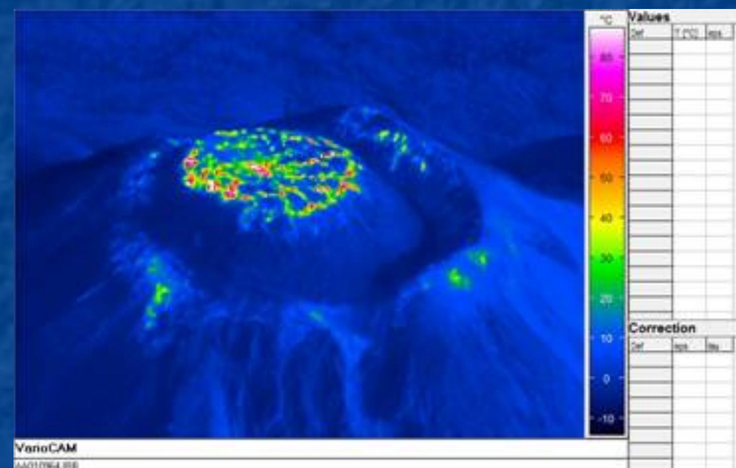
Universidad de Colima

Centro de Intercambio y Investigación en Vulcanología

Thermal monitoring at Volcán de Colima, Mexico



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John Stevenson

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Recent activity

- Current episode 12 years
- Transition between styles
- 4 periods of dome growth
- Since 2003, Vulcanian explosions (4 – 25 per day)

Explosions originating from dome e.g. 10 Jan 2010 – usually little ash

Cyclicity

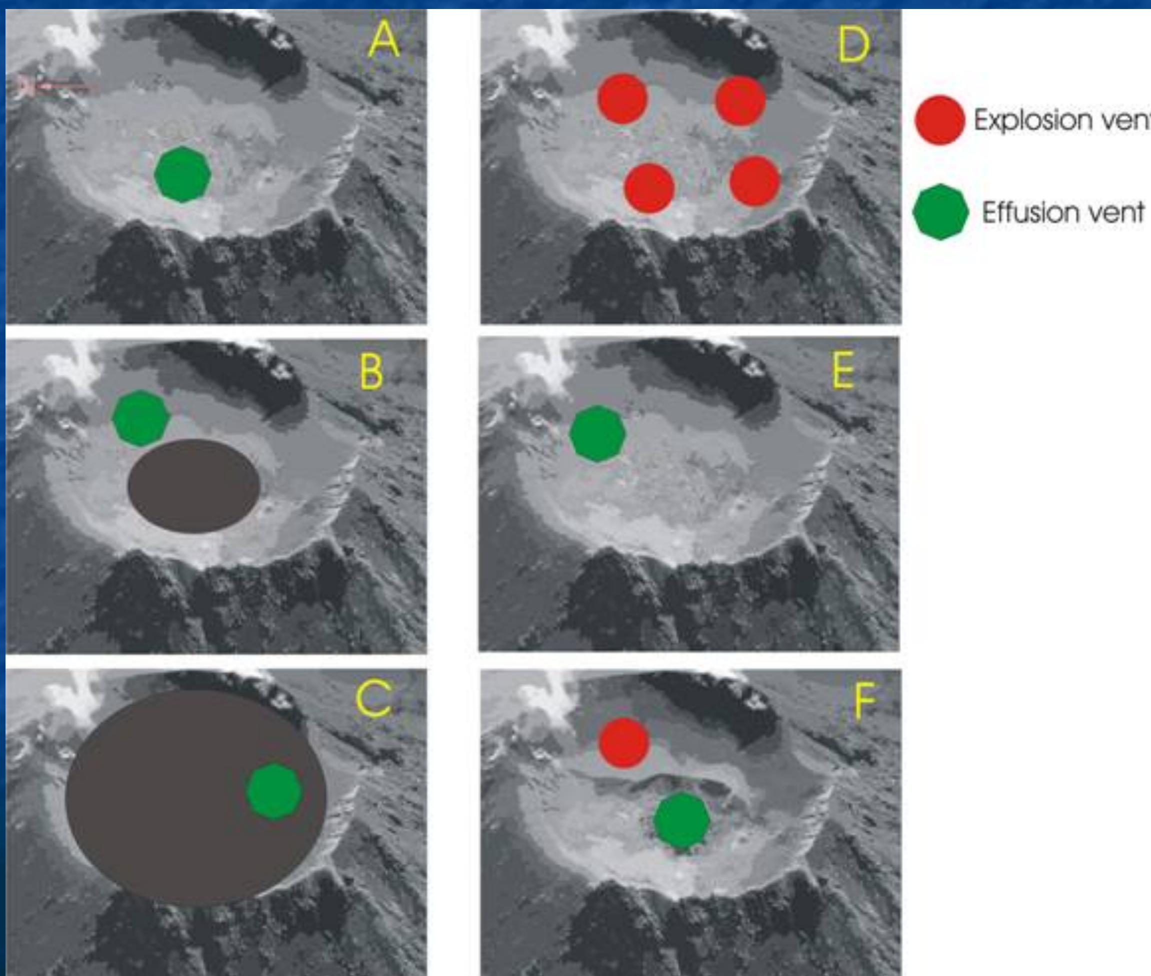
- 100 year – Plinian eruptions
  - Increase in volatiles (1 → 5% water)
- 2 – 5 year – Effusive episode & dome destruction
  - Driving ?
- 2 – 6 hours – Vulcanian explosions
  - Rapid sealing of conduit (decrease in gas flux)

Variable effusion rate & volatile-content

- **1998-9 fast effusion; 2.5 months**
- **2001-3 slow; 22 months**
- **2004 fast; 2.5 months**
- **2007-9 slow; 35 months +**

Multiple vent system

- Explosive pulses from different vents
- Effusion from different vents
- 2005 – simultaneous effusion & Vulcanian/Strombolian activity



A, B dome growth in 2001

C Pulse in effusion rate, Nov. 2002

D Explosive activity 2003 – 6

E 2004 dome growth

F Current dome growth

Thermal Monitoring

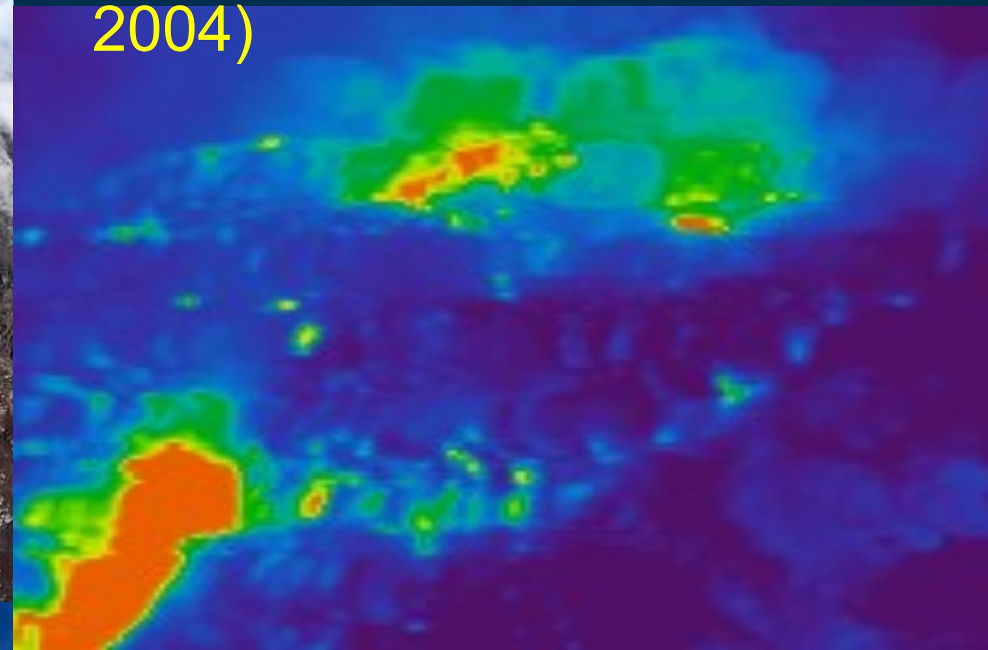
- Passive activity
  - Remote sensing of fumarole temps.
- Effusive activity
  - Characteristics of dome growth – mechanism of emplacement
  - Calculation of effusion rate
- Explosive activity
  - Characteristics – depth of source, ash contents
  - Air entrainment process
  - Real-time monitoring with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

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)

Dome growth (16 Oct. 2004)

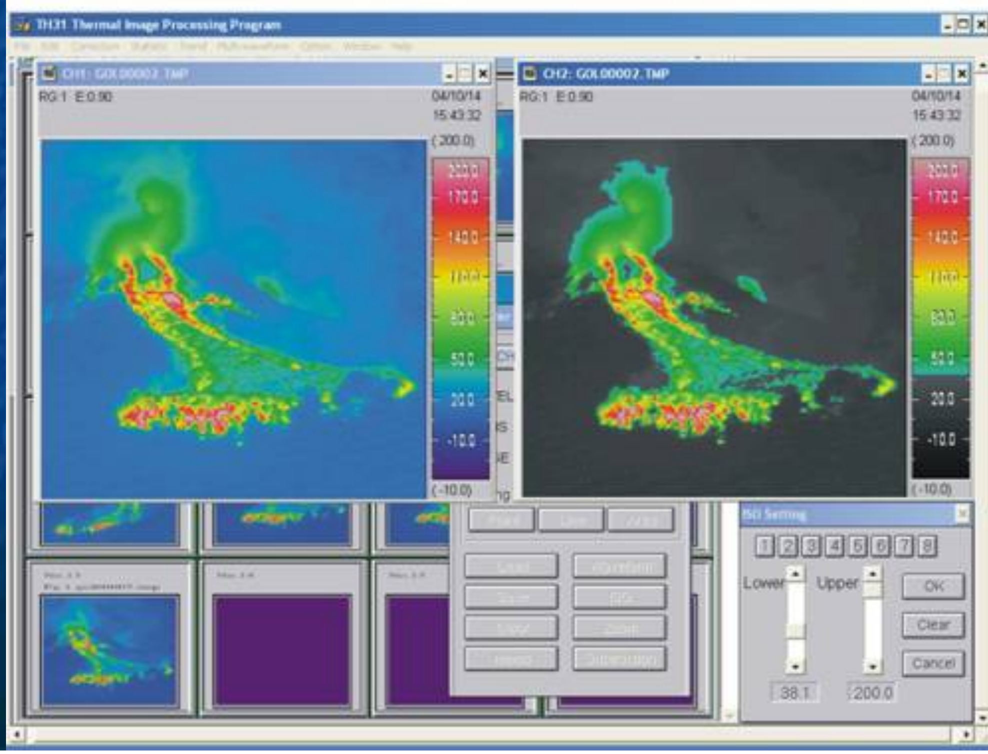


Much lower SO_2 flux compared to 1998-9 although similar effusion rate

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

Infrared – 3 effusion centres, E fracture

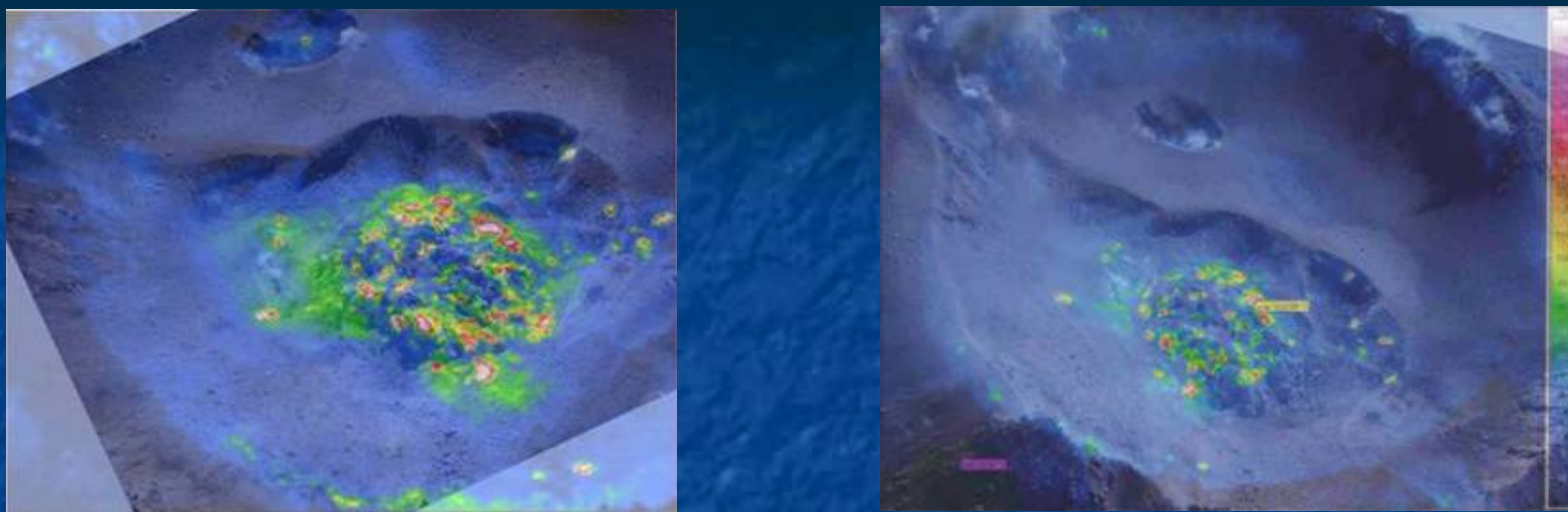
NEC camera 1.5 – 3 µm



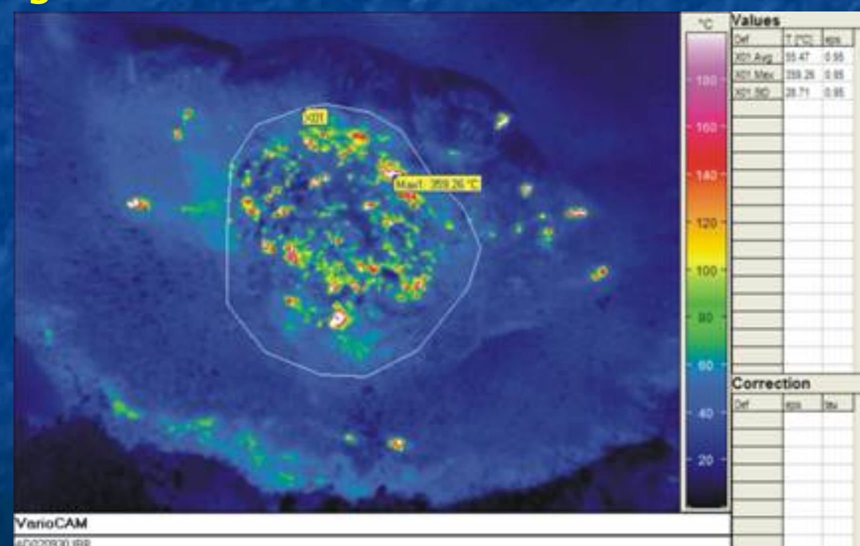
Calculation of effusion rate

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

Current eruption – started Jan. 2007



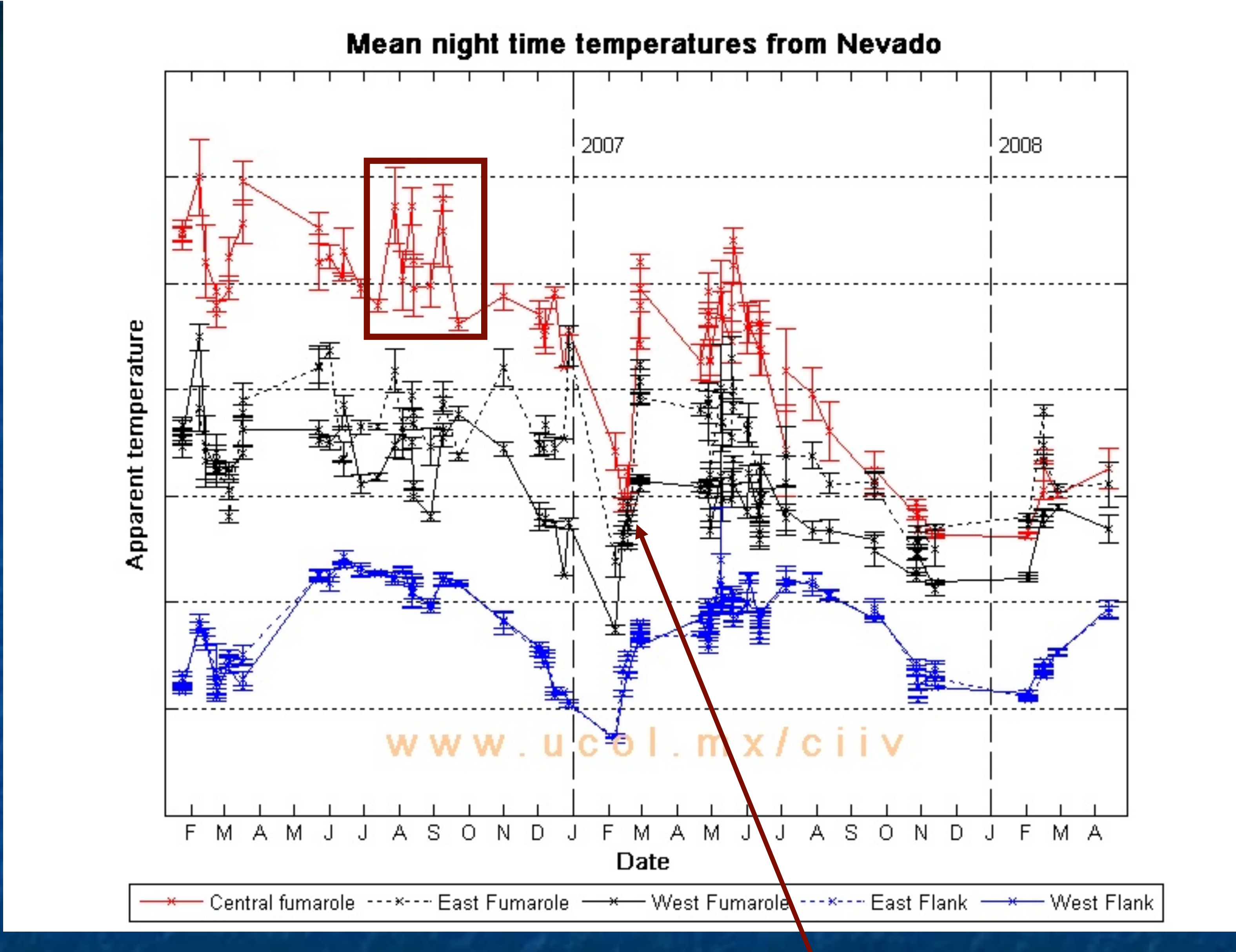
Superimposed thermal and visual images of dome on 9 Feb. 2007



