Tropical Ocean-Atmosphere Interaction in a Regional Coupled High-Resolution GCM

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Outline

- Model Description; SCOAR Model

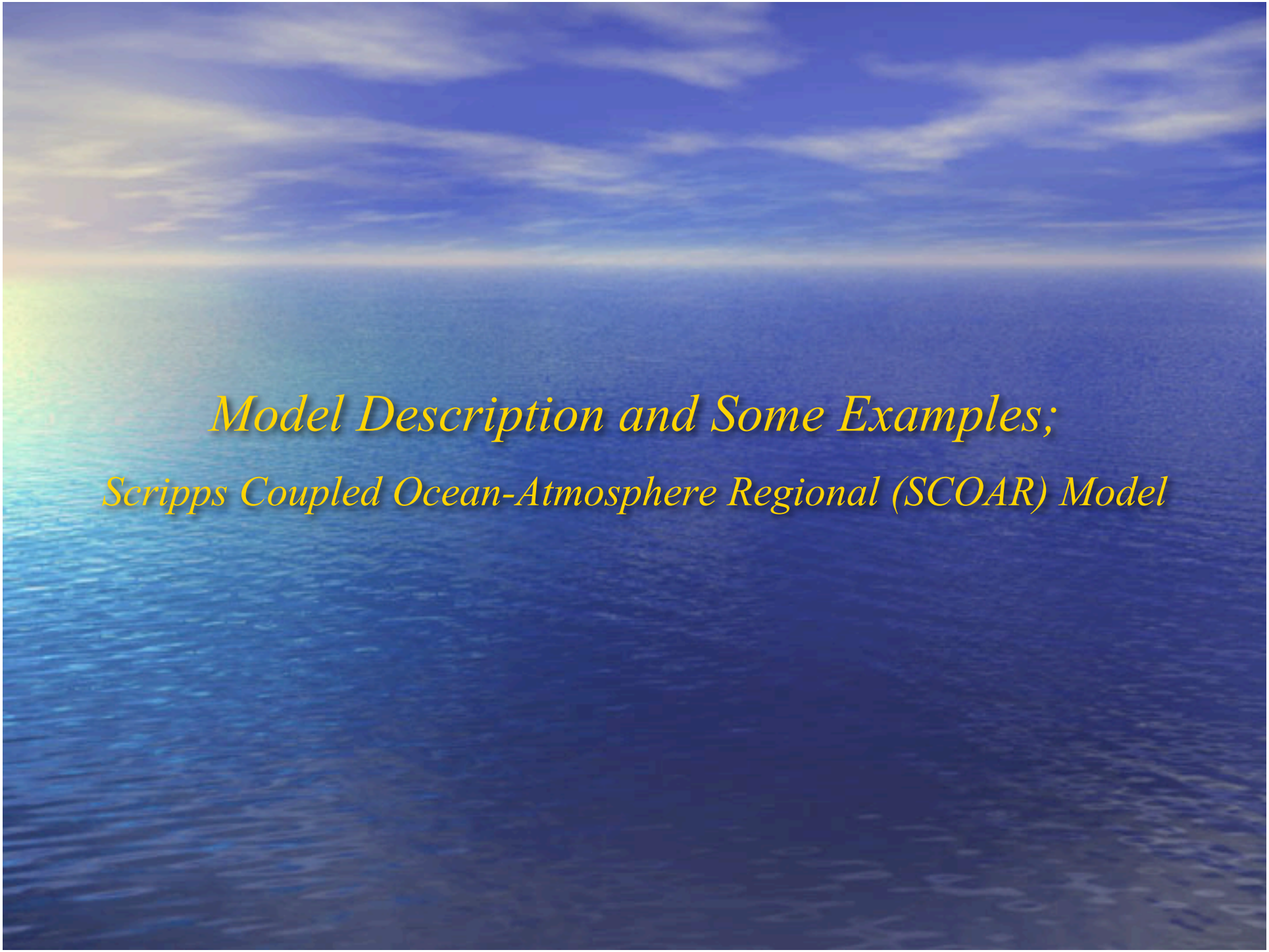
- **Part I; Air-Sea Coupling due to TIWs**
- In the Tropical *Pacific* Ocean;

  ➔ Atmospheric Boundary Layer Response to SST
- In the Tropical *Atlantic* Ocean;

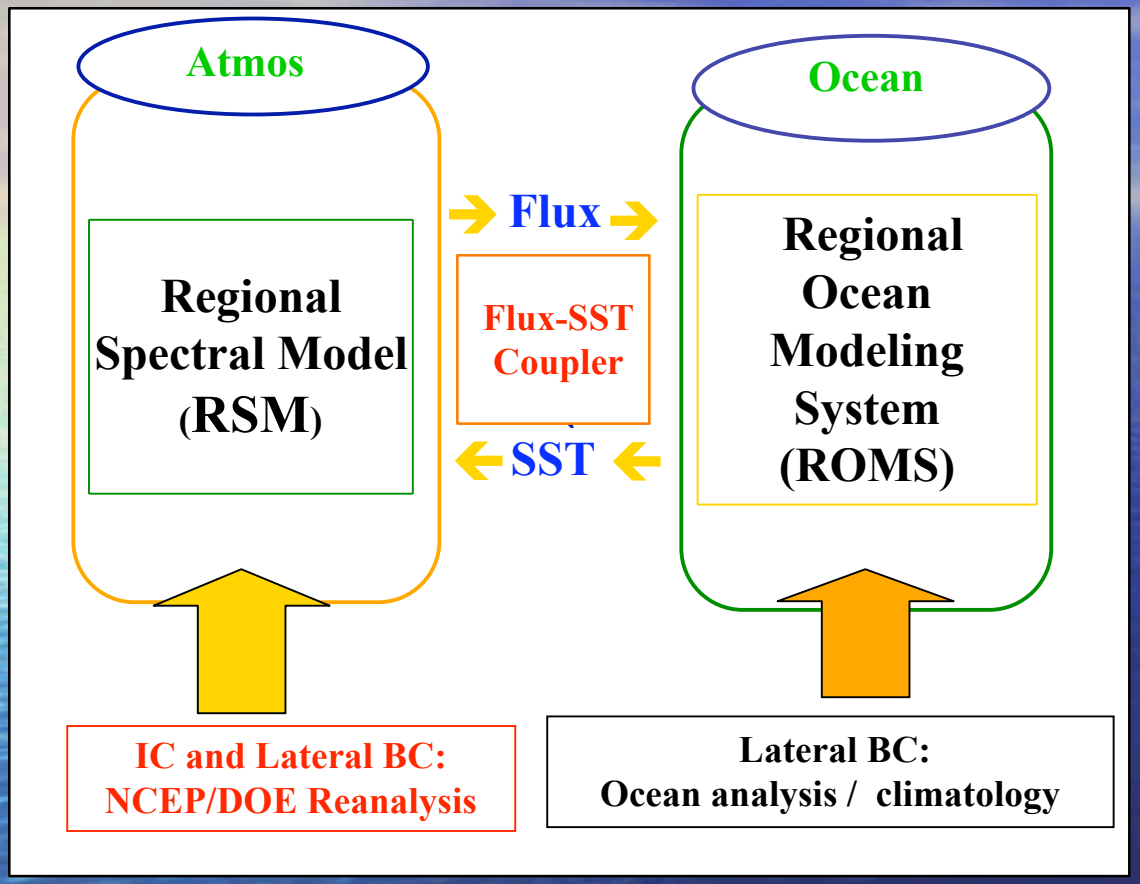
  ➔ Effect of Correlation of Wind and Surface Current; Negative Feedback.
- **Part II; Tropical Biases in the Model**

  ➔ Tropical Atlantic Biases in the Model; A Higher Model Resolution Improves Simulations.

- Summary


Model Description and Some Examples;
Scripps Coupled Ocean-Atmosphere Regional (SCOAR) Model

SCOAR Model (1)



- Bulk formula or RSM physics in ABL for momentum, heat and fresh-water fluxes
- Wind stress relative to ocean currents:

$$\tau = \rho C_d |U_a - U_o| (U_a - U_o)$$

- Various coupling frequency (3hrs, 1-day, 5-days..)

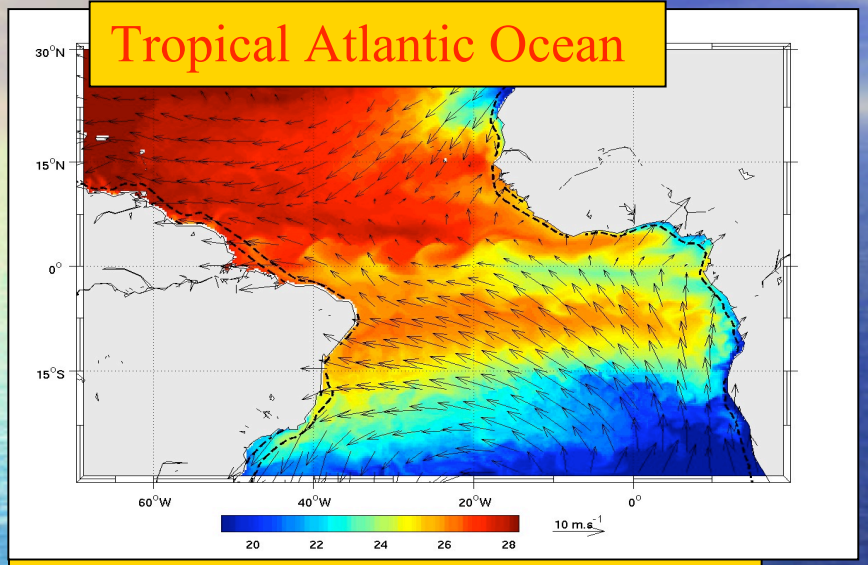
Purpose: Examine air-sea coupled feedback arising in the presence of ocean mesoscale eddies, fronts, and filaments.

