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Submesoscale coherent structures and SST gradient in ocean model simulations

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Summary

Analyzing a suite of high-resolution ocean model simulations, it is found that the strength of the simulated horizontal temperature gradient is strongly influenced by the atmospheric forcing. Within the 5 km - 300 m range in model resolution, imposing a fine-resolution forcing is far more efficient than increasing the model resolution in enhancing the simulated temperature gradient. The probability distribution of the magnitude of horizontal temperature gradient is log-normal in all cases. The submesosccale-resolving simulation produced ubiquitous, spatially stretched, coherent structures with sharp velocity gradients (vorticity or strain) that are identified as temperature fronts. They exhibit cyclone-anticyclone asymmetry. The strongest structures are overwhelmingly cyclonic, due to the inertial instability of strong anticyclones when the Rossby number exceeds unity.

Motivation and the model

Rich, ubiquitous, coherent structures emerge in ocean model simulations when the model begins to resolve mesoscale eddies. Coherent vortices and zonal jets emerge when the grid size approaches 0.1°. Their dynamics are the subject of our ongoing research. How their dynamics and statistical properties change with the model resolution and forcing has not been clarified. This study is another contribution to this important issue. The ROMS model (Curchitser et al. 2005, Shchepetkin and McWilliams 2005) is used for five simulations with their horizontal resolution and model domain ranging from 0.18° for the whole Pacific to 300 m for the Monterey Bay region. We focus on the statistics for the horizontal temperature gradient, vorticity, and strain for the simulated flow at the surface.

A quick tour of the hierarchy of runs

In our hierarchy of simulations, the output from a coarse resolution run is used as the lateral boundary condition for a finer resolution run, and so on. The five major simulations can be divided into two subsets: The first includes 3 runs called NPac2 (domain = the whole North and equatorial Pacific; horizontal resolution = 0.18°, see Huang et al. 2007), CCS (California Coastal Region; 3 km), both forced with relatively coarse resolution (~ 200 km) atmospheric forcing derived from CORE data set, and MBR (Monterey Bay and vicinity; 300m). The lateral boundary condition for NPac2 is derived from a global model simulation using NCAR CCSM. The second subsets are two runs called CAE1 (resolution = 5 km) and CAE2 (1 km), both are for the California Coastal region and are forced with relatively high resolution (~ 5 km) atmospheric forcing derived from COAMPS. All runs used 42 (except 31 for CCS) terrain-following levels in the vertical.

Statistics of horizontal temperature gradient

Spatially stretched, front-like structures are simulated in all runs but they are especially strong in the CAE1, CAE2, and MBR runs. The probability distributions of $\log_e|\nabla T|$ for the five runs, using all grid points and approximately a year of model output of daily (4-day averaged for NPac2) temperature field, are shown in Fig. 1 (dashed curve is the Gaussian fit). The PDF of $\log_e|\nabla T|$ is found to be close to Gaussian, so the PDF of $|\nabla T|$ is log-normal. For the 3 runs (CAE1, CAE2, MBR) with high-resolution forcing, $|\nabla T|$ increases with model resolution, likely due to the fact that high horizontal resolution is necessary for a faithful simulation of fronts. Despite having a slightly higher resolution than the CAE1 run, the CCS run produced much weaker $|\nabla T|$. This indicates the crucial role of high resolution atmospheric forcing in producing fine-scale temperature fronts in the submesoscale range, an issue that has further implications for subgrid-scale parameterization.

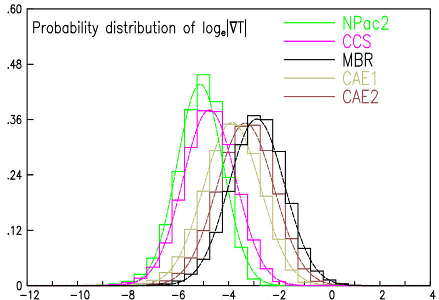

Fig. 1 The PDF of $\log_e|\nabla T|$ for the five runs.

Vorticity and strain

A further analysis confirmed that the temperature fronts produced in the submesoscale-resolving simulations coincide with regions with large vorticity or strain. Like $|\nabla T|$, the magnitude of vorticity (quantified by the Rossby number, *Ro* ~ ζ/f) increases with resolution. For the NPac2 run, *Ro* ~ *O*(0.1) and rarely exceeds 1. For the MBR run, events with *Ro* > 1 become far more common. This leads to an interesting emergent property of the flow, namely, cyclone-anticyclone asymmetry. The most intense structures in the MBR run are overwhelmingly cyclonic, due to the inertial instability of strong anticyclones with (ζ+f) < 0. This asymmetry is evident in the PDF of ζ/f, and is consistent with observations (Rudnick 2001). The frontal structures look even sharper in the map of the norm of the strain tensor compared to vorticity. This is not surprising since the dynamics of fronts is related to shear straining and deformation.

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