Ground and satellite-based monitoring of Mayon Volcano, Philippines

Kisei Kinoshita¹, Satoshi Tsuchida¹, Ernesto Corpuz², Eduardo Laguerta², Andrew Tupper³, Chikara Kanagaki¹ and Satoshi Hamada¹

¹ Faculty of Education, Kagoshima University, Kagoshima, Japan
² Philippine Institute of Volcanology and Seismology, Quezon, Philippines
³ Darwin Volcanic Ash Advisory Centre, Bureau of Meteorology, Darwin, Australia

Abstract

Automatic interval recording of volcanic clouds at Mt. Mayon, Philippines started in June 2003 as joint work of PHIVOLCS and the Kagoshima group, and evolved into a real time monitoring system accessible from Quezon and Kagoshima in April 2004. In this system, conventional visible camera is used in tandem with a near-infrared camera, which is less sensitive to atmospheric haze and able to detect hot anomalies. It is intended to provide eventually live access to imagery of the volcanic cloud on the World Wide Web. The necessity of the ground-based system in conjunction with satellite-based volcanic cloud monitoring is discussed for worldwide aviation safety, exhibiting some satellite imagery of clouds from the Mayon eruptions of 29 February, 2000.

1. Introduction

Mayon Volcano, near Legaspi in southeast Luzon, Philippines shown in Fig. 1, is the most active volcano in the Philippines with 47 eruptions in recorded history. Mayon is an andesitic stratovolcano, with a height of 2,462 m above mean sea level, and a world-renowned near-perfect symmetry. Following a major eruption in 1993 which resulted in 77 fatalities, the volcano has been again recently active with significant eruptions in 1999, 2000, and 2001 (Catane et al., 2003). Approximately 900,000 people live around the volcano; this, and the location near Asia/Pacific air routes makes eruptions an acute hazard for both local populations and international aircraft.

Volcanic monitoring and warning in the Philippines is the responsibility of the Philippine Institute of Volcanology and Seismology (PHIVOLCS). PHIVOLCS maintains a well-staffed observatory at Lignon Hill, 11 km SSE of the crater, with observation network of seismicity and tilt meters around the volcanic mountain. The remote sensing of the SO₂ emission by COSPEC is done every week. The volcanic warning service for aviation is known as the International Airways Volcano Watch (IAVW), and requires a complex set of interactions between aviation, meteorological, and volcanological agencies (International Civil Aviation Organization, 2000). Warnings for aviation are the responsibility of the Philippine Atmospheric, Geophysical & Astronomical Services Administration (PAGASA), centred in Quezon City. Volcanic ash dispersion forecasts are provided to PAGASA by two Volcanic Ash Advisory Centres (VAACs), in Tokyo (operated by the Japan Meteorological Agency) and Darwin (operated by the Australian Bureau of Meteorology). The two VAACs use satellite techniques to monitor the Philippines north and south of 10°S respectively for ash clouds, and dispersion models such as HYSPLIT (Draxler and Hess, 1998) to forecast the ash dispersion. Mayon volcano, at 13.3°N 123.7°E, lies in the Tokyo

Figure 1. Location of Mayon volcano.
VAAC area, but ash from the eruptions can drift into the Darwin VAAC area, and accordingly all agencies share information about the state of the volcano.

The recent development of the IAVW has expanded the area that a volcanic eruption is perceived to affect, and focussed attention on the need for international co-operation in volcanic hazard mitigation in the Asia/Pacific region (Tupper and Kinoshita, 2003; Tupper et al., 2003b), and also for closer ties between volcanological and meteorological agencies. One of the limitations of satellite-based monitoring of Mayon is that, being in the moist tropics, it is often obscured by cloud. While there have been some successes in satellite-based volcanic cloud monitoring (Sawada, 1987) and with satellite detection of hot spots (Wright et al., 2002), many eruptions have been completely obscured.

