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Frazil Ice Measurements Using the Shallow Water Ice Profiling Sonar

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The paper describes a series of laboratory experiments investigating the use of the Shallow Water Ice Profiling Sonar or SWIPS to detect frazil ice. These experiments together with a field component are part of a research project aimed at developing a method for obtaining concentration measurements of frazil ice in the field. The challenges that were encountered trying to produce frazil ice in the laboratory are described. A frazil ice tank was specially designed and constructed for these experiments. Both the high and low frequency models of the SWIPS were deployed on the bottom of the tank looking upward. Digital video systems together with a sieve sample technique were used to measure the size and concentration of the frazil ice particles independently. Preliminary results presented, show for the first time that a correlation does exist between the SWIPS backscattered signal levels and frazil ice concentrations.

1. Introduction

At present, there is no practical method to measure frazil ice concentrations during freeze-up in rivers. Many methods for measuring frazil ice concentrations have been investigated, including techniques based on: changes in electrical conductivity (Tsang 1985); laser Doppler velocimetry (Schmidt and Glover 1975); electromagnetic pulses (Yankielun and Gagnon 1999) and underwater photography (Daly and Colbeck 1986). However, none of these methods proved to be sufficiently accurate or robust enough for use in the field. Recently, ASL Environmental Sciences Inc., developed an underwater acoustic device called the Shallow Water Ice Profiling Sonar (SWIPS). The SWIPS is available with two different acoustic transmitting frequencies; low frequency (235 kHz) and high frequency (545 kHz). The SWIPS transmits acoustic pulses up through the water column and it was originally designed to measure ice cover thicknesses in rivers. The acoustic signals are reflected by targets in the water column, and the intensity of the reflected signals is used to differentiate between different targets types.

The SWIPS has been deployed successfully in the Peace River, AB during the past four winter seasons, and the field tests on the Peace River reported by Jasek et al. (2005) have shown that the 235 kHz SWIPS could detect the presence of suspended frazil ice. However, the acoustic returns from suspended frazil ice were found to be rather weak at this frequency. Marko et al. (2006) described the simultaneous deployment of the 235 kHz and the 545 kHz frequency SWIPS in the Peace River. They compared the performance of the two instruments and found that the high frequency SWIPS was much better at detecting suspended frazil ice than the lower frequency model. They also concluded that the lower frequency SWIPS was better for measuring slush layer thicknesses.

The purpose of this study is to explore the feasibility of converting the SWIPS output into actual suspended frazil ice concentrations. To achieve this, two parallel and complementary study components are underway: a laboratory study, being conducted in the civil engineering cold room facility at the University of Alberta, and a field study being conducted on the North Saskatchewan River in Edmonton. The laboratory study is the primary focus, and is aimed at investigating possible correlations between independently measured frazil ice concentrations and the amplitude of backscattered acoustic signals from the SWIPS. The field study is aimed at investigating different deployment techniques, and will also provide the opportunity to compare the SWIPS measurements with suspended frazil concentration estimates obtained by ice process modeling. This paper describes the laboratory experiments, presents some preliminary results and discusses further research plans.

2. Experimental Setup

Experimental study consists of generating frazil ice particles under controlled conditions in a custom made tank placed in the cold room laboratory. Figure 1 shows a photograph of the frazil ice tank which is 0.8 m wide, 1.2 m long and 1.5 m deep. Acoustic reverberation from the tank side walls was the limiting factor in setting the tank dimensions, which were designed based on preliminary acoustic tests conducted both as part of this study, and by ASL[1]. Tempered glass 19 mm thick (selected because of its excellent optical qualities, resistance to scratching and high tensile strength) was used for the two 1.2m by1.5 m side walls to allow imaging and viewing of

[1] Personal communication with David Lemon, ASL (June 2008)

the frazil ice. Stainless steel plate, 6 mm in thickness, was selected for the end walls and tank bottom. This material insures that corrosion will not be a problem and allowed us to install drains and connections for mixing propellers on the end walls and on the bottom easily. The tank's frame is constructed using 75 mm steel channel sections. The tank is mounted on four wheels to allow it to be moved in and out of the cold room easily.

