

# **Simulated HypsIRI Volcanology Data Sets**

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# Goals of Project

*The primary objective of this proposal is to create precursor HypsIRI-like data sets to examine several important volcanological questions:*

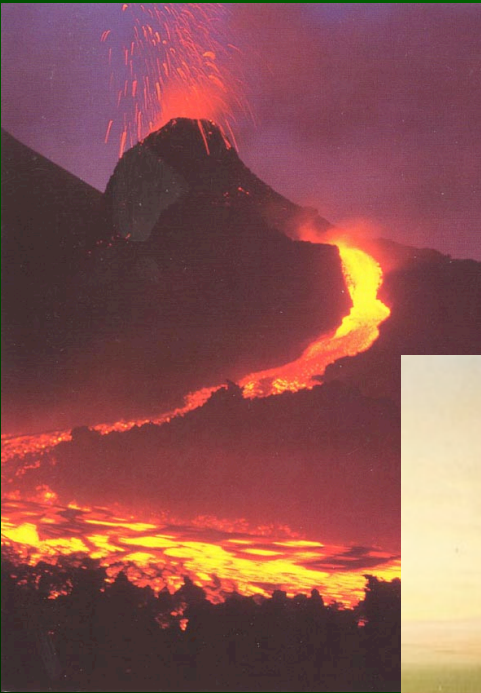
1 What do changes in SO<sub>2</sub> emissions tell us about a volcano's activity?

2 How do we use measurements of lava flow temperatures and volume to predict advances of the flow front?

3 What do changes in lava lake temperatures and energy emissions tell us about possible eruptive behavior?

*A second objective is to determine the saturation temperature for the Mid-IR band*

# ETNA



# Why Mt. Etna?

- ❖ Europe's most active volcano
- ❖ Explosive and effusive eruptions
- ❖ Massive SO<sub>2</sub> emitter
- ❖ Extraordinarily frequent remote sensing data acquisitions
- ❖ Very well monitored by INGV
- ❖ Co-I at INGV will provide all ancillary data needed

# Characteristics of Input Data Sets

	<b>EO-1 Hyperion</b>	<b>ASTER TIR</b>
<b>Bands</b>	<b>196 unique in 0.4-2.5 micron region</b>	<b>5 in 8-12 micron region</b>
<b>S p a t i a l resolution</b>	<b>30 m</b>	<b>90 m</b>
<b>Swath</b>	<b>7.5 km</b>	<b>60 km</b>
<b>Quantization</b>	<b>16 bit</b>	<b>12 bit</b>

# Ancillary Data Sets

	<b>COSPEC SO<sub>2</sub></b>	<b>Flow field Topography</b>	<b>Eruption chronology</b>
<b>Eruptions and gas emissions</b>	<b>X</b>		<b>X</b>
<b>Lava flow modeling</b>		<b>X</b>	<b>X</b>
<b>Lava lake energy release</b>			<b>X</b>

# ASTER Daytime Scenes (1 2 3)

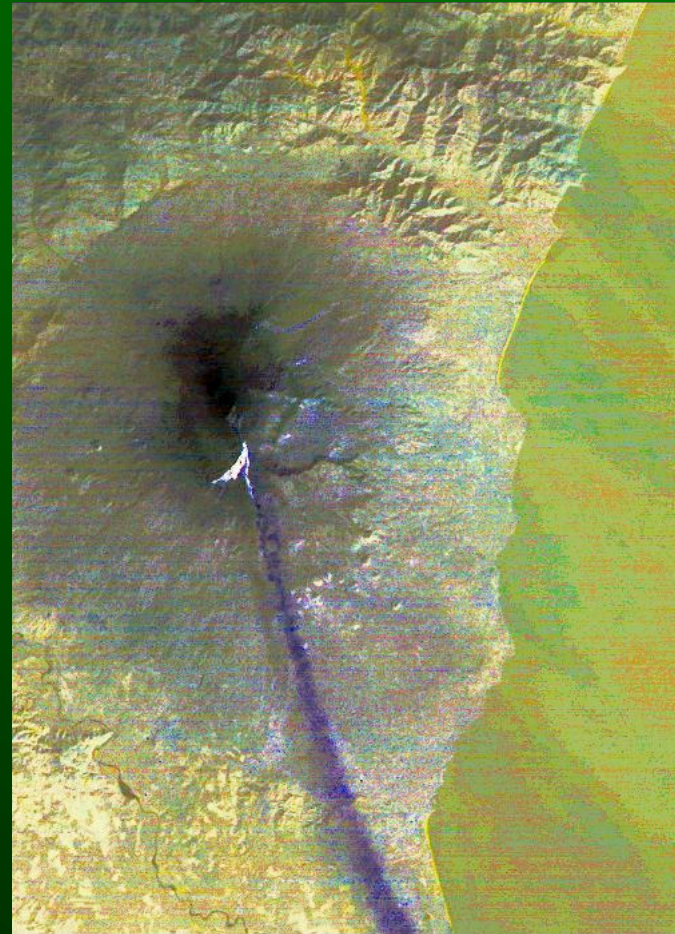
2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
7 May	29 July	5 June	15 Jan	7 Apr	26 Apr	3 Aug	19 Jun	21 Jun	7 Oct	26 May
		7 July	13 Mar	10 June		12 Aug	21 Jun	8 Aug		7 Aug
		23 July	19 July	26 June		7 Nov	14 Jul	21 Nov		
		3 Nov	11 Aug	6 Aug			21 Jul			
		30 Dec		13 Aug			30 Jul			
				22 Aug			2 Oct			

# Multispectral TIR from Daytime ASTER (1 2 3)

VNIR image: plume is gray;  
flows are not incandescent

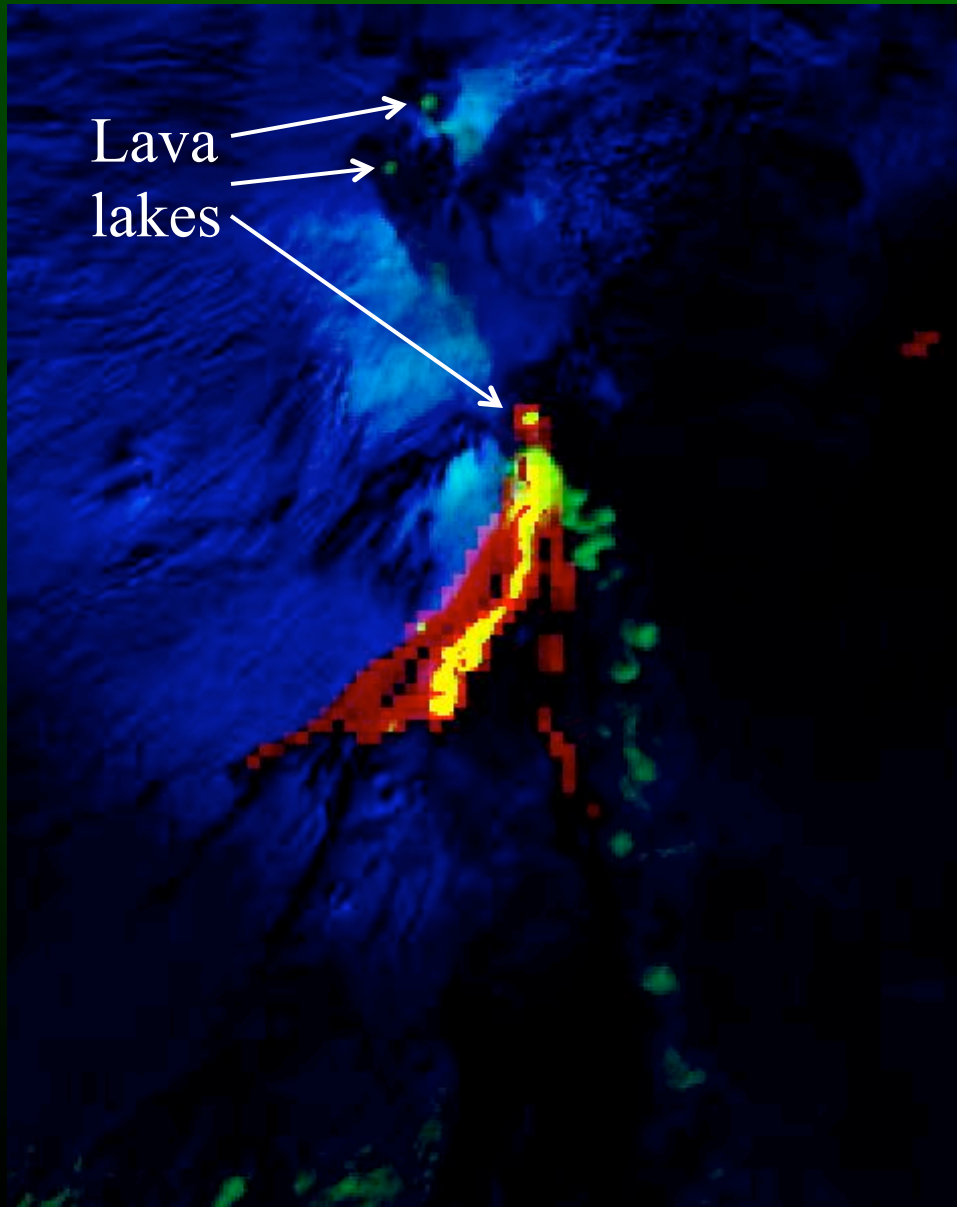


TIR image: plume composition  
is mostly ash; flows are obvious





# Multispectral Daytime ASTER (2 3)



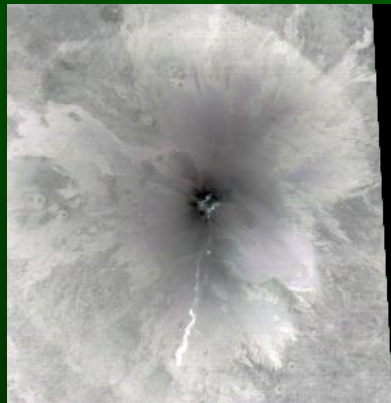
R=11um G=1.5um B=0.84um

Lava flows vary in temperature; multispectral data allow better estimation of temperatures than TIR alone.

