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Frequency based satellite monitoring of small scale explosive activity at remote North Pacific volcanoes

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ABSTRACT

Monitoring of volcanoes in the North Pacific can be an expensive and sometimes dangerous task, specifically for those located in Alaska (USA) and Kamchatka (Russia). An active frequency detection method previously used at Stromboli, Italy, uses the thermal- and mid-infrared wavelength bands from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data to detect anomalies at a volcano. This method focuses on small scale explosive activity, often referred to as Strombolian activity which can produce small spatter fields near a volcano's active vent. In the North Pacific, there are a number of volcanoes which exhibit small scale explosive activity and three are the focus of this study: Chuginadak (Mt. Cleveland) and Shishaldin in Alaska, and Karymsky Volcano in Kamchatka. Satellite images from the Advanced Very High Resolution Radiometer (AVHRR) were used to monitor the frequency of thermal features as well as the occurrence of ash plumes at each volcano. This data was then used to produce a time series spanning 2005–2010 for all three volcanoes. During this time period, each volcano underwent a series of eruptive cycles including background levels of activity, heightened frequency of small explosions (identified as precursory activity), and heightened activity typified by ash plume-producing eruptions. Each location has a unique precursory signal, both in timing and magnitude. The use of a previously developed method on a new sample set of volcanoes has proved the validity of this method as a monitoring tool for volcanoes with small scale explosive activity. This method should be applied to a larger set of volcanoes to continue the development and database production for its use as a volcano monitoring tool.

1. Introduction

Monitoring of volcanoes in the North Pacific can be an expensive and sometimes dangerous task, specifically for those located in Alaska (USA) and Kamchatka (Russia). The Northern Pacific region, although often thought of as remote, is both populated and a highly traveled air traffic route with more than 10,000 passengers and millions of dollars in cargo flying over this volcanic region each day (Neal et al., 1997), demonstrating the need for consistent methods of monitoring. Satellite remote sensing offers a safe, relatively inexpensive method for monitoring large areas where field work is logistically unrealistic (Lillesand et al., 2008). A method has been developed (Worden et al., 2014) that uses satellite imagery to review and determine the activity at remote volcanoes. This method focuses on small scale explosive activity, often referred to as Strombolian activity (Lacroix, 1904; Walker, 1973; Wohletz and Heiken, 1992), which can produce small spatter fields near a volcano's active vent. These spatter fields are detectable in satellite data as "thermal anomalies", i.e. groups of pixels with a temperature elevated over the background temperature (Harris, 2013). Their frequency and duration can be detected, monitored, and analyzed to give insights into changing volcanic systems.

The frequency detection method developed by Worden et al. (2014) uses the thermal- and mid-infrared wavelength bands from satellite data to detect anomalies at a volcano. Once the number of these 'thermal' anomalies has been determined, then an assessment is made of the weather conditions across the region and a number of other geometric and spectral factors impacting remotely sensed images. The information on thermal anomalies, cloud conditions, and spectral/geographic conditions of data acquisition is then used to calculate an estimated number of explosions that may have occurred on a weekly interval in an effort to normalize the results. This number represents the average frequency of explosions and can give an indication of the typical activity at a volcano. In addition, as the frequency fluctuates, this method can be used to track changes in the volcanic system and used to detect indications of increasing activity.

In the North Pacific, there are a number of volcanoes which exhibit small scale explosive activity that are the focus of this study. The volcanoes of interest are: (1) Chuginadak (Mt. Cleveland) and (2) Shishaldin in Alaska, USA, and (3) Karymsky Volcano in Kamchatka, Russia. All three of these volcanoes have a recorded history of small scale explosive activity, though at varying intensities and frequencies (Cleveland — McGimsey et al., 2007; Shishaldin — Dehn et al., 2002; Karymsky —

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Izbekov et al., 2004). Changes in the frequency of explosions indicate changes in the systems and can be a useful monitoring tool by analyzing weekly patterns rather than daily fluctuations that can be affected by changes in weather, satellite sensor viewing geometry and the timing of satellite overpasses.

2. Background

Volcanism in the North Pacific represents the northern most border of the Ring of Fire (Fig. 1). This region exists due to the subduction of the Pacific Plate beneath the North American Plate. This subduction environment exists for most of the Aleutian Arc, but switches to a more strike-slip margin in the western portion of the arc (Ryan and Scholl, 1993). This transitions back to a subduction environment in Kamchatka as the Pacific Plate again subducts beneath the North American Plate. The Aleutian Arc meets the Kamchatka Peninsula at a triple junction between the Pacific plate and two lesser tectonic plates — the Okhotsk Plate and the Komandorsky Plate (Scholl, 2007; Volynets et al., 2010) near the location of Shiveluch, Kliuchevskoi, Bezymianny, and Ushkovsky volcanic complexes.

The Aleutian Arc is made up of over 40 volcanoes (Wallace et al., 2000), stretching from Mount Spurr in the northeast to Buldir Island, 1580 miles to the west (Coats, 1962). Activity at these volcanoes ranges from ash plumes reaching 18 km a.s.l. (Waythomas et al., 2010) at Kasatochi volcano, interfering with air traffic and posing threats to populations, to quiescent lava flows in areas far from human habitation, such as the emplacement of lava flows on Yunaska Volcano (Simkin and Siebert, 1994).

