

Spectral Modeling of Sub-Mesoscale Mixing Processes in the Ocean

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LONG-TERM GOALS

The top-level goals of this effort are to apply the QNSE (quasi-normal scale elimination) technique of parameterization of turbulent modeling to represent ocean mixing and to test and validate the emerging QNSE-based models against the data and other models. The new mixing schemes are expected to improve the prediction of the state of the ocean on sub-meso- and meso-scales.

OBJECTIVES

We shall use the QNSE approach to explicitly account for flow anisotropy caused by stable stratification and planetary rotation. We shall obtain analytical expressions for spectral and wave characteristics of turbulence not available within the traditional Reynolds stress closure modeling. This effort will improve an intellectual framework for objective comparison of various models of turbulent mixing in the ocean.

APPROACH

This effort entails coordinated theoretical and numerical components. The theoretical component is built upon a quasi-normal scale elimination technique recently developed by the authors (Sukoriansky et al., 2005, 2006a,b). This technique implies successive ensemble averaging over fast fluctuating scales and allows one to easily introduce into consideration such parameters as the grid resolution, the degree of the anisotropy, spectral characteristics, etc. Applied to anisotropic turbulent flows with waves, this method reveals how the extra strains (rotation and stratification) modify dispersion relationships for linear waves and allows one to derive analytically expressions for various one-dimensional and three-dimensional spectra that reflect the impacts of waves and flow anisotropy. When averaging is extended to all scales, the method recovers the Reynolds-averaged, Navier-Stokes (RANS) equation-based models. Since the QNSE method is based upon a more comprehensive physical background than the RANS approach, however, the QNSE-based models are expected to become a viable alternative to their RANS-based counterparts.

The key personnel involved in this effort are the PI, Dr. Boris Galperin, at the College of Marine Science, University of South Florida, St. Petersburg Florida, and Dr. Semion Sukoriansky, at the Department of Mechanical Engineering, Ben-Gurion University of the Negev, Beer-Sheva, Israel.

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WORK COMPLETED

In the preceding effort, the QNSE theory has been applied to stably stratified flows. Although this effort has only started about one month ago, we have already obtained an important result by virtue of using the QNSE theory to recover the Gargett et al. (1981) scaling in the oceanic mixed layer. We have presented our results at two international conferences,

Sukoriansky, S., Galperin, B., and Perov, V., *A Quasi-Normal Scale Elimination (QNSE) theory of turbulent flows with stable stratification*. 18th French Congress on Mechanics, August 27-31, 2007, Grenoble, France

Sukoriansky, S., Galperin, B., and Perov, V., *Anisotropic turbulence and internal waves in stably stratified flows (QNSE theory)*. International conference “Turbulent mixing and beyond,” the Abdus Salam International Center for Theoretical Physics, August 17-26, 2007, Trieste, Italy.

RESULTS

As mentioned in the previous section, we have derived an important result pertaining to the one-dimensional (1D) spectrum of the vertical shear of the horizontal velocity in the oceanic mixed layer. Sukoriansky et al. (2005) showed that at scales weakly affected by stable stratification, the vertical spectrum of the horizontal velocity is given by

$$E_1(k_3) = 0.626 \varepsilon^{2/3} k_3^{-5/3} + 0.214 N^2 k_3^{-3}, \quad (1)$$

where ε is the rate of the viscous dissipation and N is the Brunt-Väisälä frequency. Using Eq. (1), the spectrum of the vertical shear can be written as

$$E_S(k_3/k_0)/E_B = 2 k_3^2 E_1(k_3)/(\varepsilon N)^{1/2} = 2 * 0.626 (k_3/k_0)^{1/3} [1 + 0.34 (k_3/k_0)^{-4/3}], \quad (2)$$

where $E_B = (\varepsilon N)^{1/2}$ and $k_0 = (N^3/\varepsilon)^{1/2}$ is the Ozmidov wave number. Equation (2) can be represented by a universal function of k_3/k_0 ,

$$E_S(x)/E_B = F(x), \quad x \equiv k_3/k_0. \quad (3)$$

This scaling was first suggested by Gargett et al. (1981) who noticed that “in the intermediate-wavenumber range... the collapse of the observations to a single curve $[F(x)]$ over the range $0.1 < k_3/k_0 < 1$ is remarkable...” Later, the same scaling was verified by Gregg et al. (1993) using several different data sets. They notice that “Gargett et al. (1981) are uncertain whether the spectral collapse effected by their buoyancy scaling demonstrates the existence of the Shur-Lumley buoyancy subrange or whether it is simply fortuitous... The buoyancy scaling used by Gargett et al. (1981) does collapse their observations... the same scaling is applied to PATCHEX and PATCHEX north... The results are dramatic, achieving a better collapse than obtained by Gargett et al. The collapse extends across the internal wave range ... “

Comparison of Eqs. (2) and (3) shows that the collapse is not fortuitous at all. Furthermore, it is predicted by the QNSE theory. The actual quantitative agreement is also remarkable.

