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Simultaneous diffraction and reflection imaging framework on ground penetrating radar data from Antarctica

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Summary

Ground penetrating radar (GPR) is a commonly used technology for identifying and examining ice. The low electrical conductivity and the uniformity of ice covers provide GPR with exceptional signal penetration and, thus, the ability to reveal the internal layers of glaciers. To extract the necessary information, wavefield separation and imaging processing is required. This abstract presents a simultaneous diffraction and reflection imaging (SDRI) framework for ice detection using GPR data. The framework can extract hidden information in the recorded data by using wavefield separation and enhancement, for instance, the internal small-scale diffracted objects and the internal reflection layer. The traditional methods of processing and imaging data from GPR cannot provide a comprehensive understanding of the subsurface, particularly in Antarctica, due to the mutual interference between diffraction and reflection energy. This leads to the valuable geological information being concealed. The SDRI framework allows for information from both diffraction and reflection to be obtained without any interference. The diffraction method will focus on small-scale geological features while reflection will highlight large-scale structural information. The proposed SDRI framework has been applied to a field ice GPR data set from Antarctica, demonstrating its effectiveness in uncovering the hidden geology buried under the ice.

Simultaneous diffraction and reflection imaging framework on ground penetrating radar data from Antarctica

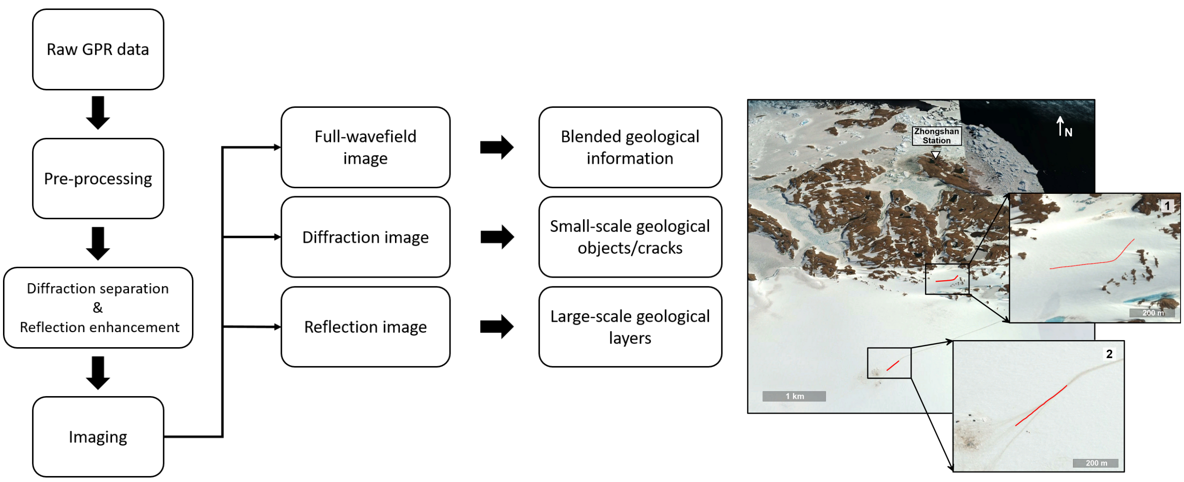
Introduction

Ground penetrating radar (GPR) is a commonly used and highly regarded technology for identifying and examining ice, as it allows for the collection of crucial information about subsurface ice conditions without the need for excavation or drilling. The low electrical conductivity of ice and the uniformity of ice covers provide GPR with exceptional signal penetration and, thus, the ability to reveal the internal layers of glaciers, which sets it apart from other methods used to study the earth's physics. Because of these advantages, GPR is widely used in scientific investigations of ice covers in the polar regions. It can help determine the position of the ice base and the thickness of the ice cover, as well as assess the total amount of ice in the cover and its impact on sea level rising (Zhao et al., 2016; Pfaffhuber et al., 2017).

