Biennial report for Permanent Supersite/Natural Laboratory

Name of Supersite

History	*https://geo-gsnl.org/supersites/permanent-supersites/new-zealand-volcanoes-supersite/*
Supersite Coordinator	*Ian Hamling,* *GNS Science, 1 Fairway Drive, Lower Hutt 5040, New Zealand*

1. Abstract

Located in the North Island, New Zealand, the Taupo volcanic zone (TVZ) is one of the most productive rhyolitic (silica-rich) volcanic system on earth. It has formed as a result of subduction of the Pacific plate beneath the Australian plate which has led to backarc rifting along the 300 km-long, 60 km-wide TVZ. Previous observations have shown ground deformation signals related to volcanic processes, geothermal activity and due to volcano–tectonic interactions but little is known about the dimensions or magnitudes of such sources. Unlike most back-arc rifts, which are usually found under oceans, the subaerial TVZ allows a unique opportunity to study the interaction between volcanism and tectonics using land-based observations. Recent measurements of the Taupo system have revealed vertical ground movements on the order of 10-15 cm over the past ~10 years. In particular, continuous GPS and InSAR shows that the region between Taupo and Rotorua is currently undergoing ~2 cm/yr of subsidence. The origin of the subsidence, which is significantly larger than observed at other volcanic centres, is likely to be complex. Although many of the volcanic centres appear to be in a period of quiescence, hydrothermal driven eruptions at White Island in 2016 and at Tongariro in 2012 have resulted in new insights into their shallow magmatic/hydrothermal systems. In the past few years, parts of the crater rim at White Island were moving at rates up to 20 cm/yr following the eruption in 2016 while localized subsidence over the eruption site on Tongariro continues 6 years after the eruption. Many of these observations would have been impossible without the support of the supersite initiative which continues to deliver huge benefits to New Zealand and the scientific community.

Scientists/science teams

<In the table below please list all scientists/science teams who used/received data >

Researcher/team 1	*Ian Hamling, GNS Science, New Zealand (Team includes multiple scientists from across GNS including: Sigrun Hreinsdottir, Nico Fournier, Charles Williams, Ted Bertrand, Laura Wallace, Tony Hurst, Geoff Kilgour.*

Scientists/science team issues

While there are many people working on the Taupo Volcanic Zone with various datasets available through the GeoNet project, the PoC is not aware of external groups working on the satellite data specific to the supersite. While to date there has been limited coordination/contact between external groups, within GNS Science the satellite data has been utilized within multiple internal groups working on various volcanic hazard related studies.

Given New Zealand's small size and limited resources the PoC is currently the primary user of the radar data. Unlike some of the other supersites that are supported by large well-funded research projects there has been limited opportunities to expand users and build teams in New Zealand. Furthermore, many of the volcanoes are not currently demonstrating signs of unrest or activity limiting their immediate interest to the international community.

1. In situ data

Type of data	Data provider	How to access	Type of access
GPS	*GeoNet*	*http://fits.geonet.org.nz*	*Public*
Seismic	*GeoNet*	*http://fits.geonet.org.nz*	*Public*
Gas	*GeoNet*	*http://fits.geonet.org.nz*	*Public*
Webcam	*GeoNet*	*https://www.geonet.org.nz/data/types/camera*	*Public*

In situ data issues

All in situ datasets which are currently acquired as part of GeoNet are freely available to all members of the public. Under the new GeoNet system, the majority of datasets can be downloaded through the FITS API for which there are extensive instructions available through https://www.geonet.org.nz/data/tools/FITS. For simple plotting without download, data can be accessed through https://fits.geonet.org.nz/.

