Higher level products to support answering HyspIRI science questions: TQ1, TQ2, and CQ3

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TQ1. Volcanoes/Earthquakes

How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?

TQ1. How can we predict and mitigate earthquake and volcanic hazards through detection of transient thermal properties?

Science Issue:

•Volcanoes can exhibit idiosyncratic behaviors leading up to eruptions. For example, SO2 production can increase dramatically, or decrease dramatically. Thermal anomalies manifest themselves in many forms: crater lakes, fumaroles, domes, etc. Transient thermal anomalies may precede earthquakes. Systematic monitoring can provide potentially effective information to aid in predicting possible eruptions and improve earthquake forecasts.

Tools:

•Satellite observations from HyspIRI TIR; requires multispectral capability to separate volcano plume constituents; requires bands in 3-5um and 8-12um for temperature determinations in range -20 to 1200C

• Historical baseline of characteristic thermal and gas emission behavior for each volcano to compare with HyspIRI observations.

Approach:

•Schedule systematic day & night TIR observations with HyspIRI over several hundred up to 1000 active volcanoes.

• Implement automatic analysis algorithms to flag anomalous thermal or gas emission activity.

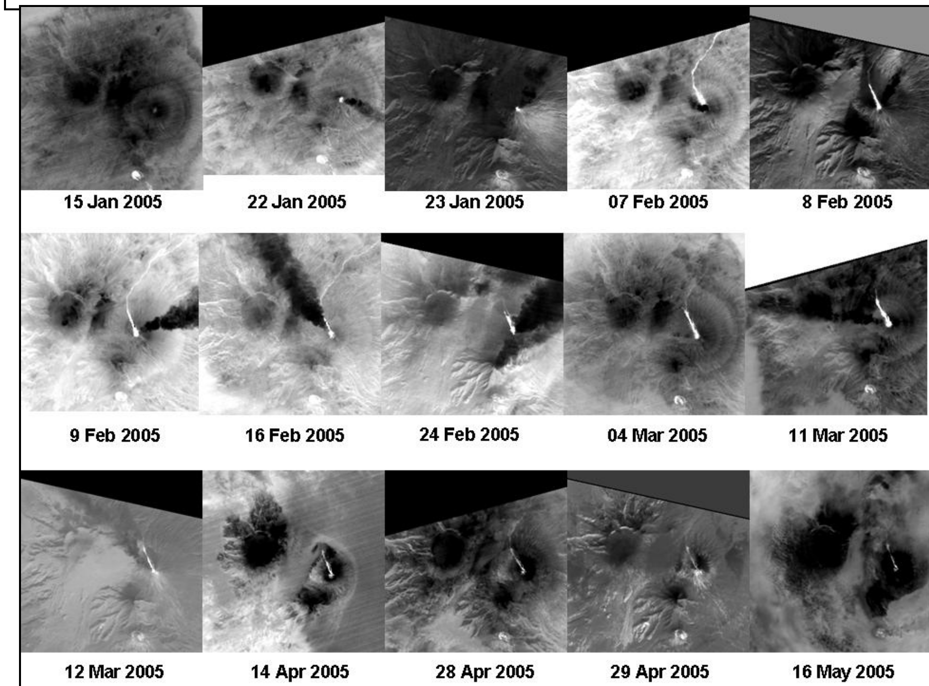
•Monitor potentially active faults with nighttime observations

Results:

• Unique, high spatial resolution TIR data from HyspIRI will improve our understanding of pre-eruption volcanic behavior; this will in turn lead to improvements in our ability to predict volcanic eruptions.

•Unique, high spatial resolution TIR data from HyspIRI will lead to improved earthquake forecasts.

TQ1a. Do volcanoes signal impending eruptions through changes in surface temperature or gas emission rates, and are such changes unique to specific types of eruptions?



Kliuchevskoy and Bezymianny volcanoes in Siberia, observed by ASTER. 15 clear-sky nighttime observations in 5 months show changes in thermal behavior of summit domes, development of lava flows and pyroclastic flows, and presence of ash and SO2 plumes. Courtesy of M. Ramsey, U. Pittsburgh.

Science Issue:

•Volcanoes can exhibit idiosyncratic behaviors leading up to eruptions. For example, SO2 production can increase dramatically, or decrease dramatically. Thermal anomalies manifest themselves in many forms: crater lakes, fumaroles, domes, etc. Systematic monitoring can provide potentially effective information to aid in predicting possible eruptions.

Tools:

•Satellite observations from HyspIRI TIR; requires multispectral capability to separate plume constituents; requires bands in 3-5um and 8-12um for temperature determinations in range -20 to 100C

• Historical baseline of characteristic thermal and gas emission behavior for each volcano to compare with HyspIRI observations.

Approach:

•Schedule systematic day & night TIR observations with HyspIRI over several hundred up to 1000 active volcanoes.

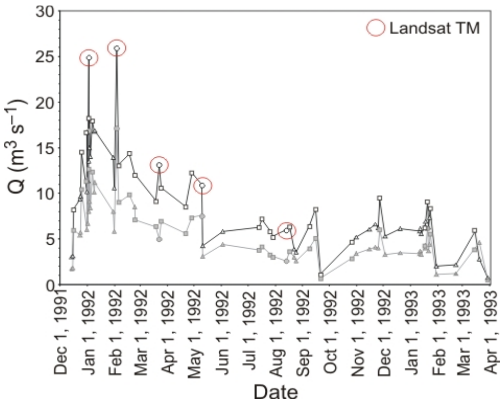
• Implement automatic analysis algorithms to flag anomalous thermal or gas emission activity.

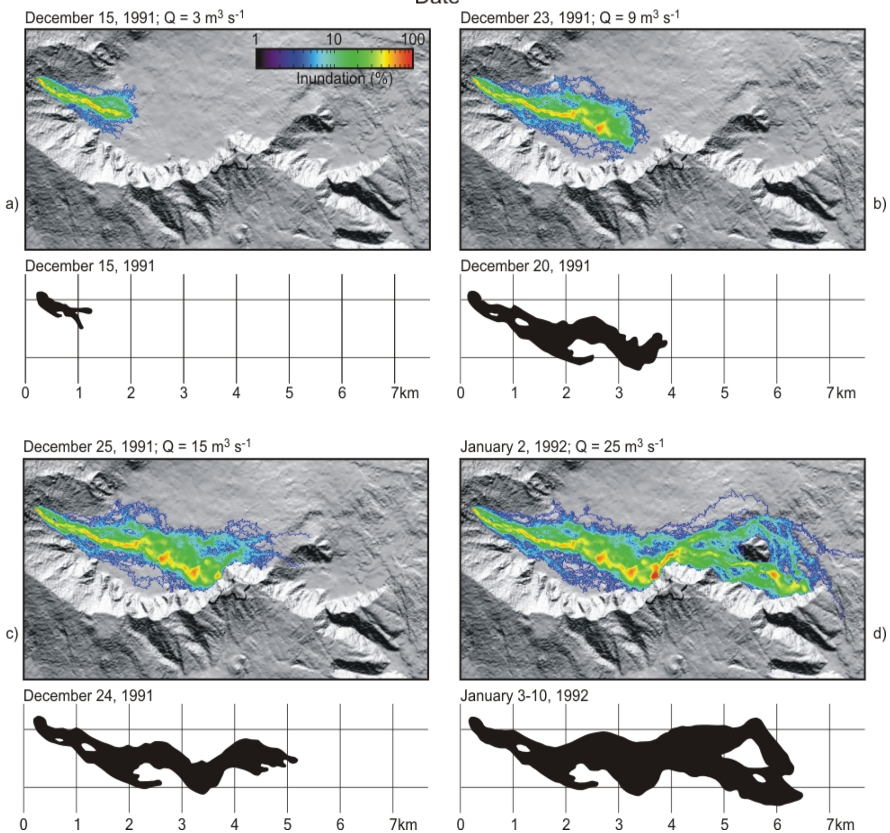
Results:

