Improving the Skill of Ocean Mixed Layer Models

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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 community and operational ocean circulation models.

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 ΦM in the surface layer of the atmospheric boundary layer (ABL) under unstable conditions (as in 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-ε (TKE and its dissipation rate) model used extensively by the European community (for example Rodi 1987) exhibits disturbing singular behavior in parts of the parameter space (Burchard and Deleersnijder 2001). Another drawback is the local nature of the closure that does not work well under free convection conditions. Yet another is ignoring the very important influence of surface gravity waves on mixing in the upper ocean. None of the Navy community ocean models such as ROMS/TOMS, NCOM and HYCOM incorporate surface wave effects; neither do they account for non-local effects under convection.

Our approach to solving these problems is to examine critically the basic concepts underlying SMC models and incorporate recent advances in turbulence modeling research 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.

Observational data to compare with turbulence models are scarce. Microstructure measurements have not become a routine staple of oceanographic measurements as CTD casts have been for decades. This has led us to make microstructure measurements during NURC/NRL 2006 DART cruises in the Adriatic Sea. In collaboration with Dr. Sandro Carniel of ISMAR, Italy, we have taken part in the DART 06A and 06B cruises in March and August of this year and collected turbulence data using a microstructure profiler.

WORK COMPLETED

We have refined the closure constants in SMC models for better performance under free convection. 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 *qmLn* 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 Stokes production into OML models. We have explored the consequences of incorporating Langmuir turbulence on the velocity structure in the mixed layer. We have shown that surface gravity waves transfer energy to turbulence in the mixed layer by the action of the Reynolds stress against the vertical shear due to the wave-induced Stokes drift. We have also shown that this transfer constitutes an important loss mechanism for swell propagating across ocean basins. 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. We have examined the efficacy of non-local models and demonstrated the importance of proper parameterization of the diffusion terms (third order moments). We have reexamined the classic experiments by Dickey and Mellor (1980) on turbulence decay in a stably stratified fluid and demonstrated that these observations can be explained without invoking a drain of TKE into internal waves. We have also applied SMC to explain the difference between mixing produced by plunging and that produced by spilling waves in the surf zone.

We have also processed and analyzed the microstructure data collected during the DART cruises (e.g. Figure 1, see *Carniel et al.* 2006 for details) and made comparisons with modeled dissipation rate and diffusivity from ROMS/TOMS model.

