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Point Receiver Acquisition and Processing for Arctic Near Surface Challenges

C. Strobbia[1], A.Glushchenko[1], A. Laake[1], P.L.Vermeer[1], S. Papworth[1], Y. Ji[2]

[1]WesternGeco, [2]Schlumberger

vermeer@slb.com

Summary

The arctic near surface can be extremely complex and challenging for land seismic exploration. In addition to the specific features of the glacial geomorphology, the geophysical impact of permafrost and ice has to be considered. The rapid transition between frozen and melted zones is associated with extreme lateral variations of the elastic parameters, producing large magnitude statics. The ice cover on frozen lakes may generate flexural waves, with large amplitude and very short wavelength. To evaluate the benefits of dense single sensor acquisition and processing, a point-source point-receiver test data set was acquired in a discontinuous permafrost area. The dense spatial sampling was found to enable 1) the identification and correction of near surface distortions and 2) the effective attenuation of coherent noise.

Introduction

Land seismic exploration in arctic regions, besides the logistic issues, can be challenging because of the great complexity of the near surface. Glacial erosion and deposition produces a complex geomorphology, with moraines, lakes, ridges and rapid lithological changes. Moreover, the presence of permafrost and frozen ground induces large and rapid variation of the elastic properties at the transition between frozen and

melted areas, and large statics. The properties of coherent noise can be highly variable, too. Surface water bodies ice covered induce low velocity anomalies as well as high amplitude, short wavelength noise.

A point-source (vibrator) point-receiver test was acquired in arctic Russia. The study area is located in a flat plane, at the border between tundra and taiga, characterized by the presence of rivers, creeks and glacial lakes. The acquisition intersects the largest lake of the area, about 3 km long, on its southern edge. The receiver line (point receivers in a grid at 5 m spacing) and two source lines (one in-line and one cross-line at 20 m source spacing) are shown on the map. To the east numerous small creeks intersect the slope of the moraine, causing strongly laterally varying near surface conditions.
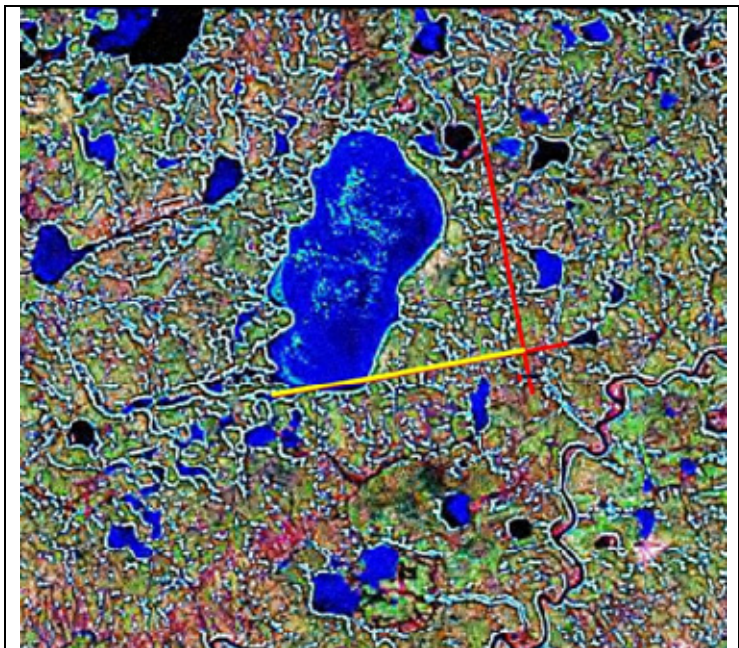

Figure 1: Location of source and receiver line on a satellite image

Arctic near surface features

Besides the typical features of the glacial geomorphology, the main geophysical factor is the state of the ground and surface water. Elastic properties of water change dramatically upon freezing, and as a consequence, the seismic velocity of unconsolidated sediments can increase from 1500m/s to almost 4000m/s. The spatial continuity of seasonally frozen ground and permafrost is therefore of primary importance for the near surface properties. In areas with discontinuous or sporadic permafrost, or with a thick seasonally frozen layer, lateral heterogeneities occur due to the transition between frozen patches and unfrozen areas, as well as to local thaw bulbs related to surface water bodies. These lateral heterogeneities have a big impact on seismic data, inducing from long-wavelength lake statics, to large statics with a very short spatial variation. The test site, located close to the present geographic limit of permafrost, is also characterized by relict permafrost, as schematically represented in Figure 2.
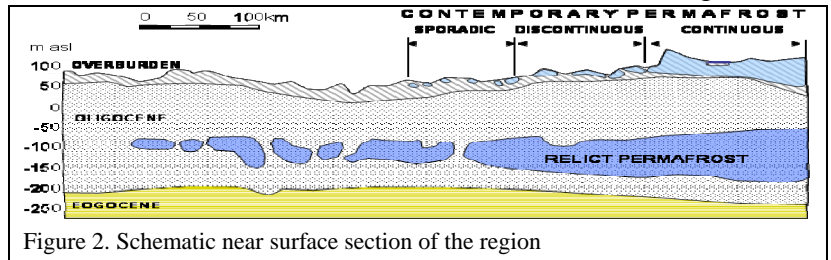

