An Autonomous Hydroacoustic System for studying long-term scattering variability*

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Abstract

A new instrument, an Autonomous Hydroacoustic System, was designed to probe a water column acoustically from the bottom to the sea surface. It is capable of operating from a depth of 100 m self sufficiently for up to 10 days. A brief description of its construction and electronic design is provided. Preliminary results from the first field study consisting of a 90-hour series of backscattering measurements are presented.

1. Introduction

Sound backscattering measurements have been carried out during the last ten years aboard r/v 'Oceania'. They have revealed dramatic diurnal changes in the average backscattering strength and varying seasonal patterns of nocturnal fish and zooplankton aggregations (Szczucka & Klusek 1996, Orłowski 1997, 1998, Szczucka 1999, 2000). The results indicate that at

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night during the warm seasons the scatterers form a strong subsurface layer at or above the thermocline. However, there is a crucial weak point in all of our results to date in that all the data from the top few metres of the water column are lost owing to reflections, sometimes multiple reflections, of the backlobe of the acoustic beam from the sea surface and the ship's hull. The solution to this problem was to invert the experimental geometry by placing the instrument on the seabed to insonify the water column from the bottom to the surface. The main advantage of such a geometry is that no external conditions (except near-bottom currents) can affect data acquisition.

The Autonomous Hydroacoustic System (AHS) is designed to operate independently from the seabed. The pressure container with computer and echosounder is anchored on the sea bed and aimed towards the surface. AHS can rapidly and continuously profile a water column. When it is released to the surface, the data are downloaded on to a PC. It is also possible to download the data by means of a removable interface cable without the need to open the container. After the batteries have been replaced, the instrument is ready to start a new series of measurements.

The AHS was subjected to testing in a field study and the preliminary results of backscattering measurements are presented to demonstrate its utility.

2. Instrument description

Enclosed in a steel pressure container, the echosounder and computer are the principal parts of the Autonomous Hydroacoustic System. The whole system consists of the pressure container, pressure sensor and upwards-pointing hydroacoustic transducer mounted on the top of the container, with an acoustic release and anchor attached to the bottom of the container. Fig. 1 shows a general view of the instrument.

The pressure container is a 1 m long steel cylinder of 20 cm diameter. The width of the walls is 6 mm and the thickness of the upper and lower covers is 8 mm. The pressure container provides the casing for the echosounder and computer, and the batteries are mounted on a 76 cm long rack which slides into the tube. Below the instrument hangs a short mooring chain, fastened to an acoustic release and a disposable 90 kg (in air) anchor. The vertical position of the entire device is stabilised by a set of 15 buoys with a total buoyancy of 100 litres. The overall system must be sturdy enough to withstand deployment and recovery in stormy weather and to cope with near-bottom currents. It weighs 120 kg and its self-buoyancy is 15 litres.

AHS can only be used in areas where the sea bottom is less than 100 metres from the surface, which is the limit of the pressure resistance of the container and transducer.

