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SAS AND SIDE SCAN SONAR SYSTEMS COMPARED: EXPERIMENTAL RESULTS FROM HUGIN AUVS

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Abstract: *The Norwegian Defence Research Establishment (FFI) and Kongsberg Maritime has an ongoing programme to develop the HUGIN autonomous underwater vehicle (AUV) for civilian and military applications. As part of this development, several different side scan sonar (SSS) and synthetic aperture sonar (SAS) systems have been integrated on different HUGIN vehicles, and experimental experience has been gained for these systems.*

This paper lists the main advantages and disadvantages of SSS and SAS; in view of critical parameters such as resolution, range, signal to noise ratio, sonar complexity and platform requirements. Data from at-sea operations from some of the systems on-board HUGIN AUVs are compared.

One of the primary applications of AUVs is detection and classification of mine-like objects. The article briefly discusses the merits of SSS and SAS systems in this context.

Systems fielded on HUGIN AUVs include the EdgeTech 2200-M dual-frequency side scan sonar, the EdgeTech 4300-MPX multi-pulse side scan sonar, the EdgeTech 4400-SAS, and the Kongsberg HISAS 1030 prototype. This selection of systems is fairly representative, in that it includes both relatively modest and relatively advanced examples of both SSS and SAS systems available on the market today.

Keywords: *Side scan sonar, synthetic aperture sonar*

1. INTRODUCTION

Autonomous underwater vehicles (AUVs) are today in operational use for military, commercial and research applications. In many cases, a side scan or synthetic aperture sonar is the main sensor.

As part of FFI’s AUV programme, a variety of SSS and SAS systems have been fielded on HUGIN AUVs. Until now, the two main applications for such sensors have been seafloor imaging for the offshore oil and gas survey industry, and detection and classification of mine-like objects for Navy users [1][2]. The required resolution and area coverage rate differs between these customers – even high-end sonars for civilian purposes can be marginal or unusable for mine classification.

As of today, 25 HUGIN vehicles have been sold to military and civilian customers in Europe, Asia and America. Combined, the HUGIN AUVs have covered a distance exceeding 120,000 km – three times around Earth at the equator. As all these vehicles are equipped with SSS or SAS systems, this has provided the HUGIN developers with extensive amounts of operational experience with such systems.

Fig.1: Left: The HUGIN I test and development AUV with the Kongsberg HISAS prototype. Middle: A HUGIN 1000 AUV with an EdgeTech 4400-SAS. Right: A HUGIN 3000 AUV with an EdgeTech dual-frequency SSS.

2. MAIN CHARACTERISTICS OF SSS AND SAS SYSTEMS

2.1. System design and complexity

The side scan sonar is traditionally a very simple sensor; basically a single-element antenna perhaps 20-200 cm long which is used for transmission as well as reception. Only very rudimentary signal processing is required for a simple SSS.

SAS, on the other hand, is by nature a much more advanced sensor. All practical SAS systems feature a multi-element receiver [3], and there are good reasons for having a separate transmitter and also a secondary receiver array for interferometry [4]. The signal processing is highly complex and computationally expensive [5]. Additionally, most SAS systems rely on tight integration with a high-grade aided inertial navigation system. It is only in very recent years that SAS has become technically and commercially viable for routine production use. The first commercial AUV-based SAS was the EdgeTech 4400-SAS delivered to the Royal Norwegian Navy (RNoN) in January 2004, as part of the HUGIN 1000 AUV [2].

2.2. Resolution, sampling and range

For side scan sonars, the along-track resolution, along-track sampling and range are closely coupled. For SAS, these three parameters are independent and can be selected freely (limited by cost and complexity). Table 1 lists (simplified) main parameters of the two classes of systems (from [6]). Typically, the maximum range of a SSS system is chosen based on the required along-track resolution, the required ping distance, and the transmit frequency (higher frequencies have stronger attenuation and thus limit the maximum achievable range).

