CQ3: Volcanoes

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Statement of overarching science questions and related sub-questions
Overarching Question:

Do volcanoes signal impending eruptions through changes in the temperature of the ground, rates of gas and aerosol emission, temperature and composition of crater lakes, or health and extent of vegetation cover?
Sub-questions:

1. What do comparisons of thermal flux and SO$_2$ emission rates tell us about the volcanic mass fluxes and the dynamics of magma ascent?

2. Does pressurization of the shallow conduit produce periodic variations in SO$_2$ flux and lava dome surface temperature patterns that may act as precursors to explosive eruptions?

3. Can measurements of the rate at which lava flows cool allow us to improve forecasts of lava flow hazards?

4. Does the temperature and composition of volcanic crater lakes change prior to eruptions?

5. Do changes in the health and extent of vegetation cover indicate changes in the release of heat and gas from crater regions?
Review of the science traceability matrix
<table>
<thead>
<tr>
<th>Science Objectives</th>
<th>Measurement Objectives</th>
<th>Measurement Requirements</th>
<th>Instrument Requirements</th>
<th>Other Mission and Measurement Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TQ1. Volcanoes and Earthquakes: How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?</strong></td>
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</tbody>
</table>
| Do volcanoes signal impending eruptions through changes in surface temperature or gas emission rates and are such changes unique to specific types of eruptions? [DS 227] | Detect, quantify, and monitor subtle variations in: 1) surface temperatures; 2) surface emissivity; and 3) sulfur dioxide concentrations at low, non-eruptive, flux background levels. Compilation of long-term baseline data sets. | Temperature measurements in the range −30 to 200 °C. TIR radiance measurements at ~8 μm; 5 sufficient other TIR bands for use in SO2 retrieval algorithm; 7-day repeat. | 4 TIR channels: 7.3, 8, 8.6, 12 μm, 2 bands between 8-12 μm.  
Pixel size ≤0.5 m  
NEAT ≤0.2 K, 0.2  
>95% abs. radiometric calibration | Nighttime data acquisitions.                                                                 |
| What do changes in the rate of lava effusion tell us about the maximum lengths that lava flows can attain, and the likely duration of lava flow-forming eruptions? [DS 226] | Area covered by active lava flows;  
Lava flow surface temperatures;  
Radiant flux from lava flow surfaces. | Temperature measurements in the range 0 to 1200 °C (active lava);  
and 0–50 °C (ambient background).  
5 day repeat. | 1 low gain channel at ~4 μm (NEAT ~ 1–2 K), 2 nominal gain channels at 10–12 μm  
Pixel size ≤30  
Rapid bright-target recovery at 4 μm (<2 pixels), bands saturate at 1200 °C | Nighttime data acquisitions.  
NIR/SWIR hyperspectral data is beneficial.  
Rapid response off-nadir pointing capability. Rapid re-tasking for acquisition of targets of opportunity. |
| What are the characteristic dispersal patterns and residence times for volcanic ash clouds, and how long do such clouds remain a threat to aviation? [DS 224] | Discrimination of volcanic ash clouds from meteorological clouds (both water and ice), in both wet and dry air masses. Day and night measurements | Four spectral channels at 8.5, 10, 11, and 12 μm;  
NEAT of 0.2 K.  
Max. repeat cycle of 5 days.  
Temperature measurements in the range −20 to 200 °C.  
Multispectral radiance measurements between 8.5 and 12 μm.  
NEAT< 0.5 K; 5-day repeat | 4 channels, 8–14 μm.  
50 nm at 8.5, 100 nm other bands  
Pixel size ≤30 m  
>95% abs. radiometric calibration | NIR/SWIR hyperspectral data valuable to assist in recognition of meteorological clouds and estimation of plume height. Nighttime data acquisitions to increase the frequency of observation. |
| What do the transient thermal anomalies that may precede earthquakes tell us about changes in the geophysical properties of the crust? [DS 227, 229] | Detect and monitor increases in TIR surface radiance surface temperatures along potentially active faults. | Temperature measurements in range −250 to 50 °C.  
5-day repeat (or better); nighttime data | 1 band at 8.8-5 μm; 1 band 7.3–8 μm, 1 band >10 μm; pixel size 100 m;  
NEAT = 0.2 K; nighttime data |                                                                                                              |
| Can the energy released by the periodic recharge of magma chambers be used to predict future eruptions? [DS 227] How can the release of energy at the surface of volcanic edifices be used to understand magma processes at depth and over time? | Detect and monitor temperature changes of volcanic edifices | Temperature measurements in range of −25 °C to 1200 °C.  
5-day repeat | 1 low-gain channel at ~4 μm (NEAT ~ 1–2 K), 2 nominal gain channels at 10–12 μm  
Pixel size ≤30 m | Nighttime data acquisitions.                                                                 |
The science of the science questions
CQ3a. What do comparisons of thermal flux and SO₂ emission rates tell us about the volcanic mass fluxes and the dynamics of magma ascent? (DS 227; 230)

