MUD, A NEW ACOUSTIC ECHOSOUNDER FOR SEDIMENT MONITORING

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ABSTRACT

A new tool to measure both sediment concentration and sediment size is being built by ASL Environmental Sciences Inc. (ASL). The Multifrquency Ultrasonic Device (MUD™) is based on ASL’s successful Acoustic Zooplankton Fish Profiler (AZFP). The MUD/AZFP echosounders can be configured with up to 4 frequencies ranging from 2 MHz to 38 kHz. The MUD prototype is based on a set of higher frequencies (2 MHz, 1.2 MHz, 769 kHz and 200 kHz) that will allow for a balance of particle size discrimination and acoustic range. While the AZFP is a high gain device for low scattering conditions and the greatest possible range, the MUD echosounder is a lower gain system that is being tuned to work in higher backscatter regimes such as the bottom or high concentrations of suspended sediment. ASL’s echosounders are designed for autonomous deployments, with small size and low power draw. They are ideal for long term monitoring studies or for installation on battery-powered autonomous vehicles. Though detuned from their Acoustic Zooplankton and Fish Profiler roots and having shorter ranges, the MUD systems will still record biological signals, making them a multi-functional tool for environmental impact studies.

INTRODUCTION

Optical methods to measure suspended sediments have been around for over 100 years with the development of the Secchi disk in 1865 by Angelo Secchi (Wikipedia contributors, 2018). Optical methods evolved to include controlled light sources such that by the 1930s, the Jackson candle turbidimeter (Illinois State Water Survey, 2018) became the United States Geological Survey’s (USGS) standard to measure turbidity. This has continued to evolve such that today transmissometers and nephelometers make optical measurements of turbidity using LED light sources. Optical backscatter devices are among the most common methods to estimate suspended sediment in-situ. While commonly used, optical instruments are limited by their range (a few centimeters). Unless multiple detectors, or in the best designs multiple light sources and multiple detectors are used, these optical instruments are also affected by signals generated by bubbles and plankton, biofouling and stability of their light sources over long periods of time (Anderson, 2018; Sader 2018)

Acoustical studies of sediments are almost as old, dating back 70-100 years (Ballard and Lee, 2017) and include studies such as Urick (1948). A great deal of research into acoustic backscatter and suspended sediments was completed in the 1970s through to the 1990’s (Stoll, 1977; Hay, 1983; Thorne et al, 1991; Zedel and Hay, 1997) and has led to successful applications in the field (Hay, 1987a; Hay 1987b). Implementation of single frequency acoustic backscatter estimates of suspended sediments (USGS, 2018) has been in the works by the USGS since 2003. For the USGS “New techniques that make use of acoustic backscatter have shown great potential for accurately and cost-effectively estimating suspended-sediment concentrations”. Among the greatest advantages is the remoteness of the measurement – while optical instruments measure a few millimeters or centimeters from the sensor, acoustic backscatter is typically on the scale of meters to 100’s of meters and can concurrently measure 100’s of independent sample volumes.

Keywords: Multifrequency acoustic backscatter, suspended sediments, turbidity.

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Acoustic backscatter sensors have some of the same limitations as optical turbidity sensors. For both, the scattering signal is usually dependent upon a mixture of variables including scatterer size distribution, concentration and material composition. When attempting to measure suspended sediments, ensuring the measurements are within sediment dominated backscatter layers instead of bubble or biologically dominated layers can be essential. Here, the profiling capability of the acoustic backscatter sensors can be used to detect the difference of a dense sediment layer versus surface bubbles or swimming biology. ASL Environmental Sciences Inc. (ASL) has further developed this type of sensor by creating a multi-frequency acoustic backscatter device. The device is also calibrated and designed to be stable over long periods of time.

ECHOSOUNDER HISTORY AT ASL

ASL’s first echosounder was the Ice Profiling Sonar (IPS-4) and was built for an oil-and-gas project off Sakhalin Island in eastern Russia in the mid-1990’s. This fourth-generation instrument was based on the IPS-3 developed by Dr. Humfrey Melling at the Institute of Ocean Sciences, Department of Fisheries and Oceans Canada. The IPS-4, and now the IPS-5, are high precision inverted echosounders used to measure the distance between the moored instrument and the ice canopy. A key feature is the low power draw which allows for battery-powered mooring measurements every few seconds for a year and longer. The IPS also uses a Digiquartz pressure sensor with 0.01% of full range accuracy and excellent stability characteristics to precisely measure the instrument’s water depth. The depth when combined with the echosounder’s distance to the ice allows for the derivation of ice draft. The Shallow Water Ice Profilers (SWIP) were then developed in the early 2000’s for maximum depths of 20 m. This allowed for use of inexpensive and less accurate stain-gauge pressure sensors without impacting the absolute accuracy of the measurements.

