Discussion of "Turbulence Measurements with Acoustic Doppler Velocimeters" by Carlos M. García, Mariano I. Cantero, Yarko Niño, and Marcelo H. García

December 2005, Vol. 131, No. 12, pp. 1062–1073.
DOI: 10.1061/(ASCE)0733-9429(2005)131:12(1062)

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The discussers congratulate the authors for their important contribution. Although acoustic Doppler velocimetry (ADV) has become a popular technique for last two decades, some researchers, including the authors, pointed out rightly that ADV signal outputs include the combined effects of turbulent velocity fluctuations, Doppler noise, signal aliasing, turbulent shear, and other disturbances. Simply, "raw" ADV velocity data are not "true" turbulence and should never be used without adequate postprocessing (Nikora and Goring 1998; Wahl 2003). Herein the discussers aim to complement the understanding of ADV turbulence measurements by arguing the effects of sampling duration and proximity of solid boundaries. They discuss also practical issues associated with turbulence measurements in natural estuarine systems with acoustic Doppler velocimeters (ADVs).

The sampling duration does influence the results since turbulence characteristics may be biased with small sample numbers. Yet, in hydraulic engineering, there has been a great variety of sampling durations used by various researchers in laboratory and field studies without systematic validation. In their study, the authors used a 2-min sampling time corresponding to 6,000 samples maximum, assuming implicitly that such a duration is long enough to describe the turbulence. Basic turbulence studies showed recently the needs for larger sample sizes (e.g., 60,000 to 90,000 samples per sampling location) (Karlsson and Johansson 1986; Krogstad et al. 2005). The discussers performed new experiments in a large laboratory flume (0.5 m wide, 12 m long) with sub- and transcritical flow conditions. The channel was made of smooth PVC bed and glass walls, and the waters were supplied by a constant head tank. Velocity measurements were conducted with a 16 MHz micro ADV equipped with a two-dimensional sidelooking head. Sensitivity analyses were performed in steady flows with 25 and 50 Hz scan rates, total sampling durations T_R between 1 and 60 min, and in both gradually varied and uniform equilibrium flows. The results indicated consistently that the streamwise velocity V_x statistical properties were most sensitive to the number of data points per sample. The first two statistical moments (mean and standard deviations) were adversely affected by sampling durations less than 100 s (less than 5,000 samples). Higher statistical moments (e.g., skewness, kurtosis), Reynolds stresses, and triple correlations were detrimentally influenced for scan durations less than typically 500 to 1,000 s corresponding to less than 25,000 to 50,000 samples. The findings are consistent with modern experimental studies of turbulence (Karlsson and Johansson 1986). Fig. 1 illustrates the effects of the sample size at a sampling location at 27 mm above the bed on the channel centerline. The data set was "cleaned" by excluding low-correlation and low signal-to-noise ratio samples, and by removing "spikes" using a phase-space thresholding technique (Goring and Nikora 2002; Wahl 2003).

The proximity of a boundary may adversely affect the ADV probe output, especially in small laboratory flumes. Several studies discussed the effects of boundary proximity on sampling volume characteristics and the impact on time-averaged velocity data (Table 1). Table 1 lists pertinent studies, including details of the reference instrumentation used to validate the ADV data (Table 1, column 2) and of the ADV systems (Table 1, columns 3 and 4). These studies highlighted that acoustic Doppler velocimeters underestimated the streamwise velocity component when the solid boundary was less than 30 to 45 mm from the probe sampling volume. Correction correlations were proposed by Liu et al. (2002) and Koch and Chanson (2005) for micro-ADV with 3D downlooking head and 2D sidelooking head respectively. The discussers observed that the effects of wall proximity on ADV velocity signal were characterized by a significant drop in average signal correlations, in average signal-to-noise ratios and in average signal amplitudes next to the wall (Koch and Chanson 2005). Martin et al. (2002) attributed lower signal correlations to high turbulent shear and velocity gradient across the ADV sampling volume. But the discussers observed that the decrease in signal-to-noise ratio with decreasing distance from the sidewall appeared to be the main factor affecting the ADV signal output. Finally, it must be stressed that most past and present comparative studies were restricted to limited comparison of time-average streamwise velocity component. No comparative test was performed to assess the effect of boundary proximity on instantaneous velocities, turbulent velocity fluctuations, Reynolds stresses nor other turbulence characteristics.

