DEVELOP NATIONAL PROGRAM

PENNSYLVANIA STATE UNIVERSITY

Predicting Pumice Raft Trajectories

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Abstract

Pumice rafts are masses of volcanic rock that are formed by large eruptions from subsurface and near-ocean volcanoes. When the hot magma from the eruption comes into contact with cool air, rapid cooling and rapid de-pressurization traps air bubbles creating pumice rock. Because of their porous nature and low density, these rocks tend to float on the water. Their size is dependent on the amount of, and speed at which, molten rock is ejected and how quickly it cools, but they have been known to reach the approximate size of Massachusetts. Among other issues, this can create hazards for shipping interests; especially if the pumice raft crosses more heavily established shipping lanes or blocks commercial ports and harbors.

This project involves the use of NASA's Earth Observing Systems (EOS) data to predict where a pumice raft will likely travel from a given point of origin, i.e. the eruption of a volcano. Using current and surface wind data, the trajectory can be determined, along with a dispersal pattern. The predictive model was validated against two documented, historical eruptions: Home Reef, Tonga in 2006; and Havre Seamount, New Zealand in 2012. The validated model was then compared to established shipping lanes, ports, and harbors to identify the extent of their impact.

Project Objectives

This project builds on work done previously by NASA's DEVELOP National Program and constructs a framework for future projects (Chojnacki, et al., 2011). The previous project utilized multispectral imagery to develop methodologies for identifying the phenomena, and this project utilizes those methodologies and more in completing its four objectives.

1. Identify known volcanoes in the study area with the potential to form pumice rafts.

2. Develop and document an accessible and practical methodology for predicting the trajectory of a pumice raft.

3. Validate methodology using documented pumice rafts produced by past volcanic eruptions.

4. Apply methodology to commercial shipping lanes and harbors to identify high risk areas that may provide a hazard for ships and crew.

Introduction

Pumice stone is used commonly as mild abrasives in cleaners, for removal of dry skin, and as decorative landscaping rock. Its light but durable nature makes it perfect for all of these applications but also presents some dangers as well. Pumice is naturally formed when hot magma from a volcanic eruption comes into contact with cool air. Rapid cooling and de-pressurization of the molten rock traps air bubbles creating the pumice stone. This most often occurs when volcanoes are near a shoreline, on an island, or even subsurface; and because of their porous nature and low density, these rocks tend to float on water. The resulting raft's size is dependent on the amount of, and speed at which, molten rock is ejected and how quickly it cools, but a single raft has been known to reach the equivalent size of Massachusetts (Chojnacki, et al., 2011).