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

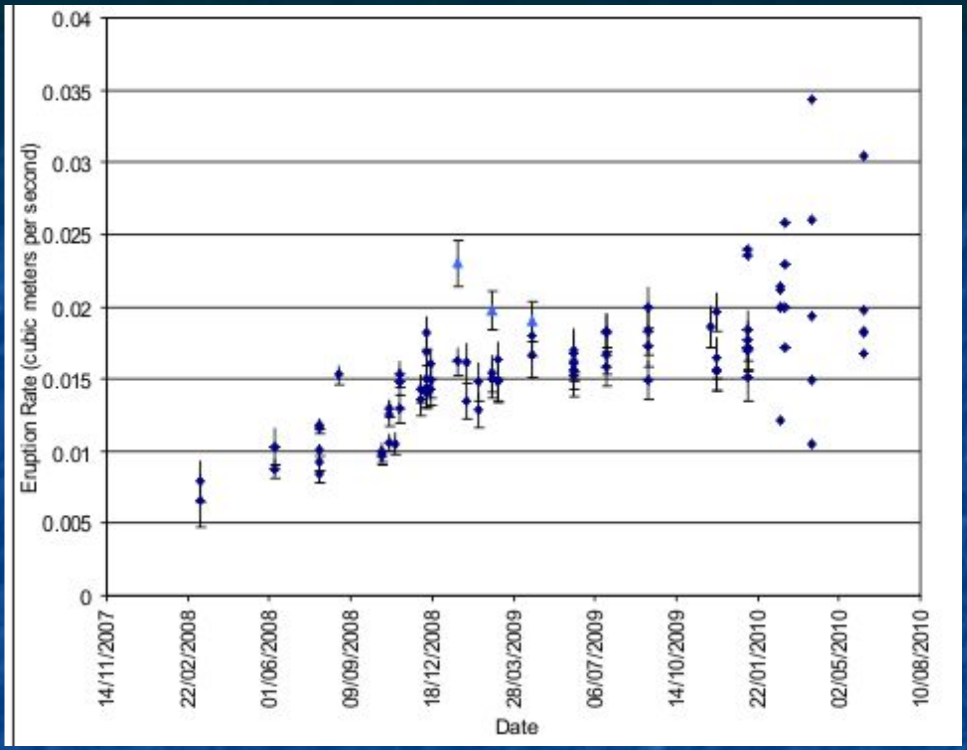
Precursors 6 months before effusion started:

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



Increase in fumarole temps.

Decrease occurred when dome made it to the surface

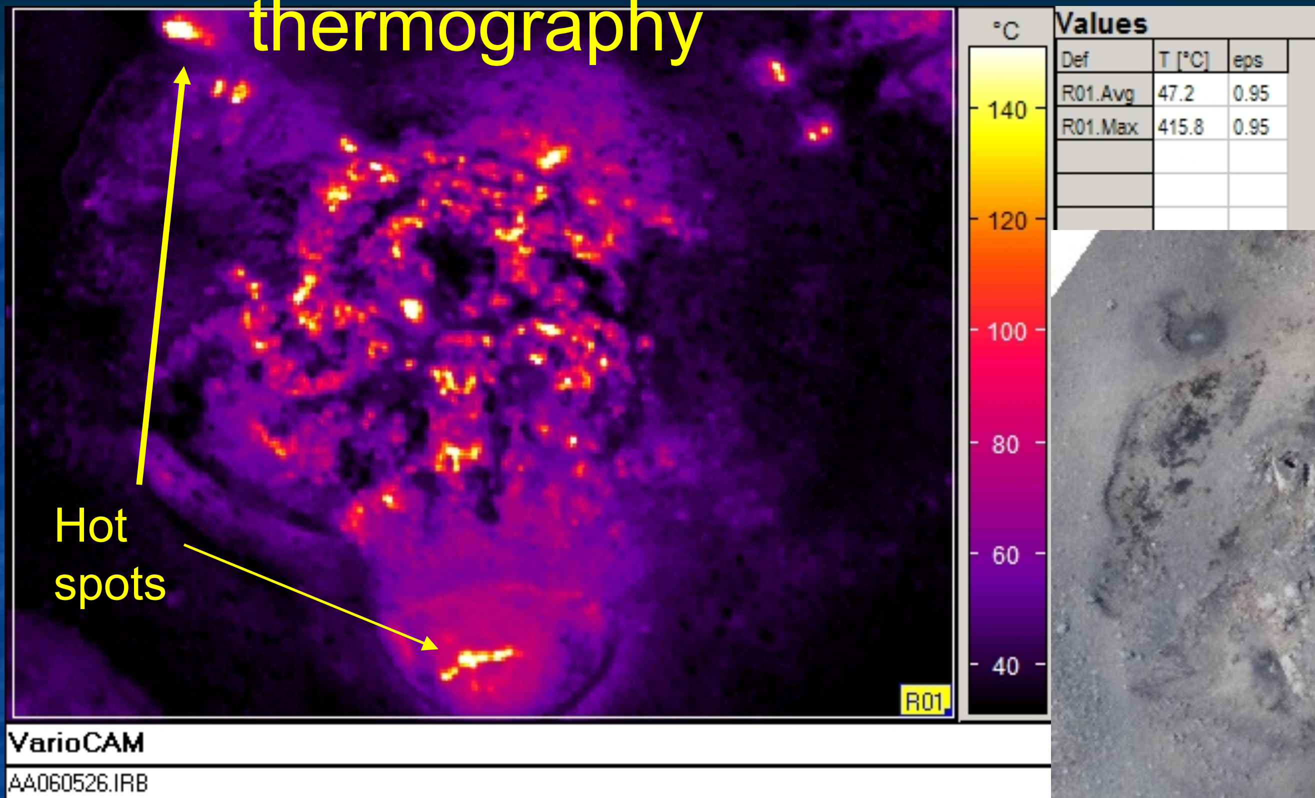


Eruption rate

- Difficult quantification
- Slow rate allows detailed observation
- Some pulsating
- What controls the effusion rate & pulsing – shallow or deep processes?

- Currently very slow effusion rate – ~ 0.02 m^3s^{-1}
- 2.1 x 10^6 m^3 on 01 June 2010

Dome evolution from thermography



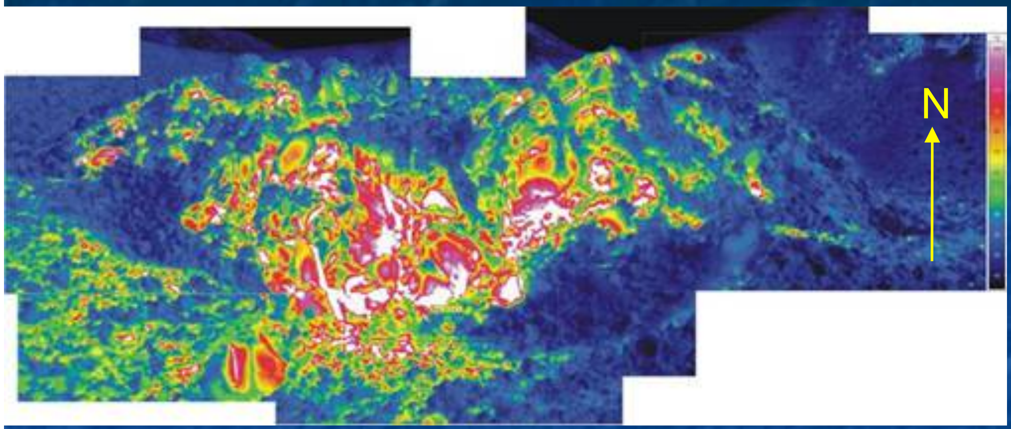
Pixel dimension = 0.45 m

Hot spots within small explosion craters

Evidence of circular structure in IR image

05 June 2007

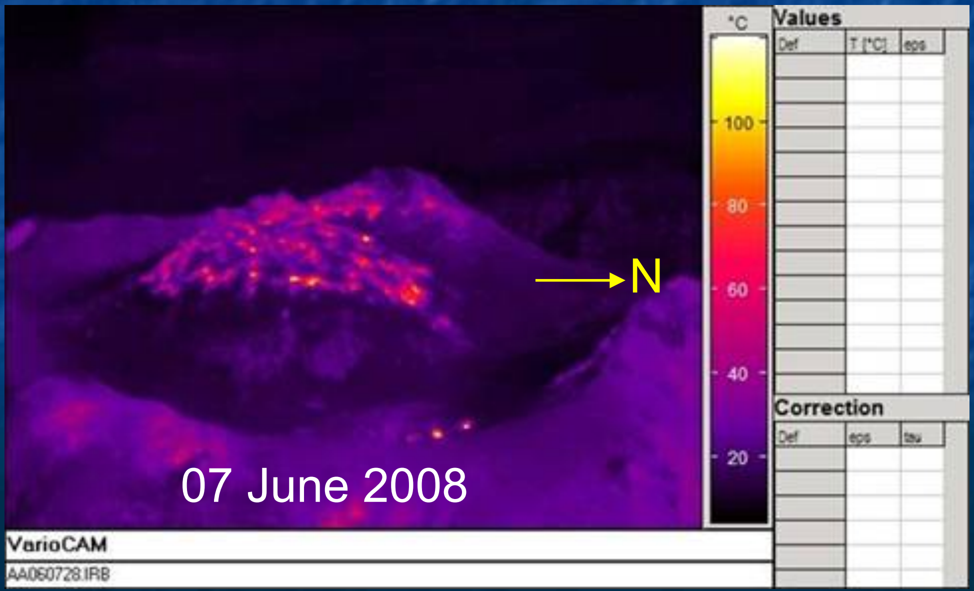
Magma extrusion



11 Nov. 2007 Pixel temps. > 500° C

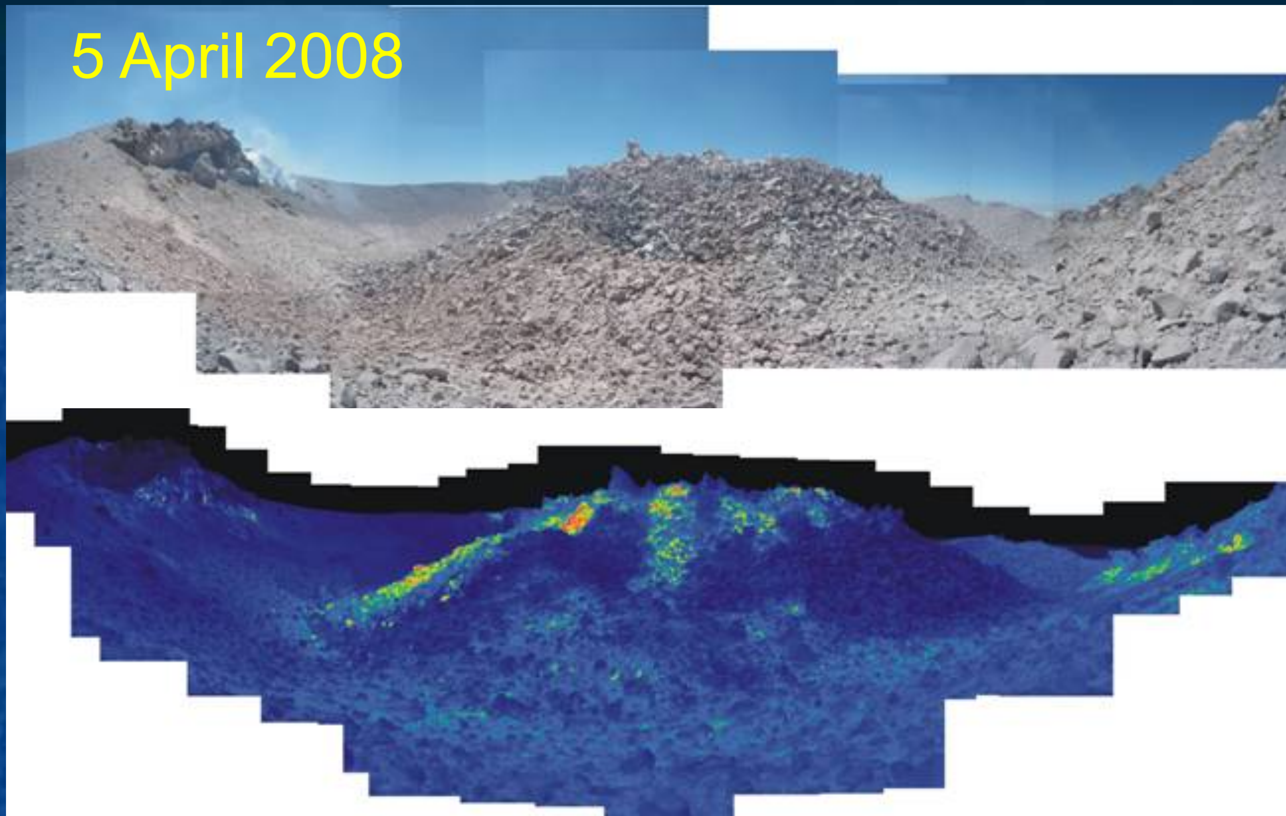
Growth directed in certain directions – small lobes

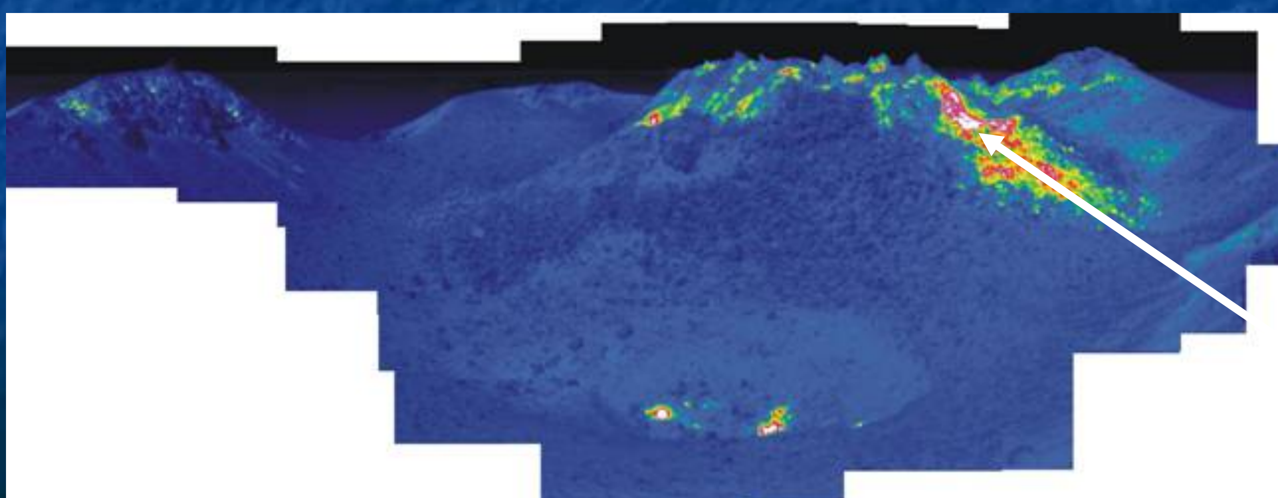
Exogenic



Larger dome – sides no longer show high temperature

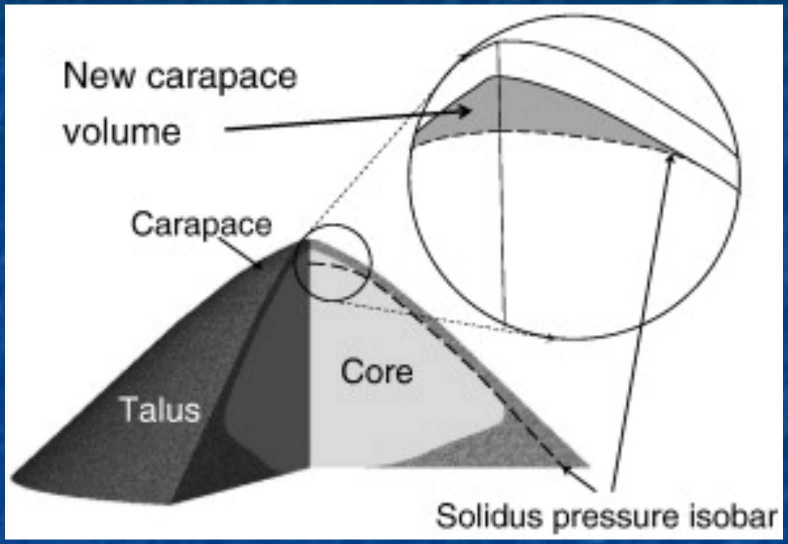
- Hot central core
- Extrusion on upper surface & sides
- Cooled lower slopes
  - Talus accumulation
  - Thermal insulation

