TQ1: Volcanoes and Earthquakes

NASA Decadal Survey HyspIRI Mission

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Outline of Presentation

1) Overarching question and sub-questions
2) Science traceability matrix
3) Alignment with Decadal Survey
4) Level 3 products planned
5) Validation of Level 3 products
6) Precursor science needed

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TQ1: Volcanoes and Earthquakes

Overarching Question:

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

TQ1: Volcanoes and Earthquakes

TQ1. Volcanoes and Earthquakes

Sub Questions:

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

- 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?

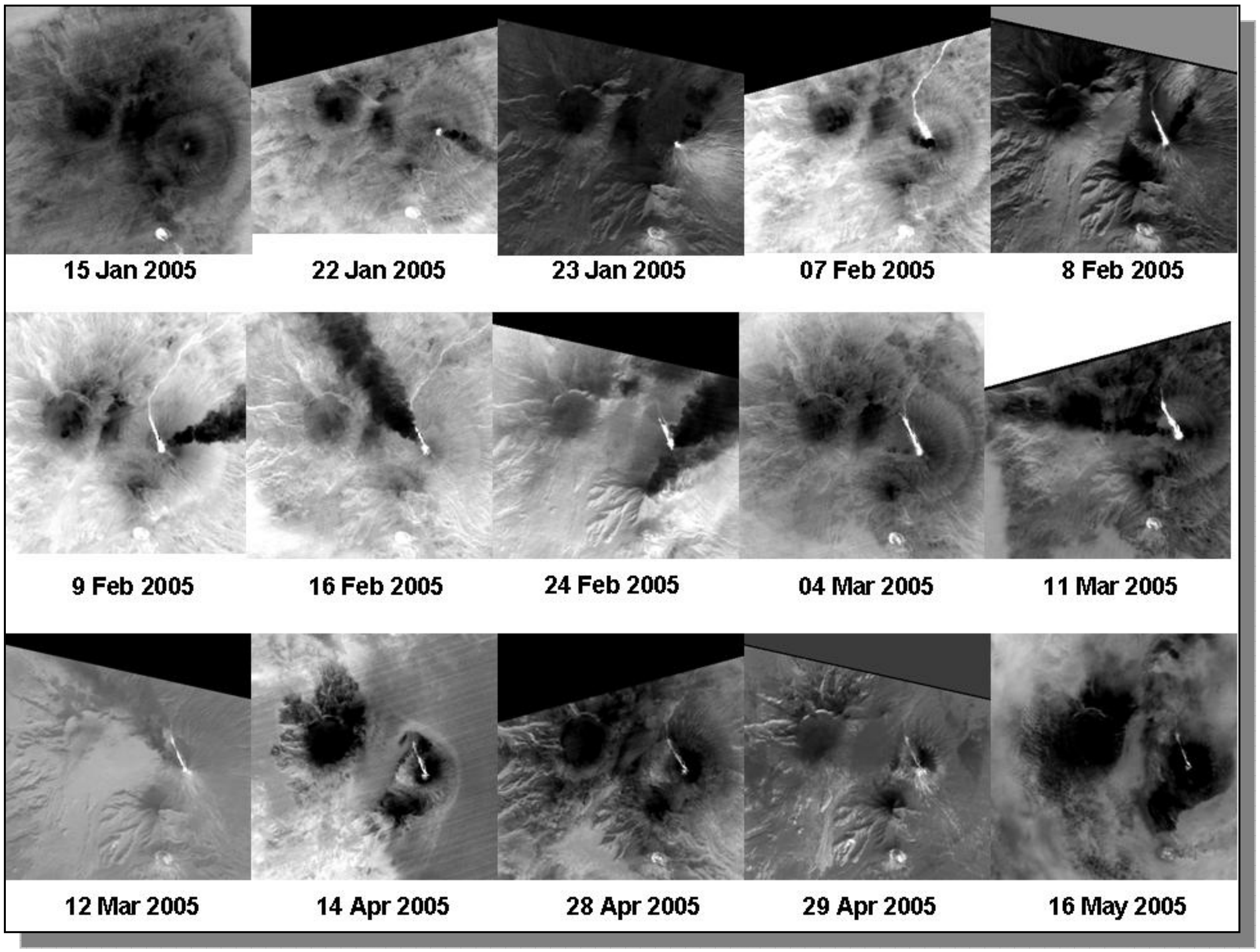
- Can the energy released by the periodic recharge of magma chambers be used to predict future eruptions?

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

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

TQ1: Volcanoes and Earthquakes

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]



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 Mike Ramsey)*

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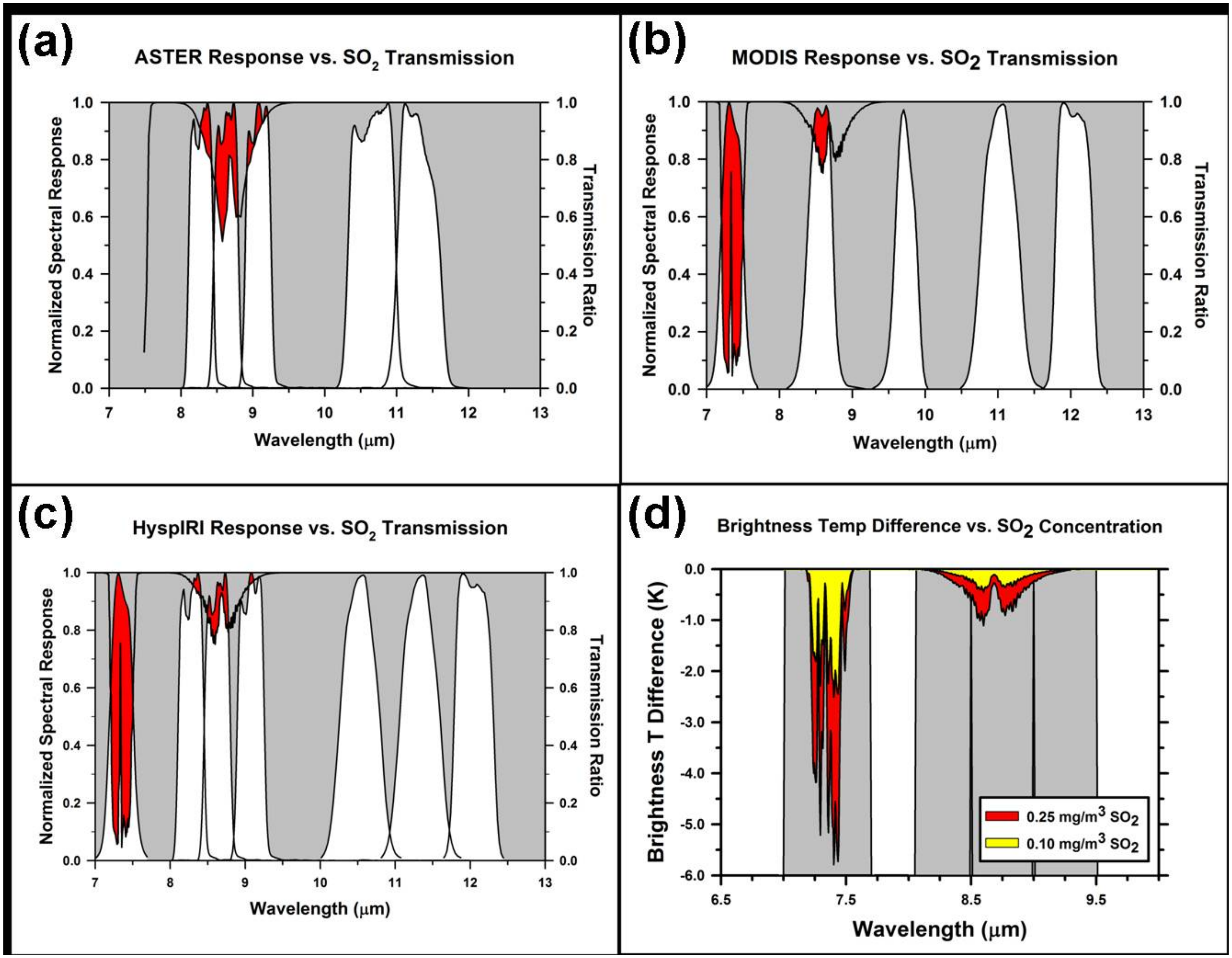
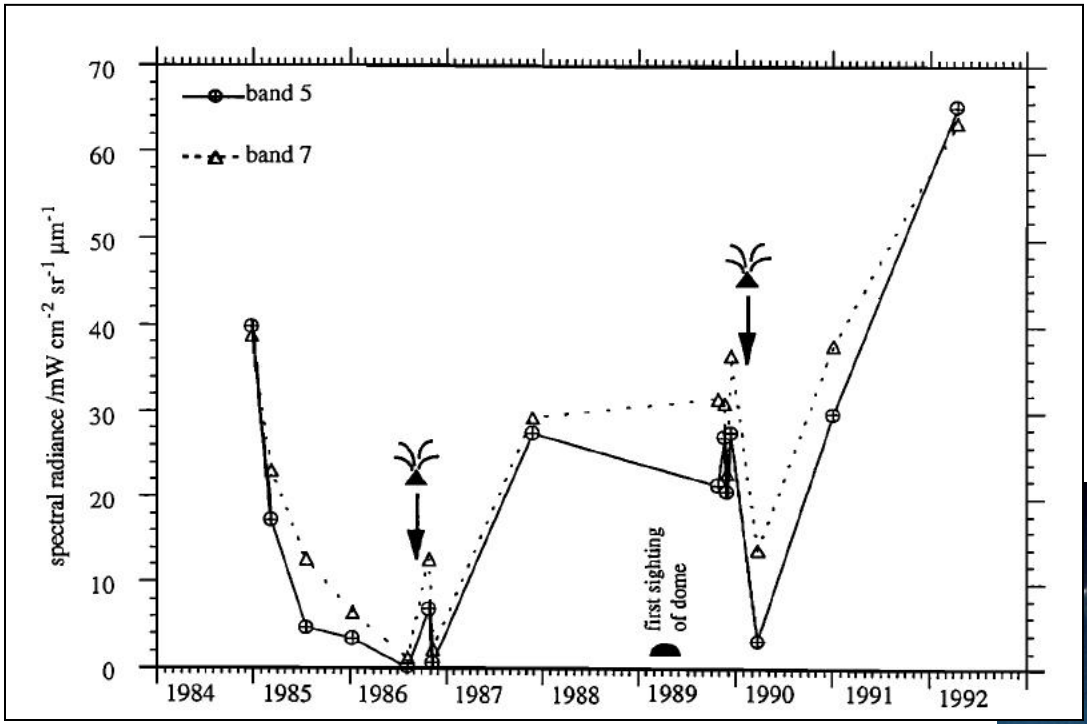


