Synthesis of TKE Dissipation Rate Observations in the Ocean's Wave Zone

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LONG-TERM GOALS

We wish to improve our understanding of turbulence and small scales processes in the oceanic near surface layer and their relation to surface waves. Better understanding of these processes will ultimately improve turbulence parameterization schemes resulting in more accurate model predictions.

OBJECTIVES

We propose to synthesize all the available near-surface turbulence kinetic energy (TKE) dissipation data, along with simultaneous meteorological, surface wave, and current measurements, and classify how various measuring schemes and surface conditions affect the results. The specific objectives of this analysis would be to publish the results and provide:

1) A consistent assessment of existing data sets.

2) Recipe/s of parameterization schemes of TKE dissipation as a function of the forcing (wind stress, wave age, wave height, buoyancy flux, stratification).

3) Estimates of the fraction of the surface energy flux into the ocean (via the surface waves) that is ultimately parted to the mean and the turbulent flow.

4) Better guidance for the design of new experiment/s to fill in existing gaps in our knowledge.

APPROACH

We will firstly gather the available data sets from various investigators. Data sets include near surface TKE dissipation rates measured from various platforms (e.g. free rising/falling profilers equipped with shear probes and fast thermistors, drag spheres). Complementary data includes vertical profiles of temperature and salinity, and hence density, atmospheric boundary layer (ABL) fluxes (wind stress and heat flux), wave parameters, and some include current measurements. Available data were collected both in the ocean and in lakes, at various geographical locations, and under a variety of atmospheric and surface wave conditions.

The various TKE dissipation, hydrographic, meteorological, wave, and current data will be put into a database. This will allow easy grouping of the dissipation values according to wind stress conditions, surface wave parameters, surface heat fluxes (e.g. convective conditions, stabilizing conditions), and hydrographic conditions (e.g. stable stratification, neutral stratification). The database will also

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14. ABSTRACT
We wish to improve our understanding of turbulence and small scales processes in the oceanic near surface layer and their relation to surface waves. Better understanding of these processes will ultimately improve turbulence parameterization schemes resulting in more accurate model predictions.

15. SUBJECT TERMS

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facilitate statistical analysis of various parameters such as the distribution of TKE dissipation rates as a function of wind stress, wave height and age, stratification, stability in the oceanic boundary layer (OBL), etc. We will also try to determine the statistical relationship between the intermittency of the turbulence and the wind/wave conditions (specifically the relations between the rate that waves break and the occurrences of enhanced dissipation rates).

Identification of the dominant forcing parameters (e.g. surface friction velocity, surface heat/buoyancy flux, wave age, absence/presence of breaking waves, absence/presence of swell) for each of the grouped dissipation data sets will allow us to determine the best apparent nondimensional parameterization groups on which to scale the dissipation (e.g. in the wave breaking zone, the swell influenced layer, and the layer beneath it). Estimates of the dominant turbulence length scales (e.g. Thorpe overturning scale) and time scales involved in the various turbulence processes will be made and related to the observed dissipation rates and the pertinent forcing. For cases of enhanced TKE dissipation we will try to determine when, and at what depth range, the Monin-Obukhov and/or convective scaling are valid and when this simple scaling breaks down.

We will quantify the fraction of energy flux E_{10} in the ABL that is dissipated in the OBL under the various wind/wave-age/wave-height conditions (estimates from various studies range between, roughly, 1% to 10% (e.g. Anis and Moum, 1995). Currently researchers are in disagreement as to the amount of energy flux from the waves to the ocean (i.e. into the surface currents). For example Crawford and Large (1996) assume that only a negligible amount of the energy that enters the wave layer indeed goes into the ocean currents. Although this assumption may work well for climate models it disagrees with results from several experimental and theoretical studies and may be a wrong assumption for forecast models of currents and waves. More importantly, if indeed 10% of E_{10} is dissipated in the OBL this may well be a manifestation that a *non*-negligible amount of energy flux enters the ocean and goes either into the mean current field or into turbulence (both will result in enhanced dissipation rates).

