RETREAT – a REal-time TREmor Analysis Tool

Patrick J. Smith[1] & Christopher J. Bean[1]
[1]Geophysics Section, School of Cosmic Physics, Dublin Institute for Advanced Studies, Dublin, Ireland.

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Rationale

- Volcanoes exhibit a very broad range of seismic source types
- In a crisis we want to know/track the source type & source location
- This is difficult to achieve with a sparse seismic network and/or when signals are emergent – particularly for continuous signals such as **volcanic tremor**
- A seismic 'array' is a cluster of stations lying outside the seismic source area
- An array can 'point' to the source location (by measuring the back azimuth)
- An array can be used to estimate lateral and vertical migration of the source
- Arrays are often used for research, but not often as an **operational tool**

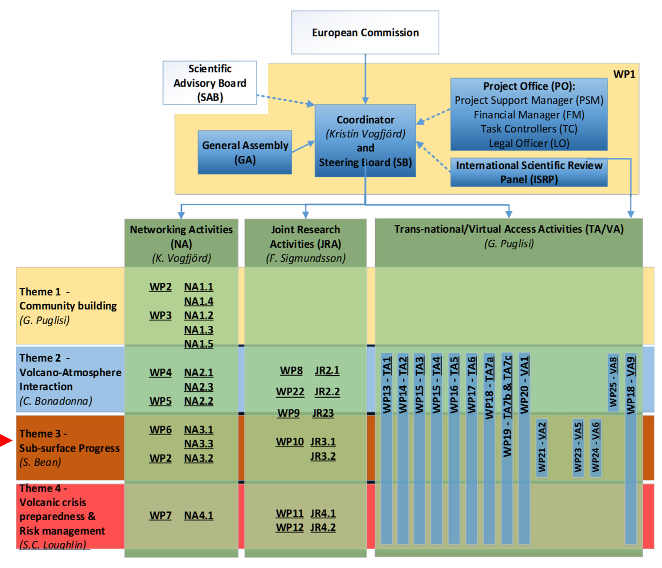
EUROVOLC Project – how this work fits in

EUROVOLC project: aims to harmonise volcanological infrastructure and communities in Europe.

Theme 3: Sub-surface processes

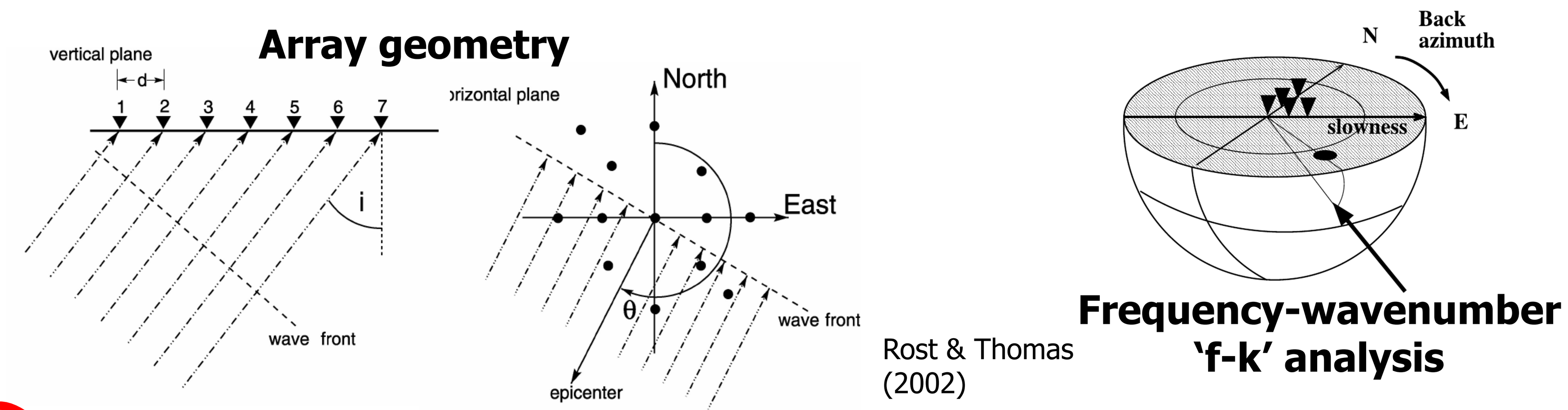
WP9: Pre-Eruptive Unrest Detection Schemes

