

Improving the Skill of Ocean Mixed Layer Models

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Grant #: N00014-03-1-0488

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LONG-TERM GOALS

The long-term goal of this effort is to improve the skill of modern 3-D numerical ocean circulation models used for studying the oceans and, in operational centers, for nowcasting/forecasting the oceanic state.

OBJECTIVES

The principal objective of this research is to improve second moment closure-based ocean mixed layer models that are in current (and potential future) use in Navy operational ocean circulation models at NAVOCEANO and FNMOC.

APPROACH

Extensive research over the past three decades has established second moment closure (SMC) as a reasonable compromise between resource-intensive techniques such as large eddy simulations (LES) and simple bulk mixed layer models (for example Large et al. 1994). The SMC approach in its most practical form reduces to a two-equation model of turbulence, with prognostic equations for the turbulent kinetic energy (TKE) and the turbulence length scale (TLS), and algebraic expressions for the mixing coefficients (Mellor and Yamada 1982; Galperin, Kantha, Hassid and Rosati 1988; Kantha and Clayson 1994 & 2000). These so-called algebraic stress closure models have become the mainstay of the US Navy operational ocean and atmosphere forecast models, for example the Shallow Water Analysis and Forecast System (SWAFS) run routinely at NAVOCEANO and Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS) run at FNMOC, as well as many civilian operational (NOAA NCEP) and research (NCAR WRF) forecast systems.

However, three decades of research and over a decade of operational use have exposed some shortcomings of the current SMC-based OML models. For example, the popular Mellor-Yamada (MY) OML models in Navy operational use, have a tendency to under-predict mixing and hence overestimate upper layer currents and SST. A related problem is the underestimation of the Monin-Obukhoff similarity function Φ_M in the surface layer of the atmospheric boundary layer (ABL) under unstable conditions (see Mellor 1973). Advances in turbulence research using methodologies such as LES, direct numerical solutions (DNS) and renormalization group analysis (RNG) have also exposed some conceptual weaknesses. The most glaring conceptual weakness is the one related to the prescription of the turbulence length scale. MY models use an ad-hoc wall correction to their TLS equation (Mellor and Yamada 1982), whereas the $K-\epsilon$ (TKE and its dissipation rate) model used

Report Documentation Page

Form Approved
OMB No. 0704-0188

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1. REPORT DATE 30 SEP 2003		2. REPORT TYPE		3. DATES COVERED 00-00-2003 to 00-00-2003	
4. TITLE AND SUBTITLE Improving the Skill of Ocean Mixed Layer Models				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Colorado, CB 429,,Boulder,,CO,80309				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The long-term goal of this effort is to improve the skill of modern 3-D numerical ocean circulation models used for studying the oceans and, in operational centers, for nowcasting/forecasting the oceanic state.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

extensively by the European community (for example Rodi 1987) exhibits disturbing singular behavior in parts of the parameter space (Burchard and Deleersnijder 2001).

Our approach to solving these problems is to incorporate recent advances in turbulence modeling research (Kantha 2003a, 2003b; Kantha and Clayson 2003) into second moment closure-based OML models. These advances are based on our increased understanding of turbulence in stratified fluids gained from observations, and large eddy simulations (LES), direct numerical simulations (DNS) and renormalization group (RNG) analysis of turbulence. The resulting OML model will be tested against available observational data to quantify improvements in modeling skill. We plan to collaborate closely with LES and RNG researchers to derive benefits from their expertise and experience in dealing with turbulence, and to bring some cross-fertilization into this field. We also plan incorporate surface gravity wave effects, both wave breaking at the surface and Langmuir cell-induced turbulence in the water column (Langmuir 1938).

WORK COMPLETED

In spite of the short time period (6 months) elapsed since the start of this contract, we have made major advances. We have reexamined the entire question of the turbulence length scale prescription and demonstrated that all the different approaches proposed since Kolmogoroff (1942) are equivalent, and a general equation for the quantity $q^m L^n$ can be derived, from which the various approaches proposed over the past five decades can be derived as subsets, provided proper attention is paid to the modeling of the diffusion terms and the values of various turbulent Prandtl numbers. We have also incorporated the effect of surface waves including wave breaking and Langmuir cell turbulence into OML models. We have formulated a universal two-equation turbulence model that can simulate any existing two-equation model such as the *k-epsilon*, *k-omega*, *k-kL*, *k-ktau*, *k-tau*, and *k-L* model.

