Bandung Institut of Technology
Lecture, April-May 2013

Remote sensing:
An efficient tool for volcanoes monitoring

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Merapi Volcano, Indonesia (2008), from National Geographic

Remote sensing :
observation of volcanoes from space,
a complementary approach to in-situ field measurements.

Outline of the course:

A Passive measurements : Require sunlight except for thermal measurements

- 1 Meteorological satellites (ash, gas detection and quantification)
- 2 Thermal measurements (eruption detection, effusion rate)
- 3. Optical imagery (DEM, structural studies, eruptive deposits characterization)

B Active measurements (radar): Do not require sunlight

1. InSAR
2. DEM
3. Deposits surface and thickness

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	Passive systems	Active systems: Ranging	Active systems: Imaging
VNIR	Aerial photography (5) Electro-optical systems (6)	Laser profiler (8)	
TIR	TIR imager (6)		
Microwave	Passive microwave radiometer (7)	Radar altimeter (8) Ground-penetrating radar (8)	Microwave scatterometer (9) Imaging radar (9)

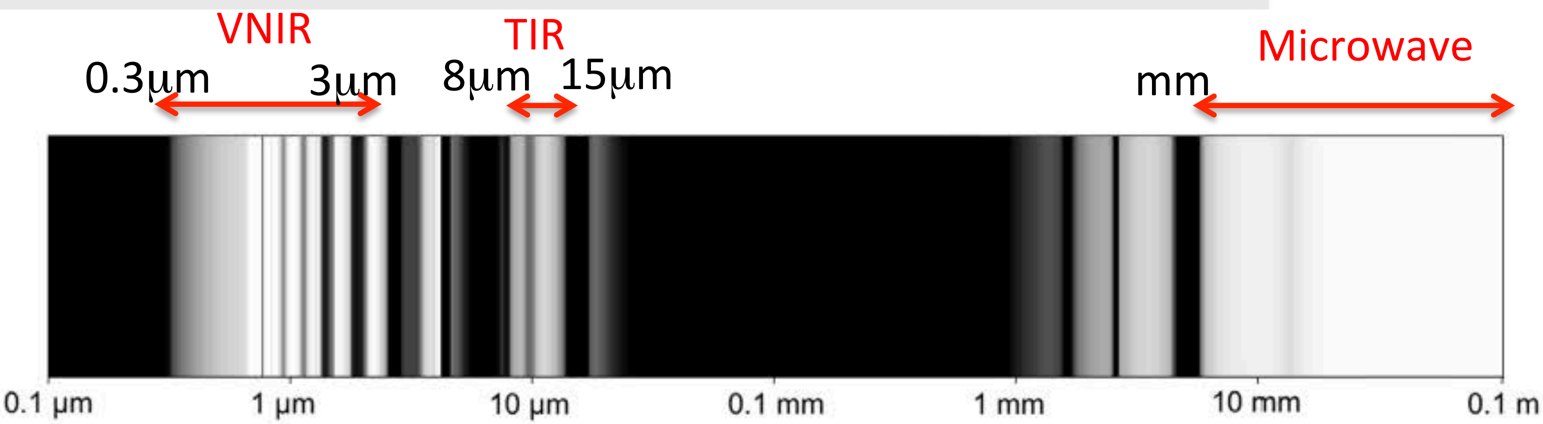

Figure 1.5. Transparency of the Earth's atmosphere as a function of wavelength (schematic). Black regions are opaque, white regions transparent.

