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The Use of Radar Methods to Determine Moisture Content in the Vadose Zone

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Research Group: This research project currently involves two graduate students (James Irving, Stephen Moysey) and one research scientist (Camille Li).

DOE Problems Addressed

Moisture content is a critical parameter affecting both liquid-phase and vapor-phase contaminant transport in the vadose zone. Any attempt to model the behavior of a contaminant in the vadose zone, in order to design for the handling or remediation of a contaminated region, must adequately account for the spatial variation in moisture content. The variation in moisture content must therefore be determined with a high level of accuracy at the relevant scale or scales, given the governing transport processes. Traditional methods of drilling and direct sampling are very time consuming, limited in terms of spatial coverage, and have the associated risk of contacting and increasing the contaminated area. One solution is to use geophysical methods which can provide a high-resolution, non-invasive means of sampling or imaging the subsurface. Of specific interest in our research is the use of radar methods - both surface and borehole - as a means of determining *in situ* moisture content.

Research Objective

The objective of our three-year research project is to determine the optimal way to use radar methods to obtain information about moisture content in the vadose zone. In our research we will focus on two specific aspects of the link between radar images and moisture content. The first aspect or question we address is: Can we use a measure of the dielectric constant of a volume of the subsurface to determine the moisture content of that volume? The second question we address is involved specifically with the issue of spatial heterogeneity. Rather than using radar data to get estimates of moisture content at specific locations, can we use the radar data to directly obtain information about the way in which the level of moisture content varies spatially?

Research Progress and Implications

This report describes the progress that has been made in our research over the past six months.

Our first task has been to improve the clarity of radar images by correcting for frequency-dependent attenuation; this is responsible for wavelet dispersion, which is displayed in the radar image as a characteristic "blurriness" that increases with depth. Previous work by Turner and Siggins has shown that the electromagnetic (EM) wave attenuation parameter for many geologic materials is roughly linear with frequency over the bandwidth of a GPR wavelet, and thus the change in shape of a radar pulse can be described using one parameter, Q*, which is related to slope of this linear region. Assuming that all subsurface materials can be characterized by some Q* value, the problem of estimating and correcting for wavelet dispersion in GPR data becomes one of estimating Q* in the subsurface and deconvolving its effects through the use of an inverse-Q filter.

We tested our method by working with ground penetrating radar (GPR) data collected over an aquifer near Langley, British Columbia. To estimate Q* from these data, a number of traces across the GPR profile were analyzed using the wavelet transform. After converting the wavelet transform scale parameter into approximate frequencies, the centroid frequency at each point in time was calculated for the traces. Plots of this centroid value versus time show a distinct downward trend due to wavelet dispersion. Using a modified version of a technique developed for seismic attenuation tomography, the slopes of best fit lines through these plots were then used to determine a general value for Q* in the subsurface. Finally, an inverse-Q filter was applied to the data to yield a GPR image of significantly higher resolution than the original. Results indicate that this technique provides an effective means of estimating general values for Q* from surface-based GPR data. This technique also has advantages over other methods of determining Q because it requires neither a reference spectrum nor the isolation of individual reflections.

The other focus of our current research is to determine how best to use and interpret the information contained in the radar data within a hydrogeologic framework. We have chosen to take a stochastic, rather than deterministic, viewpoint that allows for the incorporation of uncertainty in the measured radar parameters and in the petrophysical models that link the radar parameters to moisture content. We have identified three topics that have high priority and impact on the hydrological interpretation of radar data: i) the development and/or implementation of petrophysical models that relate the dielectric constant to water content; ii) the exploration of scale dependency of dielectric measurements in the subsurface and the consequences for hydrologic interpretation/modeling; iii) the application of methods for investigating statistically stationary and non-stationary systems using GPR. Petrophysical models relating water content and dielectric constant are generally dependent on the geometry of heterogeneity at the sub-measurement scale; as a means of choosing the appropriate model, we are exploring the use of anisotropy in the dielectric constant section obtained using cross-borehole tomography. We have also begun work addressing topics ii) and iii) above using GPR data sets, a variety of image sources and synthetic data. In particular, linear scaling relationships observed for the 1-D variograms are being extended and tested at higher dimensions using spectral methods.

Planned Activities: Over the next year, our focus will be on the development of petrophysical models for use in heterogeneous systems and on the continued examination of scaling phenomena in GPR data. In the summer/fall of 2000, both surface and borehole radar data will be acquired. With these new data sets, we will begin investigating the use of wavelet transforms on cross-borehole and surface GPR data for the detection and characterization of non-stationary systems based on hierarchical structures. We also plan to begin developing a model for the joint inversion of geophysical and hydrological data to determine hydrological parameters.