3D ground-penetrating radar over ice at Bowness Park, Calgary

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ABSTRACT

Ground penetrating radar (GPR) studies were conducted at Bowness Park, Calgary to study the character and thickness of ice and the shallow subsurface. We used Sensors and Software Inc.'s 250 MHz NOGGIN and Smart Cart system. A 3D GPR survey was conducted over a frozen lagoon at Bowness Park in Calgary. Hyperbolic velocity analysis gave ice velocities of about 0.15 m/ns with velocities decreasing into the sediments to about 0.11 m/ns. We interpret the ice thickness to be about 0.4 m from the GPR, which is consistent with auger holes drilled through the ice. Channel sediments and stratigraphy beneath the ice are interpretable from the 3D radar reflectivity. Penetration of the 250 MHz data reached about 4 m at several locations in the area.

INTRODUCTION

Ground penetrating radar (GPR) can be a useful tool for mapping the character of near-surface sediments and ice. Ice is largely transparent to radiowave signals whereas ice-sediment or ice-water interfaces can be quite reflective.

A 3D GPR survey was conducted over a frozen lagoon at Bowness Park in Calgary. We were interested in determining the ice thickness over the lagoon and imaging the fluvial sediment environment beneath the ice. We also acquired a line over the frozen land north of the lagoon.

Bowness Park is situated in NW Calgary, on the south side of the Bow River and covers about 30 hectares of land. Much of the topographic relief in the City of Calgary is a result of Quaternary rivers downcutting through the near-surface Paleocene units. Lithologically and stratigraphically the area is composed of unconsolidated sediment, mostly tills, glaciolacustrine deposits and alluvium, overlying sandstone and shale (Osborn and Rajewicz, 1998).

The survey covered a surface of 25 m by 45 m (Figure 1). We acquired 26 N-S lines, set 1 m apart. These lines were acquired in a forward and reverse manner (every second line was collected in the reverse direction to increase data acquisition speed). The data were collected with Sensors and Software Inc.'s NOGGIN 250 MHz system. The centre frequency was 250 MHz, and the separation of the antenna was 28 cm. A trace was acquired every 10 cm. All of the data were acquired using a single-offset.

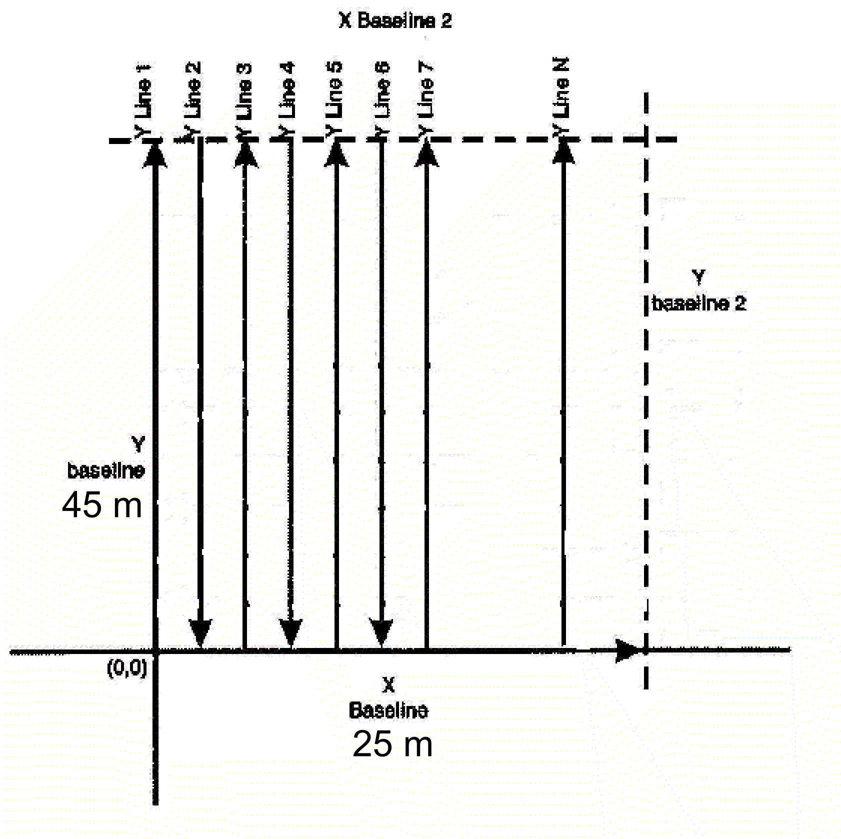

FIG. 1. Grid surveying pattern on the lagoon at Bowness Park. The X baseline has a length of 25 m and Y baseline has a length of 45 m. We acquired 26 lines parallel to the Y baseline (N-S direction).