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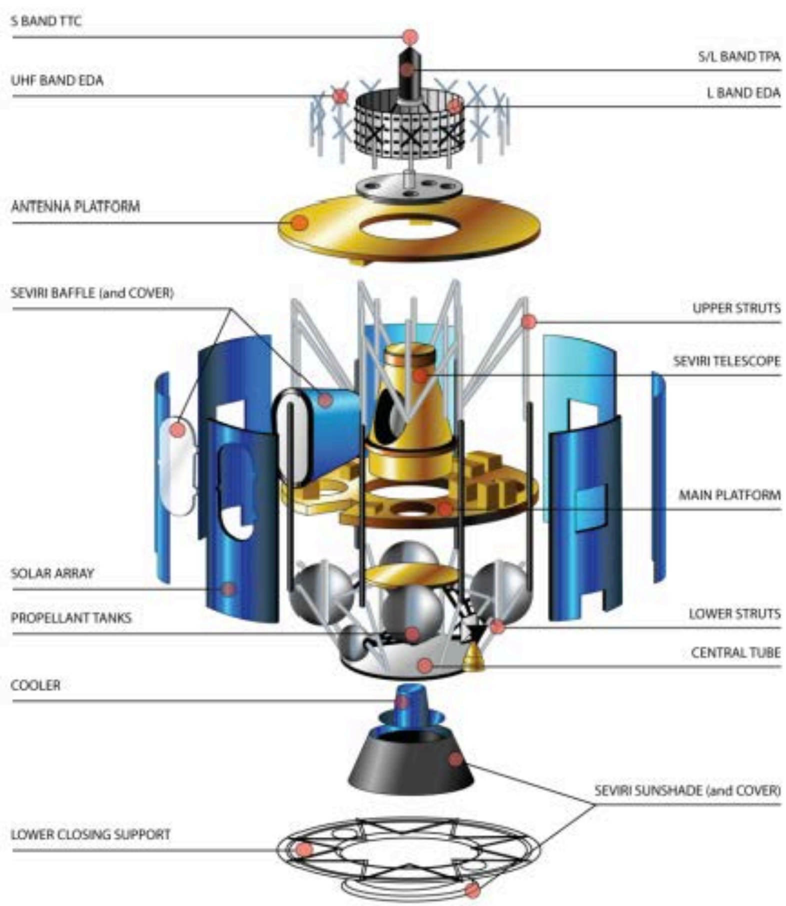
Meteosat Second Generation

4 geostationary meteorological satellites (Ø=3.2m,h=2.4m)

The MSG system provides accurate weather monitoring data through its primary instrument — the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) — which has the capacity to observe the Earth in **12 spectral channels**.