TQ1: Volcanoes and Earthquakes

Can the energy released by the periodic recharge of magma chambers be used to predict future eruptions? [DS 227]



Landsat Thematic Mapper spectral radiance through time for Lascar volcano, Chile. Volcano symbols mark Sept. 16, 1986 and Feb. 20, 1990 eruptions. Activity has been characterized by periods of dome growth punctuated by explosive eruptions with tall ash columns.

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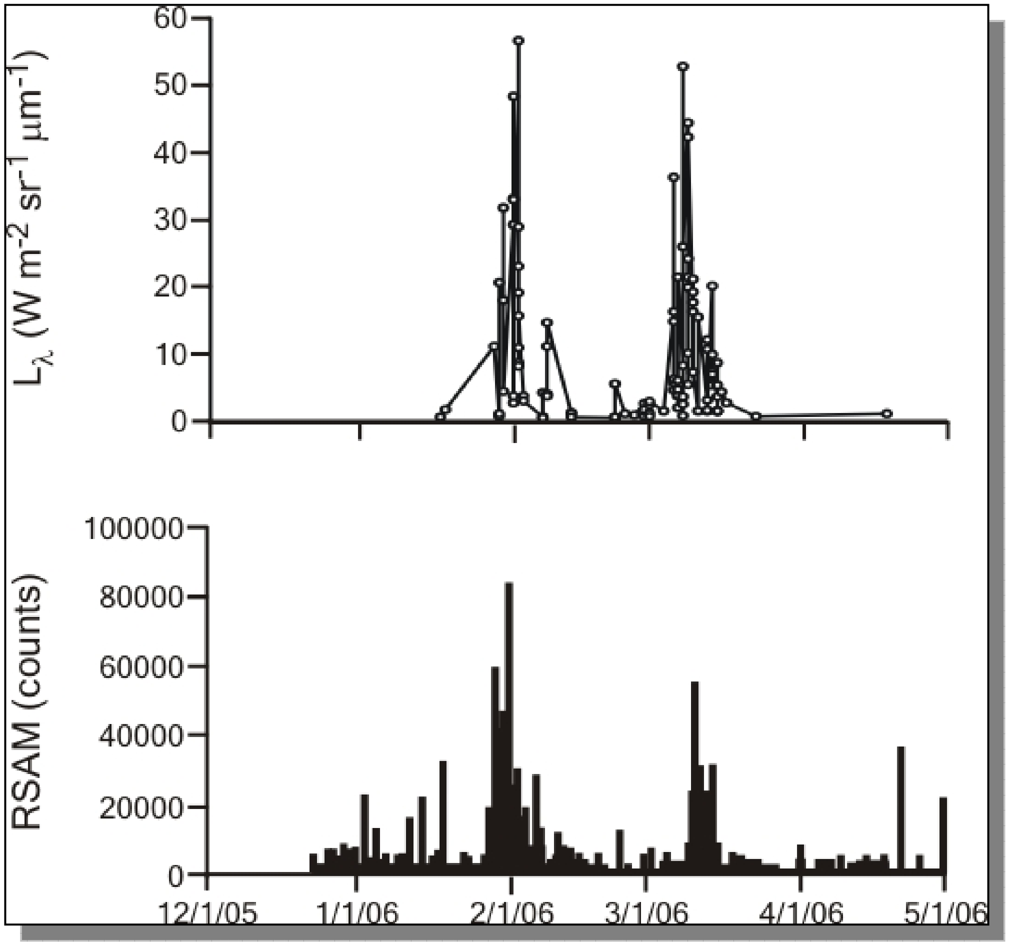
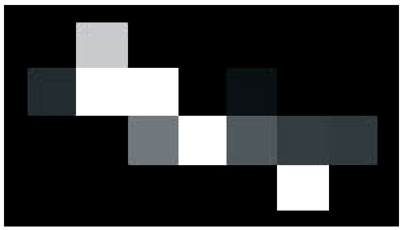


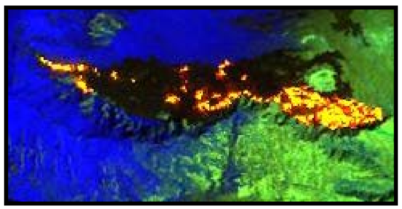
Real-Time Seismic-Amplitude Measurement System vs. satellite measured flux for Augustine volcano eruptions. Note near perfect correlation of 2 different geophysical measurements. RSAM measures volcano-tectonic earthquakes, and is related to magma movement in sub-surface. Thermal integrated radiance seems to be an excellent proxy, and thus can be used to infer behavior at depth.