The discussers were involved in high-frequency, long-duration turbulence measurements using ADVs in a small estuary (Fig. 2) (Chanson 2003; Chanson et al. 2004). Fig. 3 shows a typical raw signal output for the streamwise velocity component during one such field investigation. The sampling volume was located 0.05 m above the bed for all study duration, and the measured water depth is reported in Fig. 3 (Right vertical axis). While the ADV is well-suited to such shallow-water flow conditions, all field investigations demonstrated recurrent problems with the velocity data, including large numbers of spikes (e.g., Fig. 3, t=28,000–34,000 s). Problems were also experienced with the vertical velocity component, possibly because of the effects of the wake of the stem. Practical problems were further experienced. During one field study, the computer lost power and could not be reconnected to the ADV for nearly 50 min (Fig. 3, t=49,000–52,000 s). During other field works, the ADV sampling volume was maintained about 0.5 m below the free-surface, implying the need to adjust the vertical probe position up to 3 times per hour. Last, navigation and aquatic life were observed during all field works (Fig. 2). Fig. 2 shows a recreational dinghy passing in

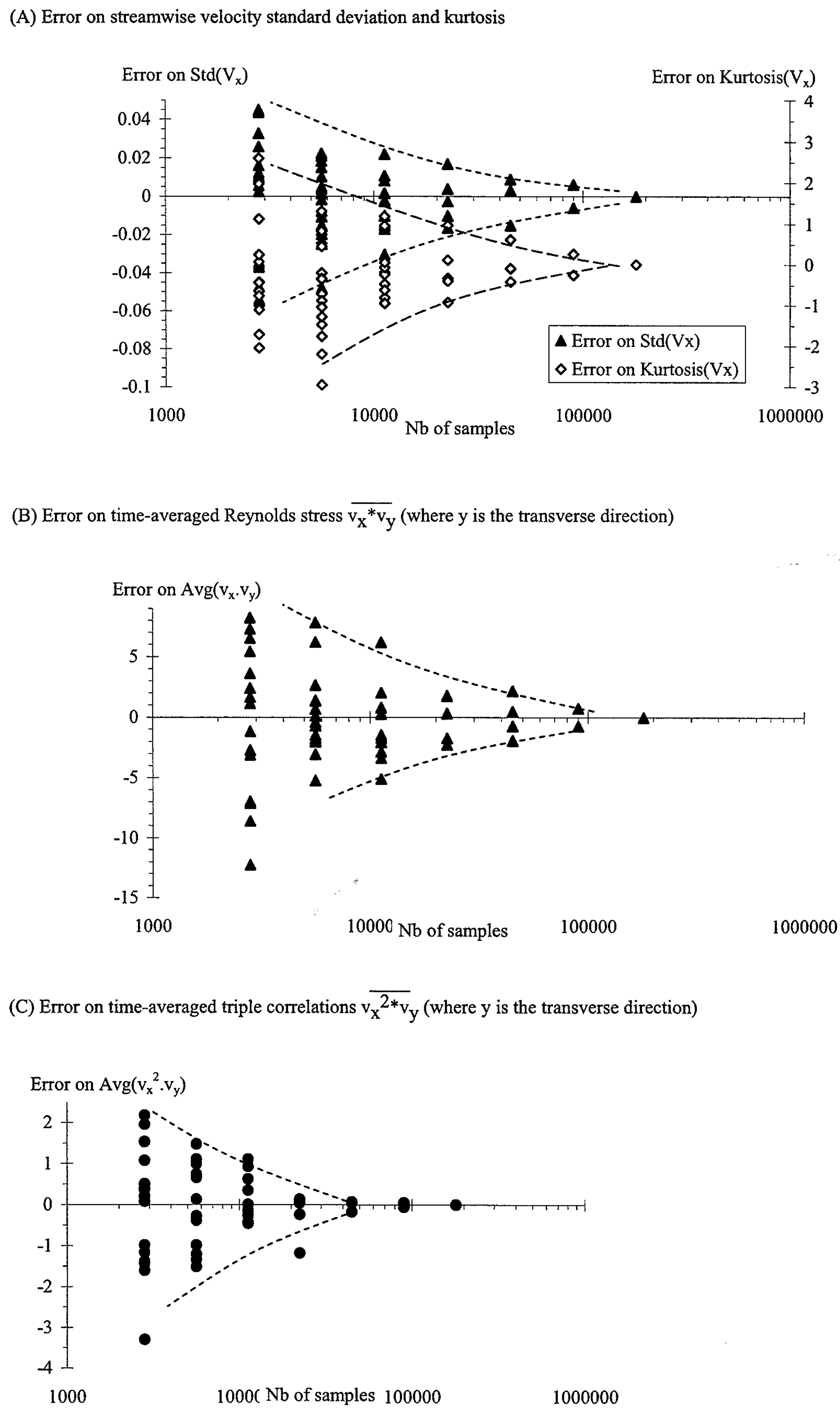

Fig. 1. Effects of data sample size on turbulence characteristics in a 0.5-m-wide, 12-m-long open channel [flow conditions: $Q=0.0404\ m^3/s$, $W=0.5$ m, $d=0.096$ m, $z=27.2$ mm, micro ADV (16 MHz) with 2D sidelooking head, sampling rate=50 Hz; velocity range=1 m/s]

