Three-dimensional node-based FEM method using unstructured grid for electromagnetic volcano monitoring systems

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In recent years, magmatic and/or phreatic eruptions occurred in many volcanos in Japan. In Aso volcano in the centre of Kyushu island, Japan, for example, a magnetic eruption occurred on November 25th, 2014, for the first time since the last magmatic event approximately 22 years ago. To monitor the activity of Aso volcano, our group in Kyoto University have been operating an electromagnetic (EM) monitoring system, ACTIVE (Array of Controlled Transient Electromagnetics for Imaging Volcano Edifice; Utada et al, 2007), around the active first crater of Aso volcano. ACTIVE system in Aso volcano consists of one transmitter that transmits electric currents into the ground through two electrodes, and several induction-coil receivers that observe only the vertical component of the magnetic field, bz. By means of this system, we succeeded in detecting temporal changes in ACTIVE response functions, amplitude ratios of bz to the transmitted electric current (nT/A), before and after the magmatic eruption on Nov. 25th, 2014.

In order to quickly analyze data obtained by the ACTIVE-type EM volcano monitoring systems, we developed a new three-dimensional forward code, by adopting the node-based finite element method (FEM). We use unstructured tetrahedral grid to represent arbitrary conductivity structure and complicated topography of volcanos. We directly solve the induction equation only in terms of the magnetic field, since only the magnetic fields are obtained in ACTIVE observations. The reasons why we adopted the conventional node-based FEM are that (1) the node-based FEM is superior to the popular edge-based FEM methods (e.g., Schwarzbach and Haber, 2013) from the perspective of the computational memory, (2) the continuity of the magnetic field is naturally guaranteed provided they are defined at nodes, (3) linear problems in node-based FEM are easily solved by iterative methods, e.g. Conjugate Gradient (CG) method, and thereby (4) we can easily implement parallel computations using MPI. It was illustrated that our forward code is able to calculate the accurate vertical component of the magnetic field, in comparison to the analytical solution of Ward and Hohmann (1988), when a horizontal electric dipole is located just on 1-D layered structure. Now we are trying to improve the convergence ratio in COCG (Conjugate Orthogonal CG; van der Vorst and Melissen, 1990) solver using the divergence free condition of the magnetic field.

In the presentation, we first introduce the ACTIVE system operated in Aso volcano and share some observed data before and after the magmatic event. Second, we show the methodology of our new three-dimensional node-based FEM code and show its accuracy through some numerical experiments.

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