Journal of Coastal Research	SI 64	1091 - 1094	ICS2011 (Proceedings)	Poland	ISSN 0749-0208

Turbulence in the Bottom Boundary Layer of Moreton Bay, Queensland, Australia

C. J. Lemckert†, P. G. Campbell‡ and G. A. Jenkins∞
‡ Griffith School of Engineering
Griffith University
Queensland, 4222, Australia
Email: †c.lemckert@griffith.edu.au
Email: ‡p.campbell@griffith.edu.au
Email:∞graham.jenkins@griffith.edu.au

ABSTRACT

Lemckert, C. J., Campbell, P. G. and Jenkins, G. A., 2011. Turbulence in the Bottom Boundary Layer of Moreton Bay, Queensland, Australia. Journal of Coastal Research, SI 64 (Proceedings of the 11th International Coastal Symposium), 1091 – 1094. Szczecin, Poland, ISSN 0749-0208

The hydrodynamic and water quality modelling of the complex coastal water environments requires detailed knowledge of the forcing and boundary conditions. It also requires knowledge of how the bed influences the water column structure, which, amongst other variables, relies on the bottom drag coefficient. In many cases the drag coefficient is merely assumed and adjusted to achieve the desired flow conditions, with the actual value being unknown. The physical properties affecting this bottom drag have been examined using a new microscale turbulence profiler and an ADCP within a channel of Moreton Bay, Queensland, Australia. From the data collected it is shown how the water column was highly dynamic and dominated by a strong bottom boundary layer, which ensured strong vertical mixing rates near the bed. The level of turbulence was observed to be a function of the current speed. Importantly, the data collected by the turbulence profiler allowed for the estimation of the bottom drag coefficient. The drag coefficient for this site was estimated at $1.4\pm0.8\times10^{-3}$. Significantly, the outcomes of this work revealed that through the use of turbulence profiling instruments it should be a relatively easy task to map the drag coefficient values over large coastal areas. This will permit the use of boundary conditions for numerical models which more closely represent real conditions.

ADDITIONAL INDEX WORDS: *bottom boundary layer, turbulence, drag coefficient*

INTRODUCTION

The coastal zone is a dynamic region, whose characteristics depend upon a broad range of physical, chemical and biological processes. These processes occur in a range of scales from the largest of ocean currents and wind patterns, which help transport various materials and shape to coastal environments; to the smallest scales of microscopic mixing processes resulting in energy losses through viscosity (heat generation) and the transport of dissolved matter through turbulent mixing and molecular diffusion. As turbulent mixing occurs at all scales it has a significant influence on the physical, chemical and biological processes of the ocean. Therefore, a more comprehensive awareness of turbulence is vital in the research development and application of coastal engineering and oceanography.

After over a century of dedicated study, turbulence is still considered a *"major unsolved problem of classical physics."* (Speziale, 1991). Basic turbulence can be explained by the use of the Navier-Stokes equations, but the more complex turbulent flows require a larger number of computations and are therefore currently impossible to solve directly. A description of turbulence made by Osborn (1978) stating that the then current nature of turbulence measurement was experimental and descriptive is still a valid statement over 30 years later.

Forms of quantifying turbulence include observational and numerical methods. Turbulent fluxes can be difficult to observe and are typically quantified through indirect methods, therefore observational methods of measuring turbulence require direct measurements of these flows for quantitative assessment. These measurements can be made from either platforms using highly specialised instrumentation (e.g. Ali and Lemckert, 2009), or through the use of mobile profiling devices; such as the relatively new TurboMAP (Turbulence Ocean Microstructure Acquisition Profiler) employed for this study. These instruments observe and record relevant fluxes in temperature and suspended sediments, among others, in the flow field (Burchard *et al.,* 2008), from which turbulence induced mixing and transport rates can be inferred.

This paper will present the results from a field study of the water column dynamics, as measured by a TurboMAP, within a 13m deep channel of Moreton Bay, Queensland, Australia. An outline of Turbulent Processes will be followed by the study's Methodology, encompassing an explanation of the chosen Instrumentation, Site selection and brief details of applied formulas. Both the ADCP and TurboMAP data will be presented with the deduced Results, concluding with the overall contribution this study provides for future Turbulence investigation.

Turbulent Processes

Lien and Gregg (2001) have shown that elevated levels of turbulence are found in boundary layers within the ocean, particularly coastal zones. Primarily the bottom boundary layer and its associated flows depict the highest amounts of turbulence, as proven by Lueck and Mudge (1997) when their most intense turbulence occurred at the deepest point of their measurements (300m below the sea surface). Moum and Nash (1999) identified three distinct regions of flow causing intense turbulence along a

continental shelf. These include along the bottom in the boundary layer formed by the bottom current, at the top of the bottom current, which is a site of potential shear, and downstream of significant internal flow structures such as internal hydraulic jumps.

