CQ3: Volcanoes

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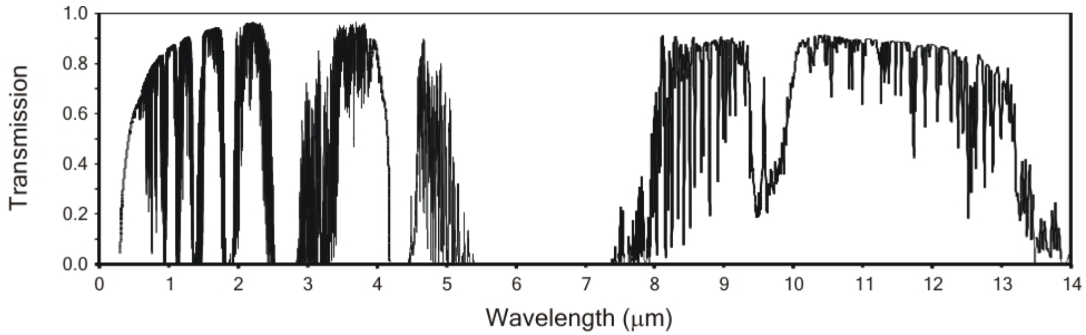
2nd HyspIRI Science Workshop, Pasadena, 11-13 August 2009

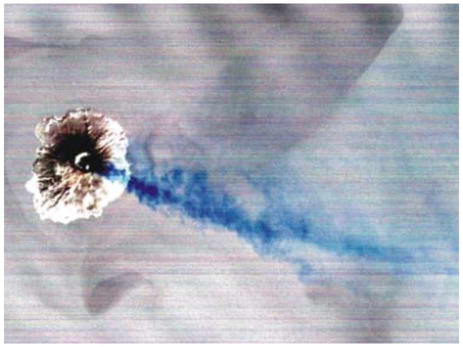
Statement of overarching science questions and related sub-questions

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?

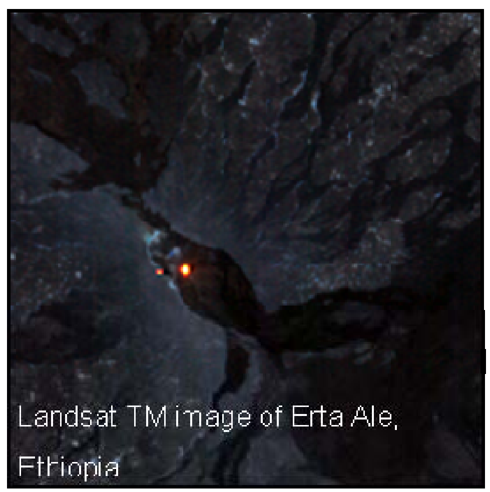
Review of the science traceability matrix

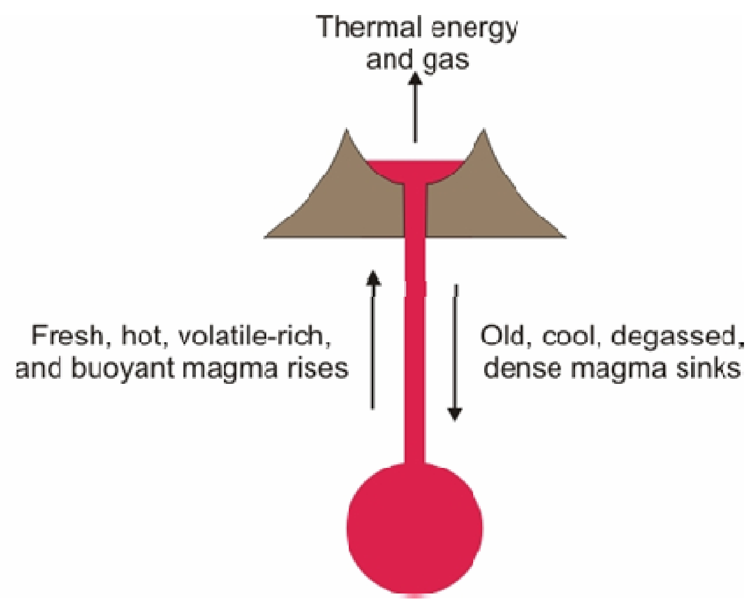
Science Objectives	Measurement Objectives	Measurement Requirements	Instrument Requirements	Other Mission and Measurement Requirements
TQ1. Volcanoes and Earthquakes: How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?				
Do volcanoes 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 SO_2 retrieval algorithm; 7-day repeat.	4 TIR channels, 7.3 um, 8.5 um, 2 bands between 9-12 um Pixel size ≤60 m NEΔT ~0.02 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 (NEΔT ~ 1–2 K). 2 nominal gain channels at 10–12 µm Pixel size ≤90 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; NEΔT 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. NEDT>0.5 K. 5-day repeat	4 channels, 8–14 µm. 50 nm at 8.5, 100 nm other bands Pixel size ≤90 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 –25C 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; NEDT = 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 (NEΔT ~ 1–2 K) 2 nominal gain channels at 10–12 µm Pixel size ≤90 m	Nighttime data acquisitions.

The science of the science questions

CQ3a. 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)

- 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)?





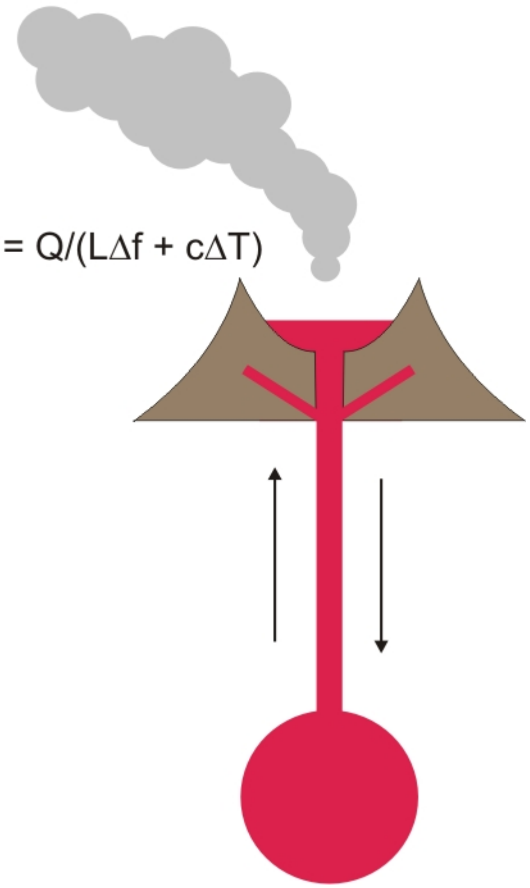
Francis et al (1993). *Nature*, 366, 554-557.

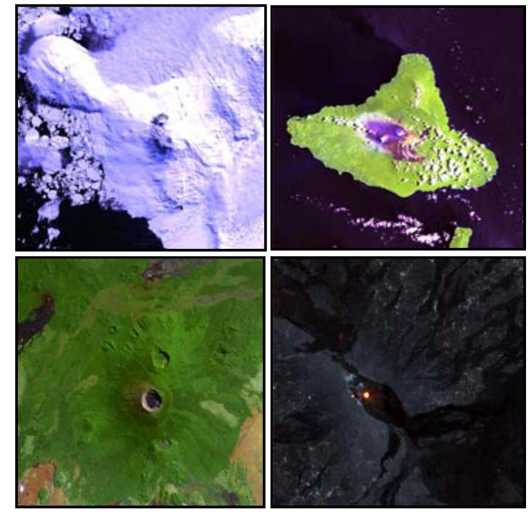
$$\text{Mass}_{gas}\ (m^3\ s^{-1}) = \phi S/\Delta S$$

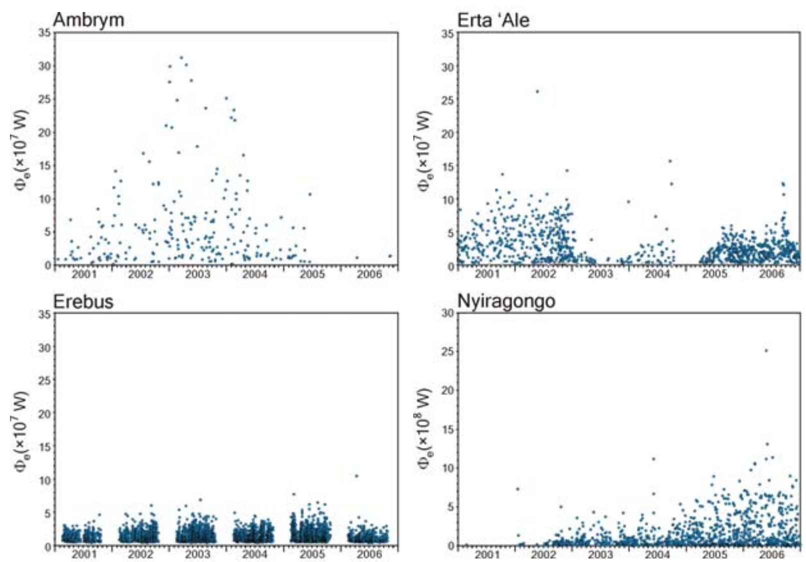
(e.g. Stix et al., 2008)

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

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

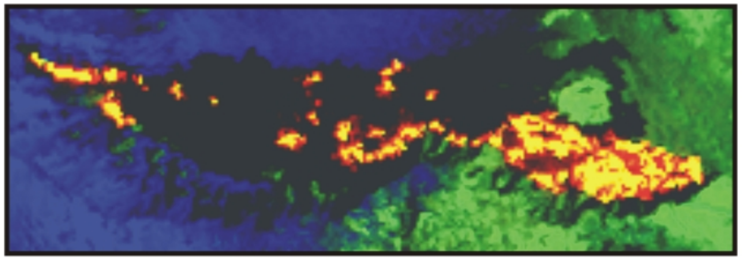




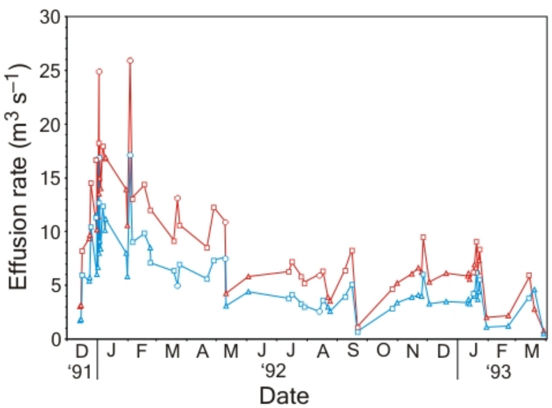


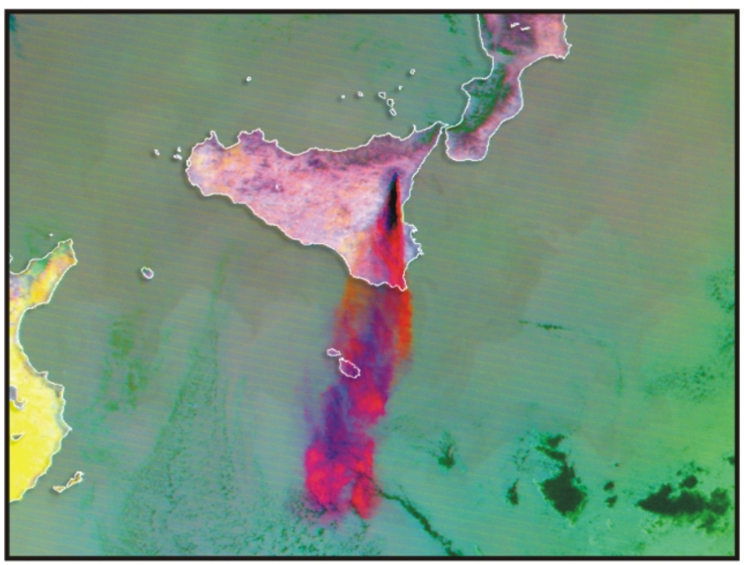
- Significant amount of antecedent data acquired by MODIS-class instruments regarding radiant flux
- HyspIRI will provide a high resolution data set from which total heat flux *and* gas flux can be determined simultaneously

