Measuring Sulphur Dioxide (SO_2) Emissions in October, 2010 Catastrophic Eruption from Merapi Volcano in Java, Indonesia with Ozone Monitoring Instrument (OMI)

José A. Morales-Collazo

Geology Department, University of Puerto Rico, Mayagüez Campus
Call Box 9000 Mayagüez, Puerto Rico, 00681

Abstract

This paper discusses sulfur dioxide (SO_2) cloud emissions from Merapi Volcano in Java, Indonesia during the eruption that started on October 26th 2010. Vigorous cloud emissions up to 15km in altitude were reported from the 4-13 of November with SO_2 mass of 227kT was calculated for the 5th of November without specifying the cloud altitude. This study uses the Ozone Monitoring Instrument (OMI) to study the emissions by Merapi from the 4-16th of November 2010 and calculate the cloud's direction, distance and SO_2 mass to determine affected areas. This study also seeks to present more accurate results to the SO_2 cloud mass in 15km of altitude. Extensive research has concluded that OMI is a remote sensor with high sensitivity to SO_2 emissions compared to AIRS and MODIS, capable of detecting the irradiance from the volcanic clouds. OMI is an ultraviolet (UV) sensor that covers wavelengths from 300-350 nm with a spatial resolution of 13 x 24 km. The images were downloaded from Mirador search engine, processed using ENVI 4.8 + IDL coupled with OMIPLOT software and values were calculated for the 15km of altitude 3image. The most vigorous cloud was detected during the 5th of November with a SO_2 mass of 93.6 kT traveling 620km southwest of Java. Affected areas include Central Java and West Java. The results assess that the previous report calculated the SO_2 mass in a lower altitude, which is not reliable since the cloud achieved higher elevations. These reports must be considered when planning emergency measurements.

Key words: Sulphur dioxide, volcanic clouds, Ozone Monitoring Instrument, Merapi volcano.

INTRODUCTION

The major contribution of sulphur dioxide (SO_2) emissions to the atmosphere is due to volcanic degassing (Thomas et al. 2011). The lifetime of SO_2 in the troposphere will depend on the climate conditions, but typically, it only stands for a few days before reacting with water vapor to form aerosols that spread rapidly around the globe (Loyola et al. 2008). Volcanic cloud emissions have a series of impacts on the environment: volcanism has significant implications in climate change (Robock 2000), the addition of SO_2 aerosols into the atmosphere can increase the possibility of acid rain being formed (Menz and Seip 2004) and also can be detrimental to the local population within the area (Mather et al. 2003).

Merapi Volcano is one of the most active in Java, Indonesia. In October 26th, 2010, a catastrophic eruption was reported from Merapi causing nearly 386 deaths and 300,000 evacuations. This eruption consisted mostly of pyroclastic flows that became vigorous during the weeks of November 4-13.

The most vigorous and explosive event was reported during November 8th with a SO_2 cloud mass of 227kT at a not reported elevation, however, most of the volcanic plumes went up to 15 ± 5 km in elevation. (BGVN36:01, 2011)

Sulphur dioxide in volcanic clouds can be easily detected by remote sensing, because this volcanic gas has a very low abundance in the atmosphere and a unique spectral signature. Values of SO_2 can be quantified by a series of satellites that vary in spectral and spatial resolution; these satellites are the Moderate Resolution Imaging Spectro-radiometer (MODIS), Atmospheric Infrared Radiation Sounder (AIRS) and the Ozone Monitoring Instrument (OMI) (Thomas et al. 2011). Previous studies have concluded that OMI is highly sensitive to the solar irradiance scattered and absorbed by the particles of the atmosphere (Levelt et al 2006), especially for SO_2, due to its signatures in the ultraviolet (UV) band (Thomas et al. 2011).

This study seeks to estimate the SO_2 mass, distance and direction of the volcanic cloud emitted from Merapi during the October, 2010 eruption to assess the affected areas and provide vital information about how much of an impact these clouds can have on these areas.

MATERIALS AND METHODS

Location

Merapi Volcano is a highly active strato-volcano located north of Central Java's capital Yogyakartathe. Merapi is the youngest and southernmost volcano of the volcanic chain extending NNW to Ungaran volcano (7°32'30"S, 110°26'30"E). It is a historical volcano of about 3 km high that formed during the Pleistocene and is located in a highly populated area in Java, Indonesia (GVP). Merapi is monitored constantly by the Merapi Volcano Observatory (MVO) were the determined eruption rate was determined to be from 5-10 year interval.

