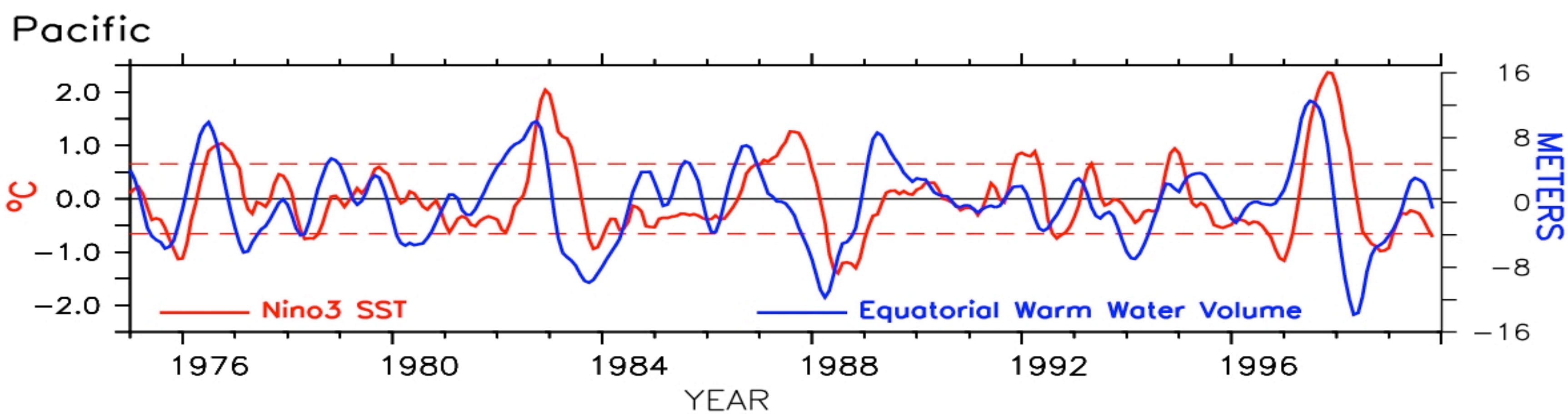
# Anomalous equatorial Atlantic and Pacific heat content and SST anomalies




**NCEP forced OGCM; HadISST 1.1 with 3-120 month filter**

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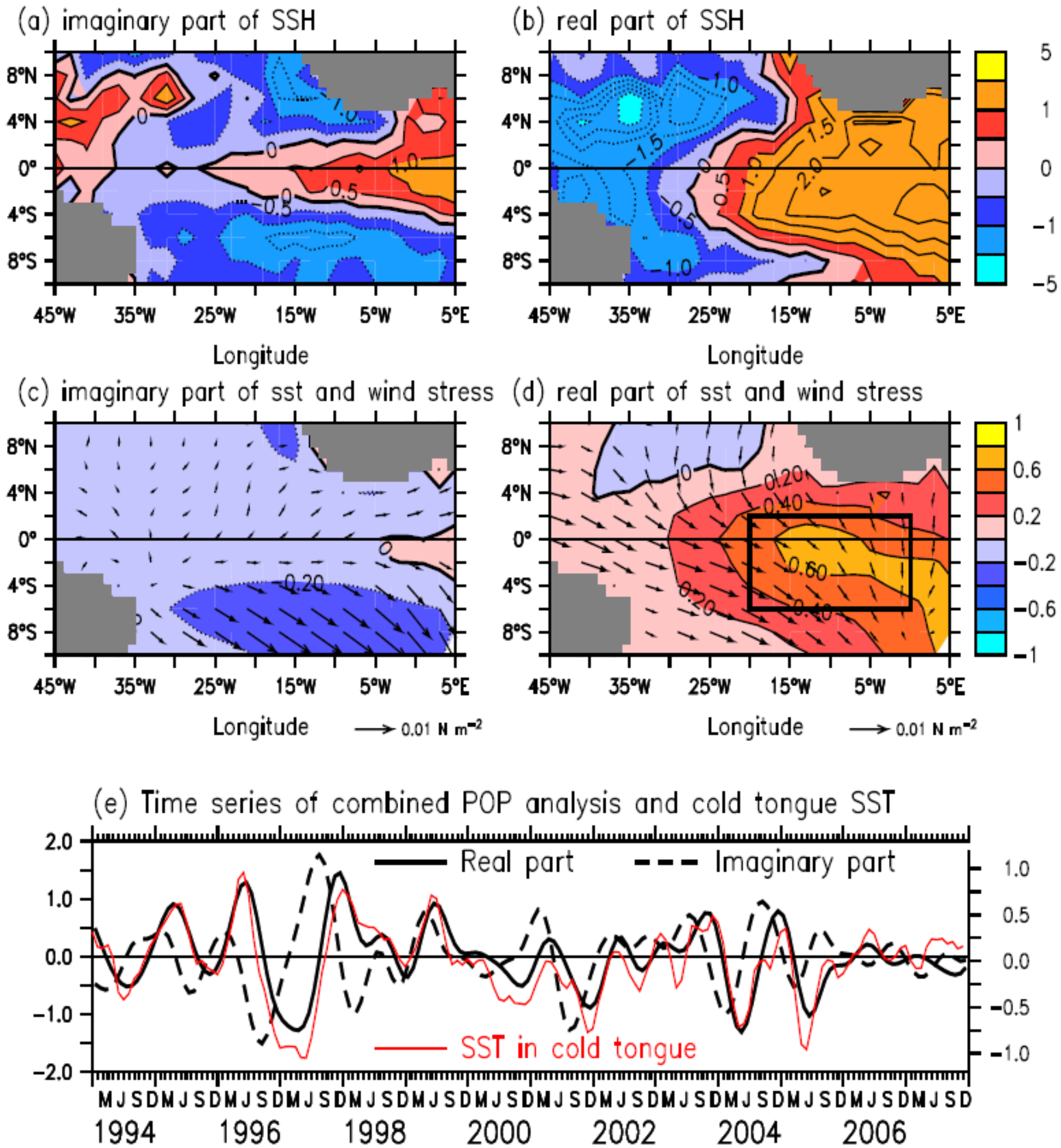
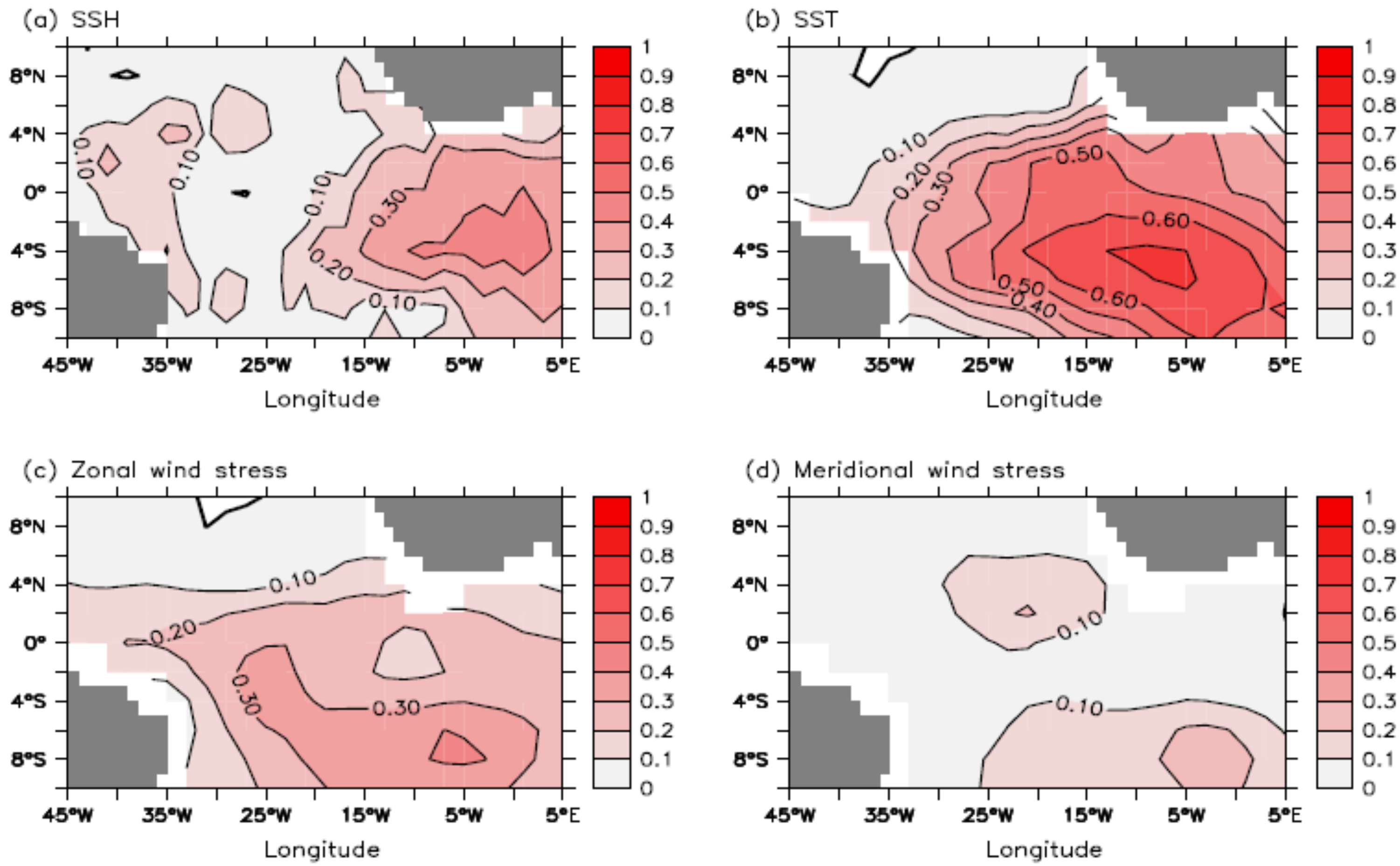
# ENSO-like variability in the equatorial Atlantic from data POP analysis 1993-2008, P = 19 months



