Interaction between the Atlantic Meridional and Niño modes

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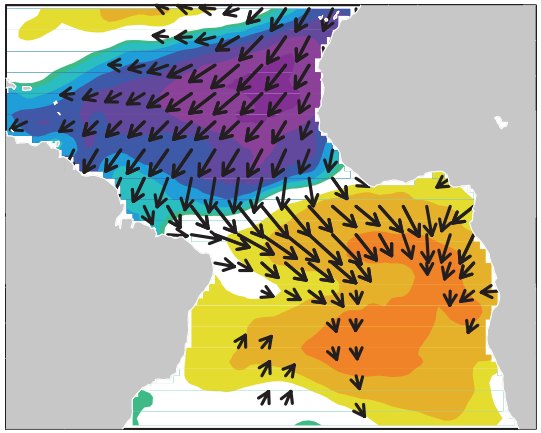
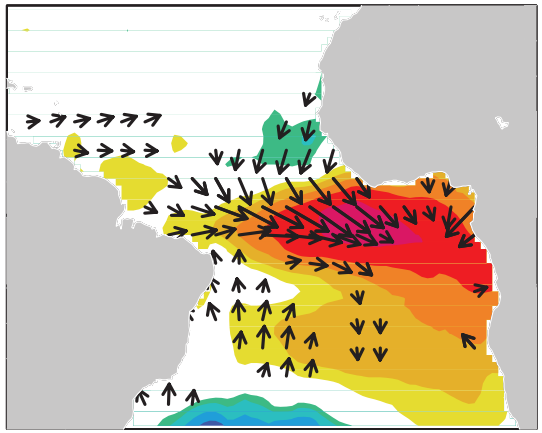




University of Washington
Physical Oceanography seminar
10 February 2010

Outline

- **The Atlantic "meridional" and "Niño" modes**

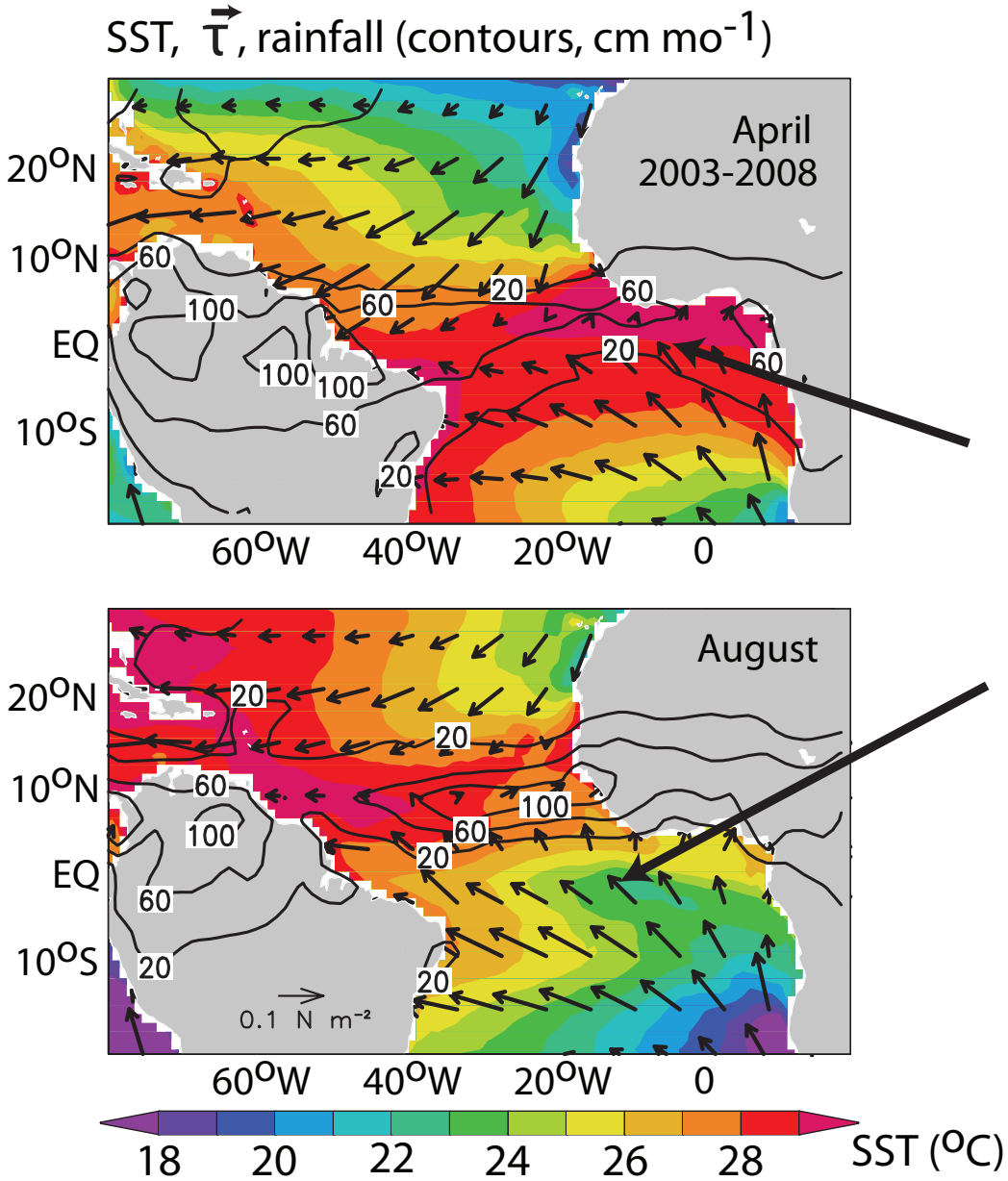
- **Interaction between the modes during 2009**

  - Observations

  - Linear wave model

- **Summary and conclusions**

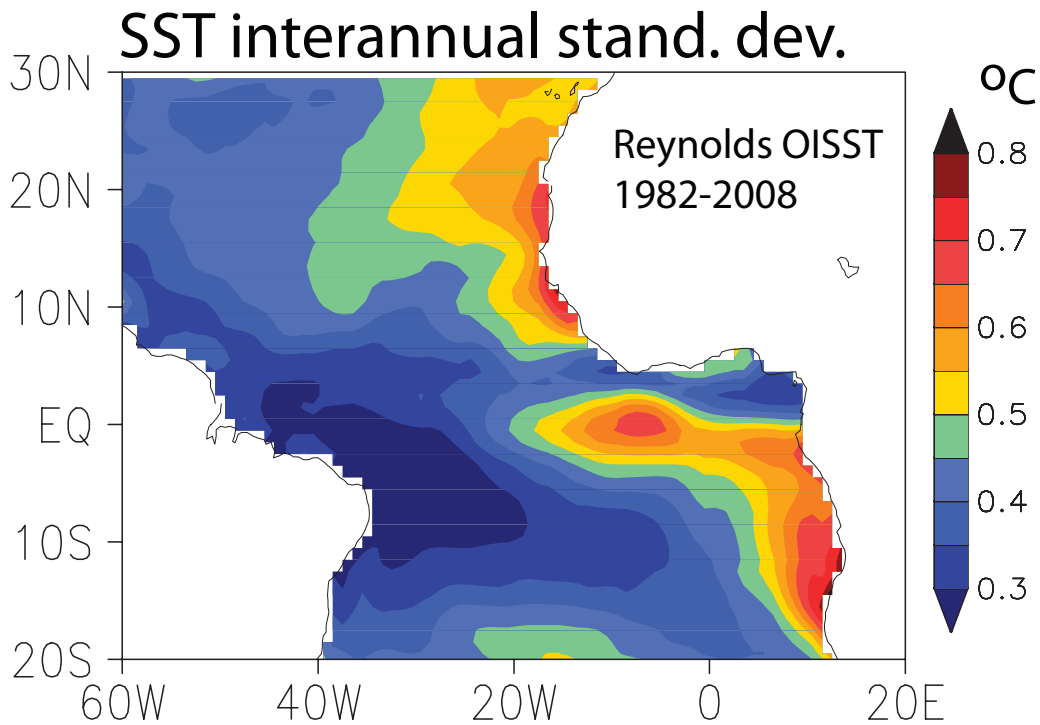
Tropical Atlantic seasonal cycle

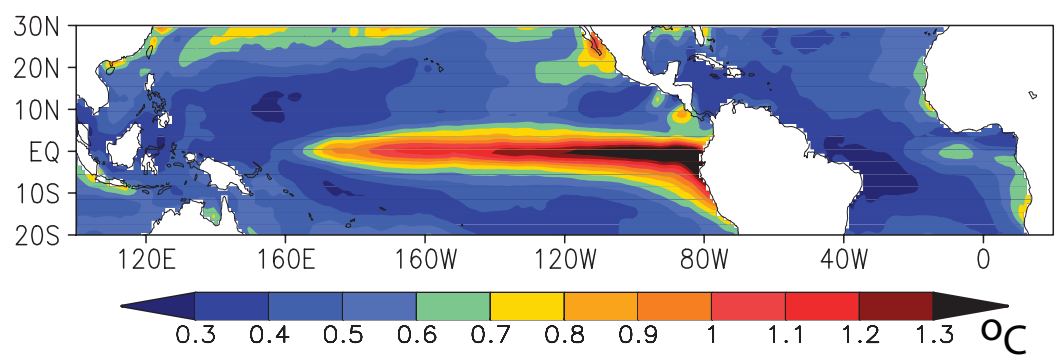


Weak meridional SST gradient during boreal spring

Equatorial cold tongue during boreal summer

Interannual variability



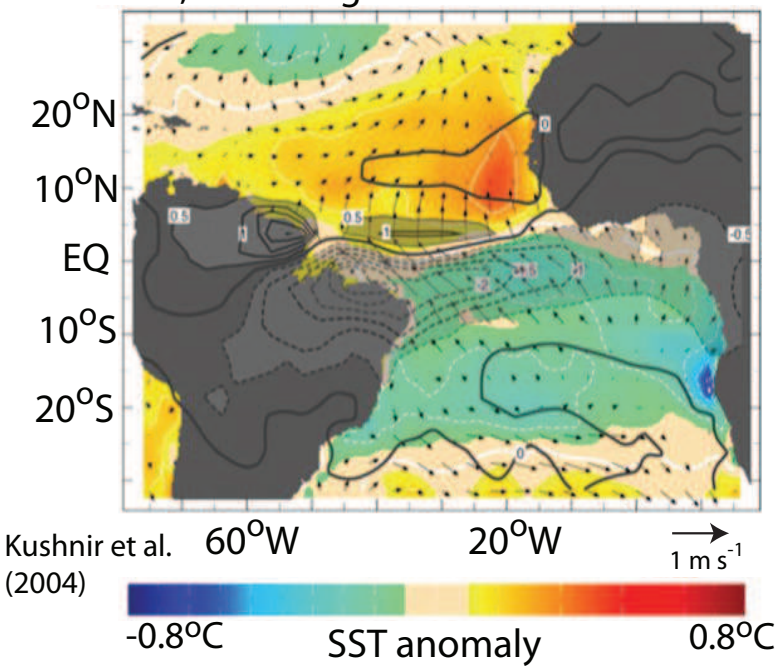


- Off-equatorial variability in Atlantic is nearly as strong as equatorial signal

