Combined current profiling and biological echosounding results from a single ADCP

David W. Velasco
Nortek Group
Boston, USA
david.velasco@nortekgroup.com

Sven Nylund
Terje Pettersen
Nortek Group
Oslo, Norway

***Abstract*— The present work describes a newly-developed Acoustic Doppler Current Profiler (ADCP) that has a fully integrated single-beam wide-band biological echosounder, thus serving a dual purpose: current measurement and biomass assessment. The system comprises a traditional 4-beam Janus configuration head, which is responsible for profiling the currents, with a vertically oriented center beam for collecting high-resolution acoustic backscatter data for subsequent biomass analysis. The system belongs to the Signature Series family of ADCPs launched in 2013 by Norwegian scientific instrumentation company Nortek. Named Signature100, it is powered by the AD2CP electronics platform, described in United States Patent 7.911.880. The four slanted beams (current profiling beams) operate at a center frequency of 100 kHz and have a range of up to 400 m with 4 m spatial resolution and sampling rate up to 1 Hz. The center vertical beam (echosounding beam) has a wider frequency band of approximately 70-120 kHz with a high dynamic range (~130 dB), and presently operating in up to three discreet pulse characteristics from a single beam set: 1) 70 kHz monochromatic, 2) 120 kHz monochromatic, and 3) 91 kHz chirp with 50 percent bandwidth and pulse compression. Acoustic pulses from the echosounder beam are interweaved with pulses for the current profiling beam for synchronous data collection. In this work we describe the system's configuration, capabilities and results from initial trials.**

Keywords—echosounding, ADCP, currents, biomass

I. Introduction

The continual global increase in human population is prompting governments to assess protein sources with greater detail. Global demand for animal-derived protein is expected to double between now and 2050 [1], driven by increasing urbanization (especially in emerging economies), improved recognition of protein's role in a healthy diet, and increased need for protein in the elderly community. Fish stocks are one source of animal-derived protein which is receiving considerable attention due to their potentially vast contribution to addressing global protein requirements. In fact, global fish production far surpass the production of all other animal protein in the world, and fish also contain many essential micronutrients, minerals and essential amino acids [2].

Fisheries scientists use a variety of tools in understanding the structure, dynamics, function and quantity of fish stocks. Acoustic technology (in the form of biological echosounders) is widely used in quantifying fish stock biomass volumes and their behavior. Acoustic technology (in the form of ADCPs) has also been used to accurately measure currents in all of the world's major water bodies over the last 30 years.

As ADCP and echosounder data complement each other well, they are often used in the same project and deployed together. However, these two technologies have historically been developed by separate companies, with different objectives, leaving the end user to integrate the two solutions together. Nortek's approach has been to leverage its expertise in underwater acoustic technology, transducer manufacturing, electronics and firmware architecture design to combine these two tools into a single instrument. This reduces the complexity of the system, increases the ease of use to the operator (data are precisely synchronized) and drives down cost as a single instrument can do the job of two.

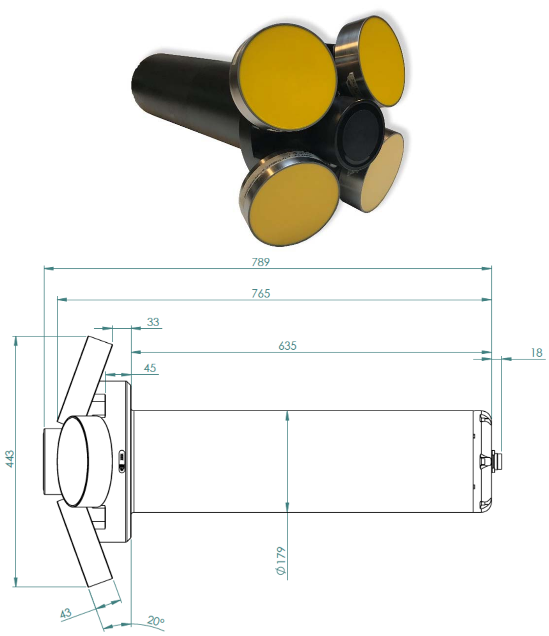

Fig. 1. Nortek's Signature100 ADCP. The four yellow transducers are responsible for measuring the currents. The center black transducer is a biological echosounder. All dimensons in mm.