# Local explained variances

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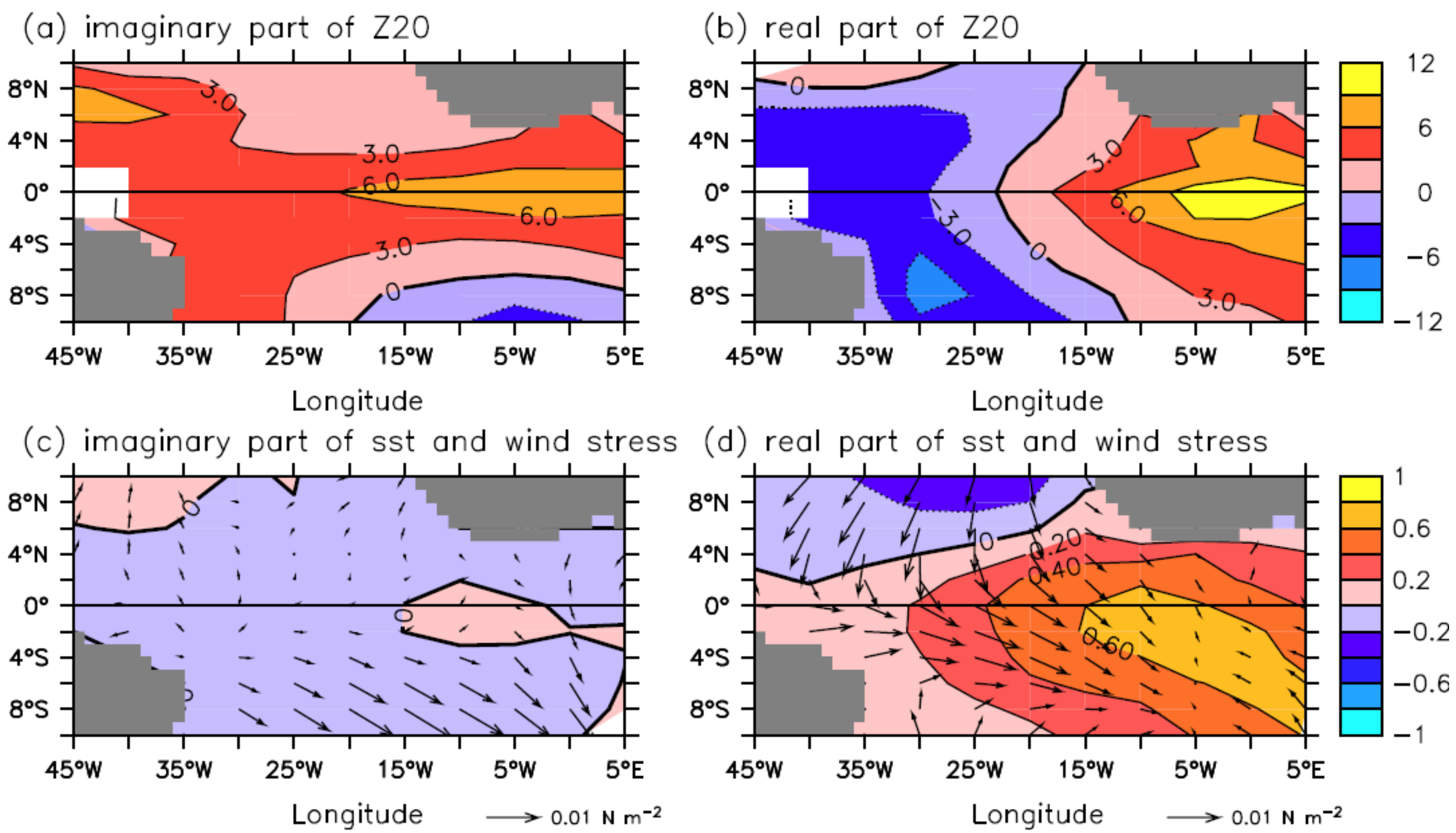
# ENSO-like variability in the equatorial Atlantic from data, but thermocline depth was obtained from a forced ocean model
# POP analysis 1958-2001, P = 30 months