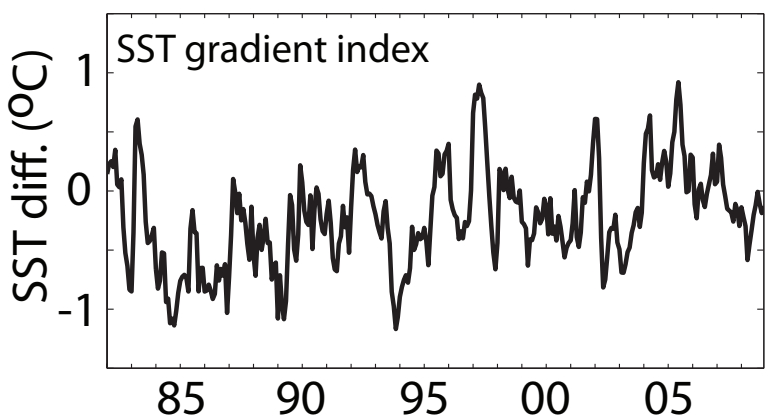
- Atlantic variability is weaker than Pacific, but important for local climate

Atlantic meridional mode

1st EOF of March-April rainfall
SST, winds regressed onto rain

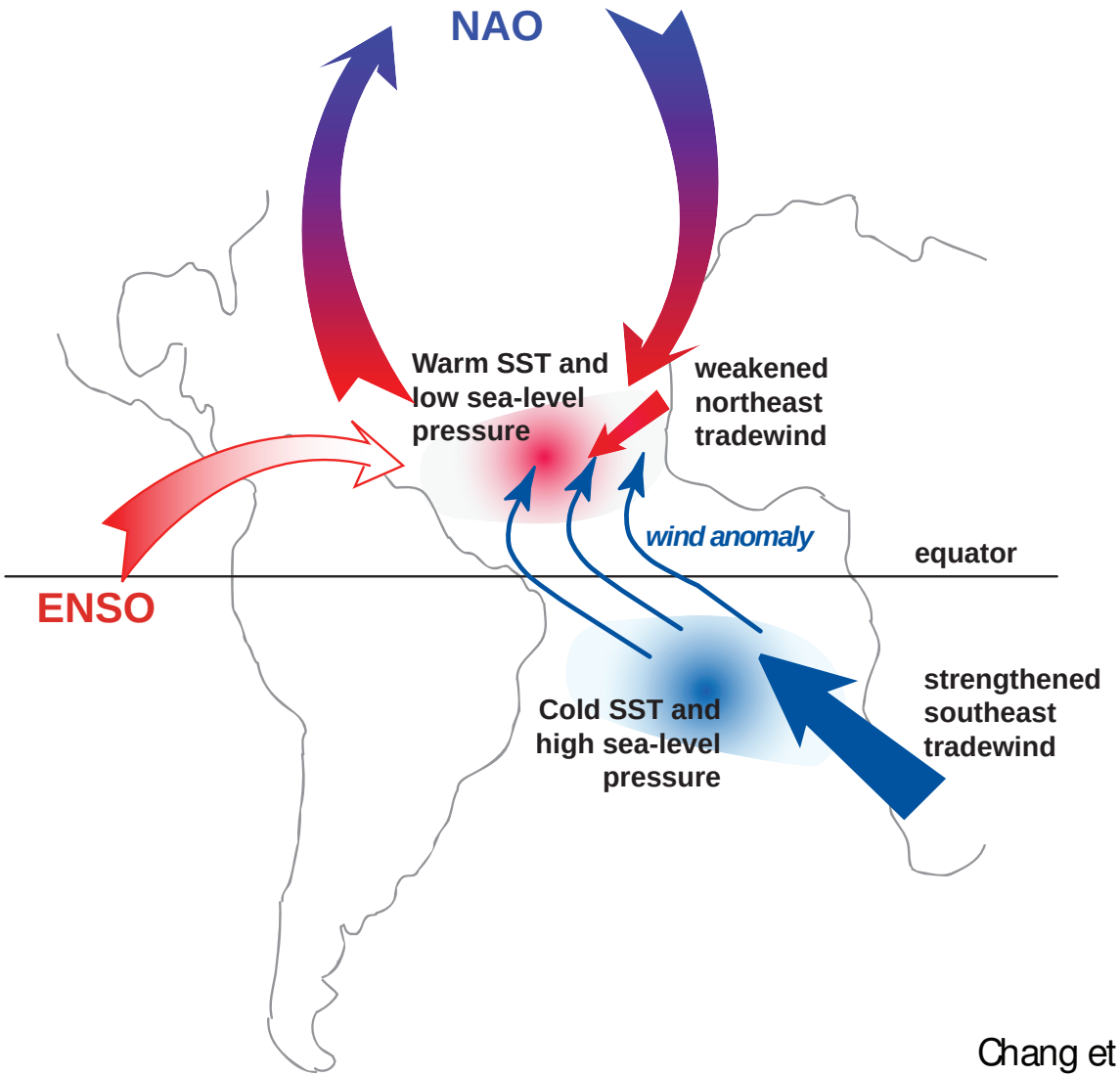


Kushnir et al. (2004)



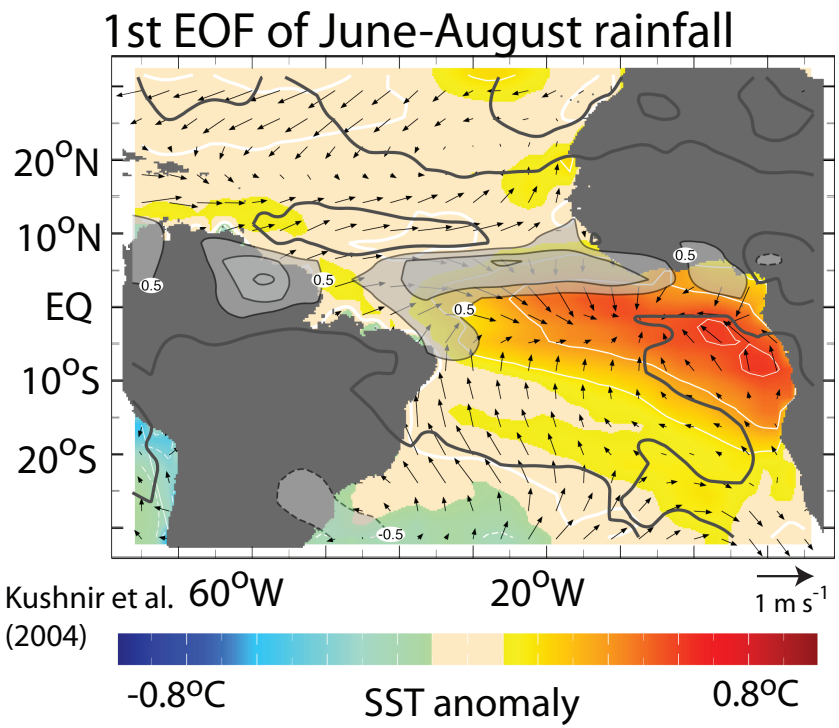
- Affects rainfall in Northeast Brazil, Sahel; tropical cyclones (*Folland et al.*, 1986; *Hastenrath and Greischar*, 1993; *Kossin and Vimont*, 2007)
  - Strongest during boreal spring, when ITCZ is most sensitive to meridional SST gradient
  - Coupled wind-evaporation-SST feedback in western equatorial region (*Chang et al.*, 2000)

Mechanisms of tropical Atlantic variability

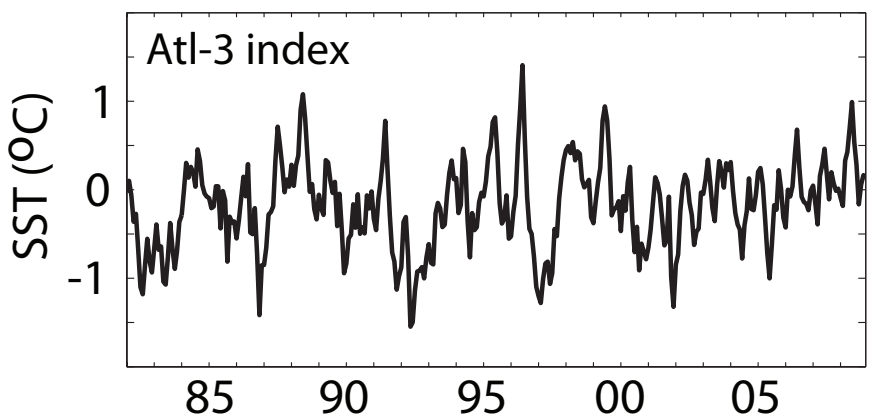


Chang et al.

Atlantic Niño



Kushnir et al. (2004)