II. System Description

A. Core AD2CP Functions

Powered by the AD2CP platform [3], the Signature100 (Fig. 1) belongs to Nortek's Signature Series family of Doppler profilers, which presently span operating frequencies from 1000 kHz to 55 kHz. Although some application-oriented features are unique to just some of the Signature Series systems, there are several elements common to all of them:

- Current profiling using proper Broadband processing, with frequency coding of the transmit pulse as opposed to phase coding, thus providing improved configuration flexibility.
- Concurrent Mode Technology (described under US Patent 7.911.880), allowing for different types of pings to be collected at the same time (within measurement interval).
- Support for vertical beam operation independent of velocity beams.
- Ethernet communication, allowing for high bandwidth communication and support of standard network protocols (HTTP, FTP, UDP, PTP, and Telnet).
- Automatic recording of raw magnetometer data, enabling post-deployment compass calibration.
- Large memory bank (presently up to 128 GB) for extended deployment time as well as ability to record high volume data such as multiple echograms.
- Significantly reduced power consumption, owing to modern electronics, high efficiency transducers, and intelligent firmware architecture.
- External LED indicator for visual confirmation of instrument's status.
- Support for internal high-accuracy Attitude and Heading Reference Sensor (AHRS) for real-time bin mapping in dynamically moving installations, such as surface buoys.

B. *Dual Purpose Applications*

The above characteristics come together in the two key functions of the Signature100: current profiling and biological echosounding. The current profiling (traditional ADCP) portion of the Signature100 is comprised of four slanted beams in a Janus configuration, operating at a center frequency of 100 kHz, with 6.1° beam width. These can profile currents over a range of up to 400 m with 4 m spatial resolution and sampling rate up to 1 Hz. The biological echosounder portion of the instrument is comprised of an independent center beam with a wider frequency band (70-120 kHz), a high dynamic range of approximately 130 dB, a beam angle of 15° at 70 kHz and 8.7° at 120 kHz and maximum output power of 120 W. This center beam can ping at the same rate as the velocity beams and also reach the same full range (400 m). When both current profiling and biological echosounding are used together, it is expected that the Signature100 can last one full year with standard battery power options in a typical configuration.

C. *Novel Transducer Design*

Traditional ADCP transducer stacks are generally comprised of three main parts: a piezoelectric ceramic, a matching layer at the front, and damping material on the back. These are encased in a cup-like housing. This housing acts to support the transducer stack and connect it to the ADCP body, but otherwise plays no active part in the acoustic performance of the entire assembly. The Signature100's slanted (current profiling) transducers are unique in the ADCP industry in that all mechanical parts in the transducer design, including the cup, actively contribute to its acoustic performance and efficiency. This approach allows the entire assembly to have a depth rating of at least 1500 m yet have a total thickness of only 43 mm, never before achieved on an ADCP of this frequency (100 kHz).

In addition to the novel design, the piezoelectric element used in the Signature100 slanted transducers are composite broadband ceramics, rather than solid disks often used on ADCPs. Although not unique to the Signature100 (Nortek's Signature55 also uses composite broadband ceramics), they are made by dicing standard ceramics and filling with a special epoxy resin. This process increases the final transducer's sensitivity while maintaining a wide usable bandwidth, two critical parameters in determining the system's ultimate profiling range, flexibility and power efficiency.

D. *Echogram Processing for Wideband Chirp*

The main function of the center single-beam transducer in the Signature100 is to record echograms that provide information on the structure and dynamics of marine biota. Echograms can be generated from up to three different pulse types: 1) 70 kHz monochromatic, 2) 120 kHz monochromatic, and 3) wide bandwidth (50%) linear chirp ranging from 68 kHz to 113 kHz centered at 90.9 kHz. The monochromatic pulses are processed internally using standard algorithms, but the chirp can be processed in one of two ways: using pulse compression or using a binned frequency response. The pulse compression technique is widely used in echosounder applications and it allows for increased range resolution as well as improved Signal-to-Noise Ratio (SNR). The resolution after pulse compression is 1.65 cm, and the internal processing can average this into a minimum bin size of 37.5 cm. In the binned frequency response method, the return is processed into five separate echograms each containing approximately one fifth of the total bandwidth.

