Welcome!

As you probably know, everything is usually work in progress. My original abstract is slightly outdated, so here is a newer version.

Villarrica is a highly active open-vent volcano in Chile, know for its active lava lake and its persistent degassing and seismic unrest. Thanks to two concurrent measurement campaigns in March 2012, the seismicity was recorded by 6 instruments positioned at the rim of the central summit crater. These instruments surrounded the source, which is somewhere within the magma column of the lava lake. Despite the seemingly similar conditions regarding distance to the source and sites, the signals were surprisingly different in both time and frequency domain. This indicated a strong influence of site effects, possibly masking the common properties of the source signal. In the following, we use independent component analysis to separate the signal into 4 components which brings out what we think, is the fundamental resonance frequency of the lava lake reservoir.

An interactive and more detailed version is available at (https://nextcloud.ifg.uni-kiel.de/index.php/s/kHXKrb9Ed7R66dZ) as HTML file.

Enjoy.

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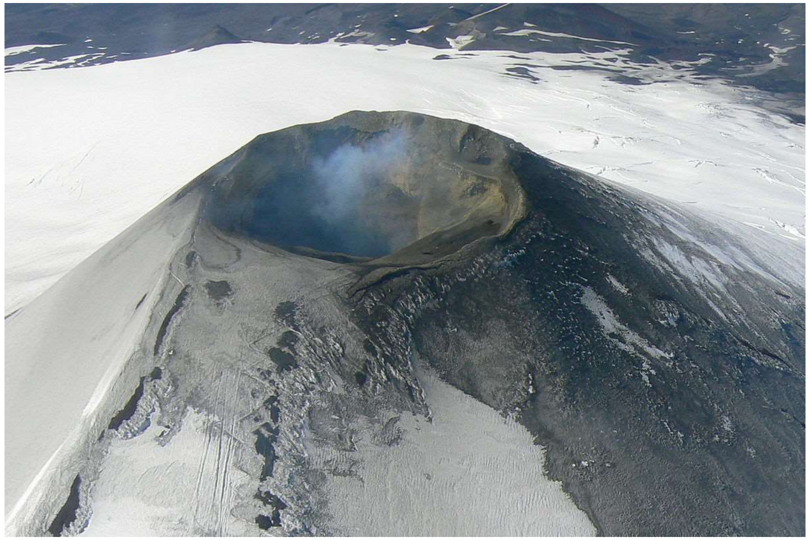
What is Villarrica's natural frequency?

