spatial and temporal position and concentration variations of the plume as indicated by the fluid conductivity data to those suggested by radar level run attenuation differences, shot-receiver attenuation difference crossplots, and attenuation difference tomograms. We find that attenuation differences generally correlate well with changes in fluid conductivity. Where correlations are not so strong, the discrepancies can be explained by the difference in support volumes for the radar and chemistry measurements, and by the effects of regularization in the tomographic inversion procedure. Our results indicate that crosswell radar imaging coupled with tracer testing can provide useful information about subsurface fluid flow and mass transport in complex fluvial aquifers.

NS23A-09 1330h POSTER

Using Spatially Integrated Crosswell Geophysics For Environmental Site Assessment

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Crosswell seismic and radar techniques provide high resolution subsurface images with precise control on depth and quantitative estimates of acoustic and dielectric properties. However, use of multi-well techniques for environmental site assessment has been hampered by (1) the lack of lateral survey continuity between adjacent well-pairs and, (2) ambiguous correlations between measured properties and relevant subsurface attributes such as lithology and fluid content. We present two spatially integrated tomographic strategies for inverting crosswell datasets which include multiple overlapping well pairs. This approach generates consistent velocity images for large site profiles while preserving the high spatial resolution obtained from transmitting signals over shorter distances. Anisotropic Tikhonov regularization is applied to ensure velocity ties at well locations. To compensate for irregular ray coverage and different survey geometries in the various well pairs, we use adaptive methods to control spatially varying model parametrization and regularization coefficients.

We demonstrate these techniques on a curtain of 17 crosswell seismic datasets and several multiwell radar surveys acquired at the former DOE Pinellas site. Using the results of a detailed examination of continuous cores recovered from the site and crosswell velocity images, we construct a high resolution map of lithology with ties to structural and hydraulic features.

URL: http://pangea.stanford.edu/j̃frank/springAGU/index.html

NS23A-10 1330h POSTER

Porous Media Contamination: 3-Dimensional Visualization and Quantification Using X-Ray Computed Tomography

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Non-aqueous phase liquids (NAPLs), if spilled into the subsurface, will migrate downward, and a significant fraction will become trapped in the soil matrix. These trapped NAPL globules partition into the water and/or vapor phase, and serve as continuous sources of contamination (e.g. source zones). At present, the presence of NAPL in the subsurface is typically inferred from chemical analysis data. There are no accepted methodologies or protocols available for the direct characterization of NAPLs in the subsurface. Proven and cost-effective methodologies are needed to allow effective implementation of remediation technologies at NAPL contaminated sites. X-ray Computed Tomography (CT) has the potential to non-destructively quantify NAPL mass and distribution in soil cores due to this technologys ability to detect small atomic density differences of solid, liquid, gas, and NAPL phases present in a representative volume element. We have demonstrated that environmentally significant NAPLs, such as gasoline and other oil products, chlorinated solvents, and PCBs possess a characteristic and predictable X-ray attenuation coefficient that permits their quantification in porous media at incident beam energies, typical of medical and industrial X-ray CT scanners. As part of this study, methodologies were developed for generating and analyzing X-ray CT data for the study of NAPLs in natural porous media. Columns of NAPL-contaminated soils were scanned, flushed with solvents and water to remove entrapped NAPL, and re-scanned. X-ray CT data was analyzed to obtain numerical arrays of soil porosity, NAPL saturation, and NAPL volume at a spatial resolution of 1 mm. This methodology was validated using homogeneous and heterogeneous soil columns with known quantities of gasoline and tetrachloroethylene. NAPL volumes computed using X-ray CT data was compared with known volumes from volume balance calculations. Error analysis revealed that in a 5 cm long and 2.5 cm diameter soil column containing 0.5 ml NAPL (7,080 mg NAPL per Kg soil), the precision of calculated NAPL volumes was ± 0.03 ml (6% error). Residual NAPL saturation in natural soil cores averaged 15% and varied spatially (inversely with porosity) from less than 1% to 70%. These results and others serve as proof-of-concept that a typical medical X-ray CT scanner has the potential to accurately quantify selected NAPLs in natural soils.

