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Study of Freeze-up Ice Characteristics on the North Saskatchewan River

J. Maxwell, F. Hicks, and M. Loewen
University of Alberta
Dept. of Civil and Environmental Engineering
University of Alberta, Edmonton, AB, T6G 2W2
josh.maxwell@ualberta.ca, fhicks@ualberta.ca, mrloewen@ualberta.ca

Many northern communities rely upon river water both for industrial and domestic purposes. When urban outfalls release warm effluents they can affect the thermal regime of a river, creating open leads which are prone to episodic frazil ice events during cold weather. This frazil ice can in turn cause problems for intakes further downstream. Thus as urban development increases, there is a greater and greater potential for outfalls to interfere with intake performance. Therefore, the purpose of this study was to document the river ice processes in an urban setting river with particular attention to the occurrence of frazil events in an open lead.

The site chosen for the study was the North Saskatchewan River in Edmonton, Alberta and this paper presents preliminary results of field investigations conducted during the winter of 2010/11. Automated time-lapse cameras were placed along the river throughout the city, in order to provide an overall record of the ice cover progression during freeze-up. Additional cameras and instruments for documenting suspended frazil ice and surface pans were deployed along, and within, a large, persistent open lead which is known to experience multiple frazil events each winter. These included a night vision time-lapse camera, high (545kHz) and low (235KHz) frequency shallow water ice profiling sonars and an acoustic Doppler current profiler.

Based upon these observations it was found that the North Saskatchewan River could be divided into two reaches, based on geomorphological features. In the upper reach, numerous islands and mid-channel bars provide multiple bridging points for the developing ice cover. The lower reach is free of islands and bars and therefore the ice cover develops sequentially from downstream to upstream. Multiple frazil events were documented, and it was determined that snowfall is the primary precipitating factor, with cold weather playing a less significant role.

1. Introduction

The majority of residents and industries within the City of Edmonton depend upon water withdrawn from, and ultimately discharged back into, the North Saskatchewan River. During the winter season, these outfall discharges can have a significant thermal impact upon the river, resulting in the development of persistent open leads in the ice cover. These open leads increase and reduce in length in response to varying meteorological conditions, becoming active frazil production zones during periods of cold, snowy weather. Frazil production throughout the winter period is a particular problem for water intakes, and this is known to be an issue for some of the intakes along the North Saskatchewan River downstream of Edmonton. The goal of this study was to investigate the urban ice regime and, in particular, to examine the important factors affecting frazil production in open leads.

There have been several ice related studies conducted on the North Saskatchewan River in the past. Choles (1997) collated all of the data related to ice processes along the North Saskatchewan River from the Bighorn Dam downstream to the confluence with the Brazeau River, 140 kilometers upstream of Edmonton. Gerard and Andres (1982) conducted a winter ice study at several sites within the City of Edmonton during the 1981/82 winter and reported that the ice cover initiated about 200 km downstream of Edmonton and progressed sequentially upstream from there. Since 2008, measurements of frazil ice have been collected by University of Alberta researchers using Shallow Water Ice Profiling Sonars (SWIPS).

To facilitate this study, two major aspects of the North Saskatchewan River winter ice processes were documented during the 2010/11 winter season. First, the progression of freeze-up along a 55 kilometer section of river passing through the city was documented using automated time-lapse cameras. The camera images were analyzed for characteristics of freeze-up such as border ice formation, ice pan concentrations and freeze-up front movement. Second, frazil events in a large open lead created by the Goldbar Waste Water treatment plant were measured using Shallow Water Ice Profiling Sonar (SWIPS) units and an Aquadop current profiler. These instruments were mounted together on a steel platform and mounted on the bed of the river. The data produced by these instruments was used to identify and document frazil events.

2. Description of Study Reach

Figure 1 presents a map of the North Saskatchewan River at Edmonton; the stationing shown refers to kilometers (km) along the river, in terms of distance downstream of the Highway 60 bridge at Devon. Also shown are the Water Survey of Canada gauge (station 42.8 km) and the Environment Canada meteorological station at the Edmonton City Centre Airport. The North Saskatchewan River at Edmonton is a gravel bed river with a mean bed material size of ~3 cm (Kellerhals et al., 1972). The study reach can be broken into two reaches based on river geomorphology. Upstream of the Highway 216 (Anthony Henday Drive) bridge, the channel exhibits an irregular meandering pattern with slight anabranching tendencies with numerous islands and mid-channel bars. The river here is partially entrenched within the valley walls (Kellerhals et al., 1972). . Downstream of the Highway 216 bridge, the channel continues an irregular meandering pattern however it loses its anabranching tendency and contains no mid-channel bars or islands. The relation of the river with the valley becomes slightly more entrenched.

The North Saskatchewan River is regulated by the Brazeau and Bighorn Dams. The Brazeau Dam began operation in 1963 and the Bighorn Dam began operation in 1972 (Kellerhals et al., 1972). From the beginning of the gauge record in 1911 to 1963, the mean flow for the winter months of November to March was 45 m^3/s (Environment Canada, 2011b). After the second dam began operation in 1972, the mean flows for the winter months from 1972 to 2010 increased to 133 m^3/s. The mean summer flows have correspondingly decreased from 339m^3/s to 245 m^3/s.

3. Equipment Setup and Procedure

Several different types of cameras were installed along the river to document surface ice conditions. Twelve automated time-lapse cameras were deployed from stations 9.2 to 63.9 km (Figure 1). Although most of these cameras had built in flashes, only those situated right at river level (stations 56.2, 57.1 and 63.9 km) were able to detect even partial ice conditions at night. In addition, the Department of Earth and Atmospheric Sciences operated two web cameras on top of the Tory Building at the University of Alberta, at river station 39.5 km. One of these was an Axis network camera (looking upstream), capable of collecting high resolution night photographs. The other (looking downstream) was a Campbell Scientific CC640 which took low resolution daytime photographs only. As Figure 1 illustrates, particular attention was focused on the open water lead downstream of the Goldbar Wastewater Treatment Plant (which extends from 50.3 km to ~63.9 km), especially in the vicinity of the instream instrumentation at 56.8 km. In particular, a Canon EOS5D single lens reflex (SLR) camera, synchronized with floodlights to facilitate the collection of night images, was situated at station 56.8 km along with two Campbell CC640 web cameras.

Figure 2 illustrates the river bathymetry (surveyed on 15-May-10) and the locations of the instruments placed in the river. These included a high (545 kHz) and a low (235 kHz) frequency SWIPS and an Aquadop acoustic Doppler current profiler (ADCP). The acoustic instruments were mounted on a steel platform covered with Teflon sheeting, and were deployed from a boat prior to freeze-up. They were positioned approximately 50 m from the right bank so as to be within the open lead throughout the winter. The communication cables from each of the three instruments were strapped together and run along the bed and up the bank to a small trailer containing control computers.

