Comparison of Acoustic Measurements of Zooplankton Populations Using an Acoustic Water Column Profiler and an ADCP

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***Abstract*- Self-contained, moored echo sounders are a means of monitoring the behavior of populations of zooplankton and small fish over extended periods of time. Such instruments, either moored at or near the seafloor looking upward, or mounted on a surface buoy looking downward, record profiles of acoustic backscatter as a time series, and thus can provide insights into the long-term behavior and distribution of these populations. Single-frequency instruments are not capable of identifying the source of acoustic backscatter as species, but nevertheless can provide valuable information with low-cost, easily-deployed instrumentation over extended periods of time. This type of data can be collected either with an echo sounder designed for the task, or as an auxiliary output of an ADCP, using the RSSI (Received Signal Strength Indicator) output. In each case, without precise instrument calibration, an estimation of volume backscatter strength can be made from the data recorded by the two types of instrument. In this paper, we will compare the capabilities of an example of each type of instrument in terms of their spatial and temporal resolution and deployment endurance for extended monitoring. Calibration issues will also be discussed.**

In June 2004, a 200 kHz Acoustic Water Column Profiler (Version 4) and a 300 kHz RDI ADCP were co-located in Saanich Inlet, BC. The instruments were mounted on a surface buoy looking downward in 150 metres water depth for a period of 10 days. The two instruments were configured to operate with similar range and time resolution. The ADCP recorded a 30-ping ensemble every minute in 1 metre range bins. The AWCP4 recorded a 3-ping average every 12 seconds with 0.5m range resolution. The sampling regions of the two instruments were not exactly co-located, but were close enough to show the same larger scale features. Echograms from the two clearly show the two primary zooplankton populations in the Inlet, one migrating diurnally, and the other remaining at depth. Data from both instruments, when converted to volume backscatter strength are in agreement within the limitations of their approximate calibrations. Examples of these will be shown. The difference in performance between the two instruments appears when longer or more-frequently sampled deployments are considered. With the spatial and temporal resolution used in the Saanich Inlet deployment, the ADCP is limited to a 20-day deployment on a standard battery pack (80 days would be possible if 2 more batteries were added in an external case). The AWCP4, in contrast, would last over 8 months operating with those parameters. Operating the ADCP to achieve high-resolution backscatter data also degrades its performance in measuring current velocity in most cases. The AWCP4 therefore allows greater temporal and spatial resolution over the extended monitoring periods of many months that are one of the primary motivations for using a single-frequency instrument. The AWCP4 has recently been replaced by a new model, the AWCP5, which has increased data storage (up to 16 GBytes vs. 138 Mbytes), greater flexibility in choice of sampling strategies and 16-bit as opposed to 8-bit digitization for greater dynamic range. The AWCP5 offers even greater advantages in time and space resolution and length of operation for acoustically monitoring zooplankton populations.

I. INTRODUCTION

Acoustic methods have been used for many years to survey and assess fish populations in the ocean. With increasing interest in the state of the ocean ecosystem as a whole, there is a correspondingly greater need for monitoring of other populations, such as zooplankton and small fish. Moored, high-frequency echo sounders provide an economical way of obtaining long-term information about the behavior of these populations. Ship-borne surveys cover greater areas, but are not practical for obtaining extended time series, while satellites can provide information only at or near the ocean surface. These instruments can be deployed to look upward through the water column, from a bottom or mid-water mooring, or looking downward from a surface mooring. Recently, such instruments have been installed on cabled observatories, where their time series information can be monitored in real time [1]. Figure 1 shows an example of three days of data from one such instrument (an ASL AWCP4) installed on the VENUS observatory in Saanich Inlet, British Columbia [1]. The record shows the diurnal migration of a strong scattering layer (most likely composed of *Euphausia Pacifica* [2]), as well as other targets, such as schools of small fish.

