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Analysis of mean velocity and turbulence measurements with ADCPs

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ABSTRACT

The present study examines the vertical structure of the coastal current in the inner part of the Gulf of Taranto, located in the Ionian Sea (Southern Italy), including both the Mar Grande and Mar Piccolo basins. To this aim, different measuring stations investigated by both a Vessel Mounted Acoustic Doppler Current Profiler (VM-ADCP) and a bottom fixed ADCP were taken into consideration. Two surveys were carried out in the target area on 29.12.2006 and on 11.06.2007 by the research unit of the Technical University of Bari (DICATECh Department), using a VM-ADCP to acquire the three velocity components along the water column in selected stationing points. The measurements were taken in shallow waters, under non-breaking wave conditions, offshore the surf zone. Due to the recording frequency of the instrument time-averaged vertical velocity profiles could be evaluated in these measuring stations. Water temperature and salinity were also measured at the same time and locations by means of a CTD recorder. A rigidly mounted ADCP, located on the seabed in the North-Eastern area of the Mar Grande basin, provided current data relative to the period 10–20 February 2014. Set to acquire the three velocity components with higher frequency with respect to the VM-ADCP, it allowed us to estimate the turbulent quantities such as Reynolds stresses and turbulent kinetic energy by means of the variance method.

Therefore, the present research is made up of two parts. The first part examines the current pattern measured by the VM-ADCP and verifies that, for each station, the classical log law reproduces well the vertical profile of the experimental streamwise velocities extending beyond its typical limit of validity up to the surface i.e. reaching great heights above the sea bed. This behavior is quite new and not always to be expected, being generally limited to boundary layers. It has been convincingly observed in only few limited experimental works. In the present study this occurred when two conditions were met: (i) the flow was mainly unidirectional along the vertical; (ii) the interested layer was non-stratified.

The second part of the research studies the turbulent statistics derived from the beam signals of the fixed ADCP by means of the variance method. This technique had the advantage of being able to measure the time evolution of the turbulent mixing throughout the entire water column, thus making it possible to perform a detailed study on momentum transfer and turbulence. The deduced vertical profiles of the Reynolds stresses and of the turbulent kinetic energy TKE showed an increasing trend toward the surface, in agreement with previous results in literature.

New data-sets of mean velocities and shear stresses, coming from field measurements, are always needed. In fact they represent the first step to derive reliable reference values of coefficients and parameters for the implementation and calibration of the used mathematical hydrodynamic models.

Consequently, an effort was made to evaluate consistent bottom drag and wind drag coefficients, on the basis of the calculated bottom and surface shear stresses, respectively.

1. Introduction

The open North-Eastern part inside the Gulf of Taranto in the Ionian Sea, along the Southern Italy coast (Fig. 1), is considered a vulnerable and sensitive area, affected by massive chemical and biological pollutant discharges due to the presence of heavy industry. The natural assimilative capacity of the sea, accomplished by initial mixing and successive dispersion, as well as sediment transport, are phenomena strictly dependent on the magnitude and directions of the current [1]. Hence, a knowledge of the coastal current pattern is desirable, being a useful support for the local authorities in the planning and management of the coastal area. This purpose may be achieved with both field measurements and

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numerical model results. Collecting a large amount of data in widespread areas is challenging because of technical and economic limitations. Numerical models represent a more rapid and a less expensive solution, simulating the hydrodynamics of extended areas with the desired level of accuracy and in a relatively short time. Nevertheless, in order to be accurate, models need to be calibrated and successively validated by field measurements [2,3]. These procedures often require as input condition the vertical laws obeyed by the current velocity in order to derive parameters involved in the model equations, i.e. the bottom roughness length or the bottom drag coefficient.

For this reason, the first aim of the present paper is to analyze the field velocity data measured by means of a VM-ADCP and to reproduce the vertical velocity profiles testing the applicability of the classical log law. The data were acquired during two cruises, carried out by the research group of the DICATECh Department of the Technical University of Bari on 29.12.2006 and on 11.06.2007 respectively. It is worth pointing out that the log law was deduced experimentally in simple pipe or channel configurations with uniform flows and it should represent accurately the velocity profile in the inner region of free surface flows [4]. Experimentally, it was proven that this distribution may be extended to the entire flow in some particular cases, referring to open-channel flows, where the maximum velocity value is observed close to the free surface [5] and also referring to tidal flows [6]. The use of the log law in a complex marine scenario is not a foregone conclusion. Moreover, in the examined case, the applicability of the log law far beyond its typical limit of validity was proven, provided that the flow was almost unidirectional and not stratified [7].

