Recent Observations of Ground Deformation at TVZ Geothermal Systems Using Multi-Temporal InSAR

Mark Harvey[1], Jim McLeod[2] and Aimee Calibugan[3]

[1]Harvey Geoscience Ltd, 51 Gifford Rd, West Hartford, CT 06119, USA

[2]Waikato Regional Council, Private Bag 3038, Waikato Mail Centre, Hamilton 3240

[3]Mercury NZ Limited, Ngahere House, 283 Vaughan Road, æwhata, Rotorua 3010

mark@harveygeoscience.com

Keywords: *Tokaanu, Ngā Tamariki, Zealand, StaMPS, geothermal, volcanic, subsidence, InSAR, Sentinel*

ABSTRACT

Ground deformation data captured by Interferometric synthetic-aperture radar (InSAR) satellites is of increasing interest for environmental monitoring of geothermal systems worldwide. This study investigates recent deformation patterns associated the NgŨ Tamariki and Tokaanu geothermal systems in the Taupo Volcanic Zone (TVZ), New Zealand. At NgŨ Tamariki, InSAR agrees with 2019-21 levelling survey results, which provides confidence in the method. At Tokaanu, vegetation covers most of the study area, which may degrade InSAR results and overwhelm subtle deformation signals.

1. INTRODUCTION

Waikato Regional Council recently conducted surface change analysis in the TVZ using Sentinel-1 satellite synthetic aperture radar (SAR) data (Harvey et al., 2019). The analyses used the Stanford Method for Persistent Scatterers (StaMPS), and results showed subsidence in the same locations as previously identified by levelling and photogrammetry surveys. This provided confirmation of the StaMPS method in the TVZ. This study undertakes StaMPS analysis on the NgŨ Tamariki and Tokaanu geothermal systems (Figure 1). Ground deformation is analysed in approximately 5 x 12-month intervals, from May 2015 ï June 2021 (Table 1), using data from both ascending and descending satellite passes.

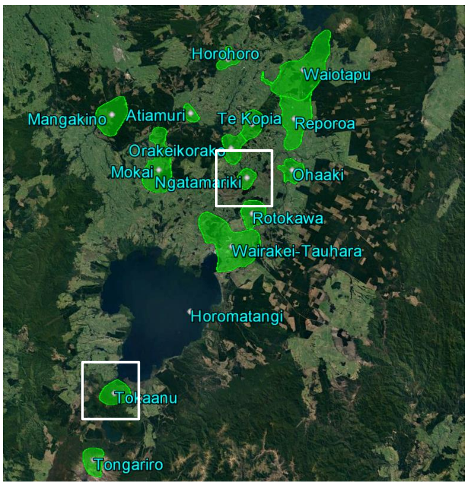

Figure 1: Ngā Tamariki and Tokaanu study areas in the Taupo Volcanic Zone. Note: green areas show geothermal system boundaries (Waikato Regional Council GIS)

2. METHODS

2.1 StaMPS Background

This study uses the Stanford Method for Persistent Scatterers (StaMPS), which is similar to persistent scatterer interferometry (PSI), but with superior results in vegetated areas (Osmanoĵlu et al., 2016). StaMPS is a satellite-based remote sensing method that allows the measurement of ground deformation associated with extraction and reinjection of geothermal fluids. StaMPS uses reflected satellite radar signals to accurately measure ground displacement. The method relies upon a ñstackò of satellite images collected over time, to identify persistent scatterers (PS). PS are surface objects that reflect radar, including roof tops, bridges, dams, antennae, large rock outcrops, and other prominent built/natural features. Using this method, the motion of each PS can be very precisely measured, and ground deformation can be determined.

2.2. Processing Workflow

In StaMPS, interferograms are formed between a single master image and a number of available ćslavesô acquired on different dates. The first step was to download available Sentinel-1 images from ascending and descending orbits for the study area and covering the five monitoring periods (processing stacks) of interest (Table 1). After download, the study areas were extracted from the satellite data using the Sentinel Application Platform (SNAP) software. This reduced the size of data and decreased processing time.