Figure 2. Schematic near surface section of the region

Large lakes can be problematic due to ice coherent noise modes. Seismic sources deployed on floating ice sheets radiate a large part of the energy as flexural (F) waves. F-waves are bending waves mainly propagating in the ice cover: a realistic modeling in very shallow water requires including the water layer and the sub-bottom sediments, but the kinematics is well approximated by the first asymmetric mode of Lamb waves (Figure 3). Amongst the Lamb modes, considering the minimum operable ice thickness and the frequency range of interest, only the first asymmetric (flexural) and the fist symmetric (extensional) mode are expected : it can be shown that for the measurements of flexural waves a sensor spacing of 5m or less is required.
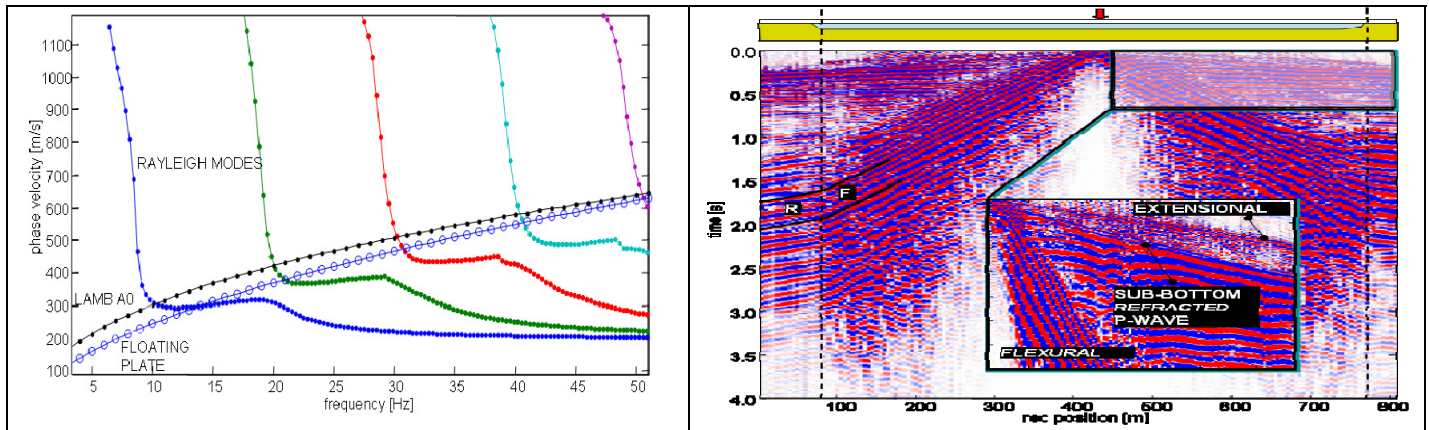

Figure 3. Modeling of ice modes (left) and real data acquired on the lake (right).

The roughness and heterogeneities of the ice cover are crucial for the scattering of the ice noise modes: though more severe in sea ice, this factor has to be considered also on land with lake ice.

Single sensor data analysis

The acquired data are characterized by extreme lateral variations in the properties of coherent noise. Shots on the lake are characterized by a large amplitude flexural wave, and by the presence of a weak extensional wave. Rayleigh waves are present in shot gathers off the lake, and the transition between F- and R-wave (mode conversion) is abrupt and associated with horizontal reflections (Figure 3). The high amplitude F-wave has a low velocity (200m/s to 400m/s) and strong inverse dispersion, peak energy between 10 and 20 Hz, and a short wavelength (down to 10m at 20Hz). The suppression of this strong flexural ice wave is one of the main objectives of the processing.

The shot gathers off the lake have coherent noise with a much higher velocity: the inverse dispersion, with a phase velocity increasing from 500 m/s to 900 m/s, is due to the seasonally frozen layer at the surface. The continuity of the SFL is influenced by the presence of creeks and surface water, and the surface wave velocity has several strong lateral variations. The same sharp and large lateral velocity variations affect the reflected signal and induce statics (Figure 4). These short scale lateral variations can be identified with single-sensor refraction statics.

