Improved Modeling of SST in the Pacific Cold Tongue: Implications for the NCEP GODAS and CFS

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It would be difficult to overemphasize the importance of the Pacific cold tongue (CT) in global hydrological and biogeochemical cycles, as it plays a key role in the formation of tropical cloud and precipitation patterns, the supply of nutrients for surface ocean biological productivity, and carbon cycling. The east-central tropical Pacific is the largest oceanic source of CO_2 to the atmosphere. Furthermore, large SST anomalies associated with El Niño and La Niña events are manifested as variations about the mean state of the cold tongue, which have long been known to influence weather patterns globally.

In spite of the importance of the equatorial Pacific cold tongue in global hydrological and biogeochemical cycles, most ocean general circulation models and coupled atmosphere-ocean general circulation models produce a cold bias in the east-central equatorial Pacific ocean, including an exaggerated westward extent of the cold tongue. The core ocean model of the present National Centers for Environmental Prediction (NCEP) Climate Forecast System (CFS), Modular Ocean Model version 3 (MOM v.3), also exhibits such a cold bias in the cold tongue region, up to 1°C on the annual mean (Fig. 1).

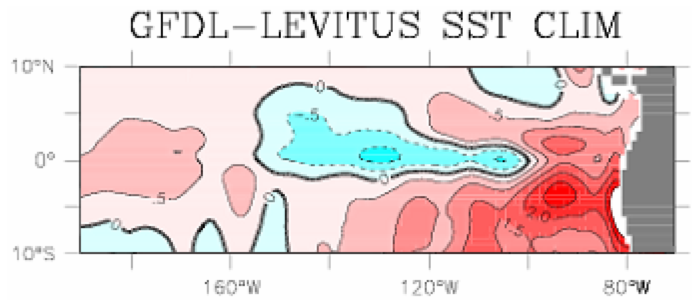

Fig. 1 Annual mean SST bias in the east-central tropical Pacific Ocean in the GFDL MOM v.3 ocean model. Figure adapted from Vecchi et al. (2005).

The existence of the Galápagos Archipelago on the equator near 90°W, made famous after the nineteenth century expeditions of British naturalist Charles Darwin, presents the potential for topographic interaction with the equatorial current system and other processes related to the cold tongue. Currently, the Global Ocean Data Assimilation System (GODAS), the oceanic component of the CFS, does not include the Galápagos Islands.

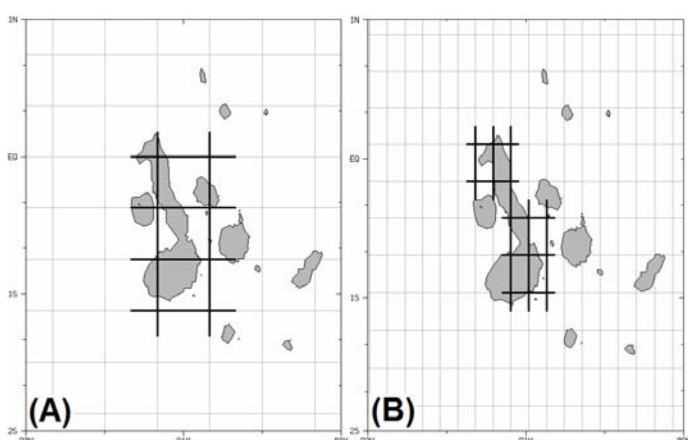

Fig. 2 Implementation of the Galápagos Islands in the present study in the coarse (A) and fine (B) simulations.

A reduced gravity ocean general circulation model of the tropical Pacific Ocean (Gent and Cane, 1989) was recently used to determine the improvements to the simulated Pacific cold tongue region arising from increased horizontal resolution and the inclusion of the Galápagos Islands (Fig. 2).

It is found that a more realistic treatment of the Galápagos Islands results in the obstruction of the equatorial undercurrent (EUC) (Fig. 3), which leads to improvements in the simulated spatial structure of the cold tongue, including a basin-wide warming of up

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to 2°C in the east-central Pacific (Figs. 4, 5, and 6a).