The second step was to compute individual interferograms using SNAP, combining the single master images with slave images. The resulting ćstacksô were input to StaMPS for PS analysis. StaMPS then outputs mean line-of-sight (LOS) velocity for all PS in the area of analysis for the time interval of observation. Removal of the tropospheric phase contribution (atmospheric noise) was undertaken using the linear model included in the Toolbox for Reducing Atmospheric InSAR Noise (TRAIN) (Bekaert et al, 2015).

Each mean annual PS velocity estimate is derived from a time series of elevations recorded over the period of observation. Standard Error (SE)(± mm/year) provides a measure of uncertainty for each estimate. The estimate is based on a linear regression through the series; PS displacement change through time may not be smooth (e.g. signal noise from vegetation, often superimposed on a gradual deformation signal). Controlled experiments show InSAR derived velocities are often within 1 mm/year of conventional GNSS (Cigna et al., 2021). Satellite data from ascending and descending orbits (orbit passes 81 and 73 respectively) were then combined to provide an estimate of vertical deformation. Further details of the method used to derive vertical motion are provided in Manzo et al. (2006).

At Tokaanu, all reported motions are relative to an area (100 m radius) located in Turangi township. At NgŨTamariki, all reported motions are relative to an area (100 m radius) centred on the Aratiatia Dam.

Table 1: InSAR processing stacks

Orbit Pass	Stack Size	First Image	Last Image	Master Image
73	17	14/05/2015	1/06/2016	22/11/2015
73	19	1/06/2016	3/05/2017	10/12/2016
73	29	15/06/2018	23/04/2019	30/11/2018
73	30	5/05/2019	29/04/2020	13/11/2019
73	23	11/05/2020	30/05/2021	18/01/2021
81	14	27/05/2015	27/04/2016	5/12/2015
81	15	21/05/2016	28/04/2017	15/02/2017
81	28	10/06/2018	24/05/2019	19/12/2018
81	29	12/05/2019	24/04/2020	27/10/2019
81	29	18/05/2020	25/05/2021	26/11/2020

3. TOKAANU

Five-year average results show an area of weak subsidence (<10 mm/year) centred near thermal ground at Hipaua (white arrow Figure 2). However, uncertainty expressed as standard error (SE) is high across the study area, often approaching or exceeding the deformation rate (Figure 3).

The primary component of uncertainty is the signal noise seen in PS time series. For example, PS located near the Te Mahau Marae at Waihi Village (blue arrow Figure 2) show large time series noise (5 - 10 mm/yr) (Figure 4 & Figure 5). The SE for these series (and other series in the study area) may result from actual surface motions and/or interference from surface vegetation and atmospheric affects. The contribution of vegetation to signal noise is supported by the SE map, which shows SE is generally lower at the Turangi township (white star) than in surrounding vegetated areas (Figure 3). Sources of noise may overwhelm any gradual deformation signal. The GEONET GNSS continuous monitoring station located near Turangi (TGRI) is also affected by equipment and/or environmental signal noise (2 ï 6 mm/year) (Figure 4 & Figure 5).

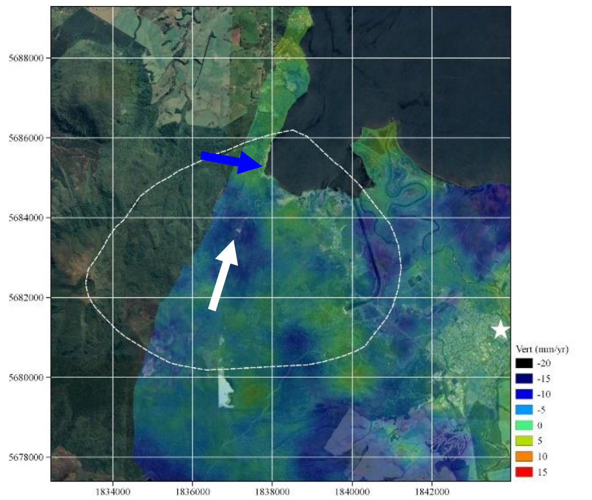

Figure 2: Mean vertical deformation rate at Tokaanu for the five monitoring periods (2015-21). White arrow shows location of thermal ground near Hipaua. Blue arrow shows location of the Te Mahau Marae at Waihi Village. All motion is relative to location at the Turangi township (white star).

