GROUND-BASED THERMAL MONITORING

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Thermal monitoring

- Remote sensing – often is the first signal of a new eruption for remote volcanoes
- Fumarole direct temperature measurements
- Spring water temperatures
- Radiometer – large pixel detectors
- Temperature of PFs, lahars
- Thermal imaging

Thermal imaging

- Recent development of IR cameras
  - Getting cheaper
  - Stable calibration
  - Lightweight, portable instruments

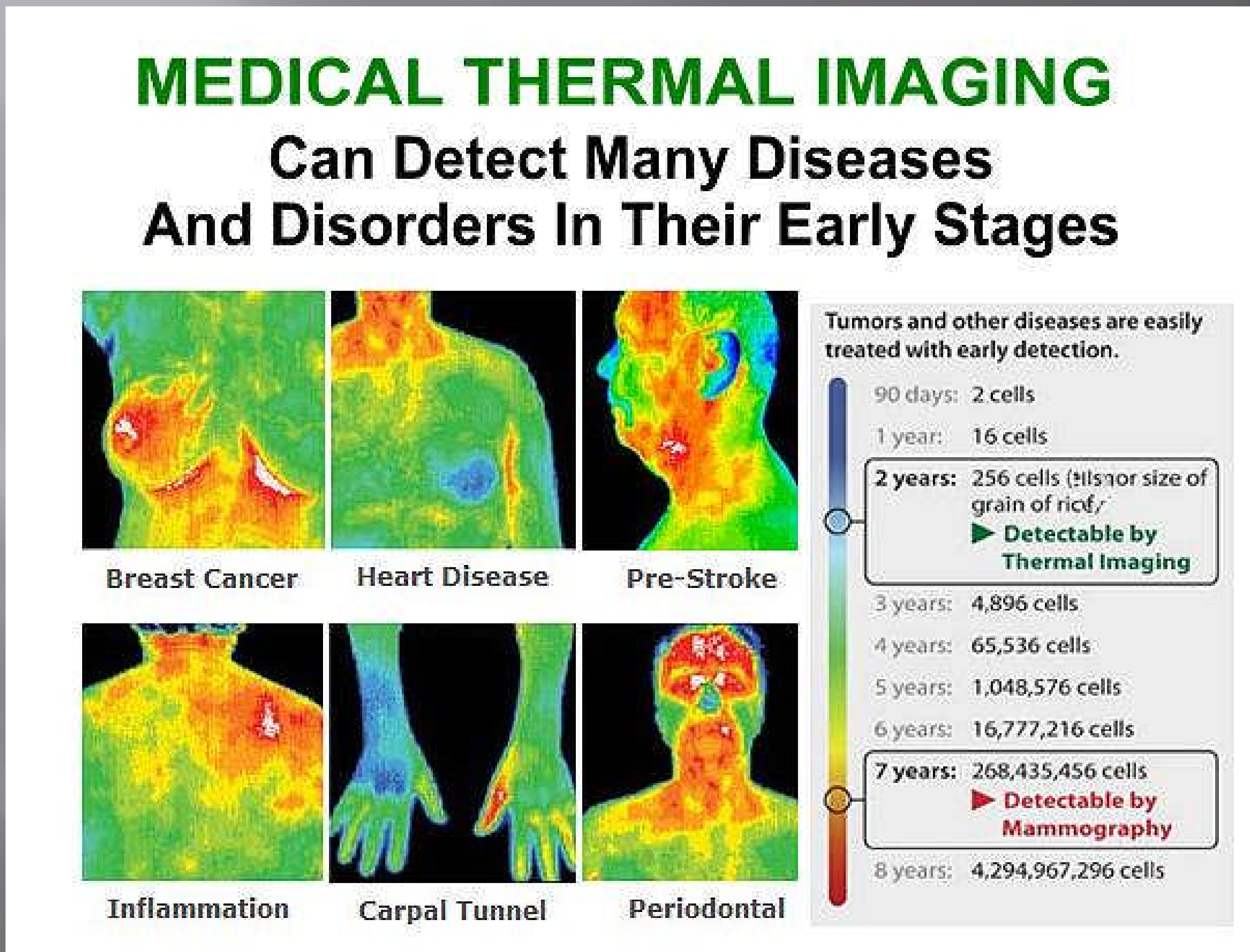
Thermal infrared 7.5 – 13 μm
Sensitivity - <0.1°C
Fast – up to 60 Hz

VarioCAM thermal camera

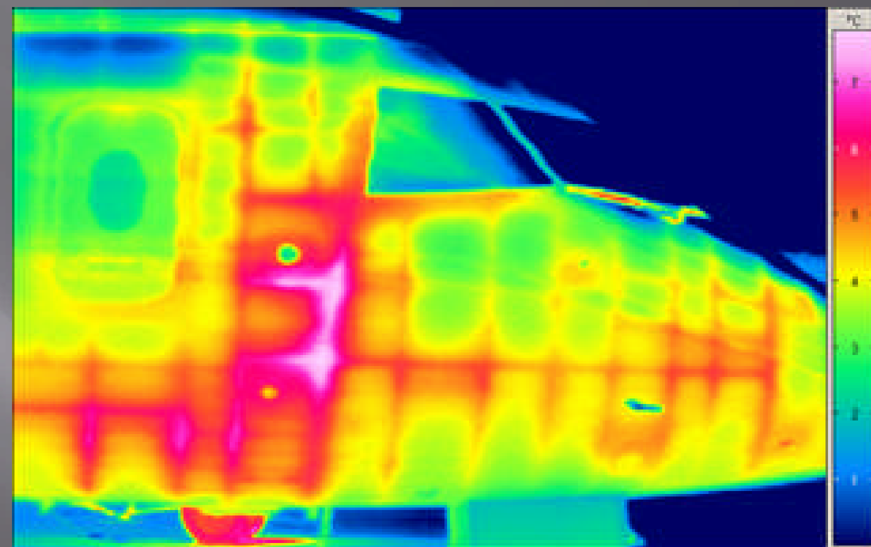
320 x 240 model

- German camera
- Hr model 640 x 480
- Resolution enhancement 1280 x 960
- 8 – 13 µm
- 50 Hz Firewire
- SD cards
- 32,000 Euro (43,000 USD)

Thermal imaging



Applications



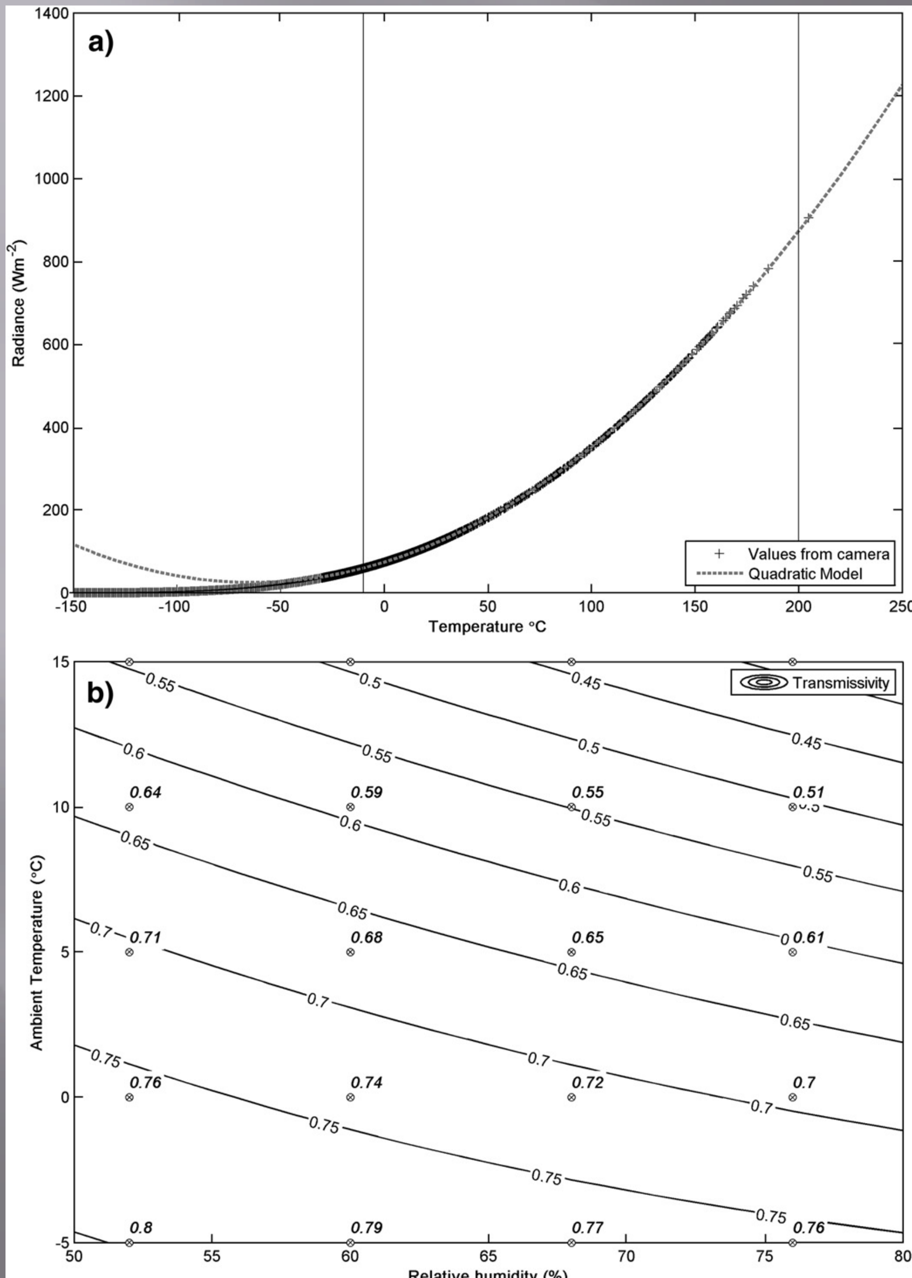
Moisture Behind Drywall

Thermal imaging of volcanoes

- Passive activity
  - Remote sensing of fumarole temps.
- Effusive activity
  - Characteristics of dome growth – mechanism of emplacement
  - Estimation of effusion rate
- Explosive activity
  - Characteristics – depth of source, ash contents
  - Air entrainment process
  - Real-time monitoring with radiometers

Operation

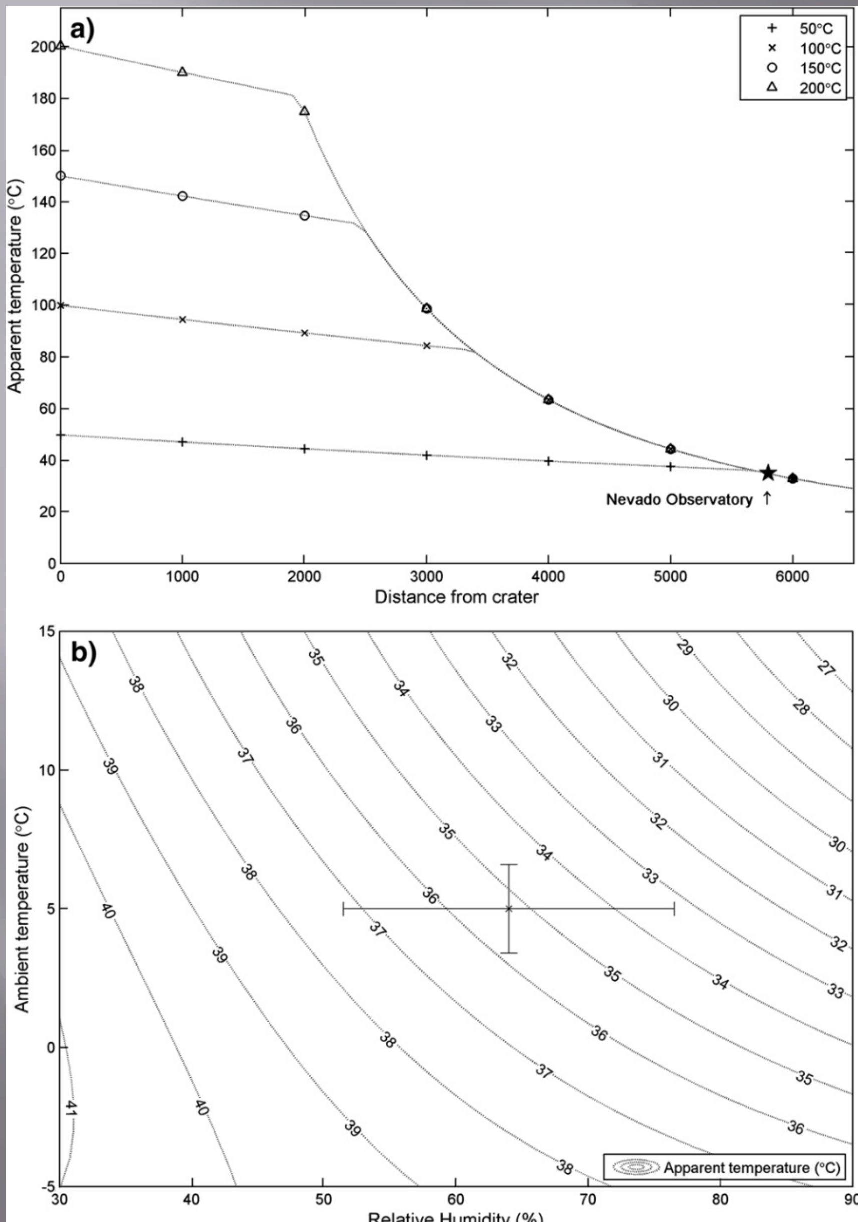
- Emissivity of rocks
- Absorption of atmosphere – relative humidity
- Atmospheric models used



Comparison of object temperature and radiative heat flux.
Dotted curve represents temperature/radiative heat flux conversion function.
Agrees with Plancks-law over the range of interest (−10 to 200 °C)

Transmissivity of a 5800 m path at 4000 m elevation using the Tropical Atmosphere Model.
The contours are interpolated from values calculated using the MODTRAN code

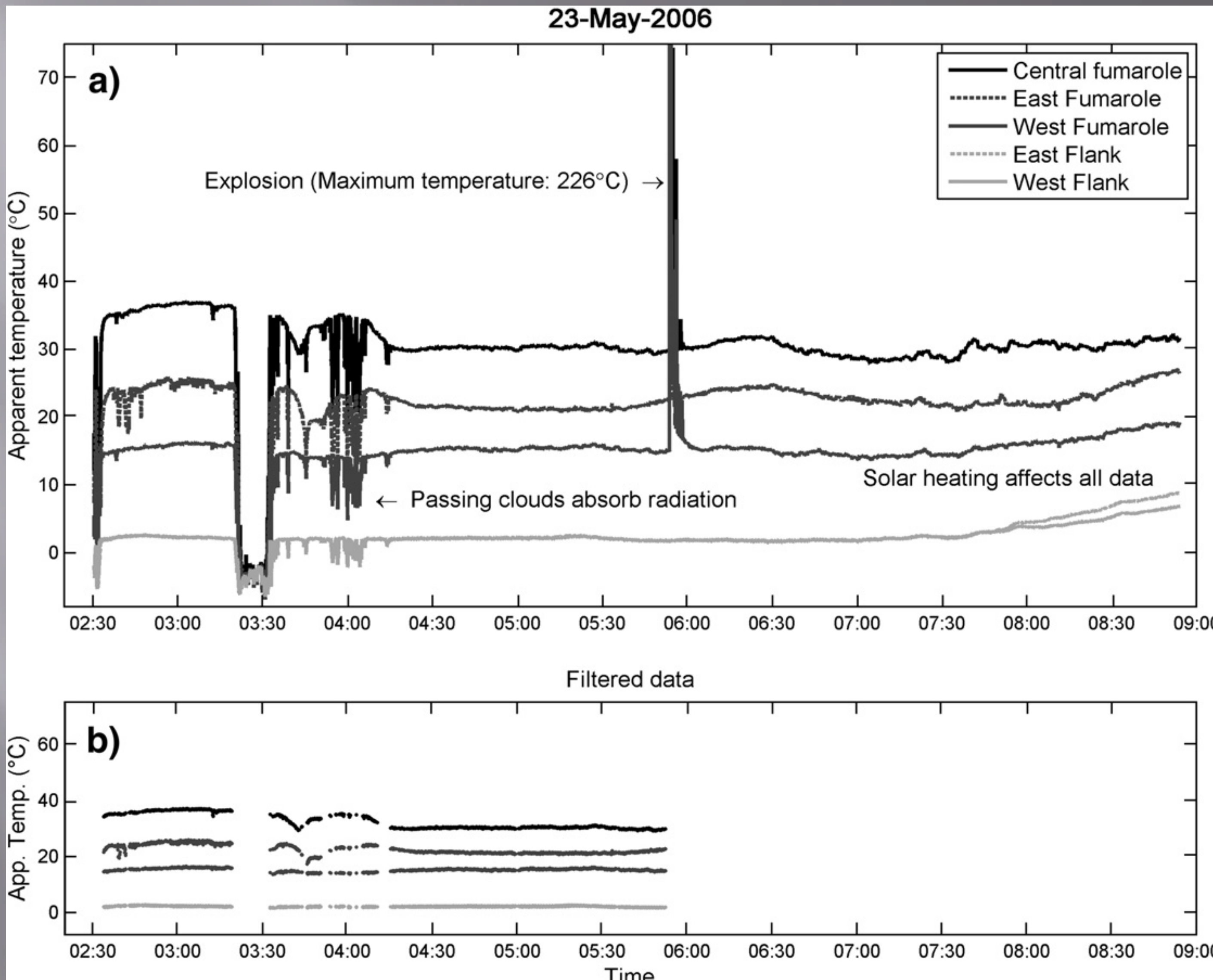
Models of apparent fumarole temperatures



a) Distance versus apparent temperature for theoretical fumaroles. The radiating areas and temperatures of the fumaroles are: 102 m^2 at 50 °C; 36.1 m^2 at 100 °C; 19.2 m^2 at 150 °C; 12.1 m^2 at 200 °C. Areas correspond to an apparent temperature of ~35 °C at typical atmospheric conditions of 5 °C and 64% relative humidity. 2 regimes. (i) apparent temperatures are controlled by the atmospheric transmissivity; (ii) control is dominated by the pixel size.

