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GeoHazSA: Southern Andes Supersite

Coupled geohazards at Southern Andes: Copahue-Lanín arc volcanoes and adjacent crustal faults

History	*https://geo-gsnl.org/supersites/permanent-supersites/southern-andes-supersite/*
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1. Abstract

The Southern Andes (33°-46°S) is a young and active mountain belt where volcanism and tectonic processes pose a significant threat to the communities nearby. In fact, only recent eruptions caused evacuations of 250-3500 people and critical infrastructure is present there. The segment here considered corresponds to a low altitude orogen (<2000 masl on average) but characterized by a high uplift rate as a result of competing tectonic and climate forces. This Supersite focuses on a ca. 200 km long segment of the Southern Andes where 9 active stratovolcanoes (Copahue, Callaqui, Tolhuaca, Lonquimay, Llaima, Sollipulli, Villarrica, Quetrupillan and Lanín) and 2 distributed volcanic fields (Caburgua and Huelemolles) are located, just along a tectonic corridor defined by the northern segment of the Liquiñe-Ofqui Fault System (LOFS). Activity of the LOFS has been detected prior to some eruptions and coeval with some others. There are several tectonic and volcanic models to be investigated that derive from a strong two-way coupling between tectonics and volcanism, recently detected by either geophysical techniques or numerical modeling. Hazards in the segment derive mostly from the activity of some of the most active volcanoes in South America (e.g., Villarrica, Llaima), others with long-lasting but weak current activity (e.g., Copahue) or some volcanoes with low eruptive frequency but high magnitude eruptions in the geological record (e.g., Lonquimay). Since the beginning of the 20th century ~80 eruptions have been recorded in this area. Remote sensing techniques coupled with ground-based seismic methods allowed tracking of the effusive stage of the 2011-2012 Cordón Caulle eruption and geodesy became a current tool of volcano monitoring in SERNAGEOMIN, with remote sensing as the most promising method in terms of data coverage and time series. Volcanoes included in this Supersite are especially active and there is evidence of both magmatic and non-magmatic ground deformation, registered mainly from InSAR data at Copahue and more recently Lonquimay, Llaima and Villarrica volcanoes. The growing network of continuous GNSS stations deployed in this segment is a perfect complement and is already revealing interesting patterns of crustal deformation likely related to current activity the LOFS and its possible interaction with volcanoes. A preliminary spatio-temporal analysis suggests postseismic relaxation after the Maule earthquake and as a driver for instability of the volcanic systems.

2. Scientists/science teams

Researcher/team 1	***Name, affiliation, address, e-mail, website/personal page of team leader***
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Scientists/science teams issues

This Supersite is not hosted by a single institution but in a number of institutes/universities and thus the capability is distributed and somewhat disperse. Scientists of the Supersite are also in charge of multiple programs and projects, which priorities are sometimes in conflict. This is not surprising being in fact the reality of developing countries with small science communities and institutions without permanent funding for emerging programs. Taking into account this situation, we have focused on a reduced number of case-studies, explored our best networking capacities and hired PhD students under our advice.

1. In situ data

<In the table below please list all in situ data types available for the Supersite>

Type of data	Data provider	How to access	Type of access
Seismic data (waveforms and time series)	*SERNAGEOMIN*	*Formal request**	*Limited to GSNL scientists upon request or registered public*
GPS time series	*SERNAGEOMIN*	*Formal request**	*Limited to GSNL scientists upon request or registered public*
Gas (DOAS, multigas)	*SERNAGEOMIN*	*Formal request**	*Limited to GSNL scientists upon request or registered public*

** For a formal request fill the form in* https://www.portaltransparencia.cl/PortalPdT/ingreso-sai-v2?idOrg=1065

In situ data issues

Access to in-situ instrumental data in Chile is not straightforward, although the law recognizes the obligation of public agencies in providing information obtained with public funding. However, public agencies are moving to a more open style and they have protocols for data request, that are explained in the web pages of each public institution, which are mostly satisfied in time. There are challenges and technical issues in data storage and sharing because (for example seismic data from the monitoring network) is not designed for pattern recognition and retrospective analysis but mostly real-time short-term forecasting. There are also cultural issues in terms of collaborative work, with distrust about sharing data and a sort of capture of institutions and programs by the public officers. The modest budget for science also poses a dilemma between basic an applied science being public agencies under pressure to respond to only to short-term needs. However, this view is changing and especially young scientists and technicians are now more able to share data being involved in join efforts aimed to better

understand processes beyond the short-term response, which remains as priority. As a result of this more open style, SERNAGEOMIN has a form for data request and some IT issues are being solved to share data more efficiently.