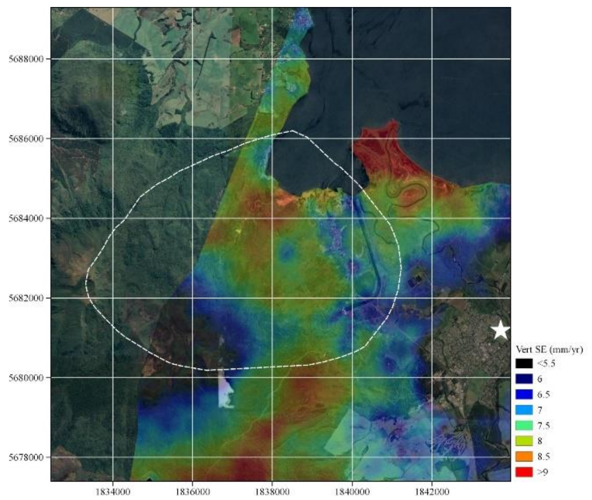

Figure 3: Mean vertical deformation SE at Tokaanu for the five monitoring periods. Note: SE incorporates error from both time series noise and kriging interpolation.

ISSN2703-4275

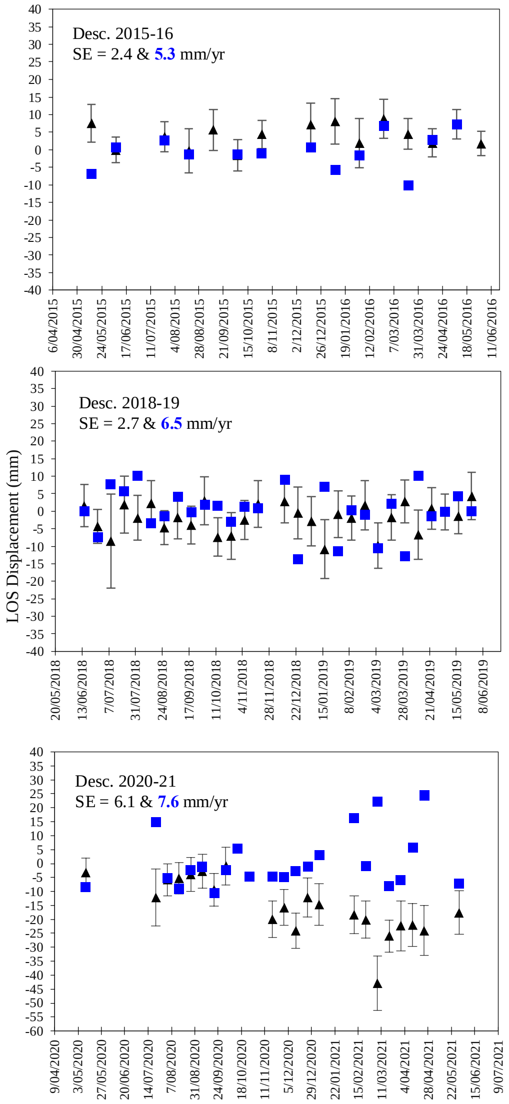

Figure 4: Time series for descending orbit PS located near the Te Mahau Marae at Waihi Village (blue squares) and the TGRI GeoNET continuous monitoring station near Turangi (black triangles)