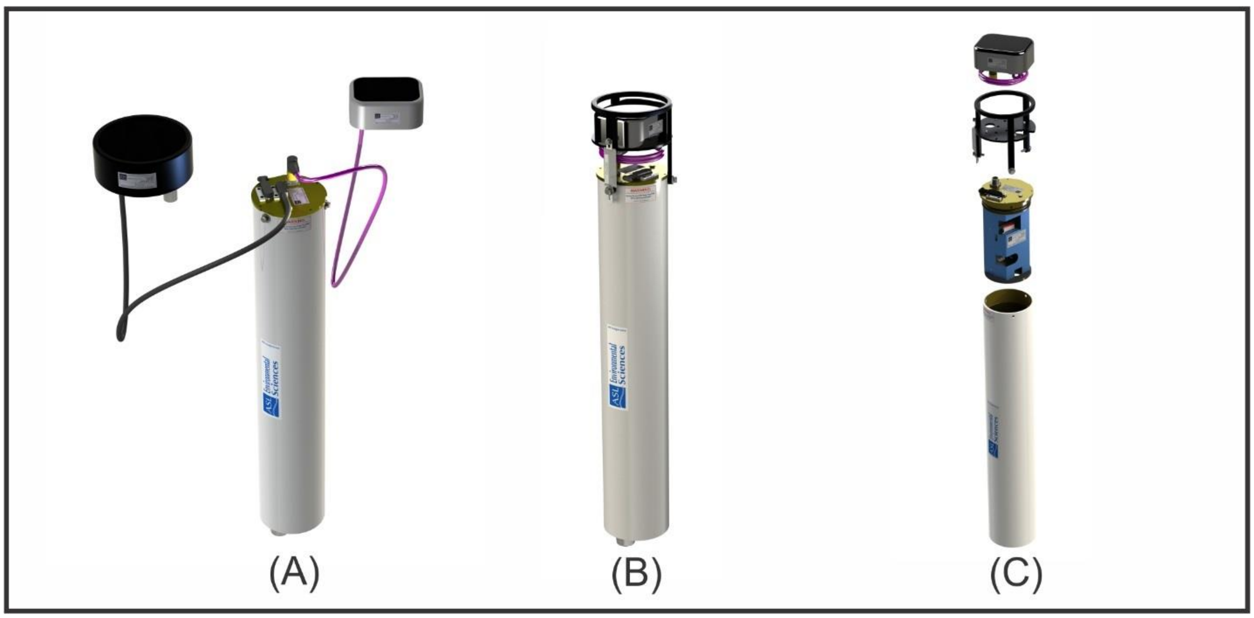

Figure 1. Illustration of different MUD/AZFP configurations: A) A single round 38 kHz transducer and 3 different frequency transducers in a rectangular pressure housing. (B) A single frequency 200 kHz transducer. (C) Illustration of the pressure case, electronics, transducer guard and the quad frequency transducer(s).

In the year 2000, the first Acoustic Water column profiler (AWCP) was built to measure acoustic backscatter of scatterers suspended in the water column. The AWCP A/D converters were upgraded to 16 bits around 2007 and the memory capacity was increased to allow up to 32 GB. The new A/D converter allowed more resolution in the measurements, and the extra memory allowed acoustic and ancillary data to be sampled much more rapidly than in the generation 4 units. To better distinguish the size distribution and concentrations of scatterers within the water column, multiple frequency AWCP units started to be made around 2009. Next, the Acoustic Zooplankton Fish Profiler (AZFP) was released in 2012. The AZFP functioned much like an AWCP, but its logarithmic amplifier provided a much larger dynamic range than the AWCP. We are now developing the Multifrequency Ultrasonic Device (MUD) as an evolution of the AZFP platform. This will allow us to use a common hardware platform with up to four frequencies between 38 kHz and 2 MHz (Figure 1). Existing AZFP calibration facilities will also be useable with MUD. One of the key differences in MUD’s hardware over the AZFP will be a reduction in gain to allow it to work in high concentrations of suspended sediment and at the water/seabed interface.

INSTRUMENT CHARACTERISTICS

The MUD echosounder contains up to four acoustic channels with frequencies between 38 kHz and 2 Mhz. The initial prototype’s 200 kHz, 769 kHz, 1.2 MHz and 2.0 MHz frequency combination was chosen because it has a high frequency combination which allow for the discrimination of the particle size distribution, while the lower frequency 200 kHz provides extended ranges and deeper penetration into high concentration suspended sediments such as turbidity flows. Table 1 summarizes the beam angle and source level parameters for the most common frequency combinations for the MUD and AZFP. Lower frequencies, based on the full range of AZFP frequencies, will provide even greater ranges and deeper penetration into high concentration suspended sediments. The highest frequencies can be located within a single housing and the lower frequency transducers are housed separately. The beam pattern of a 200 kHz transducer is shown for illustrative purposes as an example in Figure 2.

Table 1. Acoustic parameters of the MUD and AZFP

AZFP		
Frequency (kHz)	Nominal -3 dB Beam Angle (˚)	Nominal Source Level (dB)
2000	7	212 *
1200	7	211 *
769	7	210 *
455	7	210
200	8	210 *
125	8	210
67.5	10	205
38	12	208

* Targeted frequencies for the prototype MUD. Subject to change for the production units of MUD.