In this work, the Signature100's echosounder beam was not calibrated for absolute backscatter. However, Nortek is developing a process to allow operators to perform this calibration such that accurate Volume Backscatter Strength (S_v) and Target Strength (TS) can be computed. As such, all backscatter data presented here is relative to the instrument itself and reported as SNR in decibels (dB).

E. *Raw Return Signal Storage*

In order to expand the system's flexibility, the Signature100 is able to store the complex demodulated return signal. The system allows storage of the in-phase (I) and quadrature-phase (Q) components of the return signal at 45.45 kHz (50% of the center frequency). Additionally, the system can also store the transmit pulse for a complete data set. Despite the system having a large memory bank, recording of raw demodulated signal can surpass the memory's limits, so a configurable recording scheme is implemented. The operator can specify the spacing between the pings or their interval (e.g. store every Nth ping, or all pings for N minutes every hour). The ability to store the raw return signal allows the operator to post-process the data using whatever technique is most suitable for their particular application, as well as perform post-processing calculations for TS and S_v.

III. Field Validation

Field trials have been done as part of the Signature100's development, and here we highlight one such deployment carried out in the Mediterranean Sea. The location was just south of Toulon, France, and the deployment lasted from the morning of 10/Nov/2017 until the afternoon of 15/Nov/2017. Water depth at the site was about 470 m and the instrument was mounted up-looking on a subsurface buoy at the top of a short mooring. Raw heading data from the Signature100 (not shown) indicates the buoy observed a strong spin moment on its 7 minute descent, rotating at about 3-4 revolutions per minute, which is not unreasonable during such deployments. For fixed installations (not this case), this spinning can be a source of raw magnetometer data allowing for compass calibration in post-processing. After about 3 hours on the bottom, the buoy stabilized and subsequent data shows the mooring was very stable throughout the rest of the deployment, with only a gentle rotation (less than one revolution every few hours) and a very minor variation in tilt (less than 1°).

A. Current Data

The ADCP portion of the instrument was configured to transmit 60 pings at 0.25 Hz, repeating the sequence every 5 minutes, with single ping data being recorded for quality control purposes. Current profiling was set for 60 depth cells of 10 m each (15 ms pulse) with a blanking distance of 1 m. Variable particle distribution in the water column caused the maximum usable range to oscillate from about 230 m to 420 m (beyond the instrument's specifications), especially during the first half of the deployment, as evidenced by the SNR data of the four slanted beams shown in Fig. 2. As expected, times of reduced SNR coincide with lower along-beam signal correlation values, indicating limit of usable data which is taken at 50% correlation. But despite the variations in particle distribution, over 68% of the data is above this 50% correlation threshold.

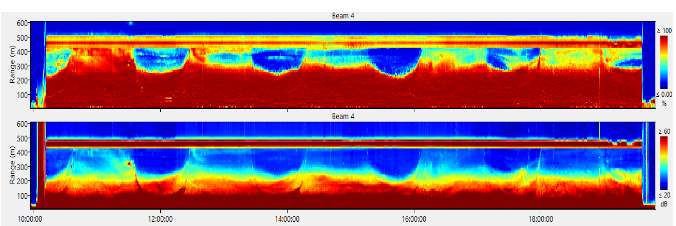

Fig. 2. Signal correlation (top) and SNR (bottom) from the slanted beams for the duration of the deployment.

A mid-depth current maxima is observed early in the deployment, although most of the fastest currents appear to be confined to the top of the water column (Fig. 3). Unfortunately these are not well captured some parts of the deployment due to limited quantity of scattering particles from about 300 m above the instrument, but can be seen during other times when increased particle distribution drives longer profiling ranges.

