INFLUENCE OF THE ADCP GEOMETRY ON THE RESULTS OF MEASUREMENT

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The problem of verification of the fundamental rule of operation of Acoustic Doppler Current Profiler assuming the uniform current field within the four acoustic beams is studied. Analysis of scattering differences observed in four beams allows us to conclude about the homogeneity or inhomogeneity of the flow field. Geometry of the measurement performed by the ADCP is presented. The distance between beams, sampling volume and vertical resolution are studied in connection with the system parameters and depth of beam penetration. The so called anomaly index is invented in order to find the areas of the strongest variability. Examples of the inhomogeneity of the acoustic field within the measuring setup are presented and analysed. Differences observed in the strength of echosignal obtained by ADCP (150 kHz) and ELAC echosounder (30 kHz) are also analysed. Some reasonable explanations are examined, like the resonance of gas bubbles included inside the bodies and directional response of animals

INTRODUCTION

For some years the oceanographers are trying to use the Acoustic Doppler Current Profilers to collect the information concerning the marine biological objects, especially their concentration, configuration and behaviour. Except the profiles of water velocity, ADCP delivers valuable data on the total backscattering strength of the targets enclosed in the water column. ADCP works at “Janus configuration”, with four acoustic transducers mounted at 90° azimuthal increments, with each beam pointing 20 or 30° off the instrument axis. In a vessel-mounted system, the transducers are mounted in the ship hull and aimed downward; in a moored system the transducers look upward. The four beams record the acoustic signal scattered by the neutrally buoyant particles, the Doppler shift of its frequency is determined and the velocity vector of the sea current is calculated. In order to compute the Doppler shift precisely, the received signal must be amplified to a constant level. The amplification is done by an automatic gain control and its values are stored in separate files. This by-product – *Received Signal Strength Indicator* - is proportional to backscattering strength *SV*, which is a combination of abundance and backscattering cross-section of scatterers. The standard calibration methods are impossible to be applied in the case of the inclined beams, so in order to obtain the *SV* values the computational formula given by the producer is exploited [2, 6]. It makes use of the technical parameters (pulse length, transmit power, etc.) and of the environmental characteristics (e.g. temperature, absorption coefficient) as well.

1. EXPERIMENTAL GEOMETRY

An ADCP does not make a point measurement of current velocities [7]. For this system the directly measured velocities are the radial speed of the flow along its inclined acoustic beams, and the “true” velocity vector is derived from these along-beam velocities. Derivation assumes that the flow is homogeneous in the horizontal plane over the distance separating the beams and that there is no changes of the current field from beam location to beam location. Flow homogeneity means that the water velocities do not change significantly in magnitude and direction within the footprint of the acoustic beam. In fact this is not true and the estimate of current vector depends not only on the amplitude of the components but also on their spatial variability. Possibility of finding the homogeneous field of flow decreases with increasing distance from the transducer: the bigger range, the less probable is the homogeneous flow. Horizontal inhomogeneity of the flow over the distance separating the beams is caused by turbulent eddies with scales comparable to and smaller than *AB* (see Fig.1b). Spatial variations in the flow field on scales smaller than this will not be discern. So, for the satisfactory estimate, the time averaging must span many such eddies. Additionally, the horizontal spatial frequency of measured current is limited by the averaging within the beamwidth.

