GEO Geohazards Supersites and Natural Laboratories

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GROUP ON EARTH OBSERVATIONS

Committee on Earth Observation Satellites

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Biennial report for Permanent Supersite/Natural Laboratory

New Zealand Volcano 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.

Data provided through the supersite has been pivotal in our ongoing monitoring of White Island and in the immediate response to the tragic eruption in December 2019. Following the eruption, deformation was largely focused around the eruptive vent area and SW crater wall which began rapidly moving downslope as was observed following an eruption in 2016. Data acquired over the Tongariro Volcanic Centre continue to reveal shallow subsidence above the 2012 Te Maari eruption site with the remainder of the volcanoes being in a period of relative quiescence. Many of the observations made to date, most notably around White Island, would have been impossible without the continued support of the supersite initiative.

2. Scientists/science teams

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 teams' 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. Within GNS Science the satellite data has been utilized within multiple internal groups working on various volcanic hazard related studies with a focus over the stratovolcanoes which have demonstrated periods of unrest over the last decade.*

To date, 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.

3. 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/.

4. 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*

Satellite data issues

TerraSAR-X data has proved invaluable for enhanced monitoring of White Island. However, the 6-day latency between acquisition and delivery has limited its usefulness during periods of heightened unrest, such as the tragic eruption in December 2019. 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 its use over the central caldera systems has been from longer term Persistent Scatterer analyses.

Unfortunately, a more limited number of acquisitions made by RADARSAT-2, coherence issues throughout the study region, and limited capacity of the PoC, the RADARSAT-2 quota has not been utilised. While the fault lies with the PoC for the lack of usage, with additional staffing in the coming months, we would ask that the quota be kept in place so that we can exploit the valuable dataset through the next reporting period.

Research results

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 has experienced two phreatic eruptions since the start of the supersite including the tragic eruption in December 2019 which killed 21 people.

The deformation timeseries over White Island has now been updated from mid-2017 to present, including the period building up to the eruption. In addition to the deformation timeseries, we have also continued to use the radar amplitudes to help estimate the lake level. During 2018, the lake experienced a period of filling until reaching pre-2016 levels (Figure 2). This coincided with line-of-sight

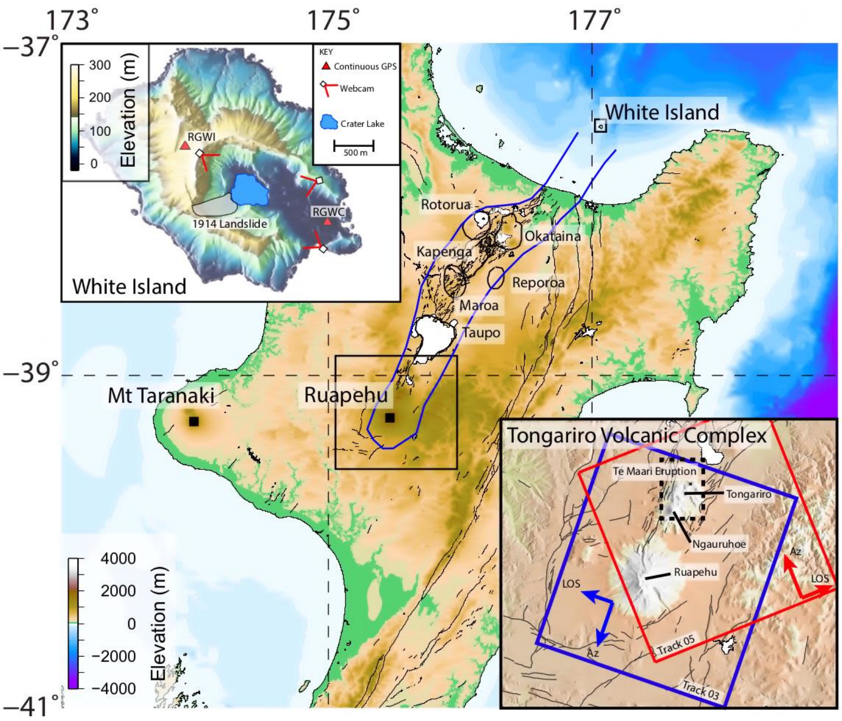

Figure 1. Map showing the location of White Island and the Tongariro Volcanic Complex within the central North Island of New Zealand

