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

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LONG-TERM GOALS

The ultimate goal of this project is to improve our understanding of turbulence and small scale processes in the oceanic near surface layer and their relation to surface waves and meteorological forcing. Better understanding of these processes will result in the improvement of turbulence parameterization schemes and therefore in more accurate model predictions.

OBJECTIVES

Our approach is to gather and synthesize the available near-surface turbulence kinetic energy (TKE) dissipation data, along with their simultaneous meteorological, surface wave, and current measurements, and classify how various measuring schemes and surface conditions affect the results. The specific objectives of the current 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 rates, ε, 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

Gather available data sets from various experiments which include near surface TKE dissipation rates measured from a variety of platforms (e.g. free rising/falling profilers and quasi-horizontal gliders equipped with shear probes and fast thermistors, submarine and ship-bow mounted shear sensors, acoustic travel-time current meters, 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. The available data that will be used were collected both in surface layers of the ocean and lakes, at various geographical locations, and under a range of atmospheric and surface wave conditions.

The available TKE dissipation rates, 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 facilitate statistical analysis of various parameters such as the distribution of TKE dissipation

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14. ABSTRACT
The ultimate goal of this project is to improve our understanding of turbulence and small scale processes in the oceanic near surface layer and their relation to surface waves and meteorological forcing. Better understanding of these processes will result in the improvement of turbulence parameterization schemes and therefore in more accurate model predictions.

15. SUBJECT TERMS

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rates as a function of wind stress, wave height and age, stratification, stability in the oceanic boundary layer (OBL), etc. We will try to determine statistical relationships between the intermittency of the turbulence and the wind/wave conditions and the relation between the rate of wave breaking 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.

Table 1. Summary of meteorological and wave data for the various experiments analyzed (ranges are given in most cases): U_{10} is the 10- m wind speed, τ is the surface wind stress, u_{*w} is the water surface friction velocity, H_s is the significant wave height, T_s is the period at the peak of the wave spectrum, and F is the rate of wind energy input into the waves.

Instrument	U_{10} [m/s]	τ [N/m^2]	u_{*w} [m/s]	H_s [m]	T_s [m]	$F \times 10^4$ [m^3/s^3]	***Refer.***
Shear probes (free falling profiler)	8.6	0.104	0.010	3.3 (swell)	15.0 (swell)	6.94	Gregg (1987)
Shear probes (submarine)	5.2-8.2	0.041-0.102	0.006-0.010	0.56	4.0	0.77-2.97	Osborn (1992)
Shear probes (free rising profiler)	12.6	0.252	0.016	1.0 (wind) 3.0 (swell)	4.0 (wind) 12.0 (swell)	12.7	Anis and Moum (1995)
BASS and Dragsphere	6.9-15.7	0.104-0.902	0.010-0.030	0.16-0.49	1.4-2.4	0.96-18.2	Terray et al. (1996)
Acoustic current meter (bow mounted)	8.0-11.8	0.079-0.377	0.009-0.019	0.88-2.62	3.4-6.3	0.78-6.42	Drennan et al. (1996)
EM velocity probes (bow)	16.8-19.2	0.067-0.779	0.008-0.028	0.97-4.32	4.5-11.6	2.30-56.5	Soloviev (2001)
Shear probes (free falling profiler)	6.8-10.2	0.046-0.194	0.005-0.012	0.55-1.61	3.6-4.3	2.20-10.3	Greenan et al. (2001)
Shear probes (quasi-horizontal glider)	6.9-9.9	0.056-0.127	0.005-0.012	0.62-1.25	3.6-4.3	1.53-14.2	Greenan et al. (2001)

Quantification of 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 an inaccurate 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 (we note that in both cases TKE dissipation rates may be enhanced).