NS31A CC: 220 C-E Wednesday 0830h

Near-Surface Geophysics: Evaluation and Management of Water Resources I Posters *(joint with H, GC, PP, ED)*

Presiding: **R Knight,** Stanford University

NS31A-01 0830h POSTER

Modeling of Velocity Variations and Water Content Estimations from GPR Measurements in a Controlled Vadose Zone

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Ground Penetrating radar (GPR) is a geophysical method that uses high frequency electromagnetic (EM) waves to image the shallow subsurface. Over the last ten years, the GPR (with other geophysical methods) was successfully used to estimate the water content or hydraulic properties of the soil.

We simulate a vadose zone by injecting water in a sand box that contains buried objects. GPR monostatic profiles (with 1200 MHz monostatic antennae) are performed in order to calibrate and compare the water content estimations with the real water content present in the sand box. We obtain four GPR data sets for different saturation degrees: dry sand, water level at 72 and 48 cm depth and, finally, after draining. For each data set, we performed also two common midpoint (CMP) profiles using the 900 MHz bistatic antennae. No distinguished reflections are observed from the top of the saturated zone, and this is because of the existence of a capillary fringe above the water level. The capillary fringe is the zone in which water rises by capillarity from the water table to the surface.

The mean dielectric constants are calculated from average velocities derived from hyperbolic reflections (or diffractions) coming from the bottom of the sand box (or objects buried in the sand). In general, GPR velocity decreases rapidly with depth and this is primarily a result of increasing water content with depth. Knowing that a layer can be divided in more layers depending on the depth of the reflections (or diffractions) recorded, the sand box is shared into three layers: dry sand, unsaturated (capillary fringe) and fully saturated sand. Afterwards, we convert the average dielectric constants, found previously, into real dielectric constants for each layer.

In order to estimate the volumetric water content (the ratio of water volume to total sample volume) for each layer, we combine the GPR measurements with three relations linking dielectric constant to water content of the sample. From these water contents and knowing the volume of sand considered, we can estimate the water quantity in the sand box for each water level. Subtracting the water volume estimated for dry sand to the water volume obtained for different water levels, we find the variations in water quantities in the sand box, which can be compared to the water quantities injected in the sand box. In spite of the uncertainties in the determination of the average velocities, the variation of water quantities calculated are very close to the water quantities injected in the sand box.

By using a Finite Difference Time Domain (FDTD) modeling method, we try also to model the diffractions coming from three buried pipes: steel pipe, air-filled PVC and water-filled PVC pipes. In order to fit the real data, we use a 3rd order ricker source. The reflections from the pipes are well modeled and the amplitude ratio between direct arrivals and reflections on the pipes is respected. The polarity of the reflection coming from the air-filled PVC pipe is opposed and is not as strong as the signals coming from the steel and water-filled PVC pipes.

URL: http://Phineas.u-strasbg.fr

NS31A-02 0830h POSTER

Seismic Investigation of Glacial and Postglacial Sedimentation for the Evaluation of Local Water Resources in Sudbury, Ontario

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The City of Sudbury in Ontario, Canada, contains 330 lakes that cover a total area of 12% of the City's extent. Lake Wanapitei is the largest (13.28 km^2) and deepest (117 m) and contains approximately 4.9 km^3 of water. Baseline geophysical surveys have been conducted of the geology and substrata of the lake basin to expand our understanding of its origin. Lake Wanapitei occupies a bedrock basin that is considered to enclose a 37 million year old meteorite impact structure, 5 km in diameter, that has been modified by glacial erosion. The basin sits on the border between the Proterozoic Southern Province (Huronian sandstones) and Archean Superior Province (granites), and is transected by olivine diabase dikes 50 to 120 m wide. High resolution 'chirp' seismic surveys of the lake basin show at least 40 m of sediment fill comprising a thick lateglacial glaciolacustrine succession overlain by postglacial sediment. Lateglacial sediments accumulated between 10,500 and 10,000 years ago as the margin of the Laurentide Ice Sheet withdrew northwards leaving a series of moraines (e.g., Cartier and Rawhide Moraines). These moraines comprise large volumes of glaciofluvial sediment, often 'kettled' as a consequence of the burial and melt of dead ice blocks. A large raised delta with a surface at 300 m asl along the northern perimeter of Lake Wanapitei records ponding of a high level ice marginal lake (Glacial Lake Algonquin) and the supply of sediment south into the lake from the retreating ice margin. Seismic data record at least three buried river channels where glaciofluvial sediment was supplied to Lake Wanapitei from the north. The sediment cover is non uniform throughout the lake and shows evidence of differential compaction and slumping over the impact crater. Also evident are several faults recording ongoing neotectonic activity.