WORK COMPLETED

We have contacted the PI's responsible for various field studies during which TKE dissipation measurements were carried out in the near surface layers of both the ocean and lakes and have acquired most of the available data sets. The acquired data sets have TKE dissipation data collected from various platforms. These include free rising/descending profilers, using shear sensors (direct estimates of dissipation; Gregg, 1987; Anis and Moum, 1995) or fast thermistors (indirect estimates of dissipation via e.g. a fit to the Batchelor spectrum; Stips, pers. comm., 2001), ship-bow mounted sensors (Drennan et al., 1996; Soloviev, pers. comm., 2001), submarine mounted sensors (Osborn et al., 1992), and moored instruments (miniature dragspheres, acoustic travel time current meters, and two-axis laser-Doppler velocimeters; Terray et al., 1996). Several of these data sets include relatively detailed surface wave information such as wave-height, wave-period, and wave-age as well as surface meteorological data. However, some of the other data sets, although including surface meteorological data, lack detailed surface wave information and have only wave estimates from the ship's bridge observations.

The acquired data sets have been put in an initial data base subdivided according to the various measurement platforms used. We have started with an analysis of six of the TKE dissipation sets divided, roughly, into two main groups: the first group includes relatively shallow measurements (mostly on the order a few meters or a few significant wave heights) made either from ship-bow mounted instruments (Drennan et al., 1996; Soloviev, pers. comm. 2001) or moored instruments (Terray et al., 1996); the second group includes dissipation estimates made to larger depths (10m or more and 10-20 times the significant wave heights) from profilers using shear sensors (freely descending profiler, Gregg, 1987; freely ascending profiler, Anis and Moum, 1995) and from a vertically profiling submarine using shear sensors as well (Osborn et al., 1992). We note that these data sets comprise both a relatively diverse variety of sensor and platform types as well as a variety of geographical locations and meteorological forcing conditions.

To set a common framework for comparison of the data sets, as well as to compare the data to the widely used constant stress-layer parameterization, we firstly analyzed the dissipation estimates in the so called wall-layer coordinates (Fig. 1). Using this parameterization the dimensionless TKE dissipation rate is given by $\varepsilon/(u_*^3/\kappa z)$ and the dimensionless depth by gz/u_*^2.

