

Discriminating glacial and volcanic seismicity at Llaima and Villarrica volcanoes, Chile

Oliver Lamb ✉ olamb@email.unc.edu 🐦 @olamb245

Jonathan Lees, Luis Franco Marin, Jonathan Lazo, Andres Rivera, Michael Shore, Stephen Lee



Llaima, February 2019

Villarrica, January 2020

1: Highest risk volcanoes in Chile

- Villarrica and Llaima are two of the most active volcanoes in Chile
- High priority targets for OVDAS, the national volcano observatory
- >14 km² of glacial ice present on each volcano
- Icequakes have not been studied in detail at either volcano

Problem:

- Icequakes may be mistaken for low-frequency volcanic earthquakes, and vice-versa

- Risk of false alarms or missed warnings from misidentification

Project goals:

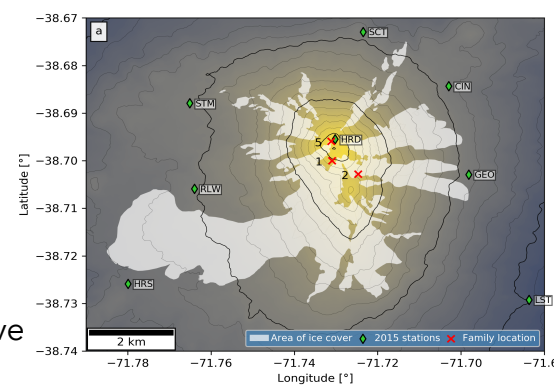
- Estimate the quantity and location of icequakes at Llaima and Villarrica
- Characterize the source mechanism(s)
- Develop criteria for efficiently identifying icequakes

2: Previous results - Llaima (2015)

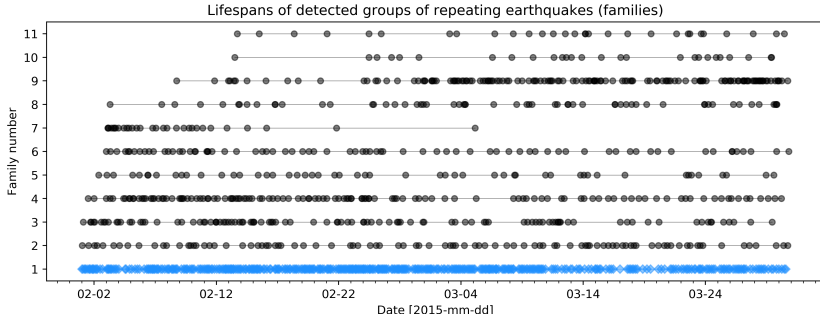
- Previous work in 2015 found hundreds of potential icequakes at Llaima

- Locations and other characteristics suggested cryogenic sources

- However, evidence was not conclusive and further work was required



Source locations for 3 families in 2015



Duration and times for repeating events in 2015

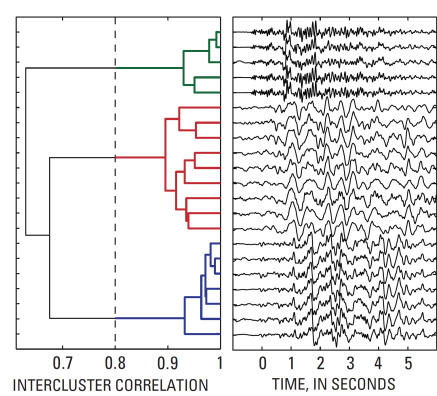
To read more on our analysis of the 2015 data, find the open-access article at Volcanica at the URL below:

www.jvolcanica.org/ojs/index.php/volcanica/article/view/56

3: Methods

To detect potential icequakes:

- Apply multi-station STA/LTA detection algorithm
- Match events by similarity using cross-correlation
- Organise into families using hierarchical clustering



Example of hierarchical clustering (adapted from Buurman and West, 2010)

