NS43B-4054

Rational Experimental Design for Electrical Resistivity Imaging

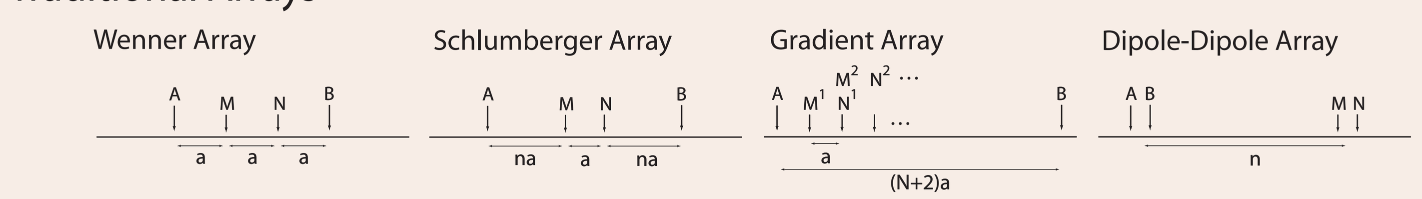
Vanessa Mitchell[1], Adam Pidlisecky[2], and Rosemary Knight[1]

[1]Stanford University Department of Geophysics, vmitchel@stanford.edu, rknight@stanford.edu
[2]University of Calgary Department of Geoscience, adampid@ucalgary.ca

Background and Motivation

Electrical resistivity imaging (ERI) surveys typically use one of a small number of standard data acquisition arrays, originally designed to have analytic solutions to Poisson's Equation in a homogeneous half-space. However, research has shown that non-standard arrays may produce improved-quality data.[1] The value of non-standard arrays, given experimental constraints raises the question: **how do we design a survey, in terms of spatial and temporal sampling, to image a subsurface process or region most accurately**?

Traditional Arrays

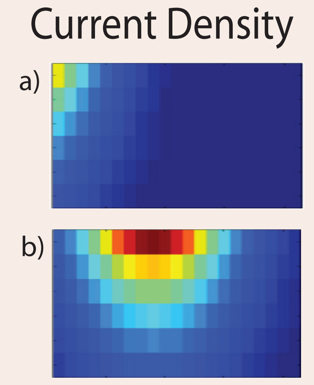


While previous work has focused on classical optimized experimental design theory to address this question[2], we propose instead a method for rational experimental design. By rational design, we mean **incorporating prior information about a site and the expected target into the design process for an acquisition array**.

Rational Design Algorithm

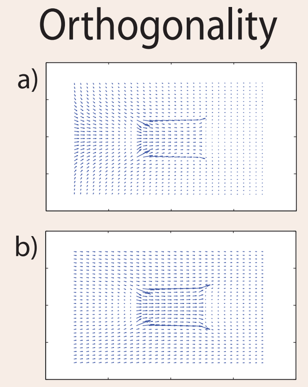
Our rational experimental design algorithm uses a prior conductivity model to select source configurations based one key criteria: maximizing the orthogonality of current vectors from any two source configurations within a specified region. Choosing sources based on this principle maximizes the amount of unique information content between two configurations by sampling the region from as different an angle as possible. The algorithm further selects arrays that provide sufficient current density to discern signal from measurement noise.

Current Density



Magnitude of the current density within a region of interest for 2 source locations:
a) (13.5,0) (17.5,0)
b) (25.5,0) (29.5,0)

Orthogonality



Current vectors within a region of interest for 2 source locations:
a) (-2.75,0) (2.75,0)
b) (-22.75,0) (22.75,0)

Sensitivity Measures

We use three sensitivity measures to evaluate the performance of the algorithm-selected array (ASA). The Furman measure perturbs model elements relative to a homogeneous field, calculating the change in the electrical response at specified locations.[3] The depth of investigation (DOI)[4] measure uses inverted models to determine the depth below which the data no longer inform the inversion. The resolution matrix uses the column-sums of the Jacobian to measure the average impact a change in a model parameter has on data observed at all other locations in the model.[5]