• Unique, high spatial resolution TIR data from HyspIRI will improve our understanding of pre-eruption volcanic behavior

• This will in turn lead to improvements in our ability to predict volcanic eruptions.

TQ1b: 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?





Wright et al. (2008). *Geophysical Research Letters,* 35, L19307.

Science Issue:

• After lava composition, the volumetric effusion rate (modulated by surface cooling) determines how far a lava flow can extend from the vent before it solidifies. Effusion rates vary dramatically during eruptions, but can be quantified using infrared satellite data (top left; AVHRR, ATSR and TM data). By acquiring high spatial resolution TIR data, HyspIRI will allow us to determine effusion rates twice every five days during a lava flow forming eruption for any volcano on Earth. These data can be used to drive numerical models that predict the hazards that these flows will pose

Tools:

• Satellite observations from HyspIRI TIR; requires band at ~4 μm (saturation temperature of ~1600 K) with moderate-high spatial resolution (<100 m) for determining the area of active lava at any given time during as eruption and estimating the radiant energy flux from the flow surface.

• Pre-HyspIRI DEMs (e.g. SRTM) of all volcanoes likely to erupt basaltic lava flows

• Time-series of effusion rates determined using higher temporal resolution MODIS data for calibration.

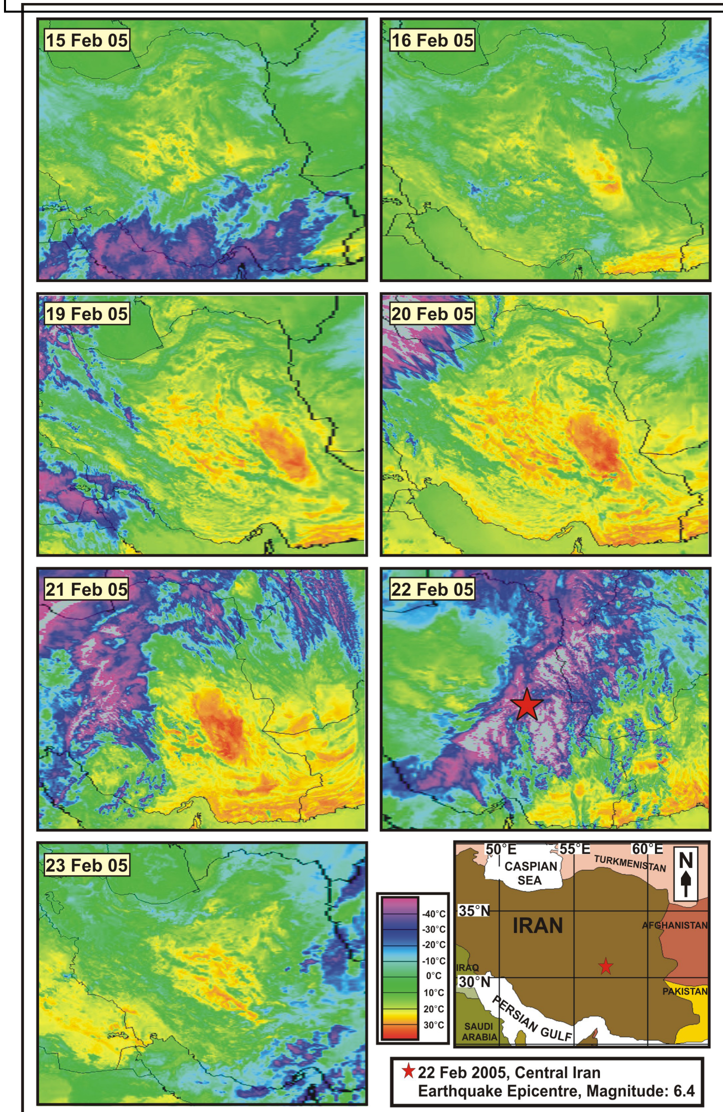
Approach:

• Implement automatic analysis algorithms to flag anomalous thermal activity, determine active lava area and thermal flux, and, subsequently, a HyspIRI-derived effusion rate. Using this, a DEM, the vent location as recorded in the HyspIRI data, and a numerical lava flow model, generate simulations of likely lava flow paths for the given effusion rate. Autonomously update the hazard simulation as most recent HyspIRI derived effusion rates become available (lower left).

Results:

• A global, near-real-time lava flow hazard assessment tool, driven by HyspIRI TIR data.

What do the transient thermal infrared anomalies that may precede earthquakes tell us about changes in the geophysical properties of the crust?



Science Issue:

- Prior to major earthquakes, the build-up of stresses deep below can manifest itself in the emission of spectroscopically distinct, narrow non-thermal IR bands. When volcanoes become activated, they are expected to exhibit the same type of non-thermal IR emission before the arrival of a thermal pulse at the surface.

Tools:

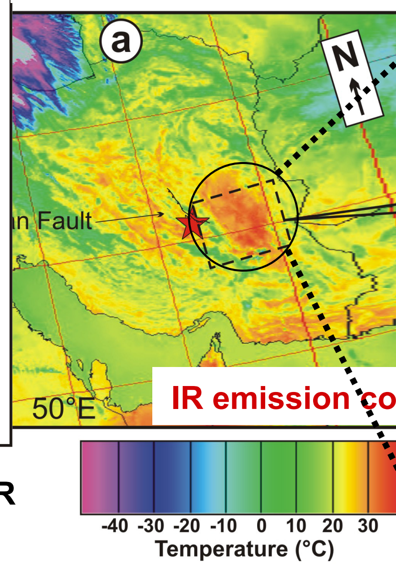
- Satellite observations; Narrow bands in the 10.7-12.5 μm range.