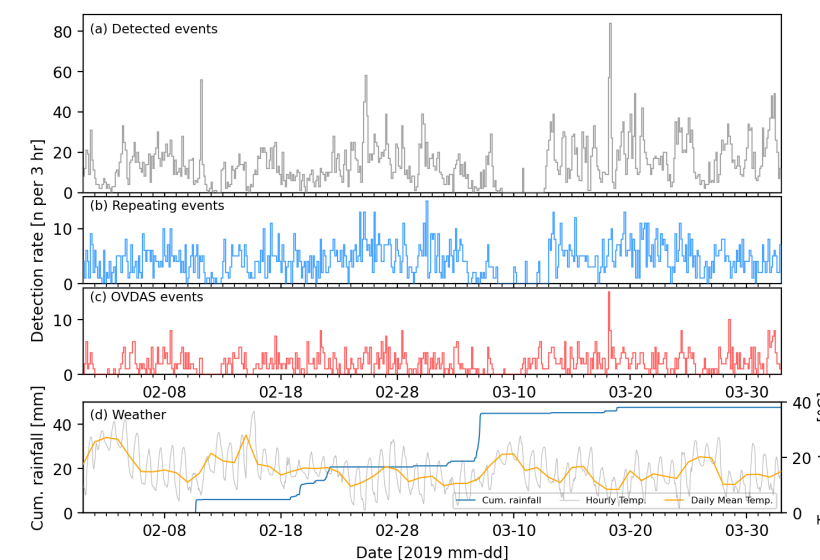
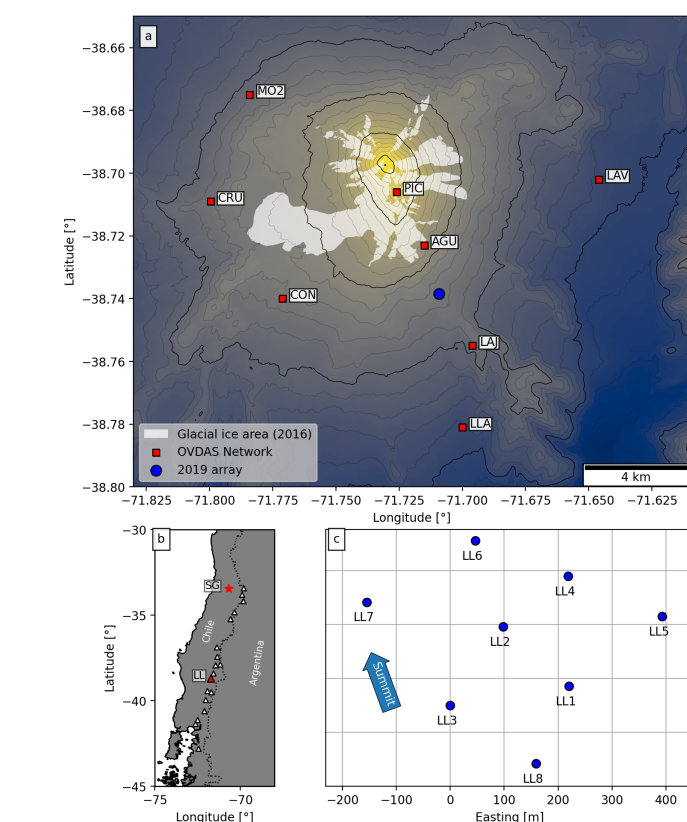
4: Llaima micro-seismic activity - 2019

- Focus on using data from permanent OVDAS network, supplemented by temporary array of seismometers and microphones

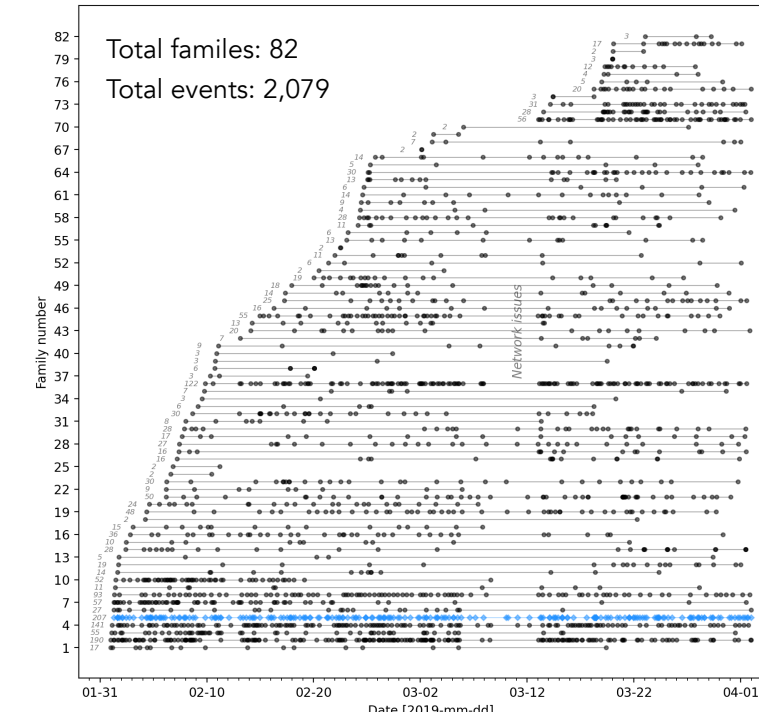
- Compared to 2015, we use wider criteria to define repeating events, and a different location method (see section 5)

