Monitoring of zooplankton vertical distribution and abundance with acoustic water column profilers

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Abstract- High-frequency acoustic backscatter measurements have long been used as a method to detect zooplankton populations in the ocean. Ship-borne echo-sounders can map distributions over relatively large areas, but are not practical for following developments over long periods of time. Self-contained echo-sounders, either moored at depth looking upward, or mounted on surface buoys looking downward produce time series of acoustic backscatter that are a means for monitoring long-term vertical distribution and behaviour of zooplankton populations. These instruments can also be integrated into cabled observatories to allow near real-time interrogation and monitoring. In this paper, we describe acoustic water column profilers and present representative data from self-contained moorings and cabled observatories.

Introduction

For much of the past hundred years, the biology of the ocean zooplankton has only been vaguely understood. Until recently, very infrequent and widely spaced discrete samples and net tows provided not much more than the crudest of outlines of oceanic food webs and species relationships. While great advances have been made in continuously recording electronic instrumentation, subsurface data on populations of fish, zooplankton and other creatures is still largely collected from ships using sampling nets. High-frequency echo sounders mounted on ships, especially in conjunction with net sampling, can map the abundance and spatial distribution of zooplankton [1,2]. While fairly large areas can be surveyed quickly in this fashion, it is impractical for monitoring changes continually over time.

Moored echo sounders can monitor backscatter from zooplankton over extended periods, with relatively high resolution both in time and depth. They can be mounted either on a surface buoy looking down, or subsurface, inverted to look upwards, either on the bottom or on a mid-water mooring [3,4,5]. These instruments are usually single-frequency devices, and therefore cannot separate the contributions to the backscatter signal from different size classes within a population. High levels of turbulent microstructure can also contribute significantly to the backscatter [6,7,8]. In the absence of significant turbulence, where the population is dominated by a single species, or if the member species differ markedly in their behaviour, moored single-frequency instruments can be used for monitoring long-term changes in zooplankton behaviour and abundance. Multi-frequency devices are an improvement over the single frequency instruments, since they can discriminate or classify several size classes of water column scatterers, from small zooplankton to fish.

The duration, frequency and depth resolution of sampling by moored self-contained instruments are constrained by power and data storage limitations, and the data are only available after (and if) the unit is recovered. Incorporating an inverted echo sounder into a cabled observatory allows the information to be monitored in near real time, and with greater freedom in the choice of sampling interval and depth resolution. In this paper, we describe the operating principles of acoustic water column profilers and present examples of data from all three types of installation.

Instrument description

In general, Acoustic Water Column Profilers operate much as radars or sonars, generating an acoustic 'ping' that propagates through the water column, and then listening for returning echos reflecting from particles in the water column (Figure 1). Sampling rates of up to one ping per second are possible, with averaging in both time and range to increase signal to noise and reduce data requirements. Where the expected density of scatterers is very low, longer transmit pulse lengths can be used. Conversely shorter pulses provide better spatial resolution for higher densities. Details of instrument specifications are described elsewhere [3, 5, 10].

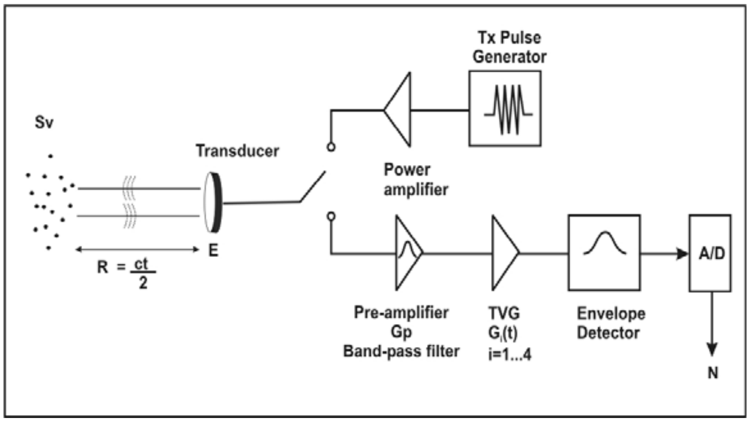

Figure 1. The generalized signal path for an Acoustic Water Column Profiler.