As Figure 2 illustrates, the SWIPS instruments are mounted on the bottom of the tank, as are four of the propellers used to generate turbulence (so as not to interfere with the acoustic beams from the SWIPS). The tank was constructed with 8 propellers, two on each end wall and four in the bottom. Four variable speed motors can be attached to any of the 8 propeller connections located outside the tank on the side walls and bottom. This flexibility allowed us to optimize the turbulence generated inside the tank. Preliminary tests using polystyrene beads showed that bottom mixing is a better choice because, air bubble entrainment, which must be avoided since air bubbles corrupt the SWIPS returns, is less likely and because the bottom propellers produce more uniform mixing. The propellers are made of plastic to reduce frazil accumulation on the blades, and they are driven by variable speed NEMA 34 DC electric motors (1/3 H.P., 13.4 in.-lbs. of torque, max speed 1750 rpm), which are each equipped with speed controllers. A laser tachometer is used to precisely control the motor speed so as to be able to vary the intensity of the turbulence in the tank. As seen in Figures 1 and 2, a Plexiglas base plate is used to secure the High and Low frequency SWIPS to the tank bottom and hollow PVC tubes are used to secure the SWIPS cables.

The University of Alberta's Civil Engineering Cold Room facility is used. As seen in Figures 1 and 2, both SWIPS units are being tested, each oriented to point upwards at the suspended or floating frazil ice. Each SWIPS is connected to a PC, located outside of the cold room, using 10 m long data cables. Two RTD electronic thermometers (accuracy ±0.1%) are both connected to PCs as well and used to record the water and air temperatures in the cold room. A digital video system is used to take images of the suspended frazil ice particles for independently quantify frazil concentrations. The digital video camera is placed approximately one meter in front of the tank, and it is connected to a PC, also located outside of the cold room. This PC is equipped with software (Video Savant 3.0, IO Industries) that allowed us to control the image capturing parameters such as the frame rate and exposure time, and also to store the recorded images to a hard drive.

For imaging purpose, two light sources have been tested to determine the optimal conditions for photographing the suspended frazil. A 1000 Watt spot light covered by a diffusive light box placed on opposite side of the tank from the camera, with and without polarizer filters, and an Argon Ion laser sheet oriented vertically as shown in Figure 3. The spot light illuminates the frazil ice particles across the entire 80 cm tank width. As a result, even at low concentrations the tank appears to be full of frazil ice; that is the concentrations appear much higher than the actual value. Even with a limited depth of field, the frazil ice particles that are in focus are obscured by out of focus particles. The laser sheet proved to be a more effect way to illuminate the frazil ice particles because it does not have the depth of field issue. Digital images of the frazil ice are also taken using an SLR camera. A sieving technique is used for direct measurement of frazil ice concentration. Three 15.5 cm diameter stainless steel sieves, having a cross sectional area of

0.019 m^2, and mesh size of 2 mm are used for sampling. The sieves are suspended on a string and lowered to the tank bottom and as shown in Figure 4.

3. SWIPS Parameters

A series of preliminary experiments have been conducted to identify the effect of varying the SWIPS pulse length and gain on the intensity of the backscattered signals. Experiments showed that using pulse length of 68 µs (this is the value recommended by ASL for field deployments) and the maximum gain of four for the low frequency SWIPS produced very low amplitude returns see Figure 5 (a). Using a pulse length of 25 to 68 µs and the lowest gain setting of one for the high frequency SWIPS produced saturated signals when the frazil ice was present in the tank, see Figure 5 (b). Backscattered signal power levels are proportional to the duration of the transmitted pulse and that is why shortening the pulse length decreases the saturation[2]. Pulse lengths of 17 µs and 68 µs for the high and low frequency SWIPS, respectively are used.

Both SWIPS units are equipped with a variable gain board. Time-varying gain at the receiver facilitates conversion of the amplitude versus time into amplitude versus range data automatically (knowing the sound speed in water) by approximately adjusting for the signal transmission loss over time/range due to beam spreading, and attenuation in the water column (Marko et al 2009). Thus a direct calibration for acoustic losses is not required and target ranges and strengths are estimated using the relative strengths of the 16-bit digitized returns expressed in digital counts (Marko et al 2009). The high frequency SWIPS is set to the lowest available gain of one to minimize the received acoustic energy and avoid saturated signals. The low frequency SWIPS is set to the highest available gain of four to maximize the amplitude of the reflected acoustic signals.