WORK COMPLETED

Most of the available data sets for various field experiments during which TKE dissipation rate and wave measurements were carried out in the near surface layers of ocean and lakes have been acquired (see Table 1 for a summary). A variety of instruments and platforms have been used to measure the TKE dissipation rates and while several of the data sets include detailed surface wave measurements, some have only wave estimates (height and period) from the ship's bridge observations. Wind speeds for the various data sets analyzed so far range from 5.2-19.2 *m/s* with wave heights and periods between 0.16-4.32 *m* and 1.4-15.0 *s*, respectively (see Table 1). Several of the TKE dissipation data sets include relatively shallow measurements on the order of a few significant wave heights (Drennan et al., 1996; Terray et al., 1996 Soloviev, pers. Comm. 2001), while some of the data sets include deeper measurements spanning the whole mixed layer (ML).

In order to compare the various data sets we have used a common framework and scaled the TKE dissipation estimates in wall layer coordinates. In this parameterization the dimensionless TKE dissipation rate is given by $\varepsilon/(u_*^3/\kappa z)$ and the dimensionless depth by gz/u_*^2. If indeed this scaling holds then $\varepsilon/(u_*^3/\kappa z) \sim 1$, however, as noted from the examples shown in Fig. 1, this is most often not the case and a large number of data show that wall layer scaling severely underestimates TKE dissipation in the SL. Moreover, bootstrap statistics of the wall layer scaling show that mean values of $\varepsilon/(u_*^3/\kappa z)$ range from 3.6 and up to 34.5 (Table 2).

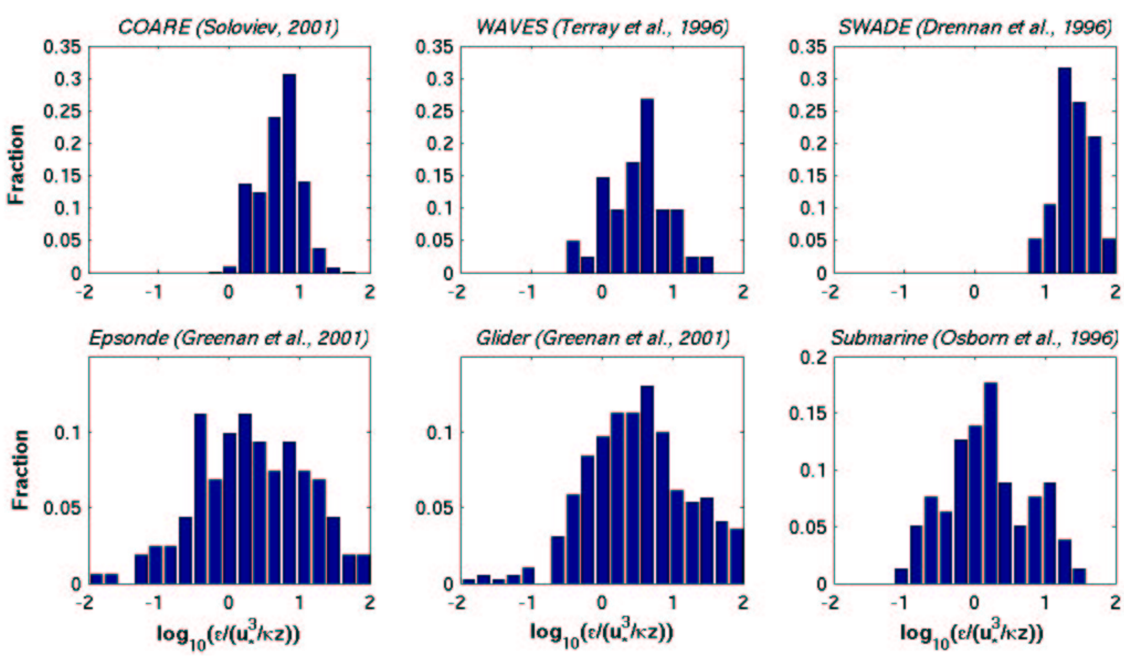

Figure 1. Histogram of dimensionless TKE dissipation rate, $\varepsilon/(u_*^3/\kappa z)$. In cases where ε follows this scaling we expect $\varepsilon/(u_*^3/\kappa z) \sim 1$. It can be seen that simple wall layer scaling largely underestimates the majority of the data analyzed here. (Sources for the data sets are noted on the individual panels.)

