GEOELECTRIC AND GEOELECTROMAGNETIC METHODS APPLIED TO VOLCANOES -- CHALLENGES AND BENEFITS OF NUMERICAL SIMULATION TECHNIQUES

Klaus Spitzer

Institute of Geophysics, TU Bergakademie Freiberg

Electromagnetic methods may tell us about subsurface structures and dynamics that cannot be seen by other methods as, e.g., seismics or gravity. They are complementary to these methods and, thus, gain additional information to construct a more complete and comprehensive picture of the Earth's interior. A necessary prerequisite, however, is that the electric parameters, mainly the electric conductivity but also the dielectric number or the magnetic permeability, are affected by these processes or correlated to these structures. Marine volcanoes are particularly demanding when it comes to applying electric or electromagnetic methods to investigate their interiors. First, the surrounding, highly conductive sea water represents a significant difference in conductivity with respect to the volcanic body, second, the volcano's topography has great impact on the electromagnetic response, and, third, the surrounding sea bed topography heavily distorts electromagnetic fields in certain frequency bands. By neglecting these issues severe misinterpretations are the inevitable consequence. This talk therefore addresses the state of the art in numerical simulation and inversion strategies for geoelectric and geoelectromagnetic methods and shows how the problems described above may be tackled. In particular, finite difference and finite element discretization schemes for the solution of the respective boundary or initial value problem are described including their appropriate boundary conditions. The advantages of unstructured grids over tensor product or Cartesian grids are demonstrated and their superiority is shown with respect to surface or subsurface topography, marine bathymetry, and source geometry. The finite element technique is especially suitable to treat geometrically demanding problems and, therefore, it will be considered in its variational formulation. Linear and higher-order basis functions, p- and h-refinement , stability conditions and equation solvers are addressed, the latter in terms of run time and memory requirements. By approaching simulation problems we necessarily encounter questions of computer hardware and architecture as well as parallelization issues. Different coding strategies are presented and their pros and cons are discussed with respect to efficiency, control, and development time. On the physical side, the so-called secondary field approach is an elegant way to solve electromagnetic problems in an alternative manner leading to better behaved fields and avoiding strong gradients or singularities. Furthermore, electric anisotropy is challenging but does give further insight into many geoscientific problems as fracture systems and hydrothermal regimes that may be of great importance particularly with respect to volcanoes.

In the inversion part, mainly common Gauss-Newton approaches are presented and different parametrization schemes are discussed on the basis of regular and unstructured grids leading to so-called three-grid approaches for certain techniques. When talking about inversion we consequently allude to the following crucial questions:

- What are the mapping characteristics of the overall process of measurement and inversion?
- How can we assess the confidence limits of the inverse model?
- What are the influences of different inversion and regularization methods, the parametrization and the data error?
- How can we use our understanding of the process to improve the experimental design?

As an example, I will demonstrate the simulation of plain wave magnetotelluric fields applied to Stromboli volcano. One major issue is the incorporation of the Stromboli topography using a digital terrain model so that nearly all geometric features affecting the electromagnetic response are considered and an electromagnetic view on Stromboli becomes possible, which is as close to reality as possible. By carrying out a number of different synthetic experiments we realized that not only the topography of Stromboli island itself is influencing the behavior of the fields but even stronger the topography of the surrounding seabed within a radius of several tens of kilometers. This will finally lead to questions related to spatial data sampling, experimental design and resolution analysis, which help to gain optimum information on our targets and realistically assess the potential and the limits of electromagnetic exploration methods.