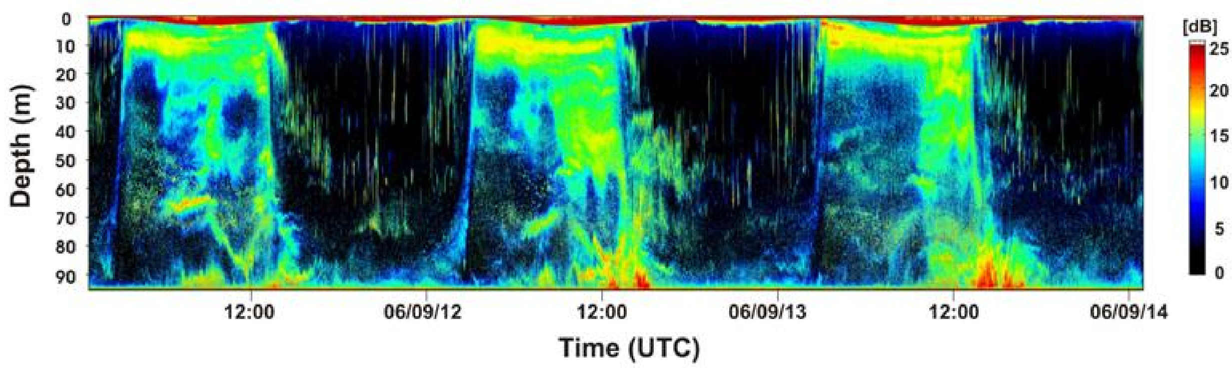

Fig. 1 Backscatter signal over 3 days from a 200 kHz inverted echo sounder mounted on the VENUS array in Saanich Inlet, BC.

Similar time series can be collected using the RSSI (Received Signal Strength Indicator) channel on an RD Instruments ADCP; an example from a Swiss lake [3] is shown in Figure 2.

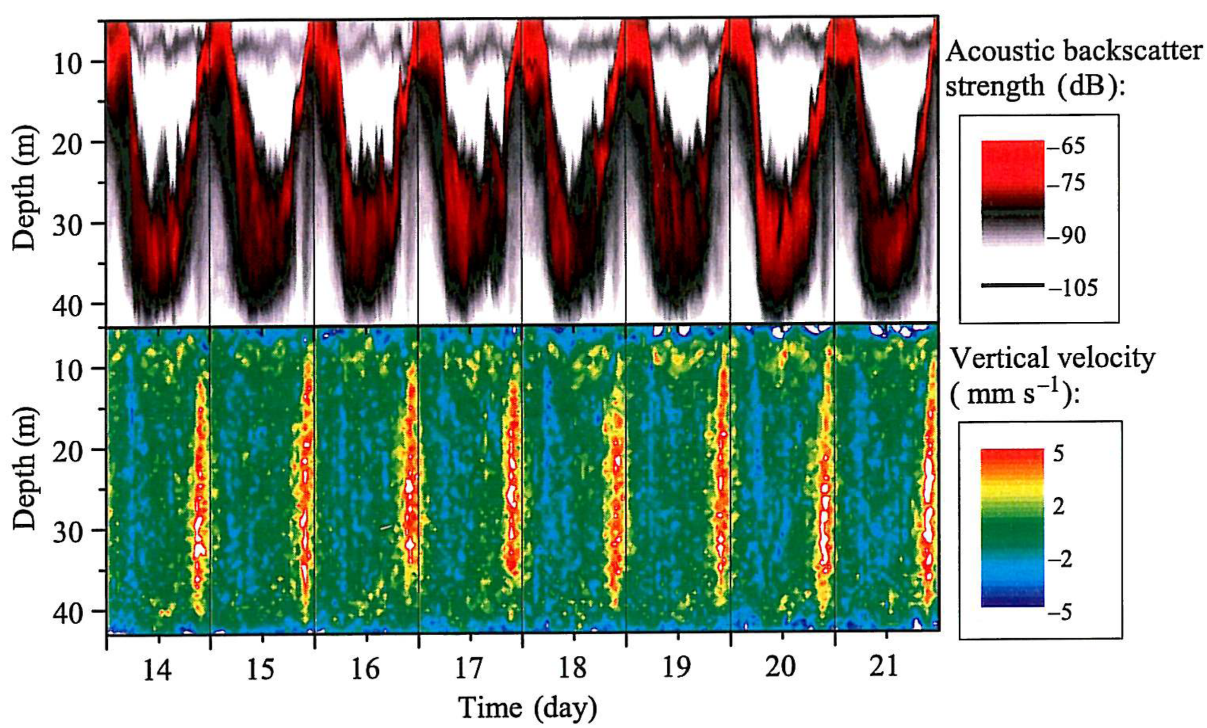

Fig. 2 Acoustic Backscatter strength (upper) and vertical velocity(lower) from a 614 kHz ADCP in Lk. Hallwill, Switzerland, June 2001, from [3].