(LOS) decreases of a region of the crater floor in both ascending and descending datasets at rates of ~50 mm/yr consistent with shallow inflation (Figure 2). As was previously observed, an area at the back of the lake also showed evidence of uplift as the lake began to fill from mid-2017 until 2019 and again from mid-2019 until the eruption. Unfortunately, coherence is frequently lost at the back of the lake making it difficult to build a continuous timeseries. However, the observed uplift was in line with ground observations of a mixture of mud, steam and water fountaining at the rear of the lake, increased gas emissions and earthquakes prior to the eruption in December 2019 (GeoNet Volcanic Alert Bulletin, 2019/11).

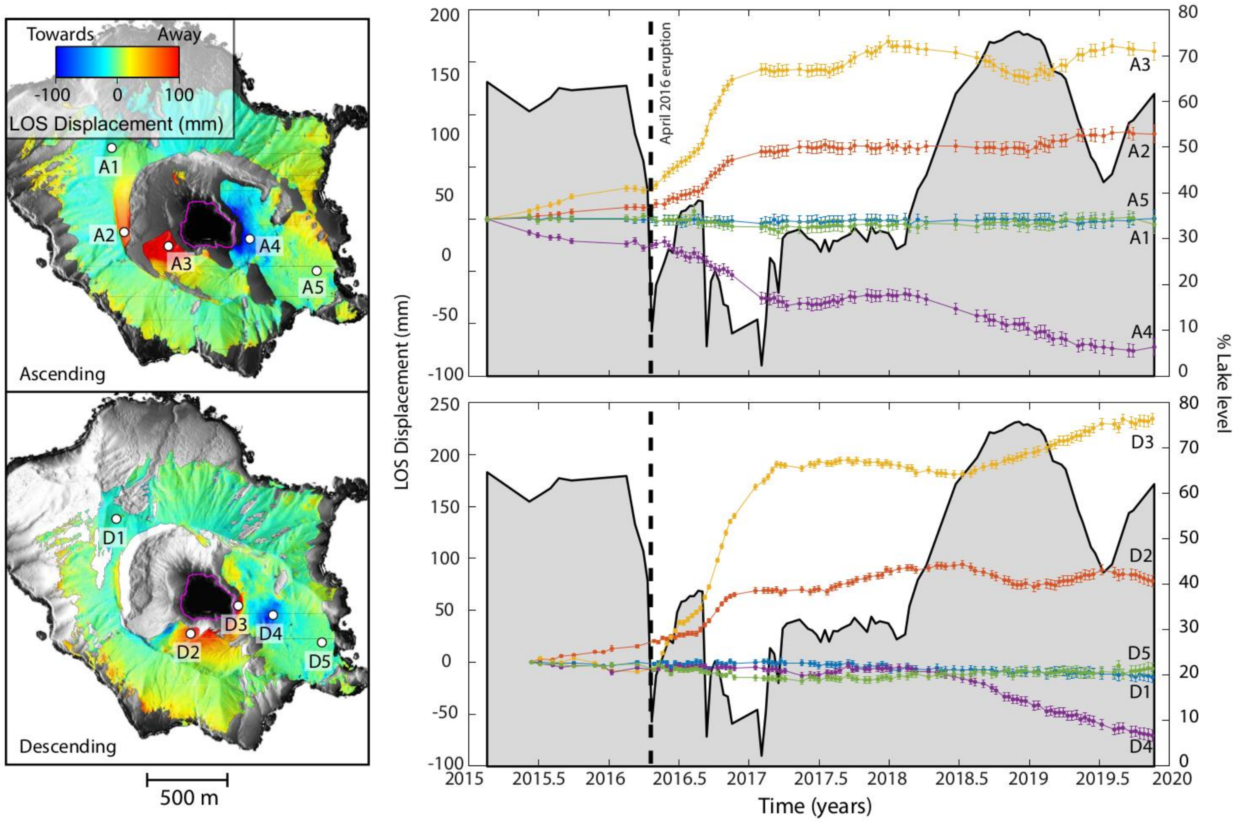

Figure 2. Best fitting displacement rate from January to November 2019 and timeseries for ascending and descending TerraSAR-X data over White Island from Hamling (2020). The pink line shows the outline of the crater lake. For the timeseries, the grey polygon shows a proxy for the water level in the lake based on radar amplitude images as described in Hamling (2017). The dashed black line shows the timing of the 2016 eruption. Positive displacements indicate motion away from the satellite.