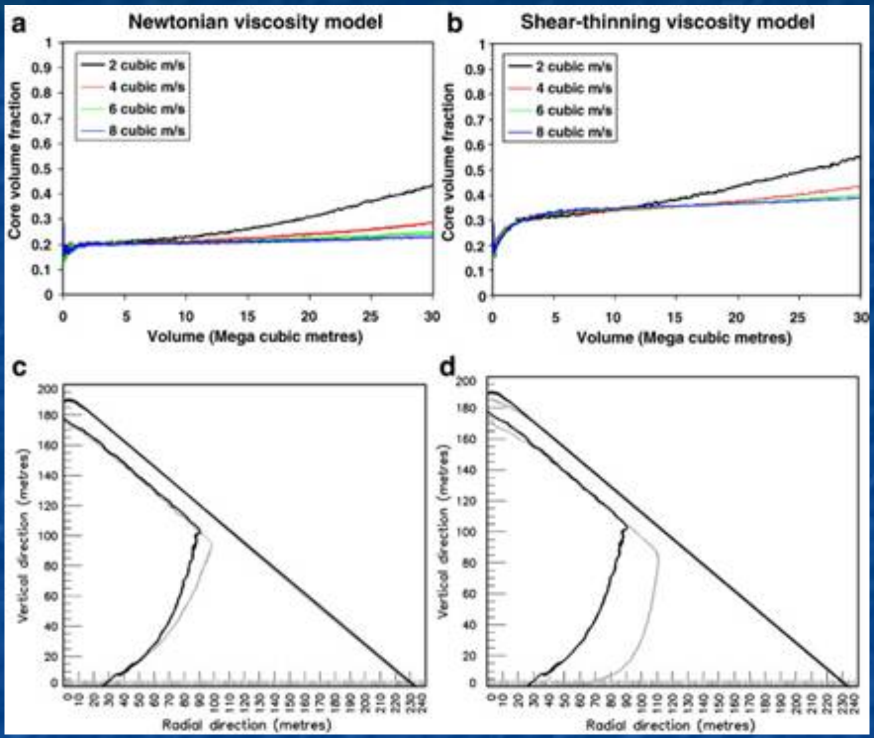




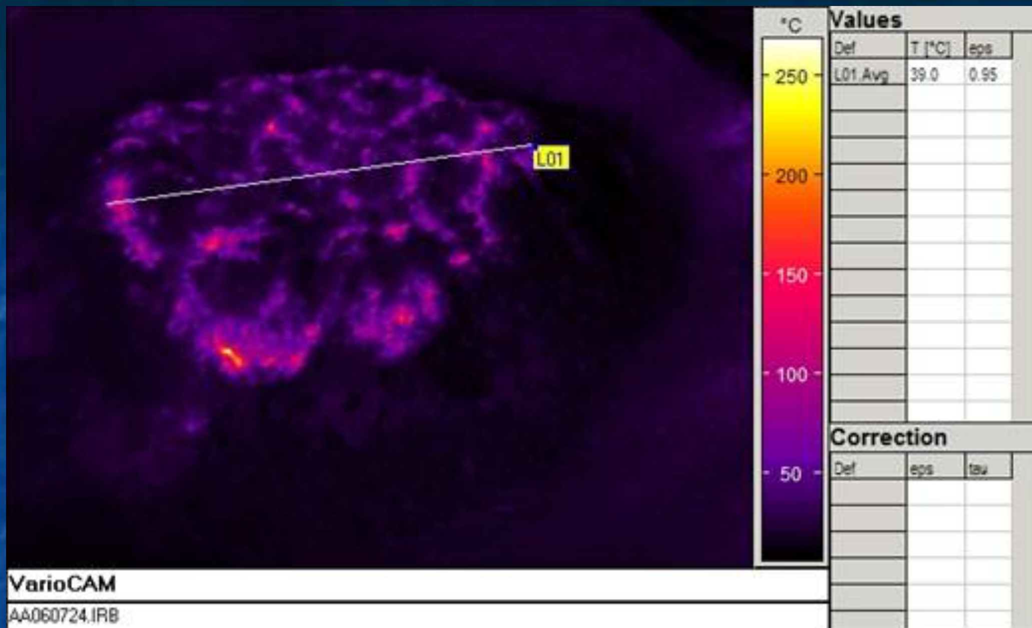
Hotspot – 321° C
Extrusion with rockfall
or explosive vent

Dome structure





- Recent numerical modelling increasing understanding of dome structure – Hale et al. 2009
- Colima case – 2 orders of magnitude lower effusion rate
- Study core, talus development; exo- or endogenous growth


°C
250
200
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L01
Values
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T [°C]
eps
L01.Avg
39.0
0.95
Correction
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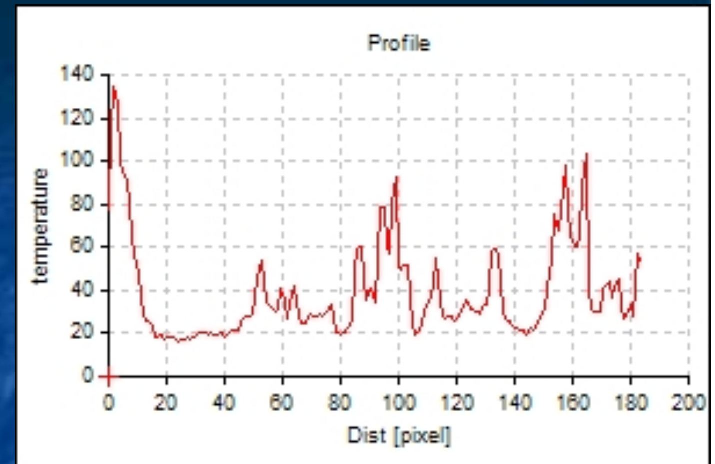
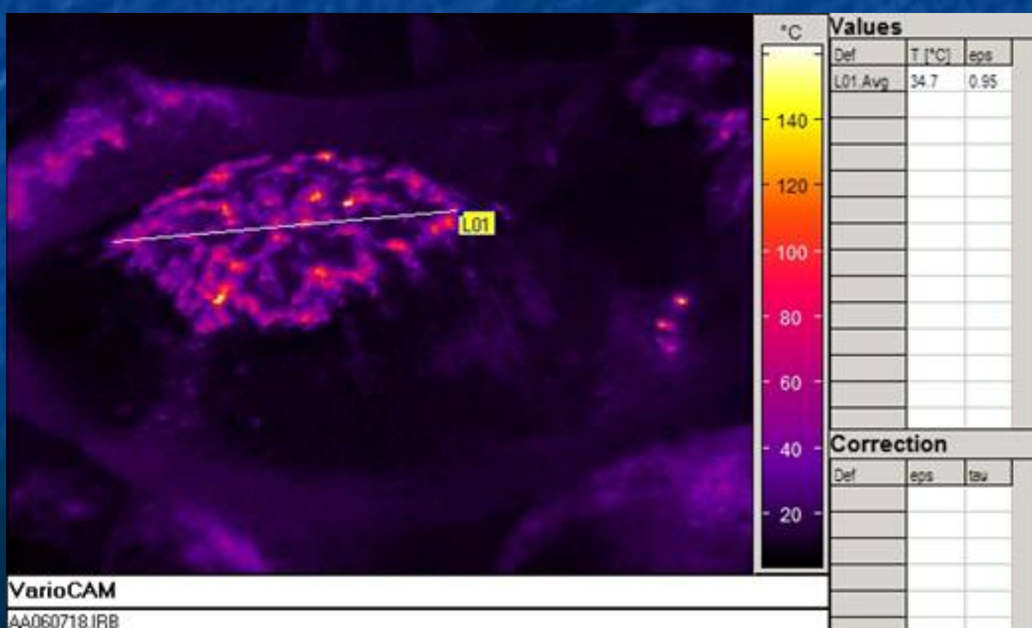
eps
tau
VarioCAM
AA060724.IRB


Profile
temperature
Dist [pixel]
0
20
40
60
80
100
120
140
160
180
200


°C
140
120
100
80
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Values
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T [°C]
eps
L01.Avg
34.7
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Correction
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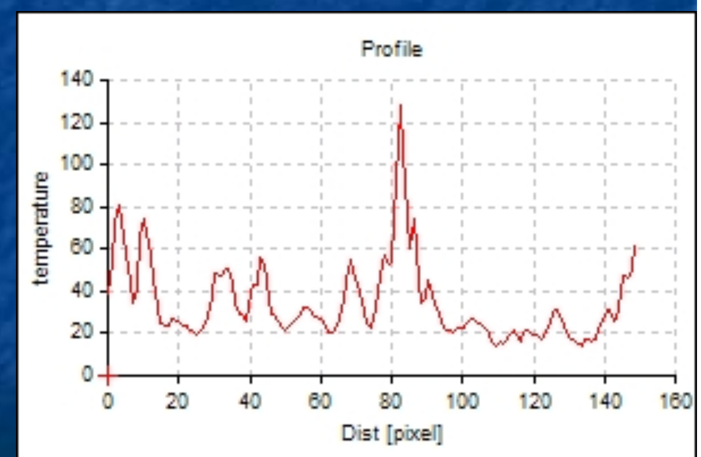
VarioCAM
AA060718.IRB


Profile
temperature
Dist [pixel]
0
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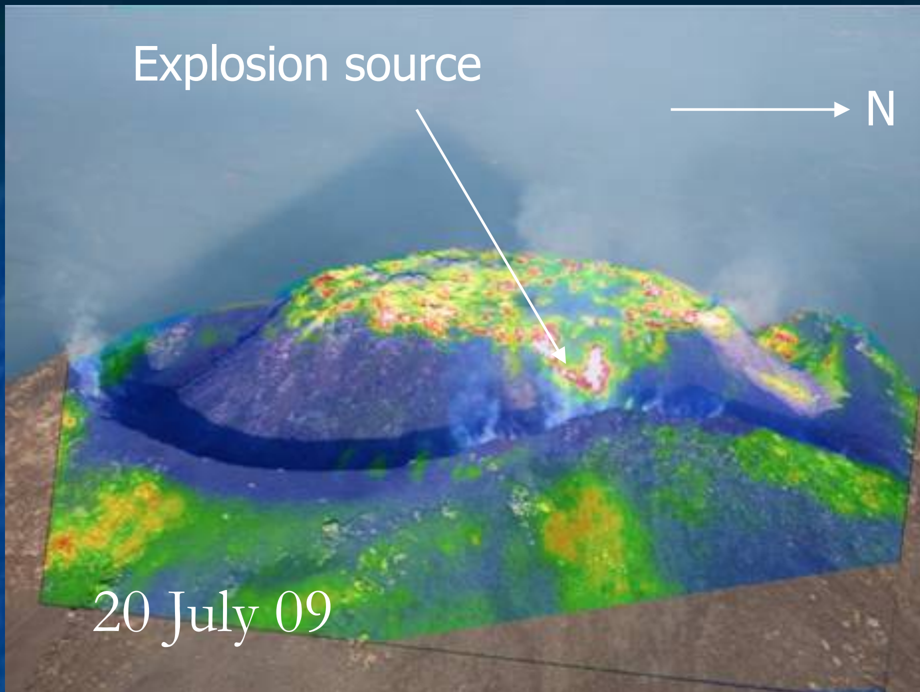
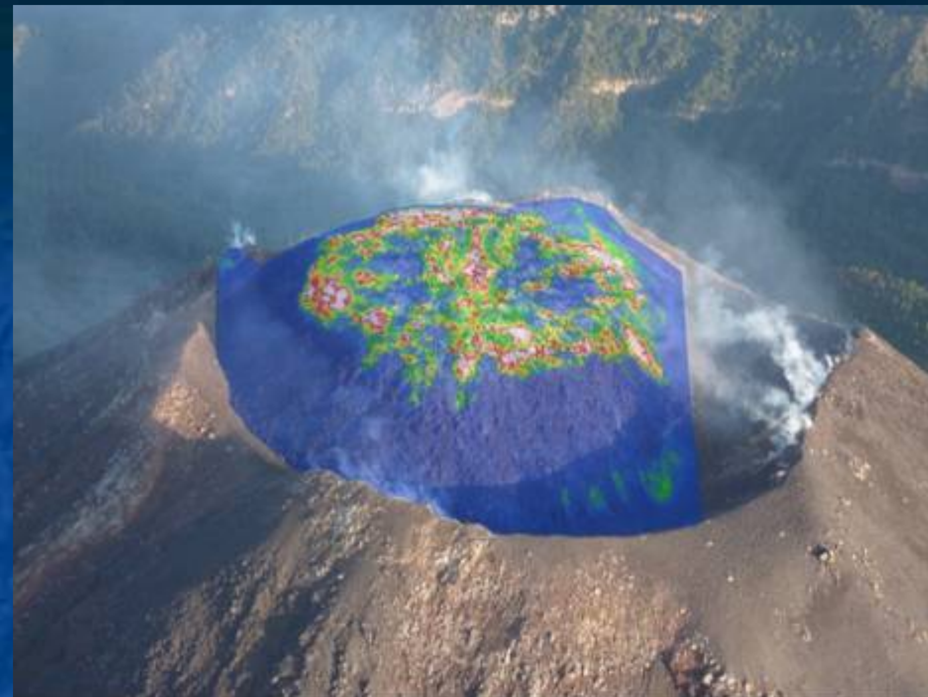
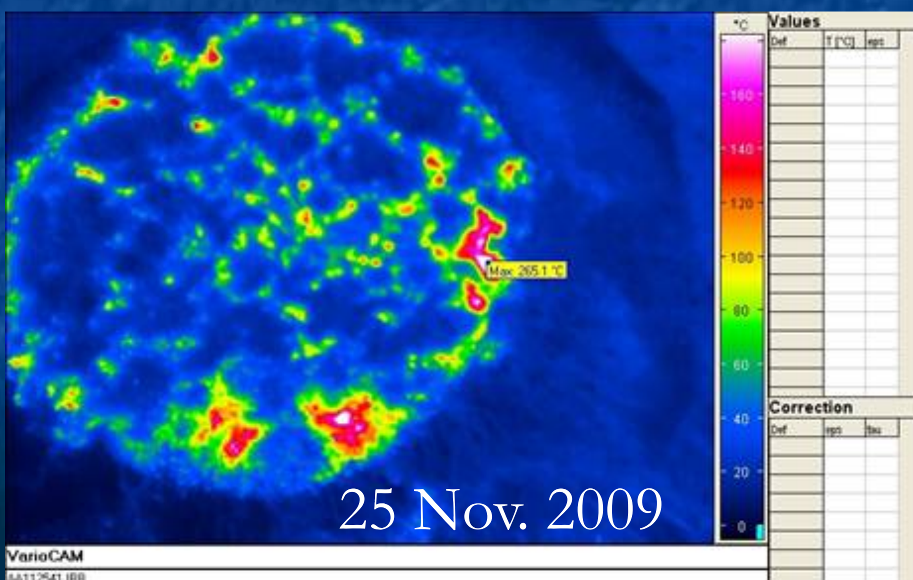
40
60
80
100
120
140
160

