Image Recordings of Eruption Clouds at Bulusan and Mayon Volcanoes, Philippines

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Abstract
The methods, results, and prospects of image recording of volcanic clouds are discussed by considering two volcanoes in the Philippines, Mayon and Bulusan. At Mayon volcano, video and network cameras are utilized for automatic time-interval long-term recordings. Near-infrared and night-shot modes in addition to the conventional visible mode are adopted there. Since the inception of recording in June 2003, the daily activity of the volcano was the almost continuous ejection of white vaporous plumes. Explosive eruptions with lava ejections that occurred in July–August 2006 and December 2009 were recorded during both daytime and nighttime. Near-infrared and night-shot modes were very effective for observing flows and falls of hot lava and also the foreboding indication of hot lava glow at the summit crater some months earlier at nighttime. At Bulusan volcano, video recording using a digital high-vision video camera with smooth interval mode began in November 2010. Records of explosive eruptions in late 2010 were obtained during daytime at a fixed point located 23 km from the crater.

Key words: Bulusan volcano, Mayon volcano, interval recording, volcanic cloud, lava flow, near-infrared mode, night-shot mode

I. Introduction
Investigating volcanic clouds is very important for understanding volcanic activity, managing volcanic hazards to inhabitants and aircraft, and predicting tephra fall onto the ground. As the features of volcanic clouds change from day to day and through longer periods of time, long-period recording is necessary. To keep long-time-period data manageable, recordings at fixed time intervals are effective for obtaining time-lapse video records, which may reveal dynamic features of the atmospheric flow in rapid motion.

The Philippines contain many active volcanoes with historical eruptions (Fig. 1a; Catane et al., 2005), the catastrophic eruption of Pinatubo in 1991 being one of the largest to have occurred in the 20th century (Newhall and Punongbayan, 1996). Since the Pinatubo eruption, Mayon volcano (Fig. 1b), near Legazpi City in southeast Luzon, has been the most active volcano in the country. Following a major eruption in 1993 that resulted in 77 fatalities, the volcano has recently become active again with significant eruptions, during which lava sometimes flowed to the foot of the volcano, in 1999, 2000, 2001, 2006, and 2009. See Bornas et al. (2013) for a description of the recent activity of this volcano and the monitoring network there.

Likewise, Bulusan volcano (Fig. 1b) in Irosin caldera, at the southeastern tip of Bicol Peninsula in Luzon, is one of the most active volcanoes in the...
Philippines. Explosive activity with ash ejection occurred in 2006, 2007, 2010, and 2011. The locations of prominent active volcanoes in Luzon are shown in Fig. 1.

Automatic interval recording of volcanic clouds at Mt. Mayon with video and digital cameras was begun in June 2003 as a joint effort of the Philippine Institute of Volcanology and Seismology (PHIVOLCS) and the Kagoshima University group; a network camera–computer system with Internet connection was added in April 2004 for real-time monitoring accessible in Quezon City, metro Manila, and Kagoshima (Kinoshita et al., 2004). Using these cameras, daily steam-emission activities, as well as the 2006 eruption that included many lava flows down to the foot of the volcano, have been recorded. Numerous nighttime images of the hot lava flows were obtained by near-infrared (NIR) camera and by video camera using the night-shot mode (Kinoshita et al., 2007, 2008). Video records of the December 2009 lava eruption were also obtained, although the network camera–computer system had been damaged by heavy rain associated with Super Typhoon Reming (Durian) near the end of 2006.

Video observations at Bulusan volcano began in November 2010. We here provide a brief summary of recent eruptions at Bulusan, observation records at Mayon volcano, and preliminary results of the video recordings at Bulusan.