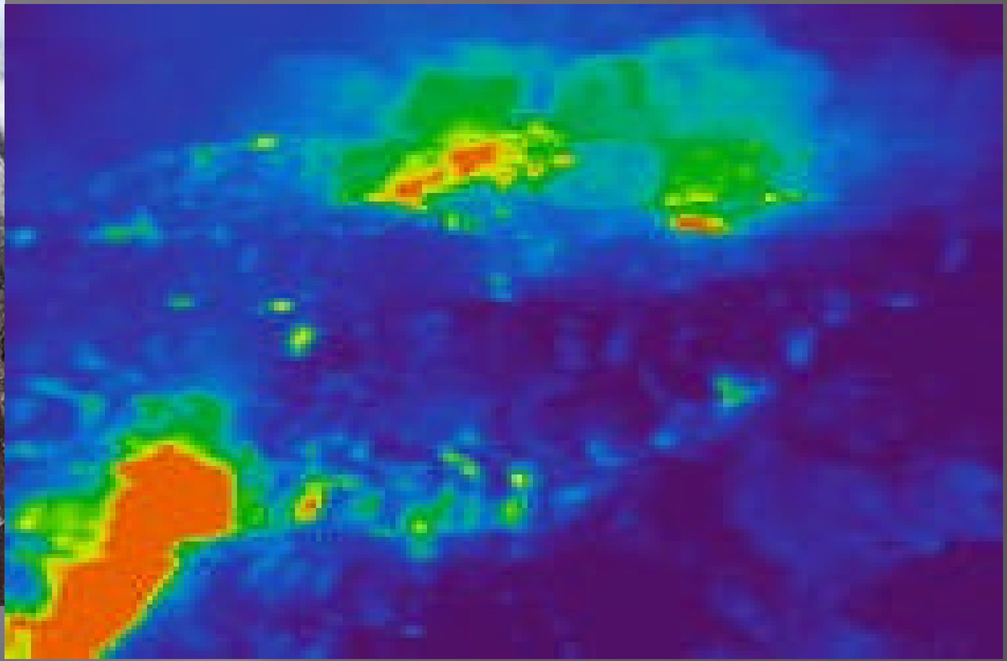
b) Effect of atmospheric conditions on apparent temperature. Contour lines of apparent temperature show how it changes with weather conditions. Error bars represent mean variation within a 24 hour period.

Stevenson & Varley 2008 JVGR



Data processing – filter for clouds and explosions

Dome growth (16 Oct. 2004)



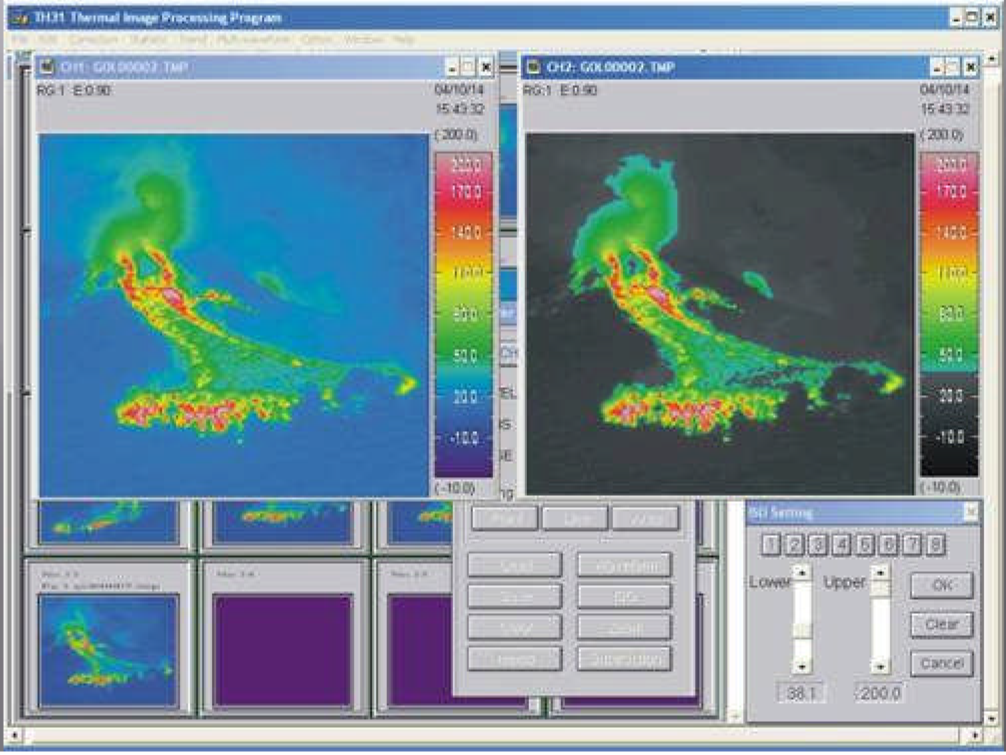
Much lower SO_2 flux compared to 1998-9 although similar effusion rate

→ magma arrived with lower volatile contents – volume degassed during explosive events during 2003-4

Infrared – 3 effusion centres, E fracture

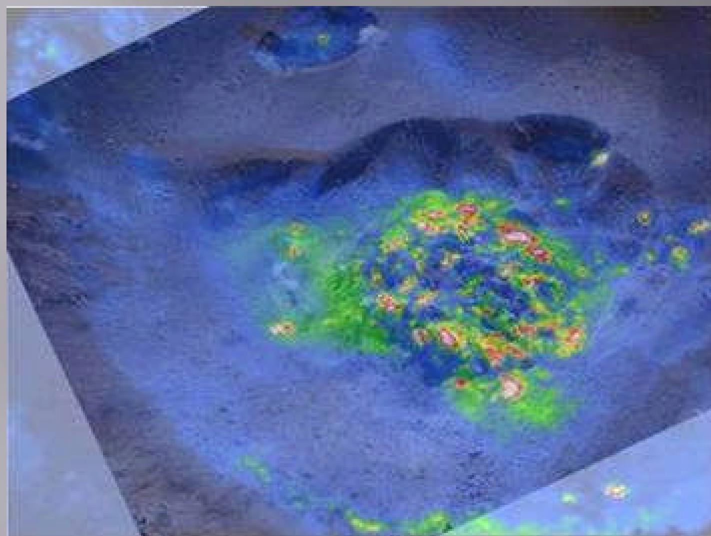
NEC camera 1.5 – 3 µm

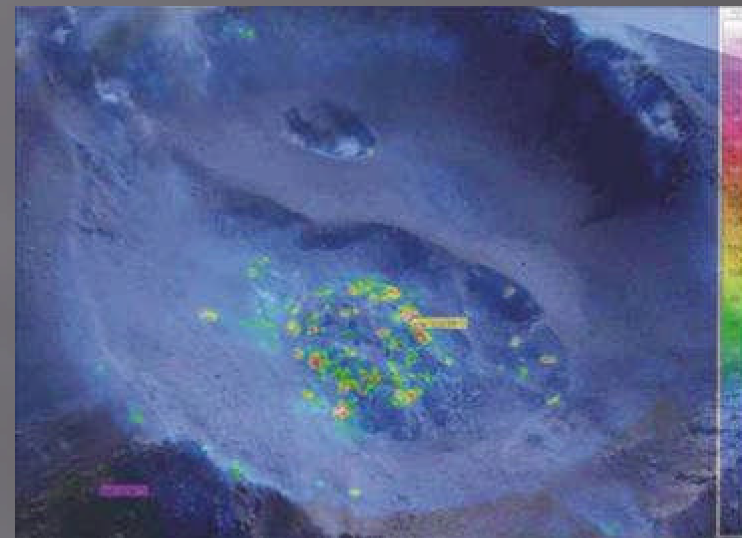
Calculation of effusion rate



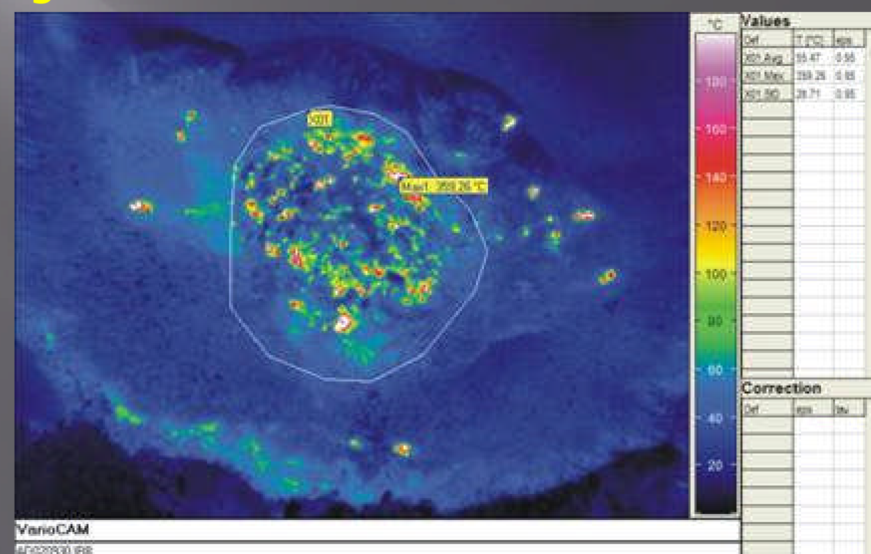
- Thermal radiance used to calculate effusion rate
- Comparison with satellite data (AVHRR & MODIS)
- Also calculated using photos and GIS

Recent eruption – started Jan. 2007





Superimposed thermal and visual images of dome on 9 Feb. 2007

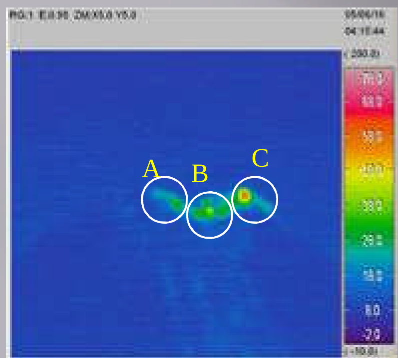


Thermal image with white areas having temperatures > 200° C.

Precursors 6 months before effusion started:

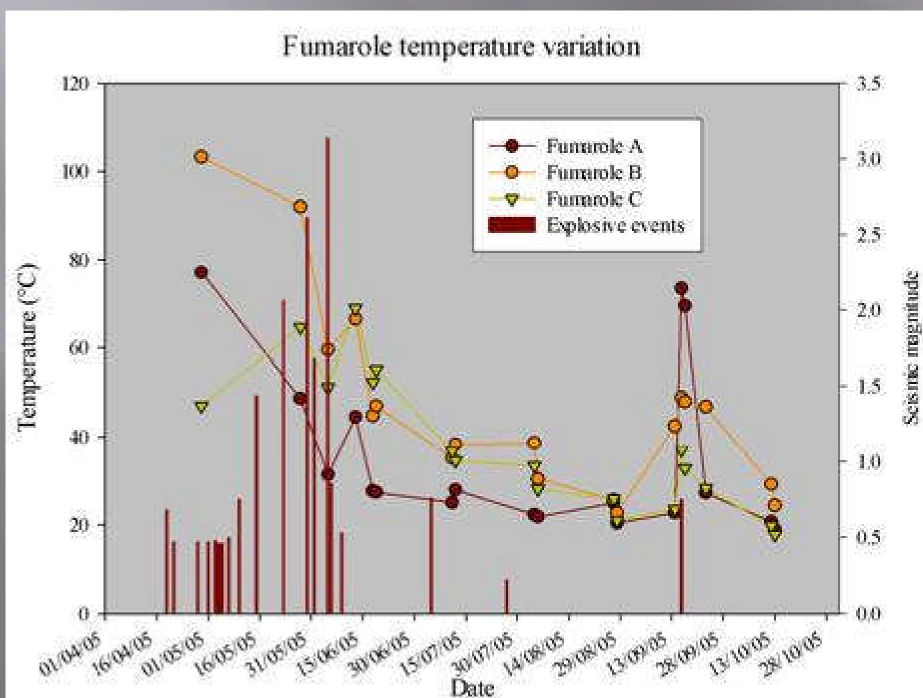
- Increase in B in spring waters
- Seismicity – increase in LP events
- Increase in fumarole temperature

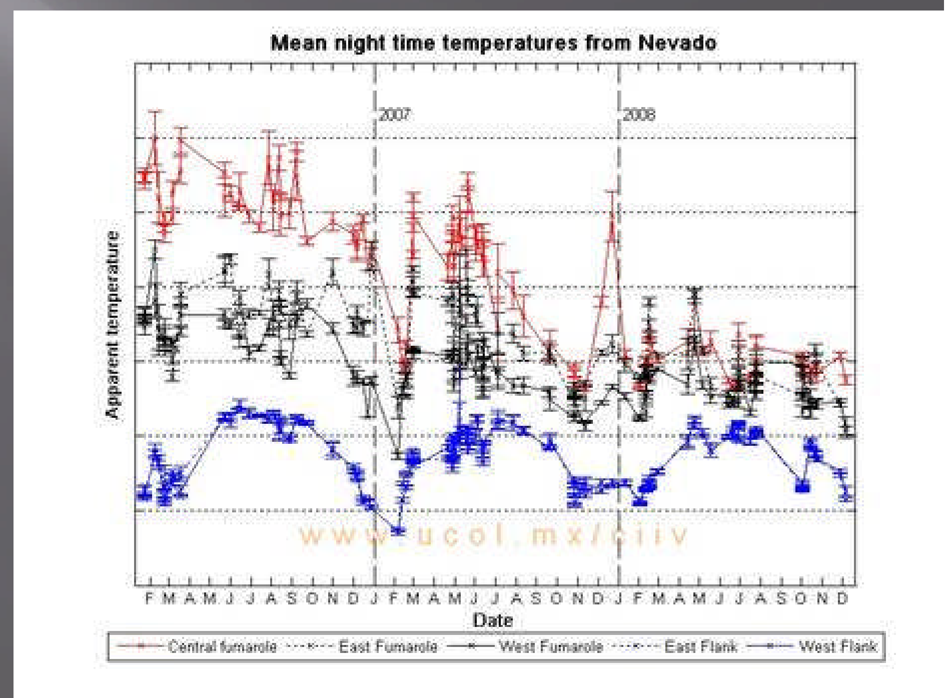
Remote sensing of fumaroles

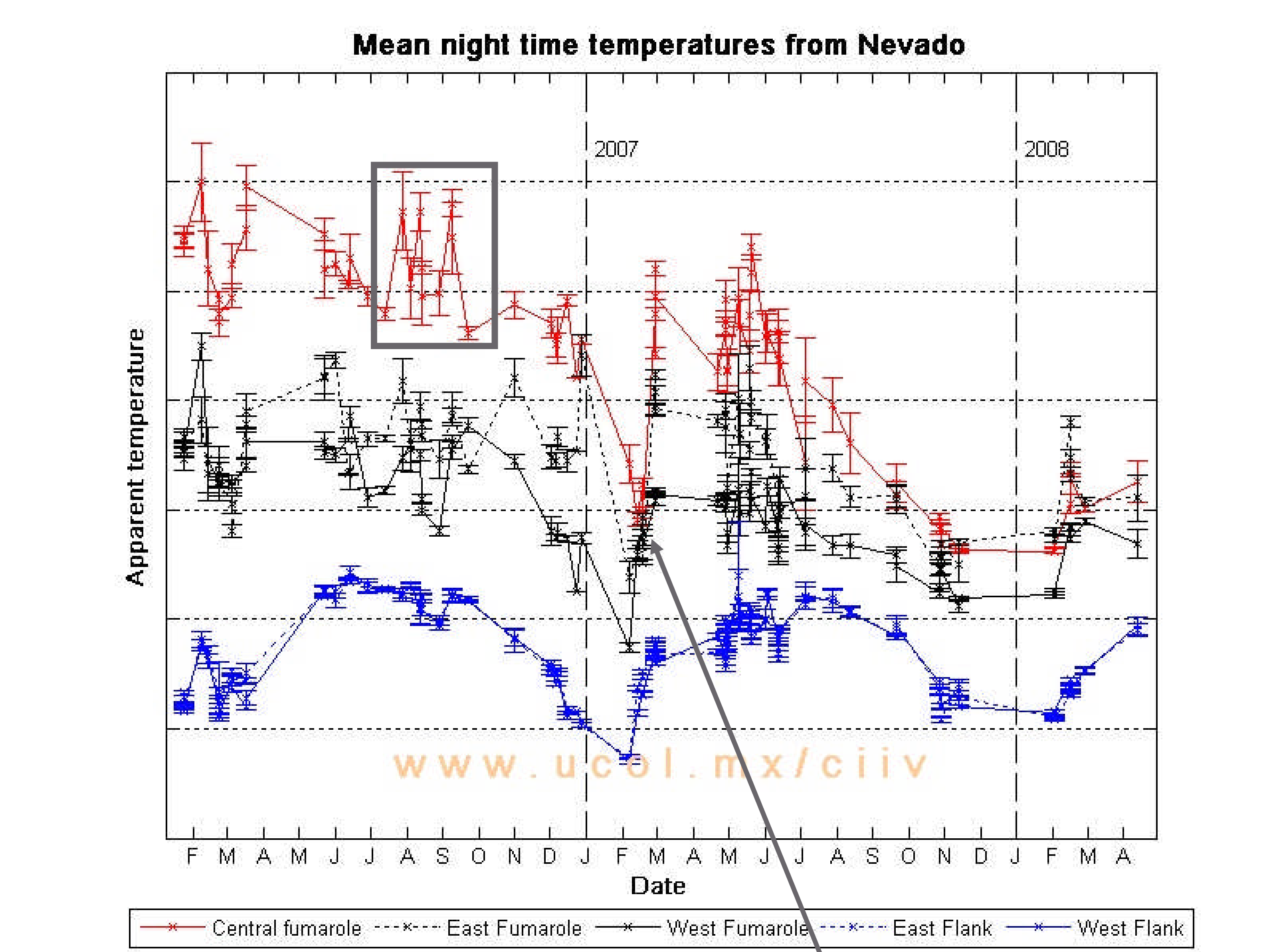


3 fumarole zones monitored

- Decreasing tendency during 2005-2007; 2008 onwards fairly constant
- Negative anomaly prior to 5 June event
- Temperature increases and decreases related to explosions
- Relatively large pixel size and large distance for atmospheric effects but sufficiently sensitive to detect small variations



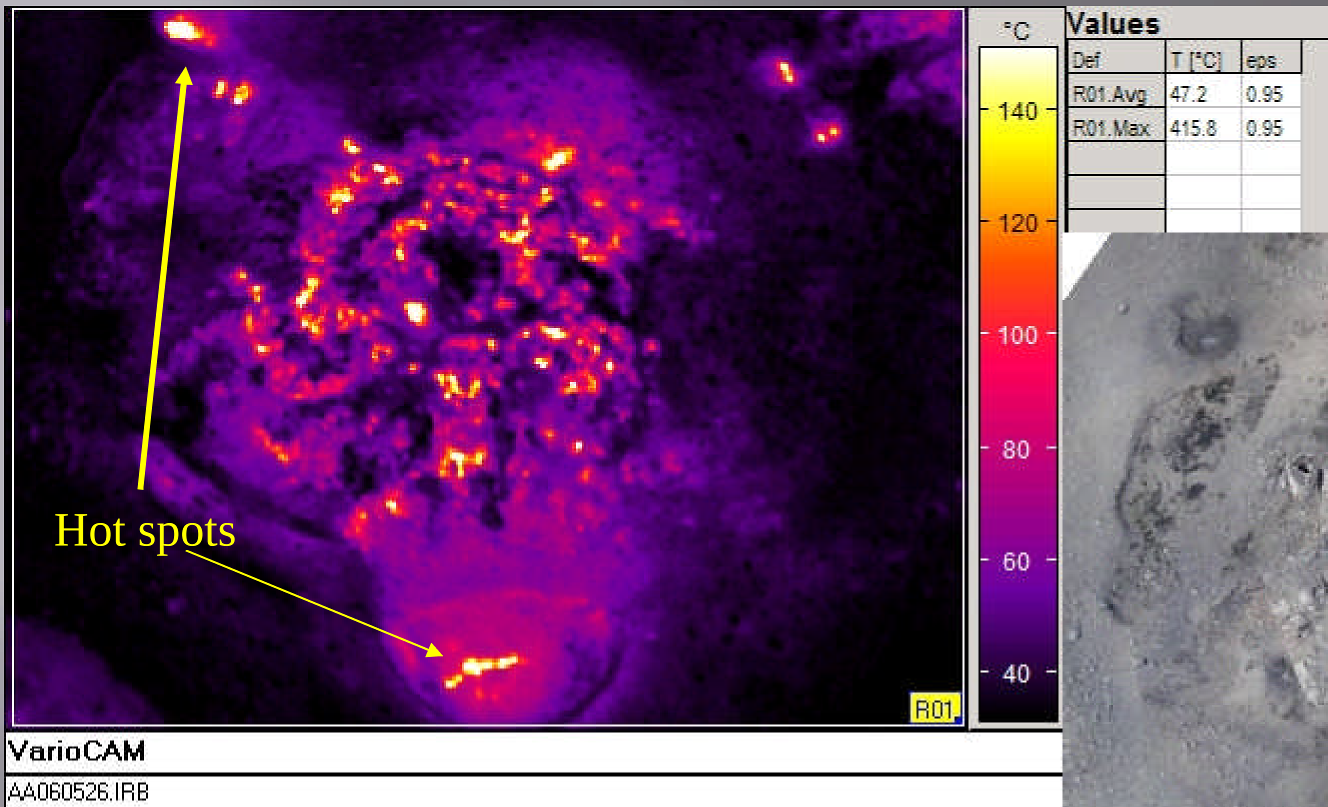




Increase in fumarole temps.

