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Multi-dimensional electromagnetic modeling and inversion with application to near-surface earth investigations

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Abstract

Electrical conductivity of the earth provides information about porosity, water saturation, salinity, clay content, and organic matter that cannot be duplicated by other geophysical methods of investigation. However, there is a complex relationship between conductivity structure and the geophysical data measured at the Earth's surface. In various fields of investigation, interpreting geophysical responses with a locally one-dimensional (1-D) approximation to earth structure often yields useful results, especially if constrained to avoid artifacts not demanded by the data. However, in many instances, the locally 1-D assumption breaks down, and the lateral variations in structure must be included explicitly in a quantitative model. In this paper, we discuss the state of the art in modeling and inversion of 1-D, 2-D, and 3-D earth conductivity structures. Pertinent issues include capabilities and limitations of the various common field measurement systems, methods to predict the geophysical response, and incremental response sensitivity, to earth structure, in addition to techniques for iteratively estimating an earth model that maximizes resolution without sacrificing model stability. Examples are shown from applications to groundwater resource evaluation, archeology, precision agriculture, contaminant distribution mapping, and vadose zone hydrology. Electrical and electromagnetic data sets in precision agriculture can be enormous and difficult to treat easily in multi-dimensional inversion. Higher dimensionality analysis is, perhaps, best suited for subsets of the data where lateral variation is most extreme or the data simply cannot be fit using 1-D models. One of the most useful new techniques for interpreting precision agriculture datasets

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may be that termed 1.5-D inversion, wherein layer resistivities and depths of local 1-D models are laterally constrained with respect to neighboring values or a large-scale average structure.

Keywords: Geophysics; Electrical conductivity; Electromagnetics; Modeling; Inversion

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Nomenclature

1-D	one-dimensional
2-D	two-dimensional
3-D	three-dimensional
CDI	conductivity depth imaging
dc	direct current
E&EM	electrical and electromagnetic
EC_a	apparent soil electrical conductivity
ERT	electrical resistivity tomography
GCM	ground conductivity meters
GPR	ground penetrating radar
HEM	helicopter EM
IP	induced polarization
LCI	laterally constrained inversion
MCI	mutually constrained inversion
MT	magnetotellurics
PA	precision agriculture
PACES	pulled array continuous electrical sounding
RMT	radio magnetotellurics
TE	transverse electric
TEM	transient electromagnetic method
TM	transverse magnetic
VETEM	very early time electromagnetic

Greek letters

ε	dielectric permittivity
σ	electrical conductivity
ρ	electrical resistivity
μ	magnetic permeability
μ_o	dielectric permittivity of free space