Both SWIPS logged data at a 1 Hz interval and used a 9.1mm bin size. The high frequency SWIPS initially used a pulse length of 34 μs, this was switched to 68 μs on 5-Jan-11 to explore if it would improve suspended frazil ice detection. The low frequency SWIPS employed a pulse length of 68 μs throughout the entire season. The SWIPS gain settings at deployment were set to one for the low frequency and three for the high frequency. On 21-Dec-10 the low frequency gain was adjusted to four and on 5-Jan-11 the high frequency gain was set to three. The gain settings were increased to determine if it would improve the detection of frazil ice in the open lead. It was found that the adjustment of gain and pulse length did not have significant impact upon the performance of the high frequency SWIPS. The increase in gain on the low frequency slightly improved the detection suspended frazil ice. The ADCP collected 3 dimensional velocity profiles at a rate of 1 Hz averaged into 5 minute intervals with a 10 cm bin size. Data was logged both internally by each individual unit and in real-time on computers in the small trailer situated on the adjacent river bank.

Water temperatures sensors were deployed at various sites along the study reach to collect data throughout the winter. Each of the acoustic instruments (the two SWIPS and the ADCP) were equipped with temperature sensors. In addition, a water temperature sensor (recording at 5 minute intervals) was deployed approximately 20 meters away from the bank at this same site (Figure 2) to capture any thermal pulses that might occur in response to local outflows from the power plant here. Combined water temperature and water level sensors (Schlumberger D1501-10 m Minidivers) were also deployed along the river upstream and downstream of the instrument site (Figure 1), taking measurements at 5 minute intervals. Not all of these sensors have yet been retrieved, due to unusually high water levels on the North Saskatchewan River this spring and summer. The water temperature readings from the low frequency SWIPS are shown in Figure 3, along with air temperatures (Environment Canada, 2010a) and water levels at the Water Survey of Canada WSC gauge at 42.8 km (Environment Canada, 2010b).

4. Results and Discussion

The 2010/11 freeze-up progressed rapidly from initial frazil pans to a complete ice cover. This was due to a prolonged period of cold weather (Figure 3(a)) beginning on 16-Nov-10 and lasting until 24-Nov-10. The first frazil pans at the instrumentation site (station 56.8 km) appeared at 15:30 on 16-Nov-10. The freeze-up front passed the acoustic instruments at station 56.8 km at 23:30 on 19-Nov-10. The entire river within the Edmonton city limits had a complete ice cover by 23-Nov-10. The rise in water level caused by the passing freeze-up front can also be seen in Figure 3c. The treatment plant open lead melted out the ice cover rapidly, as be seen in Figure 7 where the ice surrounding the outfall is melted within a hour of the ice passing. From the waste water treatment plant, the open lead melted through 6.5km of ice expose the instruments at station 56.8 km to open water at 22:00 on 26-Nov-10. For the remainder of the winter, the tail of this open lead oscillated upstream and downstream of the cameras located at station 63.9 km. The distance the open lead tail oscillated over is unknown as no additional camera stations were installed downstream of station 63.9 km.

The camera photographs were analyzed qualitatively to characterize the progression of freeze-up. The islands and mid-channel bars in the reach upstream of the Highway 216 bridge exhibited substantial border ice and thermal ice growth as illustrated in Figure 5(a,b,c,d). Between station 9.2 and 19.3 km, a bridging event occurred three days prior to the arrival the downstream ice front (Figure 5). This was due to the mid-channel bars and islands of the upstream reach which provide multiple bridging locations for a developing ice cover. In the downstream reach, border ice growth was negligible; ice features during freeze-up were restricted to frazil pans, rafts and the freeze-up front. Figure 6 (a,b,c,d) and Figure 7(a,b,c,d) shows the progression of freeze-up from frazil ice pans to an intact ice cover at two locations in the reach downstream of the highway 216 bridge. In the downstream reach, the freeze-up progressed in a linear fashion from frazil pans to rafts to a complete ice cover. This was seen in the observations of Gerard and Andres (1982) who noted that the ice cover initially forms downstream of Edmonton and progresses steadily upstream.

The SWIPS instrument data recorded the evolution of freeze-up at station 56.8 km. It was found that the first frazil event occurred at 08:00 on 17-Nov-10; this event lasted about six hours and was accompanied by an increase in frazil pan concentration. A second larger frazil event occurred at 16:30 on 18-Nov-10 and continued overnight until 07:00 on 19-Nov-10.

In total, the high frequency SWIPS detected 2 freeze-up frazil events and 32 open lead frazil events. These events were of varying intensities and were qualitatively classified as light, medium or heavy. Figure 8 and Figure 9 give examples of a heavy intensity frazil event detected by both the high and low frequency SWIPS. In this case both the SWIPS units were able to detect the frazil particles; however the high frequency detects a greater number of particles and at closer to the water surface. Figure 10 and Figure 11 gives examples of a light intensity event, detected by the high and low frequency SWIPS. In this case, the low frequency does not detect the frazil particles in any detail while the high frequency gives clear results. This difference in detection between the high and low frequency SWIPS has been documented in previous studies (Ghobrial et al. 2009a, 2009b and 2010).

Based upon the preliminary analysis of the high frequency SWIPS instrument data, frazil events began occurring at air temperatures below -6°C, with super-cooled water. At other times, air temperatures of -15°C were recorded along with super-cooled water, yet no frazil was detected by the SWIPS or visually. It appeared that frazil had a greater likelihood of forming during the morning hours of 06:00 to 12:00 or during snowfall events. The frazil events shown in Figure 8 through 11 are marked on the air temperature graph in Figure 3(a). While both events occurred at air temperatures of around -20˚C, the 13-Jan-11 was of light intensity and the 17-Feb-11 event was of heavy intensity. There was no correlation found between the intensity of the open lead frazil events and the air temperature. It was also found that snowfall increased the probability of frazil forming, however once again there was no detectable correlation between snowfall and frazil event intensity.

5. Summary

As northern communities continue to develop and expand, the potential for open lead frazil events to create problems for downstream water intakes will only increase. An understanding of the parameters required for frazil formation will become more important as this development advances. This paper documented a study of the winter ice regime on the North Saskatchewan River at the City of Edmonton. This study had two objectives; to characterize freeze-up within the city limits and to study the occurrence of frazil events in an open lead. Using automated time lapse cameras, shallow water ice profiling sonars and acoustic Doppler current profilers the 2010/11 ice processes of this urban river were documented as along with the occurrences of the frazil events in an open lead.

