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1.0 Introduction

Up until 1996, acoustic Doppler technology was primarily used in current profilers. For single-point current meters, other technologies such as propellers, electromagnetic sensor, and acoustic travel time were used. A significant reason was price – all current profilers at the time cost more than US$20,000 – but there were also technological challenges that had not been solved. More specifically, the deep ocean with its low acoustic scattering strength has posed a real challenge for manufacturers and required improvements in transducer design, transmit/receive design and in overall power consumption.

Over the last few years, the technological situation has changed quite radically. The majority of all single-point current meter sold in 2002 used Doppler technology and many large oceanographic institutions now face the transition between older (but proven) technologies and the new families of Doppler current meters. Given the length of the average ocean deployment (typically 0.5–3 years), the choice of the next generation current meters is neither simple nor trivial.

This report describes some of the work Nortek has done to ensure quality results with the "Aquadopp" current meter in the deep ocean. We also show results from tests in the Mediterranean and in the clear waters of the Sargasso Sea near Bermuda.

2.0 The signal strength

Doppler current meters rely on acoustic backscattering to operate (Fig. 1). When an acoustic pulse is transmitted, a small fraction of the energy comes back to the instrument. This signal is processed for Doppler shift and the water velocity is calculated. The method is now standard, and various

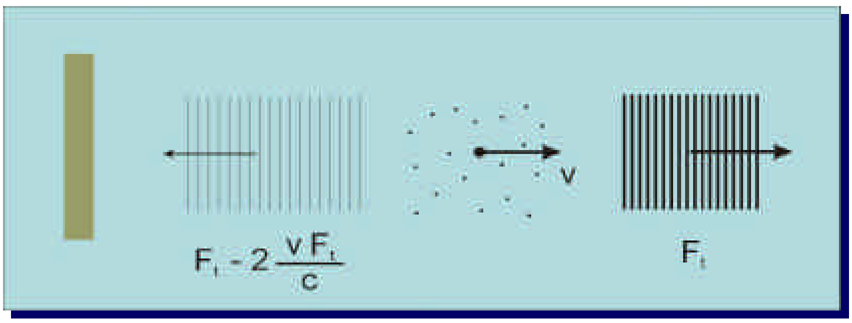

Fig. 1 – Acoustic backscattering

implementations have been around for at least 20 years. The amount of energy that comes back from the water depends on the number of particles (usually biological material) that are suspended in the water column. Very clean water means few particles and weak signal. If the signal is too weak, the velocity estimate will no longer be correct and the current meters measure the wrong velocity.

It has long been known that the amounted of suspended matter is very low in the interior of the ocean. As a result, the expected echo is very weak. In this sense, deep water Doppler current meters represent one of the 'last frontiers' for the use of Doppler technology to measure velocity.

2.1 Transmit power

The first and most obvious path to overcome weak acoustic echo is to increase the transmit power. However, this is not a viable path since this modification directly increases the power consumption. For long term deployment, this can potentially make the instrument impractical. As the 6000-m Aquadopp evolved, we still increased the transmit power by 3 dB (doubling the power) since having enough signal is so critical for getting error free data. If warranted by later improvement, the power level can be reduced to increase the deployment time per battery unit.

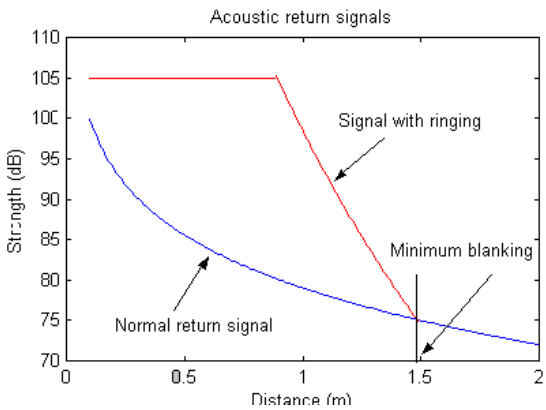

Fig. 2 – When the return the signal is weak, the acoustic ringing dominates the measured signal for some time after transmit. To avoid getting bad data, the ringing must be allowed to die out before sampling can start. Since the echo from the water gets weaker with time, the net effect of ringing is to reduce the sensitivity of the Doppler current meter. Ringing is specific instruments where the underwater housing is made from metal

