The improvement of the simulated SST seasonal cycle in the equatorial eastern Pacific by surface wave-induced vertical mixing

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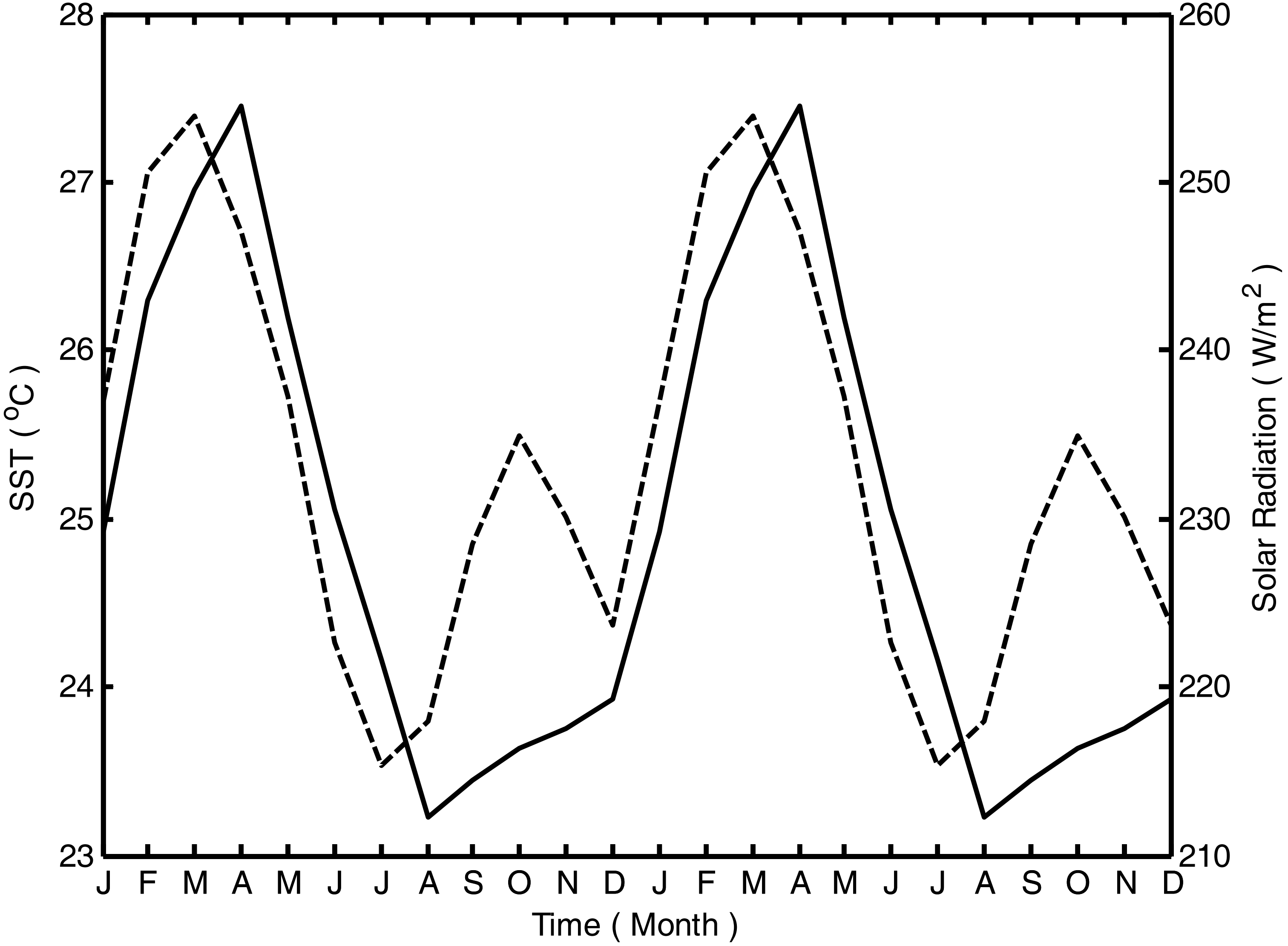
1. Introduction



The seasonal cycle in the equatorial eastern Pacific (110° W-90° W, 5° S-5° N).
Solid line, SST; Dashed line, Shortwave Radiation