The internal reflection layer morphology of the ice cover is a key target for ice GPR detection. It contains information about the flow process of the ice cover and the history of ice and snow deposition, making it a valuable climate record archive. In addition to the internal reflection layer, various diffraction bodies in the ice structure can also serve as a record of geological events that occurred during the historical deposition of ice and snow, similar to fossils (Guo et al., 2022). Ice cracks, caused by local shearing and stretching stress due to ice movement, can be found in both the surface snow layer and the depths of atmospheric and sea ice. Accurately detecting the position of these hidden cracks is crucial for conducting safe polar ground surveys. This abstract presents a simultaneous diffraction and reflection imaging (SDRI) framework for ice detection using GPR data. The framework can extract hidden information in the recorded data by using wavefield separation and enhancement, for instance, the internal small-scale diffracted objects and the internal reflection layer. Imaging them separately provides more information. The proposed SDRI framework has been applied to a field ice GPR data set, demonstrating its effectiveness in uncovering the hidden geology buried under the ice.

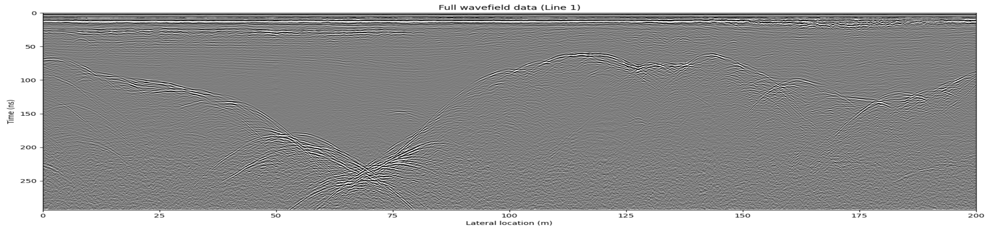
SDRI framework for ice detection

The proposed DRI framework for ice detection using GPR data is depicted in Figure 1(a). The process involves pre-processing the raw data, diffraction separation using plane-wave destruction (PWD), and reflection enhancement through structural filtering (Fomel, 2002). This results in three separate datasets: full wavefield, diffraction, and reflection. The migrated images are generated using FK domain migration assuming a 1D velocity profile (Stolt, 1978). Finally, the geological information can be interpreted based on the various datasets that target different geological targets.

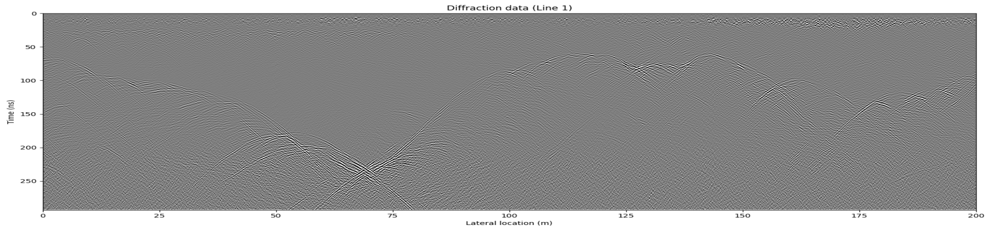


(a) (b)

Figure 1 *(a) The proposed SDRI framework for ice detection using GPR data. (b) Satellite image of the surveying area near Zhongshan Station.*



(a)



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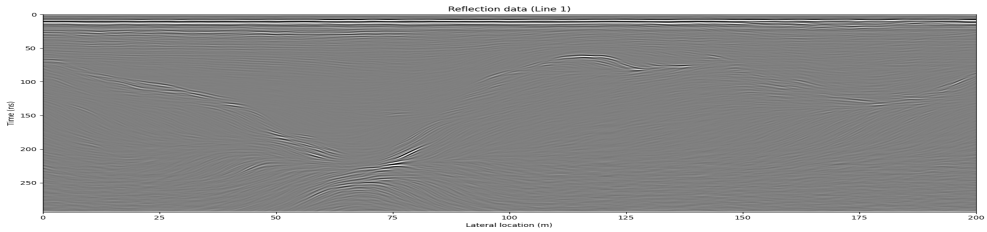