D9.1: Seismic changes as an unrest detection tool
Task 9.1**: Using seismic tremor as a real-time unrest indicator**

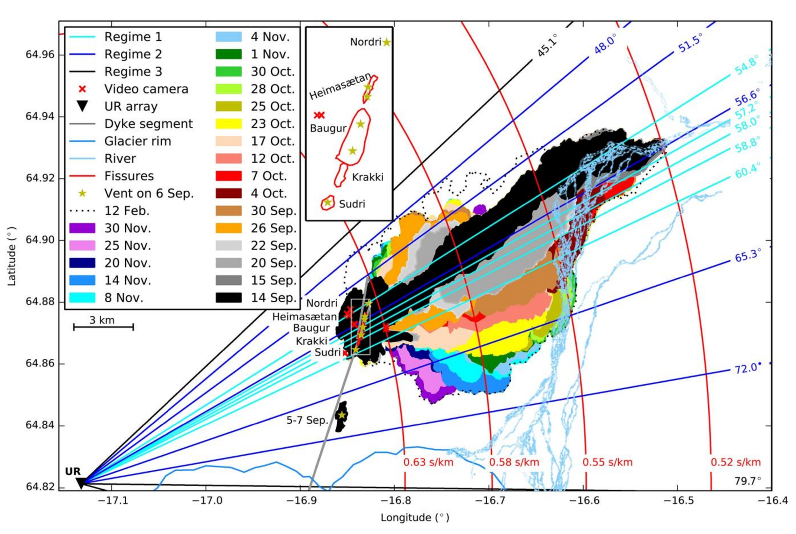


Seismic arrays – how they work

- Plane-wave assumption
- Slowness = inverse of apparent velocity across array
- Determining delay times (via beamforming) gives direction from which waves are arriving
- Perform beamforming in frequency/spectral domain
- Form beams with different slowness vectors (grid search over horizontal slowness values)
- Compare the amplitudes or the power of the beams and identify which gives the highest energy
- Derive the slowness and back azimuth from the magnitude and angle/phase of the wavenumber vector



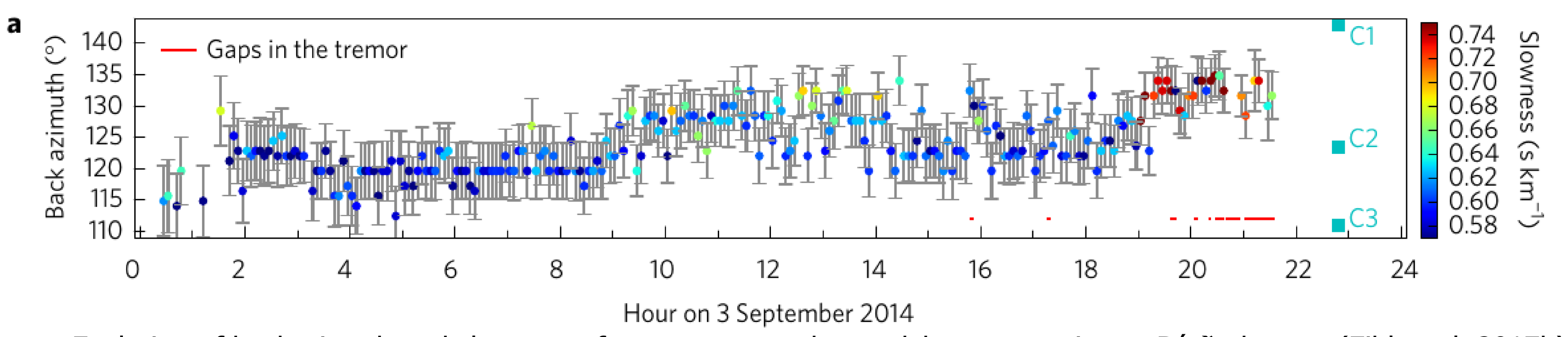
Tracking tremor using arrays: FUTUREVOLC