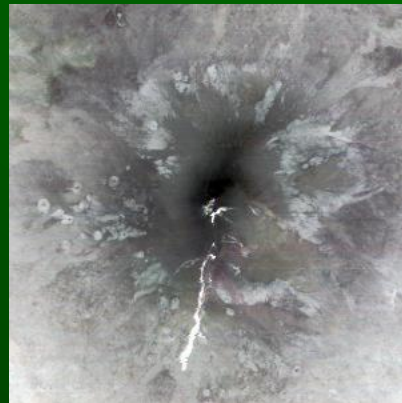


# Selected 2002 ASTER Night TIR (1 2 3)

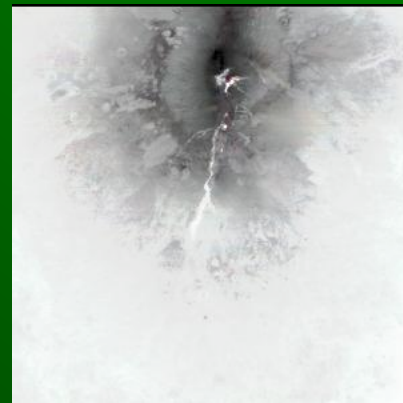
January 19



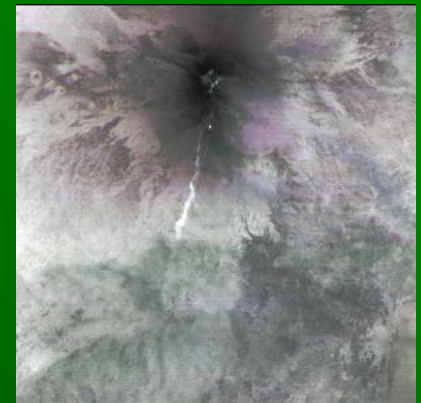
January 28



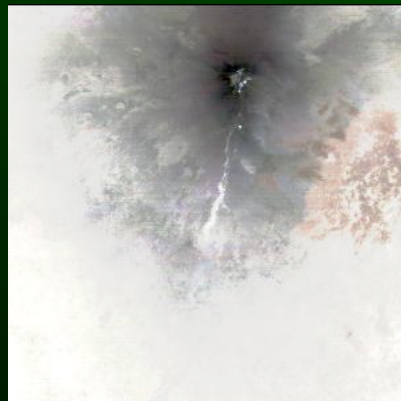
May 11



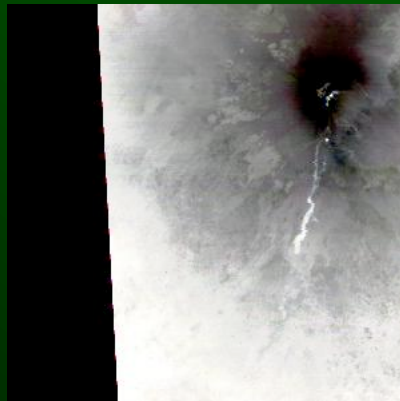
May 20



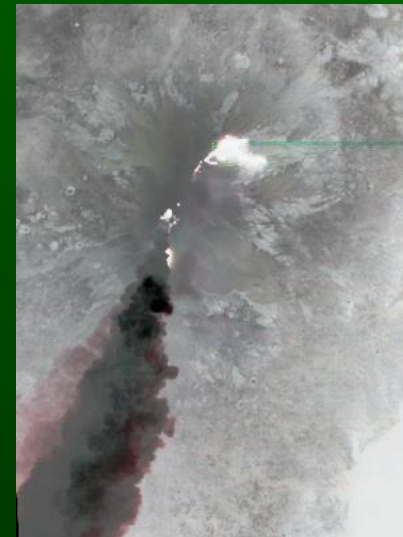
June 28



July 23



October 27

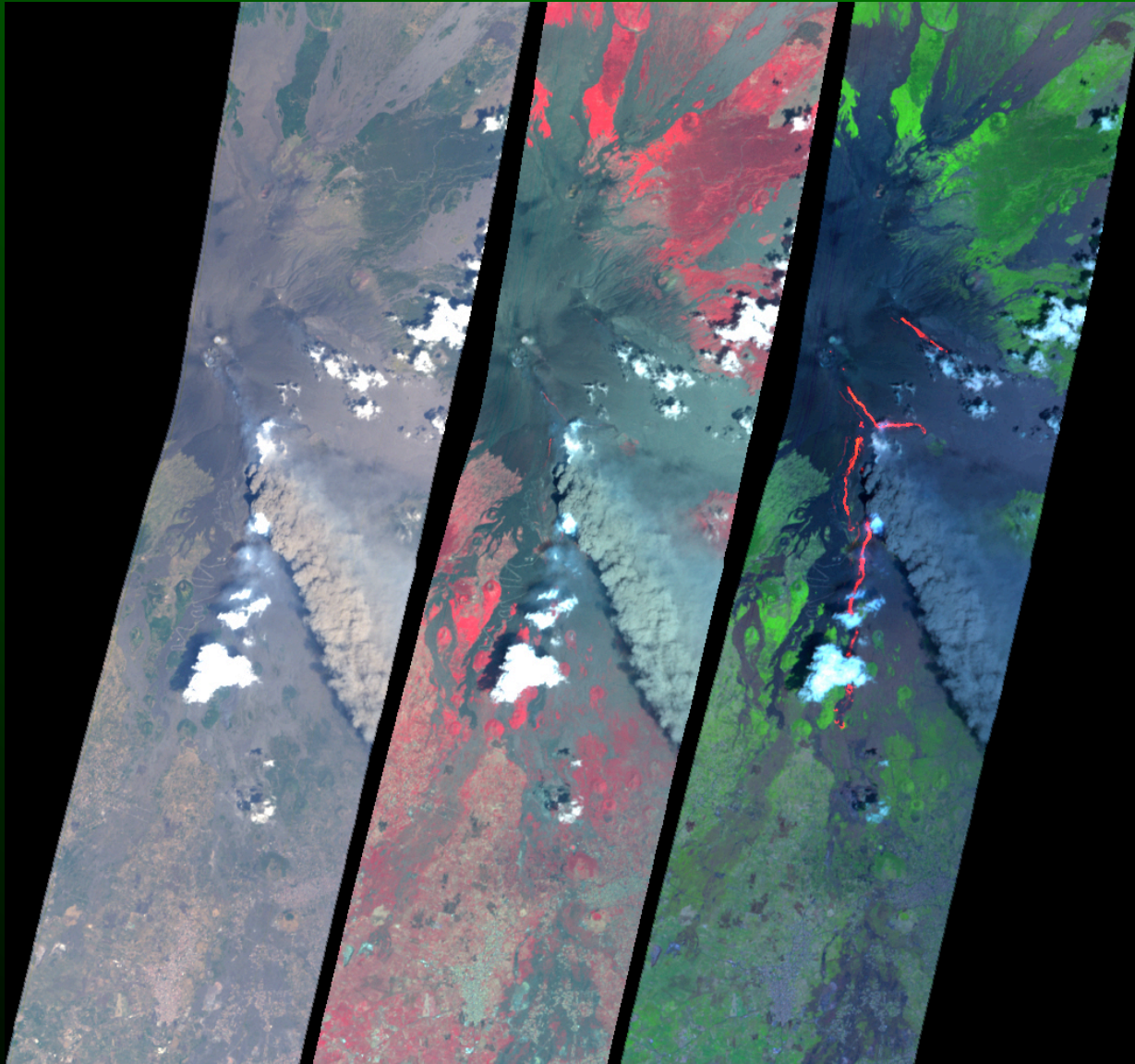


# EO-1 Hyperion Daytime Scenes (2 3)

EO1H1880342009281110pf\_sgs\_01  
EO1H1880342008206110kf\_sgs\_01  
EO1H1880342008152110kf\_sgs\_01  
EO1H18803420071901110kf\_sgs\_01  
EO1H1880342007134110kf\_sgs\_01  
EO1H1880342006303110pf\_sgs\_01  
EO1H1880342006298110pf\_sgs\_01  
EO1H1880342005316110kf\_sgs  
EO1H1880342005302110kf\_sgs  
EO1H1880342005205110pf\_hgs  
EO1H1880342004283110pw\_sgs  
EO1H1880342004260110kw\_pfl  
EO1H1880342003223110kf\_sgs  
EO1H1880342003207110kx\_hgs  
EO1H1880342003177110ky\_sgs  
EO1H1880342001267110kp\_sgs  
EO1H1880342001242110po\_sgs  
EO1H1880342001203110kp\_sgs  
EO1H1880342001194110po\_sgs

# July 22, 2001 Hyperion Etna Data (2 3)

0.65-0.55-0.44    0.87-0.65-0.55    1.65-0.87-0.65

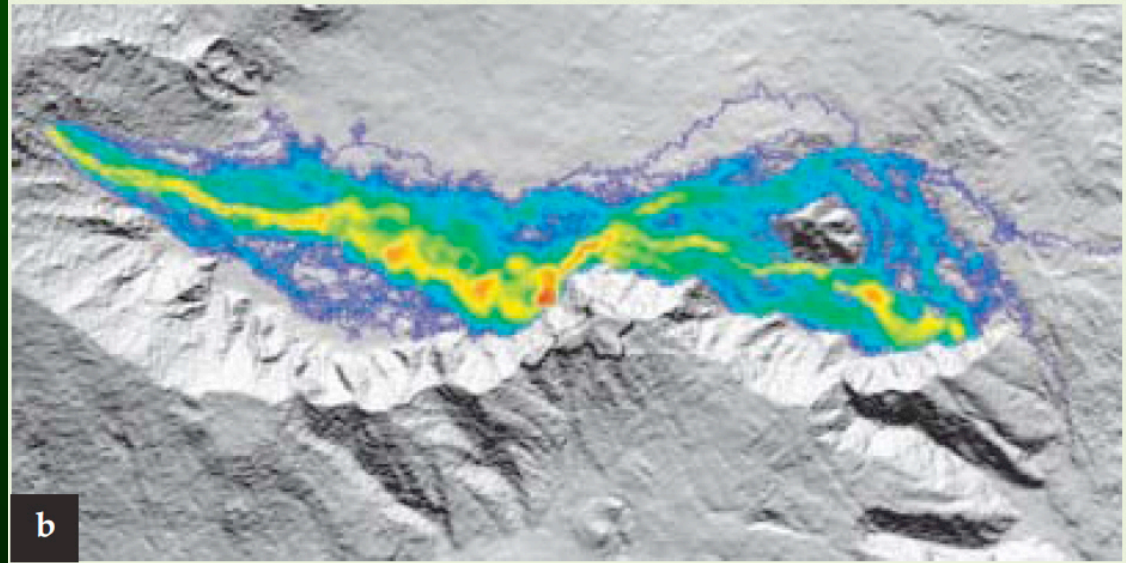
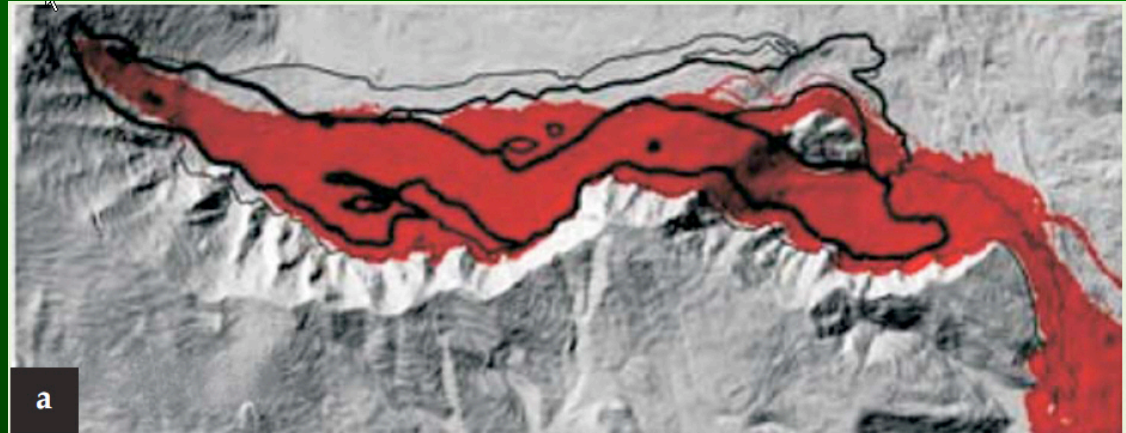
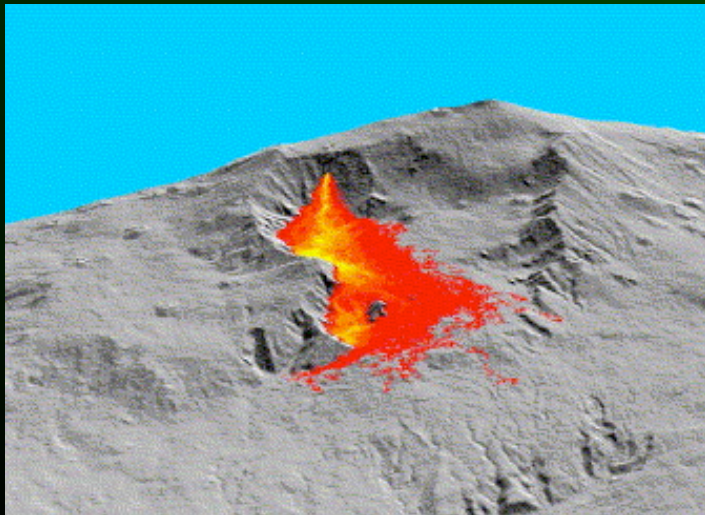