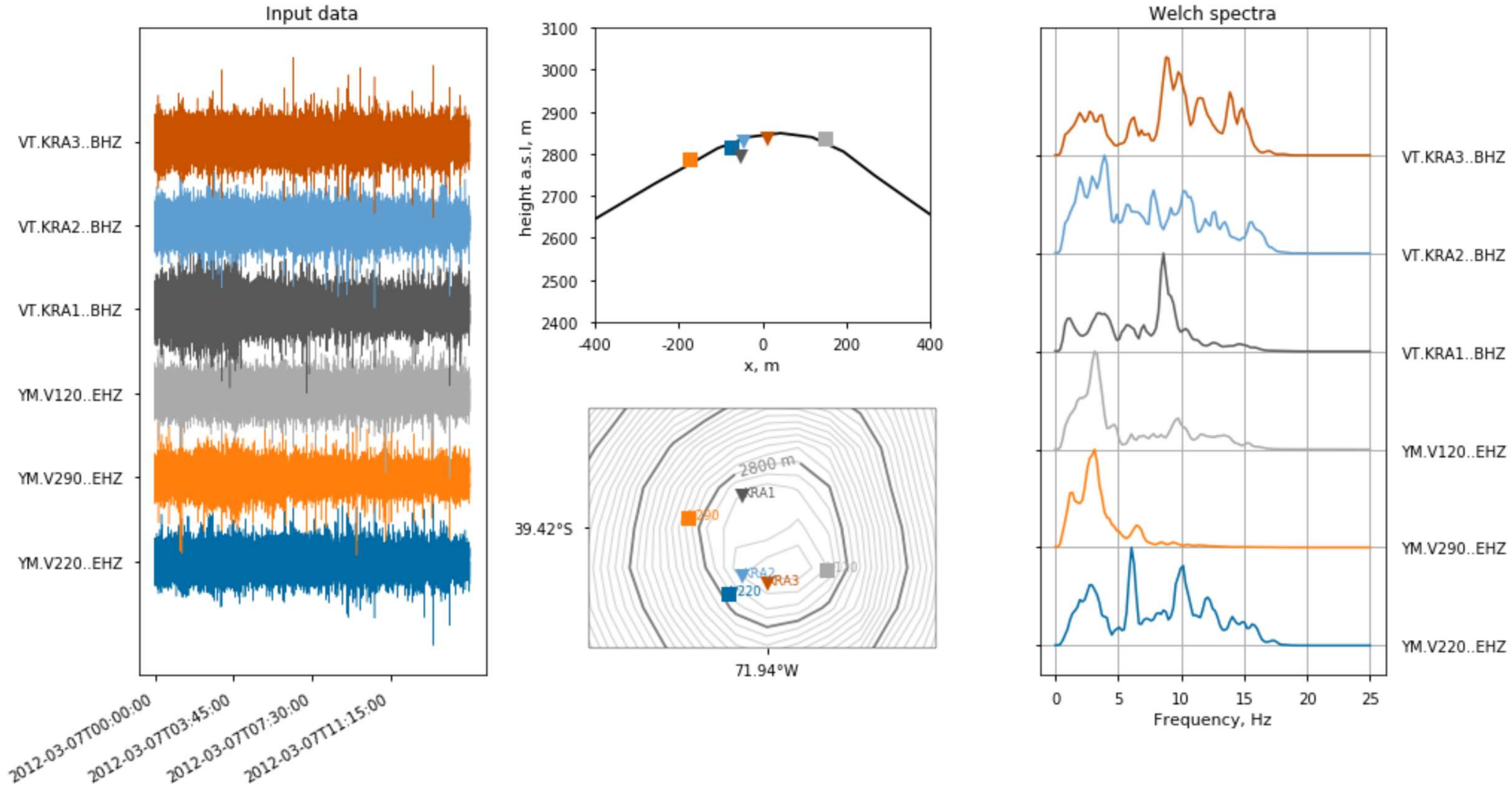
Villarrica's central summit crater hosts an active lava lake from which a persistent seismic tremor originates.

- Is there a resonance frequency all?
- If so, what's its frequency?
- What can we learn about the plumbing system?



(https://commons.wikimedia.org/wiki/File:Villarica_Volcano_(aerial_view)1.jpg#/media/File:
By Sarah and Iain (https://www.flickr.com/photos/sarahandiain/) - https://www.flickr.com/photos/sarahandiain/363467848/in/set-72157594490018394/ (), , Link (https://commons.wikimedia.org/w/index.php?curid=6524667)

Six seismometers from two temporary seismic networks (Rabbel & Thorwart (2019) (https://doi.org/10.5880/GIPP.201202.1), Waite (2010) (https://doi.org/10.7914/SN/YM_2010)) positioned at the crater rim show inconclusive frequency spectra. This probably indicates strong site effects.