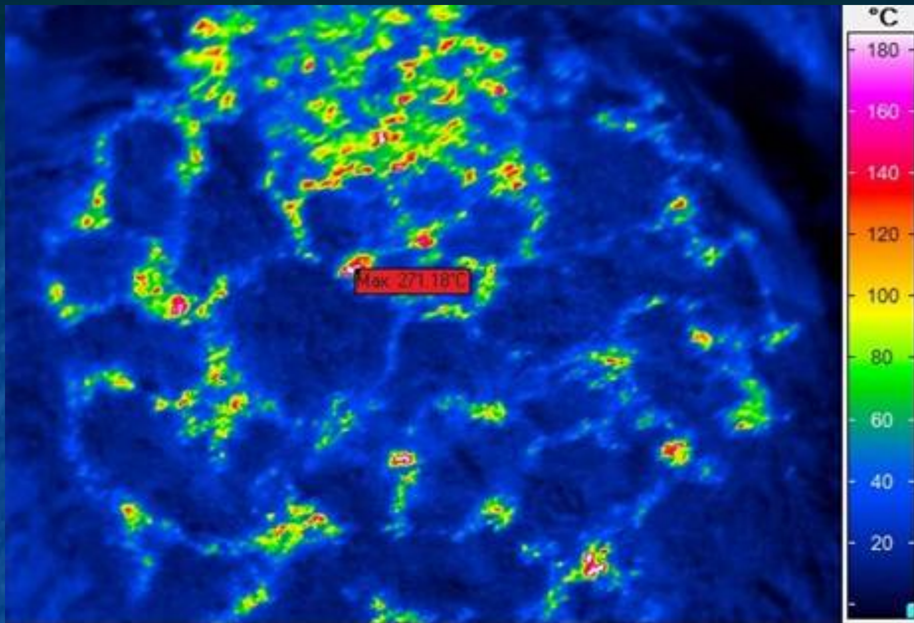
07 June 2008







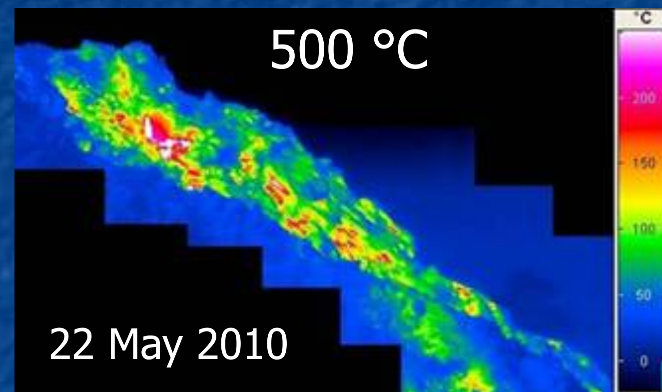
- Persistent hotspots
- Hot outside upper surface
- Fractures – gas flow

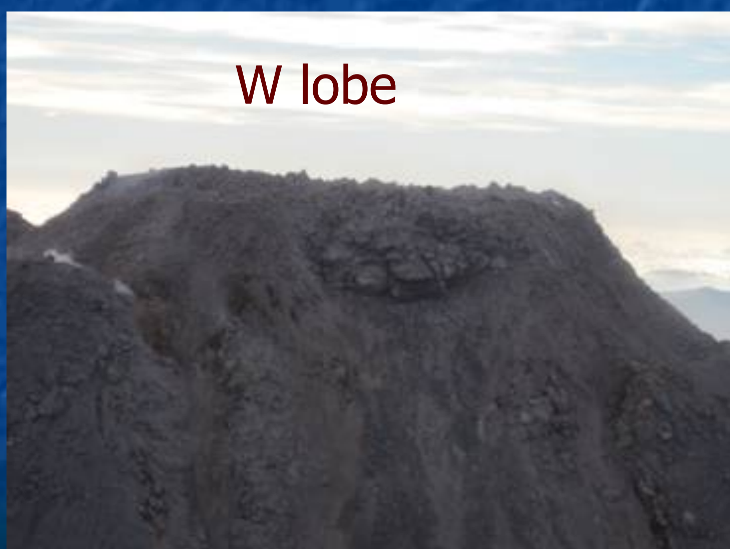


Dome cooling – polygons
→ columnar jointing

26 Dec. 2010

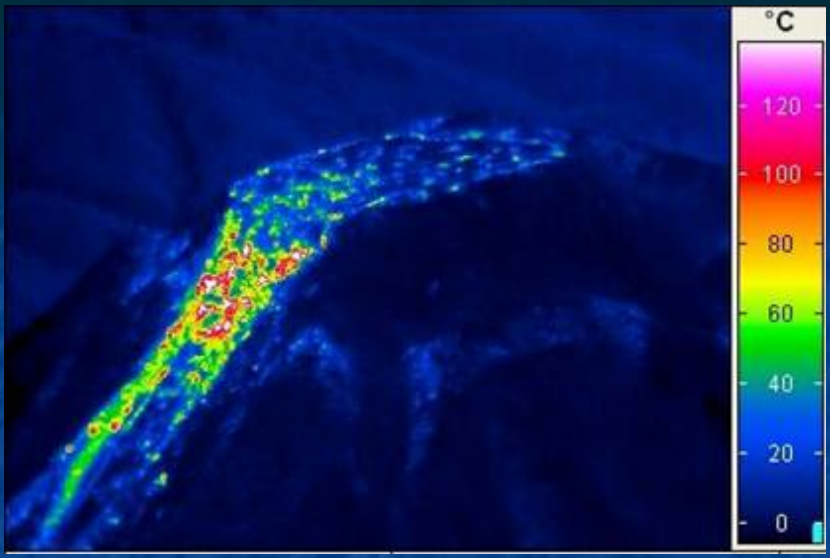
- Steepening & unloading on W dome side from rockfalls
- New lobe appears





25 February 2010

29 March 2010



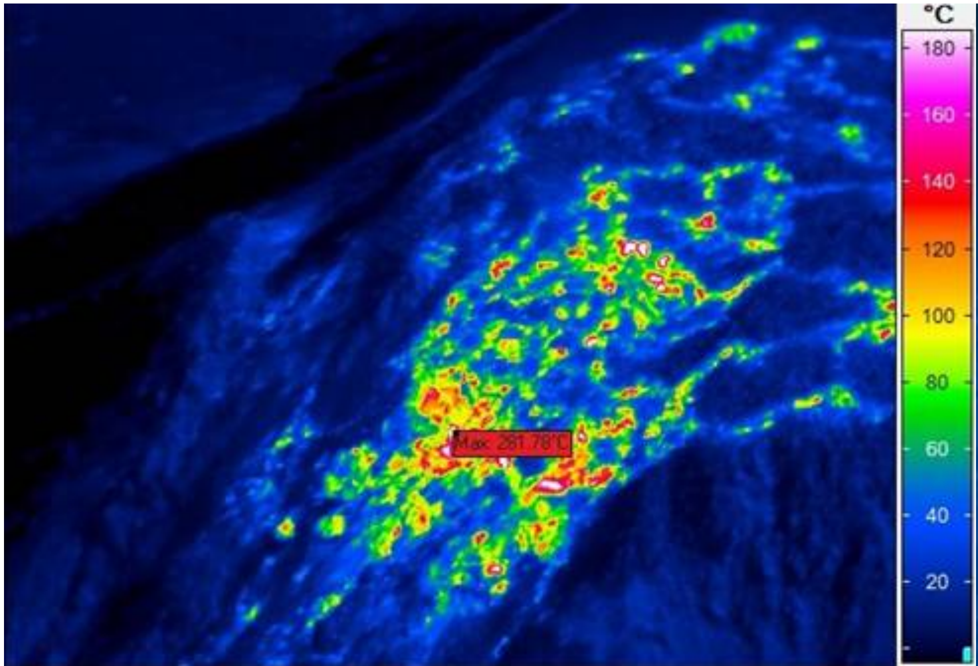
01 June 2010

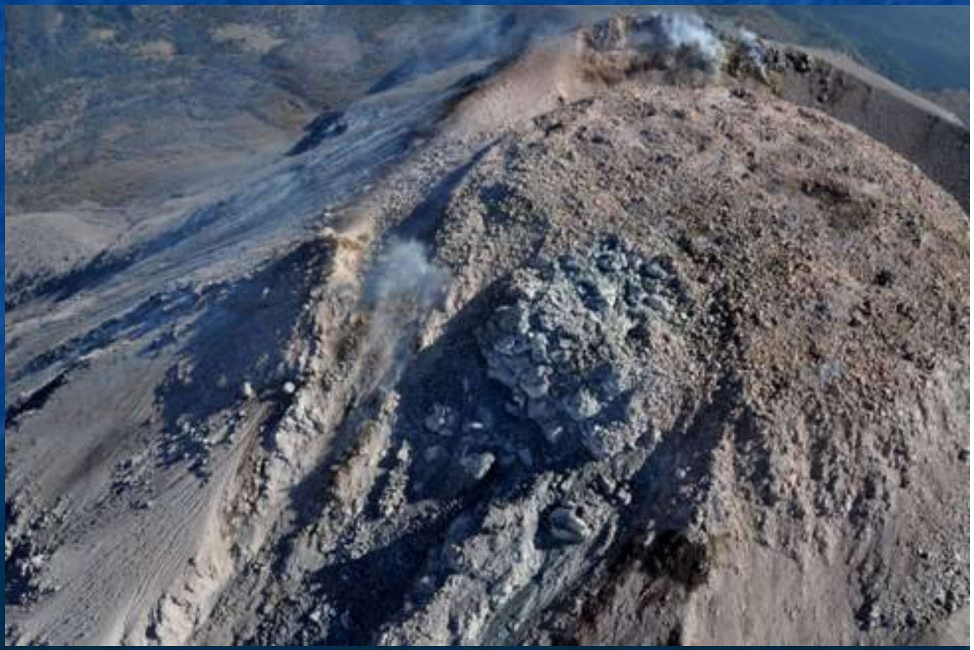
Rockfall – 20 February

Dome collapse hazard

- > Aspect ratio than previous domes
- 2004 dome partially collapsed; PF to 6.1 km
- Greater risk of larger vol. collapse
- Increase in effusion rate - increased pressurization
- Quantification – Sulpizio et al. 2010