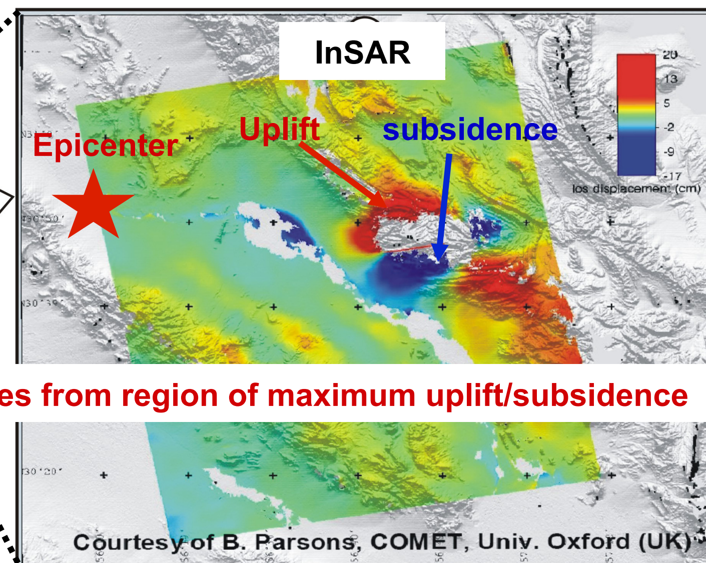
Approach:

- Schedule repetitive observation. Difference spectra.

Results:

- Spectroscopically distinct non-thermal IR bands can appear before earthquakes, mixing with the thermal signature. Same for volcanoes.



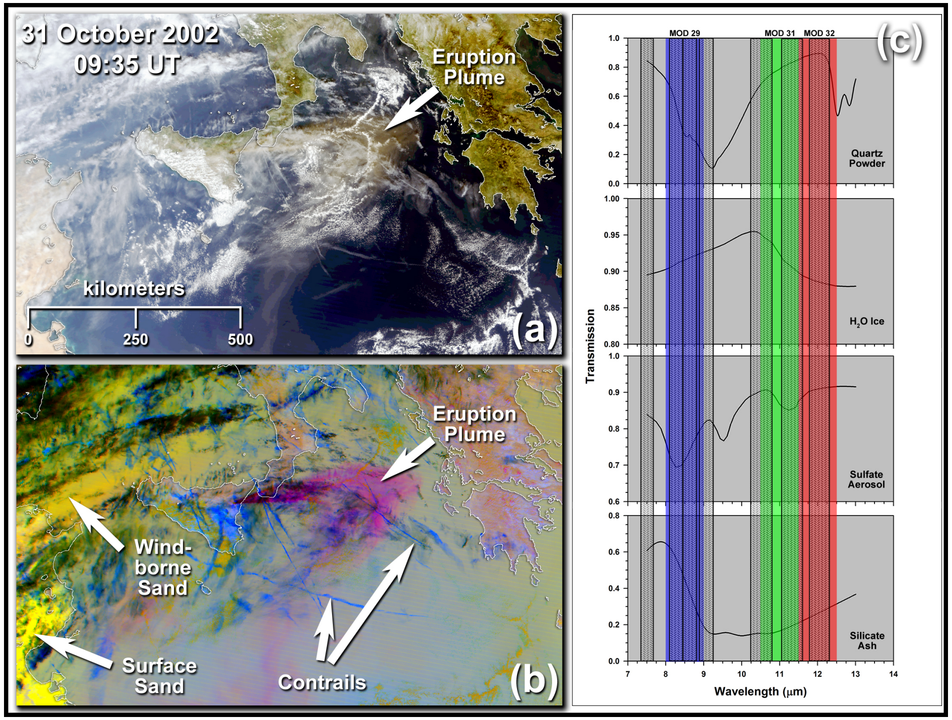


M=6.4 earthquake in Iran 22 Feb. 2005
Good viewing conditions
(similar to Southern CA)

AVHRR

courtesy Saraf et al. 2008

TQ1d: What are the characteristic dispersal patterns and residence times for volcanic ash clouds and how long do such clouds remain a threat to aviation?



Detection of Eruption Plumes in the Thermal Infrared (TIR)

(a) MODIS true-color composite of data acquired over Mount Etna illustrating the difficulty of distinguishing a plume from surrounding meteorological clouds; (b) False-color composite of MODIS TIR data (Ch. 29, 31, 32 displayed in blue, green, and red, respectively) illustrating the unique spectral signatures of the eruption plume (silicate ash), jet contrails (ice), and windborne sand; (c) Model transmission spectra for silicate ash, sulfate aerosol, ice, and quartz powder (representing sand). The blue, green, and red color bars represent MODIS Ch. 29, 31, and 32, respectively; the shaded bars represent the proposed HyspIRI TIR channels. HyspIRI will have three channels in place of MODIS Ch. 29 and three channels in place of MODIS Ch. 31 and 32, enhancing our ability to detect and track eruption plumes and clouds.

Science Issue

The ash plumes generated by explosive volcanic eruptions pose a significant hazard to jet aircraft. Current air traffic protocol is to clear the airspace in the vicinity of the erupting volcano, but the ash plumes may be transported hundreds to thousands of kilometers from their sources. The use of true-color images to discriminate volcanic plumes from meteorological (met) clouds, and other suspended aerosols and particulates, is problematic (Panel (a), at left).

Tools

•HyspIRI multispectral TIR image data, 5-day revisit cycle (daytime acquisitions) at equator, spatial resolution of 60 m, and spectral channels as shown in Panel (c) (at left).

•Profiles of atmospheric temperature and water vapor, measured with radiosondes and spaceborne sounding instruments or model predictions.

•Radiative transfer model to predict radiance at the sensor given atmospheric profiles, length of optical path, and surface temperature, emissivity, and elevation (provided by DEM).

Approach

•Develop Internet portal to provide interactive plume analysis tools and on-demand modeling.

•Statistics-based enhancement of spectral contrast to discriminate eruption plume from met clouds (Panel (b), at left).

•Radiative transfer-based analysis tools to confirm presence of eruption plume and materials derived from plume

Results

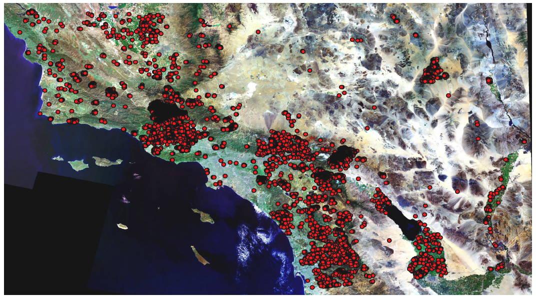
On-demand detection and tracking of eruption plumes via Internet portal, with 2 (1 day + 1 night) HyspIRI revisits per 5 day cycle at equator, and more frequent coverage at higher latitudes.