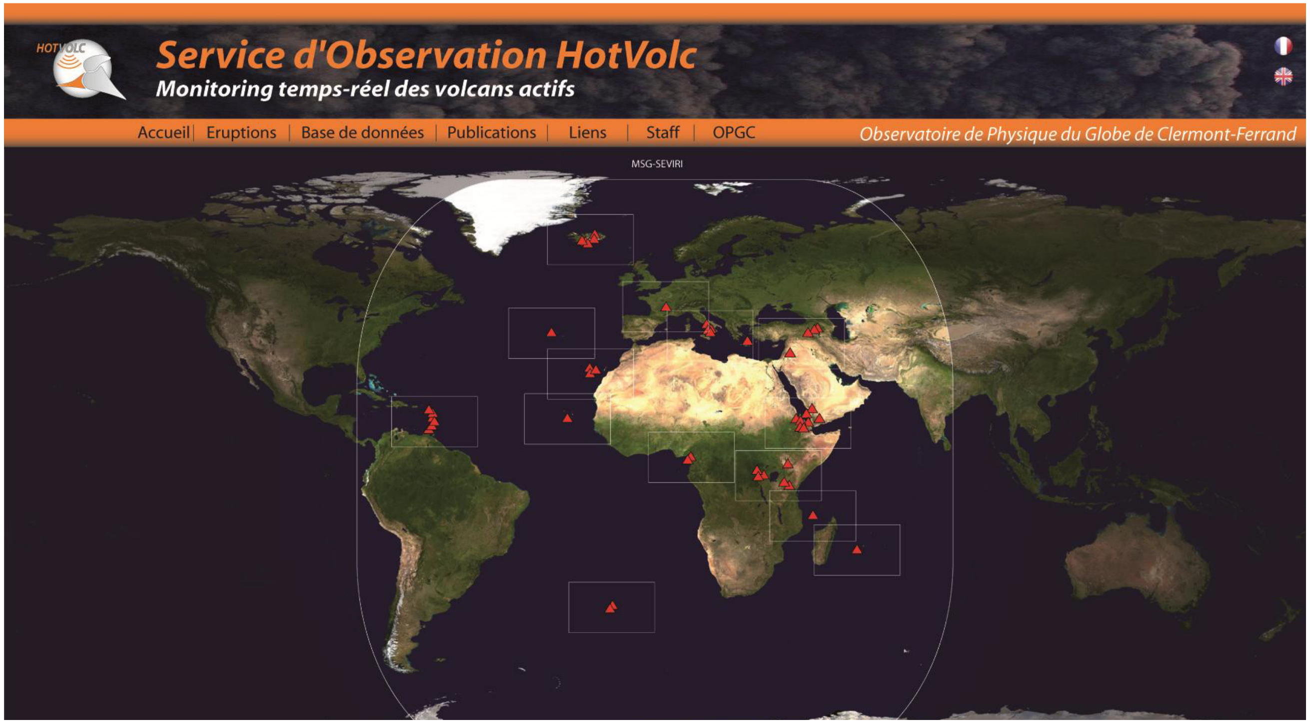
Repeat time: 15 min

4 channels in the visible
(1HRV –resolution 1km
otherwise resolution 3 km)
8 channels in the thermal IR
(resolution 3 km)

Meteosat Second Generation

<u>Can be used to :</u>

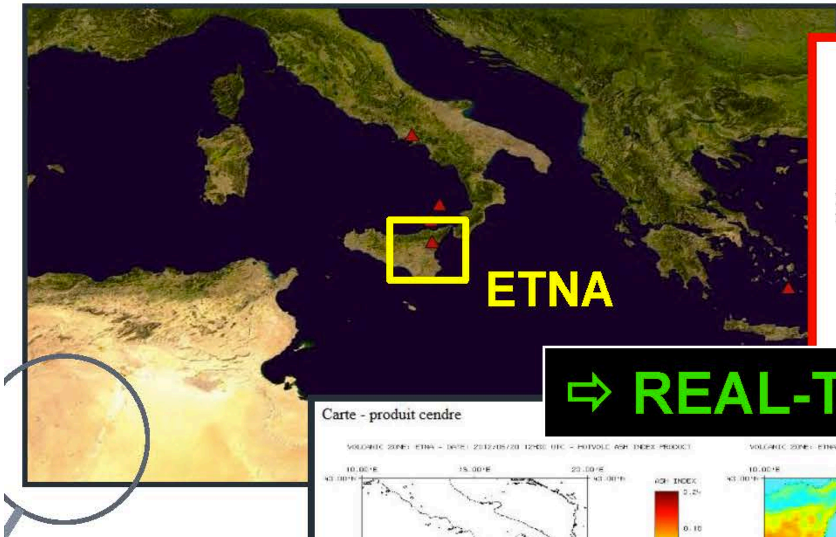
-detect ash and estimate ash concentration (*Prata et al, 89*)
-detect and estimate SO_2 concentrations (less efficient than UV absorption)
-to detect lava flows and estimate flow rates (thermal anomalies)