Parameter	SSS	SAS
Cross-track (range) resolution	$\delta r = \frac{c}{2B}$	
Along-track (azimuth) resolution	$\delta x \approx \max(D, \frac{\lambda r}{D})$	$\delta x \approx \frac{3}{4} d$
Sampling distance	$\Delta x = \frac{2Rv}{c}$	Any (typically, $\Delta x \approx \delta x$)
Maximum slant range	$R \leq \frac{\lambda}{D} \delta x_{req}, R \leq \frac{c}{2v} \Delta x_{req}$	$R = \frac{cD}{4\alpha v}$

Table 1: Performance parameters for SSS and SAS. c is the speed of sound, B is transmit bandwidth, D is the length of the sonar (for SAS: the receiver), d is the length of each receiver element, λ the transmit wavelength, v is platform speed, and α is a SAS overlap factor (slightly) greater than 1.

It is worth noting that some of the SSS limitations may be mitigated by advanced techniques such as dynamic focusing, use of multiple pings in the water simultaneously, or formation of multiple beams from the received data. High-end SSS systems such as the Klein 5000, the EdgeTech 4300-MPX or the EdgeTech 4500-DF use techniques like these (at the cost of substantially increased system complexity). One limitation that cannot be overcome is that along-track resolution deteriorates with range in the far field – while the SAS along-track resolution is constant at all ranges (provided the SAS system is functioning properly). Fig. 2 shows an example of this.

As can be seen, none of the SAS parameters depend on transmit frequency – provided the chosen frequency has sufficiently low attenuation to allow reception from maximum range. However, given a receiver length *D* and element size *d*, the choice of frequency has other consequences:

- A higher frequency requires a shorter synthetic aperture. This in turn means that shadows will be more clearly defined for a higher-frequency SAS.
- On the other hand, a lower-frequency SAS system will allow multi-aspect imaging [7][8].
- Backscatter from the seafloor and objects is frequency dependent. Some materials become acoustically transparent at low frequencies.
- The lower the frequency, the higher the signal to noise ratio at long ranges.