4. Experimental Methods

During each experiment, the same procedure is followed. First the cold room temperature is set to -10 ºC. The bottom propellers are then turned on to a speed of 300 rpm. We have found that this speed is high enough to ensure that skim ice does not form on the water surface, but is not so high that air bubbles become entrained. Air and water temperatures are recorded simultaneously. Sampling by both SWIPS units is initiated using the settings described above, a ping rate of 1 Hz, and a sound speed of 1403 m/sec for both units, assuming pure water at 0 ºC. The digital video system is used to record images of the frazil ice throughout the entire experiment. The water is mixed until it supercools and frazil ice particles begin to appear in the water. The experiment is allowed to run until the frazil ice concentration in the tank reaches a certain value. For these preliminary experiments we defined the concentration to be low, medium or high based on visual observation. The mixing propellers are stopped to stop frazil production once the specified concentration is reached. Then, immediately before the surface starts to freeze, three sieve samples are taken during each experiment, each from different quadrants of the tank. The sieves are lowered using strings down to the tank bottom, moved to an undisturbed spot, and then pulled up vertically to the water surface. Using this sampling method each sieve collects the frazil ice particles from a volume of water equal to the area of the sieve times the height of the water column. The sieved samples are then weighed and averaged and then the frazil ice mass concentration can be calculated.

[2] Personal communication with John Marko, ASL (April 2009).

5. Results and Discussion

Using the laser sheet for illuminating the frazil ice eliminates the depth of field issue. A typical image taken with the digital video image system is displayed in Figure 6. The frazil ice particles appear as white pixels against a black background. The disk shaped ice particles can appear as lines, ellipses or circles in the images depending on their orientation. Further image processing and analysis is required to obtain quantitative data from these images. SLR digital camera photos can be used to capture clear images of frazil ice flocs (Figure 7).

First the repeatability of measurements made using the sieving technique was tested by repeating the identical experiment 3 times. Measured concentrations ranged from 0.39% to 0.44% with a variation of approximately 10%. Then, three experiments were conducted at low, medium and high concentration and mass concentrations measured using the sieving technique found to range from 0.07 to 0.26 %. Figure 8 shows a photo of a sieved sample of frazil ice that has been placed in a bucket prior to being weighed. The data from these experiments is listed in Table 1. These concentrations are comparable to those estimated in previous laboratory studies: e.g., 0.065 to 0.609% (Ettema et al 2003) and 0.01 to 1 % (Ettema et al 1984).

Table 1: Estimated frazil ice concentrations using grab sample technique:

Exp#	W_{Ice} (gr.)			Average (gr.)	Concentration %
	Sample 1	Sample 2	Sample 3		
20	18.4	17.6	16.4	17.5	**0.07**
21	35.5	74.1	27.2	45.6	**0.19**
22	56.3	63.1	62.7	60.7	**0.26**

A typical plot of SWIPS data is shown in Figure 5. This plot indicates that the frazil ice concentration increased to a maximum, then decreased as particles began sticking to the tank walls and flocculating and then rising to the water surface. The average duration of active frazil formation was approximately 12 minutes. Supercooling temperatures of -0.07 to -0.12 ˚C have been observed. During each of the above mentioned three experiments, the exact time when the propellers were stopped was recorded and SWIPS signal profiles were time averaged over the last 4 minutes just prior to propeller stoppage. In Figure 9 time averaged SWIPS signal profiles at zero concentration and 0.26% are compared. The background profile (zero concentration) was subtracted from the measured time-averaged profiles at the three concentrations and these net profiles are presented in Figure 10. Subtracting the background eliminates the effect of the minimum lookout range as well as the surface returns and the effect of any impurities present in the water. It is important to note that the reason that the net signals are stronger at smaller depths is because of acoustic near field effects that require more investigation[3]. The net profiles were then depth averaged giving a single estimate of the average signal amplitude at each concentration. Figure 11 (a) and (b) presents concentration versus SWIPS average signal amplitudes for low and high frequency units respectively. These two plots indicate that there is a strong correlation between frazil ice concentration and backscattered signal amplitude. The relationship appears to be linear for the low frequency SWIPS and nonlinear for the high frequency SWIPS. However, with only three data points this conclusion is tentative.

[3] Personal communication with John Marko, ASL (April 2009).

6. Summary

The results from these preliminary experiments are very encouraging. However, additional experiments are required at different concentrations in order to obtain a more reliable correlation. The digital images will be used to estimate concentrations and particle size distributions. These independently measured concentrations will be used to validate the concentrations measured using the sieving technique. In addition, further analysis and calibration is needed to convert the raw SWIPS signals to sound pressure levels in decibels. These preliminary experiments did produce a significant breakthrough because the data presented in Figure 11 demonstrate for the first time that it will be feasible to make quantitative measurements of frazil ice concentrations in the field using the SWIPS.