Sensor Overview

The Ozone Monitoring Instrument is a sensor that was launched in the Aura spacecraft on July 15th, 2004 from California. The satellite circulates in a 98.2° inclination in a polar orbit at 705 km of altitude (Levelt et al. 2006). A field of view of 114° allows a global coverage with a pixel size of 13 x 24 km^2 at nadir and cover a spectral resolution in the visible wavelengths (350-500 nm) and UV regions (270-380 nm) (Thomas et al. 2011). These characteristics of OMI enable the sensor to measure accurately both passive degassing and explosive clouds (Levelt et al. 2006).

OMI detects sulphur dioxide clouds by relating the differential absorption of reflected solar radiance between the gas and the ozone (O_3) present in the atmosphere. This property allows the study of volcanic plume altitudes, extent and SO_2 content (Thomas et al. 2011).

Data Products

Since the most vigorous emission from Merapi volcano was reported for November 8th, the images to be used in OMIplot were selected for November 4th to 16th a few days before and after the emission. Data products were downloaded from Nasa's Mirador search engine as specified by Simone E. Carn in a tutorial prepared for OMI (Carn 2011). This tutorial specifies that the data downloaded must be labeled under OMSO2 orbital data files to assess accurate results (Reyes, 2011)

Data processing

Data was processed and analyzed with Environmental for Visualizing Images (ENVI) coupled with Interactive Data Language using OMIplot program for selective for SO_2 retrievals (Carn 2011). The procedure for data analysis was done based on Carn 2011 tutorial with a few variations. A total of 16 images were downloaded for the dates of interest within a minimum and maximum latitudes ranging from -10 to -4 and minimum and maximum longitudes from 105 to 115 degrees respectively. OMIplot process images for different elevations in the atmosphere: PBL (planetary boundary, TRL (3 km), 5km and 15km, since the plumes reported went approximately 15km high, the image to be used to calculate the SO_2 mass will be the one labeled as 15km. For this analysis, since Merapi is a volcano of 3km high an analysis of the 3km column will not be considered since concentrations will be extremely high and will not be accurate. The output from OMIplot includes a scale bar of SO_2 mass (minimum and maxima must be established) for the plume, which is the region of interest and the surrounding areas, which is the background of the image (Reyes, 2011).

OMIplot uses the Linear Fit (LF) algorithm, developed based on earlier techniques used for Solar Backscattered UV (SBUV) and Total Ozone Mapping Spectrometer (TOMS) instrumentation (Thomas et al. 2011). This algorithm considers ten bands that correlate with the minimum and maximum absorption of SO_2 (Thomas et al. 2011). This method relies on the molecular scattering, the gas absorption bands and the aerosols present in the atmosphere mostly, however, the algorithm is highly dependable to the plume altitude where errors increase significantly with increasing column SO_2 amounts (Thomas et al. 2011).

The cloud mass calculated using the procedure established by Carn 2011, is a combination of both the plume and the background data given by the processed image. To obtain the actual SO_2 cloud mass, a correction that consists of four parameters should be applied (eq. 1). SO_{2cloud} is the plume mass obtained directly from OMIplot, A_{cloud} is the area selected to calculate the plume mass, SO_{back} is the collected information from the background (near 0) and A_{back} is the area selected for the background mass.

$$(1)\ SO2_{cloud\ mass} = SO2_{cloud} - \left(\left(\frac{Aback}{Acloud}\right) * SO2_{back}\right)$$

RESULTS

For the purpose of this project, an image for each day was analyzed individually to obtain the SO_2 cloud mass, the distance and the orientation of the plume. The four parameters to be used in the correction were obtained from OMIplot and compiled to apply the correction (eq. 1). Both cloud and background mass obtained were in kilotons (kT) and each area in square kilometers (km^2)

SO_2 cloud mass emissions were plotted in function of time for the sixteen days of interest in the 15km column (Figure 1). During the days form the 4th to the 5th of November; there was an increase in emissions from 29kT to 93kT, which was the most vigorous emission in the event. The next day, the cloud mass decreased to 22kT and then for the following days the emissions continued decreasing to cloud masses lower than 3kT. In previous studies using OMI, the most vigorous emissions of SO_2 cloud mass was calculated during November 8th for 227kT at an unknown column elevation (BGVN36:01 2011). For the same day, the calculated SO_2 cloud mass in this study was 6.81kT (Figure 1). Due to a typical systematic error of OMI, error bands overlapped the mass cloud for the 10th and 11th of November, such values were extrapolated in figure 1.