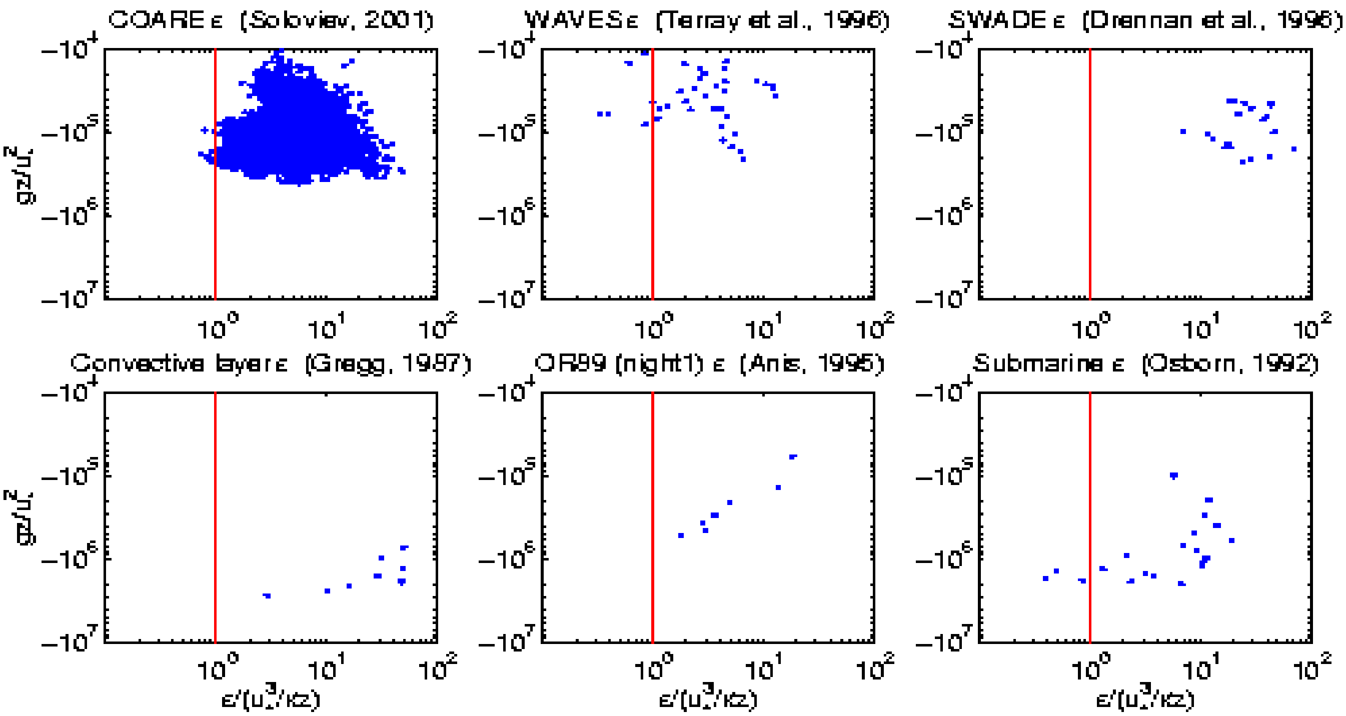

Figure 1. Dimensionless dissipation rate, $\varepsilon/(u_*^3/\kappa z)$, as a function of dimensionless depth, gz/u_*^2. The constant stress layer is represented by the vertical line (red), $\varepsilon/(u_*^3/\kappa z) = 1$ (ε is the TKE dissipation rate, u_* is the friction velocity in water, $\kappa = 0.4$ is von Karman's constant, and z is the depth). The upper panels represent dissipation estimates taken in relatively shallow depths (a few meters at most) from ship-bow mounted sensors and from moored instruments. The lower panels represent dissipation estimates made from profiling instruments and on average extends to greater depths (10 m or more). Sources for the data sets are noted on the individual panels.

Next, we analyzed the same six data sets but now using the proposed scaling of Terray et al. (1996) based on their WAVES data set. This parameterization scales the TKE dissipation with the rate of energy input, $\rho_w F$, from the wind to the waves and the significant height, H_s, of the wind-waves. The depth is scaled by the significant wave height (for details see Terray et al., 1996). This scaling, proposed for the intermediate depth region beneath a thin near surface layer of a thickness of about one significant wave height, predicts a decay with depth as z^{-2}. Terray et al. (1996) noted that below this layer the dissipation rate asymptotes to values following wall layer scaling while above this layer, i.e. in the thin near surface layer, the dissipation rate was observed to be high and roughly constant.

We computed the vertically integrated dissipation rates, ε_I, in the near surface layer (between the surface and a depth commensurate with the measurement depth) in order to quantify the fraction of wind energy flux, E_{10}, in the ABL that is dissipated in the OBL ($E_{10} = \tau_o U_{10}$; τ_o is the surface wind stress and U_{10} is the wind speed at 10 m height). Other studies (Anis and Moum, 1995; Greenan et al., 2001) have shown that the vertically integrated dissipation rates in the OBL, in the presence of waves, were several times larger than 1% of E_{10} as predicted by wind stress production (Oakey and Elliott, 1982). Our computed ε_I in the surface layer possibly accounts for a large part of the wind energy flux that is dissipated in the OBL. However, since we did not include the deeper layers we should consider ε_I computed here more like a *lower* limit on the total wind energy flux dissipated in the OBL.