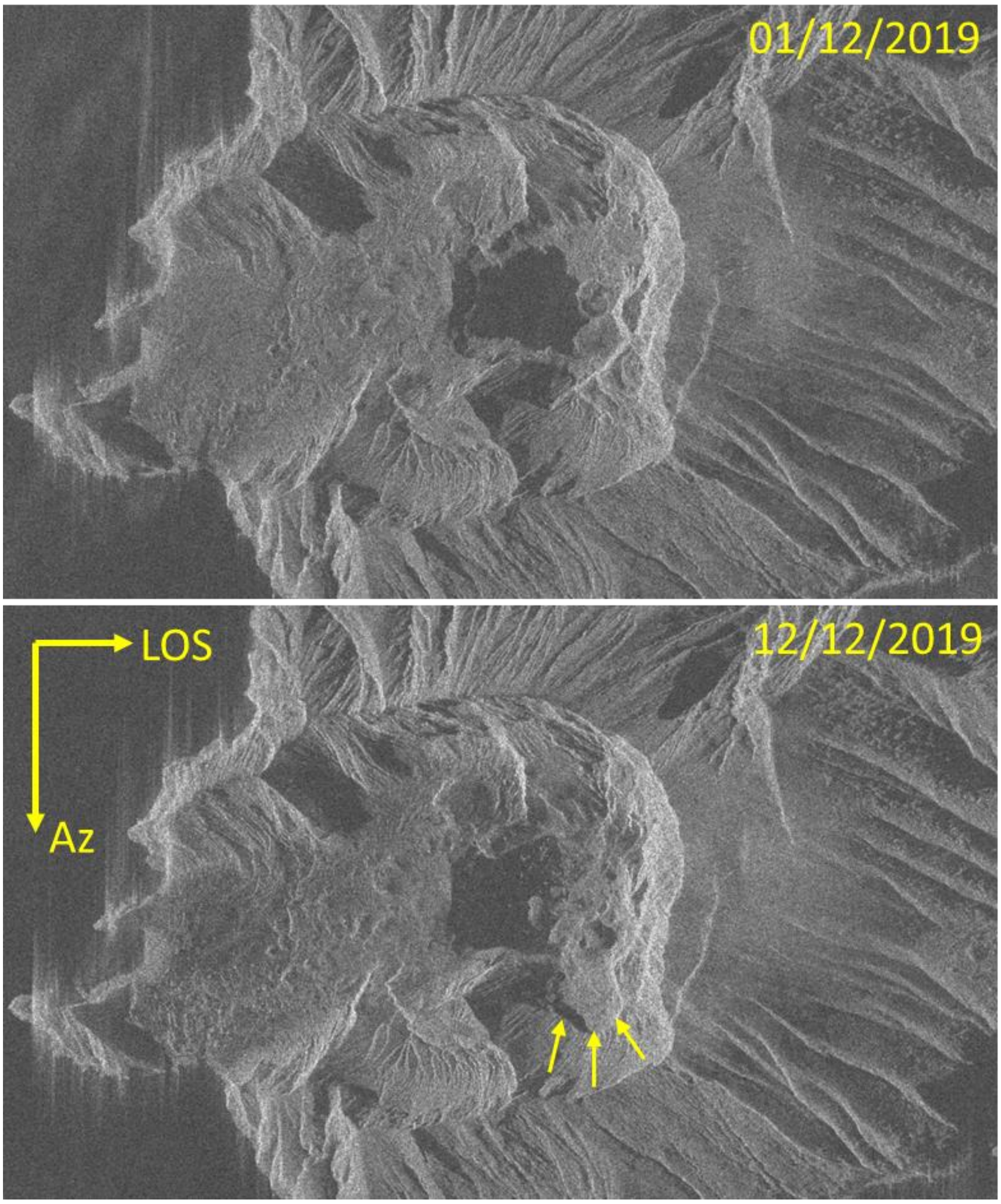

Figure 3. Descending amplitude images acquired before and after the 2019 eruption. The small yellow arrows highlight the newly formed landslide scarp.