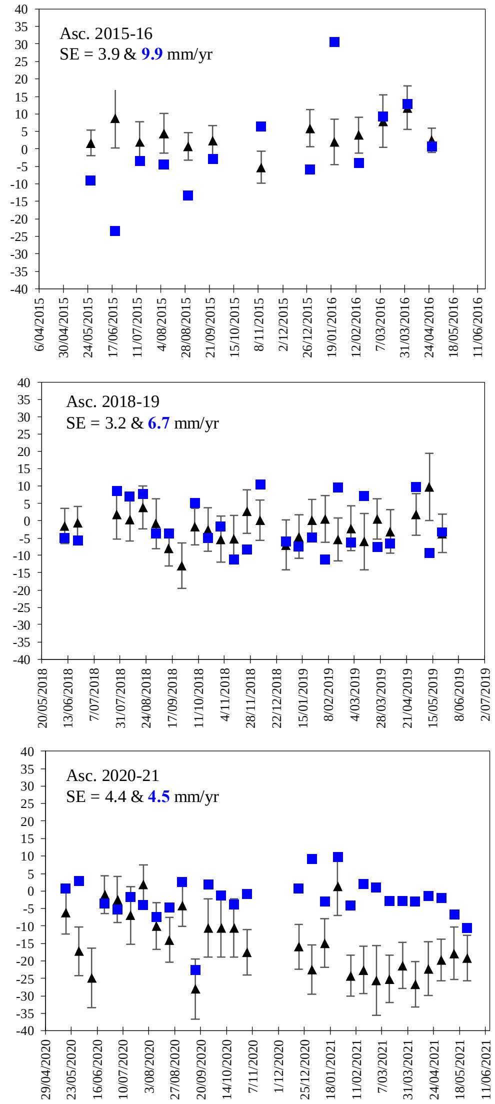

Figure 5: Time series for ascending orbit PS located near the Te Mahau Marae at Waihi Village (blue squares) and the TGRI GeoNET continuous monitoring station near Turangi (black triangles). Y-axis units are mm.

4. NGĀ TAMARIKI

InSAR results generally show minor subsidence at NgŪ Tamariki geothermal field. The power plant and surrounding well pads subside weakly (<5 mm/year) relative to the Aratiatia Dam. This area of low subsidence extends to the south, across the system boundary. Areas to the north through southwest of the power plant are subsiding at slightly greater rate (5 ï 10 mm/year) (Figure 6). These rates are consistent with a recent levelling survey (also relative to the Aratiatia Dam); weak subsidence (-5 mm/year) near the plant (black contours in Figure 6), with slightly greater (-5 to -9 mm/year) rates in the north (white arrow Figure 6).

Production and reinjection at NgŪTamariki are very deep, and there is nearly 100% reinjection from the binary power plant. These factors may explain the lack of a strong subsidence signal at NgŪ Tamariki. Low signal-to-noise ratios are evidenced by the generally weak vertical motion signals (<10 mm/year)(Figure 6), often approached or exceeded by the uncertainty of the signals (SE > 5 mm/year) throughout the mostly vegetated study area (Figure 7). As at Tokaanu, the large SEĝs may result from high frequency surface motions and/or interference from surface vegetation and atmospheric affects. The contribution of vegetation to signal noise is supported by the SE map, which shows SE is generally lower (< 5 mm/year) at the power plant and well pads than in surrounding vegetated areas (Figure 7 & Figure 8). The GEONET GNSS continuous monitoring station located at the nearby Aratiatia Dam (ARTA) is also affected by equipment and/or environmental signal noise (<5 mm/year)(Figure 9).

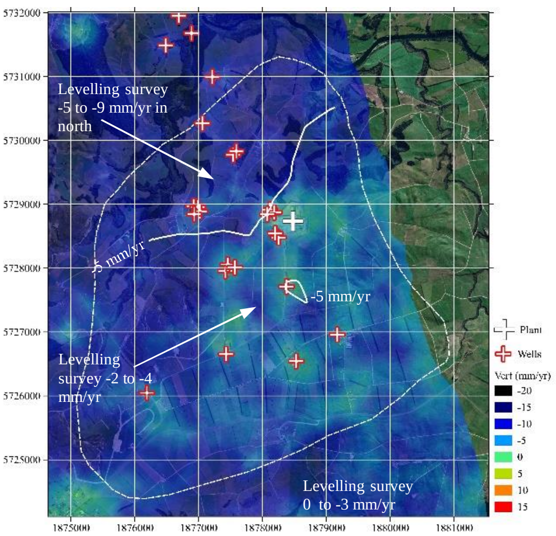

Figure 6: Mean vertical deformation rate at Ngā Tamariki for the five monitoring periods (2015-21). White lines are contours (-5mm/yr) from the recent levelling survey (2019-2021). All motion is relative to the Aratiatia Dam. White dash line is the geothermal system resource boundary.