# SO<sub>2</sub> Determination with ASTER TIR(1)\*\*

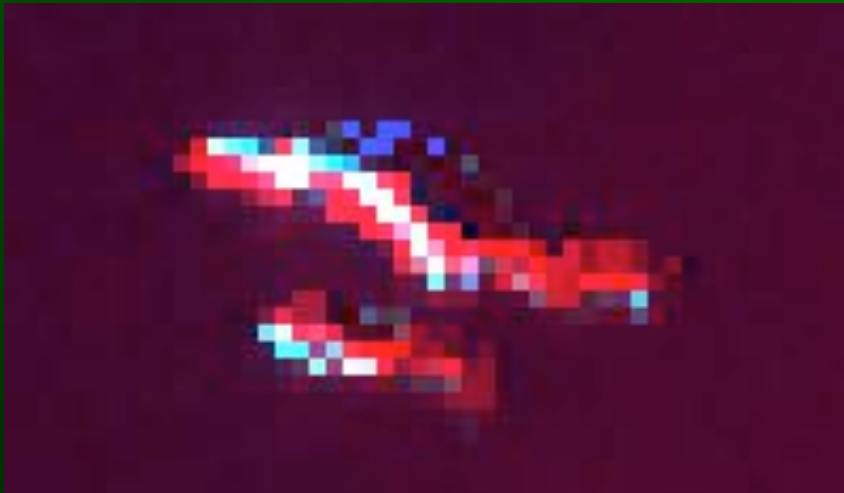
Will be discussed  
in following talk  
by Vince Realmuto

# Lava Flows, Energy Radiated, Extent (2)

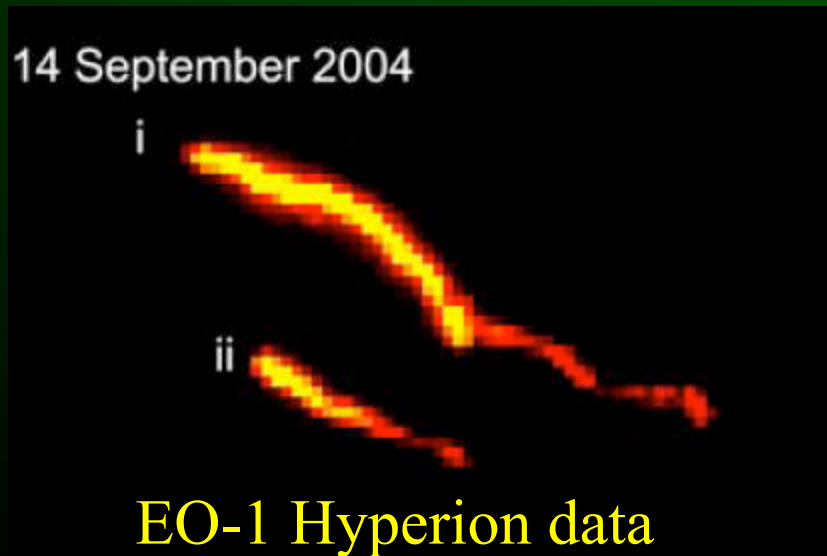
Lava flow models require DEM data, effusion rates, and Temperature distributions



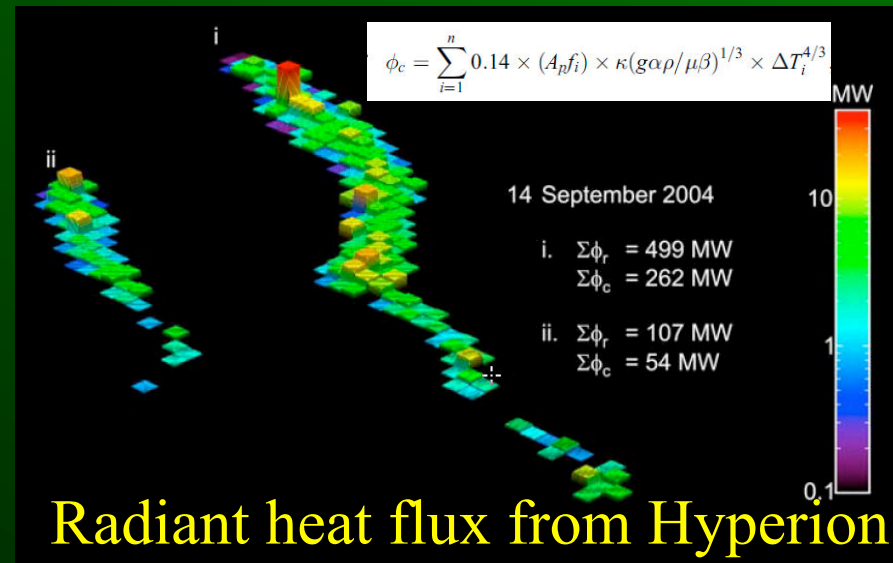
# Lava Flows, Energy Fluxes (2)



Sept 14, 2004 nighttime combined ASTER + EO-1 Hyperion data for lava flows; most TIR pixels are saturated.