- The flux of gas and thermal energy from a volcano can be used to determine the mass of magma required to balance those fluxes. Over what time scales do mass fluxes at Earth’s volcanoes vary and by how much? Does this vary as a function of tectonic setting? During ascent, how is magma partitioned between the surface (the erupted component) and the subsurface (the degassed but not erupted component)?


Landsat TM image of Erta Ale, Ethiopia

• Significant amount of antecedent data acquired by MODIS-class instruments regarding radiant flux
• HyspIRI will provide a high resolution data set from which total heat flux and gas flux can be determined simultaneously

\[
\text{Mass}_{\text{gas}} \ (m^3 \ s^{-1}) = \frac{\phi S}{\Delta S}
\]

(e.g. Stix et al., 2008)

\[
\text{Mass}_{\text{thermal}} \ (m^3 \ s^{-1}) = \frac{Q}{(L \Delta f + c \Delta T)}
\]

(e.g. Francis et al., 1993)

Mass_{thermal} = Mass_{gas} then all the magma was erupted as lava

Mass_{thermal} < Mass_{gas} then some magma was stored as intrusions
CQ3b. Does pressurization of the shallow conduit produce periodic variations in SO2 flux and lava dome surface temperature patterns that may act as precursors to explosive eruptions? (DS 50; 227; 230)

- Precipitous drops in SWIR radiance detected by Landsat TM from Lascar’s summit crater were followed by significant explosive eruptions.

- Cyclicity is increasingly recognized as characteristic of explosive silicic dome-forming volcanoes.

- What physical processes control this behavior? Can we use HyspIRI to recognize changes that signify transitions between phases of these cycles.

• Unlike previous missions, HyspIRI’s VSWIR and TIR instruments will allow us to quantify and monitor temporal variations in gas flux and in high temperature fumarolic activity on lava dome surfaces.
What process cause pressure to build up within the shallow conduit?

Can such pressurization be recognised in a suite of geophysical data?
Rockfall data courtesy of Montserrat Volcano Observatory
CQ3c. Can measurements of the rate at which lava flows cool allow us to improve forecasts of lava flow hazards? (DS 50; 226)

- The rate at which a lava flow cools exerts a fundamental control on the distance from the vent at which it solidifies. The surface temperature of an active lava flow, and how this vary spatially and temporally, is therefore key information for parameterizing and validating numerical models that forecast lava flow hazards.
\[ L(\lambda) = \sum_{i=1}^{n} f_i(L, T_i) \]

<table>
<thead>
<tr>
<th></th>
<th>In-situ*</th>
<th>Hyperion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake area (m²)</td>
<td>910</td>
<td>1000</td>
</tr>
<tr>
<td>Radiant flux (MW)</td>
<td>5-30</td>
<td>10</td>
</tr>
<tr>
<td>Max. T (°C)</td>
<td>1174</td>
<td>1138</td>
</tr>
<tr>
<td>Mean T (°C)</td>
<td>350-450</td>
<td>60% in this range</td>
</tr>
</tbody>
</table>

*Oppenheimer et al. (2004), *Geology*; Wright et al., in review
Wright et al., in review.