Acknowledgments

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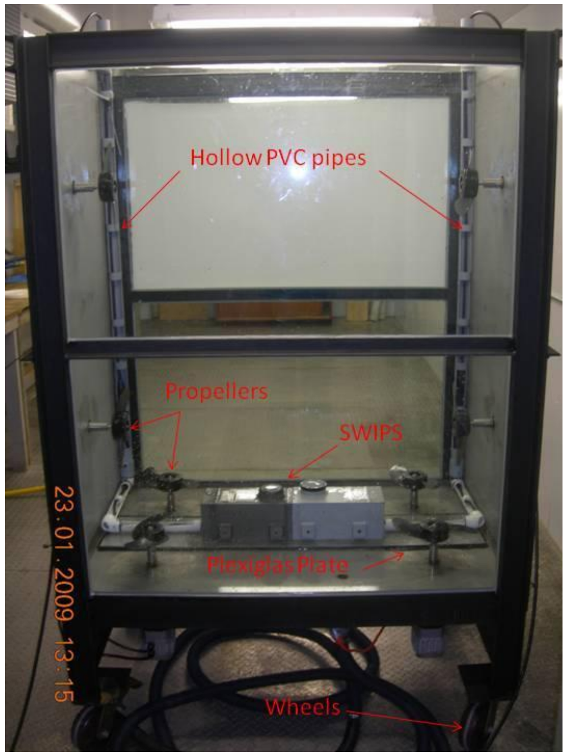


Figure 1: Front view of the frazil ice tank.

Figure 2: Top view of the frazil ice tank setup showing the high and low frequency SWIPS, the Plexiglas base plate, and cables inside the hollow PVC tubes; two of the side mounted propellers and the four bottom mounted propellers are also shown.