This study only covered the 2010/11 winter season and the results are based upon a preliminary analysis. While additional monitoring seasons may add to this data, some conclusions can be drawn. The North Saskatchewan River within Edmonton can be divided into two reaches, separated by the Highway 216 bridge. This division is due to the geomorphological characteristics of the reach. In the upstream reach, islands and mid-channel bars provide multiple locations for frazil pan or rafts to bridge and form an ice cover. In the reach downstream of the bridge freeze-up progressed sequentially from downstream to upstream without premature bridging as there are no mid-channel features to obstruct the flow of ice. Fewer conclusions can be drawn about the open lead frazil events without further analysis. Frazil ice can begin to form at air temperature below -6°C. During snowfall events and in the hours between 06:00 and 12:00 frazil in the open lead is more likely to form. Lower air temperatures or the occurrence of snowfall did not correlate with increased frazil event intensities.

6. Acknowledgments

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7. References

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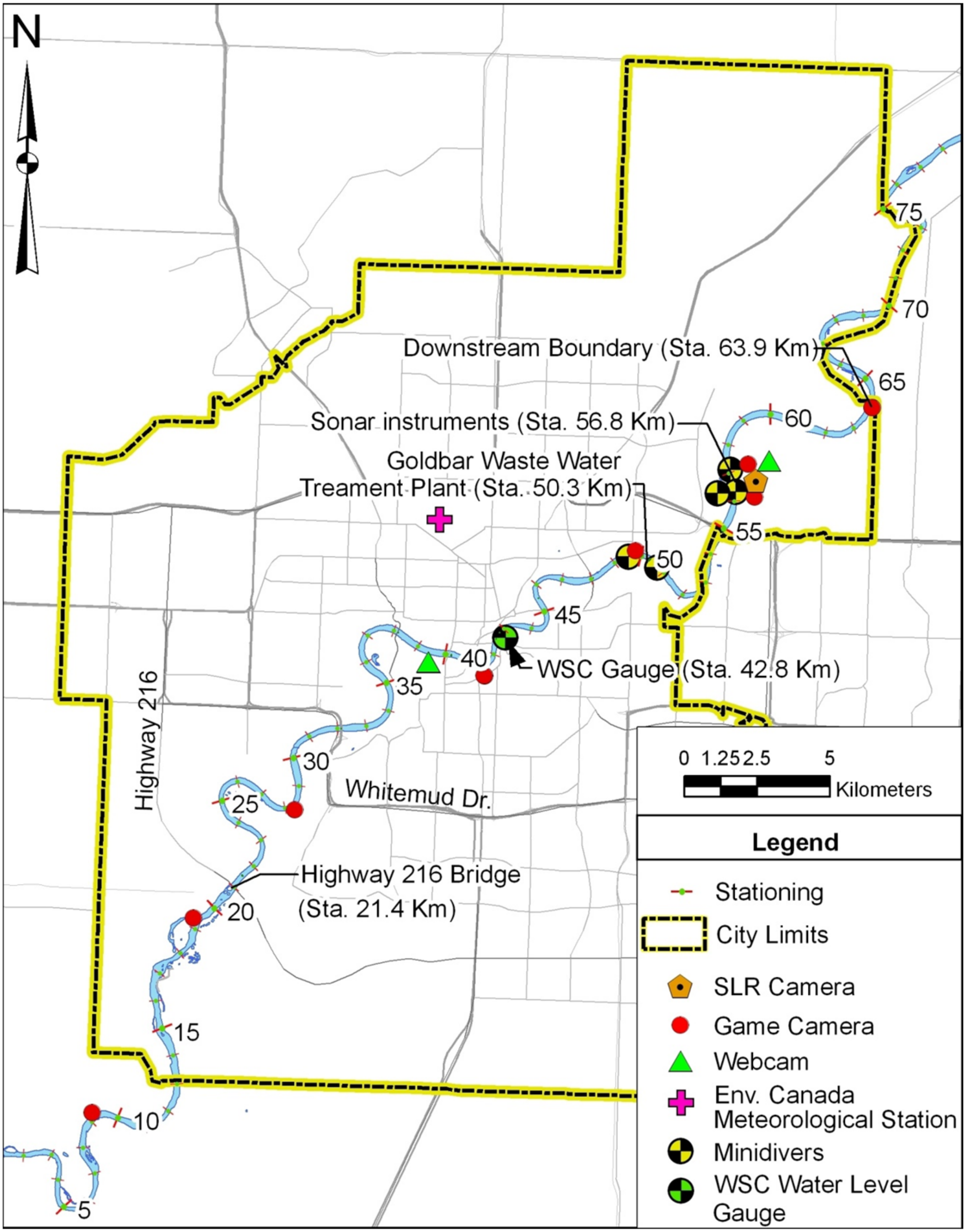


Figure 1. Locations of cameras and instruments along the North Saskatchewan River at Edmonton.