The spuriously semiannual SST cycle in EP

eraged over the annual cycle. In the coastal region adjacent to South America, CCSM3 overestimates the SST by 1.8°C. While earlier generations of CCSM overestimated the surface insolation off South America by more than 50 W m^{-2} in the annual mean, CCSM3 tends to slightly underestimate the surface shortwave flux. The much smaller error in insolation results from several modifications to the cloud parameterizations introduced in CCSM3 (Boville et al. 2006) partly to address this issue. The observational comparison suggests that the alongshore surface stress in CCSM3 may still be too weak, and this may partially explain the 1.8°C error in SST. It should be noted that the surface stress produced by CCSM3 is stronger than that in CCSM2 by up to 0.1 N m^{-2}, partly because of the increased resolution in the atmosphere (Hack et al. 2006). In the case of Africa, CCSM3 underestimates the SST by 3.5°C even though it produces a realistic alongshore stress and slightly underestimates the surface insolation. The effects of other physical processes, including ocean upwelling, on the SST biases are examined further in Large and Danabasoglu (2006).

e. The semiannual SST cycle in the eastern Pacific

CCSM3 produces a fairly strong semiannual cycle for SST in the eastern tropical Pacific that does not occur in the real climate system (Large and Danabasoglu 2006). The region where this discrepancy is particularly evident lies between 5°N–5°S and 110°–90°W. An observational climatology for the seasonal cycle in SST for this region can be derived from the Hadley Centre's sea surface temperature dataset (HadISST) (Rayner et al. 2003). The annual and regional mean temperature from CCSM3 is 25.5°C, and this compares well with the HadISST estimate of 25.2°C. However, the simulated and observed seasonal cycles in the regional mean SST are quite different. The CCSM3-simulated annual cycle has a sine-wave amplitude roughly half that observed and is phased 1.4 months late, while the sine-wave amplitude of the semiannual cycle is roughly twice that observed. The causes for these systematic biases in the model physics have not yet been identified.