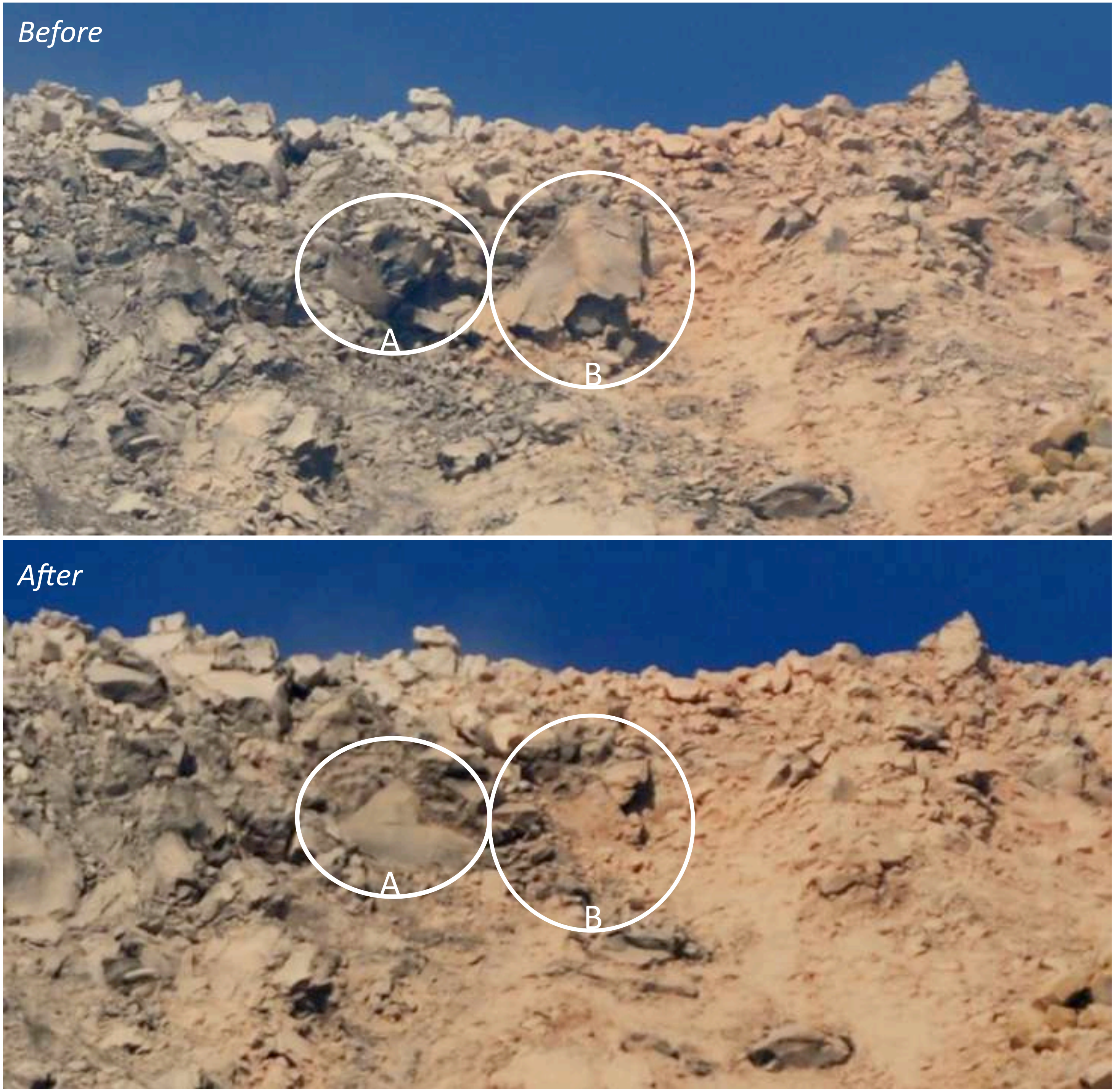
Current lobe W side





Infrared images of rockfalls

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



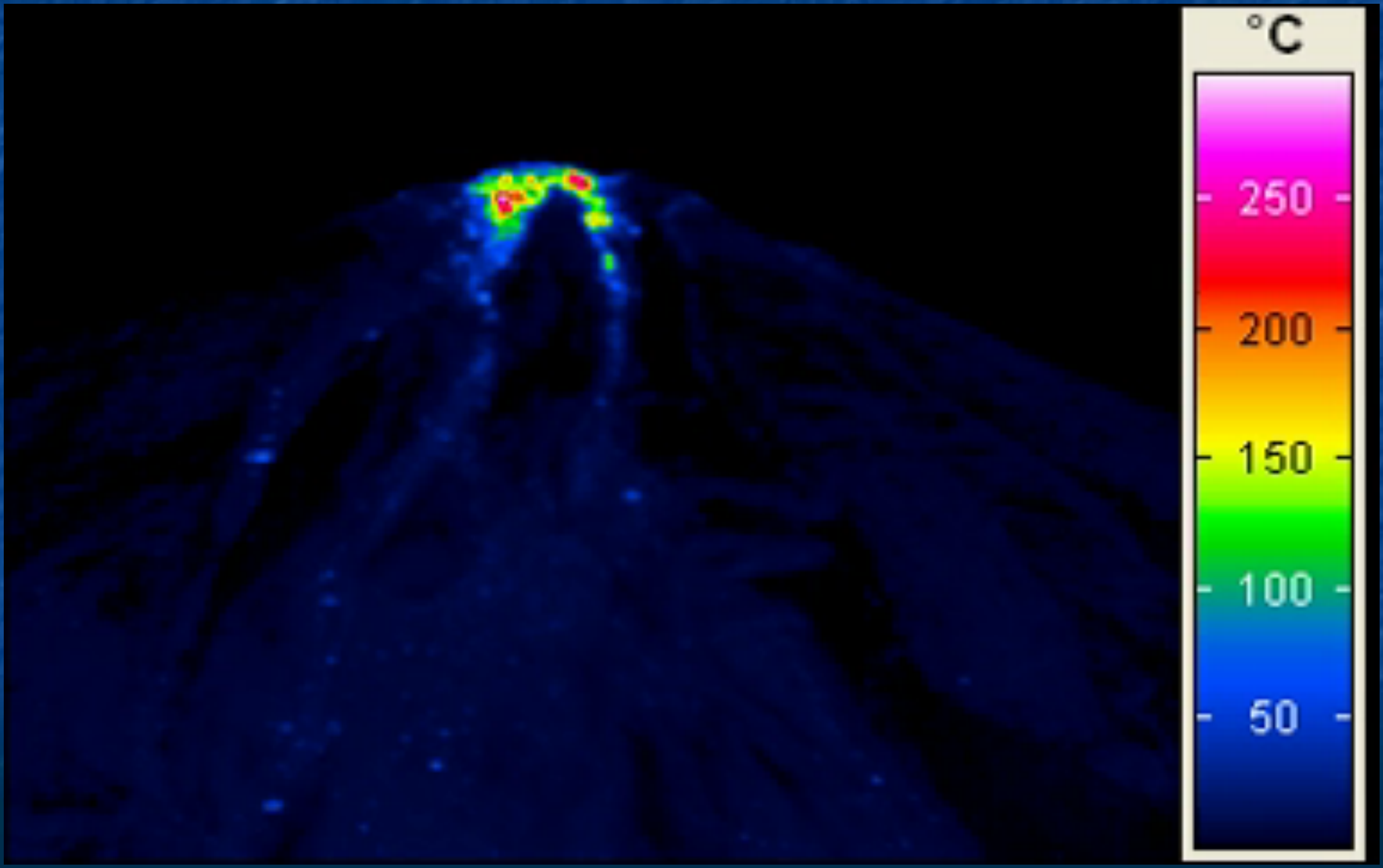
Rockfall quantification

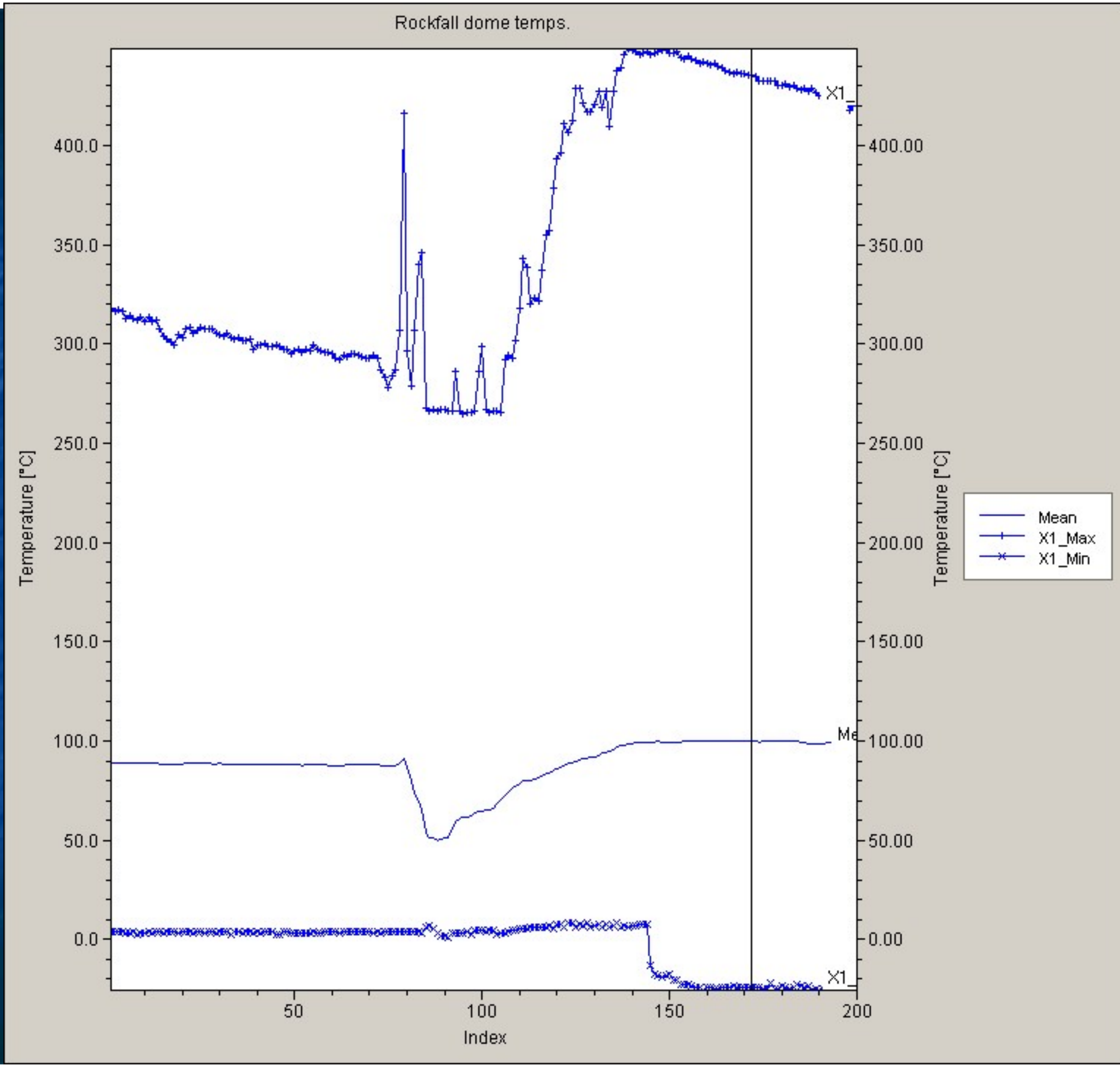
26.05.2010
Rockfall
17:42 – 17:48

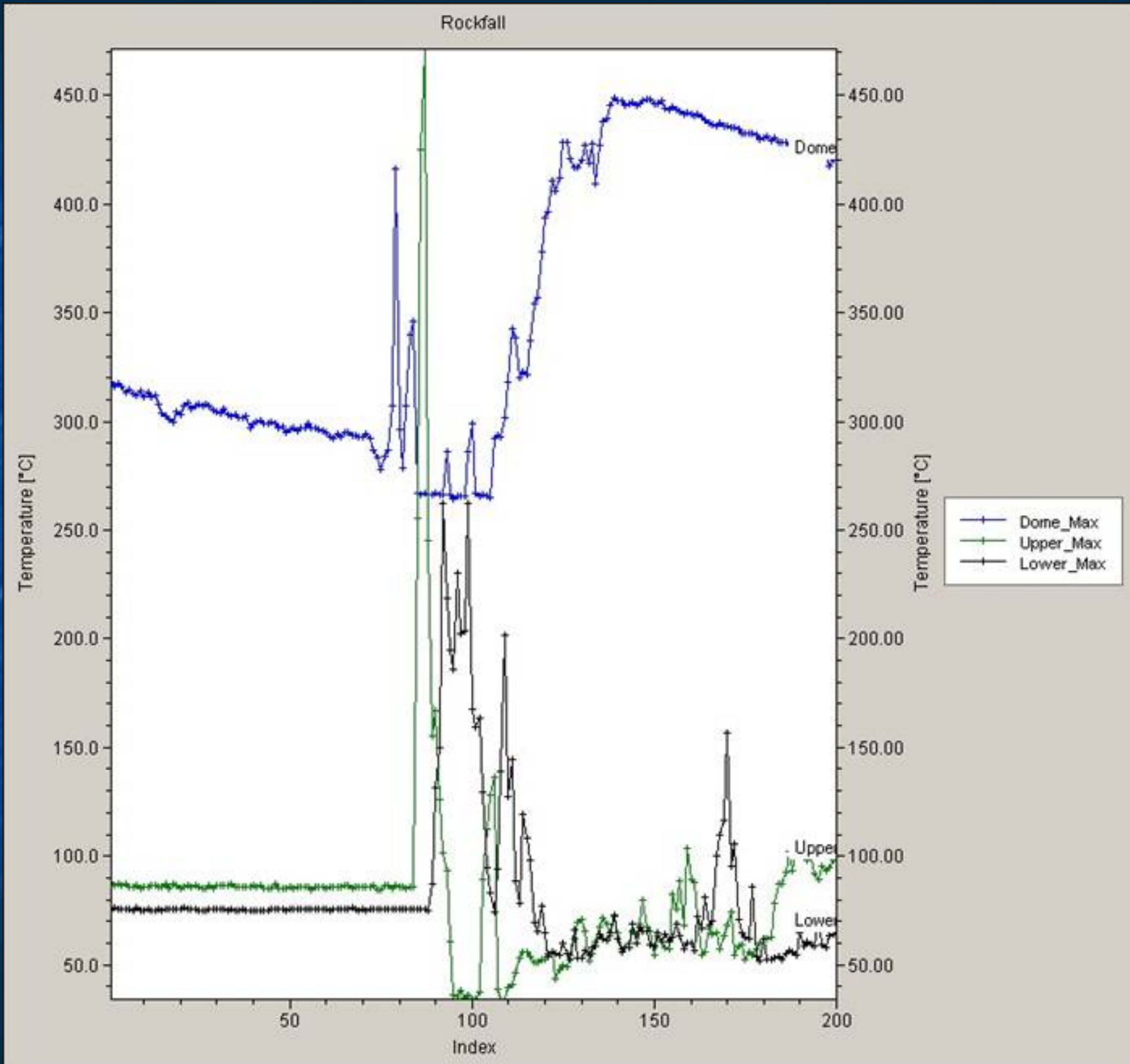
- A = 250 m^3
- B = 558 m^3

- Comparison with seismic signal
- Quantify volumes lost

04 Jan. 2011 - rockfall

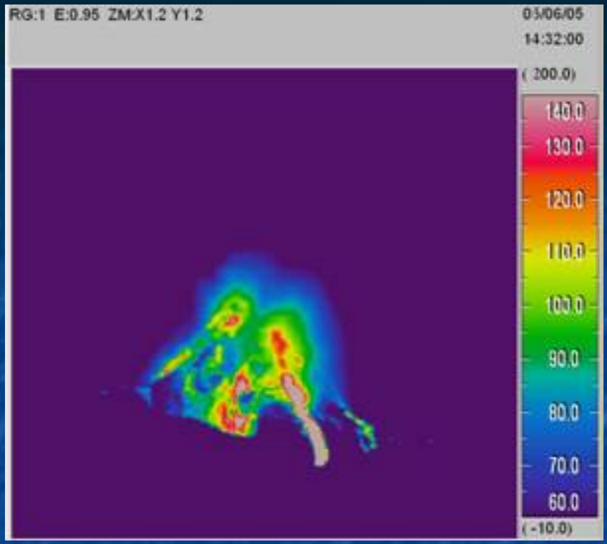



Rockfall dome temps.
Temperature [°C]
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
X1_
Me
X1_
50
100
150
200
Index
Mean
X1_Max
X1_Min

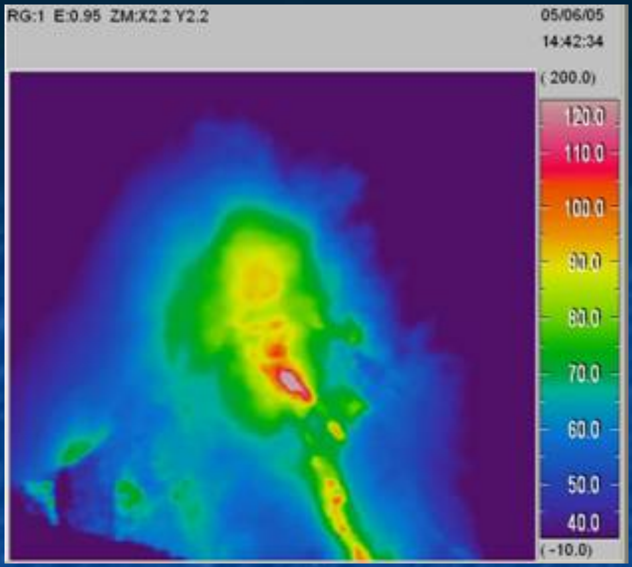


Rockfall
Temperature [°C]
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
Dome
Upper
Lower
50
100
150
200
Index
Dome_Max
Upper_Max
Lower_Max

