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Remote sensing data types and techniques for lahar path detection: A case study at Mt Ruapehu, New Zealand

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ABSTRACT

Mt Ruapehu is New Zealand's most active onshore volcano. In 2007, the volcano produced a large lahar following a break-out from the summit Crater Lake. Here, satellite and airborne remote sensing and image processing is used to extract the path of the lahar using ASTER and SPOT5 visible and near infra-red imagery, ALOS-PALSAR L-band synthetic aperture RADAR data, and airborne LiDAR. The results obtained from each of these datasets were compared to the lahar deposit manually digitized from aerial photography. SPOT5 imagery produced the most accurate map of the lahar deposit (77% correct), even though these data were acquired a year after the event. This is attributed to the spatial resolution of the data. The ALOS-PALSAR coherence mapping calculated from images acquired 2 months before and nine months after the lahar was not as accurate as that obtained using the optical imagery (43% correct), but this was still considered an important tool for acquiring data during cloudy periods. LiDAR topographic data, collected to constrain geomorphic changes caused by the lahar, was the least accurate in terms of mapping the lahar path (28% correct). No single technique was deemed to be the most accurate under all circumstances, and a combination of data types would produce the best results. By combining the satellite and LiDAR data, it was possible to accurately classify 92% of the lahar path.

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1. Introduction

This paper investigates the ability of various remote sensing data types to detect a breakout lahar deposit from the summit Crater Lake of Mt Ruapehu, New Zealand on the 18th March 2007. Similar work performed around the world suggests that a remote sensing approach is a successful and cost-effective solution for mapping the source and extent of volcanic debris (Crowley et al., 2003; Harris et al., 2006; Kerle & van Wyk de Vries, 2001; Terunuma et al., 2005). However, commonly used techniques often have to be tuned to site-specific requirements, and little work has been done to compare some of the more common types of data available. For example, we found that optical data, successfully used for mapping of volcanoes since the 1980s, have limited applicability in New Zealand during the Austral winter because of dense cloud coverage. Alternatively, Synthetic Aperture Radar (SAR) data can be successfully used in cloudy environments but does not work well in densely vegetated regions or in areas covered by snow (Hanssen, 2001). Four data sets were tested in this study: (i) SAR imagery from the PALSAR sensor of the ALOS satellite; optical from (ii) SPOT5 and (iii) TERRA-ASTER satellites; and (iv) airborne LiDAR topographic data. If used together, SAR and optical data provides complete coverage and has no limitations from weather or daylight conditions. Although not tested here due to the lack of data, ASTER also acquires night-time thermal imagery that may be an additional option if the flow exhibits a higher temperature than its surroundings as has previously been demonstrated with pyroclastic flows (Carter et al., 2008).

Synthetic Aperture Radar data from C-band ERS-1/2, RADARSAT-1, ENVISAT and L-band JERS-1 satellites have been successfully used for mapping of various ground changes caused by forest fires (Ranson et al., 2003), flooding (Geudtner et al., 1996; Oberstadler et al., 1997), and landslides (Rott & Nagler, 2006; Singhroy et al., 1998). Terunuma et al. (2005) used data from JERS-1 and ERS-1 satellites for mapping of lahar and pyroclastic flows at Mt. Unzen through the use of three products derived from SAR data: backscatter intensity, coherence, and differential interferometry. Some well known limitations of SAR data are temporal decorrelation and low spatial resolution (Hanssen, 2001). The resolution of the ALOS PALSAR sensor used in this study is 15 m, while the average resolution of most SAR sensors ranges between 10 and 30 m, and the highest resolution (3 m) is currently achieved by the RADARSAT-2 satellite in ultra-fine beam mode (Joyce et al., in press).The PALSAR data used here should provide results superior to those previously documented using lower spatial resolution SAR sensors.

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The ability of differential SAR interferometry to measure deformations at sub-centimeter scales has been widely utilized in geophysics for mapping ground deformations of various types including, but not limited to, earthquakes (Jacobs et al., 2002; Wright et al., 2001), volcanic activity (Lundgren et al., 2003), and anthropogenic deformations due to mining and fluid extraction (Schmidt & Burgmann, 2003). However, differential interferometry is able to detect lahar-related changes only if significant deposition or removal of material has occurred. It is expected therefore that differential interferometry, coupled with relatively high resolution, should produce useful results with respect to lahar flow path detection.

Progressing from historic use of the Landsat series (Francis, 1989), a variety of optical and infrared sensors are now available to provide data suitable for debris flow deposit mapping. Landsat and other sensors with similar spatial resolution such as SPOT and ASTER, are still commonly used as they provide a good compromise between spatial coverage and detail (Davila et al., 2007; Joyce et al., 2008; Kerle et al., 2003; Torres et al., 2004; Tralli et al., 2005). Hyperspectral imagery is less frequently available or utilized; although it has potential for compositional analysis of deposits (Crowley et al., 2003). Limited use of the very high resolution satellite sensors available, such as Quickbird or IKONOS, has been documented in the scientific literature (Huggel et al., 2006). This may be an indication of the high cost of these data, though it also lends credibility to the huge potential and utility of sensors with a lower spatial resolution between 10 and 30 m that provide coverage over larger regions. Lower spatial resolution satellites (e.g. AVHRR, MODIS) have been found to be inadequate for debris mapping (Kerle et al., 2003), but have proven useful for multiscale studies of volcanoes and are particularly beneficial for their high temporal resolution (Patrick et al., 2003).