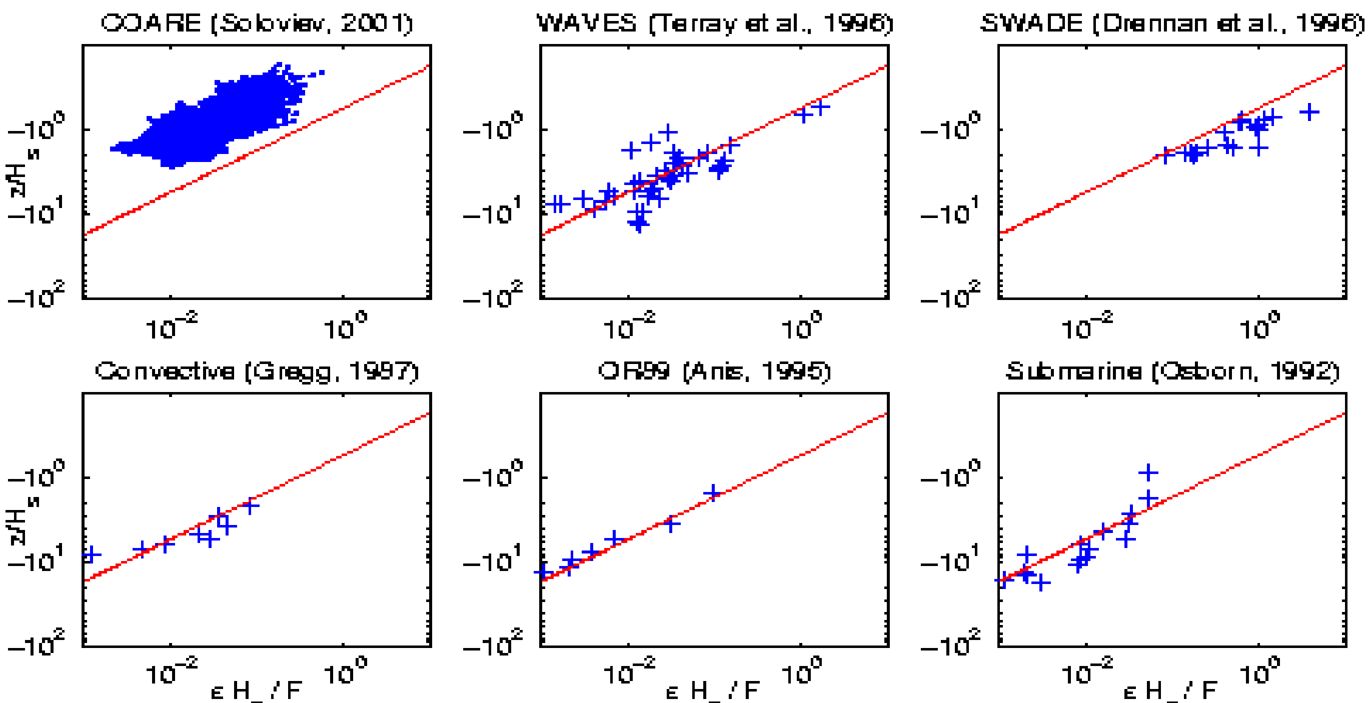

Figure 2. Dissipation rates vs. depth in the scaled coordinates of Terray et al. (1996). The solid line (red) represents the best fit of the WAVES data: $\varepsilon H_s/F = 0.3(z/H_s)^{-2}$. Data sets are as in Fig. 1.