Amplitude images captured following the eruption showed that the base of the previously moving landslide collapsed during, or soon after, the eruption (Figure 3), something not clearly visible from other observations at the time. Immediately following the eruption, the landslide area and crater wall began moving rapidly with almost 0.5 m of LOS displacement in 5 months (Figure 4). At the same time the vent area began subsiding at rates of ~100 mm/yr during 2020 (Figure 4).

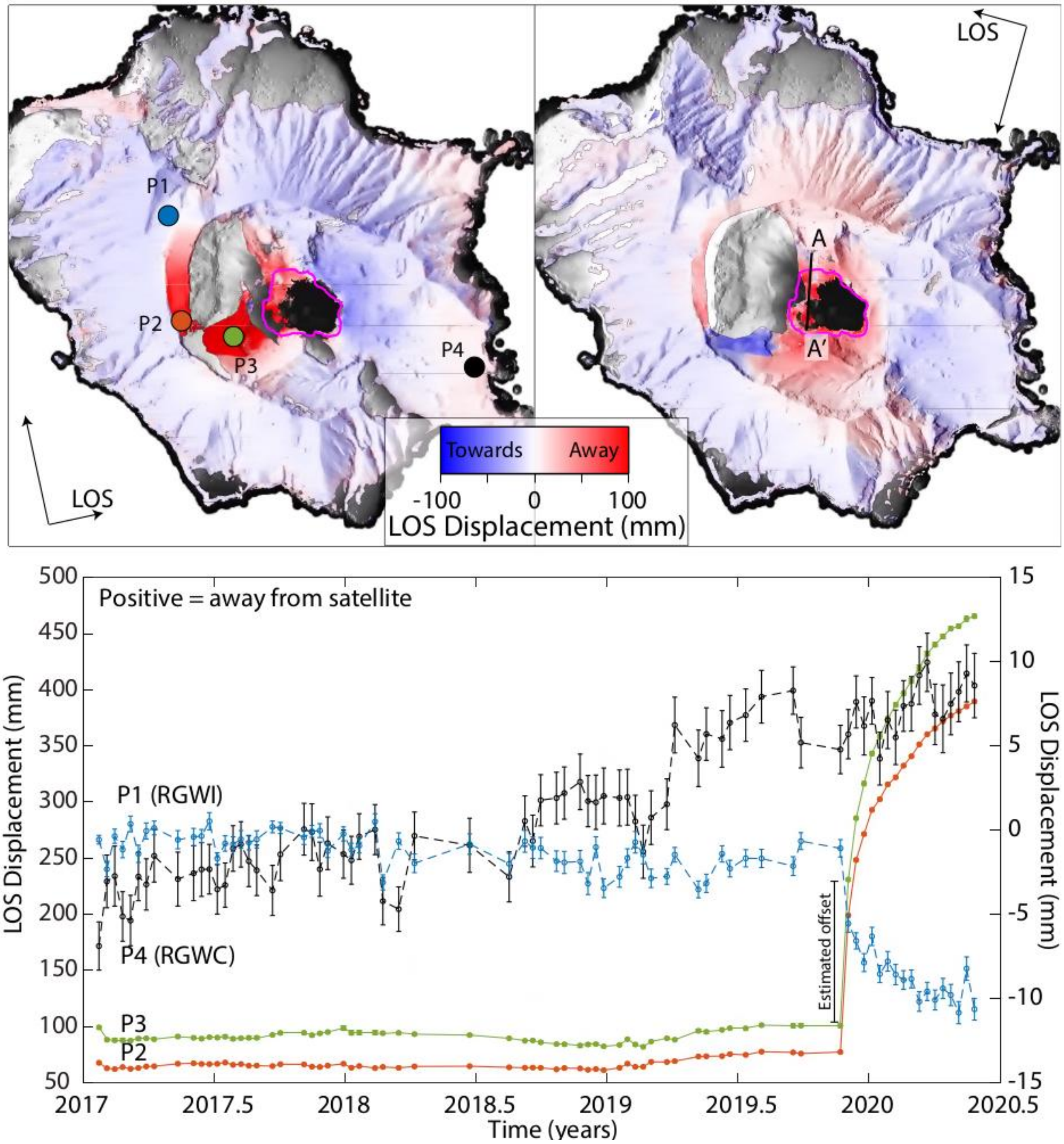

Figure 4. LOS displacement maps following the 2019 eruption of White Island. Bottom, timeseries plots for selected points located on the landslide and at pixels collocated with GPS sites (RWGC and RGWI. Note the two different scales for the landslide (left) and GPS (right) timeseries.