12 September 2004
i. $\Sigma \Phi_1 = 305$ MW
$\Sigma \Phi_2 = 136$ MW

14 September 2004
i. $\Sigma \Phi_1 = 499$ MW
$\Sigma \Phi_2 = 262$ MW
ii. $\Sigma \Phi_1 = 107$ MW
$\Sigma \Phi_2 = 54$ MW

16 September 2004
i. $\Sigma \Phi_1 = 143$ MW
$\Sigma \Phi_2 = 241$ MW
ii. $\Sigma \Phi_1 = 21$ MW
$\Sigma \Phi_2 = 36$ MW
• By providing data in the NIR, SWIR, MIR and TIR, HyspIRI will allow for more accurate determination of lava surface temperatures and cooling rates than has been possible using TM, ETM+, or ASTER.
CQ3d: Does the temperature and composition of volcanic crater lakes change prior to eruptions? (DS 226; 227)

- Lakes act as chemical traps and calorimeters
- HypsIRI’s TIR and VSWIR instruments will allow us to identify changes in the temperature, area, and color of volcanic crater lakes for changes (increased volatile flux, increased temperature, seismic activity) that may indicate volcanic unrest
CQ3e. Do changes in the health and extent of vegetation cover indicate changes in the release of heat and gas from crater regions? (DS 230; 231)

- Gaseous and particulate emissions from active volcanoes adversely impact surrounding ecosystems. \( \text{SO}_2 \) quickly converts to sulfuric acid aerosol, deposition of which is harmful to both humans and vegetation. Fluorine, adsorbed onto ash particles which may be distributed over a wide geographic area, is detrimental to both human and animal physiology. HyspIRI’s VSWIR and TIR instruments will allow us to monitor \( \text{SO}_2 \) fluxes from active volcanoes and the dispersal and deposition of ash clouds, and quantify the effect that these processes have on the surrounding landscape.
Landsat TM, Masaya volcano, Nicaragua
Alignment with the Decadal Survey
p. 50: Societal Challenge: extreme event warnings. "..., and volcanic eruption (and landslide) warnings to enable effective evacuation planning"

p. 226, Table 8.1: “Volcanic eruption prediction: What observations can improve the reliability of hazard forecasts?”

p. 227, Table 8.1. “Volcanic eruption prediction: How can multiple change patterns and measurements (topography, gas, temperature, vegetation) at craters be better interpreted for eruption forecasting?”

p. 227, Table 8.1: “What pre-eruption surface manifestations are amenable to remote measurement from orbit?”

p. 230: “....However, direct observational constraints on the style and dynamics of magma ascent are still lacking. Such constraints are crucial for forecasting the replenishment and pressurization of shallow magma chambers that may potentially feed volcanic eruptions.”
Level 3 products: plans and validation
CQ3 L3 products = TQ1 L3 products (volcanic thermal/\(\text{SO}_2\) alert/fluxes)

Any other suggestions????
Precursor science
Simulating the response of HyspIRI to active lavas
Calibrating HyspIRI’s $L_4$-to-radiant flux relationship

$L_4 \sim aT^4$ (600K<T<1500K)

$\Phi = \sigma T^4 \text{ (W m}^{-2}\text{)}$

$\Phi = 1.89 \times 10^7 (L_{4,\text{target}} - L_{4,\text{bg}})$

Calibrated for MODIS; $L_4$ in W m$^{-2}$ sr$^{-1}$ $\mu$m$^{-1}$

How have Earth’s volcanoes behaved in the past?

- Possible to extend time series back (to a certain extent, and subject to internal calibration) to late 1970s using a combination of MODIS, ATSR, and AVHRR
What is the relationship between heat and mass flux?

\[
Q = \frac{\phi}{\rho(C_p\Delta T)} \times A
\]


- What is the nature of the relationship between surface heat flux, flow area, and lava effusion rate?
CQ3: Volcanoes

• What do comparisons of thermal flux and SO$_2$ emission rates tell us about the volcanic mass fluxes and the dynamics of magma ascent? (DS 227; 230)

• Does pressurization of the shallow conduit produce periodic variations in SO$_2$ flux and lava dome surface temperature patterns that may act as precursors to explosive eruptions? (DS 50; 227; 230)

• Can measurements of the rate at which lava flows cool allow us to improve forecasts of lava flow hazards? (DS 50; 226)

• Does the temperature and composition of volcanic crater lakes change prior to eruptions? (DS 226; 227).

• Do changes in the health and extent of vegetation cover indicate changes in the release of heat and gas from crater regions? (DS 230; 231)