Multiple tremor sources identified by array analysis of Holuhraun eruption seismic data (Eibl et al. 2017a)

During the Bárðarbunga eruption in Iceland in 2014, multiple coincident tremor sources – including lava effusion – were identified by using array analysis of data from the UR array installed as part of FUTUREVOLC (left)

As well as lava effusion, dyke propagation towards the surface beneath the ice also generated tremor. It can be seen on UR array migrating laterally and upwards towards the surface, based on slowness values (below)



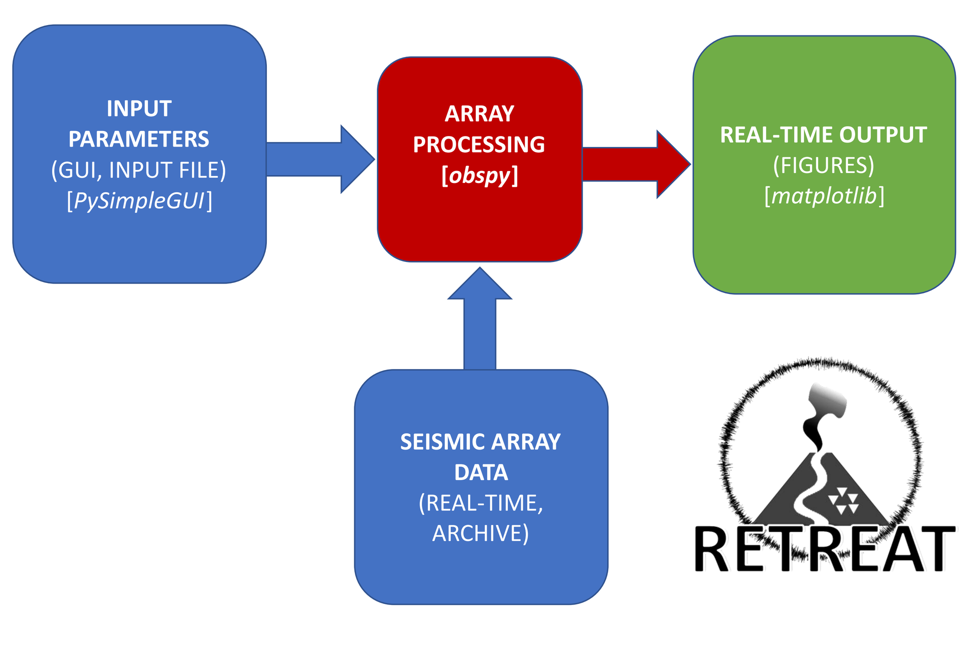
Evolution of backazimuth and slowness of tremor source due to dyke propagation at Bárðarbunga. (Eibl et al. 2017b)

RETREAT – a Real-time Tremor array analysis tool

Translating research achievements into an operational tool

Developed a new software tool that uses seismic array data and array processing to track volcanic tremor signals in real-time:

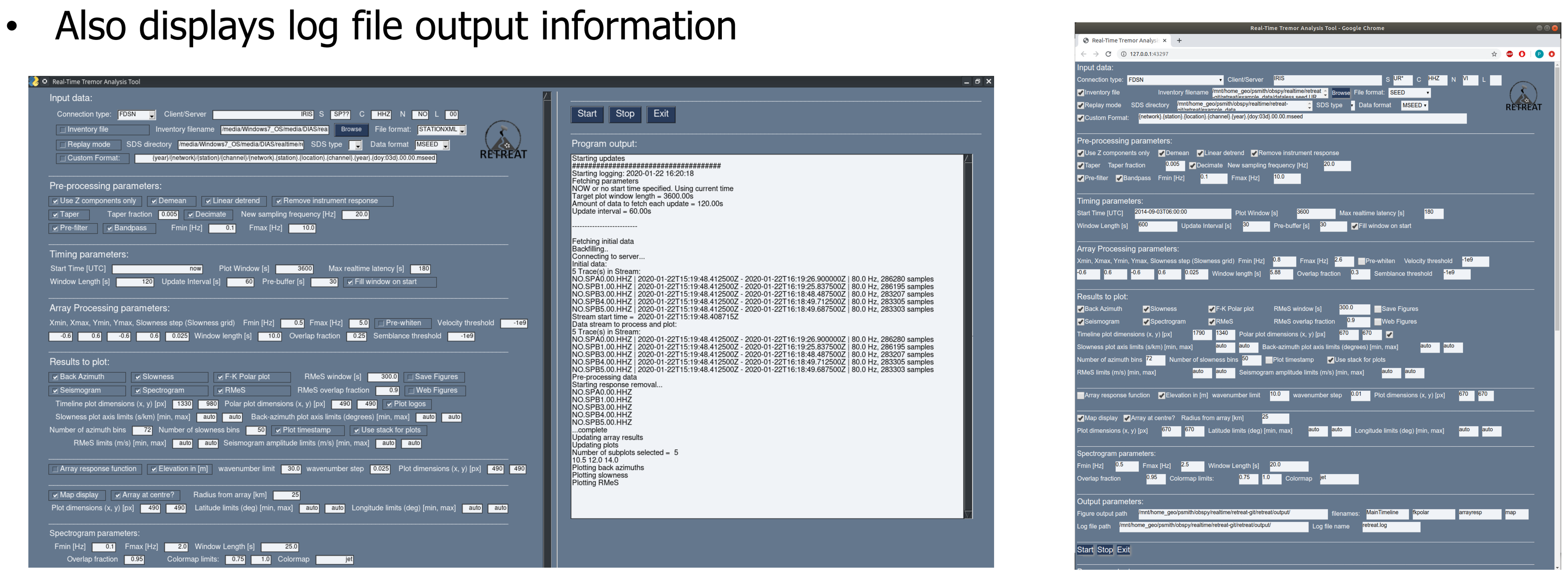
- Open-source, python-based tool
- Utilizes the popular *obspy* seismology toolbox
- GUI and web interface
- Performs *f-k* (frequency-wavenumber) analysis to determine back azimuth and slowness
- Works on both real-data and archive data sources



Schematic overview of RETREAT software package, showing main input and output elements and processing workflow