There are up to 32 GB of data storage available, and the standard battery pack allows the MUD to sample on four channels to 10 m range, pinging every 2 seconds for 220 days. The pulse width is selectable between a frequency dependent minimum of 85 µs to 150 µs and 900 µs. The echo return can be averaged in range or over entire bursts of pulses. The MUD contains a logarithmic receiver with a wide dynamic range. Its instantaneous dynamic range of over 80 dB allows it to be operated without a time-varying gain. The instrument can be installed looking upward or downward from either a taut-line mooring or a mooring frame on the seabed. In configurations where there are separate transducers, it is possible to have some frequencies, such as the highest frequencies, looking downward at the seabed at short range, and the longer frequencies looking upward to long ranges. Given the commonality of parts between the AZFP and MUD, the production version of the standard MUD will be rated for depths of up to 300 m. With build-to-order transducers and housings, a deep-water version of MUD could be deployable to as deep as 6000 m.

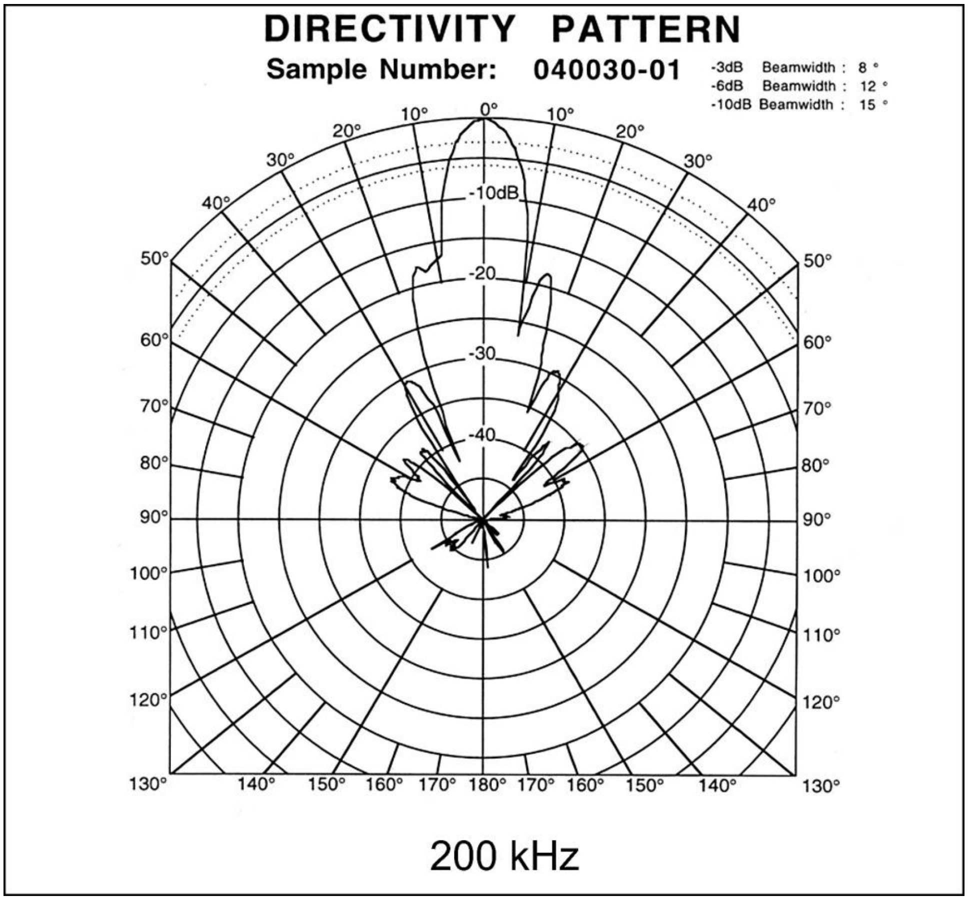

Figure 2. Example beam pattern for a 200 kHz transducer.

Figure 3 illustrates the sampling schematically for an instrument with four channels. Sampling may be regularly spaced or in bursts; in either case, averaging in range or in time is optional. When a ping is to be emitted, transmission occurs from the highest frequency transducer first. After the listening period for that channel (determined by the maximum sampling range selected) has elapsed, the next channel down in frequency transmits, and so on until listening is complete for the last channel. The sequence is repeated at the selected ping rate; if burst sampling has been selected, transmissions cease after the number of pings per burst is reached, and the sequence starts again after the burst period has elapsed. The maximum sampling range, pulse length and range bin size may be set independently for each channel.

