Passive seismic investigations of subaquatic permafrost

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Large quantities of organic carbon are known to be sequestered within subaquatic permafrost as gas hydrates. Therefore, knowledge of the extent and thaw rate is of critical importance to our understanding of global climate change. Investigations of sub-aquatic permafrost have focussed on its physical characteristics via drilling or probing, and through the limited application of geophysical methods. Active seismic methods have been most widely employed, especially for petroleum exploration, but recently passive methods have been used to investigate the seabed using ambient noise. The Horizontal-to-Vertical Spectral Ratio (HVSR) method has previously been shown to accurately determine permafrost thaw depth below the sea floor in marine and lacustrine environments, based on the collection of seismic data over a period of weeks. In this study, we test the use of short-term seabed HVSR seismic surveys and explore possibilities for optimizing the method in a wide variety of subaquatic environments.

The method was successfully used in a thermokarst lake, a lagoon and river channels of the Lena Delta (Russia), as well as in marine shelf environments in the Laptev Sea (Russia) and Tuktoyaktuk Island (NW Canada). Study areas where validation data was available were preferred and selected when possible. A passive seismic measuring device, consisting of a watertight metal cannister containing three-component broad-band seismometers, was lowered down to the sea floor from a small boat and left to collect data for 3-4 minutes. The data was recorded at a sample rate of 100Hz.

Post-processing and analysis were done with MATLAB. The three seismic signals were individually detrended, the offset was removed and the power spectral density was calculated. The smoothing function proposed by Konno and Ohmachi (1998) was applied to each signal with a smoothing coefficient of 40. Lastly the H/V (Horizontal / Vertical) amplitude was calculated. The H/V amplitude was plotted against signal frequencies from 0 to 50 Hz. The peak resonance frequency is believed to indicate the ice-bonded permafrost table (IBPT) thereby enabling us to determine thaw depth from the H/V plots, assuming a simple 2-layer model: thawed layer over frozen ground, characterized by low and high wave speeds, respectively.

Results generally display a good correlation, on average within 0.6 meters, between the thaw depth determined from HVSR and from physical validation, although HVSR often generates a thaw depth deeper than indicated by validation data. This may be a result of complex permafrost
systems where several “zones” of frozen and unfrozen ground, of varying thickness, is present below the water bodies.

We conclude that the method has the potential to be an effective (fast) non-invasive tool for investigating the extent and, if repeated, the thaw rate of subaquatic permafrost. Further field testing is planned in order to continue the development and optimization of the method.