A critical piece of data for volcanic cloud monitoring is the height of an eruption. The greater part of ascent of volcanic clouds is driven by convection (Woods, 1998), and the amount of water entrained into, or already present in an eruption plume, substantially influences the height of ascent of small-to-medium sized eruptions (Graf et al., 1999; Woods, 1993). However the dynamics of volcanic clouds are still imperfectly understood, with relatively few reliable observations taken of volcanic cloud ascent (Sparks et al., 1997). The location and activity of Mayon Volcano make it an ideal subject for study of eruption clouds. The PHIVOLCS observatory at Lignon Hill provides a well-staffed, secure observational site. In addition, a PAGASA upper-air station (WMO 98444) is located in Legaspi, although recently radiosondes have been seldom performed due to resource issues (E. Adug, PAGASA, personal communication, 2003).

In this note, we show some satellite imagery of clouds from the eruptions of 29 February, 2000. Then we explain the ground observation system, and discuss the preliminary results.

2. The 29 February 2000 eruption

2.1 Summary of eruption

The 29 February 2000 eruption was a Vulcanian phase of a sequence of mostly Strombolian activity that began in May 1999 (Catane et al., 2003; Smithsonian Institution, 2004). PHIVOLCS had recommended evacuation of the population by 23 February 2000; on that night lava emission commenced, and ash and gas explosions occurred from 24 February to 1 March. Of these, only the eruptions beginning on 29 February and continuing to early 1 March were clearly visible on satellite imagery. In addition to the local effects, the eruptions caused major disruption to aviation, in part because of various difficulties in obtaining and receiving aviation warnings. However, no aircraft encounters with the ash clouds were reported. The total volume of pyroclastic deposits from the eruption was estimated at 13,907,810 m$^3$ (Catane et al., 2003).

2.2 Satellite imagery of eruption clouds

The major operational algorithm for volcanic clouds detection in the region is the ‘reverse’ absorption algorithm (also known as the ‘split-window’, ‘brightness temperature difference’, or ‘aerosol vapour index’ technique) (Prata, 1989a, b), which is used in combination with visible and infrared imagery (Tupper et al., 2004). Figure 2 shows four infrared images during the dispersion of three of the ash clouds observed during this period. In this image, pixels with negative Brightness Temperature Differences (suggesting ash) are overlaid in dark grey. Clouds A and B appear to derive from the same explosion, at 0701 UTC, but dispersing at different rates. A notable point is that cloud A shows no negative pixels. Examination of scatter diagrams for the eruption (Prata et al., 2001) further suggests that there is no detectable ash signal in cloud A, but strong ash signatures in clouds B and C. It appears that either glaciation of water onto the ash aerosols within the high level cloud obscured the ash signal, or that the cloud contained insufficient ash to detect.
Figure 3 shows trajectory forecasts from NOAA (Draxler and Rolph, 2003) and Bureau of Meteorology (Draxler and Hess, 1998) implementations of HYSPLIT, with FNL and LAPS data respectively. The data were consistent at high levels (not shown for the HYSPLIT/LAPS run); however variations in the lower level wind fields have produced slight differences in the lower levels.

In the HYSPLIT/FNL trajectories, the right-most line shows the forecast path of a cloud at a height of 14 km, which is consistent with the observed movement of cloud A and the coldest observed temperature in that cloud. The middle trajectory, at 6000 metres altitude, is consistent with the much slower movement of clouds B and C. The explosion leading to the release of cloud C does not appear to have been specifically reported (Smithsonian Institution, 2004), which is unsurprising given the darkness, and heavy ash-fall from earlier activity. Heavy ashfall at the ground was reported to the west and southwest of the volcano (Smithsonian Institution, 2004), consistent with the lower level trajectories in both sets of model output.

Figure 2. Infrared GMS-5 imagery of eruption clouds from the 29 February 2000 eruption, labelled A, B, and C. Images times are nominally 0832, 1025, 1230, and 1730 UTC - satellite scanning time over Mayon is approximately 10 minutes later.