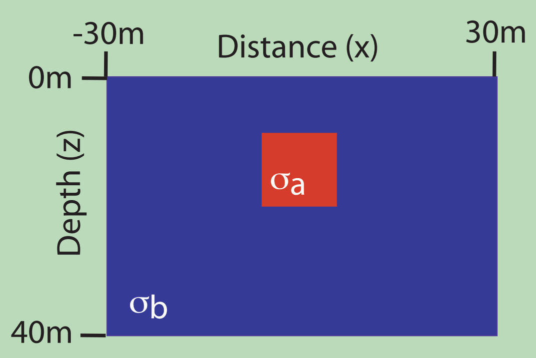
Furman Measure	DOI	Δ DOI	Model Resolution
$S_F = \frac{1}{src}\sum_{src}\sum_{pert}\left\|\Delta V^{pert\,i} - \Delta V^{hom}\right\|$	$S_{DOI} = \frac{m_1(x,z) - m_2(x,z)}{m_{1ref}(x,z) - m_{2ref}(x,z)}$	$\Delta S_{DOI} = S_{DOI}^{ASA} - S_{DOI}^{TRAD}$	$S_J = \sum_j \frac{\partial f_i}{\partial m_j}$

Numerical Simulations

Initial Model Description

38 surface electrodes maximum
0.5 m minimum offset
σ_a = 5 mho/m, σ_b = 50 mho/m
|Current density| > 0.5 (noise threshold)

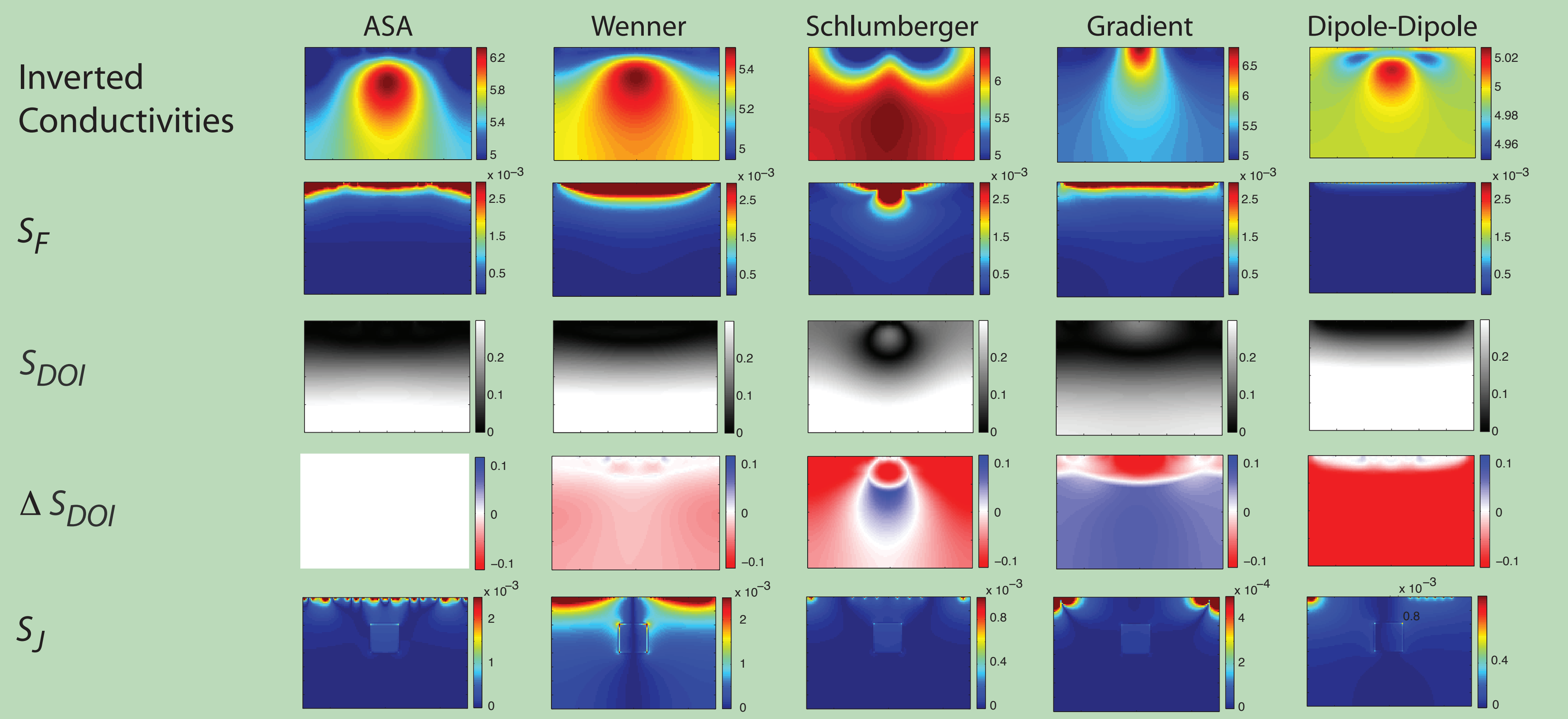
9 unique configurations
9 pole potential measurements per source