<u>Tongariro Volcanic Centre</u>

Using acquisitions from 2015 to late 2019, small baseline interferograms were formed to generate an InSAR timeseries over the Tongariro Volcanic Center (Figures. 1 and 5). In general, there is little evidence of deformation across most of the TVC except for the localised zone of

LOS increase above the 2012 Te Maari eruption site (Figures 5 and 6). With both the ascending and descending data showing a LOS increase, it suggests that the observed deformation is predominantly in the vertical component; in this case, subsidence. Based on the timeseries data constructed here, the maximum displacement rate between 2015 and 2019 is ~15 mm/yr (Figure 5).

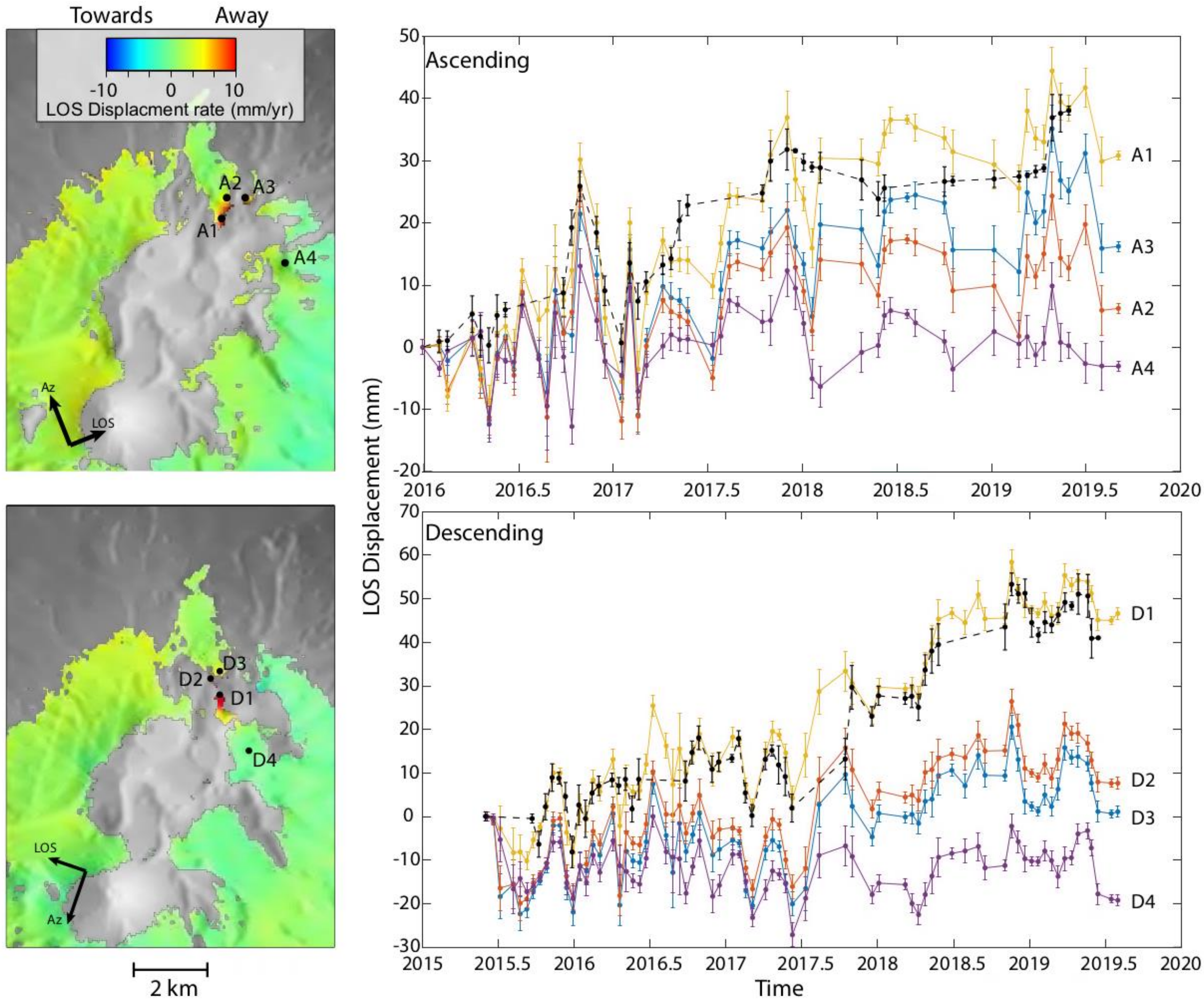

Figure 5. Best fitting displacement rate derived from timeseries data over the Te Maari eruption site from 2015 to 2019 for the ascending (top) and descending (bottom) CSK datasets from Hamling; 2020. The right panel shows the displacement history at the points (A1-4, D1-4) plotted on the best fitting displacement rate. Positive displacements indicate motion away from the satellite. The black dashed line in each plot is the timeseries derived from only the summer acquisitions at points A1 and D1.

Across the TVC, snow cover as a result of the high elevations adds an additional source of decorrelation over large areas. This is most notable in winter acquisitions, leading to widespread loss of signal over the summit areas. To improve the spatial coverage of the estimated displacement rates, interferograms formed using only summer acquisitions increases the number of pixels by ~30% compared with winter images significantly increasing the coverage near the summit of Ruapehu and Tongariro (Figures 5, 6). Using the summer *acquisitions, over the Te Maari eruption site the average displacement rate is ~30 mm/yr consistent with Miller et al. (2018). Interestingly, the location of the subsidence is ~500 m west of that found by Hamling, Hreinsdóttir, et al. (2016) and is more focussed on the vent area suggesting a shallowing of the deformation source with time (Miller et al. 2018). In the ~3 years after the eruption, the area of subsidence was about 4 km 2 but this has reduced to ~1 km 2 in 2019 (Hamling 2020)*