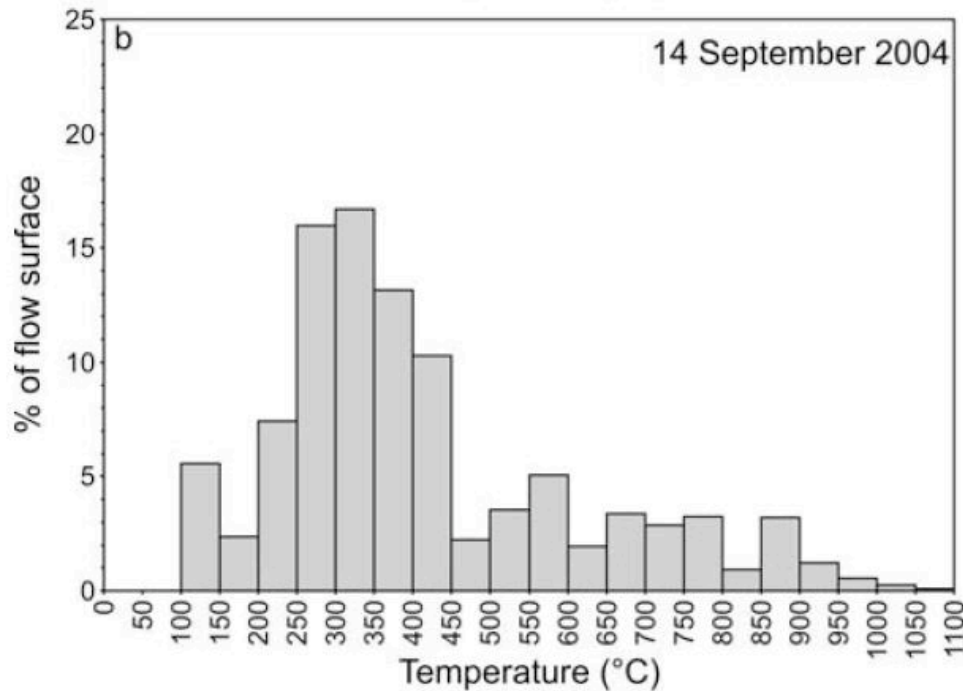
EO-1 Hyperion data



Radiant heat flux from Hyperion

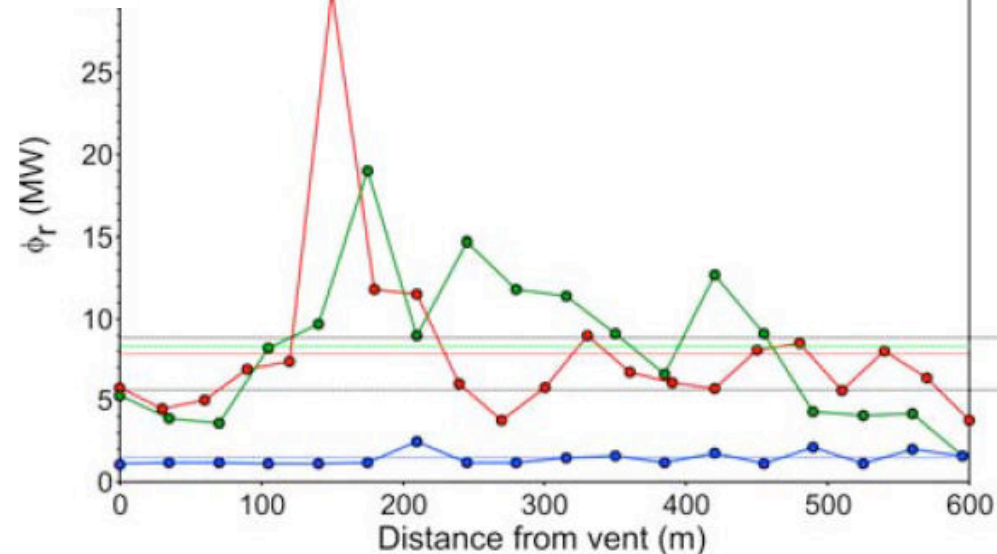


# Lava Flows, Energy Fluxes (2)

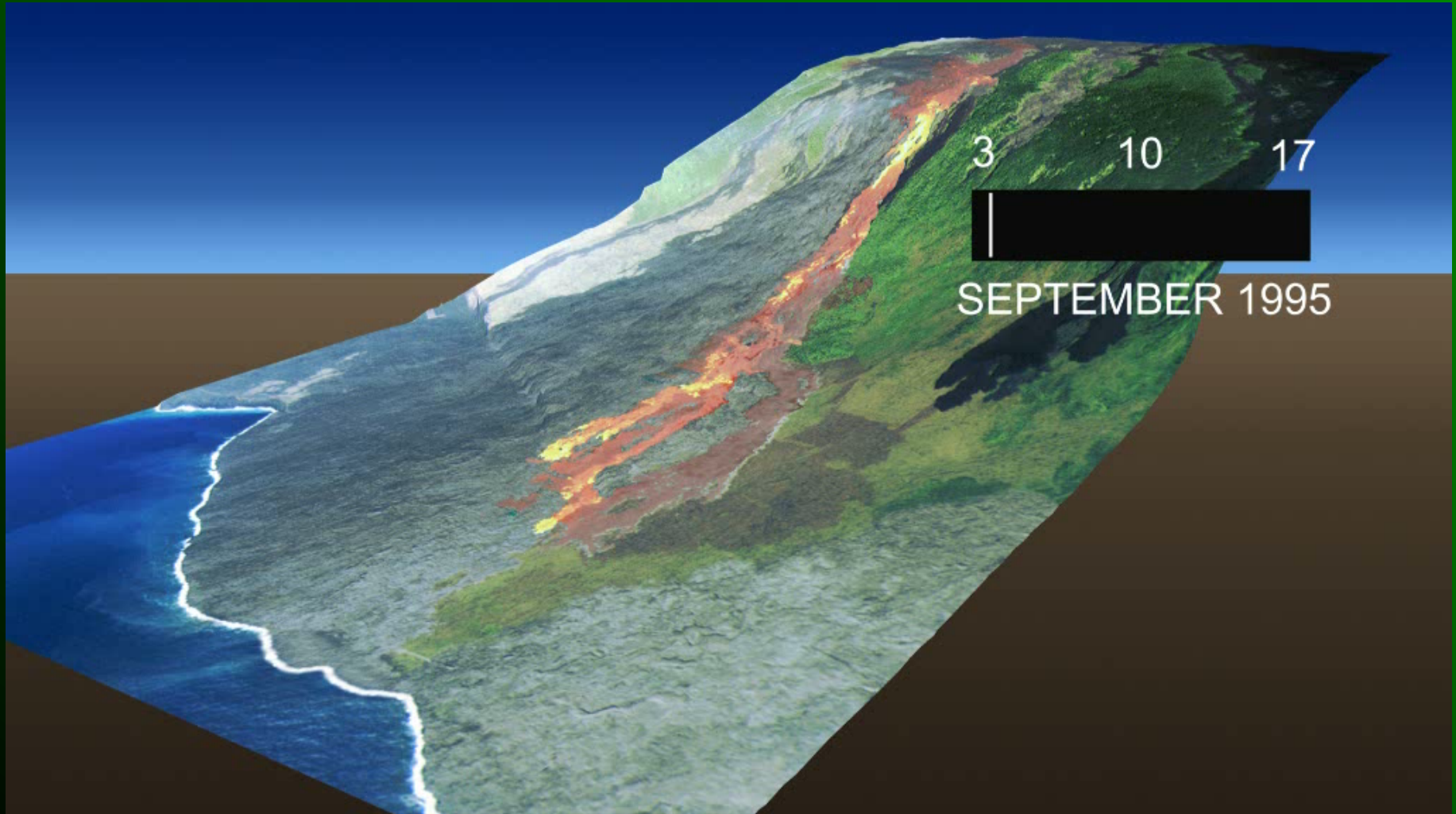


Temperature histogram for flow unit I from Hyperion data

Radiant heat flux as a function of distance from the vent. September 14 is red curve.



# Lava Flow Dynamics (2)



# Lava Flow Dynamics (2)

To Do: Use Temperature and energy measurements in lava flow model (FLOWZ) to predict flow extent.

# ETNA Craters

Central Crater:  
Bocca Nuova & La Voragine

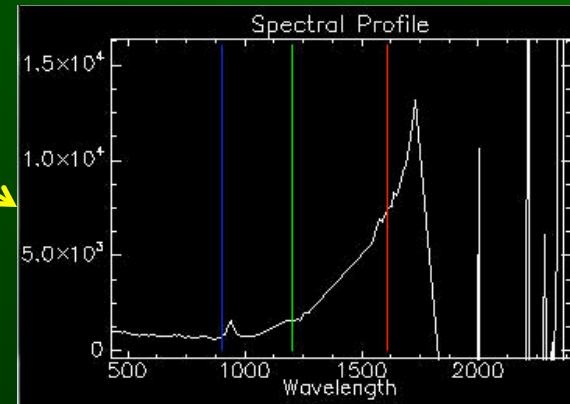
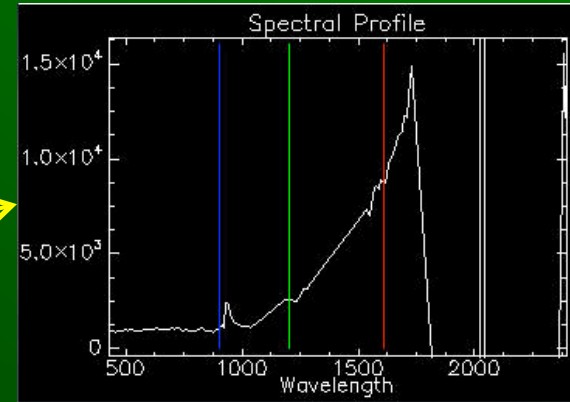
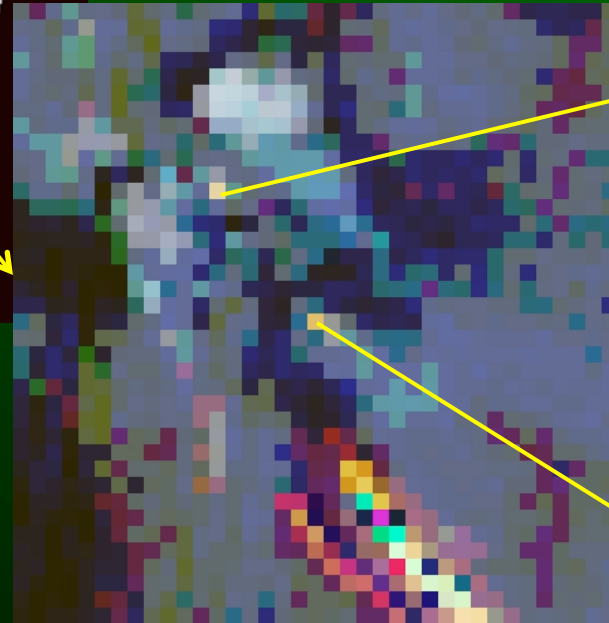
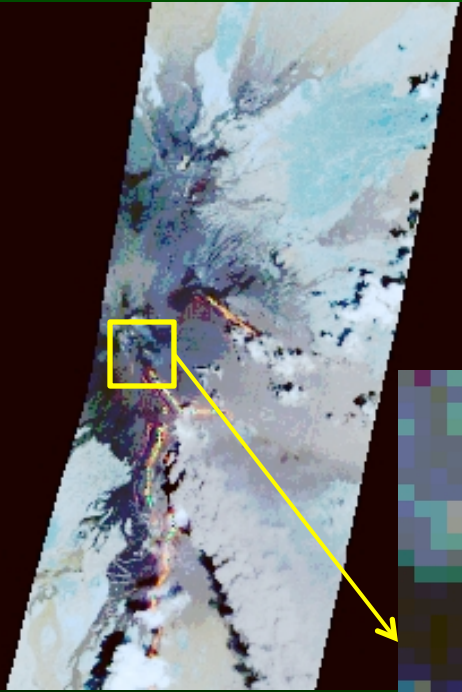
Southeast Crater

Northeast Crater



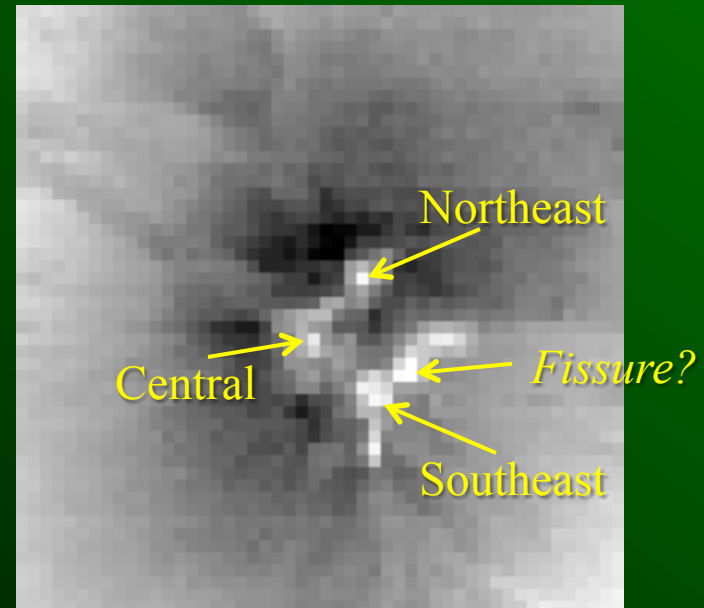
# Craters, Energy Fluxes (3)\*\*

July 22, 2001 EO-1 daytime image of craters and flows. Radiance of incandescent craters fills one pixel; 60m size allows only pixel integrated temperature to be estimated.



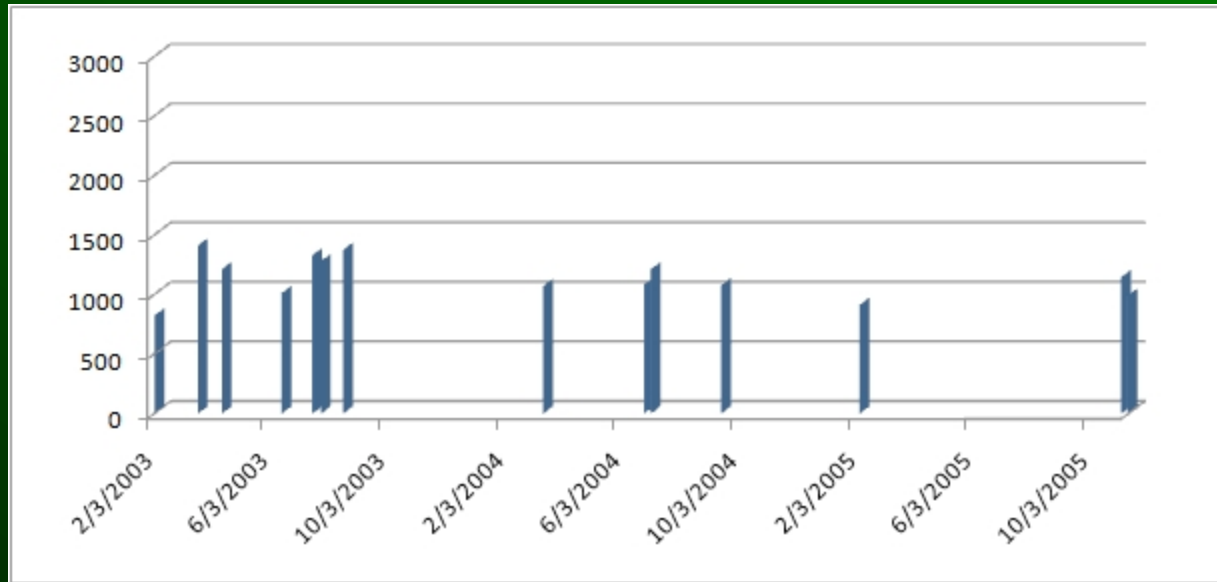
# Craters, Energy Fluxes (3)\*\*

- ❖ Between 2000 and 2010, 61 ASTER cloud-free nighttime TIR scenes were acquired (~6/yr, or one scene every 2 months)
- ❖ Summit area was extracted, and maximum radiance of craters was determined.
- ❖ *Still to do: compute total flux from craters*