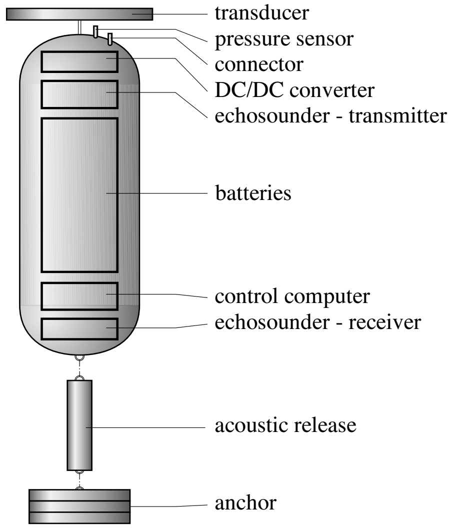

Fig. 1. General view of the Autonomous Hydroacoustic System

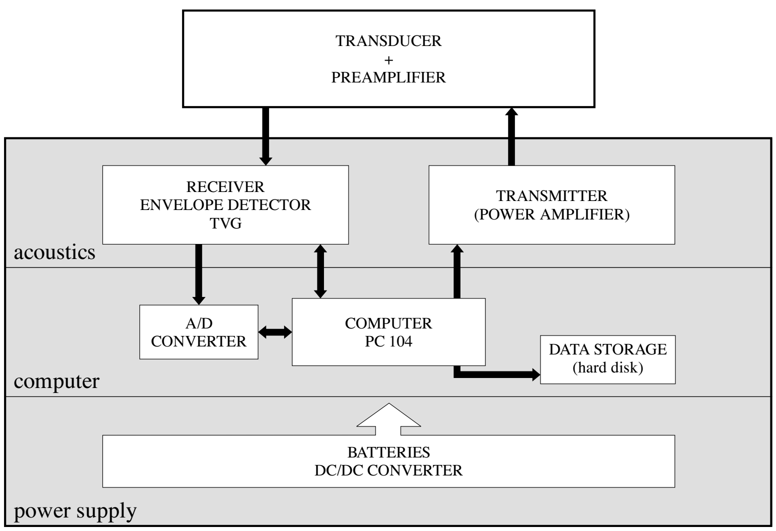

Fig. 2. Diagram of the electronic system

The internal electronics, control systems and batteries are installed on a frame. A simplified diagram of the electronic block is presented in Fig. 2. The echosounder operates at 130 kHz, which allows for the detection of scatterers as small as 2 mm in size. The programmable transmitter is controlled individually by the PC104 system. The transmitting pulse length is adjustable, as is the pinging rate. The receiver circuitry of the echosounder consists of an amplifier and an envelope detector. The time varied gain (TVG) of the system can be implemented as any function in a dynamic range of 80 dB.

The computer controls the external pressure, echosounder triggering, power supply relays, and data logging rates. The unit is programmed in C-language and assembler, with the executable stored in EPROM. All data together with the deployment logging history file are stored for post-processing. The CPU can communicate with an external computer via a 9600 baud serial port.

Power is delivered from a 24 V, 120 Ah battery bank via a voltage converter. The number of batteries in the bank depends on the calculation of the energy required. Where working temperatures are low ($\sim 4^\circ$C), the battery capacity should be increased by 20%. The battery voltage is continuously monitored by the control computer, and if the voltage level drops below the critical value the computer will automatically stop pinging. During the breaks in pinging the instrument is maintained in sleep mode to conserve battery power.

Sampling is performed by a 12-b analogue digital converter. The sampling rate of 8 kHz ensures a depth resolution of 0.09 m. The instrument is currently programmed to collect data for 52 seconds every 10 minutes. The chosen pulse duration of $\tau = 0.3$ ms gives a spatial pulse length of 0.22 m, and the pulse repetition time of $t_r = 800$ ms results in a 52 second duration of the 64-ping series.

The capacity of the batteries and hard disk are such as to make deployments of 10 days' duration possible. The apparatus is capable of continuously collecting backscattering information. It acquires and stores data in the form of digital samples of the echo envelope.

3. Preliminary results

This particular experiment took place in the Słupsk Furrow ($\varphi = 55^\circ 18.2'$N, $\lambda = 16^\circ 49.4'$E; depth ~ 70 m) from 16 to 20 October 2001. The location of the measurement site is shown on the map (Fig. 3). The thermohaline conditions are presented in Fig. 4. Despite the late autumn, there was still a marked thermocline with a temperature difference of about 8°C. The echosounding series started at 21:30 h on 16 October and ended at 16:00 h on 20 October. A total of 544 blocks of 64 pings were recorded (34 816 transmissions in all). The data were recorded in the form