To process the data, we used Win EKKO and EKKO Mapper software, from Sensors & Software Inc. Plan-view maps of the near-surface structure at different times and depths were computed to analyze the horizontal distribution of the subsurface features. A 3D volume cube was assembled using the Sensors & Software's 3D analysis package.

DATA ANALYSIS

The GPR data acquired over the frozen lagoon at Bowness Park are of good quality. We interpret a reflection from the bottom of the ice and also reflections from the sediments beneath the ice (Figure 2).

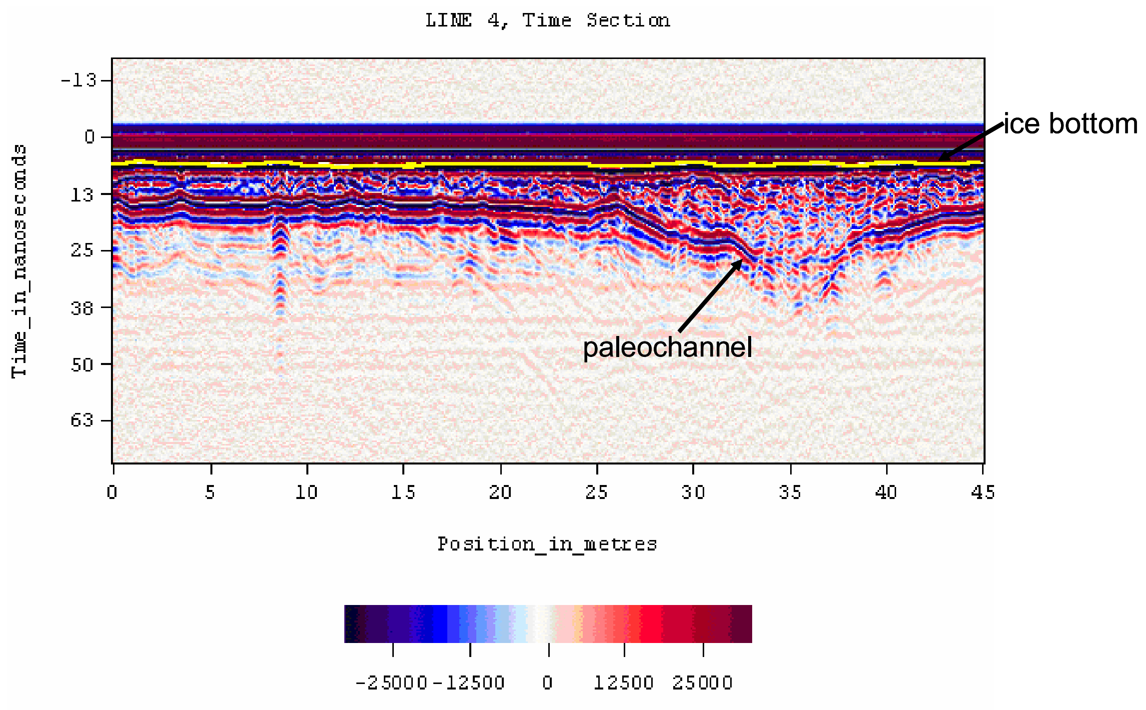

FIG. 2. A 2D line from the 3D survey acquired over the frozen lagoon at Bowness Park, Calgary.

Horizontal bedding and channel structures are evident deeper in the data and we were able to identify these on the 3D volume (Figure 3).