Figure 3. Forecast trajectories for clouds from the 0701 UTC eruption. Left panel: NOAA/HYSPLIT display using FNL data, trajectories starting at 3000, 6000, and 14000 metres. Right panel: Bureau of Meteorology HYSPLIT using LAPS data, trajectories starting at 2462 (mountain top), 3000, and 4500 metres.
This reflects a common difficulty with ground-based volcanic cloud reporting; the higher level clouds tend to have finer ash particles and little noticeable fallout away from the eruption source, and tend to be less well observed.

NOAA/AVHRR data will generally give a clearer picture of volcanic ash clouds due to data and spatial resolution, and a better separation between the 11 and 12 µm channels (Tokuno, 2000). Figure 4 is a reverse absorption image shortly after the release of cloud C. The 12-11 µm signal for clouds B and C is clear, but the AVHRR results are consistent with the GMS imagery in having no substantial reverse absorption image for cloud A.

3. Interval recordings with visible-spectrum cameras

Video monitoring at Mayon Volcano Observatory in Lignon Hill commenced on 22 June, 2003, with the installation of a digital camera to take one photo an hour, and a video camera recording for 0.5 seconds every ten minutes. This time interval has been found to be suitable for monitoring the evolution of volcanic clouds in experiments at Japanese volcanoes (Kinoshita et al., 2003). The digital camera Sharp MD-PS1 operated for 58 days until 19 August. A part of the records, at 7, 12 and 17 o’clock in the Philippine standard time (= 8+UTC) every day during June 24 - Aug. 19, 2003 are shown in http://arist.edu.kagoshima-u.ac.jp/volc/mayon/photo.htm.

During this period, the volcano has been ejecting plumes from the summit crater almost always in the visible scenes, though the activity at the volcano has been relatively quiet without strong eruptions. The heights and directions of the plumes were analysed by comparing with wire frame images and scales, with the following results (Hamada et al., 2004): (1) Cloud-free scenes are rather limited to morning and evening, as the clouds develop to cover the summit in the daytimes in sunny days. (2) Average height of the rising plume is about 560 m from the summit for the analysable scenes during 24 June and 16 August 2003, where blow down cases and the directions difficult to estimate the height are excluded. (3) There is a seasonal variation even in this short term.

As the English manual of the digital camera was not supplied and the indications in its display screen are only in Japanese, the restart of the camera was not successful with hand-made quick notes only. The SONY video camera DCR-TRV22 has been set for the interval recording, which is equipped with the display and a manual both in English. The restarts have been successful in unavoidable power shortages beyond the capacity of the uninterrupted power supply, such as the typhoon, troubles in the power plant and supply lines, and the renovation change in the observatory for new systems. During 22 June 2003 and 24 February 2004, records for 167 days are obtained, while the data for 77 days are lacking. All the data with the summit scenes have been converted into.
mpeg movies, which are under investigation. It should be noted that more than half of the days recorded are cloudy without the view of the volcano, and good views are rather limited in the morning and evening because of the tropical weather and the orographic effect of the high mountain. Some of the highlighted scenes until 21 September 2003 are displayed at http://arist.edu.kagoshima-u.ac.jp/volc/mayon/video/video.htm

Fig. 6 shows typical patterns of the plume flow according to the wind around the summit height: For fresh wind, the plume flows almost horizontally without rising as shown in (a), as the buoyancy is lost by quick mixing with the ambient air, in contrast to the rise up to the balanced height under mild wind as shown in (b). If the wind is so strong to form a mountain lee wave, the plume is blown down along the flank of the mountain and then rise as shown in (c). Such features are in common with the plumes at Sakurajima and other volcanoes well observed with the height around 1km. A different feature is that the blow down seems to be confined to the middle of the flank, without descending to the ground level, indicating that the Froude number is not so large as in the cases of the former ones, owing to the crater height more than twice of the former.

