Forecasting volcanic eruption sequence based on field data and physical models

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Volcanic eruptions often continue for more than a few months or years; the intensity and the style of eruptions remarkably change with time. It is, therefore, desired to forecast such eruption sequences on the basis of field observations during the eruptions. For this purpose, the basic idea of data assimilation is useful. The data assimilation is composed of two mathematical problems: forecasting the system evolution based on forward physical models and determining the model parameters based on inversion analyses of field observations. We are interested in how the mathematical characteristics of the forward models for volcanic eruptions affect those of their inversion problems. In this presentation, we focus on two problems: (1) the estimation of model parameters of magma plumbing system from field observations of magma discharge rate and ground deformation, and (2) the estimation of magma discharge rate of explosive eruptions from tephra-fall deposits.

The inversion problem of magma plumbing system

The eruption sequence is characterized by the evolution of magma discharge rate (Q) and chamber pressure (P) during eruption. To describe the evolution of Q and P, we formulated a model of magma plumbing system composed of a conduit and a magma chamber in elastic rocks. In this model, the effects of gas-exsolution and gas-escape on conduit flow are considered, which leads to complex features of volcanic eruptions such as a transition from a lava-dome forming eruption to an explosive eruption. The eruption style (i.e., evolution of Q and P) is sensitively dependent on model parameters related to geological and petrological conditions (e.g., volume and depth of magma chamber and magma properties). To forecast the eruption sequence, these model parameters need to be estimated from time-varying observations of Q and P through an inverse analysis.

Generally, because of the strong non-linearity of the conduit-flow model, it is mathematically and computationally difficult to investigate the influence of each observation on the estimation of the model parameters. We express the trade-off relationship between the model parameters utilizing analytical solutions of the conduit-flow model (e.g., Koyaguchi, 2005; Kozono and Koyaguchi, 2009), and show that the key parameters that affect the time evolution of P and Q are fundamentally different between explosive and effusive eruptions. Because of this difference, model parameters constrained from the observations of Q and P also depend on whether the eruption is effusive or explosive.

The inversion problem of tephra dispersion

The estimation of magma discharge rate (i.e., Q) is one of the key issues for forecasting volcanic eruption sequence. For explosive eruptions, the value of Q can be estimated from observations of tephra dispersion. The forward model of tephra dispersion is composed of the eruption column dynamics model and the advection-diffusion model. The former describes the supply rate of tephra particles from an eruption column just above the volcano as a function of altitude (referred to as the supply rate function). The latter describes the transportation of tephra particles from the source (i.e., the eruption column just

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above the volcano) to the ground surface.
The above two models have distinct features in the inversion problem. The singular value decomposition (SVD) analysis indicate that the inverse problems of the advection-diffusion model is highly ill-conditioned so that the number of basis functions expressing the supply rate function is limited regardless of the number of data of tephra-fall deposits. On the other hand, the eruption column model indicates that the form of the supply rate function is strongly correlated with the eruption conditions such as Q. We, therefore, attempt to develop a method to estimate the value of Q from the supply rate function expressed by the limited number of basis functions. Some preliminary results on this problem will be presented.

Keywords: volcanic eruption, data assimilation, conduit flow model, tephra dispersal model

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