Wright and Pilger, (2008), *J. Volcanol. Geotherm. Res.*

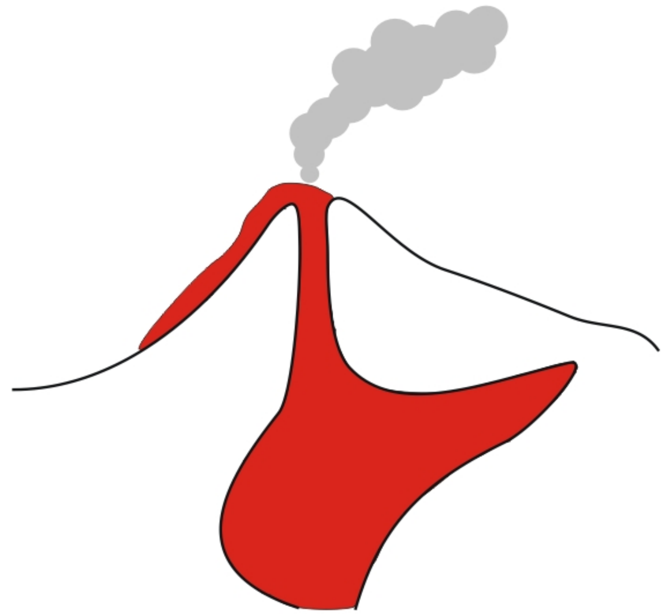


Landsat TM, Mount Etna





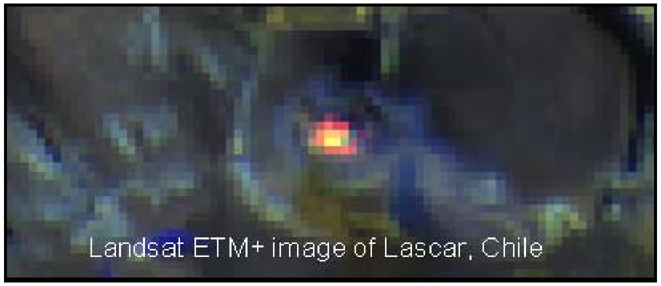
MODIS, Mount Etna

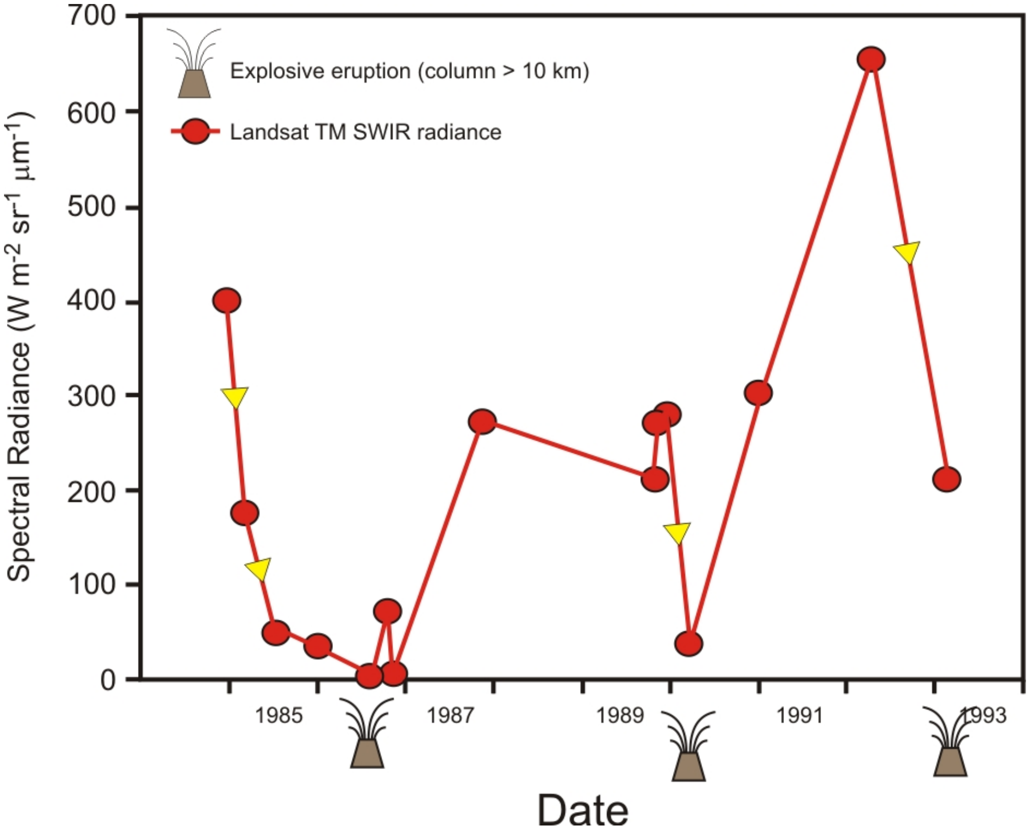


$Mass_{thermal} = Mass_{gas}$ then all the magma was erupted as lava

$Mass_{thermal} < Mass_{gas}$ then some magma was stored as intrusions

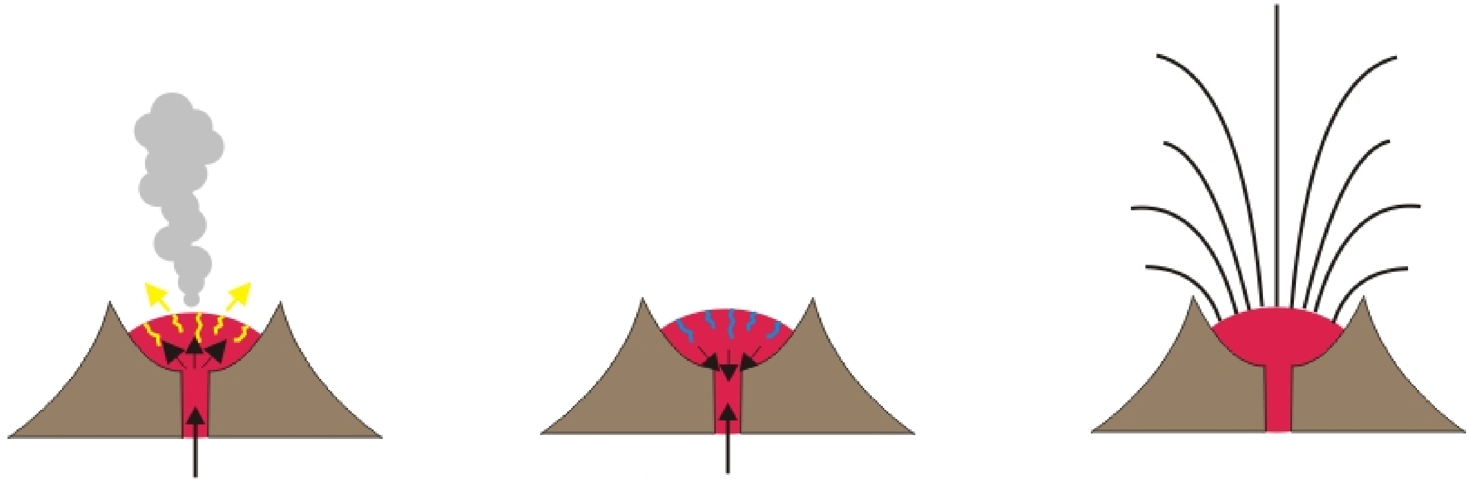
CQ3b. Does pressurization of the shallow conduit produce periodic variations in SO_2 flux and lava dome surface temperature patterns that may act as precursors to explosive eruptions? (DS 50; 227; 230)





- 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

Oppenheimer et al., (1993), *J. Geophys. Res.;* Wooster and Rothery, (1997), *Bull. Volcanol.*

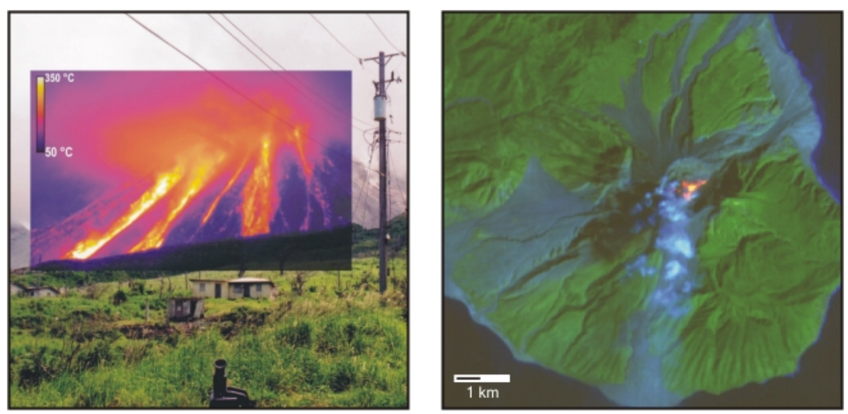


Fresh, volatile-rich magma, rises, promoting dome growth, high thermal flux and gas flux through the permeable upper conduit and dome.
Gas can escape freely

Dome subsidence begins. Reduced permeability of shallow conduit and dome leads to decrease in fumarolic thermal and gas flux from dome surface.
Gas cannot escape freely