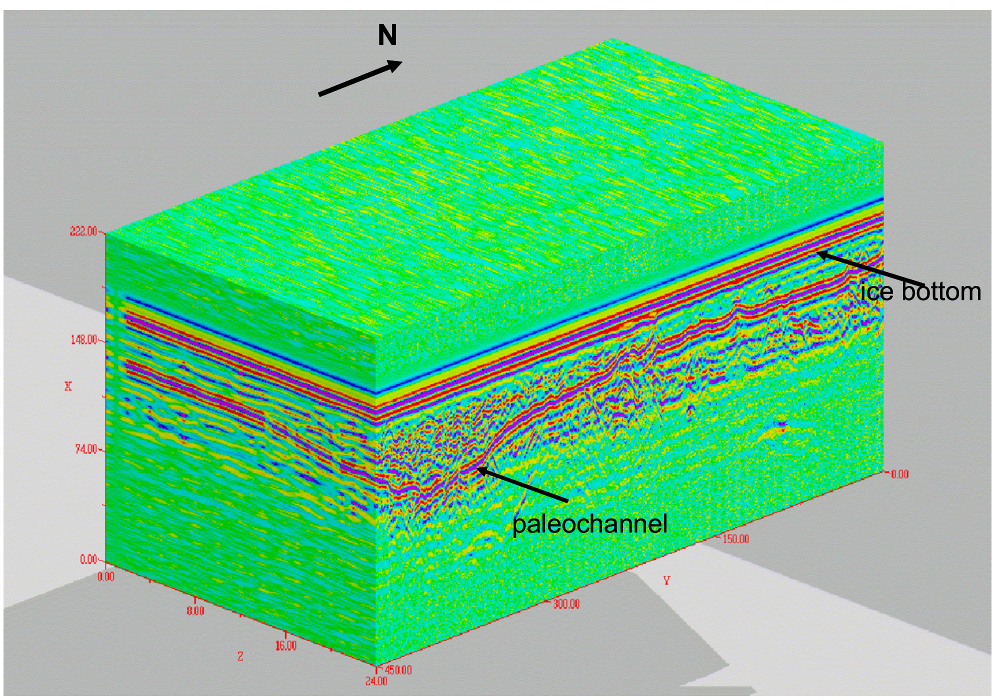

FIG. 3. The 3D volume of the lagoon data, viewed from the south. A paleochannel is indicated in the south-east part of the volume.

Dipping structures that are an indication of sediment deposition in a fluvial environment are also evident on lines acquired over frozen land several hundred meters north of the lagoon (Figure 4).

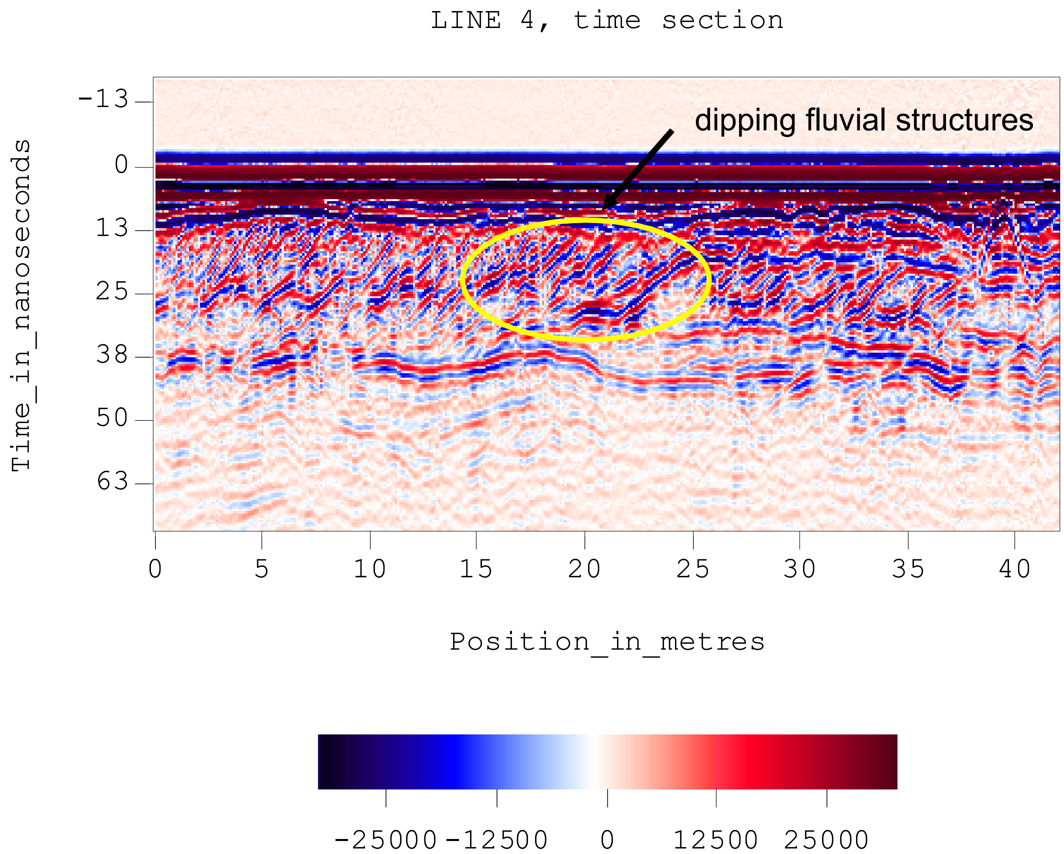

FIG. 4. A 2D line acquired over frozen land at Bowness Park, Calgary. Dipping structures indicate deposition in a fluvial environment.