II. Volcanic cloud ejection activity at Bulusan volcano

Bulusan volcano (1565 m a.s.l.), shown in Fig. 2, is a stratovolcano with several vents and fissures around its summit, some of which have opened recently. The volcano formed during the post-caldera activities stage following the formation of Irosin caldera at 41 cal ka BP (Mirabueno et al., 2007; Kobayashi et al., 2014). Its historical
record of eruptions began in 1852 and consists of 15 events until 1995, a time period including a 45-year repose period (which was the longest) extending from 1933 until the volcano erupted in 1978 (PHIVOLCS, 2002; Catane et al., 2005). Most of these eruptions were mild ash ejections from the summit crater with volcanic explosivity index \( VEI = 2 \), but the strongest ones, which occurred in 1980 and 1981, were phreatic eruptions with \( VEI = 3 \). The \( VEI \) was devised by Newhall and Self (1982) to classify the explosivity of eruptions on a scale of 0–8 according to the volume of ejected volcanic products.

After being quiescent from 1995, Bulusan volcano began a series of eruptions from summit craters on 21 March 2006. In the following, we briefly summarize recent eruptive activities on the basis of published bulletins of PHIVOLCS (2006–2011a), an internal report (PHIVOLCS, 2011b), and records at the Bulusan Volcano Observatory of PHIVOLCS (Tubianosa, 2008) and Delos Reyes et al. (2014). Philippine Standard Time, which is UTC + 8 h, is used throughout the paper.

Table 1 lists in chronological order the eruptions with heights exceeding 500 m above the summit that have occurred since 2006. The list also includes prominent eruptions for which column height could not be observed because of cloud cover or darkness but for which strong signals, such as volcanic earthquakes detected by the seismograph network, rumbling sounds, and ashfall deposits in near-by villages, were obtained. Figure 3 is a typical example of the ashfall distribution caused by an explosion, which occurred in the middle of the night on 15 November 2010. Surveys of ashfall deposits have been conducted by the Bulusan Volcano Observatory, PHIVOLCS, for many phreatic eruptions.

The features of recent volcanic activities are classified into three active periods, March–June 2006, October 2006–October 2007, and November 2010–May 2011, with the other periods being relatively quiet. In the active times, explosive eruptions ejecting ash columns with heights of a few kilometers occurred occasionally, as did mild eruptions of ash or ash-and-steam clouds with heights of 0.5–1 km. Continuous emission of a steam plume with a height of less than 0.5 km was often observed in the active periods, especially before and after the eruptions. White steam plumes with heights of less than 0.4 km were observed occasionally during the noneruptive periods.

Values of the emission rate of sulfur dioxide \( (SO_2) \) by the volcanic plume were obtained by a scanning operation using a remote-sensing apparatus called FLYSPEC mounted on a car. The values were 942 tons per day \((t/d)\) on 26 June 2006, 597 t/d on the next day, and 500 t/d on 25 May 2007. These values indicated a small amount of magma intrusion into the volcano.

After considering all the seismograph network data, low \( SO_2 \) emission rates, eruption records, especially the absence of juvenile materials in the ash erupted and others, PHIVOLCS summarized the recent activities as phreatic, caused by the interaction of heat from small volumes of intruded magma with an overlying water-saturated zone.
beneath the summit, which developed overpressures released during each explosion.

The explosive eruptions produced ashfall deposits with thicknesses of 1–5 mm in the downwind direction, as shown in Fig. 3. Heavy rains soon after eruptions sometimes brought lahars that flowed into villages and disturbed traffic. Fortunately, no one has been injured in recent eruptions of Bulusan. The alert level was raised by PHIVOLCS to 1–2 during most of the active periods. The permanent danger zone (PDZ), within which the public is advised not to enter, is defined by a 4-km radius around the volcano. The alert level on a scale of 0–5 and stand-down procedures are made available at the PHIVOLCS Web site.

On 10 November 2010, we began video recordings of eruption clouds at Bulusan Volcano Observatory in Sorsogon, as described in Sect. IV. The location of the observatory is indicated in Fig. 3. However, before presenting the video report for Bulusan volcano, we next discuss Mayon volcano from records accumulated over several years.