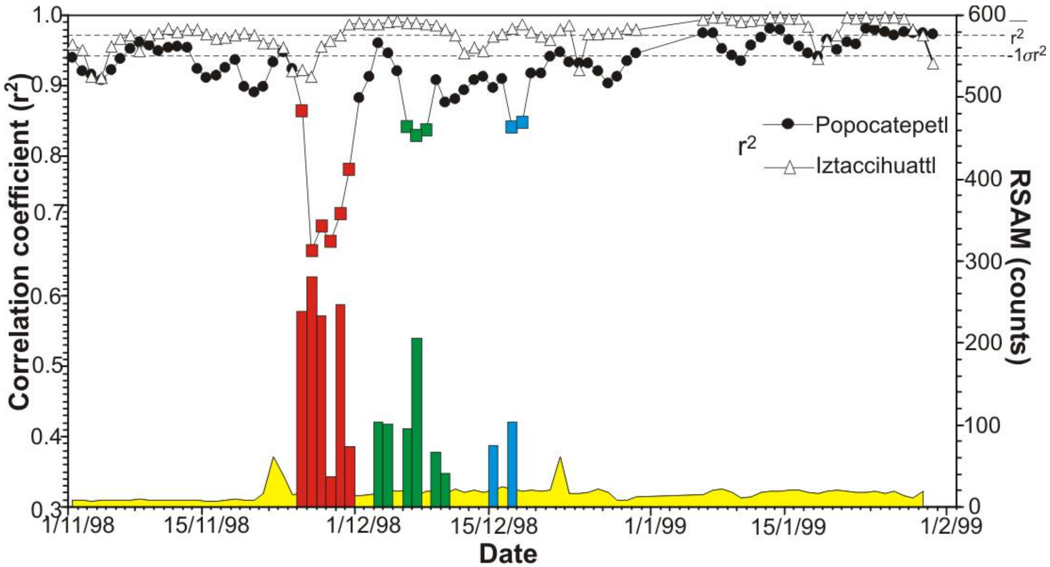
Overpressure results in an explosive eruption. Dome growth resumes, the cycle begins again

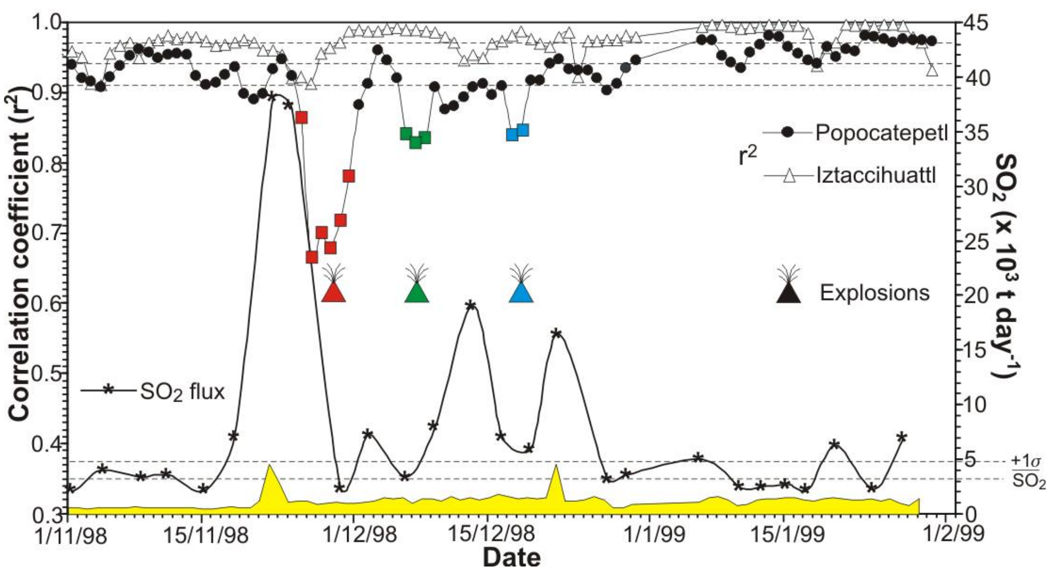
Matthews et al., 1997, *Bull. Volcanol*.

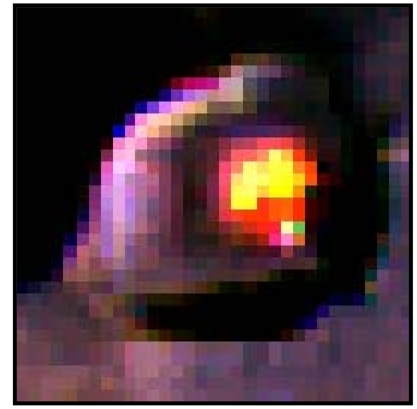


Soufriere Hills Volcano, Montserrat

• 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



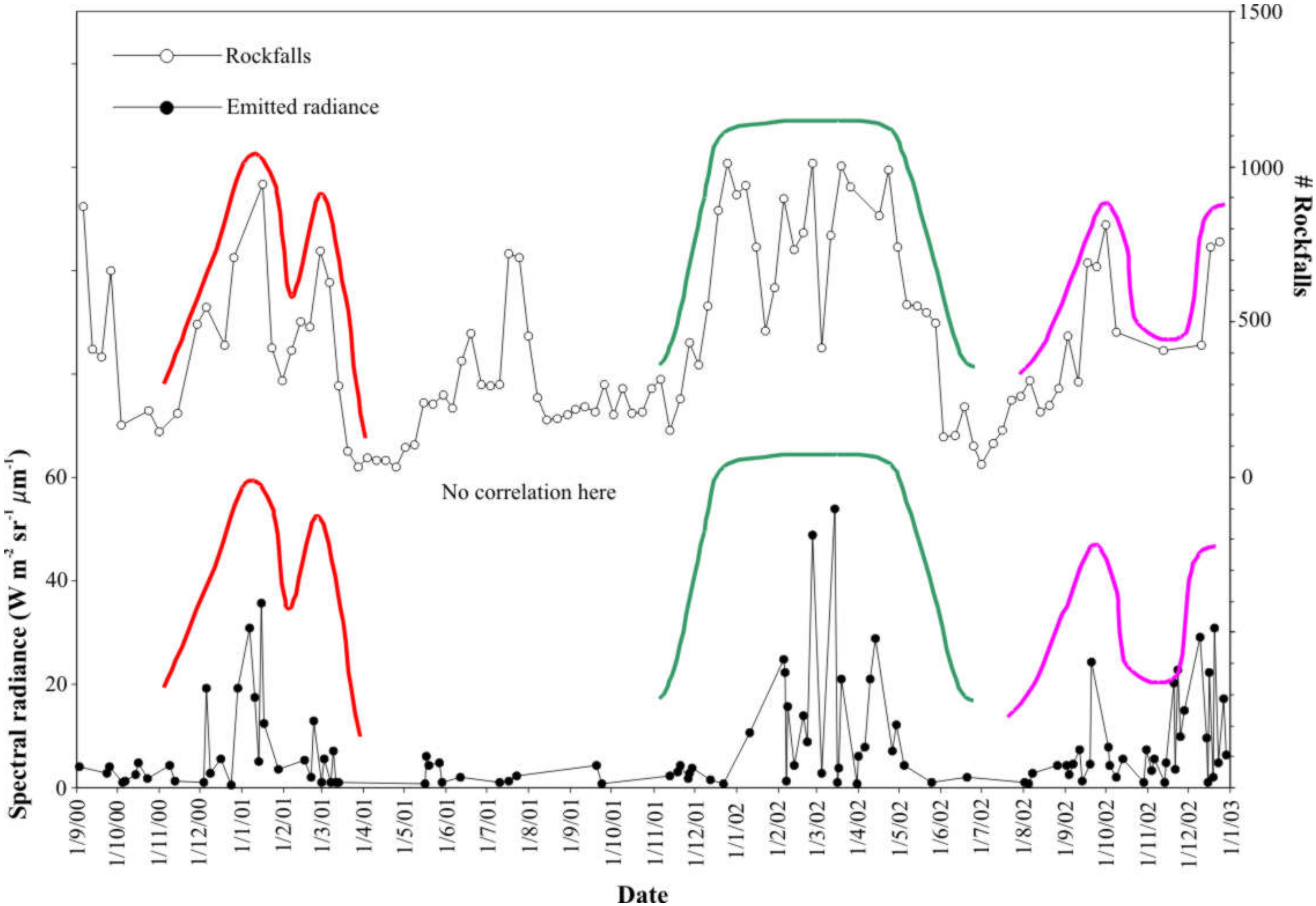




Landsat TM, Popocatepetl, Mexico

- What process cause pressure to build up within the shallow conduit?
- Can such pressurization be recognised in a suite of geophysical data?

Wright et al., (2002), *J. Geophys. Res.*

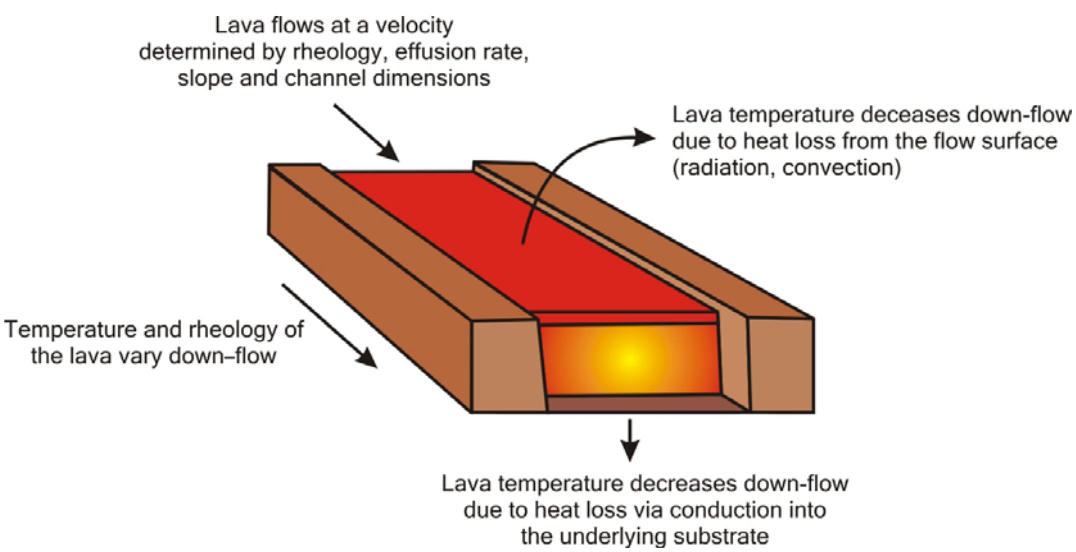


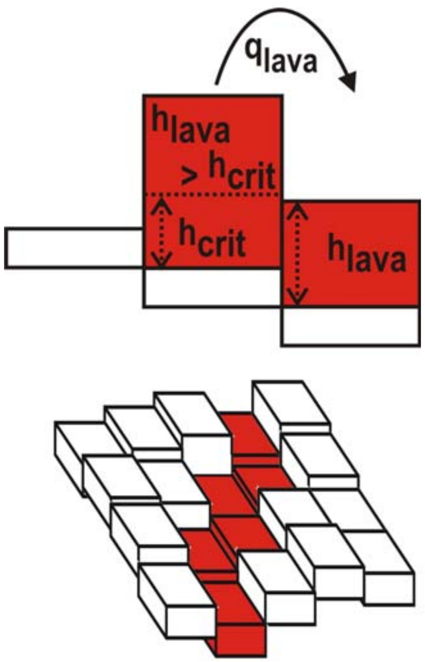
Rockfall data courtesy of Montserrat Volcano Observatory

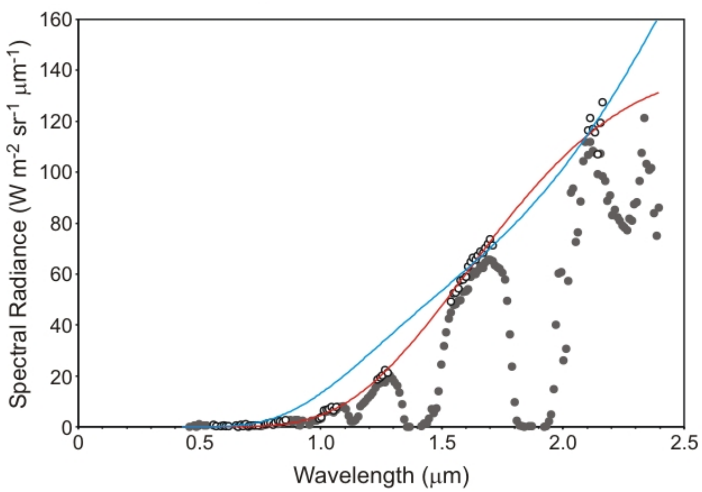
CQ3c. Can measurements of the rate at which lava flows cool allow us to improve forecasts of lava flow hazards? (DS 50; 226)

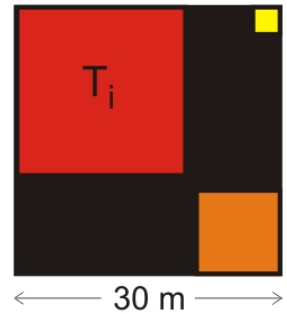
Mt. Etna, Sicily

- 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.