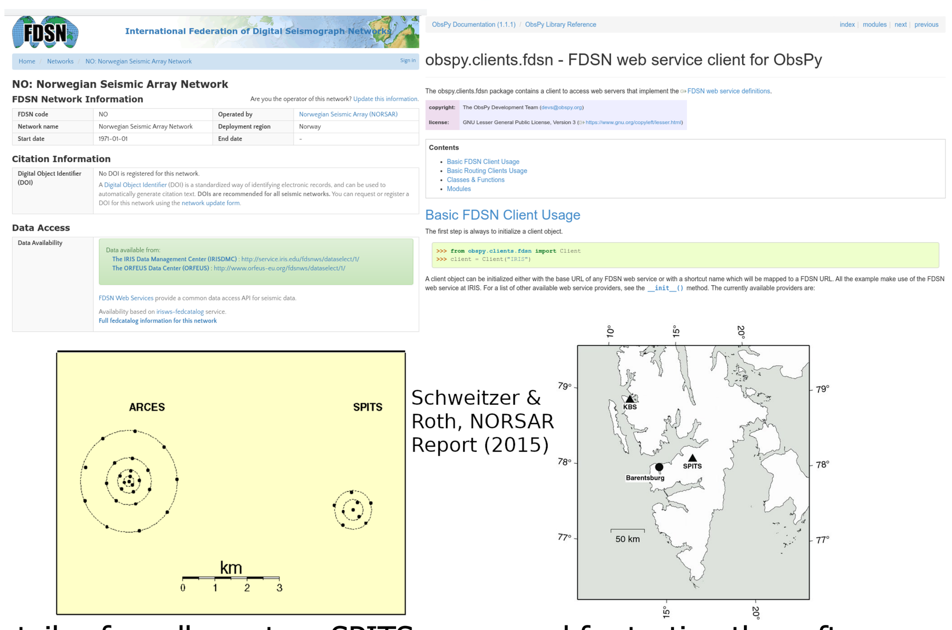
GUI interface

- Built using *PySimpleGUI* python package
- GUI and web (browser) versions
- Allows configuration of input parameters controlling:
  - Data source – real-time or archive (including metadata)
  - Data pre-processing steps
  - Timing options – amount of data to process
  - Update/refresh interval
  - Array processing parameters
  - Output options – choice of figures
- Also displays log file output information



Example screenshots of RETREAT GUI and web interfaces

Example Output 1 – Real-time data



Details of small-aperture SPITS array used for testing the software

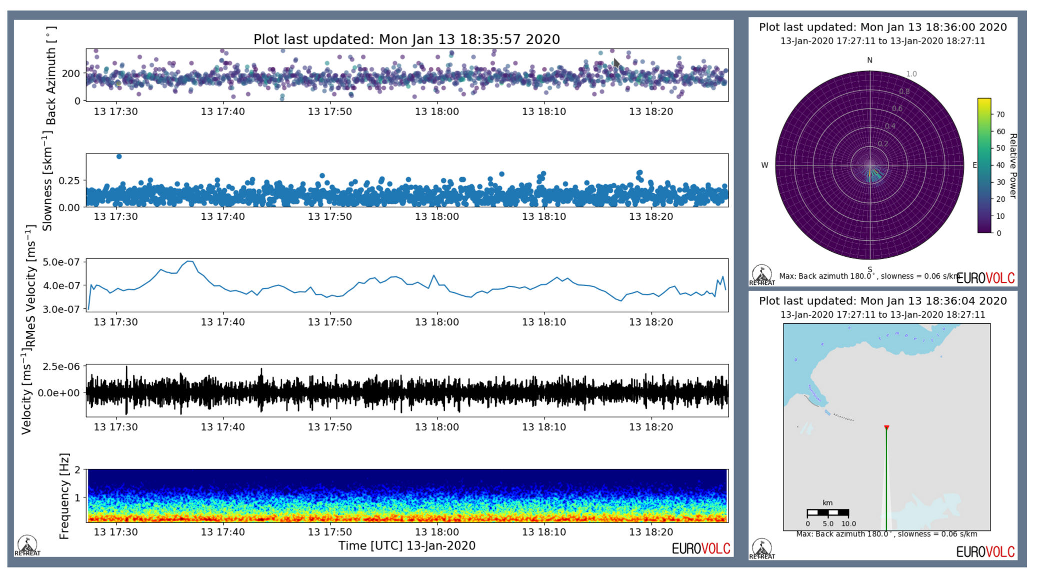
Real-time data sources implemented so far:

- obspy FDSN client
- obspy seedlink client

Tested using real-time data (via IRIS) from small-aperture SPITS array in Spitsbergen, part of larger NORSAR seismic array

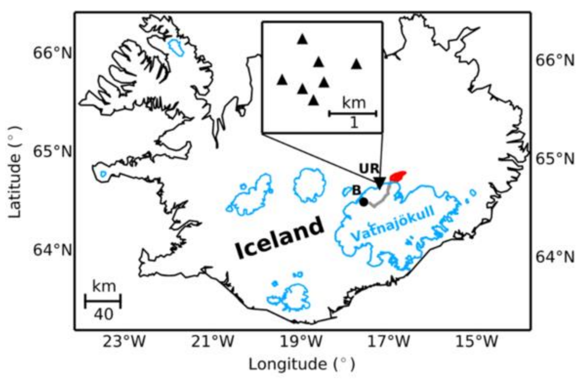
Example of output produced by analyzing real-time data from the SPITS array using the RETREAT tool:

- Timeseries of backazimuth & slowness
- Envelope, seismogram and spectrogram
- Polar representation of power from *f-k* results
- Backazimuth projected onto map



Example of RETREAT output figures. Time window is 1 hour, updating every 60 seconds. Processing takes <1 minute on desktop machine in this example

Example Output 2 – Archive data



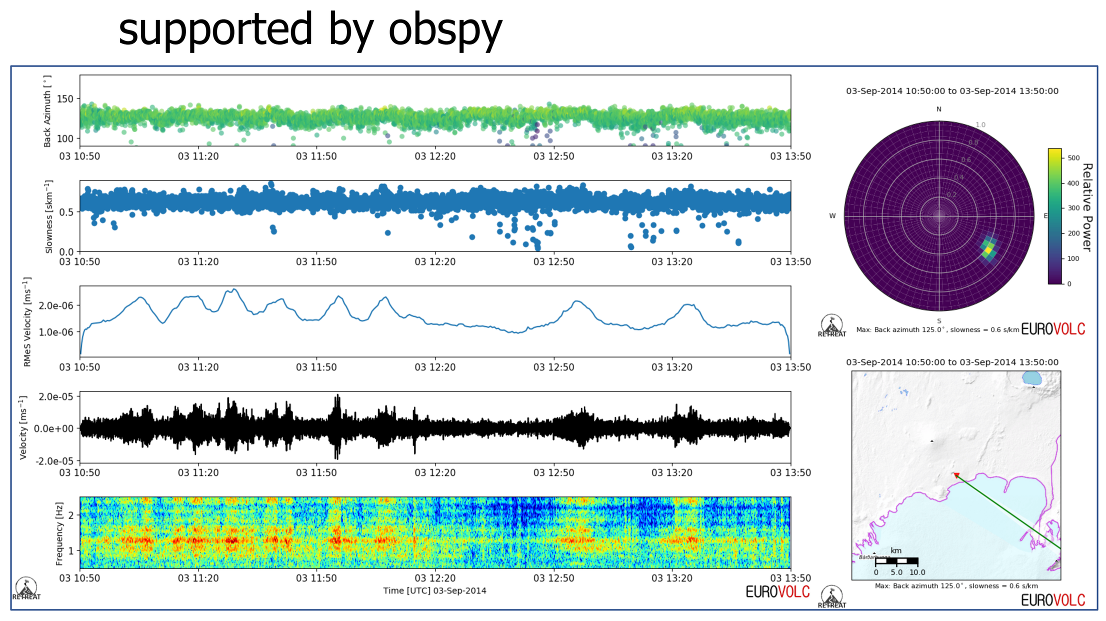
Map of UR seismic array deployed as part of FUTUREVOLC

- 'Replay' mode using existing archive seismic array data has also been implemented to allow analysis of non-real-time datasets
- Uses customisable Seiscomp Directory Structure (SDS) and accepts all common data formats supported by obspy

Example results from analysis of data on 03 September 2014 using the RETREAT software (right):

Corresponds to part of the same time period analysed in Eibl et al., (2017b) in FUTUREVOLC

Results using RETREAT show an excellent match with the previous analysis.



Summary

- Volcanoes can display pre-, syn- and post-eruptive tremor. One important means of better understanding processes driving tremor is to track the spatio-temporal evolution of its 3D location. This is best achieved using seismic arrays.
- **RETREAT** - a python-based software tool has been successfully developed for operational use that uses seismic array data and array processing techniques to help detect, quantify and locate volcanic tremor signals in real-time.
- The tool has been tested on both real time and archived data and is ready for testing and implementation in a volcano monitoring setting at observatories.

Contact: psmith@cp.dias.ie

Download link: https://git.dias.ie/paddy/retreat

References

- **Eibl et al. (2017a),** Multiple coincident eruptive seismic tremor sources during the 2014–2015 eruption at Holuhraun, Iceland, JGR
- **Eibl et al. (2017b),** Tremor-rich shallow dyke formation followed by silent magma flow at Bárðarbunga in Iceland, Nature Geoscience.
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Acknowledgements

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