### III. Image recordings at Mayon volcano

Mayon volcano has been moderately ejecting vaporous plumes almost continuously without strong eruptions for many years. However, lava ejections from the summit crater have occurred recently at 1- to several-year intervals, as described in Sect. I. Since image recordings began in 2003, lava ejections have been observed in 2006 and 2009.

#### 1) Methods of long-term camera observation

Automatic long-term observation at Mayon Volcano Observatory of PHIVOLCS started in June 2003, with the use of digital video and still cameras. Located at Lignon Hill, Legazpi City, Albay, Philippines, the observatory is 11 km south–southeast from the summit crater of Mayon volcano (Fig. 4). A Sony video camera (DCR-TRV22) with a 1/4-inch charge-coupled device (CCD) was set mostly for interval recordings of 0.5 s every 10 min, enabling 3-month records on a mini-DV cassette. The interval was adjusted to be shorter during very active episodes.

A digital still camera (Sharp MD-PS1) with an interval mode for visible light was set to take one photograph every hour as a backup for the video camera recording. It operated for 58 days from 23

<table>
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<th>Date</th>
<th>Time</th>
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<td>25 May</td>
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![Table 1](image)

June to 19 August. An overview of the long-term activities of a volcano can be seen at a glance in an album of digital still-camera scenes, although short-term phenomena may often be missed because of the long time interval.

A pair of Axis network cameras with visible and NIR modes was installed and connected to network attached storage (NAS) in February 2004. The network camera operated as a server with a small data capacity, which was supplemented by NAS via an Intranet. The system has been connected to the Internet since April 2004 for real-time monitoring accessible from Quezon and Kagoshima. Internet traffic between the servers at the nearby stations has often been unstable under tropical conditions during thundersqualls. Therefore, the local storage of data has been very important for research studies. Fortunately, internet connectivity was good at the time of the summer 2006 eruption, enabling access to the network cameras from Japan through many days.

The NIR mode was attained by using a filter (Fuji film IR84) to shield visible light with wavelengths less than 840 nm from the camera (Axis 2420-IR Sensitive), which has coverage for both visible and NIR light. The advantages of NIR mode include easy identification of hot lava and clearer discernment of faint aerosols, which

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Fig. 3  Map showing distribution of ash fall (broken line) by the eruption on 15 November 2010 (PHIVOLCS, 2011b). Bulusan Volcano Observatory in Sorsogon is indicated by an open square.
would be almost undetectable in ordinary view with visible light because of the clear contrast with the background fine sky, which is very dark in NIR view. The visible network camera was an Axis 2120, and the network-attached storage was a Logitec LHD-NAS120 with a capacity of 120 GB. The network cameras were set to store visible images every 10 min during daytime and NIR images every hour during day and night.

The night-shot mode of the video camera (DCR-TRV22) is useful for acquiring images of hot lava at nighttime, as the camera becomes infrared-sensitive when the infrared cut filter (ICF) installed inside the camera body is removed. Figure 5 describes schematically the optical paths of visible and NIR lights with the two kinds of filters (Kinoshita et al., 2003). Because the photo-CCD is originally sensitive to both visible and NIR light up to about 1100 nm, the ICF is necessary to attain good color balance in the conventional camera, as shown in Fig. 5a. The night-shot mode switch mechanically moves the ICF out of the optical path so that NIR light reaches the CCD along with visible light (Fig. 5b), which increases the bulk sensitivity, similar to an IR-sensitive network camera without an ICF. An NIR image is obtained by attaching an IR filter, as shown in Fig. 5c, without ICF.