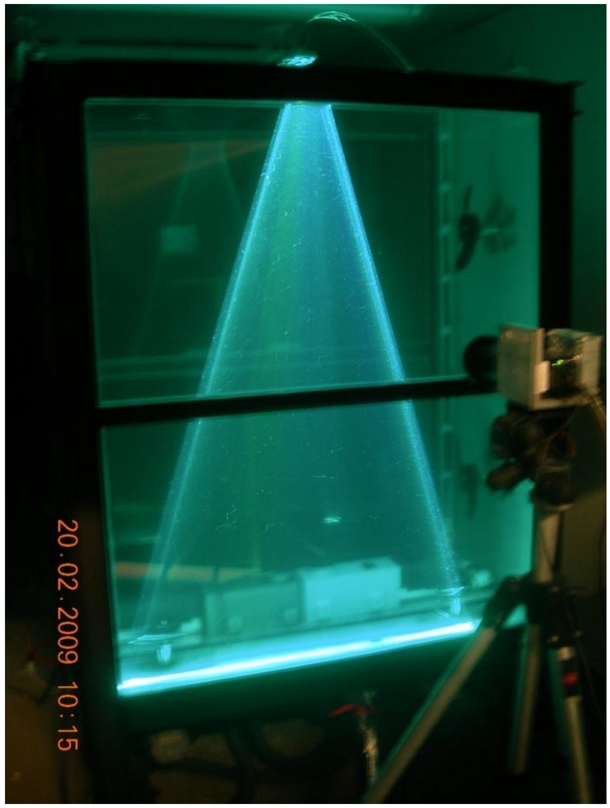
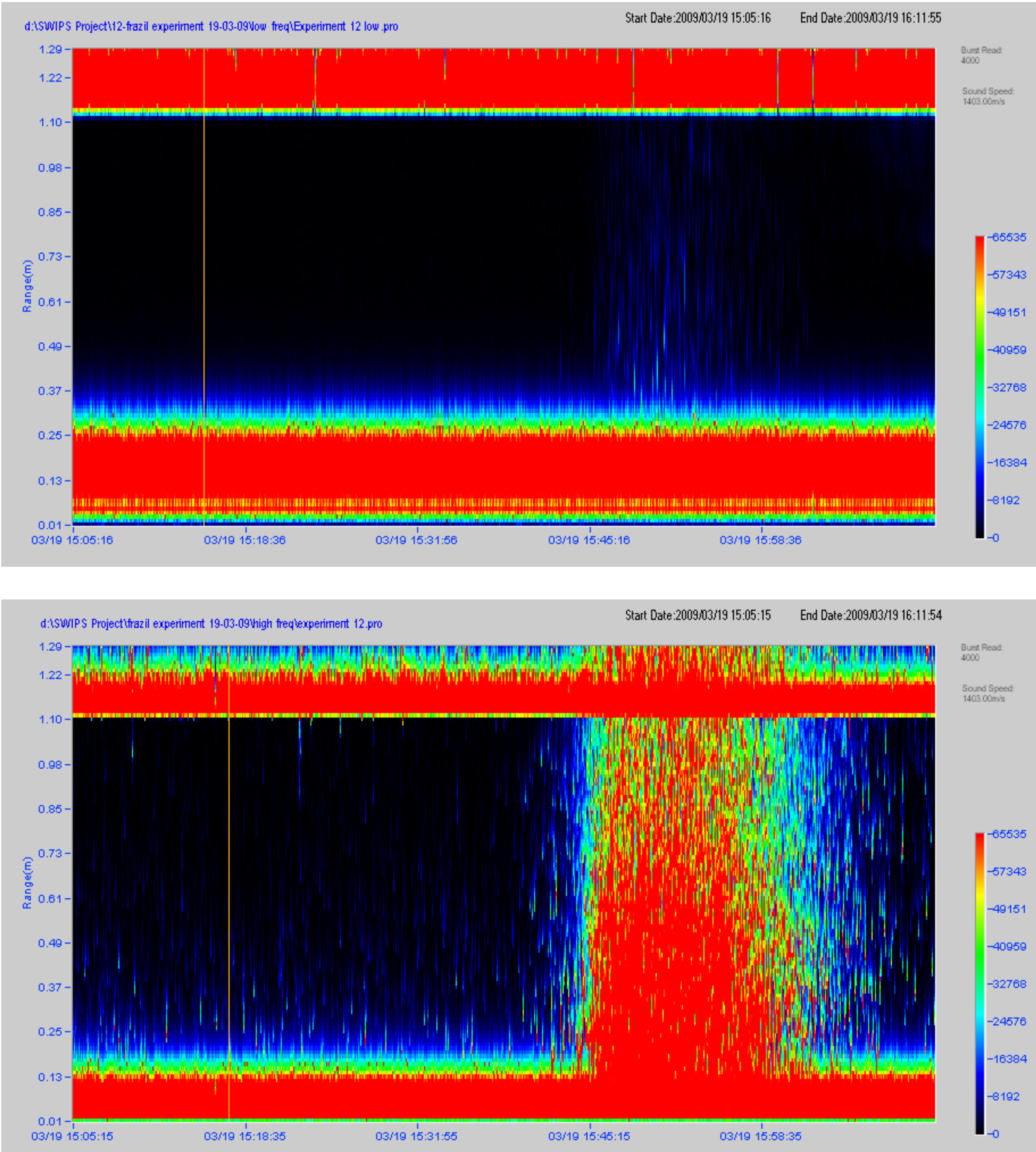


Figure 3: Experimental setup using a laser sheet for lighting.

Figure 4: Photo showing one of sieves being lowered.



(a)

(b)

Figure 5: Typical SWIPS signals for a complete frazil experiment conducted at air temperature of -10°C. Backscattered signal are in counts (N) on a color scale, black for 0 N returns, and red for 65535 N fully saturated returns. The vertical axe represents the water depth (m), and the horizontal axe represents date and time. (a) Low frequency SWIPS for pulse length of 68 μs. (b) High frequency SWIPS for pulse length of 25 μs.

Figure 6: Digital video image taken using a laser sheet for illumination.

Figure 7: Picture of a suspended frazil ice floc using an SLR camera.

Figure 8: Photo showing a sieved frazil ice sample.