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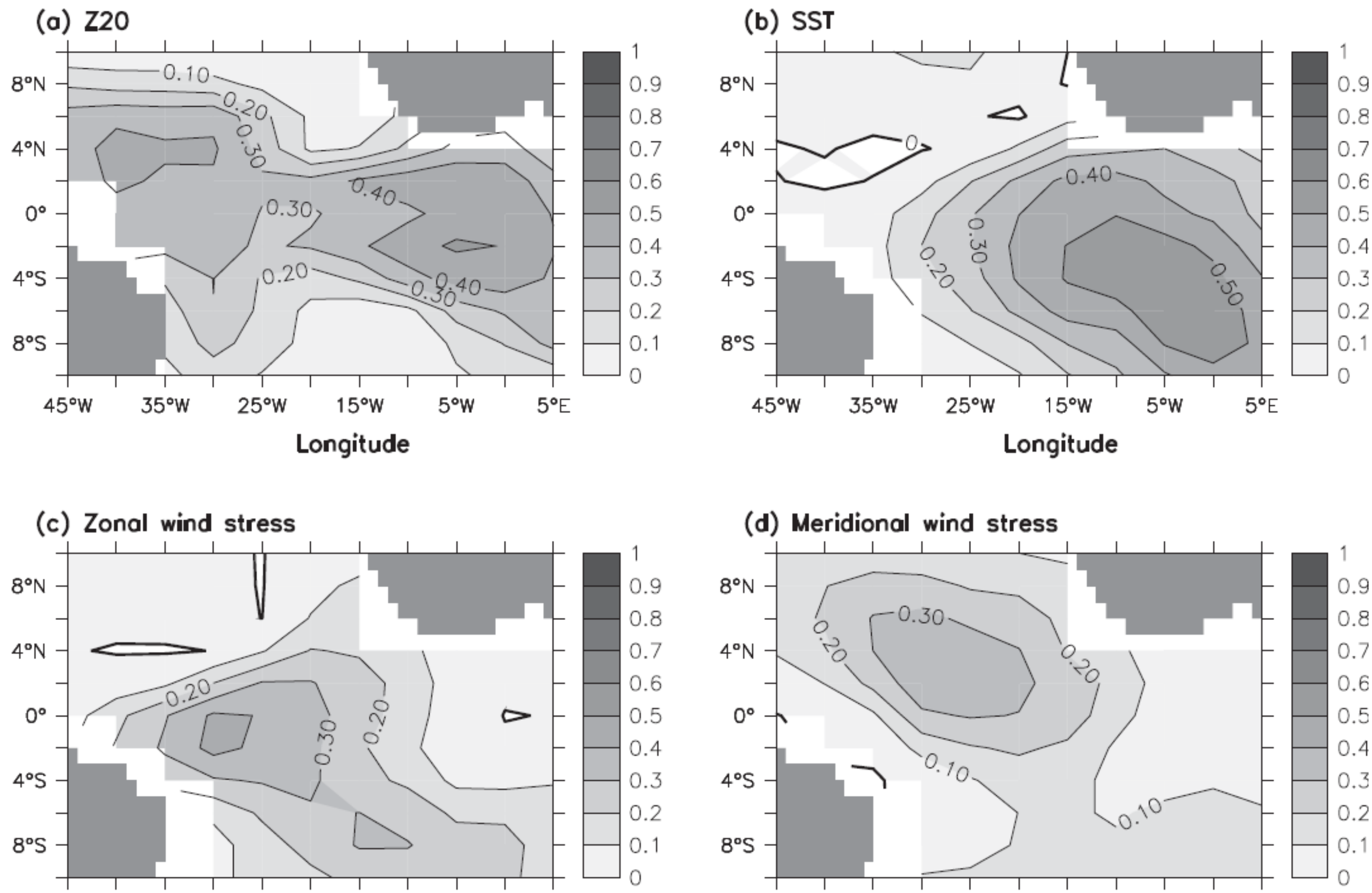
# Local explained variances, Z20 from forced ocean model run

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## Summary: Interannual variability

• POP analysis reveals that the zonal mode is an oscillatory normal-mode of the observed coupled system, obeying the delayed-action/recharge oscillator paradigm for ENSO.

•The zonal mode explains a large amount (>50%) of SST variability in the east.

• Variations in equatorial averaged SSH, a proxy for upper ocean heat content, precede SST anomalies by 4-5 months, a quarter of the period (20-30 months). SST anomalies are stationary and there is no zonal propagation on average.

• Net surface heat flux generally damps SST.

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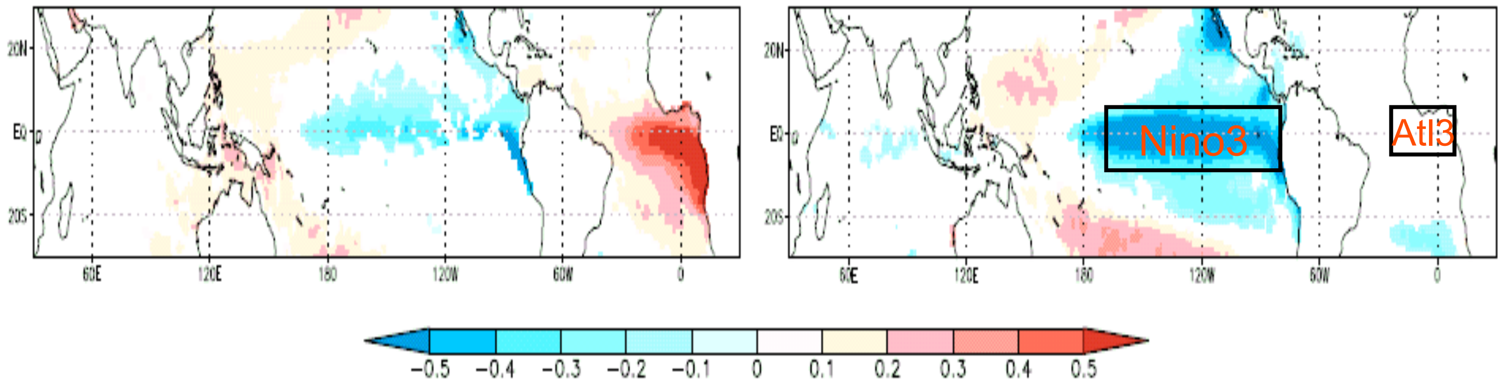
# 3. Impact on ENSO

**Regression of Equatorial Atlantic (Atl3) summer SST on**

**boreal summer SST** | **boreal winter SST**




**Rodriguez-Fonseca et al, 2009**

**Ding, H., N. S. Keenlyside, and M. Latif (2011): Impact of the Equatorial Atlantic on the El Niño Southern Oscillation. J. Climate, subm.**

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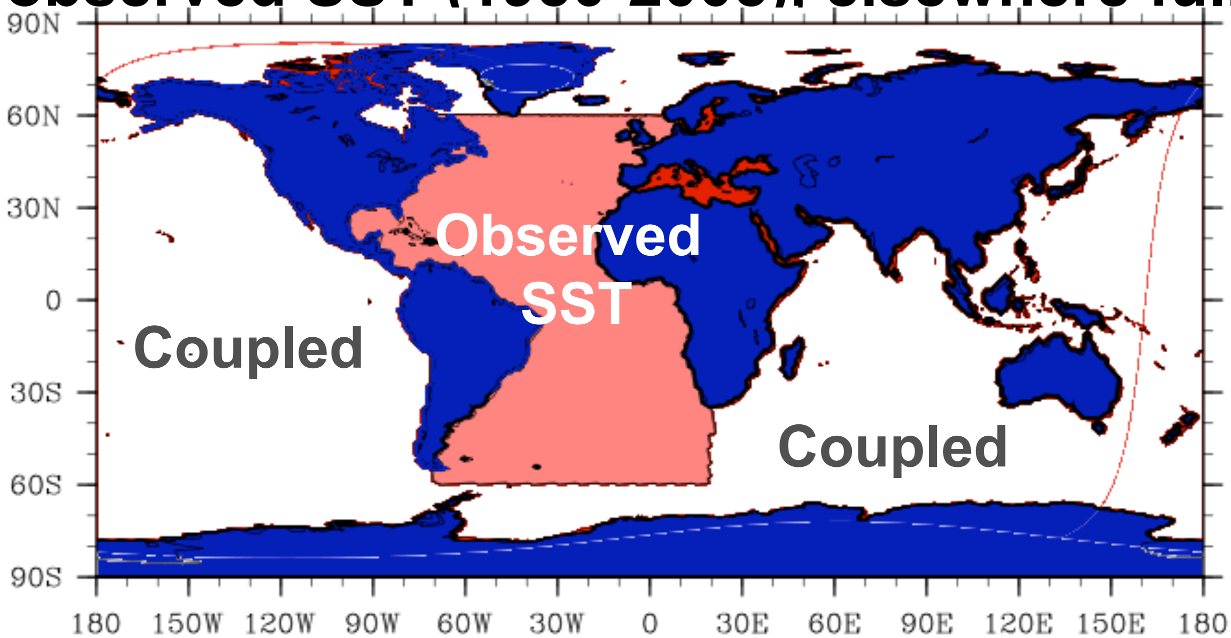
# Model and experiments