Data processing

The processing flow consists of Digital Group Forming (DGF) followed by surface-consistent deconvolution, post-DGF coherent noise attenuation, several iterations of velocity analysis with residual reflection statics, multiples attenuation, CMP sorting and stacking. The full DGF workflow involves attenuation of incoherent and coherent noise, refraction static correction, amplitude perturbation corrections (surface-consistent spectral compensation), before spatial anti-alias filtering and down-sampling to 20m.

Single sensor time perturbations are stable and coherent with local surface wave velocities, and the computed refraction solution indicates notable short-wavelength statics. The static corrections provide good alignment of events. Its effectiveness for short wavelength statics can be shown on a strong shallow reflector, present in all shot gathers. A sample shot gather is provided in Figure 4. This reflection is the top of a relict permafrost layer, at a depth of about 100m, whose presence in the region is confirmed by the literature. The dense sampling in the near offset allows, as a by-product, imaging this interface: relict permafrost can be a drilling hazard since it can seal natural gas accumulations. This interface is of further interest because the large impedance contrast generates strong surface multiples and can be associated with long wavelength statics.
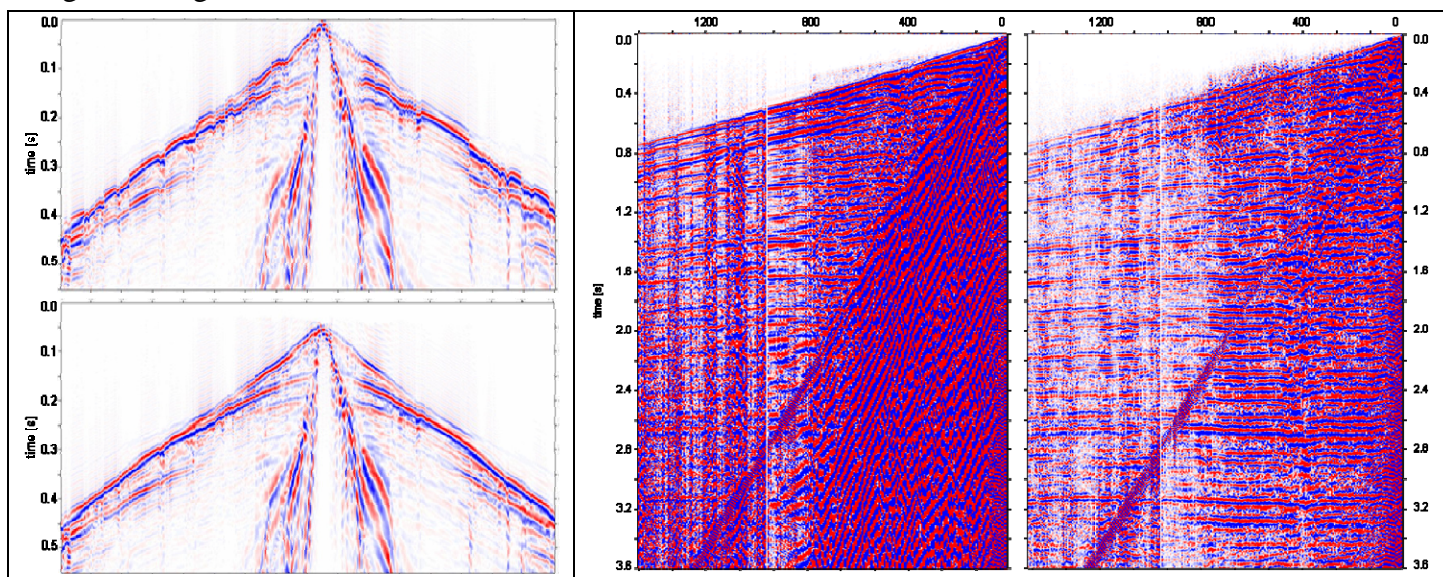

Figure 4: Effect of the single-sensor static correction (left), and example of coherent noise attenuation (right)

Results

The short wavelength statics are particularly important, because they induce notable shifts at a very short spatial scale, several milliseconds between adjacent traces. The statistical analysis of statics shows that the short wavelength component has a range exceeding 15ms within a 50m distance . The straight summation of 10 traces, without single sensor (intra-array) statics, results in strong attenuation of the high frequencies. It is clear that the correction of small-scale time and amplitude perturbations is an important element of the Digital Group Forming (DGF). The effects of the rapid lateral variations below the apparently regular surface have to be corrected to avoid spatial smearing, to preserve the frequency content and the stack power.