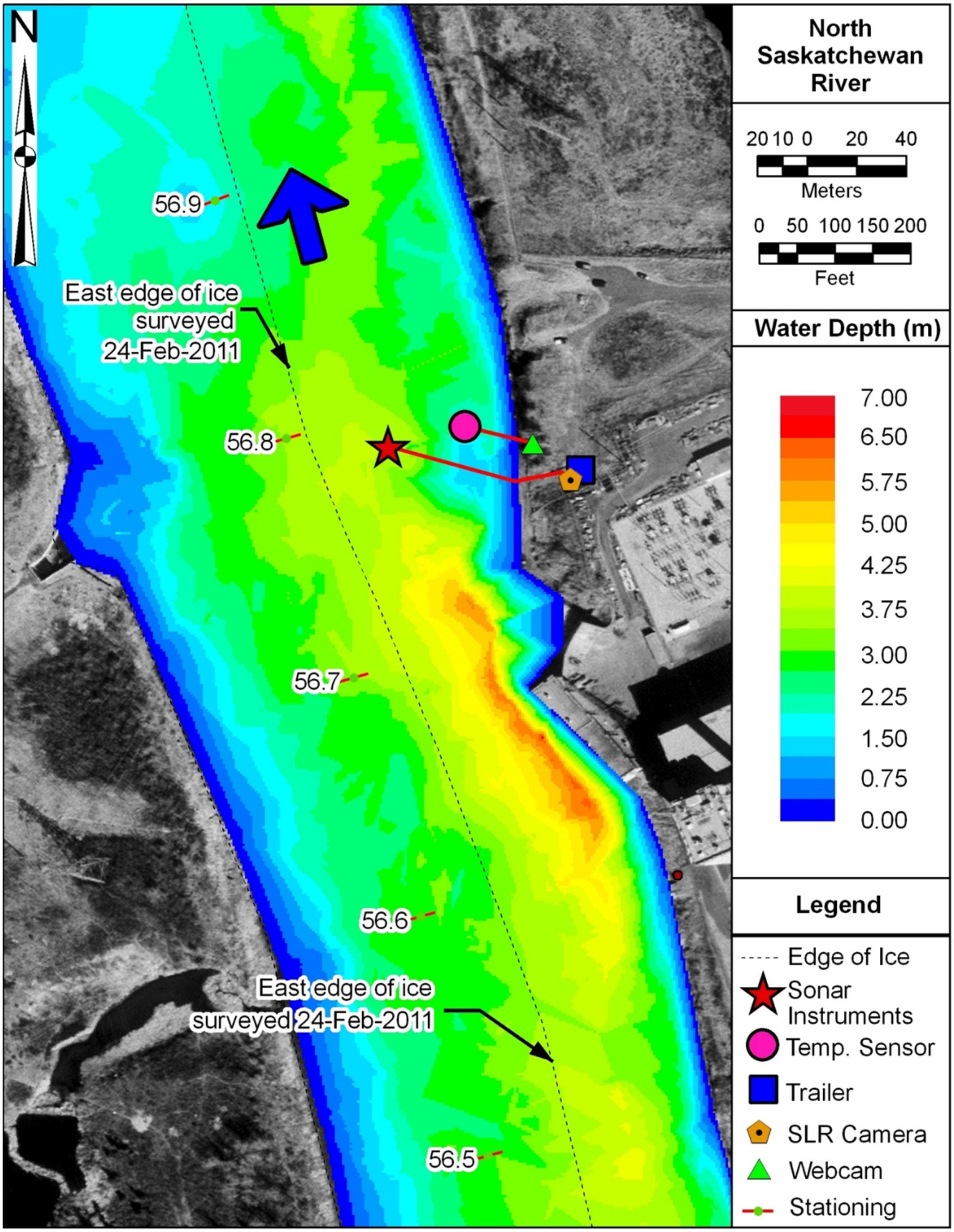


Figure 2. Location plan for in-stream sonar instrumentation site.

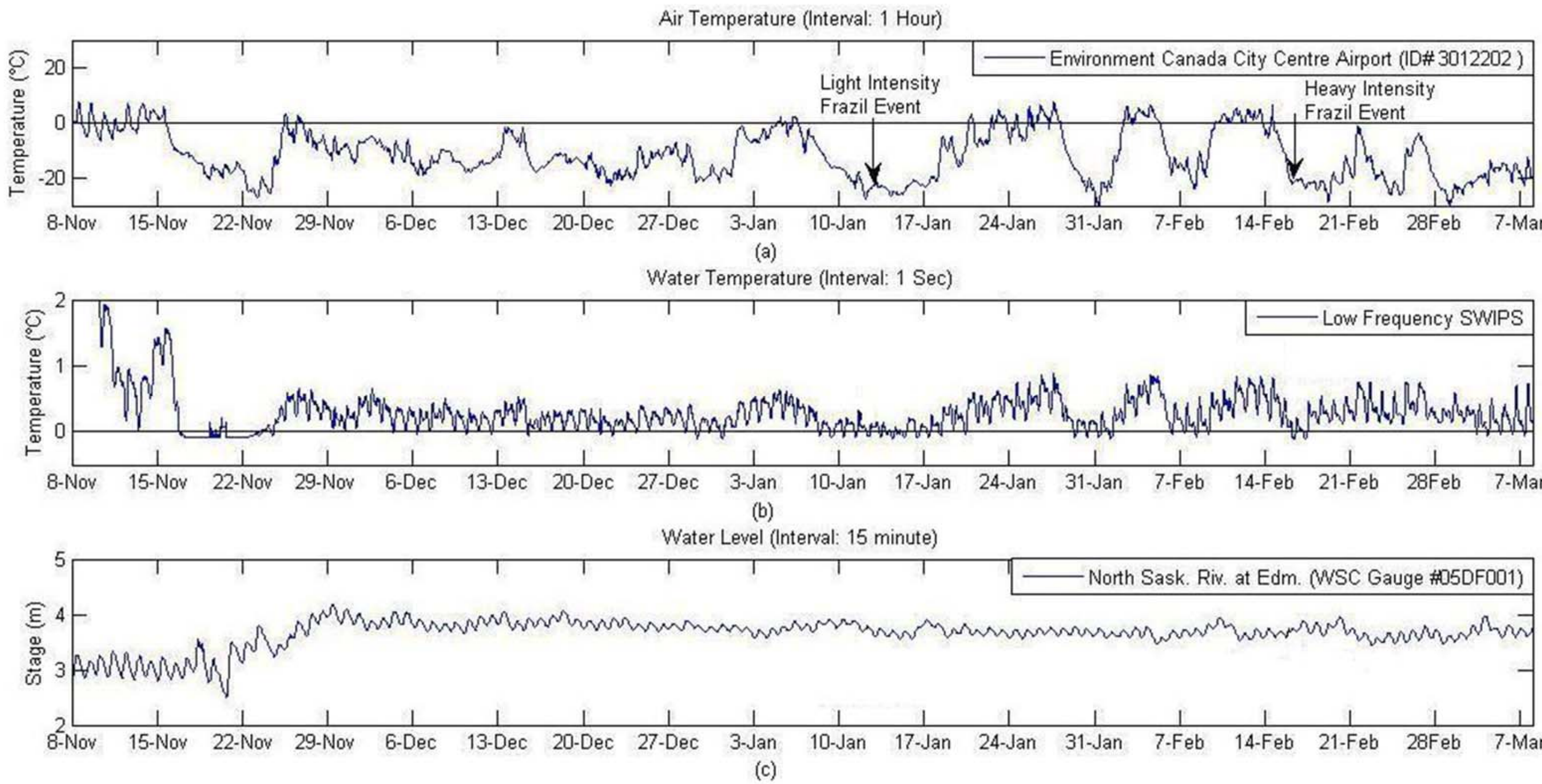
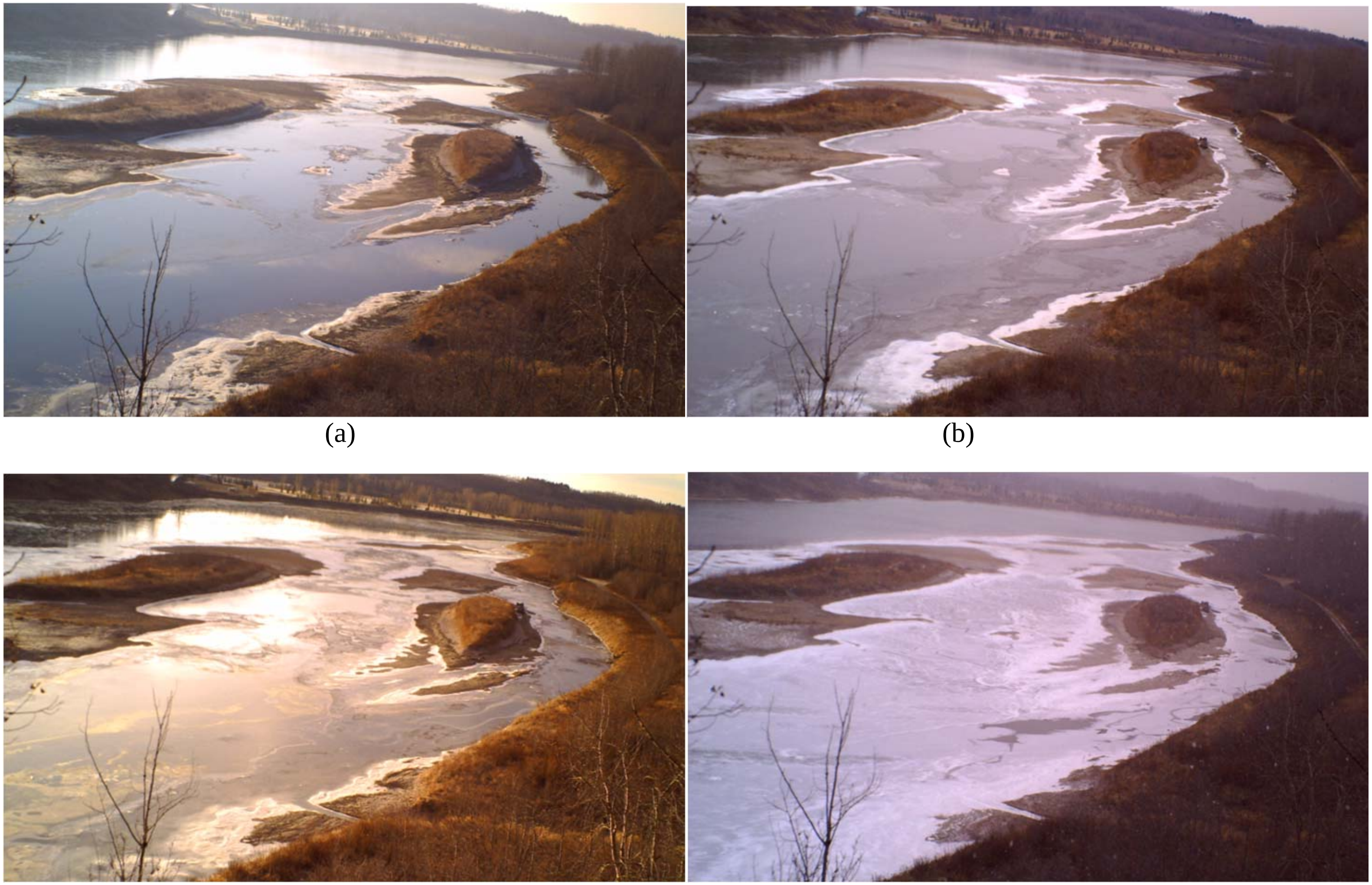