TQ2. Global Biomass Burning

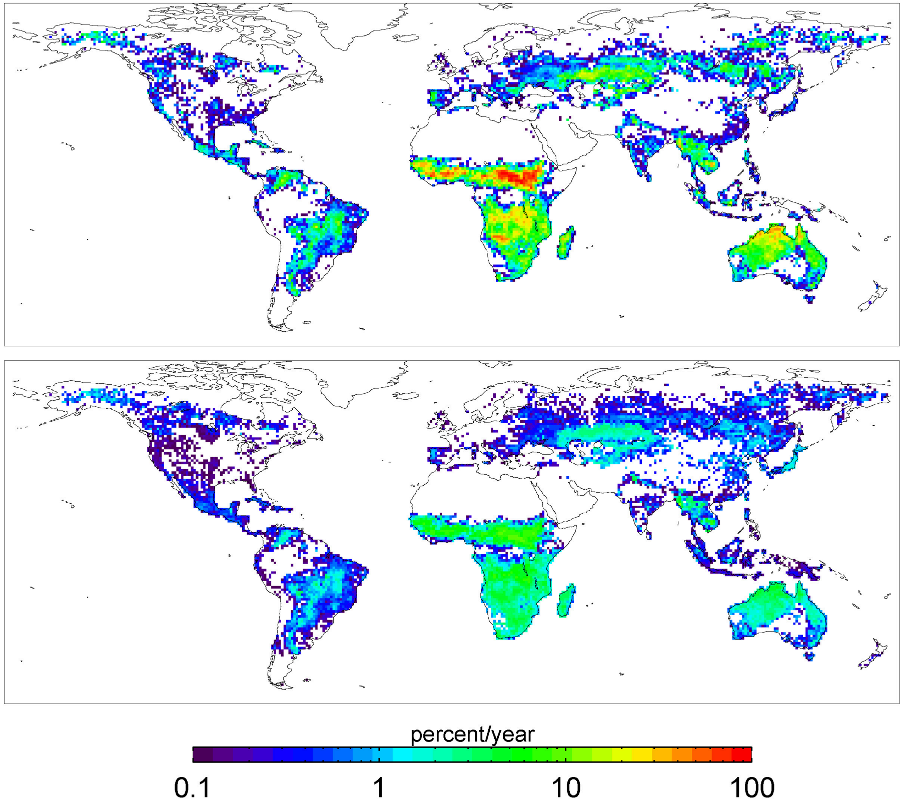
What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?

TQ2a: How are global fire regimes (fire location, type, frequency, and intensity) changing in response to changing climate and land use practices? [DS 198]

MODIS active fire detections 2000-2006 for Southern California



2001-2004 mean annual burned area derived from Terra MODIS active fire observations (top) and accompanying one-sigma uncertainties (bottom), expressed as fraction of grid cell that burns each year. From Giglio et al. (2005), *Atmos. Chem. Phys. Discuss.*, 5, 11091-11141

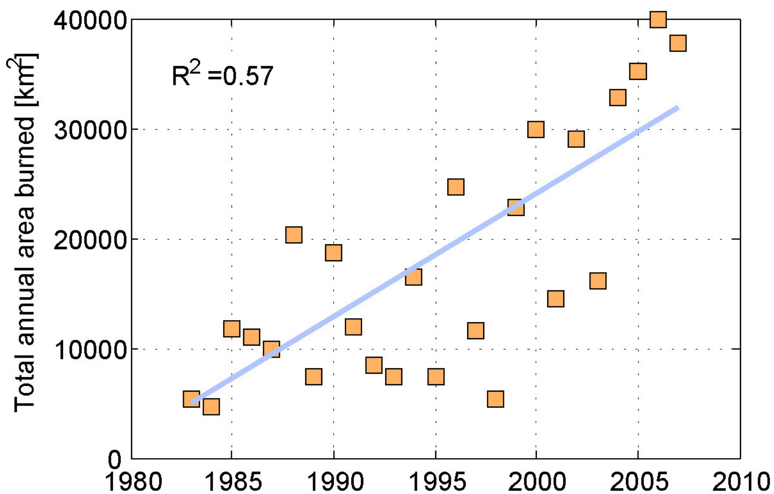


- Science issue
  Fire regimes vary considerably on a regional and global scale. Mapping fire location, type, frequency, and intensity at different times can contribute to an understanding of how they are affected by a changing climate and land use patterns.

- Tools
  Requires long-term regional or global data sets of thermal infrared imagery (low and normal gain channels at 4 and 11 μm). HyspIRI TIR data has a significantly improved capability of mapping flaming and smoldering fires. HyspIRIs greatly expanded spatial and temporal coverage can provide large sample sizes. Requires further pre-fire and post-fire thematic maps of climate variables and land use.

- Approach
  The HyspIRI thermal infrared data will provide large samples of detailed fire characteristics that are useful for statistical modeling of fires and their behavior. The database of fire detections can be analyzed in conjunction with thematic data sets of climate and land use.

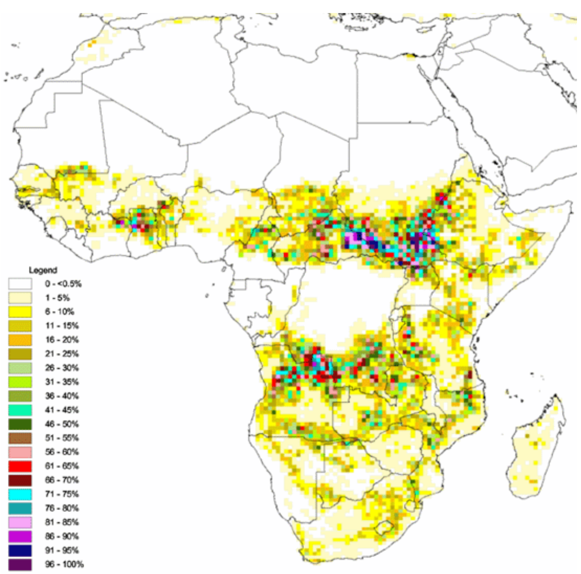
TQ2b: Is regional and local fire frequency changing? [DS 196]



Total annual area burned in the United States 1983-2007. From Schneider (2008). Data from National Interagency Coordination Center