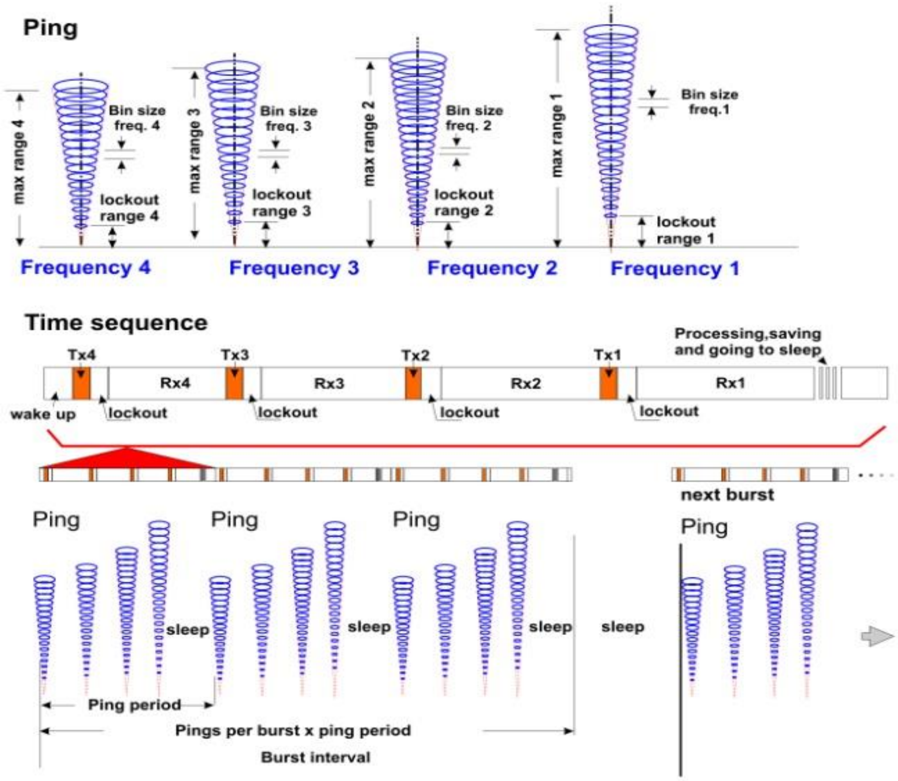

Figure 3. Schematic of the instrument sampling scheme showing the ping and the burst.

CALIBRATION

A key feature of ASL's acoustic backscatter echosounders is their factory calibrations. MUD echosounders will be calibrated in house using a calibrated Reson (TC4035) hydrophone which has an accuracy of ±1 dB, just as we do with the AZFP. The calibrated hydrophone measures the on-axis signal strength across a small indoor test tank at a range of 1 m from a sound source. The ambient temperature is about 19˚C and the transducer is located at 0.5 m water depth. The calibrated Reson hydrophone is used to calibrate the MUD source level; the Reson is then replaced by a secondary calibrated source, which transmits to the MUD to calibrate the MUD's receive response. The beam width is provided by the transducer manufacturer.

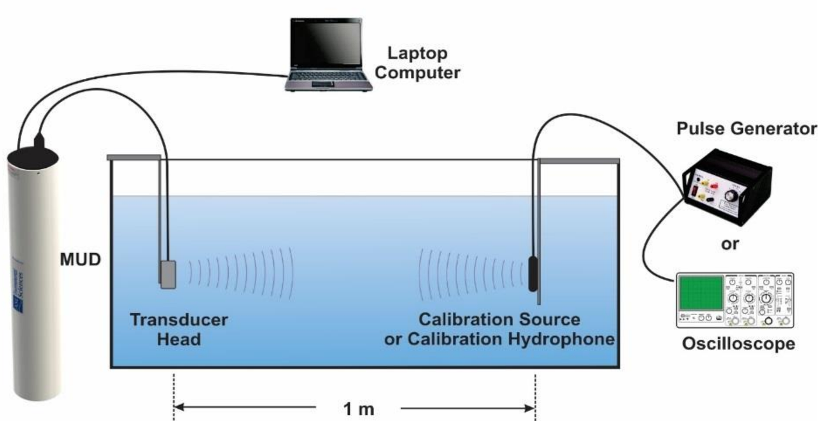

Figure 4. Indoor calibration setup of the transducer using a sound source which is calibrated with a calibrated hydrophone.

A secondary calibration is done in an outside tank (Figure 5). A ½ inch diameter tungsten carbide sphere is suspended in the center of the beam at a range of about 3.8 m (Figure 6). Frequencies over 1 Mhz use a 0.394 inch target. A special mat is used inside of the water filled tank to dampen echoes from the back and sides of the tank. If the first indoor calibration was successful, the measured returns from the target sphere will be within 1 dB of the nominal value.

Figure 5. Outdoor calibration tank.

