Final report by Galina Nataliya

Although the initial research topic for the stay at ERI was linked with the study of eruptive volcanic jets, I also participated in another project run by Prof. Ichihara and dedicated to volcano monitoring. Thus, the summary of the results obtained during my stay can be summarized in the following way:

1. Refining the widespread model of eruptive jets [Brodsky et al., 1999] with the experimental approach;
2. Linking the experiment on eruptive jets with the seismological data from the 2022 Hunga Tonga–Hunga Ha'apai (HTHH) eruption;
3. Probing the seismic background level (SBL) technique using the data from the Klyuchevskoy volcano group (Kamchatka).

1. Refining the widespread model of eruptive jets [Brodsky et al., 1999] with the experimental approach.

The current model of eruptive jets proposed by Brodsky et al. (1999) links the reaction force F and the mass discharge rate as $F = \dot{m}v$ (v is the exit velocity of the erupted material). However, Tada et al. (2023) theoretically predicted that the reaction force F includes not only the momentum change but also the pressure difference between the interior and the vent, and the friction force on the vent wall. Thus, when the pressure difference and friction are considered, $F = \frac{3}{2}\dot{m}v$ [*].

Using the apparatus designed by Tada et al. (2023) (Fig. 1), we continued their series of experiments. With the obtained measurements of the reaction force and other parameters, we investigated the relation (*) with depending on the nozzle shapes and nozzle size (area). Also, we compared incompressible (water) and compressible (air) jets.

For water jets, the relationship $F_{jet}\rho A = \frac{3}{2}\dot{m}^2$ is satisfied for all nozzles (Fig. 2). However, not all air jets satisfy that ratio, especially for significant values of $\dot{m}$ (Fig. 3). We are going to revise the theory of compressible jets, and the series of experiments with the other nozzle shapes have been carried out.

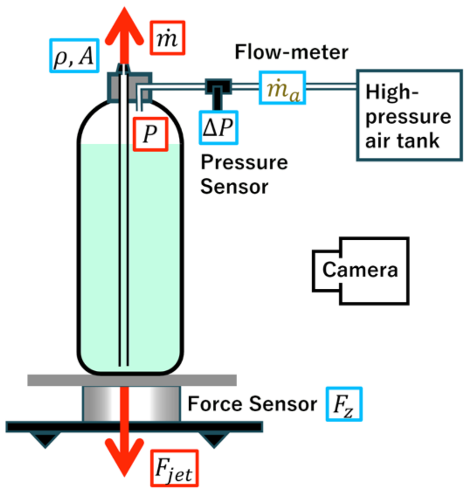

Fig. 1: Experimental apparatus designed by Tada et al. (2023)

The collaboration on this project will be continued. We are going to change the parameters of the fluid, such as density and viscosity, as well as the gas-liquid mixing ratio, and investigate the effect of these variables on the ratio [*].

The results from this part have been presented at the JpGU Meeting 2025 and the IAVCEI General Assembly 2025.

