Simulating Turbulence in the Ocean

Turbulence on scales of only a few hundred meters or less can impact the large-scale ocean circulation. Yet, such small-scale turbulence cannot be directly represented in ocean general circulation models, but must be parameterized. Even the finest-resolution global ocean general circulation model being run today cannot explicitly resolve processes smaller than 10 km in the horizontal.

To represent sub-grid processes such as eddy mixing and turbulence in climate studies, many ocean and climate modelers have been using constant mixing coefficients. They are starting to realize, though, that more realistic simulations require more realistic parameterization of the mixing processes. "The good old days of modeling climate using constant mixing coefficients are over," according to a recent comment by a well-known oceanographer.

The field, however, is still far from having a comprehensive system of parameters that capture the physics of the various types of ocean turbulence and their effects. In fact, most of the mixing parameters used in today's ocean models are not derived from observations of actual ocean turbulence, but are either borrowed from atmospheric boundary layer models (*e.g.*, the KPP parameterization developed by William Large and colleagues) or derived from laboratory experiments and closure theories. Because the three-dimensional nature of turbulence makes it difficult to observe in the open ocean, observations of naturally occurring turbulence in the ocean are still sparse and insufficient to develop comprehensive mixing schemes.

Modern computing, though, has made possible the development of limited-area models in which the larger 3D structures of turbulent flow can be explicitly represented. The technique is called large-eddy simulation (LES). Oceanic mixing processes can be studied with LES models and the derived mixing coefficients can then be used to represent small-scale flow in basin-scale models.

Dailin Wang, with the IPRC Indo-Pacific Ocean Climate Team, has been conducting series of large-eddy simulations to study various small-scale mixing processes and develop a parameterization scheme for vertical mixing. His approach

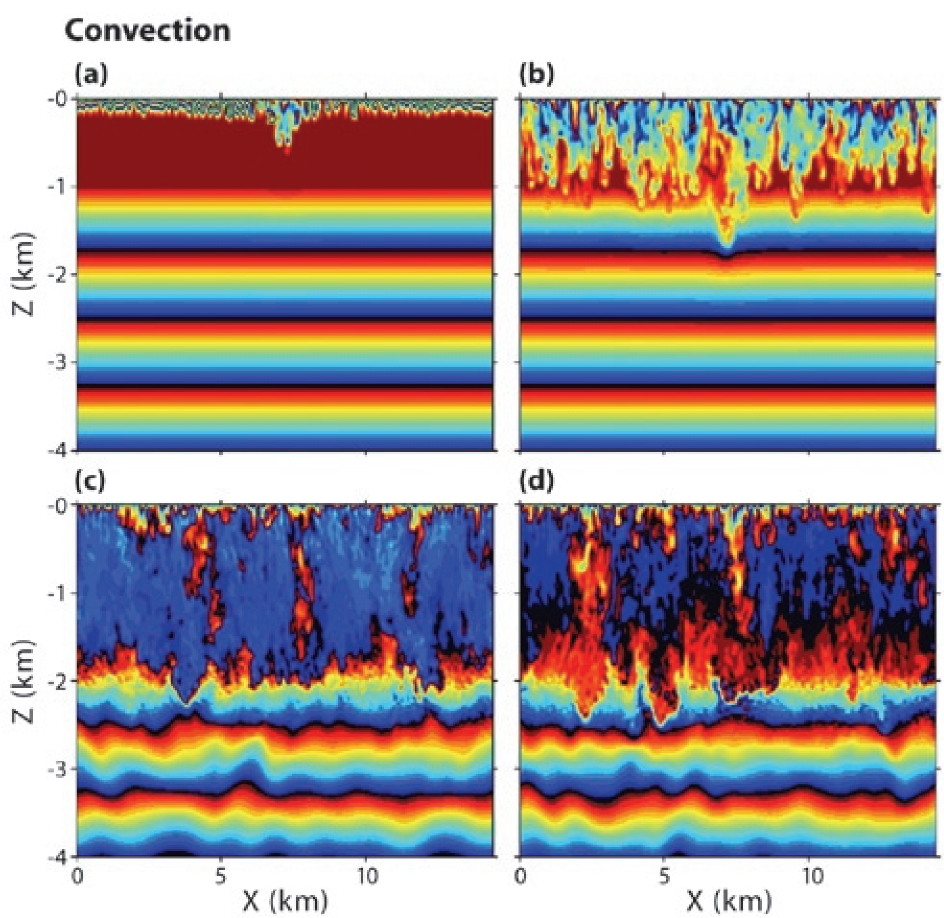

Figure 1. Temperature sections of the deepening of the mixed layer due to convection: (a) surface cooling generates a temperature gradient in the surface layer, with cooler water forming over warmer water; (a–d) as the gradient increases and becomes unstable, convection occurs. After 131 hours, the convective plumes have penetrated the ocean to a depth of about 3000 m, and have deepened the mixed layer.

is to conduct experiments under a wide range of oceanic conditions, such as different seasons and latitudes. From the results, he extracts laws that capture the essence of the particular mixing process, and he derives an appropriate mixing scheme.