These three regions are prime examples of the primary causes for turbulence in coastal waters. The bottom boundary layer, internal hydraulic jumps as well as shear, wind and tides are widely accepted processes of turbulence generation (Grant and Madsen, 1986; Burchard *et al.,* 2008; Lien and Gregg, 2001).

Bottom boundary layers are zones that encompass the turbulent mixing of heat, salt, momentum and dissolved matter. Within these layers the frictional dissipation of energy occurs and has a significant effect on momentum balances. It is here that the exchange of particles, chemicals and organisms between the ocean floor and water column above takes place, which subsequently influences physical, chemical and biological processes (Grant and Madsen, 1986).

The bottom boundary layer consists of a well-mixed layer of water observed in the first few metres above the marine bed. The generation of turbulence in this layer is due to winds, tides, wave-current interaction and topography (Grant and Madsen, 1986). Therefore, the bottom boundary layer was the focus of this project, and all measurements were undertaken to facilitate the determination of the turbulence occurring along the marine bed of the region.

METHODS

Instrumentation

The TurboMAP (JFE, 2009) instrument consists of an aluminium formed cylindrical case 2m long and 0.15m in diameter. The profiler carries two standard shear probes, an FP07 thermistor, combined Conductivity and Temperature (C-T) package, strain gauge pressure transducer, a high-resolution bio-optical sensor (data not presented in this paper) and an internally mounted three-axis accelerometer. Completely assembled the profiler weighs approximately 35.7kg in air and 3kg under water and descends at a nominal velocity of 0.5m/s which can be adjusted using buoyancy elements. The TurboMAP can record data on both the down and up-cast, yet for the benefit of this study only the down-cast data was required. The sampling rate of the shear and FP07 probes is 512Hz, all other data is post processed to 512Hz. Post-processing the FP07 and strain-gauge data produces two extra channels – a temperature gradient and mean falling speed. From this combined type of data, levels of turbulence dissipation and mixing properties can be derived (e.g. Wolk et al, 2001).

An Acoustic Doppler Current Profiler (ADCP) (Teledyne, 2009) was used to measure the water column velocity profile. It was mounted on the boat (looking downwards) and its data was used to support measurements recorded with the TurboMAP.

Study Site

Moreton Bay is located in South-East Queensland, Australia, not far from Brisbane. It is a shallow embayment sheltered by North Stradbroke Island in the south and Moreton Island in the north (Lanyon, 2003). The bay is approximately 100km long with a width varying from 1km at the southern end to 31km at the northern end (Abal and Dennison, 1996). Four major rivers contribute to Moreton Bay's extensive freshwater catchment, including the Pine, Brisbane, Caboolture, and Logan Rivers. A north-south tidal circulation dominates the eastern section and can range from 1m to 2m (Abal and Dennison, 1996).

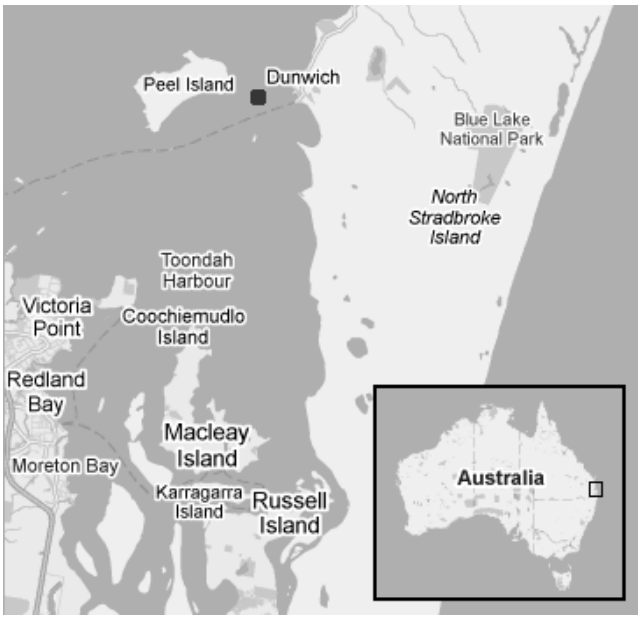

Figure 1. Map of Moreton Bay, the location of the measurements taken has been marked between Peel Island and Dunwich (maps.google.com.au)

A search for a suitable deployment site was undertaken at the southern end of Moreton Bay, in the channel between Dunwich and Peel Island, as shown in Figure 1. The ideal site had a water depth greater than 10m and comprised of a soft, sandy bottom void of rocks and foreign objects (that may have damaged the TurboMAP sensors.) The first TurboMAP deployment was conducted at 10:55hrs. Casts were repeated approximately every 20 minutes for the following six hours until a total of 21 Profiles had been recorded. Just before 14:00hrs it was noticed that the source supplying power to the TurboMAP was failing and at this stage the power source was changed to ensure correct data retrieval.