We have used some of the GPR data processing steps as outlined by various authors (e.g. Young et al., 1995, Fisher et al., 1996, Peretti et al., 1999).

Processing steps used to analyze these data were: temporal filtering (DEWOW) to remove very low-frequency components, time gain (an automatic gain control was applied) to compensate for the rapid attenuation of the radar signal and to enhance deeper reflectors, and background subtraction to remove the air and ground wave from the time section and enhance shallow reflections. As expected in Figures 2 and 5, the effect of the background subtraction filter was to enhance the dipping events. This worked well in eliminating the air and the ground wave, but also eliminated the horizontal reflections that are part of the structure; therefore, subtraction sections were used only to analyze the dipping and shallow events that were compromised by noise.

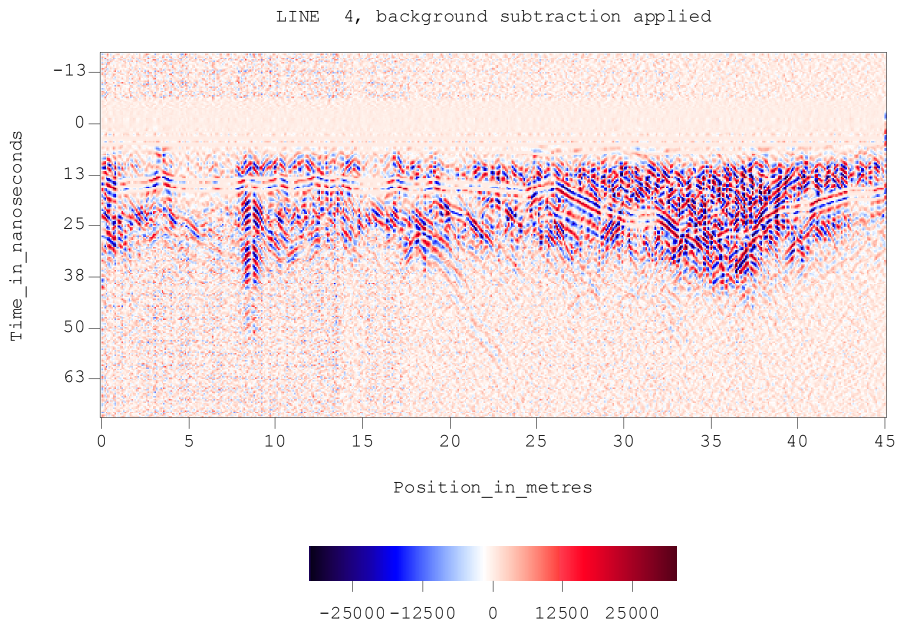

FIG. 5. 2D line from the 3D survey acquired over the frozen lagoon at Bowness Park, Calgary. A background subtraction process was applied. This had the effect of “removing” the horizontal events and enhancing the dipping ones.

Migration is used to focus the hyperbolic responses of anomalies. A series of 2-D migration tests were performed with different velocities for ice. We found that velocities of 0.14 m/ns, 0.15 m/ns, and 0.16 m/ns gave good results. This is illustrated in Figure 6.