- **MPI CGCM (ECHAM5 T63, L31) with MPI-OM (1.5°, L40)**
- **Tropica**
  **l**
  **A**
  **tlantic - observed SST (1950-2005), elsewhere fully coupled**
- **Five ens ean**




**The period from 1970 to 2005 has been analyzed**

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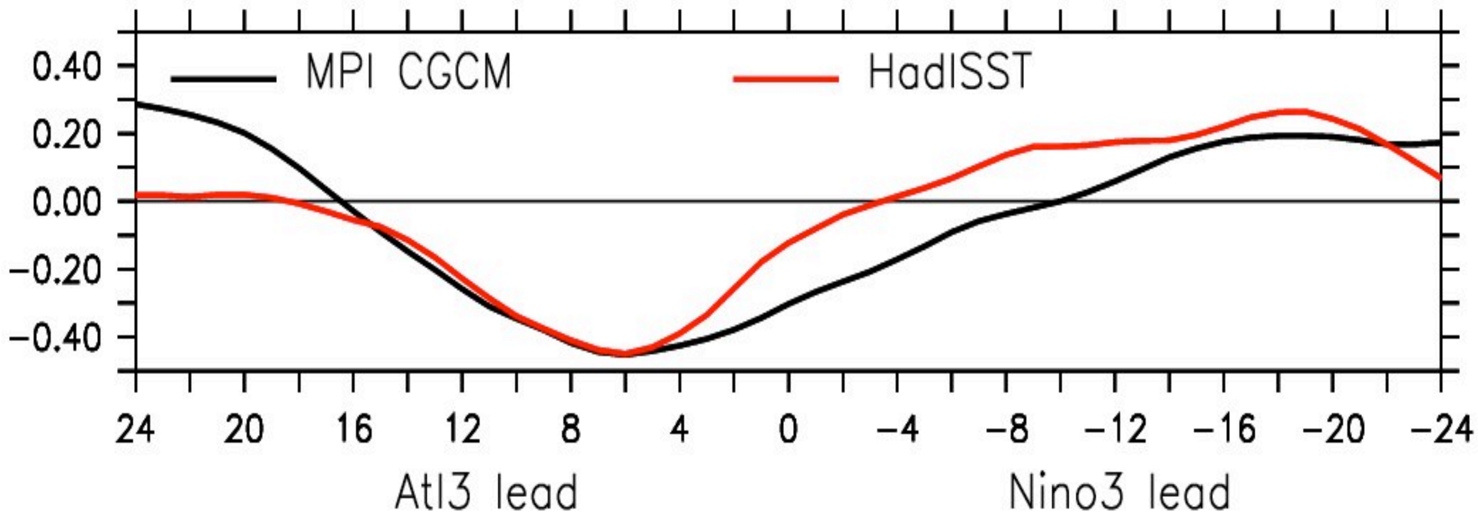
# Cross correlation: Atl3 and Nino3 SST




**Nino3: 150W-90W,5S-5N** **Atl3: 20W-0W,3S-3N**

**Warm SST anomalies in the tropical Atlantic produce cold SST anomalies in the tropical Pacific six months later, vice versa.**

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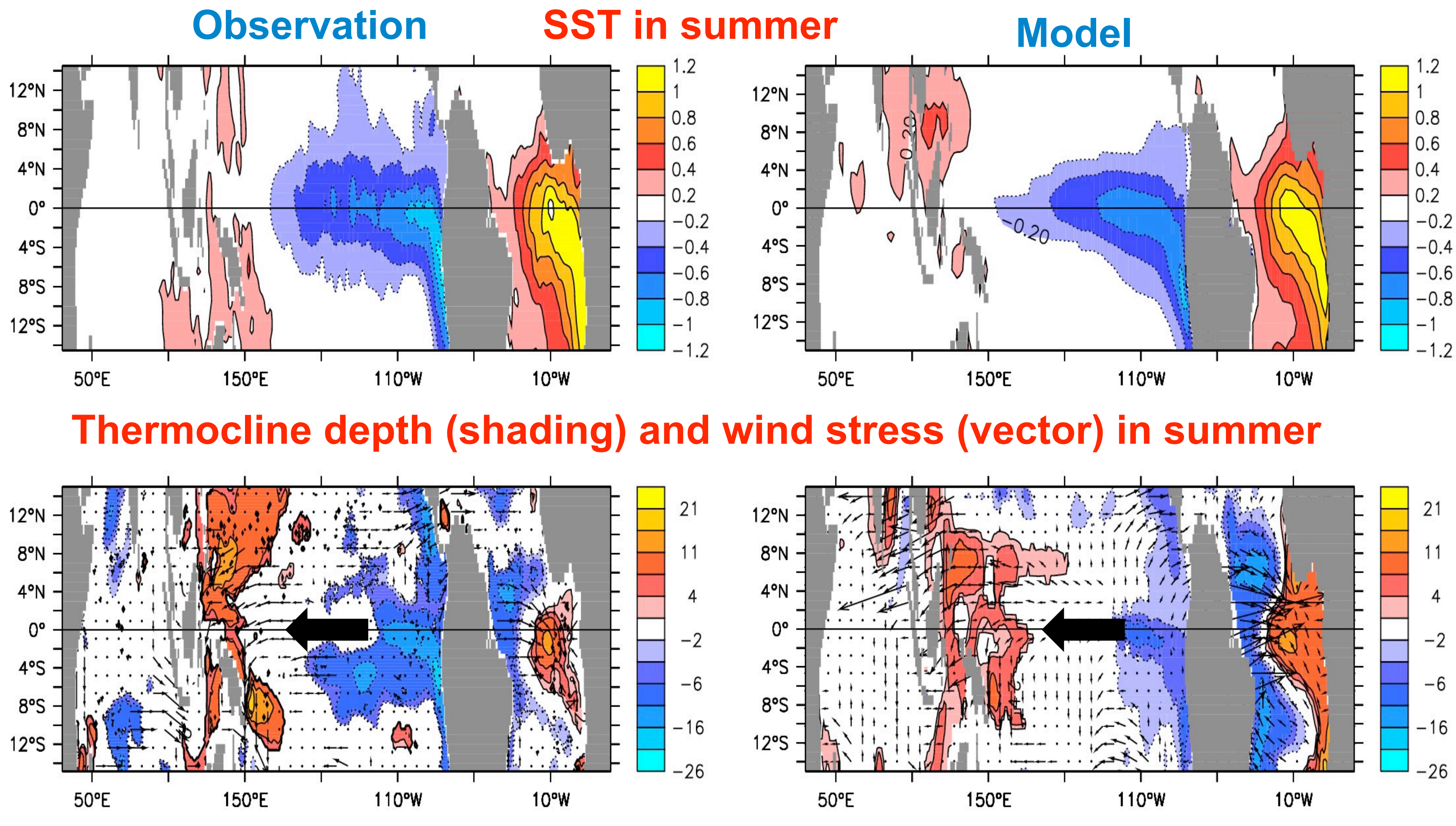
# SST (upper), thermocline depth (lower) and wind stress (lower) associated with tropical Atlantic




