Harmonic tremor during 2011 eruption at Shinmoedake, Japan

*Minoru Takeo[1]

1. Earthquake Research Institute, University of Tokyo

Volcanic tremor is a continuous seismic signal that is observed near active volcanoes and is often accompanied by evidence of subterranean movement or pressure fluctuation due to a physical or chemical process inside the volcano. However, the source of volcanic tremor is still poorly understood. Most existing tremor’s models, except for Julian’s nonlinear channel flow model (Julian, 1994), consider an acoustic resonance in the magma channels, but mechanism to excite this resonance has not been identified until now.

During 2011 eruption at Shinmoedake, Japan, we observed a series of volcanic tremors including harmonic tremor which exhibits a set of narrow, evenly spaced frequency peaks. Natsume *et al.*(2018) perform non-linear time-series analysis on a harmonic tremor recorded near the crater. They found that the stable oscillation of the harmonic tremor is predominantly a limit cycle, implying that the harmonic tremor is generated by self-sustained oscillation. In this paper, I propose a new model of harmonic tremor and reproduce the topological characteristics of observed harmonic tremor using the new model. I formulate a lumped-parameter model of incompressible viscous fluid flow through a partially constrictive path, which seems to be realistic modeling in a shallow part of conduit. I consider inertias and resistances in the upstream and in downstream pipes. The upstream pipe is connected to a large chamber with pressure of Po. Lengths and radiuses of the pipes and the constrictive path could be set flexibly in this model. This model leads to a third-order system of nonlinear ordinary differential equations with functions of area of throat, fluid velocities in upper stream and in downstream. The equations of the model are as follows:
Mass conservations in upstream and in downstream of the constricting path; Conservation of momentum in upstream and in downstream of the constricting path; Equations of motion in upstream pipe and in downstream pipe; Elastic law of the constrictive path;
Typical frequency of the harmonic tremor is 1~2Hz and the wavelength seems to be hundreds meter, so these signals were recorded within a distance of one wavelength, being little affected by wave propagation. Therefore, assuming that these observed signals represent only linear transformations of one parametric function of the nonlinear tremor model, we can compare topological characteristics of observed and simulated signals to evaluate validity of the new model. When the resistance of downstream is larger than that of upstream, a self-sustained oscillation starts in a suitable parameter range. For different driving pressure (Po), numerical solutions exhibit steady flow, simple limit-cycle oscillation, limit-cycle oscillation with double-loops or with quadruple-loops, and a chaotic oscillation. Changing Po in time, I succeed in simulating a harmonic tremor which has same topological characteristics with the observed harmonic tremor in several portions of time series (see Figure 1).

Keywords: volcanic tremor, nonlinear oscillation, chaos

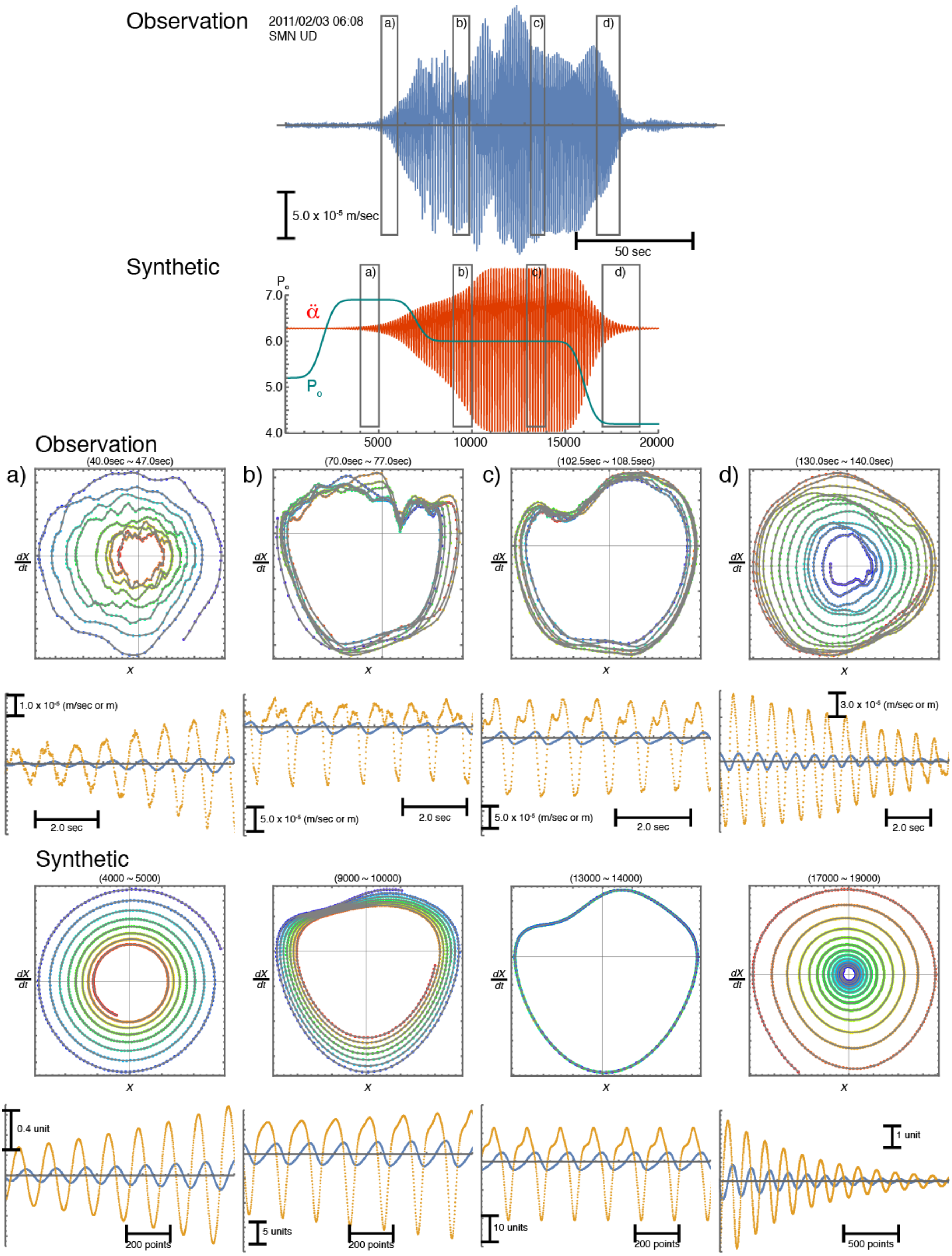
Observation
2011/02/03 06:08
SMN UD
a)
b)
c)
d)
5.0 x 10⁻⁵ m/sec
50 sec
Synthetic
P₀
7.0
6.0
5.0
4.0
ä
5000
10000
15000
20000
Observation
(40.0sec ~ 47.0sec)
(70.0sec ~ 77.0sec)
(102.5sec ~ 108.5sec)
(130.0sec ~ 140.0sec)
dX/dt
x
1.0 x 10⁻⁵ (m/sec or m)
2.0 sec
5.0 x 10⁻⁵ (m/sec or m)
3.0 x 10⁻⁵ (m/sec or m)
Synthetic
(4000 ~ 5000)
(9000 ~ 10000)
(13000 ~ 14000)
(17000 ~ 19000)
0.4 unit
200 points
5 units
10 units
1 unit
500 points

Figure 1