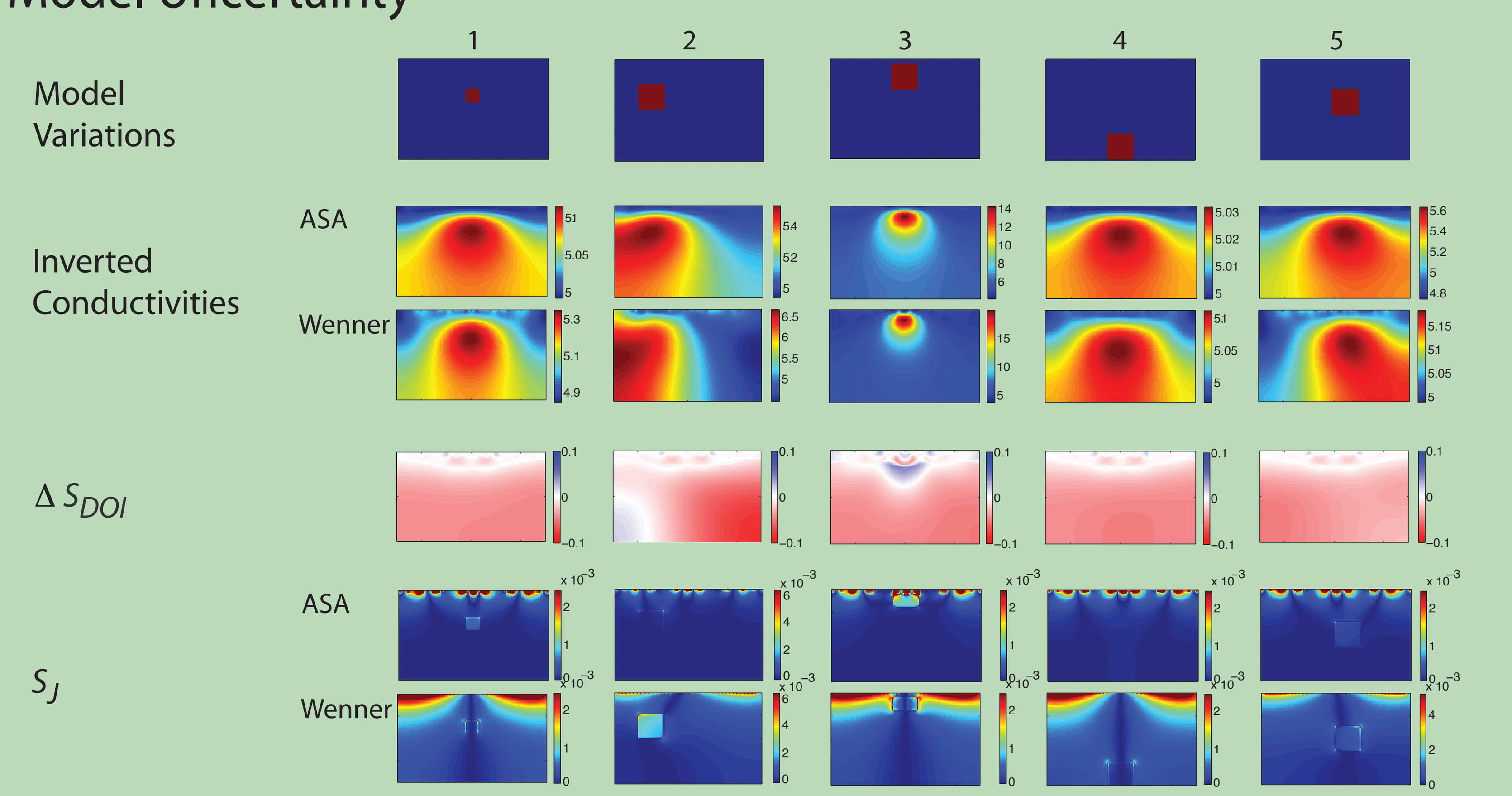
ALGORITHM-SELECTED ARRAY

	Source (x,z)		Potential (x,z)
±	(-29.75,0)	(-21.75,0)	(0,0)
±	(-2.75,0)	(2.75,0)	(5.75,0)
±	(18.25,0)	(21.75,0)	(7.25,0)
±	(-2.75,0)	(0.75,0)	(15.75,0)
±	(-13.75,0)	(-10.75,0)	(19.75,0)
±	(-2.75,0)	(10.75,0)	(-5.75,0)
±	(8.25,0)	(21.75,0)	(-7.25,0)
±	(-4.75,0)	(-2.75,0)	(-15.75,0)
±	(21.75,0)	(26.25,0)	(-19.75,0)