2.2 Acoustic ringing

When designing a deep-water acoustic system, one of the challenges to overcome is the problem of acoustic 'ringing'. The ringing is an effect whereby some fraction of the transmit energy propagates around in the underwater housing and disturbs the echo coming back from the water. The effect of ringing is insidious and it has two aspects: It forces the user to increase the time before the return signal strength can be measured (see Fig. 2) and it acts as a narrow band noise source. The first issue reduces the effective signal strength quite significantly and the second issue can give rise to errors in the velocity – errors that on first sight appears to be correct when in fact they are not. This is in contrast to the classical effect of low signal strength, which is a velocity measurement that is biased low. The combination of the two can get quite confusing, as referenced in early tests conducted by WHOI within the Ultramoor program, where data in an early version of the 6000-m Aquadopp showed clear signs of interference from ringing.

Fig. 3— The 6000-m Aquadopp transducer head. The three "eyes" are the acoustic transducers. The white portion is the transducer housing, which is made from a plastic material. All metal parts are made from Titanium gr. 2

In the case of the Nortek 6000-m Aquadopp, we used plastic materials to isolate the transducers from the titanium housing. This stops the energy from propagating back into the housing and removes the potential interference with the weak echo scattered back to the instrument. The net effect of this improvement is to increase the SNR (the Signal-to-Noise Ratio) by 10 dB, which is the same as saying that the particle concentration can be 10% of what it would have to be if the acoustic ringing had not been eliminated.

2.3 Ocean scattering

For the purpose of looking at acoustic scattering, data shows that the water column in the open ocean can effectively be divided into four zones:

- **The upper 100 m.** Light penetrates and this zone is characterized by high biological activity. The acoustic scattering is strong and getting adequate SNR is not an issue. In this zone, Aquadopps can be operated with reduced transmit power to save power.
- **The bottom 100 m**. Fine sediments are lifted into suspension by turbulence generated as the water flows over the bottom. In this zone, the SNR is adequate and a profiling instrument has a useful range. In terms of instrument design, this is an “easy” part of the water column, even if the bottom is located 6000 m below the surface. Even early versions of the 6000-m Aquadopp (which had some ringing) worked well in this zone.
- **From the surface to 1000 m.** In this zone, there is a gradual decrease in the SNR as you move downwards. There is still biological activity and the SNR is generally adequate. There is a chance that the SNR may change with the seasons, so we generally recommend that Aquadopps deployed in this zone are configured for maximum output power.
- **From 1000 m below the surface to 100 m above the bottom.** This is the most challenging area, characterized by minimal biological activity and very weak acoustic scattering. The fine tuning and extra work that has been done to the 6000-m Aquadopp design is motivated by a desire to make the instrument work in this zone. The Aquadopp should always be configured for maximum power output when deployed in this part of the water column.

2.4 Test results

The Aquadopp records the strength of the acoustic echo in the form of a “count” unit that is proportional to the logarithm of the return signal. To arrive at a number that is relevant to the quality of the velocity data, we first subtract the electronic noise level and then scale the data to units of dB. We then arrive at an “SNR” value (Signal-to-Noise Ratio) that can be used to predict the quality of the velocity data. For standard deployments, the noise level is recorded in the “diagnostic data”, which always starts out by collecting a velocity sample with no transmit pulse, effectively recording the electronic noise level. Alternatively, the signal level in air can be used as a first estimate. The SNR of the Aquadopp is defined as:

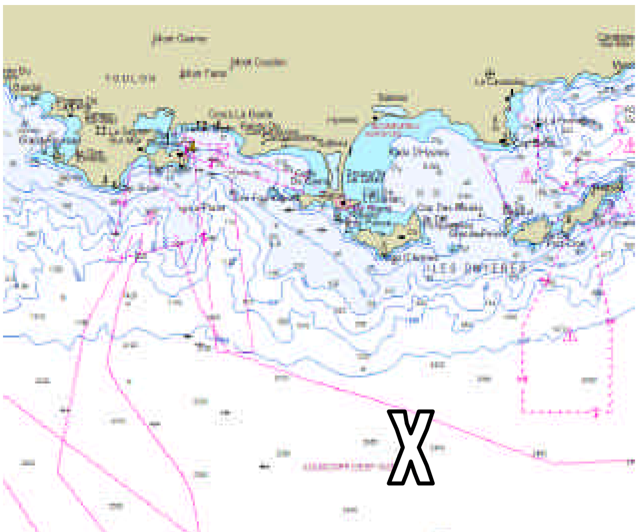

Fig. 4 — Test site for Aquadopp lowered to 2500 m south of Toulon on the Cote d'Azur. The tests were carried out by Thetis SA.

