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

Hyodae Seo
Scripps Institution of Oceanography

Art Miller, John Roads (SIO)
Markus Jochum (NCAR)
Ragu Murtugudde (Maryland)

NCAR CGD Seminar
August 23, 2006
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
Purpose: Examine air-sea coupled feedback arising in the presence of ocean mesoscale eddies, fronts, and filaments.

- **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..)

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
- Eastern Tropical Pacific Ocean
- Central America
- 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

Stronger shear

Weaker shear

Combined EOF 1 of SST and WS Vector

Warm
Cold
Coupling of SST and turbulent heat flux

Latent Heat Flux and SST

Sensible Heat Flux and SST

Observed: -40~50 W/m²/K

Evolving SST generates perturbations in turbulent heat flux (and also radiation flux).
Coupling of SST and wind stress

\[ \nabla T \cdot \tau = |\nabla T| \cos \theta \]
\[ \nabla T \times \tau \cdot k = |\nabla T| \sin \theta \]

Chelton et al. 2005

MODEL
Atmospheric Feedback?
In the Atlantic Ocean...

Effect of Correlation of Wind and Surface Current on TIWs

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

\[
\bar{U} \cdot \nabla \bar{K}_e + \bar{u}' \cdot \nabla \bar{K}_e = -\nabla \cdot (\bar{u}' p') - g \rho' w' + \rho_o (-\bar{u}' \cdot (-\bar{u}' \cdot \nabla \bar{U})) + \rho_o A_h \bar{u}' \cdot \nabla^2 \bar{u}' + \rho_o \bar{u}' \cdot (A_v \bar{u}') + \bar{u}' \cdot \bar{\tau}'
\]

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

\[1/4^\circ \text{ ROMS} + 1/4^\circ \text{ RSM}\]

6-year simulations 1999-2004;

Effect of correlation of wind and current
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...

(a) x-component only 10/28/2000

North: opposite ➔
(-) CORR

South: aligned ➔
(+) CORR
Correlation of wind and current (95%)

- Wind and current are **negatively** correlated over TIW region.
- Wind-current coupling \(\Rightarrow\) **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%.

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

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

6-year mean SST from 1999-2004
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

(a) SST: H
(b) SST: H–L

(a) Wind: H, 20m/s
(b) Wind: H–L, 1 m/s