Report of Research Activities at ERI:

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Location: Earthquake Research Institute (ERI), University of Tokyo
Dates: June 1 – November 30, 2017
ERI host: Asst. Prof. Kiyoshi Baba

My six-month research visit to ERI had three main objectives:

1) Initiate scientific collaboration between Drs. Baba and Koyama of ERI and myself;
2) Develop an efficient, flexible electromagnetic forward modelling code that can be applied in areas of complex topography/bathymetry, such as the area of new volcanic island Nishinoshima;
3) Use the code to study the effect of Nishinoshima's bathymetry and magma chamber on EM responses.

During my stay at ERI I successfully completed the first two objectives. I had a very pleasant working environment and have initiated collaboration with researchers not only in ERI, but also in JAMSTEC, and with some of the visiting researchers at ERI. I hope to further develop these collaborations.

I have developed an electromagnetic forward modelling code based on a finite-element (FE) method. The code allows accurate approximation of complex model geometries with adaptive unstructured meshes. To make it possible to develop and test a state-of-the-art forward modelling approach in as short a period of time as six months, I used the open source FE library *deal.II*. This library is based on fully unstructured hexahedral meshes which typically require 4-10 times fewer elements than tetrahedral meshes to obtain the same rate of convergence. In addition, *deal.II* allows for a high level of parallelization and scales to several thousand processors. The code also allows high-order elements. and I have shown that it is advantageous to use higher-order elements to obtain accurate solution at the same time utilizing less degrees of freedom.

I have verified the accuracy of the code on a known bench-mark model COMMEMI 3D-2, by comparing the EM responses of the new FE code to a robust integral-equation code *x3d*. This comparison demonstrated an excellent agreement.

At the moment, I am working towards completion of the last objective. The current implementation even-though flexible and robust still requires further improvements to be more suitable for real-world applications. Firstly, a part of the code employs direct solver MUMPS. For meshes necessary to accurately approximate Nishinoshima's bathymetry the memory requirements of this solver are large, and it needs to be substituted by preconditioned iterative solver. My choice is conjugate-gradient solver with the auxiliary-space Maxwell preconditioner (AMS). This preconditioner is now part of *Hypre* library, and should be relatively straightforward to implement.

Secondly, it is necessary to implement a goal-oriented mesh refinement. Such an approach would allow to adaptively refine mesh only in places that affect the solution at the receivers. At the moment, we adaptively refine the mesh based on the properties of the solution everywhere in the modelling domain. Goal-oriented mesh refinement would significantly reduce the mesh size.

With the help of these developments it should be possible to image Nishinoshima's magma chamber and this should help to understand processes that are involved in the development of new continental crust.

During my stay in ERI I have presented my research at the SGEPSS fall meeting held in Kyoto, and delivered two seminar talks. I plan to present the results of Nishinoshima’s modelling study at the EM induction workshop that will be in Denmark in August 2018, and intend to prepare a publication based on this modelling study.

I enjoyed my time in ERI, and hope to continue this collaboration in the future. I would like to thank Drs. Baba and Koyama for inviting me, and allowing to join the exciting Nishinoshima project. I also would like to thank International Research Promotion Office for funding my application and making my stay in Japan pain-free.