Satellite Remote Sensing of Volcanic Activity in New Zealand

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Abstract— **Mt Ruapehu is New Zealand's most active volcano. In 2007, the volcano produced a large lahar following a crater lake dam wall breach, in addition to a minor eruption and small associated lahars. Here, satellite remote sensing and image processing is used to extract the path of the major lahar, and to compare the results achieved through classification of ASTER visible and near infra-red imagery to those derived from ALOS-PALSAR L-band synthetic aperture RADAR data. This study also details how remote sensing can be used to derive temperature values useful for monitoring volcanic activity. Eleven ASTER thermal images were acquired to extract the temperature of the crater lake and a linear correlation coefficient (r2) of 0.94 was achieved when compared to field survey. The results herein demonstrate the utility of satellite remote sensing for mapping and monitoring volcanic activity in New Zealand.**

Keywords- remote sensing; temperature; geology

I. Introduction

Mt Ruapehu is an active volcano in the central North Island of New Zealand (Figure 1). As the site of two large and popular ski fields (Whakapapa and Turoa), it is important to map and monitor the volcanic activity to provide a better understanding of potential risks and hazards to the region. A variety of characteristics of the volcano are monitored at a minimum of a monthly basis using in-situ measurements of crater lake temperature, airborne gas measurements (SO_2, CO_2 and H_2S), as well as qualitative observations related to the colour and level of the crater lake. Networks of permanent seismic and deformation stations record data continuously. In addition, a webcam acquires daily images of the summit. Satellite remote sensing provides another potential monitoring tool, though to date has not been included extensively in New Zealand volcano monitoring plans. It is fitting to develop and calibrate any remote sensing techniques on an already well understood site such as Mt Ruapehu. By developing procedures that are effective for Mt Ruapehu, it may be possible to extrapolate these techniques to other regional volcanoes that are more difficult to access.

A. *Lahar Mapping*

In March 2007, the crater lake at the volcano summit breached its tephra dam wall, sending a lahar down the south east slope of the volcano and along the Whangaehu River. As the crater lake is closely monitored, the lahar came as no surprise to volcanologists and many in-situ monitoring tools were in place to capture the event. Aerial photography was flown before and after the event to characterise the extent of the flow. This study aims to assess the utility of satellite remote sensing for mapping the lahar path using ASTER visible-near infrared imagery acquired immediately after the event, and ALOS-PALSAR L-band synthetic aperture RADAR, acquired several months later.

Volcanic debris has previously been successfully mapped and measured with remote sensing, though few methods of automatic detection have been reported and it appears that the technique of favour is manual digitisation. The normalized difference vegetation index (NDVI) is commonly used for its ability to enhance the difference between volcanic deposits and surrounding vegetated areas [1, 2]. 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 multi-band display incorporating different input dates [2, 3], principal components analysis and image subtraction [4].

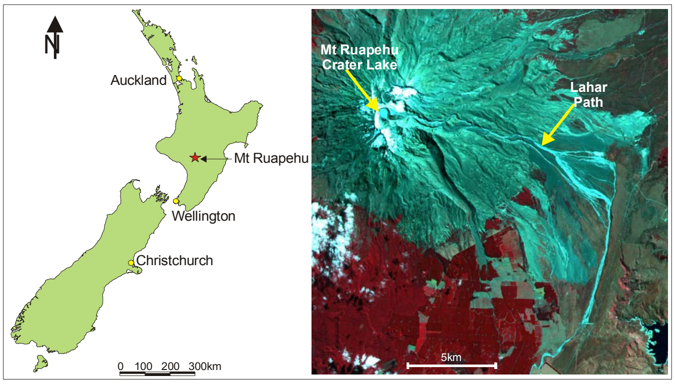

Figure 1: Location of Mt Ruapehu and ASTER VNIR image acquired 25 March 2007

B. *Crater Lake Temperature Monitoring*

In September 2007, a minor eruption on Mt Ruapehu caused changes in the temperature of the crater lake. The temperature was measured in-situ to increase from approximately 14°C to 34°C soon after the eruption. Several

ASTER thermal scenes were obtained before and after the event to determine if satellite thermal data of Mt Ruapehu could provide an alternate or complementary means for monitoring. The goal here was therefore to determine the correlation between satellite derived and in-situ measured temperatures of the crater lake.

Thermal monitoring of crater lake temperatures, lava and thermal anomalies, has been conducted since the 1980s, initially using the thermal sensor on board the Landsat series of sensors [5-11]. The number of thermal applications has since increased with the development of more sophisticated techniques such as sub-pixel analysis with multi-band thermal sensors such as ASTER [12-14], MODIS [15-17] and AVHRR [18-20]. Alerts for thermal anomalies observed on a global scale are available freely on the internet, utilising both MODIS and GOES image data [16, 17, 21]. These however need to be viewed with caution as the alerts are not sensitive to merely warm features (e.g. minor crater lake heating), and will also be triggered by other non-volcanic sources of heat such as a bushfire [21].