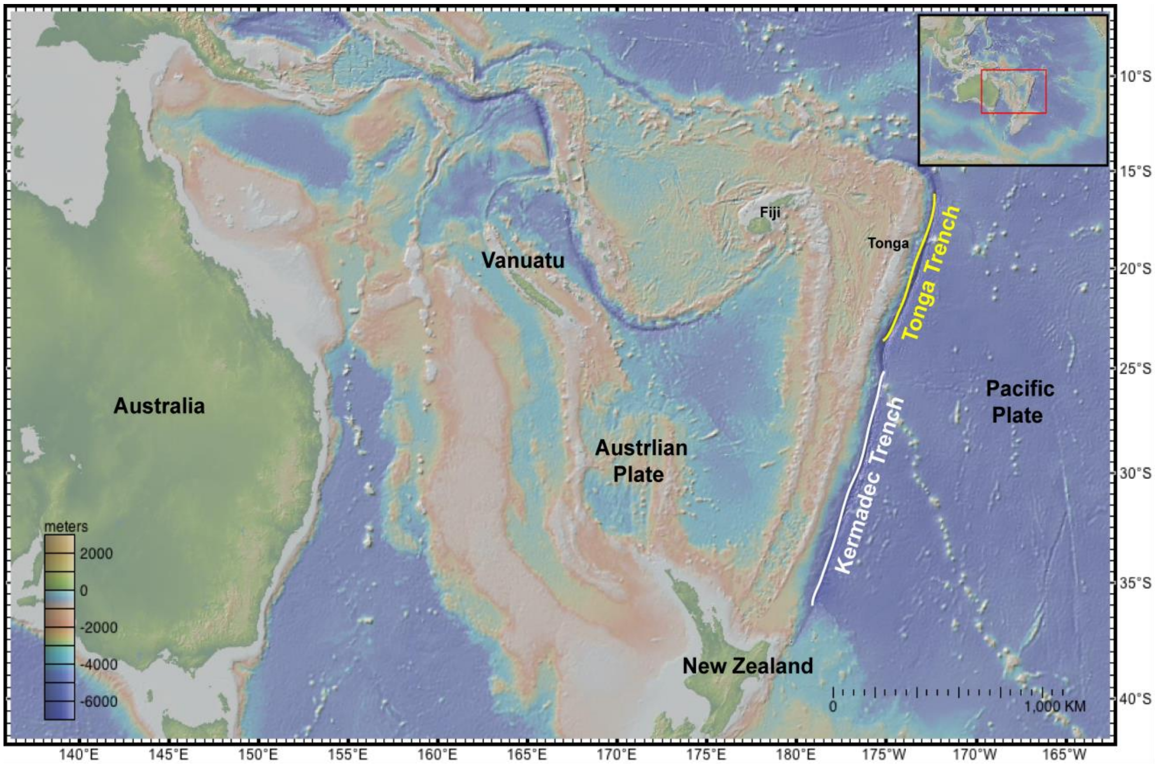
Community Concerns

An object of this size, floating around the ocean, presents a host of hazards. Although typically considered a low frequency event, surveys have revealed that pumice rafts have been observed in all of the major oceans over the last 200 years and are particularly abundant in the Pacific Ocean (Bryan, et al., 2012). When they do occur, local fishing and shipping are greatly affected. Pumice rock can choke nearby waterways, killing indigenous marine life and endangering manmade structures such as dams. More to the purpose of this project, as harbors and shipping lanes are blocked by the debris; the pumice obstructs maritime shipping and travel. Pumice rock can also cause problems for ships that attempt to pass through the rafts by clogging the seawater intakes and causing the engine cooling system to fail, thus overheating the engines (Chojnacki, et al., 2011).

Study Area

Although pumice rafts are a global phenomenon, this project focused on the Southwestern Pacific Ocean. More specifically, an area bounded by the eastern Australian coast to the west, and the Kermadec and Tonga trenches to the east (figure 1). From this area, two specific events became the focus for the project based on the availability of collected data and the wealth of documentation.

Figure 1 – Project Study Area



Home Reef, Tonga

The first of the two events occurred at Home Reef, Tonga, located between Metis Shoal and Late Island in the Tonga Islands. In August of 2006, an eruption occurred forming a transitory island, or pumice cone, which was subsequently eroded by wave action over the following eight months. Pumice rafts produced by the initial eruption, and subsequent airborne cooling, covered over 440 square kilometers, moving towards the Vava'u Islands before turning westward and arriving in Fiji and Vanuatu around mid-September. Local sea travel around the islands of Fiji was nearly brought to a standstill. Soon after, the pumice raft dispersed into tendrils measuring tens to hundreds of kilometers long, covering an ocean area of approximately 1,600 square kilometers. Fragments of the raft were still being found seven months after the original eruption (Bryan, et al., 2012).

Havre Seamount, New Zealand

On August 9th, 2012, a naval vessel belonging to the Royal New Zealand Navy came across what was described as a floating pumice island measuring 482 kilometers long and 48 km wide. A lieutenant aboard ship was quoted as saying, "The rock looked to be sitting two feet above the surface of the waves, and lit up a brilliant white color in the spotlight. It looked exactly like the edge of an ice shelf." Using imagery obtained by NASA's Moderate Resolution Imaging Spectro-radiometer (MODIS), it was determined that this pumice raft originated from Havre Seamount, located near the L'Esperance and L'Havre Rocks in the Kermadec Islands of New

Zealand (Bryner, 2012). Unnoticed, this subsurface volcano, from an estimated 700 to 1,100 meters below the surface of the ocean, erupted around July 18th, 2012. This eruption created a pumice raft estimated at 450 by 250 kilometers by August 13th, which then dispersed over an area of 270,000 square kilometers by August 19th (Havre Seamount, 2012).

Study Period

This project utilized data from August 2006 to October 2013. Although most of the research and validation was constrained to the months immediately following the Home Reef and Havre Seamount eruptions, the analytical portion of the project employed data from the entire period.