- Preliminary results add more evidence to prevalence of icequakes at Llaima volcano

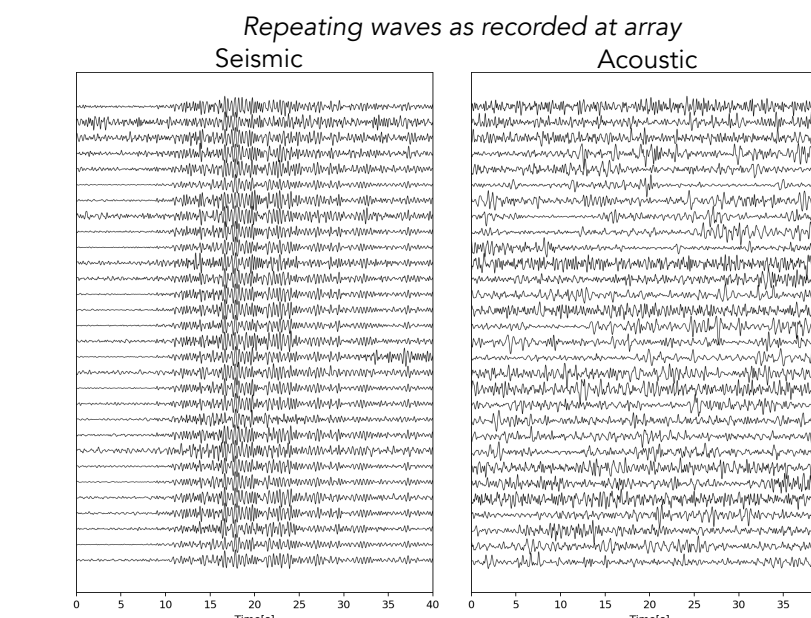
Below: map of stations at Llaima in 2019



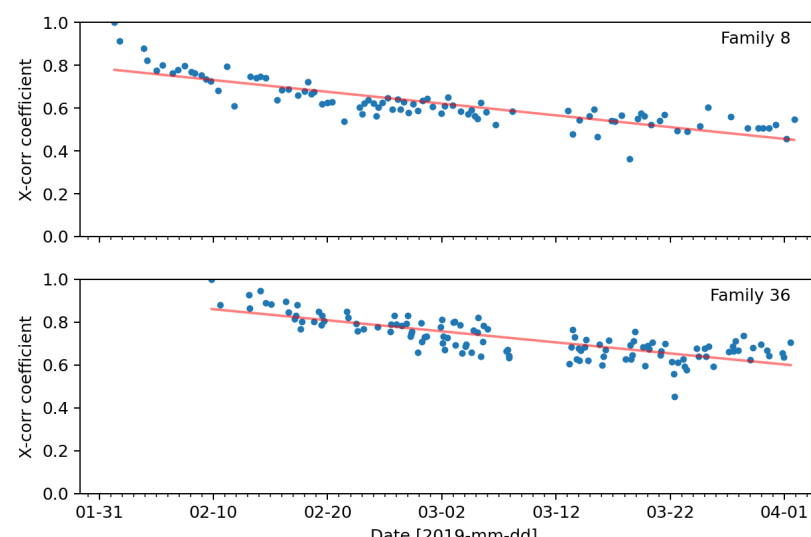
Below: Duration and times for repeating events in 2019



Total families: 82
Total events: 2,079



Above: Examples of repeating seismic events and acoustic data recorded at same station, showing no co-seismic acoustic activity. Below: Cross-correlation of all events in family, relative to 1st event, shows gradual decrease, possibly indicating source motion.