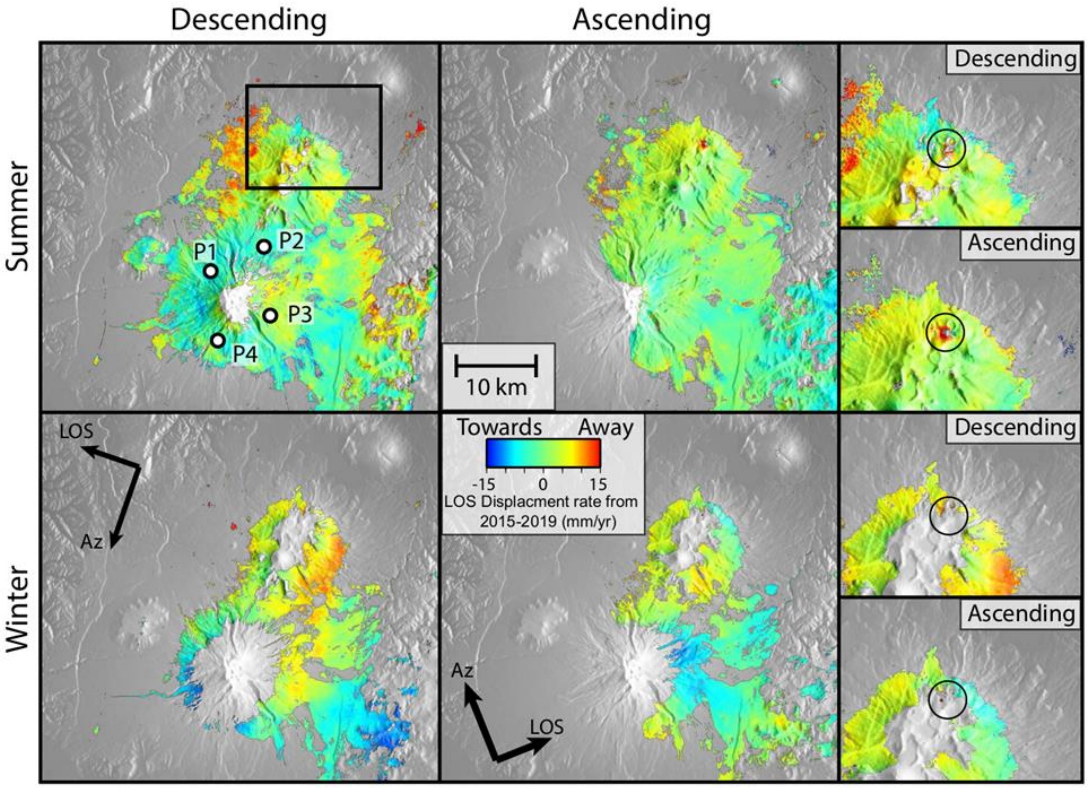

Figure 6. Best fitting displacement rate using summer and winter only interferograms from between 2015 and 2019 from Hamling; 2020. The right-hand column shows a zoom in of the area around the Te Maari eruption site which is highlighted by the black circle. Positive displacements indicate motion away from the satellite.

Central TVZ

Previous studies, using archived Envisat and ALOS-1 data, have shown that deformation through the central volcanic zone is dominated by widespread subsidence extending from north of Lake Taupo through to Rotorua and Okataina (Figure 7, Hamling et al., 2015). Using