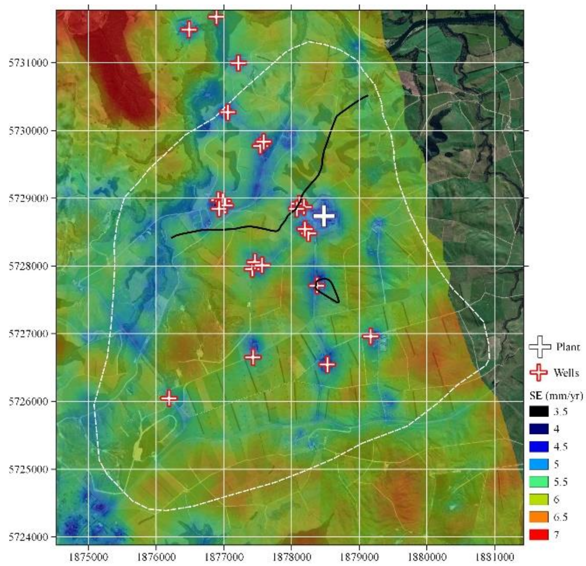

Figure 7: Mean vertical deformation SE at Ngā Tamariki for the five monitoring periods. Note: SE incorporates error from both time series noise and kriging interpolation. White dash line is the geothermal system resource boundary. Black lines are contours (-5mm/yr) from the recent levelling survey (2019-2021)

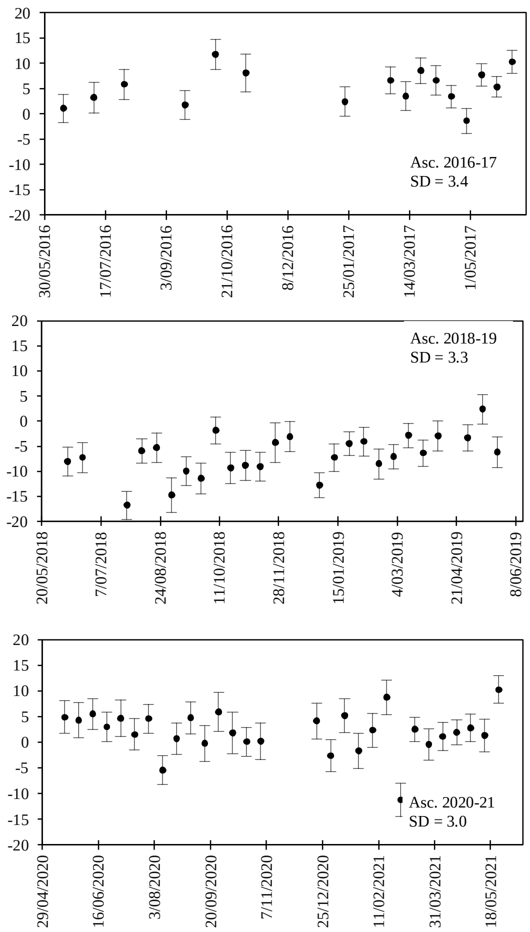

Figure 8: Time series for PS located at the Ngā Tamariki power station. Y-axis units are mm. Note: Levelling survey measurements (2019-2021) at the power station generally range from -4.5 mm/yr to -3.3 mm/yr (± 2-3 mm/yr).