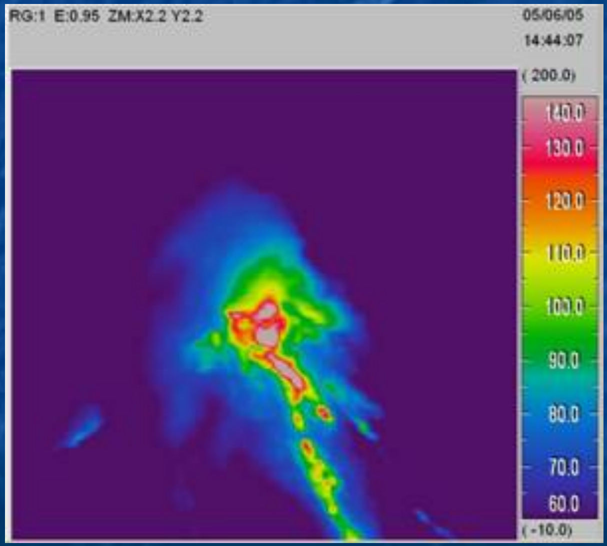
Explosive activity



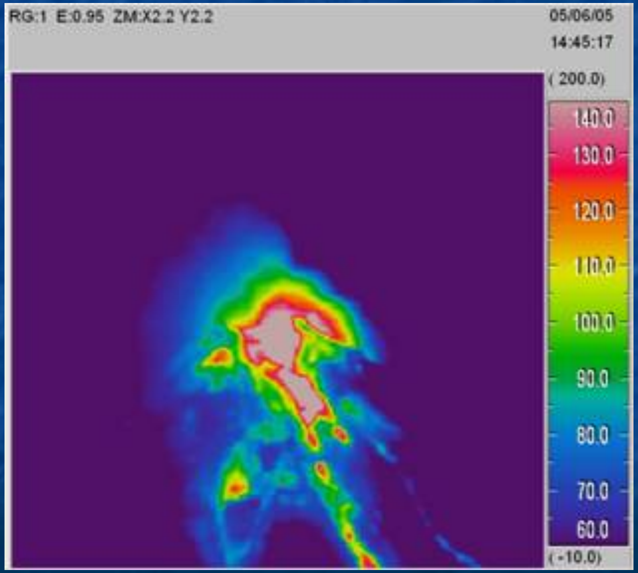
Temperature max: 199°C



Temperature max: 138°C



Temperature max: 186°C

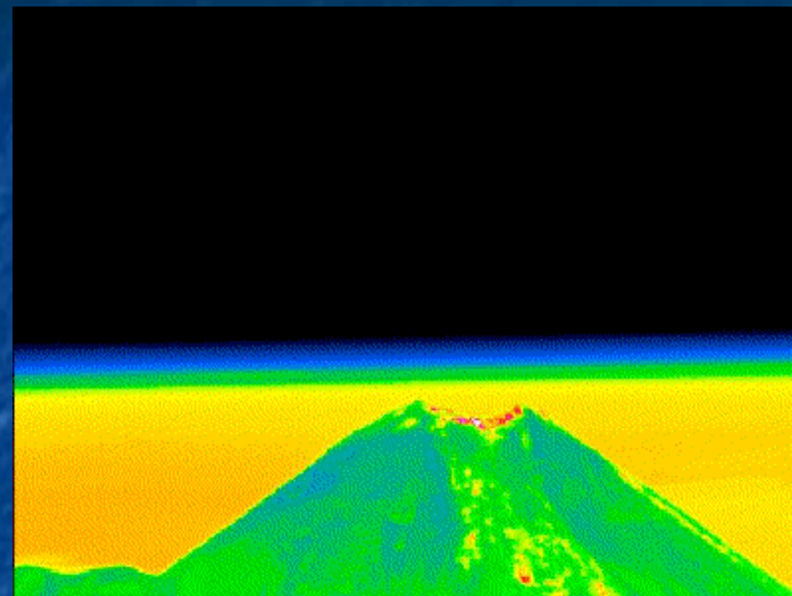


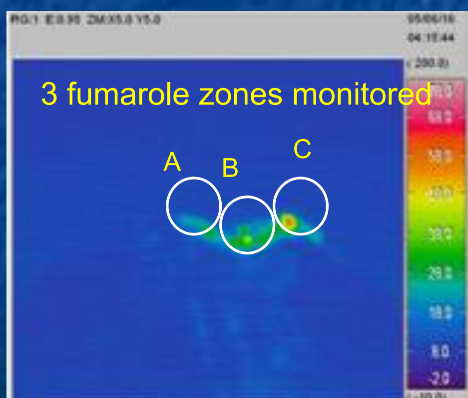
Temperature max: 199°C

Explosion 05 June 2005

Explosion monitoring

VarioCAM infrared camera 8 – 13.5 µm



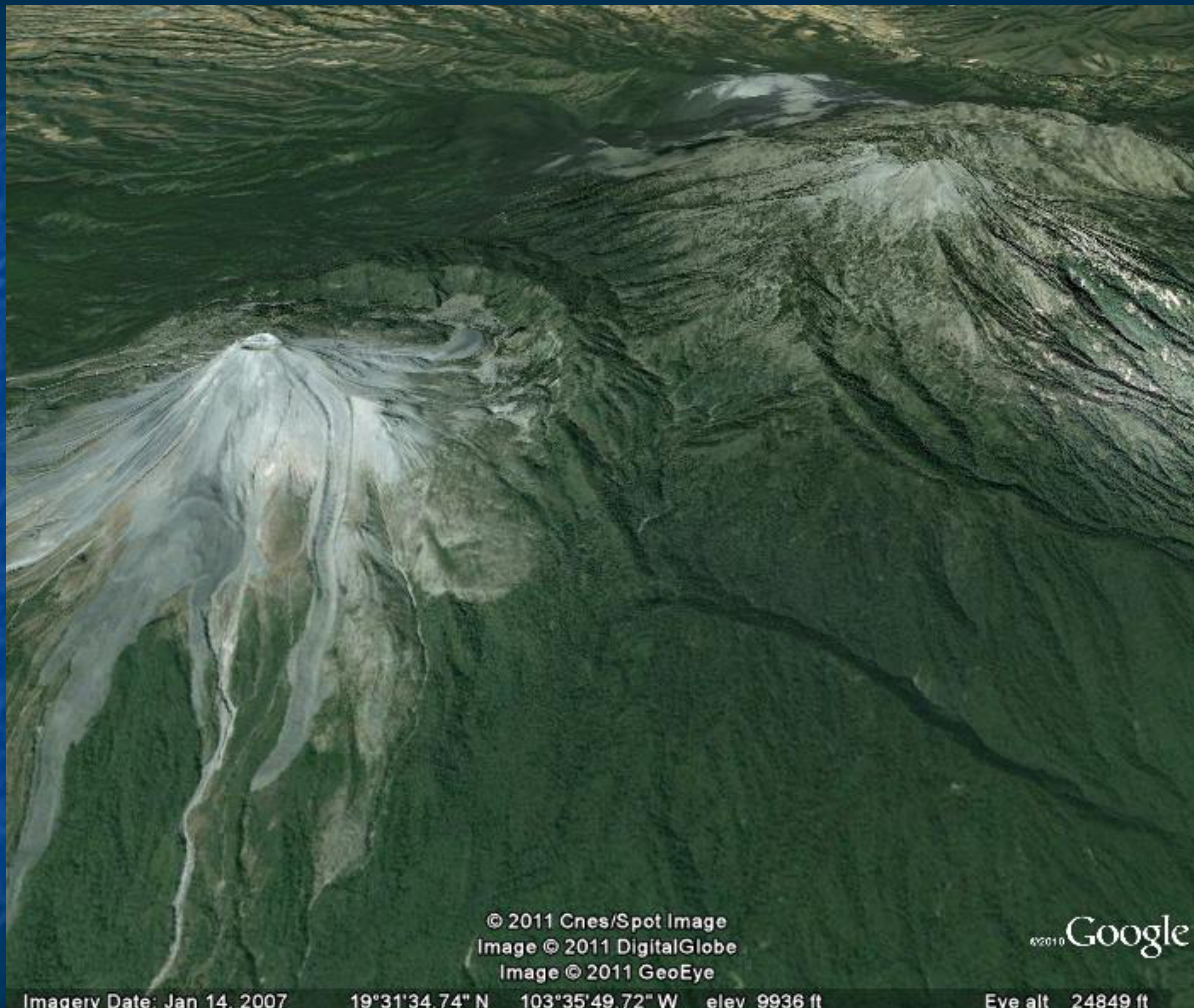


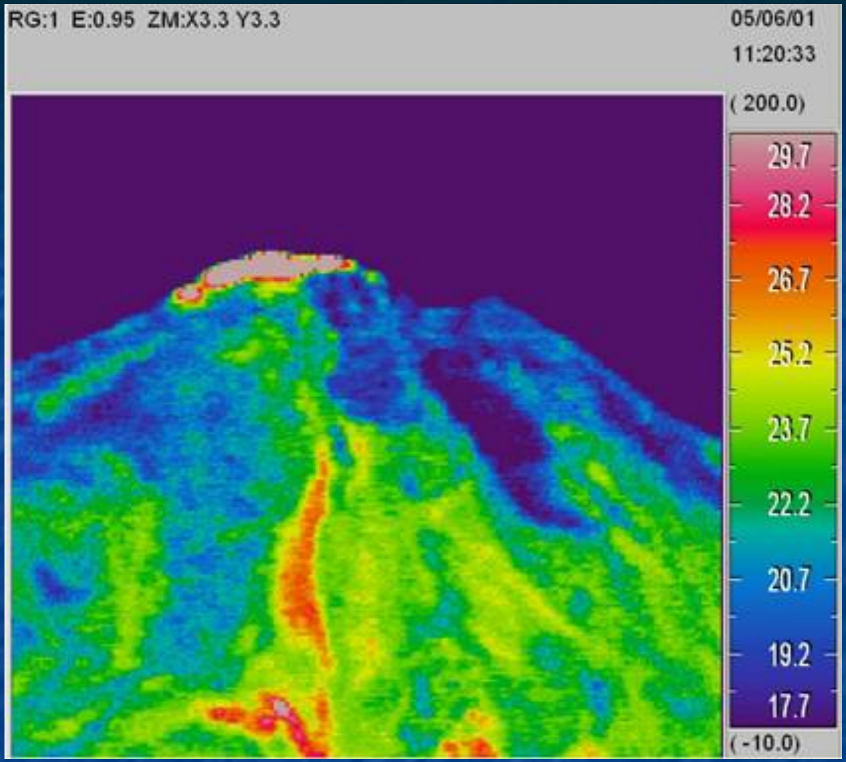
Fumarole temperatures monitored

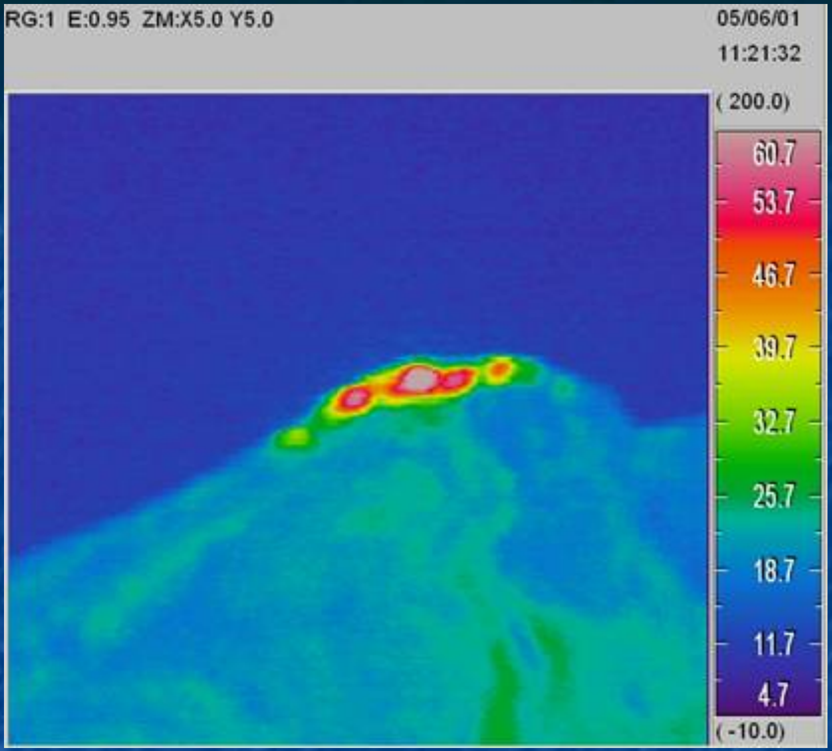
-Looking for long-term trends

-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.


© 2011 Cnes/Spot Image
Image © 2011 DigitalGlobe
Image © 2011 GeoEye
Google
Imagery Date: Jan 14, 2007
19°31'34.74" N
103°35'49.72" W
elev 9936 ft
Eye alt 24849 ft



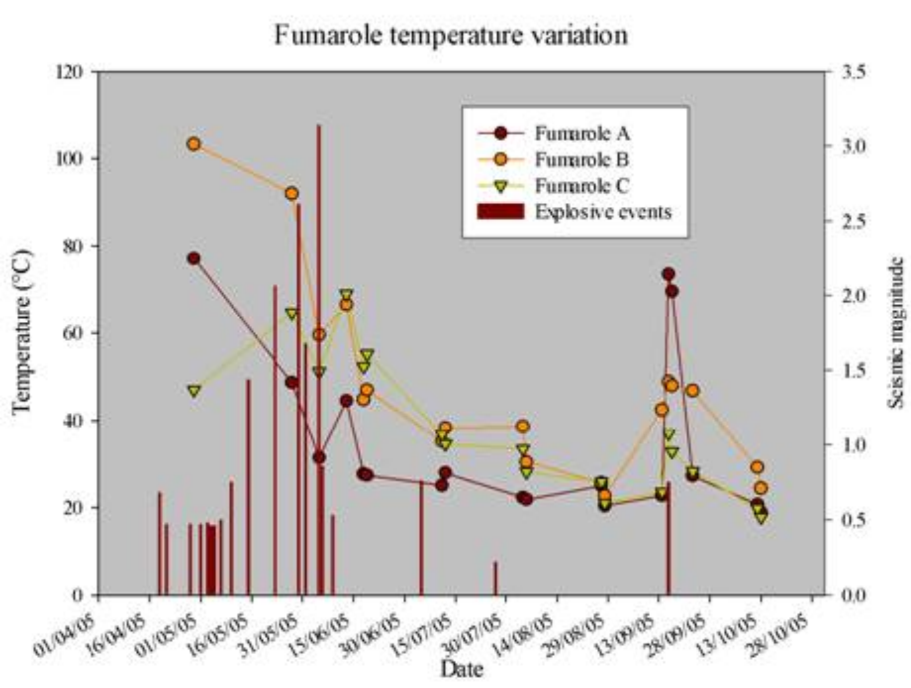


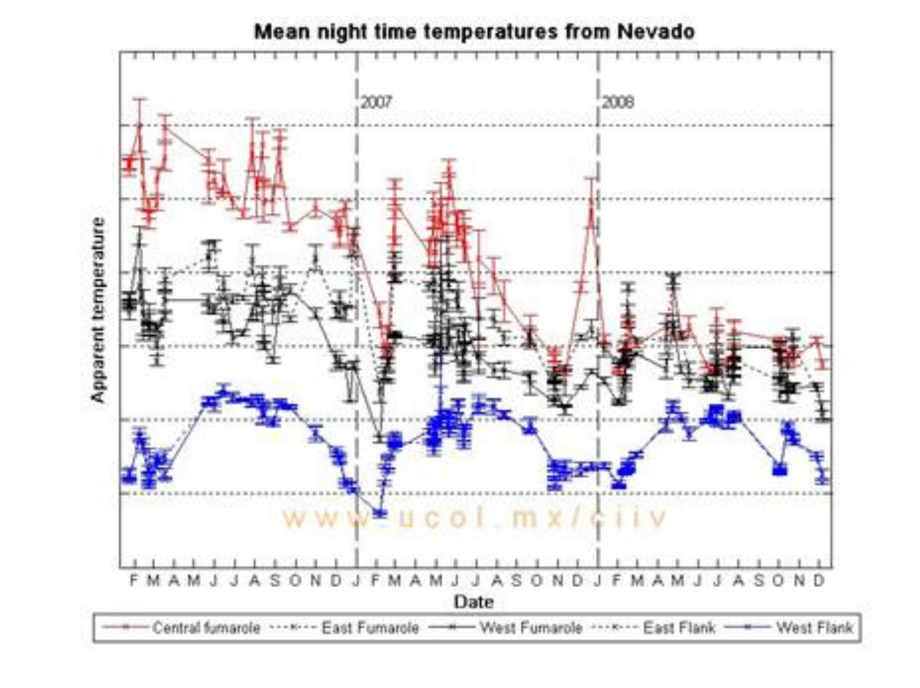
SW Fumaroles 01 June 05: 58.9 y 75.2 °C – temperatures last measured in-situ in 2002, rim fumaroles up to 250° C.

Hot pyroclastic flow deposit from 30 May explosion.

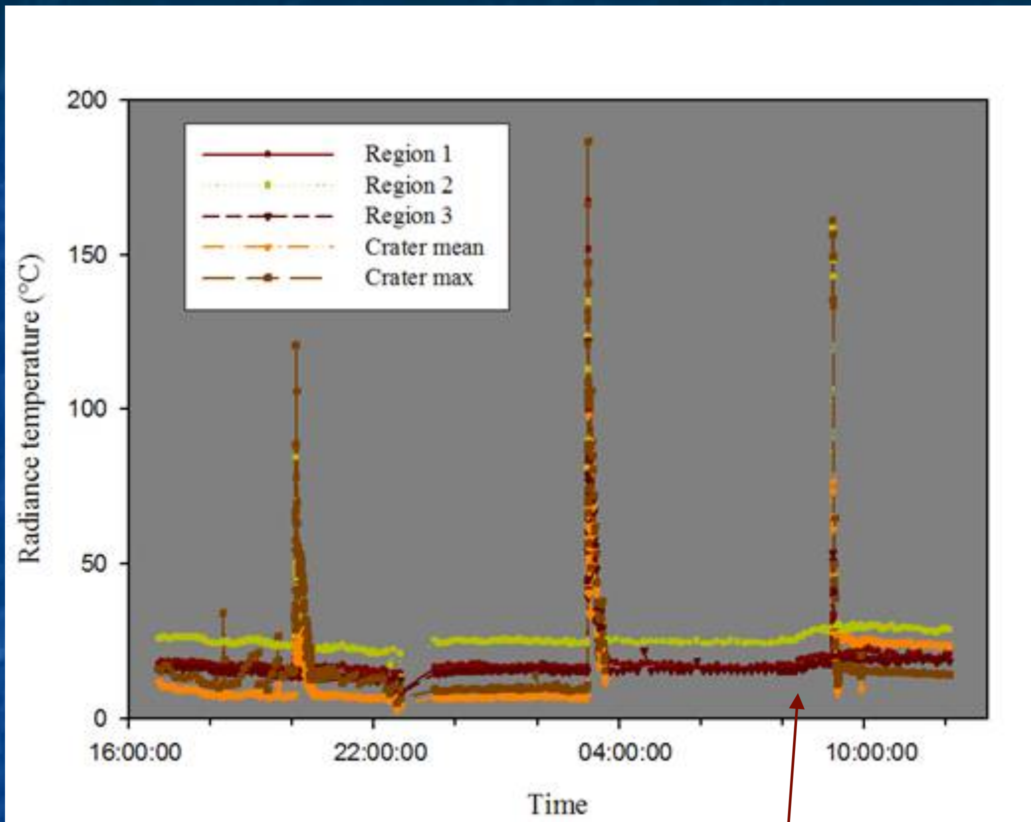
Remote sensing of fumaroles

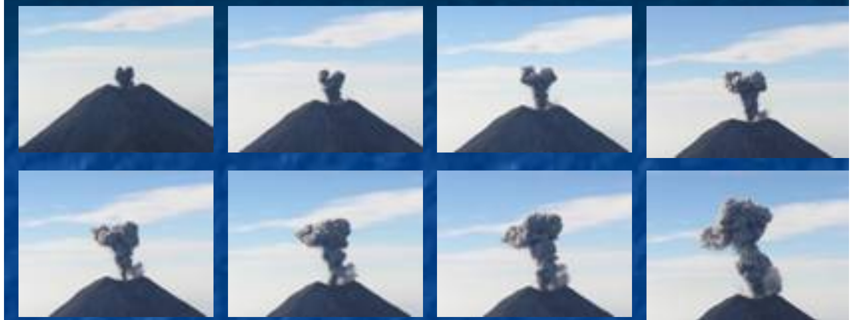
- Decreasing tendency during 2005-2007; 2008 onwards fairly constant
- Negative anomaly prior to 5 June event
- Temperature increases and decreases related to explosions
- Relatively large pixel size and large distance for atmospheric effects but sufficiently sensitive to detect small variations