The obstruction of the EUC is related to the improvements east of the Galápagos Islands, and for the basin-wide reduction of the tropical cold bias through an equatorial dynamical adjustment leading to much reduced entrainment-mixing (Fig. 6b), as well as reduced meridional import/export circulation.

In many respects, simply increasing the resolution without including the Galápagos Islands did not result in improvements, but instead exacerbated the cold bias and produced an EUC that is too strong east of where the islands should be. On the other hand, differences due to the Galápagos Islands without increasing the horizontal resolution were negligible. Only when the Galápagos Islands were given a proper treatment with sufficient horizontal resolution did a more realistic depiction of the CT and a reduction in the tropical cold bias problem emerge. In other words, the horizontal resolution must be fine enough to produce an EUC that extends far enough eastward, but the Galápagos Islands must be there to obstruct it.

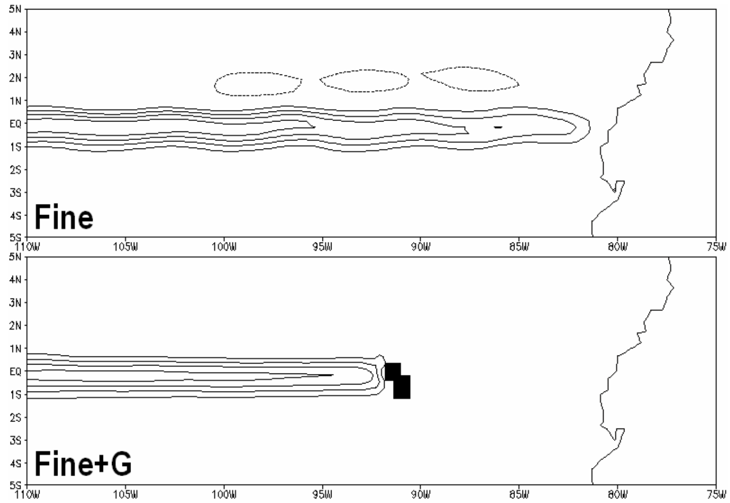


Fig. 3 Sep-Nov mean zonal velocity at 80m (cm s^{-1}) in the fine resolution experiments with and without the Galápagos Islands. Zonal velocity is contoured every 10 cm s^{-1}.

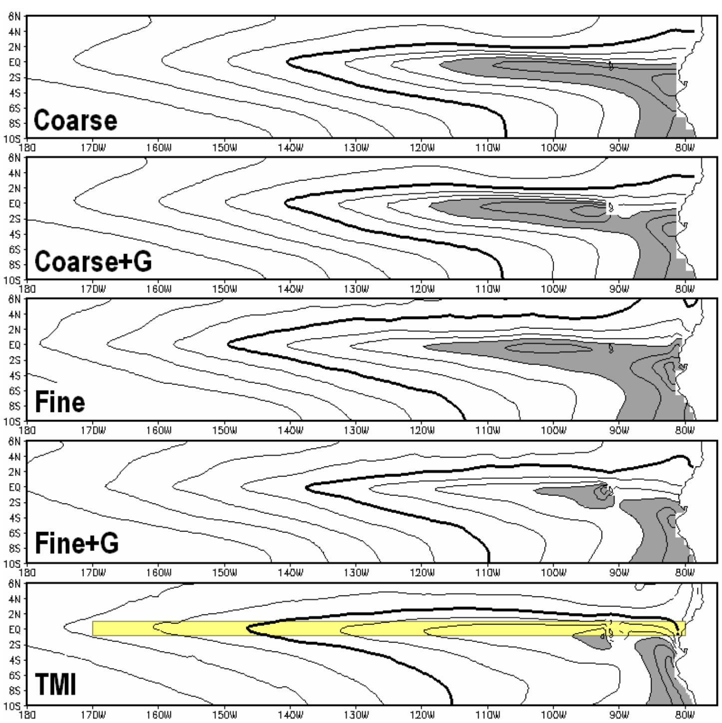
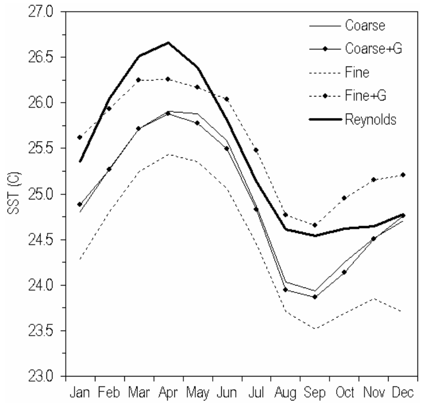