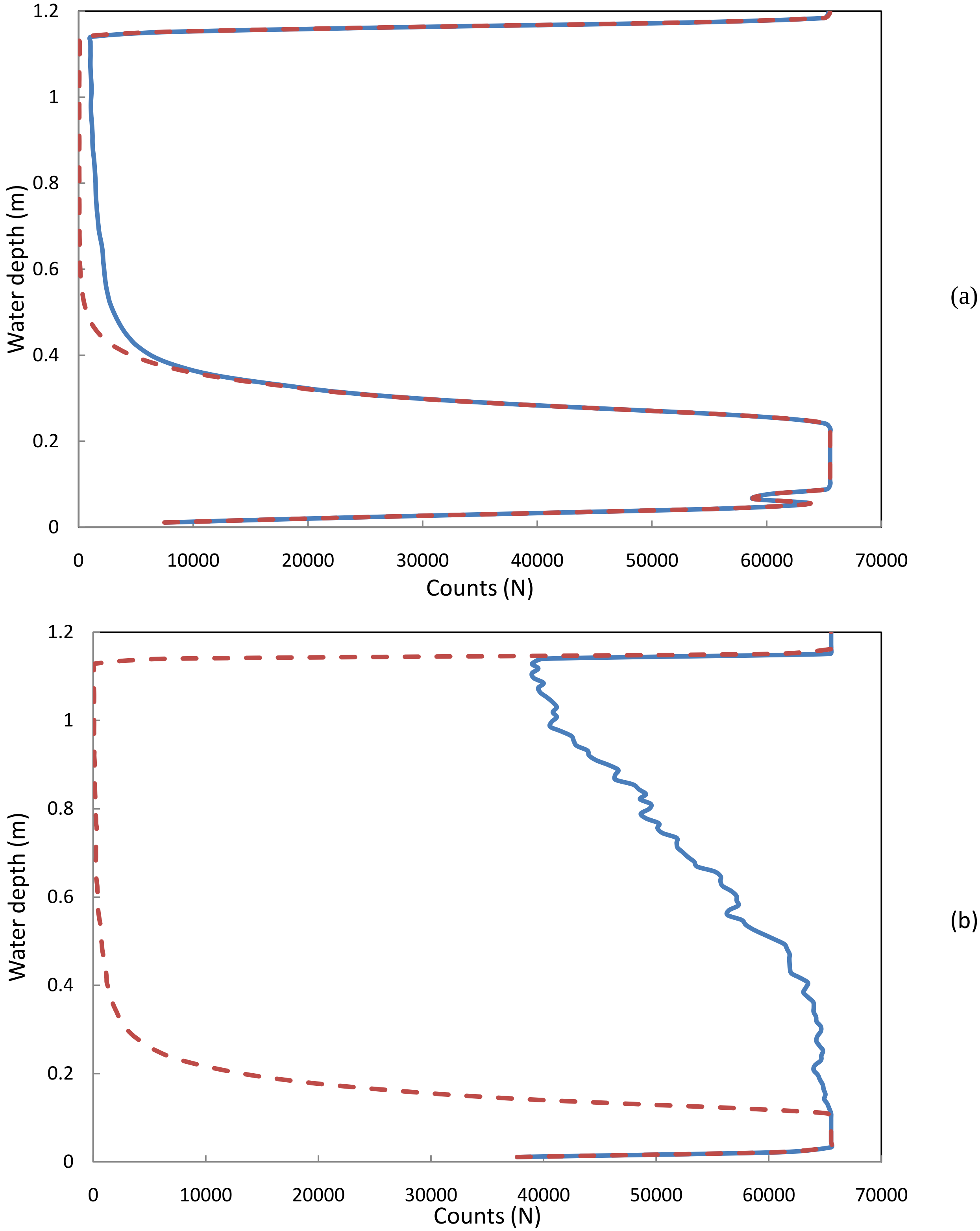
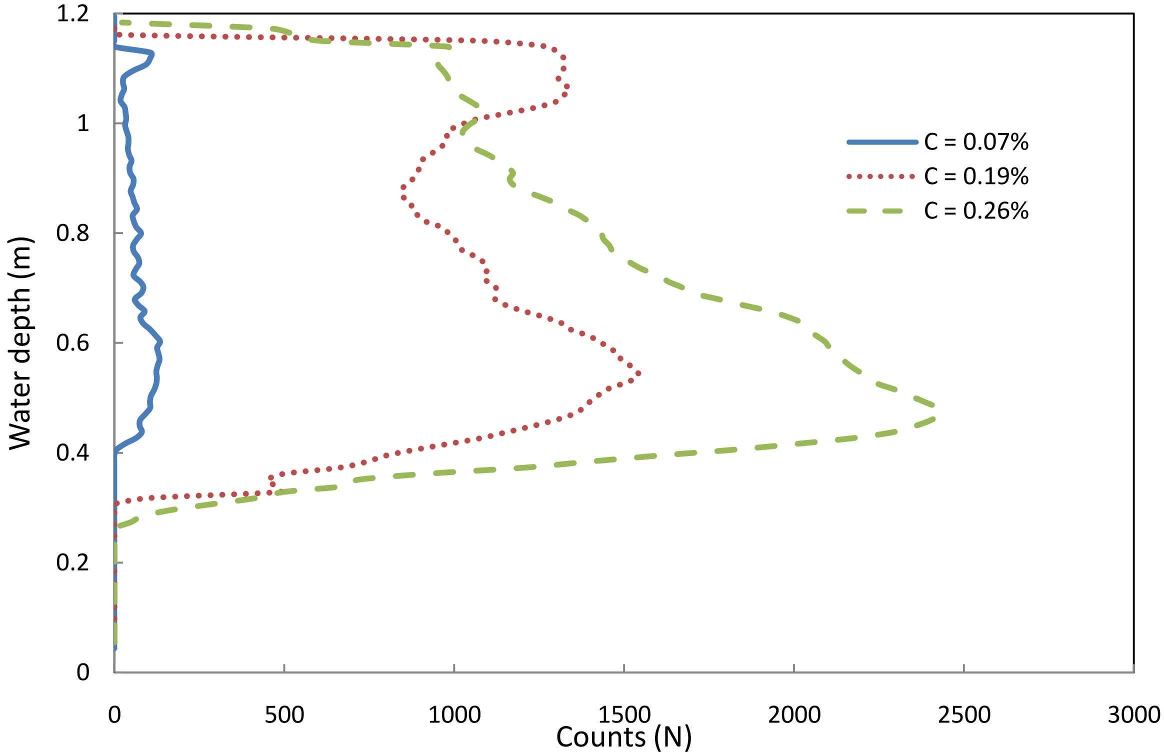