Figure 3. Air (Environment Canada, 2010a) and water temperatures presented with water level (Environment Canada, 2010b).

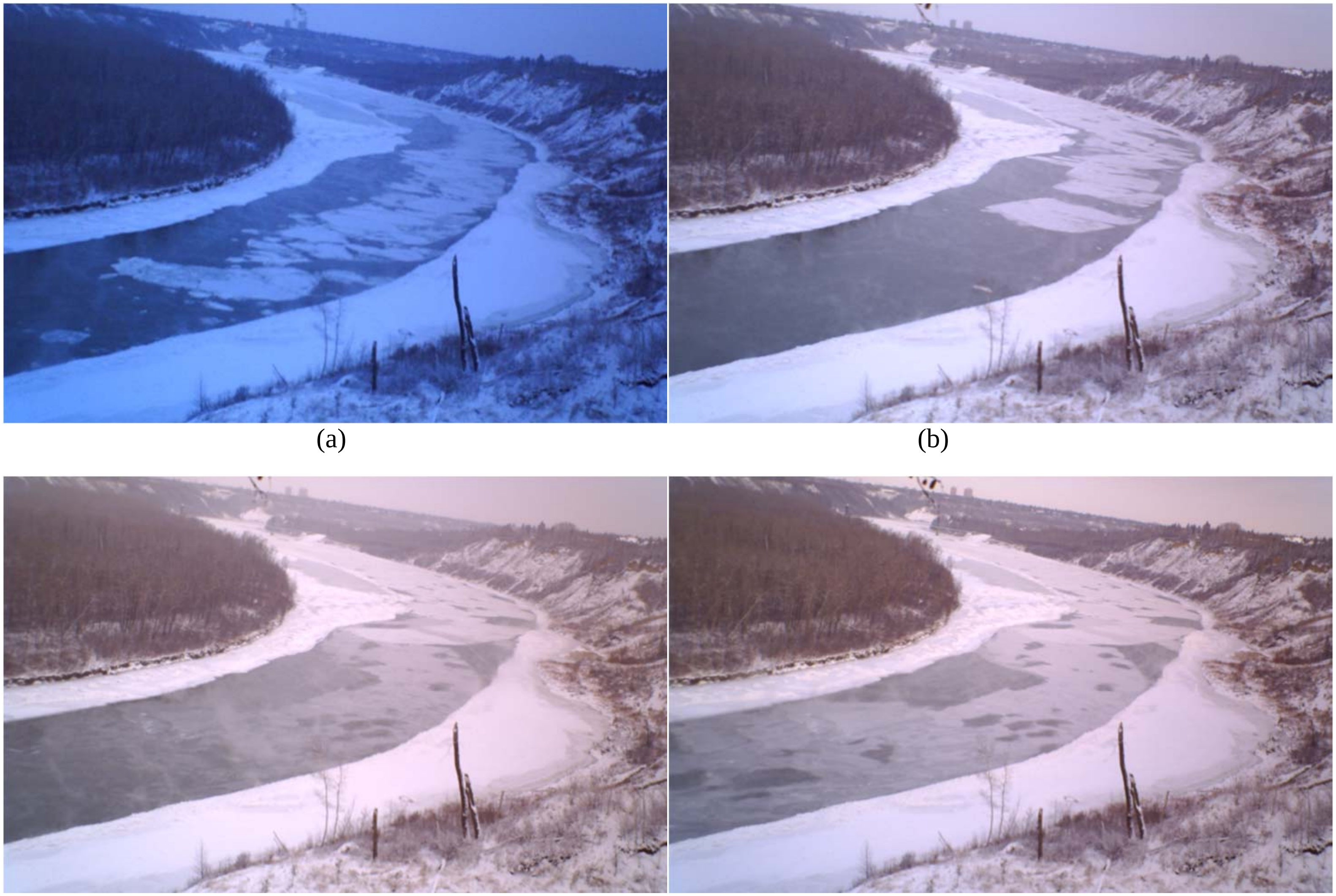


(a) (b)

(c) (d)