The video imagery has also shown a remarkable scope of interactions between the volcano and the moist atmosphere (Figure 7). In particular, we have been able to see the frequency with which plumes from Mayon interact with convection forming on the mountain.

Figure 6. Typical scenes of the plumes at Mayon volcano.  
(a) Horizontal flow,  
(b) Rise and flow,  
(c) Lee wave pattern.

Figure 7. Three sequences of still shots from video recording of Mayon during 2003, showing, top to bottom: orographic cloud formation on 23 June 2003, shallow convection in the plume from the volcano,
gradually evolving into deep convection on 11 August 2003, and rapid formation of deep convection about the plume on 15 August 2003.

enabling the transport of trace amounts of volcanic materials to high altitudes even in the absence of explosive eruptions (Tupper et al., 2003a).

4. Network camera system to take visible and near infrared images

On 24 February 2004, we installed a network camera system that has a visible and near-infrared camera in parallel, as shown in Fig. 8. The near-infrared camera allows clearer discernment of ash cloud (Kinoshita et al., 2004), and also the detection of high-temperature anomalies, as in the case of 2001 eruptions. Although the sensitivity of the camera is not as high as that of high-sensitivity camera for the nighttime, it has relatively inexpensive, and therefore expendable, and ideal for exploratory investigations. The system is modular in design, easily maintained, expandable and suitable for both research and real-time applications.

The system operated as a local network to store visible images every ten minutes during 5:30 and 18:30, and near-infrared images every one-hour continuously. The numbers of the image files were thus limited, not because of the capacity of the network attached storage, but for its easy maintenance. A wide scope of view is adopted for the visible camera as shown in Fig. 9a to see the flow of volcanic cloud, while a little close-up is done for the near-infrared camera as shown in Fig. 9b to see the hot anomaly at the summit crater. The interval recording by the video camera has been continued as a backup of the system. The set-up of three cameras are shown in Fig. 10.

Figure 8. System design for visible and near-infrared network camera system.

Figure 9. Scope of the view for the network cameras.

Figure 10. Three cameras at Mayon Volcano Observatory. From the left to the right, near-infrared and visible network cameras connected to the hub, and a video
camera standalone. The power is provided through uninterrupted power supply. Since April 2004, the network camera system is connected with Internet, and real time access is possible from Quezon and Kagoshima. We are now constructing a semi-real time homepage for the worldwide demand. A schematic diagram to show the flow of the information is shown in Fig. 11. Conservative policy is necessary to protect against the destruction by hackers.

5. Conclusions

The February 29, 2000 eruption of Mayon volcano was one of the few recent events where volcanic ash could be detected from space for Mayon volcano. While the lower level eruption clouds showed ash using the reverse absorption technique, the higher cloud did not.

Following the success of the initial installation of time-lapse video and still camera recording systems at Mayon, we installed a network camera system with near-infrared and visible images, which is now connected with the Internet. It may contribute to real time monitoring of the eruption, and to the investigation of volcanic clouds in the tropical atmosphere. Tentative results are displayed in the homepage “Continual Observation of Eruption Clouds at Mayon Volcano”, http://arist.edu.kagoshima-u.ac.jp/volc/mayon/.

The tropical weather and the orographic effect of the high mountain are the problematic to the ground monitoring, and good views are rather limited in the morning and evening because of the diurnal change of the weather.

Acknowledgments

We are grateful to Kagoshima University and PHIVOLCS for the support of this project. We gratefully acknowledge the assistance of the staff at Lignon Hill observatory in running and maintaining the video equipment, Mr. R.A. Valerio of PHIVOLCS for the network operation, and Paul Stewart of the Australian Bureau of Meteorology, and Barbara Stunder and the team at the NOAA Air Resources Laboratory (ARL) READY web site (http://www.arl.noaa.gov/ready.html) for the provision of HYSPLIT output.

References