A different prediction of the wall layer scaling is that the fraction of the wind energy flux in the ABL, E_{10} ($E_{10} = \tau U_{10}$; τ is the surface wind stress and U_{10} is the wind speed at 10 m height) that is dissipated in the OBL is on the order of 1% (Oakey and Elliott, 1982). However, it is noted that laboratory and field measurements in combination with a model used by Richman and Garrett (1977) predict a higher percentage (4-9%). Statistics of the vertically integrated dissipation rates, ε_I, in the SL (depths on the order of a few wave heights and less than 10 m for all sets in this analysis), show that in the presence of waves the values are significantly higher than the wall layer predicted 1% (see Table 2; also note that since we did include only the SL one needs to consider ε_I computed here more like a *lower* limit on the *total* wind energy flux dissipated in the OBL.).

Instrument	E_{10} [W/m^2]	ε_I/E_{10} [%]	$u_*^3/\kappa z$ x10^7	$\varepsilon/(u_*^3/\kappa z)$	***Reference***
Shear probes (free falling profiler)	0.89	14.6	0.90-34.2	30.2 (18.2-41.2)	Gregg (1987)
Shear probes (submarine)	0.21-0.83	5.97 (3.25-8.03)	0.63-49.4	3.6 (2.6-4.8)	Osborn (1992)
Shear probes (free rising profiler)	3.16	10.2	7.2-64.5	6.5 (3.1-10.8)	Anis and Moum (1995)
BASS and Dragsphere	0.72-14.2	1.94 (1.36-2.67)	12.0-1230	4.9 (3.4-6.7)	Terray et al. (1996)
Acoustic current meter (bow)	0.66-3.89	11.2 (7.92-15.1)	9.79-104	34.5 (23.3-50.0)	Drennan et al. (1996)
EM velocity probes (bow)	0.45-14.9	1.87 (1.84-1.89)	4.96-657	6.2 (6.1-6.3)	Soloviev (2001)
Shear probes (free falling profiler)	0.18-1.29	6.0 (3.9-8.4)	0.36-10.1	9.7 (6.7-12.9)	Greenan et al. (2001)
Shear probes (quasi-horizontal glider)	0.15-1.43	4.7 (2.5-7.5)	0.34-22.1	11.0 (9.1-13.4)	Greenan et al. (2001)

Table 2. Summary of scaling results for the various experiments. Variables are defined in the text. (bootstrap mean value and 95% confidence interval are given in parentheses).

Following Terray et al's (1996) suggested scaling of ε, we have binned the scaled dissipation values, $\varepsilon H_s/F$, in scaled depth bins, z/H_s, and computed the mean and 95% bootstrap confidence intervals for each bin (F, is the rate of energy input from the wind to the waves and, H_s, is the significant height of the wind-waves; values used are given in Table 1). Results of this scaling are presented in Fig. 2.

RESULTS

Our results indicate that for the majority of the data sets analyzed the widely used wall layer parameterization severely underestimates the TKE dissipation estimates in the SL and in most cases we found $\varepsilon/(u_*^3/\kappa z) >> 1$ in the SL (depths of several wave heights, but less than 10 *m*). More specifically, average dissipation estimates commonly exceeded $u_*^3/\kappa z$ by at least a factor of ~4 while most where larger by an order of magnitude or so (largest value was more 30 times $u_*^3/\kappa z$).
The wave parameterization proposed by Terray et al. (1996) was found to hold for several of the data sets in which enhanced dissipation rates have been observed in the SL (Fig. 2). Specific examples are the data sets collected from the quasi-horizontal glider (Greenan et al., 2001), the submarine (Osborn et

al., 1992), as well as part of the data collected with Epsonde (Greenan et al., 2001). A noted exception is the COARE data set (Fig.2, left upper panel); although these data seem to roughly follow the expected depth dependence of $(z/H_s)^{-2}$ they lie consistently above the best fit of the WAVES data: $\varepsilon H_s/F = 0.3(z/H_s)^{-2}$**.** We suspect that this may be the result of underestimating *F*, the rate of energy input from the wind to the waves. In this case, *F*, was estimated from the surface friction velocity and significant wave height which were the only available wave and meteorological and wave parameters.