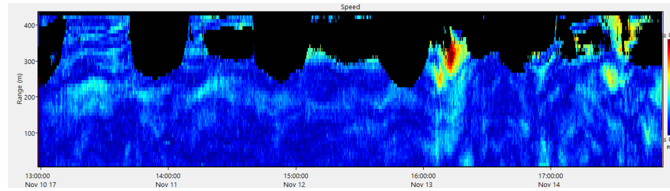

Fig. 3. Current speed for duration of deployment.

B. Echosounder Data

The echosounder portion of the Signature100 was configured to transmit all three pulse types supported, although only the 70 kHz monochromatic is presented here. Each pulse had a 1 ms transmit duration and were transmitted at 1 Hz. The echosounder pulses interweaved with the current profiling pulses at a ratio of 3:1 (i.e. every three echosounder pings to one current profiling ping). The echosounder pulses' return was recorded in 0.75 m depth cells.

From the echosounder data (Fig. 4) it is possible to identify schools of fish, swarms of smaller organisms (krill and/or zooplankton) and even individual fish. Although the present lack of a calibrated return signal prevents calculation of Sv, insights about the distribution, structure and presence/absence of biota over time and depth can be drawn from this deployment. Additionally, echograms coupled with interweaved current profiles into a single system provide valuable information on the behavior marine life.

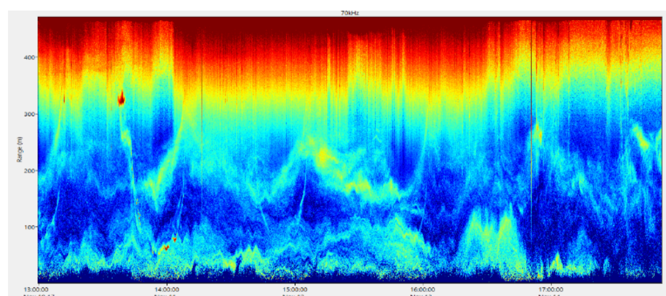

Fig. 4. Echogram from 70 kHz monochromatic pulse for duration of deployment. Scale is relative to instrument (not S_v) in dB. Closer details are provided in subsequent figures.

Four different features were selected from the echogram for presentation: plankton/krill diel migration, internal wave structures, passing surface vessels, and migration due to changes in current regime. The first type of feature is shown on Fig. 5. Although no trawling was conducted during the deployment to ground-truth the nature of the scatterers, it is reasonable to assume the features shown represent either plankton or krill (or both) migration, as the same patterns are widely observed in similar data [4]. The diel nature of the movement drives measurable vertical currents of approximately 5 cm/s upward during dusk hours, with the reverse pattern at dawn.

