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Timeline for Aviation Management with Precursory Signs of a Large-scale Eruption

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1. Introduction

A VEI 4 eruption of Eyjafjallajökull in 2010 April paralyzed European airspace for almost a week, making it the costliest disruption to aviation in history. Similar event may occur in Japan if Sakurajima on Kyushu island erupts massively. However, Japan neither has a volcano alert level system for aviation nor a detailed volcanic hazards mitigation plan. Even worse, current researches on real-time ash identification and air-ground communication also neglect early warning and pre-eruption mitigation and preparedness. Here, standing on the shoulders of volcanologists, we developed a timeline for aviation management before the onset of a large-scale eruption, including nighttime standby and evacuation issues. Putting it simply, we established linkage between timing for action and simulated ash fall scenarios of Kagoshima Airport. We hope our work can assist airliners to mitigate volcanic hazards risks timely, proactively, effectively and can be extended to other stakeholders in the future.

2. Application of PUFF model

First, we employed the PUFF model developed by Tanaka (1994) to simulate the ash fall given the volume of ash as that of 1914 Taisho eruption, 0.5 km^3. PUFF was developed at Alaska Volcano Observatory in the wake of Redoubt volcano eruption. In this research, because PUFF does not take complex movement within the ash plume into consideration, we adjust the parameters to be much larger than in practical use and introduce an altitude-varying radius of column (z/8, z in meter) to better fit the ash fall results proximal to the vent. We set the eruption duration at 8 hours with a uniform eruption rate, set the time step at 1 minute and 840 particles are generated in every time step, the altitude of the generated particles in each time step are determined by function

$$z(t) = 12000 - (12000 - 500)\cdot\exp\left(-\frac{t}{30}\right),$$

t in second. We assume the column height as 12000m above sea level, set the particle size following logarithmic Gaussian distribution with its standard deviation 1.0 centered at -2.4 on a log scale. The horizontal diffusion speed of the random walk is set at $c_h = \sqrt{5}\,m/s$, the vertical diffusion speed is much smaller and is set at $c_v = \sqrt{0.05} m/s$. Furthermore, the diffusion speed of the random walk on the horizontal direction decreases with distance from the vent and increases with altitude, thus, we set the amplification function as:

$$c_h' = c_h\left[1 + \frac{z}{330}\exp\left\{-\left(\frac{r}{70}\right)^2\right\}\right]$$

$$(z\ is\ altitude\ in\ meter, r\ is\ distance\ in\ km)$$

We set the wind field homogenously 9m/s. According to our simulation, the sediment is sensitive to the wind speed, if the wind carries ash north, which is possible, simulation shows thickness of up to 18 cm. Fortunately, the prevailing eastward wind direction will result in 3 cm accumulation of ash.

3. Utilization of real-time forecast

Secondly, even though the prevailing wind carries ash east, we advise airlines and airport to prepare for the atypical north wind blow. Remember in 2010, ashes from Eyjafjallajökull was carried southeast by atypical wind and consequently paralyzed European airspace for a week, thus, we propose airline to prepare for the worst-case scenario. From above, we know that 0.5 km^3 ashes can lead to a 18cm accumulation under the 9m/s southernly wind. Proportionally, 2mm accumulation, which is the threshold to close the airport, can be caused by a volume of $0.00556km^3$ ashes. Now, the problem become, how can we estimate the ash volume in advance. Fortunately, we can calculate the volume of ash through the deformation in a real-time manner, which means, we are not able to deduce the volume of the actual future eruption from now-available deformation data, but we can calculate the volume of ash if the volcano erupts now. The function is given as follows:

$$\varepsilon_r = \frac{(p^2-2r^2)\Delta V}{2\pi(p^2+r^2)^{2.5}}$$

where Δv is the volume of ash, p is the depth of pressure source, r is the distance from the vent to the extensometer, ε_r is the deformation. The depth of the pressure source is measured at 4 km below Minamidake. Let $\Delta v=0.00556km^3$, $r = 2800$m (the distance from HAR station to Minamidake), ε_r equals $1.0197 * 10^{-7}m$. Also, let $\Delta v = 0.5km^3$, $\varepsilon_r = 9.176 * 10^{-6}m$.

4. Timeline

Finally, we can work out a timeline guiding airline's mitigation work against volcanic hazards. When the deformation at HAR station creeping up below the threshold of $1.0197 * 10^{-7}m$, airline should prepare for any potential negative impact from small-scale eruption, for instance, temporary closure of runway. When the deformation at HAR station breaches the threshold of $1.0197 * 10^{-7}m$, indicating a possible closure from the unfavorable wind direction, airline should declare condition level 2, initiating the preparation work for evacuation and standby at night. Furthermore, swarms of earthquake and tremor suggest the eruption is impeding, this sign should be perceived as the trigger of evacuation. Because in many cases swarms of earthquakes happen only 20 minutes before the eruption, airline should line up the aircraft on the taxi way for faster take off. If the deformation at HAR station breaches the threshold of $9.176 * 10^{-6}m$, airline should evacuate the aircraft and staff, no matter whether earthquake swarms (See Figure 1).

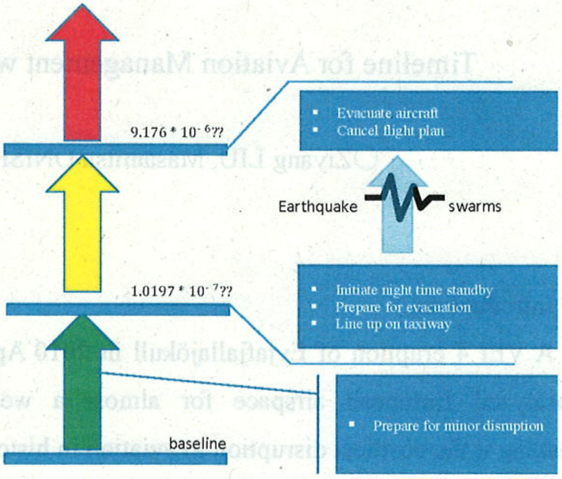

Figure 1. Decision-making timeline

5. Conclusion

We used 1914 Taisho eruption to validate the parameters of PUFF model which is modified to better simulate the ash fall. We set the threshold of initiating night-time standby and compulsory evacuation to be 2mm deposit and 18 cm deposit respectively. Then, based on worst-case scenario, we calculate the volume of eruption capable of reaching the thresholds and subsequently get the corresponding deformation at HAR station. Of course, in practice researchers do not rely on readings from only one station, this work can serve as a prototype and more can be done to assess the hazards on a quantitative basis.

References

1) Tanaka, H. L., 1994. Development of a prediction scheme for volcanic ash fall from Redoubt volcano, Alaska, Proc. First International Symposium on Volcanic Ash and Aviation Safety, U.S. Geological Survey, Bulletin 2047, 283-291.