2) Daily activities

The volcano was ejecting white vaporous plumes from the summit crater almost continuously through most of the scenes, and moderate ejection activities occurred without strong eruptions. Fine-weather scenes are rather limited to early morning and late afternoon because orographic clouds that cover the mountain with an altitude of 2462 m above mean sea level develop during the daytime on sunny days. The height of the rising plumes was a few to several hundred meters above the summit under mild or weak winds, but the plumes crept downslope or blew down below the summit height under prevailing strong winds. Figure 6 shows typical scenes under mild wind (a and b), strong wind (c), and weak wind (d). By comparing the first two images, we see that

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![Image of geomorphological map of Mayon volcano](image1.png)

**Fig. 4** Geomorphological map of Mayon volcano. Filled circle indicates locality of Mayon Volcano-Ligöñon Hill Observatory. Slope gradation map (Sasaki et al., 2008) was used as base map. Contour interval is 20 m.

![Image of optical paths diagrams](image2.png)

**Fig. 5** Optical paths of visible and NIR lights versus filters for a CCD camera. (a) Conventional mode sensitive to visible light. (b) Night-shot mode sensitive to visible and NIR lights. (c) NIR mode.
the faint plume shown in visible light (a) can be detected more clearly in NIR mode (b) due to its contrast with the background sky. The NIR image also exhibits detailed topography because of the shadowing of solar radiation, and the lack of vegetation on the recent lava deposits causes these to show as dark areas (absorbing NIR radiation) on the mountain slopes, in contrast to the strong NIR reflection from vegetated areas.

3) Explosive eruptions with lava ejection

From May to November 2005, the hot glow of the lava dome within the summit crater was often observed at nighttime, indicating intrusion of fresh lava from the conduit. In July 2006, a considerable amount of lava was ejected from the summit crater, resulting in lava flows that traveled in the southeast direction down to an elevation of 450 m. Numerous nighttime images of hot lava flows were obtained subsequently until the end of August by both the NIR camera and the video camera in night-shot mode (Kinoshita et al., 2007, 2008).

From June 2009, ash clouds were often ejected explosively from the summit crater, where a glow of hot lava appeared during nighttime on 14 August. Lava flows from the crater started on 14 December and lasted until the end of the year. Figure 7 shows related video images in conventional visible mode for daytime and night-shot mode for nighttime. As NIR light penetrated the mist and clouds over the hot lava to some extent, we clearly see blocks of falling lava at the leading edge and lava flows along the slope in the nighttime images. The daytime images of the lava flow, however, were obscured by covering clouds of ash and steam, which reflected visible and NIR wavelengths of solar radiation. The network camera system was damaged by Super Typhoon

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Fig. 6 Volcanic plumes at Mt. Mayon with moderate activities. (a) Visible mode image at 07:00 h on 5 July 2004. (b) NIR mage of the network camera at the same time as (a). (c) A video image at 07:35 h on 30 August 2007. (d) The same as (c) at 07:39 h on 25 March 2008.
Reming (Durian), which brought extremely heavy rain to the region around Mayon volcano on 30 November 2006, generating destructive lahars and river floods resulting in 1200 casualties.

Summaries of observation records of daily and explosive activities during 2003–2006 were reported by Kinoshita et al. (2007, 2008), and many records until 2009 are available in the form of albums and movies at the Web site "Continual Observation of Eruption Clouds at Mayon Volcano".

IV. Video recording at Bulusan volcano

1) Recording apparatus

The functions of digital recording apparatuses have changed extremely quickly in recent years. The interval recording mode was omitted in video and still cameras for home use in 2010 by most of the major manufacturers, such as Sony, and the night-shot mode is now available only in some video cameras. We chose the Panasonic video camera HDC-TM700, which is one of the few apparatuses currently available for interval recording. It has a smooth interval function for recording a frame of 1/30 s in NTSC format on an SDHC memory card every 1, 10, 30, 60, or 120 s. Its capacity of up to 64 GB is large enough for full high-vision quality with $1920 \times 1080$ pixels. However, automatic interval recording can continue for only 12 h, necessitating a restart to record further. The so-called color night mode works down to 1 lux and is less sensitive than the night-shot mode for NIR light. Nighttime recording may be possible for only very strong eruptions with lava ejection. Another problem is that superimposing the date and time is only possible by downsizing
the analog output with RCA cables or under very limited environments with full high-vision quality.