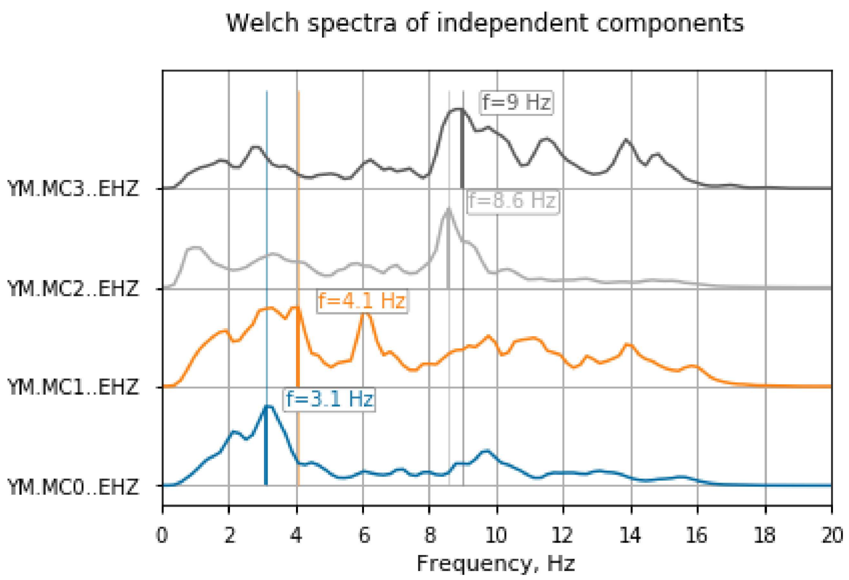


ICA = Independent component analyis

- Method of blind source separation
- Data model: the recorded signals $x(t) = (x_1(t), \ldots, x_M(t))$ is a mixture of the source signals $s(t) = (s_1(t), \ldots, s_N(t))$:
$$x(t) = \underline{A} \cdot s(t)$$
- ICA tries to recover the source signals by maximzing the non-gaussianity of the input data

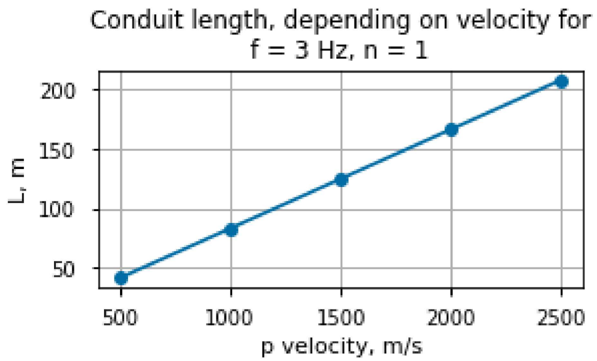
Results

- 2 spectral peaks at around 3 Hz and 8.6/9 Hz
- secondary peak at 6 Hz



Analysis and interpretation of spectral peaks

The resonance frequency f of a fluid-filled pipe depends on its length L and the acoustic (i.e. compressional seismic) wave velocity v. For the n-th harmonic $L = \frac{nv}{4f}$. For a pipe open/closed at both ends $n = 1, 2, 3, \ldots$, else $n = 1, 3, 5, \ldots$.