f. Underestimation of downwelling shortwave radiation in the Arctic

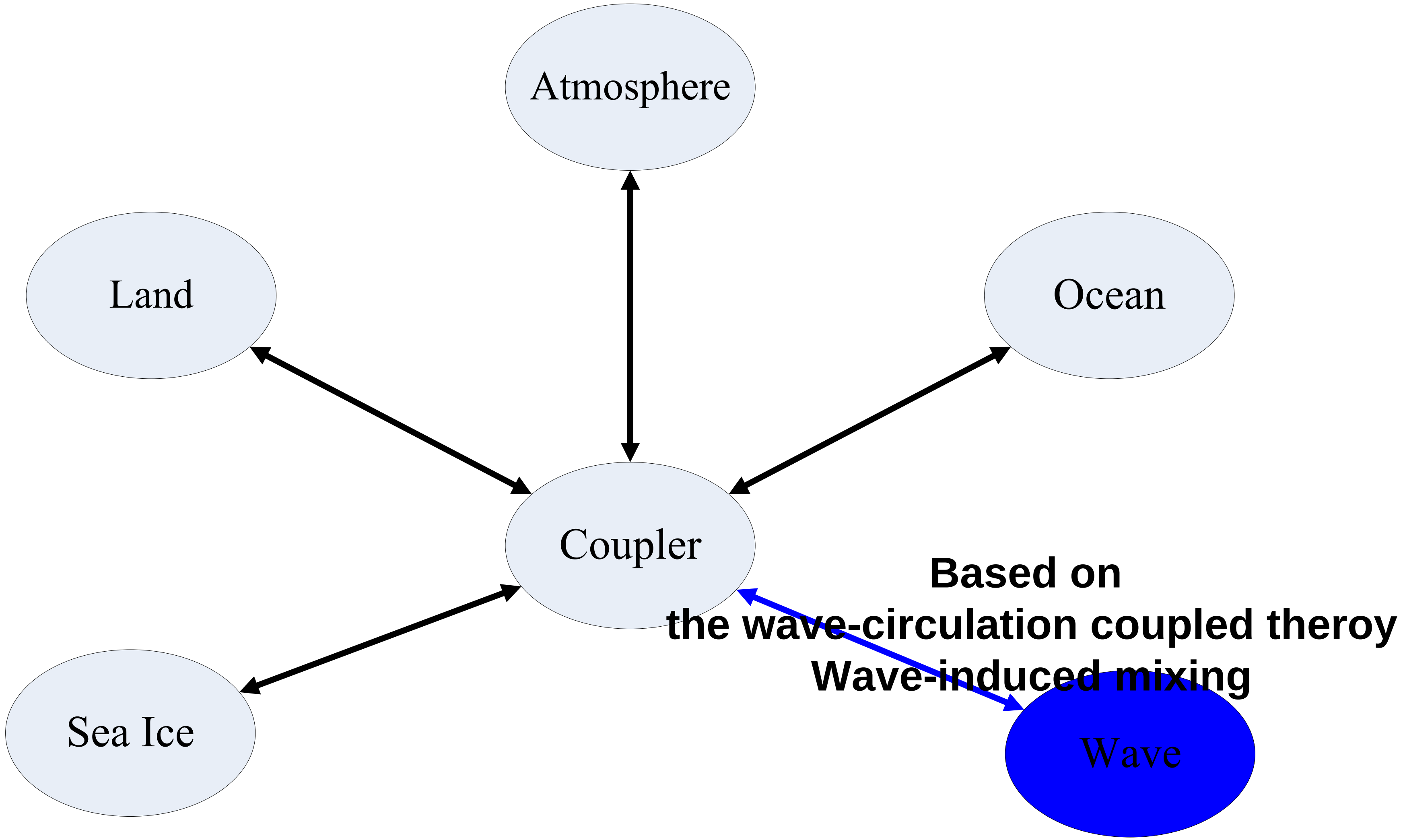
In the Arctic, CCSM3 underestimates the downwelling all-sky shortwave radiation at the surface throughout the annual cycle. The insolation is underestimated relative to in situ observations from the Surface Heat Budget of the Arctic (SHEBA) experiment (Persson et al. 2002) and to estimates from ISCCP (Fig. 15; Zhang et al. 2004). For this comparison, the ISCCP data from 1984 to 2000 has been averaged to produce a climatology. Between 70° and 90°N, the annual-mean downwelling shortwave fluxes for all-sky conditions are 91 W m^{-2} from ISCCP and 78 W m^{-2} from CCSM3. The corresponding annual-mean clear-sky fluxes differ by only −3.9 W m^{-2}, or −3%. The fluxes during the JJA season are 214 W m^{-2} from ISCCP and 169 W m^{-2} from CCSM3. The corresponding JJA-mean clear-sky fluxes differ by only 8.5 W m^{-2}, or 2.7%. Since the clear-sky fluxes are in good agreement, the underestimate of surface insolation by CCSM3 is caused by an overestimate of the surface shortwave cloud radiative forcing. It should be noted that the excessive cloudiness in winter produces an overestimate of downwelling longwave surface flux by 20 W m^{-2} for December through April. The overestimation of longwave flux partly compensates the underestimation of shortwave insolation in the total surface radiation budget. Further analysis will be required to identify the sources of these errors in the modeled cloud amount, cloud condensate path, and cloud microphysical properties.

6. Summary

The semiannual SST cycle in the eastern Pacific

ice share a nominal 1° grid with a displaced pole in the Northern Hemisphere.

The atmosphere incorporates new treatments of cloud and ice-phase processes; new dynamical frameworks suitable for modeling atmospheric chemistry; improved parameterizations of the interactions among water vapor, solar radiation, and terrestrial thermal radiation; and a new treatment of the effects of aerosols on solar radiation. The land model includes improvements in land surface physics to reduce temperature biases and new capabilities to enable simulation of dynamic vegetation and the terrestrial carbon cycle. The ocean model has been enhanced with new infrastructure for studying vertical mixing, a more realistic treatment of shortwave absorption by chlorophyll, and improvements to the representation of the ocean mixed layer. The sea ice model includes improved schemes for the horizontal advection of sea ice and for the exchange of salt with the surrounding ocean. The software has



Can the atmosphere-wave-circulation coupled numerical model be a remedy?

2. Model Description

Model linkage

1. CGCM:

CCSM3, NCAR;

Atmosphere: CAM3; Ocean: POP 1.4

2. Surface Wave Model:

MASNUM wave number spectrum model

3. Resolution :

Atmosphere: T42

Ocean:gx1v3 (about $1.1^{o} \times 0.3^{o} \sim 0.6^{o}$), 40 levels for ocean;

