

# Acoustic Doppler velocimetry (ADV) in small estuary: Field experience and signal post-processing

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## ARTICLE INFO

### Keywords:

Turbulence  
Sub-tropical estuary  
Acoustic Doppler velocimetry (ADV)  
Post-processing  
Despiking  
Velocity signal processing

## ABSTRACT

Estuarine mixing and dispersion are unsteady turbulent processes. The present understanding of estuary turbulence remains limited because of limited suitable measurement techniques and a lack of long-duration high-frequency studies of turbulent properties. Herein turbulence data were recorded in a small estuary at high-frequency using acoustic Doppler velocimetry (ADV). The data sets were analysed, and the results demonstrated that acoustic Doppler velocimetry data cannot be used without suitable post-processing in unsteady estuary flows. Even classical “despiking” techniques are not simply applicable. A new ADV data post-processing technique is developed herein for turbulence analysis of estuarine flows, and it is tested for several field studies.

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## 1. Introduction

In natural systems, mixing is driven by turbulence, and practical applications include sediment motion, release of sewage effluent, and storm-water runoff during flood events. The current knowledge is limited however, especially in estuarine zones despite their considerable practical importance. Mixing coefficient estimates are usually accurate only “within a factor of 10” at best and are rarely applicable to another system [13,10,2]. Although mixing is driven by turbulence, there has been very little systematic research on turbulence characteristics in natural estuarine systems, in particular in small systems. For example, long-duration studies of turbulent properties and structure at high-frequency are extremely limited. Most measurements were conducted for short-periods, or in bursts, often at low frequency: e.g. [1,14]. It is believed that the present situation, in small estuaries, derives partly from the limitations of suitable instrumentation.

Herein the study is focused on high-frequency turbulence data collection using acoustic Doppler velocimetry (ADV) in a small estuary. While the instrumentation is well-suited to study turbulent velocities in shallow-waters, it is assumed, wrongly sometimes, that the velocity signal outputs are “true” turbulent velocity data. This was found grossly incorrect and the paper focuses on a new ADV data post-processing technique for turbulence analysis. Several post-processing methods were

tested and a new procedure was developed. Field work data were systematically analysed. The results showed that acoustic Doppler velocimetry data should not be used without suitable post-processing and that all turbulent velocity properties may be affected by the post-processing.

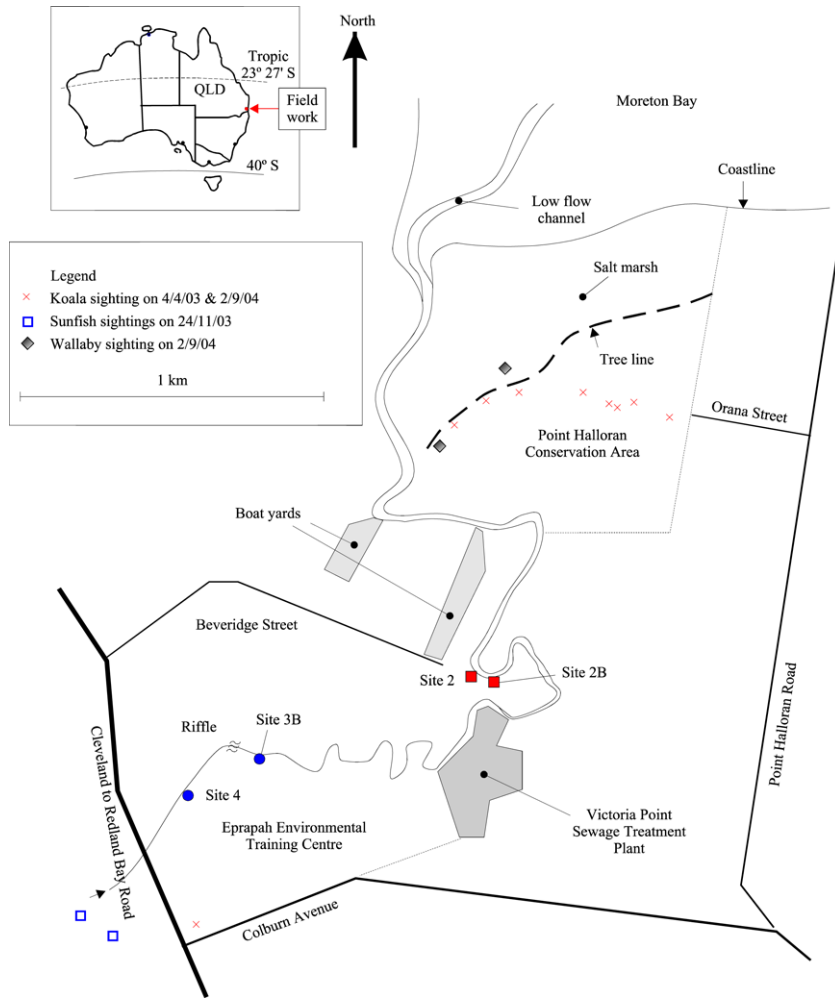
## 2. A case study: Eprapah creek estuary