NS31A-03 0830h POSTER

Estimating the Lateral Correlation Structure of the Shallow Subsurface From Surface Georadar Data

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Knowledge of the spatial correlation structure of the hydraulic properties is a key prerequisite for the detailed characterization of aquifers in general and for realistic modeling of flow and transport in particular. Whereas the vertical component of the subsurface correlation structure is often well constrained from borehole information, the nature of the lateral component of the correlation structure is generally largely unknown. The reason for this is that boreholes are generally too far apart to allow for a meaningful lateral information. Georadar data are highly sensitive to variations in the water-saturated porosity structure, which in alluvial aquifers can be regarded as a proxy for the hydraulic conductivity structure. This opens the perspective to the extract the lateral correlation structure from

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densely sampled and properly imaged surface georadar data. We explore the potential of this approach by comparing the lateral correlation structures extracted from digital photographs of a gravel quarry face exposing braided-river-type deposits with that of georadar data acquired along the upper edge of this quarry face. The observed correlation functions are well approximated by the band-limited scale-invariant von Karman covariance model. The inferred lateral correlation models are invariable of the so-called flicker noise type, but differ substantially in terms of their horizontal correlation lengths. Overall, we found that the lateral correlation structure extracted from the surface georadar data was consistent with that inferred from corresponding regions of the digital photographs of the outcropping surface structure. We also found that the estimated statistical parameters, in particular the horizontal correlation lengths, are quite sensitive to lithological variations, but rather robust with regard the to the processing of the georadar data.

NS31A-04 0830h POSTER

Quantitative Integration of Hydrogeophysical Data: Conditional Stochastic Simulation for Characterizing Heterogeneous Alluvial Aquifers

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High-resolution geophysical exploration techniques have the potential to bridge the inherent gap in terms of resolution and coverage that exist between traditional hydrological methods, such as core analyses and tracer or pumping tests. Although no geophysical technique can provide direct estimates of the hydraulic permeability structure, there are techniques that can supply constraints of the porosity distribution within an aquifer. As their hydrological counterparts, these techniques do, however, again differ strongly in terms of their resolution and coverage as well as their degree of ?hardness?. The quantitative integration of such a diverse database therefore represents one of the major challenges in the field of high-resolution hydrogeophysics. In this study, we explore the usefulness of advanced conditional simulations for this purpose. To this end, we generate a realistic model of an alluvial aquifer consisting of a 2-D scale-invariant porosity field and explore it by means of neutron porosity logs and crosshole georadar tomographic surveys. The reason for the choice of these geophysical methods is that they provide probably the most direct estimates of the porosity structure. We then use an advanced conditional geostatistical simulation approach based on simulated annealing to integrate this hydrogeophysical database. The effectiveness of this approach to characterize the detailed porosity distribution in heterogeneous alluvial aquifers is assessed by comparing the results of a variety of simulations that differ fundamentally in terms of their conditioning information. Our results indicate that this approach has the potential to allow for a realistic hydrogeophysical characterization of the porosity distribution in heterogeneous alluvial aquifer in the sub-meter range.