As a second aim, the present research intends to estimate the vertical distributions of the turbulent quantities (using a single measuring station, taking advantage of the rapid sampling of a fixed ADCP) and to compare them with trends in literature. In the quest to measure turbulence parameters the use of ADCPs has become common practice in recent years [8–10]. Also a validation by comparing ADCP Reynolds stresses with estimates from other instrumentation has been carried out [11]. More recently Wiles et al. [12] used the structure function method to estimate the TKE dissipation. In the present case, the variance method was used to compute the turbulent shear stresses and the turbulent kinetic energy TKE [13–15]. The fixed ADCP was installed in Mar Grande basin in December 2013 as part of RITMARE project funded by PON R&C 2007–2013.

Fig. 1. Location of the target area where the survey was carried out. Source: Google map.

The investigated area (Fig. 1), with composite topography and exposed to urban and industrial discharges, includes the open sea, the Mar Grande and the inner basin called the Mar Piccolo. The Mar Grande covers an area of 35 km^2 with an average depth of about 15 m and connects with the open Ionian Sea through two openings. The Mar Piccolo has a surface area of about 21 km^2 and is structured in two embayments, with an average depth of about 12 m. The area where measurements were carried out is westward of the Mar Grande, in the open sea, with depths in the range of [−15 m to −30 m].

It is worth pointing out the importance of this kind of study, because accurate estimates of mean velocities and shear stresses are essential for the study of flow structures [14]. Moreover, laboratory experiments may represent a stringent test of the ability of ADCPs to measure mean velocities and turbulence. Because length and time scales of the turbulence in a laboratory flume are smaller than those in a river or coastal area, ADCPs may resolve the turbulence better in the field, even if flow inhomogeneity could affect measurements. Therefore, it is worth doing further tests of ADCPs on site [15].

The paper is structured as follows. Section 2 briefly describes the theoretical background for both the logarithmic law and the variance technique. The survey equipment and procedure are illustrated in Section 3, together with the acquired velocity, temperature and salinity data. Section 4 illustrates and discusses the applicability and validity of the log law, while Section 5 analyses the turbulent behavior of the current in the fixed station. Finally in Section 6, the bottom stress coefficient and the wind coefficient are estimated by means of friction velocity and shear stress.

2. Theoretical background

2.1. Log law velocity profiles in turbulent flows

Two regions with distinct scalings characterize wall bounded turbulent flows: the inner region, in which the viscous effect prevails, and the outer region, with prevailing flow inertia. On the

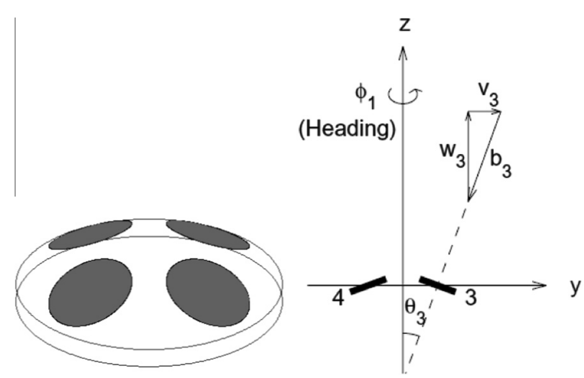

Fig. 2. The Janus ADCP configuration, from Dewey and Stringer [20], showing relation of transducer beams to coordinates axes and angles.

Table 1
Main characteristics of the VM-ADCP system and of the CTD probe.

Probe	Type	Value
VM-ADCP	Acoustic frequency	600 kHz
	Velocity range	±10 m/s horizontal; ±5 m/s vertical
	Velocity accuracy	1% of measured value ±0.5 cm/s
CTD	Pressure range	0–7000 m
	Pressure accuracy	1‰
	Temperature range	−5 to 35 °C
	Temperature accuracy	5‰