A series of field measurements were conducted in the estuarine zone of Eprapah Creek (Australia) in 2003 and 2004. Located in the Redlands shire close to Brisbane city, Eprapah Creek (Long. 153.30°, Lat. -27.567°) is a simple sub-tropical stream, 12.6 km long, flowing directly to Moreton Bay off the Pacific Ocean and with a catchment area of 39 km<sup>2</sup>. The estuarine zone is about 3.8 km long (Fig. 1). The tides are semi-diurnal and the range is about 1.5–2 m. The most upstream extent of the estuary corresponds to Sites 3B–4 shown in Fig. 1 depending upon the tidal conditions. In the estuary, the channel is about 1–2 m deep mid-stream and 20–30 m wide. This is a relatively small, shallow estuary system, where the water depth may be less than 0.7 m at low tides in several sections. It is a drowned river valley (coastal plain) type with a small, sporadic freshwater inflow, a cross-section which deepens and widens towards the mouth, and surrounded by extensive mud flats.

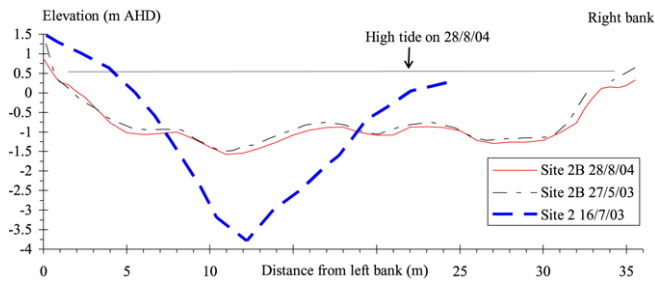
Field works took place on four different days (Table 1). Tidal conditions are summarised in Table 1 (3rd line). Acoustic Doppler velocimetry was performed mid-estuary at Sites 2 and 2B shown in Fig. 1, and the corresponding estuary cross-sections are presented in Fig. 2. For each field study, a 3-D Acoustic Doppler Velocimeter (ADV) SonTek ADV 10 MHz was deployed. The ADV probe was

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**Fig. 1.** Map of Eprapah Creek estuary – Red squares: instantaneous velocity measurement sites. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



**Fig. 2.** Surveyed creek cross-sections at Sites 2 (AMTD 2.0 km) and 2B (AMTD 2.1 km) looking downstream.

equipped with a 5 cm down-looking sensor mounted on a rigid stem and data-logged continuously at 25 Hz. The velocity range was 0.3 or 1.0 m/s (Table 1). The probe was installed about the middle of the channel in a moderate bend to the right when looking downstream. The ADV was held by a stiff metallic frame sliding on two poles (Fig. 3). The poles were driven into the river bed, and the frame and pole system did not move during the data logging. The probe was installed outside of the support system to limit the effects of support wake. In the first three studies, the sampling volume was located 0.50 m beneath the free-surface. The probe position was manually adjusted with the tide, by lowering or raising the frame every 20–60 min, to maintain the probe sensor position relative to the free-surface (Fig. 3B). For the last study, the probe

sampling volume was located 0.055 m above the bed. Further details on the field work procedures are available in [5,6,9,19].