Satellite data

Type of data	Data provider	How to access	Type of access
TerraSAR-X	*DLR*	Available after proposal submission to and acceptance by DLR (https://supersites.eoc.dlr.de/)	GSNL scientists
Cosmo-SkyMed	*ASI*	POC requests access from ASI for individual user	GSNL scientists

RADARSAT-2	*CSA*	POC requests access from CSA for individual users	GSNL Scientists
Sentinel-1A/B	*ESA*	https://scihub.copernicus.eu/dhus/	Registered public
ALOS-2	*JAXA*	https://auig2.jaxa.jp/ips/home	Successful proposals

Satellite data issues

There have been no significant data issues during the last 24 months. Due to the limited number of acquisitions made by RADARSAT-2 and coherence issues throughout the study region, the PoC has not maintained regular orders and has instead opted for Sentinel-1A/B data with 12-day repeat visits. Although RADARSAT-2 has had limited success for monitoring, it would be good to have the quota for RADARSAT-2 left open should there be a change in activity along the study area for additional imagery.

TerraSAR-X data has proved invaluable for enhanced monitoring of White Island. However, the 6-day latency between acquisition and delivery does limit its usefulness during periods of heightened unrest. If there is a way to reduce this time lag it would be hugely beneficial for monitoring.

The quantity and rapid delivery of Cosmo-SkyMed data has successfully been used to monitor ongoing deformation over the southern volcanoes of Ruapehu, Ngauruhoe and Tongariro. However, due to the unreliable perpendicular baseline and more vegetated settings along the main Taupo Volcanic zone it's use has been more limited. To maximise the use of the data, it may be beneficial to the supersite if we move one of the ascending and descending passes to cover the Auckland Volcanic Field. Due to its urban environment there should be less of an issue with coherence and, at present, very little is known about any deformation associated with the area.

2. Research results

Here we provide some detailed results which are predominantly derived from satellite data. Several papers have been published based on in situ datasets collected by GeoNet with a selection listed below but will not discussed here.

White Island

One of the main focuses of the New Zealand volcano supersite has been monitoring White Island using high resolution SAR data from the TerraSAR mission. Of New Zealand's volcanoes, White Island is the most frequently erupting and was home to one of New Zealand's worst volcanic disasters when 11 sulfur miners were killed following the collapse of part of the SW crater wall. The most recent eruption occurred on 27 April. It followed a period of minor unrest with heightened volcanic tremor and a decrease in the water level in the crater lake.

SAR data acquired from 2015 through to late 2018 have helped reveal a complex pattern of deformation from around the crater at White Island and surrounding crater walls. Prior to the

eruption, in the vicinity of the lake both the ascending and descending tracks indicate localized line-of-sight (LOS) decreases at rates of ~20–30 mm/yr (Figure 1), consistent with uplift. At the same time, points on the southwest crater wall, which failed during the 1914 landslide, indicate 50 mm/yr of LOS increase at the base of the slope suggesting slow creep of the crater wall toward the lake.