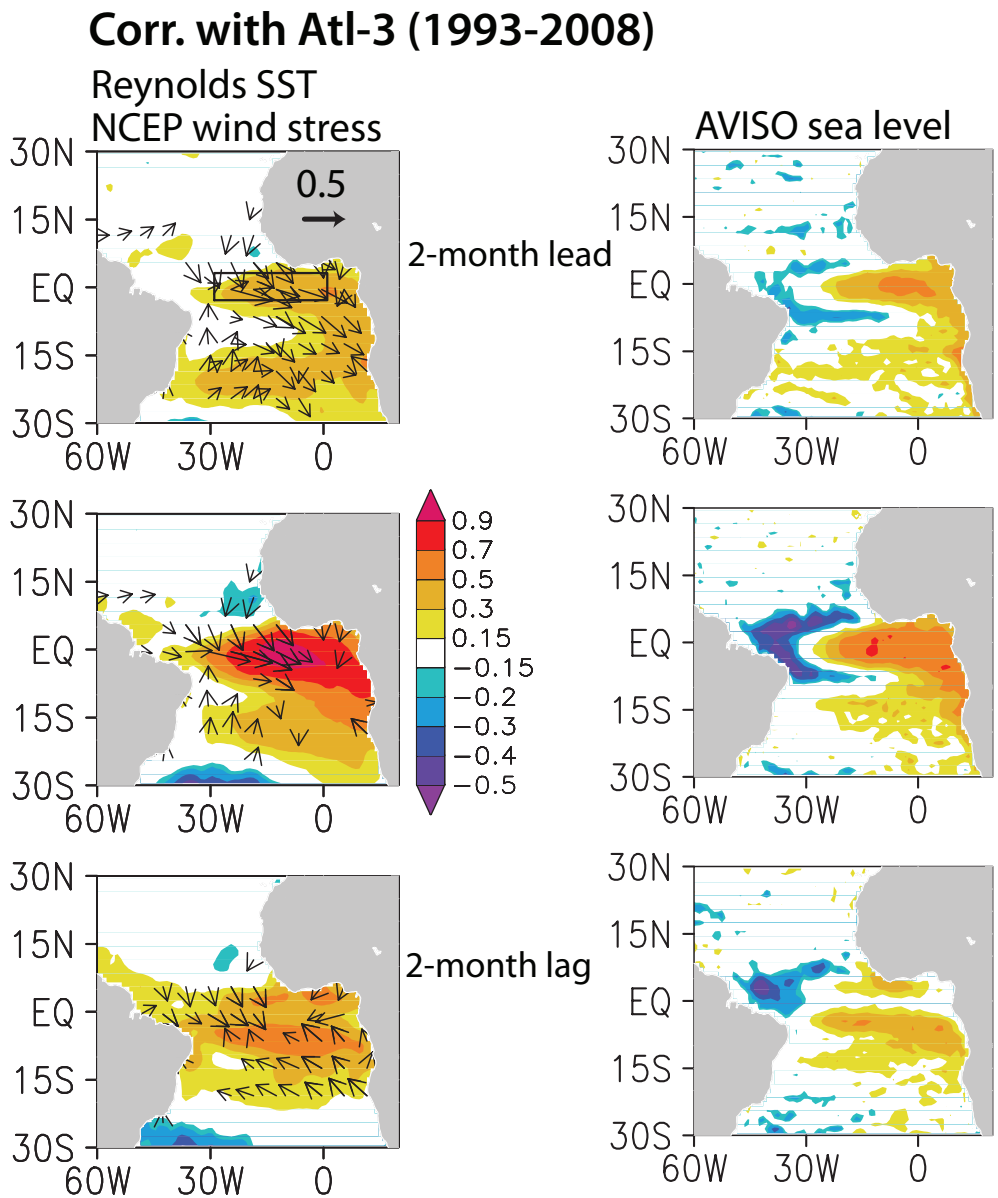


- Strongest in boreal summer, when thermocline is shallowest

- Weaker and shorter-lived than Pacific ENSO, not self-sustained (*Zebiak*, 1993; *Latif and Grotzner*, 2000; *Keenlyside and Latif*, 2007)

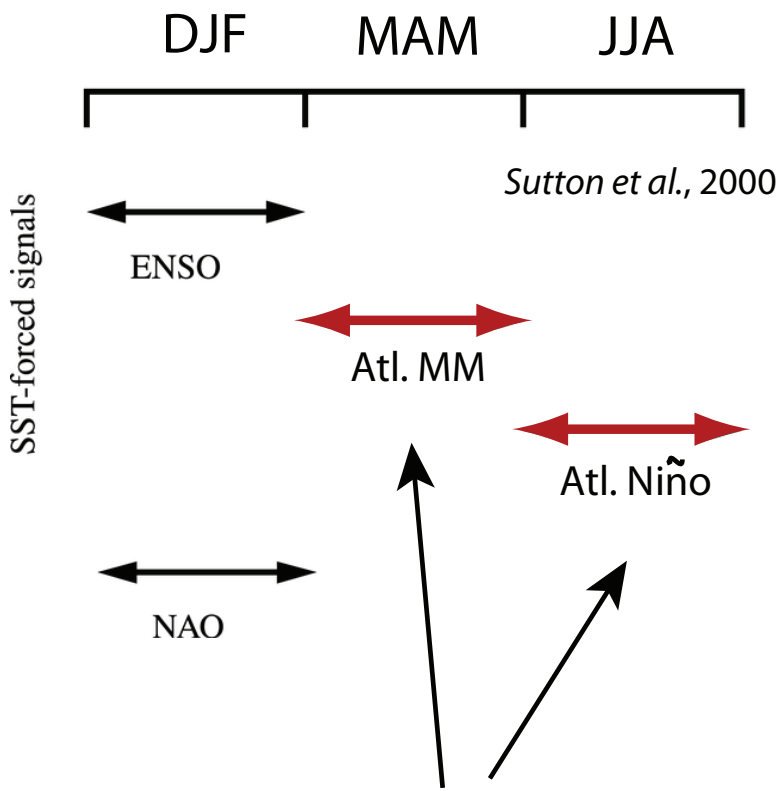
- Weak correlation with Pacific ENSO (*Chang et al.*, 2006)

Atlantic Niño mechanisms

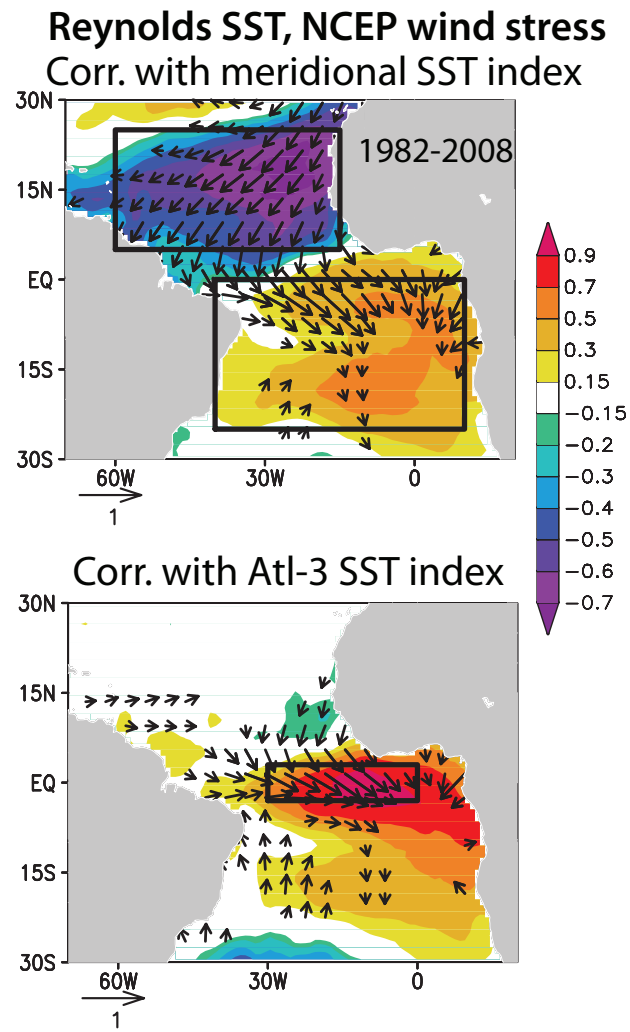


- Westerly wind stress anomalies deepen thermocline in eastern basin (*Zebiak*, 1993; *Carton and Huang*, 1994)

Interaction between the Meridional and Niño modes

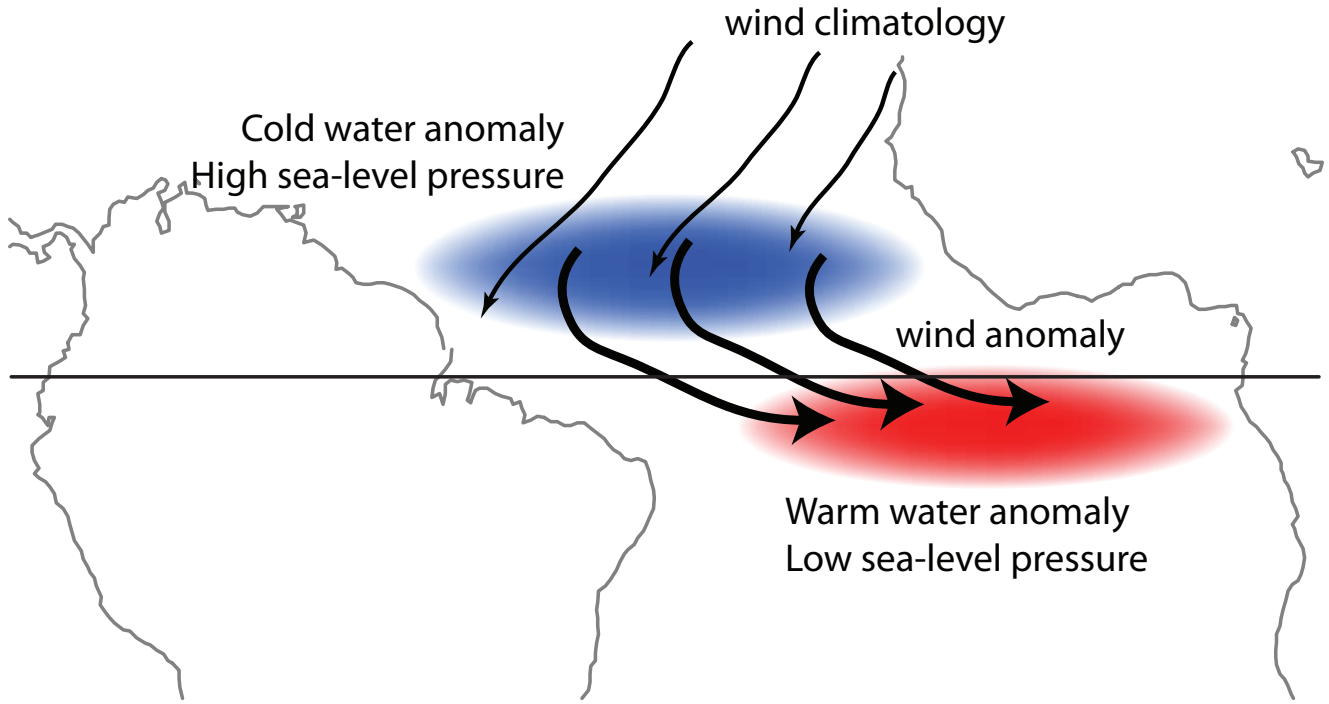


Peak of meridional mode preceeds Atlantic Niño by one season



- First proposed by *Servain et al.*, 1999.

Possible interaction mechanisms



- **Wind-SST feedback:** *wind-evaporation-SST* (*Xie*, 1999; *Chang et al.*, 2000)
  wind-thermocline-SST (*Zebiak*, 1993)
  wind-Ekman pumping-SST

- **Equatorial waves** (forced, reflected Kelvin and Rossby)
  (*Illig et al.*, 2004; *Hormann and Brandt*, 2009)

Outline

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Data

- **QuikSCAT winds** (daily, 0.5^{o} grid)
- **Satellite sea level** (AVISO, daily, 1° grid)
- **TMI SST** (3-day, 1° grid)

Anomalies relative to 2003-08 mean seasonal cycle

- **Winds, subsurface temperature from PIRATA moorings**
  4°N, 23°W: 2006-2009
  0°, 10°W: 1999-2009
  Daily averages