Early versions of the AWCP made by ASL Environmental Sciences Inc., of Sidney, British Columbia, Canada were designed for independent operation from a mooring. These are single frequency devices equipped with an 8° beam width transducer mounted on the end of the pressure case. The length of the pressure case is variable, depending on the number of batteries required for independent moored operation. For deployments of up to a year, a 1m long pressure casing is used – shorter pressure cases are available for small moorings with deployments of 3 and 6 months.

Figure 2. Some possible configurations for acoustic water column profilers.

A new multi-frequency version, the MF-AWCP, has increased data storage (up to 16 GBytes vs. 128 Mbytes), greater flexibility in choice of sampling strategies and 16-bit digitization. The new instrument supports up to four frequencies in a single transducer housing. Two lower frequencies intended to monitor fish are being added in early 2010. Table 1 illustrates very approximate detection range and size classes of targets detected for the frequencies available.

Table 1. Approximate minimum particle size detected and effective range for different acoustic frequencies**.**

Instrument Frequency (kHz)	Approximate minimum particle size detected (mm)	Representative organisms	Estimated effective Range (m)
775	2	small copepods	50
460	6	large copepods, larval euphausiids	100
200	16	larval fish, euphausiids	200
125	20	adult euphausiids, mysids, amphipods	250
70	30	small fish	estimated 275
38	50	larger fish	estimated 325

A different instrument configuration designed for long term use in a cabled underwater observatory has a plastic pressure case to avoid the requirement of periodically replacing anodes. The instrument is much smaller, as power is provided by observatory platform. In some installations, the transducer is separated from the pressure case to allow it to be mounted independently [11]. VENUS is a permanent oceanographic research facility consisting of two cabled arrays, the first located in Saanich Inlet, the second in the Strait of Georgia, on the west coast of Canada [9]. The concept of the observatory is to utilize fiber-optic cables to connect bottom mounted oceanographic instrument systems to the Internet. AWCPs are installed on both VENUS arrays and the realtime data can be viewed on the project website.

Data Examples

Data from Acoustic Water Column Profilers are usually presented as a time/depth plot of the magnitude of the backscatter signal, using a colour lookup table varying from blue through red (Figure 3). This weeklong series of daily echograms from Saanich Inlet, a deep fjord on the southwest coast of Canada, shows a number of interesting phenomena that illustrate many of the phenomena which long-term continuous monitoring can reveal.

The most striking pheonomenon is the diurnal migration of a strong scattering layer, which is most likely composed of euphausiids (*E. pacifica*) [4], known to migrate to the surface just after sunset and descend prior to sunrise in this area. Other, non-migrating species such as copepods are also present in large numbers. Short term variability at a scale of hours, and day-to-day variations, probably relate to swarms of animals passing through the instrument beam.

The abundance of zooplankton and the structure of the vertical migration change seasonally (Figure 4). Large and small individual fish, and schools of small fish also show up clearly as do clouds of near-surface bubbles under rough, windy conditions (eg. after 1500hrs in the spring panel). The scattering layers also make internal waves clearly visible. Such extended time series offer abundant opportunity for detailed investigation of these and other phenomena. Since other instruments at the VENUS site measure current profiles, it should be possible to calculate the geographic scales of zooplankton patchiness that plague sampling with nets