Precentage of total surface areas of each cell burned in the year 2000

From http://www-tem.jrc.it/Disturbance_by_fire/activities/occurglobal.htm

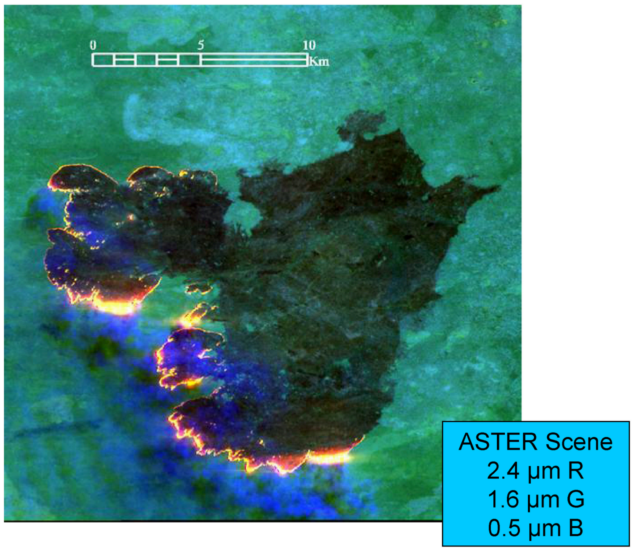


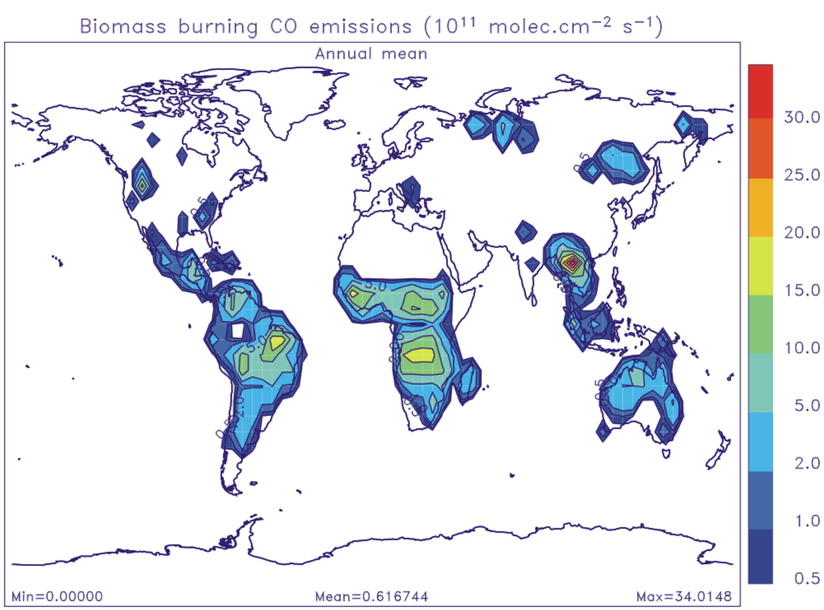
- Science Issue
  A warming climate has the potential for increased fire activity and more severe fires. Statistics show an increase in burned area in some regions but more accurate detection of fire events, in particular fire size, is necessary

- Tools
  Requires accurate detection of all fire types, including small agricultural fires and smoldering fires as small as ~10 sqm in size (difficult with coarser resolution sensors) and very hot fires, which often saturate existing sensors.
  HyspIRI TIR data has a greatly expanded spatial and temporal coverage compared to previous sensors, thus allowing for improved global fire mapping.
  Requires historical context from other sensors with measurement intercalibration to establish a baseline

- Approach
  Use HypsIRI TIR imagery to develop a comprehensive database of global fire events and compare with existing data sets of fire occurrence to determine trends in fire activity

TQ2c: What is the role of fire in global biogeochemical cycling, particularly trace gas emissions? [DS 195]





http://www.aeronomie.be/tropo/models/models_a_priori_emissions.htm

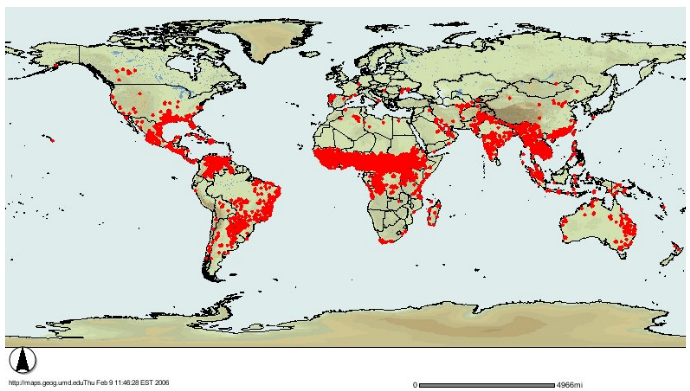
- Science issue
  Emissions from fires, such as carbon, carbon dioxide, carbon monoxide, methan, nitrogren oxides, particulate matter etc, affect the atmosphere on a local, regional and global scale. However, quantifying and modeling the impacts of such emissions is challenging and more detailed satellite imagery of fires, such as provided by HyspIRI, can contribute to this task.

- Tools
  Requires accurate fire detection including small and smoldering fires, fire monitoring, mapping of burn severity, and delineation of burned area. HyspIRI TIR data can detect fires as small as ~10 sqm in size. Also requires accurate measurements of fire temperature and fire area, as well as a fuel fire modeling element.

- Approach
  Use systematically acquired HyspIRI TIR data to develop a regional database of fire occurrence and characteristics of individual fire events. Model trace gas emission using the obtained fire characteristics.

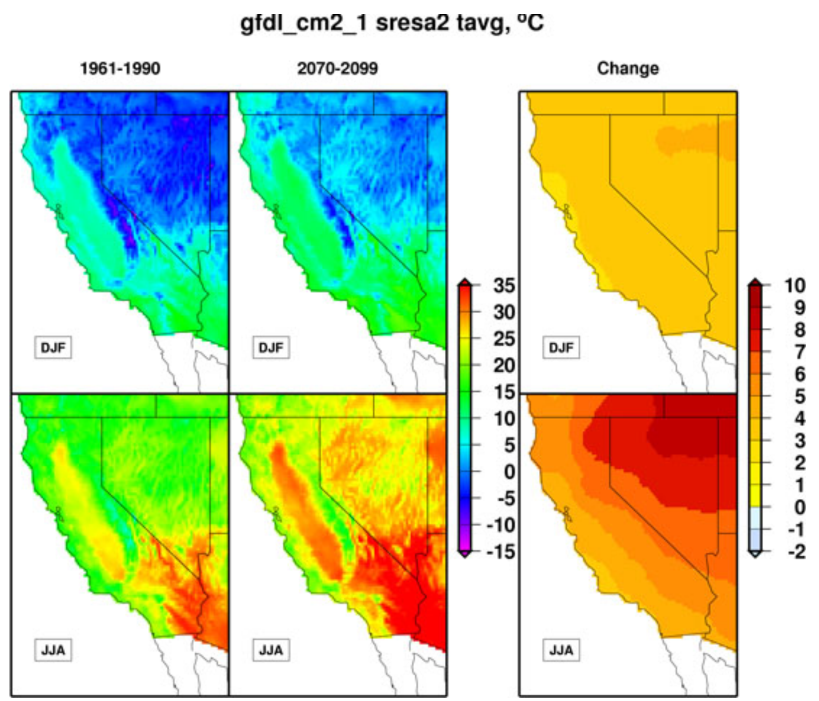
TQ2d: Are there regional feedbacks between fire and climate change?

HyspIRI can provide a more detailed database of fire events than traditional sensors (here the MODIS Active Fire Product)



http://maps.geog.umd.edu/images/modis_fire_global.jpg

Regional climate models are improving and can be used in conjunction with a fire database to investigate potential feedbacks



http://meteora.ucsd.edu/cap/images/CA_gfdl_cm2_1_sresa2_delta_tavg_1961_2070.jpg

- Science issue
  Regional and global fire activity has the potential to affect regional climate, in particular through impacts on atmospheric transmission. Furthermore, climate change has the potential to affect regional fire regimes.