All quantities are regressed onto summer Atl3 SST

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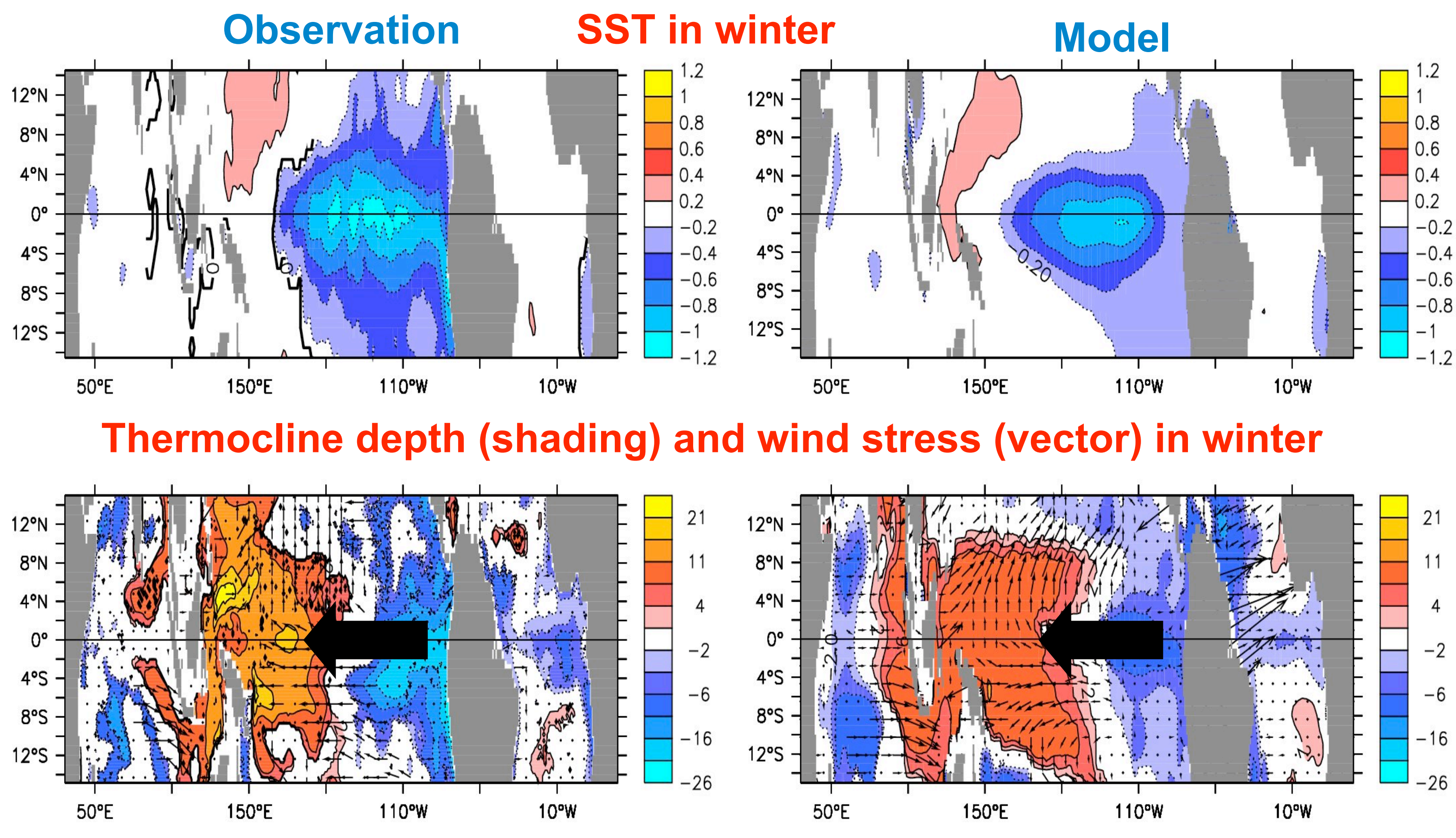
# SST (upper), thermocline depth (lower) and wind stress (lower) associated with tropical Atlantic




All quantities are regressed onto summer Atl3 SST

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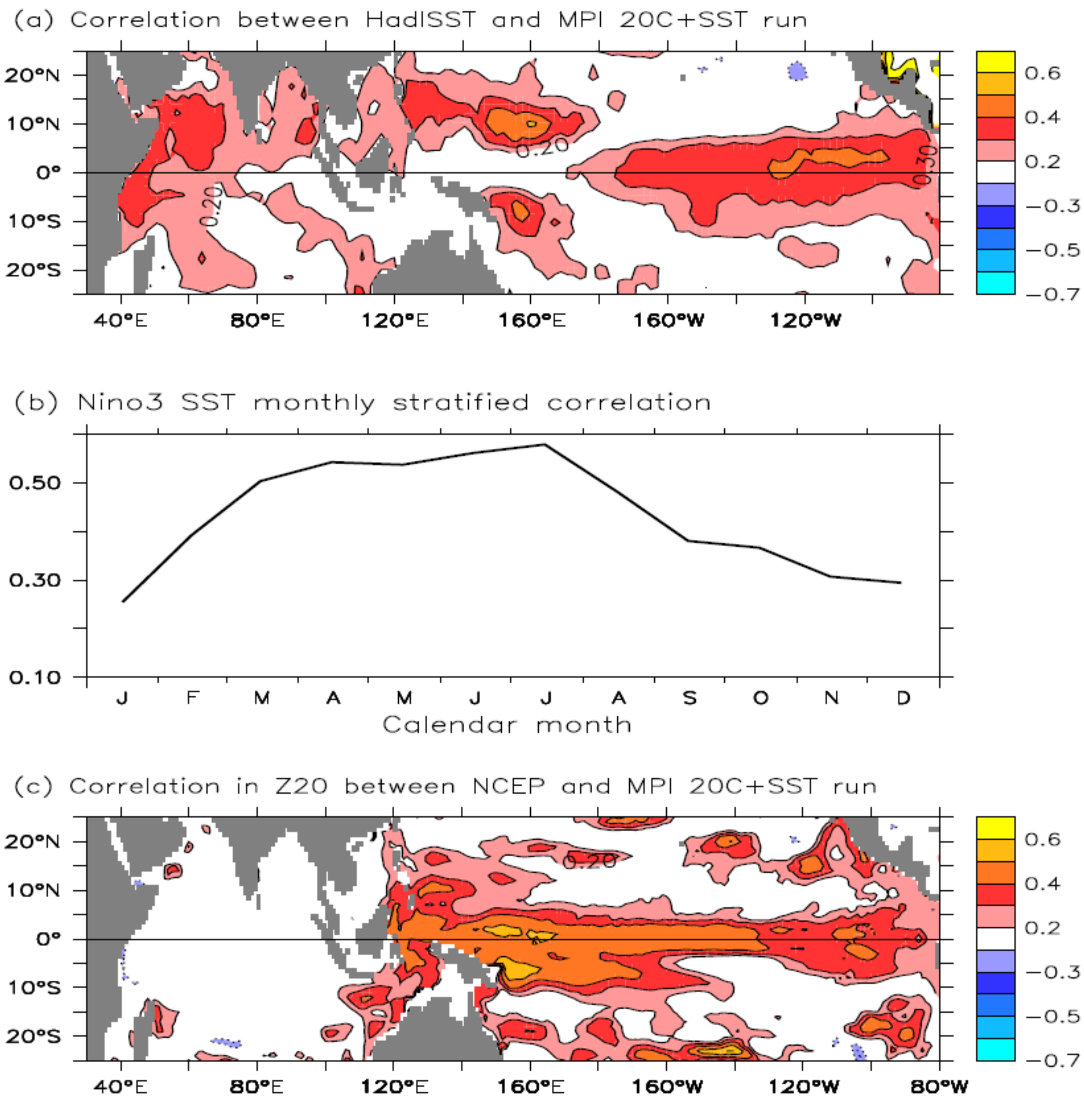
# Skill in simulating tropical Indo-Pacific SST and thermocline depth if tropical Atlantic SST is prescribed from observations