Decrease occurred when dome made it to the surface

Dome evolution from thermography



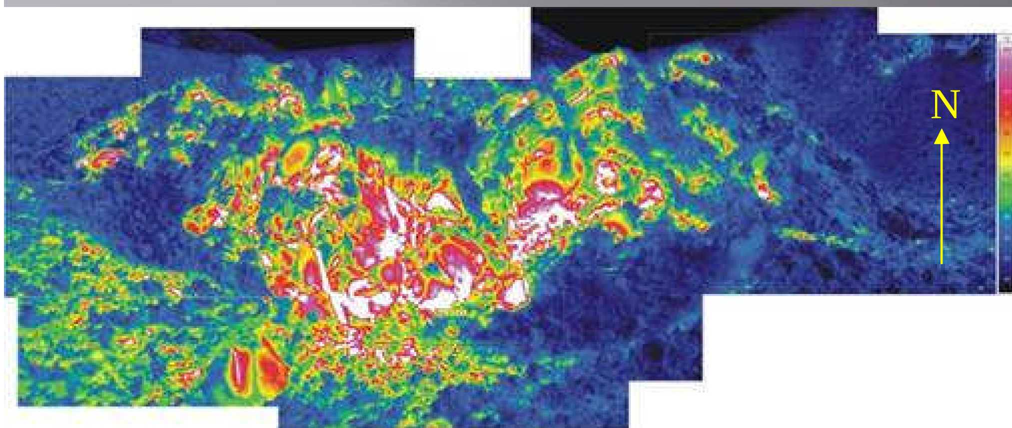
Pixel dimension = 0.45 m

Hot spots within small explosion craters

Evidence of circular structure in IR image

05 June 2007

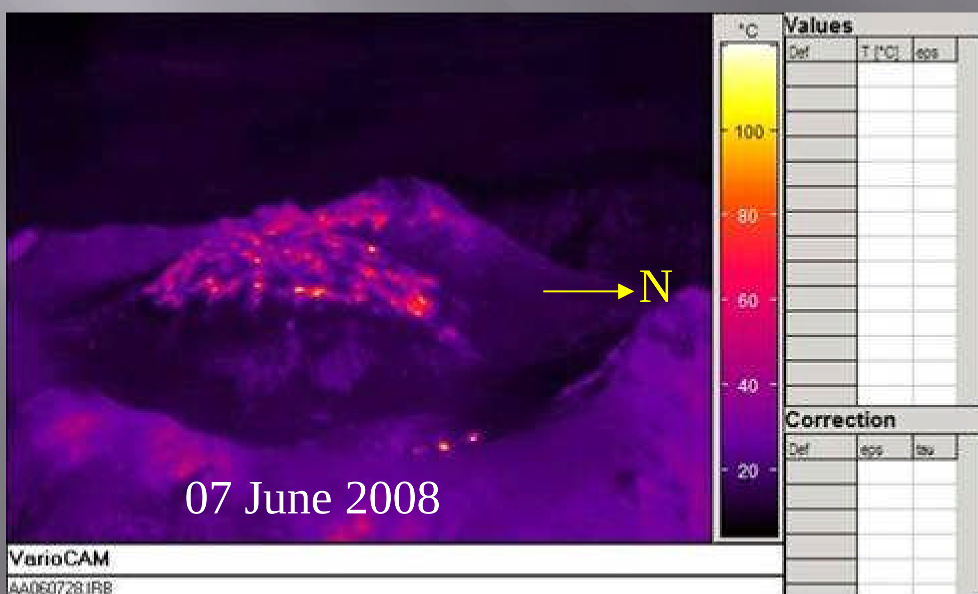
Magma extrusion



11 Nov. 2007 Pixel temps. > 500° C

Growth directed in certain directions – small lobes

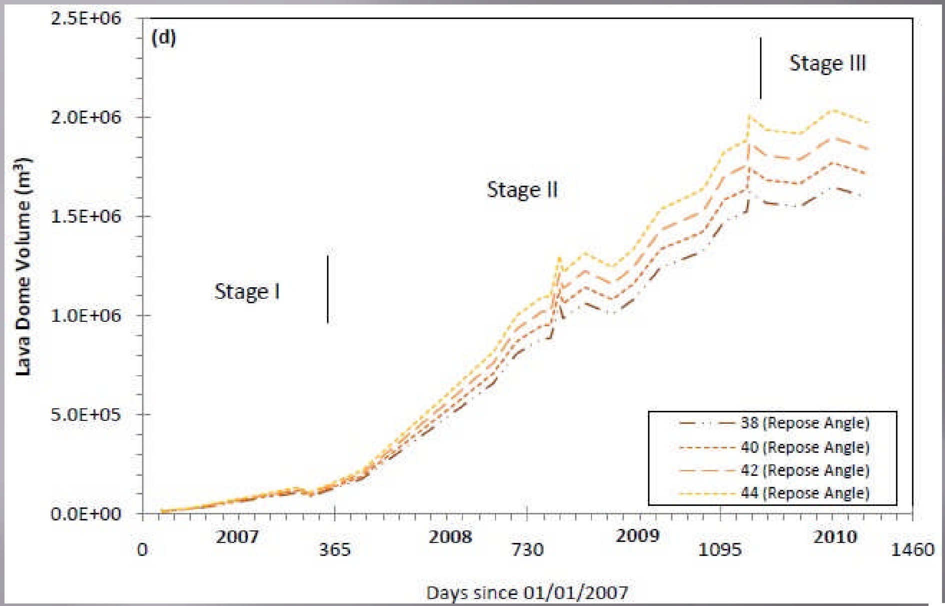
Exogenic



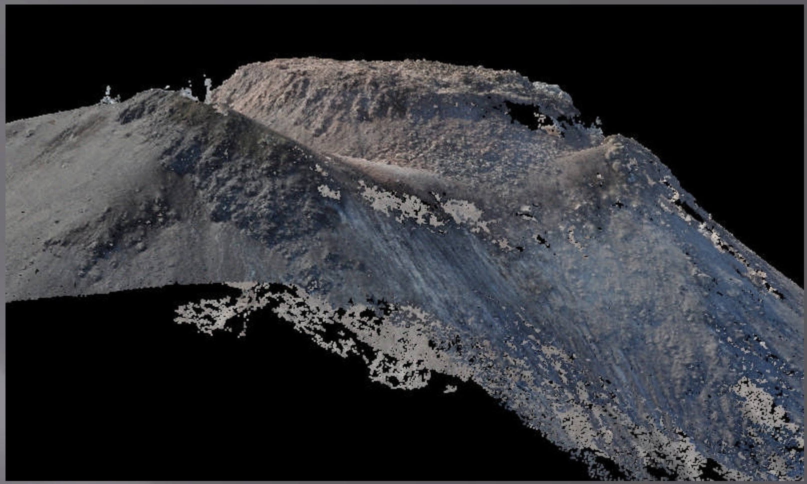
Larger dome – sides no longer show high temperature

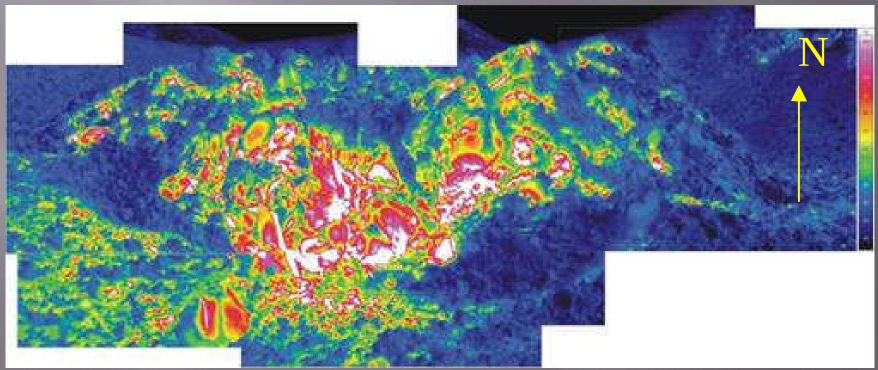
- Hot central core
- Extrusion on upper surface & sides
- Cooled lower slopes
  - •Talus accumulation
  - •Thermal insulation

2007 – 2011 dome

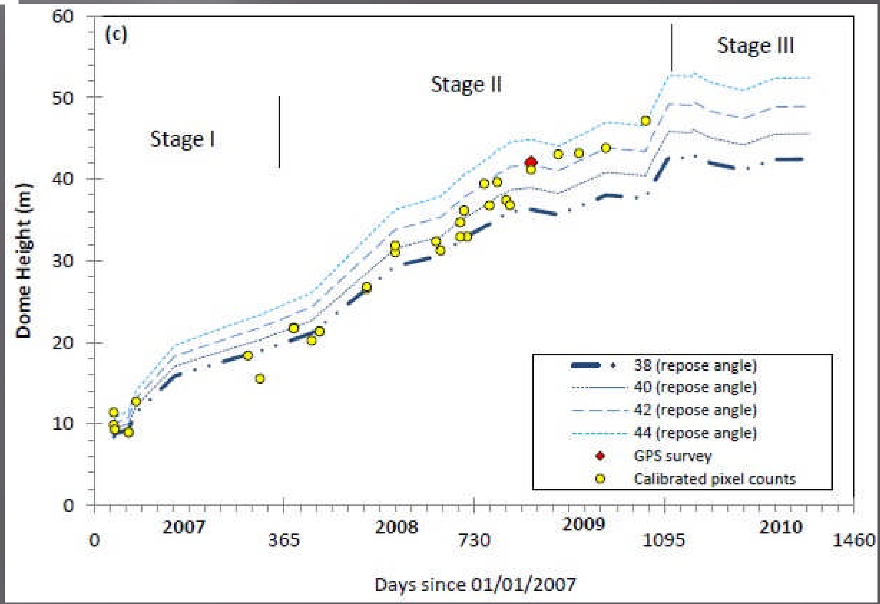


Various methods used to estimate dome volume

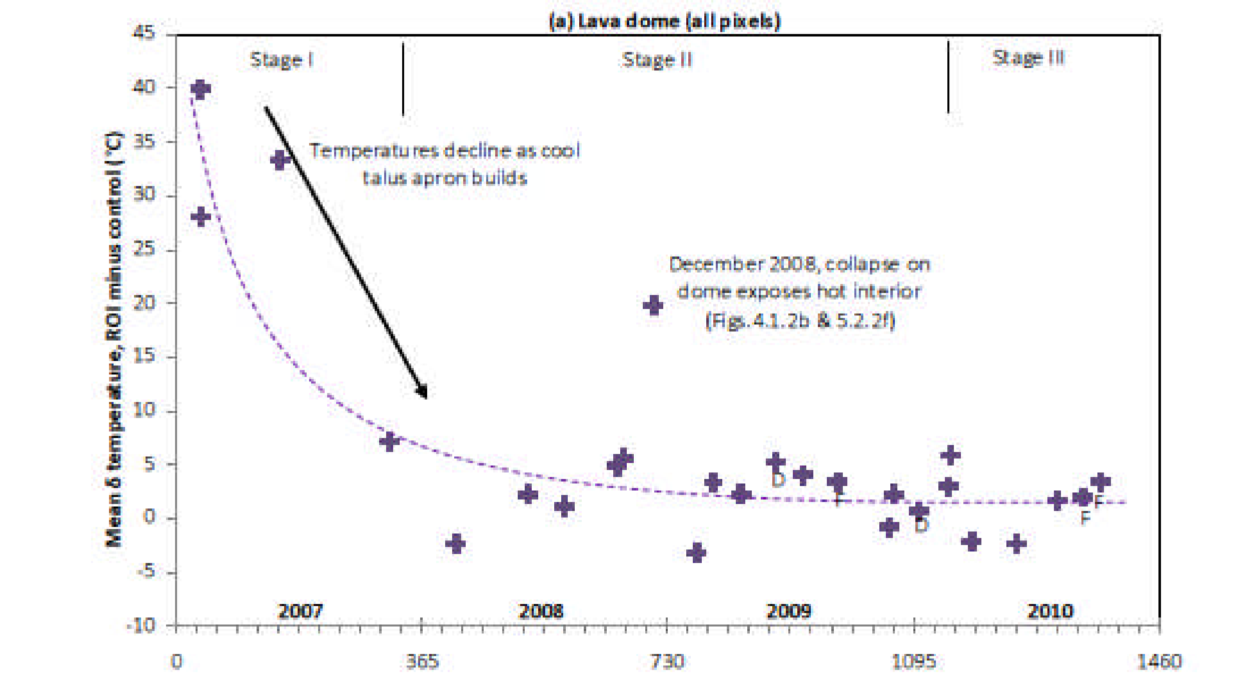


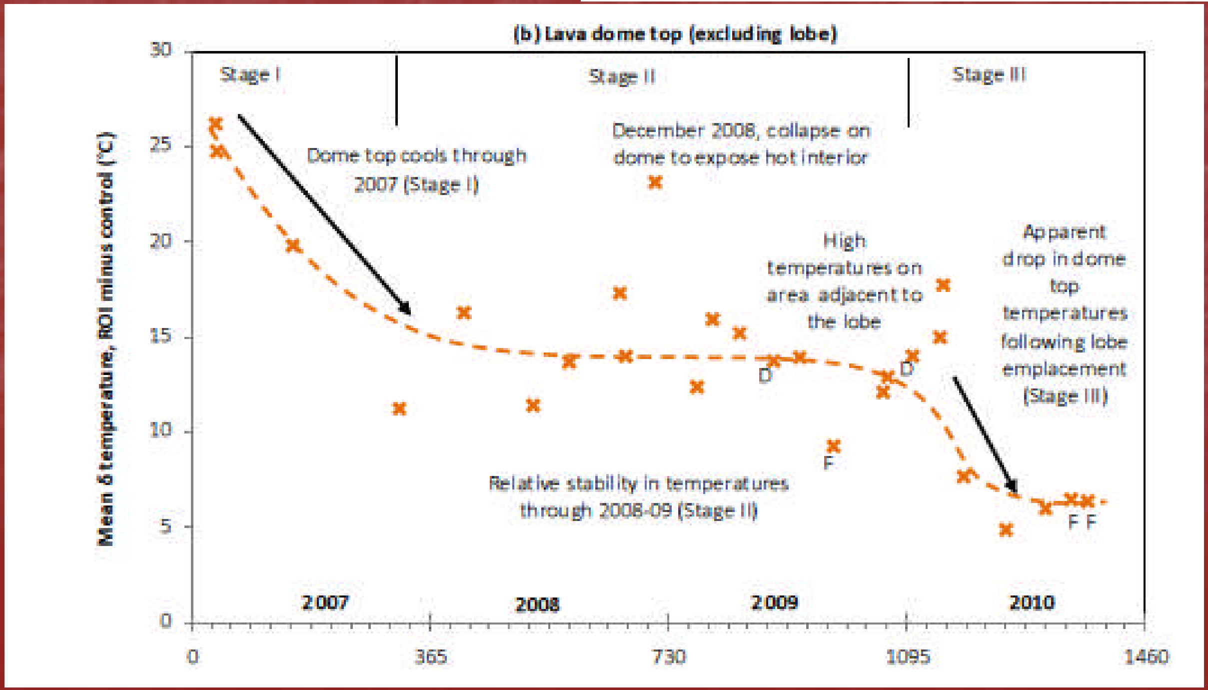


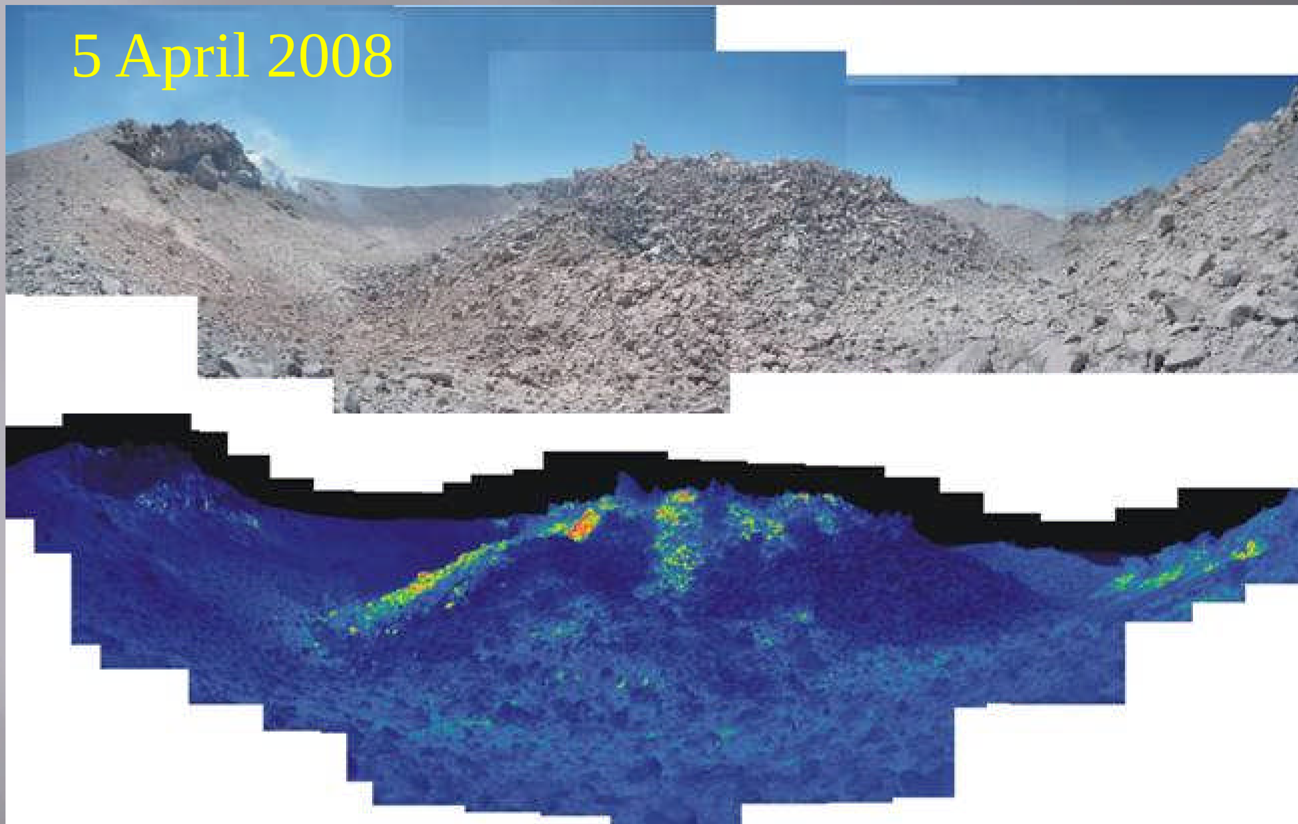
First stage – exogenic growth
11 Nov. 2007 Pixel temps. > 500° C