Seo, Miller and Roads (2006)
J. Climate, in press

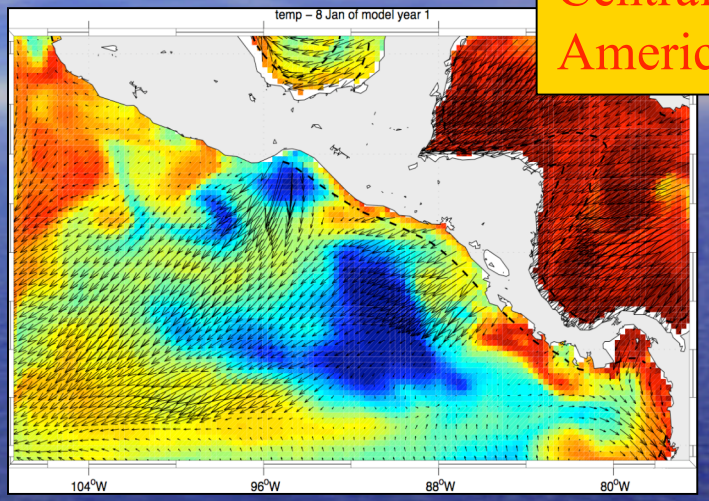
SCOAR Model (2)

It is now being used in various regions in the world ocean. Here are some examples…

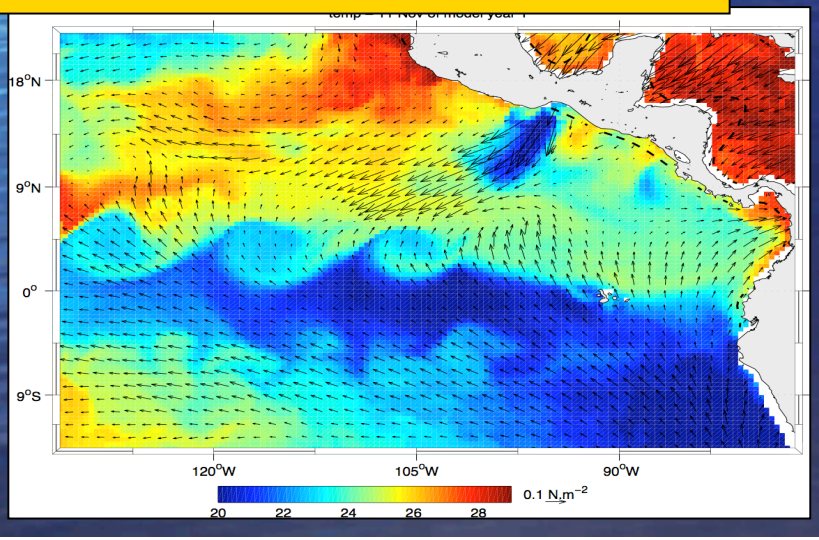
Tropical Atlantic Ocean



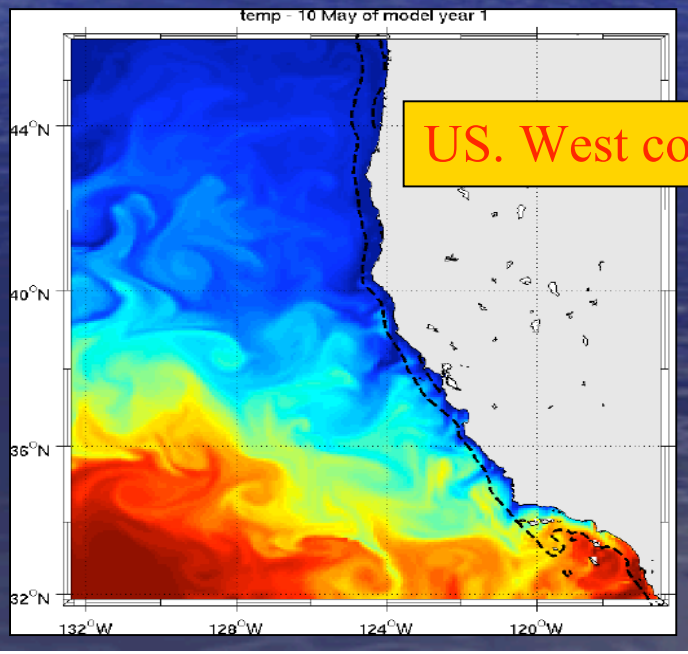
Central America



Eastern Tropical Pacific Ocean



US. West coast

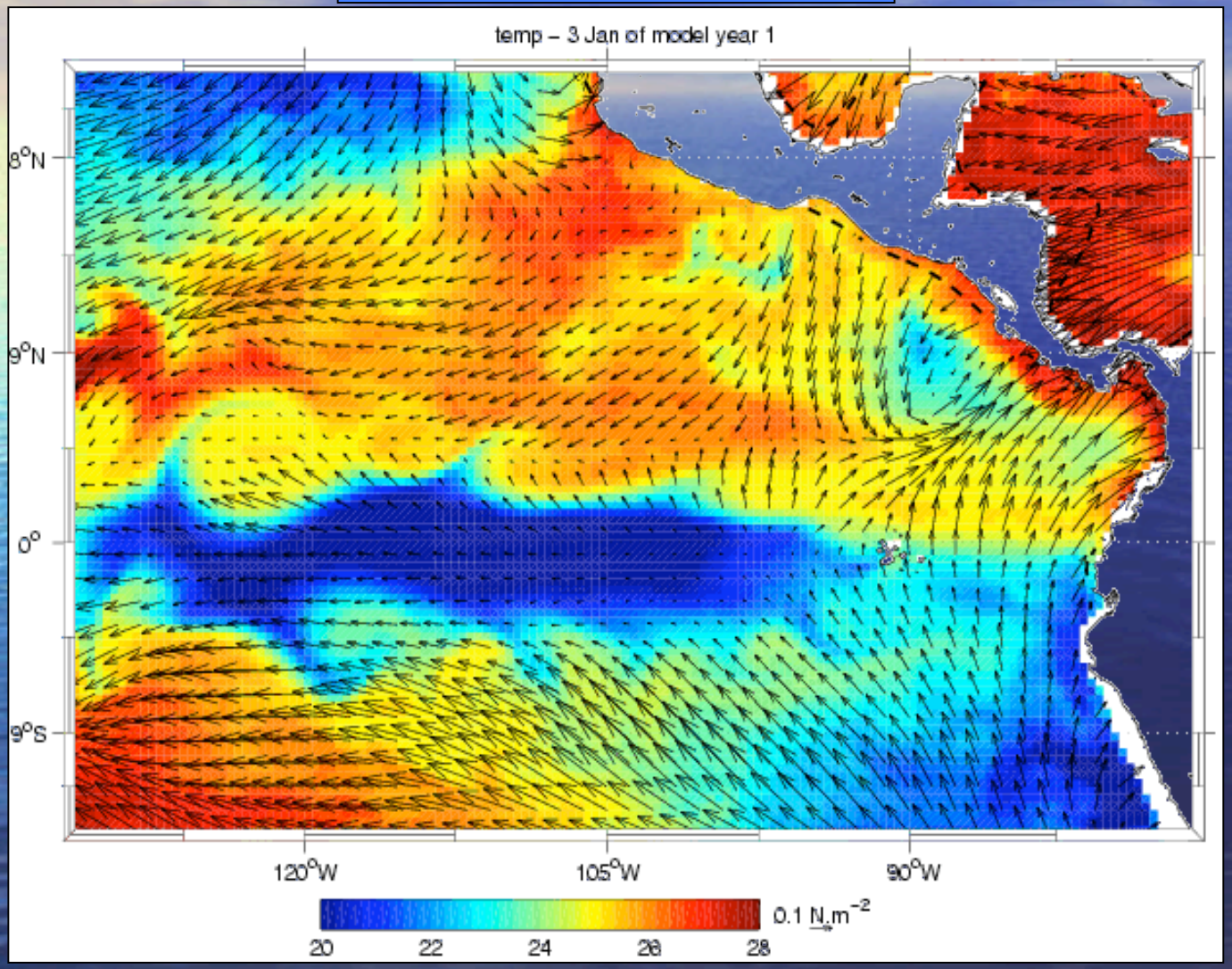



In the Eastern Tropical Pacific Ocean…
Response of Atmospheric Boundary Layer
to SST…

