Lava discharge rate estimates from thermal infrared satellite data for Pacaya volcano, Guatemala: Implications for time-averaged eruption processes and hazards

Hilary A. Morgan1, Andrew J.L. Harris1

1Geology and Mining Engineering/Sciences, Michigan Technological University, 1400 Townsend Dr., Houghton, MI 49931, 2Laboratoire Magmas et Volcans, Université Blaise Pascal, 63177, France 63000

Abstract
Pacaya is an active volcano complex in southern Guatemala that has been producing lava flows nearly continuously since 1961. Matías (2009) compiled a volcanological map of Pacaya and an associated database containing information about the 476 flows that have occurred during this time. Several attributes, including volume and eruption rate, were calculated for each flow. This information provides a unique opportunity to apply a previously developed method of calculating lava discharge rate using thermal infrared satellite data (Harris et al., 1997). Wright et al. (2001) reviewed the limitations of lava discharge rate estimates calculated using satellite thermal infrared data. The results showed that using the volume and eruption rate calculated by Matías (2009) may not provide an accurate estimate of the volume of terrain covered by the lava flow. However, the utility of this approach has been demonstrated at other geologically active volcanoes. In this investigation, 2403 MODIS and 2642 GOES images were searched to identify lava flows in Guatemala. The MODIS (MODerate Resolution Imaging Spectroradiometer) data was analyzed for all eruptions since 1961. Matías (2009) compiled a volcanological map of Pacaya and an associated database containing duration, length, area, volume, mean output rate, etc., for each flow (Figure 1).

Methods
1. Data Sources

(a) Geostationary Operational Environment Satellites (GOES) were acquired in order to supplement the data with higher temporal resolution imagery (<15 minutes).

(b) Data from the Geostationary Operational Environment Satellites (GOES) were acquired in order to supplement the data with higher temporal resolution imagery (<15 minutes).

(c) Data from the Geostationary Operational Environment Satellites (GOES) were acquired in order to supplement the data with higher temporal resolution imagery (<15 minutes).

(d) Using this information, we can calculate the total volume of terrain covered by the lava flow.

(e) The total volume of terrain covered by the lava flow is estimated using the following equation:

\[ V = \frac{A \times \rho}{\rho_s} \]

where:

- \( V \) is the total volume of terrain covered by the lava flow (m³)
- \( A \) is the total area covered by the lava flow (m²)
- \( \rho \) is the density of the lava (assumed to be 2600 kg/m³)
- \( \rho_s \) is the density of the solid material (assumed to be 2600 kg/m³)

(f) The total volume of terrain covered by the lava flow is estimated using the following equation:

\[ V = \frac{A \times \rho}{\rho_s} \]

where:

- \( V \) is the total volume of terrain covered by the lava flow (m³)
- \( A \) is the total area covered by the lava flow (m²)
- \( \rho \) is the density of the lava (assumed to be 2600 kg/m³)
- \( \rho_s \) is the density of the solid material (assumed to be 2600 kg/m³)

2. Hot spot Identification

(a) Radiance recorded from hot spots and converted to temperatures, then used to derive a mixed pixel model for a measured lava temperature (Figure 4).

(b) The pixel-integrated radiance in (f) was recorded as the background radiance.

(c) The anomalous radiance is the difference between the measured surface radiance and the background radiance.

(d) The eruption rate and area relationship for some Hawaiian lava flows is given by

\[ TADR = \frac{A}{T} \]

where:

- \( TADR \) is the time-averaged discharge rate (m³/s)
- \( A \) is the total area covered by the lava flow (m²)
- \( T \) is the duration of the eruption (s)

(e) The eruption rate and area relationship for some Hawaiian lava flows is given by

\[ TADR = \frac{A}{T} \]

where:

- \( TADR \) is the time-averaged discharge rate (m³/s)
- \( A \) is the total area covered by the lava flow (m²)
- \( T \) is the duration of the eruption (s)

3. TADR Calculation

(a) The hot spot identification was used to derive a mixed pixel model for a measured lava temperature (Figure 4).

