

ON THE STRUCTURE OF TURBULENCE AND REYNOLDS STRESS DISTRIBUTION IN THE BOTTOM BOUNDARY LAYER OF THE COASTAL OCEAN

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Summary: Turbulent flow measurements were performed in the bottom boundary layer on the U.S. Southeastern continental shelf using PIV. The experiments were performed within 2 m above the bottom, during half of a tidal cycle. A log layer was identified from the obtained velocity field realizations. The bottom boundary layer consists of powerful vortical structures ("gusts"), separated by periods of quiescent flow. In addition, the profiles of Reynolds stresses are estimated using the second order structure function of the velocity fluctuations.

INTRODUCTION

In the coastal ocean, the momentum and energy balances are influenced by several parameters, among which the bottom shear stress and the dissipation rate are of particular significance [1]. The bottom shear stress affects the circulation directly and also generates turbulence that diffuses into the flow. The dissipation rate is a controlling mechanism for the entire turbulent energy budget. Thus, understanding and modeling of ocean flows, sediment transport, pollutant dispersal, and biological processes rely on knowledge of the turbulence characteristics near the ocean bottom. Turbulent flow measurements were performed in the bottom boundary layer on the U.S. Southeastern continental shelf using particle image velocimetry (PIV). The measurements covered half of a tidal cycle within 2 meters from the ocean bed. The results include the mean velocity profile, vorticity contours as well as distribution of Reynolds stresses and dissipation rate, along with the turbulence spectra.

EXPERIMENTAL SET-UP AND DEPLOYMENTS CHARACTERISTICS

The submersible PIV system was deployed in the vicinity of the South Atlantic Bight Synoptic Offshore Observational Network (SABSOON) in a water depth of 23m. Images were recorded using two 2Kx2K digital cameras. The light sheets were produced by a dual-head, pulsed, dye lasers and transmitted via optical fibers to the submerged optical probes. Other environmental sensors were also deployed with the submersible PIV system. All the instruments were rigidly mounted on a telescopic platform with a maximum profiling range of 10 m. The platform also aligned the light sheets with the mean flow. Cameras were focused onto two sample areas of 35x35 cm² in vertical plane, and separated horizontally by 31 cm. Correlation analysis with 64x64 pixels (corresponding to 1.1x1.1cm² area in the fluid) interrogation areas, and 50% overlap between adjacent windows, yielded 63x63 2D vectors per individual instantaneous realization. Depending on natural seeding, only 85 to 90% of the interrogation areas have a sufficient number of particles to calculate the velocity. During one of the SABSOON deployments, the system was submerged continuously for 5 hours, and images were recorded at 3Hz for 20 minutes, generating 3600 realizations per run. Then the elevation was changed and another series was recorded.

The aim of this experiment was to acquire data covering accelerating, peak, and decelerating phase of the tidal cycle, and at the same time traverse the water column. Tidal currents ranged from 17 to 27 cm/sec at the lowest elevation, and up to 40 cm/sec at the highest measurement site. Surface waves signature was present in all records with streamwise wave induced flow amplitude ranging from 7 to 10 cm/sec, and a typical period of 8 seconds.

RESULTS AND DISCUSSION

The mean streamwise velocity profiles are constructed from seven data sets within 2 m above the bottom. The velocity values are normalized by the mean current speed (figure 1) obtained independently from the ship's ADCP. The data demonstrate the existence of a "log layer" within a mixed oscillatory motion and a mean current flow. Clearly, the slope of the log layer varies, presumably due to effects of acceleration and deceleration.

A major challenge is to separate between waves induced motion and turbulence while calculating the Reynolds stresses. To estimate the Reynolds stresses, we use 2nd order structure function of the velocity fluctuations. The methodology is introduced in [2] and has already been applied to ocean data by [3]. The magnitude of the structure function asymptotically approaches that of the Reynolds stress when the separation between the scale of the measured flow field is larger than the integral length scale of turbulence, but is still much smaller than the wavelength of the surface waves. The PIV data enables us to calculate the structure function as a function of the separation distance. Vertical profiles of the shear stresses are obtained by dividing the vector maps into horizontal strips and applying the structure function separately on each of them. The final manuscript will contain a comparison between the shear stress estimate from the log layer profile and the Reynolds stress calculated from the structure function.