Single-frequency measurements such as these two examples are not capable of identifying the source of the backscatter, or of separating contributions from mixed populations, but nevertheless can provide valuable information on the abundance and behaviour of zooplankton populations over extended periods of time. Precise measurement of the volume backscatter strength requires full calibration of the instruments, something that is not routinely available for them at present. However, even without precise calibration, their characteristics are usually specified sufficiently well to allow useful estimates of the volume backscatter strength to be made. The choice of instrument type for any given application involving an extended period of monitoring will depend on their relative capabilities for spatial and temporal resolution and endurance, as well their accuracy for estimating volume backscatter. Aspects of this comparison will be illustrated with data measured simultaneously by an ASL AWCP4 and aTeledyne- RDI Workhorse ADCP in Saanich Inlet, BC.

II. Instrument Description

The AWCP used in this comparison was a 200 kHz AWCP4, made by ASL Environmental Sciences Inc., of Sidney BC. The instrument was equipped with an 8° beamwidth transducer on a 3m cable, which allowed the transducer to be oriented independently of the pressure case. The particular unit used in these tests was designed for cabled operation, with external power and data storage; internal storage of 64 MByte and an external battery case were added for these tests. The instrument can ping at rates up to 1 Hz; the transmissions have a source level of approximately 213 dB re 1μPa at 1m distance. The length of the transmitted pulse can be selected between 50 and 1000 μsec. Pings can also be transmitted in bursts at selected intervals and averaged together to form an average profile. Bin averaging in range can also be done. Fig. 3 shows the signal path through the instrument up to the point at which the internal microprocessor acquires and formats the data. After transmission, echoes arriving at the transducer pass through a preamplifier and bandpass filter, then through a time-varying gain (TVG) stage and an envelope detector to the A/D converter. The amplitude is sampled at 23.3 kHz with 8-bit resolution to a selected maximum range of 200 m or less. The digitization rate provides range resolution of approximately 1/8 metre. The time varying gain has an 80 dB range, and follows an approximate 20logR +2αR form, where α is the absorption coefficient for 200 kHz sound in seawater and R is the range. The gain at which the TVG starts can be selected from one of 4 values, to allow some adjustment of the limited dynamic range of the 8-bit A/D.

The counts, N, output by the A/D range between 0 and 255 and are related to the volume backscatter strength S_v at range R by (1).

$$S_v = 20\log N - G(2R/c) - OCV - SL + 20\log R + 2\alpha R - 10\log(\tfrac{1}{2}c\tau\Psi) \quad (1)$$

where c is the speed of sound, τ is the transmitted pulse width, Ψ is the equivalent solid angle of the transducer beam, G(2R/c) is the instrument time-varying gain function in dB and OCV is the transducer receiving response. If the time-varying gain function in the instrument exactly matches the spreading and absorption losses, inspection of (1) shows that the logarithm of N is directly proportional to S_v. The TVG is an analogue circuit, and is based on an assumed speed of sound and absorption coefficient, and therefore does not usually exactly compensate for the spreading and absorption loss; correction for that difference is necessary to convert N to S_v. The difference varies with range and can be as much as 6 dB or greater, depending on the difference between the actual water properties and those assumed for the TVG. Using measured values for the TVG reduces the deviation from direct proportionality to approximately 3 dB; calculation of S_v also requires precise

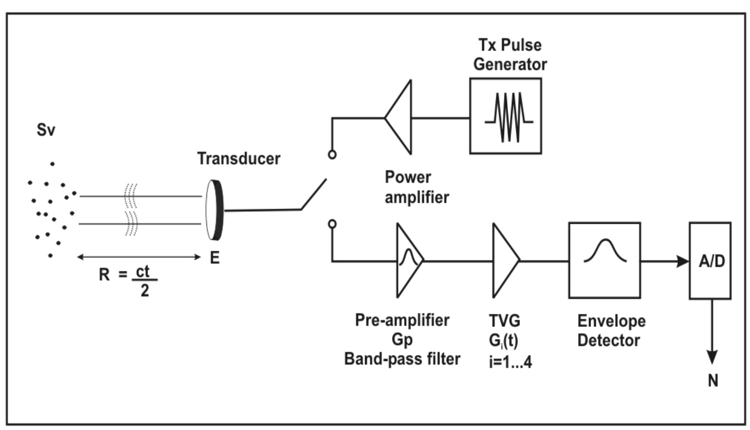

Fig. 3 AWCP4 instrument signal path

calibration of the transducer beam pattern. Approximate values for S_v can be calculated using the transducer manufacturer's calibrations.

