Harmonic Tremors at Shinmoedake

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Background
During the 2011 eruptions, both seismic harmonic tremors (ground oscillations) and acoustic harmonic tremors (air oscillations) were observed at Shinmoedake. Here we report the behavior of the time evolution of the frequency spectrum as well as the phase portraits of the harmonic tremors, providing evidence for a non-linear plumbing system at Shinmoedake.

Data
We utilized seismographs from 4 broadband seismometers located within a radius of about 3 km around Shinmoedake. Spectrograms and power spectral density methods were used to track the changes in the peak frequencies over time. Additionally, phase portraits of displacement with respect to velocity were obtained to further illustrate the change in properties of the non-linear mechanism of the harmonic tremors.

The first seismic harmonic tremor was observed shortly after 17:00 on 2011/01/30, and similar seismic harmonic tremors occurred sporadically until 2011/01/31. The seismic harmonic tremors during this time frame had obvious but indistinct harmonic frequency peaks which fluctuated and drifted over time. The fundamental peaks were noted to fluctuate about the values of 0.9 Hz, 1.05 Hz or 1.3 Hz. The first seismic and acoustic harmonic tremor occurred at 21:49 on 2011/01/31 with a clear and distinct fundamental peak at 1.5 Hz and higher overtones starting from 3 Hz and so forth. The phase portrait of particle displacement and velocity during this time frame shows a single loop.

On 2011/02/02, the longest seismic and acoustic harmonic tremor occurred over a time frame of 40 minutes from 20:43 to 21:23. The fundamental peak was located at around 0.9 Hz with clear higher overtones at 1.8 Hz, 2.7 Hz and so forth. The phase portrait of particle displacement and velocity during this time frame shows a double nested loop.

On 2011/02/03, a series of sporadic, short seismic and acoustic harmonic tremors occurred over a time frame of 35 minutes from 13:24 to 13:59. The fundamental peak was located at around 1.7 Hz with higher overtones starting from 3.4 Hz and so forth. The phase portrait of particle displacement and velocity during this time frame shows a single loop.

On 2011/02/06, a short seismic and acoustic harmonic tremor occurred over a time frame of just 2 minutes from 12:00. The fundamental peak was located at 0.9 Hz with clear higher overtones at 1.8 Hz, 2.7 Hz and so forth. Together with the returning of the fundamental mode to 0.9 Hz, the phase portrait of particle displacement and velocity during this time frame also shows a double nested loop.

Discussion
We interpret the jumps in frequency of the fundamental peak of the seismic acoustic harmonic tremor from 1.5 Hz to 0.9 Hz, to 1.7 Hz and back to 0.9 Hz as period doubling of a non-linear system rather than a change in physical dimensions of a resonant cavity. This period doubling is due to parameter change in the non-linear system describing the volcanic conduit, resulting in a bifurcation of the non-linear system.

We note that this observational result is supported theoretically by a lumped parameter model of non-linear excitation by fluid flow through a channel (B. R. Julian, 1994). Therefore, we treat this as evidence that the harmonic tremors at Shinmoedake are a result of non-linear fluid flow through the volcanic conduit rather than a resonance effect.

Keywords: Harmonic Tremors, Shinmoedake