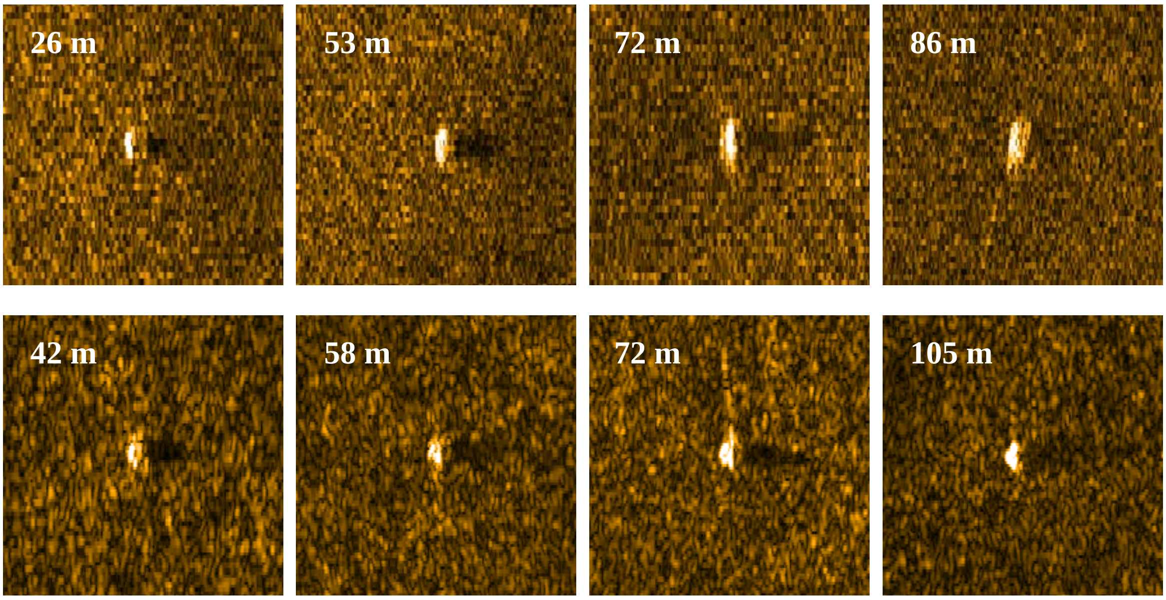

Fig.2: SSS and SAS data at different ranges. 10x10 m contact images around a frustum with base diameter 1 m. AUV altitude 12-13 m. Top: EdgeTech 4300-MPX SSS images. The theoretical along-track resolution changes from 35 cm to 50 cm. Bottom: EdgeTech 4400-SAS images. The theoretical along-track resolution is 15 cm at all ranges.

3. DATA EXAMPLES

Table 2 lists some of the main characteristics of three sensors used on HUGIN vehicles. Note that many of the parameters listed are only typical values. For the MPX sonar, the range resolution depends on the number of pulses used (the frequency band can be divided into 2, 3 or 4 to allow multiple pulses in the water).

Parameter	EdgeTech 4300-MPX	EdgeTech 4400-SAS	Kongsberg HISAS prototype
Centre frequency	410 kHz	120 kHz	100 kHz
Range resolution	2-5 cm	7 cm	3 cm
Along-track resolution	35-55 cm	14 cm	3 cm
Range	100 m	165 m @ 4 kts	200 m @ 4 kts

Table 2: Main characteristics of three sonars.

Fig. 3 shows imagery taken under similar conditions with the EdgeTech 4300-MPX SSS and the EdgeTech 4400-SAS. The 4300 is a (relatively) high-end SSS, whereas the 4400 is decidedly a low-end SAS. The along-track resolution of the SAS is thus “only” about 3 times higher than the resolution of the SSS, and the range resolution somewhat lower.

The images confirm that there is clearly a difference in resolution in favour of the EdgeTech SAS. Details such as the cable near the lower edge of the top images are much more blurred in the SSS images; the same is the case for the small rocks scattered around the images.

However, the SAS images contain a substantial amount of speckle. The speckle size is similar to the sonar resolution – about 10-20 cm. As a consequence, it may be more difficult to interpret the seafloor from the SAS images – the rocks do not stand out from the background as clearly as in the SSS images.