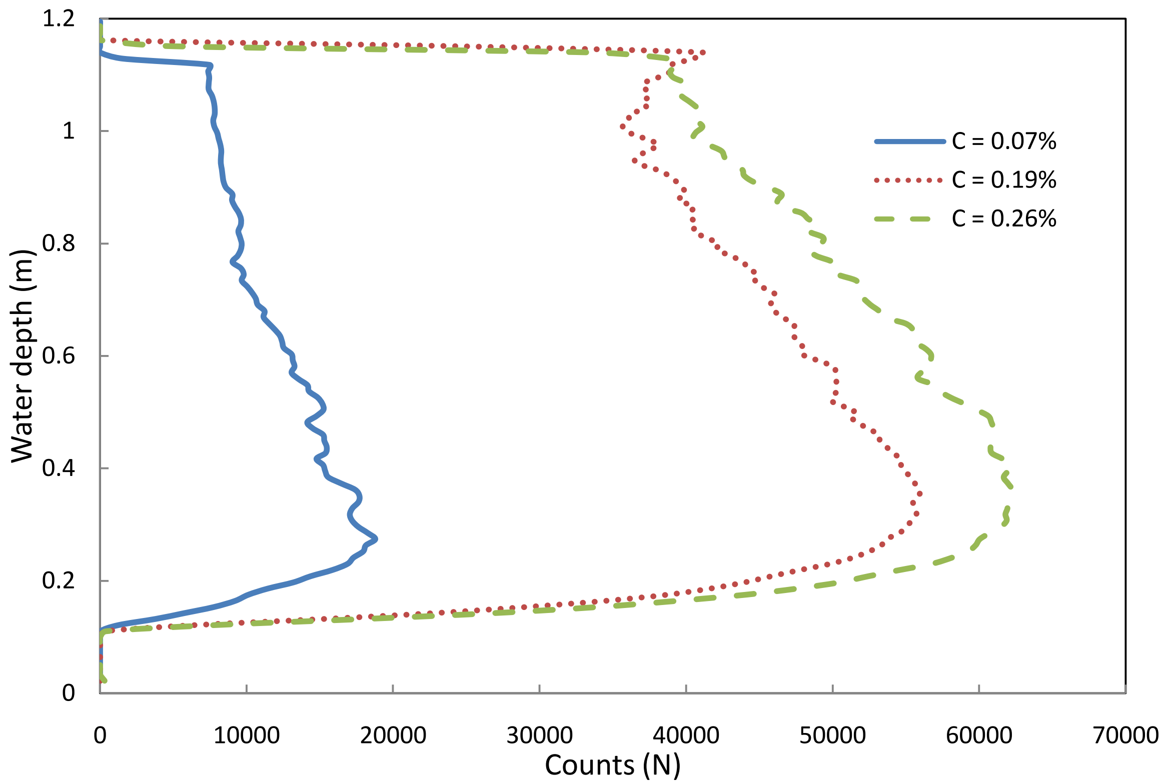