Methodology

This project was completed in association with NASA's DEVELOP National Program, which strives to "bridge the gap between NASA Earth Science and society" (About DEVELOP, 2012). As such, several of NASA's Earth observation sensors were used as keystones in this project.

Poseidon is part of the Ocean Surface Topography Mission (OSTM) and uses high-precision ocean altimetry to measure the distance between the satellite and the ocean surface to within a few centimeters. This information provides speed and direction of ocean currents as well as heat stored in the ocean. This current information is one of two influences utilized in this project's prediction model (Ocean Surface Topography Mission (OSTM)/Jason-2, 2013).

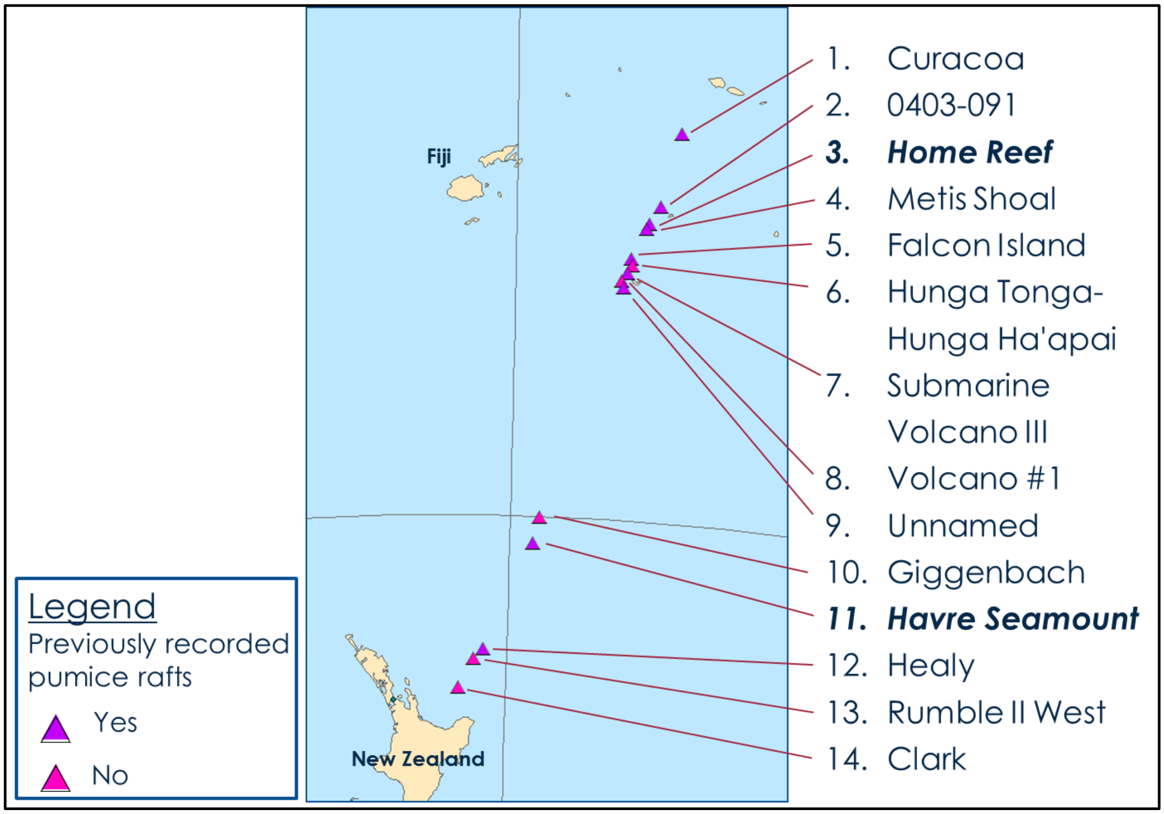
The other component was surface winds. SeaWinds is a specialized microwave radar antenna which measures near-surface wind velocity over Earth's oceans. Analyzing speed and direction of ocean winds, it (in conjunction with Poseidon's current data) allows us to predict, within a certain degree of certainty, where pumice rafts will likely travel from the point of eruption (Winds: Measuring Ocean Winds from Space, 2013).

Finally, MODIS is a multispectral imaging sensor providing thirty-six spectral bands. This allows for more coverage of the electromagnetic spectrum, and thus a more refined spectral signature than other imaging sensors, such as Landsat. However, MODIS has a lower spatial resolution at 250 to 500 meters, making smaller raft formations harder to detect and causing difficulty in tracking the larger rafts as they disperse. Still, MODIS provides the best coverage of the remote locations of the ocean surface in which these rafts travel, and the best opportunity to correlate actual pumice raft locations with projections (About MODIS, 2013).