The ADCP used for the measurements was a standard Teledyne- RDI 300 kHz Workhorse. The RSSI channel was used for the backscatter measurement, and was converted to estimated volume backscatter (S_v) as described in [4], using the nominal values for the instrument parameters.

III. SAANICH INLET TESTS

A. Installation

Saanich Inlet is a fjord on southern Vancouver Island (Figure 4), which reaches a maximum depth of 220 m in its central basin. The Inlet has a sill of approximately 70m depth. Currents in the Inlet are weak, and the water in the deep basin is exchanged only at intervals, with the result that the anoxic conditions frequently are found at depths greater than 100 m.

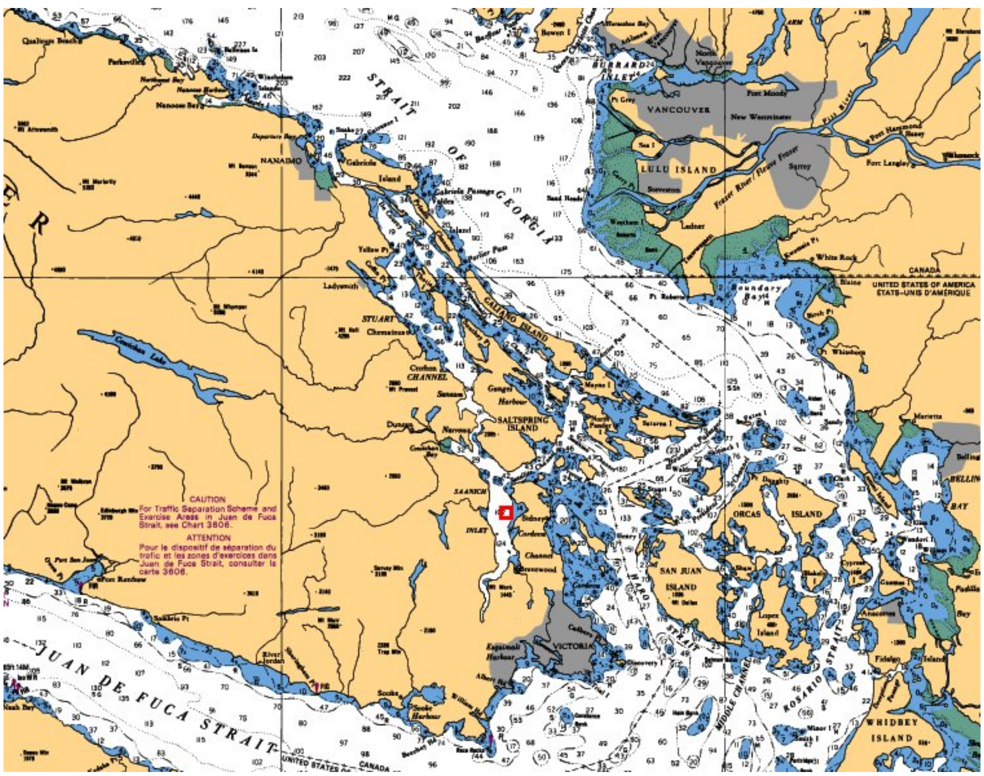

Fig. 4 Saanich Inlet; the red square shows the approximate location of the measurements.

The two instruments were mounted on a surface buoy (maintained by the Institute of Ocean Sciences) moored in 140m water depth off the mouth of Patricia Bay in Saanich Inlet (Figure 5) in late July 2004 and operated for a week. Both units were mounted in a cage hung over the side of the buoy, with their transducers pointing downward; Fig. 6 shows the cage and instrument mounting arrangement.

The AWCP4 transmitted 3 pings at 1 second spacing every 12 seconds. The echoes were averaged over 0.5 m range bins and over the 3 pings, resulting in 1 profile every 12 seconds. The ADCP recorded a 30-ping ensemble every 60 seconds at 1 m range resolution.