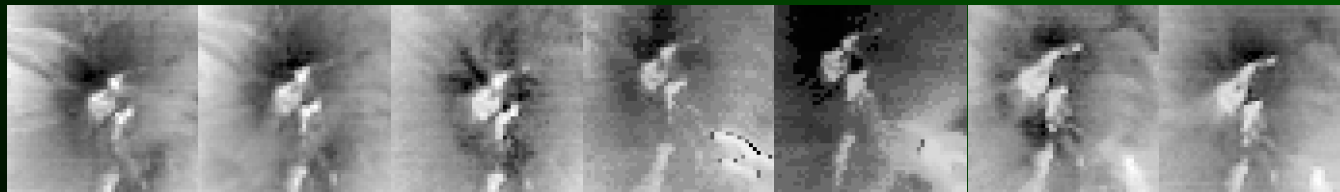
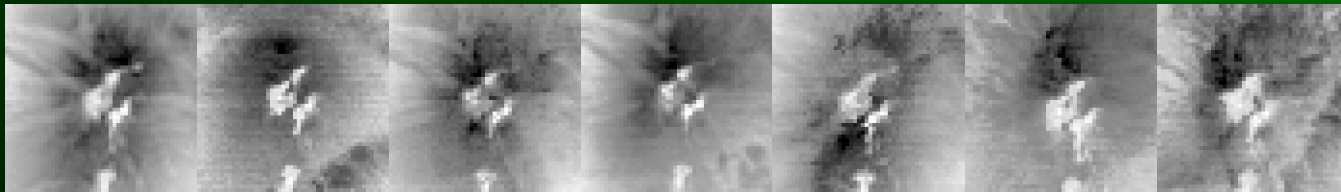
# Craters, Energy Fluxes (3)\*\* 2003-2005



★ Large eruption

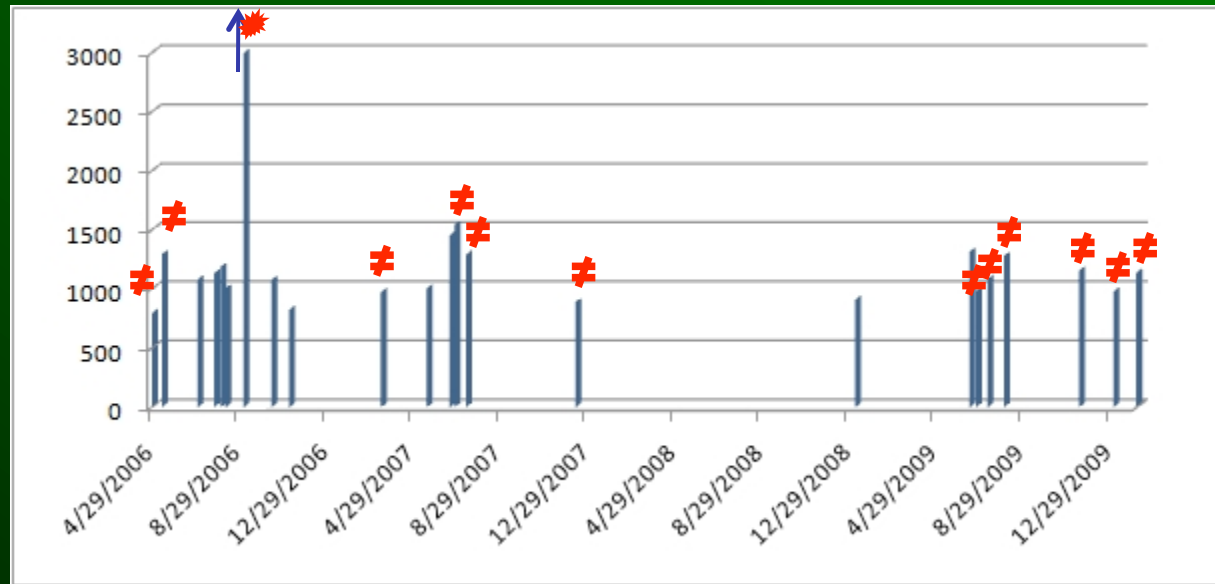
✖ No data

All dates  
reported gas and  
ash emissions

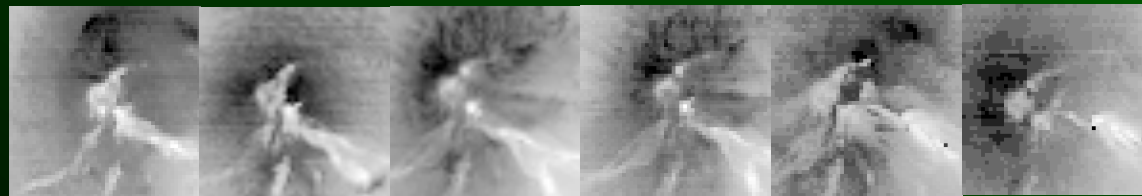
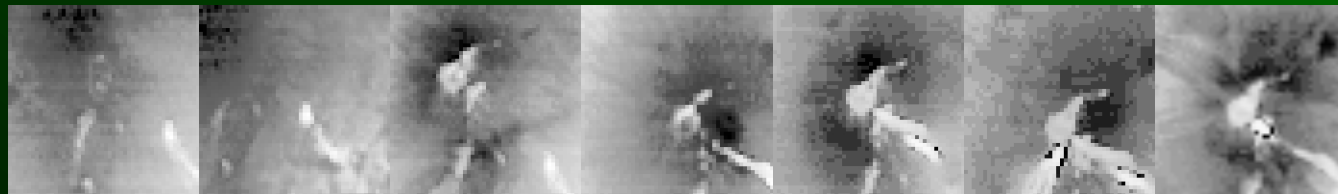




# Craters, Energy Fluxes (3)\*\* 2006-2010



- ★ Large eruption
- ✱ No data/activity



# Simulated HypsIRI Data Sets

- ❖ 5 daytime dates and 1 nighttime date were selected that were cloud-free, and had simultaneous Hyperion and ASTER acquisitions; only 1 coincided with eruption activity
- ❖ Hyperion data were re-sampled to 60m, duplicate channels removed, data scaled to radiance-at-sensor
- ❖ ASTER TIR bands were re-sampled to 60m, registered to Hyperion, data scaled to radiance-at-sensor
- ❖ 226-band images created with ENVI header files

# Simulated HypsIRI Daytime Data Sets

## Cloud-free Hyperion and ASTER Data

Hyperion	ASTER
2001-7-13	2001-7-29
2001-7-22	
2001-8-5	
2001-8-14	2002-6-5
2001-8-30	2002-7-7
2001-9-24	2002-7-23
	2002-11-3
2002-11-12	2002-12-30
2003-1-15	2003-1-15
2003-3-20	2003-3-13
2003-6-26	2003-7-19
2003-7-19	2003-8-11
2003-7-26	2003-1-15
2003-8-11	
2004-9-16	2004-6-26
2004-10-9	2004-8-6
	2004-8-22

Hyperion	ASTER
2005-3-16	2005-4-26
2005-3-18	
2005-7-24	2006-8-3
2005-10-29	2006-8-12
2005-11-5	2006-11-17
2005-11-12	2006-11-30
2005-11-30	
	2007-6-19
2006-10-25	2007-6-21
2006-11-24	2007-7-14
2006-11-29	2007-7-21
	2007-7-30
2007-5-14	2007-10-2
2007-7-9	
	2008-6-21
2008-5-31	2008-8-8
2009-10-8	2009-5-23
	2009-10-8
	2010-5-10
2011-6-30	2011-2-6
	2011-4-4
	2011-6-30

# Simulated HypsIRI Daytime Data Sets

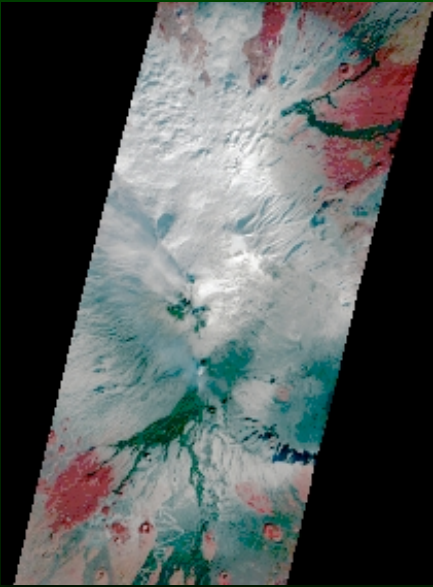
## January 15, 2003

- ❖ On 15 January 2003, ash emission increased at the 2,750-m-elevation pyroclastic cone on the volcano's upper S flank. There was also an associated increase in lava emission towards the south
- ❖ The volcano was snow covered down to the 1500m level

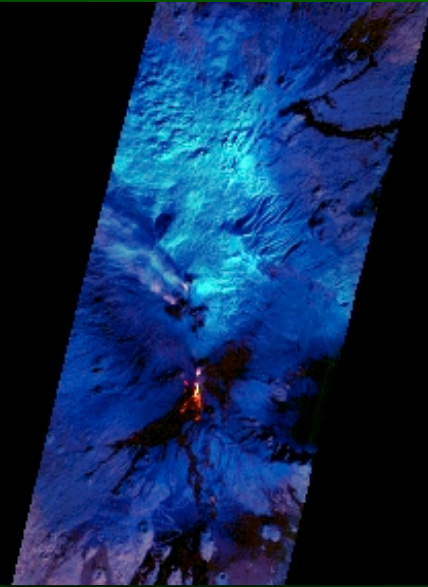
- Smithsonian/USGS Weekly Volcanic Activity Report