Ekman pumping velocity

$$-fhv_e = \frac{\tau^x}{\rho} - ru_e$$

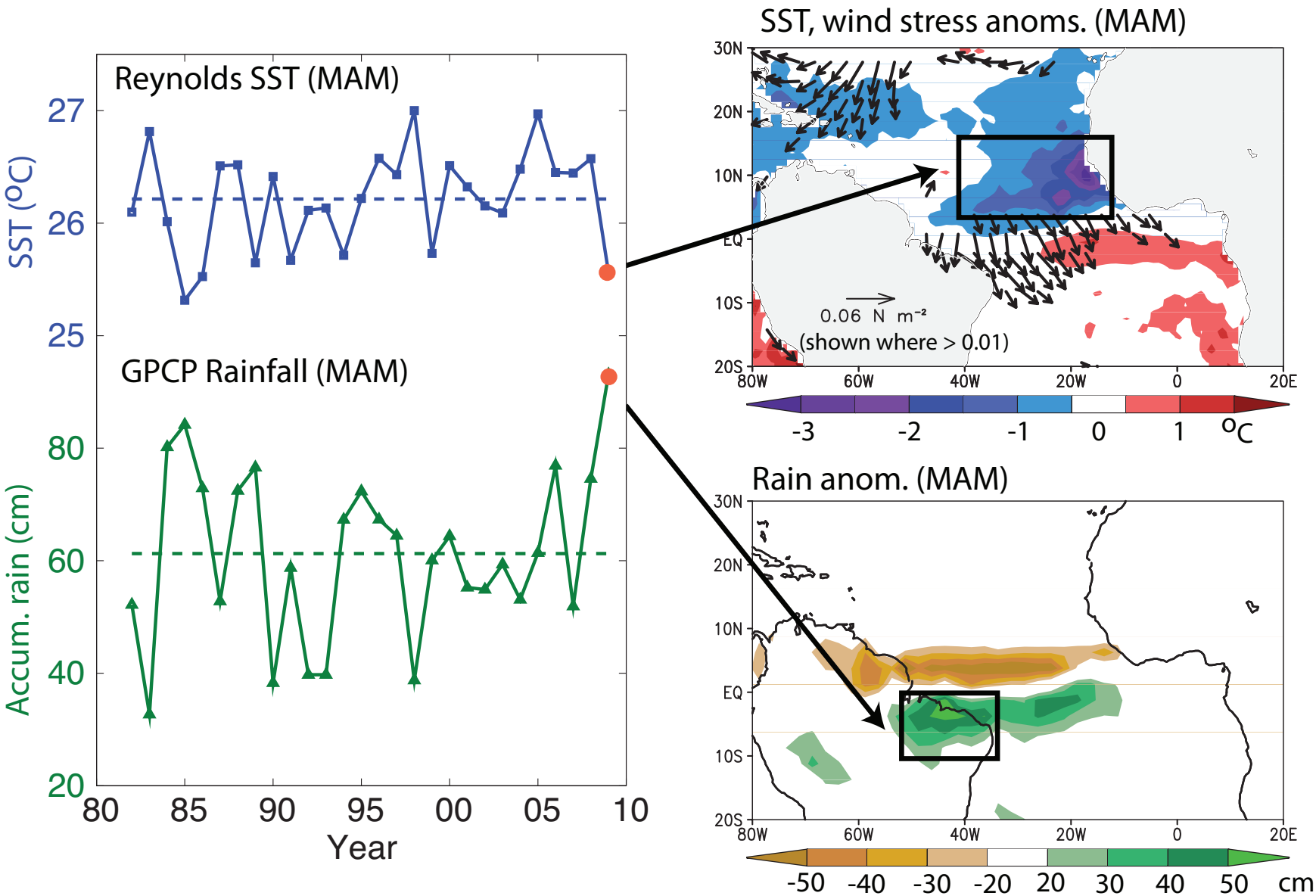
$$fhu_e = \frac{\tau^y}{\rho} - rv_e$$

$$w_e = h\nabla \cdot \vec{\mathbf{v}}_e$$

$h = 30$ m $\qquad r = 2 \times 10^{-4}$ m s^{-1}

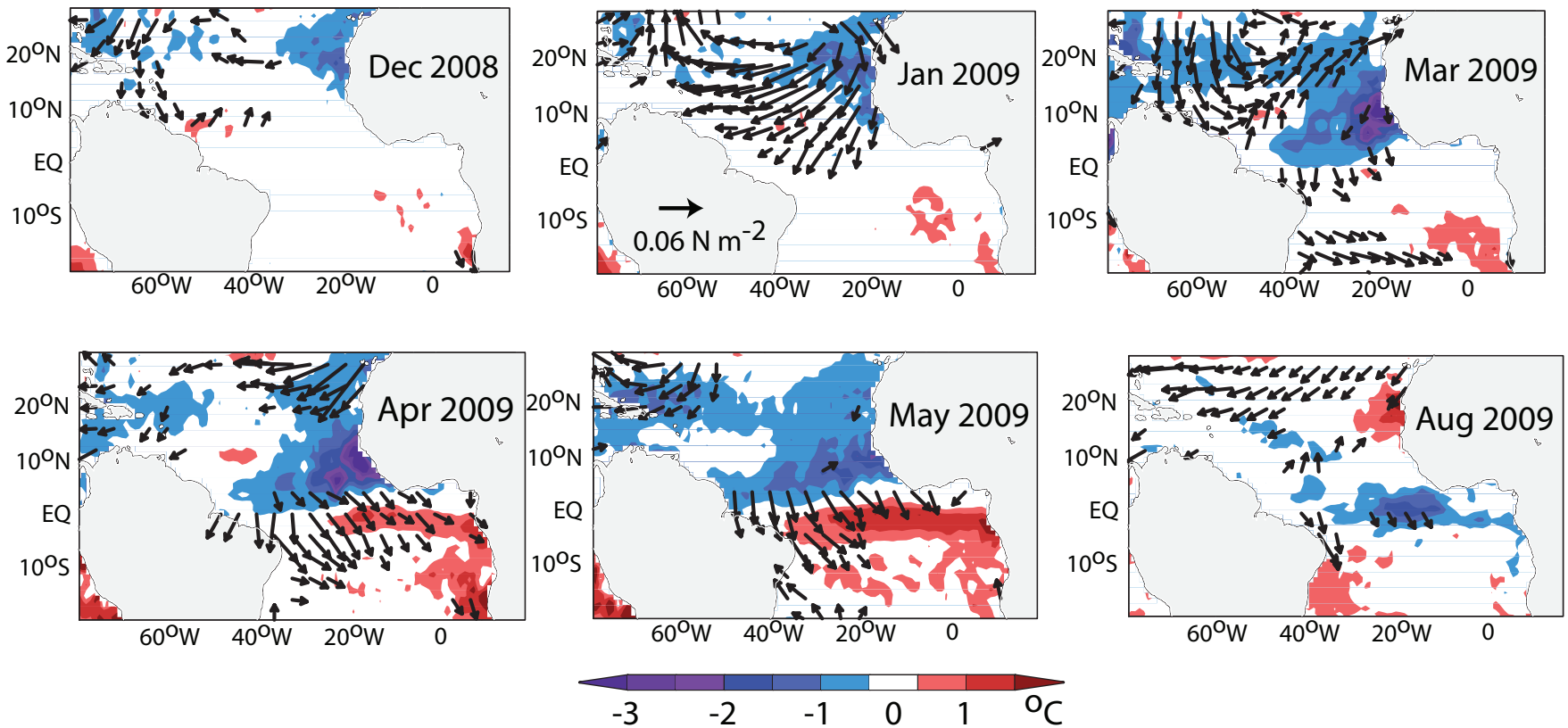
Lagerloef et al., 1999

2009 anomalies



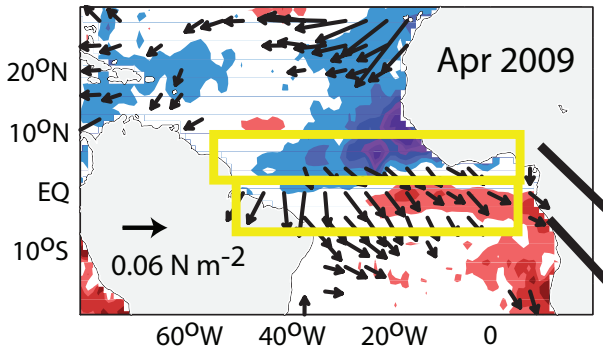
Evolution of the 2009 event

Monthly anomalies of SST, $\vec{\tau}$

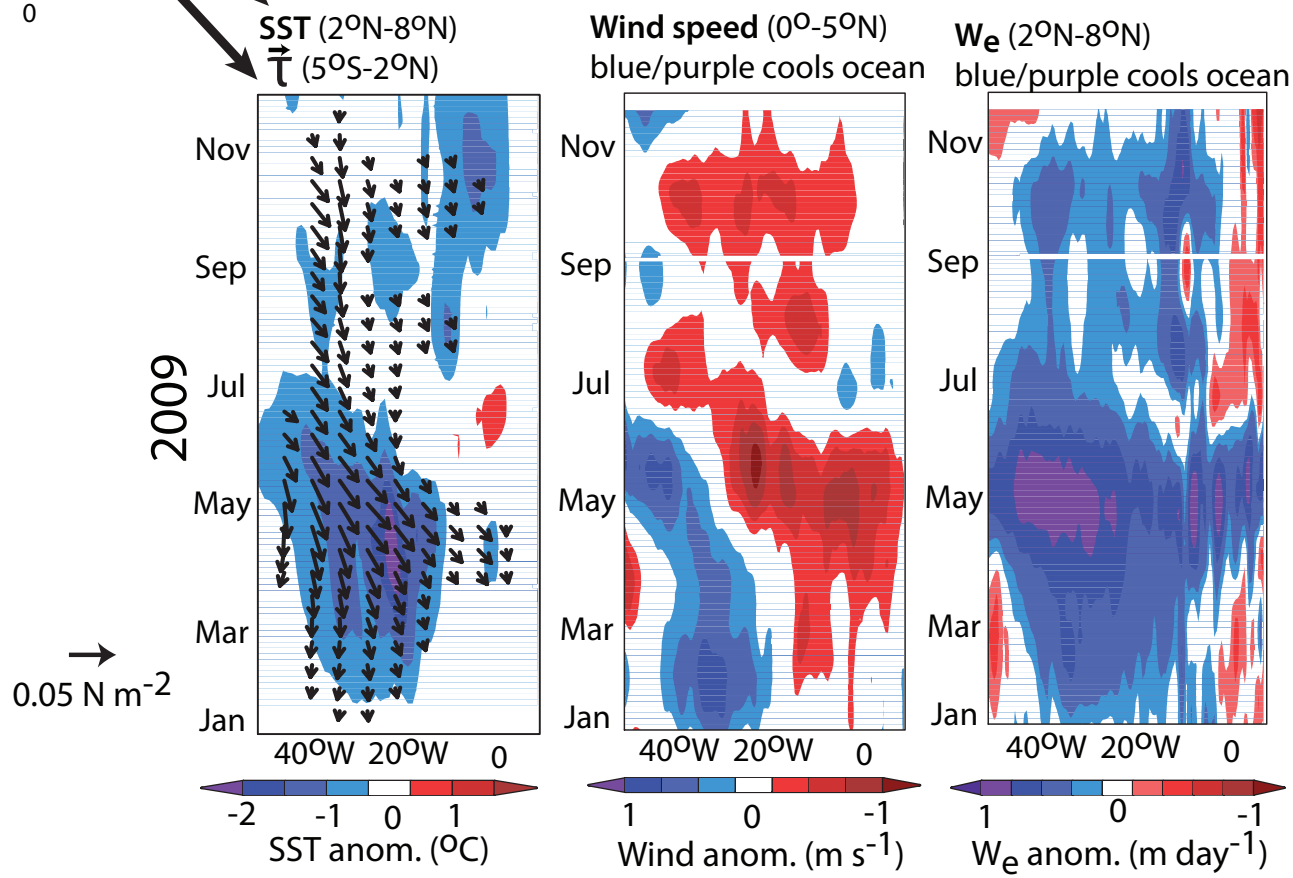


- Anomalously strong trade winds in January, followed by cooling in the north and warming along the equator