Eastern Equatorial Pacific Ocean Domain

Evolving SST and wind-stress vector in 1999-2000

45 km ROMS + 50 km RSM



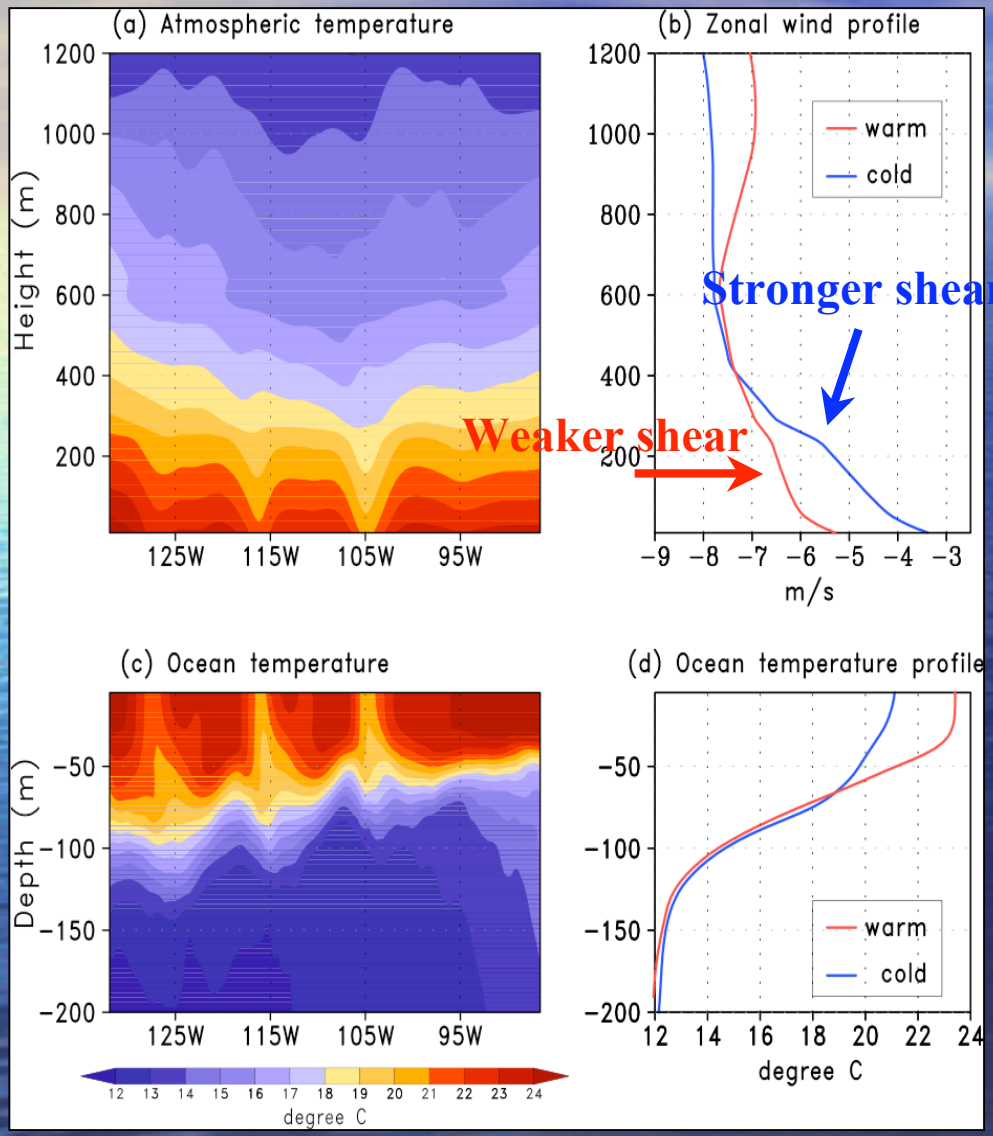
- **Coupled System**

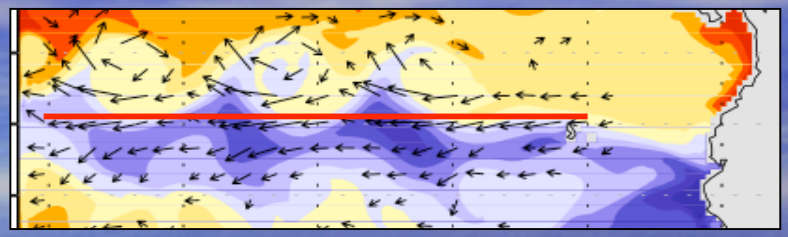
➔ *Gap Winds*

➔ Tropical Depressions and Hurricanes

➔ Tropical Instability Waves

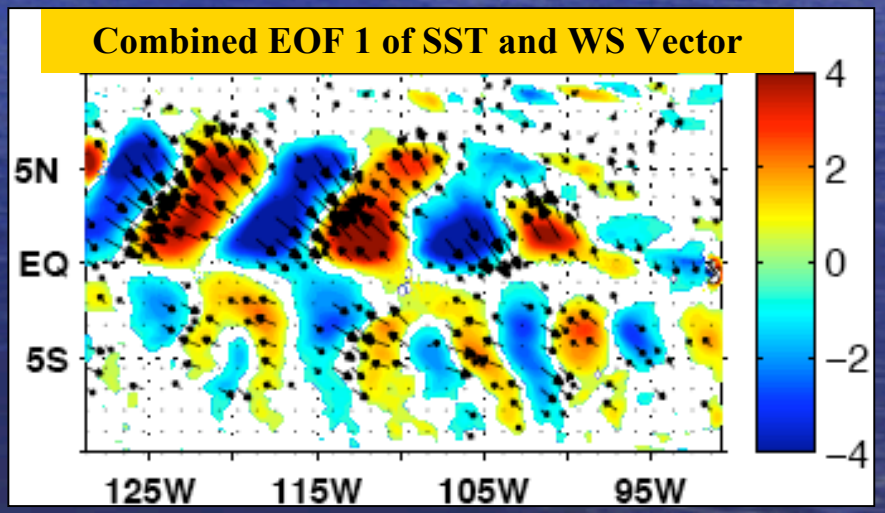
Atmospheric Stability Adjustment to the SST

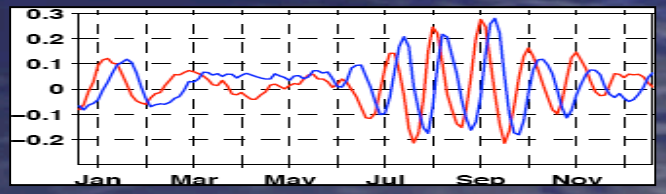




Weaker stratification of ABL over warm phase of TIWs.

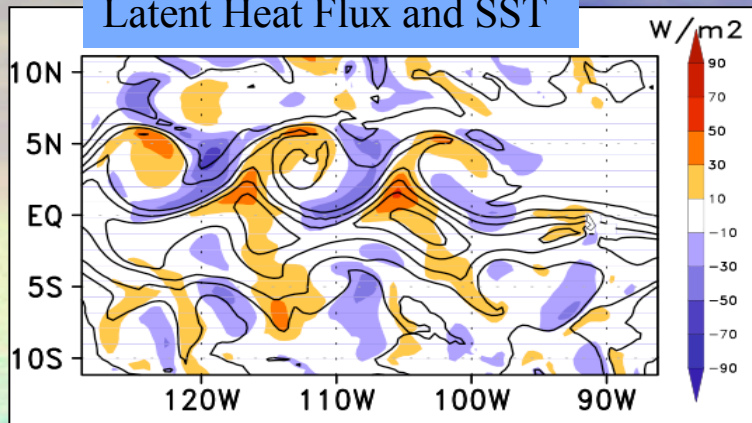
➔ Stronger wind near surface

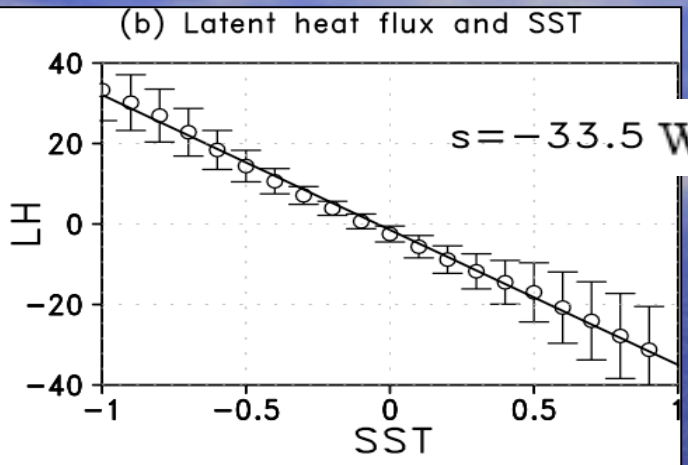




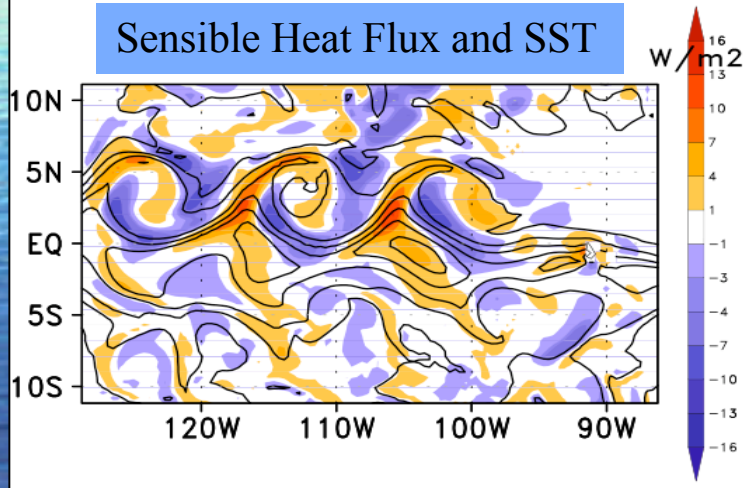
Coupling of SST and turbulent heat flux

Latent Heat Flux and SST

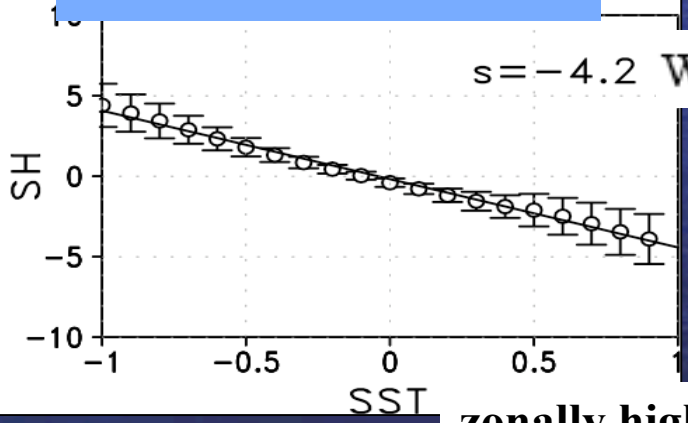




Sensible Heat Flux and SST



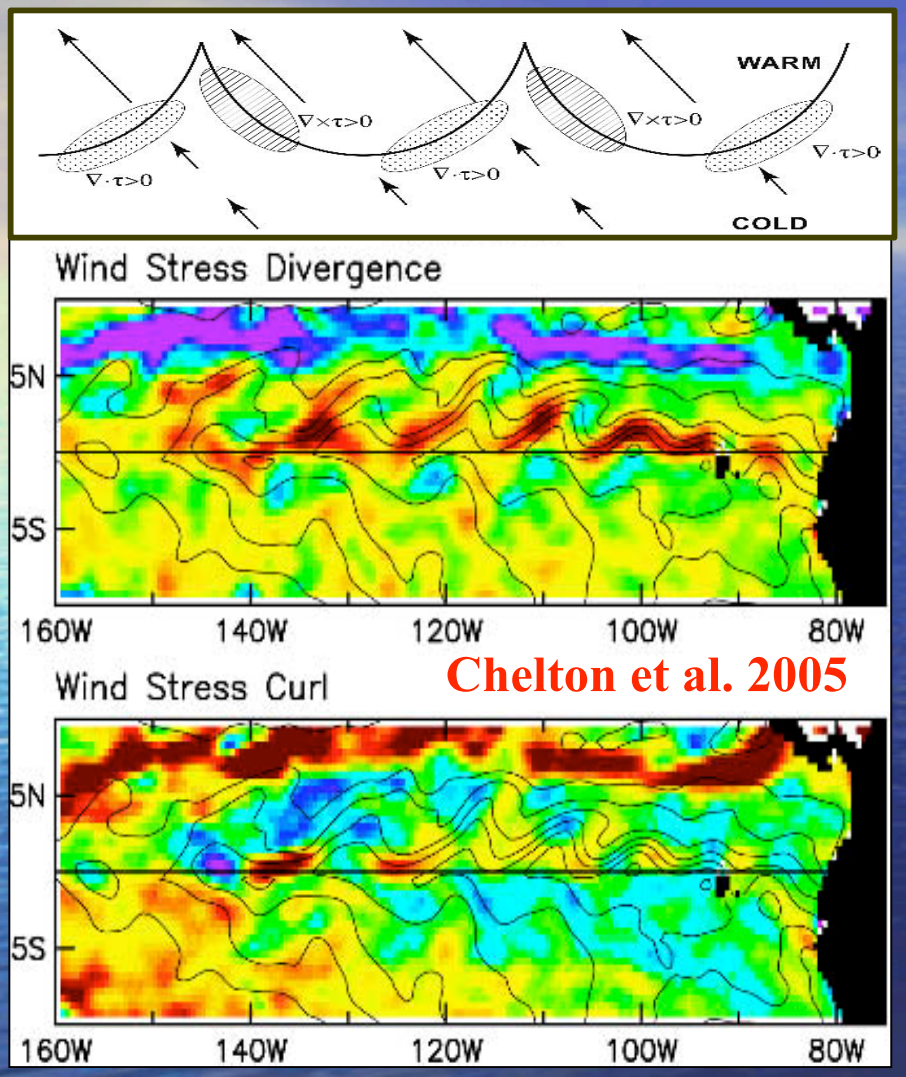
Observed: -40~-50 W/m²/K



zonally high-pass filtered SST and heat flux from 1999-2003

Evolving SST generates perturbations in turbulent heat flux (and also radiation flux).