2. Satellite data

Type of data	Data provider	How to access	Type of access
TerraSAR X	*DLR*	*Supersite data repository*	*Registered public, limited to GSNL scientists*
COSMO-Skymed	*ASI*	*Supersite data repository*	*Registered public, limited to GSNL scientists*
RADARSAT		*Supersite data repository*	*Registered public, limited to GSNL scientists*
Pleiades		*Supersite data repository*	*Registered public, limited to GSNL scientists*

Satellite data issues

No relevant data issues observed. Some volcanoes in the Supersite area are not well covered by radar acquisitions (spatially and/or temporally). In the first stage of this initiative we were building capability to request data, which took some time and requires in the long-term more experts involved. That is one of the main goals in this project: take advantage of the data to build (national or binational) capability to better use the data in both short-term monitoring and scientific understanding of the basic processes.

3. Research results

Research results are still in progress, and we had worked with some few volcanoes included in the Supersite area. We have selected Copahue Volcano as a case-study and a number of others are under inspection. We set a PhD thesis (Fernanda López, Universidad de Concepción, advised by Luis E. Lara) focused on both the atmospheric effect and the problem of big data management. The first topic is important in Southern Andes where volcanoes are usually the highest peaks and covered by snow and/or having remnants of glaciers on their slopes, right in contrast with the surrounding areas and subject to a significant insolation gradient. We requested a dataset of 88 CSK scenes, acquired in ascending and descending pass over Copahue Volcano during the 2015-2019 time span. They are available through the http://geohazards-tep.eu web site to the researchers in the Supersites team. Processing of this dataset is beginning in order to compute mean velocity of deformation and time series.

The CSK data provided by the Supersite includes several images acquired with a repeat interval of one 1 day, which allows to test whether coherence is maintained on the glaciers on top of the

Villarrica Volcano. This region is of particular interest because conduit processes in open-vent volcanoes could produce deformation signals that can only be potentially detected very close to the crater. Our preliminary analysis shows that the coherence is sustained on the glaciers only in a single 1 day interferogram from July 2011, with signals resulting from both DEM errors and ice flow. Therefore we conclude that it is currently not possible to detect signals produced by transient processes in either very shallow reservoirs or conduit processes in areas covered by ice at Villarrica Volcano with the CSK data, in agreement with our previous studies (e.g., Delgado et al., 2017, JVGR).

Villarrica Volcano hosts one of the few lava lakes on Earth and is one of the most active volcanoes in South America. The lava lake is located behind an overhang cliff and deep into the crater, and therefore direct observations of the lake are usually not possible. Thereby we have attempted to measure the lava lake depth using radar shadows with the SAR amplitude images. Despite the high spatial resolution of the CSK HIMAGE data (2 m/pixel) and a look angle of 28º, we were unable to identify changes in the amplitude images in the crater produced by changes in the lava lake level. Moreover, a similar analysis carried out with TSX spotlight data (1 m/pixel) was also unable to identify changes inside the crater that hosts the lava lake. Nevertheless, the data record clear morphological changes in the crater area before and after the 2015 Strombolian eruption, which is a promising result.

CSK time series analysis with the ISCE and GIAnT software at Villarrica Volcano are currently underway and has been delayed because of the huge amount of CSK data provided by the Supersite.

