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Minimizing Errors in Acoustical Measurements of Currents

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Abstract

Acoustic Doppler Current Profilers (ADCP's) have many advantages when compared to traditional current meters. The amount of available data is much larger and of wider use. Moreover, the instrument is usually easier to deploy on the lake or sea bottom. New kinds of instruments unfortunately also have new kinds of error sources. Errors can occur at several stages: They can be made in instrument settings, the deployment of the instrument can cause errors, and some of the values recorded by the ADCP are erroneous. Some of these errors can be made smaller by careful postprocessing of the data, or at least the erroneous values can be neglected.

1. Introduction

Acoustic current meters (Acoustic Doppler Current Profiler, ADCP) have a very different working principle compared to traditional current meters. They have no moving parts and they can measure a current field over the whole profile when deployed on the lake or sea bottom or surface. The instrument calculates all three velocity components and an error estimate from four acoustic beams. In addition to the velocity measurements the instrument can measure other variables like the intensity of the acoustic echo or the quality of the returning signal. The strength of the acoustic echo has been used in estimations of zooplankton aggregations (*Flagg* and *Smith,* 1989, *Smith et al.* 1989).

Acoustic current meters have been used widely for at least five years. During this time the instruments have turned out to be reliable and relatively accurate. One main area of use has been the instruments installed in research vessels. With these instruments it has been possible to gain new detailed knowledge about the streams in the ocean (*Johannesen et al.*, 1989, *Berezutskii et al.*, 1991). When used in research vessels the instruments are set up quite differently when compared to other kinds of self-contained ADCP deployments, so this will not be dealt with in this report. The main instrument is, however, basically similar. The comments in this study are applicable to instruments deployed in the 'traditional' way: moored at the bottom of the water body or submerged at the desired depth using floats.

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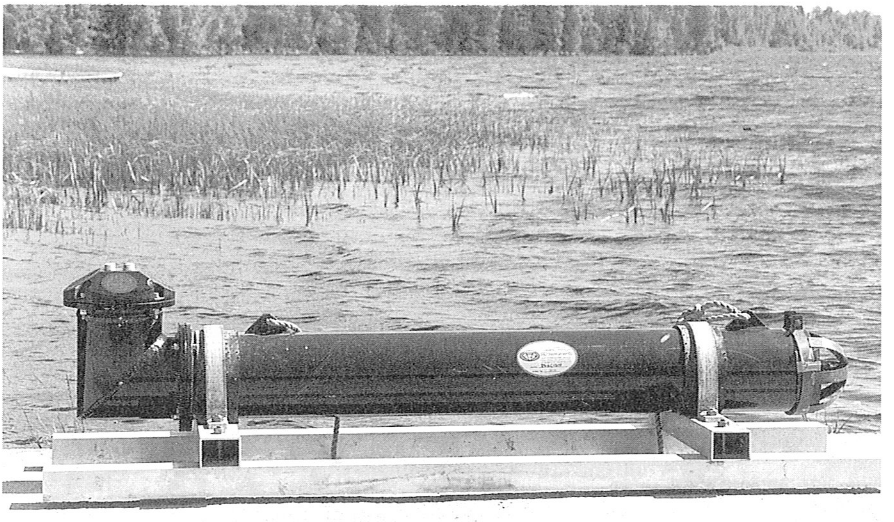

Fig. 1. The ADCP unit of the Department of Geophysics in its mounting stand.

With new broadband models the possible use of the instrument covers a range from river discharge measurements to deep sea deployments. The following discussion mainly concerns the use of older, narrowband ADCPs, and the measurements treated in the examples are from lakes. However, the handling of errors should be reasonably similar with newer kinds of instruments, even though the measurement layer thickness of the new broadband instruments can be set significantly smaller than is possible with the narrowband ADCPs. For 1200 kHz broadband instrument this vertical resolution can be as small as 0.25 m, while 1 m is the limit for the old narrowband instruments.