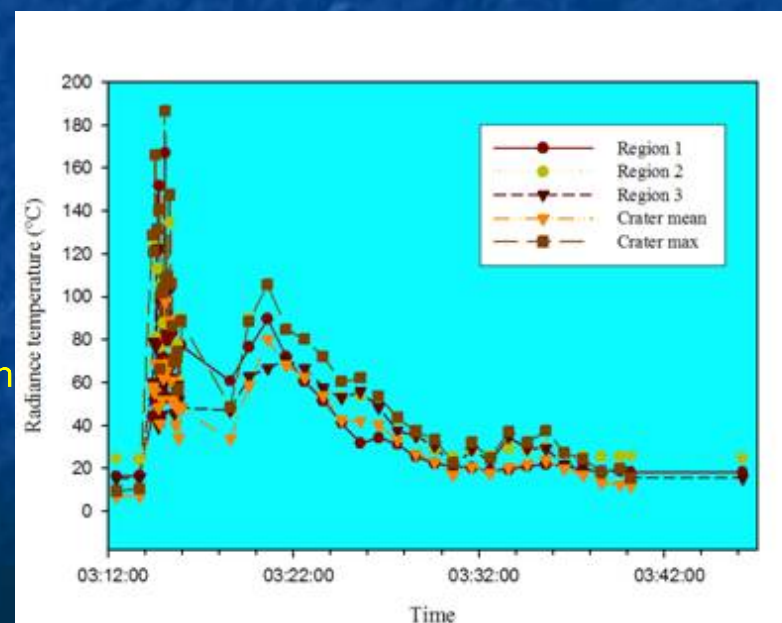
Variation in fumarole temperature

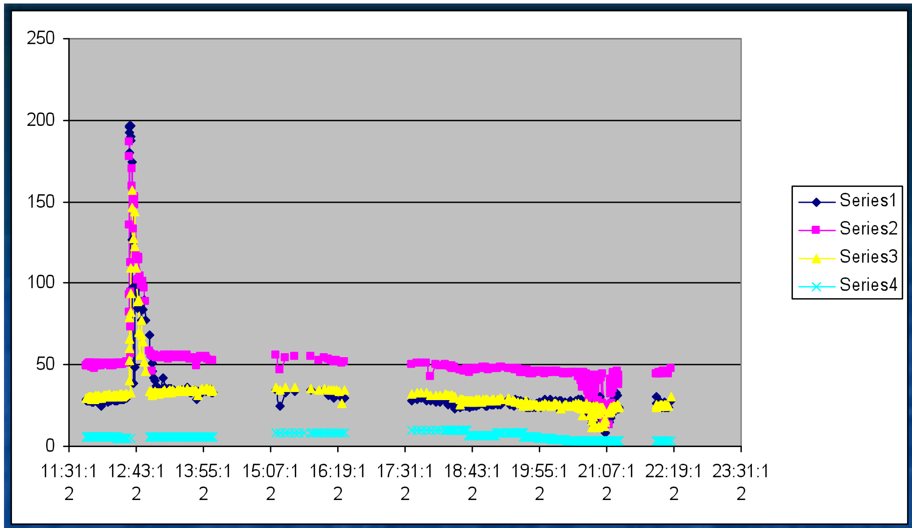




19 - 20 Nov. 2005

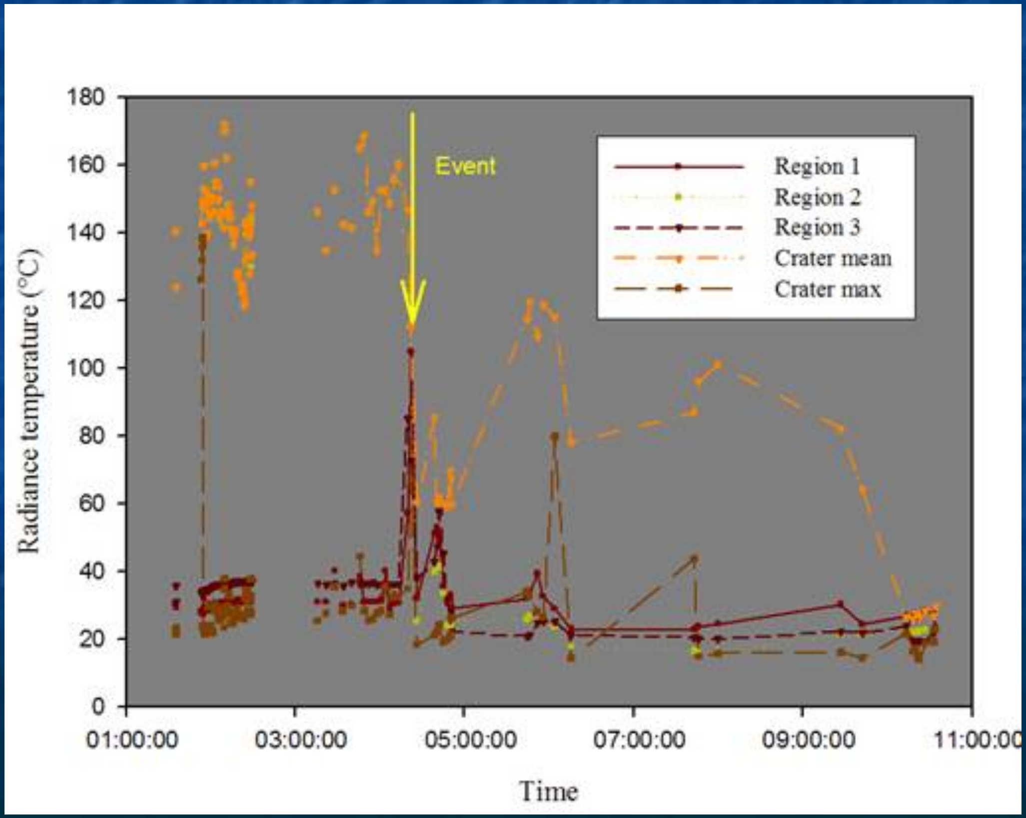
Increase in T prior to explosion

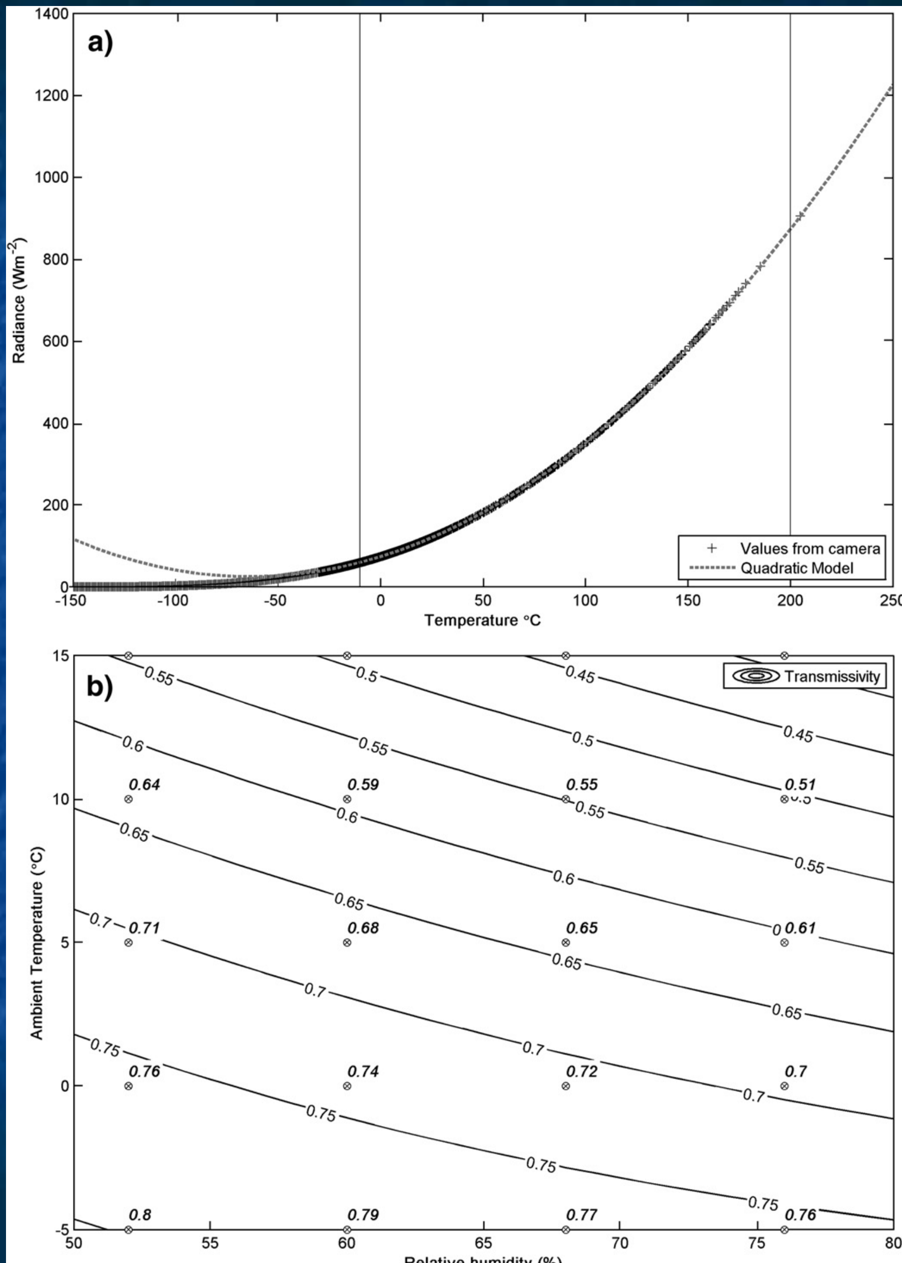




Large event of 23 Sept. – prior heating & subsequent cooling over several days

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

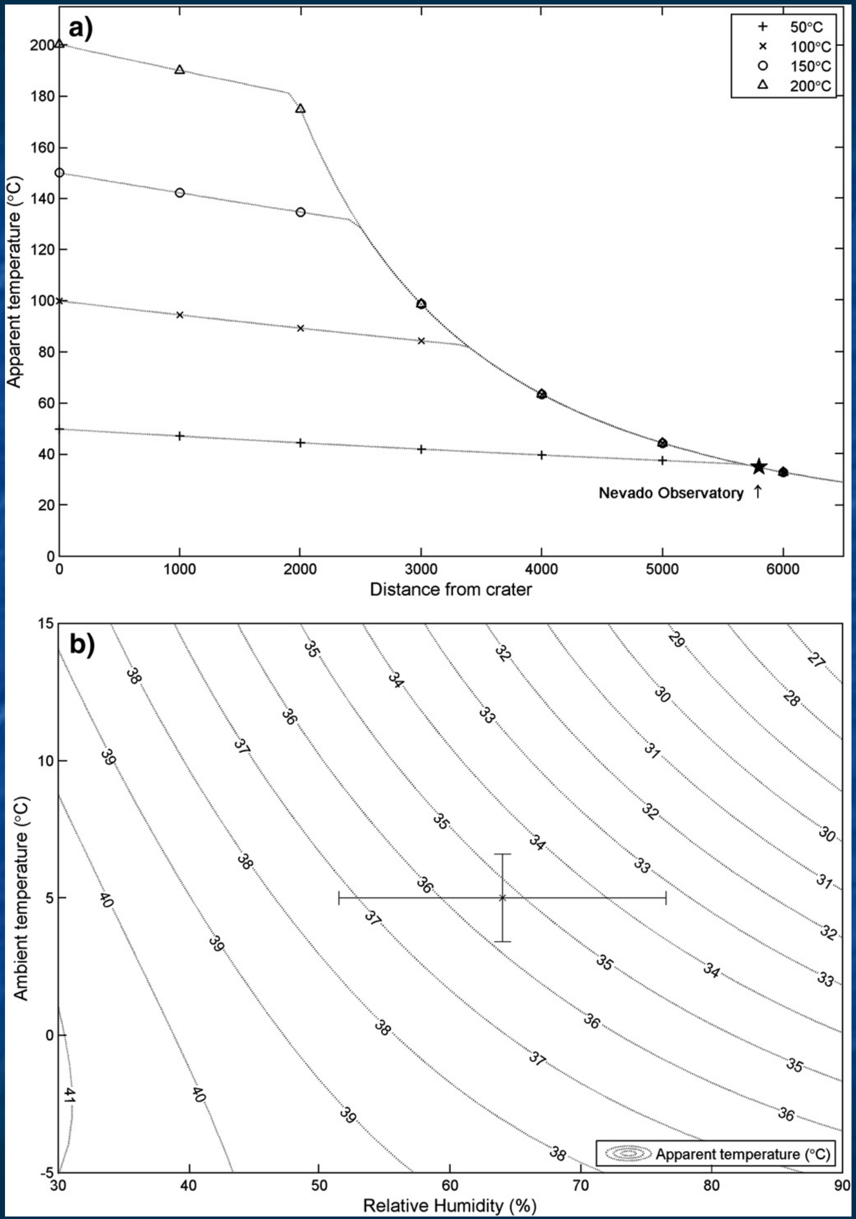




Comparison of object temperature and radiative heat flux. Dotted curve represents temperature/radiative heat flux conversion function. Agrees with the Plancks-law over the range of interest (−10–200 °C)

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

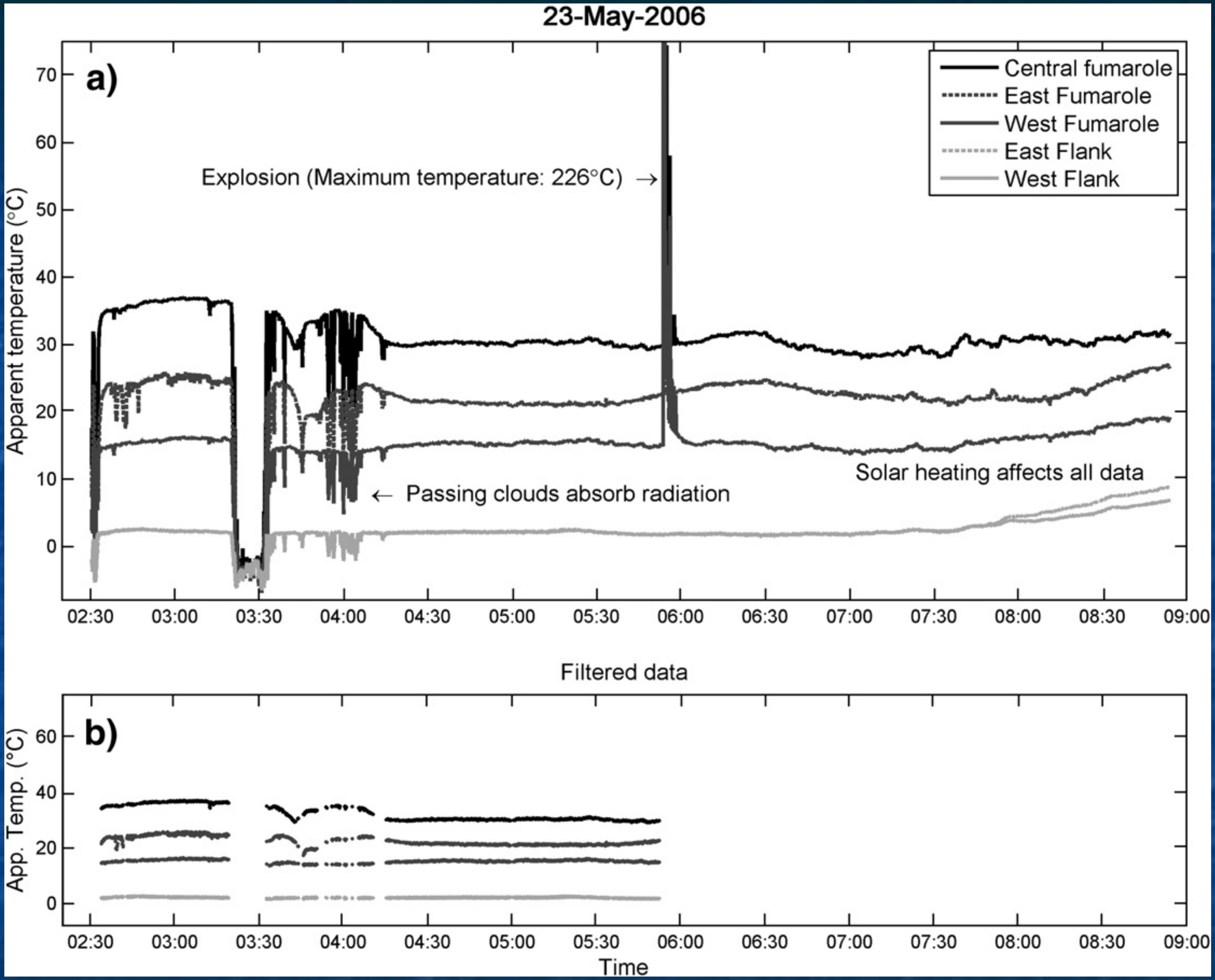
Models of apparent fumarole temperatures



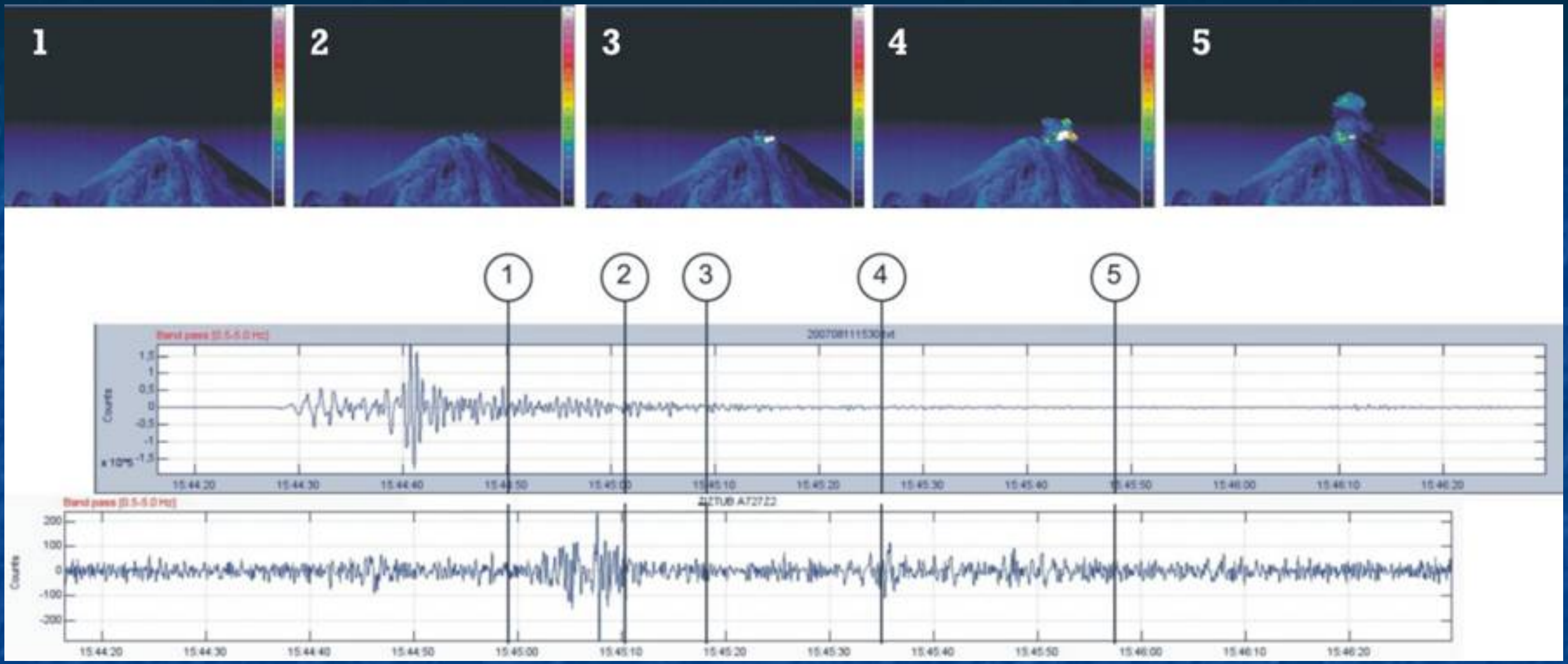
a) Distance versus apparent temperature for theoretical fumaroles. The radiating areas and temperatures of the fumaroles are: 102 m^2 at 50 °C; 36.1 m^2 at 100 °C; 19.2 m^2 at 150 °C; 12.1 m^2 at 200 °C. Areas correspond to an apparent temperature of ~35 °C at typical atmospheric conditions of 5 °C and 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



