Project Title: 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 (Paulette Tercier).

Research Objective

Moisture content is a critical parameter affecting both liquid-phase and vapor-phase contaminant transport in the vadose zone. The objective of our three-year research project is to determine the optimal way to use radar methods as a non-invasive means of determining *in situ* moisture content.

Research Progress and Implications

This report describes the progress that has been made in the third year of our 3-year research project.

One of the first steps in using radar data for the development of models of the subsurface involves interpreting the large-scale structure, or architecture, of the subsurface seen in the radar data. We have elected to adopt a facies-based approach where the radar data are divided into radar facies, defined as regions that are similar in character or appearance. Over the past year we have explored the use of neural networks to classify and identify radar facies (Moysey et al., 2002), and found this to be a very effective way of generating a model of the subsurface.

One approach in the use of radar methods to characterize the vadose zone is to determine the dielectric constant of sampled volumes of the subsurface and then use rock physics relationships to obtain estimates of water content. Using properties of sediments from Hanford, we have illustrated the source and magnitude of the uncertainty in water content estimates that are expected to arise in heterogeneous isotropic and anisotropic systems. The ability to provide such estimates of uncertainty will improve the way in which radar-derived water content values are used in modeling contaminant transport at sites such as Hanford.

In the past year we have completed the geostatistical analysis of the ground penetrating radar (GPR) data acquired at the Sisson and Lu test site at Hanford. For comparison, we have available water content estimates obtained from neutron probe data acquired at the site in 1980, 1995 and 2000. We have been working with Chris Murray, Mark Rockhold and Gene Freeman at Pacific Northwest National Lab so as to analyze both the radar and neutron probe data sets in a way that allows for valid comparison. Our encouraging results suggest that radar images contain information about the spatial heterogeneity of the subsurface that can be used to characterize the spatial variability in water content.

Another focus over the past year has been the combined collection of surface and borehole GPR data, our goal being to examine how these two data types can be best used together to quantify the distribution of water content in the vadose zone. One field site that we have found to be particularly suitable for this research is an Agriculture Canada test farm near Abbotsford, BC. The farm contains a number of piezometer wells, approximately 30 m deep, within close proximity of one another, and is underlain by a thick, unconfined, sand and gravel aquifer that is easily penetrated with GPR. To date, we have conducted one crosswell tomography survey at the site between two wells spaced 18 m apart, using 100 MHz antennas. Borehole-to-surface surveys at the same frequency were also conducted in each of the wells. In addition, we have collected surface-based data between the wells using 50, 100, and 200 MHz antennas. We are currently developing a tomographic inversion code that takes into account bending rays, and will allow us to quantify anisotropy.

We also conducted three cliff face experiments in the summer of 2001 in two different gravel pits in the Fraser Valley area of British Columbia. At each site GPR data were collected at three frequencies (50, 100 and 200MHz) and digital photographs taken of the cliff face. By overlaying the different frequency radar sections we are able to see very clearly the size and nature of the features captured by each frequency. When each of the sections is studied using semivariogram analysis we find the following correlation lengths: a correlation length of 1.7 m at 200MHz, 3.0 m at 100 MHz, and 3.6 m at 50 MHz, the change in correlation length presumably being due to the increasing support volume or spatial resolution with decreasing frequency.

Planned Activities

In the summer of 2002 we will be completing our study of quantifying uncertainty in water content estimates through accounting for heterogeneity. We will also complete the comparison of the variogram analysis of the neutron probe data and the GPR data from the Sisson and Lu site, Hanford. A related topic that will be pursued over the next year is the use of wavelets as a improved means of capturing the spatial heterogeneity in moisture content contained within the vadose zone. We will also explore improved ways of incorporating radar data into hydrogeologic models.

In the time period between June and October, 2002, we plan to have our tomographic inversion code finished and applied to the field data. We also plan to investigate, using this code, whether there is any difference in anisotropy above and below the water table. By December, 2002, we plan to have finished using the results of the borehole tomography to process the surface-based data collected at the site.

Our initial assessment of the cliff-face radar data has shown a dependence of correlation length on support volume. We will work with these data to develop an understanding of how the acquisition of multi-frequency radar data at a site can allow us to determine the true correlation length. The digital photographs will be analyzed to determine whether they can provide us with information on the “true” scale of variation at the site.

Information Access: (Publications related to this research)

Irving, J. and Knight, R., Estimation and correction of wavelet dispersion in GPR data, In: GPR 2000, Proceedings of the Eighth International Conference on Ground Penetrating Radar, Gold Coast, Australia, p. 123-129, 2000.

*Irving, J.D., and Knight, R.J., Removal of wavelet dispersion from ground-penetrating radar data, Submitted to Geophysics, March 2002.

Knight, R., Ground Penetrating Radar for Environmental Applications, Annual Review of Earth and Planetary Sciences, 29, 229-255, 2001.

Moysey, S., R.J. Knight, R.M. Allen-King and J. Caers, The construction of stochastic facies-based models conditioned to ground penetrating radar images, 4th International Conference on Calibration and Reliability in Groundwater Modelling, Universita Karlova, Prague, Czech Republic, June 2002.