needed for particles with the small sizes used here. Although the exact methods provide more accurate results, they require more computing time and memory that rapidly increases with particle size. The accuracy of measurements of particle sizes with airborne probes, radiative transfer models, and satellite retrieval algorithms depends heavily on accurate calculations of single-scattering properties of ice crystals. The petascale Blue Waters is an important resource for completing these calculations.

NEXT GENERATION WORK

Natural ice crystals larger than 50 micrometers have various shapes with much more complex internal (e.g., inclusions) and external features (e.g., surface roughness) compared to small ice crystals. Thus, calculations of scattering properties of larger ice crystals will require much larger computing resources than available on Blue Waters. We want to perform such calculations using a next-generation Track-1 system.

PUBLICATIONS AND DATA SETS

Um, J., and G. M. McFarquhar, Formation of atmospheric halos and applicability of geometric optics for calculating single-scattering properties of hexagonal ice crystals: Impacts of aspect ratio and ice crystal size. *J. Quant. Spectrosc. Radiat. Transfer*, 165 (2015), pp. 134-152, doi:10.1016/j.jqsrt.2015.07.001

Um, J., and G. M. McFarquhar, Light scattering by atmospheric ice crystals: Application to forward scattering probes. *International Symposium on Radiation*, Auckland, New Zealand, April 16-22, 2016.

McFarquhar, G. M., and J. Um, Light scattering by atmospheric hexagonal ice crystals for determination of applicability of geometric optics and formation of atmospheric circumscribed halos, *International Symposium on Radiation*, Auckland, New Zealand, April 16-22, 2016.

BUILDING A DATA ASSIMILATION FRAMEWORK FOR FORECASTING VOLCANIC ACTIVITY DURING PERIODS OF UNREST

Allocation: Illinois/25.0 Knh
PI: Patricia M. Gregg[1]
Collaborators: Yan Zhan[1] and J. Cory Pettijohn[1]

[1]University of Illinois at Urbana-Champaign

EXECUTIVE SUMMARY

A primary goal of the University of Illinois Urbana-Champaign Volcano Lab is to develop innovative strategies for combining volcano-monitoring datasets with thermomechanical models to better understand the dynamics of triggering a volcanic eruption. We use Blue Waters to develop and test a framework for **multi-data stream data assimilation** by conducting a series of eruption "hind casts" for recent eruptions at Sinabung Volcano in Indonesia. Blue Waters is uniquely capable of handling the computational expense for our ensemble-based modeling approach, which has compute times and storage requirements considerably outside the capabilities of traditional high-performance computing (HPC) resources. Ultimately, this work will provide a critical foundation for future interdisciplinary efforts to model volcano evolution and mitigate volcano disasters for vulnerable populations worldwide.

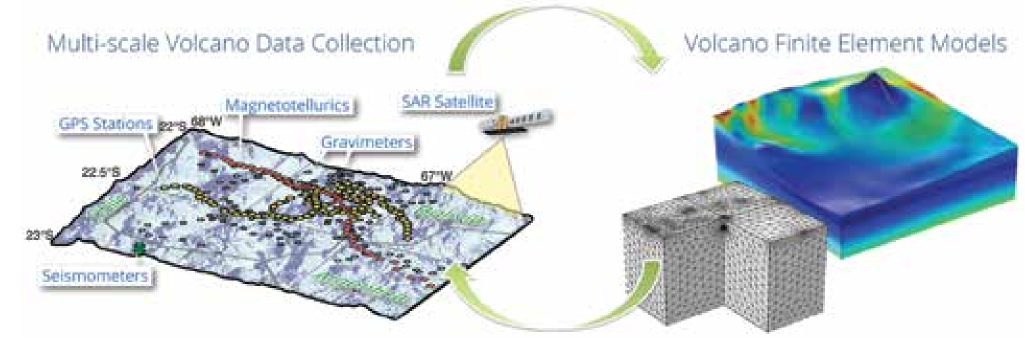

FIGURE 1: Statistical data assimilation techniques combine disparate observations with models to produce forecasts of an evolving system. The data inform the trajectory of the models and the models in turn inform future data targets and collection strategies. Left: A map depicting the NSF PLUTONS Project at Uturuncu Volcano, Boliva [7]. Right: FEM mesh and modeled stress for Sinabung Volcano, Indonesia.

INTRODUCTION

A primary motivation for investigating volcanic systems is to develop the ability to predict eruptions and mitigate disaster for vulnerable populations. In recent decades, the evaluation of volcanic activity has been greatly enhanced by coupling remote (e.g., satellite and global seismic arrays) and local observations (e.g., GPS, gas emissions, and seismometers) to provide early warning of an imminent eruption or information on the evolution of a magma system during a volcano crisis. Concurrently, thermomechanical models of magma reservoirs have significantly advanced our understanding of eruption-triggering mechanisms beyond the temporal and spatial limitations of our observations [1,2].

Volcano monitoring datasets are commonly analyzed using analytical inversions techniques or by optimizing finite element models [3,4]. While these approaches work well for combining models with one or two data streams, they are static assessments of the system state that do not provide updates or forecasts and are limited in their scope. Alternatively, statistical data assimilation methods were developed to systematically link data with models to provide model updates. Significant advancements in data assimilation have been made in many fields, including engineering, hydrology, physical oceanography, and climate modeling, to incorporate disparate datasets into dynamic, nonlinear models and provide model forecasts [5]. Sequential model-data fusion methods provide a framework for integrating large, disparate data sets into time forward, forecast models (Fig. 1). Data are used to nudge the model trajectory and provide updates of the system's evolution, and models inform future data targets.

Our current efforts on Blue Waters are focused on developing strategies for rapid assimilation of monitoring datasets into evolving geodynamic models to provide near-real-time forecasts and assessment of volcanic unrest. To that end, we are adapting data assimilation methods developed in other fields to combine observations from volcanoes experiencing unrest with thermomechanical finite element models (FEMs) to calculate volcano evolution [6].

METHODS & RESULTS

We have adapted the Ensemble Kalman Filter (EnKF, [5]) sequential data assimilation method to assimilate volcano-monitoring data from satellite and ground-based observations into geodynamic models. The EnKF utilizes a Markov Chain Monte Carlo (MCMC) approach to create suites, or ensembles, of models that are updated sequentially as new observations become available.

Preliminary results indicate that the EnKF is a powerful tool well suited for the problem of forecasting volcanoes experiencing unrest. Our Blue Waters Exploratory Allocation is allowing us to test the feasibility of a large-scale data assimilation approach for volcano monitoring. This is the **first** effort of its kind and has great potential for significantly advancing the field of volcano hazards.

WHY BLUE WATERS

The EnKF is an ensemble based sequential data assimilation method that requires calculating hundreds to thousands of finite element models at each time step. While the EnKF analysis step has been optimized to run very swiftly, the computational expense of running and storing hundred to thousands of finite element models for each time step in the EnKF analysis is cost prohibitive for traditional HPC resources. Blue Waters is uniquely positioned to handle our computational needs and has allowed us to make rapid progress and develop **ambitious** approaches without being hampered by computational limitations.