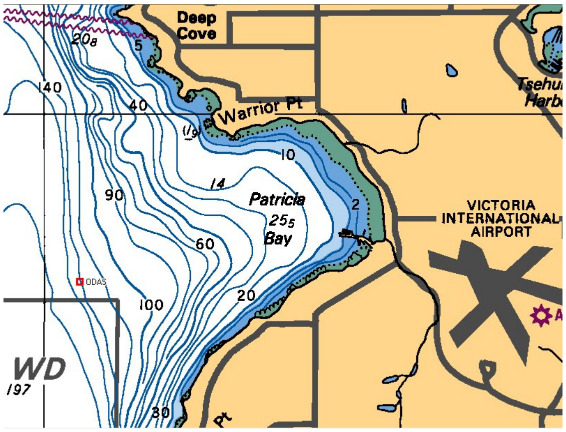

Fig. 5 Buoy location in Saanich Inlet.

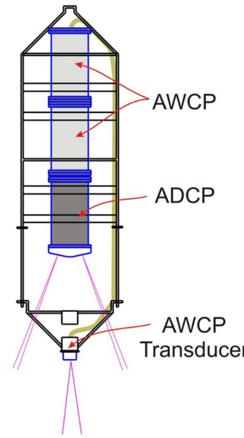

Fig. 6 Instrument mooring cage

B.   Results

The data from the AWCP4 and the ADCP were converted to estimated volume backscatter strengths, using the procedures described above. Figures 7 and 8 show echograms of S_v for July 31 and August 1 for each instrument. Two distinct scattering layers are apparent: one which migrates vertically on a diurnal cycle, and a second, generally thinner layer which remains at depth, just above the top of the anoxic layer.   The apparent sharp changes in the depth of the seafloor echo are due to rotations on the surface buoy; the cage was suspended at a small angle from the vertical, and thus changes in the buoy orientation directed the beams to portions of the seafloor with different depth and slope.