### 3. Acoustic doppler velocimetry

#### 3.1. Presentation

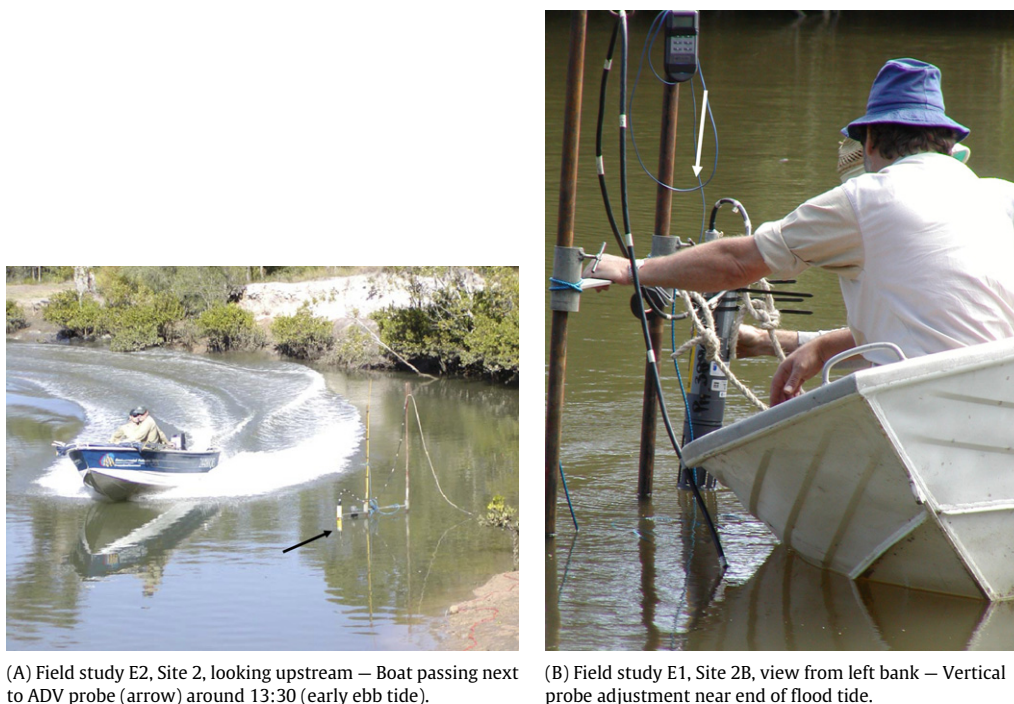
Acoustic Doppler velocimetry (ADV) is designed to record instantaneous velocity components at a single-point with a relatively high frequency. Measurements are performed by measuring the velocity of particles in a remote sampling volume based upon the Doppler shift effect (e.g. [20,16]). The probe head includes one transmitter and three receivers (Fig. 4). The remote sampling volume is located typically 5 cm from the tip of the probe, but some studies showed that the distance might change slightly (e.g. [3]). The sampling volume size is determined by the sampling conditions. In a standard configuration, the sampling volume is about a cylinder of water with a diameter of 6 mm and a height of 9 mm.

An ADV system records simultaneously nine values with each sample: three velocity components, three signal strength values and three correlation values. Signal strengths and correlations are used primarily to determine the quality and accuracy of the velocity data, although the signal strength (acoustic backscatter intensity) may be related to the instantaneous suspended sediment concentration with proper calibration [11,18,21,7]. Herein the study is focused on the velocity signals.

**Table 1**  
Field investigations at Eprapah Creek in 2003 and 2004

Field study reference	E1	E2	E3	E4
Date	4 April 2003	17 July 2003	24 Nov. 2003	2 Sept. 2004
Tides (Victoria point)	05:16 (0.67 m) 11:03 (2.22 m) 17:24 (0.57 m) 23:31 (2.41 m)	00:00 (2.63 m) 06:44 (0.60 m) 12:19 (1.92 m) 18:01 (0.59 m)	03:27 (0.21 m) 09:50 (2.74 m) 16:29 (0.46 m) 21:53 (2.11 m)	06:02 (0.40 m) 11:52 (2.21 m) 18:02 (0.56 m) 11:59 (2.29 m)
Study period	06:00–18:00	06:00–14:00	08:00–16:00	06:00–18:00
Study focus	Full tidal cycle	Flood tide	Ebb tide	Full tidal cycle
ADV sampling period (s)	10:08–10:42 10:43–10:44 11:45–12:18 11:19–11:57 11:58–12:29 12:29–12:52 12:53–13:11 13:12–13:53 13:53–14:09	6:26–14:10	8:25–15:35	7:51–13:40 14:26–17:57
ADV velocity range (m/s)	0.3 / 1.0 / 0.3 / 0.3 / 0.3 / 1.0 / 1.0 / 1.0 / 1.0	0.3	1.0	0.3
Sampling frequency (Hz)	25	25	25	25
Sampling volume location	Site 2B, 0.50 m below surface, 14.2 m from left bank	Site 2, 0.50 m below surface, 8.0 m from left bank	Site 2B, 0.50 m below surface, 10.8 m from left bank	Site 2B, 0.0525 m above bed, 10.8 m from left bank
Water temperature (°C) (mid-estuary, Site 2)	23.7 [20.4–28.4]	16.7 [15.5–18.5]	25.5 [22.7–28.0]	17.14 [15.9–18.1]
Conductivity (mS/cm) (mid-estuary, Site 2)	34.5 [23.9–48.3]	37.2 [29.8–48.4]	50.0 [42.7–55.1]	48.6 [41.0–53.6]