Coupling of SST and wind stress

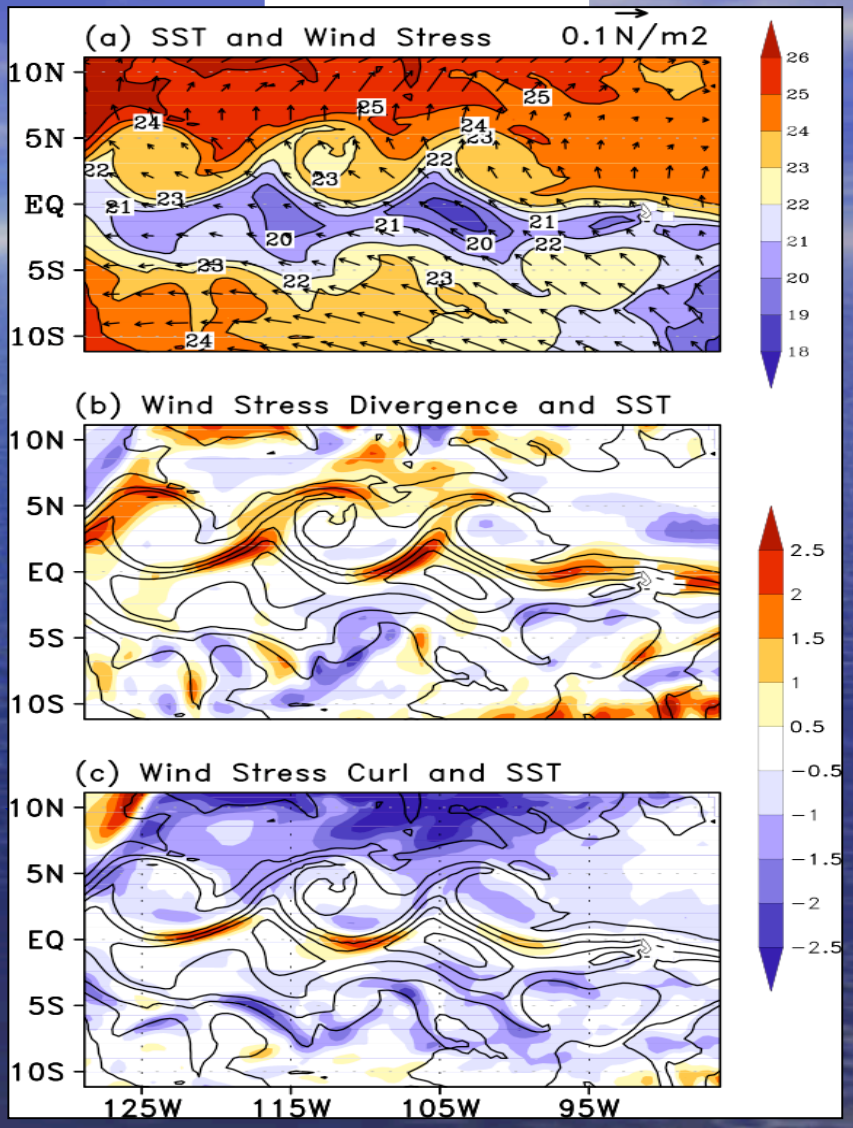


Chelton et al. 2005

$$\nabla T \bullet \hat{\tau} = |\nabla T| \cos\theta$$

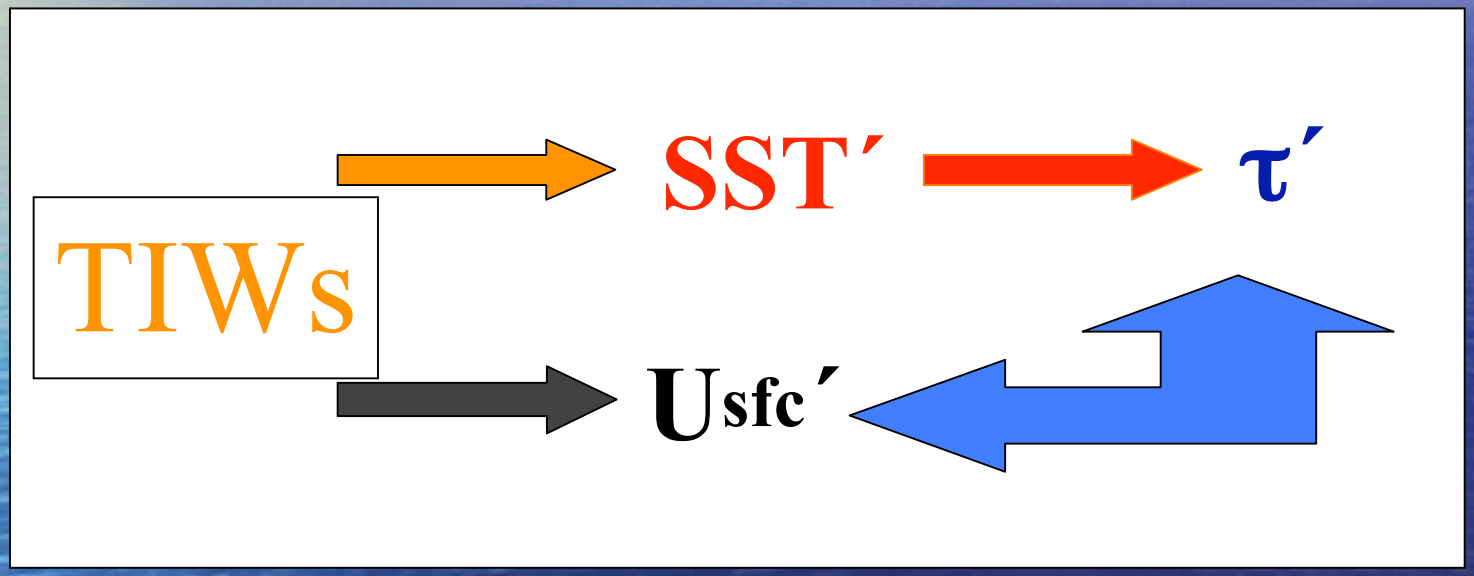
$$\nabla T \times \hat{\tau} \bullet \hat{k} = |\nabla T| \sin\theta$$

MODEL




Atmospheric Feedback?

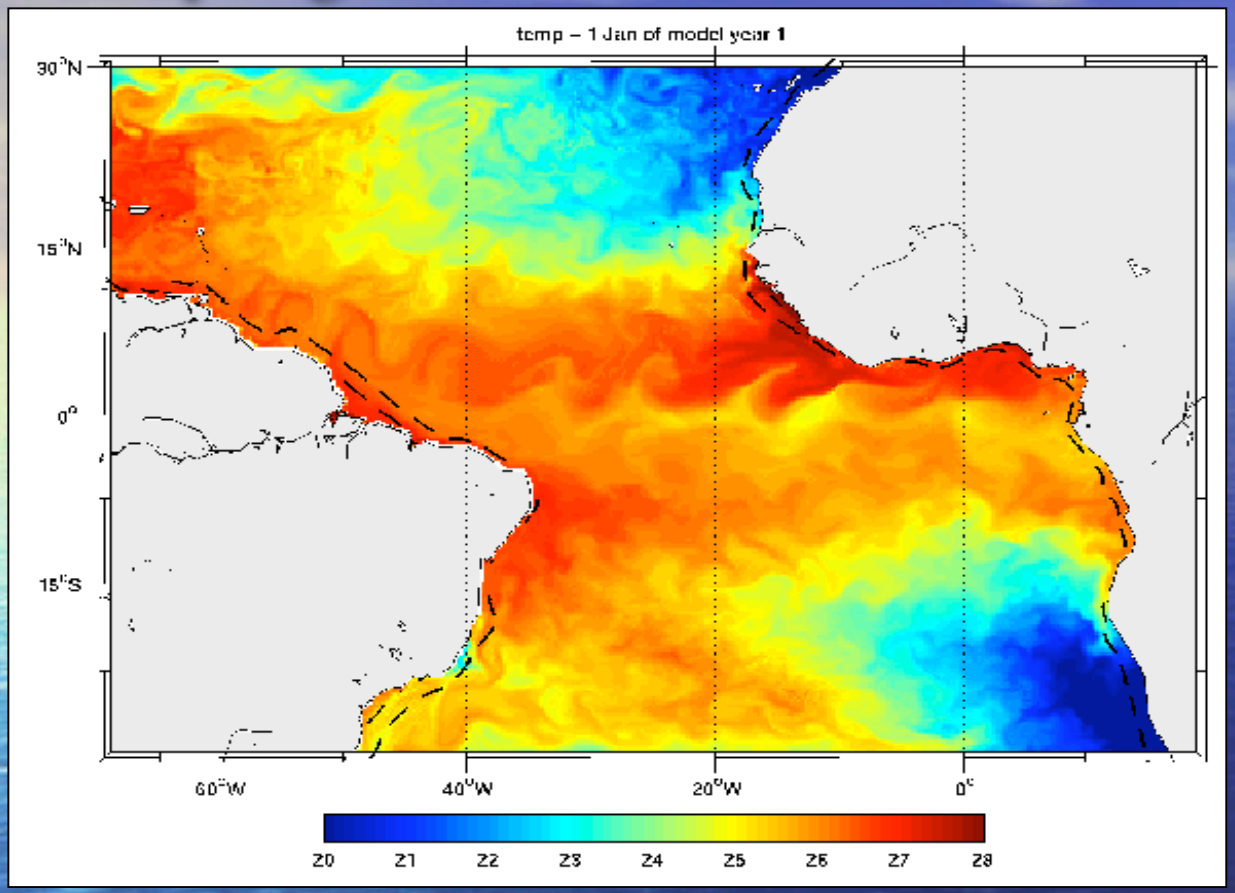
In the Atlantic Ocean...
Effect of Correlation of Wind and Surface Current on TIWs



$$\vec{\tau} = \vec{\tau_0} + \alpha\left(SST - \overline{SST}\right)$$

Pezzi et al. (2002, *GRL*) :
wind-SST coupling *slightly* reduces variability of TIWs.

Coupling of Wind and Current...