Table 1. Experimental Studies of the Effects of Boundary Proximity and Velocity Shear on Acoustic Doppler Velocimetry Data in Open Channels

Reference	Reference probe	ADV device	ADV sampling volume location affected by boundary proximity	Remarks
Voulgaris and Trowbridge (1998)	8 mW Helium-Neon LDV	Sontek ADV 10 MHz 3D downlooking	—	
Finelli et al. (1999)	Hot-film probe Dantec R14 (single-wire)	Sontek ADV Field 10 MHz 3D downlooking	$z<10$ mm, centerline data	$W=0.13$ m. Acrylic bed and walls.
Martin et al. (2002)	—	Sontek micro ADV 16 Hz 3D downlooking	—	
Liu et al. (2002)	Prandtl-Pitot tube ($\phi=3$ mm)	Sontek micro ADV 16 MHz 3D downlooking	$z<30$ mm, centerline data	$W=0.46$ m. Aluminum bed, glass walls.
Koch and Chanson (2005)	Prandtl-Pitot tube ($\phi=3.02$ mm)	Sontek micro ADV 16 MHz 2D sidelooking	$y<45$ mm	$W=0.50$ m. PVC bed, glass walls, 75 mm$\geq z \geq$7.2 mm (ADV head touching channel bed).

Notes: y=transverse distance from a sidewall; and z=vertical distance from the invert.

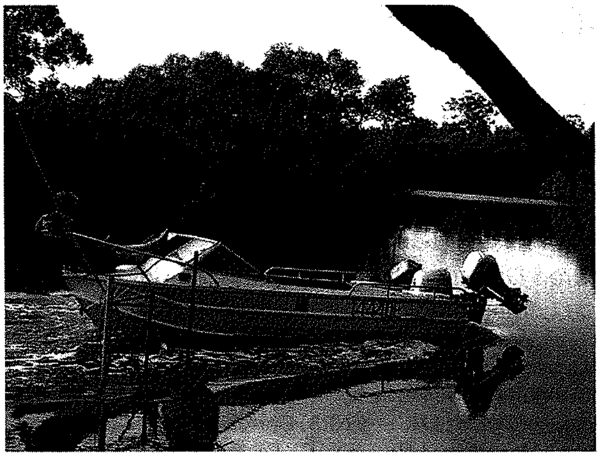

Fig. 2. Field deployment of acoustic Doppler velocimeters [boat passing beside the tripod (foreground left) supporting the ADVs at high tide]

reverse beside the ADVs. The effects of propeller wash and "bow" waves were felt for several minutes as discussed by Chanson et al. (2004). In a few instances, birds were seen diving and fishing next to the ADV location. All these events/disturbances had some impact on the turbulence data.

Careful analyses of ADV signal outputs showed that turbulence properties were inaccurately estimated from unprocessed ADV signals. Even "classical" despiking methods were not directly applicable to unsteady estuary flows. A new three-stage postprocessing method was developed (Chanson et al. 2005). The technique included an initial velocity signal check, the detection and removal of large disturbances (prefiltering), and the detection and removal of small disturbances (despiking). Each stage included velocity error detection and data replacement. The method was applied successfully to long-duration ADV records at high frequency (25 Hz). Both 10 MHz ADV and 16 MHz microADV systems were used. For all investigations, between 10 to 25% of all samples were deemed erroneous. For the data shown in Fig. 3, the number of erroneous samples corresponded to 10% of the records, or 19% of the entire study period including the power