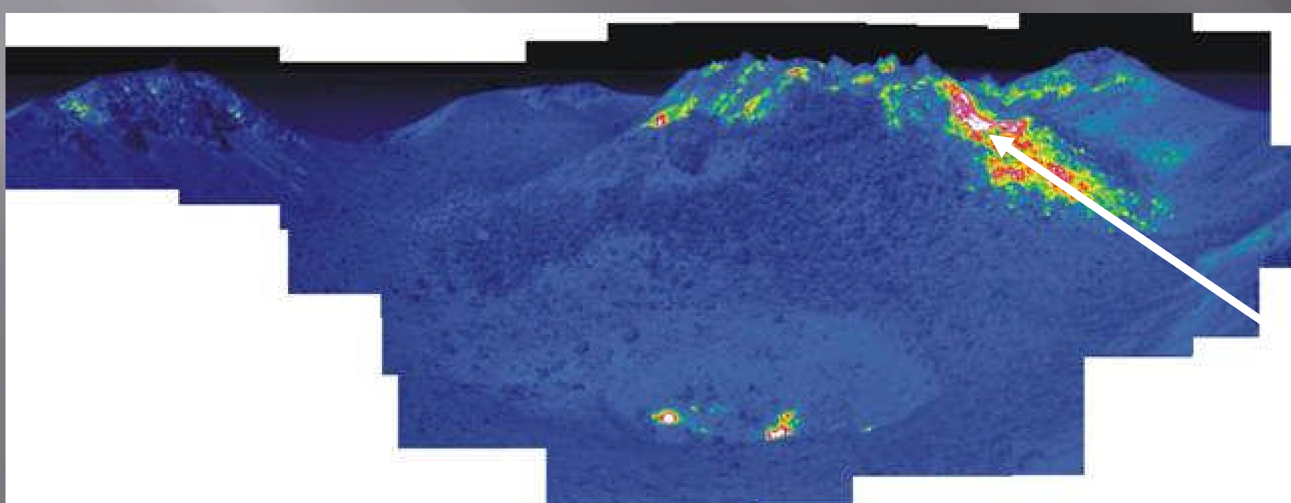


Dome thermal analysis

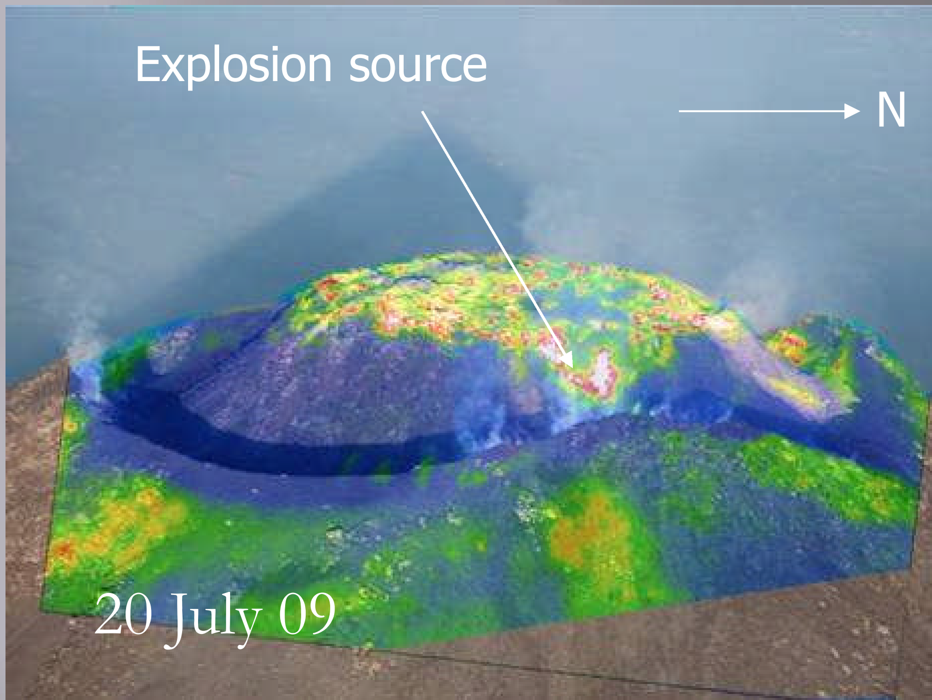


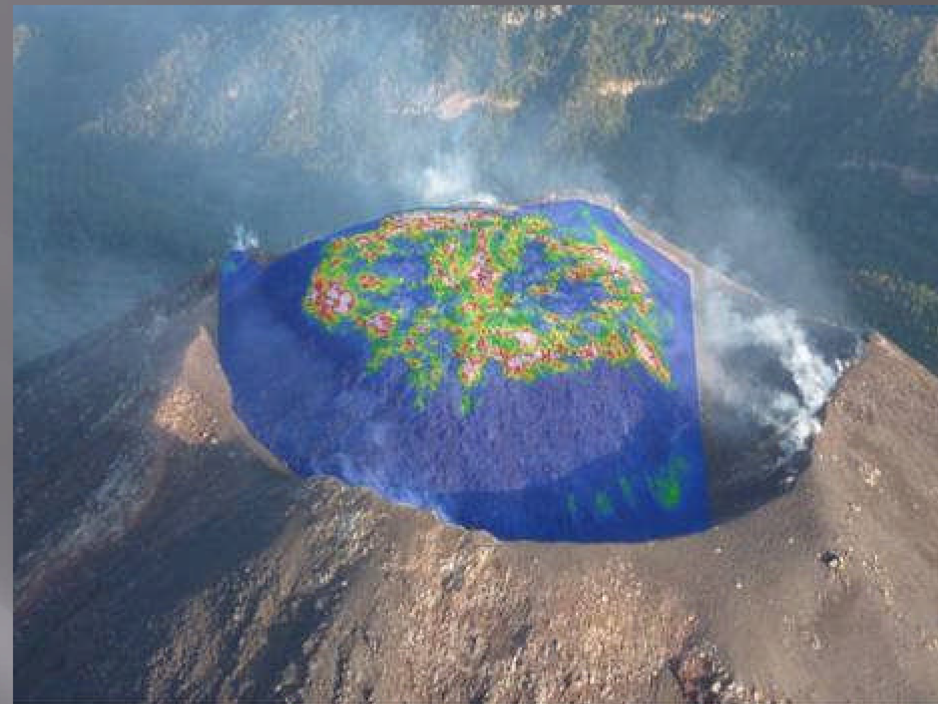


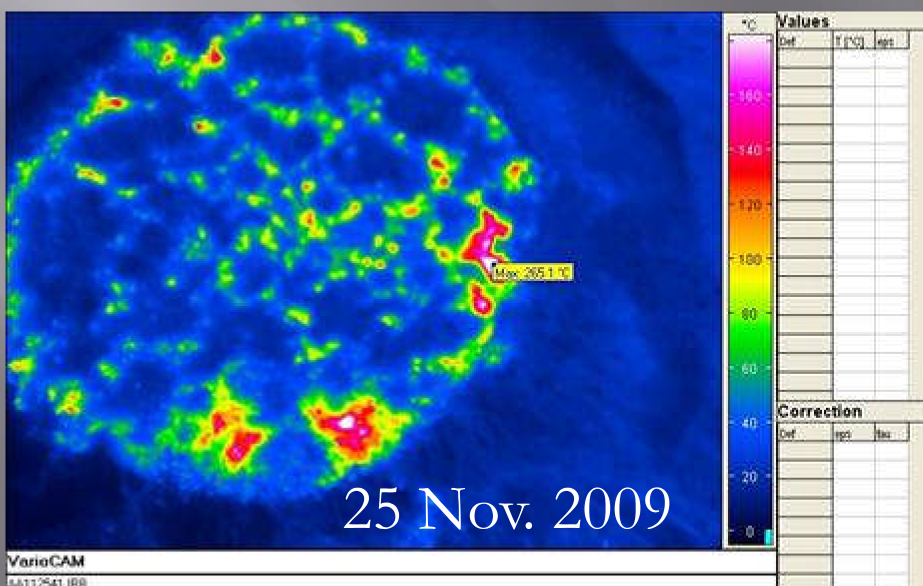




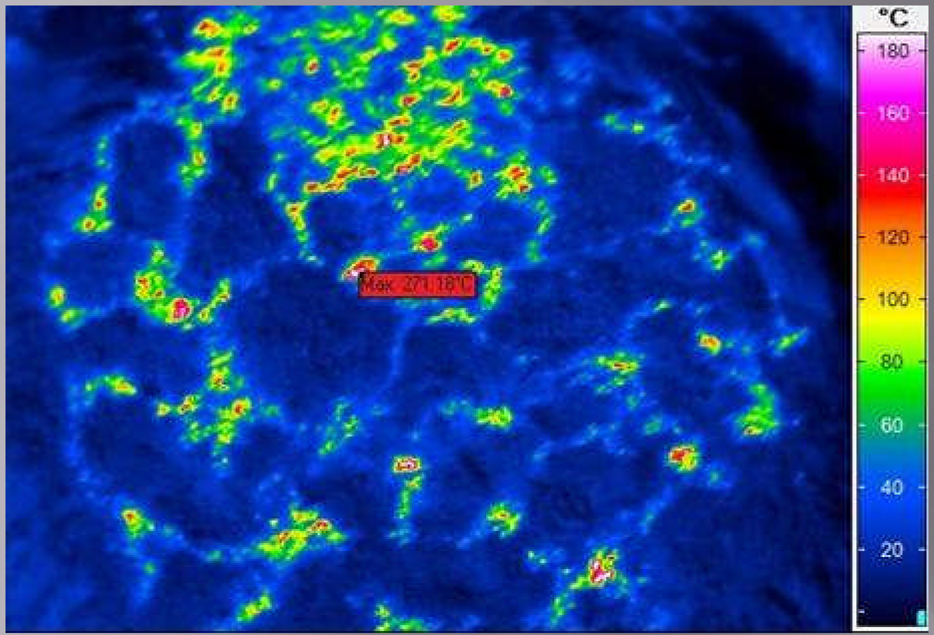
Hotspot – 321° C
Extrusion with rockfall or explosive vent







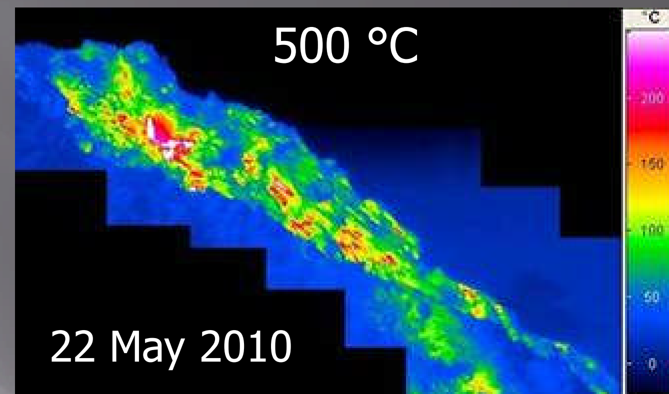
- Persistent hotspots
- Hot outside upper surface
- Fractures – gas flow

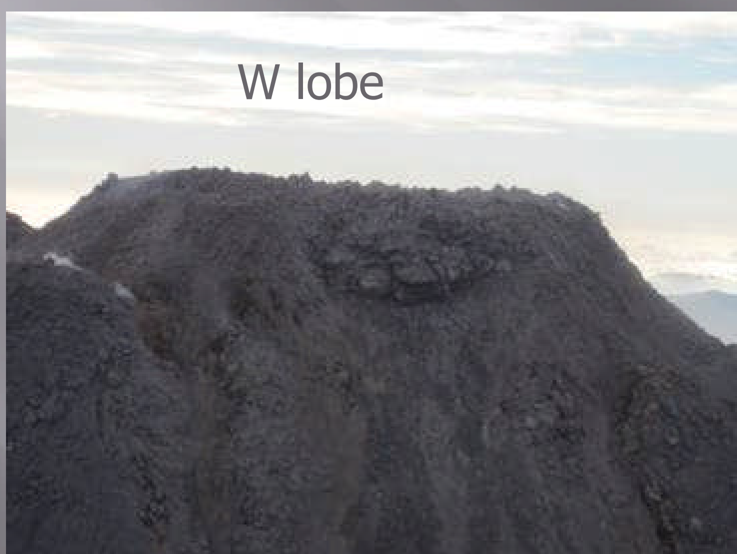


Dome cooling – polygons → columnar jointing

26 Dec. 2010

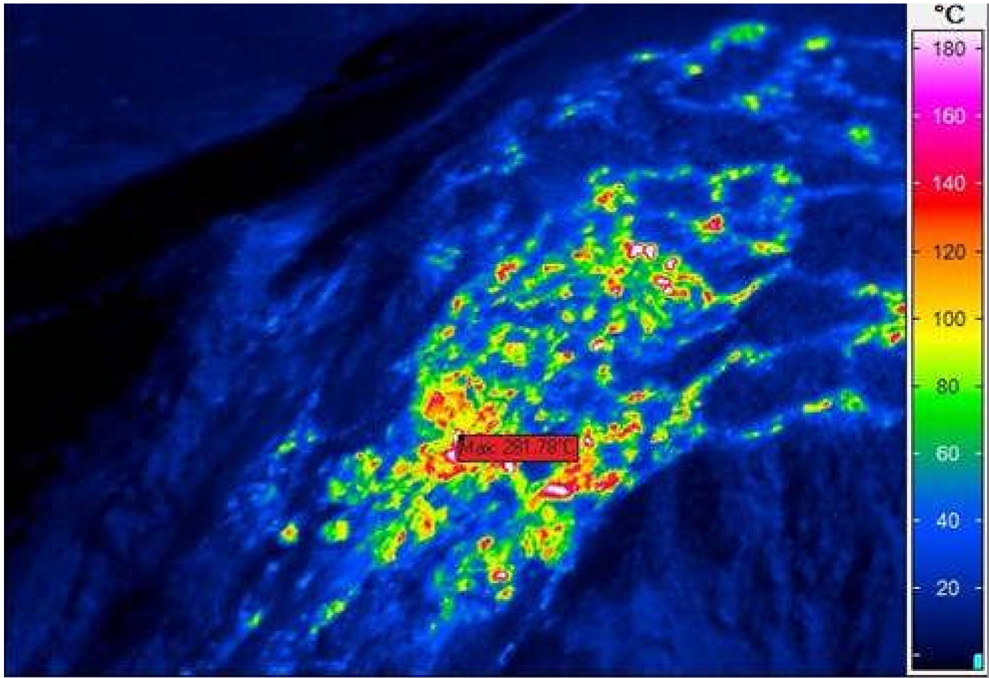
- Steepening & unloading on W dome side from rockfalls
- New lobe appears