1/4° ROMS + 1/4° RSM

6-year simulations 1999-2004;

Effect of correlation of wind and current

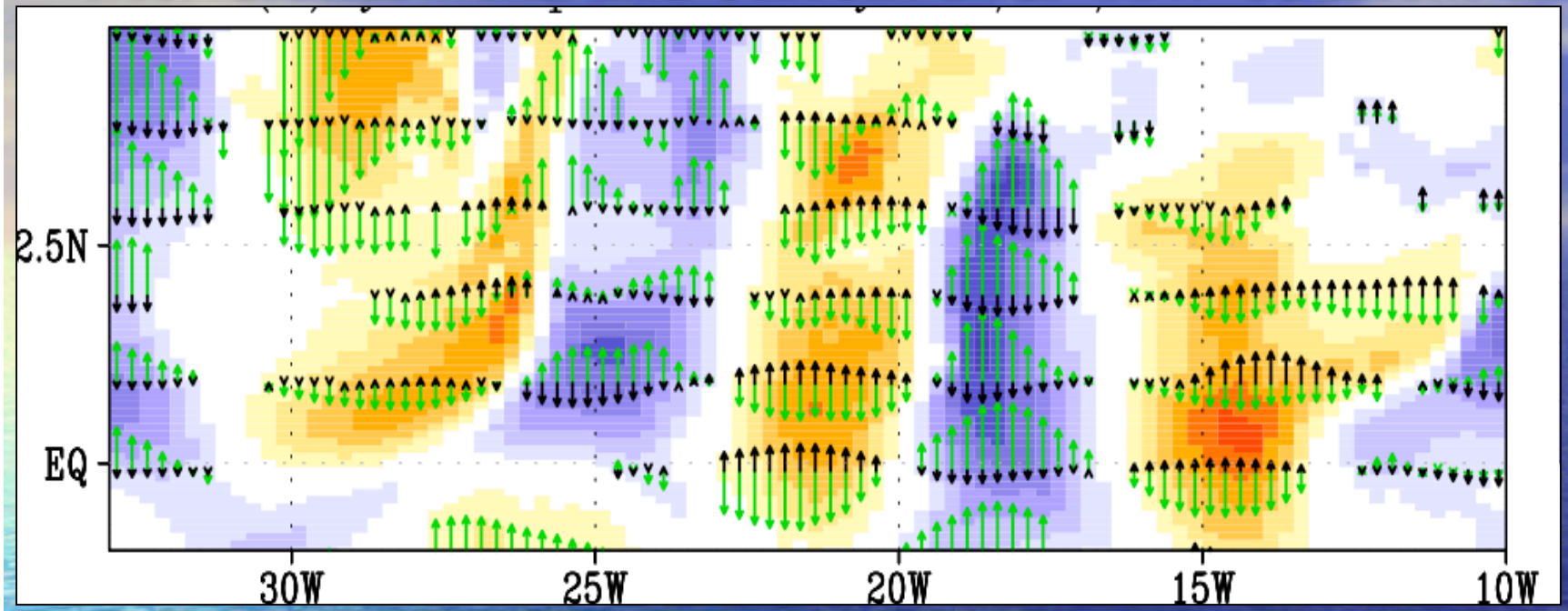
EKE Equation

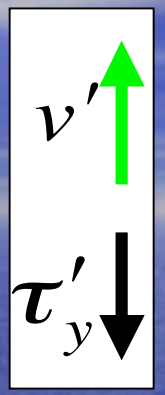
$$\vec{U}\cdot\vec{\nabla}\vec{K}_e + \vec{u}'\cdot\vec{\nabla}\vec{K}_e = -\vec{\nabla}\cdot(\vec{u}'p') - g\rho'w' + \rho_o(-\vec{u}'\cdot(-\vec{u}'\cdot\vec{\nabla}\vec{U}))$$

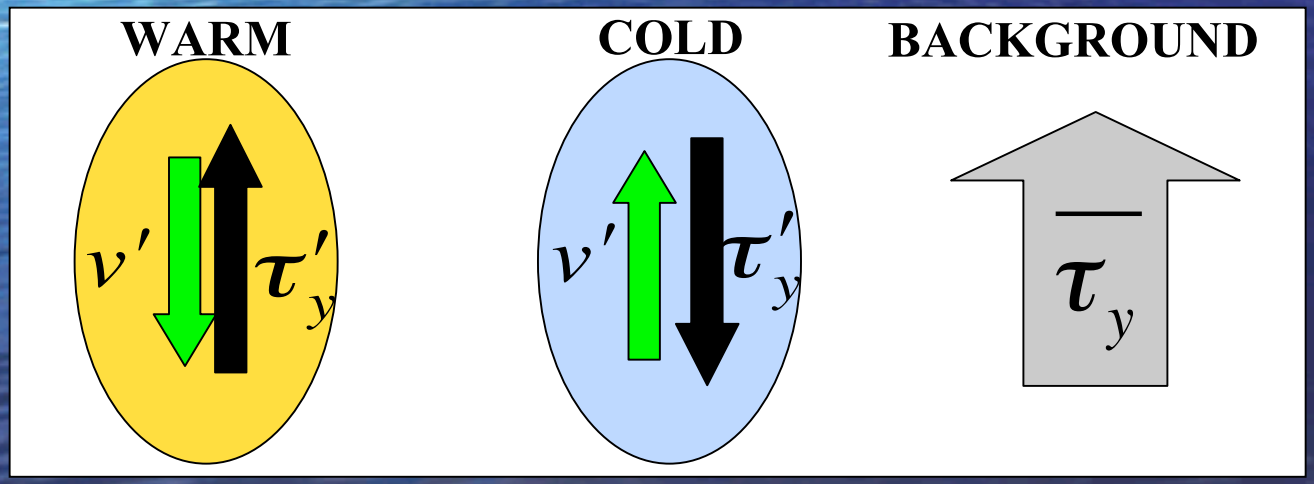
$$+\rho_o A_h \vec{u}'\cdot\nabla^2\vec{u}' + \rho_o\vec{u}'\cdot(A_v\vec{u}_z')_z + \vec{u}'\cdot\vec{\tau}_z'$$

Masina et al. 1999;
Jochum et al. 2004;

Meridional wind and current over TIW eddies...



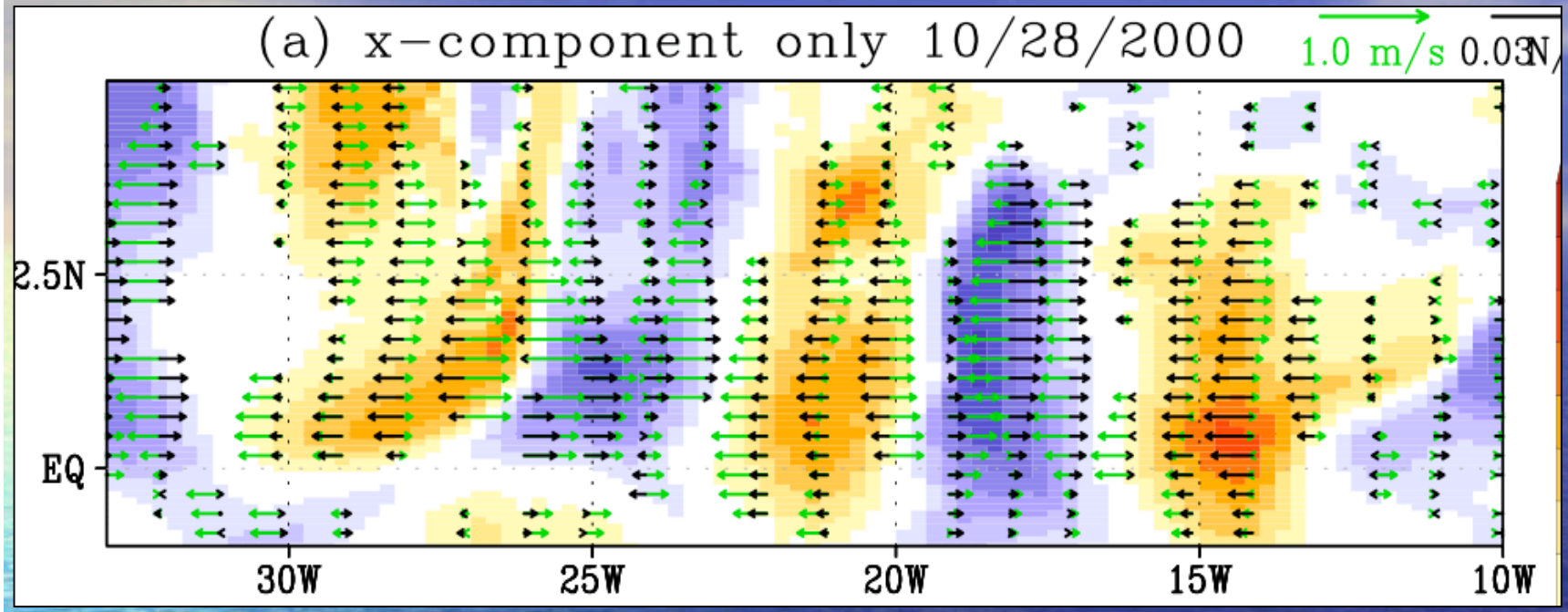




- Wind stress are in opposition of phase with current.