2) Setup at Bulusan volcano

The video camera was installed in the new observatory at Cabid-an in Sorsogon City, about 23 km north of the summit of Bulusan volcano, as shown in Fig. 3. The observatory is well staffed with permanent personnel on a 24-h basis, and the 12-h interval recording each day during the daytime is adequate for moderate volcanic activities. For emergency situations, nighttime recording may be worthwhile as very bright lava flows can be recorded by applying the color night mode.

Snapshots of Bulusan volcano taken from the observatory are shown in Fig. 8. The somewhat long distance is suitable for obtaining whole views of volcanic clouds in wide scopes, as in (a) and (c), and detailed views may be obtained by close-ups, such as (b). Because the observatory is surrounded by tall wire-net fences, the camera position can be set high, as shown in (d).

3) Eruption records of late 2010

Video recording was started on 10 November, and 14 days of records were obtained until 16 December 2010 by the staff members of the observatory. This duration of the recording belongs to the latest eruptive activities of November 2010–May 2011 after 3 years of dormancy, as described in Sect. II-3. The interval recording method was adopted only on limited occasions; most of the records were obtained by conventional manual handling, especially just after the remarkable eruptions. A few of these events, which were captured from video records with the date and time superimposed, are shown below.

In the morning of 12 November, an ash explosion occurred from the summit crater. The explosion produced an ash and steam cloud that rose to about 700 m above the summit and drifted southwest. Prior to the ash explosion, weak steaming was observed from the crater during times of good visibility. Figure 9 shows video records of the developed drifting eruption column just after the eruption. Adopting a fixed close-up view, the
column left the scope after 10 min. The bottom of the eruption column in Fig. 9 was blown down from the summit to the flank of the mountain by strong wind. The phreatic eruption was recorded by the seismic network as an explosion earthquake, and four additional volcanic seismic events were detected during the day.

On 21 November at 07:22 h, the volcano ejected a grayish steam and ash column that reached a height of approximately 2 km above the crater rim and drifted to the west. The ash ejection was accompanied by a rumbling sound and was reflected on the seismogram as an explosion-type earthquake with a duration of 9.5 min. Prior to the ash ejection, the Bulusan seismic network detected a total of 12 volcanic earthquakes. The summit area during this period was almost covered by clouds, but it was overtopped by the ash column. In Fig. 10, the shape of the mountain in a clear scene is superimposed to make the situation more understandable. The superposition was easy in a wide view, in which the distant forest functions as a scale.

An ash explosion occurred at 13:22 h on 24 November and reflected on the seismogram as an explosion-type earthquake that lasted 5 min and 50 s. The event produced a cloud of ash and steam that was 1 km high above the crater rim and slowly drifting and dissipating to the southwest. However, no deposits of ash were observed outside the 4-km PDZ, suggesting that the ash was confined to the upper slopes of the volcano. The average SO2 flux emitted by the volcano was found to be minor, 22 t/d. Although the summit was slightly above the clouds, the eruption column was difficult to recognize in the video under the misty conditions. It could, however, be revealed in enhanced images by retouching the contrast of the raw images captured from the movie.

At 14:17 h on 16 December, the volcano ejected a grayish steam and ash column that reached approximately 500 m above the crater rim and drifted to the southwest. The ash ejection was recorded as an explosion-type earthquake with a duration of 3 min. No ashfall was observed beyond the 4-km PDZ, and no SO2 was detected during the measurement on this day. At the time of the eruption, the summit area was completely covered with clouds and the eruption plume could be seen over the clouds, as shown in Fig. 11 in which the shape of the mountain is superimposed using a clear scene acquired 2 h later.