# Simulated HypsIRI Data Sets January 15, 2003

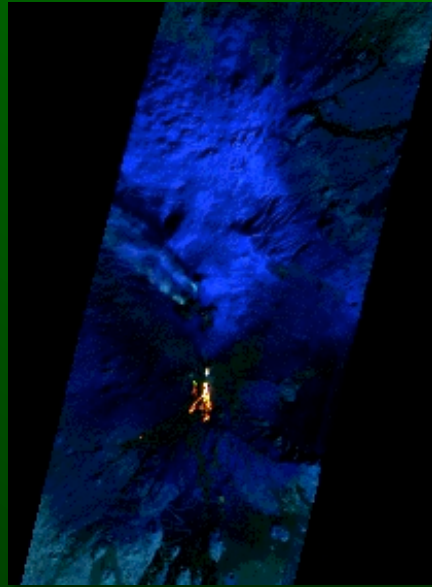
.91, .65, .55



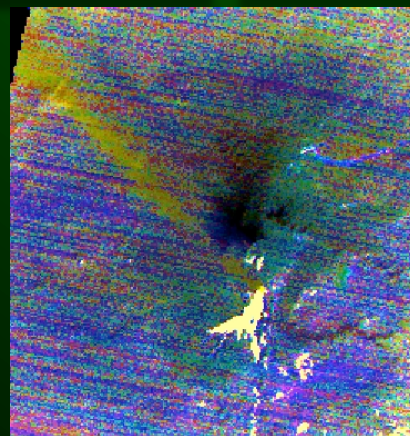
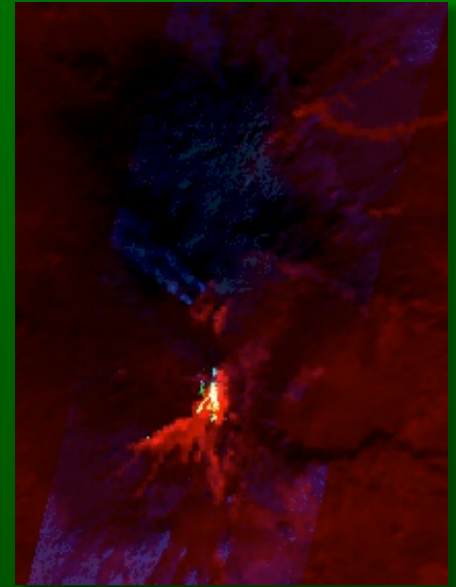
1.2, .91, .65



1.6, 1.2, .91



9.0, 1.6, 1.2

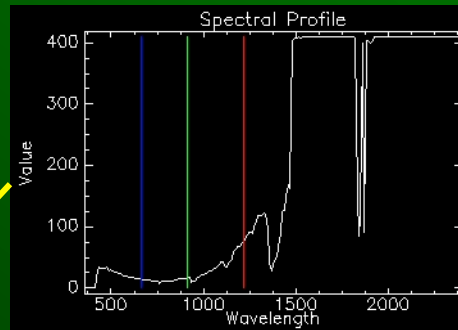
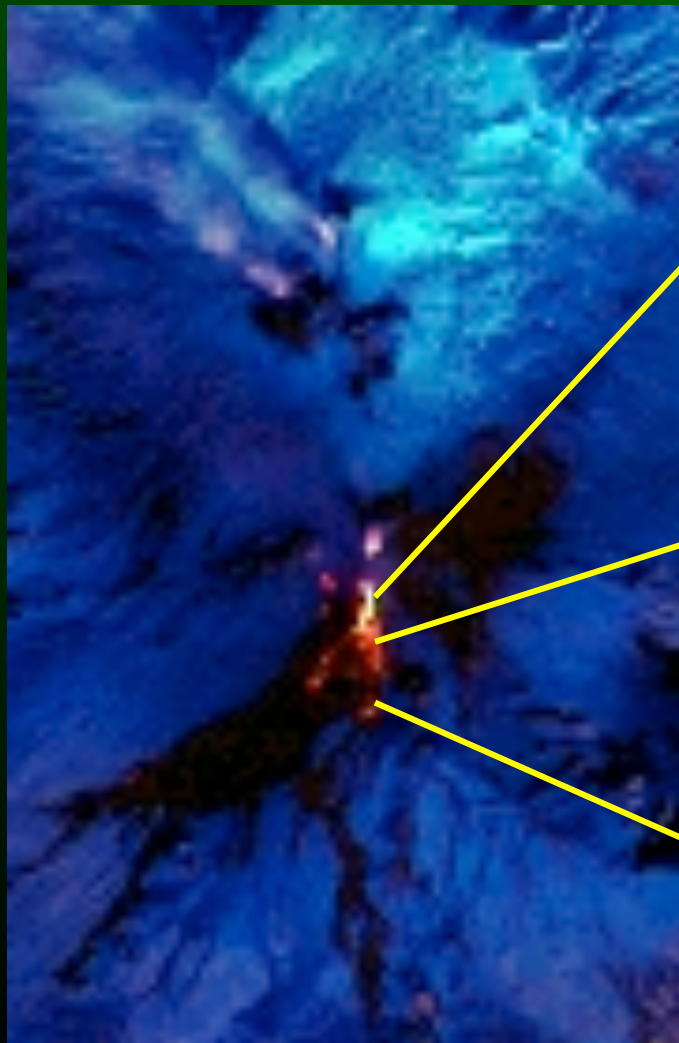


11.3, 10.6, .8.6

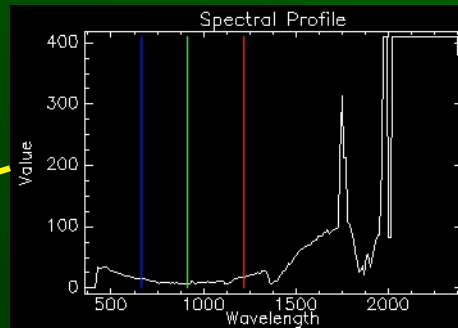


# Simulated HypsIRI Data Sets\*\*

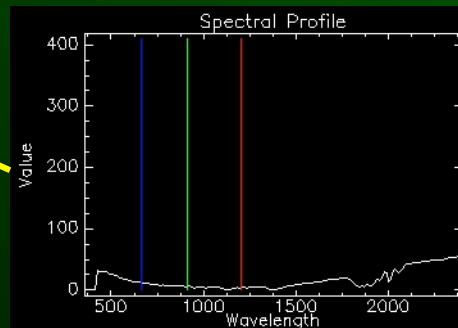
## January 15, 2003



Hottest, “saturated”  
lava



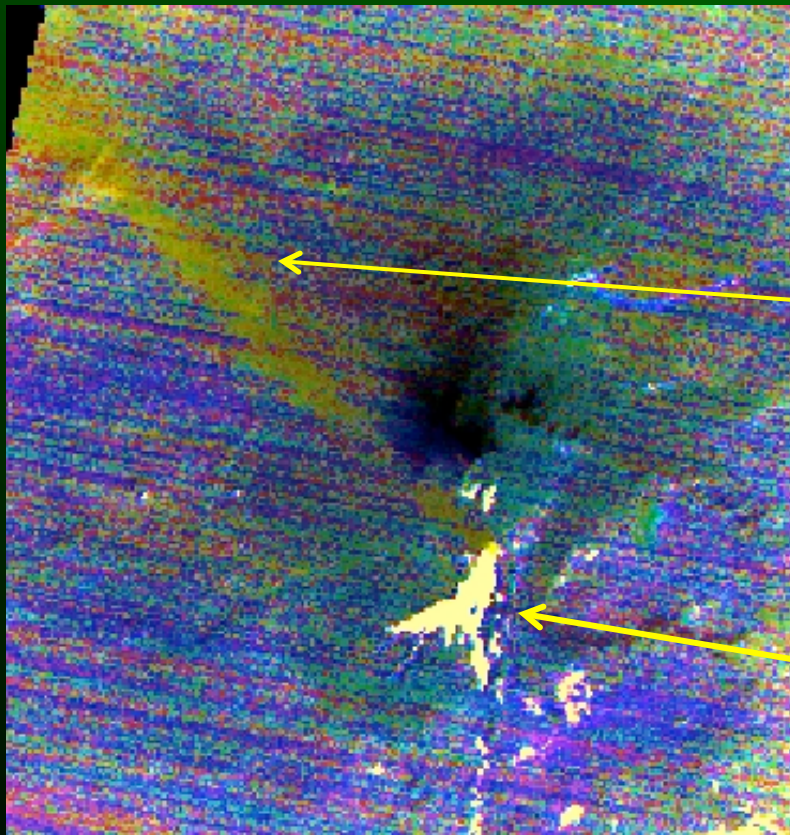
Hot lava



“Warm” lava

# Simulated HypsIRI Data Sets

## January 15, 2003: ASTER TIR



Yellow color of plume in this d-stretch image indicates that the dominant components are SO<sub>2</sub> and ash

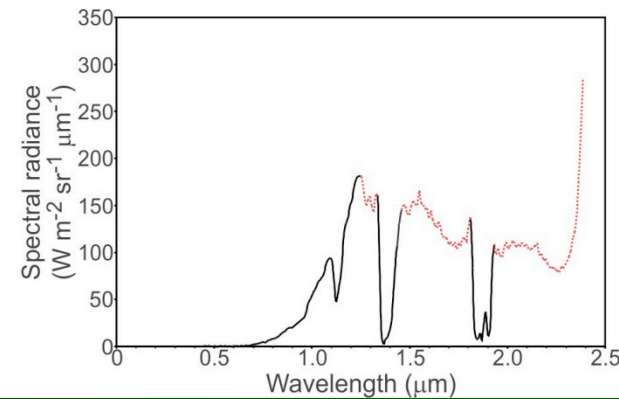
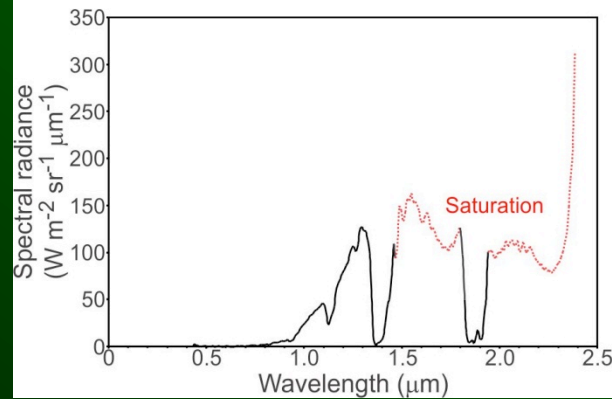
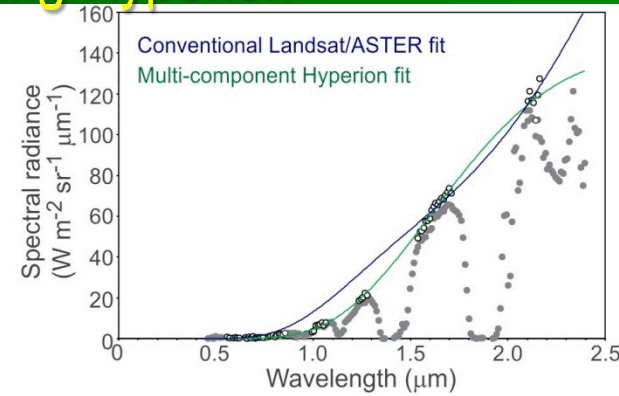
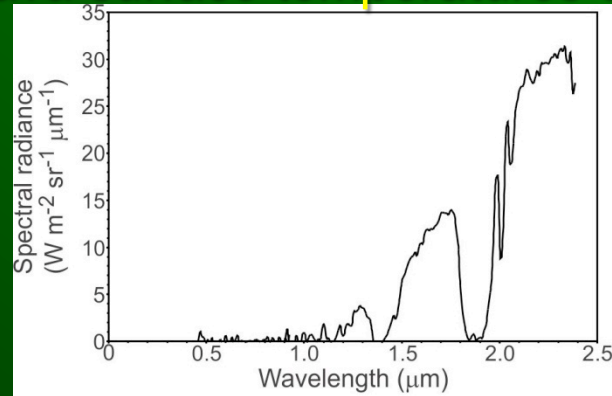
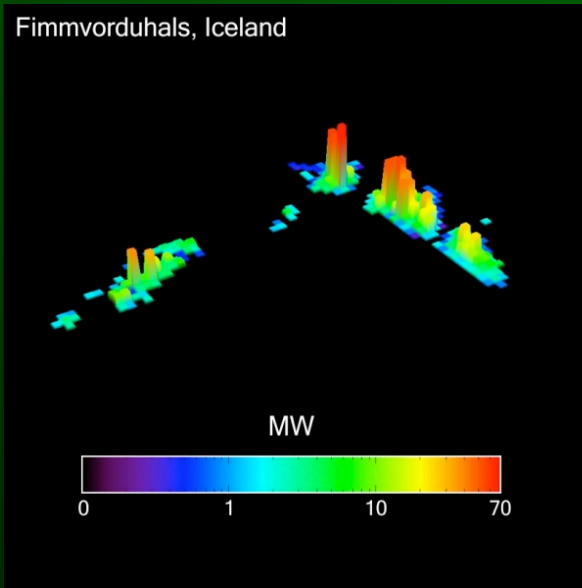
Most of lava flow is saturated in ASTER TIR channels