TQ1: Volcanoes and Earthquakes

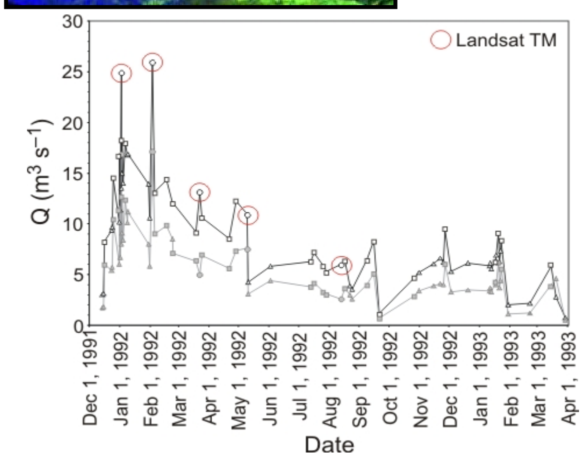
What do changes in the rate of lava effusion tell us about the maximum lengths that lava flows can attain, and the likely duration of lava flow-forming eruptions? [DS 226]

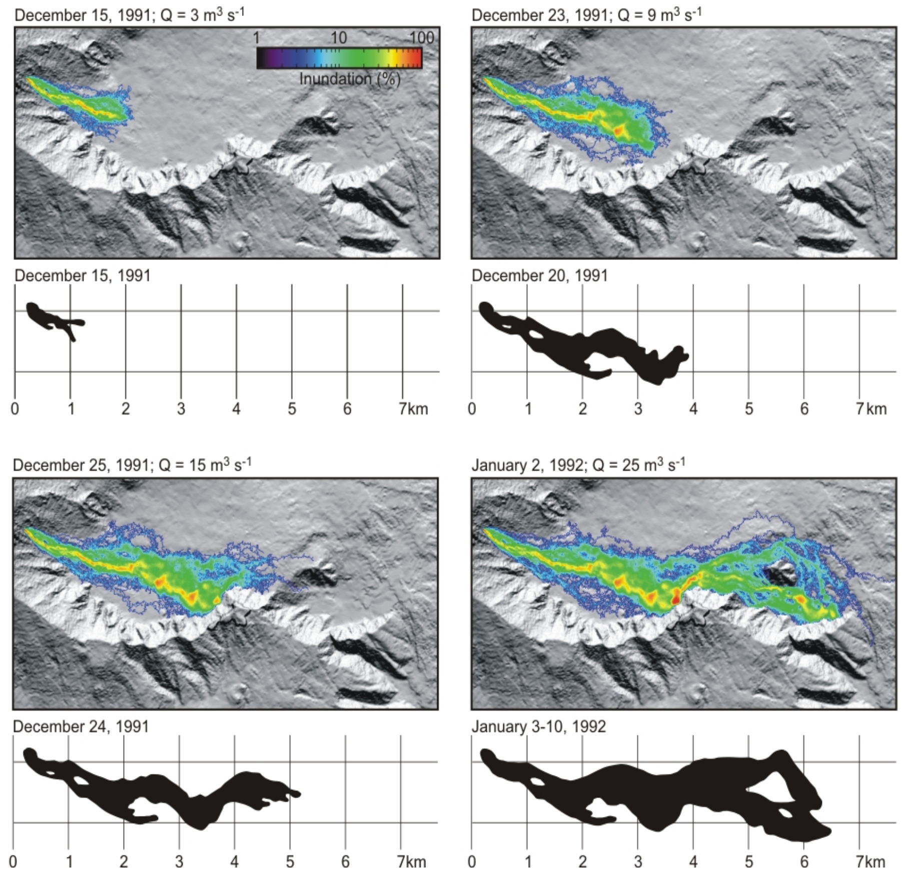


Mount Etna, Sicily
ATSR, 3 January 1992



Mount Etna, Sicily
Landsat TM, 22 March 1992





1. The length a lava flow can attain is governed by the effusion rate
2. The thermally active flow area as a function of time is proportional to the effusion rate
3. HyspIRI will allow us to determine the effusion rate twice in each 5 day period

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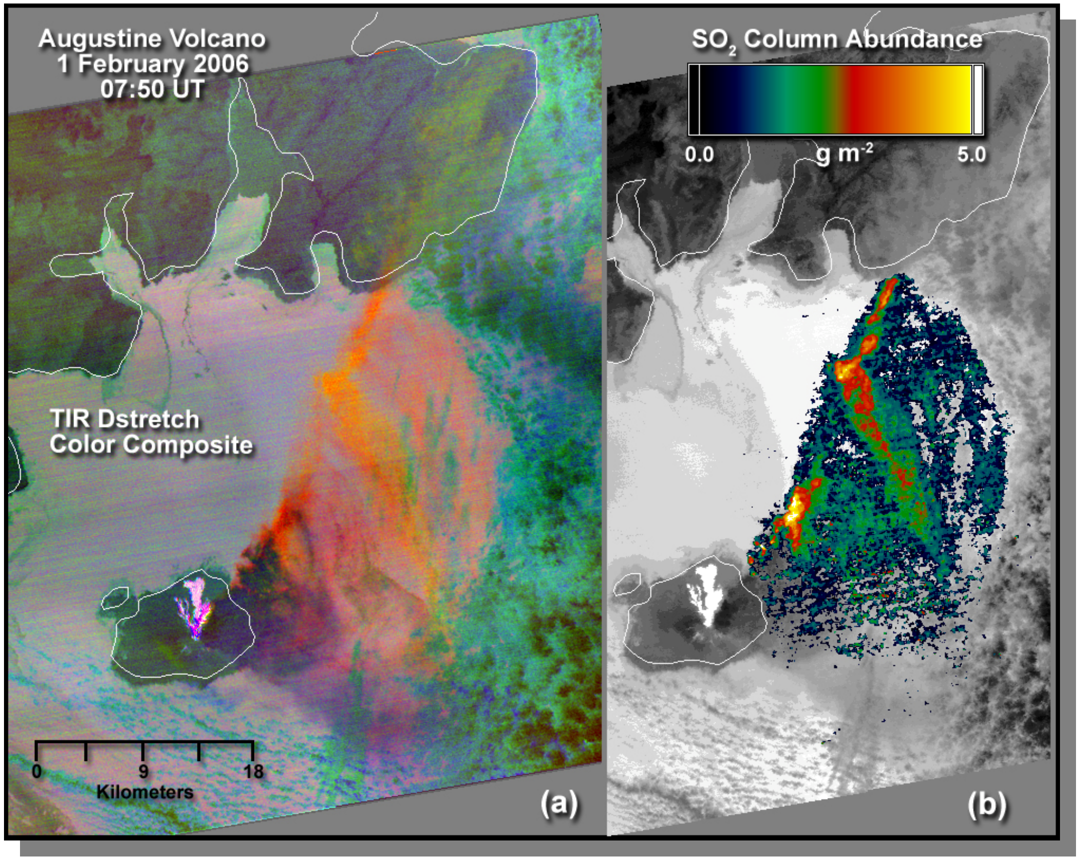
What are the characteristic dispersal patterns and residence times for volcanic ash clouds and how long do such clouds remain a threat to aviation? [DS 224]



ASTER night-time multispectral TIR image of Augustine Volcano showing eruption plume. (a) Color-composite image showing spectral variations between materials entrained in plume. Magenta display colors indicate mixtures of water droplets (steam) and silicate ash. Red, yellow, and orange display colors indicate mixtures of ash and SO2. The red and yellow component of the display color increases with relative increase of ash and SO2, respectively. (b) SO2 map derived from ASTER TIR data.