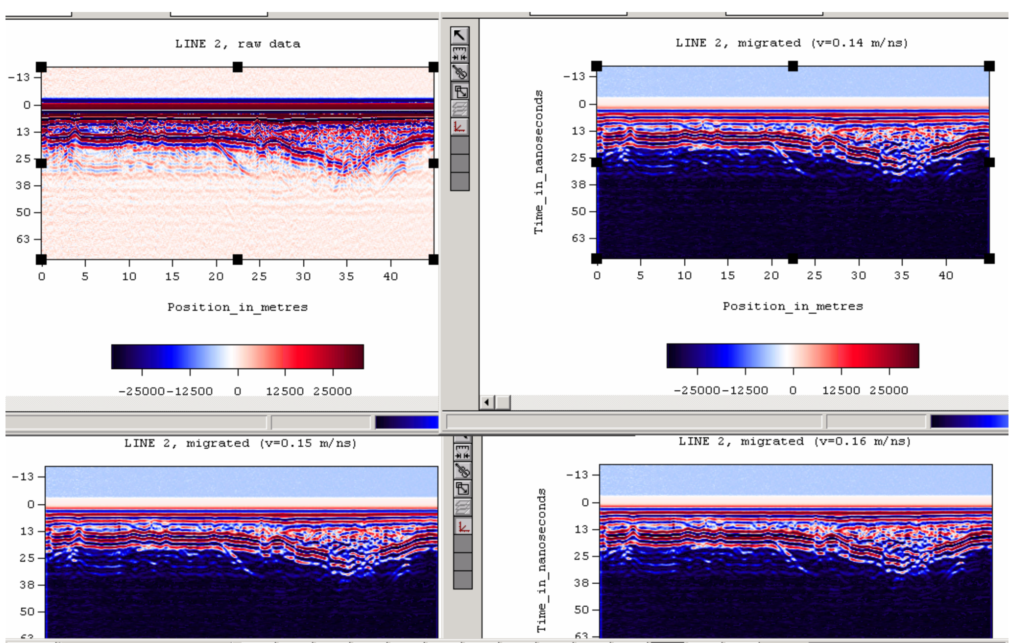

FIG. 6. Line 2 from the lagoon survey migrated with different velocities. In clockwise direction we have the time section of the raw data, and the same section migrated with velocities of 0.144 m/ns, 0.15 m/ns, and 0.16 m/ns.

The velocity value for ice, determined during acquisition by fitting a hyperbola, was 0.15 m/ns. Migrating the data with this velocity (Figure 7) provided a good image (i.e. the diffractions were collapsed and continuity increased).

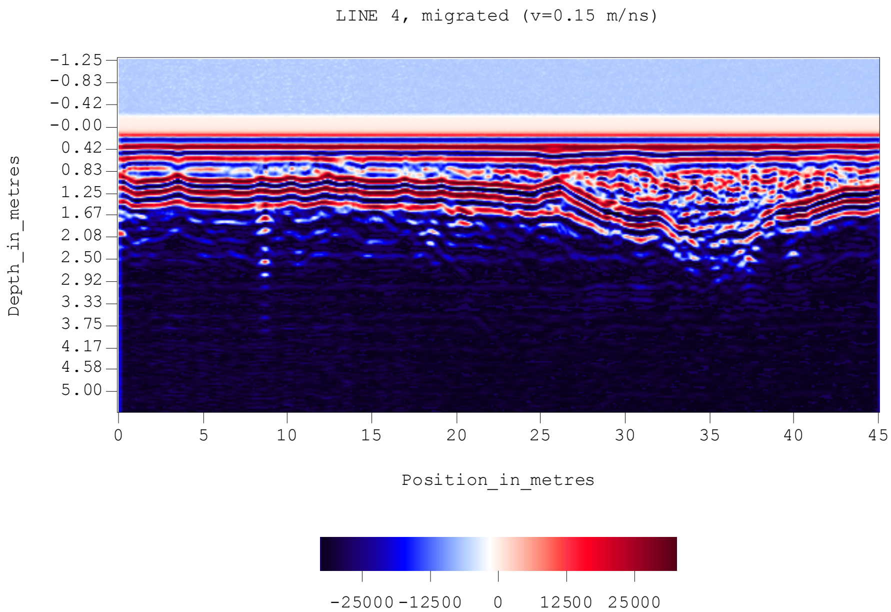

FIG. 7. 2D line from the 3D survey acquired over the frozen lagoon at Bowness Park, Calgary. The data were migrated with a velocity of 0.15 m/ns. The bottom of the ice is at 0.42 m depth.

We used this velocity to map the section to depth and interpret the event at 0.42 meters to be the ice bottom. Holes drilled through the ice gave a thickness of about 0.4 m. The maximum depth of penetration of the 250 MHz system is about 4 m (Figure 8).