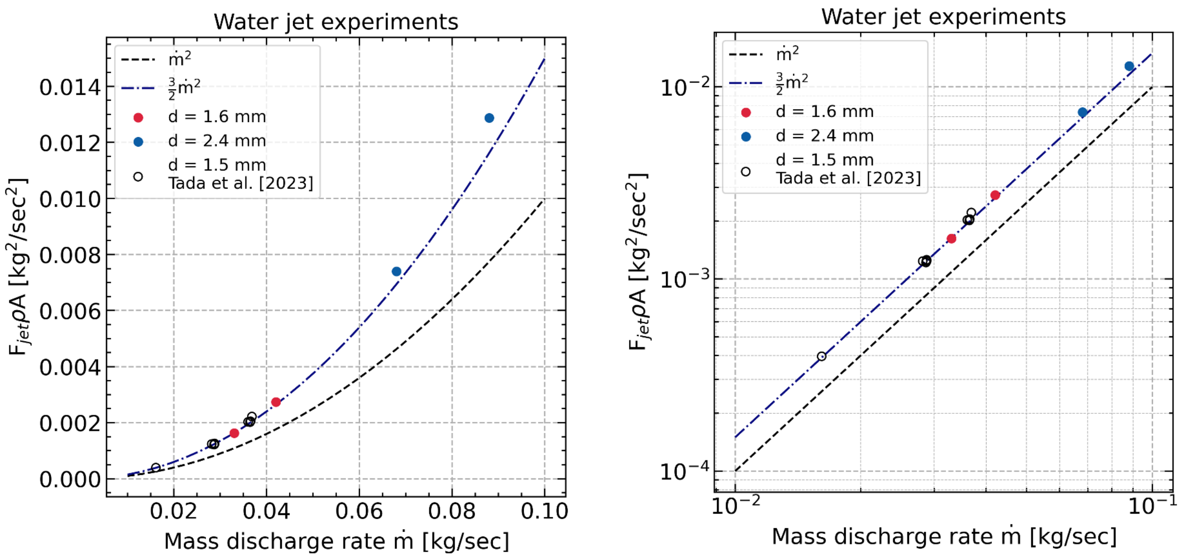

Fig.2: Mass discharge rate ṁ and reaction force F for water jets (circles are experimental data, dashed lines are theoretical distributions)

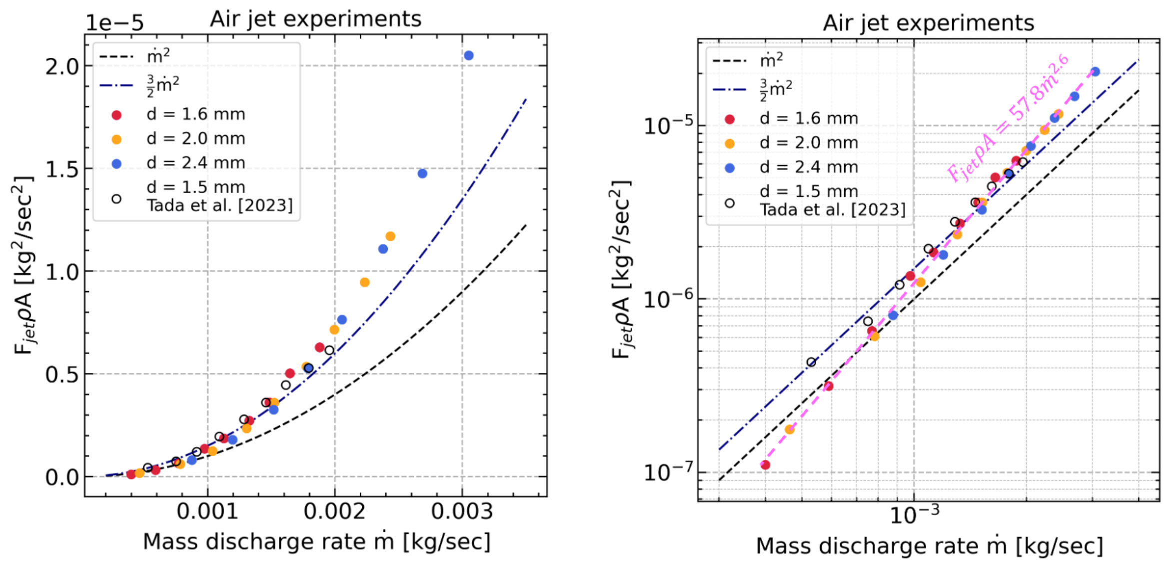

Fig. 3: Mass discharge rate ṁ and reaction force F for air jets (circles are experimental data, dashed lines are theoretical distributions)

2. *Linking the experiment on eruptive jets with the seismological data from the 2022 Hunga Tonga–Hunga Ha'apai (HTHH) eruption*

Tada et al. (2023) theoretically predicted that F_{jet} dominates Mg only in a short eruption. The single force model is not applicable to a long-lasting eruption. In the current seismological practice, many studies assume that the signals resulting from the eruptions were produced by short pulses (Poli and Shapiro, 2022; Thurin and Tape, 2023), although volcanic eruptions last for minutes or even hours. Instead of that, we calculated the theoretical waveforms using the single force source time functions from the experimental data (Fig. 4).