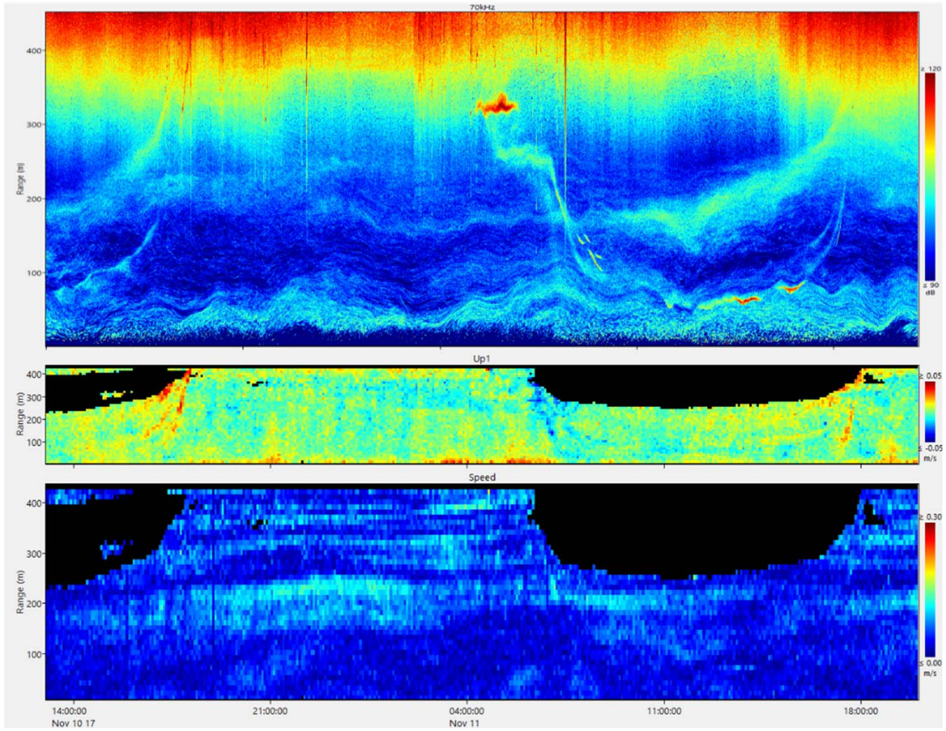

Fig. 5. 70 kHz Echogram (top), vertical velocity (middle), and horizontal current speed (bottom) for the first two days of the deployment.

Another interesting feature identifiable in the echograms are internal oscillations at varying depths and lasting up to a few hours. The echogram on Fig. 6 clearly shows their presence, distribution and duration. Internal waves are a common feature in the Mediterranean Sea, being described as earlier as the 1960s [5]. They are generated by the interaction of the mostly semidiurnal tidal flow with the variable bottom bathymetry and especially through narrow passages such as the Straits of Gibraltar and others. For the sample shown, it is estimated that some of these reach 10-15 m in height with periods of approximately 90 minutes. Although the spatial resolution of the current data (10 m depth cells) does not allow for as clear identification of these oscillations as the echogram does, nevertheless we can approximate a downward and upward velocity of about 1 cm/s with the passage of this particular event.

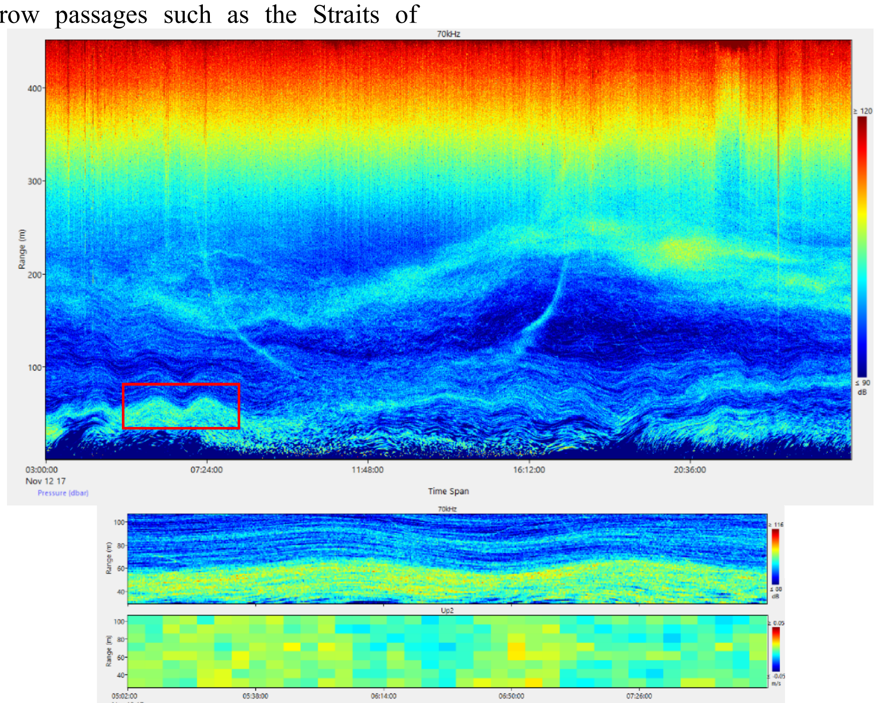

Fig. 6. Internal oscillations observed 70 kHz echogram on 12/NOV/2017 (top). Inset is a particular structure showing the echogram (middle) and the vertical velocity (bottom).