Sentinel-1A/B and Cosmo-Skymed data, updated deformation maps show that the subsidence has continued at similar rates since 2015 to 2020 (Figure 7). Preliminary models, based on the cooling and contraction of magma at depth, suggest a distributed source at ~10 km depth contracting by ~0.02 km/yr.

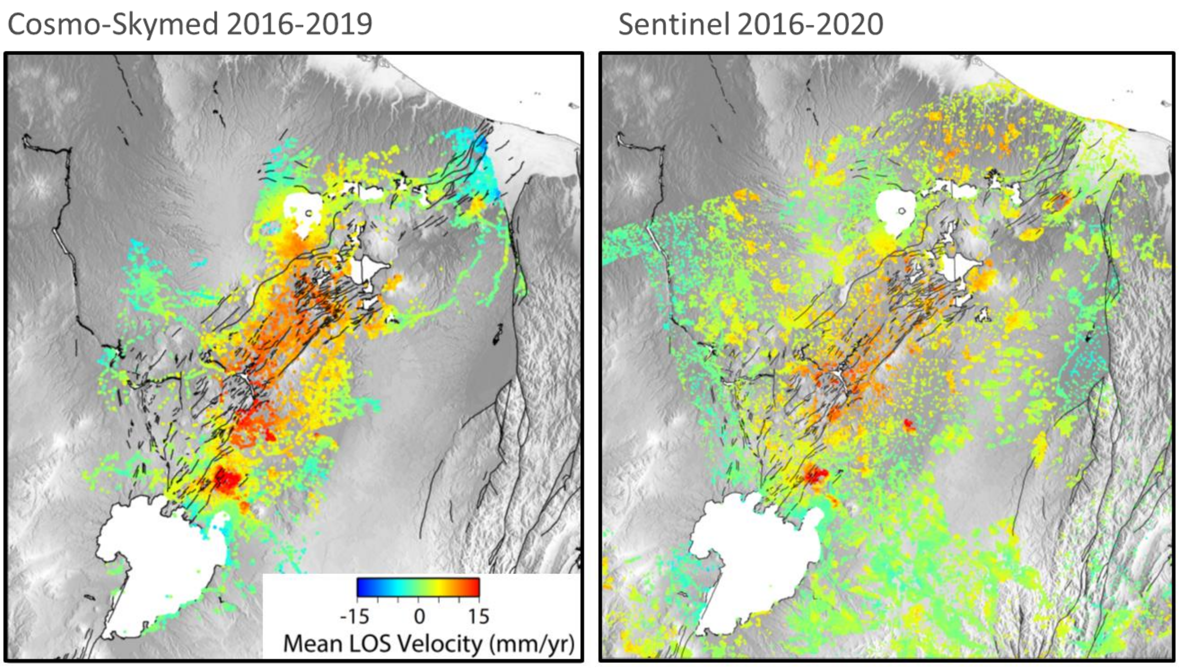

Figure 7. Cosmo-Skymed and Sentinel-1 observations of deformation over the TVZ. Warm colours indicate motion away from the satellite (subsidence). Peak deformation rates reach ~15 mm/yr in the satellites line-of-sight with localised peaks of more than 30 mm/yr focused over geothermal power stations.