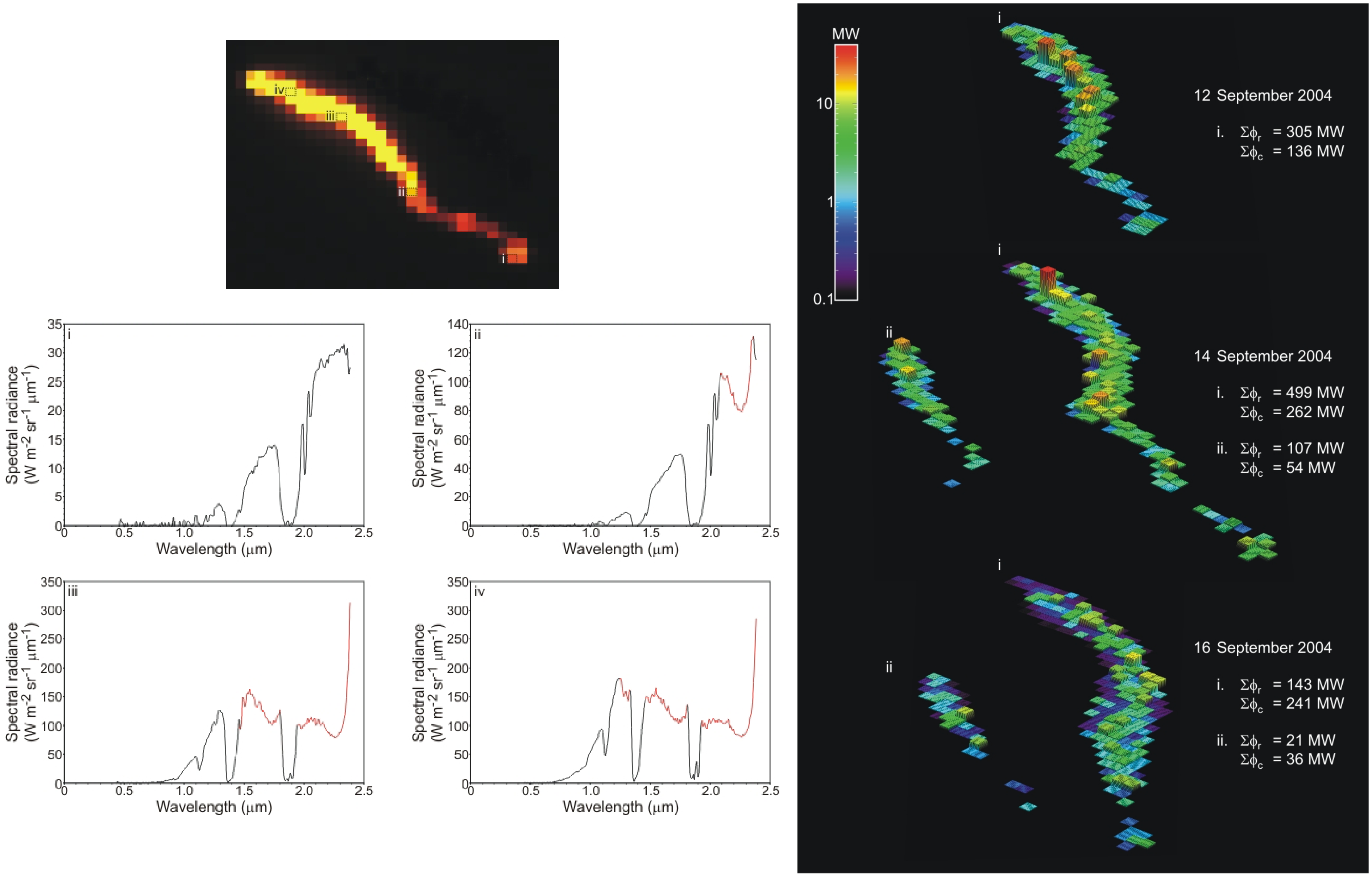




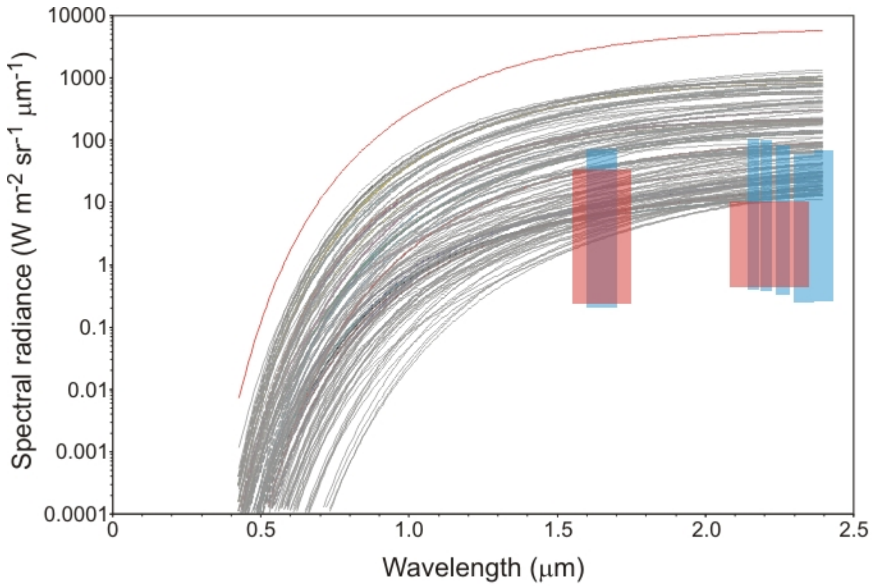
$$L(\lambda) = \sum_{i=1}^{n} f_i(L, T_i)$$

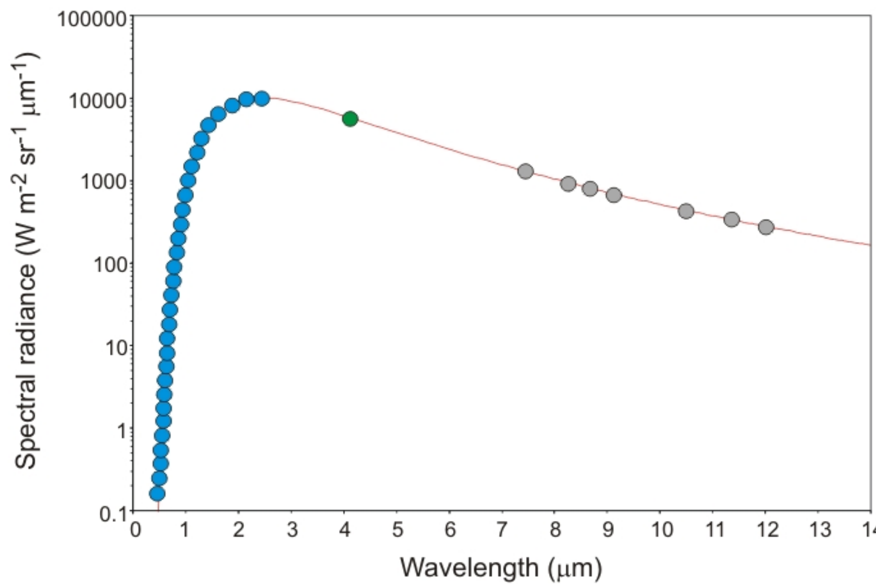
	In-situ*	Hyperion
Lake area (m^2)	910	1000
Radiant flux (MW)	5-30	10
Max. T (°C)	1174	1138
Mean T (°C)	350-450	60% in this range

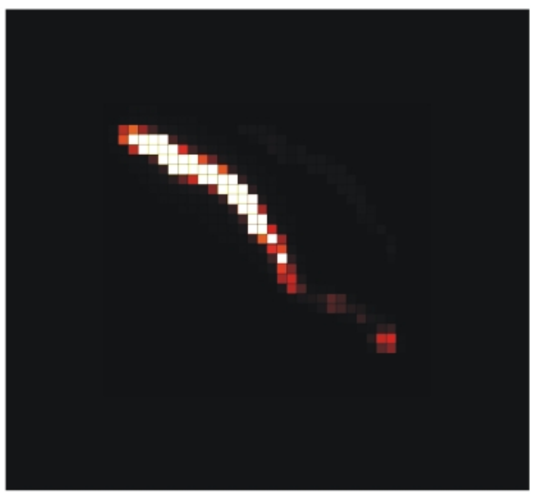
*Oppenheimer et al. (2004), *Geology;* Wright et al., in review



Wright et al., in review.