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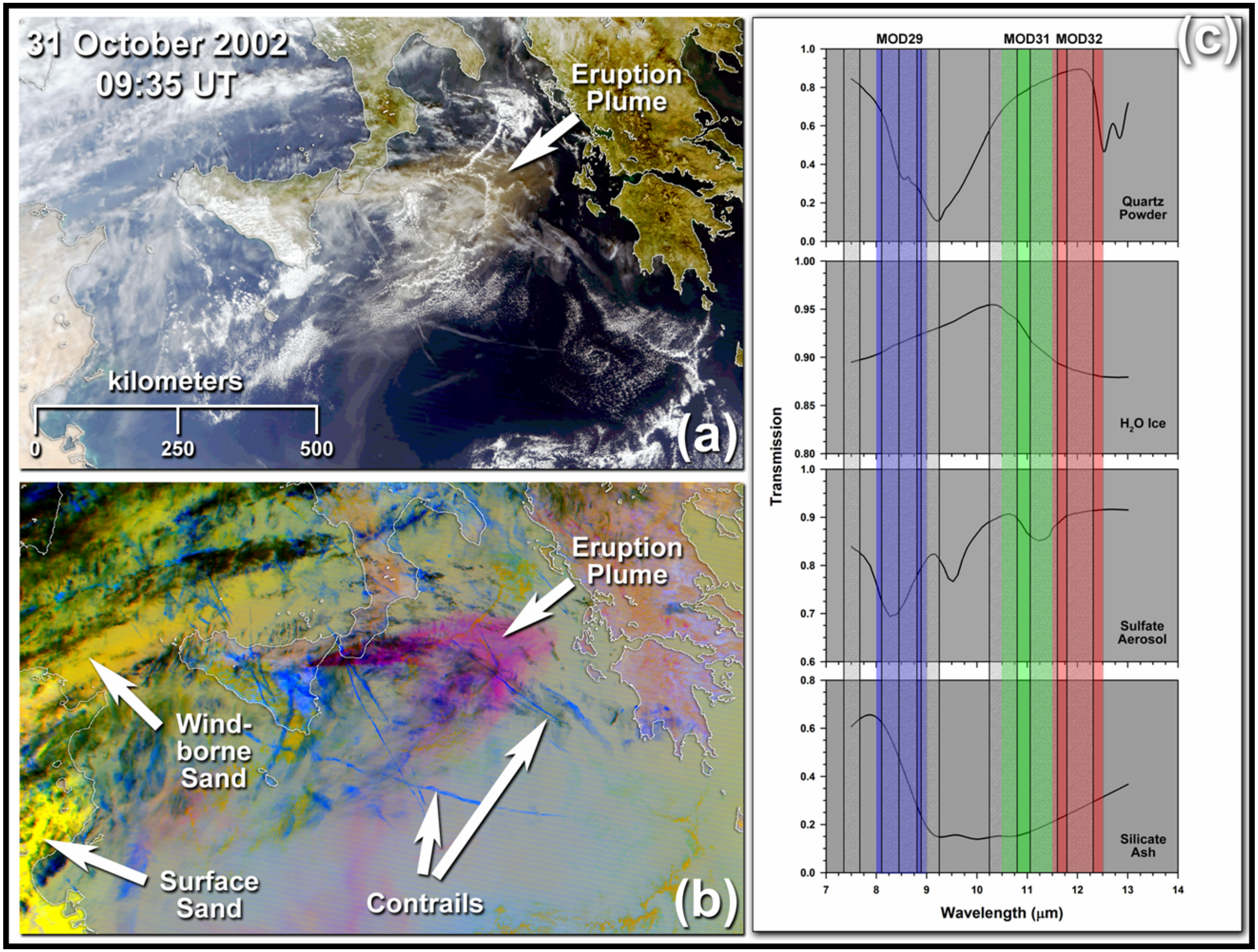
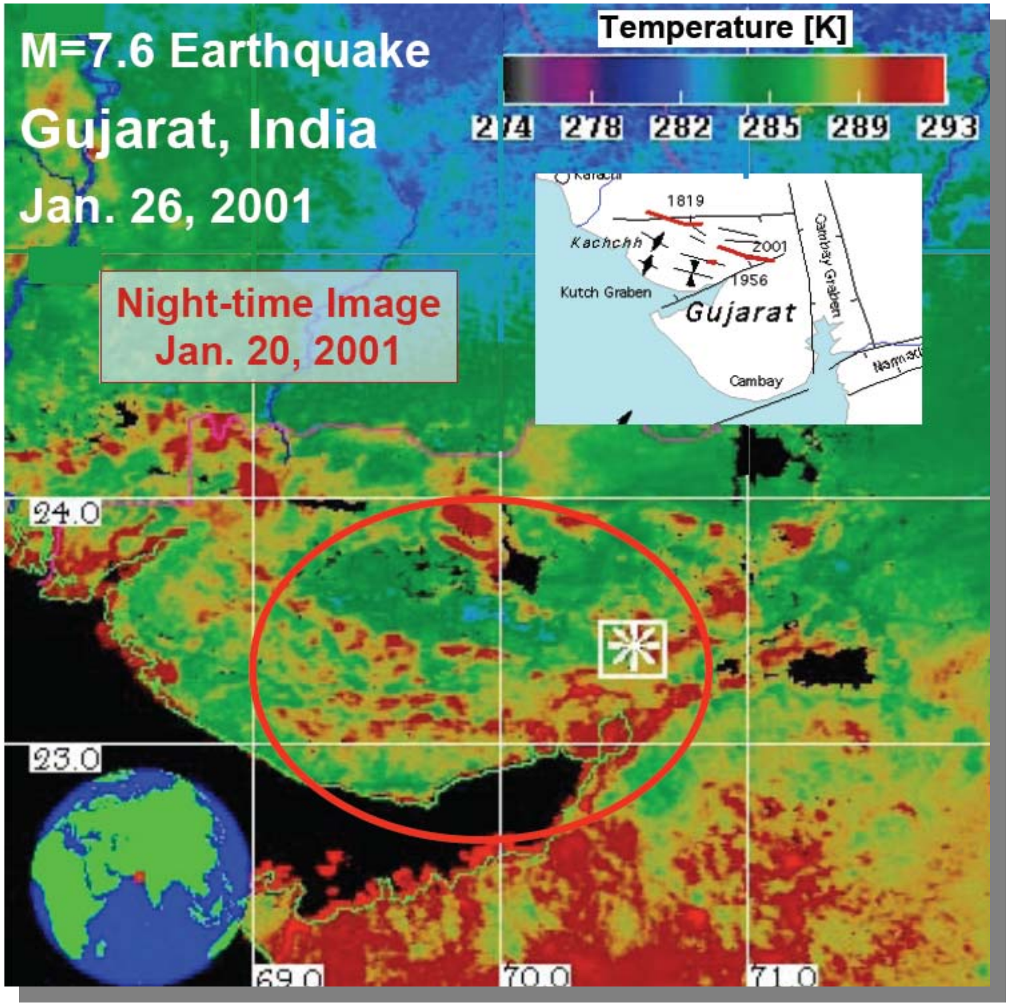
Plume Detection Based on Multispectral TIR Remote Sensing



TQ1: Volcanoes and Earthquakes

What do the transient thermal infrared anomalies that may precede earthquakes tell us about changes in the geophysical properties of the crust? [DS 227, 229]



Almost 10 days before this earthquake the known faults in the region showed up in the night-time MODIS images.

(Star = Epicenter)

The intensities fluctuated from night to night. The effect disappeared after the event.

(Ouzounov & Freund, 2004)

- Accumulation of seismic strain leads to the activation of electronic charge carriers in the stressed rock volume. These charge carriers flow out and spread into the surrounding (and overlying) unstressed rocks.
- At the surface the charge carriers recombine, thereby emitting in the mid-IR.
- This IR emission lead to a recognizable signature (TIR anomaly) in night-time satellite IR images.

