Measurements of Turbulence in the Upper Layer with AUTOSUB

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LONG-TERM GOALS

The long-term goal is to understand the dynamics of the upper layer of the ocean.

OBJECTIVES

This grant covers measurements made in conjunction with Drs. Steve Thorpe and Rolf Lueck using AUTOSUB equipped with side scan sonars and turbulence probes to examine and quantify the following phenomena:

1. the intensity, structure and decay of turbulence beneath breaking wind waves, graded according to their acoustic scattering on breaking, in different wind, buoyancy flux, and swell conditions, to provide the information necessary to construct a model of turbulence generated by breaking waves (in the presence of a buoyancy flux), in particular to assess its effects on turbulence production in the mixed layer and transport of momentum and heat. Presently, little is known even of the vortex structure/rotors produced or the persistence of turbulence beneath breaking waves (Thorpe 1995).

2. the variation of turbulence levels within and between the bands of bubbles associated with Langmuir circulation, to establish the role of Langmuir circulation in the vertical transport of heat and momentum, comparing their effects with that of breaking waves, with the objective of improving their representation in models of air-sea transfers and the mixed layer; and

3. the variation in upper ocean turbulence resulting from internal gravity waves to establish the effect of internal waves on turbulence in the upper ocean (by, for example, the stretching of vortex lines - see Thorpe, 1996).

To achieve these objectives, AUTOSUB was operated in open waters of western Scotland.

APPROACH

AUTOSUB (figure 1) is funded by the Natural Environment Research Council of the United Kingdom and the operations are located at the Southampton Oceanography Centre. The vehicle is 6.8 m long, 0.9 m in diameter, and weighs 3400 pounds in air. Propulsion is from a brushless DC motor that uses rare earth magnets on an external rotor

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Figure 1. Top panel is AUTOSUB underway for near surface test in Loch Linnhe Scotland. The lower panel shows the turbulence pressure case covered with the retractable sheath that protects the delicate probes when the vehicle is on the surface.

that holds the five blades of the propeller. Cruising speed depends on instrumentation with a nominal value of 2 m/s for a clean configuration and a speed of 1.25 m/s for our configuration. The vessel operates very smoothly with r.m.s. values 0.04 m for depth, 0.2° for pitch, 0.2° for yaw, and 0.4° for roll.

To achieve the mission objectives, AUTOSUB was equipped with (a) ARIES II control and sonars (250 kHz at 2 Hz scan rate), (b) turbulence sensors, (c) CTD - at least 2 Hz recording (for detection of fronts, etc), and (d) 300 kHz ADCP. The CTD and ADCP are part of the normal instrumentation complement on AUTOSUB.

The turbulence instrumentation used in this project were originally designed and developed for the work on the USS Dolphin. The digitization rate was 512 Hz and the analog filters on the data channels cut off sharply at 200 Hz. The data was digitized by, and stored in, a small computer, which is located inside AUTOSUB. Power came from the AUTOSUB. A timing signal comes from the ARIES II package in order to assure alignment between the two data sets.

There are eight channels of data: the cross-stream, horizontal velocity shear, the vertical velocity shear, temperature, temperature derivative, three accelerometers (for pitch, roll and heave), and pressure combined with the pressure derivative. The velocity shear data are used to calculate dissipation rate. The temperature and temperature derivative data are digitally filtered (Osborn et. al., 1992) to produce high-resolution temperature traces with resolution of millidegrees. This data offers the potential of calculating the turbulent heat flux just below the sea surface (Yamazaki and Osborn, 1993). The pressure and its derivative are filtered to produce a pressure record with sufficient resolution to resolve the wave spectra allowing calculations of wave frequency and significant wave height.

WORK COMPLETED

Measurements were made at depths of 2, 4, 6 and 10 m in four missions off the N.W. coast of Scotland with data collection of 112 hrs in winds from calm to 14 m/s. Missions consisted of repeated circuits around a square pattern, with straight runs of almost 5 km on a side corresponding to periods of about one hour. Since the winds were mostly offshore, fetch was generally limited to between 8 and 26 km. The data from the turbulence package has been analysed with dissipations calculated at 1 second intervals. The high-resolution temperature and pressure records were created with a 64 Hz sample rate. As well, the significant wave height and the period of the wind waves and swell were estimated, and the average dissipation along each leg was calculated. A paper has been finished (Thorpe et. al., 2002).

RESULTS

Dissipation follows law of the Wall scaling in the range of steady condition encountered in this data set, $1.17<z/H_s<11.6$ and $11.7<c/u_*<21.7$. This result is not inconsistent with Agrawal et. al.'s. (1992) finding since much of their sampling was nearer the surface than this data set. Terray's (1996) result was for a different range of c/u_*. Since the boundary layer appears to scale like a rigid wall, in spite of the presence of Langmuir circulation, it is possible that there are no new length and velocity scales (in addition to the distance to the surface and u_*) in this region beyond a depth of order H_s.

The acoustic data shows the bubble clouds associated with Langmuir circulation and breaking waves seen in Thorpe's previous work with the ARIES package. There is a noticeable tendency for the high values of dissipation to occur in bubble clouds. The fraction of dissipation values, which occur in bubble clouds, increases with ε. Higher values of ε occur in bubble clouds of longer horizontal extent and correspondingly lower values in the longer gaps between bubble clouds.

Conditional sampling of the data based on the strength of the acoustic scattering signal, shows the relationship between the bubble clouds from Langmuir circulation, breaking waves and temperature ramps in the mixed layer and the turbulent dissipation. Identification of breaking waves in strong winds cannot be done closer to AUTOSUB than about 4 wave periods. Thus, the dissipation from the breakers is only measured at a time after most of the decay has occurred in laboratory experiments. Still enhanced dissipation of about 50% above background is seen between 30 and 50 seconds after breaking at 2.09 m depth with an 11.6 ms^{-1} wind.

Dissipation increases in the bubble bands associated with Langmuir circulation. As well, a temperature signature can be seen although there is no peak in variance of the temperature gradient. These Langmuir bands appear to increase in width with depth in the water column.

Temperature ramps in the mixed layer (Thorpe and hall, 1980, 1987) are large eddies which exchange water vertically, in this case, taking colder, more turbulent, near surface water down and bringing deeper, quieter, warmer, water up. Thus, as AUTOSUB travels across a ramp there is a step like signature in temperature, scattering and dissipation while there is a local maximum in the small-scale variance of the temperature gradient. These eddies have predominantly horizontal vorticity perpendicular to the wind while the Langmuir cells have predominantly horizontal vorticity parallel to the wind. The interaction of these two mechanisms is still to be delineated but there appears to be a greater occurrence of ramps in the bubble clouds associated with Langmuir circulation, perhaps due to the larger vertical shear. The two processes may be non-separable in terms of their effect on the mixed layer.

IMPACT/APPLICATIONS

The development of a long range, autonomous capability to sample turbulence in the surface and near surface regimes of the upper ocean in difficult weather conditions is vital to understanding the important and complex processes that occur there.

TRANSITIONS

The technology for turbulence measurements and interpretation that has been developed by the PI through ONR funding during the last 25 years is now well established in the oceanography community.

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