$$SNR = (Amplitude\ (recorded) - Noise) \times k$$

The parameter *k* is a scale factor that varies between 0.40 and 0.45

At low SNR, two things happen: The intrinsic noise in the velocity data increases and an error is introduced in the velocity data. The exact nature of the error depends on the implementation of the Doppler velocity and the Aquadopp can underestimate the velocity when the SNR becomes too low (SNR < 1–2 dB).

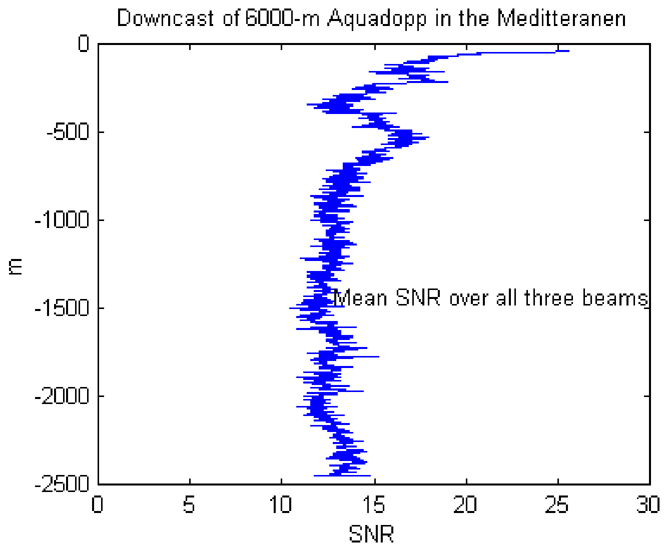

Fig. 5 – SNR data collected from the surface to the bottom in 2500 water depth in the Mediterranean.

In Fig. 5, the average signal strength (SNR) over the three beams is shown for an Aquadopp that was lowered from the surface to a depth of 2500 m in the Mediterranean off the coast of France (see map in

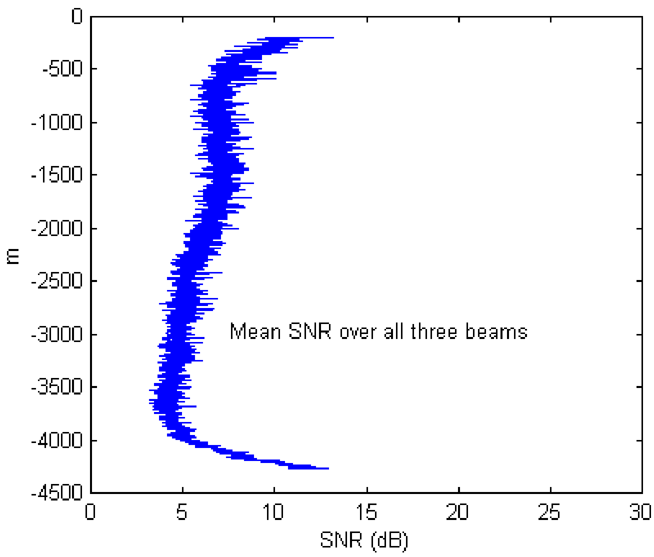

Fig. 6 – SNR data collected from the surface to the bottom in 4500 m of water in the Sargasso Sea. Data collected during transect from Woods Hole to Bermuda.

Fig. 4). The test was conducted in September 2002 and the instrument was lowered with a speed of 2.5m/s. The results show that the signal strength never goes below 10dB. This means that the Mediterranean, despite its apparent clarity on the surface, actually is biologically productive throughout the water column and provides more than enough scattering scattering for the Aquadopp to function properly. The peak in SNR around 500m is well know from acoustic scattering studies and is caused by an abundance of migrating zooplankton. There is no peak in the scattering near the bottom, which would be typical for a bottom where there is no fine sediment or where the currents are too weak to put the sediments into suspension. It is also possible that the scattering from biological material is so high that it masks the scattering from sediments suspended near the bottom. In any case, the SNR is more than adequate and the Aquadopp would provide good quality data throughout the water column.