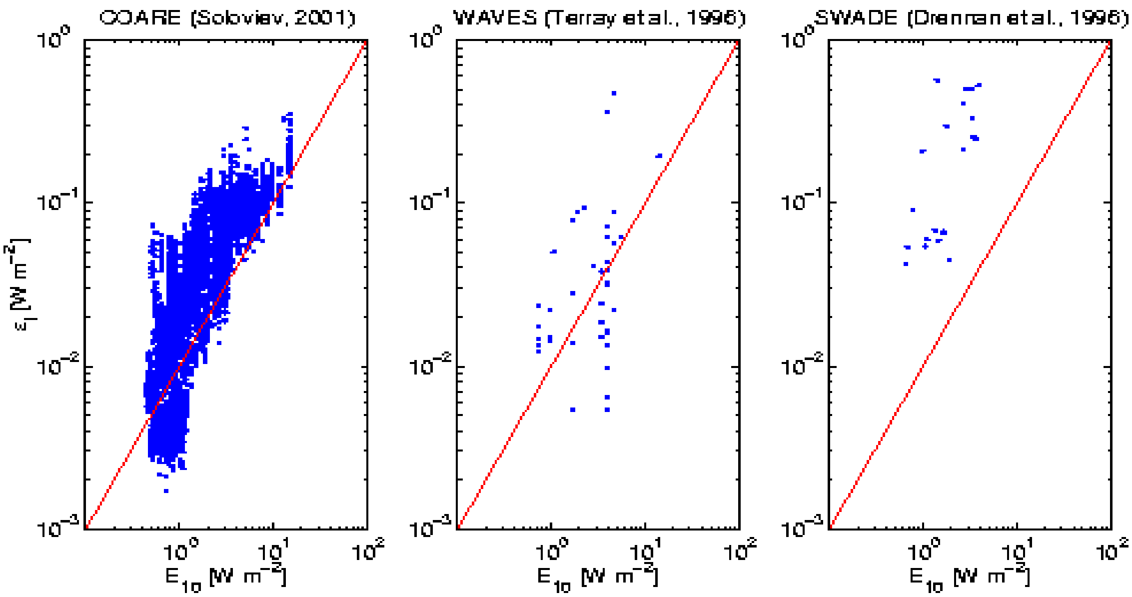

Figure 3. Depth-integrated dissipation rate, ε_I, in the near surface layer (thickness of a few H_s, the significant wave height) vs. wind power at 10m height, E_{10}. The solid (red) line is adapted from Oakey and Elliott (1982) and represents 1% of E_{10} dissipated in the oceanic boundary layer. Note the apparent difference between the WAVES (center panel) and the other two data sets. Data sets are the same as those in the upper panels of Fig. 1.

RESULTS

If the commonly employed constant stress layer parameterization is indeed to provide an accurate scaling of the TKE dissipation estimates, we expect the data to collapse around $\varepsilon/(u_*^3/\kappa z) = 1$. It is quite obvious that for the six data sets presented in Fig. 1 this scaling does not hold true for almost all the data points and enhanced dissipation rates exceed wall layer values by up to one or two orders of magnitude. This observation seems to hold for both the relatively shallow data sets (upper panels, Fig. 1) as well as for the deeper casts obtained with the profilers (lower panels, Fig. 1). From a comparison of the WAVES data set (center upper panel, Fig. 1) to the other data sets, an apparent difference is noted, namely a relatively smaller departure from wall layer scaling. For the WAVES experiment (Lake Ontario) the wind waves were strongly fetch limited (Terray et al., 1996). Moreover, wave ages, C_p/u_{*a} (where C_p is the wave-peak phase speed and u_{*a} is the air side friction velocity), of this particular data set do not exceed a value of about 7, while wave ages of the other sets are larger, e.g. 20 or more for the SWADE data set (Drennan et al., 1996) and 13 for OR89 data (Anis and Moum, 1995).

Examination of the dissipation rates scaled by the proposed WAVES parameterization (Terray et al., 1996) suggests that the six data sets examined are consistent with this parameterization. An exception is the COARE data set (Fig.2, left upper panel); although these data seem to follow the expected depth dependence (i.e. $(z/H_s)^{-2}$) they lie consistently above the line that represents the best fit of the WAVES data: $\varepsilon H_s/F = 0.3(z/H_s)^{-2}$ **.** At the moment we do not know the reason for this apparent discrepancy. We also note that for the convective conditions (Fig.2, lower left panel) the significant height of the wind waves was not available and we have used a best fit of the form of $(z/H_s)^{-2}$, as suggested by the WAVES data, resulting in a significant wind wave height of H_s = 3m. We believe that this is too high for the prevailing wind conditions of 8.6 m/s (winds were weaker before dissipation data were taken).

The majority of the data suggests that on average 5-10% of E_{10} is dissipated in the OBL. However, the fraction of E_{10} dissipated in the OBL is lower, on average, for WAVES (center panel, Fig. 3) than for the other two data sets (except at lower E_{10} for the COARE data). Together with the apparent smaller departure from wall layer scaling of the WAVES data, and noting that the waves were strongly fetch limited and relatively young, this appears to be consistent with other evidence (Thorpe, 1992) that at low wave age, when breaking occurs frequently, wind stress is effectively transferred to the water and water friction velocity can be accurately derived from the surface wind stress. However, at high wave age breaking is much less intense, so that the linkage between the wind stress and the water through the waves is weaker. In this case the rate of momentum loss from the *wave field* contributes significantly to the *effective* friction velocity and hence TKE dissipation rates in the ocean.

IMPACT/APPLICATION

Results of this work will improve TKE dissipation parameterization schemes used in oceanic models.

TRANSITIONS

Currently results are used only in our respective research groups.

RELATED PROJECTS

Other CBLAST projects.

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