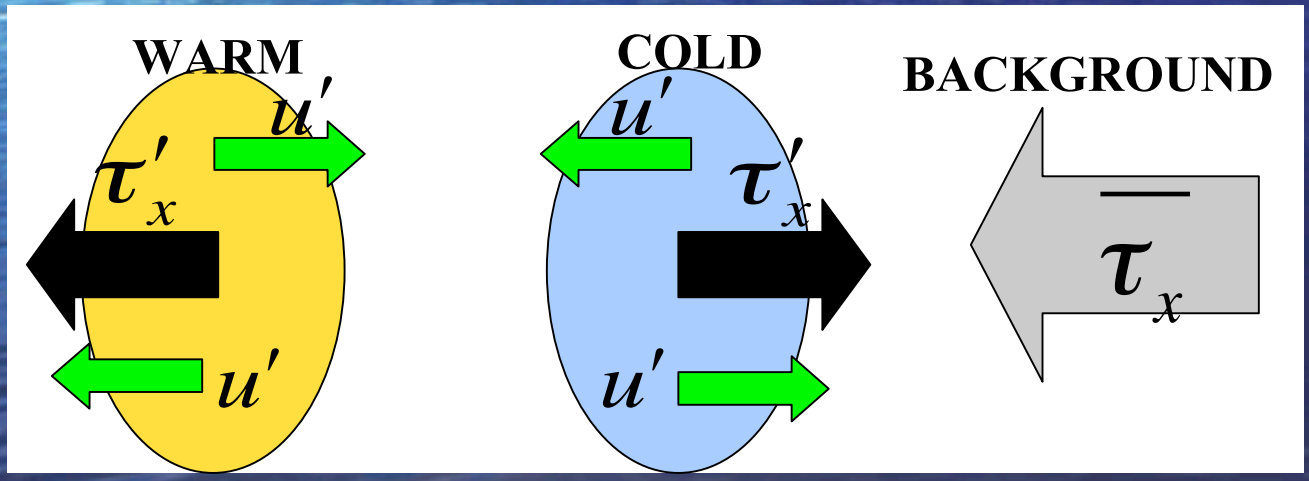
➔ *TIW current is slowed down by wind.*

Zonal wind and current over TIW eddies...



u'

τ'_x

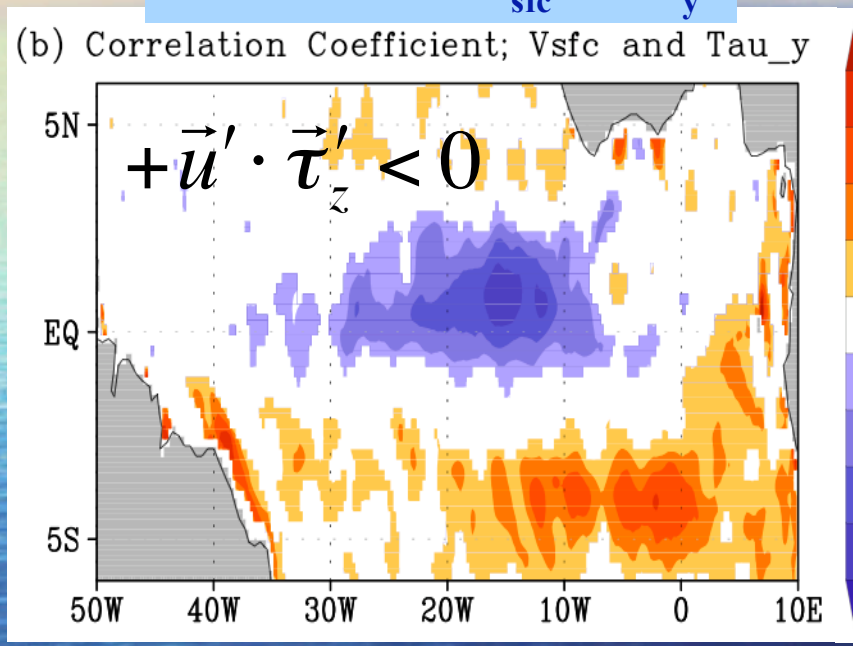


North: opposite → (-) CORR

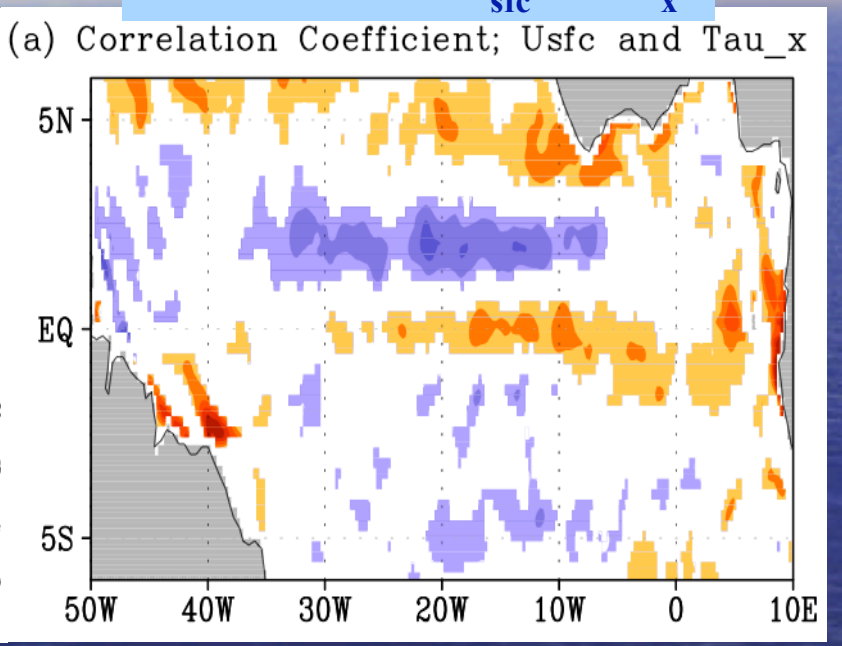
South: aligned → (+) CORR

Correlation of wind and current (95%)

Correlation of v_{sfc} and τ_y



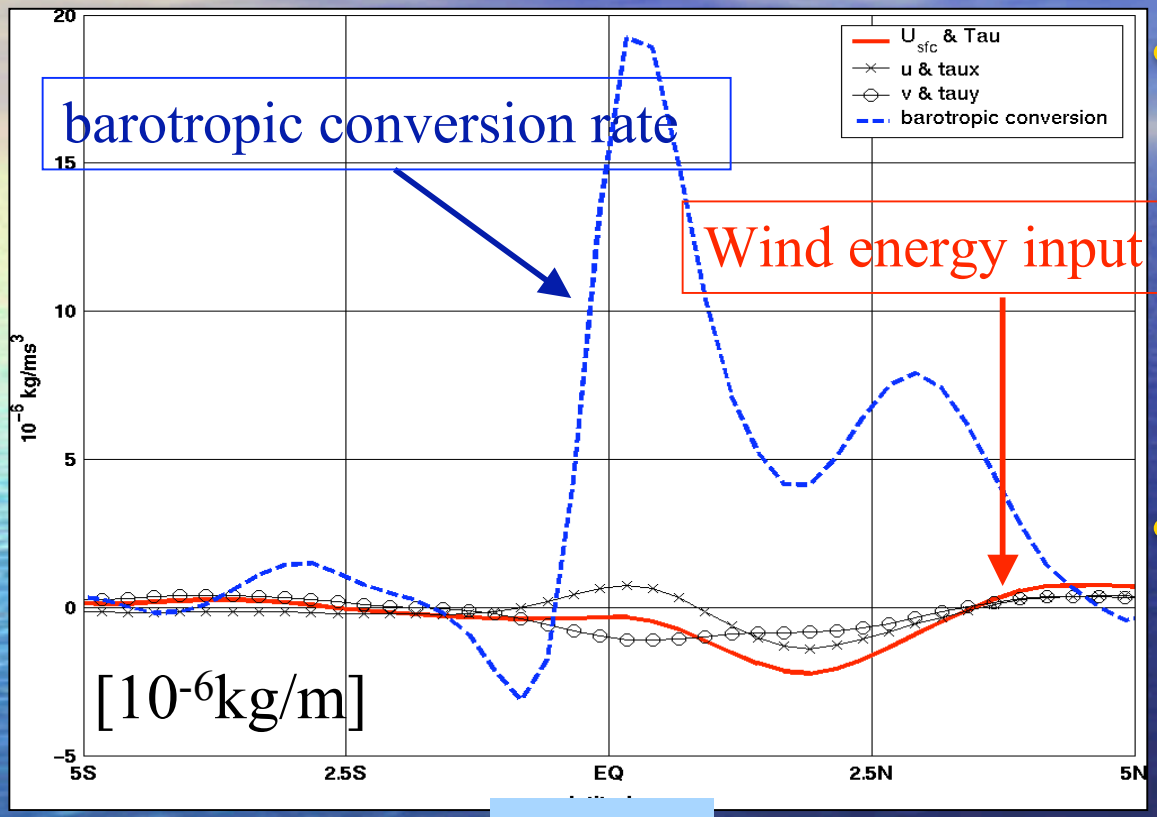
Correlation of u_{sfc} and τ_x



- Wind and current are negatively correlated over TIW region.
- Wind-current coupling → energy sink to the TIWs.

Estimated energy via coupling of wind and current

Averages over 30°W-10°W for 6 years.



- At ~2°N, wind contribution to the TIWs amounts to roughly ~40% of the barotropic convergent rate term...
- Integrated over TIW region, the contribution can be roughly ~10%.

$$\vec{U}\cdot\vec{\nabla}\vec{K}_e + \vec{u}'\cdot\vec{\nabla}\vec{K}_e = -\vec{\nabla}\cdot(\vec{u}'p') - g\rho'w' + \rho_o(-\vec{u}'\cdot(-\vec{u}'\cdot\vec{\nabla}\vec{U}))$$
$$+\rho_o A_h\vec{u}'\cdot\nabla^2\vec{u}' + \rho_o\vec{u}'\cdot(A_v u_z')_z + \vec{u}'\cdot\vec{\tau}_z'$$

Conclusion; Part I (Coupling due to TIWs)

- Coupled model well captures observed associations between undulating SST front and ABL.

1. Stability adjustment of the ABL due to SST changes vertical turbulent mixing of momentum, thus changes near-surface wind.

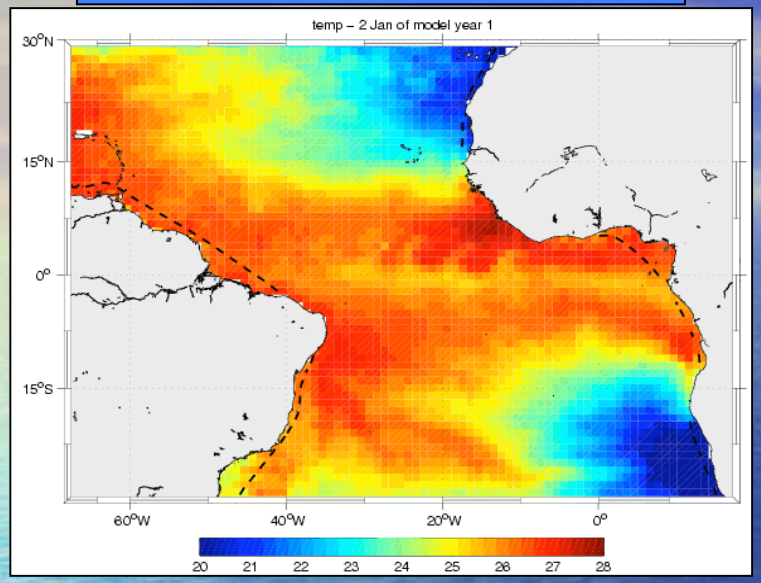
- ➔ This generates perturbation heat flux and wind stress in phase with SST.
- ➔ It thus implies further feedback to TIWs in terms of heat flux and wind stress.