The conditions in the bay during the study consisted of overcast skies and currents of approximately 0.5m/s during most of the day with only a few hours of slowed movement. This meant the instrument travelled downwards at an angle of almost 45° as the mean speed of descent was 0.5m/s. The current changed direction after high tide at 16:20hrs.

Bed Shear and Drag Coefficient Estimation

Precise hydrodynamic and sediment transport models in estuaries, rivers, lakes and continental shelves depend heavily upon a decent understanding of bottom drag coefficients.Drag coefficients are used to estimate bed roughness in numerical models and are determined using the following equation (Sanford and Lien, 1999):

$$C_{100} = \frac{u_*^2}{U_{100}^2} \qquad (1)$$

Where U_{100} is the mean velocity at height z above the bed; retrieved from the ADCP data.

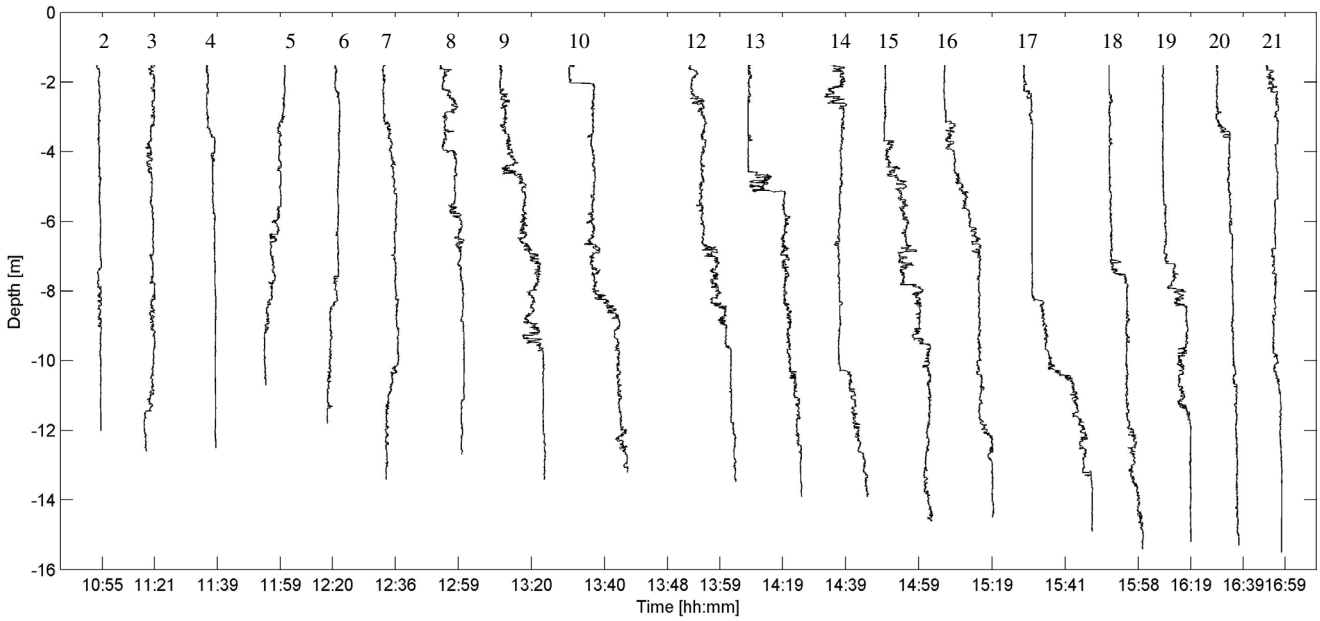

Figure 2. Stager plot of temperature profiles recorded by the TurboMAP at time recorded. The number at the top is the profile number.

There are a number of ways to estimate bed shear stress, yet the Turbulent Kinetic Energy approach is the most consistent. Following methods outlined by Ali and Lemckert (2009) u_* (shear stress) is determined using the following formula:

$$u_* = (\varepsilon \kappa z)^{1/3} \quad (2)$$

Where ε is the dissipation of turbulent kinetic energy, κ is Von Karman's constant of 0.4 and z is the height above the bed, taken throughout this study as 1m.