II. Methods

A. Lahar Mapping

Multi temporal ASTER images acquired before (9 Feb 02) and after the event (25 Mar 07) were used to distinguish the lahar from its surrounds. Imagery were orthorectified and radiometrically calibrated to each other. Vegetation indices and thresholding reduced the area of interest in the image. This was followed by an unsupervised classification, sieving and clumping to delineate the lahar. Spectral angle mapper and principal components analysis were also tested but proved less accurate than the unsupervised approach using green, red and normalised difference vegetation index (NDVI) layers as input.

For comparison, ALOS-PALSAR L-band synthetic aperture RADAR data were acquired to determine the benefits of InSAR, backscatter and coherence techniques for deposit mapping. The coherence image was deemed to be most useful, and a threshold was determined to extract the lahar feature.

A manually digitised vector of the lahar path from aerial photography was used for accuracy assessment of each of the satellite data sets. Areas of accuracy were noted, as were areas of commission and omission error.

B. Crater Lake Temperature Monitoring

The USGS Global Visualization Viewer (GLOVIS) was used to locate and purchase ASTER thermal imagery over Mt Ruapehu within the archive. This archive was continually checked on a fortnightly basis for any updates. Any imagery where the crater lake was clearly visible is purchased, regardless of the stated cloud cover level. With the exception of one image (28 Oct 2007), all images were acquired at night-time. All data were purchased as Level 1A and supplied in HDF format.

Data were processed using the ENVI/IDL (ITTVIS) image processing system. Radiometric calibration coefficients were applied, and then atmospheric correction and orthorectification were performed using rational polynomial coefficients and a local 10 m DEM. Temperature values were extracted using the emissivity-normalization method.

For each image date, the maximum temperature within the crater lake was extracted and compared to the in-situ temperatures, which were usually collected from the centre of the lake using a helicopter platform. After initial observation of the satellite derived temperatures, a consistent offset of approximately -4°C was observed when compared to in-situ temperatures. This constant value was therefore added to all satellite derived values to achieve the final comparison.

As image and field data were not acquired at the same time or date, it was not possible to relate measurements exactly to each other. Instead, a linear growth or decay was assumed between sample dates (for both field and image data) and approximate temperatures were interpolated to estimate daily values. The linear correlation coefficient was then determined between the image and field data.

III. Results and Discussion

A. Lahar Mapping

With the exception of a few minor areas of cloud cover, the classification of ASTER imagery proved to be a fast, accurate and cost effective method to map the lahar deposit (Figures 2 and 3). The widest part of the lahar path was mapped most accurately, though some narrow parts were omitted due to inadequate spatial resolution to resolve the feature. Most errors occurred closest to the summit of the volcano.

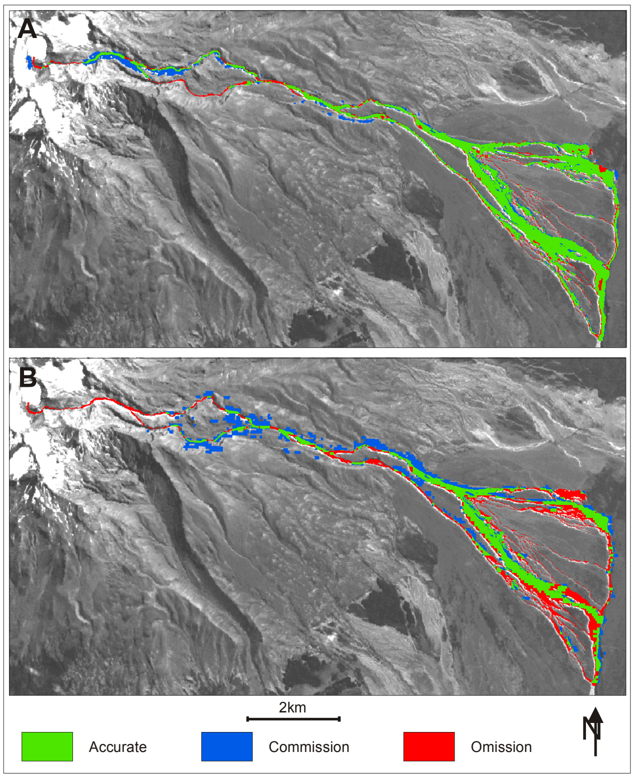

Figure 2: Classification of lahar path using (A) ASTER VNIR; and (B) ALOS-PALSAR coherence