25 February 2010

29 March 2010



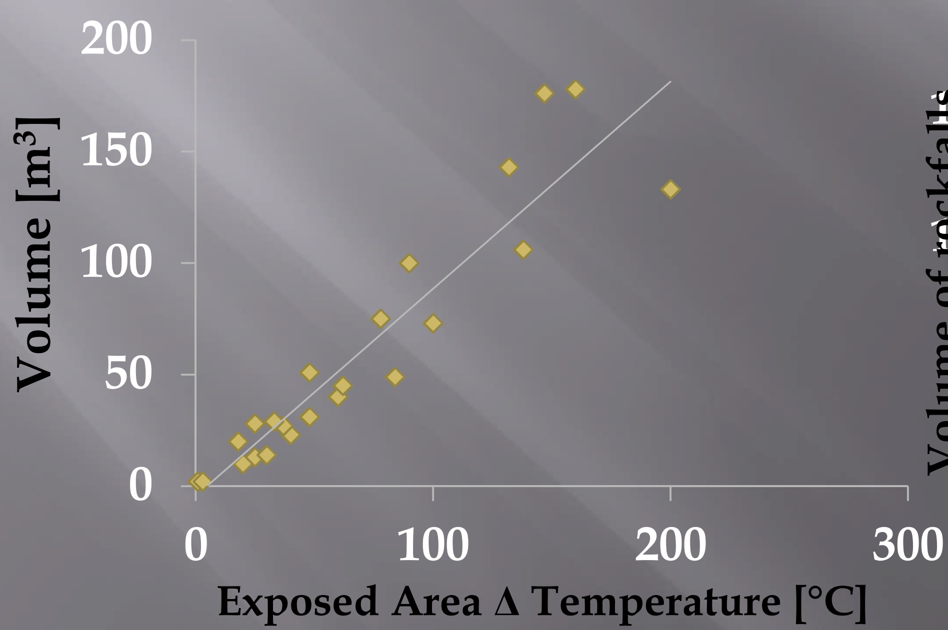
Final effusive phase: lobe W side

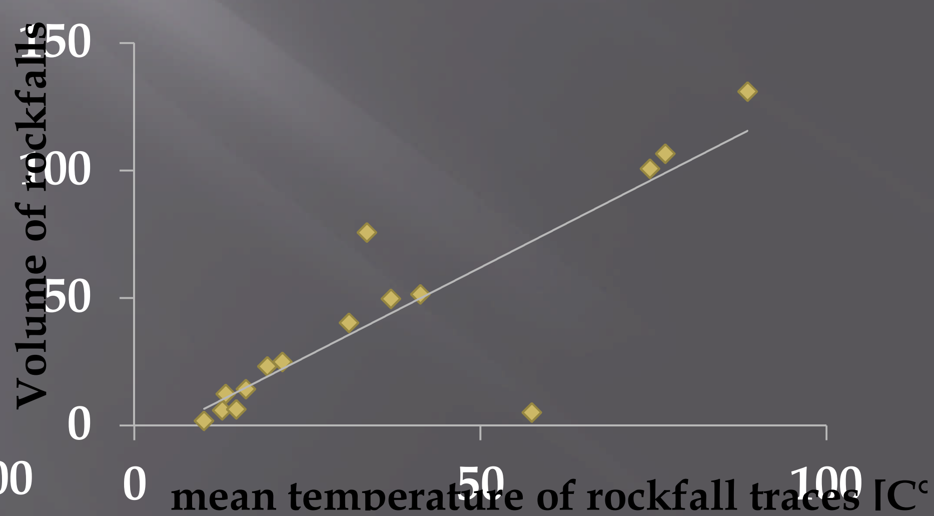
26 December 2010

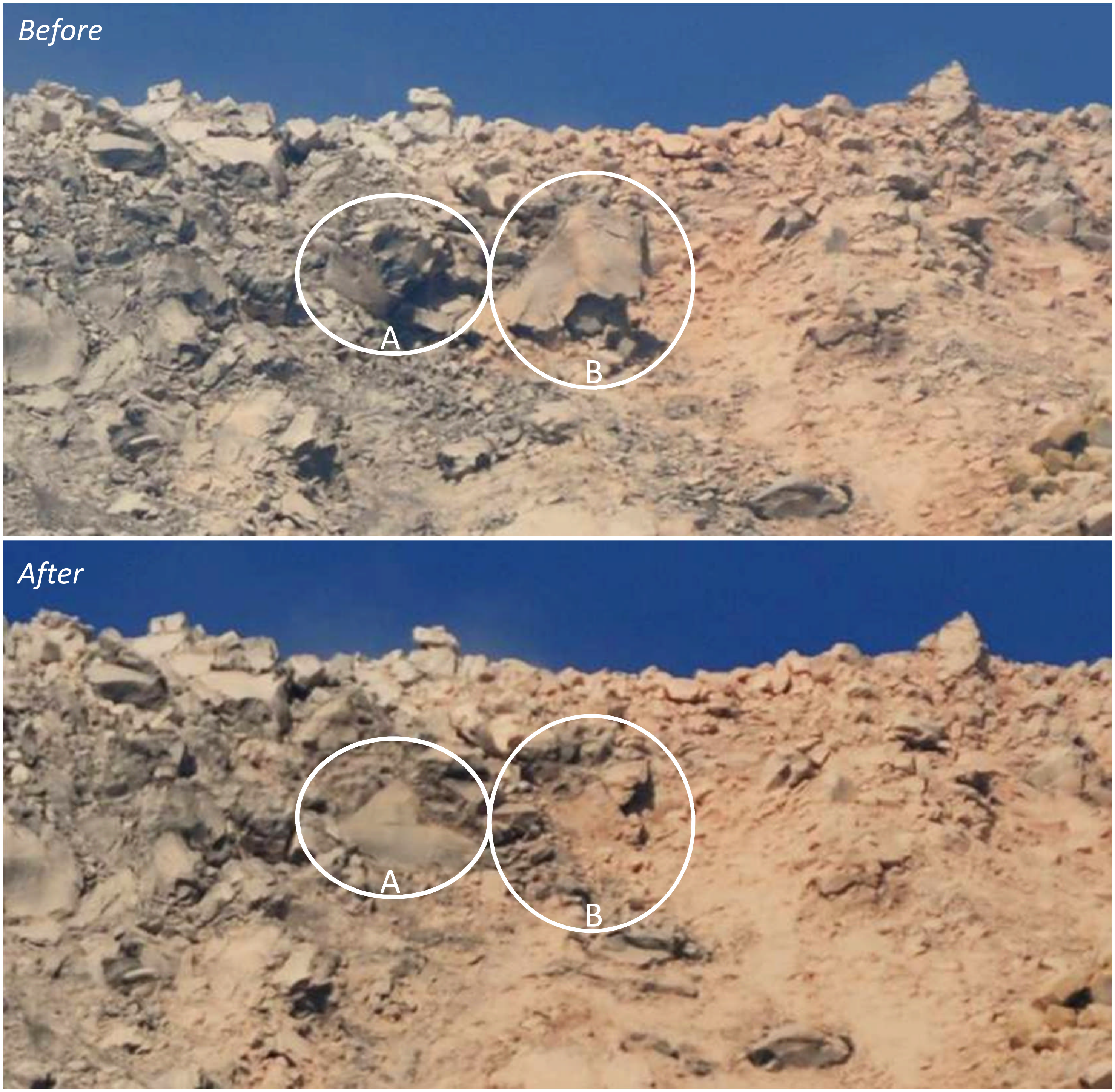
- Dome is offset to W
- Rockfalls and unloading of this part of dome reestablished growth mechanism
- New lobe formed in 2010
- Dome growth stopped
- Fresh material - rockfalls

Infrared images of rockfalls

- Estimate volume from heat flux from slope
- Investigate heating of dome before rockfall
- Relationship with explosions







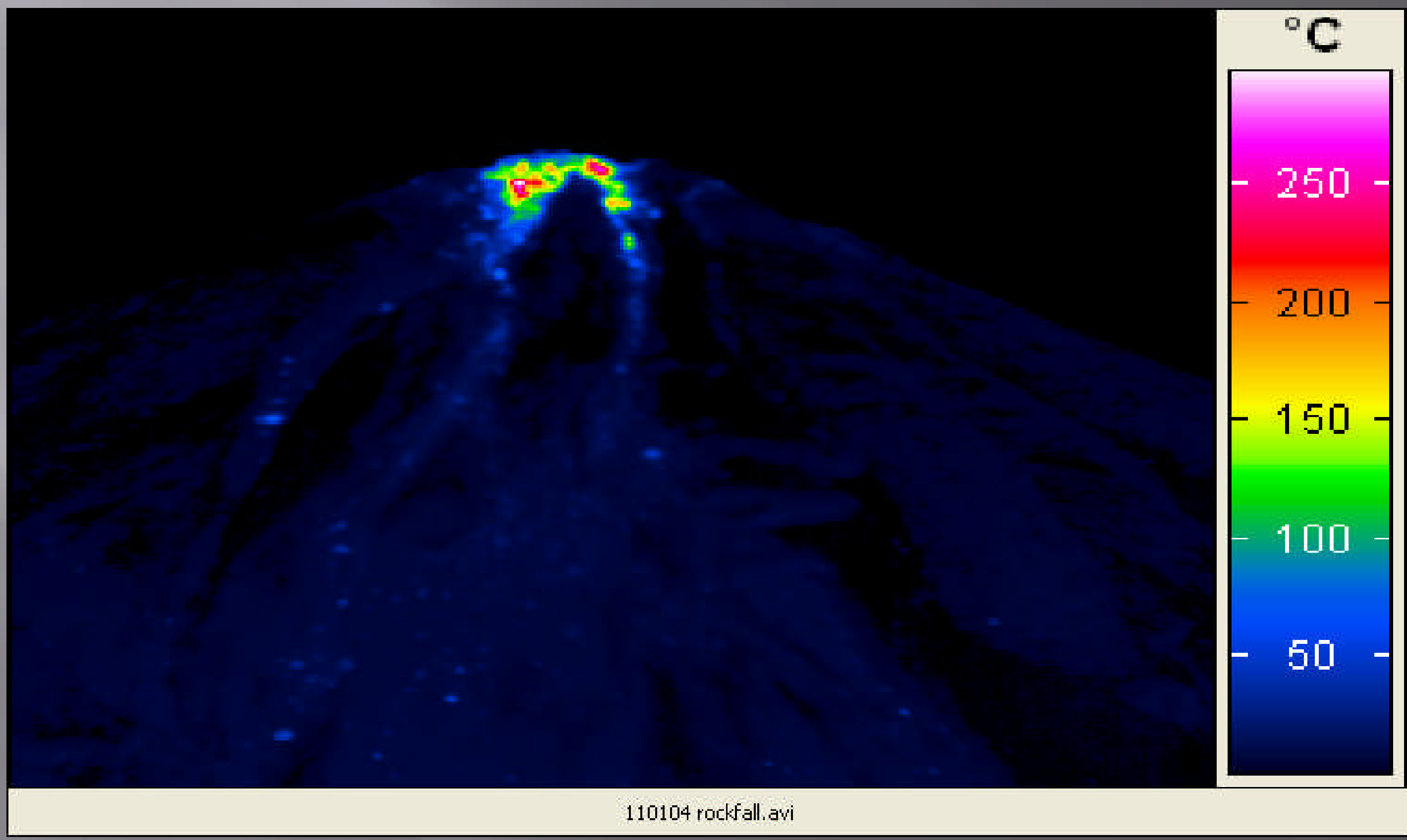
Rockfall quantification

26.05.2010
Rockfall
17:42 – 17:48

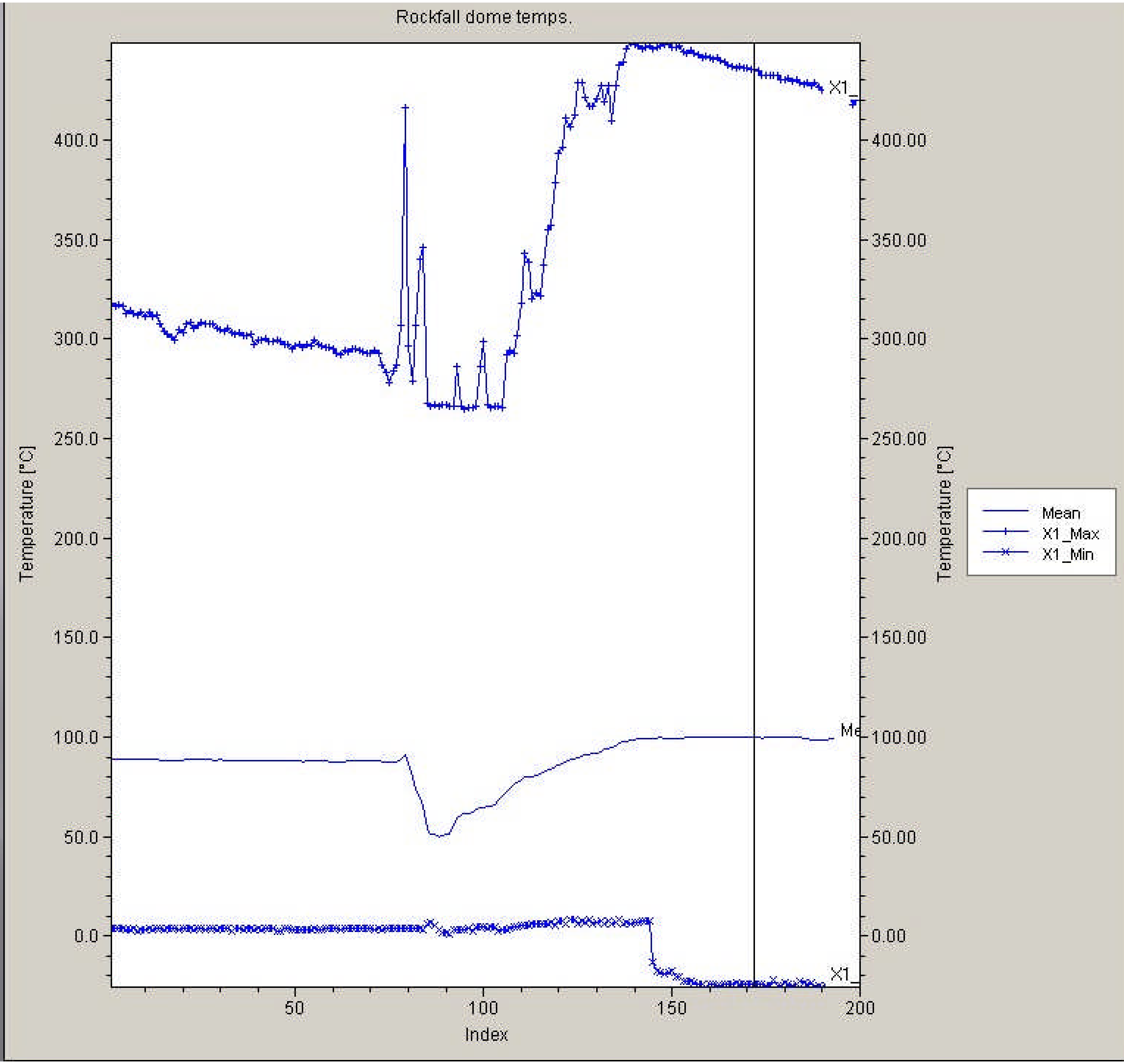
- A = 250 m^3
- B = 558 m^3

- Comparison with seismic signal
- Quantify volumes lost

04 Jan. 2011 - rockfall



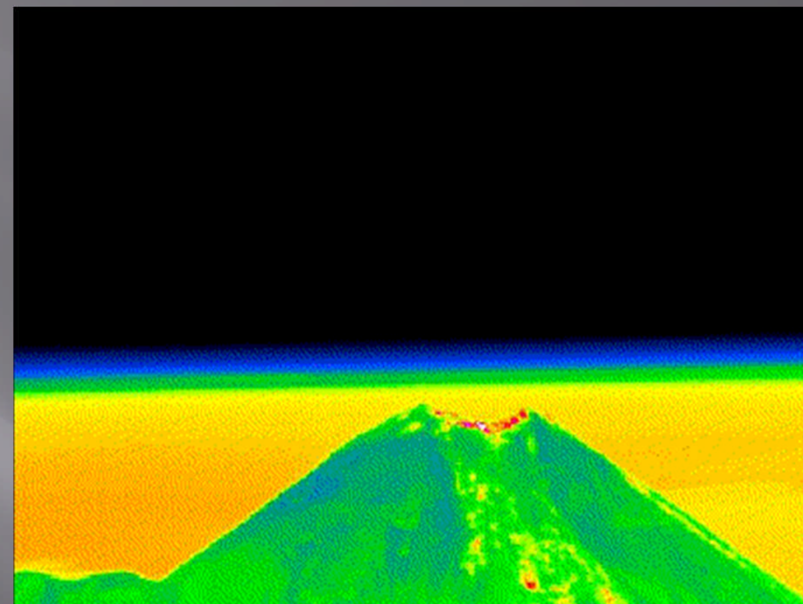
Video clip

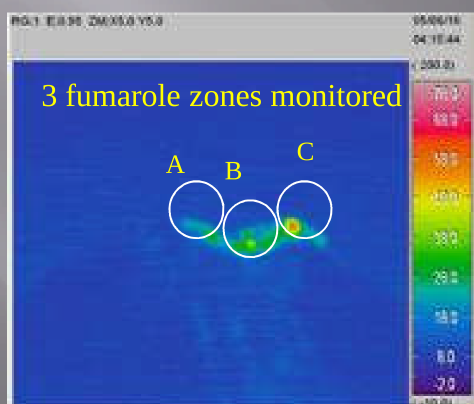


Rockfall dome temps.
Temperature [°C]
Index
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
50
100
150
200
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Mean
X1_Max
X1_Min

Explosion monitoring

VarioCAM infrared camera 8 – 13.5 μm



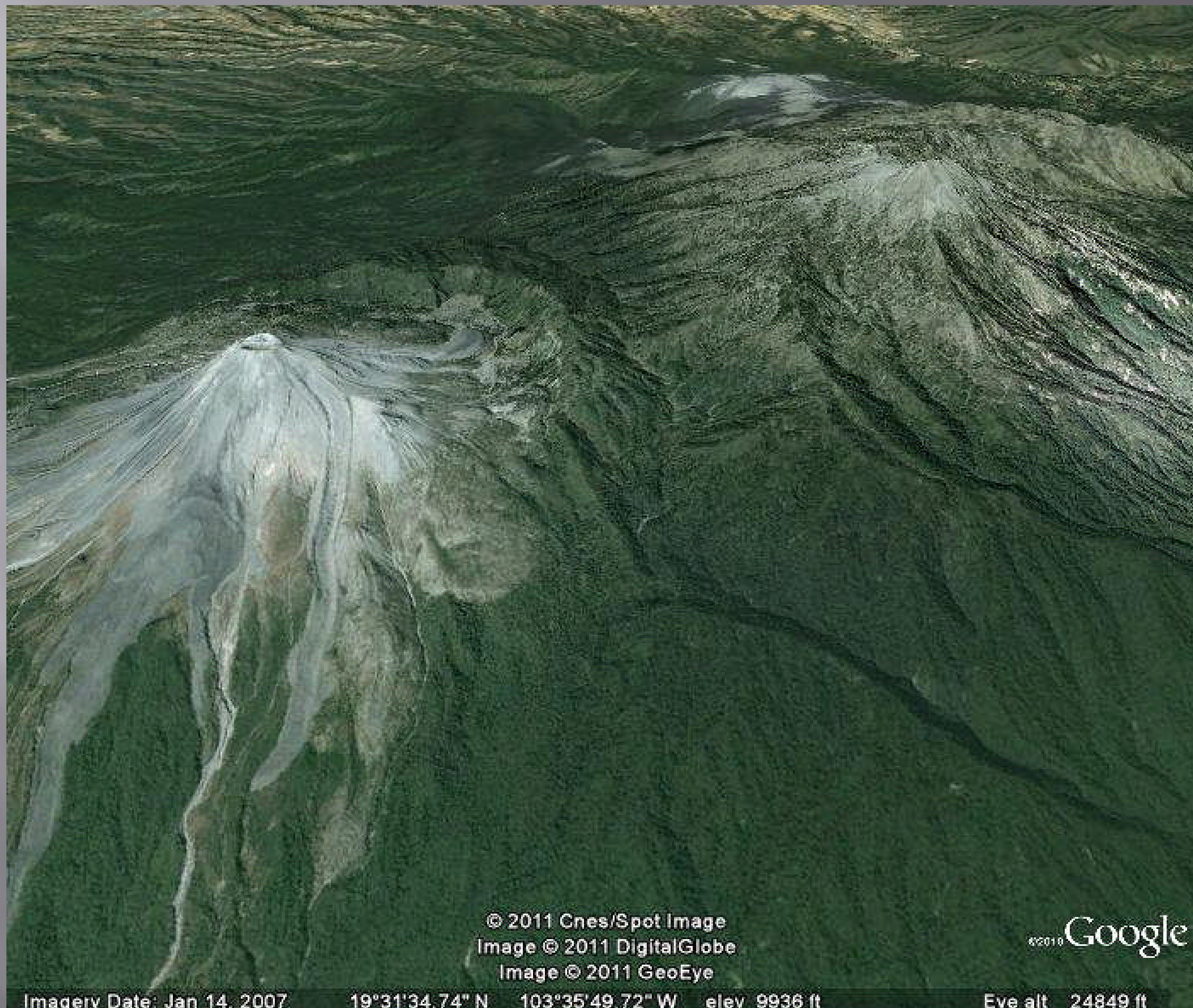


Fumarole temperatures monitored

-Looking for long-term trends

-Short-term relationship with explosions

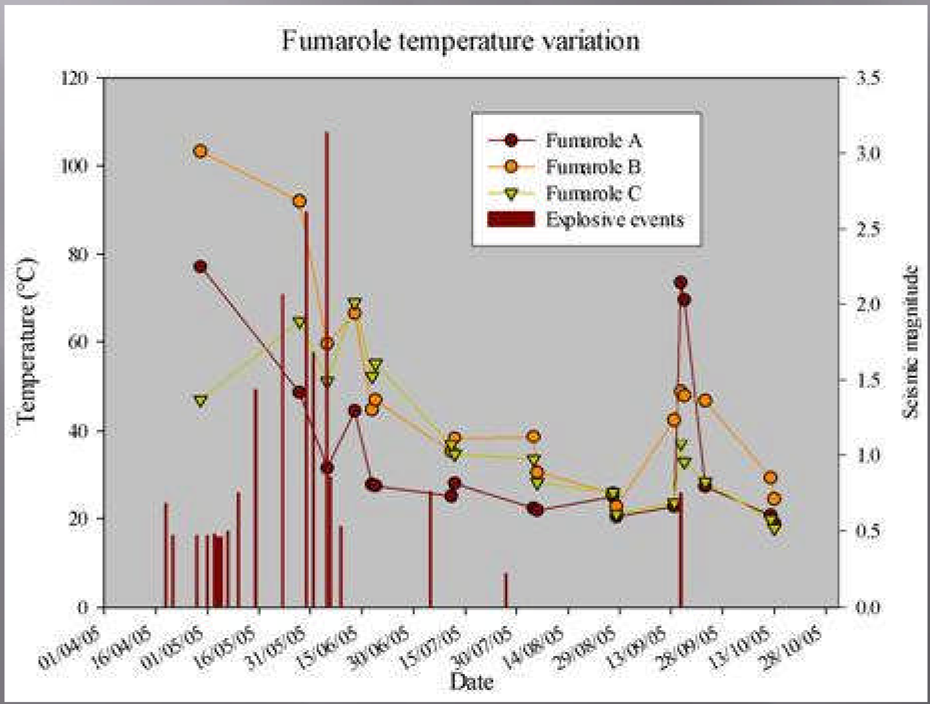
Stevenson, J.A., and N. Varley, Fumarole monitoring with a handheld infrared camera: Volcán de Colima, Mexico, 2006-2007, *Journal of Volcanology and Geothermal Research*, *177* (4), 911-924, 2008.