Research

A review of available literature and data sources revealed several common characteristics between volcanoes which have traditionally produced pumice rafts. Besides a history of violent, explosive eruptions, the magma compositions were intermediate to felsic, and all of the volcanoes inhabited a water depth range between 17 and 1100 m (Bender, Kelly, Kelly, & Walters, 2013). From this research, fourteen volcanoes within the study area were identified as having the potential to form pumice rafts, all residing along the Kermadec and Tonga trenches (figure 2). Of these, nine were identified as previously sourcing a pumice raft formation and only the two previously discussed events provided enough collected and published data to accurately validate any attempt to model their trajectory.

Figure 2 – Volcanoes with Potential Pumice Raft Formation



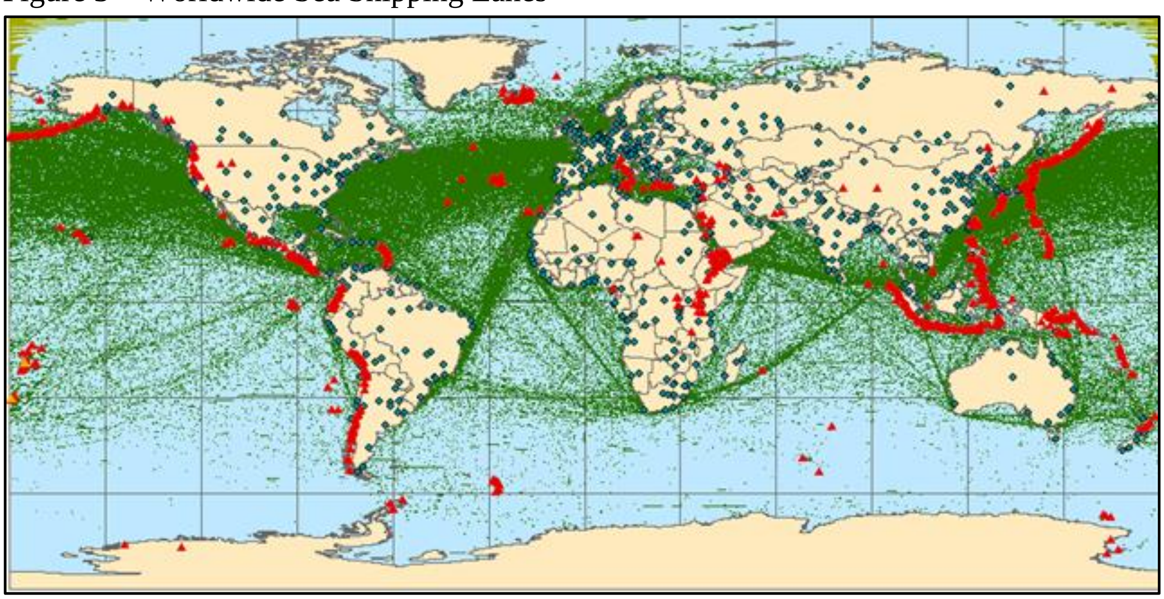
Several modeling engines were investigated for their potential to predict the pumice raft trajectories. Eventually, the National Oceanic and Atmospheric Administration's (NOAA) Office of Response and Restoration's (OR&R) Emergency Response Division's General NOAA Operational Modeling Environment (GNOME) was selected (GNOME, 2013). GNOME provided many characteristics which made it the ideal choice. First, it was readily available and easily accessible, provided free from the OR&R website. Secondly, it offered a user-friendly interface, making it ideal for use by local decision-makers in the areas affected by pumice raft events. Finally, GNOME had already proven itself valuable in the tracking of solid debris. GNOME was originally developed to track oils spills, but following the March 11, 2011 tsunami which devastated parts of Japan, it was successfully repurposed to track resulting debris in the northern Pacific Ocean. This made success likely in again repurposing it for predicting the movement of pumice rafts.