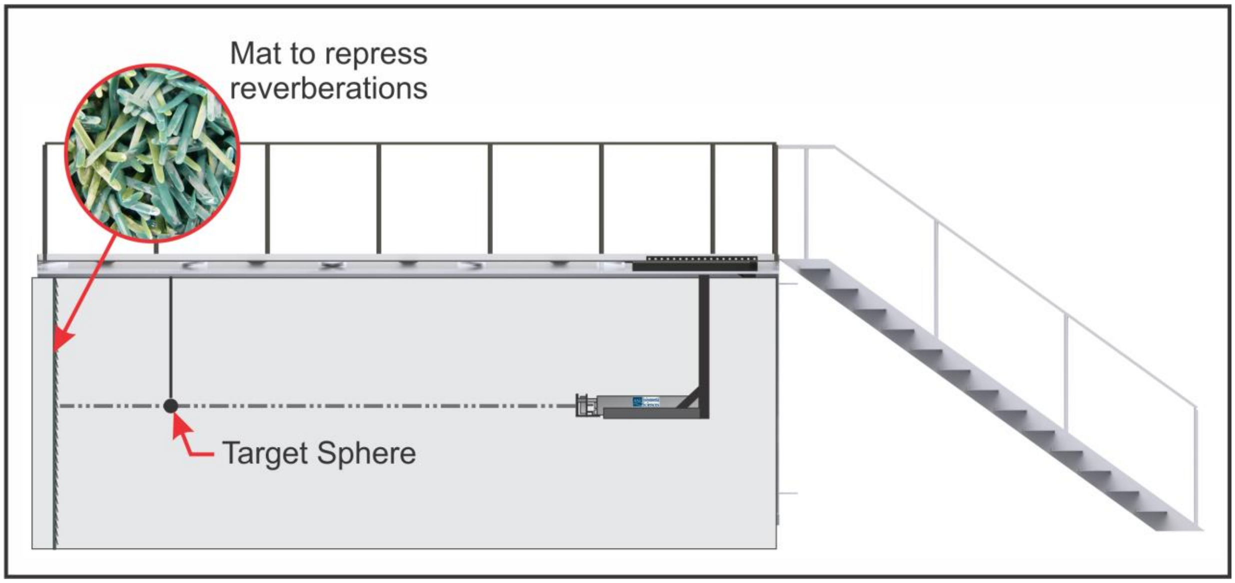

Figure 6. Outdoor calibration setup which includes a tungsten carbide target sphere.

Factory calibrations of absolute acoustic backscatter ensures consistent field results. This becomes clear when comparing to Acoustic Doppler Current Profilers (ADCP) which are commonly used as ad hoc acoustic backscatter echosounders. ADCPs are first and foremost current measurement devices and thus they do not require factory calibrations of acoustic backscatter to provide accurate Doppler derived currents. Thus, they output relative backscatter, that is not calibrated. ADCP backscatter measurements can vary between instruments and even between transducers on the same instrument. While source levels of an ADCP change with input voltage or battery voltage, making for weaker returns as the batteries become exhausted, ASL calibrated echosounders provide consistent source levels no matter what the input or battery voltage. Our records of multiple calibrations of field deployed AZFP has shown them to be particularly stable, with drifts in the source level of 0.5 dB/year. The combination of careful factory calibration, consistent source levels and extraordinary stability ensures that observed variations in acoustic backscatter is related to changes in the sediments or other scatterers and not the instruments.

EXAMPLE MEASUREMENTS OF SUSPENDED SEDIMENT

As of writing, the MUD echosounder is still in the prototyping phase. The initial field testing in planned for May, 2018. That does not mean that ASL's echosounders have never measured sediments. For example, an older generation ASL echosounder, the AWCP, has been used by Ocean Networks Canada to make sediment observations at the mouth of the Fraser River. Of particular interest are some measurements from the spring of 2012 during the Fraser River freshet. The large flux of water down the Fraser picks up increased amounts of sediments. On May 9th, 2012, during low tide, sediments were observed raining down through the water column (Figure 7).