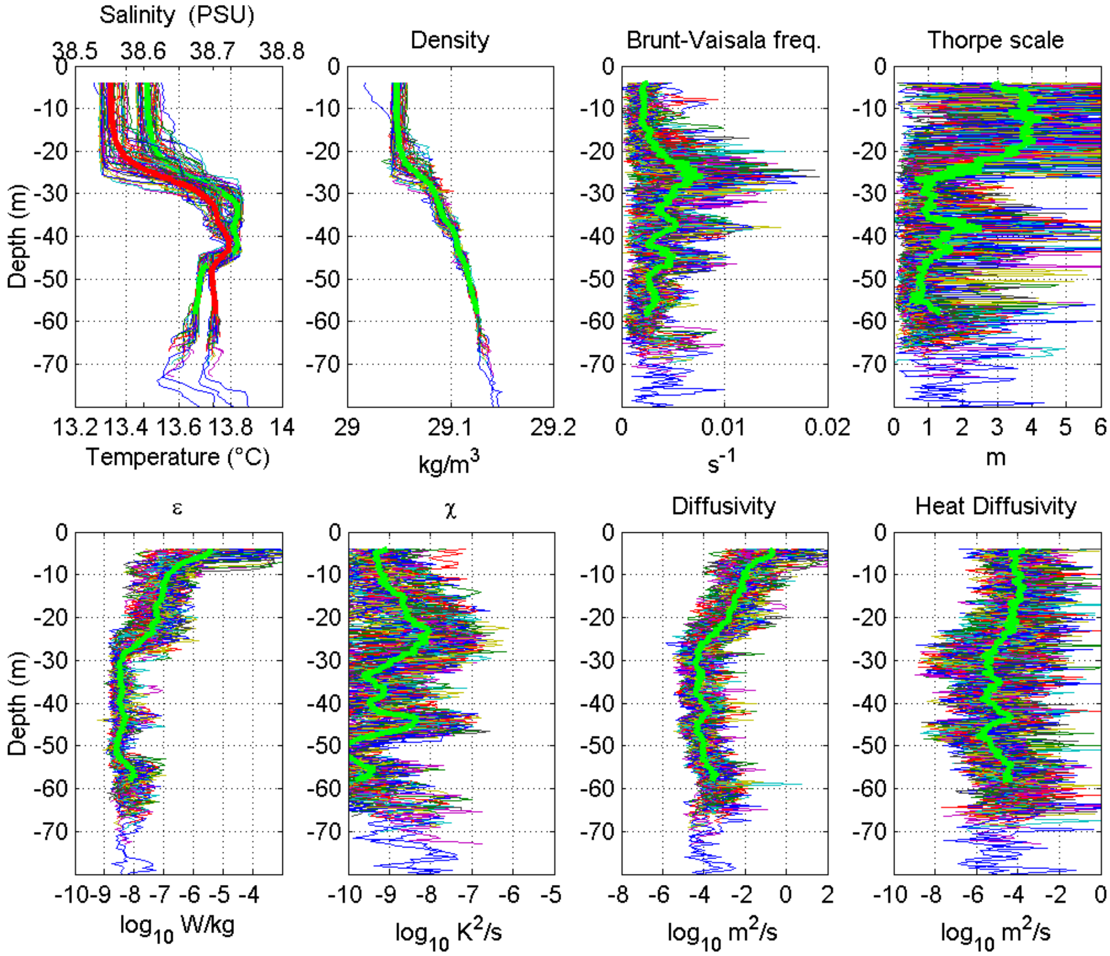

Figure 1. Profiles of temperature (°C) and salinity (psu), density (kg m-3) and buoyancy frequency (s-1), and the Thorpe scale (top panels), TKE dissipation rate (W kg-1), temperature variance dissipation rate (K2 s-1), eddy diffusivity K (m2s-1), and the heat diffusivity Kh (m2s-1) (bottom panels) measured in the Gulf of Manfredonia. A total of 43 casts were made over 2.5 hr centered spanning the midnight of March 23rd/24th. The thick green line denotes the corresponding average value. The thick red line in panel 1 denotes mean salinity.

RESULTS

Proper formulation of TLS equation enables any existing 2-equation model such as the *k-epsilon, k-omega, k-kL, k-ktau, k-tau,* and *k-L* model to be simulated. Including the transfer of energy from surface waves to turbulence via the interaction of the Reynolds stress and wave-induced Stokes drift intensifies mixing throughout the ML and changes the velocity structure in the oceanic mixed layer (see Figure 1). Wave breaking also enhances mixing but only in layers adjacent to the free surface. The refinement of second moment closure constants eliminates the long-standing problem in Mellor-Yamada type closure models of underestimation of the Monin-Obukhoff similarity function ΦM in the surface layer of the atmospheric boundary layer (ABL) under unstable conditions. The popular Kantha and Clayson (1994) mixed layer model is being updated to incorporate these latest advances. A generic closure model is also being constructed. 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 has been reexamined, based on the work of Dr. Vittorio Canuto's group at NASA Goddard Institute for Space Studies (GISS), which has used RNG methodology to advance our understanding of turbulence over the past decade (Canuto et al. 2002). Their most recent work (Cheng et al. 2004) involves a complex model for convective turbulence and we are examining ways to simplify it and bring it within the framework of 2-equation closure models. An alternative explanation for the decay of turbulence in stably stratified fluid in the classic experiments of Dickey and Mellor (1980) has been offered, in which the internal wave field seen in the experiment is postulated to have been generated in the beginning during the passage of the grid. Several papers have been published (see the publication list).