Fig. 6 shows the average SNR for a 6000-m Aquadopp that was attached to a CTD and dropped 4500m from the surface to the bottom in the Sargasso Sea near Bermuda. This part of the world ocean is well known for low biological productivity and the minimum SNR recorded during the downcast is as low as 3dB. This is almost 10dB lower than in the Mediterranean, which means that the difference in the concentration of suspended biological and inorganic material is different by a factor of 10. As the instrument moves toward the bottom, we see a steady decrease in the acoustic echo until it increases in the bottom 100–200m. From a practical point of view it is important to note that the concentration is still low compared to coastal environments. For example, a 2MHz current profiler would only have a useful range of about 2m near the bottom. This compares with a typical profiling range of 5-6m in coastal waters.

3. 0 Velocity

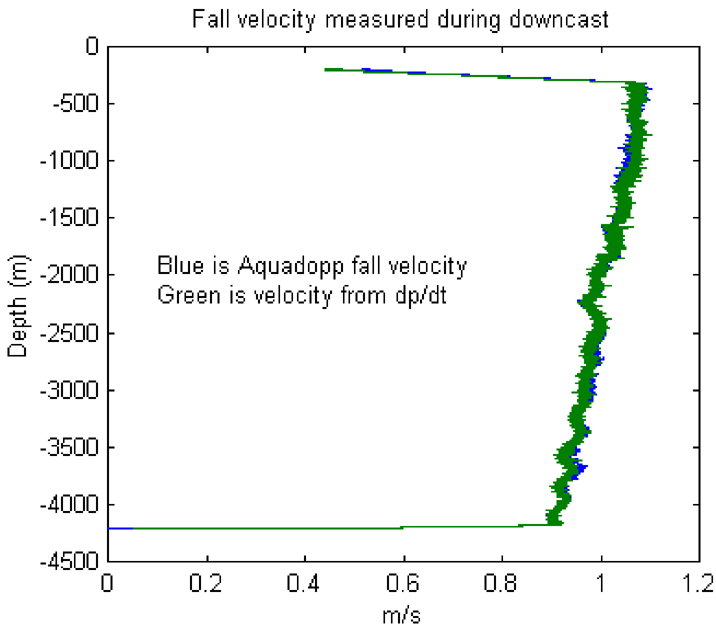

Figure 7 – Vertical velocity measured by the Aquadopp and calculated from the differentiated pressure data during the downcast

In the Sargasso test, the Aquadopp collected data (all types, including velocity, signal echo, pressure, heading, pitch, roll, and pressure) at a rate of 1Hz during the almost 1.5 hour drop from the surface to the bottom. The instrument was mounted horizontally and all beams were pointing downwards. Velocity data were collected in beam coordinates. By using the known transducer geometry, it is straightforward to calculate the fall velocity. Using data from beam 1 and 2, the fall velocity[1] is plotted using blue color in Fig. 7. A 100-second filter has been applied to remove instrument noise and the strong oscillations caused by the ship's heaving motion. The green line (mostly covering the blue line) is the differentiated Aquadopp pressure data after applying 1–2% correction for the difference between the final pressure at the bottom and the depth reported by the CTD. As can be seen, the two velocity curves fall on top of each other and a linear regression shows that the velocities are the same within 1%. In addition to being a good indicator for excellent performance of the Aquadopp in deep water, the data also shows

[1] The CTD frame was swinging back and forth during the downcast. The tilt of the frame can be measured by calculating the ratio of the velocity in beam 1 and 2. The resulting correction factor was included in the plot (maximum 1–2% of the velocity).

that there is no appreciable error in the velocity data for SNR > 3dB. This is an important result and has relevancy also for the interpretation of result collected with Aquadopp profilers.

4. 0 Conclusions

We conclude from the tests that the 6000-m Aquadopp current meter in the present configuration will provide high-quality current data also in the deep ocean. The present 2500-m test in the Mediterranean and 4500-m test in the Sargasso Sea complements previous results from a 2000-m test off the coast of Ireland and 700-m tests in the Norwegian Sea: In all cases, the SNR is high enough to produce error-free velocity data. There is one caveat - we have no data from deep-water deployments in the Arctic, which is well known for exceedingly clear surface waters.

In addition, we conclude that any velocity data collected with SNR > 3 dB can be assumed to be error free. Data for SNR lower than 3dB are not available so it is not possible to say if this really constitutes a minimum SNR level for error free data.

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