# Remote water sampling using a drone at Yugama crater lake, Kusatsu–Shirane Volcano, Japan

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Regular sampling of lake water at hot crater lakes is commonly used to monitor volcanic systems (e.g., Giggenbach and Glover 1975; Hurst et al. 1991; Rowe et al. 1992; Martinez et al. 2000; Ohba et al. 2008; Rouwet et al. 2016). Data on temporal changes in lake water chemistry are useful for identifying and predicting volcanic activity such as phreatic and phreatomagmatic eruptions (Mastin and Witter 2000; Schaefer et al. 2008; Morrissey et al. 2010). Therefore, regular water sampling and water chemistry analysis are the most straightforward and valuable methods for providing early warning of an eruption and thereby reducing risk at volcanoes with active crater lakes. However, sampling of crater-lake water by hand is difficult during volcanic unrest due to the risks of a volcanic eruption.

Drones have recently been developed that can fly for several km with a payload exceeding 1–2 kilograms, and are therefore valuable as a means of sampling lake water from remote sites. Dense acidic gas such as HCl and $SO_2$ are emitted from hot hyper-acidic crater lakes at active volcanoes, which can be problematic for drones. During volcanic unrest (including phreatic eruptions), perturbations of the water surface and strong upward air currents caused by enhanced lake-water evaporation can further hamper efforts to sample water near the lake surface.

To use a drone safely at active volcanoes with crater lakes, we tested a simple method of water sampling using a drone at Yugama crater lake, launching the drone from a remote site located 2 km north of the lake center. The drone was a six-rotor LAB645 (Enroutelab, Japan). The maximum flight duration is 40 minutes when the drone is powered by two 350 Wh (22.5 V) batteries with a total weight of 4 kg. The drone can take off with a maximum load of 12 kg. It is controlled by an operator during take-off and landing, but at other times it navigates automatically by GNSS between prefixed waypoints. Once optimal waypoints for sampling locations are programmed the drone can follow the intended route even during times of volcanic unrest.

There are some limitations to this approach. The camera view transmitted from the drone is unlikely to provide sufficient information for the operator to estimate an accurate relative height between the drone and the lake surface. Moreover, radio communications may be perturbed due to the presence of a crater wall between the drone and operation site. In these cases, adjusting the drone’s location via remote control can be difficult.

To overcome these problems without requiring any additional special equipment, the sampling waypoint can be adjusted by an observer located on a crater wall or at the lakeshore during calm period. In the case of Kusatsu–Shirane Volcano, volcanic activity was calm at the time of the test flight and therefore an observer was able to approach Yugama crater lake. The observer on the lakeshore measured the relative height between the lake surface and the drone using a laser range finder. The altitude of the sampling

 

waypoint could then be adjusted on the basis of the observer’ s reports. Consequently we obtained optimal waypoints for sampling locations.

Despite the high altitude of over 2000 m above sea level, our simple method was successful in retrieving a 250 mL sample of lake water. The procedure presented here is easy for any researcher to follow who operates a drone without additional special apparatus. We compare the lake water sampled by drone with that sampled by hand at a site where regular samplings have previously been carried out. Chemical concentrations and stable isotope ratios are largely consistent between the two techniques. As the drone can fly automatically with the aid of navigation by GNSS, it is possible to repeatedly sample lake water from the same location, even when entry to Yugama crater lake is restricted due to the risk of eruption.

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