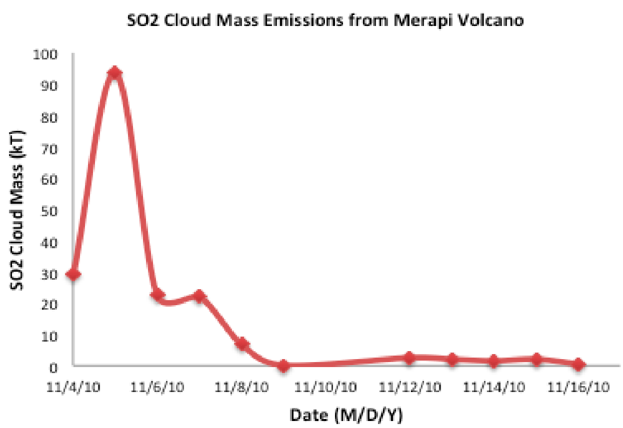

Figure 1: Change in the SO_2 cloud mass emissions from November 4-16. The peak value for this study is shown during the emission on November 5th.

The orientation of the cloud is towards the southwest of Java Indonesia since most of the images obtained show such behavior (Figure 2). Distance values were calculated to obtain the longest distance achieved by the cloud. OMIplot restricts the determination of distance to the 5km column, which may result in inaccurate values, but the purpose of the study is to obtain an average distance to have an idea how these particles spread in the atmosphere. The longest distance calculated for the plume (620km) correlates with the highest emission during the 5th of November. This cloud covered most central and southwestern part of Java and some of the nearby islands (Figure 3). Average values for the cloud distance approximated 422km, meaning that the areas within this range were affected constantly during the whole event.

CONCLUSION

The remarkable difference between the results obtained in this study and the results reported by the article BGVN36:01 2011 can be attributed to that there is a possibility that in this article the values were obtained from lower elevation clouds, for example, the 3km column which is almost near the volcano crater. Since the cloud achieved elevations of 15km and this study assessed before calculating the cloud masses, these results may be more accurate by those shown in the article.

Merapi is a highly active volcano that affects the southwestern part of Java, Indonesia. The most affected areas during this event were Central Java, West Java and Christmas Island. Government and population in these areas should consider these types of studies for emergency purposes.