Figure 9: Time averaged SWIPS signal profiles. Dashed-line: 0% frazil concentration. Solid-line: 0.26% frazil concentration. (a) Low frequency. (b) High frequency.



(a)



(b)

Figure 10: Net profiles for different frazil concentrations. (a) Low frequency. (b) High frequency. (Note: the x-axes for (a) and (b) have different scale).

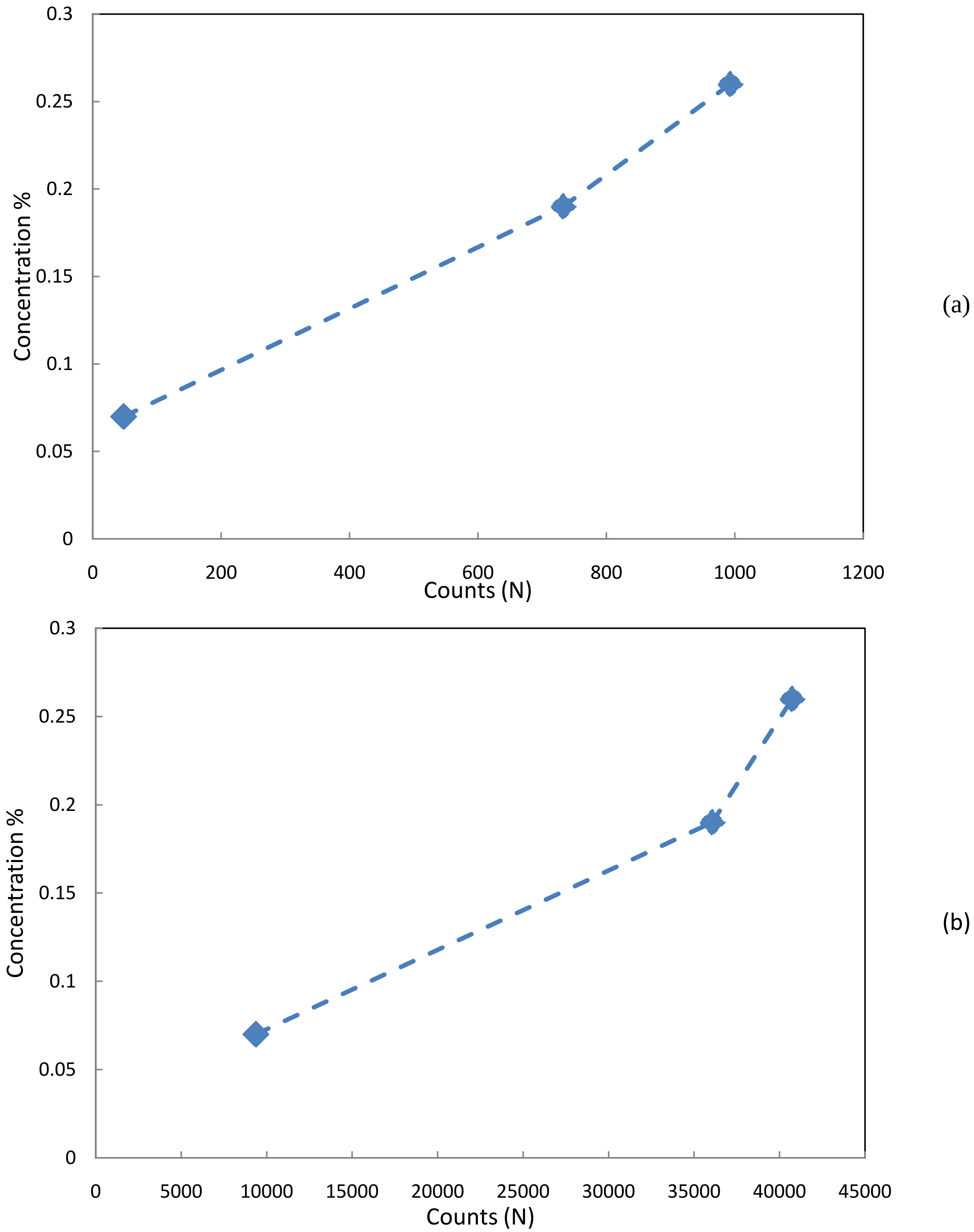


Figure 11: Plot of frazil ice concentration % versus the SWIPS returns in counts. (a) Low frequency. (b) High frequency. (Note: the x-axes for (a) and (b) have different scale).