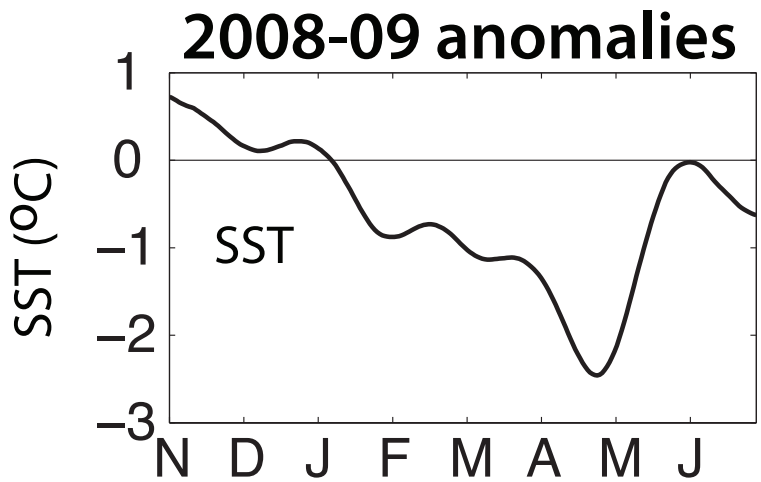
Wind-SST interaction

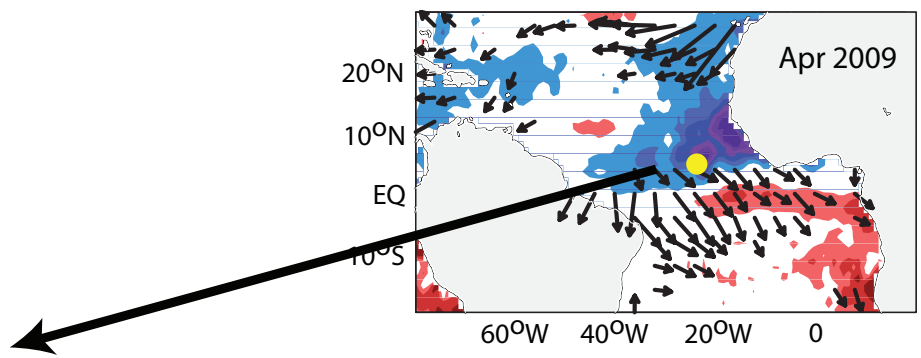


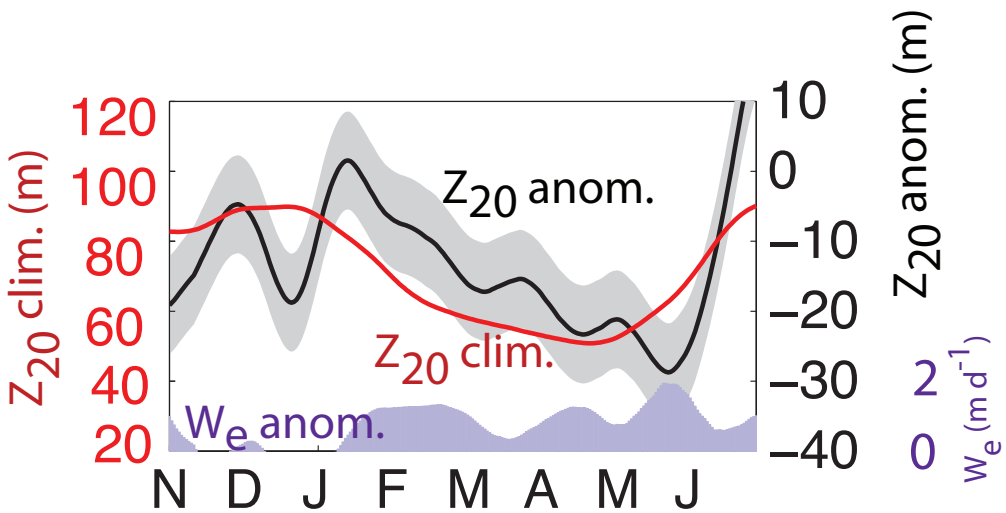
Cold SST anoms. drive anomalous northwesterly winds, enhancing wind speed and Ekman pumping.



Measurements at 4°N, 23°W

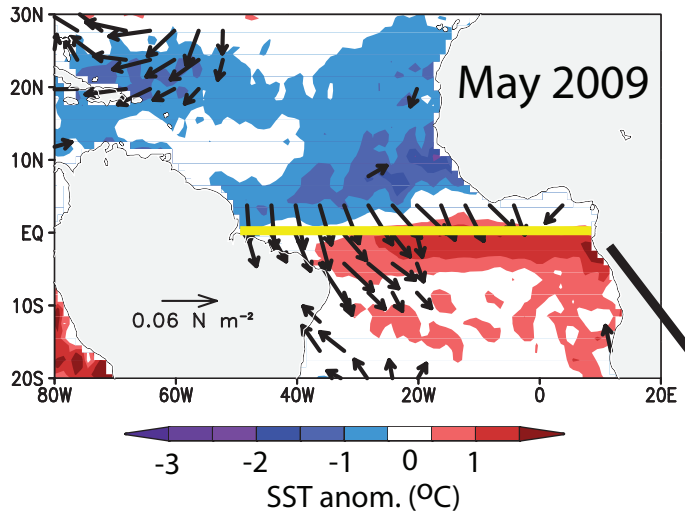


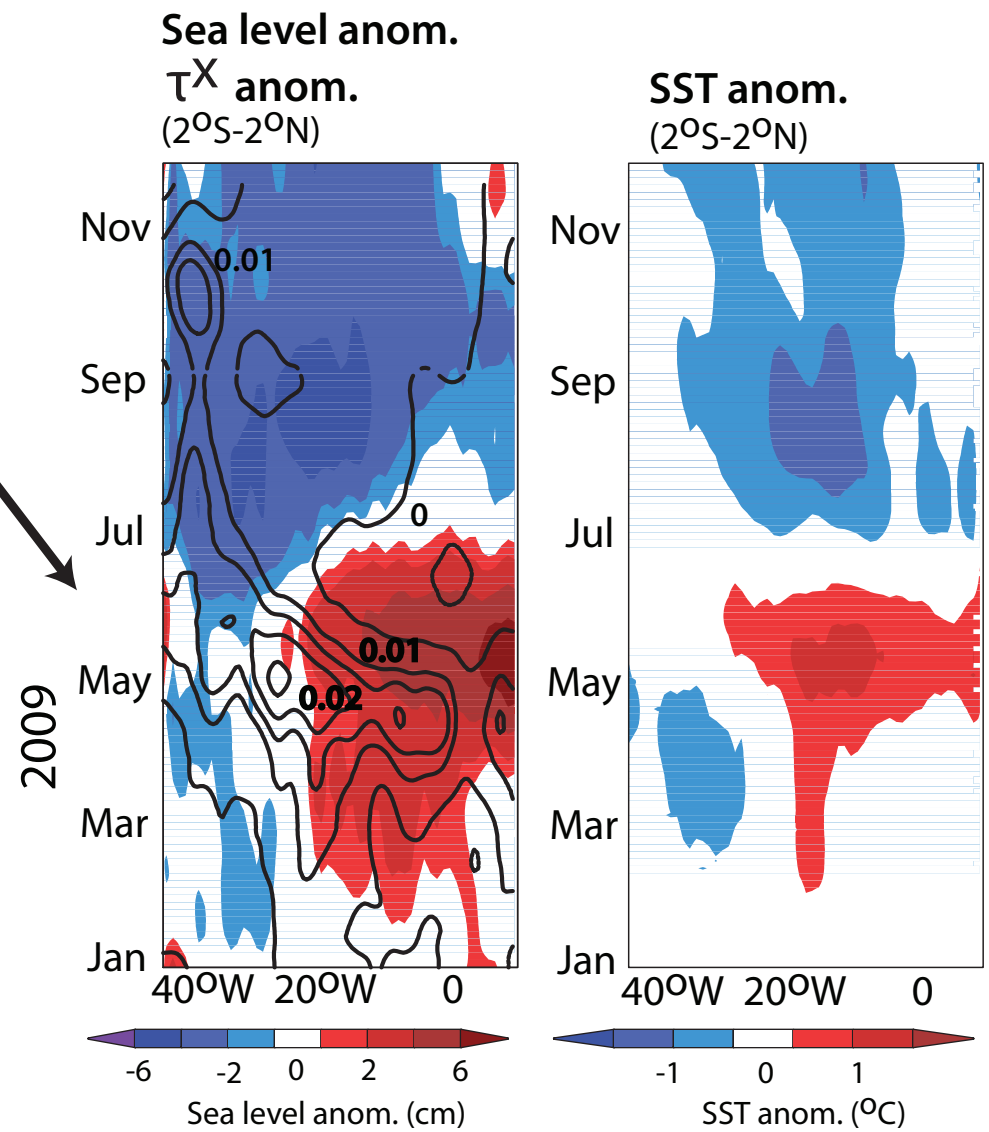




Anomalous cooling coicides with shallower than normal thermocline and stronger Ekman pumping

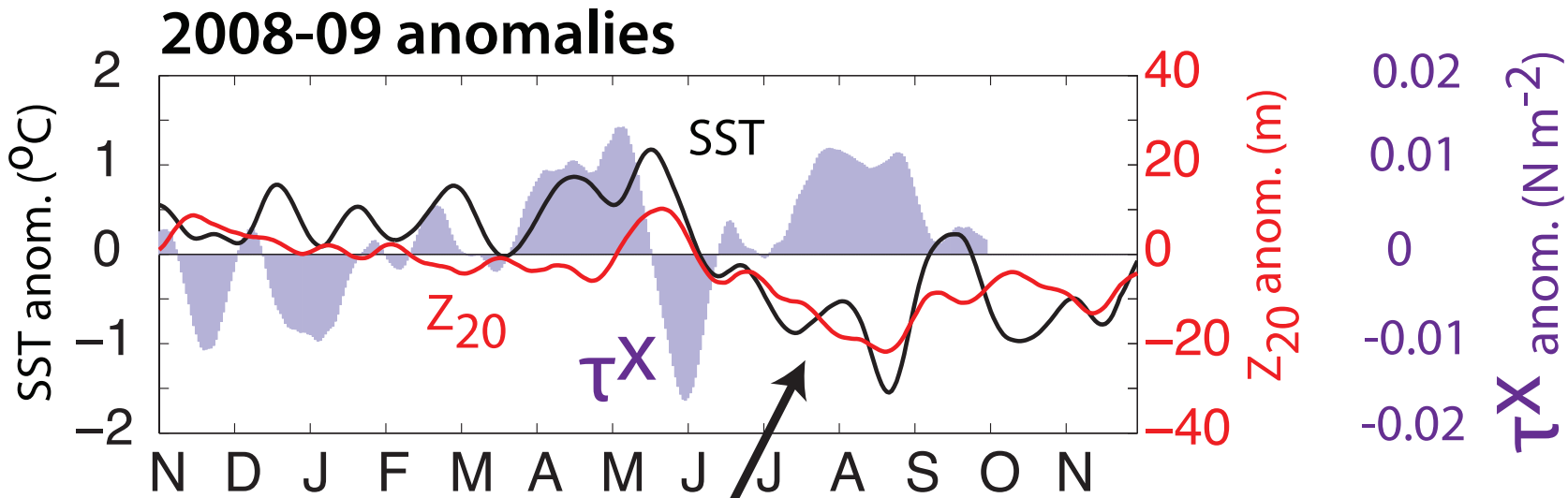
Wind-SST interaction (equator)