NS31A-05 0830h POSTER

Kriging of Scale-Invariant Data: Optimal Parameterization of the Autocovariance Model

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Scale-invariance is a common statistical property of data throughout the earth sciences that has to be accounted for in geostatistical models. A primary use of such models is to provide estimates of data at unsampled locations through a specialized interpolation technique known as kriging. We present a kriging approach based on the band-limited scale-invariant von Karman autocovariance model and explore its optimal parameterization. Although we focus on 2D anisotropic data sets, the algorithm can be readily extended to 3D problems. The proposed kriging approach is found to be rather insensitive to the absolute values of the horizontal and vertical correlation lengths as long as the aspect ratio of the structural anisotropy of the observed data is honored. In contrast, the optimal parameterization of the algorithm is strongly dependent on the roughness and complexity of the autocovariance model. Kriging of scale-invariant data may result in significant errors and artifacts when blindly following the standard practice of honoring the autocovariance models inferred from the observed data. These effects are particularly prominent for autocovariance models that represent highly complex media of the flicker-noise type, one of the most frequently observed statistical properties in scientific data. We explore the origins of these phenomena and provide clear guidelines with regard to the optimal parameterization of the autocovariance model for the kriging of scale-invariant data.

NS31A-06 0830h POSTER

Recent Developments for Interpreting SP Data to Characterize Subsurface Fluid Flow

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Surface self-potential (SP) measurements are a cost-effective, non-invasive method to characterize underground fluid flow and transport properties. Over the last five years, we have proposed several interpretation techniques, for both space and time domain SP, backed by field experiments that helped gain insight on the strengths and limitations of this method.

We have developed two inversion methods for the analysis of spatial surface SP data. One is based on the use of analytic signals and wavelets associated with the electric and flow potentials. This way, we have been able to calculate flow rate through a hydrothermal fissure on Mt. Etna. The method yields good results when the electrical conductivity of the host is 1D, but does not take into account electric potential variations arising from lateral electrical conductivity heterogeneities. To get around this problem, we have developed another inverse approach based on coupled hydraulic-electrical forward modeling and optimization with a genetic algorithm. This second method is especially useful when dealing with strong conductivity anomalies such as steel well casings that control the actual geometry of the surface electric potential, even though the SP anomalies have an electrokinetic origin. Applied to a classic SP dataset, we have been able to successfully determine the hydraulic conductivity and the thickness of the aquifer.

In time-domain SP, we have modelled the electrokinetic effect of rainfall infiltration and evaporation in an unsaturated porous medium and showed that detectable SP anomalies are generated (several mV). The sign and amplitude of SP anomalies characterize the nature (i.e. infiltration or evaporation) of the hydraulic transfers in the vadose zone. Comparison of SP and tensiometric data indicates that SP measurements characterize water flow dynamics at a larger scale (i.e. electrode separation, usually several decimetres) than hydraulic measurements and hence SP is less sensitive to soil heterogeneity.

The interpretation methodologies developed for hydrological investigations have been recently extended to the study of fluid flow in deep reservoirs during stimulation or hydrofracturing tests. Initial results show that SP monitoring can provide useful information to understand the dynamics of the reservoir.

NS31A-07 0830h POSTER

SP Response to a Line Source Infiltration for Characterizing the Vadose Zone: Forward Modeling and Inversion

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Field estimation of soil water flux has direct application for water resource management. Standard hydrologic methods like tensiometry or TDR are often difficult to apply because of the heterogeneity of the subsurface, and non invasive tools like ERT, NMR or GPR are limited to the estimation of the water content. Electrical Streaming Potential (SP) monitoring can provide a cost-effective tool to help estimate the nature of the hydraulic transfers (infiltration or evaporation) in the vadose zone. Indeed this technique has improved during the last decade and has been shown to be a useful tool for quantitative groundwater flow characterization (see the poster of Marquis et al. for a review).

We now account for our latest development on the possibility of using SP for estimating hydraulic parameters of unsaturated soils from in situ SP measurements during infiltration experiments. The proposed method consists in SP profiling perpendicularly to a line source of steady-state infiltration.

Analytic expressions for the forward modeling show a sensitivity to six parameters: the electrokinetic coupling parameter at saturation C_S, the soil sorptive number α, the ratio of the constant source strength to the hydraulic conductivity at saturation q/K_S, the soil effective water saturation prior to the infiltration experiment S_e^0, Mualem parameter m, and Archie law exponent n. In applications, all these parameters could be constrained by inverting electrokinetic data obtained during a series of infiltration experiments with varying source strength q.