- 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)

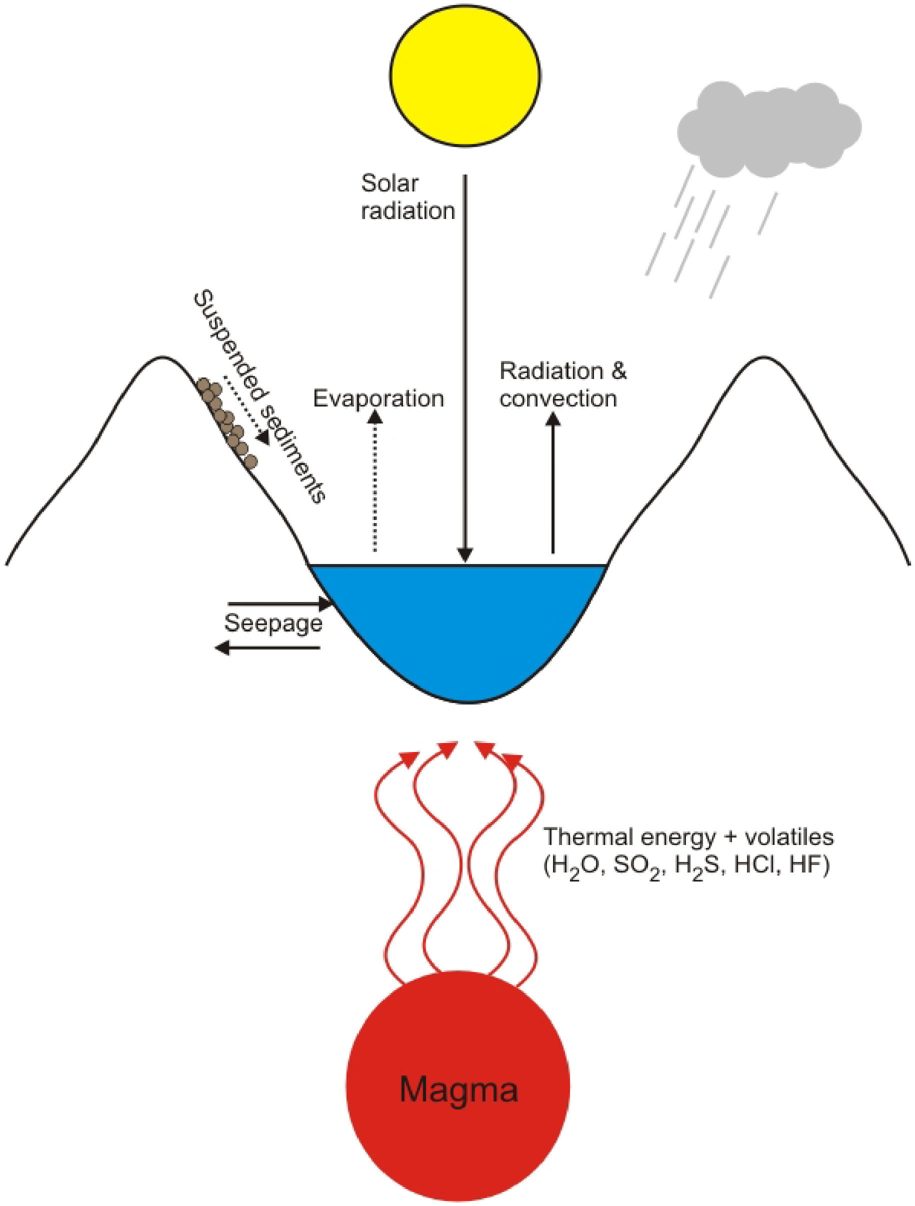
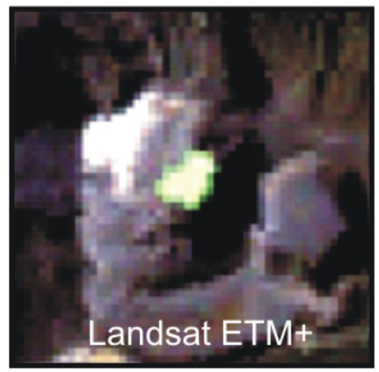
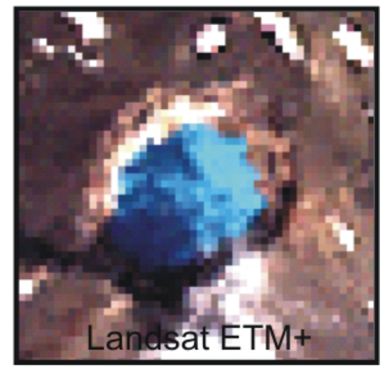
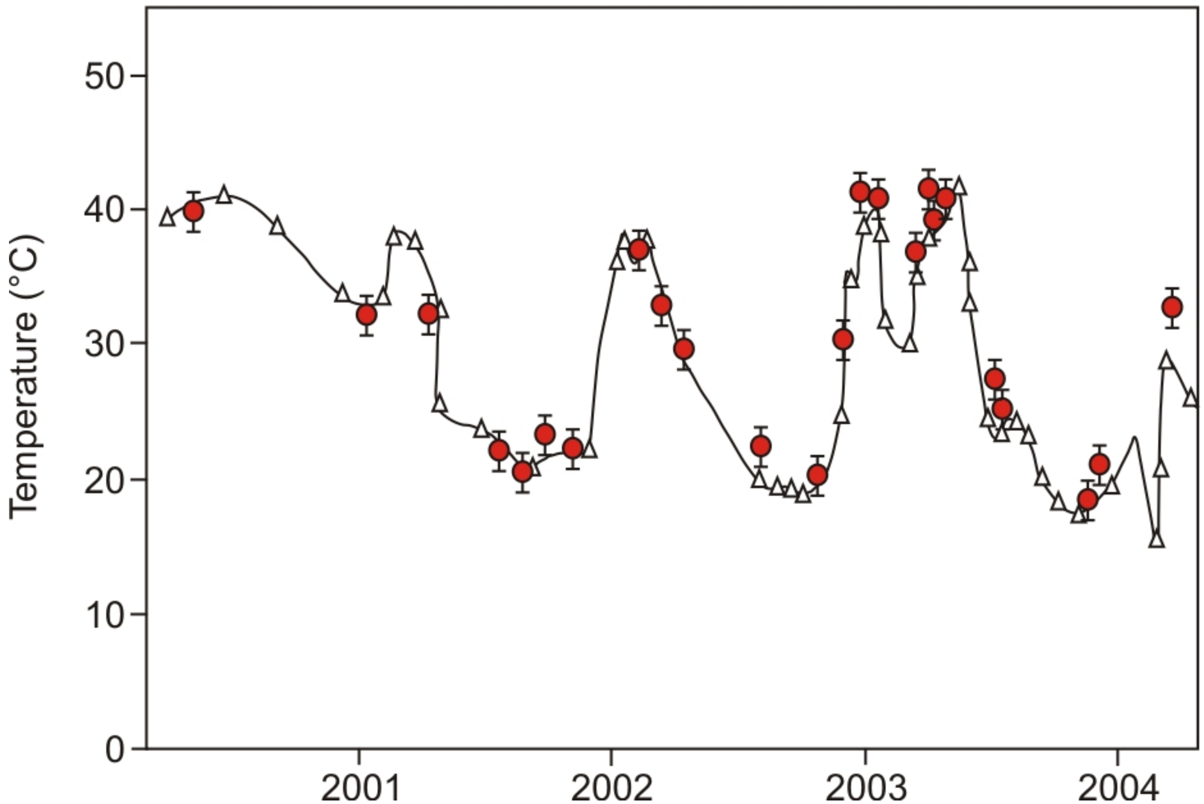


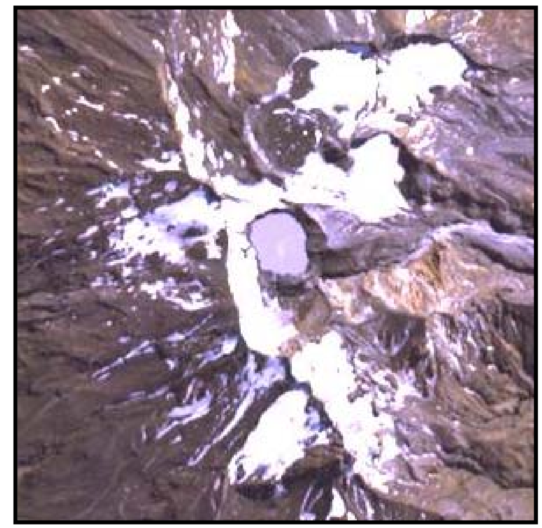
Photo: Dirk van der Made





- Lakes act as chemical traps and calorimeters
- HyspIRI'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