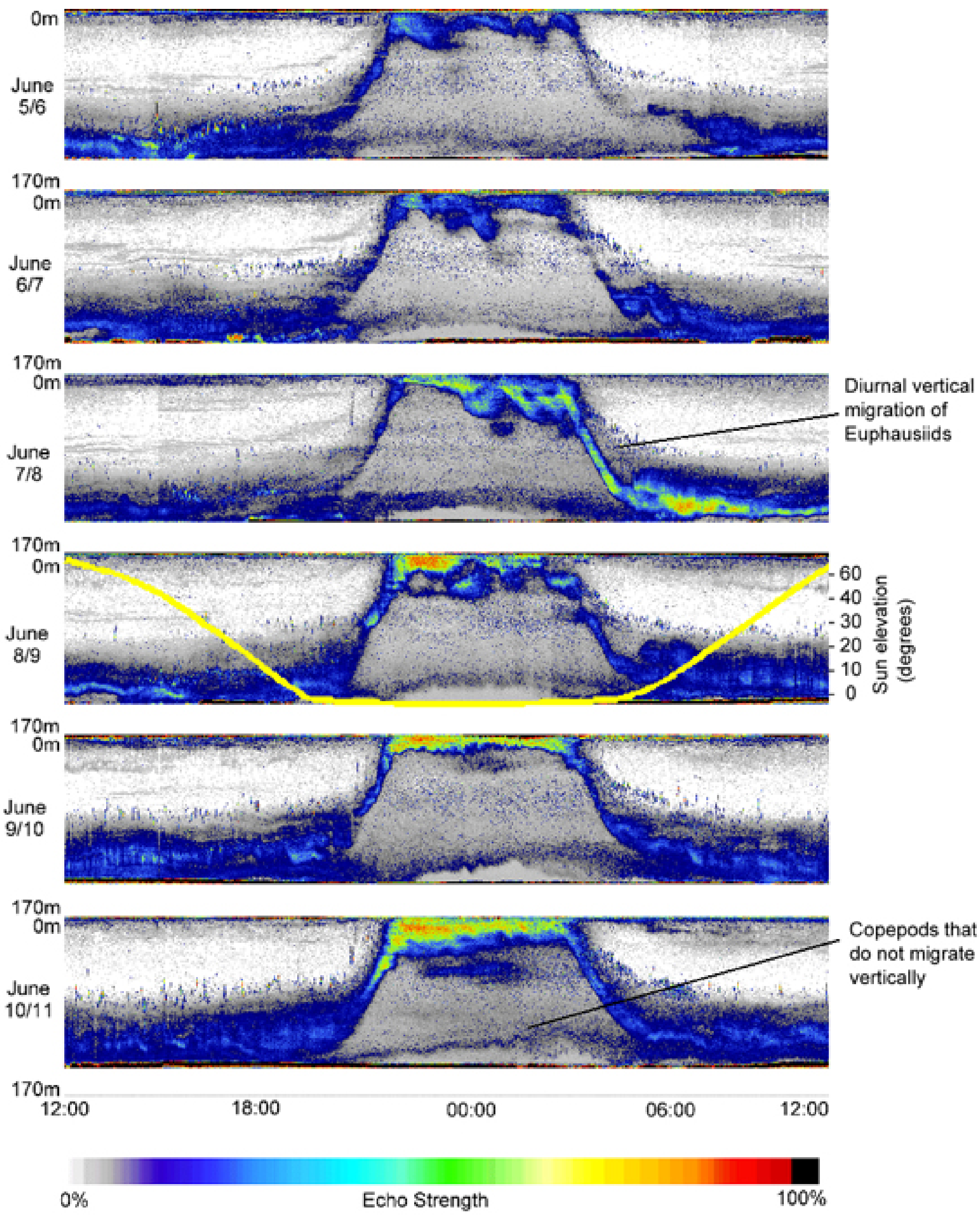

Figure 3. A week long series of echograms for June 2001, illustrating changes of vertical distribution of scatterers in Saanich Inlet, from minutes to days. Yellow line shows the approximate sun elevation on June 7. (Images have been grossly decimated for inclusion here. See reference 2, or contact the authors for higher resolution figures)