MASNUM wave model: $2^{o} \times 2^{o}$

4. Ocean vertical mixing scheme :PP,GM90

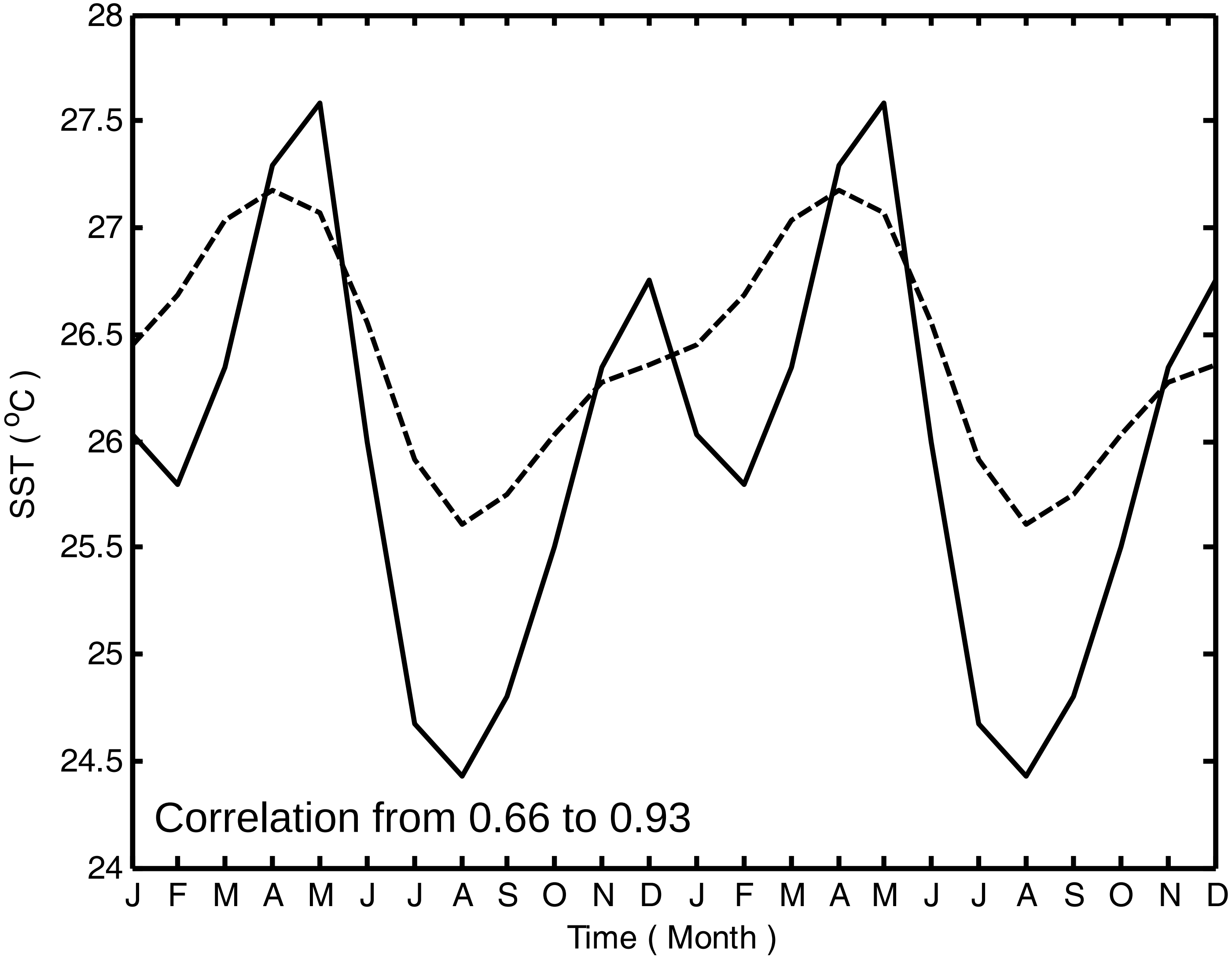
5. Simulation 300 a.

Two Experiments (251-300a)

Case 1(Without wave): The original CGCM, CCSM3,without wave-induced mixing

Case 2(With wave): MASNUM coupled model, Atmosphere-Wave-Ocean coupled model, with wave-induced mixing