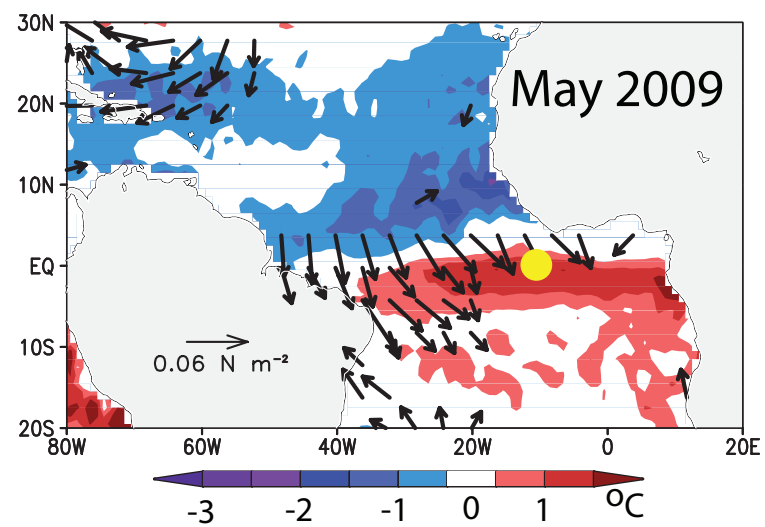


- Anomalous westerly winds depress thermocline, causing anomalous warming

Measurements at 0°, 10°W

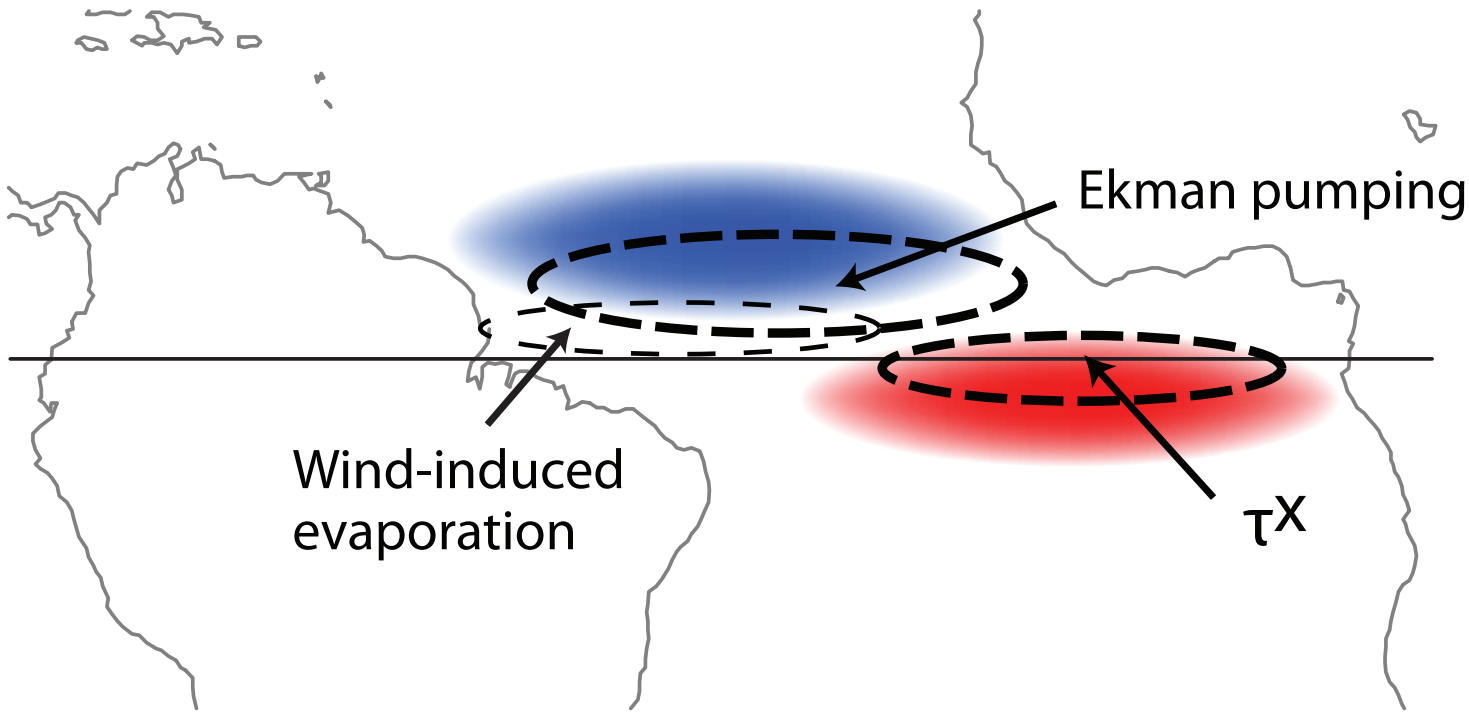


SST tracks Z_{20}



- Local winds cannot explain anomalous cooling during June-August

Interaction mechanisms



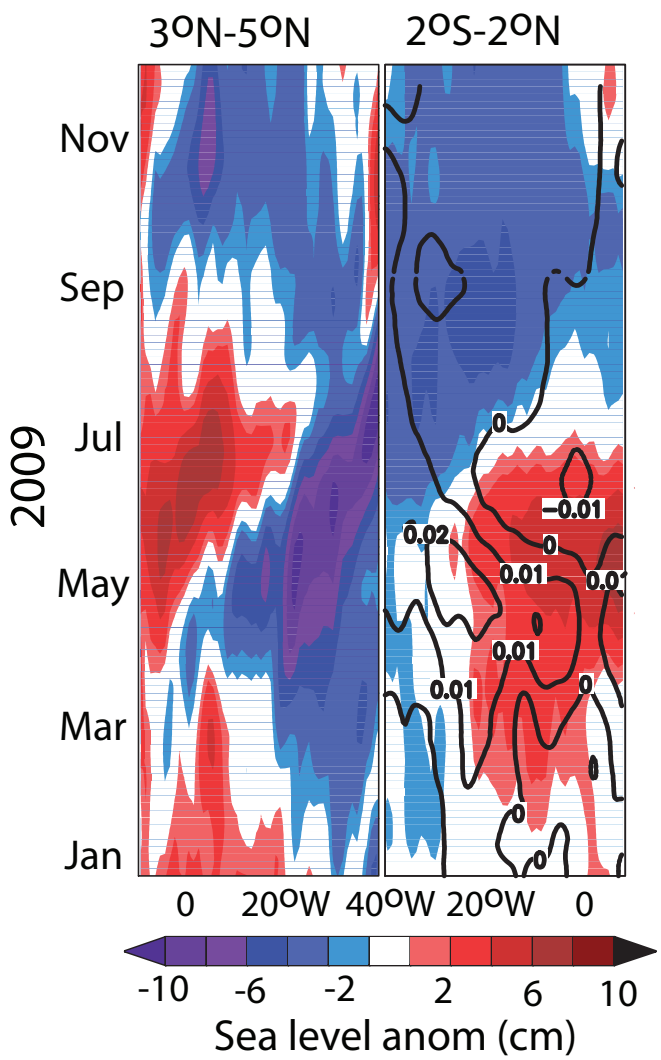
- Wind-SST feedback: wind-evaporation-SST ✓
  wind-thermocline-SST ✓
  wind-Ekman pumping-SST ✓

→ Equatorial waves?

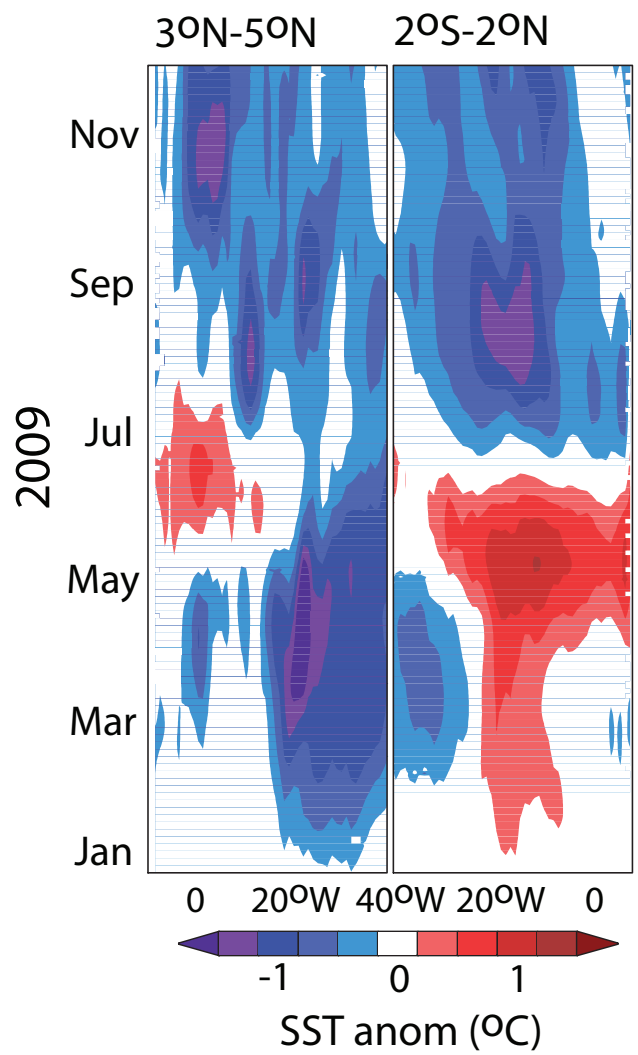
Equatorial waves

2009 anomalies

Sea level (shaded), τ^X (contours)