The Department of Geophysics has used its ADCP from autumn 1988 in three different lakes and in the Gulf of Finland (Fig. 1). The use of data varies from measurement of water exchange in a strait (*Virta et al.* 1992) to the estimation of the spreading of the limestone powder in lake liming, which is still under investigation. In the beginning there were problems in data handling because almost no software was available for data retrieving and processing. Nowadays good programs are available for instrument setting and data retrieving but we use our own software for detailed calibration and analysis (*Pulkkinen*, 1989, *Pulkkinen*, 1993).

2. *Sources of error*

2.1 *Errors in the instrument settings*

As the function of the instrument is based on fast digital processing of the received acoustic pulse, processing methods have a direct impact on the quality of the received data. The errors at this stage occur in signal filtering and analyzing. *Chereskin et al.* (1989) have dealt with this type of error in detail. These errors can usually be avoided only by taking care that the instrument has the latest firmware (EPROM) and by using correct instrument settings.

The user can directly affect measurement methods by changing the internal settings of the instrument. The current meter works satisfactorily with default settings in almost all situations, but special situations (high vertical gradients of currents, lack of scatterers) or special use of the instrument (measurement of ice motion from below) may require changes in these instrument settings. If these changes are made erroneously they may cause the instrument to malfunction.

2.2 *Errors caused by deployment*

Although an ADCP is quite easy to install when compared to traditional current meters all arrangements should be made with care. The quality of received data is affected by movement of the instrument and by instrument tilting.

If the instrument is deployed firmly on the lake or sea bottom the tilt of the instrument stays constant and resulting effects can be corrected in postprocessing of the data. Also, if the movement of a floating instrument (tilting and turning) is clearly slower than the integration interval used, the situation is quite the same. At higher tilting or turning rates it is recommended to do a coordinate transform to all measurements separately. However, this coordinate transform decreases the measurement capacity of the ADCP, so it should not be done inside the instrument.

Unpredictable errors can occur if the installation wires hit the acoustic beams. As the beams are narrow (-3 dB with 1200 kHz ADCP: 1.4°, *RD Instruments*, 1989a) the possibility of that happening is quite small. Regardless, deployment should be planned so that the possibility of these errors is minimized.

2.3 *Errors in measurements*

The measurements are most commonly limited by the geometry of the measurement. Even though the acoustic beams form a 30° angle with the vertical, part of the energy is sent straight up. The reflection of the sidelobes from the surface limits the usable part of the main beam to approximately 85 % of the whole depth.

This happens, even though the sidelobe beam is about 42 dB weaker (*RD Instruments*, 1989a) than the main beam because the surface of the water is a very strong scatterer. In practice the situation can be even worse: When real geometry and the position of the depth cells are considered the effect may be seen even lower in the water (Fig. 2). This effect is quite unpredictable, as it depends on how the water depth and the multiple depth cells match. This happens as it most obviously varies from beam to beam because of varying tilts and it may also vary during the measurement if the length of the depth cells changes with water temperature.

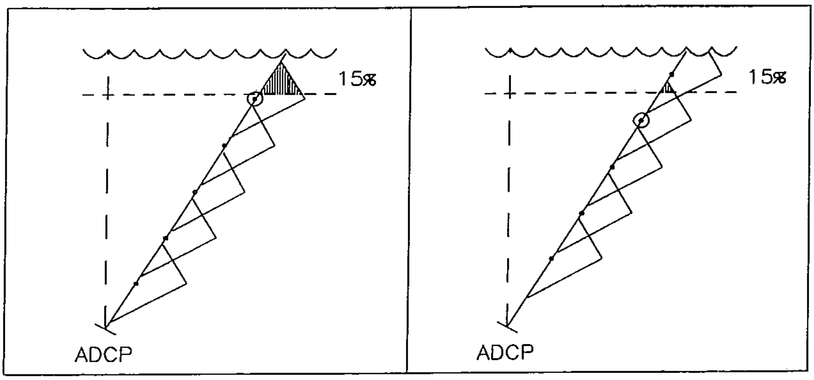

Fig. 2. The effect of the measurement geometry in two different cases. The means of the depth cells are marked with points. Circles show the lowest depth cells affected by the sidelobe reflections. In addition to the acoustic beams approximate weighting functions of the depth cells are shown.

