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Open-path TDL-Spectrometry for a Tomographic Reconstruction of 2D H_2O-Concentration Fields in the Soil-Air-Boundary-Layer of Permafrost

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The melting of permafrost soils in arctic regions is one of the effects of climate change. It is recognized that climatically relevant gases are emitted during the thawing process, and that they may lead to a positive atmospheric feedback [1]. For a better understanding of these developments, a quantification of the gases emitted from the soil would be required. Extractive sensors with local point-wise gas sampling are currently used for this task, but are hampered due to the complex spatial structure of the soil surface, which complicates the situation due to the essential need for finding a representative gas sampling point. For this situation it would be much preferred if a sensor for detecting 2D-concentration fields of e.g. water vapor, (and in the mid-term also for methane or carbon dioxide) directly in the soil-atmosphere-boundary layer of permafrost soils would be available. However, it also has to be kept in mind that field measurements over long time periods in such a harsh environment require very sturdy instrumentation preferably without the need for sensor calibration. Therefore we are currently developing a new, robust TDLAS (tuneable diode laser absorption spectroscopy)-spectrometer based on cheap reflective foils [2]. The spectrometer is easily transportable, requires hardly any alignment and consists of industrially available, very stable components (e.g. diode lasers and glass fibers). Our measurement technique, open path TDLAS, allows for calibration-free measurements of absolute H_2O concentrations. The static instrument for sampling open-path H_2O concentrations consists of a joint sending and receiving optics at one side of the measurement path and a reflective element at the other side. The latter is very easy to align, since it is a foil usually applied for traffic purposes that retro-reflects the light to its origin even for large angles of misalignment (up to 60°). With this instrument, we achieved normalized detection limits of up to 0.9 ppmv·m·$\sqrt{\text{Hz}}$. For absorption path lengths of up to 2 m and time resolution of 0.2 sec, we attained detection limits of 1 ppmv. Furthermore we realized a wide dynamic range covering concentrations between 200 ppmv and 12300 ppmv. The static spectrometer will now be extended to a spatially scanning TDL sensor using rapidly rotating polygon mirrors. In combination with tomographic reconstruction methods, spatially resolved 2D-fields will be measured and retrieved. The aim is to capture concentration fields with at least 1 m^2 spatial coverage with concentration detection faster than 1 Hz rate. We simulated various measurements from typical concentration distributions ("phantoms") and used Algebraic Reconstruction Techniques (ART) to compute the according 2D-fields. The reconstructions look very promising and demonstrate the potential of the measurement method. In the presentation we will describe and discuss the optical setup of the stationary instrument and explain the concept of extending this instrument to a spatially scanning tomographic TDL instrument for soil studies. Further we present first results evaluating the capabilities of the selected ART reconstruction on tomographic phantoms.

[1] E. Schuur, J. G. Vogel, K. G. Crummer, H. Lee, J. O. Sickman, and T. E. Osterkamp, "The effect of permafrost thaw on old carbon release and net carbon exchange from tundra.," Nature, vol. 459, no. 7246, pp. 556–9, May 2009.

[2] A. Seidel, S. Wagner, and V. Ebert, "TDLAS-based open-path laser hygrometer using simple reflective foils as scattering targets," Applied Physics B, vol. 109, no. 3, pp. 497–504, Oct. 2012.