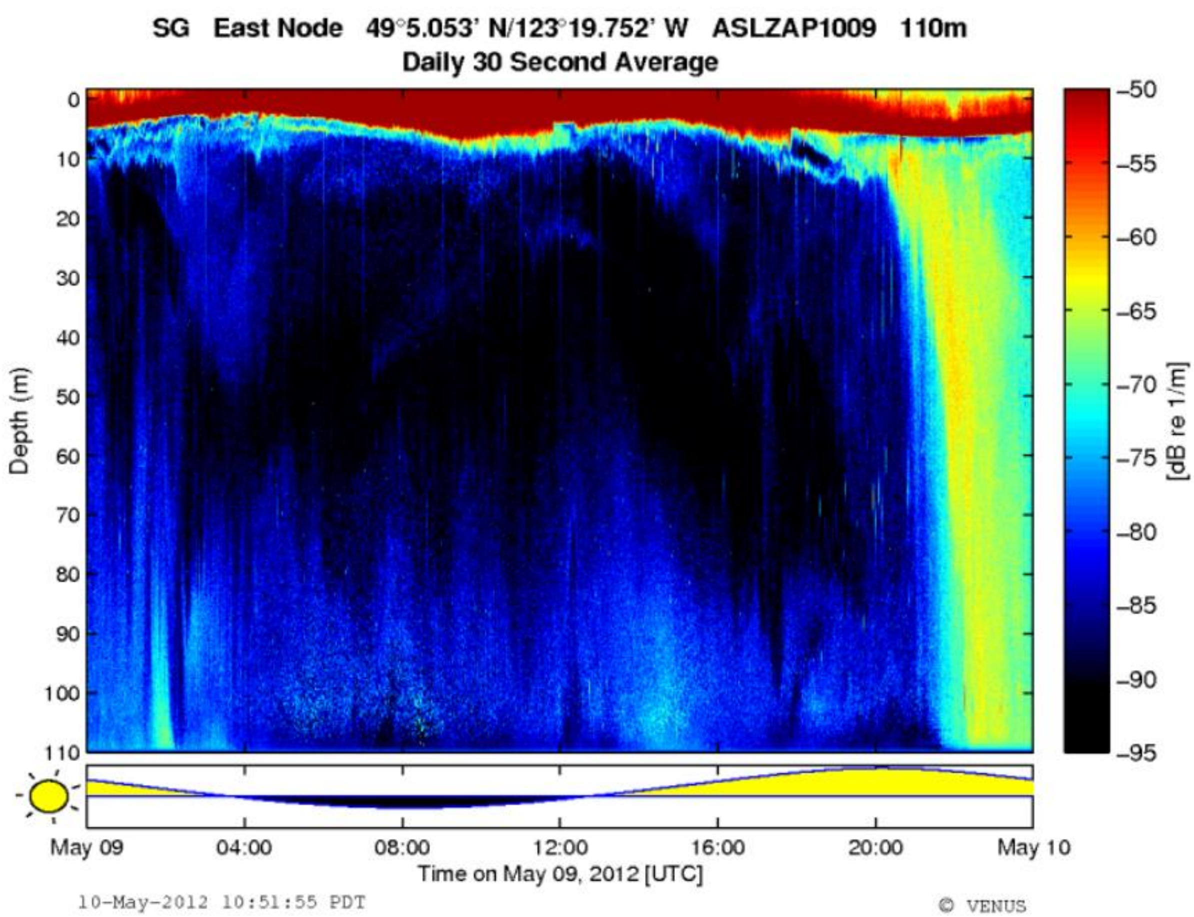

Figure 7. Cascade of suspended sediment as observed by a 200 kHz AWCP on the Ocean Networks Canada network on May 9, 2012 (ONC, 2018)

The calibrated acoustic backscatter can be used to derive Suspended Sediment Concentration (SSC). The log SSC is a linear function of Sediment-Corrected Backscatter (SCB) (Equation 11 of Landers, Straub, Wood and Domanski, 2016):

$$\mathrm{Log10}\,(\mathrm{SSC}) = \beta_1 \cdot \mathrm{SCB} + \beta_0 \qquad (1)$$

The SCB is given by the expression (equation 2 of Landers, Straub, Wood and Domanski, 2016):

$$\mathrm{SCB} = \mathrm{AB} + 20\log_{10}(\Psi r) + 2r\alpha_w + 2r\alpha_s \qquad (2)$$

Where AB is the absolute backscatter (in dB),
Ψ is the near-field correction factor and goes to unity in the far field,
r is the range of the acoustic measurement (in m)
α_w is the absorption due to the water (in dB/m) and is a function of the water temperature and salinity
and α_s is the absorption due to the sediments (in dB/m).

MULTIFREQUENCY DATA

The MUD echosounder is not only calibrated it is also multifrequency. The combination of frequencies provides a broader picture with more meaning and context than any single frequency can provide on its own. The minimum (solid line) and maximum (dashed line) volume backscattering strength for the MUD prototype as a function of range and frequency is given in Figure 8. The different frequencies behave quite differently. As an example, the 2 MHz (green solid curve) reaches a backscatter volume strength of -80 db at about 1 m, the 1250 kHz at about 2 m (red solid curve) the 769 kHz at about 5 m (orange solid curve) and the 200 kHz frequency at about 40 m (blue solid curve). These different acoustic properties allow multifrequency instruments to differentiate between changes in acoustic backscatter due to changes in concentration versus changes in the particle size distribution.