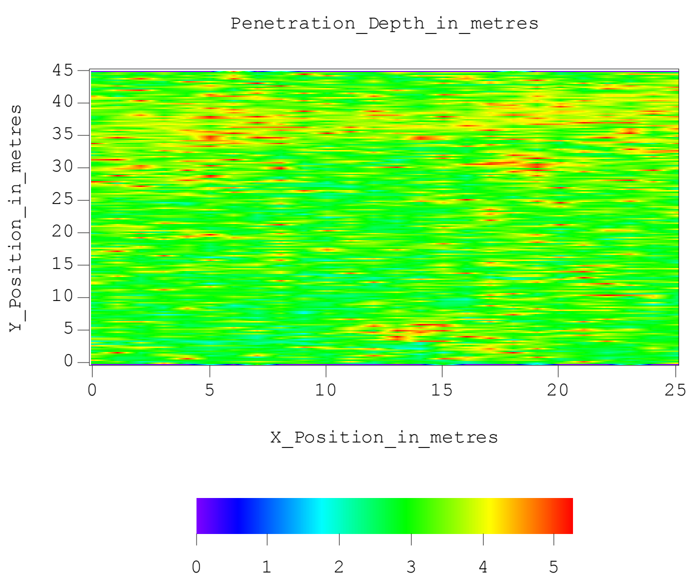

FIG. 8. Depth slice at about 4 m. This map gives the approximate maximum depth of event coherency.

Analysis of time slices creates maps of reflected wave amplitude differences within grid. The result is represented by a series of maps that illustrate the three-dimensional location of reflection anomalies. Areas of low-amplitude waves may indicate uniform matrix material or soils, while those of high amplitude denote areas of high subsurface contrast such as voids, or important stratigraphic changes (Conyers and Goodman, 1997).

On the six time slices computed (for 11, 28, 35, 47, 59, and 71 ns) we can see the horizontal distribution of the subsurface structure and we are able to determine the shape and orientation of the channel (Figure 9).

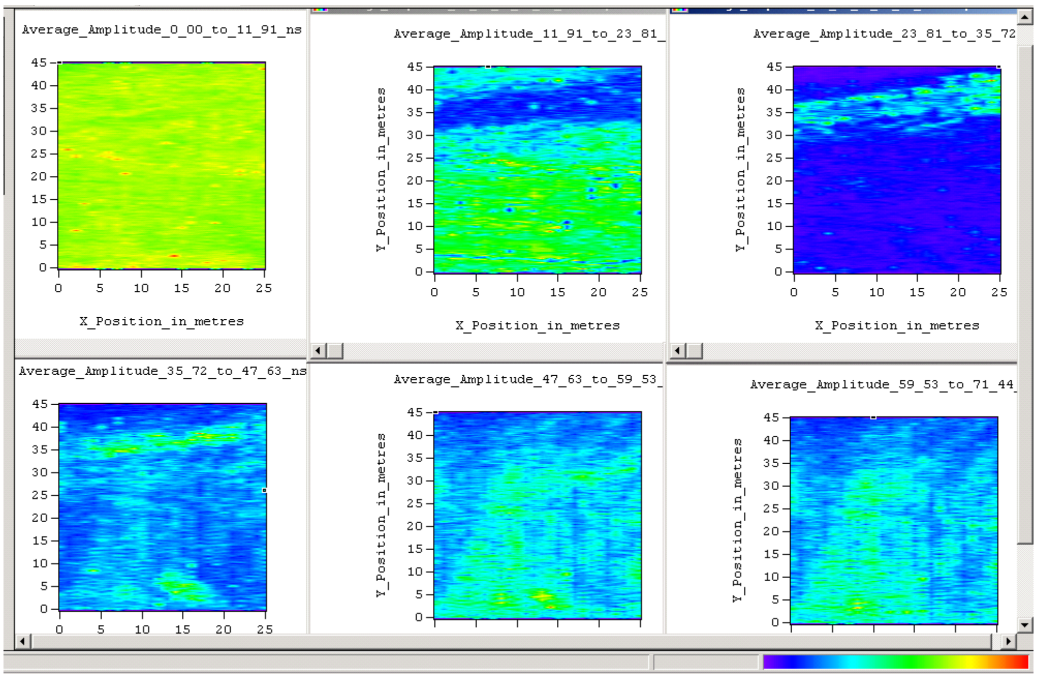

FIG. 9. Time slices of the grid acquired over the ice at Bowness Park. The amplitude increases from blue to red. On the first slice (11 ns) we can see high amplitude content, which is an indication of the high surface contrast (in this case the ice). The low amplitude content of the third slice indicates the soil. The channel identified on the 3D cube is well mapped on the time slices.

CONCLUSIONS

The GPR investigation method proved to be successful in determining the thickness of the ice and imaging the fluvial structures beneath the ice. From the GPR data acquired over the lagoon at Bowness Park we were able to determine that the bottom of the ice is at about 0.42 meters. This interpretation is supported by holes drilled through the ice. Velocity of the radar waves through ice was determined to be about 0.15 m/ns and the maximum depth from which we have information was 4 m. Analysis of the amplitude time slices assisted in determining the shape and orientation of the sedimentation channel identified on the 2D profiles.

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