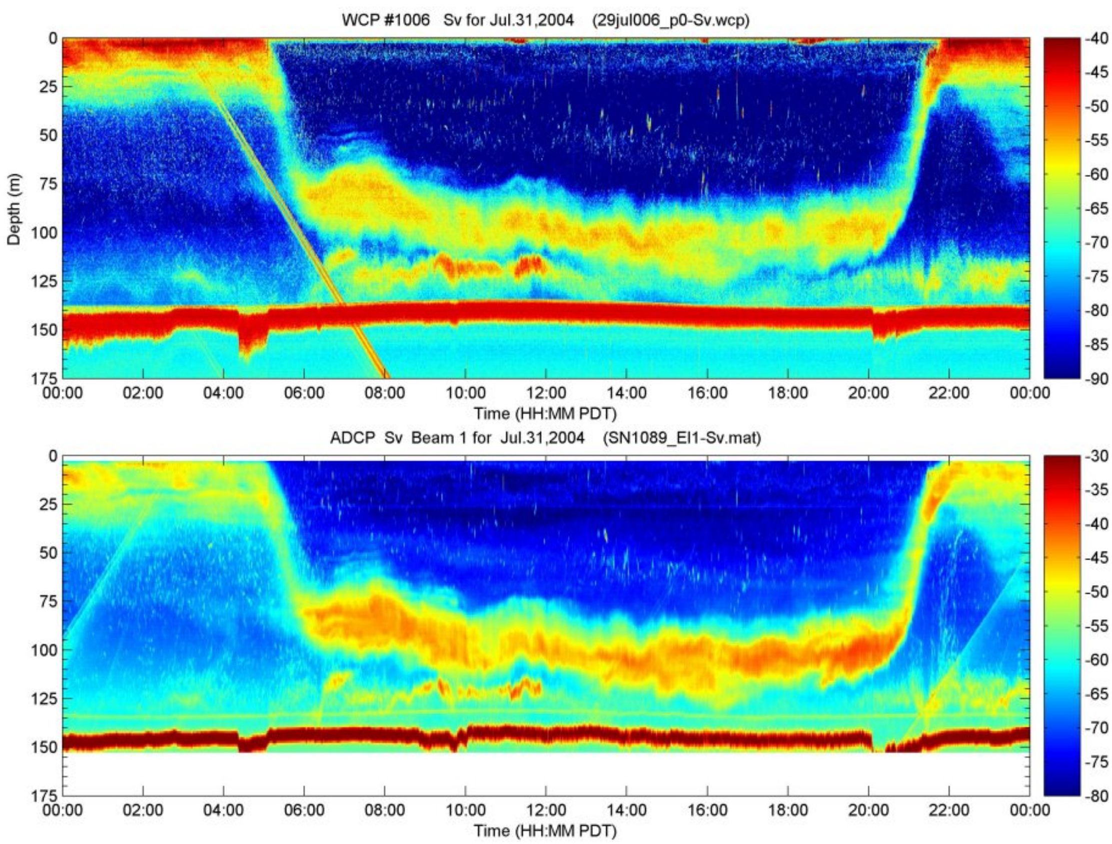

Fig. 7 Estimated S_v for July 31, 2004 from AWCFP4 (upper panel) and ADCP (lower panel).
Note the 10 dB difference in the colour scales between the upper and lower panels.

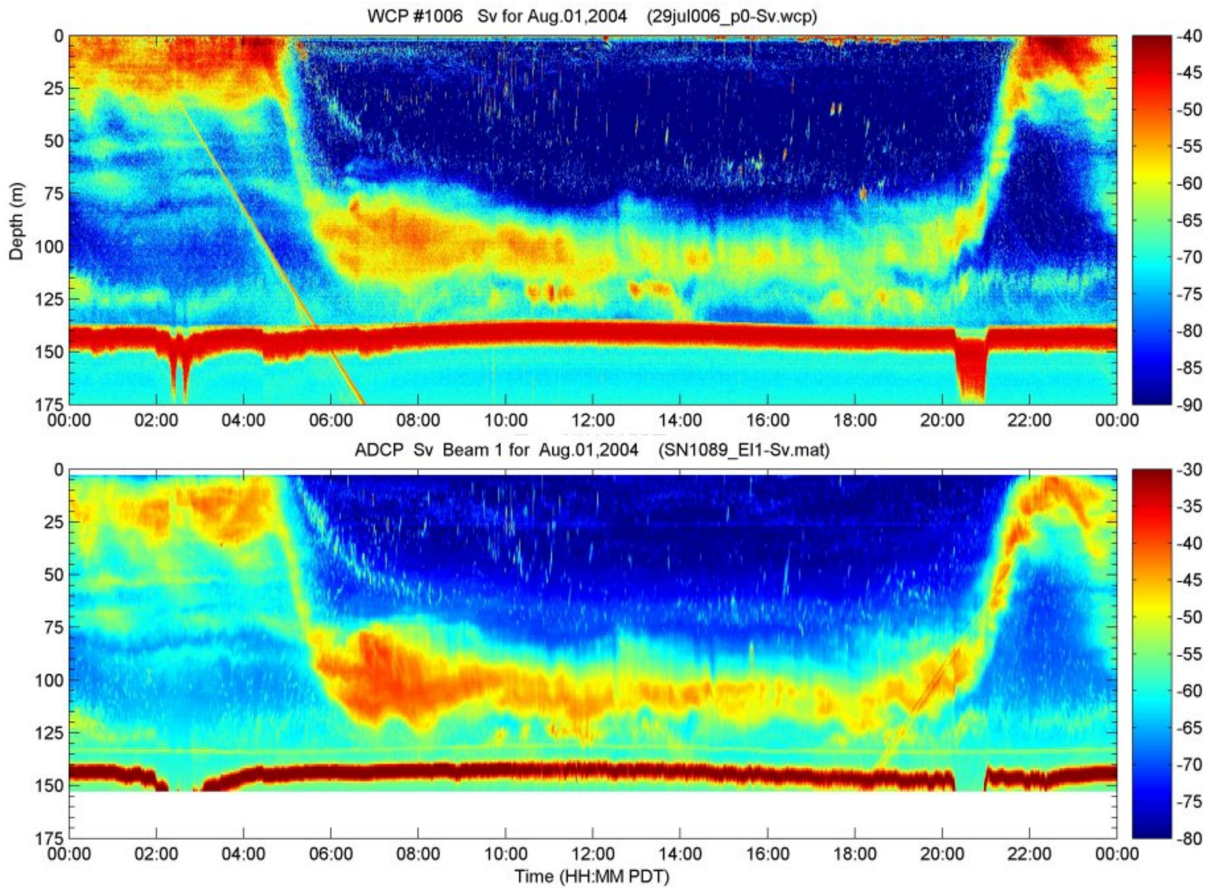

Fig. 8 Estimated S_v for August 1, 2004 from AWCP4 (upper panel) and ADCP (lower panel). Note the 10 dB difference in the colour scales between the upper and lower panels.