Following the terminology of [5], undesirable echogram features (noise) can be divided into three main categories: Impulsive Noise (IN), Transient Noise (TN), and Background Noise (BN). IN occurs over less than one acoustic ping and can often be traced to interference from a nearby acoustic source of same or similar frequency. TN can last several pings and have variable sources, such as ships passing near the echosounder (for fixed systems) or waves colliding with the vessel's hull (for vessel-mounted systems). BN lasts for hours or longer and may be traced to any continuously generated signal of same or similar frequency, such as an underwater turbine. Fig. 7 shows both IN and TN from what we interpret as a passing surface vessel. The TN reaches almost the entire profiling range of the instrument, with increasing attenuation with depth, an inverted arch pattern typical of a single strong reflector, followed by increase near-surface noise in the vessel's wake. The echogram also suggests the vessel had an active acoustic source onboard, as IN features are clearly visible in the leading and trailing edges of the main signal.

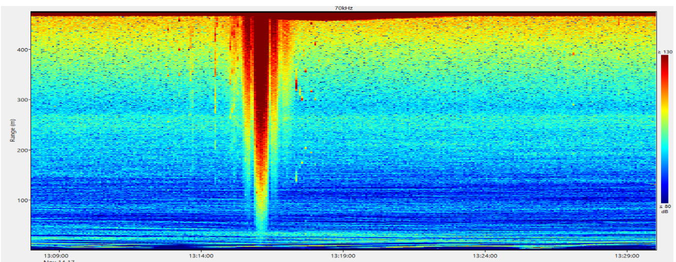

Fig. 7. Signal correlation (top) and SNR (bottom) from the slanted beams for the duration of the deployment.

The echogram data also captures a change in the near-bottom activity, which is correlated with a change in current direction near the bottom (Fig. 8). Starting around midday on 14 November, and lasting through the end of the deployment, the echosounder returned signal strength first increased within the bottom 100 m of the water column, and then it diminishes noticeably. Overall currents speeds around this time indicate negligible change (not shown). Although the data is inconclusive as to the reason for this reduction, the correlation with the relatively sudden change in current direction may be a driver. For the 30 hours preceding this change, the mean current direction at 50 m above the instrument was holding relatively steady towards the SSE, but then changed (over the course of less than 3 hours) to flow primarily to the NNW, following some further variations over the subsequent 24 hours. This means that currents that were flowing mainly from the continent switched to flow mainly from the open Mediterranean Sea. It is therefore speculated that this change impacted the local biota, shifting its location towards the continent, away from the instrument.

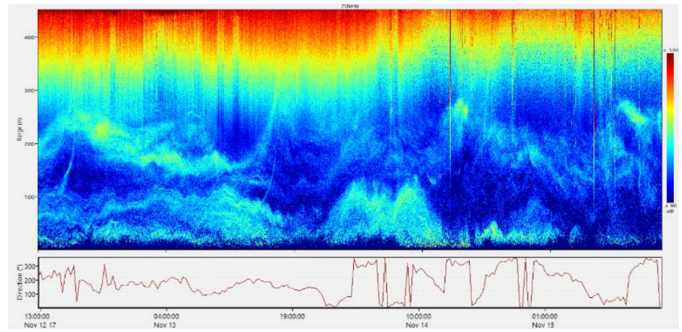

Fig. 8. 70 kHz echogram for second half of deployment (top) and current direction at 100 m above the instrument (bottom).

IV. Conclusions

A newly-developed Acoustic Doppler Current Profiler (ADCP) with a fully integrated single-beam wide-band biological echosounder has been developed and presented. The system belongs to the Signature Series family of ADCPs launched in 2013 by Norwegian scientific instrumentation company Nortek and is powered by the AD2CP electronics platform (US Patent 7.911.880). Named Signature100, it performs two key functions simultaneously over a maximum nominal range of 400 m: current profiling and biological echosounding. Some of its key features include a novel transducer design, three distinct echosounder pulse types, data processing with pulse compression, and the capability of recording the complex demodulated return signal. Details from a field validation deployment in the Mediterranean Sea were presented, with a focus on the 70 kHz echogram created by the instrument. Four main features of the echograms were discussed: plankton/krill diel migration, internal wave structures, passing surface vessels, and migration due to changes in current regime. The current profiling data complemented the echosounder data, providing greater insights into the distribution, structure and behavior of the marine life at the test site during the deployment.

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