11.3, 10.6, .8.6

# 4 micron Channel Saturation

## Retrieving lava surface temperatures using Hyperion

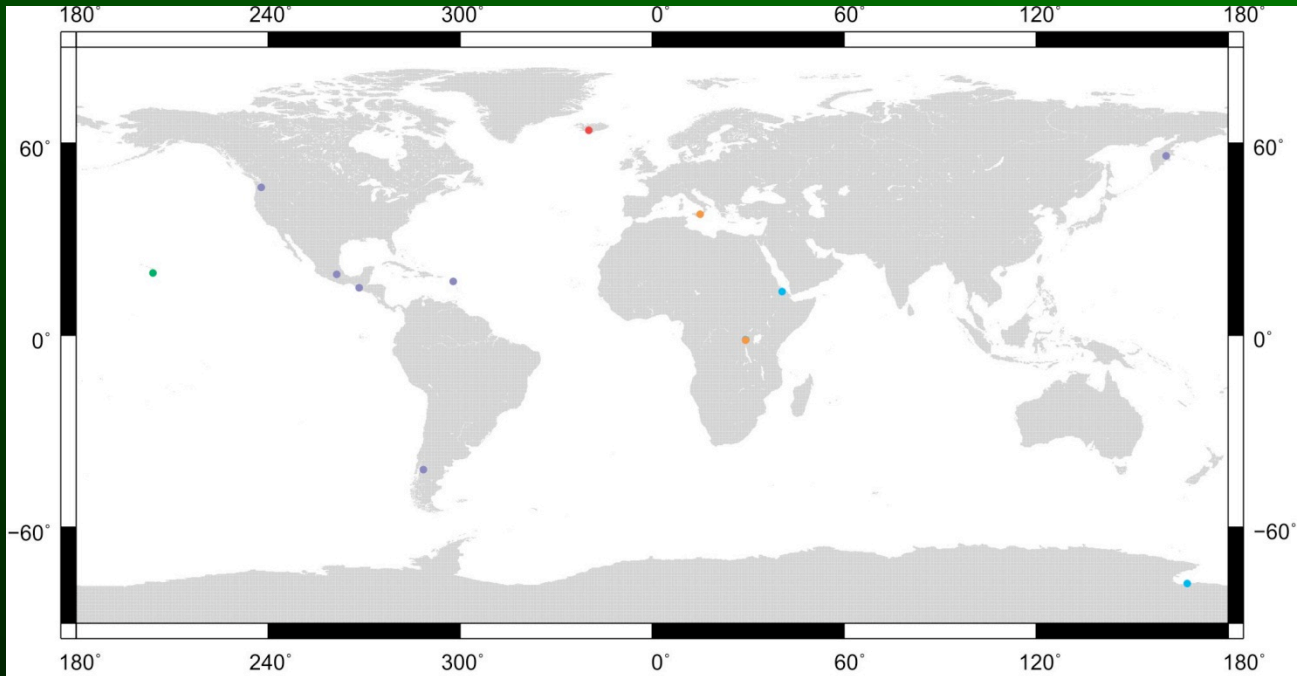
Fimmvorduhals, Iceland



- Used Hyperion images (nighttime data) to calculate the sub-pixel temperature distributions of active lavas as a first step to retrieving surface leaving radiance at 4  $\mu\text{m}$  at 30 m scale.
- Unsaturated data are always available from an imaging spectrometer, so Hyperion resolves the temperatures of even the hottest lava flows



# How hot are Earth's lava flows, domes and lakes?



10 images of 'a'a lava flows  
10 images of pāhoehoe lava flows  
20 images of domes  
20 images of lakes  
1 image of fountains

Lava fountains



Lava flows: 'a'a



Lava flows: pāhoehoe



Lava lakes

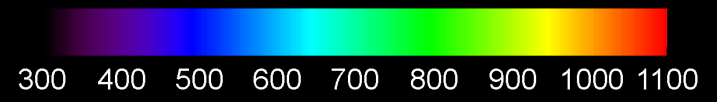


Lava domes

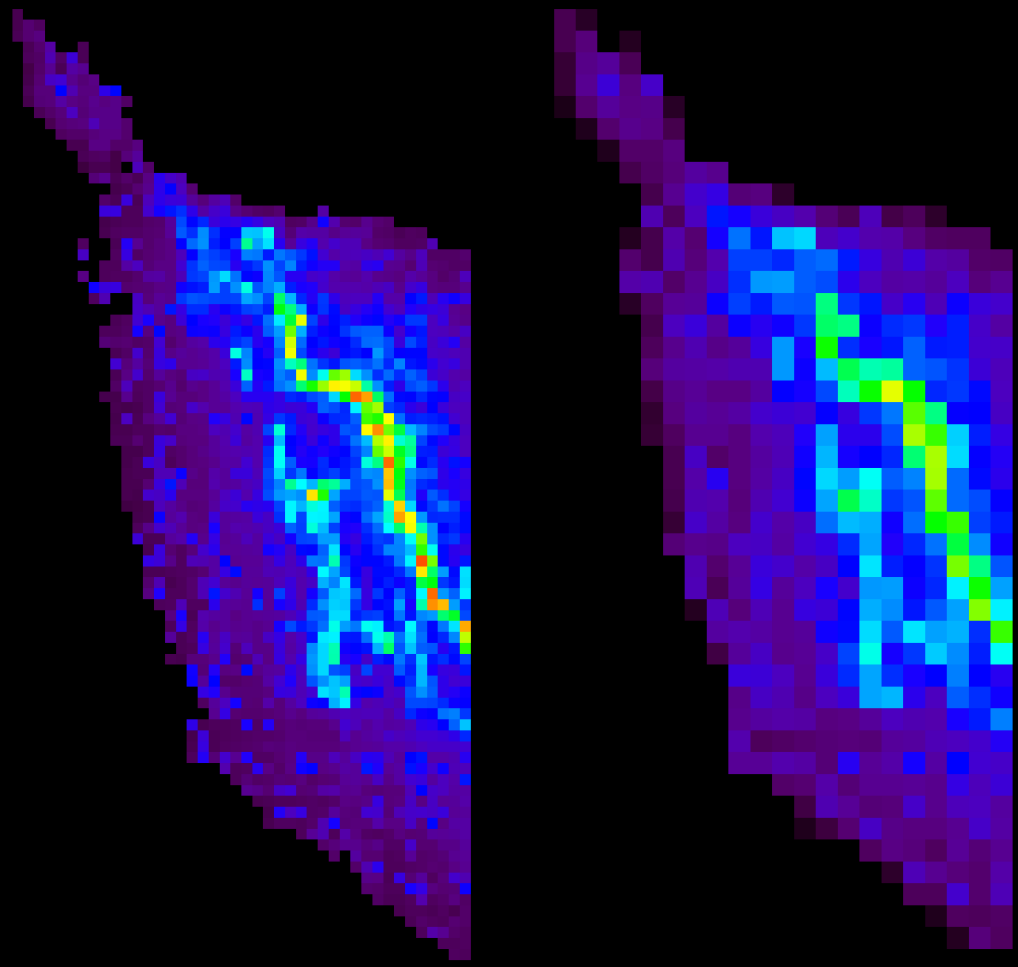


- Analyzed Hyperion images acquired at 16 different volcanoes, exhibiting the full range of common eruption styles to ensure the results were representative

4  $\mu\text{m}$  brightness temperature (K)



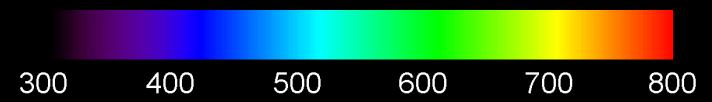
Nyamuragira (Democratic Republic of Congo)



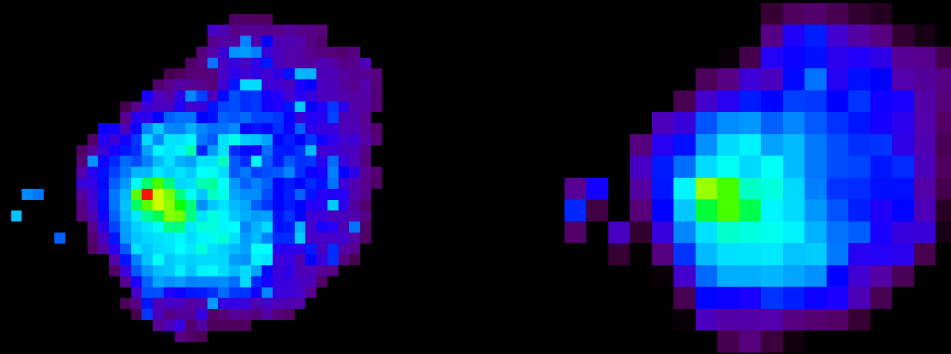
30 m

60 m

4  $\mu\text{m}$  brightness temperature (K)



Nyiragongo (Democratic Republic of Congo)



Erta Ale (Ethiopia)



