

Effects of Signal Processing and Antenna Frequency on the Geostatistical Structure of Ground-Penetrating Radar Data

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ABSTRACT

Recent research has suggested that the geostatistical structure of ground-penetrating radar data may be representative of the spatial structure of hydraulic properties. However, radar images of the subsurface can change drastically with application of signal processing or by changing the signal frequency. We perform geostatistical analyses of surface radar reflection profiles in order to investigate the effects of data processing and antenna frequency on the semivariogram structure of radar reflection amplitudes. Surface radar reflection data collected at the Boise Hydrogeophysical Research Site illustrate the processing- and antenna-dependence of radar semivariograms for a fluvial, cobble-and-sand aquifer. Compensating for signal attenuation and spreading using a gain function removes a non-stationary trend from the data and a trace-specific gain function reduces fluctuation of semivariogram values at large lags. Otherwise, geostatistical structures of surface reflection data are quite robust to the effects of data gains. Migration is observed to reduce the strength of diffraction features in the semivariogram fields and to increase the principal exponential range. Principal exponential range increases only slightly after application of migration with a realistic velocity but over-migration results in a significant artificial increase of exponential range. The geostatistical structures of radar reflection data exhibit marked dependence on antenna frequency, thus highlighting the critical importance of the scale of measurement. Specifically, the exponential ranges of radar reflection amplitudes decrease in proportion to the increased signal frequency for the 50 MHz, 100 MHz and 200 MHz range of antennas. Results demonstrate that processing and antenna frequency must be considered before the application of radar reflection data in a geostatistical context.

Introduction

In a hydrogeophysical context, ground-penetrating radar (GPR) surveys find application in contaminant characterization studies, subsurface structure mapping and hydraulic property estimation (Knight, 2001). With respect to the latter application, Olhoeft (1994) investigated the spatial persistence of radar reflections and Knight *et al.* (1996) and Rea and Knight (1998) advanced the hypothesis that the geostatistical structure of radar reflection amplitudes, as quantified by the semivariogram, could be used to infer the geostatistical structure of hydraulic properties. This hypothesis was based on the facts that radar reflections in the subsurface are caused by changes in the dielectric properties of the geologic materials and that the petrophysical parameters that determine the dielectric properties of a sedimentary unit (grain size, composition and packing) also determine the hydraulic properties.

While a direct relationship between the geostatistical structure of radar reflection amplitudes and geologic or hydraulic properties has yet to be demonstrated (Oldenborger

et al., 2003), geostatistical analysis of radar reflection data has been applied in the extrapolation of hydrostratigraphy (Langsholt *et al.*, 1998), in depositional environment comparisons (Tercier *et al.*, 2000), and in reservoir characterization where the geostatistical structure of radar reflection data was used to interpolate and extrapolate the permeability field within an unsaturated sandstone formation (Szerbiak *et al.*, 2001). Other workers may be considering or applying similar techniques as a method of obtaining critical information regarding the geologic or hydraulic property distribution away from control points. Given an increasing utilization of the technique, it is important to realize that the reliable geostatistical use of radar data may be further complicated by the dependence of the reflection image on data processing and antenna frequency.

The Boise Hydrogeophysical Research Site (BHRS) is a specific example of a site where geostatistical analysis of radar reflection data might allow interpolation and extrapolation of hydraulic properties away from borehole measurements. The BHRS is a meso-scale research site consisting of 18 boreholes completed in a shallow, fluvial cobble and sand aquifer located alongside the Boise River near Boise, Idaho. Currently, borehole-based measurements are

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