Kamchatka, Russia is home to over 70 volcanoes, producing ash plumes, lava flows, and caldera forming explosions (Braitseva et al., 1995; Schneider et al., 2000; Ramsey and Dehn, 2004). The volcanoes of Kamchatka are divided into the Central Kamchatka Depression (including the Kliuchevskoi group of volcanoes) and the Eastern Volcanic Front (including Karymsky and the town of Petropavlovsk-Kamchatsky, located only 30–35 km from active volcanoes Avachinsky and Koryaksky).

2.1. Volcanoes that exhibit small scale explosive activity

Though there is a vast range of volcanic activity types present in the North Pacific, from the ash plumes of Kasatochi volcano in 2008 (Waythomas et al., 2010) to the lava flows of Tolbachik volcano in 2012–2013 (BGVN, 2012), this work aims to provide a monitoring and detection tool for small scale explosive activity as a precursor to larger scale explosions and activity. This type of activity, similar to Strombolian type explosions, occurs at many volcanoes in the North Pacific, perhaps most notably Chuginadak (Mount Cleveland) (Reeder, 1990a; McGimsey et al., 1995; McGimsey et al., 2007) and Shishaldin (Reeder, 1990b; Dehn et al., 2002; Siebert and Simkin, 2002; Beget et al., 2003) in the Aleutian Islands, and Karymsky in Kamchatka (Izbekov et al., 2004). All three volcanoes are near the center of their respective arcs.

2.1.1. Chuginadak (Mt. Cleveland), Alaska

Mt. Cleveland is a stratovolcano that is located on the western half of Chuginadak Island in the Aleutian Arc of Alaska (Miller et al., 1998) as seen in Fig. 2. The volcano is roughly 8.5 km in diameter, symmetrically conical and rises to an elevation of 1730 m a.s.l. (Simpson et al., 2002; Dean et al., 2004). Though the volcano is quite distant from large population centers (Anchorage, the largest city in Alaska, is 1500 km (950 miles) away), there are small villages nearby, the closest being

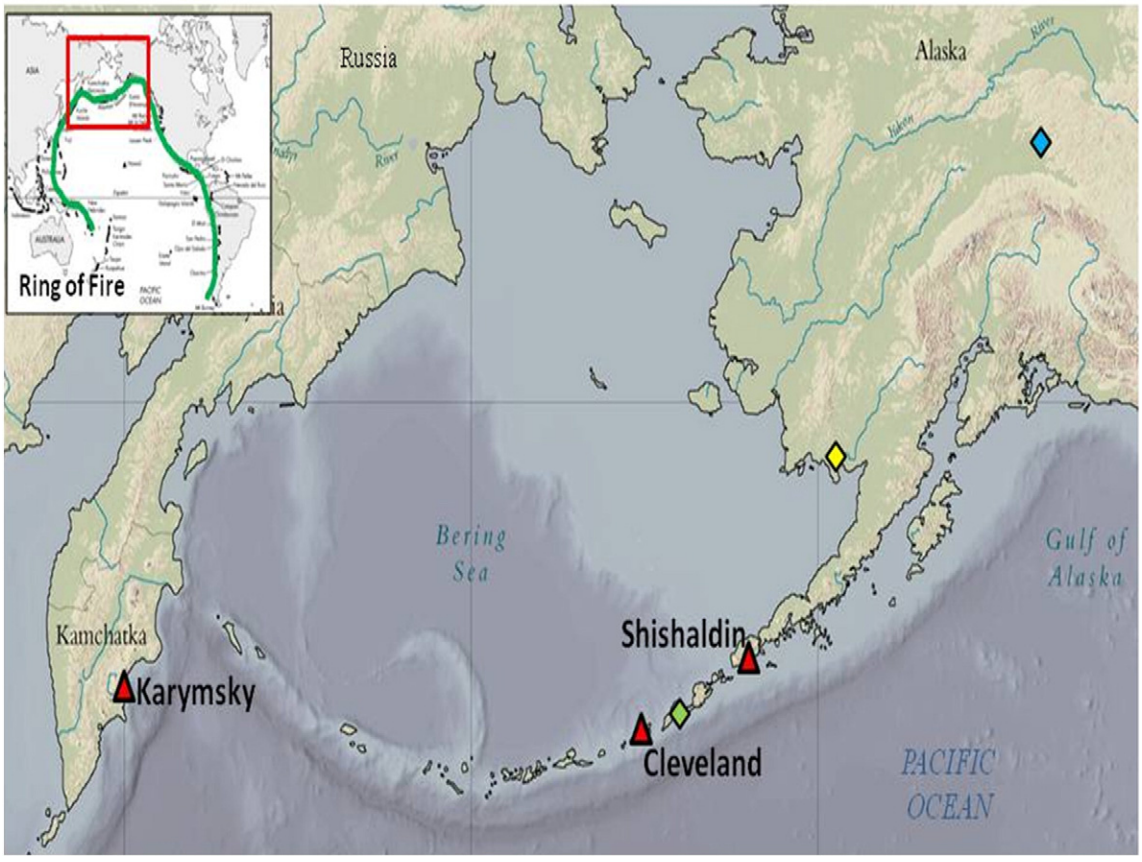

Fig. 1. Map of the North Pacific volcanic region. Red triangles indicate the volcanoes chosen for this study. The diamonds are the locations of the regional infrasound arrays in the North Pacific; blue — Fairbanks, yellow — Dilligham, green — Okmok.
Modified from Hansell et al. (2006) and Steinbeck and Fuller (2004).