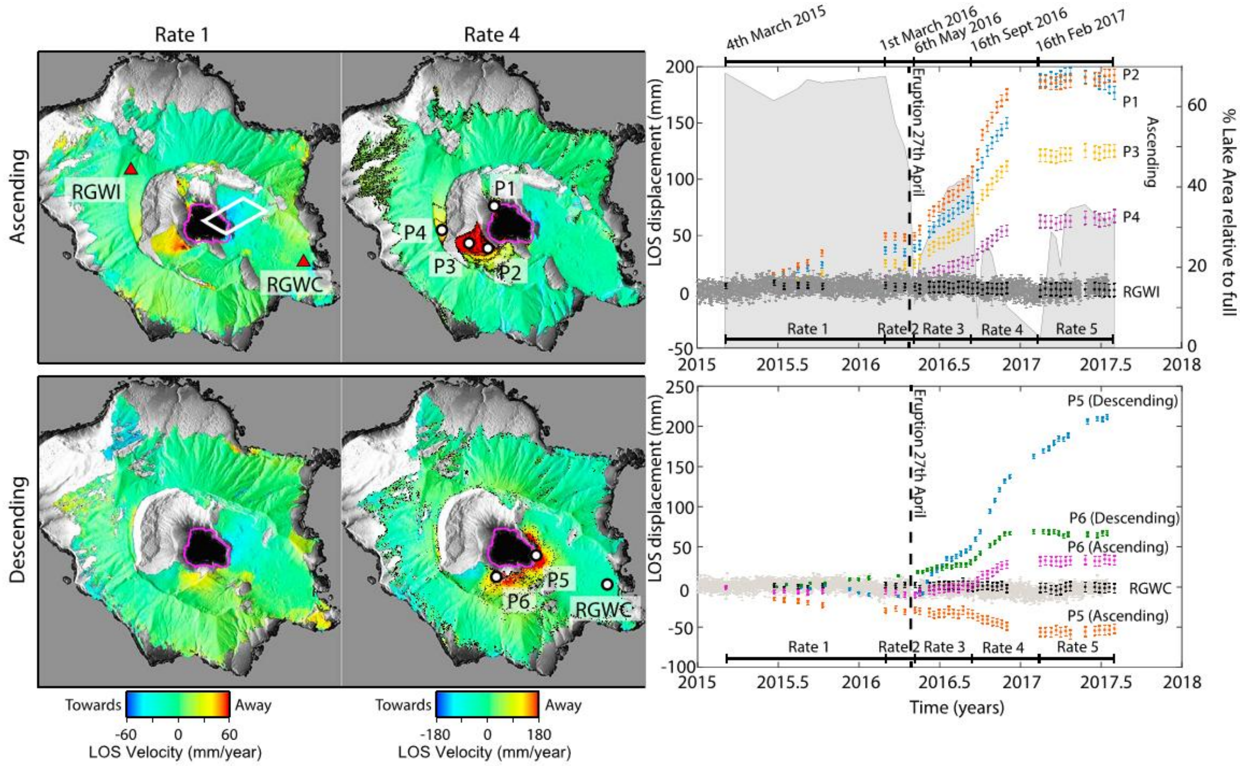

Figure 1: Best fitting ascending and descending displacement rates for two periods as indicated in the time series. The pink outline shows the location of the crater lake, and the white rectangle shows the location of best fitting inflation source as described in the main text. Contours are plotted at 50 mm intervals with warm colors indicating motion away from the satellite. The time series on the right show the displacements at points P1–P6, RGWI and RGWC as labeled. Errors are estimated from the standard deviation of phase values in a 200 by 200 m region in the east of the crater floor. The gray polygon indicates the lake level and the dashed line shows the date of the April 2016 eruption. After Hamling; 2017

Following 27 April eruption, the crater lake was almost completely emptied (Figure 2) and the rates of deformation both across the crater floor and crater walls increase significantly (Figure 1). The coincidence between the significant increase in slope velocity and drop in the lake level suggests that the lake helps to stabalise the slope by providing a confining pressure at the base (Hamling et al; 2017).