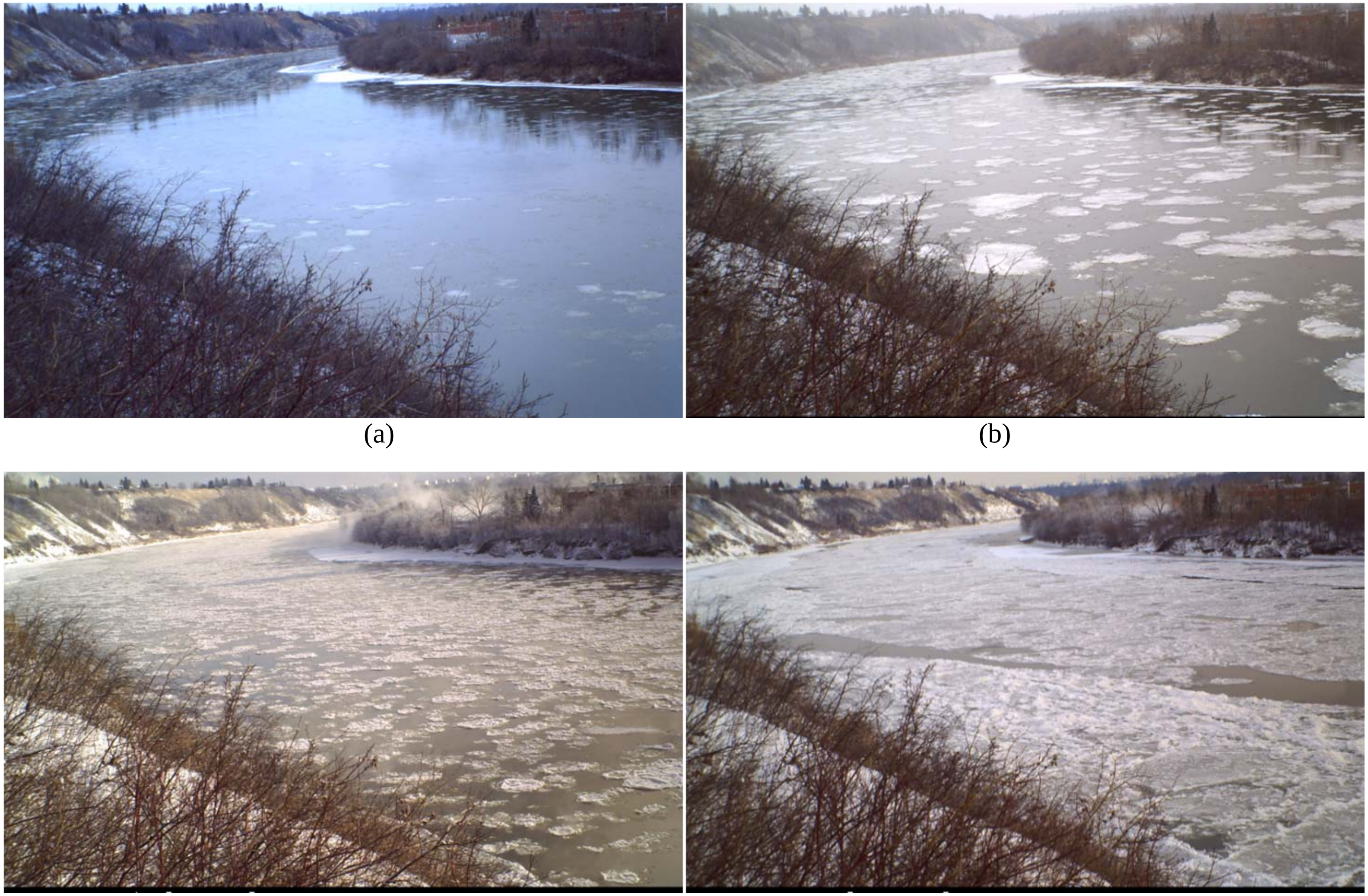
Figure 4. Images illustrating thermal freeze-up of upstream reach of river from a game camera located at Sta. 19.3. (a: 10:00 10-Nov-2010; b: 09:00 on 12-Nov-10; c: 09:00 on 13-Nov-10; d: 15:00 on 16-Nov-10)

Figure 5. Image from camera at station 9.2 km depicting freeze-up front caused by downstream bridging event. (12:00 on 21-Nov-10)



(a) (b) (c) (d)

Figure 6. Images recording freeze-up front passing camera located at station 28.2 km. (a: 08:00 22-Nov-2010; b: 09:00 on 22-Nov-2010; c: 10:00 on 22-Nov-2010; d: 11:00 on 22-Nov-2010)



(a) (b) (c) (d)

Figure 7. Images showing freeze-up front passing Goldbar waste water treatment plant at station 49.8 km. (a: 16:00 16-Nov-10; b: 11:00 on 17-Nov-10; c: 13:00 on 19-Nov-10; d: 15:00 on 20-Nov-10)