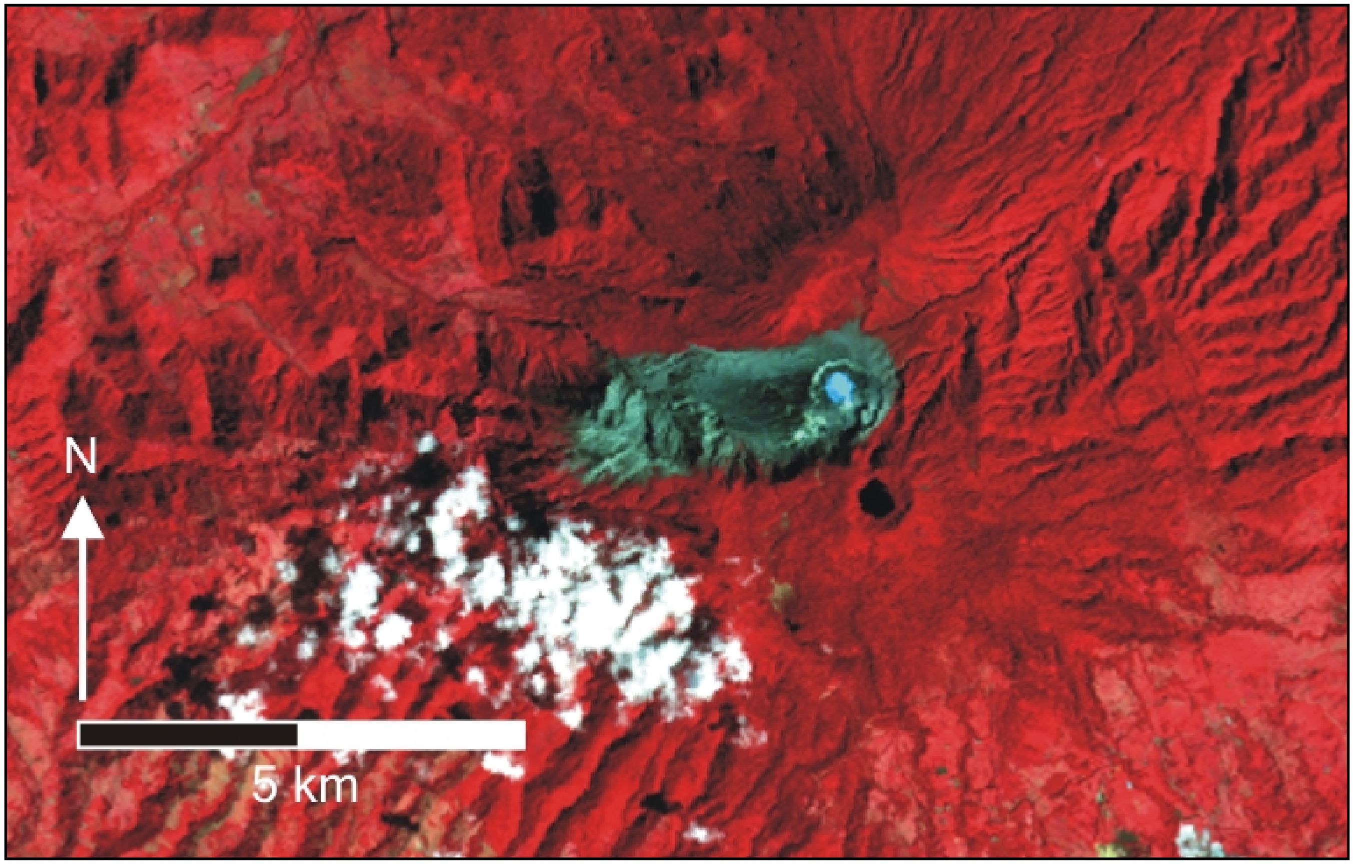




ASTER, Ruapahu, New Zealand

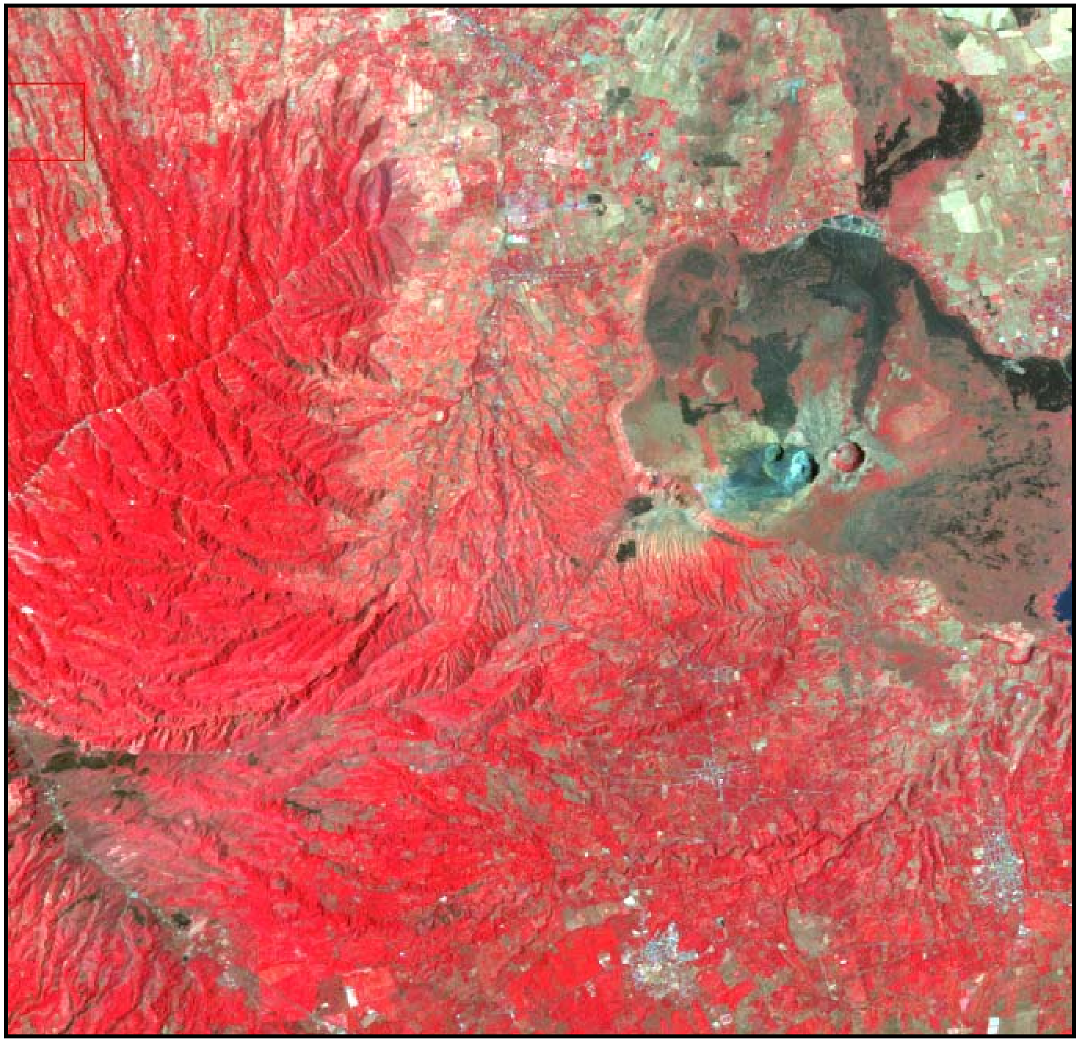
Trunk and Bernard, (2008), *J. Volcanol. Geotherm. Res.*

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)



Landsat TM, Poas volcano, Costa Rica

- Gaseous and particulate emissions from active volcanoes adversely impact surrounding ecosystems. 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 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?”

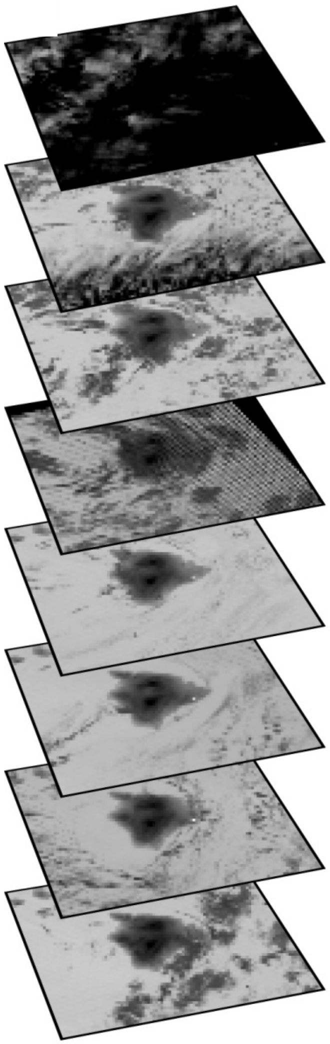
p. 227, Table 8.1. “Volcanic eruption prediction: How can multiple change patterns and measurements (topography, gas, temperature, vegetation) at craters be better interpreted for eruption forecasting?”

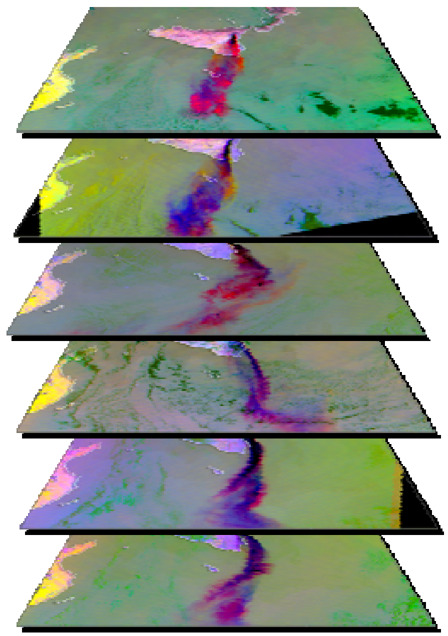
p. 227, Table 8.1: “What pre-eruption surface manifestations are amenable to remote measurement from orbit?”

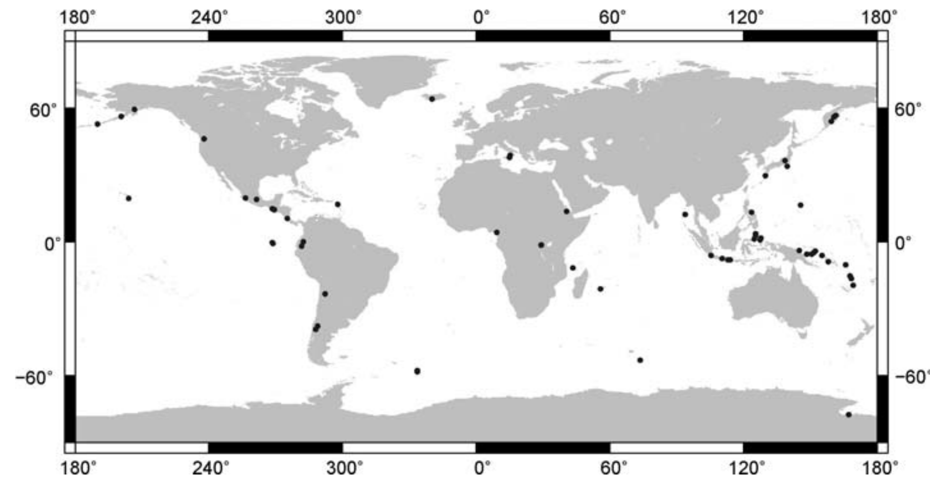
p. 230: “….However, direct observational constraints on the style and dynamics of magma ascent are still lacking. Such constraints are crucial for forecasting the replenishment and pressurization of shallow magma chambers that may potentially feed volcanic eruptions.”

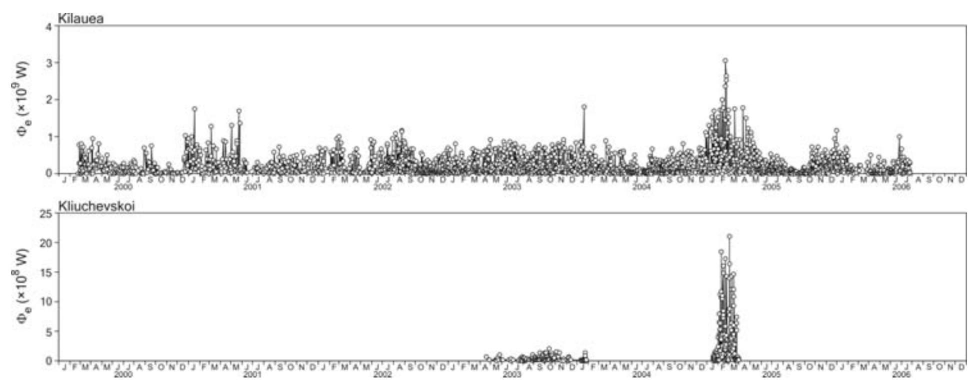
Level 3 products: plans and validation

CQ3 L3 products = TQ1 L3 products (volcanic thermal/SO_2 alert/fluxes)