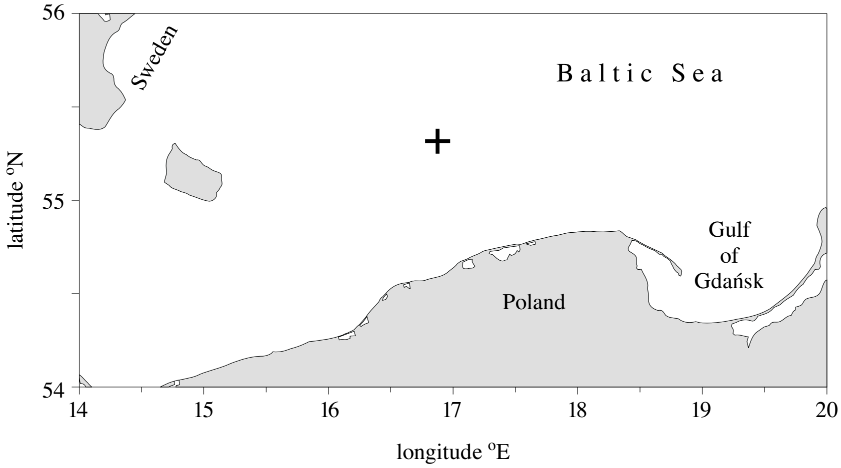

Fig. 3. Location of the observation point in the Słupsk Furrow

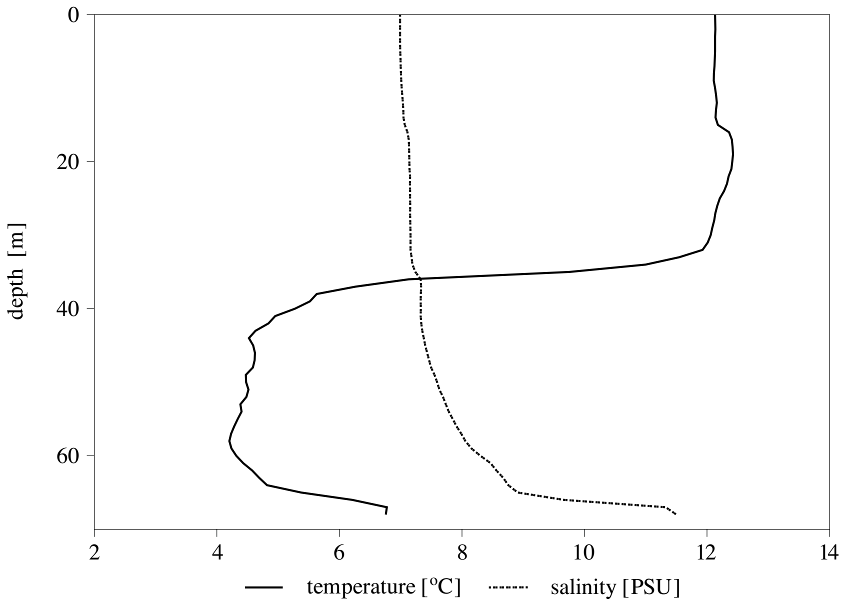

Fig. 4. Temperature and salinity profiles measured concurrently with echosounding

of a sampled envelope of the returned echo voltage (proportional to the backscattered pressure), 12-b integers sampled at 8 kHz. The data acquired were converted into the volume backscattering coefficient Sv and volume backscattering strength SV (Clay & Medwin 1977):

$$Sv = \frac{U^2}{p_0^2 \gamma^2} R^2 \frac{1}{\frac{c\tau}{2}\Psi_D},$$

where

R – distance from the source,

c – sound velocity in water,

p_0 – sound pressure on the acoustic beam axis at 1 m distance from the source,

γ – receiver sensitivity,

τ – pulse duration,

Ψ_D – solid angle formed by the acoustic beam;

$$SV = 10 \log Sv,$$

$$SV = 20 \log U - 104.76 \ \ [\mathrm{dB}].$$

The value of 104.76 is obtained by calibrating the echosounder by means of a copper sphere with a known target strength and by calculating the technical parameters of the system. The first stage of data processing involves averaging over 64 pings, which gives an approximate 1-minute mean profile of the voltage. After the voltage profiles have been recalculated, a backscattering coefficient array is constructed thus:

$$SV(z, t) \equiv SV(z_j, t_k),$$

where

$$z_j = z_0 - j\,\Delta z,$$

$$z_0 = 68.7\,\mathrm{m}, \qquad \Delta z = \frac{c}{2\ f_{\mathrm{sample}}} \cong 0.09\,\mathrm{m}, \qquad j = 1, ..., 1024;$$

$$t_k = t_0 + k\,\Delta t,$$

$$t_0 = 21.5\,\mathrm{h}, \qquad \Delta t = 10\,\mathrm{min}, \qquad k = 0, ..., 543.$$

