EXECUTIVE SUMMARY
A primary motivation for investigating volcanic systems is developing the ability to predict eruptions and mitigate disaster for vulnerable populations. Over the past three years, the Gregg Lab has been developing approaches for forecasting the evolution of volcanic systems in collaboration with the National Center for Supercomputing Applications (NCSA). The research team has implemented a high-performance computing (HPC) workflow using COMSOL. Multiphysics finite-element software that links multiphysics model outputs with geophysical monitoring data for volcanic forecasting. This project focuses on conducting large system-scale numerical experiments to investigate eruption potential and triggering mechanisms for three volcanoes targeted utilizing the unique computational configuration of Blue Waters. In addition to the scientific outcomes of this effort, the experiments mark the largest distributed implementations of COMSOL Multiphysics. This achievement is of great practical importance for finite-element applications and provides benchmarking for future efforts in other fields, such as engineering, in addition to earth sciences.

RESEARCH CHALLENGE
Currently, 500 million people worldwide live on or near active volcanoes. The team’s current efforts on Blue Waters are focused on developing strategies for rapid assimilation of volcano monitoring data sets into evolving geodynamic models to provide near real-time forecasts and assessment of volcanic unrest. To that end, the group is adapting data assimilation strategies developed in other fields to combine observations of volcanoes experiences with thermostochanical finite-element models to calculate volcanic evolution. By combining multiphysics finite-element models with volcano monitoring data the team is able to track the stress evolution of a magmatic system and provide probabilistic forecasts of volcanic unrest.

METHODS & CODES
The research team has developed an HPC workflow using Python to efficiently distribute COMSOL. Multiphysics models across Blue Waters’ compute nodes and compile model outputs for Ensemble Kalman Filter (EnKF) data assimilation at each timestep. The main computational task is evaluating hundreds of large multiphysics, mechanical finite-element models at each timestep and compiling the model data to provide a probabilistic forecast of volcanic unrest.

RESULTS & IMPACT
The team has applied Blue Waters’ allocation to investigate three active volcanic systems. In 2018, the researchers had the opportunity to track the unrest of Sierra Negra Volcano, Galápagos.

OVERVIEW OF THE SIMULATION WORKFLOW
The EnKF approach was applied to a submarine volcano monitoring data sets into evolving dynamic models to provide near real-time forecasts and assessment of volcanic unrest. By combining multiphysics finite-element models with volcano monitoring data the team is able to track the stress evolution of a magmatic system and provide probabilistic forecasts of volcanic stability during periods of unrest. Utilizing ensemble-based methods, hundreds to thousands of models are run simultaneously to track the evolution of volcanic systems. This method allows the team to evaluate stress accumulation and failure in the lead-up to volcanic eruption and to test for potential eruption-triggering mechanisms to provide a framework for early warning probability forecasts for monitoring agencies. The ultimate goal of this work is to provide a transferable data assimilation approach that can be utilized by volcanologists worldwide.

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FORECASTING VOLCANIC UNREST AND ERUPTION POTENTIAL USING STATISTICAL DATA ASSIMILATION

The volcano EnKF approach was applied to a submarine volcano monitoring data sets into evolving dynamic models to provide near real-time forecasts and assessment of volcanic unrest. By combining multiphysics finite-element models with volcano monitoring data the team is able to track the stress evolution of a magmatic system and provide probabilistic forecasts of volcanic stability during periods of unrest. Utilizing ensemble-based methods, hundreds to thousands of models are run simultaneously to track the evolution of volcanic systems. This method allows the team to evaluate stress accumulation and failure in the lead-up to volcanic eruption and to test for potential eruption-triggering mechanisms to provide a framework for early warning probability forecasts for monitoring agencies. The ultimate goal of this work is to provide a transferable data assimilation approach that can be utilized by volcanologists worldwide.

Three volcano targets were chosen for this study owing to their excellent, real-time geophysical monitoring data sets and past eruption records: (1) Sierra Negra Volcano, Galápagos, Ecuador; (2) Laguna del Maule Volcano, Chile; and (3) Axial Volcano, Juan de Fuca Ridge—a submarine volcano located off the coast of Oregon, U.S.A. Each volcano application provides unique computational and data challenges to allow the team to evaluate potential roadblocks in transferability of the data assimilation approach.

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