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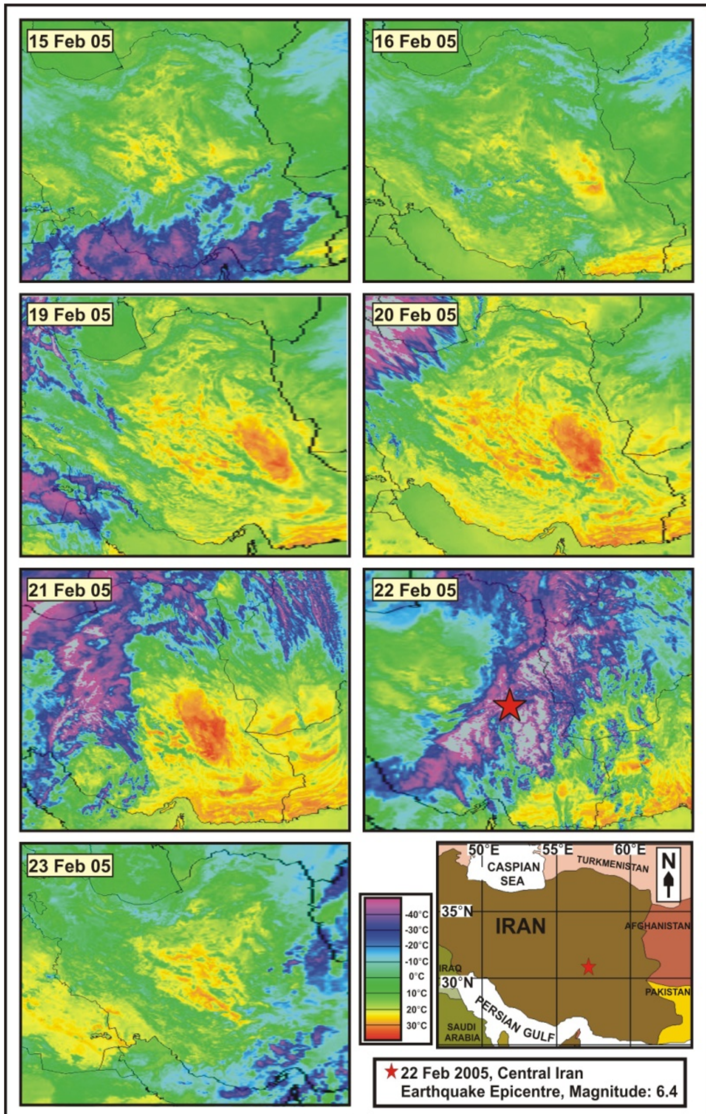
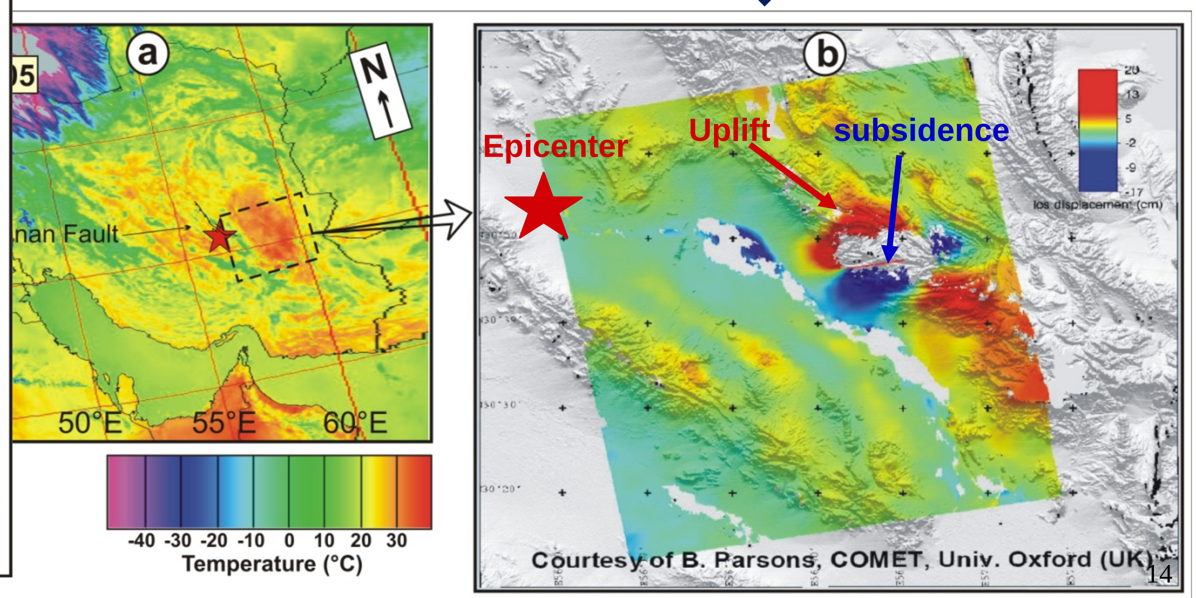
What do the transient thermal infrared anomalies that may precede earthquakes tell us about changes in the geophysical properties of the crust



M=6.4 earthquake
in Iran 22 Feb. 2005
Good viewing conditions

IR Emission comes from region of maximum uplift/subsidence



TQ1: Volcanoes and Earthquakes

Research has suggested that some earthquakes may be preceded by thermal infrared anomalies observable from satellites (Ouzounov, 2004). The anomalies have been noted to precede earthquakes by days to weeks and were associated with earthquakes M>5 and focal depths generally no deeper than 35 km, occasionally down to 50 km in earthquakes related to subduction zones. There may be a relationship between the observed increased IR flux and tectonic stress and/or processes in the atmosphere. Possible causes may be warming by greenhouse gas release over the epicentral region, changes in latent heat due to an increase of soil moisture and evaporation rate, or a quantum-mechanically driven process arising from the radiative decay of vibrationally excited states of atoms at the Earth surface which result from the recombination of electronic charge carriers stress-activated deep below, at hypocentral depth.

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TQ1: Volcanoes and Earthquakes

Science Traceability Matrix (1 of 2)

Science Objectives	Measurement Objectives	Measurement Requirements	Instrument Requirements	Other Mission and Measurement Requirements
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) sulfur dioxide emissions at low, non-eruptive flux levels. Compilation of long-term baseline data sets.	Temperature measurements in the range -20 to 100 ˚C. TIR radiance measurements at ~8 µm; 5 other TIR bands for use in SO2 retrieval algorithm; 7 day repeat.	7 TIR channels, 7-12 µm Pixel size ≤60 m NEΔT ~0.02 K. >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 m Rapid bright target recovery at 4 µm (<2 pixels), bands saturate at 1200C	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.	Four spectral channels at 8.5, 10, 11, and 12 µm; Nedt of 0.2 K, Max. repeat cycle of 5 days.	4 channels, 8-14 µm. 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. Night-time data acquisitions to increase the frequency of observation.

TQ1: Volcanoes and Earthquakes

Science Traceability Matrix (2 of 2)

Science Objectives	**Measurement Objectives**	**Measurement Requirements**	**Instrument Requirements**	**Other Mission and Measurement Requirements**
Volcanoes and Earthquakes: How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?				
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 surface temperatures along potentially active faults.	Temperature measurements in range 0 to 50C. 5 day repeat (or better)	2 channels in 8-12 um range; pixel size 100m; NEDT ~ 1K	Nighttime data acquisitions extremely necessary
Can the energy released by the periodic recharge of magma chambers be used to predict future eruptions? [DS 227]	Detect and monitor temperature changes of volcanic edifices	Temperature measurements in range of 0-1200C; 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.