This provides for the formation of an echogram, which is a plot of vertical profiles of SV over time (Fig. 5). The time scale (x-axis) starts at 21.5 and stops at 112, embracing 90.5 hours, the duration of the experiment. The hours $24, 48, 72$ and 96 relate to midnights, while the hours $36, 60, 84$ and 108 are the consecutive middays. The depth scale (y-axis) is counted from the surface (0 m) to the depth of the acoustic transducer (68.7 m). The colour scale of the echogram denotes the volume backscattering strength SV: the higher the SV level, the warmer the colour. The temporal distribution of SV shows the presence of four evident nocturnal patches of sound scattering organisms, extending from the surface down to a depth of 40 m, but they vary from one night to another. Moreover, the concentration of scatterers changes from night to night. The first (hours 21.5–31) and the third night (hours 67–80) are characterised by a high level of SV, while

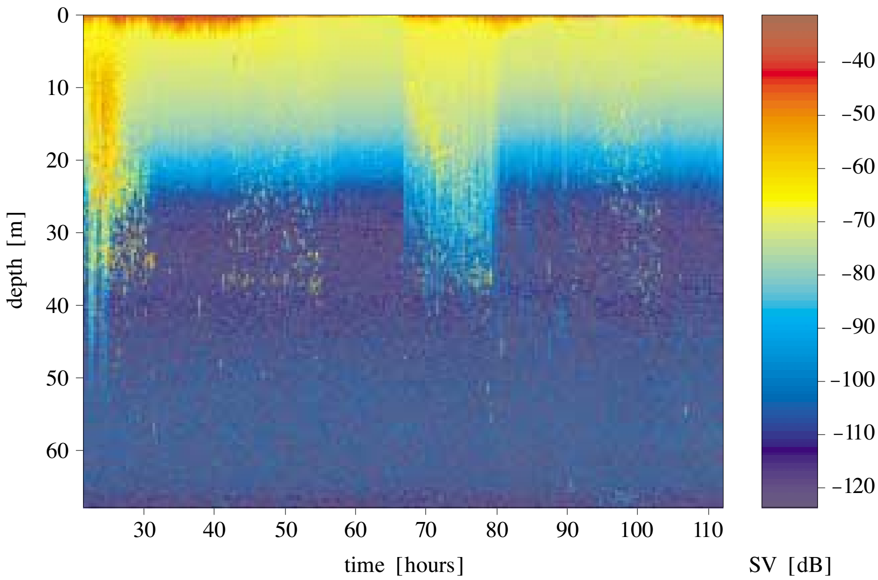

Fig. 5. Time-series data on volume backscattering strength collected during the 90.5 hour experiment in the Słupsk Furrow

the other two nights yielded lower levels of scattering. Another noticeable zone of backscattering is located just below the sea surface, especially during the first day (time interval 32–43). The most probable reasons for this phenomenon are wind waves and wave-generated gas bubbles. No backscattering was recorded below 40 m. This depth coincides with the very pronounced thermocline (see Fig. 4), which apparently constitutes an impassable barrier for the vertically migrating organisms.

The features described above can be seen more distinctly in a presentation of the SV array averaged over several days:

$$< SV(z, t) >_{24\,\mathrm{h}},$$
$$t = 0 + i\,\Delta t, \qquad i = 1, ..., 144.$$

Notice that the nocturnal aggregation disappears just before sunrise (7:30) and reappears after sunset (17:45) – see Fig. 6.

The daily and nightly mean profiles of the volume backscattering strength are compared in Fig. 7. In both cases the first 400 samples are very irregular – they appear to describe the noise field due to accidental events of single scattering objects. The differences between day and night profiles of SV are significant compared to the differences between successive night or successive day profiles. The main difference between day and night recordings occurs above the 500th sample (over 46 m from the acoustic