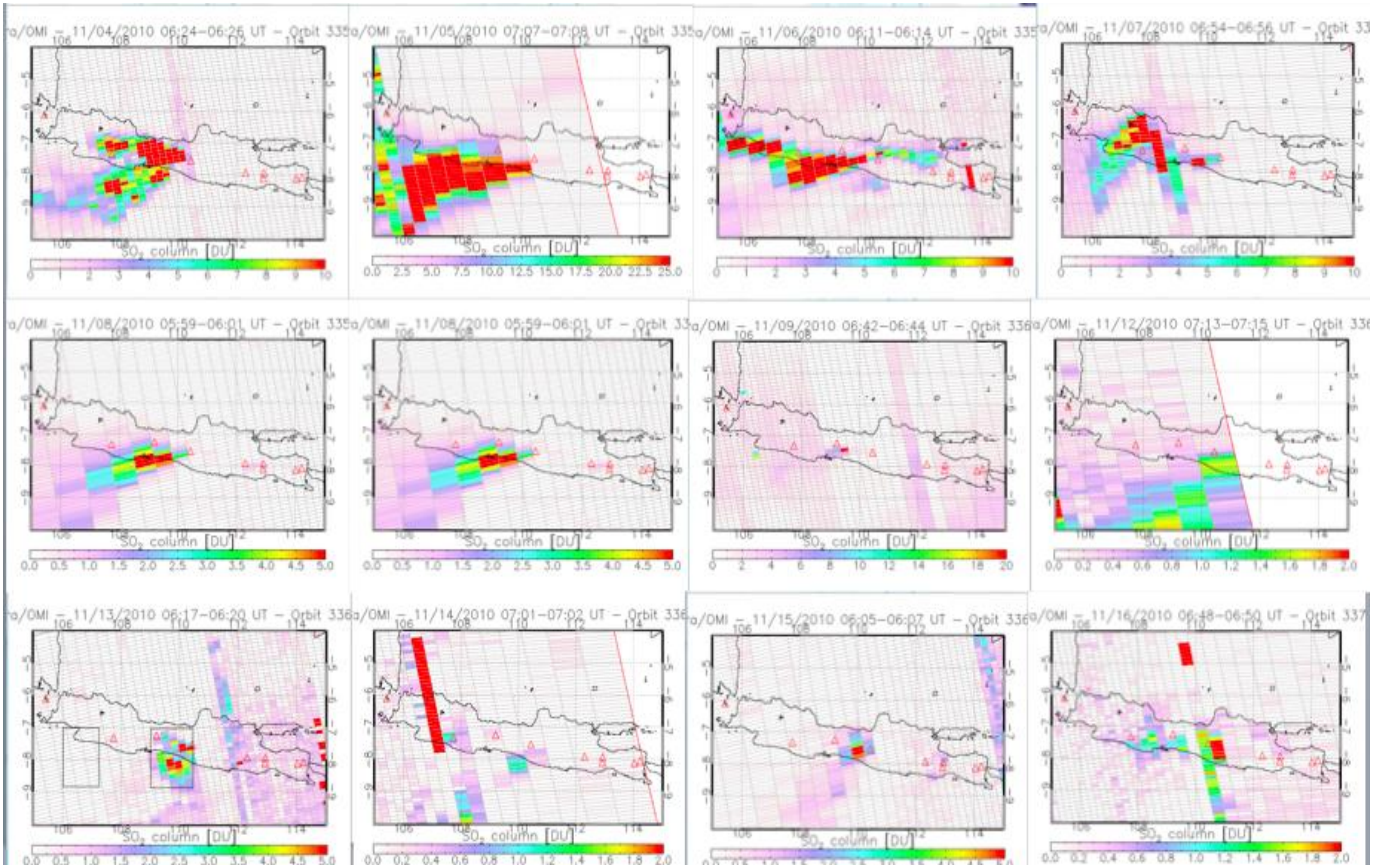

Figure 2: Processed OMI images from the 4-16 of November 2010 showing the progress of the lava plume across the selected dates. Images from November 10 and 11 were eliminated due to systematic errors. Scale bar shows red colors for higher amounts of SO_2 while white colored areas are for lower values. Note that the plume from the 5th of November shows a larger cloud with more red colored pixels covering a longer distance.