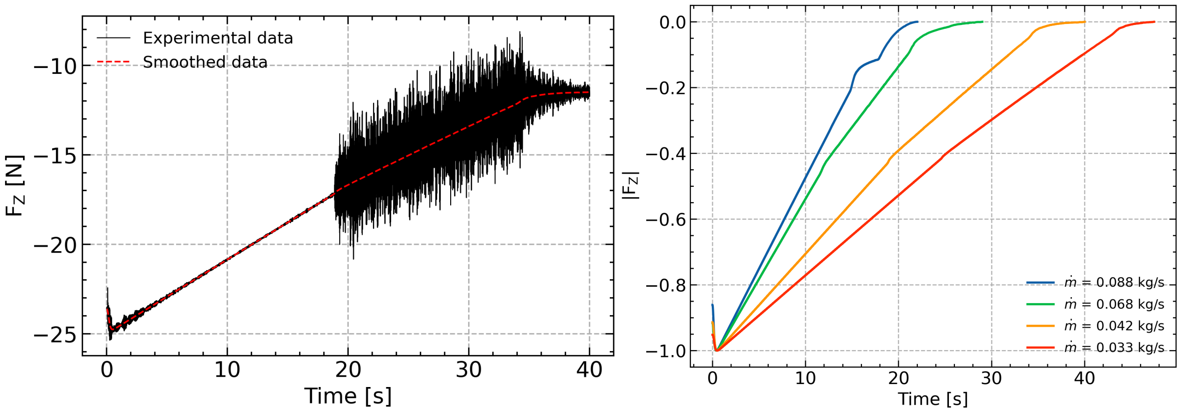

Fig. 4: Obtaining the source functions $F_s(t)$ from the experimental data (left) and the normalized $F_s(t)$ corresponding to different values of $\dot{m}$

The far-field seismic wavefield can be expressed as a convolution of the single force with $F_s(t)$ the Green's function:

$$u(t, r) = F_s(t) * G(t - t_s,\ r,\ r_s)$$

After calculating the synthetic seismograms, we saw that the unloading part, when materials evacuate from the volcano, i.e., when Mg dominates F_{jet} is not reflected in the waveforms (Fig. 5)

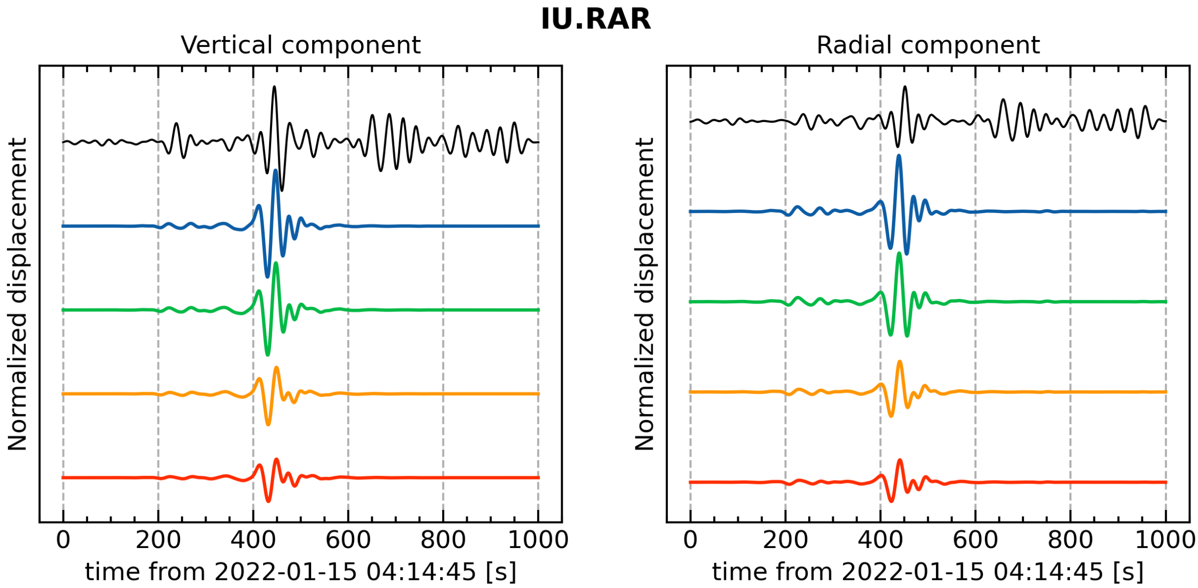

Fig. 5: Examples of real seismograms (black) from the 2022 HTHH eruption recorded at station IU.RAR and synthetic waveforms (color corresponds to Fig. 4)

The results obtained in this section have been presented at the IAVCEI General Assembly 2025.