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TQ1: Volcanoes and Earthquakes

NRC Decadal Survey

"Risks posed by hazards such as earthquakes, volcanoes, and other natural disasters have to be quantified and documented, precursors or other early warning signals have to be detected." – p. 224

"Forecasting and Mitigating the Effects of Natural Hazards

What observations can improve the reliability of hazard forecasts? What are the opportunities for early detection, ongoing observation, and management of extreme events? …How can useful information, including uncertainties, be communicated to decision makers for the benefit of society?

Enabling Science

What new observations, coupled with improved modeling capability, are most likely to advance fundamental understanding of nature? How can this understanding be used to decrease hazards arising from natural disasters…?" – p. 226

TQ1: Volcanoes and Earthquakes

NRC Decadal Survey

“Table 8.1 Solid-Earth Panel Key Questions for Satellite Observation Priorities

Earthquake Forecasting:

- Where and how fast is seismogenic strain accumulating?
- Are earthquakes predictable?

Volcanic Eruption Prediction

- What pre-eruption surface manifestations are amenable to remote measurement from orbit?
- What surface temperature change patterns are relevant?
- What can the measurement of emissions such as SO2 and silicate ash indicate, and what patterns of change are relevant?
- How can multiple change patterns and measurements (topography, gas, temperature, vegetation) at craters be better interpreted for eruption forecasting?
- How often must a volcano be observed to provide a meaningful prediction?” – p. 227

TQ1: Volcanoes and Earthquakes

NRC Decadal Survey

- Where and how fast is seismogenic strain accumulating?

- Accumulation of seismic strain leads to the activation of electronic charge carriers in the stressed rock volume. These charge carriers flow out and spread into the surrounding (and overlying) unstressed rocks.
- At the surface the charge carriers recombine, thereby emitting in the mid-IR.
- This IR emission lead to a recognizable signature (TIR anomaly) in night-time satellite IR images.

- Are earthquakes predictable?

- Earthquakes may become predictable, if data of TIR anomalies and other effects, which can be observed from satellites and/or by ground stations, can be fused to a statistically significant product.

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“Forecasting Earthquakes

- Identification of deformation events that are seismic precursors is the “Holy Grail” for earthquake research.

Forecasting Volcanic Eruptions

- However, only a small percentage of the world’s volcanoes are instrumented sufficiently to facilitate predictions of eruptions from seismic data, and use of satellite-based remote sensing could provide crucial assistance in identifying regions where volcanic unrest is likely.
- Therefore, a global observation system capable of detecting ongoing magmatic unrest will result in dramatic improvements in the understanding of volcanic activity and associated societal hazards.” – p. 229.

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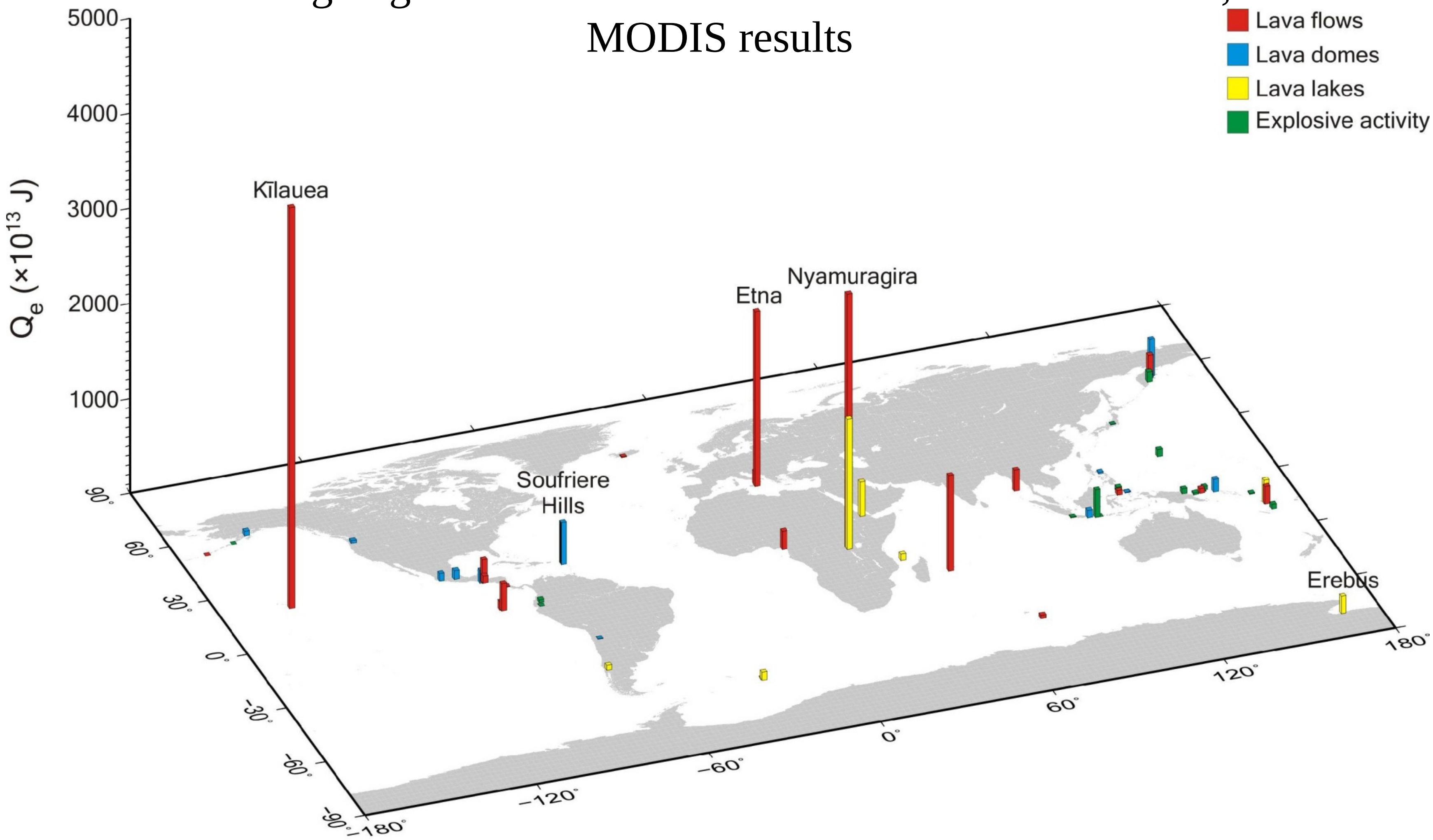
TQ1: Volcanoes and Earthquakes