Publications

Peer reviewed journal articles
Ian J. Hamling (2020): InSAR observations over the Taupō Volcanic Zone's cone volcanoes: insights and challenges from the New Zealand volcano supersite, New Zealand Journal of Geology and Geophysics, DOI: 10.1080/00288306.2020.1721545
Benson, T.W., Illsley-Kemp, F., Elms, H.C., Hamling, I.J., Savage, M.K. and Wilson, C.J., 2021. N, Mestel ERH and Barker SJ (2021) Earthquake Analysis Suggests Dyke Intrusion in 2019 Near Tarawera Volcano, New Zealand. Front. Earth Sci, 8, p.60699
Harvey, M., 2021. Sentinel-1 InSAR captures 2019 catastrophic White Island eruption. Journal of Volcanology and Geothermal Research, 411, p.107124.
Hamling, I.J. and Kilgour, G., 2021. Comment on the paper titled "Harvey, M., 2021. Sentinel-1 InSAR captures 2019 catastrophic White Island eruption. Journal of Volcanology and Geothermal Research. 411, https://doi. org/10.1016/j. jvolgeores. 2020.107124". Journal of Volcanology and Geothermal Research, p.107234.
Conference presentations/proceedings
Jacobs, Katie (2020). Ambient Noise Velocity Changes at Whakaari, White Island 2012-2020. NZ Geosciences 2020
Kilgour, G et al., (2020). The December 9, 2019 eruption of Whakaari/White Island NZ Geosciences 2020
Kilgour et al., (2020). Whakaari/White Island: a review of New Zealand's most active volcano. NZ Geosciences.
Ellis, S.M.; Illsley-Kemp, F.; Villamor, P.; Savage, M.; Kilgour, G.N.; Barker, S.; Hamling, I.J.; Dempsey, D.; Bannister, S. 2019 Mechanical interactions between rifting, silicic mush, and intrusion of melt bodies in the Taupo Volcanic Zone. NZ Geosciences 2019

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.

Research product issues

Although we do not currently have any formal research products, over the next 12-24 months we aim to routinely produce interferograms from across New Zealand for public use.

5. Dissemination and outreach

To date, InSAR observations and timeseries are a key monitoring dataset discussed in weekly volcanic hazard monitoring meetings. Additionally, the PoC has given a number of talks at New Zealand Universities highlighting the potential use for InSAR for volcano monitoring and the support provided by the New Zealand supersite.

6. Funding

Ongoing processing and analysis of SAR data has been and continues to be funded through GNS science core funding provided from the New Zealand government. Some additional funding has been sourced from external research grants for more detailed studies. Currently the PoC has ~0.3 FTE dedicated to volcano research and work related to the supersite.

7. 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 and 2019 eruptions at White Island was particularly useful for providing near-field data around the crater floor. In the case of White Island, the current analysis of the TerraSAR dataset is our primary dataset for information from the crater floor as there is currently no ground access.

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.

8. Conclusive remarks and suggestions for improvement

The continued support for the New Zealand volcano supersite is of huge value to our volcano monitoring system. Without access to the higher resolution datasets provided through the supersite our current monitoring, especially over Whakaari/White Island, would be compromised. Despite many volcanoes being in a period of relative quiescence, research conducted over the last two years and ongoing studies utilizing the vast datasets are providing new insights into volcanic processes at the volcanic centers around New Zealand.

While there are limited issues surrounding the supersite, any decrease in latency between acquisitions and delivery of the high-resolution datasets would increase the value of the data for rapid monitoring. Delays of days between acquisition and analysis reduce its effectiveness in times of an event response. The automated acquisition of Cosmo-Skymed data over the supersite is hugely beneficial for maintaining data continuity and would be highly useful across the other satellite data providers if a similar system were available.

The supersite initiative has been and continues to be of huge benefit to New Zealand. Although now delayed, the 2022 IAVCEI meeting to be held in Rotorua, in the heart of the supersite, will be a great time to publicise the New Zealand supersite.