Thus, some remarkable daytime eruptions were recorded manually just after the beginning
of the event. The cloud cover over the mountain could be managed somewhat in the fixed point observation by superimposing appropriate parts of clear scenes. A wider scope of view was preferred to obtain the drift of the eruption plumes. With improvement in the operator’s skill of handling the interval recording technique, the entire process of an eruption from the developing stage to the final dispersion stage may be obtained in compact records.

V. Remarks

Since the initiation of image recording of Mayon volcano in June 2003, eruptions with lava flows down to the foot of the mountain were observed in July–August 2006 and December 2009. Both events were preceded by some months by a nighttime observation by the NIR and night-shot modes of a hot lava glow at the summit crater. Explosive ash eruptions were another indication of the increases in volcanic activity. The daily activity of the volcano, however, was almost continuous ejection of white vaporous plumes, without strong eruptions, with plume heights of up to several hundred meters depending on wind speed. The interval records reveal these ejection activities through a long term.

The location of the observatory 23 km from the crater of Bulusan volcano is rather far as observation is often disturbed by clouds and rain during tropical weather. However, the experience of recording eruptions in late 2010 provides hope for obtaining good image records there in the future. The long distance to Bulusan is convenient for obtaining a wide view in which a large eruption cloud can be seen in its entirety and in which its drift by the wind can be observed. Even when the volcanic mountain is covered with cloud, the part of the eruption column above cloud level may possibly be observed from the far location. In fine weather, small-scale steam plumes may also be seen by close-up operation when the volcano is not in an eruptive state.

A specific feature of the video camera at Bulusan Volcano Observatory is its 12-h duration limit for automatic interval recording. Manual operation by an on-duty staff member is necessary to begin each day worth recording. The full high-visual quality of the video record is well suited to finding small plumes without much narrowing of the view angle.

Digital photographs of the eruption clouds of Bulusan volcano have often been obtained by near-by inhabitants, especially those in Irosin town 8 km south–southwest of the summit. These can be regarded as supplementary information to the video records to study the structure of the clouds. The time stamp of each photograph is helpful for coincident analysis of images shot at different places. Coincident analysis of image records of the eruption clouds and seismicity and other monitoring data may be very important for clarifying the eruption mechanism of Bulusan volcano.

Acknowledgments

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Fig. 11 A mosaic image of the eruption plume at 14:38 h on 16 December 2010, with the shape of the mountain superimposed from a clear scene at 16:24 h on the same day.
which improved the manuscript. This study was partly supported by funds from DOST-PHIVOLCS and Grants-in-Aid for Scientific Research (Nos. 21401005, 24401006) from the Japan Society for the Promotion of Science (JSPS).

Notes
1) http://www.phivolcs.dost.gov.ph/ [Cited 2014/06/19].
2) http://wwwkav.ddo.jp/volc/mayon/mayontop.html [Cited 2014/06/19].

References


フィリピンのブルサン火山とマヨン火山の噴煙映像観測

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フィリピンのブルサン火山とマヨン火山について、噴煙映像観測の方法・結果と展望について述べた。マヨン火山では、ビデオカメラとネットワークカメラを用いて長時間の間歇自動観測を行っている。そこでは普通の可視光観測とともに、近赤外光やナイトショットモードも用いている。2003年6月の観測開始以来の日常的な活動はほとんど連続的な白煙放出であった。2006年7～8月と2009年12月の溶岩流出を伴う爆発的噴火の昼夜の記録が得られた。とくに夜間の溶岩流出・落下や、その数か月前に山頂火山口に見られた高温溶岩の夜間検出に近赤外光やナイトショットモードは非常に有効であった。ブルサン火山では、滑らかな間歇撮影のできるデジタル高画質ビデオカメラによる観測を2010年11月に開始し、火口から23 km 離れた定点観測で2010年11～12月の活発な噴煙活動の記録が得られた。

キーワード：ブルサン火山、マヨン火山、間歇撮影、火山噴煙、溶岩流、近赤外光モード、ナイトショットモード

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