Fig. 4 Annual mean SST (°C) in the equatorial Pacific Ocean for the four simulated cases and TMI. SST is contoured every 1°C, the heavy contour is 26°C, and SST colder than 23°C is shaded. The yellow box indicates the index region used in the Fig. 5.

The pattern of SST warming due to the inclusion of the Galápagos Islands is similar to that of the known cold biases in ocean models and the current NOAA CFS. It is thought that such an improvement would have a considerable impact on the ability of coupled ocean-atmosphere and ocean-ecosystem models to produce realistic clouds, precipitation, biological activity, and carbon cycling in the tropical Pacific Ocean. The next logical step is to exploit these effects on interannual variability and the implications for the predictability of the couple ocean-atmosphere system. In particular, the potential benefits to the predictive skill of, for example, future iterations of the NCEP GODAS and CFS by implementing the Galápagos Islands at sufficient resolution should be given serious consideration. Preliminary sensitivity experiments are planned for the MOM v.4 within the NCEP Environmental Modeling Center (EMC).



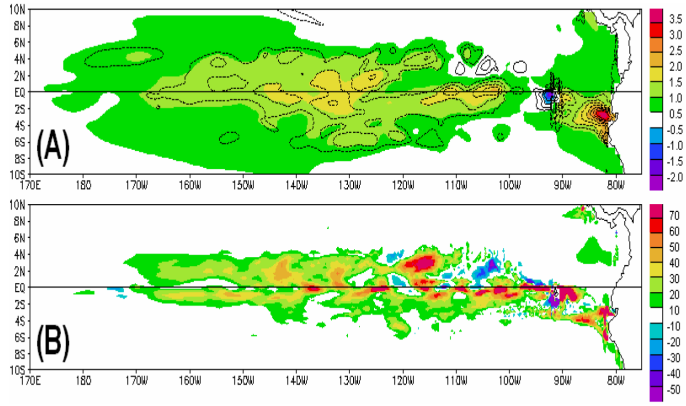


Fig. 5 Mean seasonal cycle (monthly means) of SST (°C) in the cold tongue index region (1°S-1°N by 170°W-80°W, as indicated in Fig. 4) for the four simulated cases and the Reynolds SST climatology.

Fig. 6 Sep-Nov mean SST difference (°C) (shaded), net ocean-atmosphere heat flux difference (contour interval 10 Wm^{-2}) (A), and difference in contribution to the mixed layer heat budget by entrainment-mixing (W m^{-2}) (B) fine resolution cases with and without Galápagos.

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Karnauskas, K.B., R. Murtugudde, and A.J. Busalacchi, 2006: The impact of the Galápagos Islands on the equatorial Pacific cold tongue. In revisions at the *Journal of Physical Oceanography*.

Other references:

Gent, P.R. and M.A. Cane, A reduced gravity, primitive equation model of the upper equatorial ocean. J. Computational Phys., 81, 444-480, 1989.

Vecchi, G., M. Harrison, A. Wittenberg, T. Rosati, 2005: Biases in Ocean and Coupled General Circulation Models. Workshop on the Application of EPIC2001 Data for Improving and Testing Coupled Atmosphere-Ocean Models, Seattle, WA., 11-13 May 2005.