Data Acquisition

Unsurprisingly, GNOME's major input requirements consisted of current and surface wind data. Current data was acquired from NOAA's Ocean Surface Current Analysis - Real time (OSCAR) website. The site utilized a blended product of current sources, relying heavily on data collected by NASA's Poseidon Radar Altimeter. It provided the data through a customizable user interface in five-day mean increments, allowing the user to constrain the data by timeframe and geographic area. Surface winds were similarly acquired from NOAA's National Climatic Data Center (NCDC) which also utilized a blended product, including NASA's SeaWinds Scatterometer. However, the data was provided as separate, daily files of global coverage through their file-transfer-protocol, or FTP, site.

For the final analysis, data on ports and harbors as well as sea shipping lanes were also needed. Ports and harbors were obtained as a vector file from the National Geospatial-Intelligence Agency's (NGA) World Port Index, and the sea shipping lanes were acquired from the National Center for Ecological Analysis and Synthesis (NCEAS). Ships from all over the world collect meteorological data as part of a voluntary program with the World Meteorological Organization (WMO). Included with that weather information, the ships also supply their locational data. The NCEAS collected this data from October 2004 to October 2005 and created shipping tracks for approximately 3,374 commercial and research vessels. The tracks were then converted to a raster product containing one square kilometer cells with values ranging from 0 to 1,158 indicating the volume of ships that occupied that square (figure 3). It almost certainly did not account for every ship on the sea (NCEAS estimates that it is around 11%), but for the purpose of this project, it provided an adequate depiction of shipping lanes around the world.

Figure 3 – Worldwide Sea Shipping Lanes

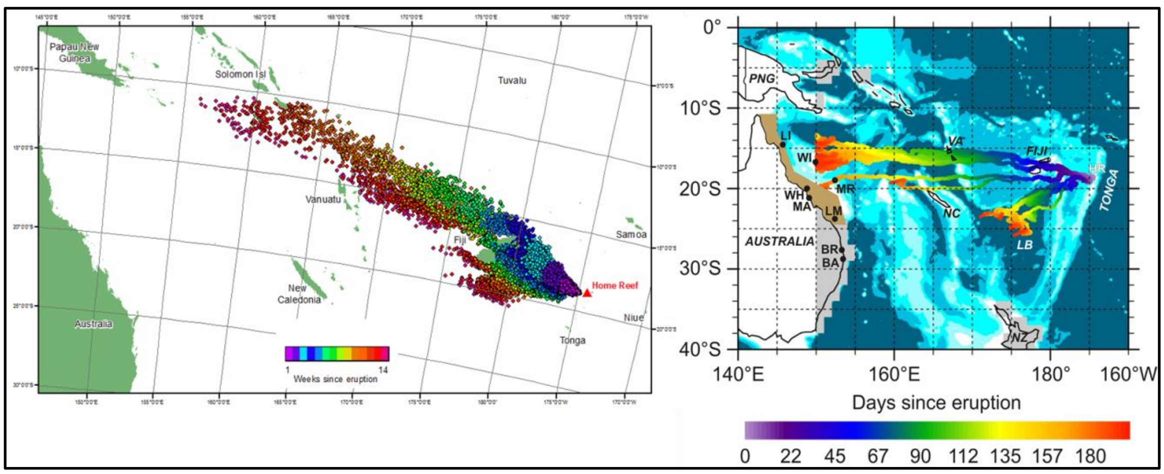


Data Processing and Validation

GNOME allows only one current and one wind file for each model and accepts only NetCDF (Network Common Data Form) format. OSCAR provided the current data as such and was easily ingested into GNOME, but the NCDC's daily wind files first had to be merged into a single file using a command-line utility before GNOME could utilize it. Once loaded into GNOME, several characteristics of pumice rafts had to be provided to ensure that the modeling engine accurately depicted its behavior. Data collected during the Home Reef and Havre Seamount events was used, and several models were run to identify the correct characteristics to get an accurate model. Each model was then compared to data collected on the actual events for validation.