- Tools
  The objectives for this task are mapping of the extent of the fire front and the confirmation of burn scars. Such measurements require the detection of flaming and smoldering fires as small as ~10 sqm in size
  Requires satellite observations from HyspIRI, in particular its multispectral TIR capability to detect fires and monitor fire activity, as well as mapping fire temperature and fire area. Further requires information on pre-fire vegetation cover, fuel condition and fuel load, as well as output from regional climate models.

- Approach
  Use systematically acquired HyspIRI TIR data to develop a regional database of fire occurrence and characteristics of individual fire events. Compare changes in regional fire activity with observed climate variables and with the output of regional climate models

CQ3. Volcanoes

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?

CQ3: 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?

Left: Ground–based thermal image of the active lava dome at Sourfiere Hills volcano, Montserrat. Variations in thermal and gas flux from other lava domes have been shown to exhibit a cyclicity that is related to the periodic generation of explosive overpressures in the shallow conduit.

Left: Crater lake at Maly Semiachik, Kamchatka. Variations in the temperature, area, and color of crater lakes has been observed to change prior to significant changes in volcanic unrest

Science Issue:

• The replenishment of a shallow magma reservoir can herald a) the onset of an eruption at a previously inactive volcanic system or, b) significant changes in eruptive behavior at already active volcanoes. Rising magma ultimately results in a flux of volatiles (such as SO_2), particulate matter, and/or thermal energy, onto Earth's surface and into it's atmosphere. Detecting and characterizing these fluxes, and the indirect effects that they have on, for example, the health of local vegetation and the thermo–physical properties of volcanic crater lakes, is important for both basic science (as a means for quantifying aspects of magma ascent dynamics and shallow conduit processes) and hazard managers (for recognizing significant changes in a volcano's behavior and predicting volcanic hazards).

Tools:

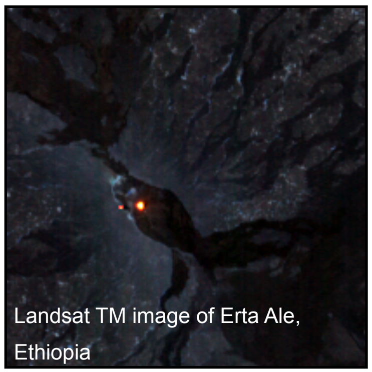
• Moderate resolution (*i.e.* Landsat/ASTER class) data from the HyspIRI VSWIR and TIR instruments.
• In–situ observations to calibrate HyspIRI–derived measurements
• Published physical, geochemical, and field–based models of volcanic processes that will use the HyspIRI–derived measurements as input or for calibration/validation.
• Historical observational baseline, compiled over decadal time–scale via previous remote sensing missions, to place the HyspIRI observations in temporal context.

Approach:

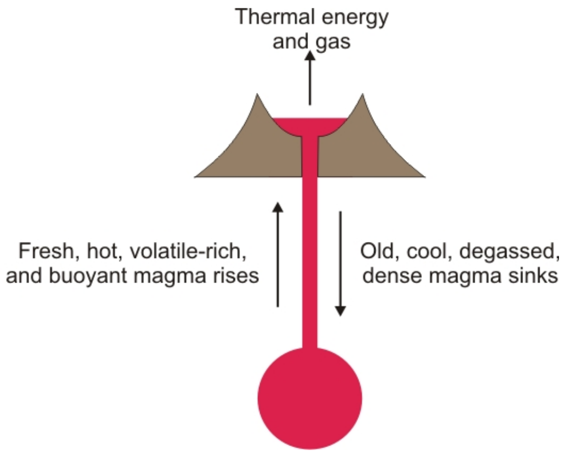
• Develop and implement algorithms to extract key physical parameters (SO_2 flux, heat flux) from HyspIRI' s VSWIR/TIR data. Develop algorithms for detecting surface compositional changes that may signal an increase in volcanic unrest.

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)

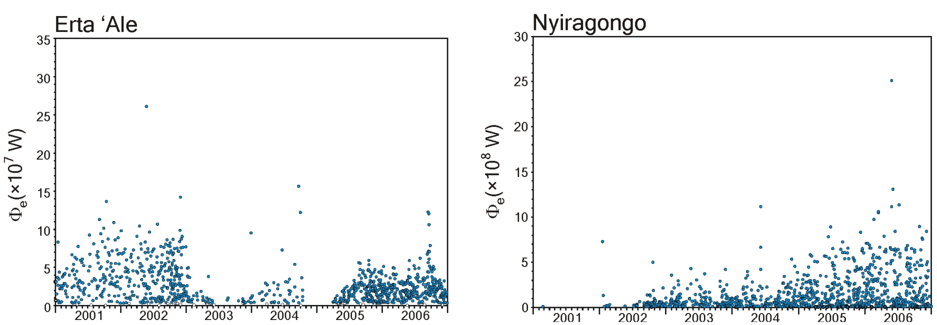
Oppenheimer et al. (2004) *Geology*, 32, 509-512.



Landsat TM image of Erta Ale, Ethiopia



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



Wright & Pilger (2008). *J. Volcanol. Geotherm. Res.*, 177, 687-694.

Science Issue:

• 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)?

Tools:

•Requires multispectral TIR capability to detect, quantify, and monitor SO_2 flux. Requires hyperspectral VSWIR data as well as multispectral data in the 4 μm (saturation temperature of ~1600 K) and 8–12 μm (ideally, at least one band with a measurement temperature of ~800 K) regions for determining lava surface temperatures. This latter measurement will be used to determine the thermal flux at the magma/atmosphere interface.

• Published geochemical and enthalpy models relating these fluxes to the volume of magma cooled and degassed.

• Knowledge of local wind field and volcano altitude to aid computation of SO_2 flux.

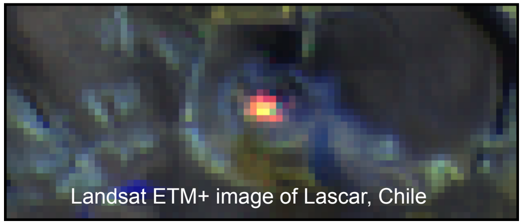
• Historical baseline of characteristic thermal (*e.g.* from MODIS, lower left) and gas emission behavior for each volcano to provide multi–year/decadal context for the HyspIRI observations.