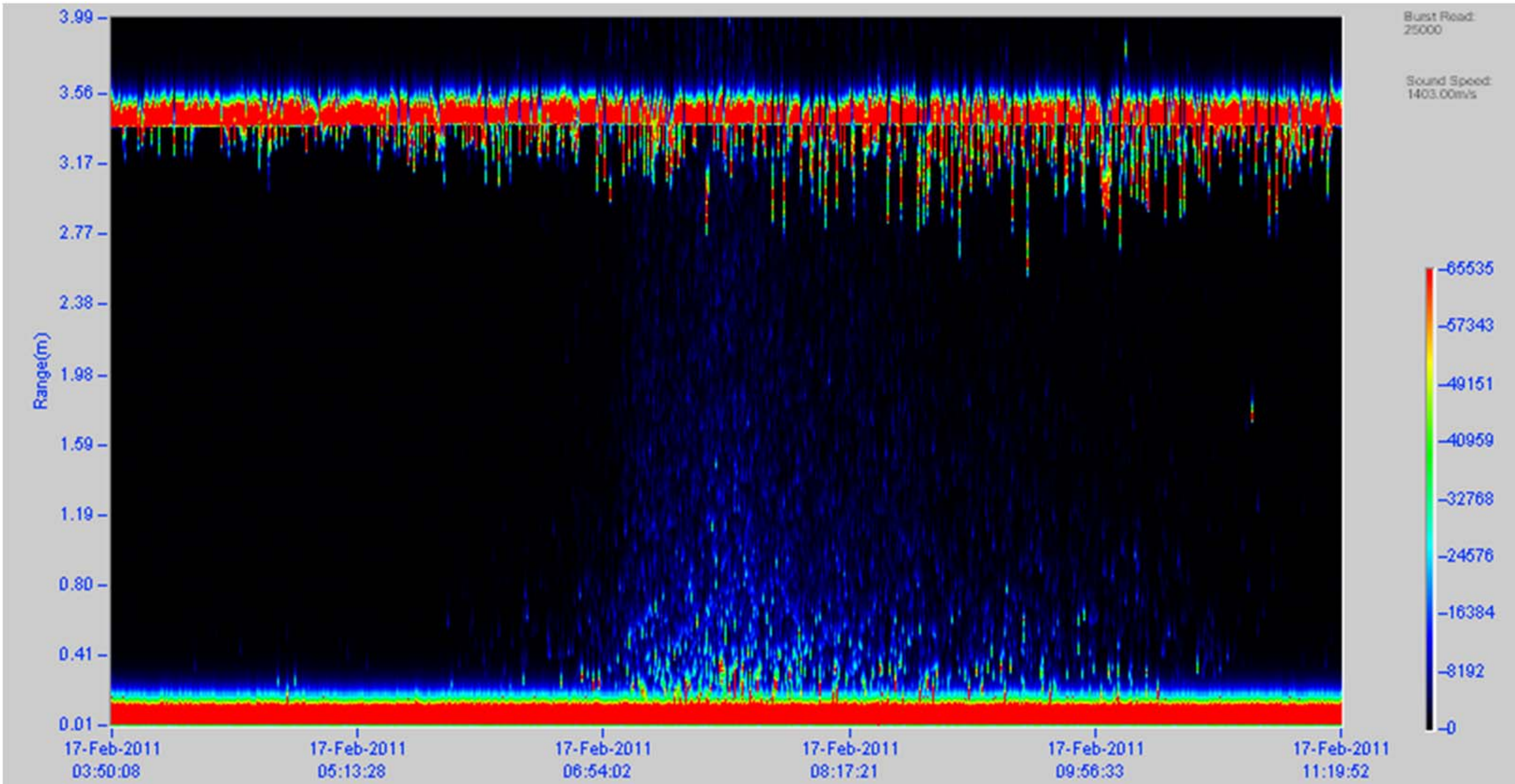


Figure 8. High frequency SWIPS data for a heavy intensity frazil event on 17-Feb-11.

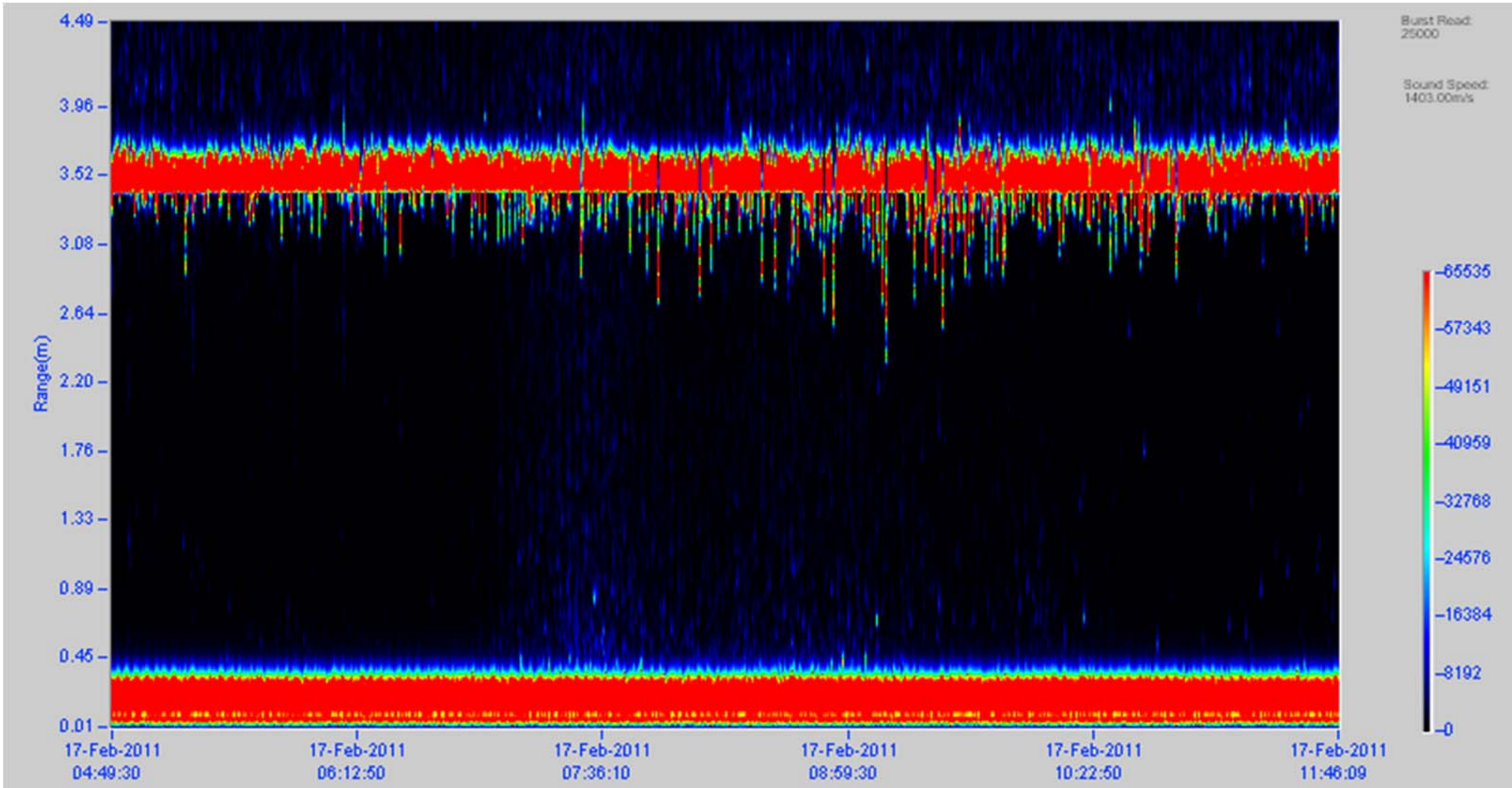


Figure 9. Low frequency SWIPS data for a heavy intensity frazil event on 17-Feb-11.