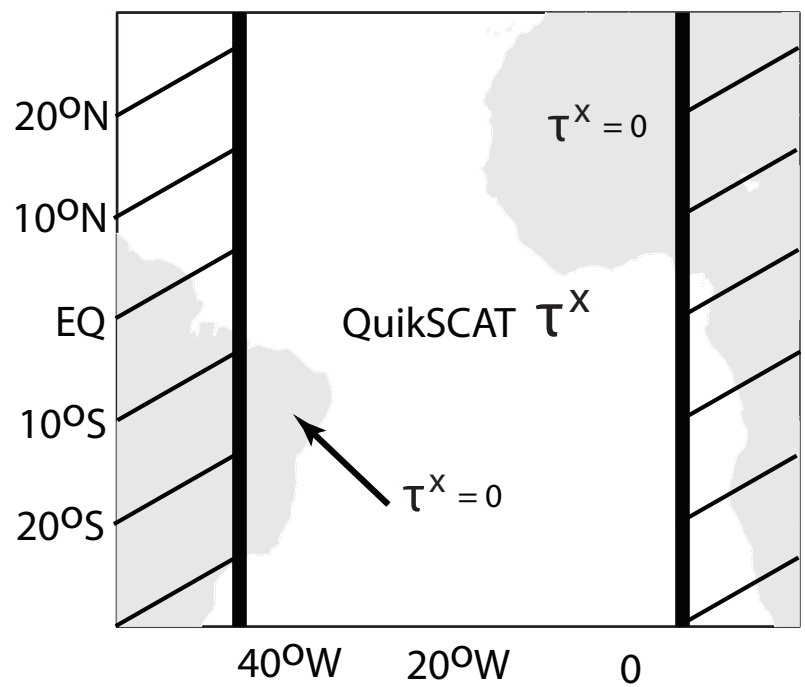
SST



Linear wave model

- Continuously stratified, longwave
  - 10 baroclinic , 15 meridional modes
  - Vertical modes from annual mean WOA05 (5^oS-5^oN)

- Merid. boundaries at 45^oW and 5^oE
  - 85% reflection efficiency



- Forced with 6-hr QuikSCAT τ^x
  - 2°-lon x 0.1^o-lat grid
  - Jan 2000 - Nov 2009