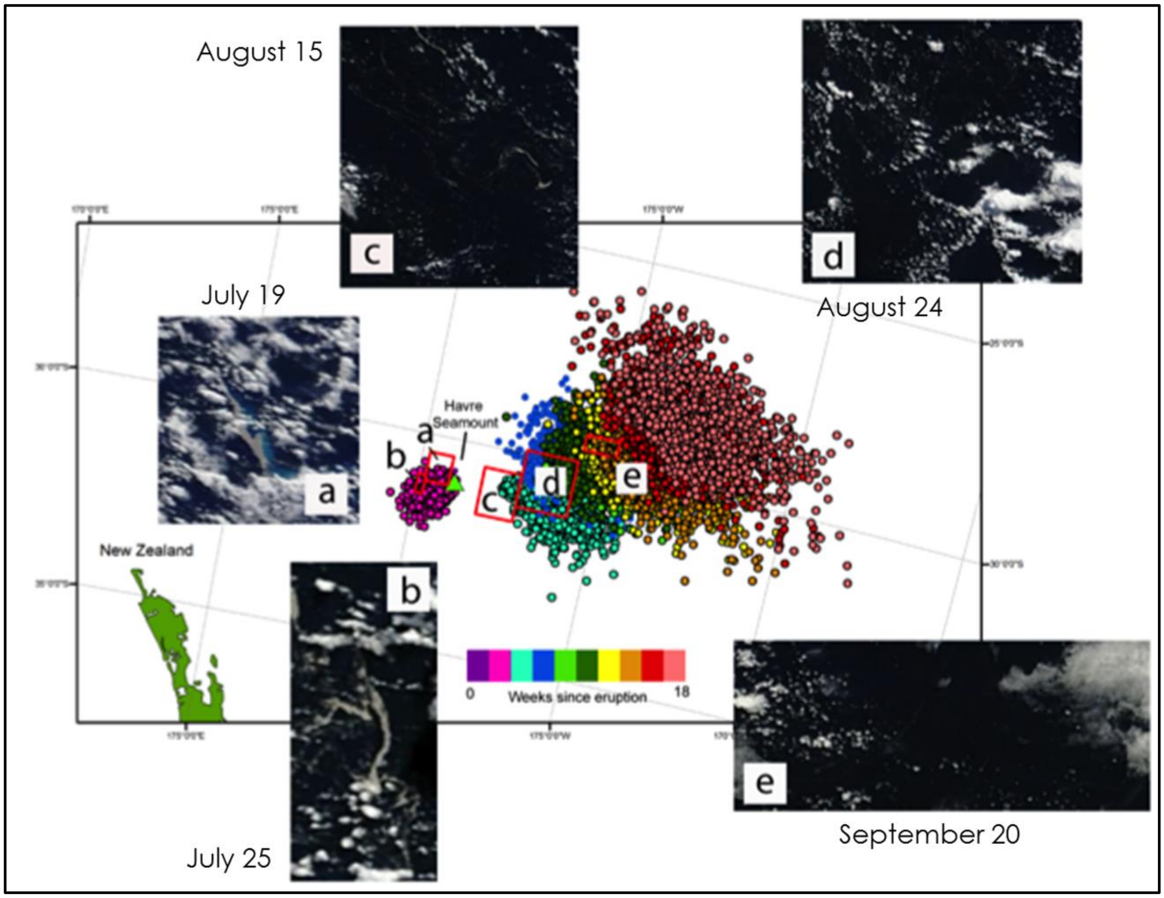
Figure 4 is a comparison of the Home Reef GNOME model (on the left) and a previously created MATLAB (matrix laboratory)-generated model published by Bryan et al. (Bryan, et al., 2012). This raft traveled over 500 kilometers in 22 days, enveloping the islands of Fiji. Both models are similar, showing a large west to northwesterly component and two smaller components moving along the southern edge of the island group. However, while the Bryan model indicates eventual landfall on the northeastern shore of Australia, the GNOME model leans more toward Papa New Guinea. Both landfalls in Fiji and Papa New Guinea were validated with in situ observations.

Figure 4 – Home Reef Model Validation



The Havre Seamount raft moved much slower than the one from Home Reef. This raft traveled 205 kilometers over a five month period. The GNOME model showed the raft rapidly dispersing as it meandered in a northeasterly direction from its source, eventually reversing direction around mid-December and falling back onto itself. There were no previous models and very few in situ observations to use in this validation, probably due to its lack of landfall, so MODIS imagery was relied on heavily to spatially and temporally correlate the model with the actual event. Figure 5 shows the correlation between the model and imagery. It also validates the quick dispersion of the raft as it becomes difficult to detect after August 15th and nearly impossible after September 20th.