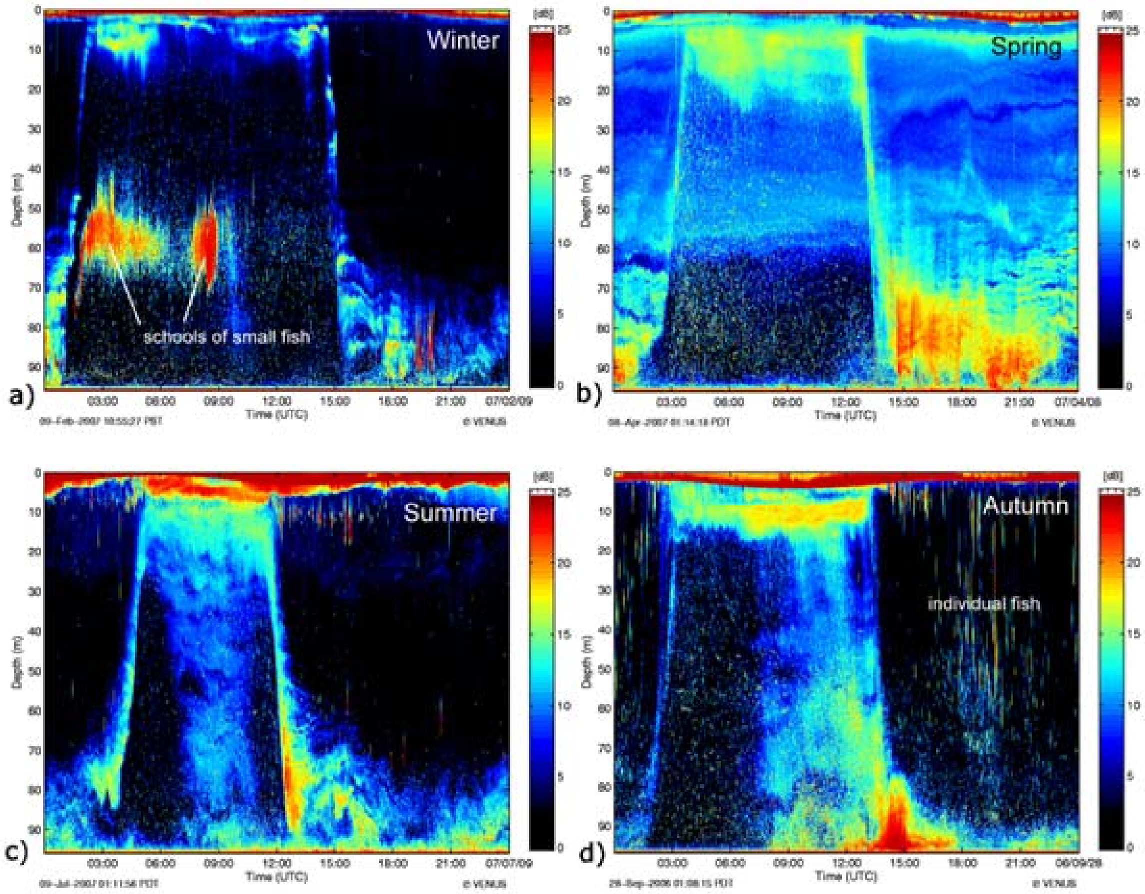

Figure 4. Representative 24 hour AWCP images from the VENUS Observatory in Saanich Inlet, on the west coast of Canada in different seasons. Diel zooplankton migration is a dominant signal, but other seasonal and temporal variations are evident. (Images have been grossly decimated for inclusion here. See the VENUS website for higher resolution images.)

Conclusions

Ship mounted acoustic sensors have been in use for monitoring fish stocks for many years, and their use for describing zooplankton stocks began in the early 1990s [eg. 12]. With the recent introduction of easy-to-use, low cost water column profilers with sophisticated internal data processing, [3], greater exploitation of the potential of dedicated acoustic water column profilers for biological sampling can be expected. These instruments, especially the new multi-frequency devices, will provide a rich data source describing the spatial and temporal distribution of many important mobile components of the food web that have been notoriously difficult to sample, and their low cost make long term monitoring programs feasible. Their small size and low power consumption has allowed them to be mounted in AUVs and Gliders, which in turn will permit wide area monitoring programs of long duration. Studies involving comparison with well-timed plankton net tows can be expected to uncover phenomena and behaviour patterns previously unknown.

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