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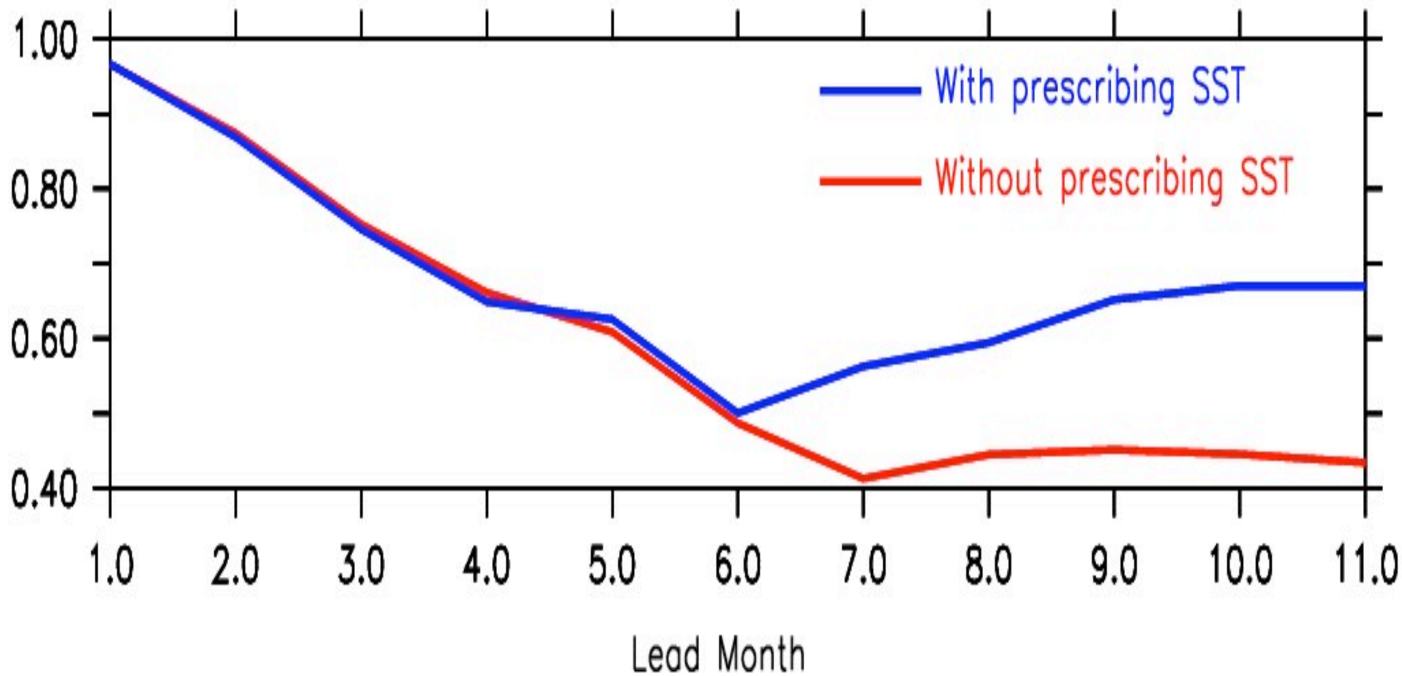
# Predicting very well tropical Atlantic variability can improve ENSO prediction

**ECHAM5/MPIOM, 1980-2005, Feb start, 9 ensemble members**

**Anomaly correlation, Nino3 SST**

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# Impact on ENSO: Summary

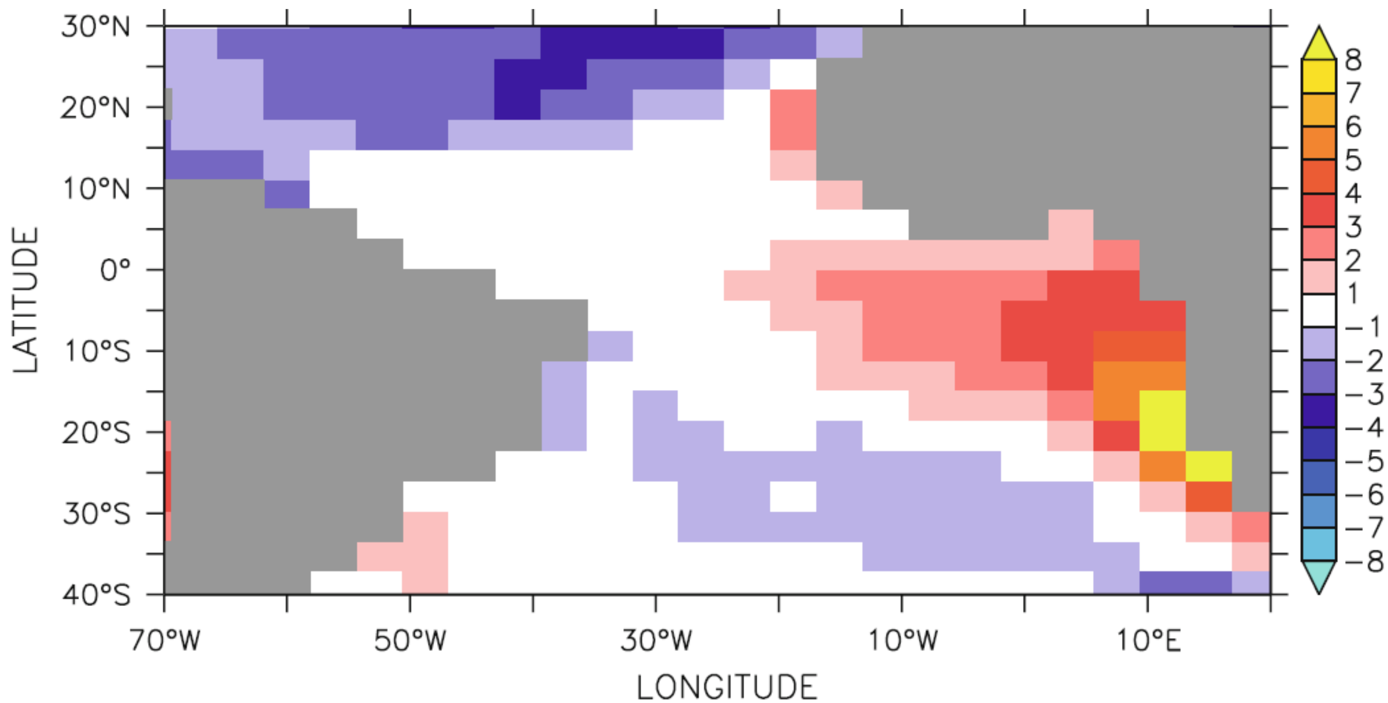
**Can tropical Atlantic variability influence ENSO?**

**Yes, coupled model results show that warm summer SSTA in the eq. Atlantic can indeed produce cold SSTA in the eq. Pacific 6 months later, and vice versa.**