Notes: water temperature and conductivity measured with YSI6600 probe; mean values [extreme values in square brackets] for the study period.



**Fig. 3.** Acoustic Doppler velocimetry field works in Eprapah Creek estuary.

Past and present experiences demonstrated recurrent problems with “raw” ADV velocity data that are evidenced by high levels of noise and spikes in all velocity components [17,16]. In turbulent flows, the ADV velocity fluctuations characterise the combined effects of the Doppler noise, signal aliasing, velocity fluctuations, installation vibrations and other disturbances. The signal may be

further affected adversely by velocity shear across the sampling volume and boundary proximity [8]. Lemmin and Lhermitte [15] and Chanson et al. [3,4] discussed the inherent noise of an ADV system. Spikes may be caused by aliasing of the Doppler signal. McLelland and Nicholas [16] explained the physical processes while Nikora and Goring [17], Goring and Nikora [12] and Wahl

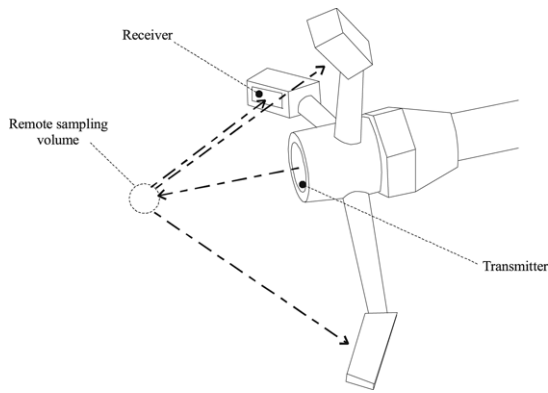
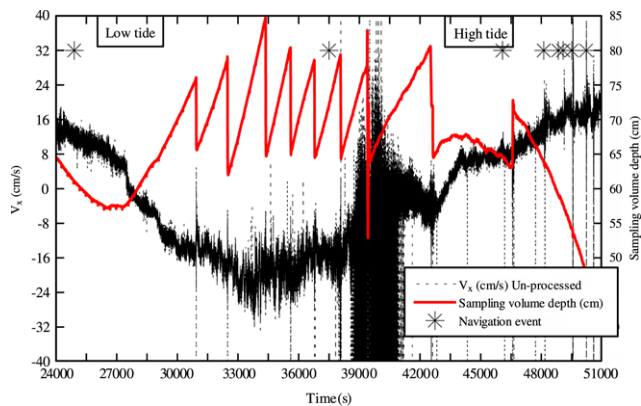
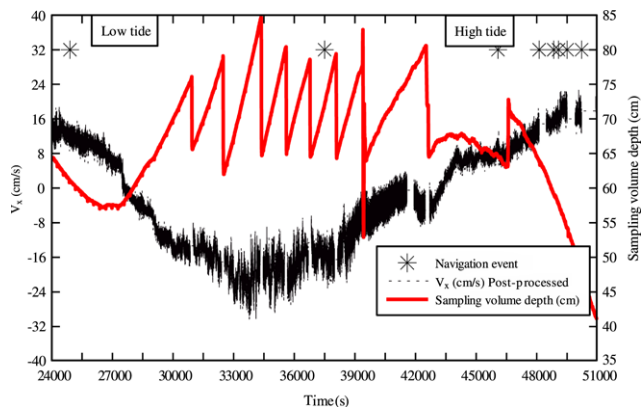


Fig. 4. Sketch of a 3D acoustic Doppler velocimeter head.



