3D refraction seismic tomography investigations in alpine permafrost at Hoher Sonnblick (Austria)

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Abstract

Between 2015 and 2017, different geophysical methods have been applied at the summit of Hoher Sonnblick, Austria, to characterize temporal and spatial variations of the active layer thickness. Here, we present the results obtained from Refraction Seismic Tomography (RST) for data collected using a 3D survey layout including borehole geophones. For the inversion of the RST dataset, an initial model was constructed based on structural information obtained from complementary geophysical methods and borehole temperature measurements, which permitted to reduce the uncertainty in the inversion. The results reveal changes in the seismic P-wave velocity related to variations in the porosity due to unfrozen and frozen rocks. Our results show that the active layer depth varies between 2 and 6 m, which is consistent to previous observations at the study area. Yet our results present the first 3D model with enhanced resolution of the active layer geometry over the entire summit area.

Keywords: refraction seismic; 3D tomography

Introduction

The Sonnblick Observatory at the summit of Hoher Sonnblick (3106 m.a.s.l.) facilitates research activities in various fields, including atmospheric and cryospheric studies. To permit an improved characterization of permafrost processes, such as spatial and temporal variations of the active layer thickness, different geophysical campaigns have been conducted.

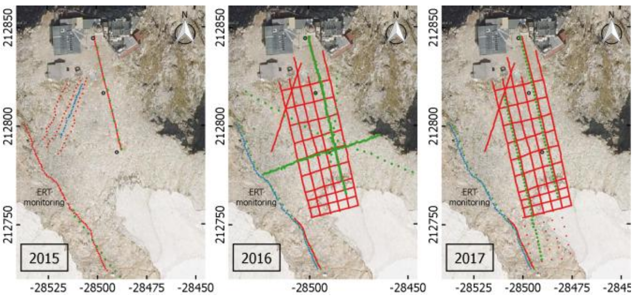

Figure 1. Orientation of the profiles for RST (green), GPR/EMI (red) and IP (blue) measurements. Black circles indicate the positions of the boreholes.

Such campaigns aim at gaining information of different physical properties by means of different methods to improve the quantitative interpretation of the inversion results. In particular, surveys have consisted of: Refraction Seismic Tomography (RST), Ground Penetrating Radar (GPR), Electromagnetic Induction (EMI), Induced Polarization (IP), and Transient Electromagnetic (TEM). Furthermore, monitoring Electrical Resistivity Tomography (ERT) datasets are collected on a daily-basis in a permanently installed profile (see Fig. 1).

Table 1. Campaigns conducted since August 2015.

	15			16					17		
	08	06	07	08	09	11	05	06	07	09	10
RST	X			X			X			X	
GPR	X	X	X	X	X	X	X			X	
EMI	X	X		X	X	X	X				
SIP	X		X		X	X	X	X	X	X	X
TEM							X			X	

Field work

Starting in August 2015, eleven campaigns have been conducted, each with a particular focus on a given objective and geophysical methods (Table 1). Measurements in 2015 permitted to define the best protocols and settings to collect data with enhanced resolution and signal-to-noise ratio (SNR). The recollection of data with such settings in 2016 and 2017 aimed at the characterization of the active layer with high spatial resolution for the entire summit (Fig. 1).

3D Refraction Seismic Tomography

Seismic methods permit to solve variations in the velocity of seismic waves, typically related to lithological interfaces. In particular, the contrasting P-wave velocities (V_p) for frozen and unfrozen materials allow the quantification of the active-layer (Draebing, 2016).

In 2016, a 3D seismic survey was conducted deploying 41 surface geophones (4 m separation; two perpendicular lines) together with 15 geophones placed at depths of 1, 2, 5, 10 and 20 m in three boreholes (Fig. 2). First break travel time picks were inverted using the algorithm by Hole (1992) and the commercial software Rayfract. To improve the results from the seismic tomography structural information obtained from GPR and EMI imaging results was used to refine the initial model for the inversion. Uncertainty in the inversion of the seismic data was quantified by statistical analysis of the inversion results obtained using an ensemble of different initial models.

Results

The obtained seismic P-wave velocities (V_p) presented in (Fig. 3) show a near-surface layer characterized by low V_p velocities (< 2000 m/s), which corresponds to unconsolidated and unfrozen rocks. The interface between the active layer and the permafrost layer is defined initially by post-processed and error-corrected borehole temperature data (Heinrich, 2017) which corresponds to seismic velocities (V_p) of ~ 2800 m/s. The active layer depth varies in a range from 2 to 6 m within the summit area, yet the results in proximity to the boreholes show agreement with previous studies (Schöner *et al.*, 2012). ERT monitoring data further allowed for a validation and an enhanced quantitative interpretation of the RST imaging results.

Acknowledgments

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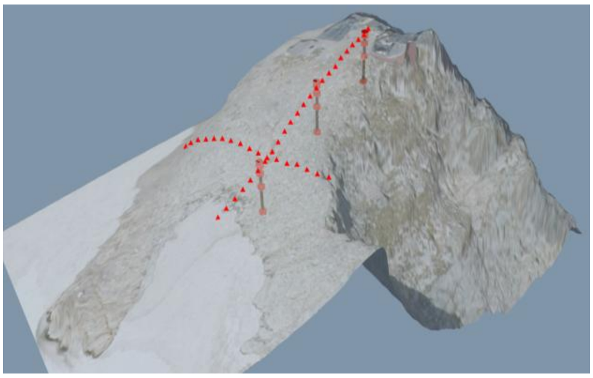

Figure 2. Locations of the 3D RST survey surface (red triangles) and borehole (red cubes) geophones.

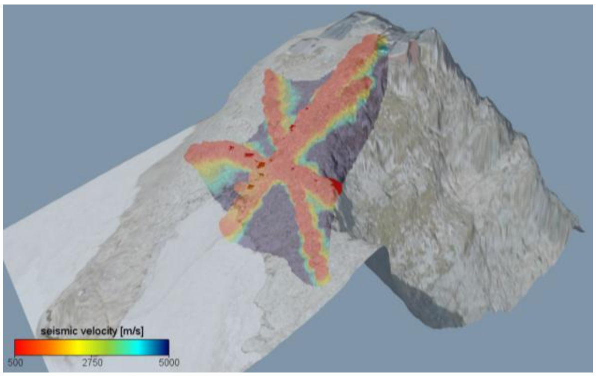

Figure 3. 3D image of seismic P-wave velocities in the summit area obtained from tomographic inversion.

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