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

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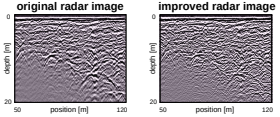
Moisture content is a critical parameter affecting both liquid-phase and vapor-phase contaminant transport in the vadose zone. Any attempt to model the behavior of a contaminant in the vadose zone in order to design for the handling or remediation of a contaminated region must adequately account for the spatial variation in moisture content at the relevant scale or scales of the governing transport processes. Traditional methods of drilling and direct sampling are 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.

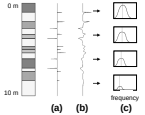
The objective of our three-year research project is to determine the optimal way to use radar methods to obtain information about moisture content in the vadose zone. Our research will focus on two specific questions:
(1) Can we use a measure of the dielectric constant of a subsurface volume to determine the moisture content of that volume?
(2) Rather than using radar data to obtain 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?

Improving the Radar Image

Problem
- GPR image displays a characteristic "blurriness" or lack of resolution that increases with depth

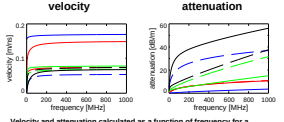
Cause
- wavelet dispersion: GPR wavelet undergoes significant broadening as it propagates
- (a) spike input
  (b) becomes attenuated
  (c) dominant frequency shifts downward





Why is it important to correct for wavelet disperion?
- to obtain a well-focused GPR image for data interpretation
- to use GPR data for the quantitative determination of subsurface electrical properties

Approach
- attenuation of EM waves is approximately linear with frequency over bandwidth of a GPR wavelet
- velocity of EM waves is approximately constant over this range
- change in shape of radar pulse can be described by one parameter, Q*, related to the slope of the linear region
- to correct for wavelet dispersion, we determine Q* in the subsurface and remove its effects from the radar image



Velocity and attenuation calculated as a function of frequency for a variety of rocks whose dielectric permittivities have been fitted using the Jonscher parameterization (Hollender & Tillard, 1998): — limestone, freshwater saturated (Coutanceau, 1989); — andesite, — shale, — gabbro, — siltstone (Turner, 1993); — granite, freshwater saturated, — dry granite, — schist measured perpendicular to the schistocity (Tillard, 1994).

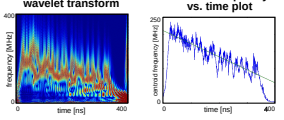
Method

step 1: compute wavelet transform time-frequency representation of a trace

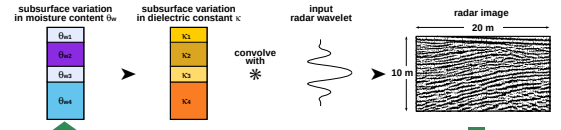
step 2: determine centroid frequency of each local amplitude spectrum down the trace and plot versus time

step 3: find the slope of the best-fit line through the centroid frequency vs. time plot and calculate Q* ∝ 1/slope

step 4: apply an inverse Q filter to the GPR data to remove the effects of wavelet dispersion



Radar Imaging for Moisture Content



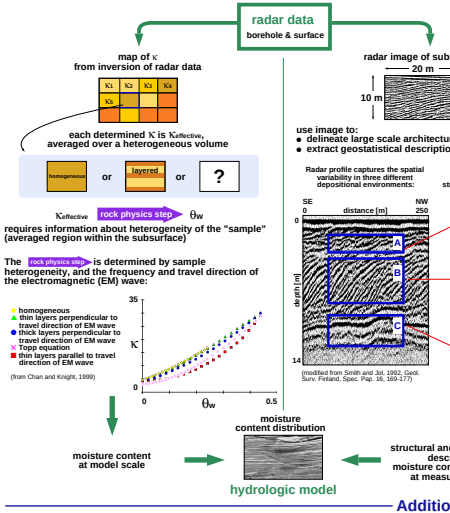
How do we go from the radar image back to information about subsurface moisture content?

Two approaches:
① radar image → inversion → map of κ → rock physics step → map of θw
② radar image → image analysis → information about structure and heterogeneity

Regardless of the approach, **STEP #1** is to improve the quality of the radar image.

Planned Activities
- acquire surface and borehole radar data sets (summer/fall 2000)
- investigate use of wavelet transforms on cross-borehole and surface GPR data for characterization of non-stationary systems
- develop model for joint inversion of geophysical and hydrological data to determine hydrological parameters

Estimating Moisture Content



Additional Information

Information Access

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