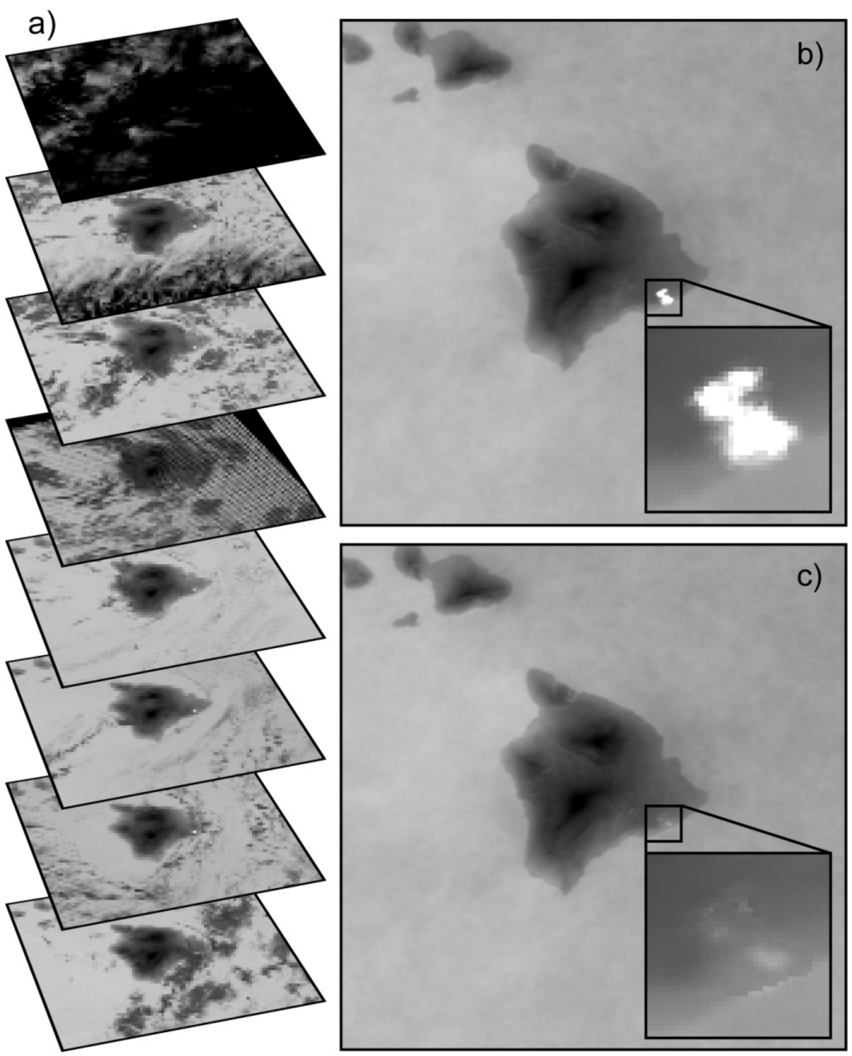
HyspIRI Volcano catalogue/thermal alert product

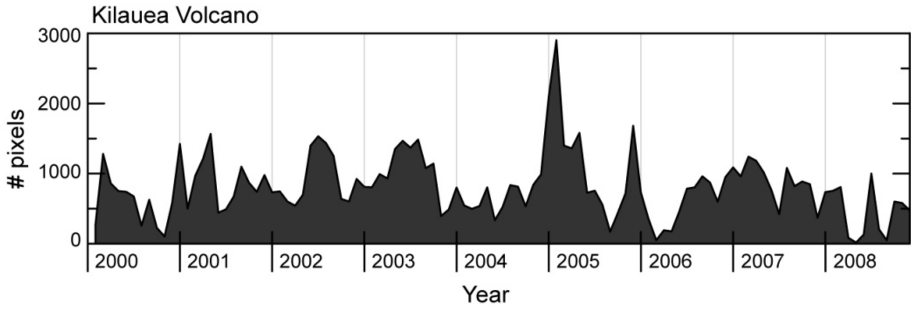
Cataloguing trends in thermal flux from Earth's volcanoes; MODIS results

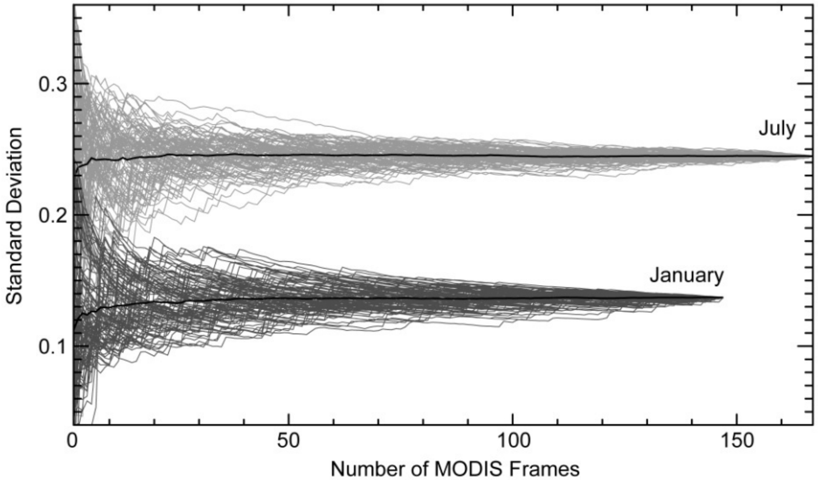


TQ1: Volcanoes and Earthquakes

A HyspIRI volcanic eruption detection/cataloguing product







Heritage (ground) GOES, AVHRR, MODIS

Your logo here

- GOES/AVHRR – U. Hawaii has demonstrated tracking of thermal activity using GOES and AVHRR
  - Rapid response but can only detect large signals
- MODIS – UH Modvolc tracks thermal activity using Normalized Thermal Index (NTI)
  - Rapid response but can only detect large signals
  - Site specific parametric adjustment can increase sensitivity

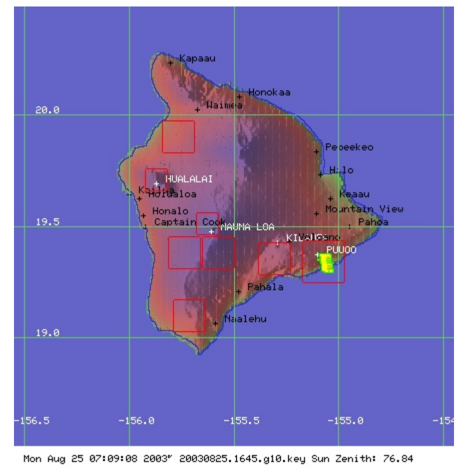
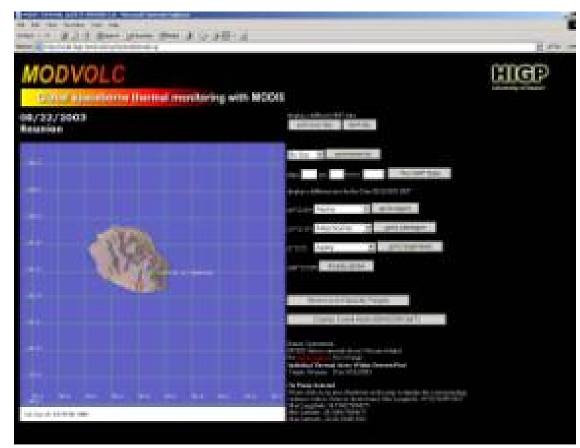


Image courtesy Hawaii Institute of Geophysics and Planetology.

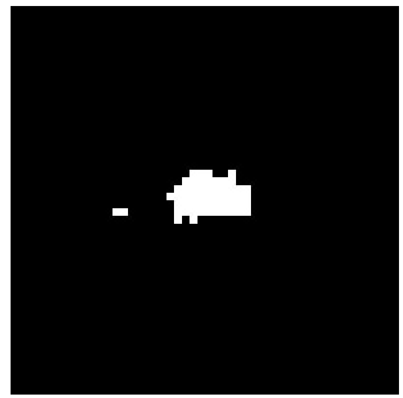


Images courtesy of UH-HIGP

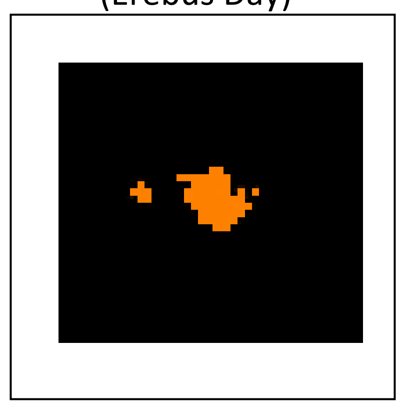
TQ1: Volcanoes and Earthquakes
Heritage (onboard) – EO-1/ASE Thermal Detection