(b) This portion was converted to an area by multiplying by the pixel size (which is different for every pixel).

(c) Then we used the derived multifield model as an assumption lava temperature (Figure 4).

(d) The usual equation can be reduced to a linear relationship, where M is a conversion factor that converts area discharged to discharge rate.

\[ M = \frac{V}{A} \]

where:

- \( M \) is the conversion factor (m³/m²)
- \( V \) is the total volume of terrain covered by the lava flow (m³)
- \( A \) is the total area covered by the lava flow (m²)

(e) The usual equation can be reduced to a linear relationship, where M is a conversion factor that converts area discharged to discharge rate.

\[ M = \frac{V}{A} \]

where:

- \( M \) is the conversion factor (m³/m²)
- \( V \) is the total volume of terrain covered by the lava flow (m³)
- \( A \) is the total area covered by the lava flow (m²)

(f) The usual equation can be reduced to a linear relationship, where M is a conversion factor that converts area discharged to discharge rate.

\[ M = \frac{V}{A} \]

where:

- \( M \) is the conversion factor (m³/m²)
- \( V \) is the total volume of terrain covered by the lava flow (m³)
- \( A \) is the total area covered by the lava flow (m²)

(g) The usual equation can be reduced to a linear relationship, where M is a conversion factor that converts area discharged to discharge rate.

\[ M = \frac{V}{A} \]

where:

- \( M \) is the conversion factor (m³/m²)
- \( V \) is the total volume of terrain covered by the lava flow (m³)
- \( A \) is the total area covered by the lava flow (m²)

4. Results

(a) The TADR and cumulative volume for each of the four lava flows were plotted in Figure 6.

(b) The TADR calculations were modified to approximate the values found by Matías (2009).

(c) This was achieved by manipulating the conversion factors "M" of the intermediate temperature model so that it amounted to the intermediate temperature calculated by Matías (2009). The value of "M" for flow 1 was different than for flow 2 (Figure 7).

(d) The cumulative volume for all four lava flows, starting with the first flow of 2010, was plotted (Figure 7).

(e) Two cycles could be identified: a short period of volumetric increase followed by a more rapid period of decrease.

(f) The long-term steady rate of increase was similar for each of the three long duration flows. This rate was suggested as being representative of the supply rate from the magma chamber to, and out of, the conduit.

Discussion: Conduit Convection

Assuming that Pacaya receives a constant supply of magma in the conduit, a supply rate could be estimated based on the eruption cycles defined here. The hypothesis is based on the premise that the magma continuously supplied to the conduit at a certain rate and is supported by (Geyger et al., 1971) original suggestion that the topographic, and chemical consistency of (basaltic) means that a steady supply to an open magma chamber. Two types of activity were observed: long, low TADR periods (Type 1), and short, high TADR periods (Type 2). It is possible that during Type 1 cycles followed by Type 2 cycles. This may be implied by the release of accumulated (pressurized) magma from a storage system (Figure 8). Additionally, the May 2010 eruption shows a high TADR burst at the start of eruption, consistent with hydrostatic influence as the upper portion of the conduit is deformed.

Discussion: Hazard Mitigation

This investigation provides a new method for the calculation of the time-averaged discharge rate and Type 2 activity in both MODIS and GOES imagery. Continued long-term monitoring of radiances may provide a means of determining the relative rate of identification of cycles, and hence the ability to assess risk to lava flows. Only MODIS data showed the potential for producing reasonable estimates of discharge rate. MODIS data could be used to produce a new hazard map based on various observed TADR and historic and possible vent locations.

Planned Work

Continued work will include surveying differences in lava characteristics, uncertainty of the total volume estimates, and environmental factors such as slope angle.

Acknowledgment

This research was supported by NASA's Grant NAG5-10975. We thank the following people for their help and comments:...