(A) Instantaneous velocity data before post-processing.



(B) Instantaneous velocity data after complete post-processing.

Fig. 5. Instantaneous velocity data ( $V_x$  component), probe sampling volume depth data and navigation events during the field study E2 on 7 July 2003 at Site 2 – Time is expressed in seconds since midnight (GPS time).

[22] developed techniques to eliminate these “spikes”. These methods were developed for steady flow situations and tested in man-made channels.

### 3.2. Velocity measurement experience in a small estuary

In Eprapah Creek, the acoustic Doppler velocimetry system provided instantaneous values of the three velocity components. It was oriented with the  $xy$ -plane being horizontal, the  $x$ -direction aligned with the flow direction and positive downstream, and the  $z$ -direction positive upwards. Typical results are shown in Fig. 5. Fig. 5 presents the  $V_x$  velocity component recorded during the field study E2 for 7 h 44 min, starting at low tide ( $t = 24,240$  s)

and ending during the early ebb tide. The low and high tides (slack tides) corresponded to about the periods of zero streamwise velocity. Fig. 5A shows the un-processed (raw) velocity data. The right vertical axis corresponds to the sampling volume depth below the free-surface, and the vertical see-saw steps highlighted the manual vertical displacements of the velocimeter to maintain the sampling volume about 0.5 m below the free-surface. Fig. 3B shows a vertical probe position adjustment. Navigation events are also marked with an asterisk (\*) in Fig. 5, while Fig. 3A illustrates such a boat passage. For all field works, the present field experience demonstrated recurrent problems with the raw velocity data, including a large numbers of spikes. For example, a lot of “noise” is seen in Fig. 5A between  $t = 39,000$  and  $41,000$  s, but smaller numbers of “spikes” are also seen between  $t = 31,000$  and  $51,000$  s. The noise was probably caused by a combination of Doppler noise and aliasing errors around high tide slack, and it did not characterise true turbulent velocities. Some problem was also experienced with the vertical velocity component, possibly because of some wake effect of ADV stem. Since the probe was mounted vertically down-looking, vertical velocities were small and these effects were deemed negligible.

Practical problems were further experienced. During the last field study (E4), the computer lost power and it could not be reconnected to the ADV for nearly 50 min. For the first field work (E1), two notebook computers were used alternately to data log the ADV outputs and to backup the data. The interchange of computers lasted less than 2 min and was carefully recorded. For the other two field works (E2 and E3), the velocity data were recorded continuously into a single data file. Details of data records are given in Table 1. For the first three field trips, the ADV sampling volume was maintained about 0.5 m below the free-surface and the vertical probe position was adjusted up to 3 times per hour at mid-tide (Fig. 3B). Lastly, navigation and aquatic life were observed during all field works (Fig. 3A). They were found to have some impact on the turbulence data. In several instances, birds were seen diving and fishing next to the ADV location, while in other occasions fish were jumping out of the water next to the probe.

In summary, the present experience suggested that turbulence properties could not be extrapolated from the unprocessed data sets during field works. Classical ADV “despiking” techniques were tested in-depth, especially the acceleration thresholding and phase-space thresholding methods [12,22]. The results demonstrated systematically that “conventional” ADV despiking techniques were not suitable for velocimetry data collected in a natural estuarine system. Indeed velocity fluctuations might be induced by large disturbances such as aquatic life, navigation and experimental procedure as observed first-hand. Even in optimum conditions, natural estuarine systems are characterised by unsteady flows, and the hydrodynamics cannot be assumed to be quasi-steady over a statistically-meaningful data sample. However the selection of more appropriate techniques is difficult since no independent data sets are available. Existing comparisons between “despiking” techniques are often limited to a comparison of the number of removed spikes, and of the differences in turbulent velocity fluctuations and in Reynolds stresses.

## 4. ADV data post-processing technique

### 4.1. Presentation

Turbulent velocity analyses were conducted systematically for all field data. The present experience yielded a new three-stage post-processing method for estuarine studies. The post-processing technique includes (1) an initial velocity signal check, (2) the detection, removal and replacement of large disturbances and (3)