NS31A-08 0830h POSTER

Ground-Penetrating Radar Diffraction Velocity Analysis

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Over the past decade, much research has been done on the use of reflection ground-penetrating radar (GPR) data in the development of hydrologic models. A challenge in using GPR data in this manner is accurate imaging, such that the data that we record (i.e., a series of traces collected along a profile line that contain reflection events in time) are properly transformed into a map of subsurface reflectors in depth. A key requirement for proper imaging of reflection data is an accurate velocity model of the subsurface. In seismic studies, this model is obtained through the analysis of data collected at multiple source-receiver offsets. However, most commercial GPR systems contain only one receiver antenna, so it is extremely time consuming to acquire multi-offset data. As a result, the velocity field used for radar imaging is most often simply a constant value, or at most a $v(z)$ function, obtained from analysis of a single common midpoint (CMP) survey. In all but the simplest of subsurface scenarios, this type of velocity field is inadequate for proper imaging of GPR data.

To address this issue, we present here a method for the estimation of subsurface EM-wave velocities from common-offset GPR data. Instead of relying on multiple offsets for velocity information, we use diffractions contained within the common-offset data to estimate velocity as a function of horizontal position and depth. Our methodology involves the following steps: First, an initial subsurface velocity model is chosen, which is simply a best guess of the average velocity, or a $v(z)$ function obtained through the traditional means of analyzing one CMP. Next, we apply residual migration to the migrated image for a wide range of velocity ratios; this process migrates the data with a number of velocities defined by constant ratios relative to the original velocity model. Through visual inspection of the residually migrated images, we then pick the velocity ratio that best focuses the GPR image in areas containing diffractions; this information is used to define a perturbation of the GPR image. Finally, we invert the image perturbation to obtain an appropriate update to our velocity model that is consistent with the diffraction information. We iterate this procedure until we have obtained the velocity model that best focuses our image. Initial testing on field GPR data indicates that, for data sets containing an adequate number of diffraction hyperbolas, this method can yield reasonable subsurface velocity models as a function of horizontal position and depth.

NS31A-09 0830h POSTER

Mapping Porewater Salinity with Electromagnetic Methods in Shallow Coastal Environments: Tampa Bay, Florida

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The feasibility of predicting porewater salinity based on surface electromagnetic and resistivity methods was assessed in the shallow coastal waters and wetlands of Tampa Bay, Florida. The most successful method combined an initial core or surface resistivity measurement with pore water samples in order to determine formation factors in the shallow marine sediment. Data were collected over broader areas of interest using Geonics, Inc. EM-31 and EM-34 electromagnetic instruments and the Advanced Geosciences, Inc.

SuperSting R8 marine resistivity instrument. To map coastal porewater conductivities, the EM instruments were adapted for use in shallow marine waters (< 1 meter). In such high-conductivity environments, interpretation of EM readings requires processing with layered models of terrain conductivity that include direct sampling data. Typically, nearby marine resistivity readings are necessary to distinguish between equivalent EM model solutions. Porewater conductivities estimated from the layered EM models and the resistivity-derived formation factors show very good agreement with measured pore water conductivities. The use of EM systems in very shallow waters has potential application in locating prospective submarine groundwater discharge in areas that are difficult to reach with conventional towed marine resistivity arrays. Electromagnetic and direct sampling data show that salt exclusion by mangroves significantly increases pore water conductivities, and hence terrain conductivity readings within 10m of a mangrove shoreline. Terrain conductivities fall off to background values within 15m of the mangrove shoreline. The marine EM-31 measurements were effective at sensing the magnitude and lateral extent of high and low salinity porewaters within wetlands and mangrove lined ditches and ponds, which may be useful for interdisciplinary studies of coastal ecosystems.