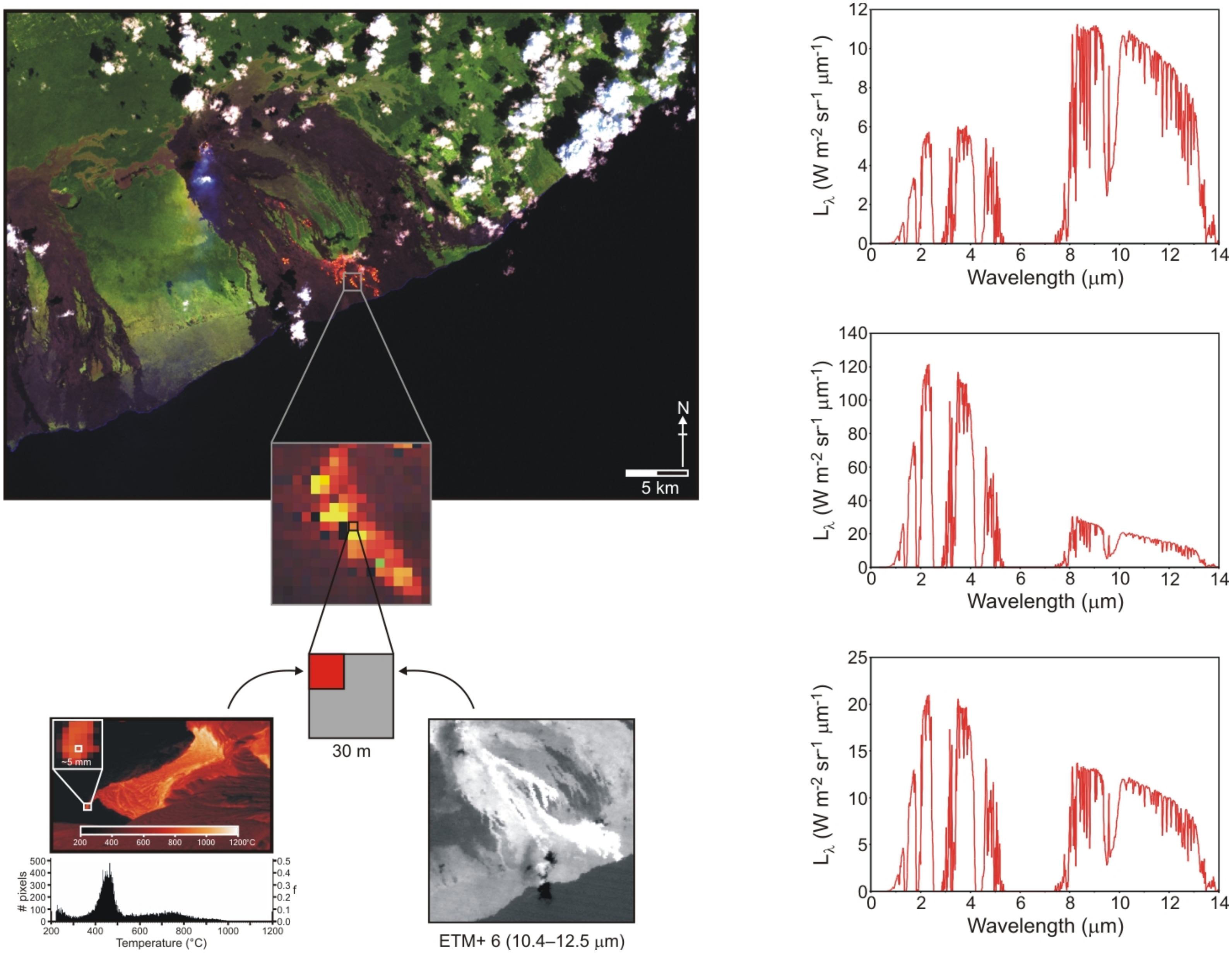


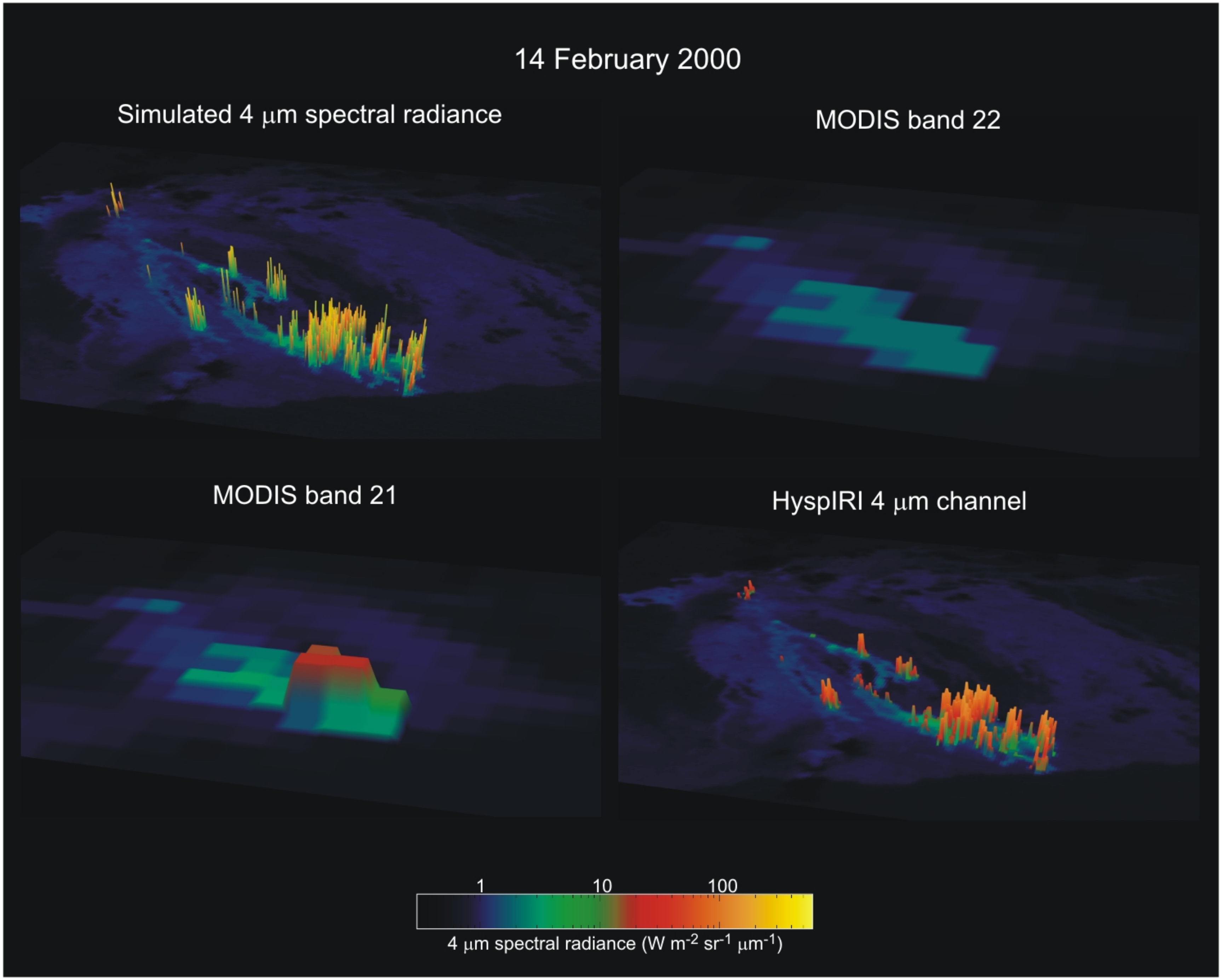


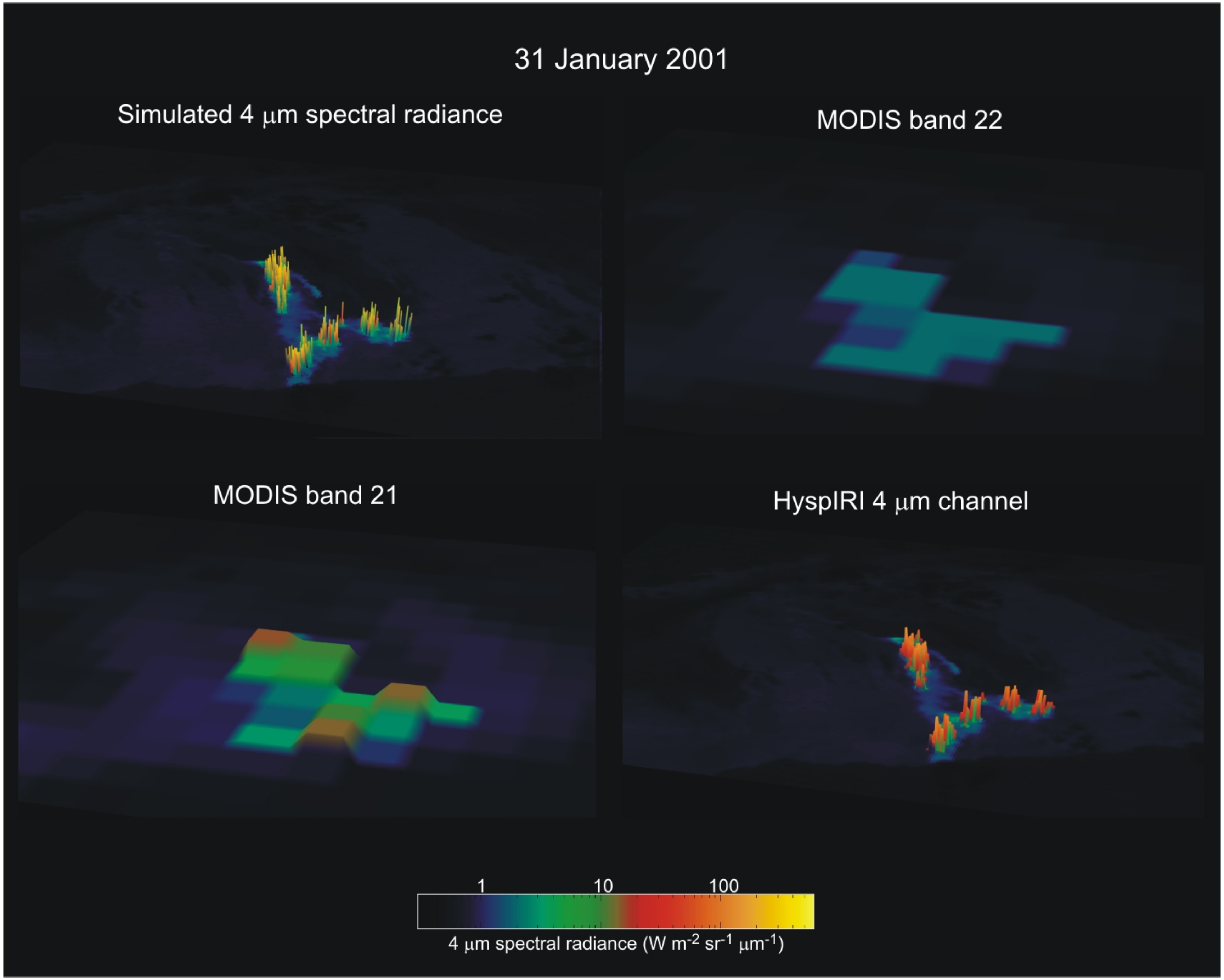
Any other suggestions????