2. Wind stress anomaly generated by SST of TIWs in turn slows down the TIW currents; a negative correlation indicates that coupling of wind and current acts as an EKE sink to the TIWs (≈ Pezzi et al. 2002)

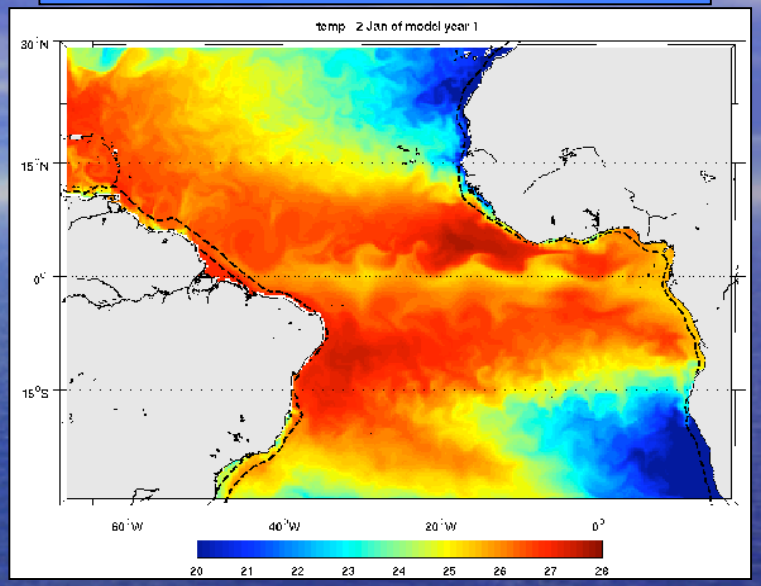

In the Atlantic Ocean...
Effect of Model Resolution on the Tropical Biases

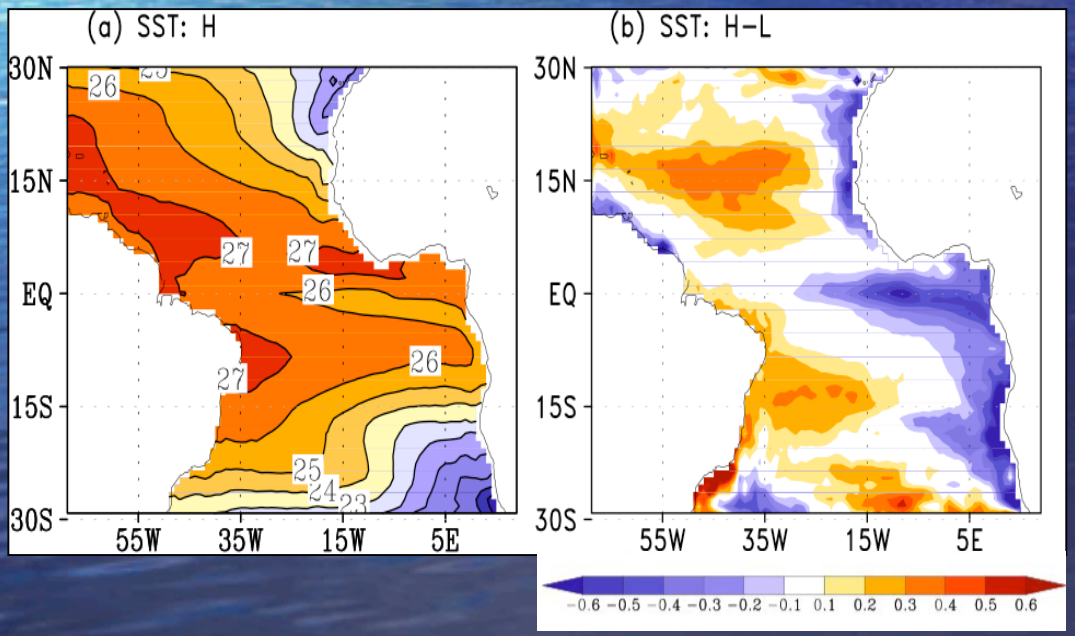
Improving Mean SST

LL: 1° ROMS + 1° RSM



HL: 1/4° ROMS + 1° RSM

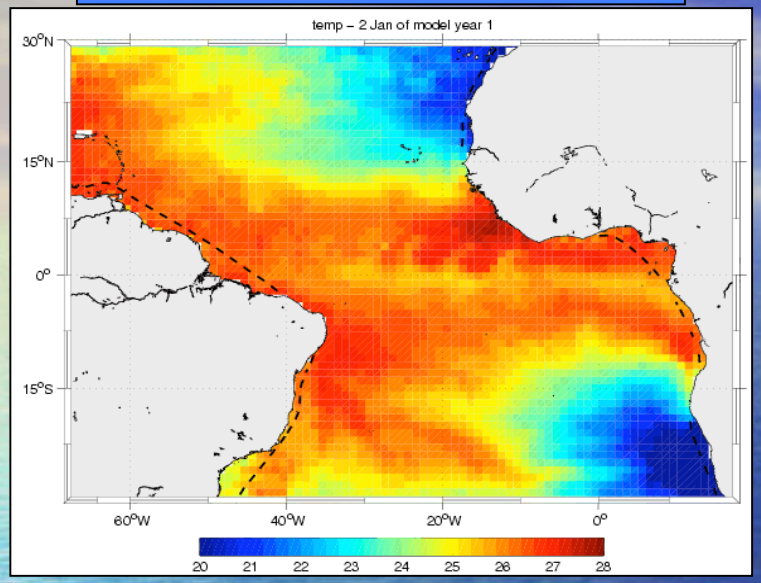




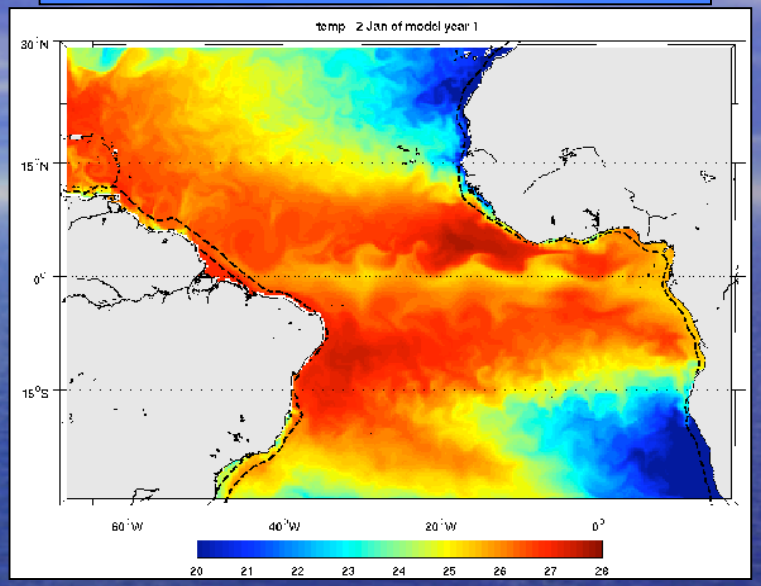
- 6-year mean from 1999-2004
- Resolving oceanic mesoscale features improves simulation of Tropical Atlantic Climate (*Seo et al. GRL 2006*).

Further Improving mean SST....