Initial Results



Model Uncertainty



Discussion

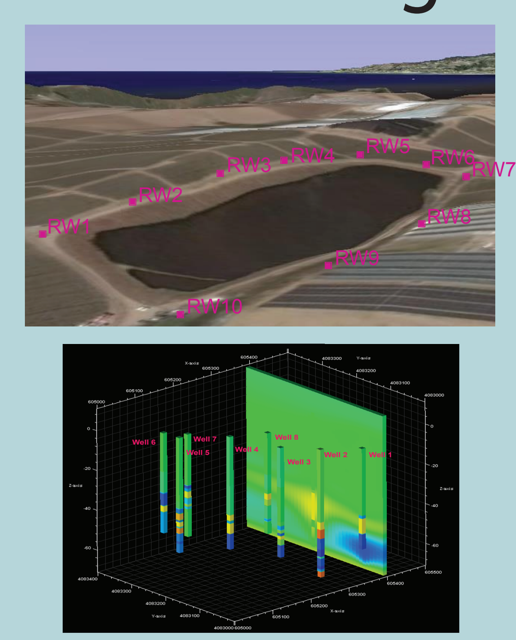
The three sensitivity measures give very different evaluations of the ASA performance relative to the four traditional arrays and in the model variations.

The Furman measure is only included in the initial results because it is insensitive to changes in the conductivity model. It only depends on the electrode locations in each array. This measure suggests the Wenner, Schlumberger sounding, and gradient arrays have the greatest sensitivity to the imaged region. By contrast, the DOI indicates the ASA, Wenner and gradient arrays provide the best sensitivity. Evaluating the inverted models and the model resolution provides the greatest correlation between measured sensitivity and reliability of inverstion results. These results suggest a uniform, increased level of sensitivty to the target interior has a larger impact on the reliability of inverted data than sensitivity magnitudes alone.

The 5 model variations used to evaluate array performance, given model uncertainty, support this interpretation. Based on reliability of the initial conductivity inversions, only the Wenner array is used for comparison. Examining the relationship between how well the target is constrained in the inversions, and the Δ DOI and model resolution for these scenarios, highlights the two main conclusions of our study:

1) **An elevated sensitivity to the target interior in the model resolution corresponds to a better-constrained inversion.**
2) **The ASA produces clearly more reliable inversion results only when the target, or some portion of the target, falls in the specified region of interest,** emphasizing the importance of good prior information in rational experimental design.

Field Testing



Our method for rational experimental design is being tested on an infiltration pond off Harkin's Slough in Watsonville, CA. Using well log information from monitoring wells around the pond, as well as seismic and GPR data from the pond base, we developed a prior conductivity model of the pond. With this starting model we applied the rational experimental design algorithm in which the target is the infiltration process at ~ 5 m depth. We are monitoring infiltration in this zone with time-lapse ERI using both an ASA and a Wenner array to test the performance of the two arrays in a real -world setting.

References

[1] Furman, A., T.P.A Ferre, and A.W. Warrick (2002). "A sensitivity analysis of electrical resistivity tomography array types using analytical element modeling." *Vadose Zone Journal* **2**:416-423.

[2] Haber, E., L. Horesh, and L. Tenorio. "Numerical methods for optimal experimental design of large-scale ill-posed problems." *Inverse Problems, To appear.*

[3] Furman, A., T.P.A. Ferre, and A.W. Warrick (2004). "Optimization of ERT surveys for monitoring transient hydrological events using pertrurbation sensitivity and genetic algorithms." *Vadose Zone Journal* **3**:1230-1239.

[4] Oldenburg, D.W. and Y. Li (1999). "Estimating depth of investigation in dc resistivity and IP surveys." *Geophysics* **64**(2):403-416.

[5] Friedl, S. (2003). "Resolution, stability and efficiency of resistivity tomography estimated from a generalized inverse approach." *Geophysics Journal International* **153**:305-316.