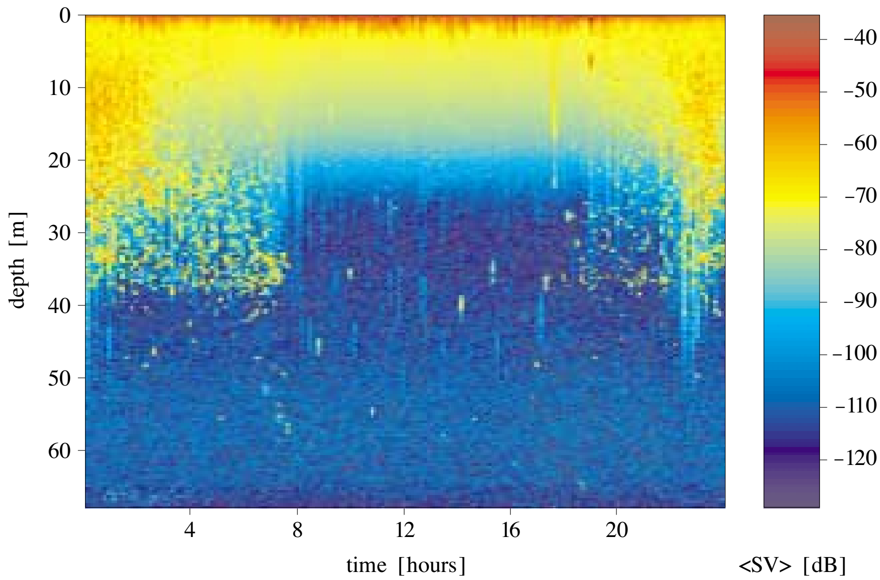

Fig. 6. *SV* data averaged over several days

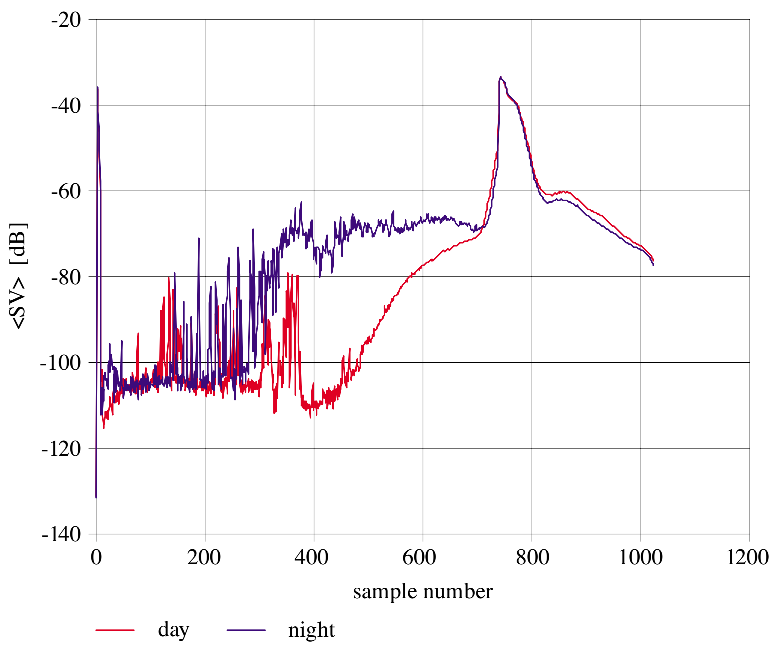

Fig. 7. Depth profiles of the volume backscattering strength averaged over all daily measurements (red curve) and over all night measurements (blue curve)

source). At the beginning, the predominance of the night profile reaches almost 30 dB, while closer to the surface this difference decreases, and just before reaching the surface the day values become dominant. This observation accords well with the previously mentioned surface agitation and bubble generation. The sea surface reflection dominates the whole echo. It appears as a sudden jump in echo intensity at sample 740 and is identical for both day and night. The next figure (Fig. 8) presents the scattering anomaly calculated for night and day and smoothed by a low-pass filter:

$$SV\text{anomaly}(z)_{\text{day, night}} = < SV(z) >_{\text{day, night}} - < SV(z) >_{\text{total}},$$

where

$$< SV(z) >_{\text{night}} = 10\log\left[\frac{1}{N}\sum_{t=\text{sunset}}^{t=\text{sunrise}} < SV(z,\,t) >\right],$$

$$< SV(z) >_{\text{day}} = 10\log\left[\frac{1}{D}\sum_{t=\text{sunrise}}^{t=\text{sunset}} < SV(z,\,t) >\right],$$

$$< SV(z) >_{\text{total}} = 10\log\left[\frac{1}{K}\sum_{k=0}^{543} SV(z,\,t_k)\right];$$

N, D, K – the respective number of samples collected at night, during the day and in total.