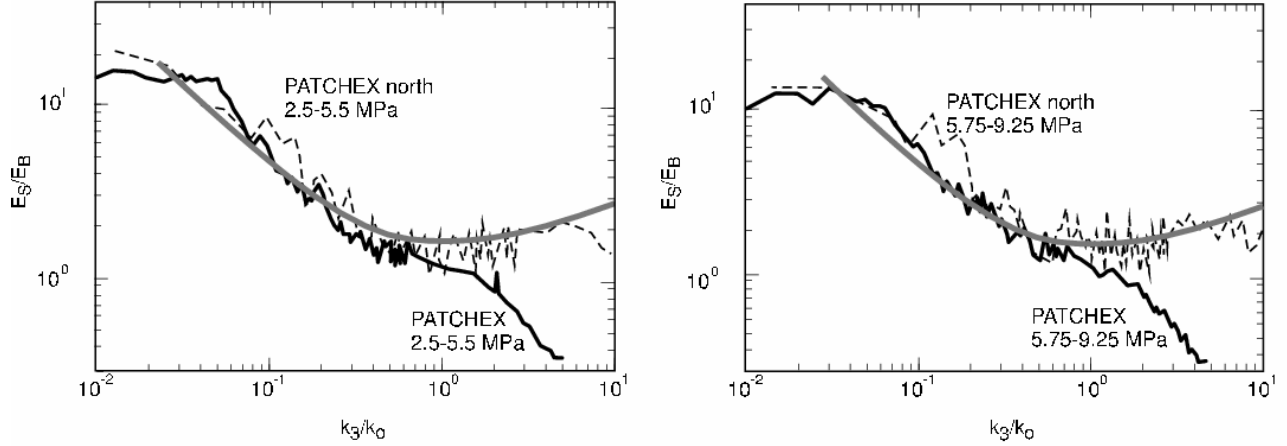


Figure 1. Comparison of the data from Gregg et al. (1993) with the analytical prediction by the QNSE theory, Eq. (2), shown by the gray lines.

Figure 1 compares Eq. (2) with the observational data by Gregg et al. (1993). Although all data points collapse well on one line for $k_3/k_0 < 1$, there is a discrepancy between the observations for $k_3/k_0 > 1$. The theoretical expression (2) is in very good agreement with the data from PATCHEX north while for PATCHEX, the agreement is good only for $k_3/k_0 < 1$. The difference can be understood if the strength of turbulence, measured by the magnitude of the buoyancy Reynolds number, $R_b = \varepsilon/\nu N^2 = (k_d/k_0)^{4/3}$ is taken into account (here, ν is the molecular viscosity and k_d is the Kolmogorov wave number). Using the data from Gregg et al. (1993), we find that for PATCHEX, $R_b \cong 14$ and $k_d/k_0 \cong 7$, while for PATCHEX north, $R_b \cong 125$ and $k_d/k_0 \cong 37$. Comparing these values with Fig. 1, we see that for PATCHEX, the inertial subrange of isotropic 3D turbulence was practically absent while for the data from PATCHEX north the 3D subrange was well established. From the data-theory comparison in Fig. 1 we can learn that Garrett et al. scaling pertains to the buoyancy-dominated turbulence rather than the internal wave dynamics. Note that the theoretical explanation of the Garrett et al. scaling has been given here for the first time.

IMPACT/APPLICATIONS

The QNSE theory will be extended to account for the planetary rotation which, potentially, may lead to the analytical derivation of the Garrett-Munk spectrum of internal gravity waves. The QNSE method can, in principle, be extended to flows with inverse energy cascade (this is not trivial but we have already done this in the past). This method may enhance our understanding and modeling capabilities of a broad variety of problems ranging from the small-scale vertical mixing to large-scale anisotropic tracer dispersion. These problems have important implications for the sub-mesoscale modeling used in the Navy operations.

RELATED PROJECTS

In an ongoing project supported by the US Army Research Office, we are applying the QNSE theory to modeling of the atmospheric boundary layers. A QNSE-based RANS model developed in the course of that project yielded performance superior to that delivered by conventional Reynolds stress models

used in HIRLAM (High-Resolution Limited Area Model installed at the Swedish Meteorological and Hydrological Institute) and WRF (Weather Research and Forecasting model installed at NCAR). At the present time, a QNSE-based RANS model is being installed as an optional boundary layer physics package in WRF. It is supposed to be included in the new release of WRF in the spring of 2008.

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