RESULTS

From the TurboMAP instrument 14 channels of data were available for analysis after processing the original information. Of the 21 profiles recorded, Profiles 1 and 11 were damaged due to excess coupling and power source failure. However each of these issues was noticed at the time the profiles were made and the casts were repeated ensuring there would be no missing data.

Figure 2 shows a stagger plot of temperature of Profiles 2 to 10 and 12 to 21 (Profile 1 and 11 have been excluded). These plots show each of the profiles and the time they were recorded. The figure shows how the water column structure changed significantly with time as different types of water were advected past the study site. The larger fluctuations observed around 13:49hrs indicate a possible increase in turbulent activity, although it is pointed out that high fluctuations in temperature do not necessarily mean high turbulence levels. Also note that the depth of the site (approximate maximum level of temperature recording) shows the change in tidal levels. Variations of this occurred as the result of slight deviations in the exact deployment location of TurboMAP on a bed that was not necessarily level.

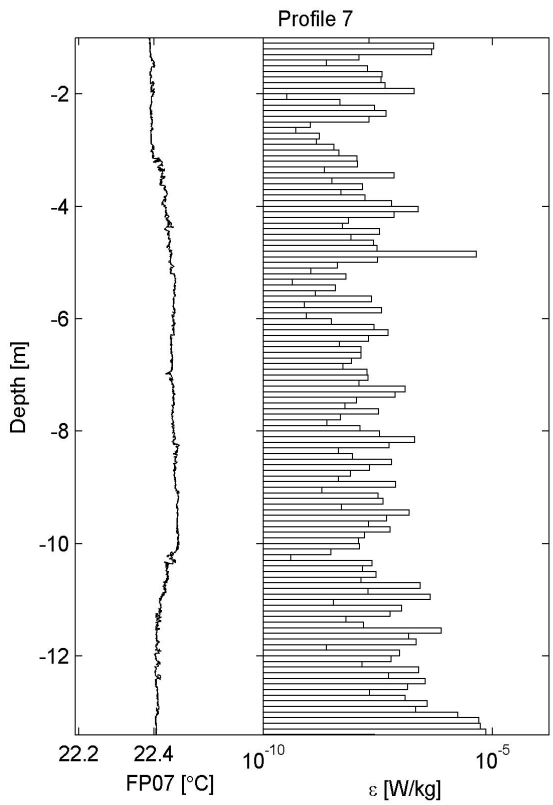

Figure 3. Energy dissipation values of Profile 7 plotted against the FP07 temperature profile.

ANALYSIS AND DISCUSSION

A clear correlation in the temperature plots of Figure 2 can be seen when they are related back to the tide times recorded by the ADCP. The first three profiles show stable temperatures where stratification may have been present while the following three profiles show that the temperature began to vary more throughout the water column. Profiles 8 to 17 show even larger temperature variations with clear signs of stratification followed again by stable temperatures experienced in the last profiles.

The first 7 profiles, which were recorded when the tide was low and as the tide began to changed, exhibited elevated shear measurements below a depth of 8m. Figure 3 shows the energy dissipation rates experienced throughout the water column during Profile 7. At a depth greater than 10.2m the dissipation rates were generally high and the temperature relatively constant, indicating the existence of a bottom boundary layer. The overall results indicated the tidal current generated a bottom boundary layer. Such results have also been seen by Lueck and Osborn (1986), Osborn (1978) and Lueck *et al.* (1983).

Using the derived water column velocity data from the ADCP and the dissipation estimates from the TurboMAP, it was possible to derive C_{100} for the study period using Equations (1) and (2). Results of this estimate are presented in Figure 4. The mean value was found to be $1.4\pm0.8\times10^{-3}$. Research carried out by Sanford and Lien (1999) this value is in reasonable agreement to their $2.0\pm0.6\times10^{-3}$. This value would be recommended to further studies of the area and for use in numerical models.

CONCLUSIONS

Moreton Bay revealed a clear bottom boundary layer present throughout the study even though it dissipated slightly as the tide changed. This layer was strongest during low tide, yet still very observable at high tide. The overall cause of the bottom boundary layer appeared to be tidal circulation and stratification with possible minor influences from topography. Comparing the results to previous studies, the levels of turbulence are relatively close. This agreement in turbulence values confirms the validity of the study with further solidarity provided by the concluded drag coefficients agreement with that of Sanford and Lien (1999).

The values obtained throughout the study can be recommended for use in numerical modelling and continuation of studies in Moreton Bay and surrounding areas. This study has provided a valuable base for further studies into turbulence on the Gold Coast and possibly around Australia.