3. Results



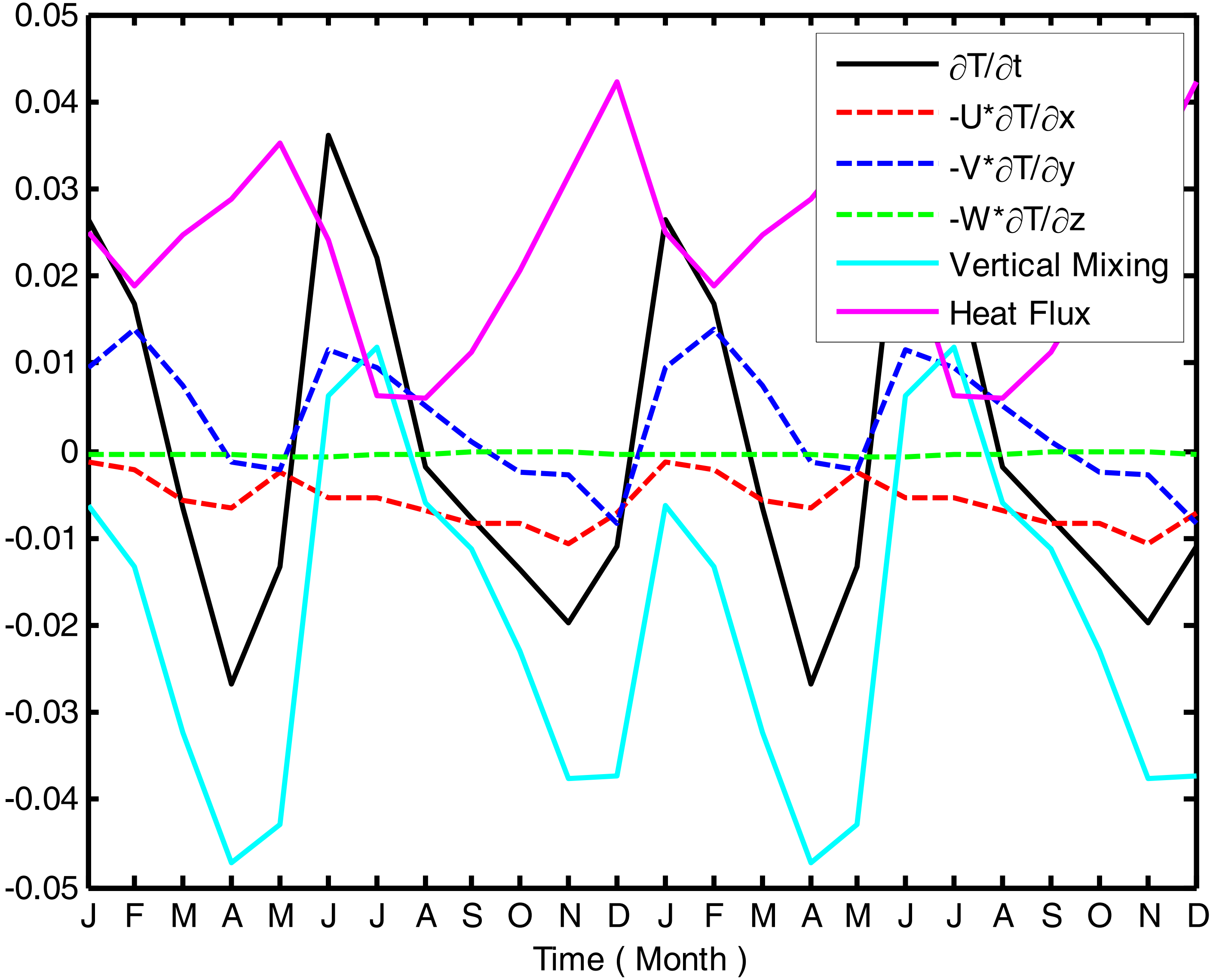
Simulated SST in the EP (110° W-90° W, 5° S-5° N)
Solid line, Without Wave; Dashed line, With Wave

Why does the With Wave experiment remove the spurious semi-annual cycle?