**Influence of tropical Atlantic variability on ENSO**

# 4. Implications for model development

**The Tropical Atlantic SST bias in the Kiel Climate Model (KCM)**




**The zonal SST gradient along the equator is reversed in many models**

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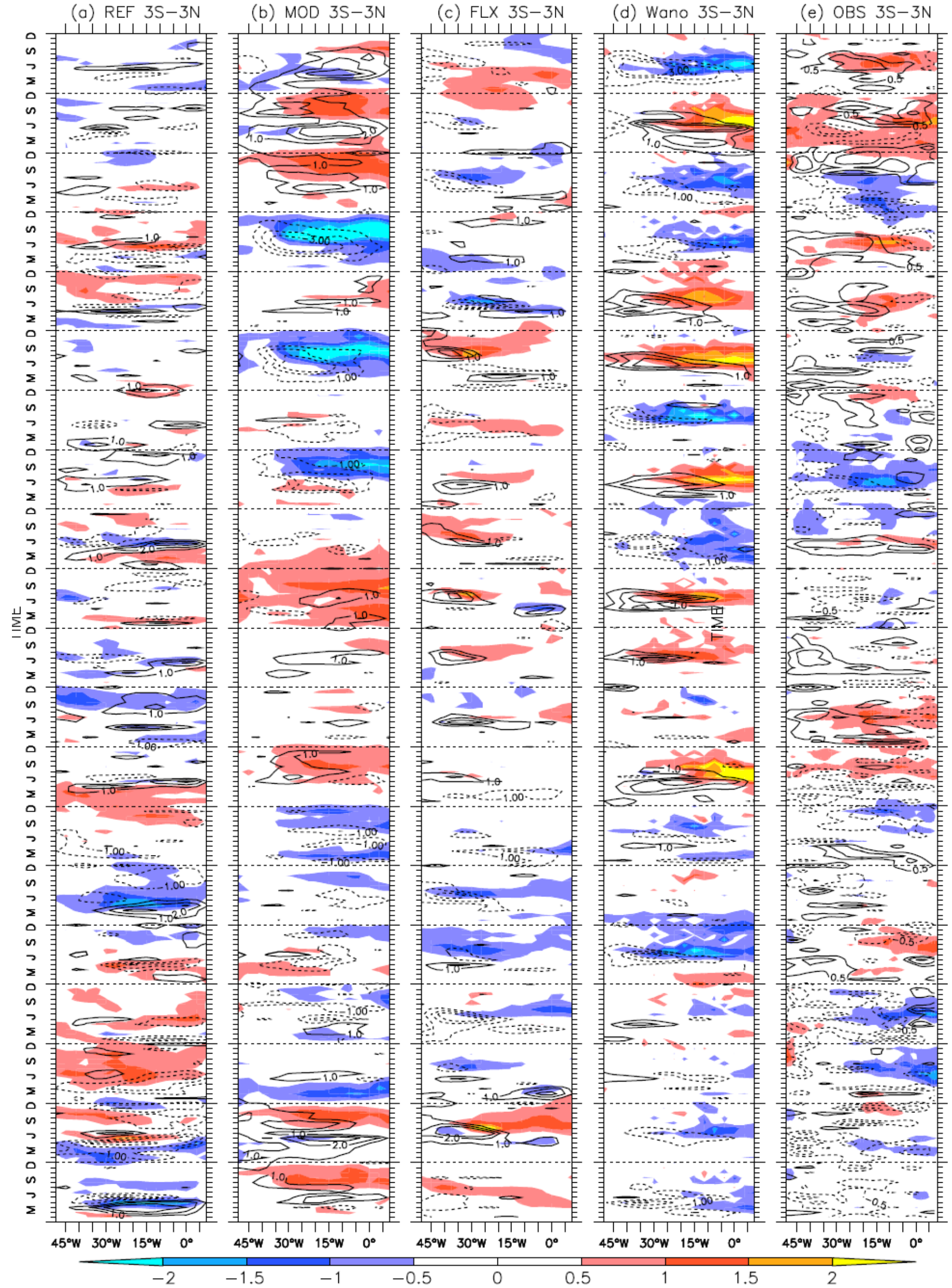
# Sensitivity of eq. Atlantic SST variability to model formulation




**Obs: 1980-1999**

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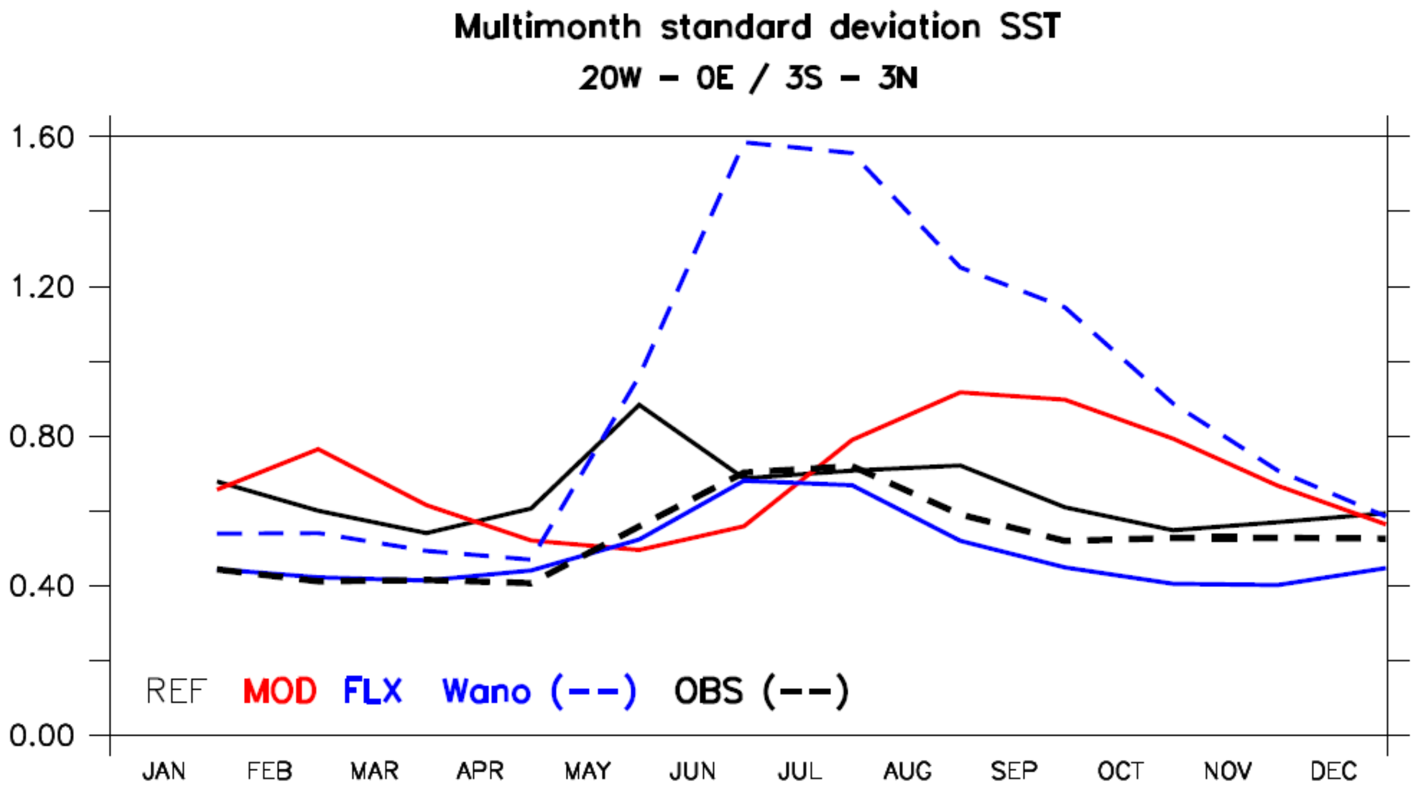
# Sensitivity of eq. Atlantic SST variability to model formulation phase locking to annual cycle