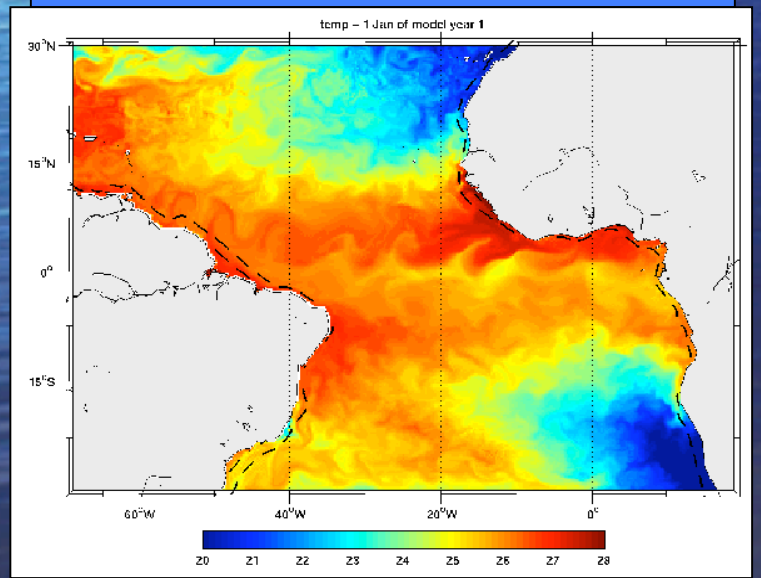
LL: 1° ROMS + 1° RSM



HL: 1/4° ROMS + 1° RSM



HH: 1/4° ROMS + 1/4° RSM

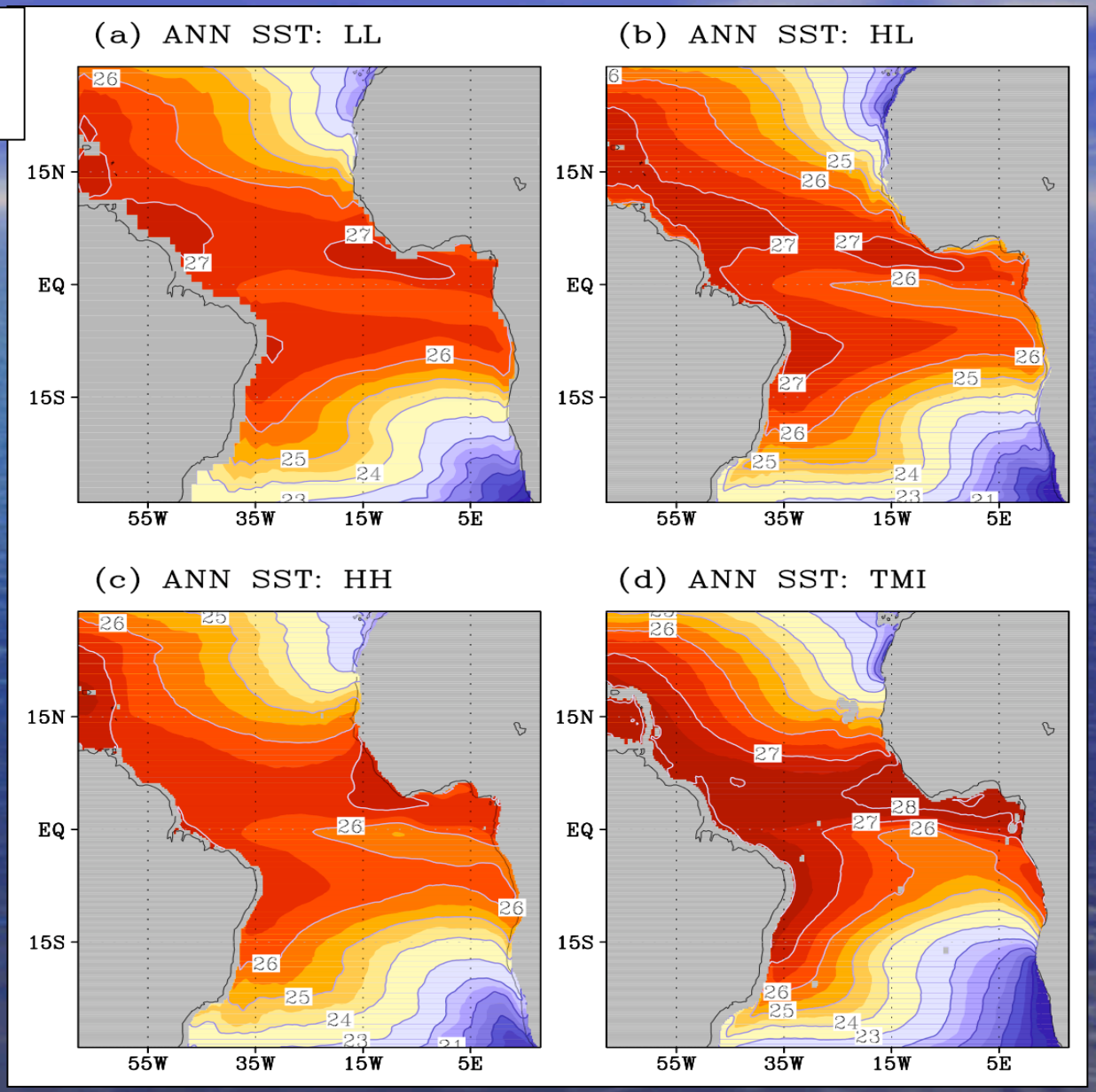


- Toward more realistic simulation with the identical 1/4° resolutions in the ocean and atmosphere;
- Allows ocean-atmosphere feedback on ocean mesoscales and also expects an improvement in rainfall.

Biases of mean SST in the model

6-year mean SST from 1999-2004

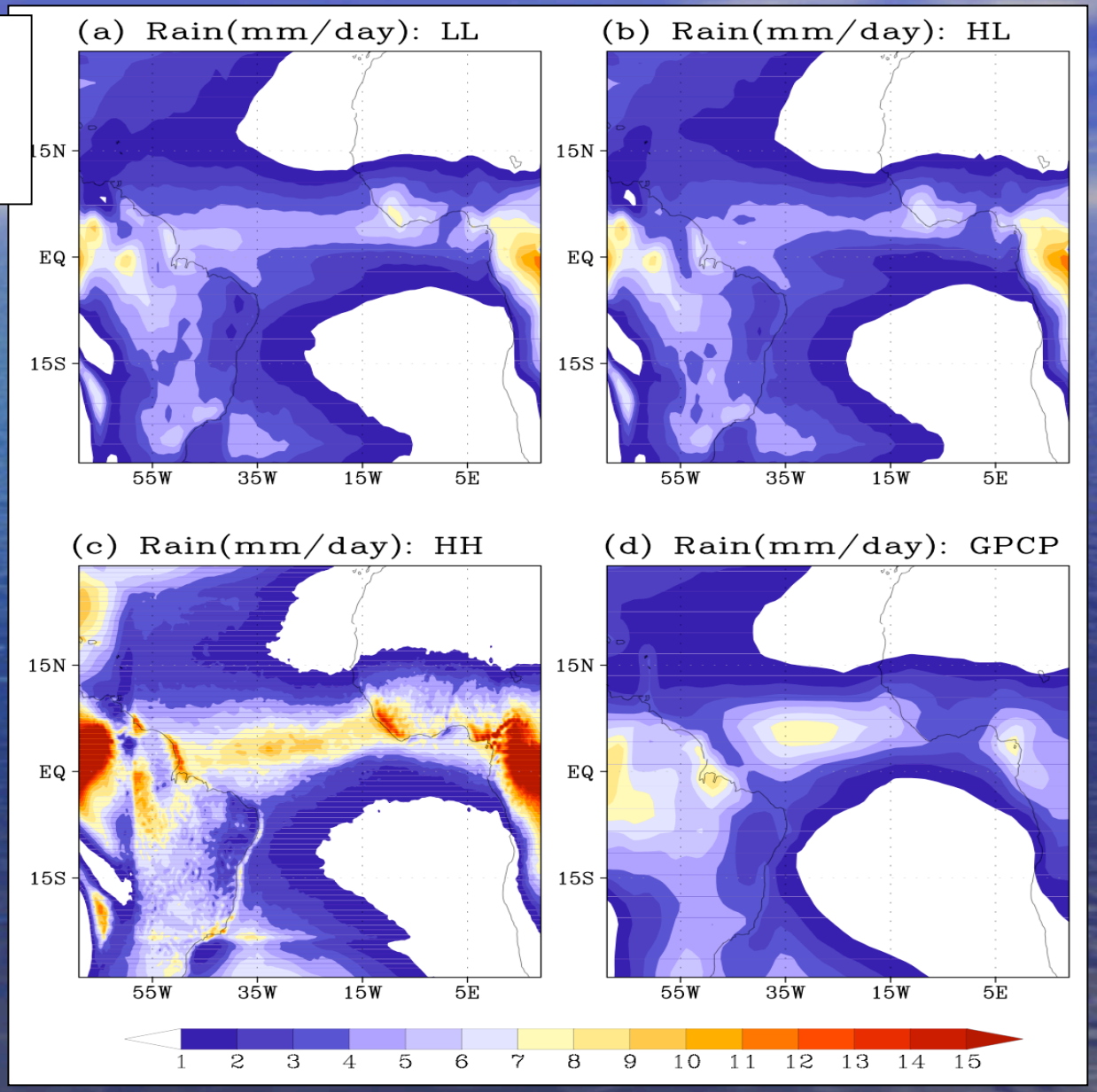
- Increasing model resolutions in the coupled model yields a further improvement in mean SST, in particular, of a spurious warm pool south of Equator.



Also improved the mean precipitation...

6-year mean rainfall (mm/day) from 1999-2004

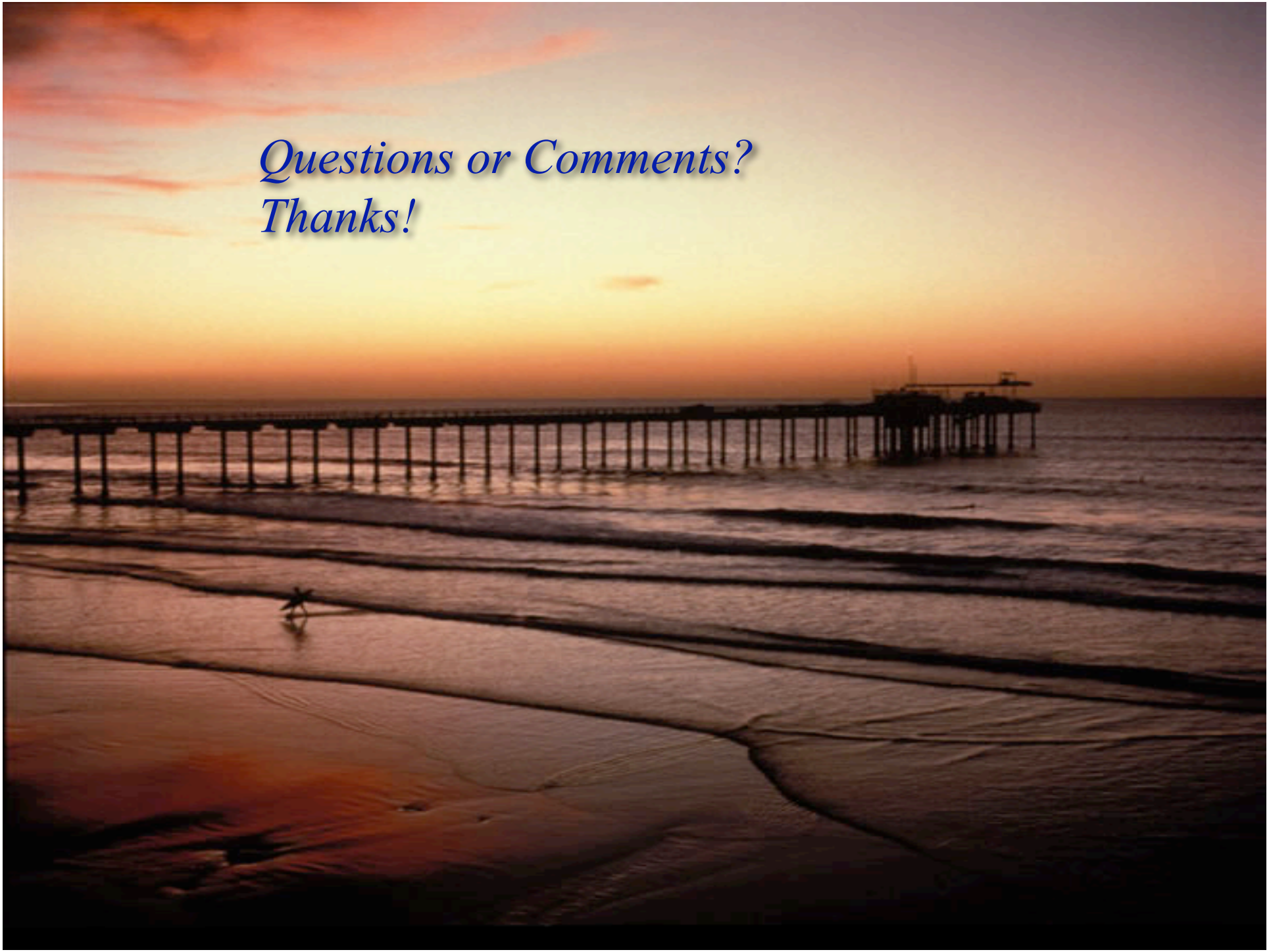
- Increasing RSM resolution yields a more realistic precipitation and mean ITCZ.



Conclusion; Part II (Tropical Bias in the Model)

- Increasing ocean resolution to resolve mesoscale features reduces the warm bias at the coastal upwelling regions (~0.6°C).
- ➔ *Ocean mesoscale feature does matter in the mean SST in the tropical Atlantic Ocean.*

- Increasing atmospheric resolution to match the fine ocean grid further improves SST by cooling warm ridge south of equator.
- Mean precipitation and marine ITCZ compare better with OBS.
- ➔ *Atmospheric resolution in a coupled model is important in improving simulation of ITCZ.*


Questions or Comments?
Thanks!

Extra; Mean SST and Wind