5: Llaima micro-seismic locations - 2019

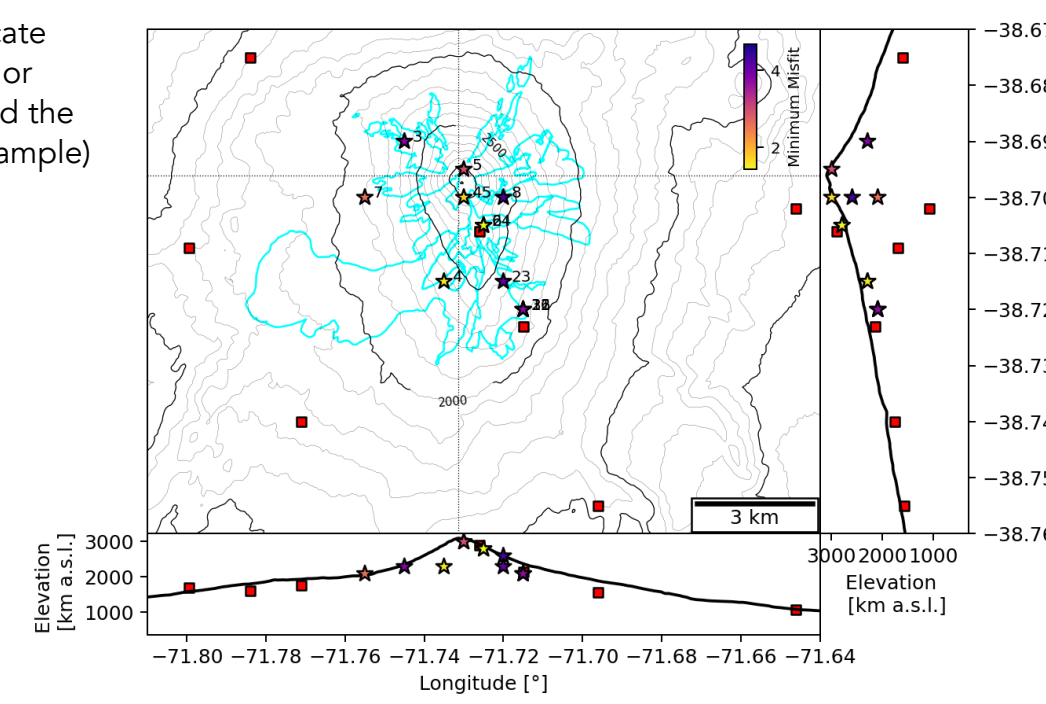
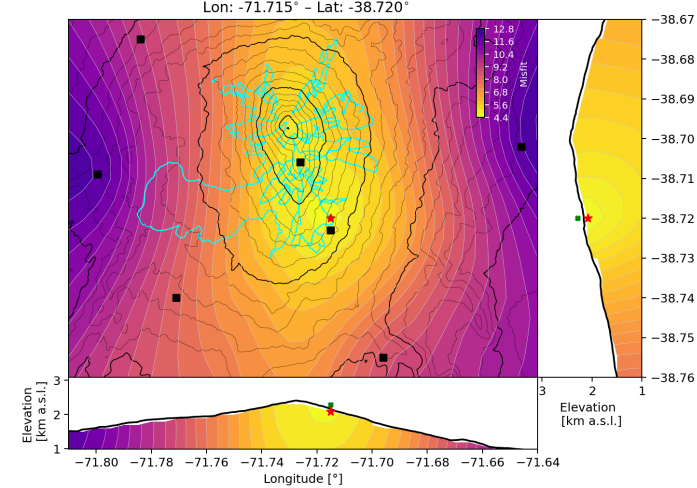
- Vast majority of events are too small to be located with conventional arrival-time approaches

- We obtain centroid location estimates by cross-correlating waveform envelopes between all station pairs and performing a 3D grid search over potential source location S-wave lag times (Wech and Creager 2008)

- The final location is that which optimizes the inter-station envelope cross-correlations

- To reduce the misfit around locations, we use this approach on median waveforms (i.e. stacks) of families with ≥30 events

Results from the largest families (see right) indicate shallow locations near the summit, often below or near a glacier. However, the uncertainties around the family locations are large (see below for one example)