The turbulent flow in the bottom boundary layer consists of domains with powerful vortical structures (“gusts”), separated by periods of quiescent flow as illustrated by the time series of vorticity magnitude (figure 2). For the subsequent analyses, the flow is classified into categories of high (figure 3), intermediate, and low (figure 4) instantaneous mean vorticity magnitude. Conditional sampling of the Reynolds shear stresses based on the vorticity magnitude shows that almost all the contribution to the Reynolds stresses are made by the high and intermediate vorticity magnitude events. This trend is consistent with previous observations at lower current speed [4]. During periods of low vorticity magnitude, the shear stresses are essentially zero. Thus, shear stresses, and as a result turbulent production, are generated only in flow domains containing large vortex structures, i.e. during periods of gusts. On the other hand, the dissipation rates estimated from the spectra and by direct calculation of local velocity gradients indicate that dissipation occurs continuously and increases only slightly during gusts [1]. This trend is consistent with the shapes of the conditionally sampled turbulent spectra, showing that the gusts affect mostly the large scales, and have much less effect on the small scales. Consequently, the intermittent passage of large-scale vortical structures has a weak effect on the local dissipation rate, which is dominated by the more uniform distributions of the background small-scale turbulence. Data analysis that will be presented in the final manuscript will also examine the occurrence of bursting, ejection and sweeps, and their effects on production and dissipation.

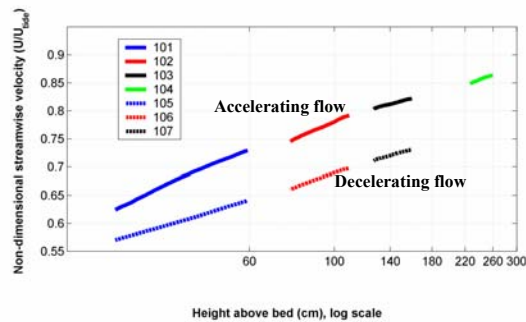


Figure 1: Mean velocity profile in the ocean bottom on a semi-log scale, normalized by the mean current speed

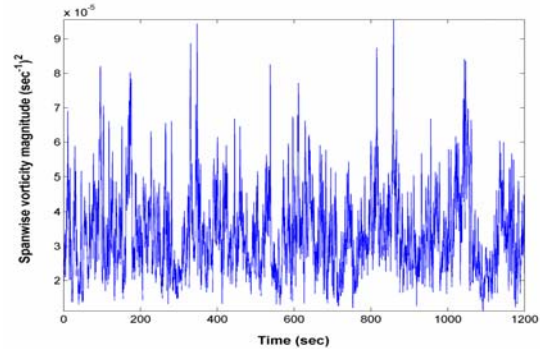


Figure 2: Time series of the mean vorticity magnitude over an entire vector map

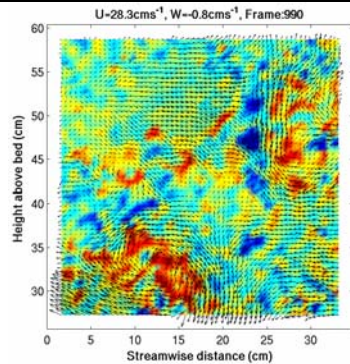


Figure 3: Instantaneous vorticity contour plot demonstrating the presence of strong vortical motion

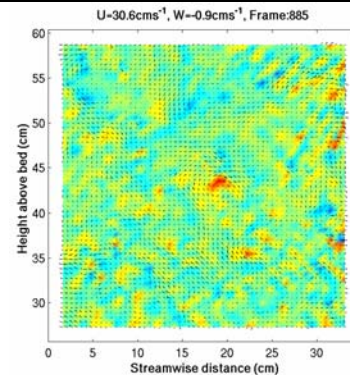


Figure 4: Instantaneous vorticity contour plot demonstrating the presence of a quiescence flow

References

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