3. Probing the seismic background level (SBL) technique using the data from the Klyuchevskoy volcano group (Kamchatka)

Most often, episodes of volcanic unrest and eruptions are accompanied by a variety of seismic signals, so that seismic observations have become one of the most effective methods to monitor volcanoes. Among them, the seismic background level (SBL) monitoring has proven to be a promising new technique that retrospectively allowed the identification of the volcanic unrest before the eruption of Shinmoe-dake and Iwo-yama in 2017-2018. In order to estimate further potential of SBL in volcano monitoring, we applied it to seismic data recorded at active volcanoes of the Northern group of volcanoes (NGV) in Kamchatka during the eruptive sequence of 2022-2023.

For a more reliable interpretation of the SBL time series, we also combined the seismological observations with the thermal anomalies detected by the Himawari-8 satellite. Also, in order to distinguish between the Bezymianny and Klyuchevskoy volcanoes, we introduced a modified approach to detect thermal anomalies. Additionally, we performed the Rayleigh wave analysis to estimate the source of volcanic tremor. Moreover, investigating the Shiveluch eruption, we found that SBL can detect non-eruptive processes occurring in the magmatic systems. Thus, SBL time series appear to be a useful new seismic observation tool, especially in conjunction with more traditional approaches, to better quantify the magnitude and significance of volcanic unrest.

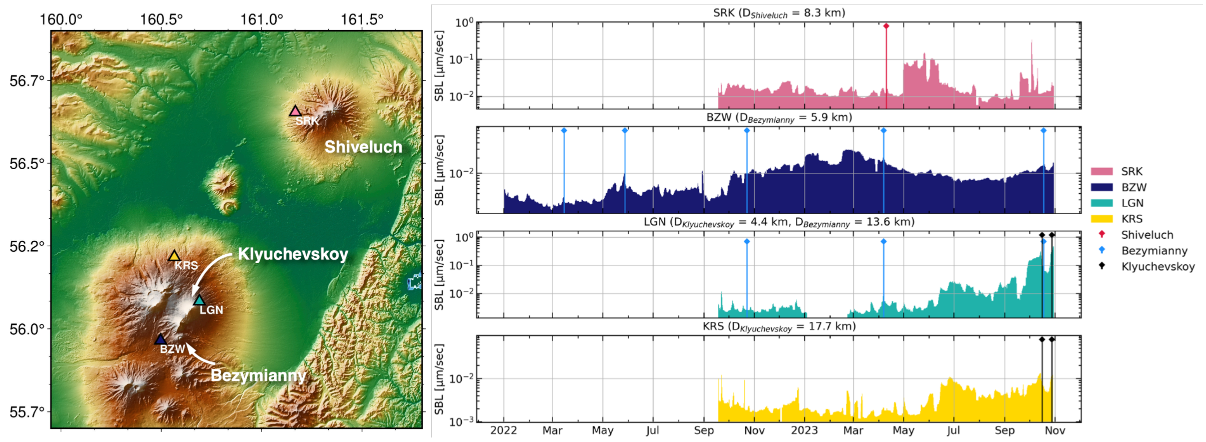

Fig. 6: Map of the region with the stations (right) and the resulting SBL time series (right)

The results of this section were presented at the JpGU Meeting 2025 and Japanese Volcanological Society Meeting 2025. A manuscript was written and submitted to the *Earth, Planets, and Space* journal.

The social part of staying at ERI was as important as the scientific one. I would like to thank Prof. Ichihara for all the support and opportunities provided; it was a great pleasure to work together. Also, I would like to thank Prof. Nishida for our discussions and his help with my seismological investigations, as well as for some financial support during my stay. Many thanks to all members of the Volcano Research Center, the department of ERI to which I belonged. It is a great environment to perform research, I truly enjoyed the convivial atmosphere and our informal gatherings and travels. Special thanks to the ERI International Office, Prof. Kinoshita, and the team who gave me the opportunity to come to Japan and made my stay as comfortable as possible. Also, I want to thank Prof. Itoh, who told me about the visiting program and supported me at different stages of the stay. And of course, many thanks to the international community of ERI and our lunch group (it would be impossible to list everyone here), these 1.5 years would be miserable without you all.