The fine spatial sampling, besides enabling single sensor perturbation corrections, allows efficient filtering of the strong but non-aliased coherent noise. An example is shown in Figure 4. The coherent noise cone in raw data is characterized by high amplitude, low velocity F-wave, with scattering, obscuring completely the reflection signal. The flexural wave can be efficiently removed and the signal is recovered.

After noise suppression and perturbation corrections, the single-sensor data are anti-alias filtered, considering the designed spatial down-sampling to 20m. After DGF a standard processing flow is run. For reference, a conventional data-set is simulated with a straight sum of traces within groups of 20m. Figure 5 shows the comparison between the point receiver stack and the simulated conventional. The large improvement is attributed to intra-array perturbation corrections and better noise attenuation on non-aliased data.
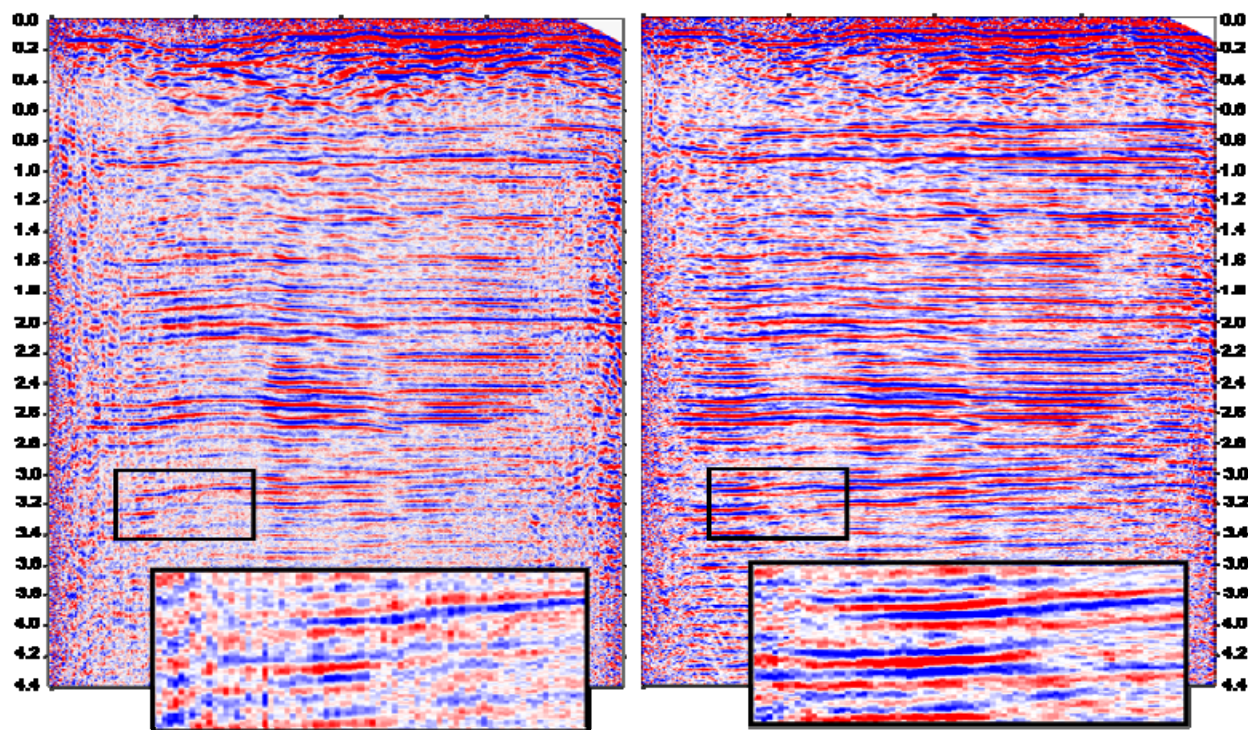

Figure 5: Comparison of the stacks of simulated conventional (left) and point receiver (right) processing

Conclusions

The acquired data-set offers the opportunity to test the benefits of single sensor approach in complex near surface conditions, with strong noise and short scale perturbations.

The non-aliased coherent noise recording enables several approaches for the near surface characterization based on surface wave analysis. The variations of the properties of coherent noise, for instance, identify the transitions between frozen and melted areas.

The results of the processing confirm that, in arctic complex near surface conditions, the use of densely sampled single-sensor data and a specific processing can bring a substantial improvement to the final result. With the non-aliased sampling of the ice modes it is possible to achieve better noise attenuation and signal preservation. The intra-array correction of time and amplitude perturbations maximize the signal to noise ratio and the frequency and preserve the signal attributes, for cleaner pre-stack data.

All these elements contribute to produce a seismic image with a higher signal to noise ratio, higher frequency and resolution, higher fidelity for the extraction of attributes.