- Damping: $A\, c_n^{-2}$, $A\, c_1^{-2} = (12 \text{ months})^{-1}$

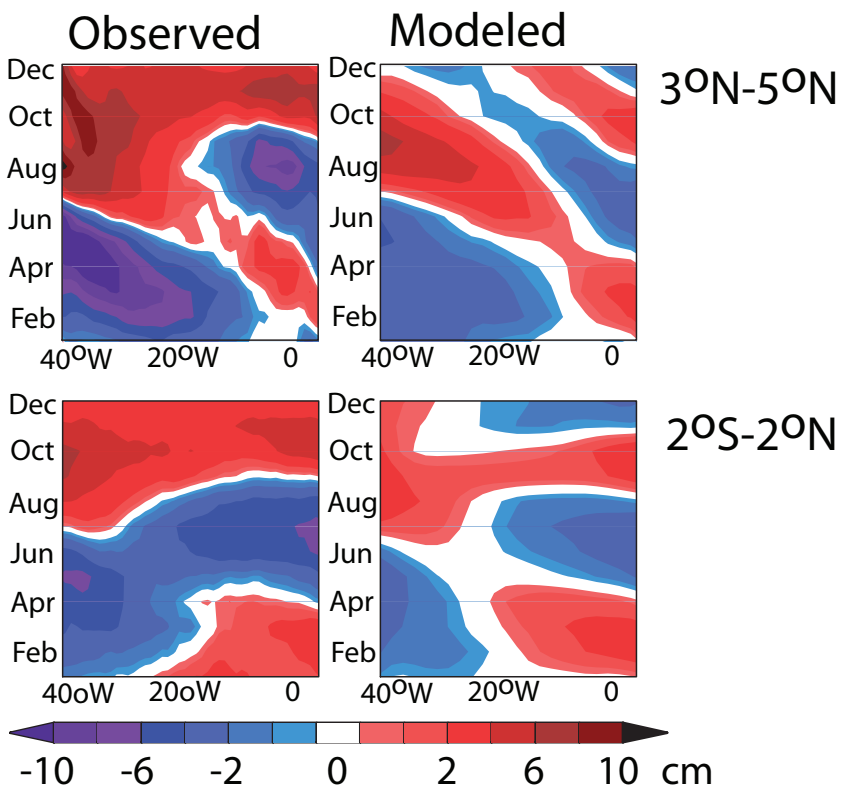
Yu and McPhaden, 1999

Nagura and McPhaden, 2009

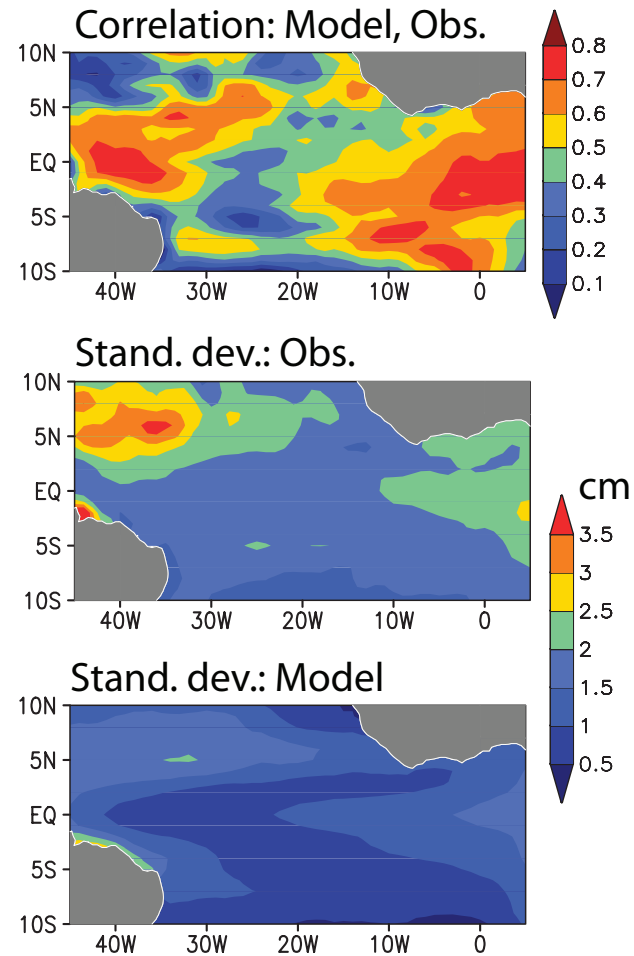
Ding et al., 2009

Wave model validation

Seasonal cycle of sea level
2001-09

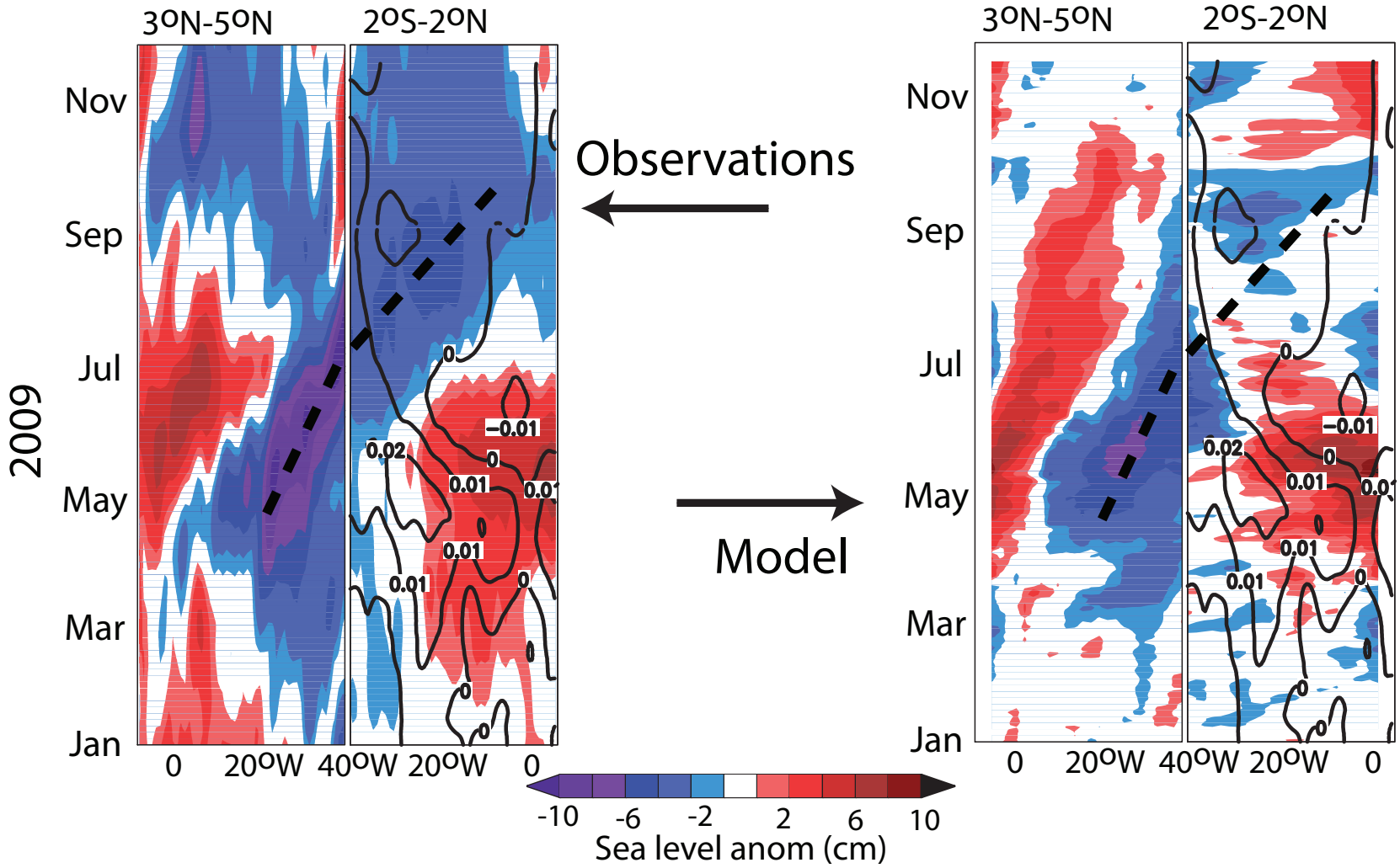


Interannual variability
2001-09



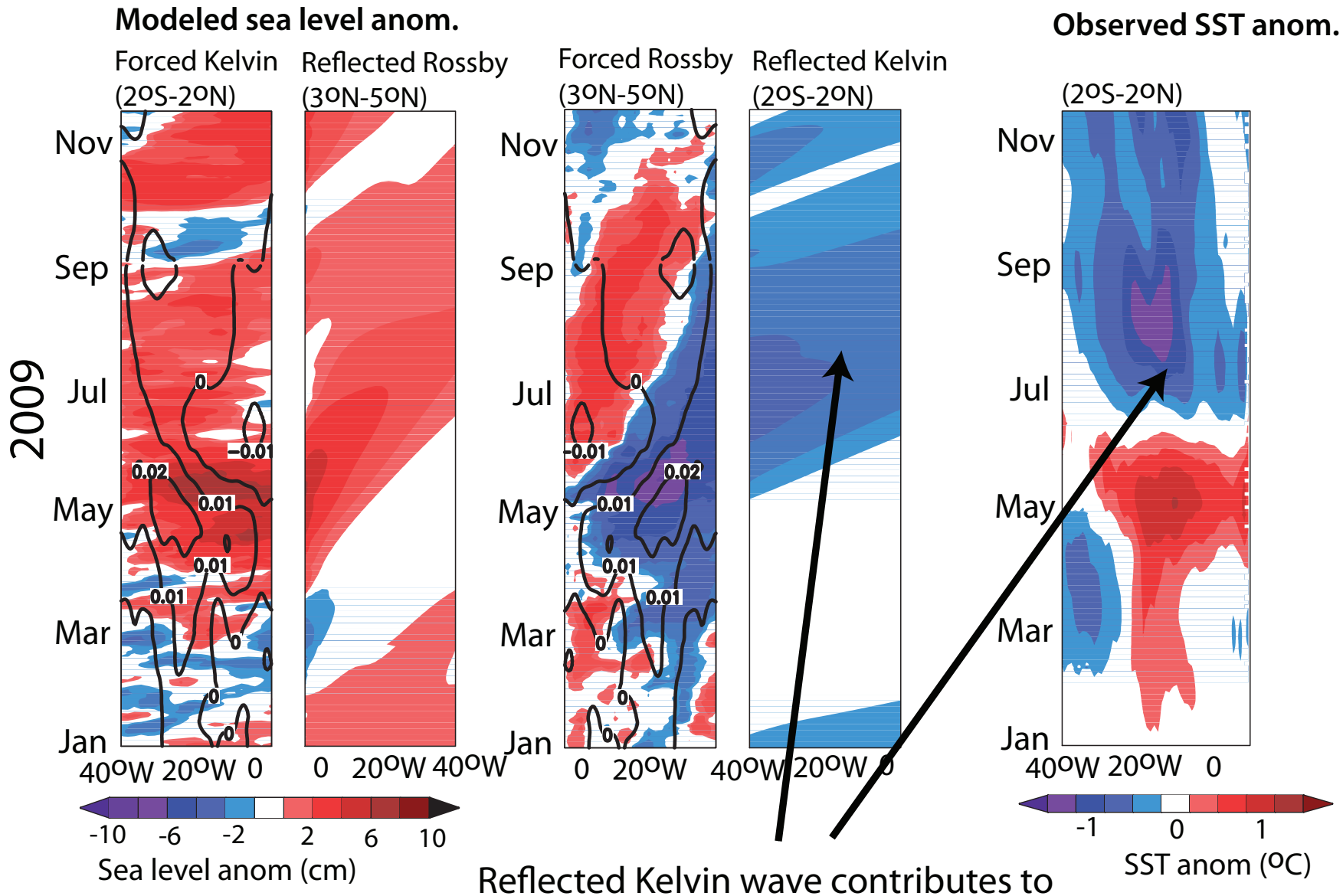
- Seasonal cycle and interannual variability of sea level are simulated, though with reduced amplitude

2009 sea level anomalies



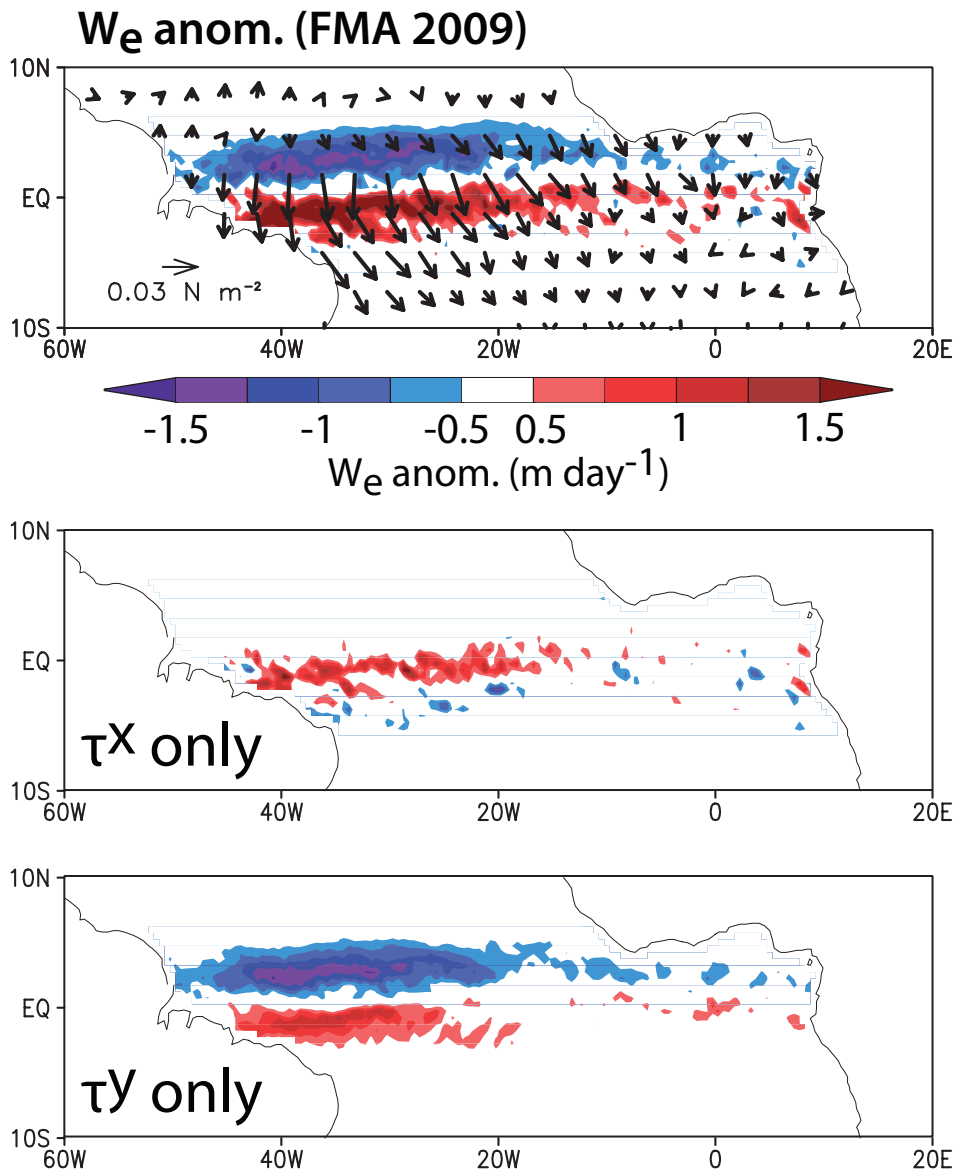
- Model qualitatively reproduces interannual variability, though Rossby and Kelvin amplitudes are weaker than observed

Forced and reflected waves



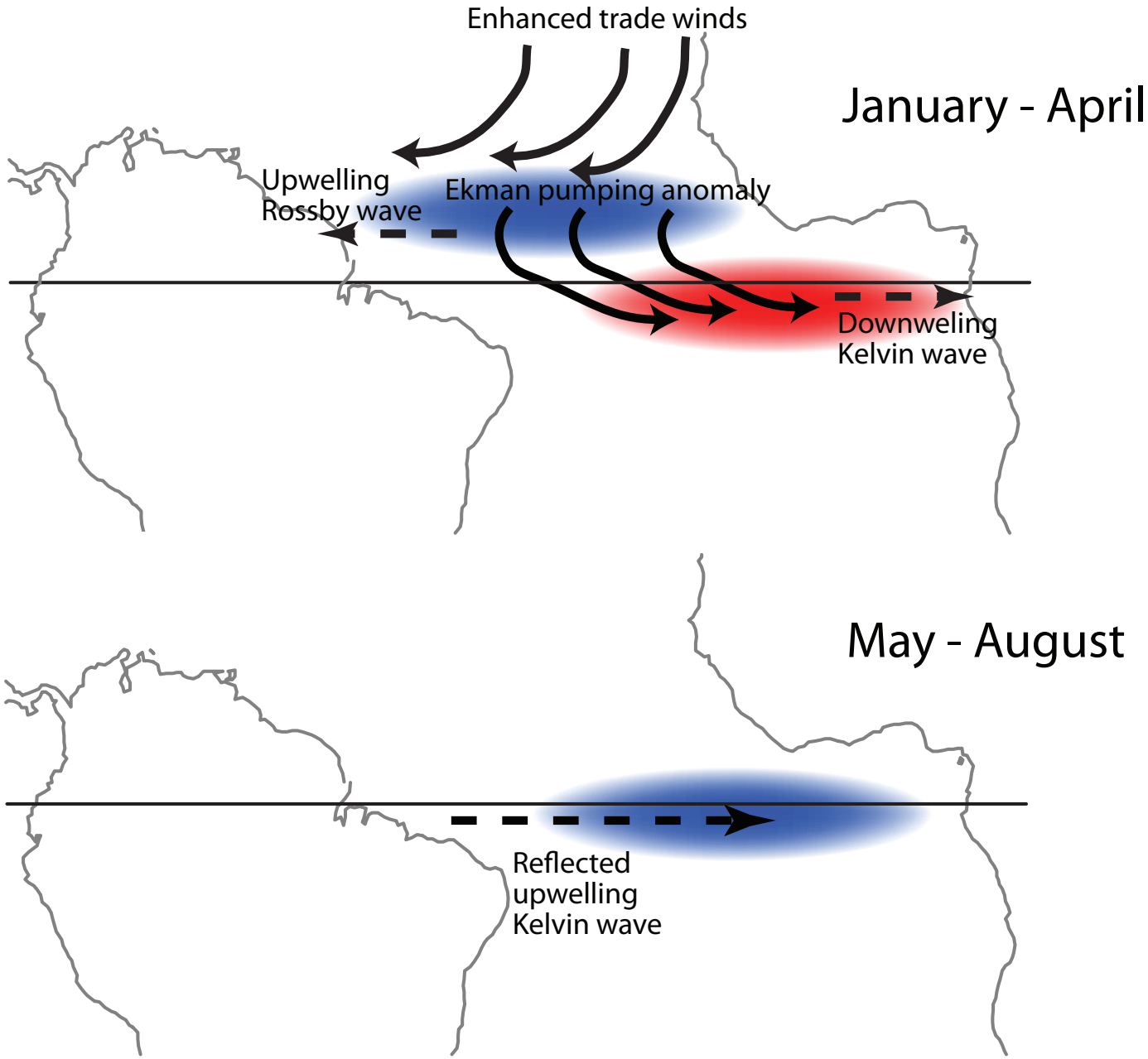
Reflected Kelvin wave contributes to anomalous cooling during June-August

Role of τ^y



- Anomalous southward shift of ITCZ contributes to anomalous Ekman pumping, upwelling Rossby wave

Summary


Enhanced trade winds
January - April
Upwelling
Rossby wave
Ekman pumping anomaly
Downweling
Kelvin wave
May - August
Reflected
upwelling
Kelvin wave

Conclusions

- Meridional mode interacts with the Niño mode through coupled wind-ocean dynamics-SST interactions. Wind-evap-SST interaction appears to be weaker and limited mainly to the western equatorial warm pool.

- Ekman pumping anomaly centered near 4°N and zonal wind anomaly on equator generate upwelling Rossby wave, which reflects into Kelvin wave and cools eastern equatorial SST with a lag of ~3 months.