URL: http://gulfsci.usgs.gov/tampabay/index.html

NS31A-10 0830h POSTER

Re-evaluation of Spatial Sensitivity of Low-Induction-Number Frequency-Domain Electromagnetic-Induction Instruments: Implications for Improved Efficiency in Field Surveys

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A series of simulations were done using one-dimensional, forward numerical models to examine the sensitivity of two commonly used, low-induction-number, frequency-domain electromagnetic-induction instruments (Geonics Inc., EM31 and EM34) to spatial variations in electrical conductivity. In these simulations, a relatively thin layer whose electrical conductivity differed slightly from background was moved to successively greater depths in an otherwise homogeneous half-space. Inputs to the models reflected the fact that only certain combinations of transmitting frequency and intercoil separation are possible for each instrument. The calculated responses were converted into weighting functions, which indicate the proportion of the measured secondary electromagnetic field arising from different depth intervals. Comparisons of results from different frequency-intercoil separation combinations were made possible by normalizing the results with respect to intercoil separation. The results contradict the prevailing view of the spatial sensitivity of these instruments. Specifically, for a given electrical conductivity, the shape of the weighting function varies with the induction number. In other words, the proportion of the measured response contributed by different depths depends on the combinations of transmitting frequency and intercoil separation built into each instrument. There exist instruments in which frequency and intercoil separation can be varied more freely, and thus the vertical distribution of sensitivity can be altered to improve depth discrimination. In addition, weighting functions from horizontal and vertical magnetic dipole orientations are very similar, implying that each orientation is essentially equally sensitive to any given depth. Contrary to the previous view, the shape of both functions indicates that sensitivity peaks at the surface and declines exponentially with depth for both dipole orientations. Therefore, measurements using both orientations provide little additional information. As a result, using one dipole orientation in field surveys can yield significant savings of time and operating costs without compromising data quality and utility.

(The use of trade, product or firm names in this publication does not constitute endorsement by the U.S. Government.)

NS31A-11 0830h POSTER

Investigation of Water Migration Through the Vadose Zone of the Miami Oolite Using High-Resolution 4D Ground Penetrating Radar.

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Despite implications for groundwater vulnerability and aquifer recharge, the anatomy of vadose zone flowpaths and ponded water layers remains largely unknown. Data available at present rely either on interpolation between point measurements, or broad brush geophysical methods which lack the resolution to exactly define how or where moisture pulses migrate to the water table. Ground Penetrating Radar (GPR) has the capacity to image aquifer structure and dynamics at a sub-meter scale. However, its true potential has been restricted because conventional 2D and pseudo 3D GPR images are distorted by out-of-plane reflections and interpolation artefacts.

We present first field trials with a new full-resolution 3D radar system which allows the rapid acquisition of precisely located and repeatable radar grids, with cell size of 5-10 centimetres, over sites larger than a thousand square meters. These dense 3D volumes accurately image the complex sedimentary structure of the Miami Oolitic Limestone. Applying the new radar to hydrological investigation introduces the possibility of monitoring the migration of moisture pulses, as the system enables precise relocation of the radar antennae and repetition of surveys several times per day. As site geology remains constant, any variation in the 3D radar image is due to changes in water content. Porosity in the Miami Oolite ranges from 0.4 to over 0.6 and calculations using the Topp equation show that for this medium, radar velocities may easily halve as the moisture content approaches saturation. This gives rise to significant time-shifts even at lower saturations. In radar images, varying moisture contents are visible as both time-shifts and amplitude changes. The time-shift data indicate varying levels of rock saturation, and the amplitude changes show the locations of ponded water layers and active flow paths. Our results demonstrate that GPR is capable of monitoring both individual rainfall events and seasonal moisture variation within the Miami Oolite, at a resolution far greater than that allowed by alternative methods. Further development of this radar system and its application to groundwater investigations represents a significant advance in monitoring techniques and will lead to increased understanding of vadose zone flow.

NS33A CC: 220 C-E Wednesday 1330h

Near-Surface Geophyscis: General Session Posters *(joint with H, S, T, C, GC, PP, ED, MR)*

Presiding: **J J Daniels,** Ohio State University

NS33A-01 1330h POSTER

Exploration Depth of Multi-frequency Helicopter EM Systems

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Due to the high resolution of hilicopter electromagnetic (HEM) systems, they are being widely used for shallow earth resistivity mapping problems. The traditional investigation of the exploration depth of a HEM system is based on the model of a single-frequency coil array over a layered earth. In this paper we extend the study to the multi-frequency HEM systems. We first determine for each frequency channel of a HEM system the maximal depth of a target, beyond which it cannot be identified from the EM signal. This is mathemically realized by assuming that the abnormal signal from the target is three times larger than the noise level of the HEM channel. Since each frequency channel of an HEM system has a different noise level and for different frequency channel the EM field has different penetration depth, we choose the biggest value of these depths as the depth of exploration.