We have also made model runs for the observational period of DART06A using the navy community model ROMS/TOMS. Figure 2 compares the TKE dissipation rate and diffusivity from ROMS/TOMS compared with observed values at a station in the Gulf of Manfredonia in March 2006. Both General Length Scale (GLS) and Mellor-Yamada 2.5 (MY25) turbulence model results are shown. While the agreement is generally good, the deep mixing rates in the model are not consistent with observed values.

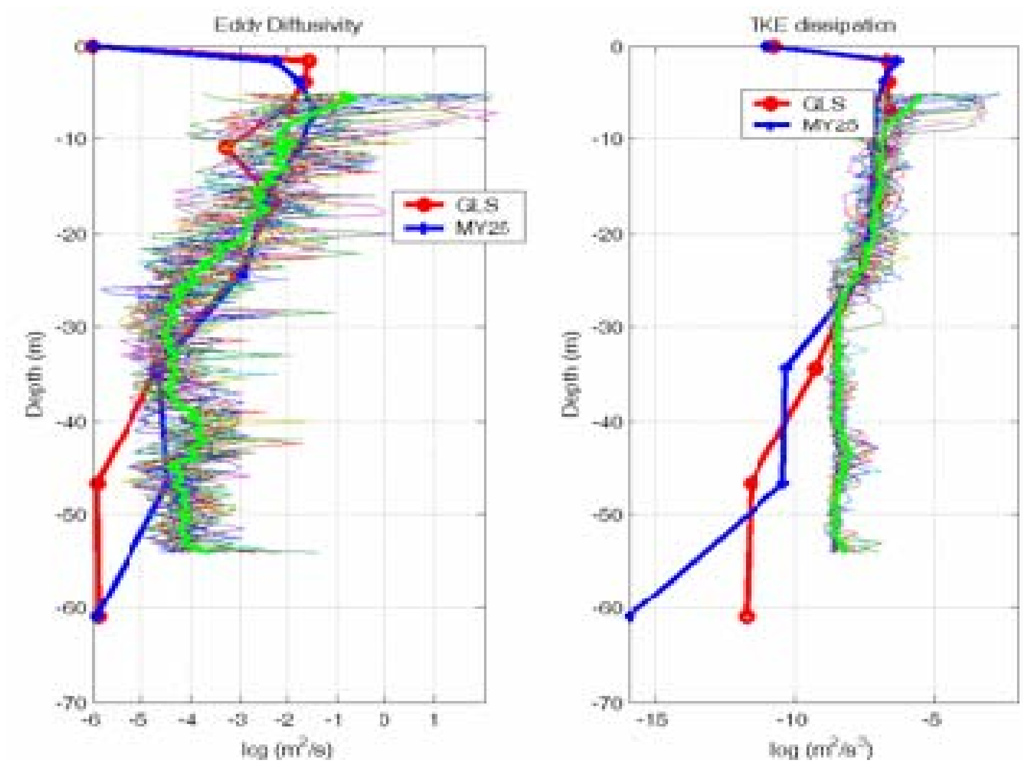

Figure 2. Comparison of modeled eddy diffusivity (left) and TKE dissipation rate (right) with observed values at a station in the southern Adriatic Sea on March 23rd. Thick green line denotes the mean of the observations, and red and blue lines the ROMS model results.

IMPACT/APPLICATIONS

Accurate depiction of many quantities of interest to worldwide 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 materials such as spilled oil are 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 Navy modelers for possible use in their community and operational models.

RELATED PROJECTS

1. Subgrid-scale Parameterization in 3-D Ocean Models: The Role of Turbulent Mixing (PI - Dr. Sandro Carniel of ISMAR, Venice, Italy) – NICOP.

2. Astronomical Tides and Turbulent Mixing in ROMS/TOMS (PI - L. Kantha) – N00014-06-1-0287. Started February 2006.

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