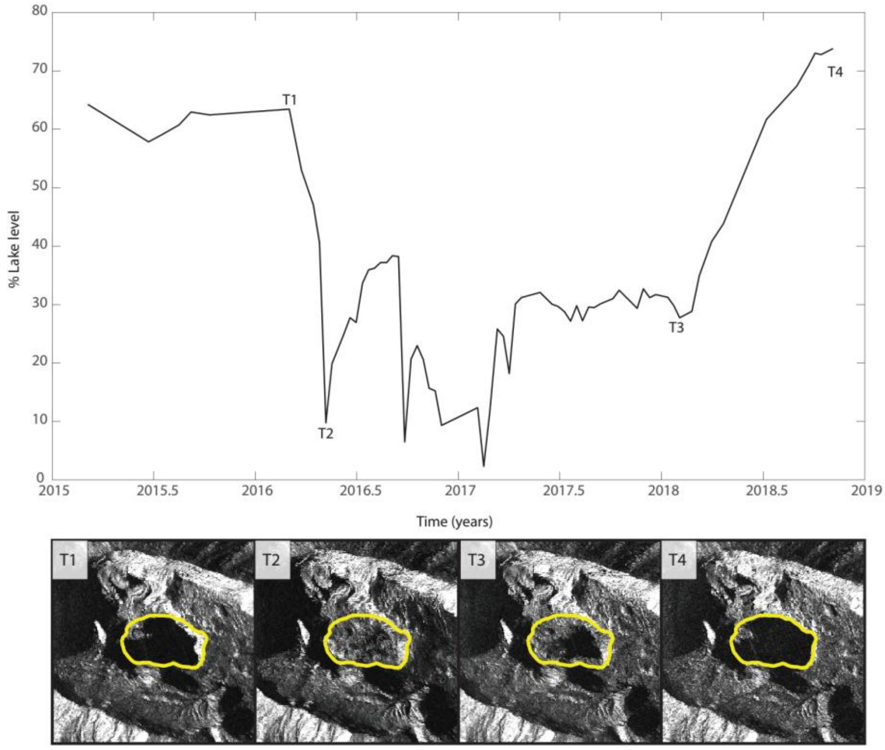

Figure 2. Top: Updated estimate of the crater lake water level. The estimate is made relative to the yellow line shown in the lower panel. Since early 2018 the lake has been steadily rising after the emptying episodes associated with the 2016 eruption.

Through the early part of 2017, deformation around White Island was concentrated at the back of the crater floor where the lake had been removed. This area continued to subside (Figure 3) until mid-2017 when it began uplifting. This is coincident with uplift of the main crater floor which started at a similar time.

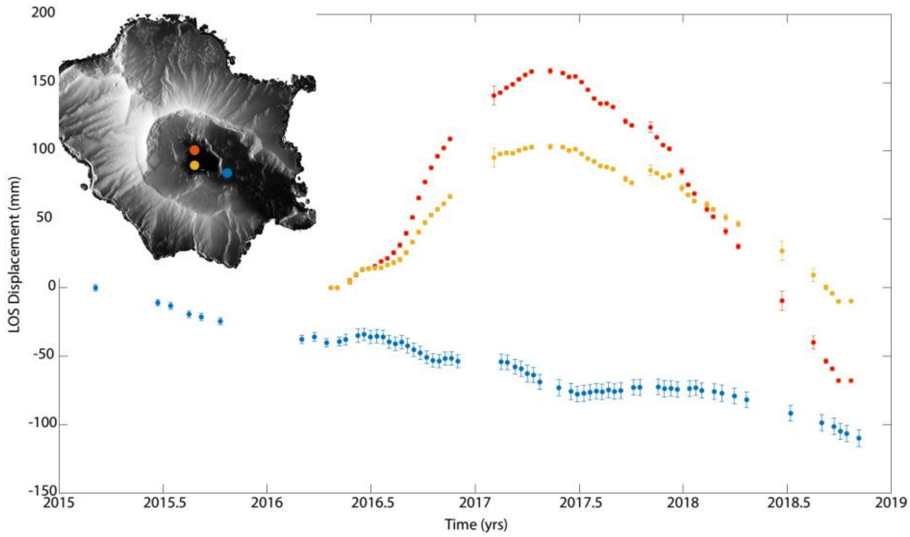

Figure 3. Deformation timeseries derived from the ascending dataset. The different coloured dots show the locations of the individual timeseries within the crater area.

Central Taupo Volcanic Zone, Tongariro, Ngauruhoe and Ruapehu.

Deformation around the southern volcanoes of Ruapehu, Ngauruhoe and Tongariro remains focused over the 2012 eruption site of Tongariro with no indication of deformation at the other centres. Both Cosmo-SkyMed and Sentinel data indicate continued subsidence of ~10 mm/yr since 2016 over the main eruption site (Figure 4).