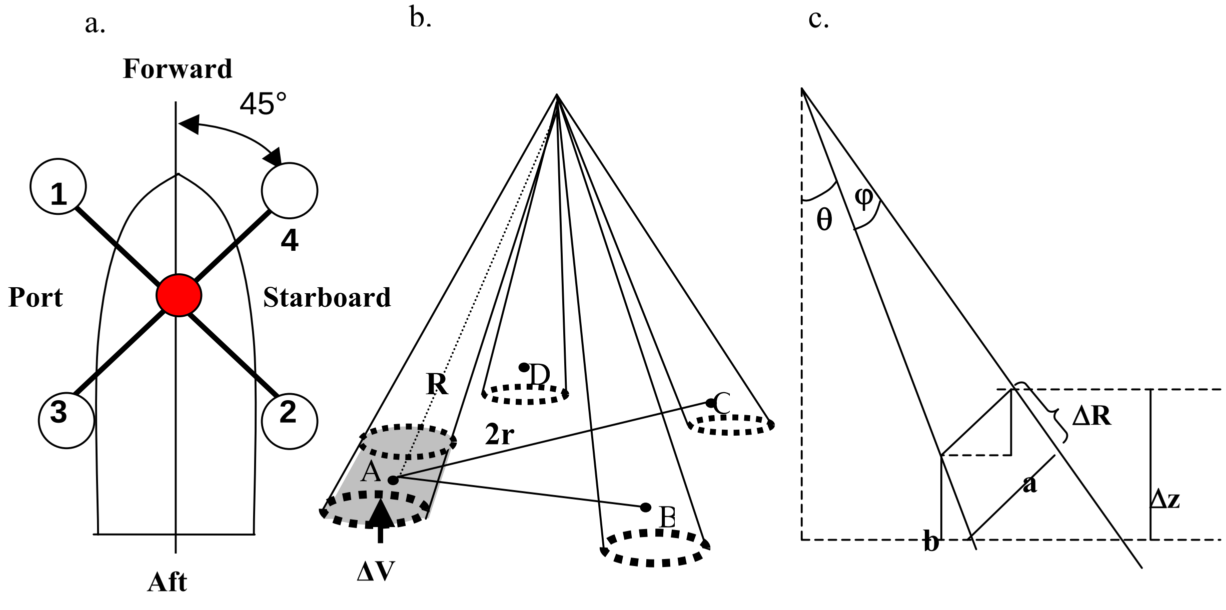

Fig.1 a). ADCP installation onboard r/v “Oceania”; b). distances between four beams of ADCP; c). depth resolution.

In the case of r/v “Oceania” the ADCP transducers are set up in a way shown in Fig.1a.

The distance between the opposite beams is *AC*=2*r* and between the adjacent beams is $AB = r\sqrt{2}$, where $r = z\,\mathrm{tg}\,\theta$ is the horizontal distance between the vertical axis of the whole system and the beam centre (Fig.1b). The sampling volume ΔV is approximated by the cylinder form:

$$\Delta V = \pi\,(R\tan(\varphi/2))^2\,\Delta R \tag{1}$$

The vertical resolution of the ADCP depends not only on the pulse length ΔR but also on the beamwidth φ (Fig.1c)

$$\Delta z = a + b = \Delta R\cos\theta + R\varphi\sin\theta \tag{2}$$

Depth dependence of all these variables for the case of ADCP mounted in the hull of r/v “Oceania” - $\theta = 30°$, $\varphi = 4°$, $\Delta R = 4.6$ m- are collected in the below table. It can be seen that for the ranges of some tens metres the distance between beams as well as the sampling volume are seriously increasing.

range [m]	AC [m]	AB [m]	ΔV [m^3]	Δz [m]
10	11.5	8.2	1.3	4.4
50	57.7	40.8	33.2	6
100	115.5	81.6	132.7	8

In our opinion, variability in spatial configuration of scatterers reflects in some sense the inhomogeneity of the flow field. Therefore, our interest is focused on the areas where the enhanced movement of scatterers takes place. The good indicator of such spots can be the difference between arithmetic mean of *SV* values and the “true” mean of *SV*. We call it the anomaly index I_A. Its definition is the following:

$$I_A = 10\log\frac{1}{4}\sum_{i=1}^{4} Sv_i - \frac{1}{4}\sum_{i=1}^{4} SV_i = 10\log < Sv > - < SV > \tag{3}$$

where:

$$SV_i = 10\log Sv_i$$

2. EXPERIMENTAL EVIDENCE

Fig.2 presents a 4-day series of stationary observation performed by the up-looking Broad Band ADCP moored at the bottom (depth 65 m, frequency 300 kHz, inclination angle 20°, beamwidth 2.2°). Thermohaline situation was quite simple: the upper 50 m was the mixed Baltic water of constant temperature 4°C and salinity 7 PSU. Below this layer the old water from the North Sea of the temperature 7°C and salinity 14 PSU resided. The upper chart is an echogram of values averaged over 2 meters in depth and 2 minutes in time. Regular nocturnal aggregations of bottom fauna were observed at the depth of 60 m, but in the subsurface area some intensification of the scattering was observed only during the first night. It started about 20:00 and disappeared at 4:00 the next morning. The lower part of Fig.2 shows the anomaly index (3) with blanked values greater than 2 dB. It can be seen that during the first night of measurement, the anomaly index greater than 2 dB covers the location of the subsurface scattering layer. During the next nights the anomaly index has the positive values in locations where we can expect the dense scatterer formation, despite they are not visible on the echogram in the upper part of Fig.2. It means that the anomaly index is a parameter sensitive to movement of targets, as we could expect.