3. *Minimizing the errors in data processing*

Errors in instrument settings are hard or almost impossible to correct afterwards. Means for addressing errors in signal filtering have been carefully examined by *Chereskin et al.* (1989). These errors are instrument-dependent and they are effectively rectified in newer firmware versions. The correction of these filtering errors is partly possible (*RD Instruments*, 1989b). This correction is also affected by the instrument type and by the version of the instrument firmware.

The effects of the tilt of the instrument can be corrected in addition to the calibration if the coordinate transform is not performed on the data inside the instrument. This can be done to all recorded variables. The effect of the correction depends on the degree of the tilt and the algorithm used. Big maximum errors may be added to the data with simple correction methods especially if the vertical gradients are high (*Pulkkinen*, 1993). When the maximum errors become smaller the profiles will become smoother. An example of such correction done with two algorithms is given in Fig. 3. In general, the maximum errors in estimation of generated profiles at maximum velocity of 20 cm s^{-1} were in simple profiles usually less than 2 cm s^{-1}, but in a complex profile it could be over 4 cm s^{-1}. More severe than the magnitude of the error may be the fact that in steadily mounted deployments the errors occur always in the same part of the profile.

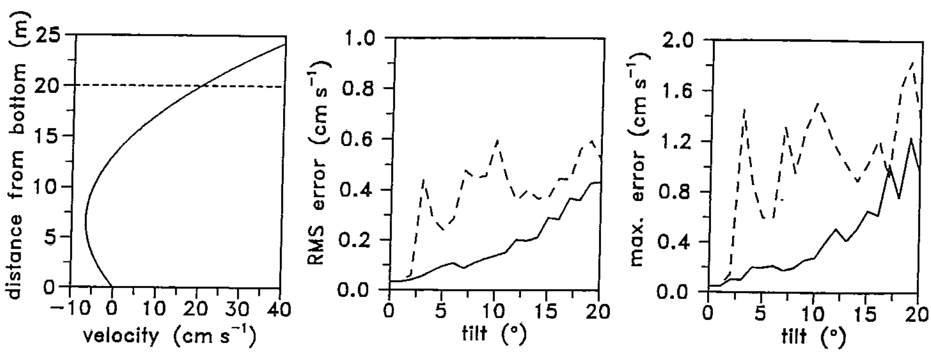

Fig. 3. A test profile and root mean square (RMS) and maximum errors between the test profile and estimated profile as a function of tilt as estimated with two different algorithms (*Pulkkinen*, 1993). Only data below 20 m was used in the estimation of the errors.

Some acoustic baffles have been used in order to minimize the sidelobe reflections from the surface. These baffles are located over the measuring head of the ADCP and they reflect or absorb the side lobes. One problem is that these - quite big - baffles disturb normal currents. If it is not possible to use such baffles, one should eliminate the effect of the reflections from the data. These reflections usually make horizontal currents smaller. Because the effect of the surface echo can commonly be seen in acoustic echo recordings the part that is unreliable data can then be estimated (Fig. 4). In Figure 4 the values of the acoustic echo are from beam values. Coordinate transforms have been made for velocity components.

As the functioning of the ADCP is based on the passing of sound in water the velocity of this sound should be known precisely. This is the only way to determine the accurate measurement depths. In practice this means that one must know the temperature and salinity profiles of the water body. If this is not possible, simple corrections can be done by correcting the temperature measured by the ADCP (T_{ADCP}, Fig. 5). If there are no big changes in the temperature profile and the temperature estimate is good the errors in depth positioning may remain moderate - less than 10 % of the depth resolution - when compared to the actual depth resolution of the instrument. However, if high changes in the temperature profile are expected it would be wise to record temperature and salinity profiles.

