A BOOTSTRAPPING METHOD FOR PARAMETERIZATION DEVELOPMENT OF OVERFLOW MIXING FOR CLIMATE MODELS

Tamay M. Ozgökmen
RSMAS/MPO, 4600 Rickenbacker Causeway, Miami, FL 33149, USA - tozgokmen@rsmas.miami.edu

Abstract
Mixing in overflows may have a significant effect on the oceanic thermohaline circulation. The drastic separation between the scale of mixing and horizontal grid size in climate models is spanned by dividing the problem into several sub-problems: direct numerical simulation (DNS) is used to develop a subgrid-scale model of stratified mixing for large eddy simulation (LES); LES is used to develop mixing parameterization for an ocean model (HYCOM); in-situ observations are used to validate regional overflow simulations with HYCOM; and finally, the so-called marginal sea overflow boundary condition (MSBC) is used as a parameterization of an entire overflow for climate studies, on the basis of an ensemble of experiments using high-resolution HYCOM.
Keywords : Stratification, Circulation Models.

The main objective of this effort is to develop parameterizations of overflow mixing for ocean general circulation models used in climate studies. Given the challenging multi-scale problem of representing the net effect of mixing taking place on the order of the overturning (Ozmidov) scale of O(10 m) in climate models, with typically 100 km horizontal grid resolution, the so-called bootstrapping technique has been pursued. By noting that most of mixing taking place near the density interface between the gravity currents and the ambient fluid is carried out by overturning eddies, and the smaller scale structures arising from the break-down of these eddies into turbulence mainly play a role in energy dissipation, subgrid-scale models have been developed for large eddy simulation (LES) using direct numerical simulation (DNS) results as ground truth [1]. Then, LES of gravity current simulations are used to provide testbeds and benchmarks for ocean general circulation models [2]. HYCOM is a suitable OGCM for this problem because it is designed to prohibit entirely all diapycnal mixing, except for that prescribed by parameterizations. Benchmark LES of bottom gravity currents are then used to develop parameterizations of entrainment as a simple algebraic function of the layer shear Richardson number [3, 4]. This parameterization is then tested extensively for regional simulations of overflows, namely for the Mediterranean Sea overflow using the in-situ observational data from the Gulf of Cadiz Experiment, and the Red Sea overflow [5] using the Red Sea Outflow Experiment. Both of these studies indicated that these overflows were satisfactorily reproduced, and no further fine-tuning of the parameterization was needed. It was noted that the Red Sea overflow appears to be more challenging than the Mediterranean Sea overflow, because the former bifurcates into narrow channels and accurate representation of domain geometry becomes as important as the representation of mixing. In order to make the final step from regional overflows to climate model scale, the results from the so-called marginal sea boundary condition (MSBC, [6]) and regional Mediterranean Sea overflow simulations are compared under a variety of climate conditions, represented by different combinations of changes in the properties of the Mediterranean Sea overflow and the ambient North Atlantic water. Consistent results are obtained from HYCOM and MSBC, indicating that MSBC can be used as a well-founded parameterization of the Mediterranean Sea overflow in climate models [7].

In summary, bootstrapping technique consists of using DNS as ground truth for LES, LES as benchmark for idealized HYCOM, observational data sets to validate regional simulations of overflows, and regional simulations to fine-tune and validate MSBC, such that the needed range of scales from small overturns to climate model grid size could be spanned for this particular problem.

In addition, LES of gravity currents have been used to conduct studies of more delicate processes. In particular, the behavior of turbulent gravity currents in the presence of ambient stratification is studied for cases in which equilibrated product water masses are formed [8]. The main objective was to explore how the ambient stratification impacts entrainment and the properties of product water masses, which are of ultimate interest to climate modelers. Results also show that, for the case of constant slope angle and linear ambient stratification, the gravity current separates from the bottom such that the entrained mass flux is independent of the slope angle. The product mass transport and product salinity then depend only on the ambient stratification, and these quantities are approximated as simple algebraic functions of the ambient stratification parameter that modify the source properties. Also, by recognizing that oceanic overflows follow the sea floor morphology, which shows a self-similar structure at spatial scales ranging from 100 km to 1 m, the impact of topographic bumps on entrainment in gravity currents is investigated [9]. It is found that in the case of smooth bottom, the overturns can only dilute the upper part of the overflow, and the densest water masses near the bottom escape dilution and set equilibrium level of the product water mass. Bottom roughness and in particular form drag exerted on the overflows are then recognized as an important mechanism that needs to be considered.

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