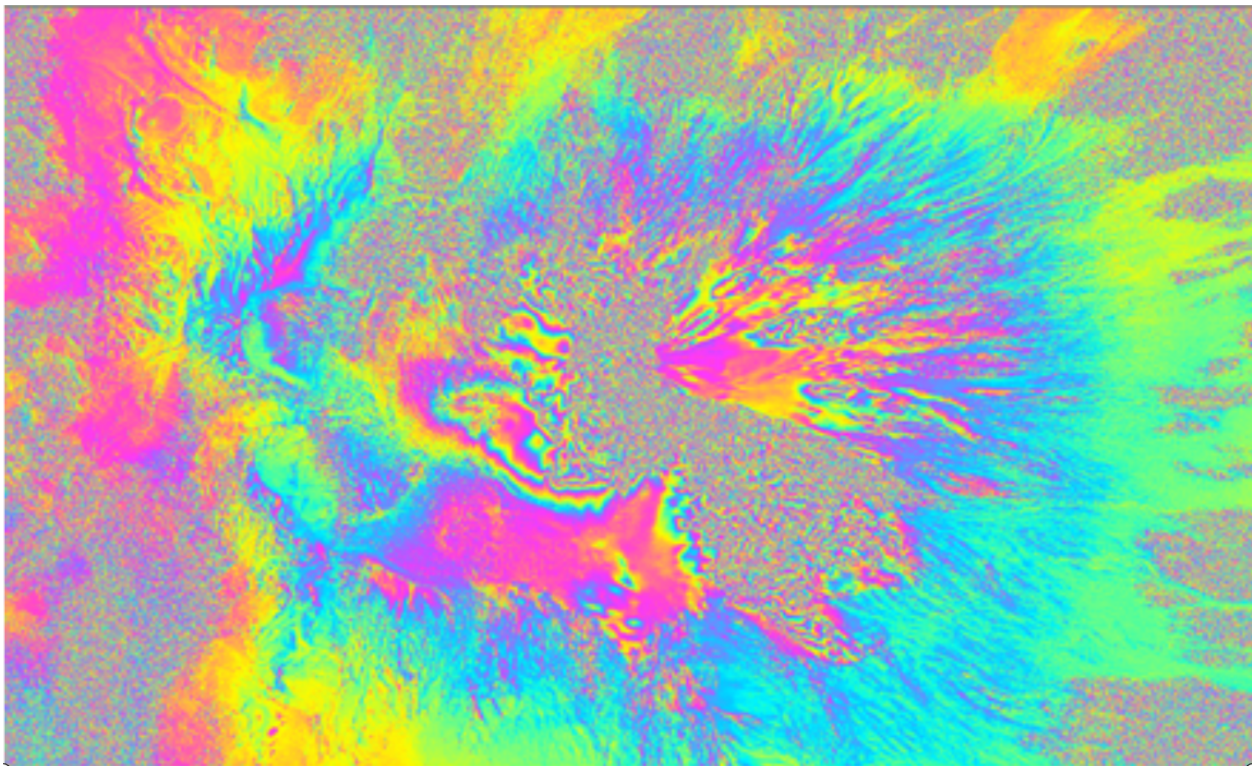

Fig. 1. One day interferogram (July 2011) showing loss of coherence in the glacier area of Villarrica Volcano.

On the other hand, interferograms for 5-6 years have been produced for Llaima Volcano whereas an additional focused survey was performed for Villarrica Volcano in the 2011-2013 segment.

Finally, computing capability for processing radar images has been built at the Southern Andes Observatory. We expect to continue working with satellite imagery, and be able to process more "fresh" images according also with the level of activity showed by the volcanoes at the Supersite.

Publications

No publications yet available

Research products

No research products yet available.
For the first time we requested images for Sollipulli Volcano, which has any data imagery and is virtually unknown for geodesy. Sollipulli Volcano erupted violently ca. 2.5 ky ago in a VEI 5-6 explosive eruption.
A special request from this Supersite to the ESA allowed acquisition Sentinel 1 images in ascending and descending orbits every 6 days between Copahue and Sollipulli, and every 12 days for Villarrica-Quetrupillán-Lanín transversal chain. This is an unprecedented cover for these volcanoes and will allow integration with GNSS data.
Areas of interest have been selected for request of Pleiades images, which will serve for production of high resolution (up to 0.5 m) DEMs. The latter will be used for geodesy and also as input for physical models of debris flows (LaharZ, LahaFlow) and others.
Preliminary analysis of potential precursory deformation related to conduit processes at Villarrica Volcano was not successful but served as experience and allowed to detect morphological changes.