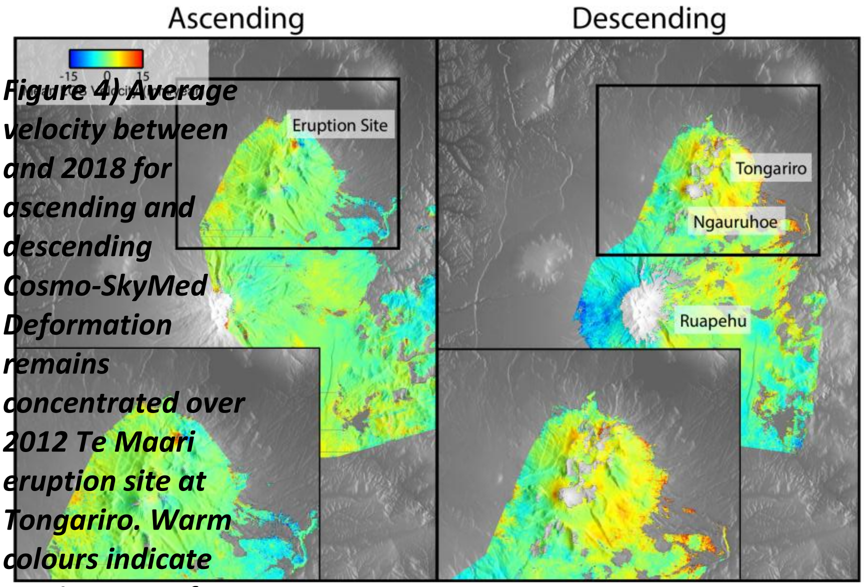

Figure 4) Average velocity between 2016 and 2018 for ascending and descending Cosmo-SkyMed data. Deformation remains concentrated over the 2012 Te Maari eruption site at Tongariro. Warm colours indicate motion away from the satellite.

Deformation through the central volcanic zone has continued to be dominated by widespread subsidence extending from north of Lake Taupo through to Rotorua and Okataina (Figure 5, Hamling et al., 2015). Current work has been focused on the Okataina Caldera are at the north of the TVZ where we are looking at methods to integrate InSAR, GPS, seismology and magnetotelluric data to better image the distribution of melt at depth. Constraining the inversion of geodetic data with the crustal resistivity, is providing an improved estimate of source depth of cooling magma bodies which we infer to be causing the subsidence (Figure 5).