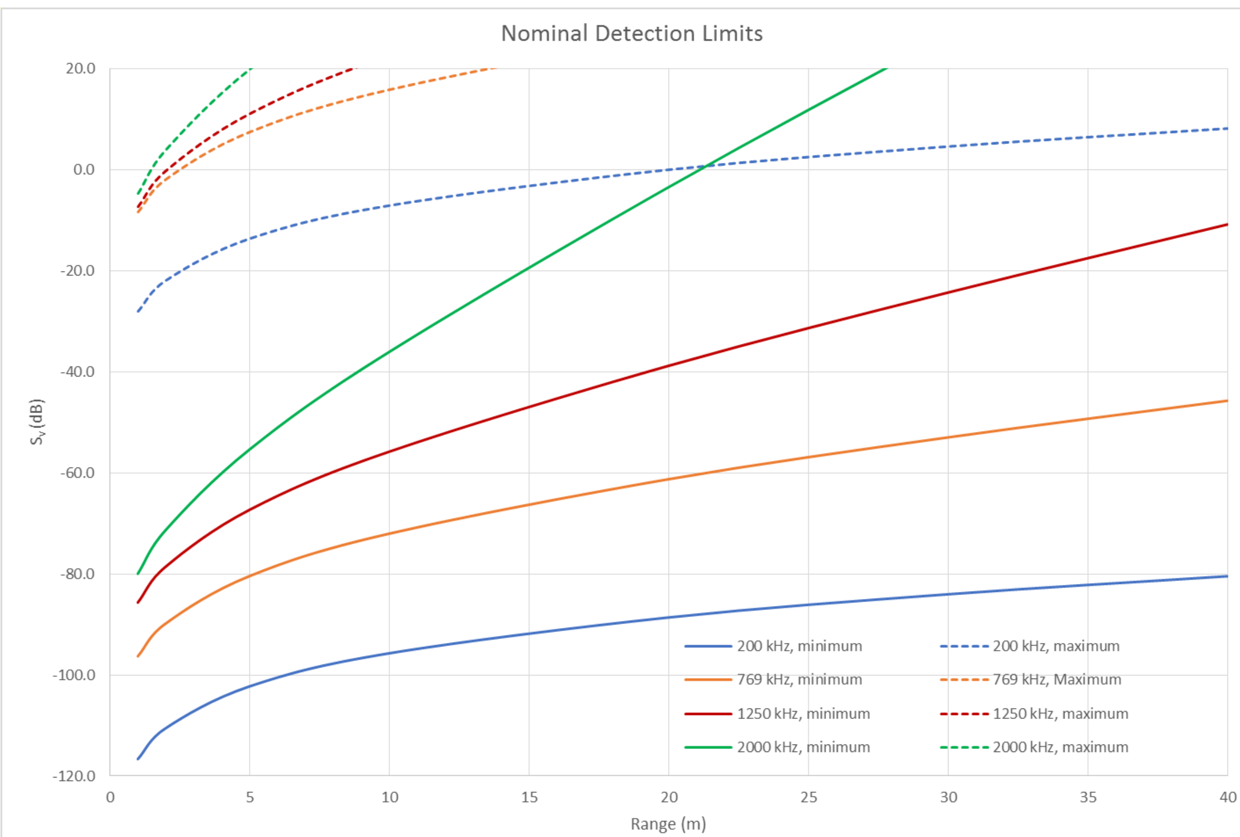

Figure 8. The minimum (solid line) and maximum (dashed line) detectable volume backscattering values as a function of MUD frequency and range.

ASL first ventured into the multifrequency echosounder domain through the SWIP product line. The SWIP comes in one of two frequencies: 235 kHz SWIP which is used to examine the ice cover and the slush layer beneath the ice cover and the 542 kHz SWIP which is used to look at the ice cover and the frazil ice below it. These two frequencies of SWIP were used to estimate the particle size distribution and concentrations of frazil ice within the water column (Marko and Jasek, 2008 and Marko and Jasek, 2010). Figure 9 illustrates how each frequency responds differently to the scatterers within the water column. The 235 kHz SWIP is well tuned to see the slush layer which appears as the “icicles” below the surface ice from late on January 12 to January 13. When this same time period is viewed using the 542 kHz SWIP, the slush layer is obliterated by the frazil ice which is evident through most of the water column.

The world of acoustic instrumentation has changed from when the two different SWIP sounder frequencies were first introduced. Multifrequency units which integrate multiple frequencies into a single instrument are now the most popular instruments we build. In 2017, only 25% of the instruments that we built were single frequency, all the rest were multiple frequency, and in most cases they were 4 frequency AZFP’s.