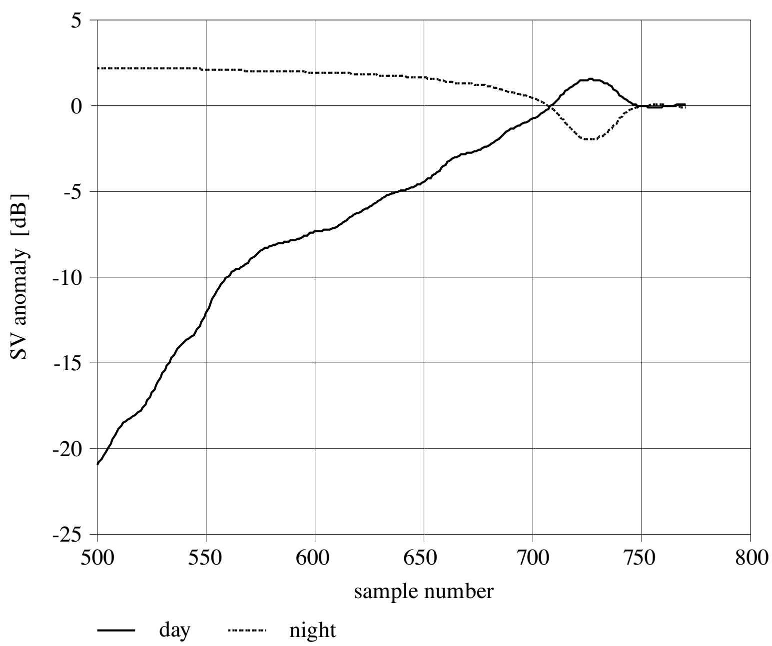

Fig. 8. Volume backscattering anomaly for the mean day and night profiles

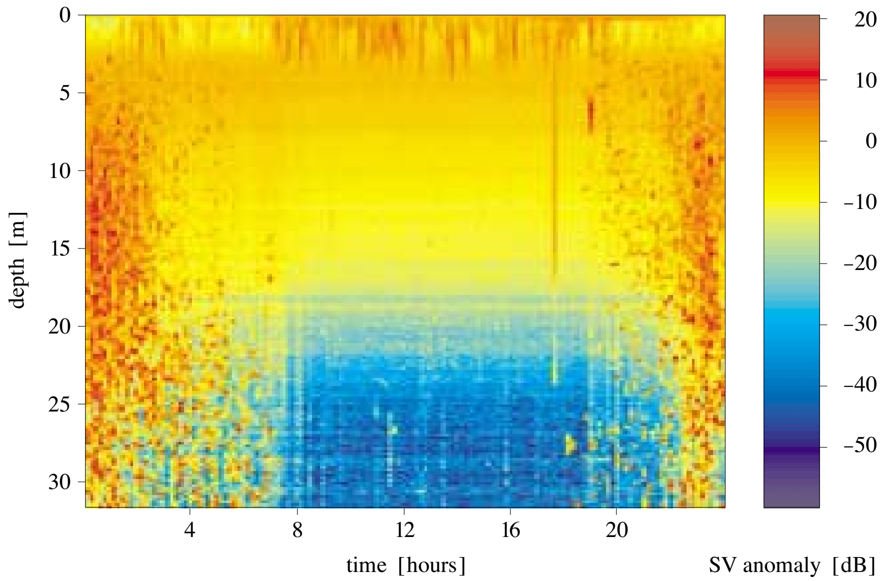

Fig. 9. Volume backscattering anomaly for the mean day profiles

Another useful characteristic of the day-night variability is the volume scattering anomaly and variance. The SV anomaly matrix