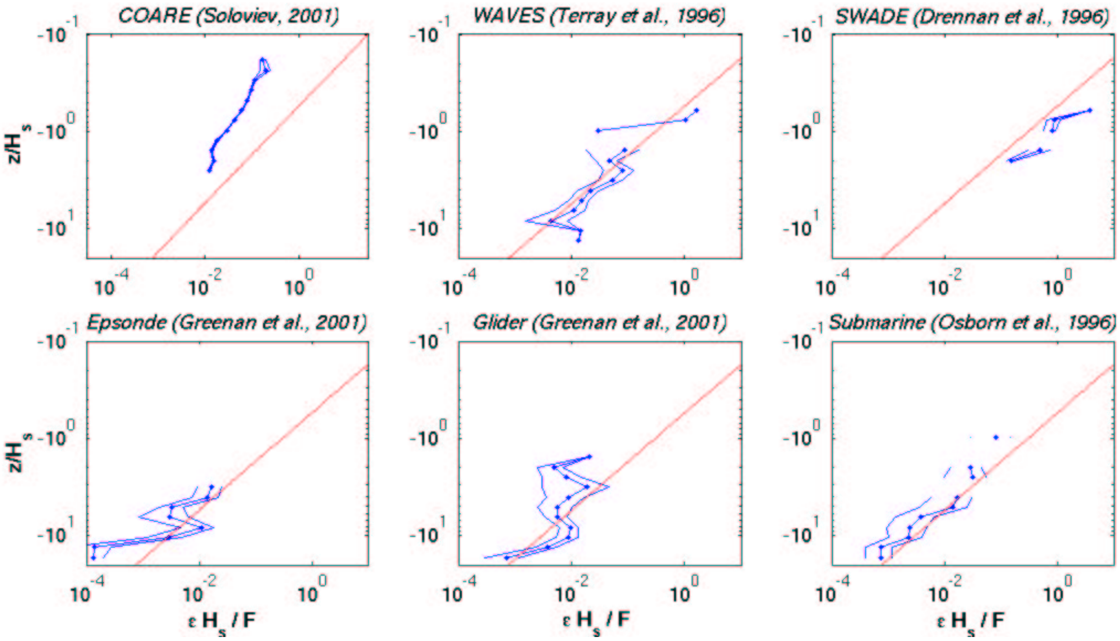

Figure 2. Example of dissipation rates vs. depth in the scaled wave coordinates of Terray et al. (1996). The solid line (red) represents the best fit of their WAVES data: $\boldsymbol{\varepsilon H_s/F = 0.3(z/H_s)^{-2}}$ **.**

The estimate of the fraction of E_{10} dissipated in the OBL suggested by Oakey and Elliott (1982), i.e. Anout 1%, was found to be an underestimate once the near surface TKE values were taken into consideration. Most of the data sets examined show that 5% and up to more than 10% of E_{10} are dissipated in the OBL. This conforms closely to the values suggested by Richman and Garrett (1977). Some of the data we have analyzed suggest that when the waves are fetch limited and/or relatively young, there might be a better conformity to features predicted for the wall layer (e.g the fraction of E_{10} dissipated in the OBL is closer to the predicted 1%). This behavior is consistent with other evidence (e.g. Thorpe, 1992) and we are currently examining the effect of wave age more closely.

IMPACT/APPLICATION

Results of this work will improve TKE dissipation parameterization schemes used in oceanic models and our understanding of turbulence and small scale processes in the oceanic near surface layer.

TRANSITIONS

Results are currently used in our respective research groups.

RELATED PROJECTS

Other CBLAST projects.

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