Geophysical Research Abstracts
Vol. 19, EGU2017-851-2, 2017
EGU General Assembly 2017

Visible-near infrared spectroscopy as a tool to improve mapping of soil properties

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Spectroscopic measurements, which are non-destructive, precise and rapid, can be used to predict soil properties and help estimate the spatial variability of soil properties at the pedon scale. These estimations are required for quantifying soil properties with higher precision, identifying the changes in soil properties and ecosystem response to climate change as well as increasing the estimation accuracy of soil-related models.

Our objectives were to (i) predict soil properties for nested samples (n = 296) using the laboratory-based visible-near infrared (vis-NIR) spectra of air-dried (<2 mm) soil samples and values of measured soil properties for gridded samples (n = 174) as calibration and validation sets; (ii) estimate the precision and predictive accuracy of an empirical spectral model using (a) our own spectral library and (b) the global spectral library; (iii) support the global spectral library with obtained vis-NIR spectral data on permafrost-affected soils.

The soil samples were collected from three permafrost-affected soil profiles underlain by permafrost at various depths between 23 cm to 57.5 cm below the surface (Cryosols) and one soil profile with no presence of permafrost within the upper 100 cm layer (Cambisol) in order to characterize the spatial distribution and variability of soil properties. The gridded soil samples (n = 174) were collected using an 80 cm wide grid with a mesh size of 10 cm on both axes. In addition, 300 nested soil samples were collected using a grid of 12 cm by 12 cm (25 samples per grid) from a hole of 1 cm in a diameter with a distance from the next sample of 1 cm. Due to a small amount of available soil material (< 1.5 g), 296 nested soil samples were analyzed only using vis-NIR spectroscopy.

The air-dried mineral gridded soil samples (n = 174) were sieved through a 2-mm sieve and ground with an agate mortar prior to the elemental analysis. The soil organic carbon and total nitrogen concentrations (in %) were determined using a dry combustion method on the Vario EL cube analyzer (Elementar Analysensysteme GmbH, Germany). Inorganic C was removed from the mineral soil samples with pH values higher than 7 prior to the elemental analysis using the volatilization method (HCl, 6 hours). The pH of soil samples was measured in 0.01 M CaCl2 using a 1:2 soil:solution ratio. However, for soil sample with a high in organic matter content, a 1:10 ratio was applied. We also measured oxalate and dithionite extracted iron, aluminum and manganese oxides and hydroxides using inductively coupled plasma optical emission spectroscopy (Varian Vista MPX ICP-OES, Agilent Technologies, USA).

We predicted the above-mentioned soil properties for all nested samples using partial least squares regression, which was performed using R program. We can conclude that vis-NIR spectroscopy can be used effectively in order to describe, estimate and further map the spatial patterns of soil properties using geostatistical methods. This research could also help to improve the global soil spectral library taking into account that only few previous applications of vis-NIR spectroscopy were conducted on permafrost-affected soils of Northern Siberia.

Keywords: Visible-near infrared spectroscopy, vis-NIR, permafrost-affected soils, Siberia, partial least squares regression.