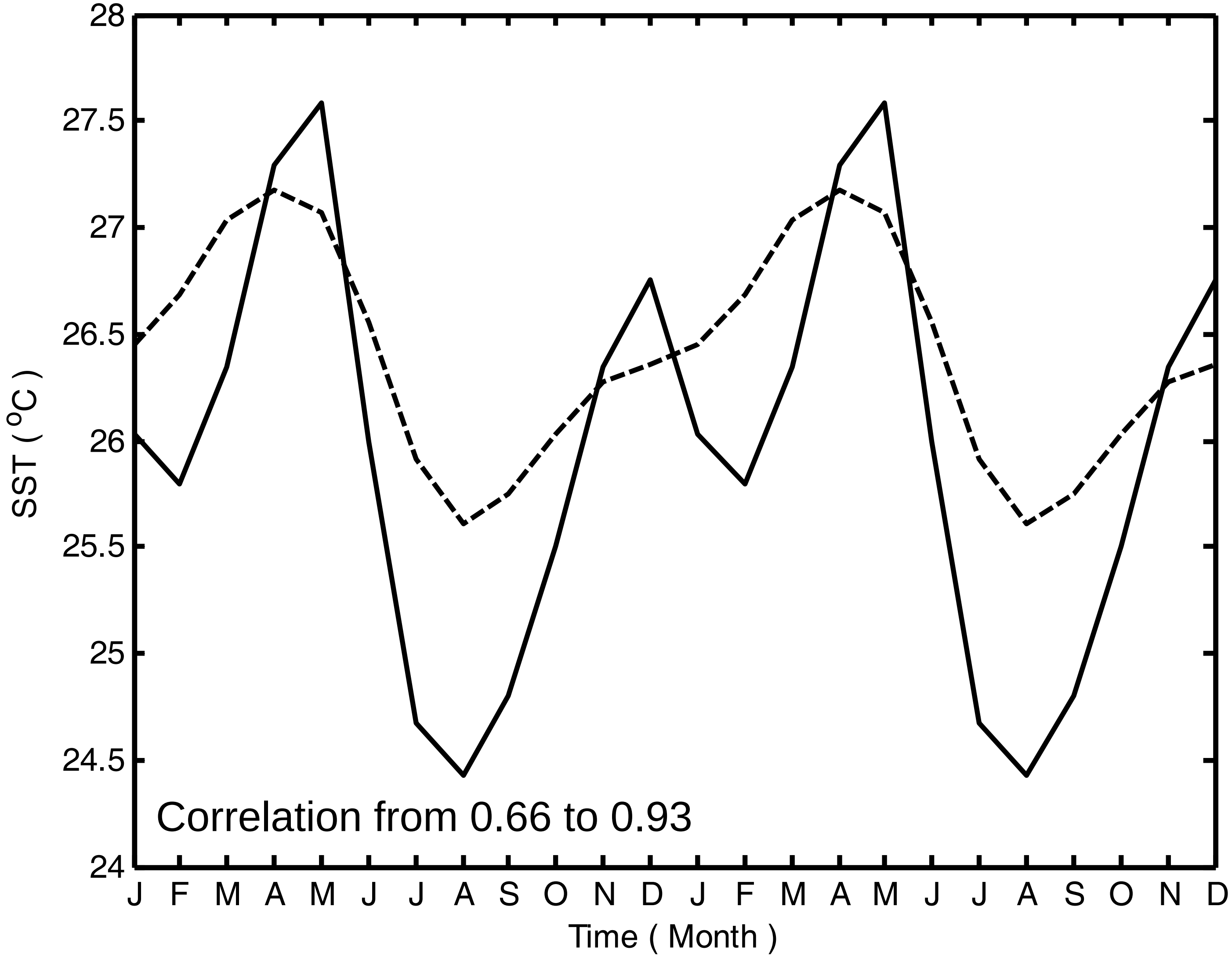
The temperature equation for the ocean surface layer

$$\frac{\partial T}{\partial t} = -u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y} - w\frac{\partial T}{\partial z} - A_{hv}\left.\frac{\partial^2 T}{\partial z^2}\right|_{z=-\Delta z_1} + \frac{F_A}{\rho_0 c_p \Delta z_1}$$

Include wave-induced mixing



The difference (With Wave minus Without Wave) of various terms in the SST equation
Black line, local SST change rate ($\partial T/\partial t$); Red dashed line, zonal advection;
Blue dashed line, meridional advection; Green dashed line, vertical advection;
Cyan line, vertical diffusion; Magenta line, net surface heat flux



Simulated SST in the EP (110° W-90° W, 5° S-5° N)
Solid line, Without Wave; Dashed line, With Wave

4 Summary

- Despite the improvement, the new coupled model simulates a relatively weak amplitude of the SST annual cycle in the equatorial eastern Pacific.
- The heat budget analysis shows that the wave-induced vertical mixing change plays a key role in the model improvement.
- This study suggests that the coupled model bias of the semi-annual SST cycle in the equatorial eastern Pacific is due to oceanic mixing that is not properly represented in coupled models.
- Wave-induced mixing effects in the upper ocean layer are too important to be ignored.

Thanks!