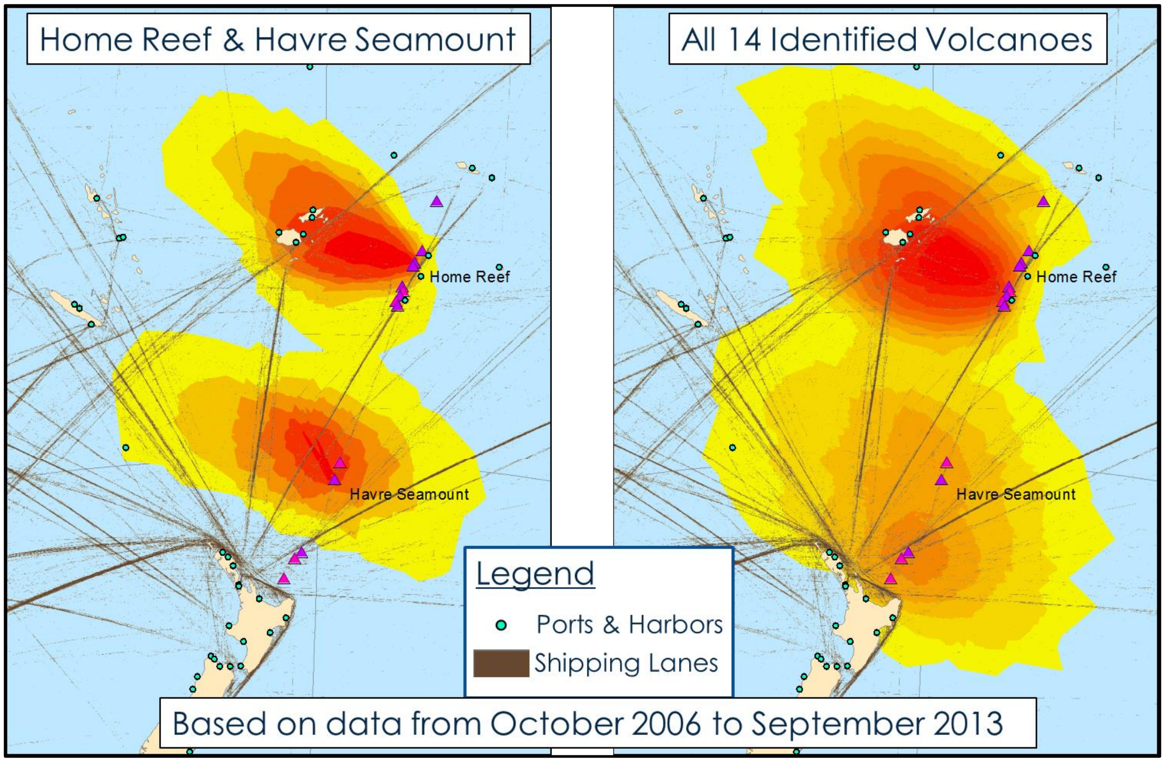
Figure 5 – Havre Seamount Model Validation



Data Analysis

Several products were created, based on the GNOME model validations, two of which can be seen in figure 6. Both of these products utilized seven years of historical data as a basis for identifying high risk areas that may provide hazards for ships and crew should a pumice raft event occur. They also identify ports and harbors that are in danger of becoming inundated should the raft make landfall in that area. The depiction on the left focuses exclusively on the two volcanoes that figured prominently in this project, while the depiction on the right represents the culmination of all fourteen previously identified volcanoes.

Figure 6 – Immediate Area Risk Maps



Results & Discussion

In relating to the stated objectives, fourteen volcanoes in the study area were identified as either historically or potentially producing pumice rafts during an eruption. Also, the specific methodology for setting up and utilizing GNOME to predict pumice raft trajectories has been fully documented and is available by contacting NASA's DEVELOP National Program. This user's guide, in conjunction with the general GNOME documentation provided by NOAA's Office of Response and Restoration will provide local decision makers with all of the instructions necessary to utilize this methodology to enhance their navigational warnings. All finalized data and deliverables from this project have already been made available to GNS Science in New Zealand for this purpose.

The validation of GNOME for use as a predictive model for pumice raft trajectories was considered successful. However, the lack of data for further validation limits this achievement. It is hopeful that future events will provide further data to expand the validation and provide more information on the characteristics and behaviors of pumice rafts. Finally, along with the documented methodology, several analytical products were created, providing an improved capability to predict the impact of pumice raft events on local populations and commercial sea travel.

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