The use of additional geospatial information, such as pre-event images, is considered vital for accurate identification of volcanic deposits. Without the additional contextual information and knowledge of pre-conditions, damage assessment is not possible, and volcanic debris could be mistaken for other features in the image. It is possible to use the tonal and textural features of an optical image to detect deposits, or alternatively to create a DEM of the region from some satellite imagery (e.g. ASTER, SPOT), which can be useful in volumetric analysis of debris deposits where other methods such as airborne LiDAR is too expensive or ground surveys are impractical (Hubbard et al., 2007; Huggel et al., 2008; Lipovsky et al., 2008). The great advantage of satellite remote-sensing is that it gives a ‘before’ view: in general, most LiDAR data is acquired post-event so there is no equivalent baseline dataset.

Few methods of automatic detection of volcanic debris flow deposits using optical and/or infrared remote sensing have been reported in the literature, and it appears that the technique of favour is manual digitising. The Normalized Difference Vegetation Index (NDVI) is commonly used for its ability to enhance the difference between volcanic deposits and surrounding vegetated areas (Castro & Carranza, 2005; Harris et al., 2006; Kerle & Oppenheimer, 2002). The NDVI can also be combined with a threshold value to delineate the deposit. Other techniques that have been used to aid visual interpretation of changes due to volcanic activity include a multiband display incorporating different input dates (Calomarde, 1998; Castro & Carranza, 2005), principal components analysis (Davila et al., 2007), and image subtraction (Torres et al., 2004).

The methods used in this study were executed with as little manual interpretation as possible, and only using contextual editing in the final stages of the processing. Therefore, with a calibrated time series of data it would be possible to reproduce the same method to provide similar and thus objective results. With this intention, four different datasets were evaluated (ALOS-PALSAR, ASTER, SPOT5, and LiDAR) for mapping a lahar deposit at Mt Ruapehu, New Zealand. The datasets and processing techniques can be used independently or combined for deposit mapping in other volcanic regions around the world.

2. Study site

Mt Ruapehu is the largest and most active andesitic stratovolcano in the central North Island of New Zealand (Fig. 1). It lies at the southern end of the Taupo Volcanic Zone, an intra-arc rift developed in association with subduction of the Pacific Plate beneath the Indo-Australian Plate (Wilson et al., 1995). The 110 km^3 composite cone rises to 2797 m above sea level and supports a number of small glaciers, permanent snow fields, and a summit Crater Lake. It is surrounded by a ring-plain constructed of distal pyroclastic fall, and lahar and fluvial deposits derived from the volcano (Donoghue, 1991; Hackett & Houghton, 1989). Historic activity at Ruapehu has consisted of very frequent, relatively small-to-medium phreatic and phreatomagmatic eruptions (e.g. 1895, 1969, 1975, 1988, 2007) (Gregg, 1960; Healy et al., 1978; Nairn et al., 1979) and more prolonged magmatic eruptions such as in 1945 (Beck, 1950; Oliver, 1945; Reed 1945) and 1995–96 (Bryan et al., 1996; Nakagawa et al., 1999). At least five vents have been active during the Holocene, but historic activity has been confined to the southern crater which is normally occupied by a hot, acidic Crater Lake with a (pre-1995) volume of c. 9 million m^3 lying at an elevation of 2530 m (Christenson & Wood, 1993).

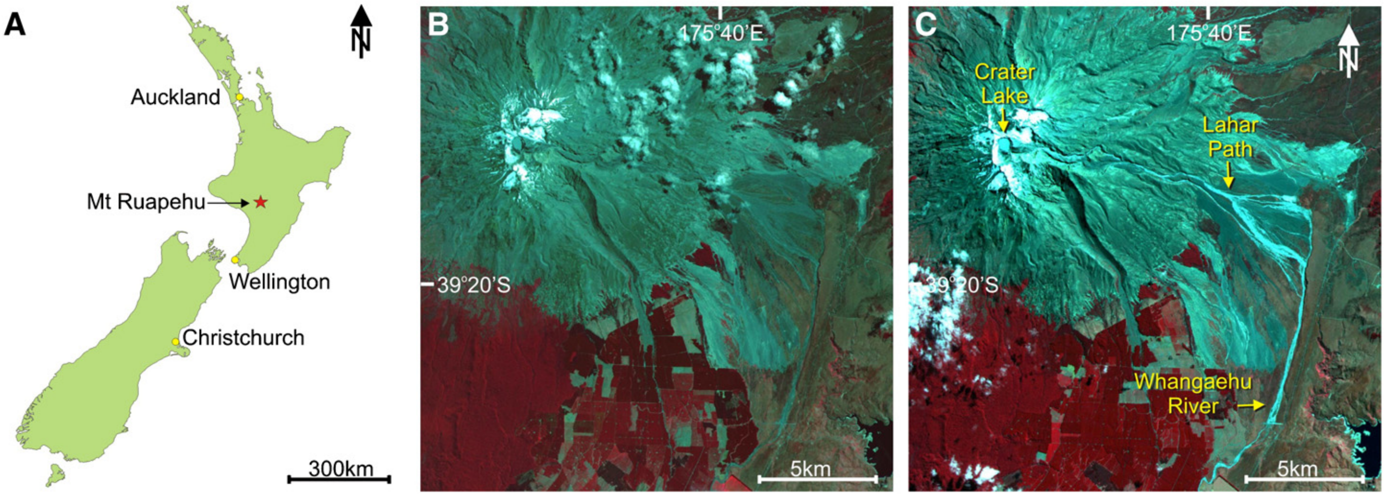

Fig. 1. Study site location (A) Mt Ruapehu location in New Zealand; (B) ASTER imagery before the lahar (9 February 2002); and (C) after the lahar flow (25 March 2007).

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