Harmonic frequencies for
L=125 m, v=1500 m/s

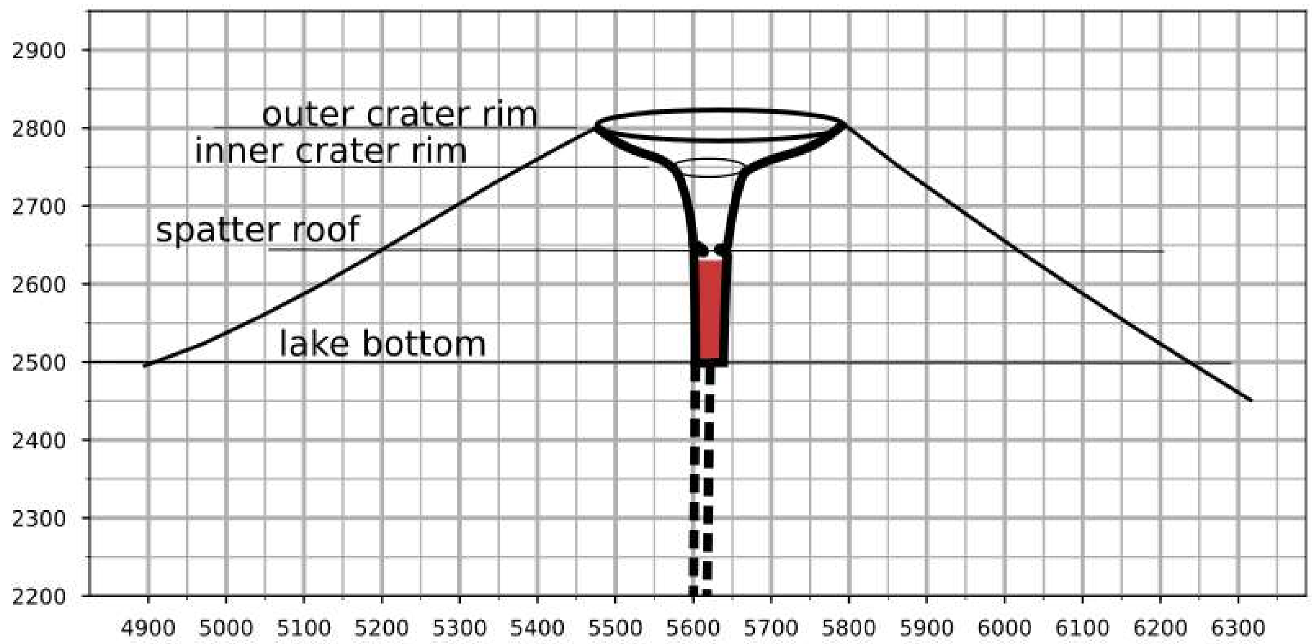
# Harmonic	f, Hz
1	3
2	6
3	9
4	12

For $f =$3 Hz and $v =$1000-2000 m/s, the pipe would have a length of 75-150 m which is in excellent agreement with the estimates of the lake depths by [Richardson & al. (2014) (https://doi.org/10.1002/2014JB011002)](https://doi.org/10.1002/2014JB011002).

Hence **3 Hz might be the natural resonance frequency of the lake reservoir**.

Interestingly, the presence of the 6-Hz peak indicates a pipe model with either two closed or open ends, rather then one open (the free magma surface) and one closed (the lake bottom) end. Possibly, the spatter roof - despite its usual opening - acts as lid.

Geometry of the lava lake



based on [Moussallam et al. (2016) (https://doi.org/10.1016/j.epsl.2016.09.012)](https://doi.org/10.1016/j.epsl.2016.09.012);
[Richardson & Waite (2013) (https://doi.org/10.1002/jgrb.50354)](https://doi.org/10.1002/jgrb.50354), (numbers are in meter)

Further considerations

- **How is the lava lake supplied?** There must be a supply conduit, as it is unlikely that the lake terminates directly at the magma chamber - especially since that would then be ~150m below the surface.
- **Can we see this feeding conduit as well as a resonating body?** And what could be its relation in terms of width and length compared to the lake reservoir. Below is an estimate of the resonance frequencies of a 100-10000 m long pipe. For a 1000 m conduit frequencies would be so low that they may not be detected by our instruments.
- **How does dampening, attenuation and elastic coupling to the host rock play together?** And what role plays it in terms of signals recorded at larger distances? The instruments at the crater rim are basically positioned at the opening/end of the pipe.
- **Which velocity to use?** Villarrica is persistently degassing and it is assumed that vigourous convection takes place in the conduit system. Hence, the magma in the lake reservoir must be enriched in gas and thus have a relatively low velocity. If we assume the frequency f and length L of the pipe to be known (since they match the observations and independently obtained estimates), we could infer the p-wave velocity of the magma.

I look forward to a discussion :-)

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Also contact me if you like to discuss:

- seismicity of Villarrica
- ambient noise/seismic interferometry techniques at volcanoes
- earthquake statistics
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