Precursor science

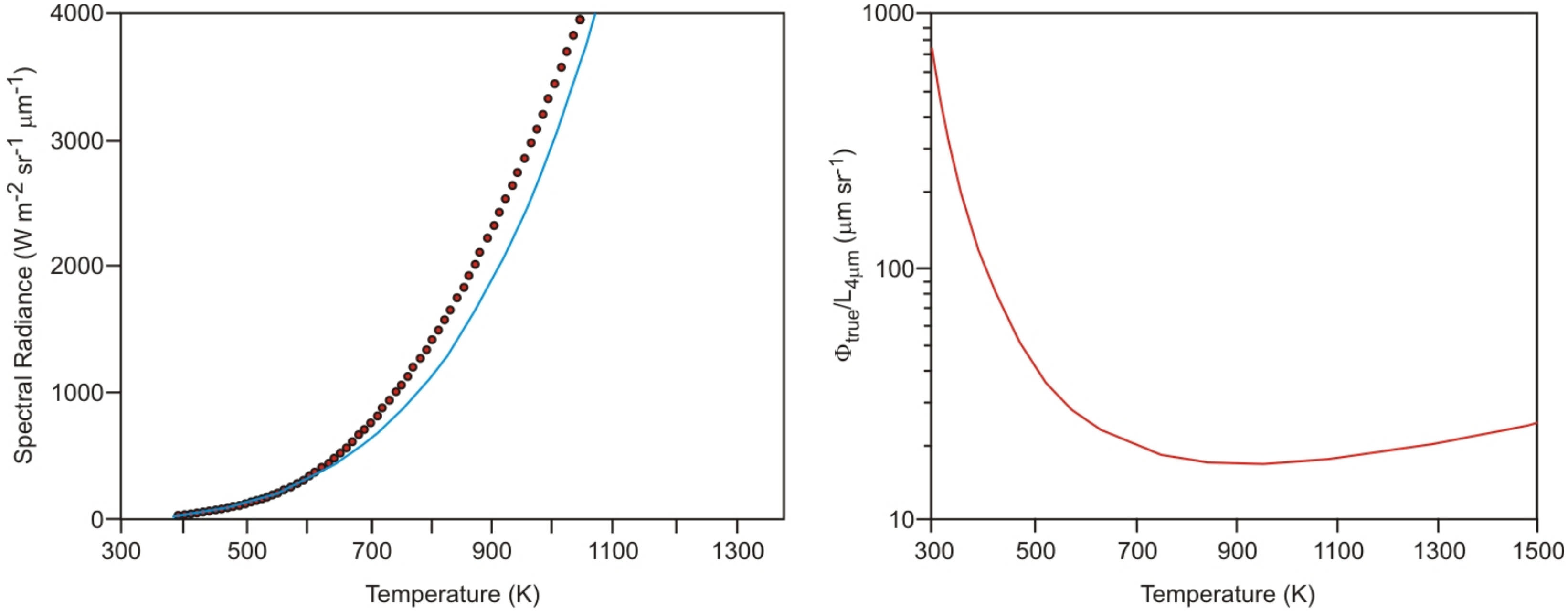
Simulating the response of HyspIRI to active lavas




14 February 2000
Simulated 4 μm spectral radiance
MODIS band 22
MODIS band 21
HyspIRI 4 μm channel
1
10
100
4 μm spectral radiance (W m-2 sr-1 μm-1)


31 January 2001
Simulated 4 μm spectral radiance
MODIS band 22
MODIS band 21
HyspIRI 4 μm channel
1
10
100
4 μm spectral radiance (W m-2 sr-1 μm-1)

Calibrating HyspIRI's L_4-to-radiant flux relationship



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

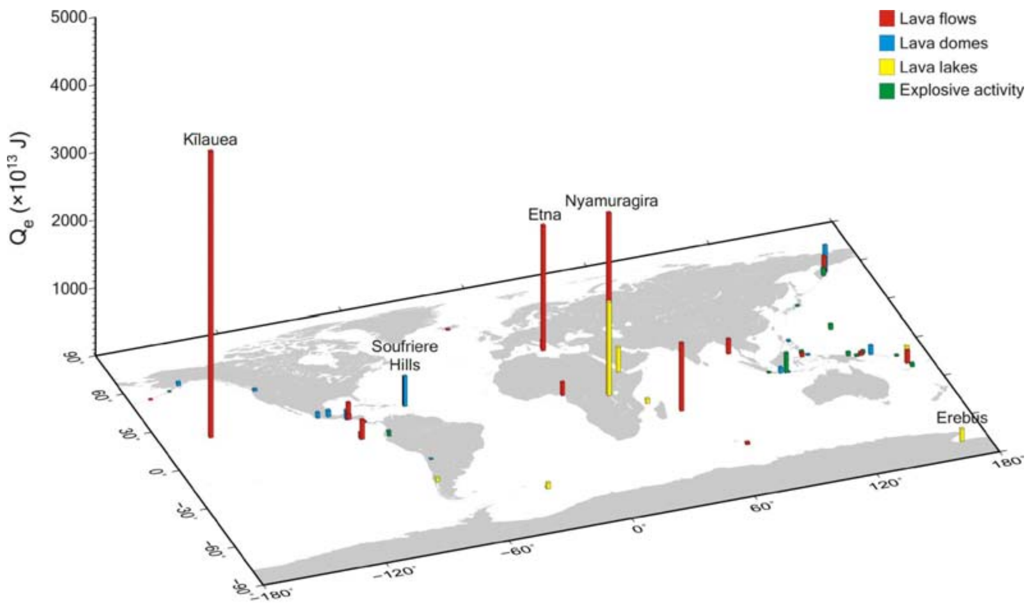
$\Phi = \sigma T^4$ (W m^{-2})

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

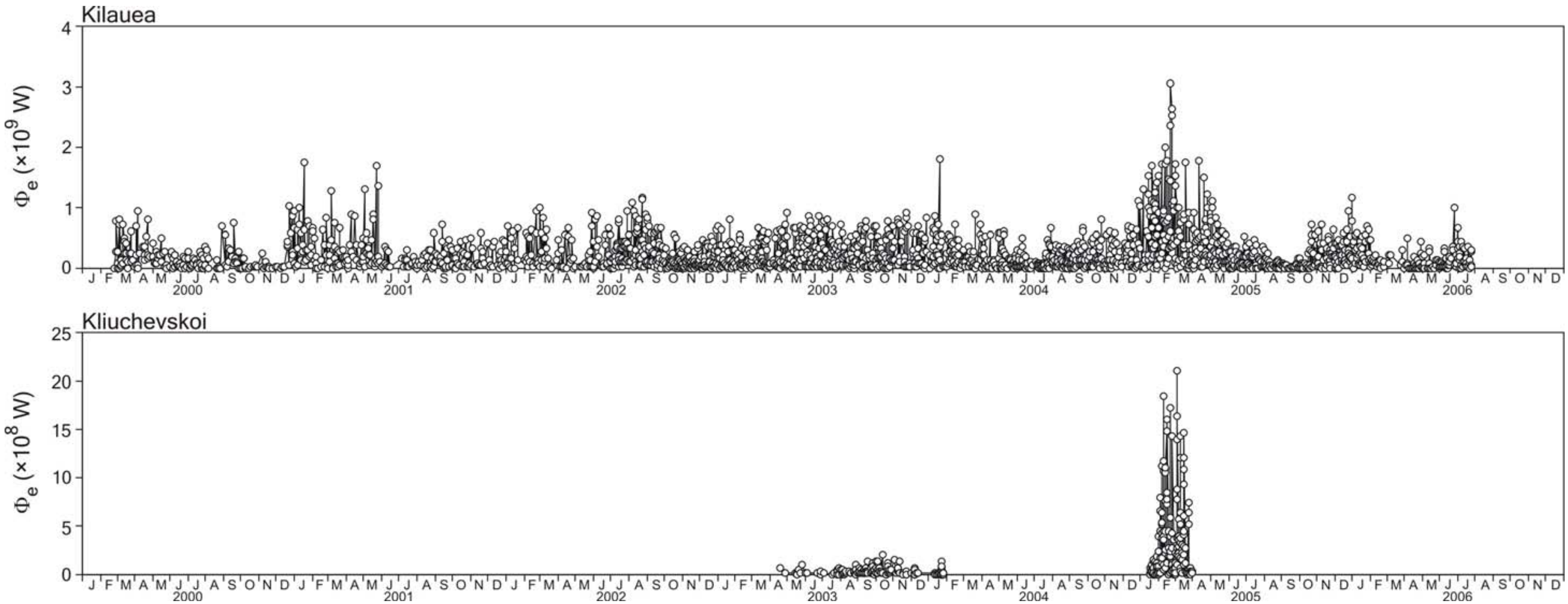
Calibrated for MODIS; L_4 in W m^{-2} sr^{-1} μm^{-1}

Wooster et al., (2003), *Remote Sens. Environ.*

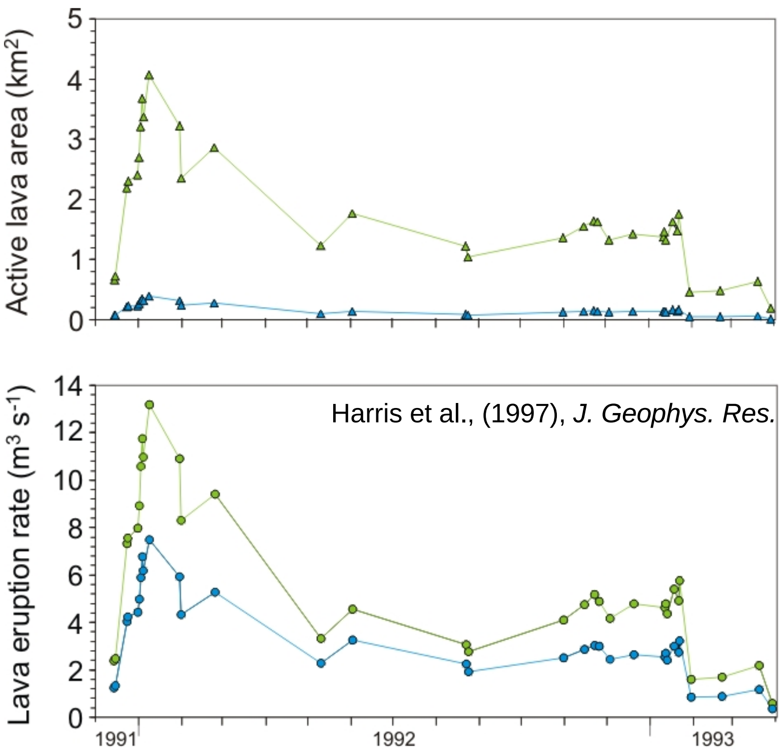
How have Earth's volcanoes behaved in the past?



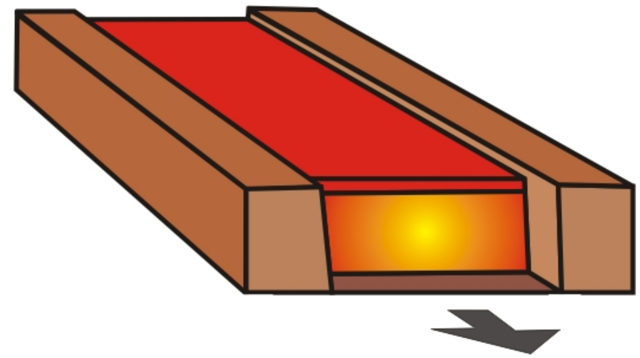
- Possible to extend time series back (to a certain extent, and subject to internal calibration) to late 1970s using a combination of MODIS, ATSR, and AVHRR



What is the relationship between heat and mass flux?

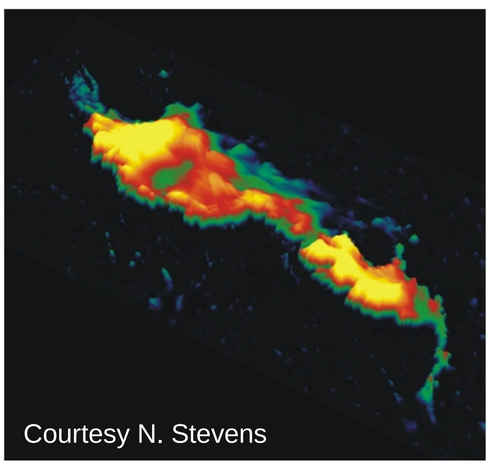


Harris et al., (1997), *J. Geophys. Res.*



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

Wright et al., (2001), *Earth. Planet. Sci. Lett.*



- 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)