Proceedings 44th New Zealand Geothermal Workshop
23 - 25 November, 2022
Auckland, New Zealand
ISSN2703-4275

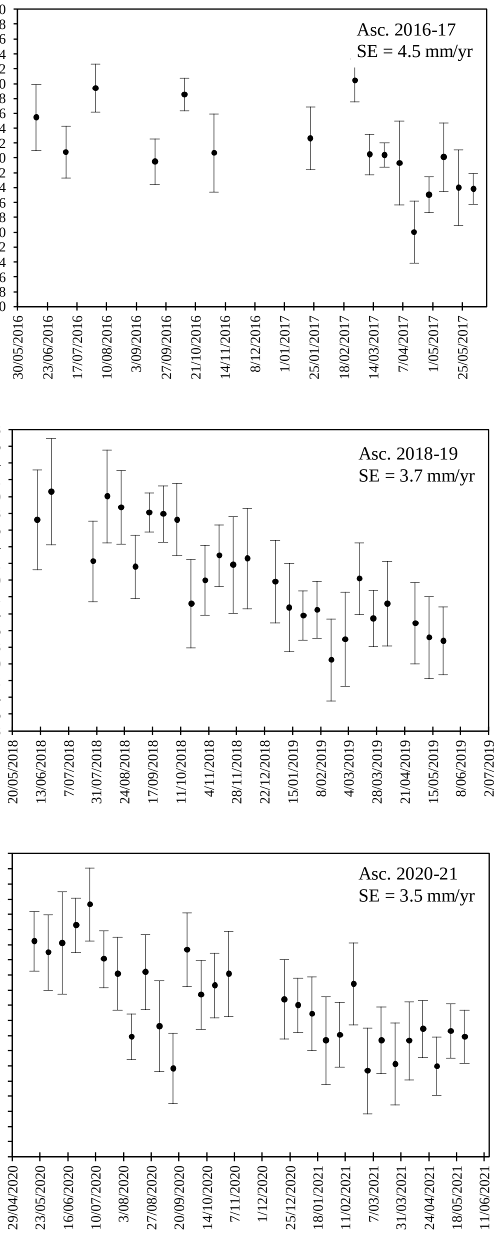

Figure 9: Time series for the Geonet continuous GNSS monitoring station at the Aratiatia Dam (data from same days as Sentinel-1 satellite passes). Y-axis units are mm of vertical displacement.

5. CONCLUSIONS

This study investigates recent deformation patterns associated the NgŪ Tamariki and Tokaanu geothermal systems in the Taupo Volcanic Zone (TVZ), New Zealand. At NgŪ Tamariki, weak subsidence shown by InSAR agrees with recent ground-based levelling survey results, which provides confidence in the method. Neither NgŪ Tamariki nor Tokaanu show a strong subsidence zone associated with the geothermal system boundary. The comparative lack of subsidence at NgŪTamariki may result from the much greater depth of geothermal production and reinjection, plus the practice of 100% reinjection of fluids from the binary power plant. At Tokaanu, it is possible that subtle deformation is occurring, but the signal is overwhelmed by interference from vegetation that covers most of the study area.

REFERENCES

Bekaert, D.P.S., Walters, R.J., Wright, T.J., Hooper, A.J., Parker, D.J., (2015). Statistical comparison of InSAR tropospheric correction techniques. Remote Sensing of the Environment, 170, 40ï 47.

Cigna, F., Esquivel Ramírez, R., & Tapete, D. (2021). Accuracy of Sentinel-1 PSI and SBAS InSAR Displacement Velocities against GNSS and Geodetic Leveling Monitoring Data. Remote Sensing, *13*(23), 4800.

Harvey, M.C., Luketina, K.M., McLeod, J., and J.V. Rowland (2019). Geothermal Subsidence and Inflation in Taupo: A Comparison of Detection Methods. Proceedings 40th New Zealand Geothermal Workshop.

Manzo, M., Ricciardi, G. P., Casu, F., Ventura, G., Zeni, G., Borgström, S., and Lanari, R., (2006). Surface deformation analysis in the Ischia Island (Italy) based on spaceborne radar interferometry. Journal of Volcanology and Geothermal Research, 151(4), 399-416.

Osmanoĵ lu, B., Sunar, F., Wdowinski, S., & Cabral-Cano, E. (2016). Time series analysis of InSAR data: Methods and trends. ISPRS Journal of Photogrammetry and Remote Sensing, 115, 90-102.