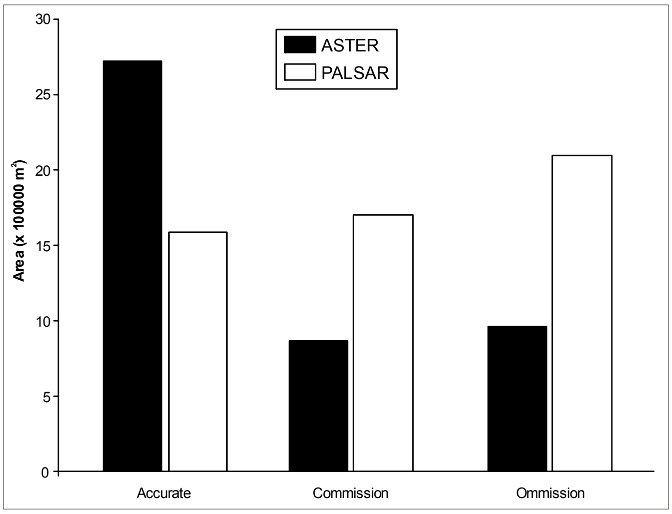

Figure 3: Classification accuracies for ASTER and PALSAR data

A clear lahar related signal was observed on the coherence image calculated for the pair of ALOS-PALSAR images acquired both before and after the event. Interestingly, the signal was still observable on imagery obtained nine months after the event. This technique is therefore useful for both delayed image capture, and also during periods of cloud cover. However, the lower spatial resolution of the coherence image in comparison to the ASTER data resulted in higher commission and omission errors, and lower overall accuracy.

B. Crater Lake Temperature Monitoring

Eleven ASTER thermal images had been purchased at the time of writing (although there is now an on-going commitment to continue this work). Over the same period, 16 measurements were made in-situ. A direct comparison between the ASTER derived and in-situ crater lake temperature measurements is shown in Figure 4. The correlation coefficient between these two data sets returns a value of $r^2 = 0.95$.

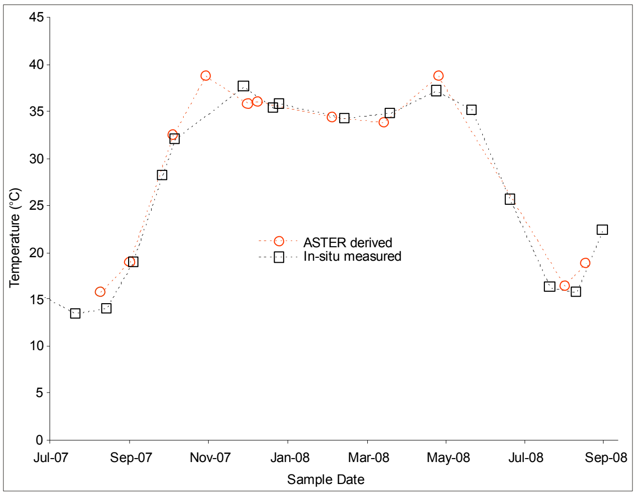

Figure 4: Comparison between ASTER derived and in-situ measured crater lake temperatures

Minor differences between the two datasets are apparent, though it is impossible to determine at this stage whether these differences are real, or an artifact of different sampling regimes. To date, no image has been acquired on the same day or time as a field sample. The most apparent anomaly in the image derived temperatures dataset was found on the 22nd November 2007. However, due to the paucity of field data around this date, it cannot be declared an outlier and may indeed be an accurate temperature reading.

The close correlation between these datasets holds great potential for developing a monitoring plan incorporating thermal imaging for New Zealand's volcanoes. The imagery provides additional data points in between scheduled sampling dates to help better understand temperature fluctuations on Mt Ruapehu. Perhaps of greater utility is the potential to use satellite thermal imaging to monitor other volcanoes in the region that are difficult or dangerous to access. While remote sensing should never completely replace field survey, it is also noted that this technique provides a significant time and financial cost saving.

IV. Conclusions

The work completed on Mt Ruapehu represents the early stage of developing protocols for using earth observation data for monitoring New Zealand's volcanic regions. Both ASTER and PALSAR imagery were capable of mapping the extent of a lahar, though the spatial resolution of PALSAR results in lower classification accuracies. The thermal imagery available from ASTER has also been proven to provide accurate values of temperature fluctuations in the Mt Ruapehu crater lake when compared to in-situ sampling measures. It is already clear that a multi-sensor approach is required, incorporating in-situ, airborne and satellite measurements. The development and implementation of a sensor-web strategy should greatly improve our ability to monitor and understand volcanic activity.

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VI. References

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