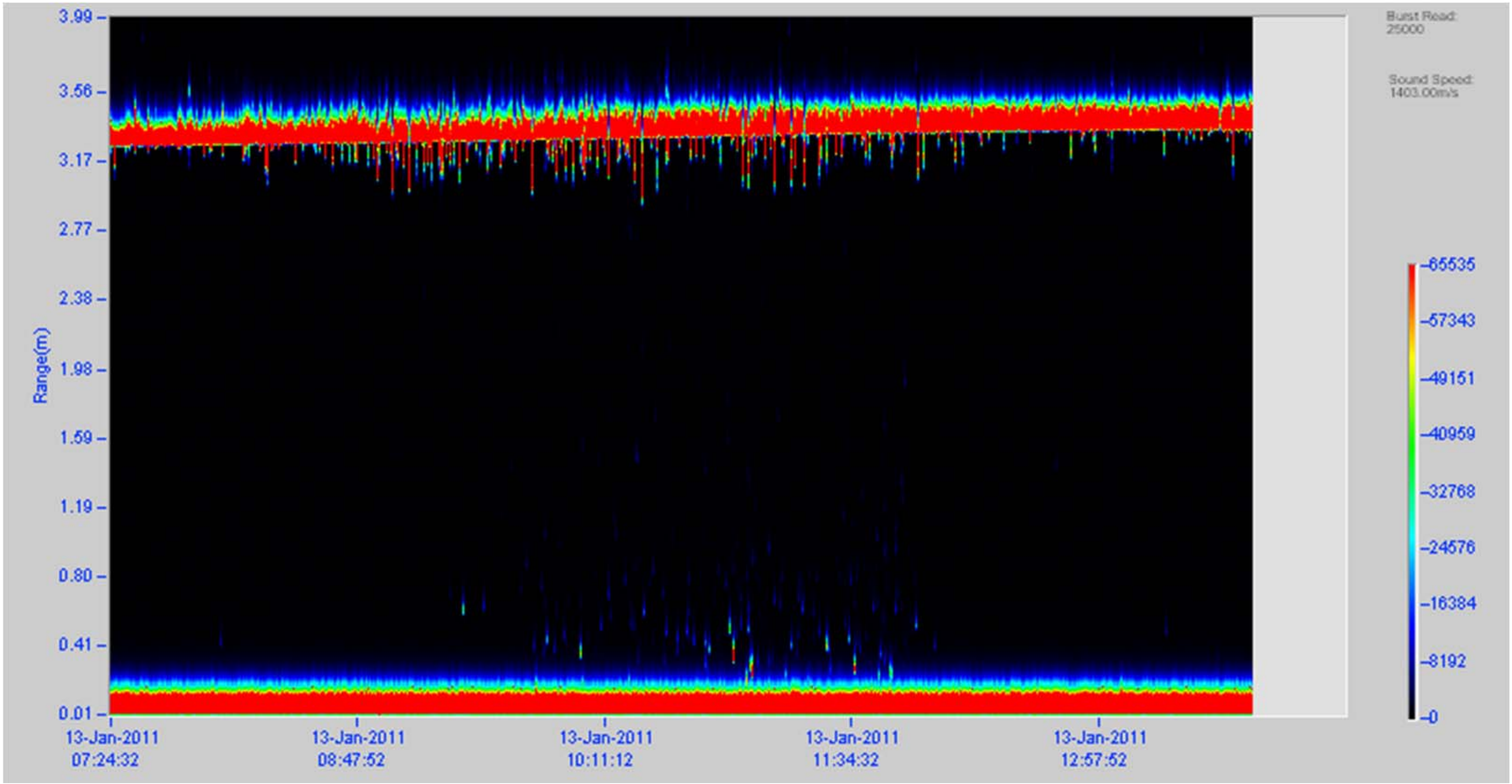


Figure 10. High frequency SWIPS data for a light intensity frazil event on 13-Jan-11.

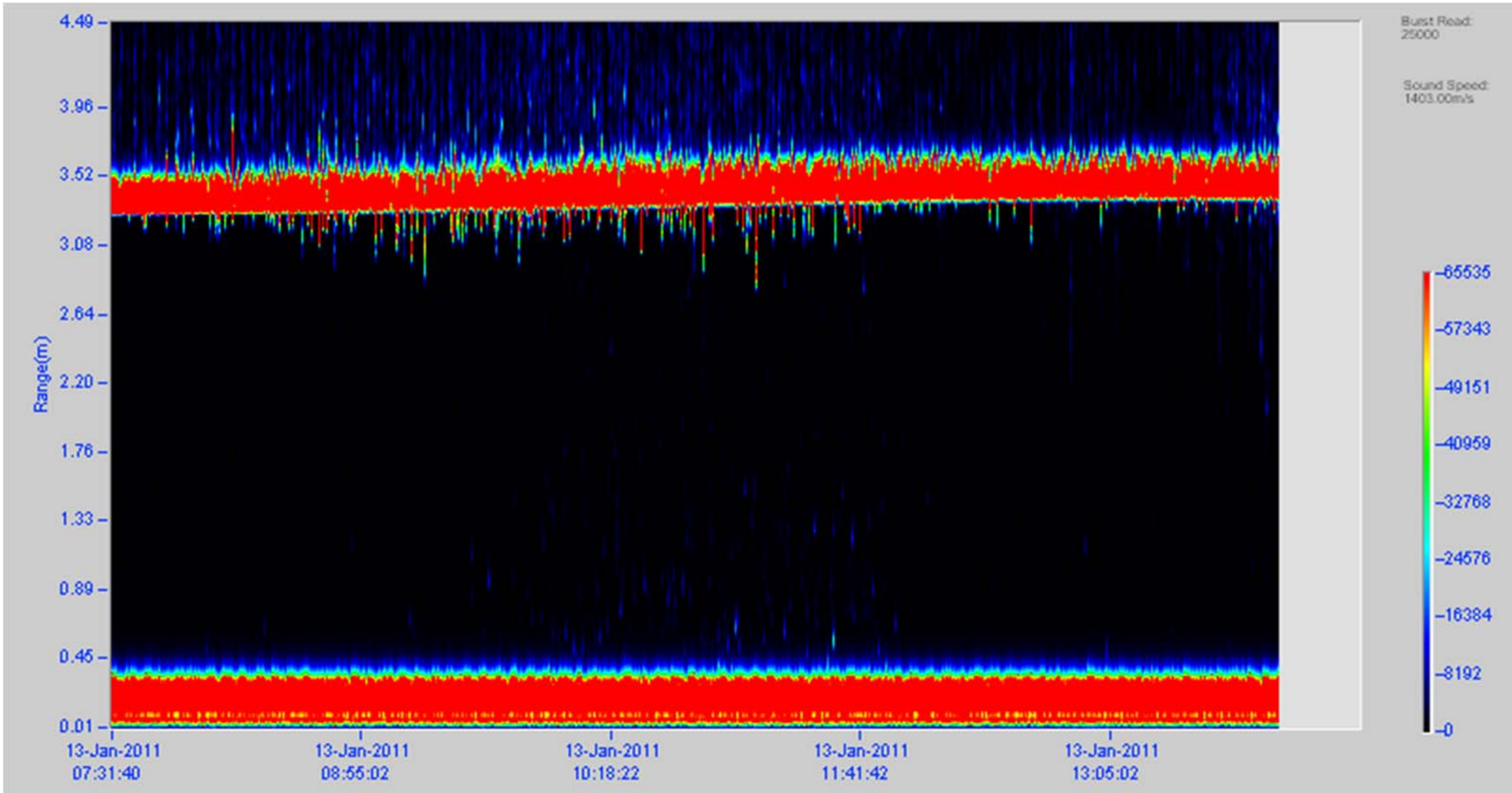


Figure 11. Low frequency SWIPS data for a light intensity frazil event on 13-Jan-11.