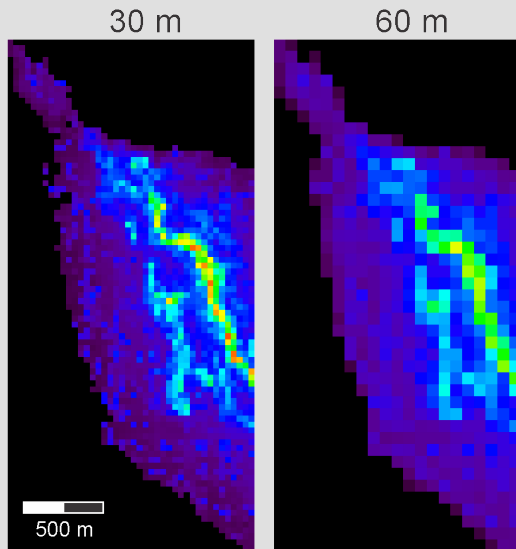
30 m



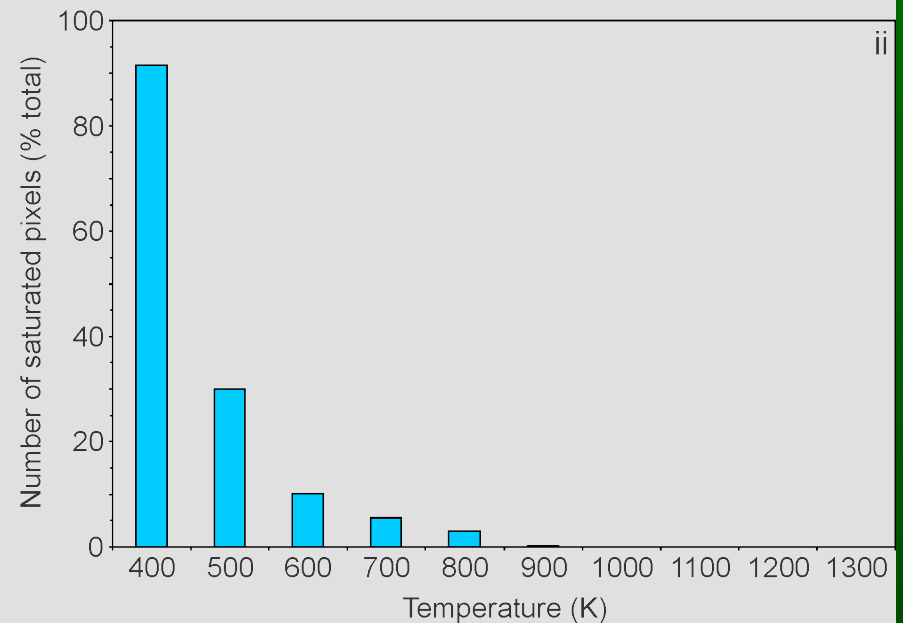
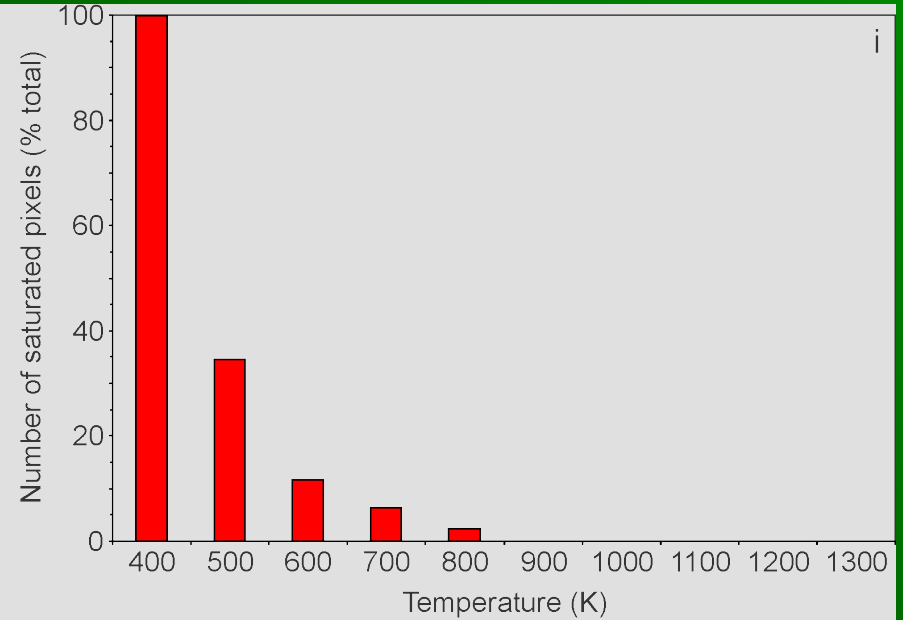
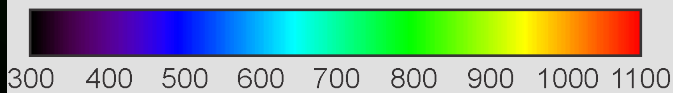
60 m

# Calculated incidence of HypsIRI 4 $\mu\text{m}$ channel saturation as a function of $L/T_{\text{sat}}$

$T_{\text{sat}}(\text{K})$	$\#_{\text{sat}}(\text{i})$	$\#_{\text{sat}}(\text{ii})$
400	471	432
500	163	142
600	55	48
700	30	26
800	11	14
900	0	1
1000	0	0



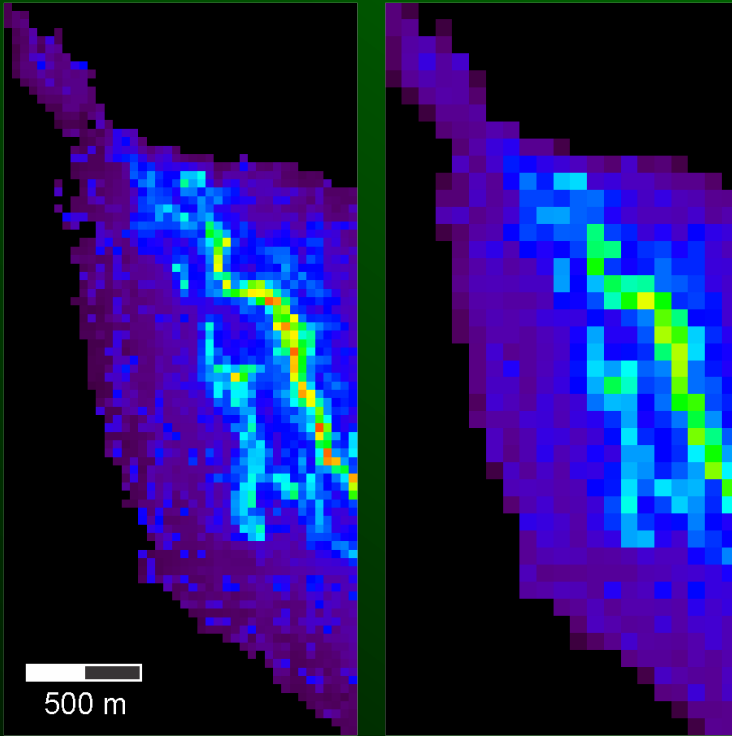
4  $\mu\text{m}$  brightness temperature (K)



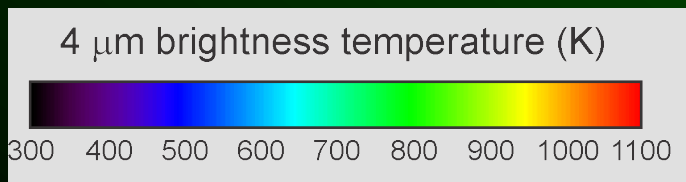
*Conclusion: set  $4\ \mu\text{m}$   $T_{\text{sat}}$  no less than 1100 K*

Hyperion

HyspIRI



- Aggregation of four most radiant pixels at HyspIRI resolution yields a  $T_{4\mu\text{m}}$  of 1041 K



# HyspIRI Volcanology Project Outreach

## HyspIRI Volcanology Project

### HyspIRI Volcanology Precursor Data for Mt. Etna

The Hyperspectral Infrared Imager or HyspIRI mission will study the world's ecosystems and provide critical information on natural disasters such as volcanoes, wildfires and drought. HyspIRI will be able to identify the type of vegetation that is present and whether the vegetation is healthy. The mission will provide a benchmark on the state of the world's ecosystems against which future changes can be assessed. The mission will also assess the pre-eruptive behavior of volcanoes and the likelihood of future eruptions as well as the carbon and other gases released from wildfires.

The HyspIRI mission includes two instruments mounted on a satellite in Low Earth Orbit. There is an imaging spectrometer measuring from the visible to short wave infrared (VSWIR: 380 nm - 2500 nm) in 10 nm contiguous bands and a multispectral imager measuring from 3 to 12 um in the mid and thermal infrared (TIR). The VSWIR and TIR instruments both have a spatial resolution of 60 m at nadir. The VSWIR will have a revisit of 19 days and the TIR will have a revisit of 5 days. HyspIRI also includes an Intelligent Payload Module (IPM) which will enable direct broadcast of a subset of the data.

The data from HyspIRI will be used for a wide variety of studies primarily in the Carbon Cycle and Ecosystem and Earth Surface and Interior focus areas. The mission was recommended in the recent National Research Council Decadal Survey requested by NASA, NOAA, and USGS. The mission is currently at the study stage and this website is being provided as a focal point for information on the mission and to keep the community informed on the mission activities.



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## HyspIRI Preparatory Data Sets for Volcanology

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HyspIRI is a Tier 2 mission recommended to NASA by the National Research Council's Decadal Survey report. One of the main goals of the HyspIRI mission is to provide global observations of surface attributes at local and landscape spatial scales (10's of meters to hundreds of kilometers) to map volcanic gases and surface temperatures, which are identified as indicators of impending volcanic hazards; as well as plume ejecta which pose risks to aircraft and people and property downwind. We will create precursor HyspIRI data sets for volcanological analyses, using existing data over Mt. Etna, Italy. We have identified 12 EO-1 Hyperion data acquisitions, 12 near-coincident ASTER data acquisitions, and a MIVIS aircraft data acquisition, covering six eruptive periods between 2001 and 2007. These three data sets provide us with 30 m hyperspectral VSWIR data and 90 m multispectral TIR data (satellite) and 10 m multispectral TIR data (aircraft). They will allow us to examine temporal sequences of several Etnaean eruptions. We will address the following critical questions, directly related to understanding eruption hazards: 1) What do changes in SO2 emissions tell us about a volcano's activity? How well do these measurements compare with ground-based COSPEC measurements? 2) How do we use measurements of lava flow temperature and volume to predict advances of the flow front? 3) What do changes in lava lake temperatures and energy emissions tell us about possible eruptive behavior? Mapping SO2 emissions will be done using REALMUTO Software applied to our precursor HyspIRI data sets. We will calculate, through data analysis and models, the column abundance of SO2 all along Etna's plumes. Results will be compared with coincident COSPEC ground measurements at Etna obtained daily by Istituto Nazionale del Geofisica e Vulcanologia in Catania, Sicily. Examining the time history of SO2, compared with eruption history, will provide us some indication of the correlation between the two.

Data from the VSWIR and TIR will allow us to determine radiant temperatures over a wide range: edges of lava flows at 100C, to magmatic lava at 1100C. This improved characterization of flows is a crucial input into flow models for predicting run-out lengths. Similarly, improved accuracy for determining temperatures of lava lakes will provide better insight into the internal plumbing of Etna, and the state of magma ascent from depths.


**Project Highlight**




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# SELECTED CONCLUSIONS

- ✱  $T_{\text{sat}} 4\mu\text{m channel} > 1100\text{K}$

- ✱ Short repeat time mandatory for volcano monitoring: Hyperion and ASTER do not provide sufficient frequency at 10-16 days, given cloud cover. HypsIRI repeat of 5 days (daytime) PLUS nighttime acquisitions will be stunning for volcanology.

- ✱ Lava flow energy fluxes with topo and flow models can be used to estimate flow duration and extent. Requires very frequent flow observations (~several days) to measure dynamics.

- ✱ Crater activity (T, energy flux) monitoring requires very frequent observations to investigate correlation with eruption potential; questionable at present