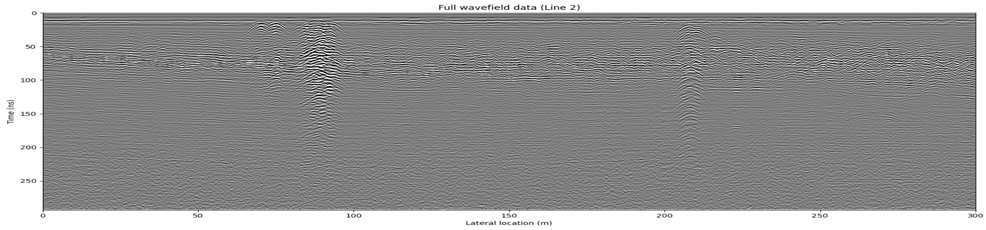
(c)

Figure 2 *GPR data sets along Line 1. (a) Recorded full wavefield. (b) Separated diffractions. (c) Enhanced reflections.*

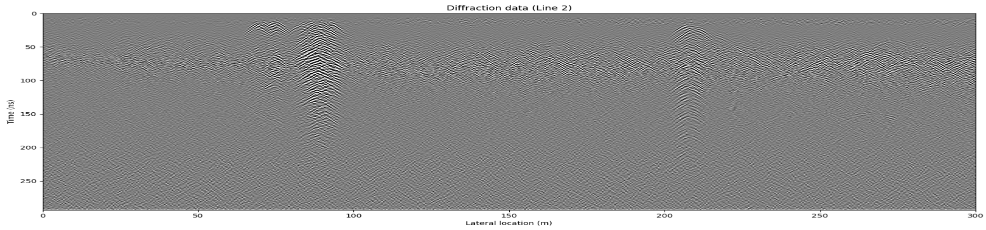
Field GPR case study - an example from Antarctica

To assess the effectiveness of the proposed SDRI framework, we conducted an Antarctica field data case study. The data set is a shallow ice GPR data set with a depth of approximately 25 meters, and it consists of two zero-offset GPR lines. The satellite image of the surveying area near Zhongshan Station in Antarctica is shown in Figure 1(b). Line 1 is situated closer to the mountainous area and is about 200 meters long, while Line 2 is situated further away from the mountainous area and is approximately 300 meters long. Note that GPR data resemble much to seismic zero-offset data, although with different frequency range. Figure 2 showcases the GPR data sets along Line 1, including the recorded full wavefield, the separated diffractions, and the enhanced reflections. Compared to the recorded full wavefield, the separated diffractions in Figure 2(b) reveal more diffracted energy that was previously buried under strong reflection energy. In the shallow area located in the top left and right corners, many weak diffractions can be seen, which may be related to small-scale boulders or rocks falling from the nearby mountains. The enhanced reflection data in Figure 2(c) provides a clearer picture of ice layering. Figure 3 displays similar GPR data sets along Line 2. It is evident that the strong diffraction energy in Figure 3(b) originates from cracks. Additionally, the enhanced reflection data in Figure 3(c) provides clearer layering information that was previously obscured by the diffractions related to the cracks.

We also provide some initial geological interpretation based on the proposed SDRI framework after migration. Figure 4 and 5 shows the interpretation along Line 1 and Line 2 respectively, and it is clear both diffraction images can better delineate the locations of small-scale geological bodies. Meanwhile, reflection images are especially useful to track the geological layers, where it is more difficult to observe in the original recorded data. Based on the diffraction image along Line 1, we can determine that the average ice thickness is around 12 meters and there may be numerous boulders buried beneath the snow



(a)