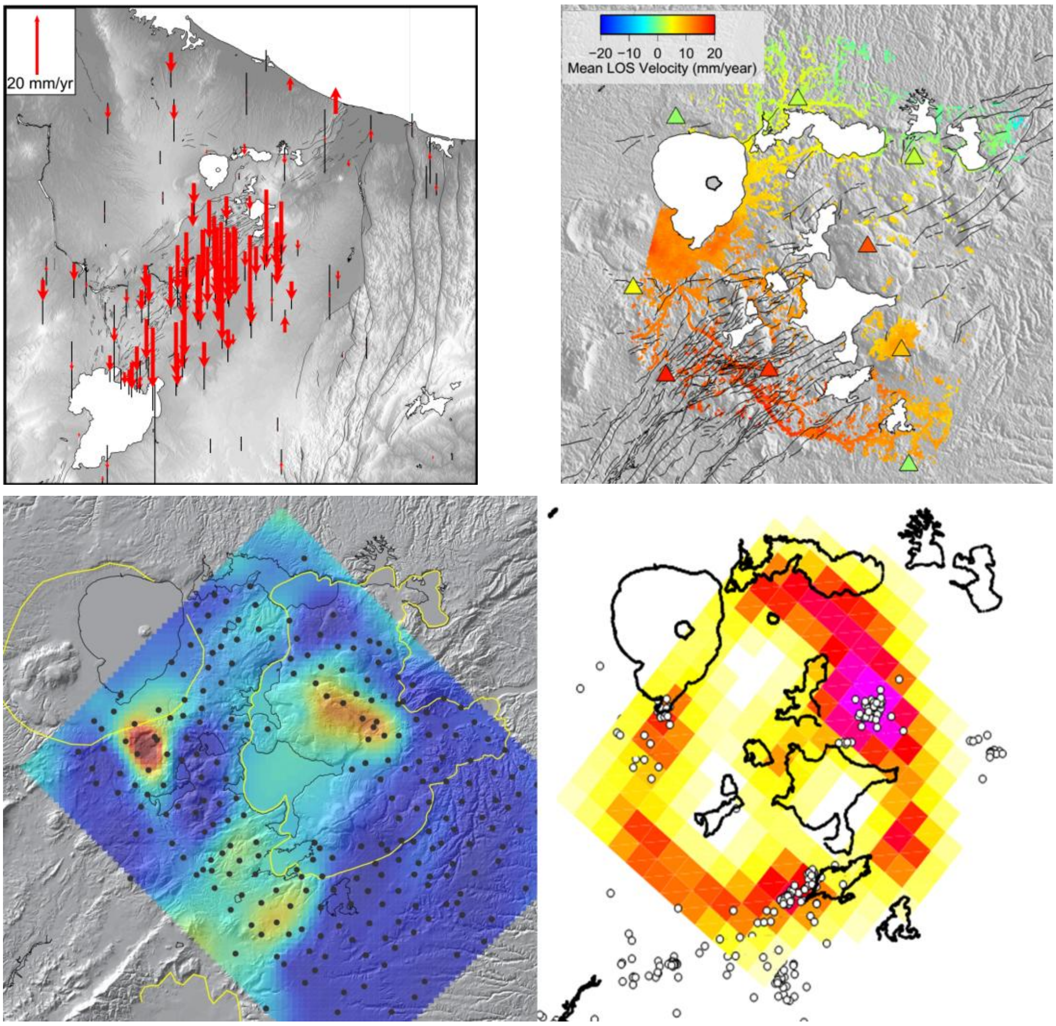

Figure 5: Top Left) Vertical GPS velocities over the central TVZ. Top Right) Mean LOS displacement over the Okataina Caldera derived from Cosmo-SkyMed data between 2012 and 2014. Triangles show the local GPS displacement rates converted into the satellites look direction. Bottom) Comparison between MT and contraction model at 5 km depth. By using the MT as a penalty function contraction is focussed into zones of low resistivity.

Publications

Peer reviewed journal articles
Jolly, A., Lokmer, I., Christenson, B. and Thun, J., 2018. Relating gas ascent to eruption triggering for the April 27, 2016, White Island (Whakaari), New Zealand eruption sequence. Earth, Planets and Space, 70(1), p.177.
Miller, C.A.; Currenti, G.; Hamling, I.J.; Williams-Jones, G. 2018 Mass transfer processes in a post eruption hydrothermal system : parameterisation of microgravity changes at Te Maari craters, New Zealand. Journal of Volcanology and Geothermal Research, 357: 39-55; doi: 10.1016/j.jvolgeores.2018.04.005
Schaefer, L.N., Kennedy, B.M., Villeneuve, M.C., Cook, S.C., Jolly, A., Keys, H. and Leonard, G., 2018. Stability assessment of the Crater Lake/Te Wai-ā-moe overflow channel at Mt. Ruapehu (New Zealand), and implications for volcanic lake break-out triggers. Journal of Volcanology and Geothermal Research.
Rastin, S.J., Gledhill, K.R. and Unsworth, C.P., 2018. A Detailed Spatiotemporal Wavelet Study to Improve the P-Phase Picking Performance for the 2007–2010 Shallow Earthquake Swarms near Matata, New ZealandA

Detailed Spatiotemporal Wavelet Study to Improve the P-Phase Picking Performance. Bulletin of the Seismological Society of America, 108(1), pp.260-277.

Holden, L., Cas, R., Fournier, N. and Ailleres, L., 2017. Modelling ground deformation patterns associated with volcanic processes at the Okataina Volcanic Centre. Journal of Volcanology and Geothermal Research, 344, pp.65-78.

Edwards, M.J., Kennedy, B.M., Jolly, A.D., Scheu, B. and Jousset, P., 2017. Evolution of a small hydrothermal eruption episode through a mud pool of varying depth and rheology, White Island, NZ. Bulletin of Volcanology, 79(2), p.16.

Godfrey, H.J., Fry, B. and Savage, M.K., 2017. Shear-wave velocity structure of the Tongariro Volcanic Centre, New Zealand: Fast Rayleigh and slow Love waves indicate strong shallow anisotropy. Journal of Volcanology and Geothermal Research, 336, pp.33-50.

Walsh, B., Jolly, A.D. and Procter, J., 2017. Calibrating the amplitude source location (ASL) method by using active seismic sources: An example from Te Maari volcano, Tongariro National Park, New Zealand. Geophysical Research Letters, 44(8), pp.3591-3599.