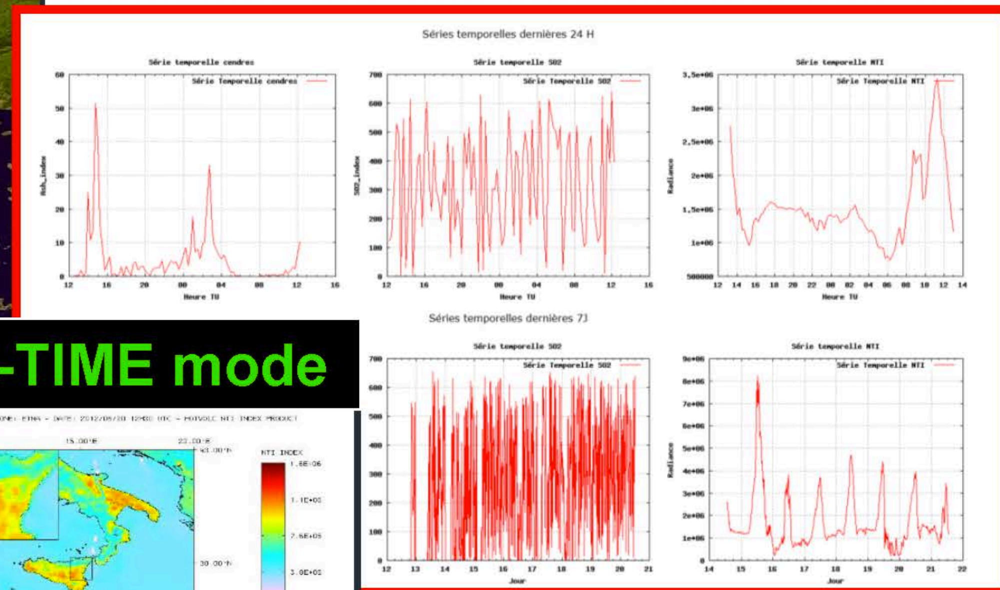


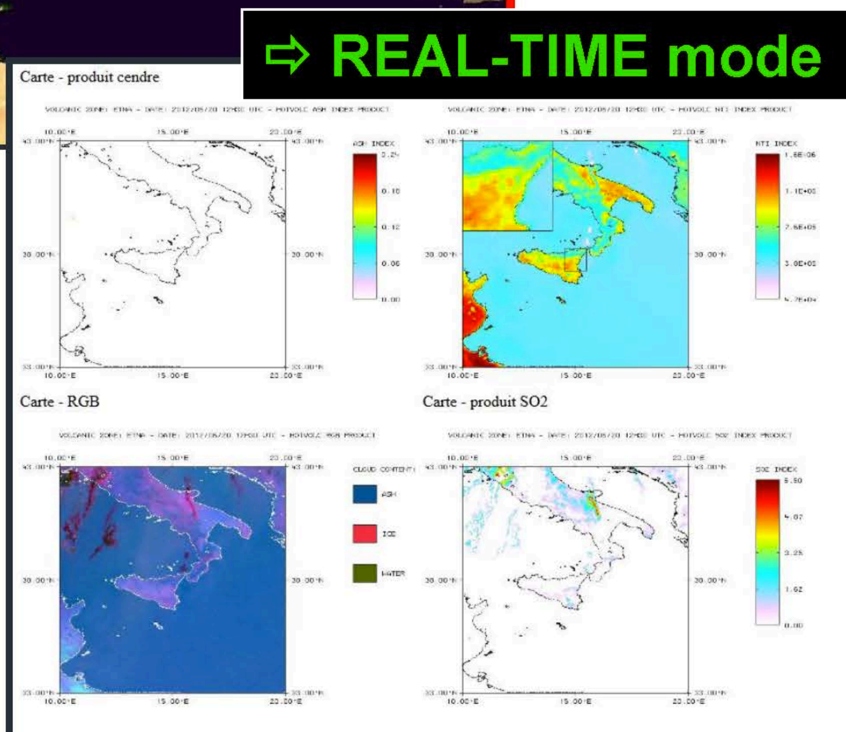
http://wwwobs.univ-bpclermont.fr/SO/televolc/hotvolc/index.php