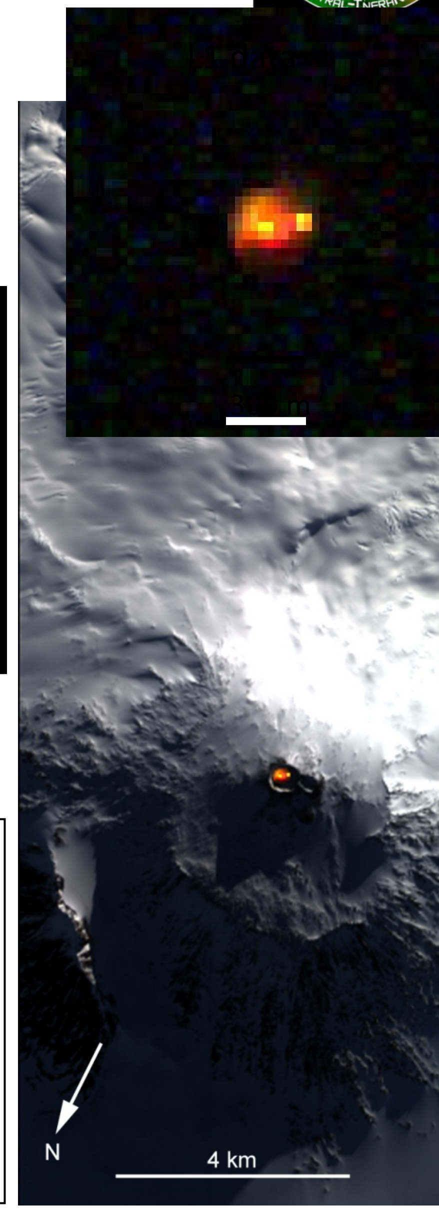
- EO-1
  - Onboard thermal event detection in use since 2004 based on onboard Hyperion spectral signature
  - Onboard event detection can trigger:
    - Subsequent imaging
    - Alert Notices
    - Generation of thermal summary and quicklook context images

ASE Onboard Thermal Classifier Thumbnail (Erebus Night)



ASE Onboard Thermal Classifier (Erebus Day)



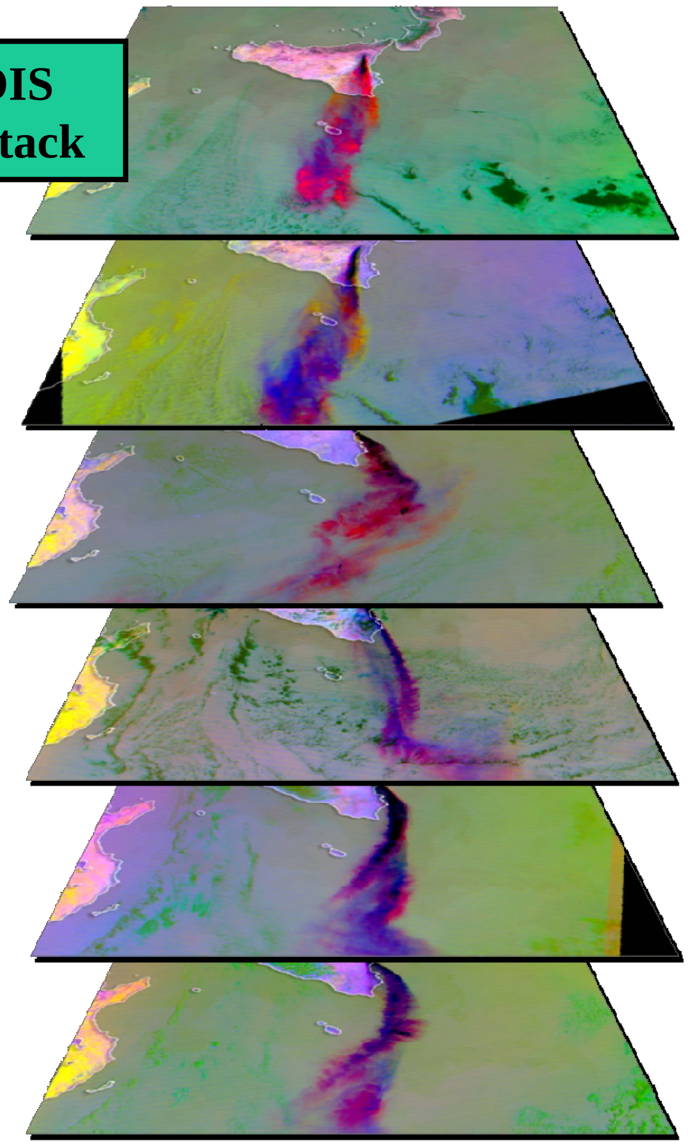


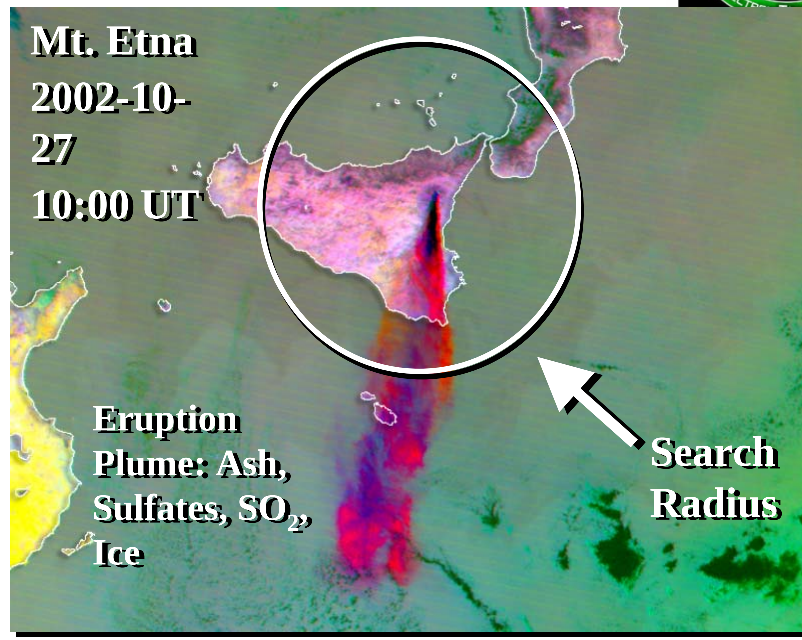
TQ1: Volcanoes and Earthquakes

A HyspIRI volcanic plume detection/cataloguing product

MODIS Data Stack

TIME





Plume Tracker Project

- Automated Detection of Eruption Plumes Based on Machine Learning Techniques
- Define Search Radius Centered on Volcano
- Exploit Unique Spectral Characteristics of Eruption Plumes
- Exploit Persistence of Plumes over the Course of an Eruption

TQ1: Volcanoes and Earthquakes

- Do we need a real-time volcano alert capability? Requires on-board processing, similar to EO-1 operations.
- Do we need a real-time alert capability for major seismic events? Requires data fusion from HyspIRI with other satellite and ground station data.

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Volcano alert and thermal flux product: Heritage from MODVOLC and EO-1 verify that procedure is possible. Testing of alert vs. MODVOLC (or its successor) is straightforward for large anomalies. Validation for smaller anomalies will require cooperation with ground personnel or volcano observatories.

Volcano plume detection: Select a few known sources of SO_2, like Mt. Etna and Kilauea, to validate and quantify algorithm performance.

Pre-earthquake thermal infrared (TIR) anomalies: Determine the spectroscopic characteristics of TIR anomalies and develop algorithms to differentiate them from normal ground temperature anomalies.

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Volcano alert and thermal flux product:

- Systematic mining of MODIS, Landsat and ASTER data archives to baseline non-eruptive activity of all active volcanoes
- Construct 35 year time-series for each volcano, on pixel-by-pixel basis to define background
- Determine thresholds for alerts based on volcano's history

Volcano plume detection:

- Develop automatic SO_2/ash detection algorithms; determine sensitivity needed for gas detection and set thresholds
- Develop on-board data processing to send down only images where plumes are detected

Earthquake thermal anomaly

- Is effect real? What is mechanism? What is spatial and temporal scale?