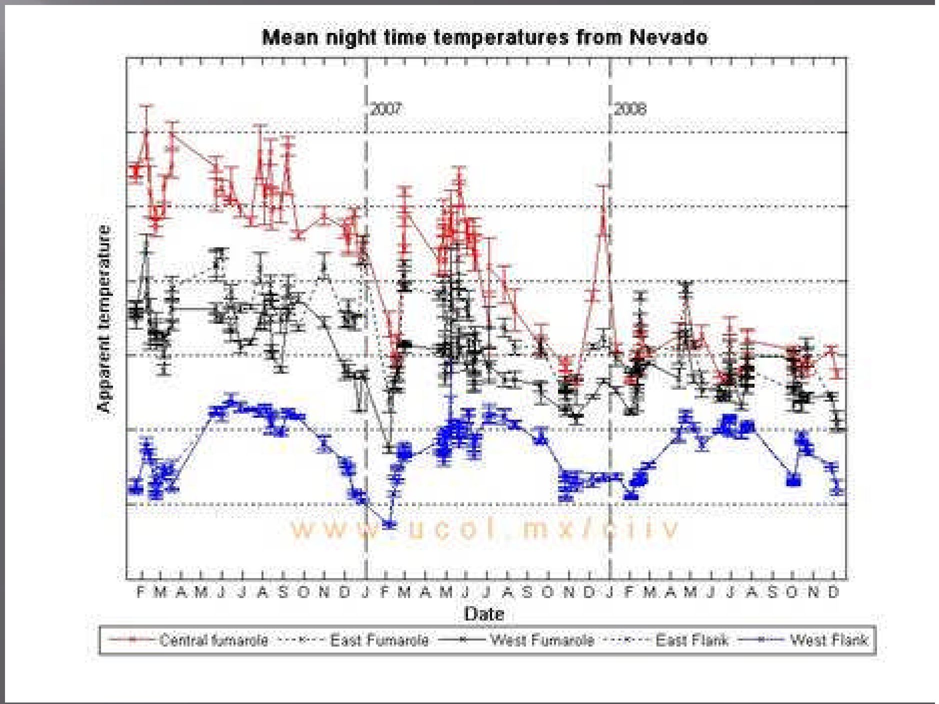


Viewing platform on Nevado de Colima

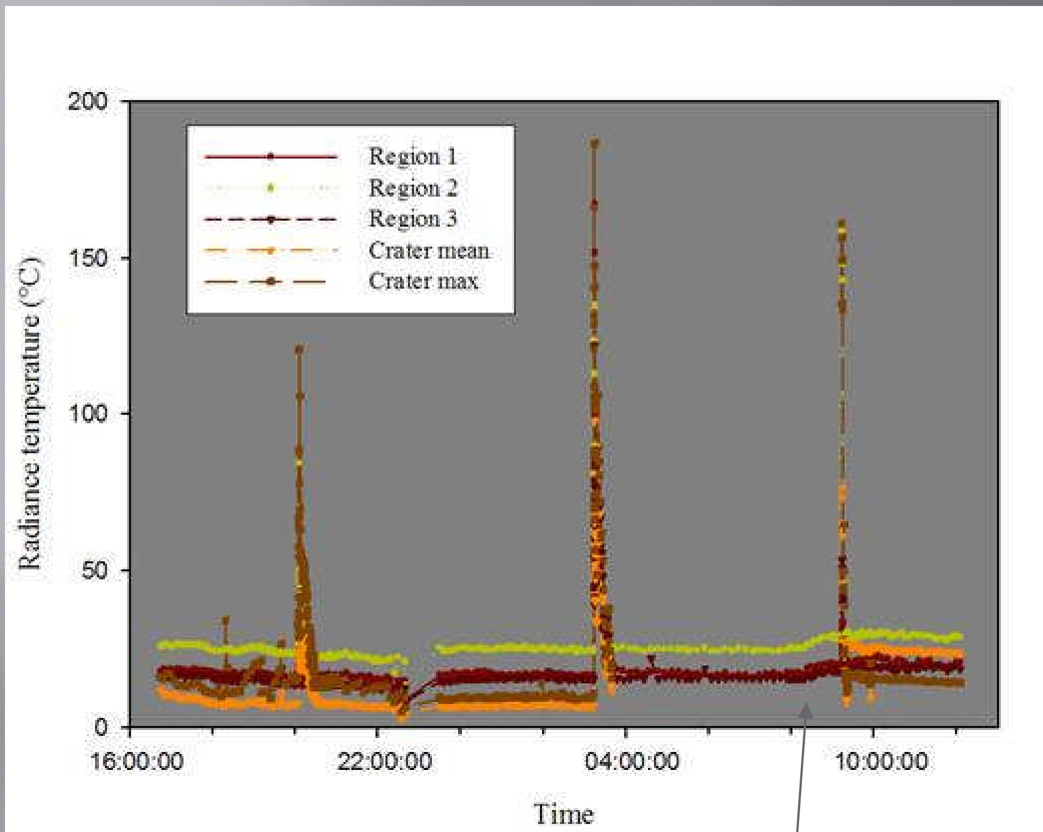
Remote sensing of fumaroles

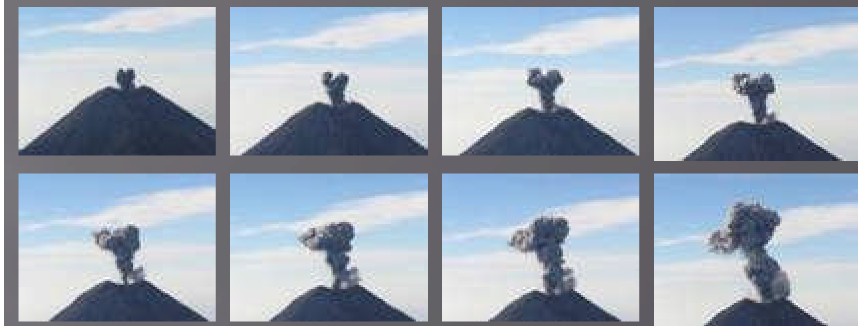
- Decreasing tendency during 2005-2007; 2008 onwards fairly constant
- Negative anomaly prior to 5 June event
- Temperature increases and decreases related to explosions
- Relatively large pixel size and large distance for atmospheric effects but sufficiently sensitive to detect small variations

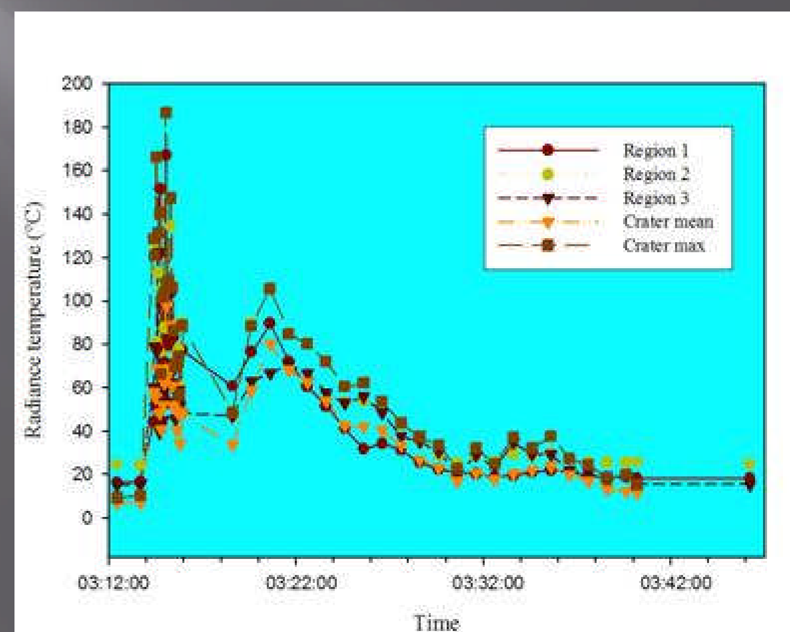




Variation in fumarole temperature

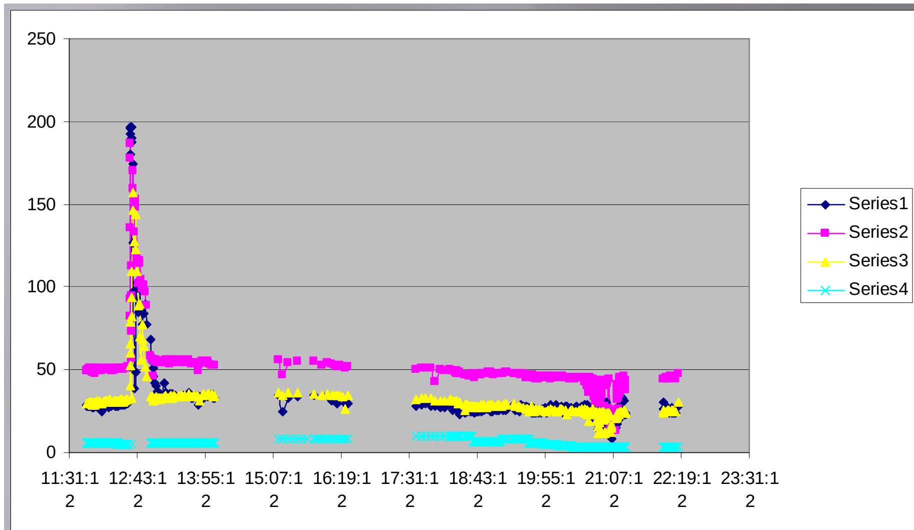






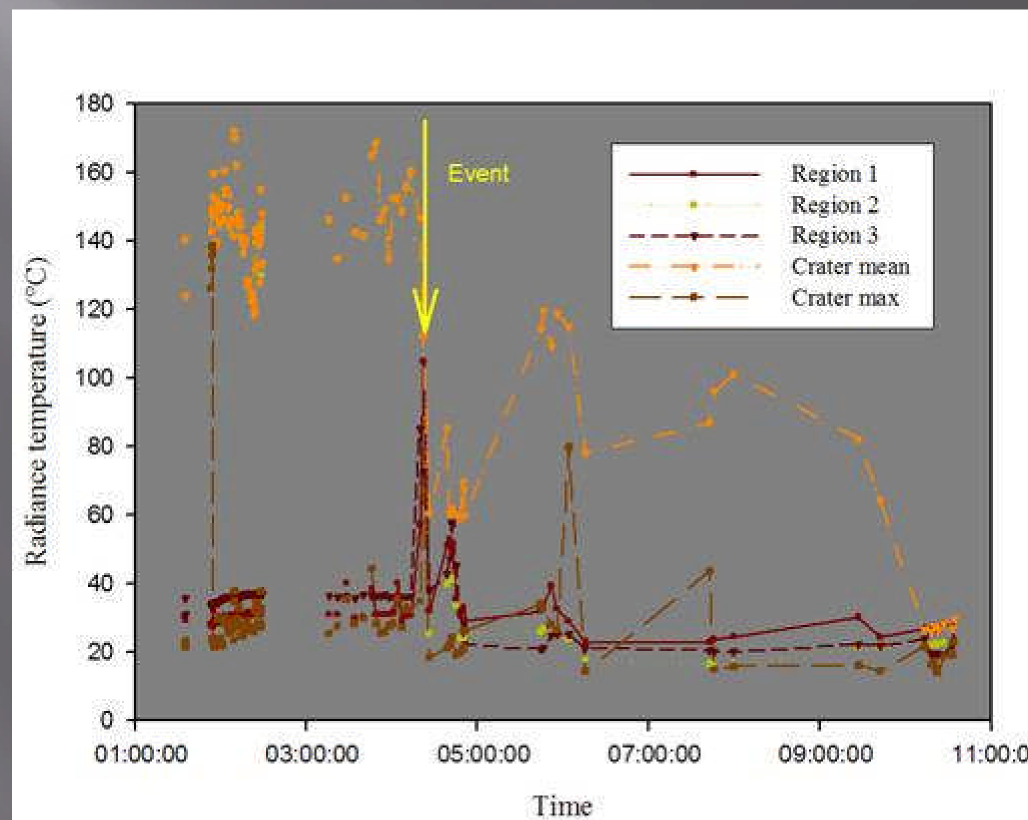
19 - 20 Nov. 2005

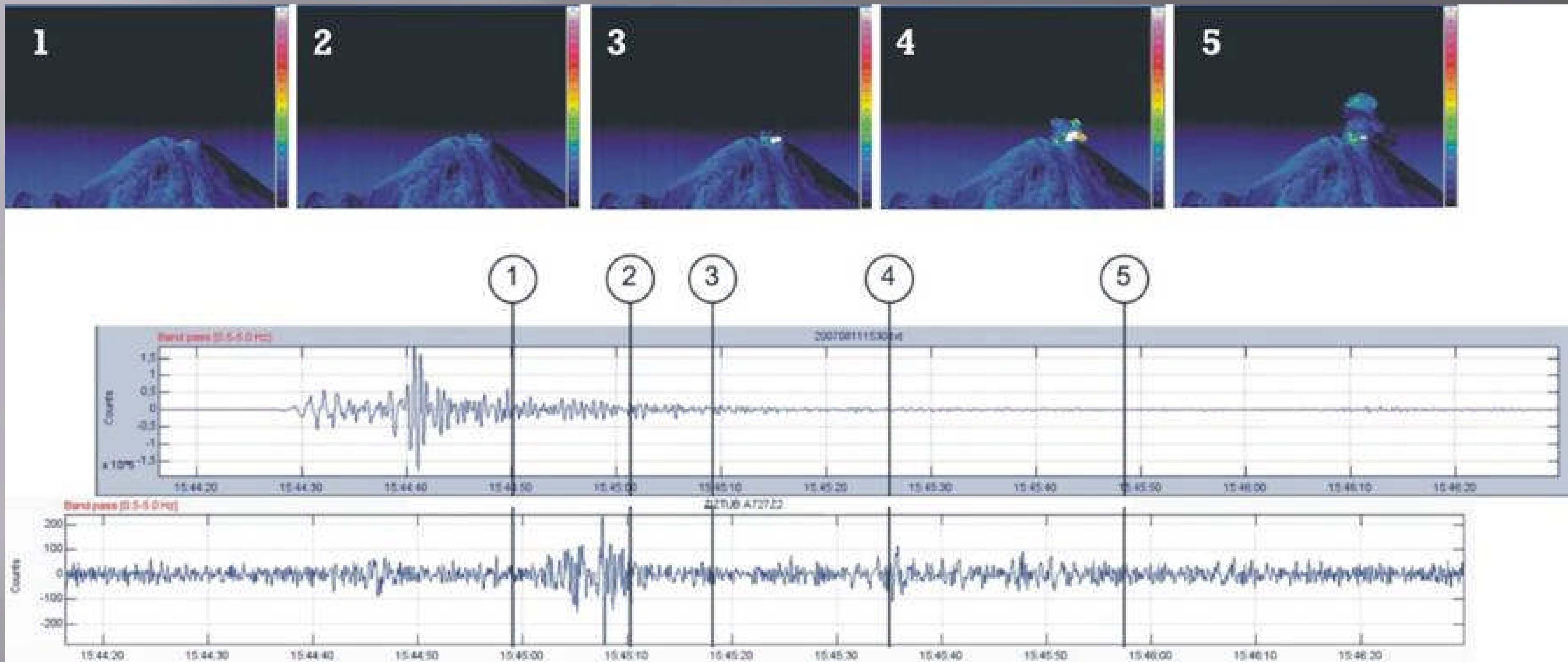
Increase in T prior to explosion



Large event of 23 Sept. – prior heating & subsequent cooling over several days

Large event of 27 July – large heating prior to event, then cooling





Explosion 11/08/07

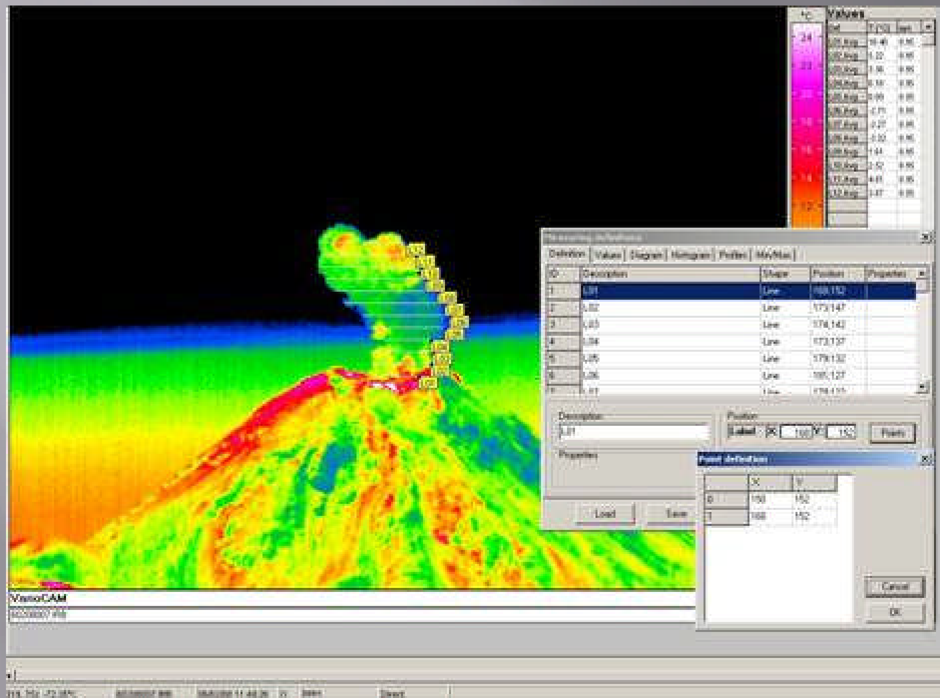
2nd pulse produces acoustic emission but no seismicity detected

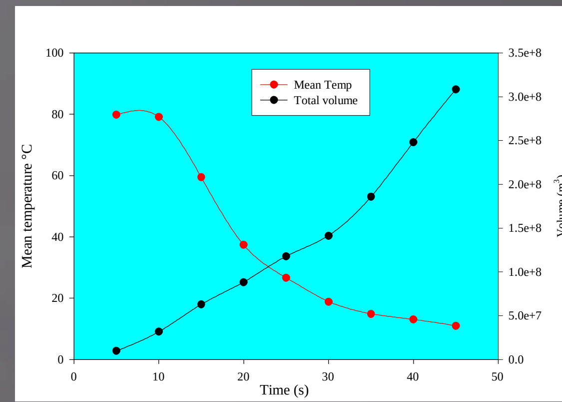
2 sources shown in thermal images – one rich in ash, the other poor