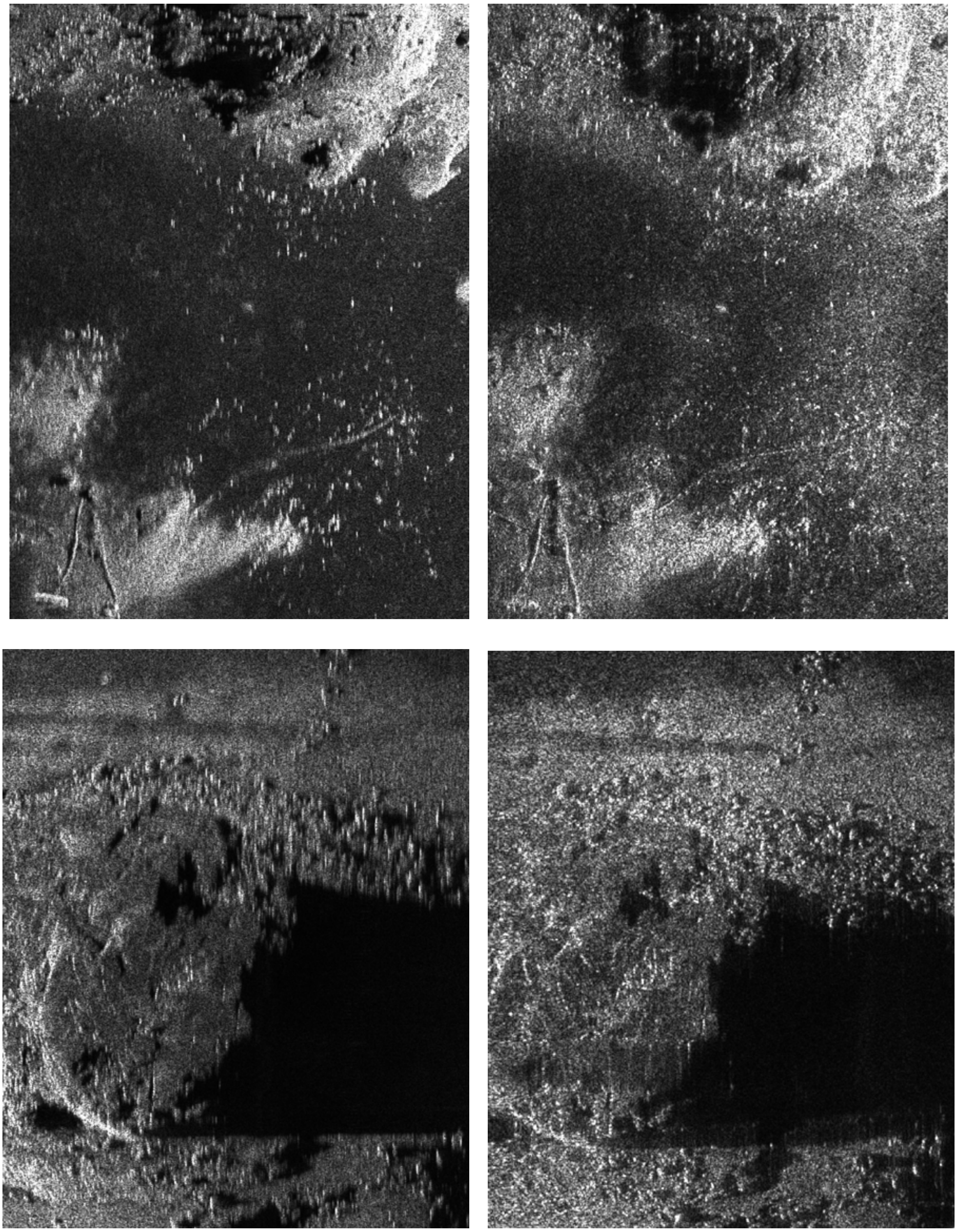

Fig.3: EdgeTech 4300-MPX SSS (left) and 4400-SAS (right) images of two areas near Bergen, Norway. Top: 20-80 m range, 80 m along-track (port side). Bottom: 25-75 m range, 60 m along-track (starboard side).