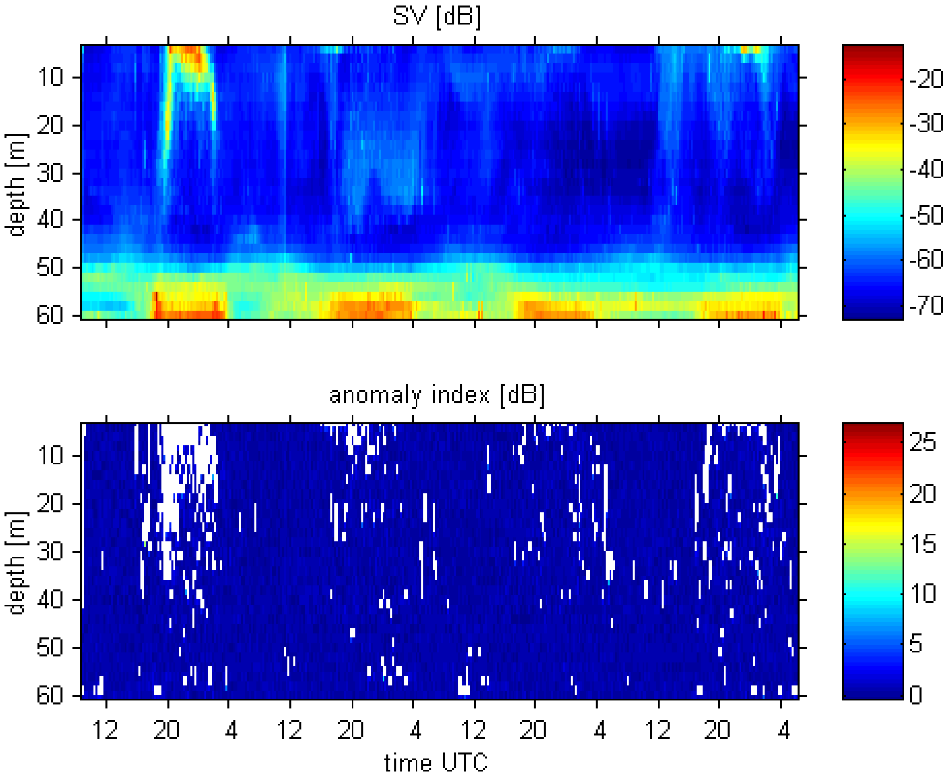

Fig.2 Echogram and anomaly index for the series conducted on 24 –28 April 2001 in the Słupsk Furrow by means of bottom-moored ADCP (300 kHz).

Another application of the anomaly index is shown in the next picture (Fig.3). It illustrates the results of measurement performed at the anchor station by means of vessel-mounted ADCP (frequency 150 kHz, inclination angle 30°, beamwidth 4°). Simultaneously measured CTD conditions are also shown. All the time, a distinct scattering layer is seen at the halocline. It becomes wider at night and at the same time some other layer is constituted at the depth 20-40 m. The anomaly index, shown in the lower part of Fig.3, takes the large values in the area of nocturnal aggregation of scatterers and, during the day, in the subsurface area, where no aggregations were observed. Nevertheless, an intense movement of scatterers took place in this area.

In our last year paper [6] the case was described where two echograms were compared: derived by ADCP and by ELAC echosounder. These echograms were not the same and the most intriguing feature was that some strong scattering layer seen at lower frequency (30 kHz) was almost invisible at the higher frequency (150 kHz). This fact was interpreted only on the basis of resonant scattering at 30 kHz by the gas inclusions. It was concluded from the model calculations that off-resonant slope of the *TS* versus *ka* curve for 150 kHz was about 25 dB lower than the resonant peak of this curve for 30 kHz. The reason for this could be both, small fish (juveniles of sprat and herring) and jellyfish, observed close to the ship in big