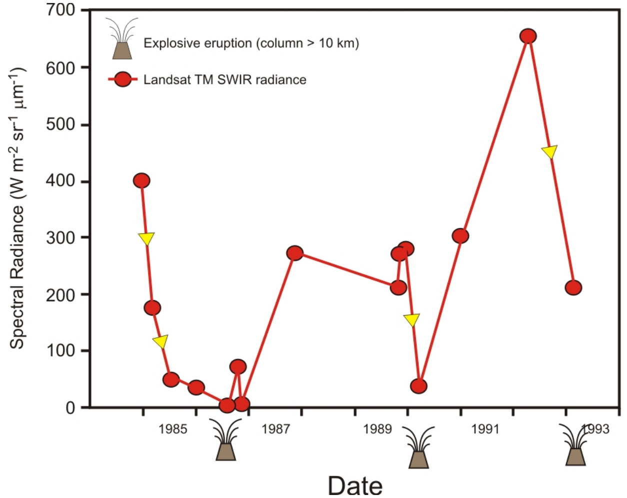
Approach:

• Use systematically acquired day and night VSWIR and TIR observations for several basaltic volcanoes that exhibit persistent lava lake activity (*e.g.* Erta Ale, Nyiragongo) and several volcanoes that frequently produce basaltic lava flows (*e.g.* Etna, Piton de la Fournaise).

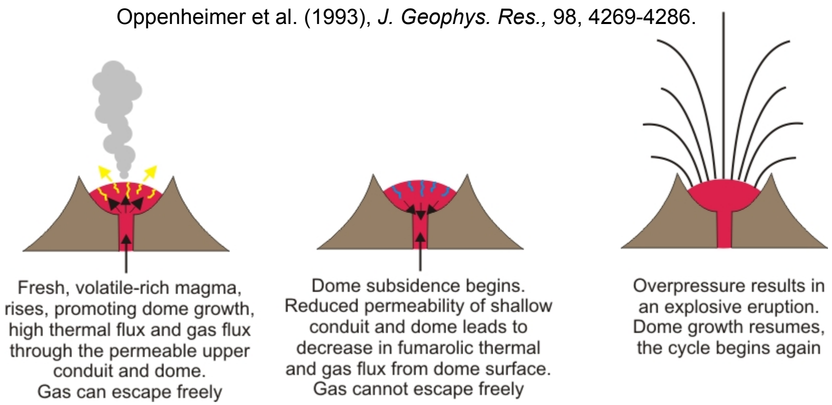
• Field campaign to acquire in–situ SO_2 and thermal flux data at a single target for calibration purposes.

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)





Oppenheimer et al. (1993), *J. Geophys. Res.*, 98, 4269-4286.



Matthews et al. (1997), *Bull. Volcanol.*, 59, 72-82.

Science Issue:

• Cyclicity is increasingly recognized as characteristic of explosive silicic dome–forming volcanoes. Precipitous drops in SWIR radiance detected by Landsat TM from Lascar's summit crater during the 1980s and 1990s were followed by significant explosive eruptions (middle left). A model, based on field observations, has been proposed to explain these cycles (bottom left). Explosive overpressure results when gas cannot escape freely from the shallow conduit resulting in a decreased gas flux *and* decreased abundance of high temperature fumaroles on the dome surface. Can we use HyspIRI to recognize similar patterns, at other potentially explosive volcanoes?

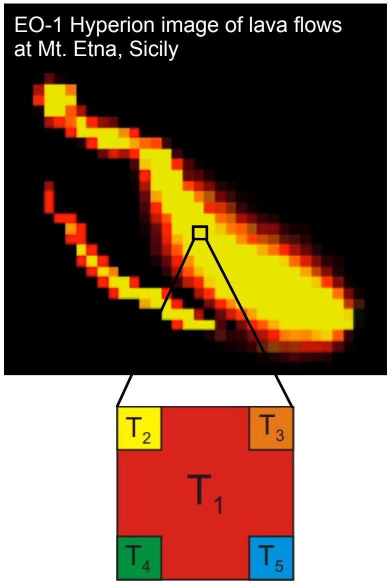
Tools:

• Satellite observations from HyspIRI. Requires multispectral TIR capability to detect and monitor SO_2 degassing rates over time; requires hyperspectral VSWIR data as well as multispectral data in the 4 μm (saturation temperature of ~1600 K) and 8–12 μm (ideally at least one band with a measurement temperature of 800 K) regions for determining the abundance of high temperature fumaroles on dome surfaces and how this changes through time.

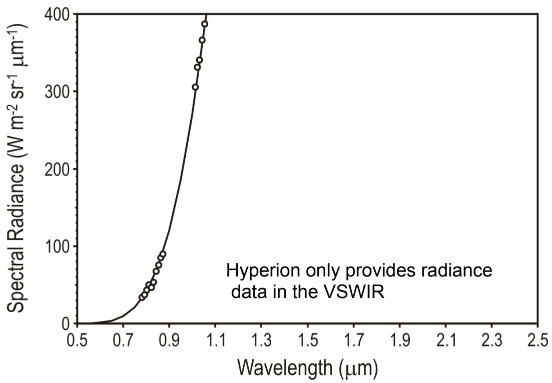
Approach:

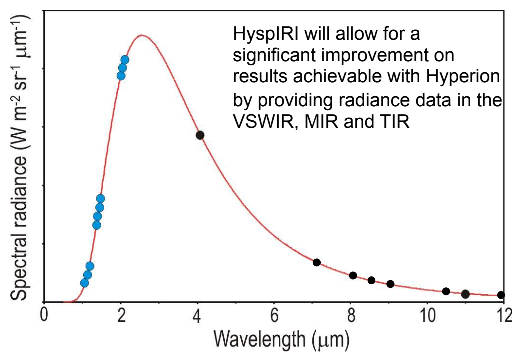
• Use systematically acquired day and night VSWIR and TIR observations for a subset of active volcanoes known to host silicic lava domes (*e.g.* Popocatepetl, Soufriere Hills Volcano) to determine temporal changes in degassing rate and the surface temperature characteristics of active lava domes.
• Use historic archive of thermal flux data from MODIS to place the HyspIRI observations in temporal context.

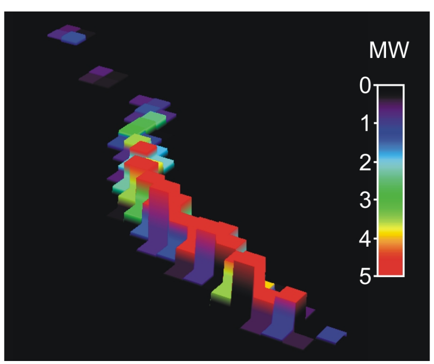
CQ3c: Can measurements of the rate at which lava flows cool allow us to improve forecasts of lava flow hazards? (DS 50; 226)



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







Radiant cooling of the active lava channel shown above, determined from the EO-1 Hyperion VSWIR imaging spectrometer

Science Issue:

• 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.

Tools:

• Satellite observations from HyspIRI. Requires hyperspectral VSWIR data as well as multispectral data in the 4 μm (saturation temperature of ~1600 K) and 8–12 μm (ideally, at least one band with an upper measurement temperature of 800 K) regions for un–mixing the sub–pixel radiative components of active lava flow surfaces (left). These temperature data can be used to estimate energy fluxes from flow surface and subsequently, lava cooling rates (left).