Lamb, S., Moore, J.D., Smith, E. and Stern, T., 2017. Episodic kinematics in continental rifts modulated by changes in mantle melt fraction. Nature, 547(7661), p.84.

Hamling, I.J. 2017 Crater lake controls on volcano stability : insights from White Island, New Zealand. Geophysical Research Letters, 44(22): 11,311-11,319; doi: 10.1002/2017GL075572

Conference presentations/proceedings

Hamling, I.J.; Kilgour, G.N. 2017 Deformation from an active crater: insights into volcano dynamics from White Island, New Zealand, using High Resolution SAR data. p. 346-347 IN: Fringe 2017 Workshop : the 10th International Workshop on "Advances in the Science and Applications of SAR Interferometry and Sentinel-1 InSAR"

Hamling, I.; Bertrand, E; Hreinsdottir, S; Williams, C; Bannister, S. Estimating the distribution of melt beneath the Okataina Caldera, New Zealand: an integrated approach using geodesy, seismology and magnetotellurics. 19th General Assembly of Wegener

Research products

We do not currently have any formal research products beyond those made available from published works which are available upon request. Timeseries from GPS and other datasets generated through GeoNet are all available to the public. Over the next 24 months we are aiming to automate much of the InSAR processing and hope that we will be able to offer interferograms and derived timeseries as an additional dataset through GeoNet.

3. Dissemination and outreach

Results from the supersites have been presented to a number of regional council members to inform them of ongoing activities in monitoring of volcanic hazard in New Zealand. InSAR results, where applicable, are discussed in weekly volcanic hazard monitoring meetings to help inform. The PoC has given a number of talks at New Zealand Universities highlighting the potential use for InSAR in volcano monitoring and the New Zealand supersite as well as at national and international conferences/workshops.

4. Funding

To date, work directly related to analysis and processing of SAR data has been and continues to be funded through GNS science core funding. Limited additional funds have been sourced from external research grants for more detailed studies. Currently the PoC has ~0.4 FTE dedicated to volcano research and work related to the supersite.

5. Stakeholders interaction and societal benefits

Beyond the scientific community, the main stakeholders who benefit from the supersite has been GeoNet for enhancing the monitoring capabilities in time of crisis. TerraSAR-X data following the 2016 eruption at White Island was particularly useful for providing near-field data around the crater lake. Fortunately, activity at most of the volcanic centres remains quiet. However, in the event of a future eruption or increased activity these data will have direct benefits to local authorities, regional councils and civil defence. To date, results from SAR observations have been utilized during hazard monitoring meetings to provide additional information not captured by our current ground-based monitoring systems.

6. Conclusive remarks and suggestions for improvement

As we approach the end of its fourth year of the New Zealand volcano supersite, it continues to be of considerable value to the monitoring of New Zealand volcanoes. Considering that many volcanoes are currently in a period of relative quiescence, there has been limited outside interest in the supersite. However, research conducted over the last two years and ongoing studies utilizing the vast datasets are providing new insights into volcanic processes at volcanic centers around New Zealand.

While there are limited issues surrounding the supersite, any decrease in latency between acquisitions and delivery would increase the usability of the data for monitoring. Delays of days between acquisition and analysis can make the observations redundant after an event has happened. Much of the New Zealand landscape is vegetated to some degree meaning that longer temporal or spatial baselines cause rapid decorrelation of the signal. As a result, in the past years Radarsat-2 data has not been utilized because of the longer repeat times compared to the regular ascending and descending data provided by the Sentinel-1 mission. Although not currently used, having an open allocation to data should an unrest event begin would be invaluable to support response efforts. Similarly, given the coherence issues with some of the Cosmo-SkyMed scenes it would be beneficial to the supersite if a portion of the imagery could be re-tasked over the Auckland volcanic field where the urban environment will enhance its usability.

In summary, the supersite initiative has been and continues to be of huge benefit to New Zealand. In the coming years we are working to gain additional funding and increased interest in the supersite both within New Zealand and internationally. With the

announcement that the 2021 IAVCEI meeting to be held in Rotorua, in the heart of the supersite, this is a great time to publicise the New Zealand supersite.