Explosion 11/08/07

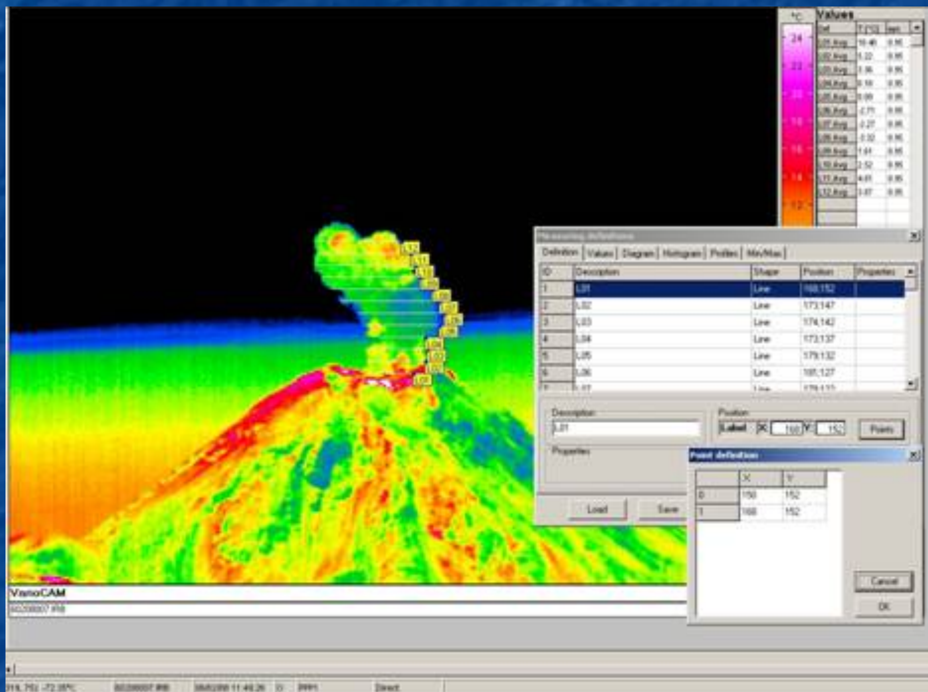
2nd pulse produces acoustic emission but no seismicity detected

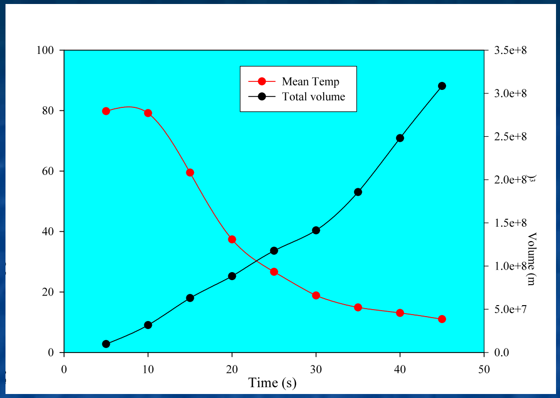
2 sources shown in thermal images – one rich in ash, the other poor

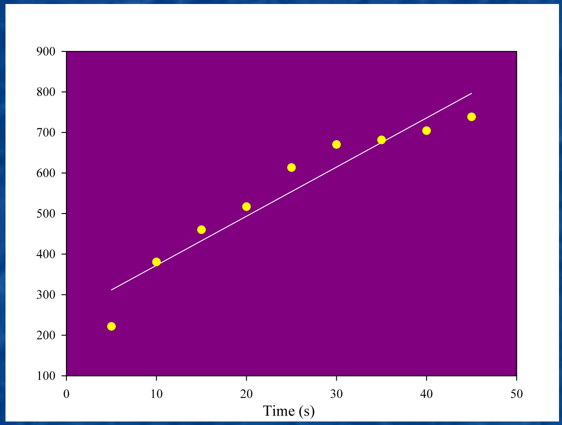
Infrared images

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

Column processes







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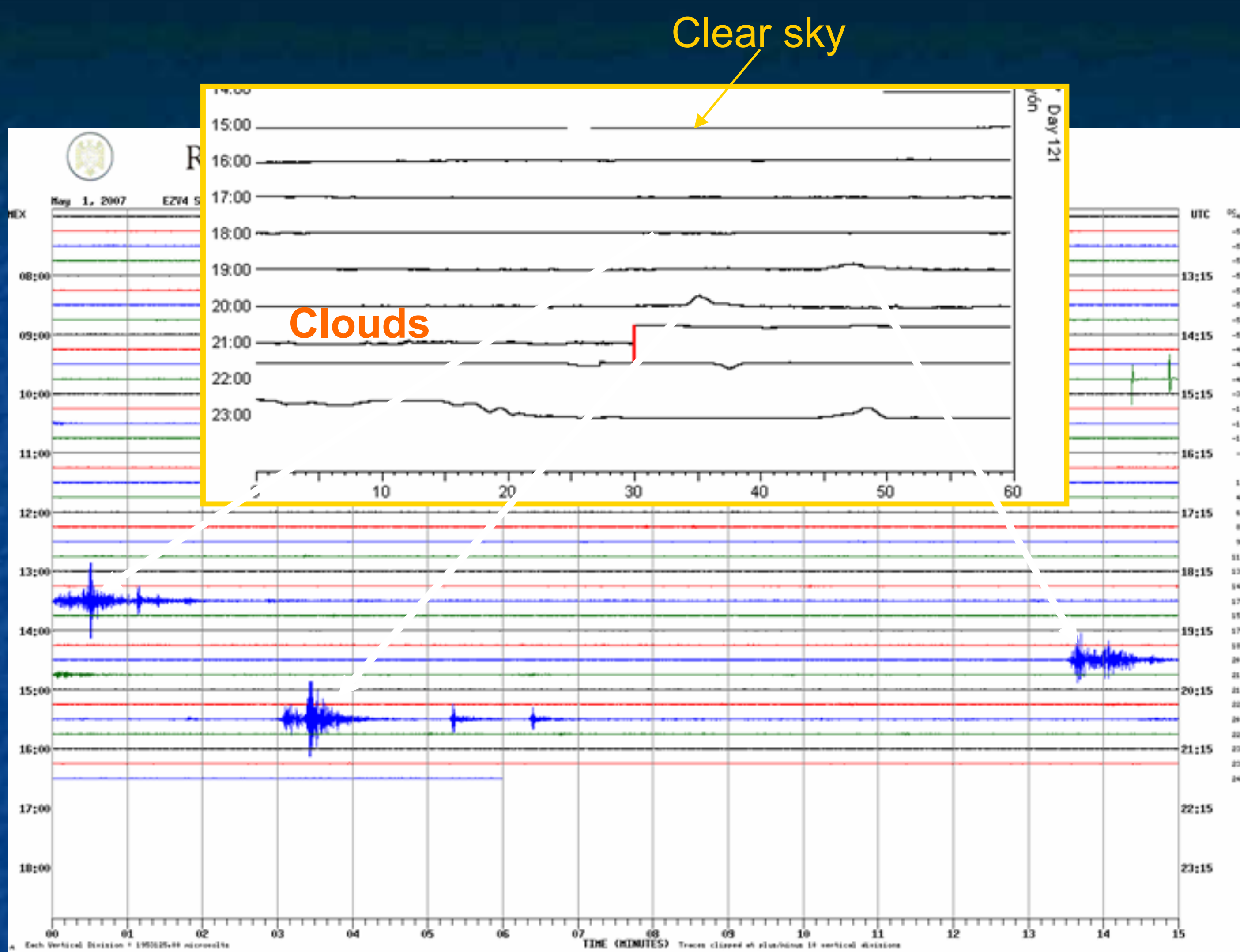
Thermal sensors - radiometers

- Permanent real-time monitoring system

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

Combined with seismic/ infrasound data
- Depth of the explosion

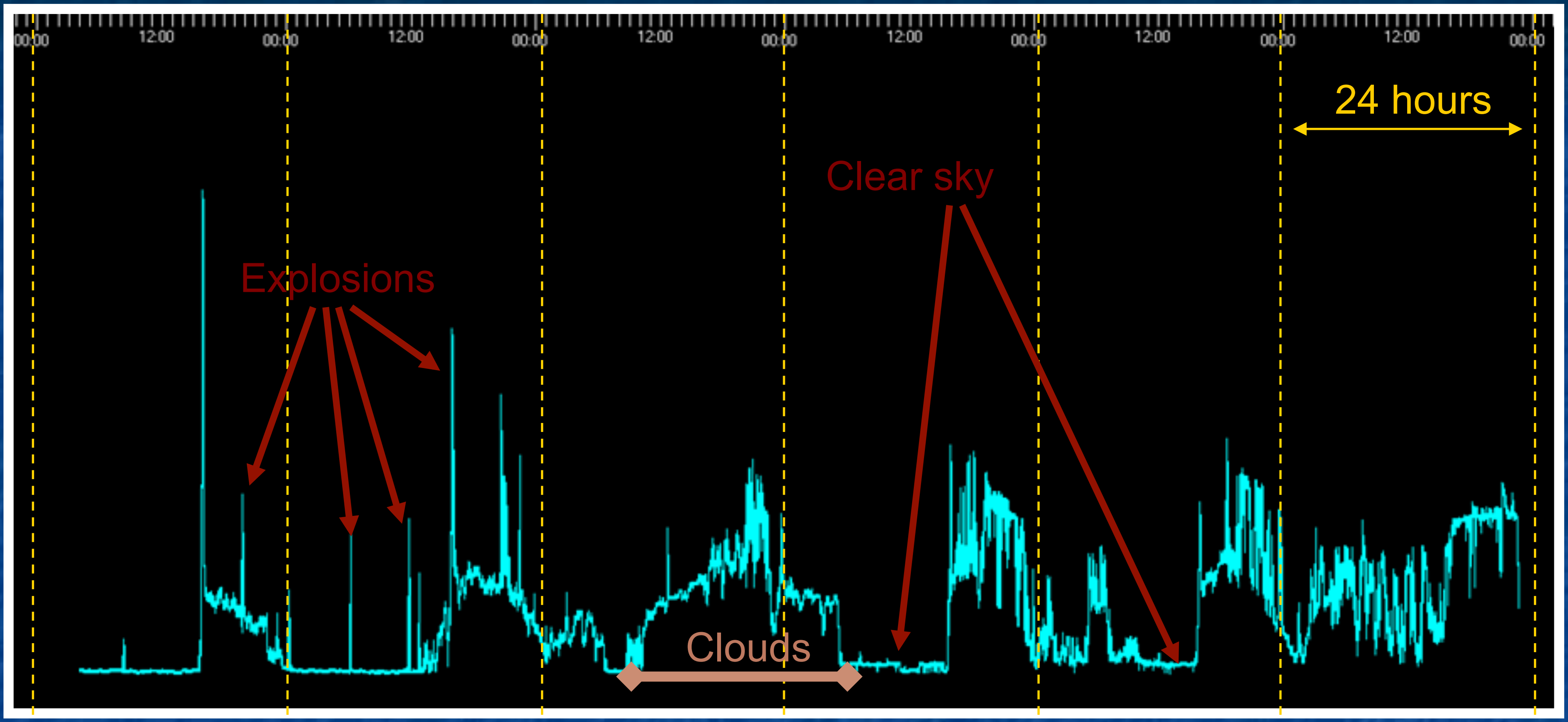
3 stations to be installed with telemetry



Real time monitoring system

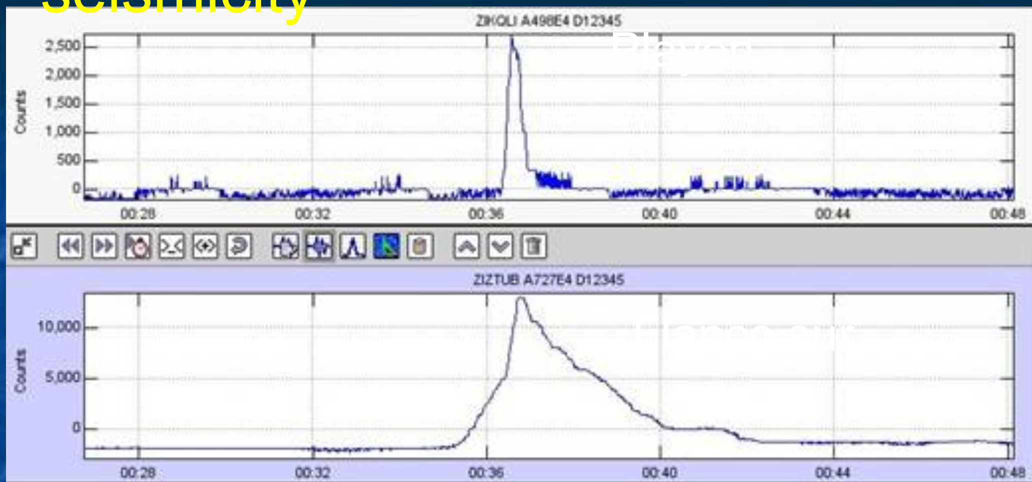
- comparison with seismic data

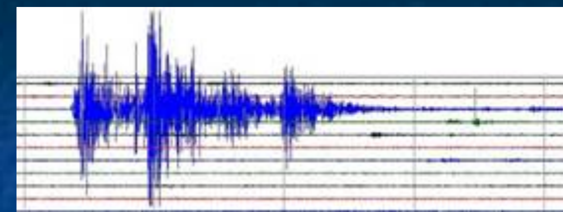
Radiometer data



- Relationship between seismicity and explosion column temperature is not straightfor
- 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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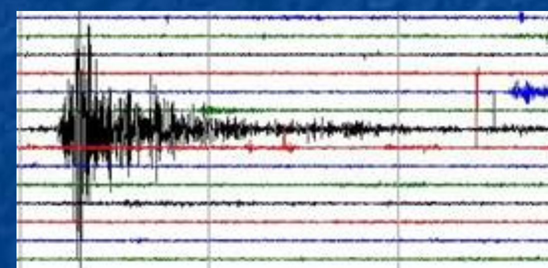

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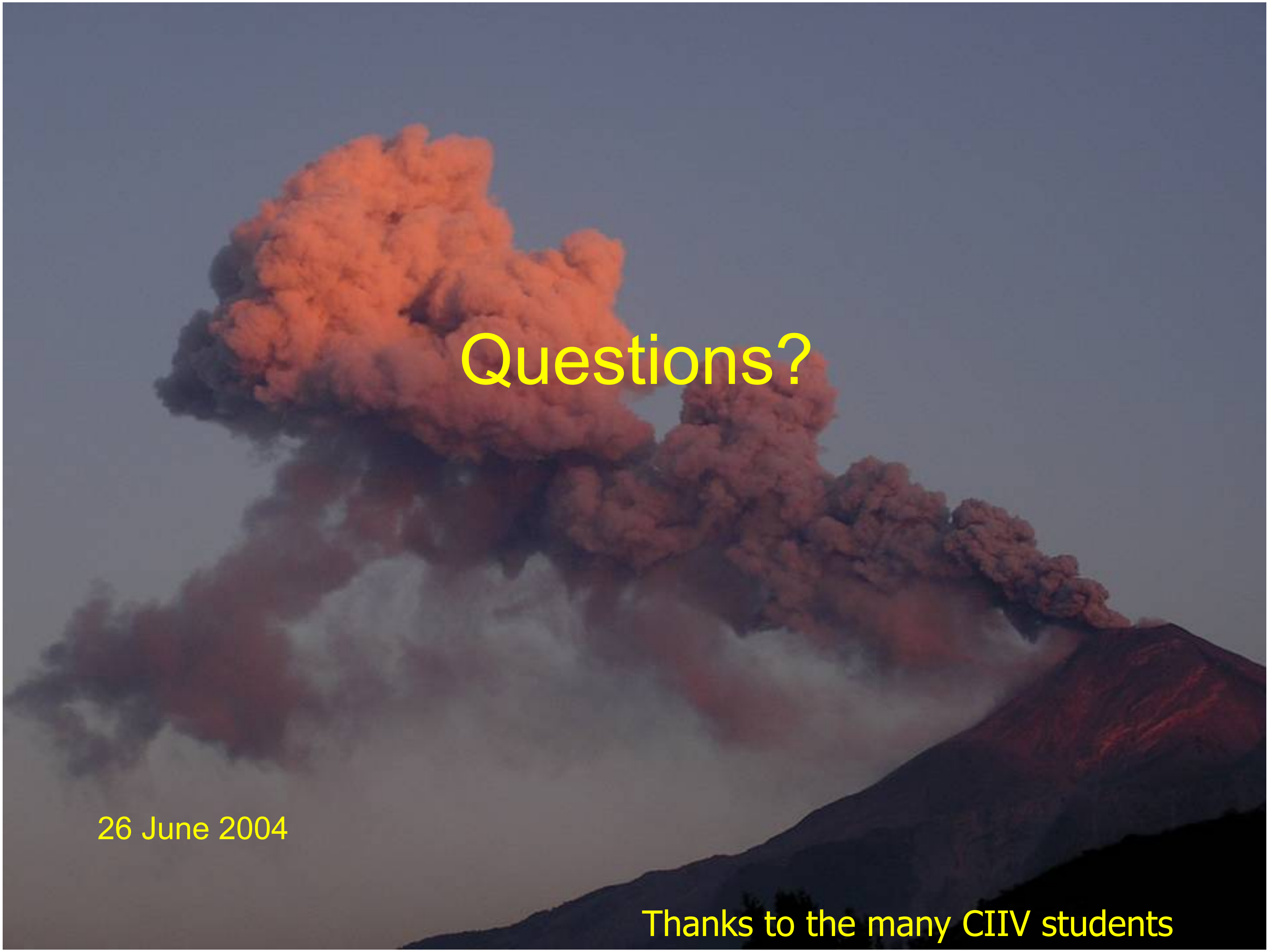
‘Cold’ gas releases occur but also hot puffs with no seismicity


Questions?
26 June 2004
Thanks to the many CIIV students