RESULTS

The question of proper formulation of TLS equation has been addressed (Kantha 2003b, Kantha and Carniel, 2003); Langmuir cell-induced turbulence has been studied and incorporated along with wave-breaking effects (Kantha and Clayson 2003); and second moment closure constants have been refined (Kantha 2003a) to eliminate the long-standing problem in Mellor-Yamada type closure models of underestimation of the Monin-Obukhoff similarity function Φ_M in the surface layer of the atmospheric boundary layer (ABL) under unstable conditions (Fig. 1, see also Mellor 1973). The popular Kantha and Clayson (1994) mixed layer model is being updated to incorporate these latest advances. A universal generic length scale equation that can simulate any previous closure model such as the *k-epsilon*, *k-omega*, *k-kL*, *k-ktau*, *k-tau*, and *k-L* model is being constructed (Kantha and Carniel 2004). The question of improved performance under unstably-stratified flow conditions is being addressed via non-local closure models. The down-the-gradient model for diffusion terms is being reexamined, based on the work of Dr. Vittorio Canuto's group at NASA Goddard Institute for Space Studies (GISS), who have used RNG methodology to advance our understanding of turbulence over the past decade (Canuto et al. 2002). Several papers have been published and some are in the works.

IMPACT/APPLICATIONS

Accurate depiction of many quantities of interest to world-wide naval operations, such as the upper layer temperature and currents, requires the use of skillful ocean mixed layer (OML) models.

Operationally, this contributes to better counter mine warfare capabilities through better and more accurate tracking of drifting objects such as floating mines. Other drifting material such as spilled oil is also better tracked and counter measures made more effective. Other applications include search and rescue. The improved mixed layer model code will be transitioned to NRL, NAVOCEANO and FNMOC for possible use in their operational models.

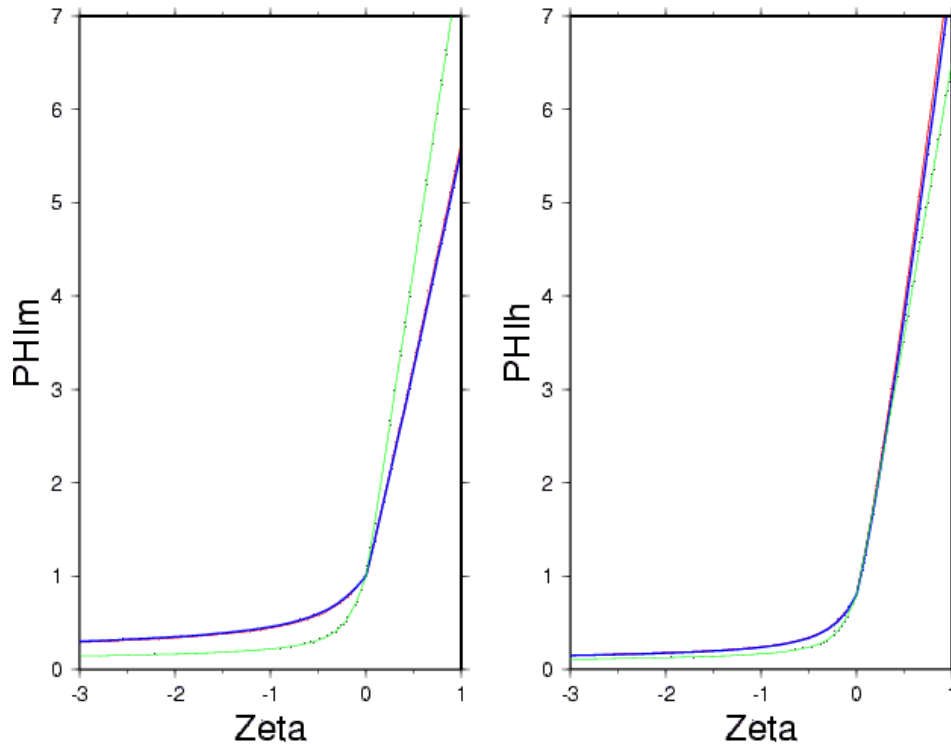


Figure 1. Monin-Obukhov similarity functions for momentum (left) and heat (right) in the atmospheric surface layer plotted against the Monin-Obukhov similarity variable (for details see Kantha 2003a). MY closure (green line) considerably underestimates Φ_M under unstable conditions, whereas Kantha (2003a) and Cheng et al. (2002) closures agree well with observational data from the Kansas experiment.

RELATED PROJECTS

The Role of Ocean Color Data and Primary Productivity Models in Assessing the Skill of Numerical Circulation Models (N00014-02-1-1043).

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