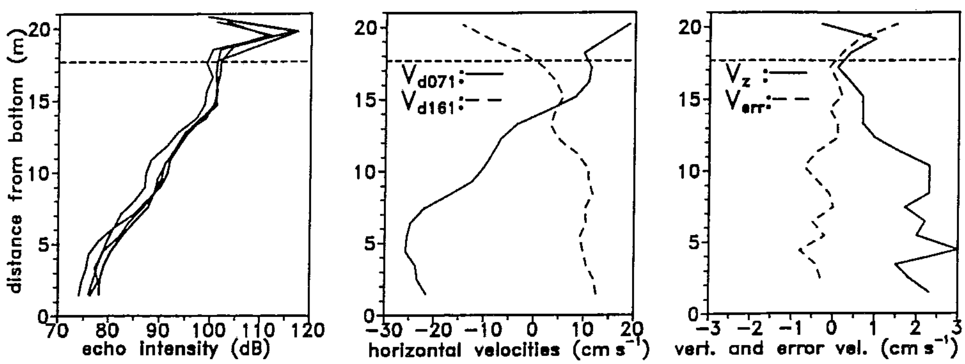

Fig. 4. Echo amplitude and velocity components as measured by the ADCP in Lake Päijänne on 26.6.1989 at 23:02. Values over the dashed horizontal line are disturbed by surface reflections. Values are 10 min. averages.

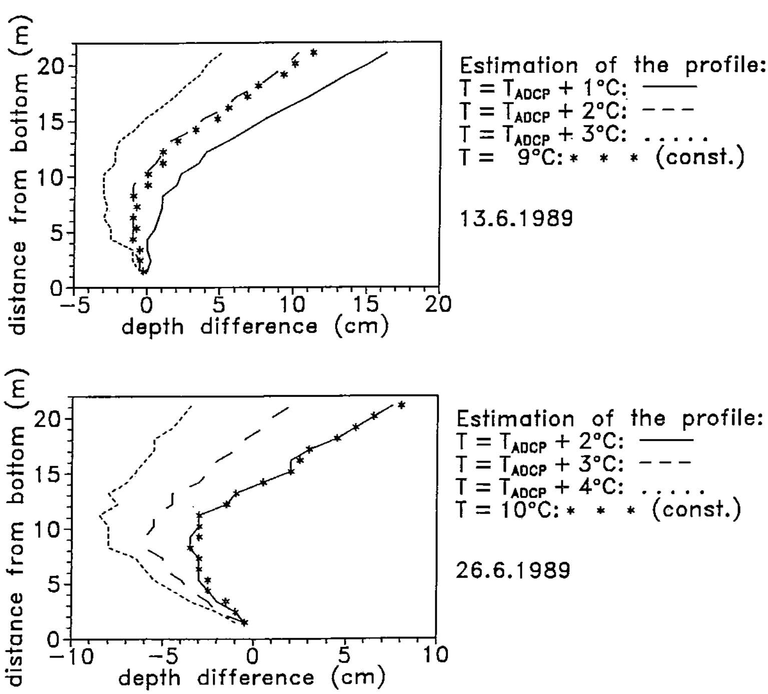

Fig. 5. Differences in the positions of the ADCP depth cells when compared to positions estimated with temperature profile data. Values are differences d(T-profile)-d(estimated). Profiles are from 13.6. 1989 and 26.6.1989.

4. *Conclusions*

Even though acoustic current measuring is far more reliable and accurate than the use of traditional propeller-based current meters, there are certain uncertainties one should be aware of. Since the numerical processing of the data starts inside the instrument, knowledge of the system is essential in collection of the data. Different options for data collection concerning the amount and quality of the data also requires knowledge. The opportunities to collect 'extra' data (other than current velocity data) may help in understanding unclear situations.

The possibility of error is present at all stages of measurement, from the instrument settings to data processing. In order to eliminate or minimize these errors or in order to separate errors from useful data one should at least know some basics of instrument usage and one should proceed with the data processing stage with special care. Knowledge about the measurement methods may also help present more reliable methods for data processing.

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