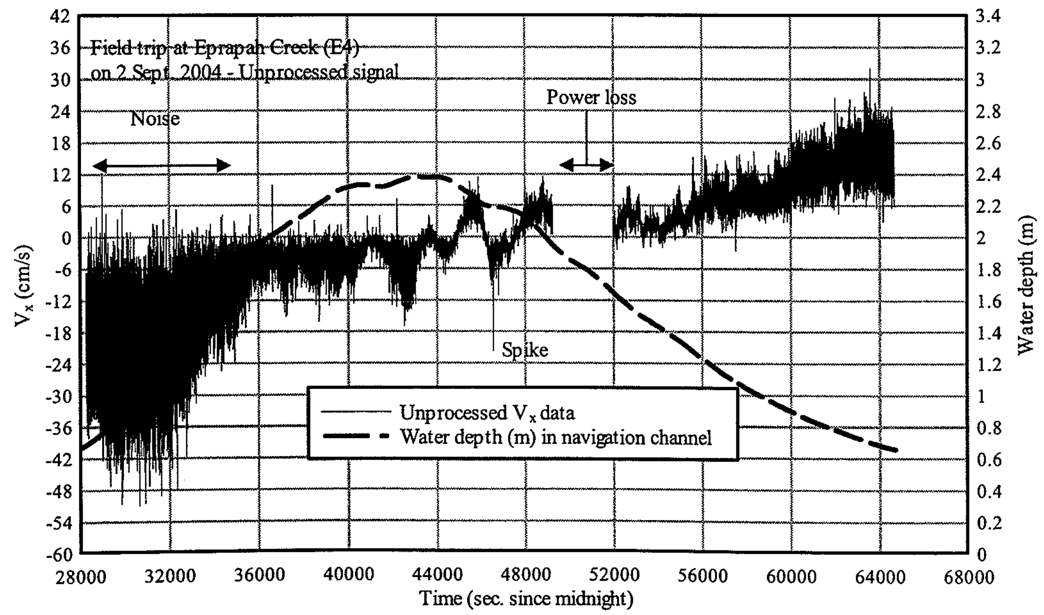

Fig. 3. Field data from ADV deployment in a small estuary: streamwise velocity V_x component (positive downstream, unprocessed "raw" signal) and measured water depth [time in seconds since midnight field work: Sept. 2, 2004, ADV (10 MHz) with 3D downlooking head; sampling rate=25 Hz, continuous sampling; velocity range=0.30 m/s; sampling volume located 0.052 m above bed and 10.8 m from left bank

failure. Field observations illustrated that unprocessed ADV data should not be used to study turbulent flow properties, including time-averaged velocity components.

In summary, the authors' contribution was a timely notice that acoustic Doppler velocimeters have intrinsic weaknesses and that their signal outputs are not always "true" turbulence measurements. In this discussion, it is demonstrated that in steady open channel flows, the sampling record must be larger than 5,000 samples to yield minimum errors on first and second statistical moments of the velocity components. Significantly longer records (more than 50,000 samples) are required for accurate determination of higher statistical moments (e.g., skewness and kurtosis), Reynolds stresses, and triple correlations. Further ADV signal outputs are adversely affected by the proximity of solid boundaries, particularly when the sampling volume is located less than 30 to 45 mm from the wall. Recent field observations in a small estuary showed also that ADV records may be affected by various disturbances including wildlife and manmade interferences. Comparative analyses of long duration, high-frequency data sets highlighted the needs for advanced postprocessing techniques. It is hoped that the authors' contribution and the present discussion will stress enough the needs to educate and adequately train technicians, engineers, scientists, and researchers deploying ADVs in the field, including portable ADV systems.

Acknowledgments

The discussers acknowledge helpful discussions with Professor Shin-ichi Aoki (Japan).

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December 2005, Vol. 131, No. 12, pp. 1062–1073.
DOI: 10.1061/(ASCE)0733-9439(2005)31:12(1062)

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The paper by Garcia et al. deals with the problem of correctly measuring turbulence parameters with acoustic Doppler velocimeters (ADV; trade names ADV for Sontek and NDV for Nortek). The authors focus on the effects of sampling frequency and Doppler noise on turbulence parameters. To avoid loss of turbulence information, they suggest that data should be sampled above a determined frequency. In addition, noise should be removed by estimating the noise contribution. Their approach is based on a model-derived procedure. First, it would have been of interest to compare the modeled spectra with those obtained from their measurements to validate their model and instrument assumptions for the flow cases discussed. Second, the deviation from the -5/3 slope in the measured spectra due to filtering and/or noise effects has not been highlighted.

We investigated the authors' conclusions using a Vectrino (Nortek) ADV. Different from their instruments, a Vectrino has four receivers symmetrically spaced around the central emitter. The applied sampling frequencies, the relative position, and the size of the measuring volume, however, were identical to the NDV. Using four receivers allows measuring the vertical velocity component simultaneously in the two planes. This configuration enables the direct estimation of noise effects so that suitable correction procedures such as the one proposed by Hurther and Lemmin (2001; hereinafter called HLP) can be applied. The HLP takes advantage of the redundancy of the vertical velocity obtained in the two instrument planes.