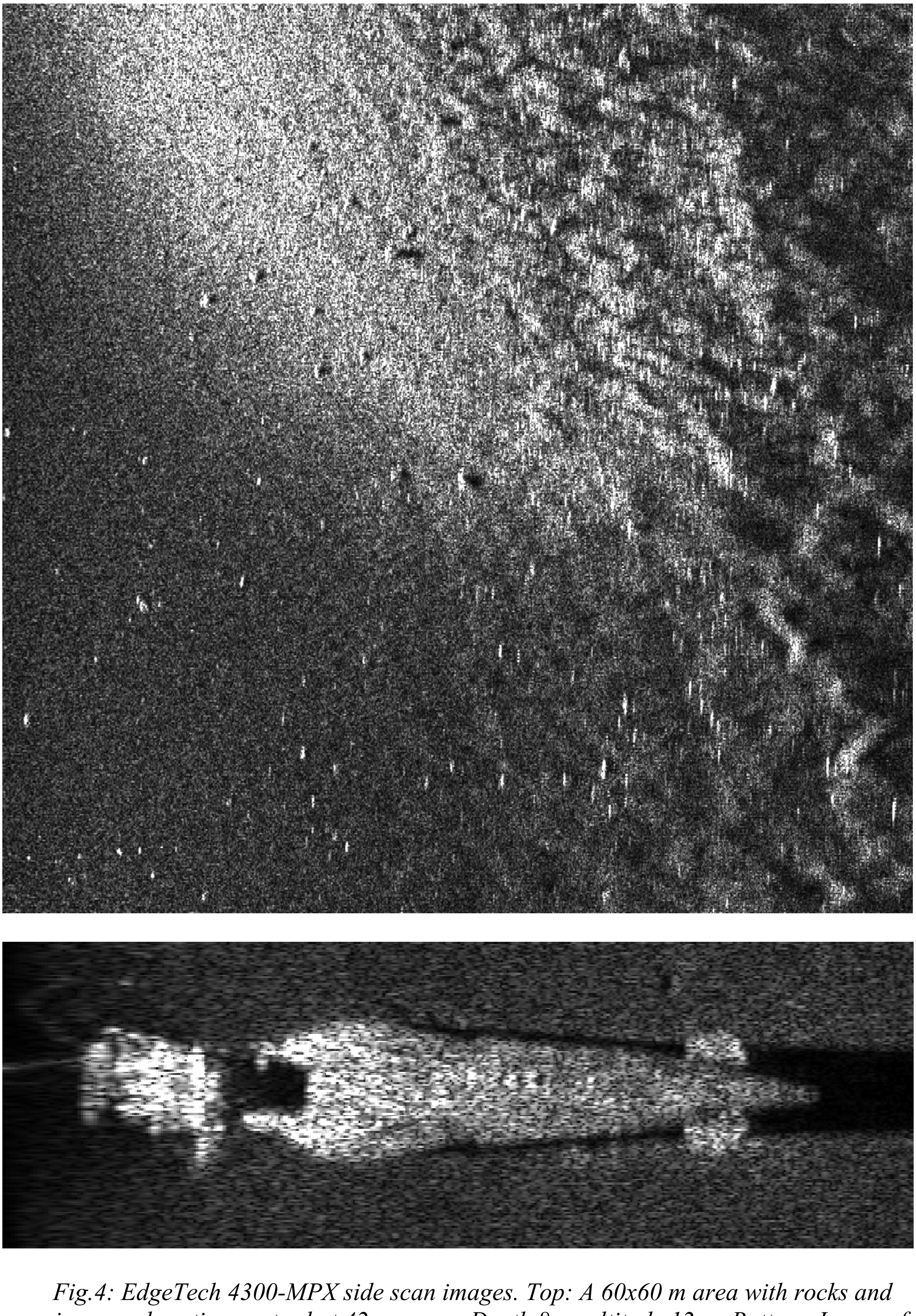

Fig.4: EdgeTech 4300-MPX side scan images. Top: A 60x60 m area with rocks and varying reverberation centred at 42 m range. Depth 8 m, altitude 12 m. Bottom: Image of the sunken submarine U-735 centred at 25 m range. Depth 175 m, altitude 20 m.