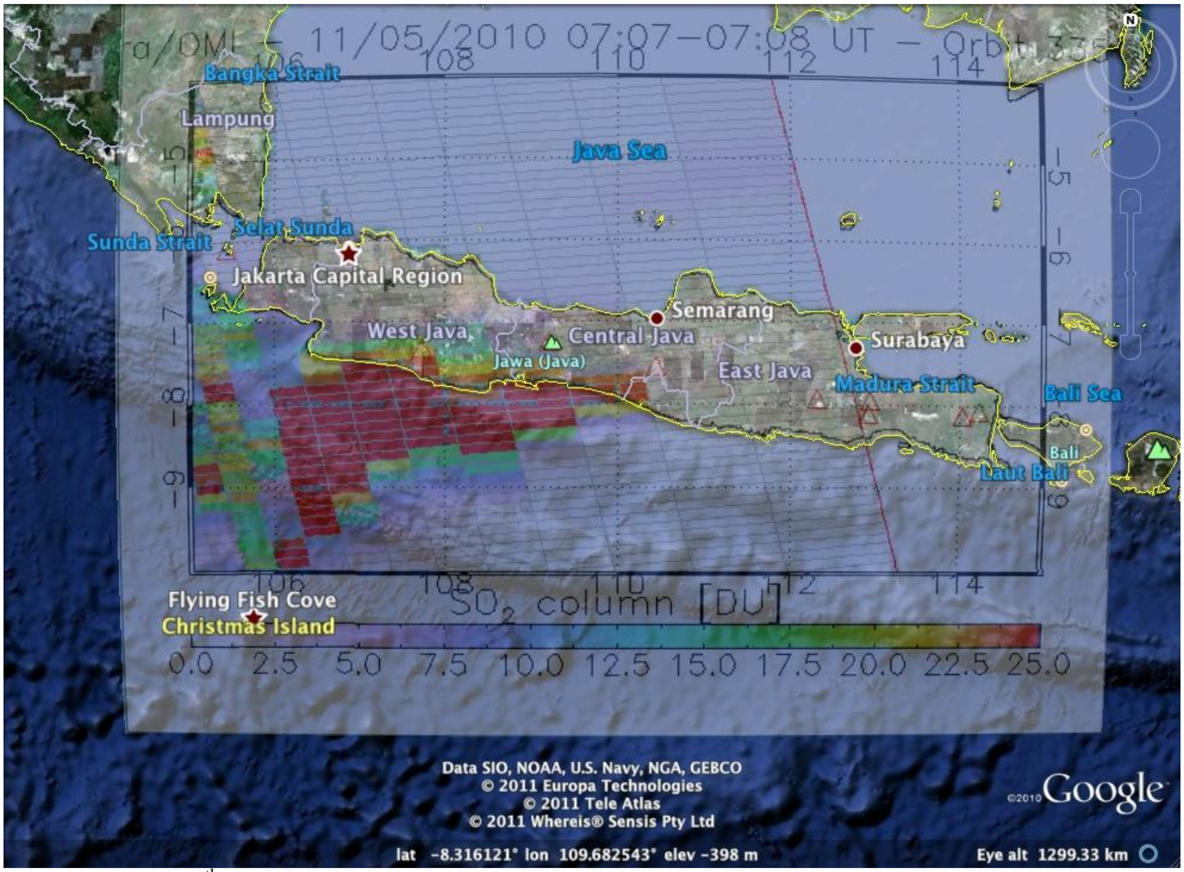

Figure 3: November 5th OMI image overlapped on the Google Earth satellite image of Java Indonesia. The image shows the affected areas by the most vigorous emission in this study. (Java, Indonesia, -8.316121 and 109.682543, Google Earth, 2006-2007, accessed November 2011)

RECOMMENDATIONS

For future works, it will be useful to make a whole analysis of the event from the day it started in October 26th to November 30th 2010. This will help assess the whole eruptive event and determine a more accurate change of the SO_2 cloud mass during that time. It will also be helpful to compare the columns from 3km, 5km and 15km to precisely show the difference between values obtained at different elevations. It will be impressive to see a comparison of these results using other satellites such as MODIS and AIRS to assess different results that will help get more reliable results.

REFERENCES

BGVN Bulletin Global Volcanism Network, (2011) Eruption started 26 October 2010; 386 deaths, more than 300,000 evacuated, 36:01.

Carn, S.A, (2011), Lab. Exercise: OMI data analysis using OMIplot. NSF Pan-American Advanced Studies Institutes (PASI), 1-9.

Google Earth, (2011),

GVP Global Volcanism Program, Merapi Volcano Summary, http://www.volcano.si.edu/world/volcano.cfm?vnum=0603-25,(Accessed October 15, 2011)

Krueger, A., Carn, S., Krotkov, N., Serafino, G., Vicente, G., (2009), Detection and Monitoring of Sulfur Dioxide from Satellite-
based UV Sensors, 1-9.

Levelt, P.F., Gijsbertus H.J. van der Oord, Dobber M.R., Mälkki, A., Visser, H., De Vries, J., Stammes, P., Jens O.V. Lundell, Saari, H., (2006), The Ozone Monitoring Instrument, IEEE Transactions on Geosciences and Remote Sensing, Vol. 44, No5., 1093-1101.

Loyola, D., Van Geffen, J., Valks, P., Erbertseder, T., Van Roozendael, M., Thomas, W., Zimmer W., Wiβkirchen K., (2008) Satellite-based detection of volcanic sulphur dioxide from recent eruptions in Central and South America, Adv. Geosci., 14, 35-40.

Mather, T. A., Pyle D. M., Oppenheimer C., (2003), Tropospheric Volcanic Aerosols, Geophysical Monograph, 139, 189-211.

Menz, F.C. and Seip, H.M., (2004) Acid rain in Europe and the United States: an update. Environmental Science & Policy, 7, 253-265.

Reyes, C., Rodríguez L., (2011), Measurements of SO_2 volcanic clouds from active volcanoes in Costa Rica, using the Ozone Monitoring Instrument (OMI), UPRM Undergraduate Research, Geology Department, 1-50.

Robock, A., (2000), Volcanic Eruptions and Climate, Reviews of Geophysics, 38, 2, 191-219.

Thomas, H.E., Watson, M., Carn, S.A., Prata, A.J., Realmuto, V.J., (2011), A comparison of AIRS, MODIS and OMI sulphur dioxide retrievals in volcanic clouds, Geomatics, Natural Hazards and Risk, Vol. 2, No. 3, 217-232

Yang, K., Krotkov N.A., Krueger A.J., Carn, S.A., Bhartia P. K., Levelt, P.F., (2007), Retrieval of large volcanic SO_2 columns from the Aura Ozone Monitoring Instrument: Comparison and limitations, J. of Geophysical Research, Vol. 112, 1-14.