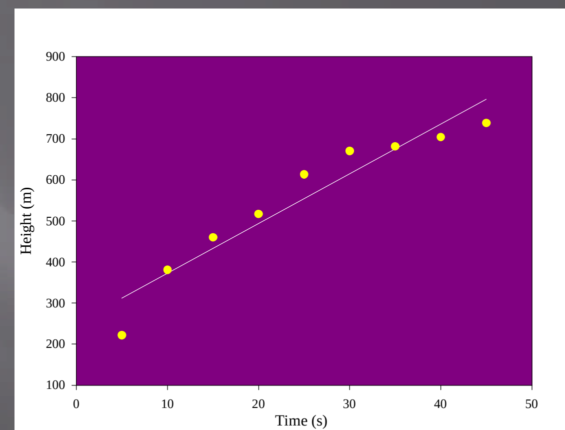
Infrared images

- Calculation of heat flux
- Thermal expansion, air entrainment process
- Influence of ash particle fraction

Column processes





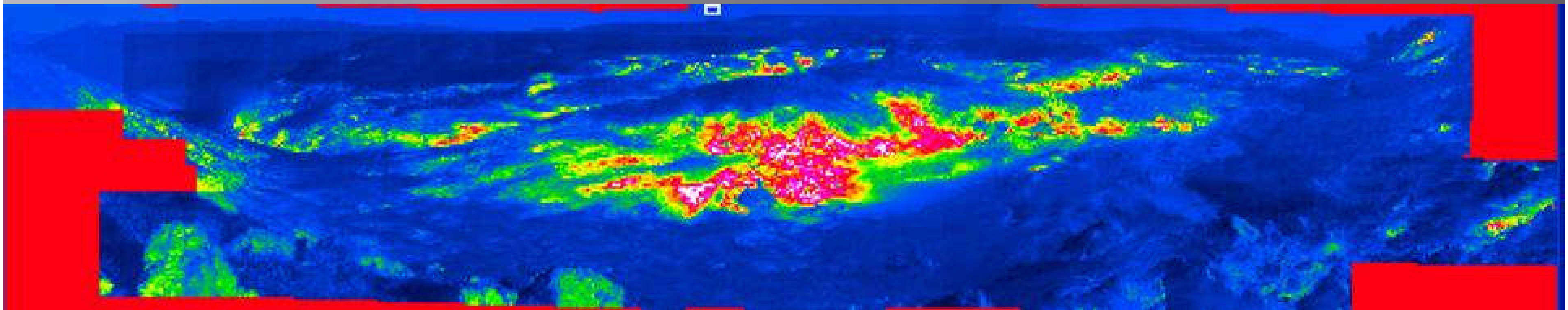


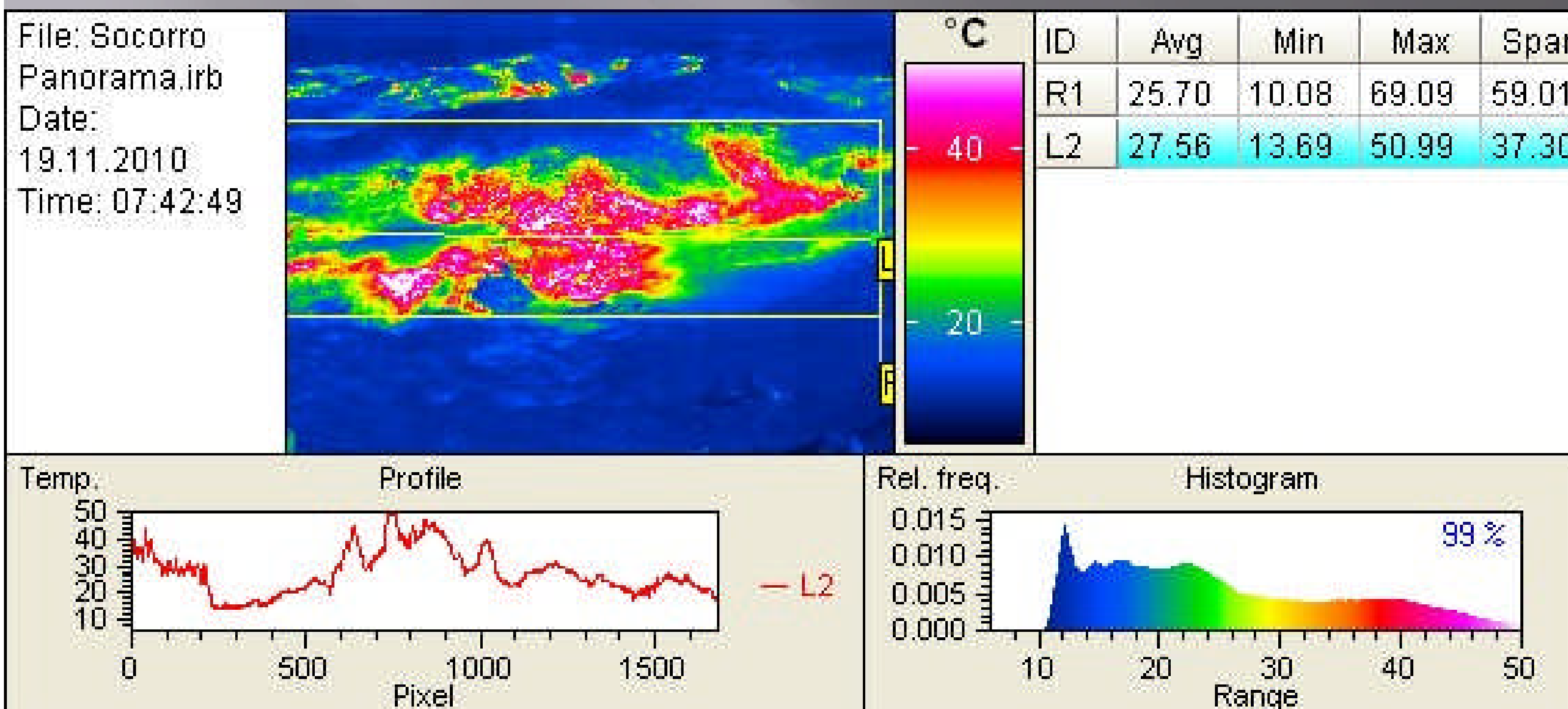
10 March 2006 15:54



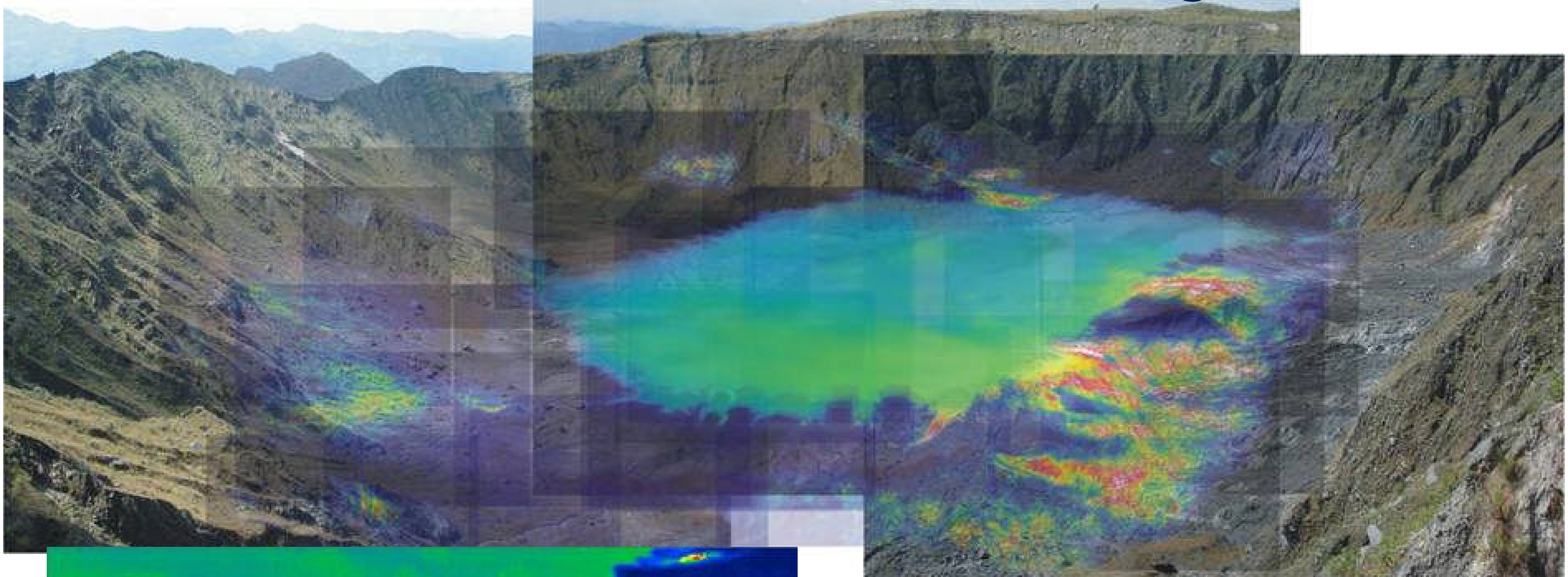


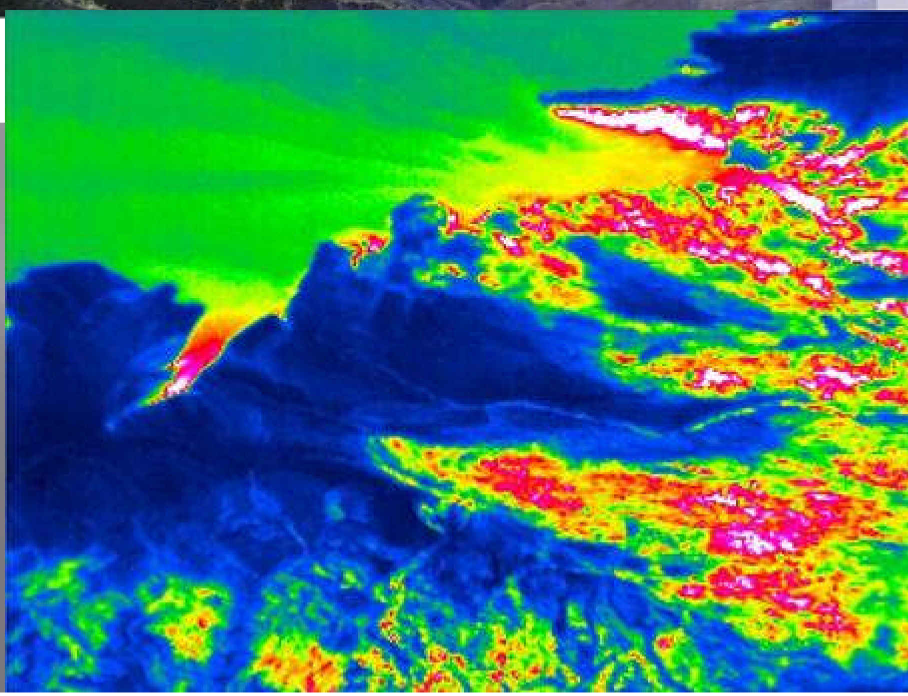

Isla Socorro - Study of active dome




File: Socorro Panorama.irb
Date: 19.11.2010
Time: 07:42:49
°C
40
20
ID | Avg | Min | Max | Span
R1 | 25.70 | 10.08 | 69.09 | 59.01
L2 | 27.56 | 13.69 | 50.99 | 37.30
Temp.
Profile
Pixel
L2
Rel. freq.
Histogram
99 %
Range

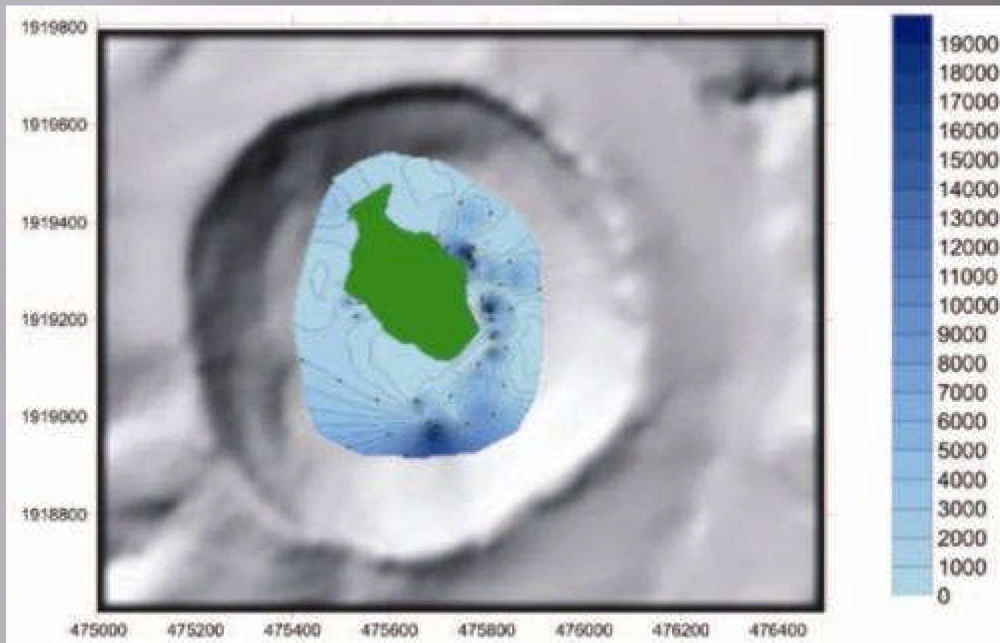
Crater Lake monitoring





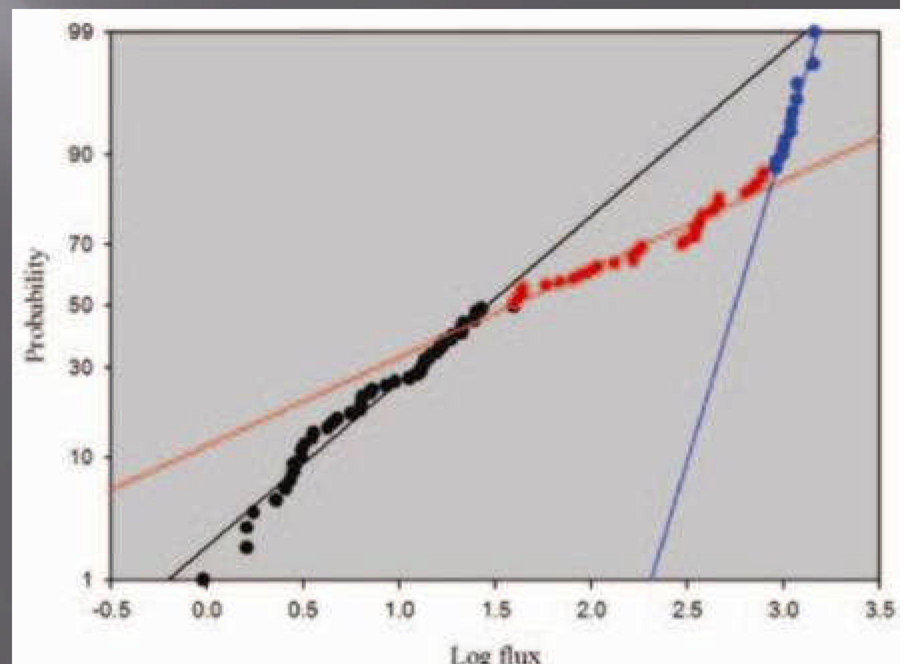
El Chichón, Mexico

Gas emission from sides and beneath lake

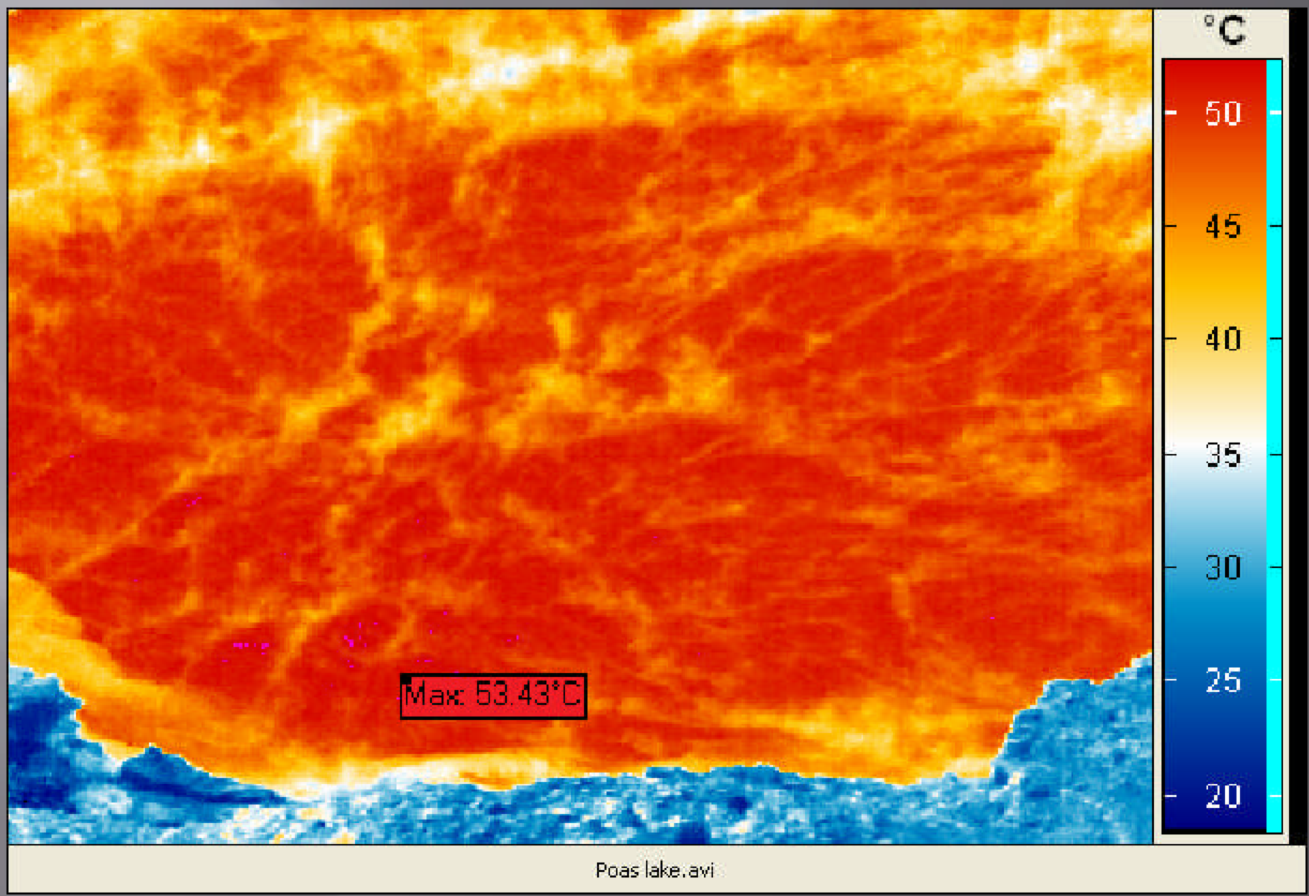


CO_2 flux survey

- Survey carried out of crater floor
- Emissions related to deep processes
- Controlled by geological structure
- 3 populations on cumulative flux plot