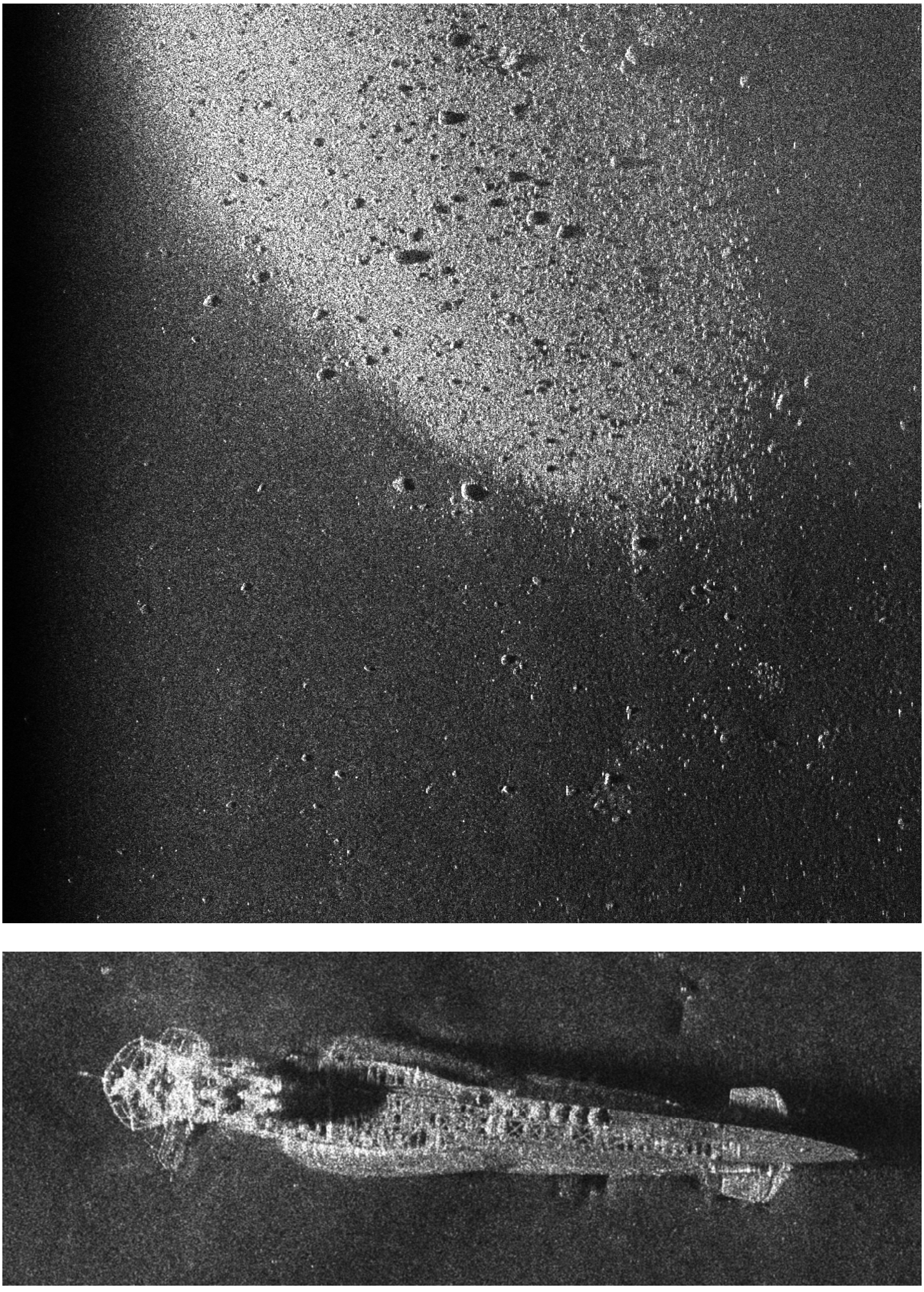

Fig.5: Kongsberg HISAS prototype images of the same areas as in Fig.4. Top: A 60x60 m area centred at 38 m range. Depth 10 m, altitude 10 m. Bottom: U-735 centred at 65 m range. Depth 175 m, altitude 20 m.

Fig. 4 shows imagery taken with the EdgeTech 4300-MPX; Fig. 5 shows the same areas imaged with the Kongsberg HISAS prototype (also known as SENSOTEK SAS [8][9]). HISAS is a high grade SAS with more than 10 times higher along-track resolution than the MPX. As can be expected, the image quality is substantially better. Because of the high resolution, the speckle is much more fine-grained and does not detract from the interpretation of the scene.

The wavy pattern at far range with the SSS is caused by direct surface returns. HISAS uses a shaped transmit beam to reduce acoustic multipath. Some multipath can still be seen in the top image, which is a particularly tough case: An area with strong reverberation at close range, followed by an area with much weaker seafloor returns.

The difference between the two submarine images is dramatic. Notice also that the SAS image is taken at significantly longer range – 65 m vs 25 m.

4. CONCLUDING REMARKS

This article has focused on direct comparisons between a good SSS and two different SAS systems. In addition to the superiority of high-resolution SAS in these comparisons, it is important to remember that a system such as HISAS 1030 has a number of additional advantages – much longer range, and the ability to do multi-aspect imaging and high-resolution interferometry. The end result is that SAS allows much more reliable detection and classification of small objects.

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