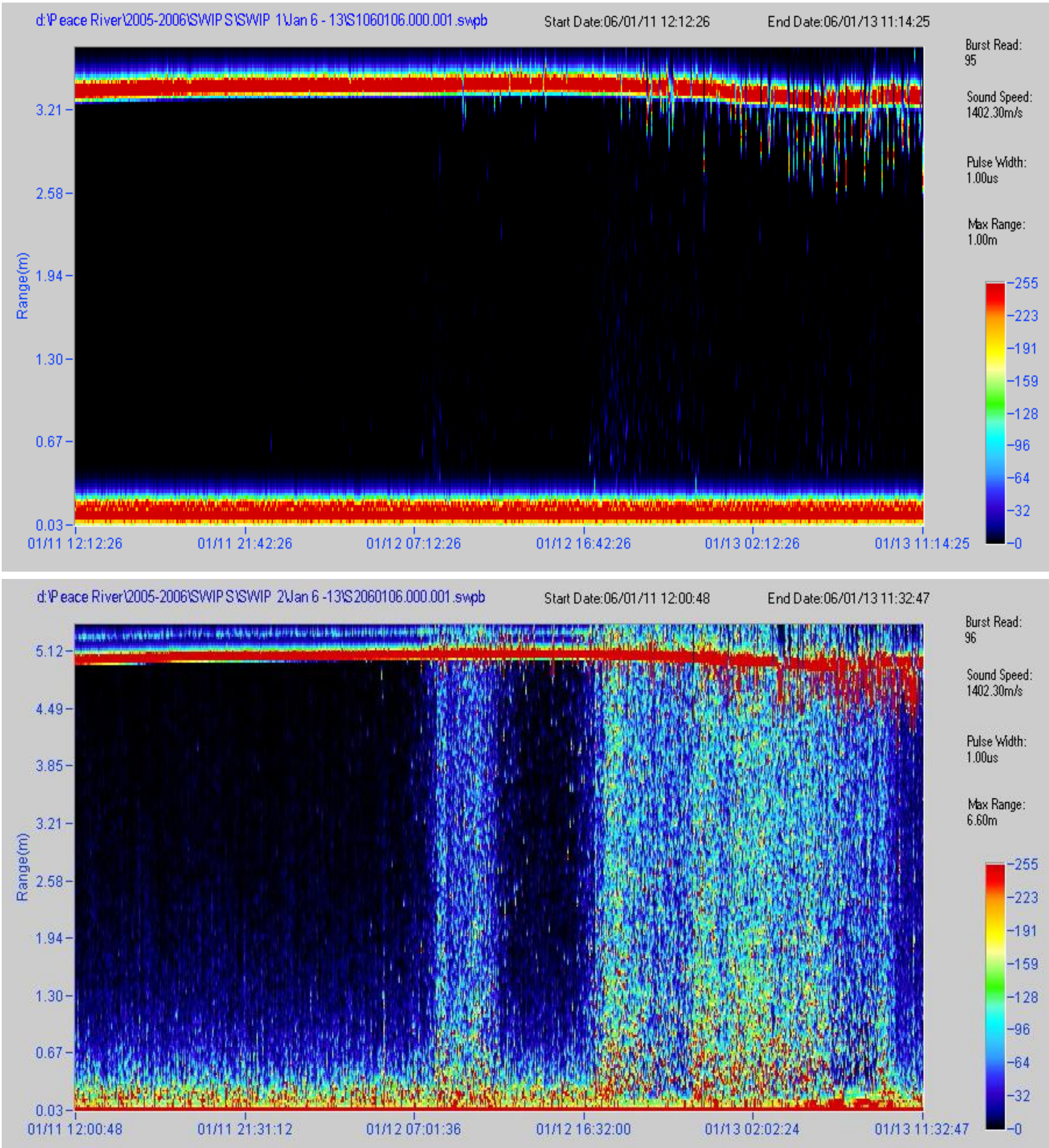

Figure 9. Frazil ice as detected from a 235 kHz SWIP (top) and from a 546 kHz SWIP (bottom) from January 11-13, 2006 on the Peace River (Marko and Jasek, 2008).

CONCLUSION

ASL's new Multifrequency Ultrasonic Device (MUD) takes advantage of several advances in acoustic backscatter (ABS) techniques and technology. Acoustic backscatter has become a more common and accepted surrogate for suspended sediment concentration, given the extensive research by academia and the development of applications such as the Sediment Acoustic Index Method of the USGS (Landers, Straub, Wood and Domanski, 2016). These applications and methods take advantage of ABS characteristics such as the ability to measure remotely (10's of meters away from the instrument) with better sensitivity to coarse grain material than optical sensors. Much of the current ABS observations are based on the widespread use of Doppler current profilers, which provide uncalibrated acoustic backscatter as one of their quality control parameters. These ad hoc ABS sensors, which are designed to produce high quality current profiles, have limits related to sensitivity, interoperability and spatial resolution when it comes to ABS measurements.

ASL's calibrated echosounders are specifically built to provide high quality and stable ABS data. The new MUD echosounder will be factory calibrated by two methods to within 1 dB of known standards, producing consistent absolute backscatter measurements. The MUD echosounder is based on the electronics of ASL's AZFP, which have proven to be stable, with a drift of less than 0.5 dB per year. The MUD echosounders will be build-to-order with one to four frequencies, with frequencies ranging from 2 MHz to 38 kHz. The frequencies can be chosen to be among the highest offered frequencies for the best discrimination in changes in both overall suspended sediment concentrations and particle size distribution of small particles. Choosing lower frequencies will provide better range and penetration into dense suspended sediments. The prototype MUD is a compromise, with a combination of three of the highest frequencies to detect particle size distribution changes and a lower 200 kHz transducer to penetrate into turbidity flows which are the intended targets for the first field tests in May 2018. An advantage of any ABS device is its profile (typically vertical) of concurrent backscatter from many discrete sample volumes. In comparison to single optical backscatter sensors, this allows for better spatial awareness of the sources of strong backscatter signal, such as sediments, air bubbles or biology. The high vertical (12 cm – frequency dependent) and temporal (1 Hz with four frequencies) resolution of the MUD echosounder allows for better detection and discrimination of all sources of backscatter than a single point optical backscatter device. This allows the MUD echosounder to be used concurrently for its intended purpose, measuring suspended sediment, and for measuring environmentally important parameters such as secondary productivity (zooplankton and fish) or potentially for some critical primary productivity (eel grass and seaweed).

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