Regularization of VLF inversion using rank order smoothing

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Least-squares inversions are generally applied to recover resistivity distribution models from electromagnetic induction data. Since the defined inversion problems are underdetermined and ill-posed, various operators are implemented to regularize the process. Smoothing operators, which are simple finite difference matrices penalizing the resistivity differences between neighboring cells, are implemented in the most applications and aims to result with smooth structure boundaries. These smooth models often have over-smoothing structure boundaries which are rather difficult to interpret. Considering this, we have defined a smoothing operator based on rank order filtering. These non-linear filters are known with their ability to eliminate low-frequency changes while keeping boundary information.

In image processing, rank order filters are implemented by determining ranks of pixels within a given filter window and assigning the value of the pixel corresponding to the desired rank, defined by the user, to the central pixel. Filtering is completed by repeating the process for all pixels. Correspondingly, we have penalized the difference of each cell from its neighboring cell corresponding to the defined rank value. Contributions from other cells are also calculated and damped with a Gaussian curve according to their difference from the defined rank. In our implementations we have used median (50%) as the desired rank value since higher or lower values were biasing the inversion to minimize resistors or conductors.

In the trials with synthetic data, inversion with the rank order smoothing is observed to be able to recover boundaries successfully while minimizing misfit. For the field implementation, we used the VLF-R measurements collected over the rupture area of the North Anatolian Fault Zone. The data are modeled using both rank order smoothing and traditional smoothing operator for comparison. The recovered models show that the rank order smoothing resulted with models with more evident boundaries, revealing the known faults better.