$$SV\text{anomaly}(z,\, t) = SV(z,\, t) - < SV(z) >_{\text{total}}$$

expresses temporal changes in the SV relative to the long-term mean value and is depicted for the upper 30 m in Fig. 9. The red colour describes the positive values of the volume scattering anomaly, where $SV(z,\, t)$ is greater than the mean. This involves the surface layer at a depth of 2–3 m during daylight hours and a depth interval of 3–30 m at night. The yellow, green and blue areas describe the depth and time regions where the scattering is weaker than the mean. This relates to all the day values except the thin subsurface layer. The variance of the volume backscattering strength

$$\text{var}\, SV(z,\, t) = 10 \log \left[\frac{1}{M} \sum_{m=1}^{M} [Sv(z,\, t) - < Sv >_{24\,\text{h}}]^2 \right]$$

calculated for the upper 15 m is shown in Fig. 10. Each of the 144 thin vertical bars shown in this figure represents a 1-minute averaged profile separated by 10-minute intervals. The striped structure of this image can be explained by variable wind conditions – these can change very considerably during 10-minute intervals. While the mean values reflect the features common to many days, the variance represents the day-to-day variability.

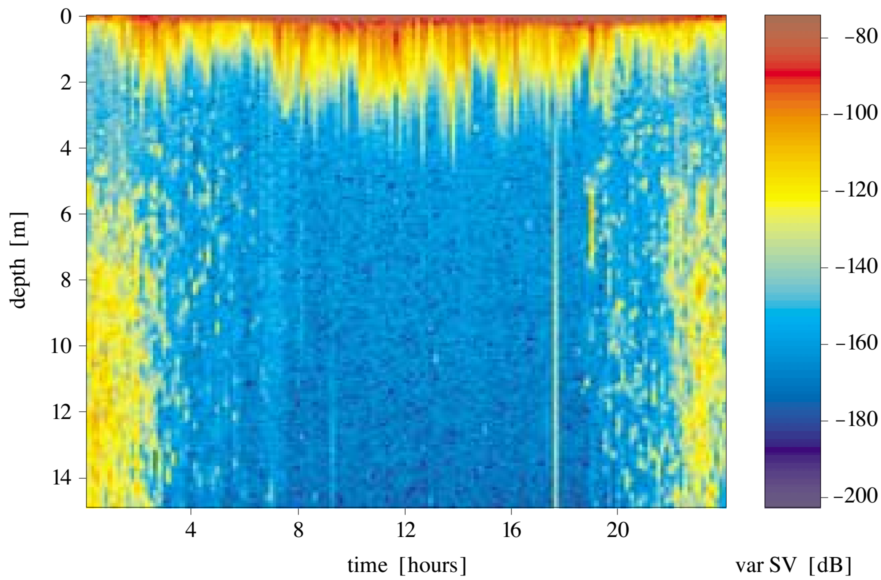

Fig. 10. Variance of volume backscattering strength

The greatest variance evidently occurs in a thin subsurface layer of up to 2 m depth. We emphasise again the correlation of this fact with the activity at the sea-atmosphere boundary.

4. Conclusions

The AHS was designed and tested for a field study in the Baltic Sea. The device has been described in detail. Acoustic data collected in the Słupsk Furrow over a four-day period has enabled us to determine the temporal characteristics of biomass distribution, to calculate the scattering anomaly, interdiurnal variance and depth variability. The mean values illustrate the features common over days, while the variance demonstrates the day-to-day variability. The concentration of scatterers changes from night to night, demonstrating a specific diurnal migration pattern. A noticeable zone of backscattering is located just below the sea surface, probably due to wind waves and wave-generated gas bubbles. No backscattering was observed below a depth of 40 m, where a very pronounced thermocline was located. For vertically migrating organisms this could well have constituted an impassable barrier.

The results were obtained by means of an Autonomous Hydroacoustic System (AHS), a device only recently designed and constructed. This instrument consumes little power, is relatively inexpensive, and is very useful for probing the subsurface sea layer, something that cannot be done with an echosounder pointing downwards from a ship. It enables the user to avoid disturbances caused by the ship and sea surface, such as gas bubbles, waves and reflections. Its use also avoids cable losses and saves ship time. The balance and stability of AHS appear to be excellent.

The AHS can be reconfigured for use in a variety of autonomous modalities, thereby allowing other types of acoustic measurements to be made easily.

Acknowledgements

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