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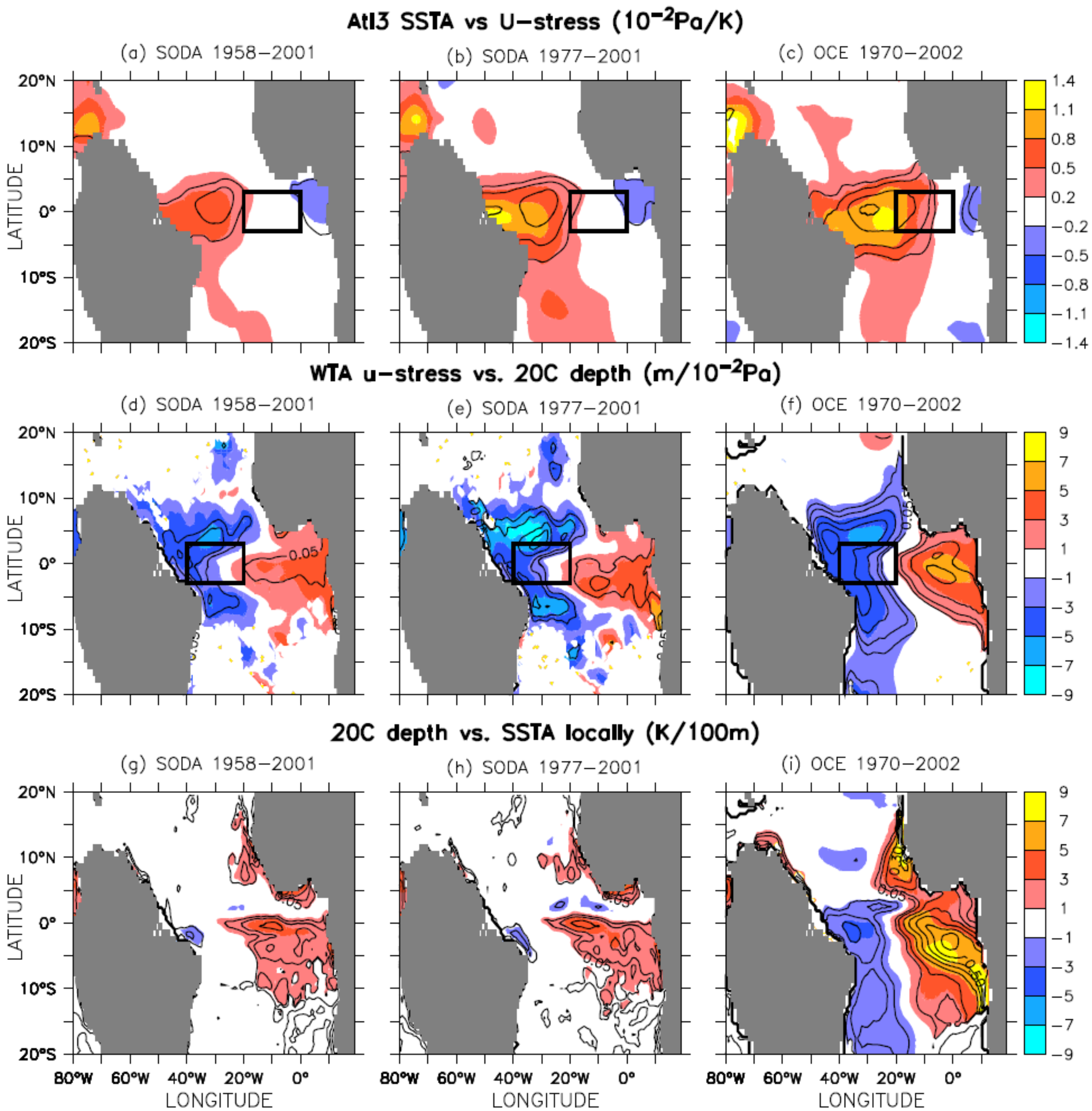
# Components of the Bjerknes feedback, SODA vs. OGCM

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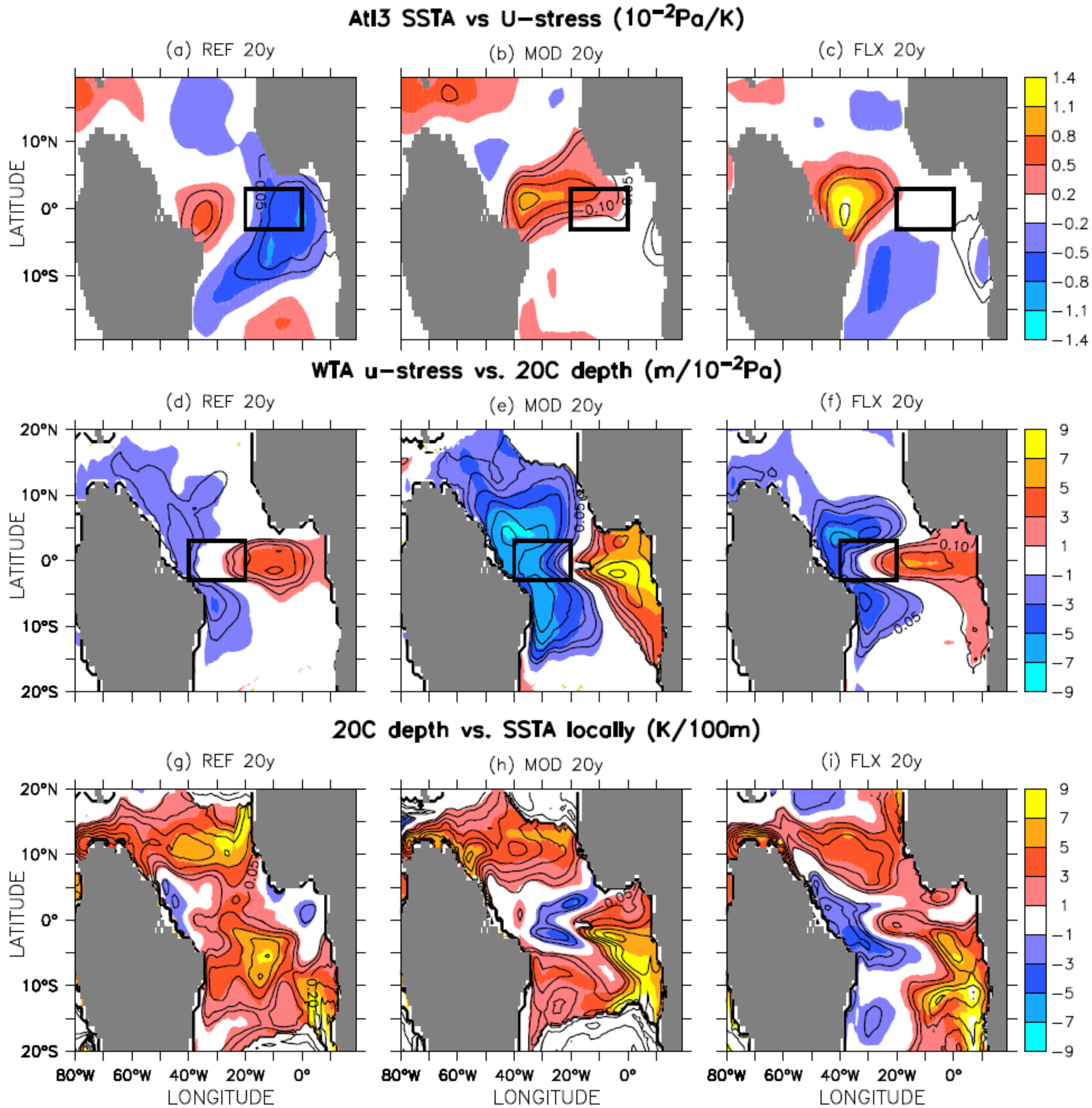
# Components of the Bjerknes feedback, 3 CGCMs

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# Conclusions

1. **The seasonal cycle contains a strong subsurface dynamics (wave) component; the strong semi-annual cycle is due to the excitation of a resonant basin mode**
2. **Eq. interannual variability is ENSO-like, and the zonal mode (QB) explains a lot of variance**
3. **It significantly impacts ENSO in the Pacific and ENSO forecasts can be potentially improved by predicting eq. Atlantic SST**
4. **The sensitivity of interannual variability to model formulation is large and the successful simulation of the TA climatology remains a big challenge**

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