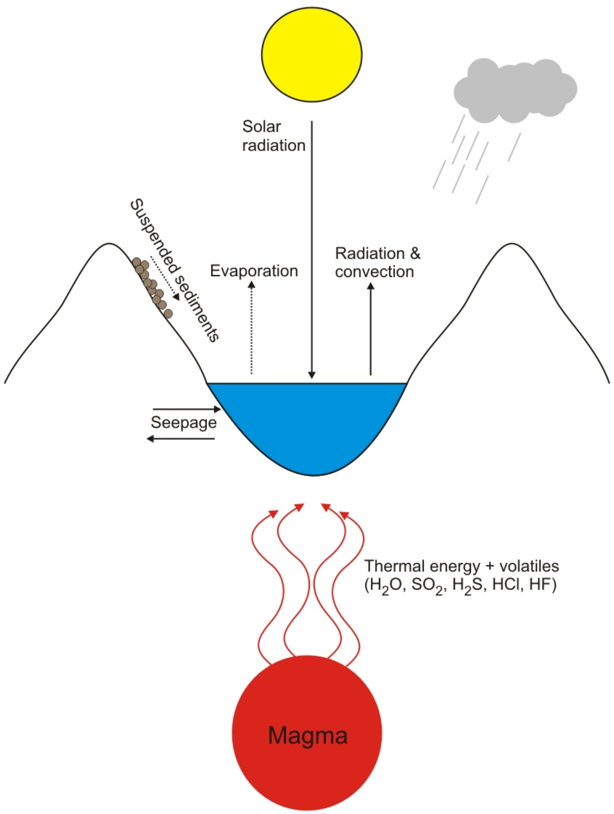
• Published numerical models of lava flow motion which will take the HyspIRI–derived temperature/cooling data as an input.

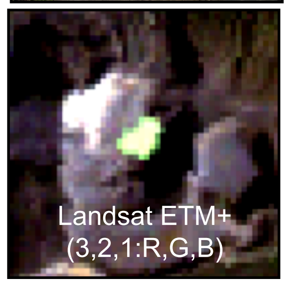
• Heat flux estimates derived from simultaneously acquired high temporal/low spatial resolution sensors (*e.g*. MODIS) as both a point calibration and to assess the short time scale variability of heat fluxes during eruptions.

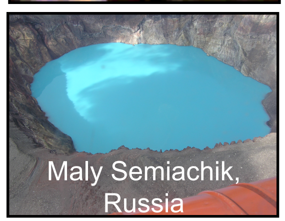
Approach:

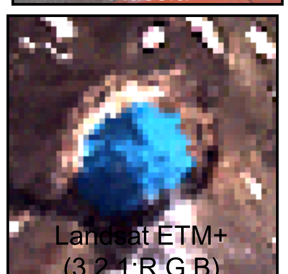
• Schedule nighttime VSWIR and TIR observations during eruptions that produce basaltic lava flows. Systematic nighttime VSWIR and TIR acquisitions for high priority volcanoes that frequently erupt lava flows (*e.g*. Kilauea, Etna, Piton de la Fournaise). Potential application for the JPL volcano sensor web and U. Hawaii's low resolution MODVOLC global volcano monitoring system as a means to autonomously perform the tasking for other volcanoes that erupt lava flows less frequently (*e.g*. Fernandina, Galapagos).

CQ3d: Does the temperature and composition of volcanic crater lakes change prior to eruptions? (DS 226; 227).









Science Issue:

• Some 100 Holocene active (*i.e.* within the last 10,000 years) volcanoes host crater lakes. These lakes act as chemical condensers and calorimeters that allow us to quantify energy and chemical fluxes from their associated magma bodies. Several eruptions have been observed to follow increases in lake water temperature. Variations in water color can result from increased suspended sediment content (caused by elevated seismicity and turbidation due to degassing through lake floor sediments), and changes in scattering properties due to changes in chemical composition. HyspIRI's TIR and VSWIR instruments will allow us to monitor these volcanoes to identify changes in the temperature, area, and color of volcanic crater lakes for changes that may indicate enhanced volcanic unrest.

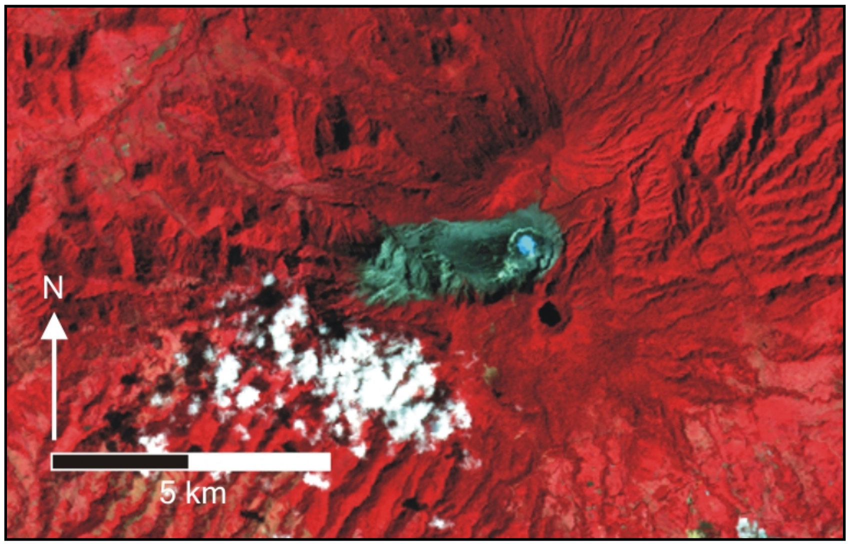
Tools:

• HyspIRI's VSWIR (for quantifying lake color and area) and TIR (two bands in the 8–12 μm region) for monitoring lake water surface temperature.
• Published enthalpy models of crater lake systems to be used as the basis for converting lake water temperatures to thermal fluxes.

Approach:

• Systematic day (VSWIR) and day and night (TIR) observations of 100 Holocene active volcanoes know to host crater lakes.
• Field campaigns (Poas volcano, Costa Rica) to acquire ground based VSWIR spectra and thermal camera data for calibration purposes.

CQ3e: Do changes in the health and extent of vegetation cover indicate changes in the release of heat, gas, and ash from crater regions? (DS 230; 231)



Landsat TM, Poas volcano, Costa Rica

Science Issue:

• 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 (left). 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.

Tools:

• HyspIRI' s VSWIR instrument for monitoring vegetation health.
• TIR data (two bands in the 8–12 μm region) for mapping low temperature volcanogenic heat sources and the spatio–temporal distribution of volcanic ash.
• TIR data (7 bands in the 8–12 μm region) for quantifying and monitoring SO_2 degassing rates.
• Published data and modes regarding the rate at which SO_2 is converted to sulfate aerosol
• Pre–eruption/archival thematic maps/image maps showing how landscape disturbance has progressed through time prior to HyspIRI launch for a subset of volcanoes.

Approach:

• Automated vegetation health change detection algorithms for a selection of active and potentially active volcanoes.