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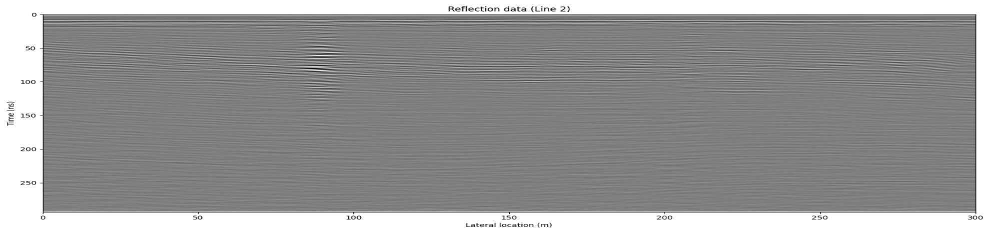
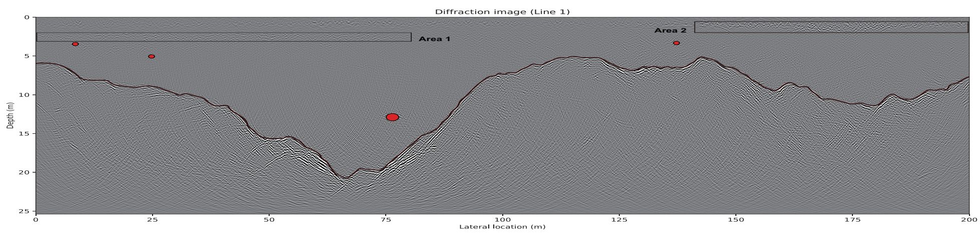
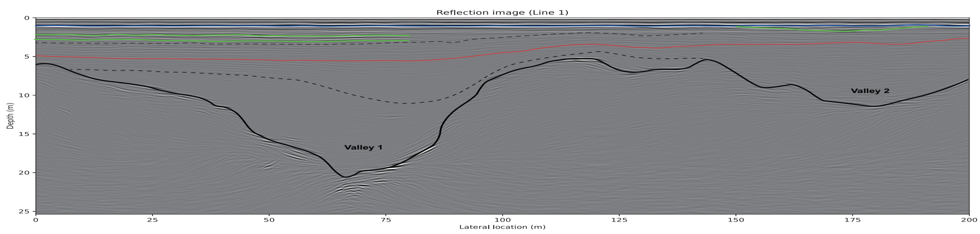


(c)

Figure 3 *GPR data sets along Line 2. (a) Recorded full wavefield. (b) Separated diffractions. (c) Enhanced reflections.*

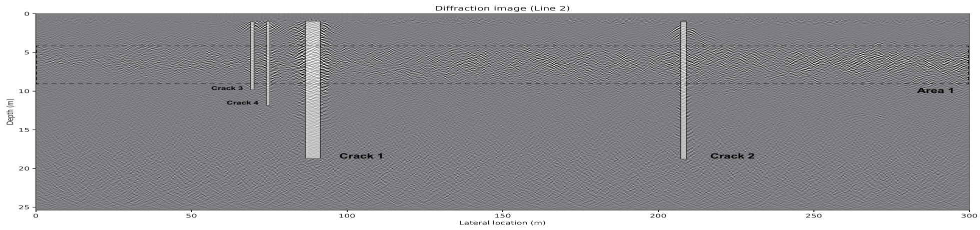


(a)



(b)

Figure 4 *Geological interpretation on migrated GPR images along Line 1. (a) Separated diffractions. (b) Enhanced reflections.*



(a)

(b)

Figure 5 *Geological interpretation on migrated GPR images along Line 2. (a) Separated diffractions. (b) Enhanced reflections.*

and ice in this area. In the diffraction image along Line 2, two significant cracks (around 90 meters and 120 meters) can be easily identified. These cracks are quite deep, reaching over 20 meters, and could pose a potential hazard to the nearby Station airport. In addition, the ice and snow deposition layer located at a depth of 6 meters in Figure 5(a) may contain a large number of small scatters, suggesting a different deposition process than the upper and lower ice and snow layers.

Conclusion

We introduce an SDRI framework to extract the necessary information, such as the sub-ice base topography, internal reflection layer, internal diffracted objects, and ice cracks. The framework can extract hidden information in the recorded data by using wavefield separation and enhancement, for instance, the internal small-scale diffracted objects and the internal reflection layer. The proposed SDRI framework has been applied to a field ice GPR data set, demonstrating its effectiveness in uncovering the hidden geology buried under the ice. It is suggested that SDRI framework should become a standard for GPR data interpretation. In the future, diffractions can be imaged differently than reflections, and local apparent velocity variations can be applied to better focus the diffractions due to strong 3D effects.

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