Different models are implemented in the study of this paper, including a layered earth model, a dipping plate or a dyke, a 3D ore body, etc. We use as example the Fugro DIGHEM system with three horizontal coplanar (HCP) coils (380 or 900, 7200, 56kHz) and two vertical coaxial (VCX) coils (900, 5500Hz). The following conclusions are obtained:

1. Except for a steeply dipping sheet, the HCP coil array has a larger depth of exploration than the VCX coil array;

2. The depth of exploration may be obtained from different frequency channels for different target geometries and different conductivity contrasts between the target and host rocks. This means that for a specific target geometry and conductivity contrast, we need to search such a frequency channel that offers the maximal value for depth of exploration;

3. Among the factors that influence the depth of exploration, the noise level of the HEM system is the key. The other factors include the geometry of the target and the conductivity contrast between the target and the host rocks, and the relative location between the HEM system and the target;

4. We have assumed in this paper three times the noise level as the threshold in defining the depth of exploration of a HEM system. If the HEM data have a high quality, e.g. with good system calibration and data processing, this factor might be reduced, so that the depth of exploration can be greatly improved.

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Effect of Electrode Position Errors on Electrical Resistivity Tomography Data

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The electrical resistivity tomography (ERT) method has proven to be a valuable geophysical tool for a variety of shallow subsurface imaging tasks such as contaminant monitoring, fracture detection and moisture content mapping. Inversion artifacts are features of the tomographic image that are not attributable to the actual subsurface material properties. Limitations of tomographic imaging arise due to the difficulty of quantifying the origin of these artifacts and, thus, the reliability of tomographic images. Environmental and engineering geophysical surveys are often such that target sizes or the scale of heterogeneity may be of the same order of scale as the experiment dimensions. At these small scales, errors in electrode positions may significantly contaminate ERT data and artifacts may populate large portions of the tomographic volume. Variations in the data due to errors in source and/or receiver coordinates may overwhelm variations in the data due to changes in material properties. The dependence of the data on electrode mislocations is characterized by the sensitivity of electrical potential to both source and receiver positions. Analytical sensitivities and synthetic forward models are used to investigate the effect of electrode position errors on ERT data. In the homogeneous case, the sensitivities of potential with respect to source/receiver positions are purely geometrical and dependent on the electrode-electrode separation according to a inverse squared-distance relationship. The homogeneous sensitivities illustrate the robustness with respect to position errors of different data types (pole vs. dipole) and different electrode geometries (cross-hole vs. common-hole). In the heterogeneous case, the sensitivities of potential with respect to source/receiver positions are described by scattering-type equations and thus, magnitudes of the sensitivities depend not only on electrode-electrode separation but also electrode-heterogeneity separation. Accordingly, for surveys in which electrodes may be close to the target, sensitivities to source/receiver positions can be high; corresponding data errors can significantly exceed measurement precision. Furthermore, for a given electrode pair, the sensitivities to source/receiver positions are asymmetrical and the sensitivity to receiver position is equal to the sensitivity to source position for the reciprocal electrode arrangement. The implication is that, in a inverse paradigm, only the relative source-receiver location error will be determined for a given electrode pair. Multiple electrode combinations may alleviate this problem. Finally, while results are specific to the ERT problem, the general methodology is applicable to other types of geophysical data that may be contaminated by source/receiver position errors.

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Characterization of Shallow Subsurface Electrical Conductivity Features and Heterogeneity Using Wavelet Analysis and Geostatistics

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Depositional and geochemical processes act on multiple spatial scales and time scales. As a result, variations in geological field properties are often non-stationary in space and scale. An adequate understand-