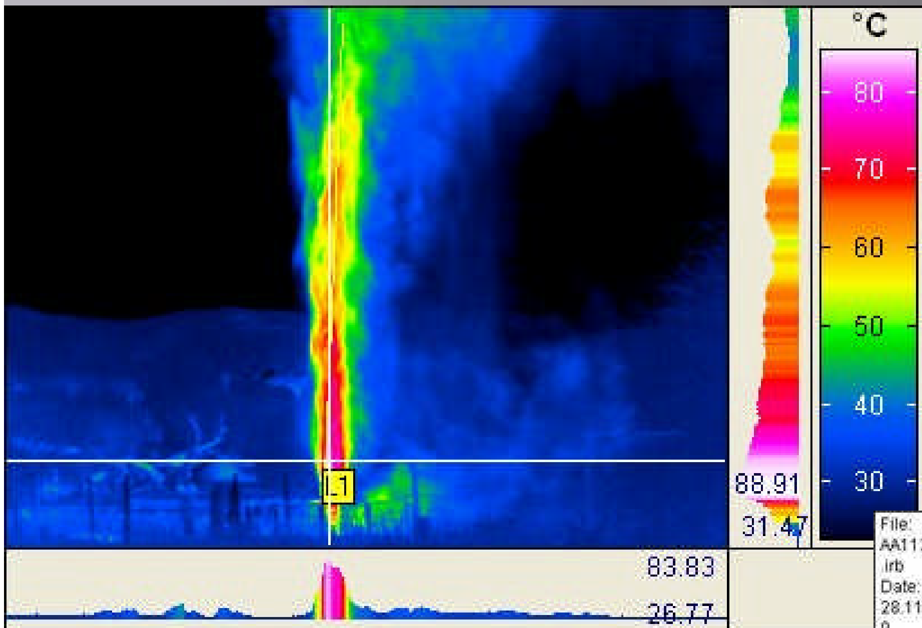
Poás, Costa Rica

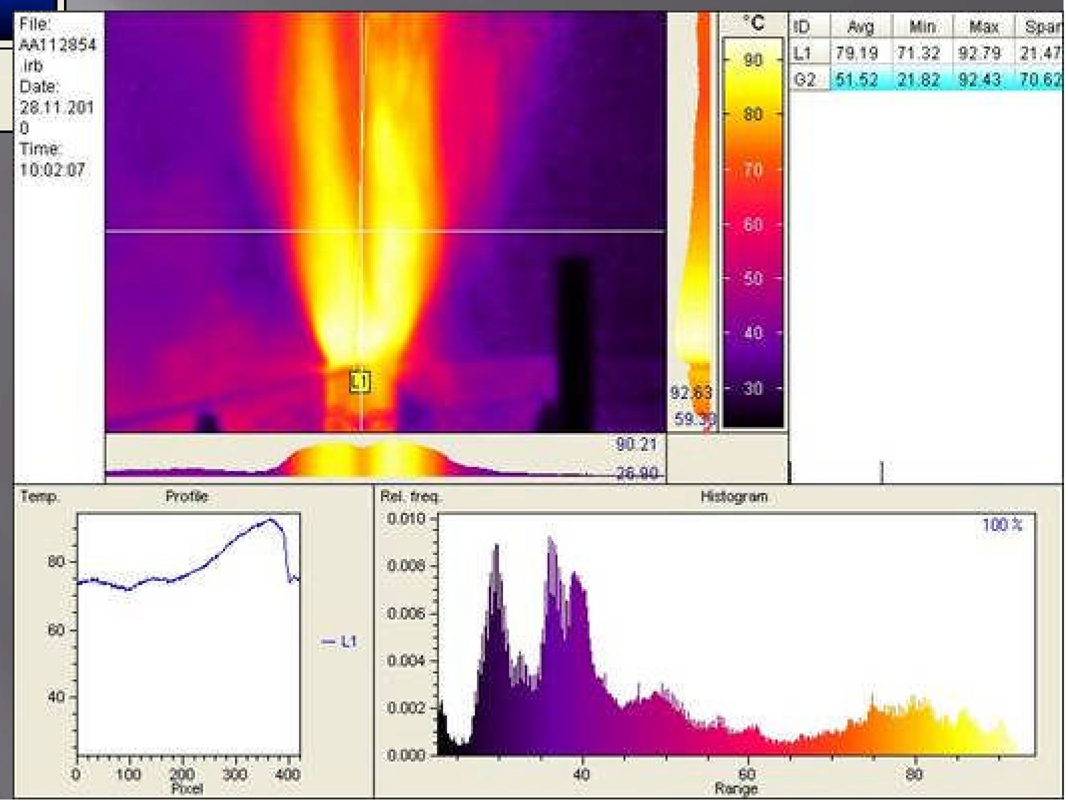


Convection within crater lake

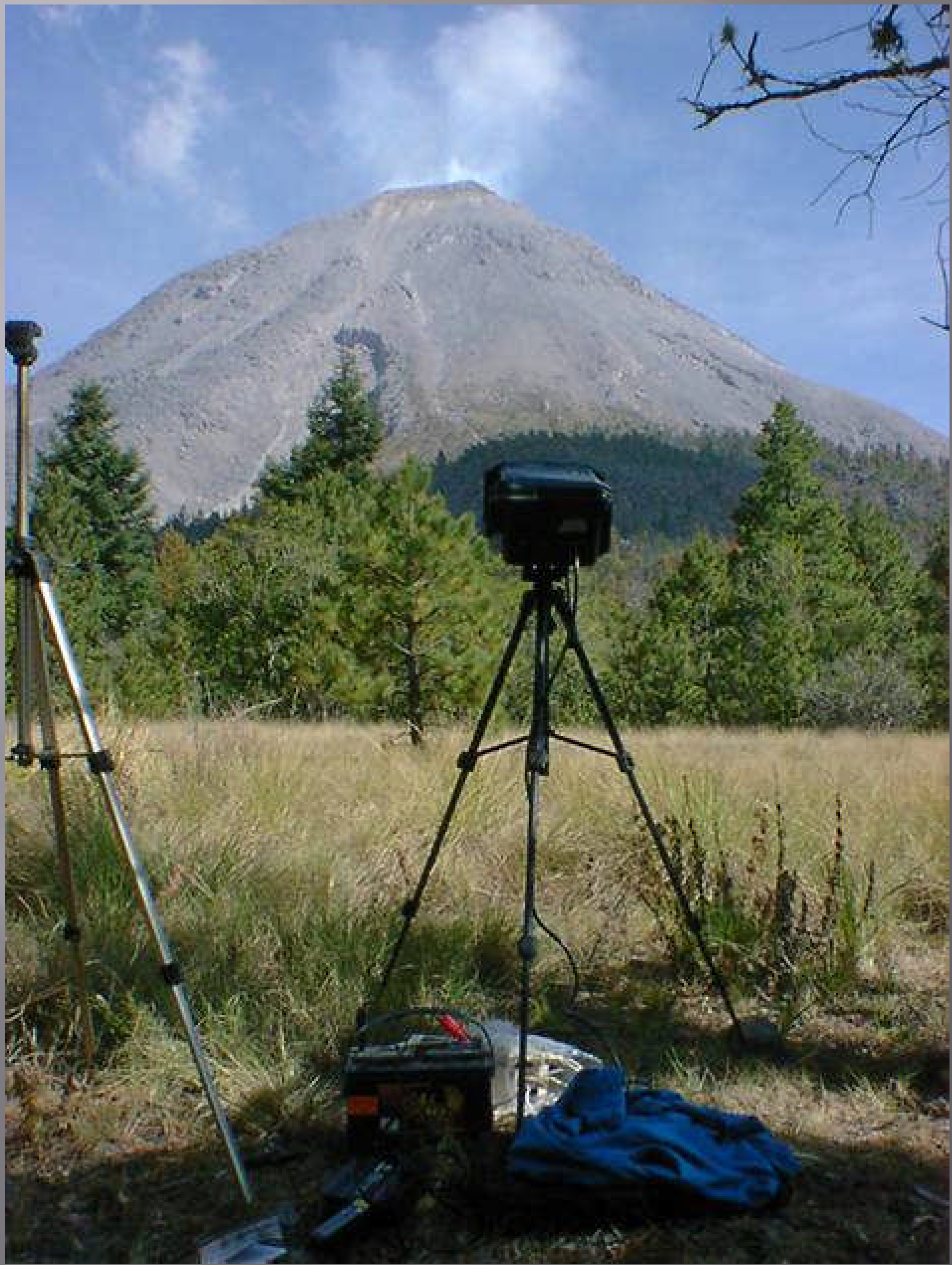
Video clip

Geyser – Ixtlán de los Hervores





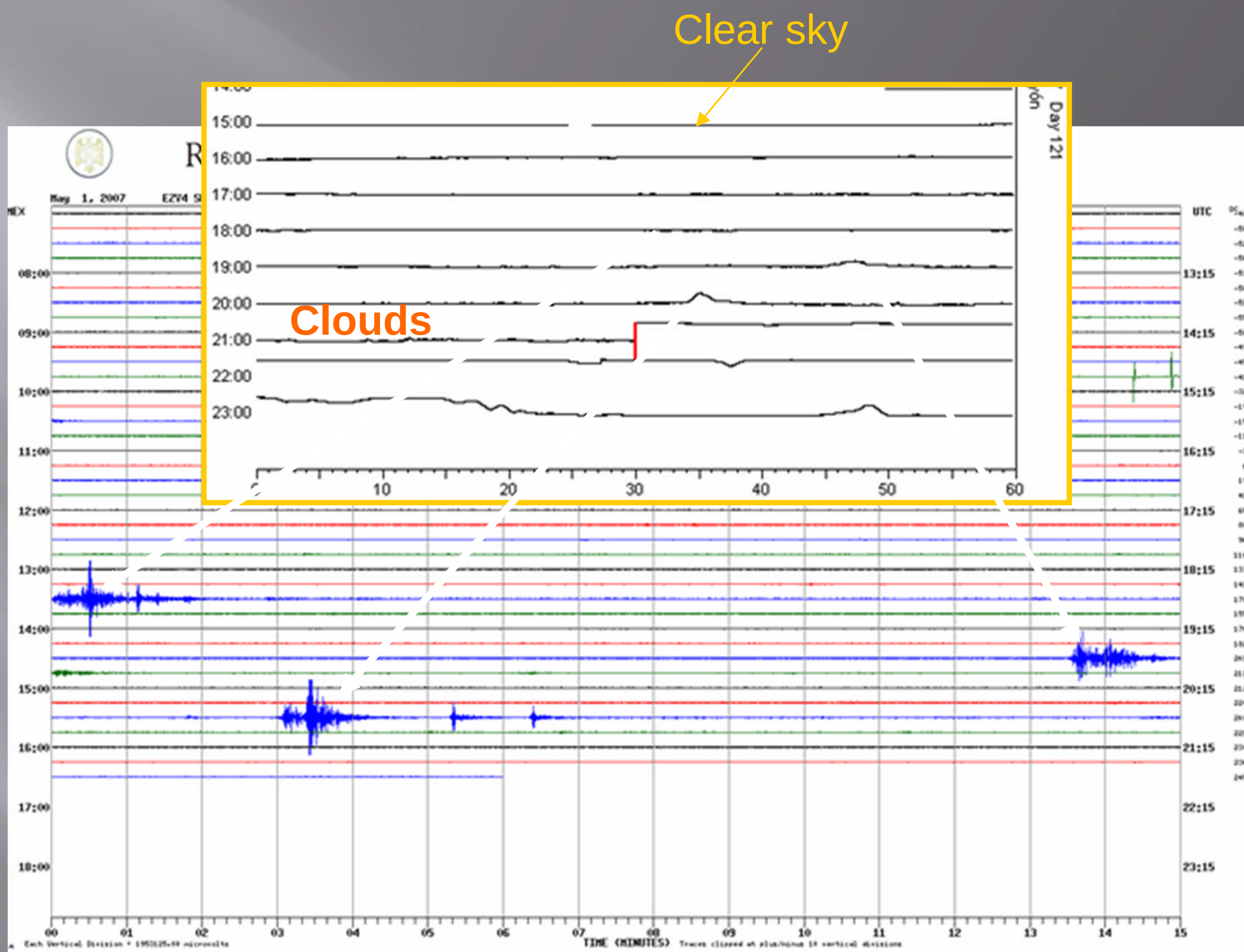
THERMAL SENSORS - RADIOMETERS



- Permanent real-time monitoring system

Possible to calculate
- Ascent velocity
- Gas flux
- Characterize event

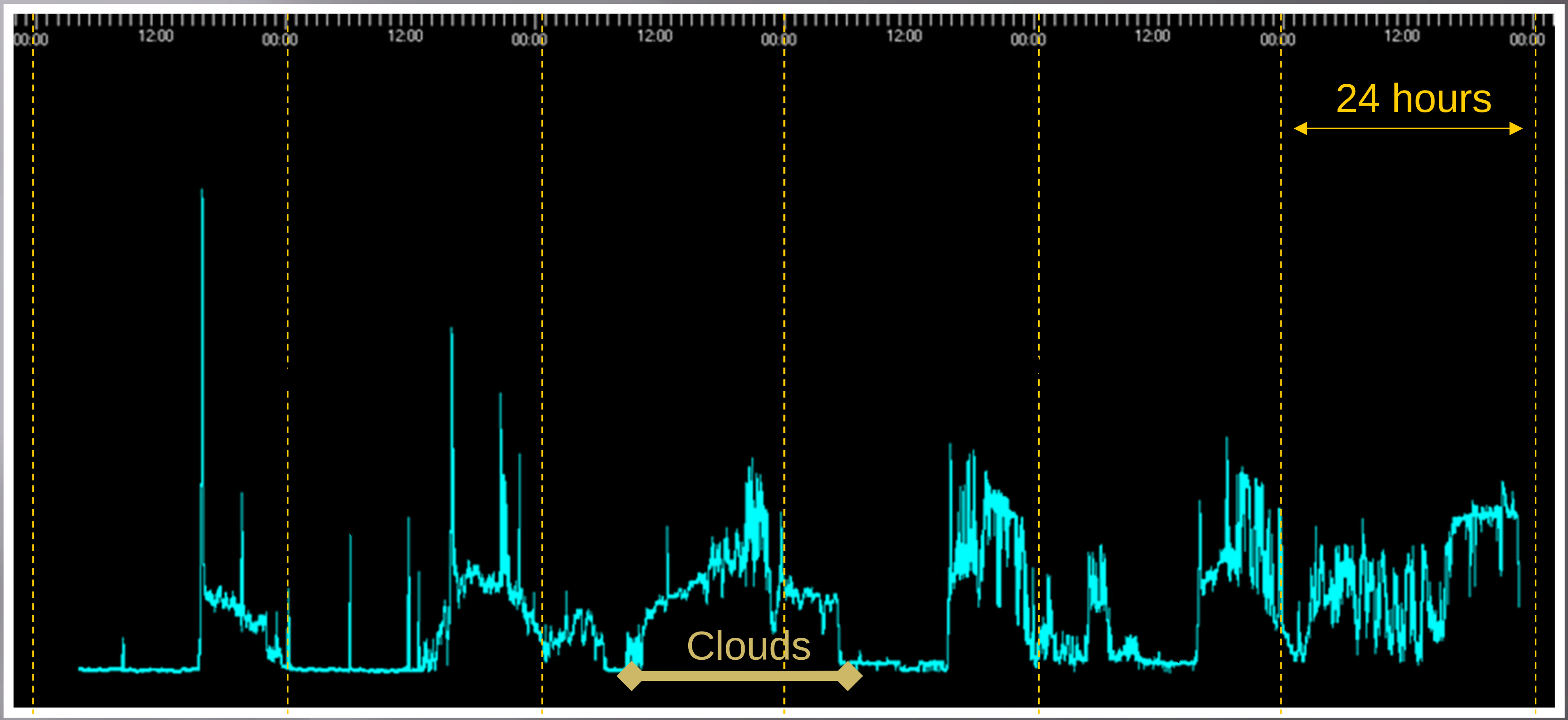
Combined with seismic/infrasound data
- Depth of the explosion



Real time monitoring system

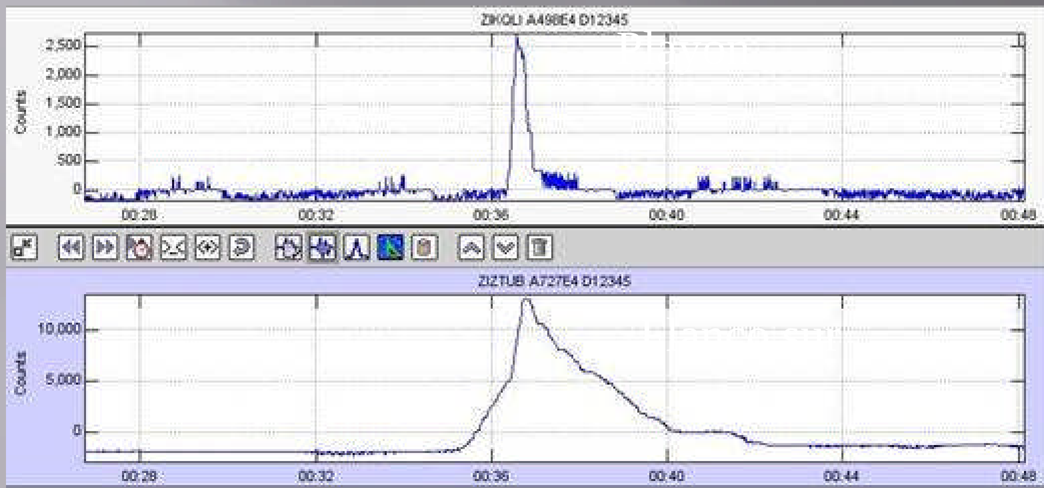
- comparison with seismic data

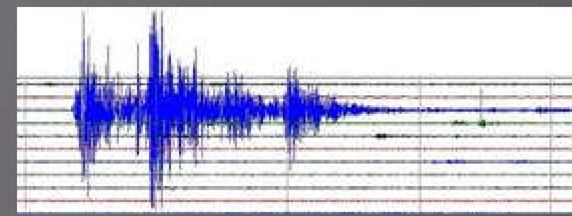
Radiometer data



- Relationship between seismicity and explosion column temperature is not straightforward
- Influenced by
  - Variation in ash-contents – difficult to quantify
  - Cooling from air entrainment
  - Source depth
  - Energy release characteristics – impulsive or emergent, pulses, multiple vents

Comparing thermal emission of explosion column with seismicity





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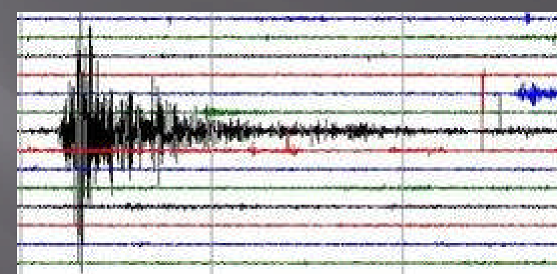

03/08/07 12:03

‘Cold’ gas releases occur but also hot puffs with no seismicity