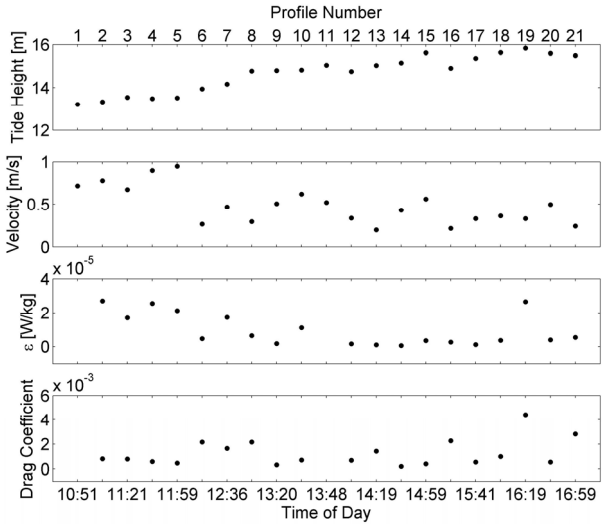

Figure 4. Plot of tidal height, water velocity at a height of 1m above the bed, the dissipation level at 1m above the bed and the derived drag coefficient at 1m above the bed presented as a function of time.

LITERATURE CITED

Abal, E.G., and Dennison, W.C. 1996. Seagrass Depth Range and Water Quality in Southern Moreton Bay, Queensland, Australia. *Marine and Freshwater Research* 47, 763-771.

Ali, A. and Lemckert, C. J., 2009. A traversing system to measure bottom boundary layer hydraulic properties, Estuarine Coastal and Shelf Sciences, doi:10.1016/j.ecss.2009.04.017

Burchard, H., Craig, P.D., Gemmrich, J.R., Van Haren, H., Mathieu, P.P., Meier, H.E.M., Nimmo Smith, W.A.M., Prandke, H., Rippeth, T.P., Skyllingstad, E.D., Smyth, W.D., Welsh, D.J.S. and Wijesekera, H.W., 2008. Observational and numerical modelling methods for quantifying coastal ocean turbulence and mixing. *Prog. in Oceanography* 76, 399-442.

Grant, W.D. and Madsen, O.S., 1986. The Continental-Shelf Bottom Boundary Layer. *Annual Review of Fluid Mechanics* 18, 265-305.

Google, 2009. Google maps Australia, <maps.google.com.au> (May 8, 2009)

Japan Oceanographic Data Centre. 1997. "What is the ADCP?", <www.jodc.go.jp> (May 21, 2009)

JFE ALEC Co., Ltd. (2009) "TurboMAP", <http:// www.jfe-alec.co.jp/html/english_top.htm> (June 4, 2009)

Lanyon, J.M., 2003. Distribution and abundance of dugongs in Moreton Bay, Queensland, Australia. *Wildlife Research* 30, 397-409.

Lien, R.-C. and Gregg, M.C., 2001. Observation of Turbulence in a tidal beam and across a coastal ridge. *Journal of Physical Oceanography* 30

Lueck, R.G. and Mudge, T.D., 1997. Topographically Induced Mixing around a Shallow Seamount. *Science* 276, 1831-1833.

Lueck, R.G., Crawford, W.R. and Osborn, T.R., 1983. Turbulent Dissipation Over the Continental Slope Off Vancouver Island. *American Meteorological Society* 13, 1809-1818

Lueck, R. and Osborn, T.R., 1986. The Dissipation of Kinetic Energy in a Warm-Core Ring. *Journal of Geophysical Research* 91, 803-818.

Moum, J.N. and Nash, J.D., 1999. Topographically Induced Drag and Mixing at a Small Bank on the Continental Shelf. *Journal of Physical Oceanography* 30, 2049-2054.

Osborn, T.R., 1978. Measurements of Energy Dissipation Adjacent to an Island. *Journal of Geophysical Research* 83, 2939-2957

Sanford T.B., Lien, R.-C., 1999. Turbulent Properties in a homogeneous tidal bottom boundary layer. *Journal of geophysical Research* 104, 1245-1257.

Speziale, C.G., 1991. Analytical methods for the development of Reynolds-stress closures in turbulence. *Annual Review of Fluid Mechanics* 23, 107-157.

Teledyne RD Instruments, 2009. Sentinel ADCP, <www.rdinstruments.com> (May 21, 2009)

ACKNOWLEDGEMENTS

The authors would like to acknowledge and thank Casey Brennan, Lincoln Heitman and Jurgen Zier for their assistance and guidance throughout the study.