The two instruments show very similar patterns and relative scattering strengths, but there is an approximately 10 dB overall difference in the estimated S_v between the two instruments in the deep scattering layer, with the ADCP showing the higher values. (There is less difference apparent in the returns from near-surface layer.) This is likely due at least in part to the difference in target strength of the scatterers with frequency (300 kHz for the ADCP, 200 kHz for the AWCP4), with the remainder arising from the uncertainties in the calibration of the two instruments. A more accurate absolute calibration of the two instruments would be required to establish the actual difference in S_v at the two frequencies; that could be achieved by using a calibrated target with known backscatter target strength to measure the on-axis response and beam pattern in each case.

IV. Discussion

In this example, the results from the two instruments are quite comparable, although the AWCP4 had somewhat higher resolution both in time and in space. Significant differences in capability appear, however, when deployments for long periods are considered, and when the performance of the ADCP for measuring currents is included as a factor. With the spatial and temporal resolution used in the Saanich Inlet deployment, the ADCP is limited to a 20-day deployment on a standard battery pack. The AWCP4, in contrast, would last over 8 months operating with those parameters. (The standard AWCP4 battery is equivalent in energy storage to 3 standard ADCP batteries; with two additional batteries in an external case, the ADCP would have been able to operate for 80 days using the Saanich Inlet settings.)

Operating the ADCP to achieve high-resolution backscatter data also degrades its performance in measuring current velocity in most cases. In the configuration used in these tests, the expected maximum velocity profiling range is 83 m of the total 150 m depth, with a standard deviation in the velocity data of 2.8 cm/sec. Increasing the bin size to 4 m (i.e. reducing the range resolution by a factor of 4) reduces the standard deviation to 0.7 cm/sec and increases the maximum velocity profiling range to 103 m. Even with sacrificing optimal current velocity performance in the ADCP, the AWCP4 allows much greater temporal and spatial resolution over the extended monitoring periods of many months that are one of the primary motivations for using a single-frequency instrument.

Figure 9 shows an example of a krill swarm in the Southern Ocean, detected simultaneously by a 125 kHz AWCP4 and a 300 kHz ADCP during a 4 month deployment [5]. The AWDCP4 resolution was 0.5 m in range and 2 minutes in time, while that of the ADCP was 8 m in range and 4 minutes in time. The effect of the finer resolution in the AWCP record can clearly be seen.

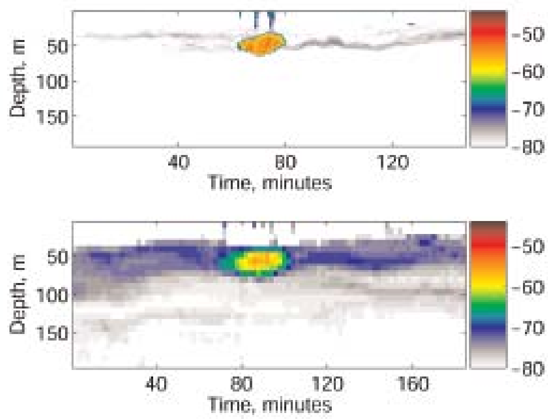

Fig. 9 Echograms showing a krill swarm detected by AWCP4 (upper) and ADCP (lower), from [5].

The AWCP4 has recently been replaced by a new model, the AWCP5, which has increased data storage (up to 16 GBytes vs. 138 Mbytes), greater flexibility in choice of sampling strategies and 16-bit as opposed to 8-bit digitization for greater dynamic range. The AWCP5 also includes an option for recording the variance of time and range-averaged returns. Using the same sampling parameters as were used for the AWCP4 in Saanich Inlet, but also recording variance, the AWCP5 would be able to operate for 280 days; without recording variance, the endurance would be 320 days. In both these cases, the limiting factor is the battery capacity, rather than data storage. Finer time and space resolution is therefore possible for shorter durations; for example a sampling plan which averages 5 1-Hz pings every 5 seconds with 0.2 m range bins and records variance would allow a 135 day deployment on a standard battery and require 14 GBytes storage. The AWCP5 therefore offers even greater advantages in time and space resolution and length of operation for acoustically monitoring zooplankton populations, coupled with greater flexibility in selecting sampling plans.

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