Research product issues

Research products are still in progress. We plan to publish scientific results in regular journals but also contribute to shape a new national capability that could be integrated to the operational volcano monitoring at SERNAGEOMIN.

4. Dissemination and outreach

Existence of the Supersite has been informed in scientific and professional meetings, as well as internal technical meetings at SERNAGEOMIN. Deputy Coordinator Loreto Cordova has the Supersite project as one of her scheduled dues for 2020 and thus we expect to enhance its

development. Once results are available we plan to exploit them in outreach activities. We are planning to get complementary funding to better disseminate the results and to build capability. The latter is mostly focused on PhD students (e.g., Fernanda López) that can do high-quality research using these images together with in-situ data.

5. Funding

All the activities have been funded from SERNAGEOMIN, or grants and scholarships granted to members of the scientific team. Supersite Coordinator is partially funded by FONDAP 15110017 Center for Integrated Risk Management (CIGIDEN); PhD student Fernanda López has a Conicyt scholarship; CoI Tassara is part of The CYCLO Millenium Nucleous.

6. Stakeholders interaction and societal benefits

This is the first stage of the Supersite and no stakeholders interaction and societal benefits have been transferred yet, since no deformation has been registered at the volcanoes included in the Supersite. Since deformation is one of the most important parameters for monitoring volcanic activity, InSAR results really improve the geodetic monitoring, mainly on those volcanoes where we don`t have ground networks. ONEMI (Emergency Office) is one of the agencies interested in the results of this Supersite, and is also the contact for the Sendai Protocol. DGAC (Aerial Traffic Control Office) is also potentially interested. They will be approached when the Supersite enters its production stage and results become available.

7. Conclusive remarks and suggestions for improvement

We have had an extremely complex setting of the first stage because of institutional reasons and volcano crisis at Nevados de Chillán volcanic complex. As the Supersite represents a small and dispersed scientific community, coordination is not an easy task. However, the Supersite partially solved this and data request begun in a regular manner. First attempts to interpret data are still in progress but promising results are envisioned.
Some remarkable advances are:

- *First images for Sollipulli Volcano, which is virtually unknown.*
- *Special Sentinel 1 acquisition for Copahue-Sollipulli (every 6 days) and Villarrica-Lanín (every 12 days)*
- *Areas of interest selection for Pleiades images for geodesy and as input for modeling of volcanic products.*

- *PhD student (Fernanda López) in her second year, working on atmospheric correction and exploitation of time series. First outcome is a critical review of published model for Cordon Caulle, where opposite deformation patterns have been proposed. She has an already coordinated stage with Andrew Hopper at the University of Leeds for working on the atmospheric corrections.*

- *Supersite helped to take decisions in order to implement InSAR analysis as a monitoring tool at OVDAS (the Volcano Observatory of SERNAGEOMIN). Basic capacity for processing this kind of data was installed and InSAR products are now better understood by most of the team working in volcano monitoring.*

As a personal view as project coordinator, I think this initiative is more than merely another research project. Issues are those expected for a small scientific community with scarce institutional support, affiliated to institutions that accomplish their mission with small budget and many dues. In this context, this initiative would be a trigger for a transition from small-scale (and hence dependent of the manual inspection of data) observation of geological processes to large-scale automatized processes, where big amount of data will be normal. The latter could change the style of volcano monitoring in Chile. The Supersite is also adding some tension in terms of data access and that motivated revision of procedures, which we hope would result at the end in an easier access to in-situ data and more collaborative research. Our weakness in terms of a small team dispersed in several institutions could become a strength in terms of open and volunteer scientific collaboration, and serve as a model for other initiatives. For instance, this network is already able to get funding for training new young scientists and capacity building.