For example, to develop a parameter for convection in the ocean, Wang has been conducting a slew of large-eddy simulations under a wide range of Rossby numbers, which represent the ratio of inertial forces in a fluid to the (apparent) forces arising from Earth's rotation. Figure 1 is an example of a solution of a large-eddy simulation. It is a snapshot of ocean temperature at different stages during deep convection induced by surface cooling. The convective plumes have horizontal scales of only a few hundred meters. Shallow convection, for instance nighttime convection in the tropics, occurs on scales even smaller than this.

In this set of experiments on the effects of different Rossby numbers, Wang found that the ratio between heat-flux mixing due to turbulence and surface-buoyancy flux, a key parameter in the Kraus-Turner-Niller mixed-layer model, is a function of the Rossby number (Wang, 2003). As the Rossby number decreases (Earth's rotation becomes more important), the ratio decreases. The equation Wang developed can also be used to test and construct other one-dimensional models of convection.

Wang is now extending this approach to other mixing processes. For instance, Figure 2 shows the deepening of the mixed layer at the equator due to wind mixing. A comparison of Figures 1 and 2 shows that convection and wind stirring bring about ocean mixing in different ways: Convection deepens the mixed layer through penetration of convective plumes, whereas wind stirring does so through Kelvin-Helmholtz shear instability, which forms large eddies in the shape of rolls.

With such experiments as these, Wang is learning more about how different forms of turbulence affect ocean mixing. The new parameterizations, with their improved physical basis, should help to make climate-change simulations with the next generation of ocean circulation and ocean-atmosphere coupled models more realistic.

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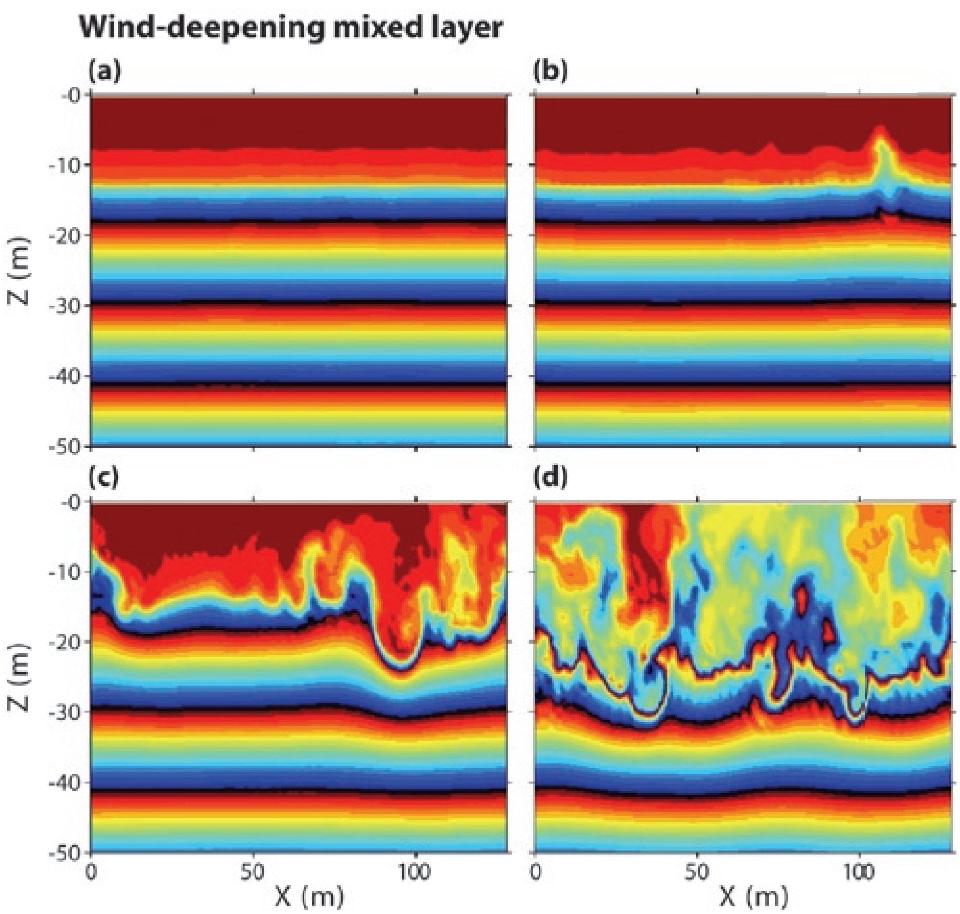

Figure 2. Temperature sections of the deepening of the mixed layer due to wind stirring; (a) as the surface shear grows, it becomes unstable and rolls begin to form; (b–d) with time, many rolls form, overturn, and cause turbulent mixing, stirring the ocean to a depth of 30 m.