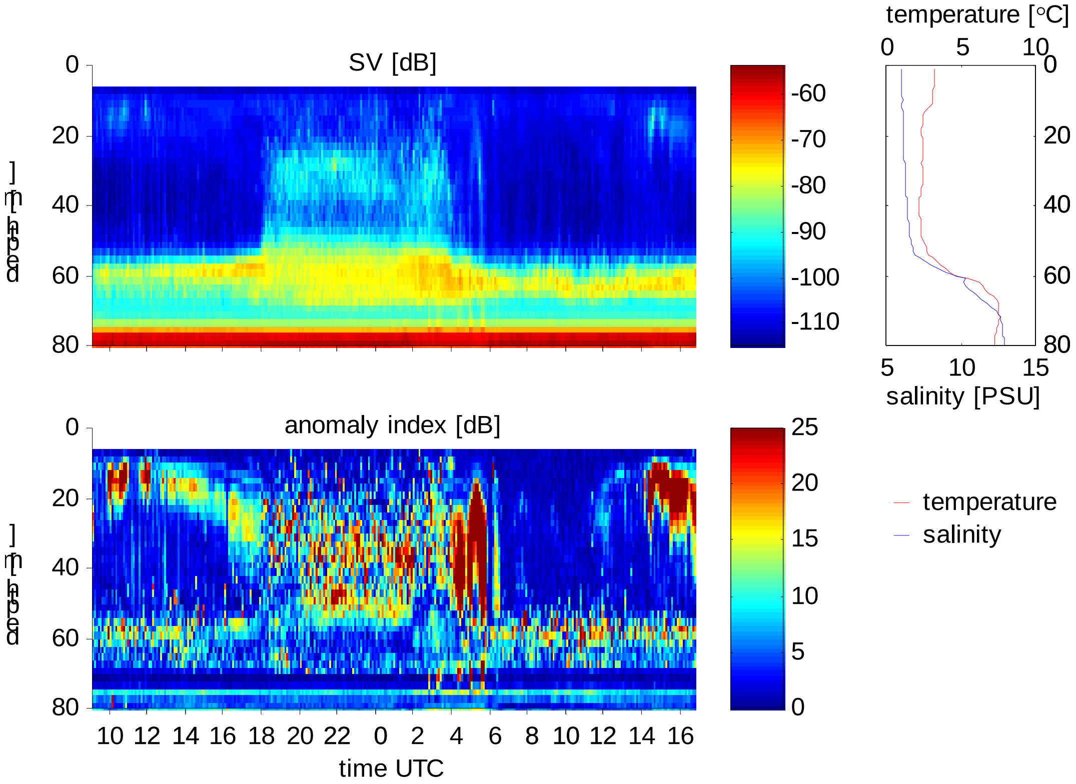

Fig.3 Echogram, anomaly index and temperature-depth dependence for the series conducted on 3 –4 April 2005 in the Bornholm Deep. Vessel-mounted ADCP (150 kHz).

abundance. Experimental studies of the target strength of jellyfish in the Black Sea [3] and the African waters of the Atlantic [1] show that *TS* increases both with the size of animal and with the frequency. For the individual of the moderate diameter of 6.5 cm the *TS* difference at 38 and 120 kHz reaches 5 dB. In our case the frequency gap is bigger and we can also expect the stronger effect on *TS*, and, consequently on the recorded *SV*.

An additional explanation of the observed phenomenon is also possible: the directivity of scatterers. We have to realise that standard echosounder works with the acoustic beam directed along the vertical, while ADCP makes it at the angle of 30° (or 20°), so the target strength of the same objects ensonified by both systems are different. Basing on the paper by Stanton et al. [4], it was shown in [5] that in the case of nonisotropic scattering we have

$$\sigma_{bs}(\theta) = D^2(\theta)\sigma_{bs}(0) \qquad (4)$$

where θ is an angle between the direction of the acoustic beam and a normal to the vertical cylinder axis. D(θ) is scattering directivity of a body, which for small θ can be described by the function

$$D(\theta) \approx \frac{\sin\Delta}{\Delta}, \quad \Delta = kL\sin\theta \qquad (5)$$

L is a length of the cylinder, *k* is a wavenumber. Under assumption that Δ<<1, θ<<1, the following approximation can be used:

$$D(\theta) \approx \exp\left\{-0.2(kL)^2 \theta^2\right\} \quad (6)$$

Calculations showed that the change of the tilt angle from zero to several degrees causes the fall of the target strength from a few to tens of decibels, depending on the frequency. The higher is the frequency, the bigger is the effect. At the working frequency of our ADCP (150 kHz) the TS difference between 0° and 12° is -12 dB , while for ELAC echosounder (30 kHz) it is only -0.5 dB.

Both factors, resonant-nonresonant scattering by the gas inclusions, as well as the directionality of scatterers relative to the beam angle, can explain the observed difference in the echograms recorded simultaneously by the 150 kHz ADCP and 30 kHz ELAC echosounder.

3. SUMMARY

Nowadays, ADCPs are routinely used by all oceanographic vessels (even by many commercial ships) to navigate and measure the movement of water masses. Derivation of current velocity, however, is based on the unrealistic assumption about homogeneity of flow field. Horizontal inhomogeneity of the flow over the distance separating the beams is caused by turbulent eddies with scales comparable to and smaller than beam separation.

In our opinion, variability in spatial configuration of scatterers reflects in some sense the inhomogeneity of the flow field. In many circumstances, the field of scatterer concentration is strongly inhomogeneous even in a short distance from the transducers, what is a confirmation of the heterogeneity of a flow field.

The anomaly index is a good indicator of local differences in the scatterer concentration. It increases in the regions where *SV* values recorded in one beam differ significantly from the others.

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