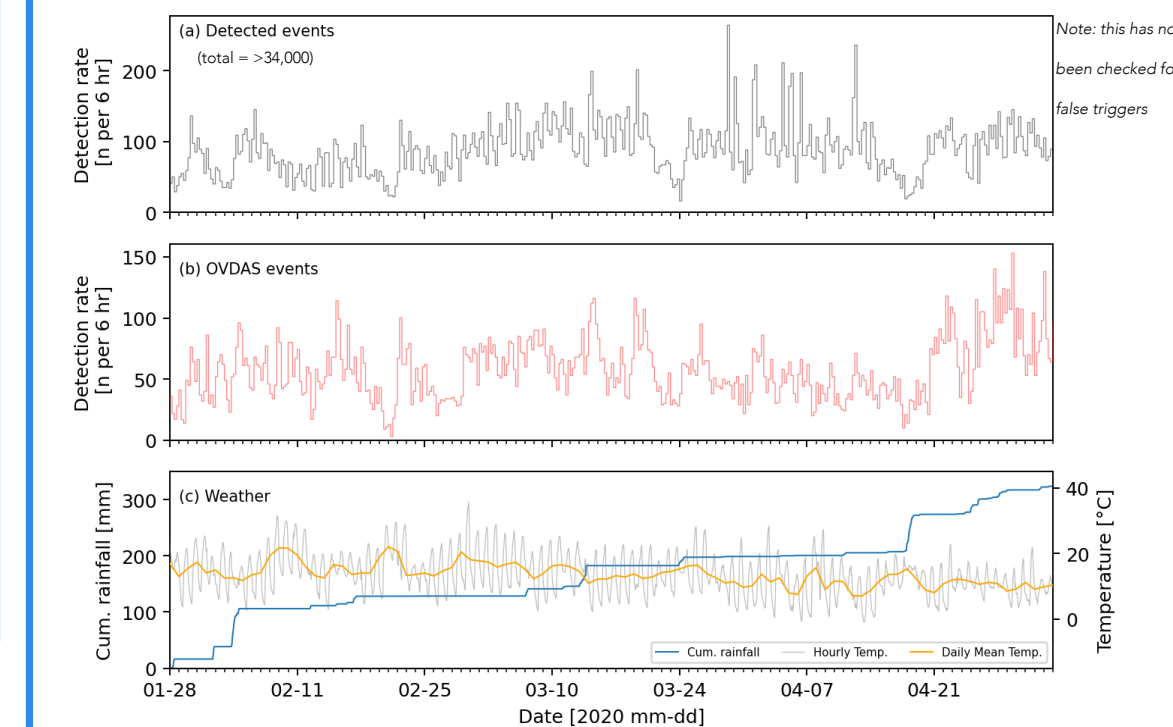
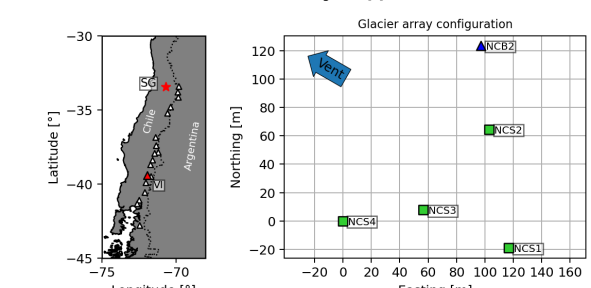
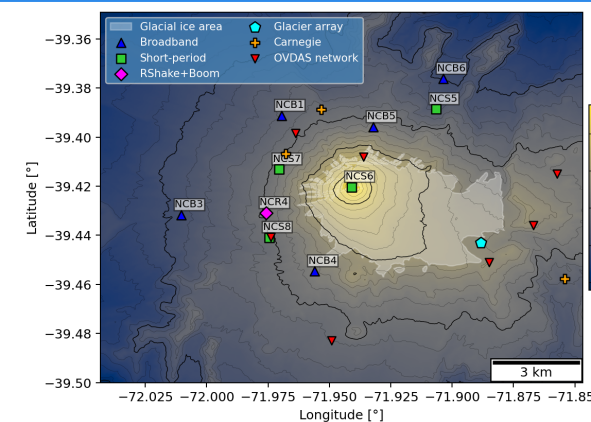
7: Villarrica

- Network of seismometers and microphones deployed around Villarrica in January 2020

- Originally planned to be recovered in April 2020, but retrieved in January 2021

- Preliminary analysis suggests intense micro-seismic activity from January to May 2020

- Signals include strombolian explosion signals, identified by co-seismic acoustic waves



8: Key findings and future directions

- Thousands of micro-seismic events found at Llaima volcano

- Many events can be sorted into persistent families

- Likely related to persistent shear failure at ice-rock interface on base of glaciers on volcano

- Develop criteria for identifying icequakes at Llaima and Villarrica

- Expand research to other ice-covered volcanoes in Iceland with the University of Iceland