HotVolc

Time series



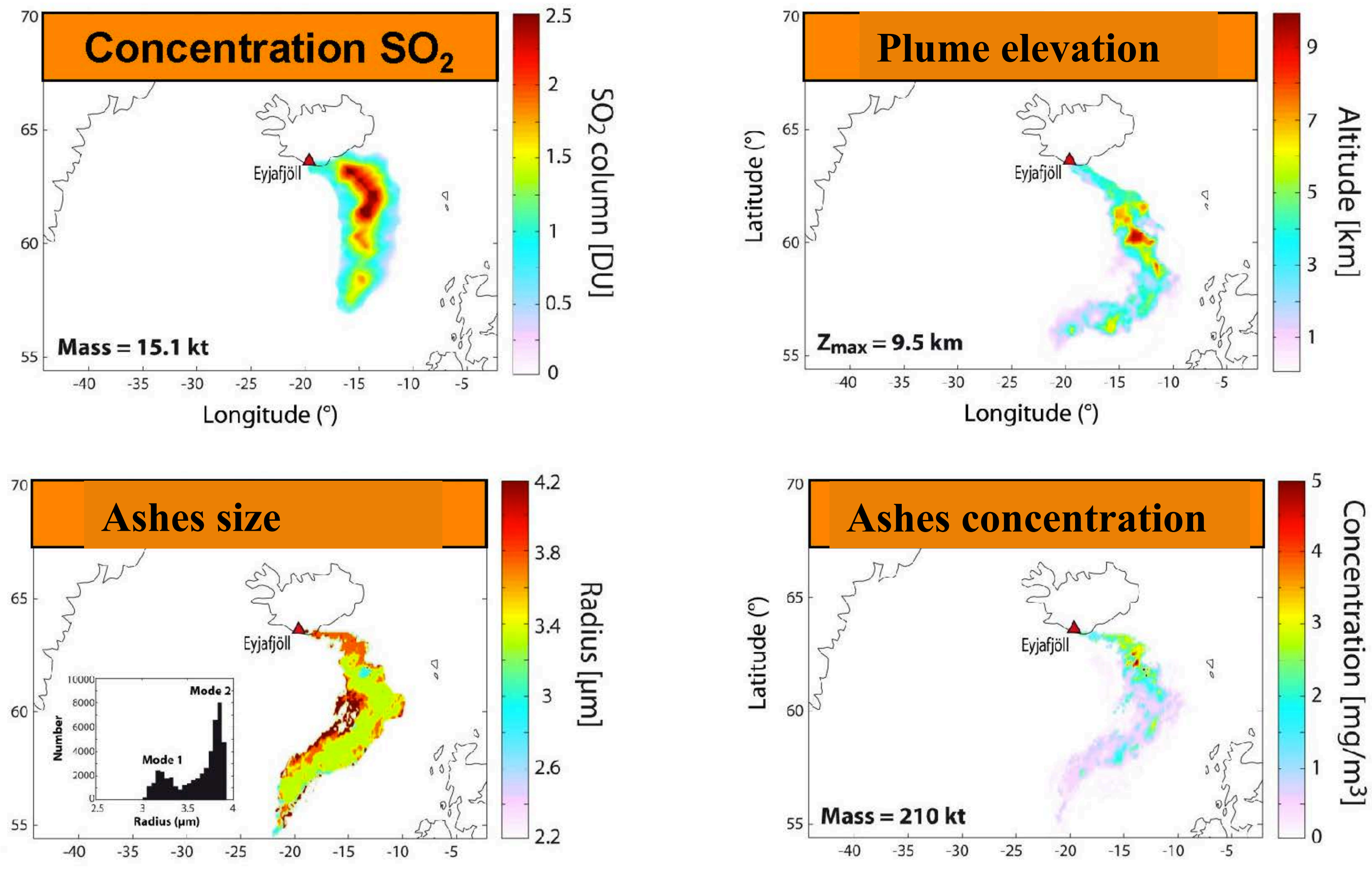




Maps

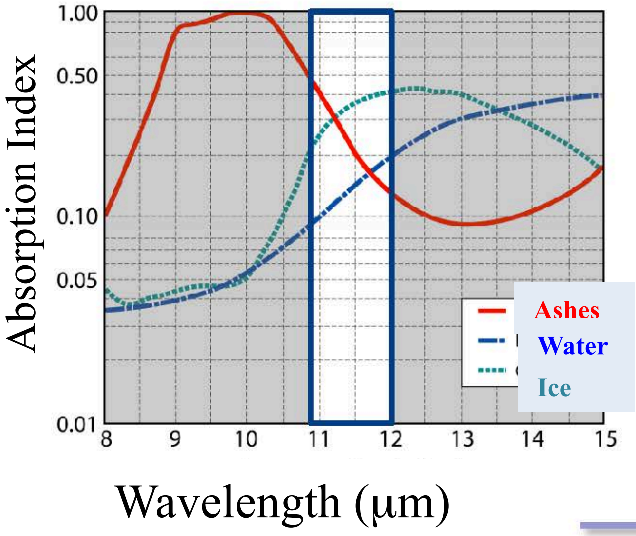
From Gouhier et al., CNFGG, 2012

HotVolc



From Gouhier et al., CNFGG, 2012

Ash detection: the « Split-Window » method from Prata, 1989



Between 10.8 µm and 12 µm

Ashes → Absorption **decreases**

Water → Absorption **increases**

Ice → Absorption **increases**

$$BTD[10.8\text{-}12] = Tb_{IR\ 10.8\ \mu m} - Tb_{IR\ 12\ \mu m}$$

Ash clouds

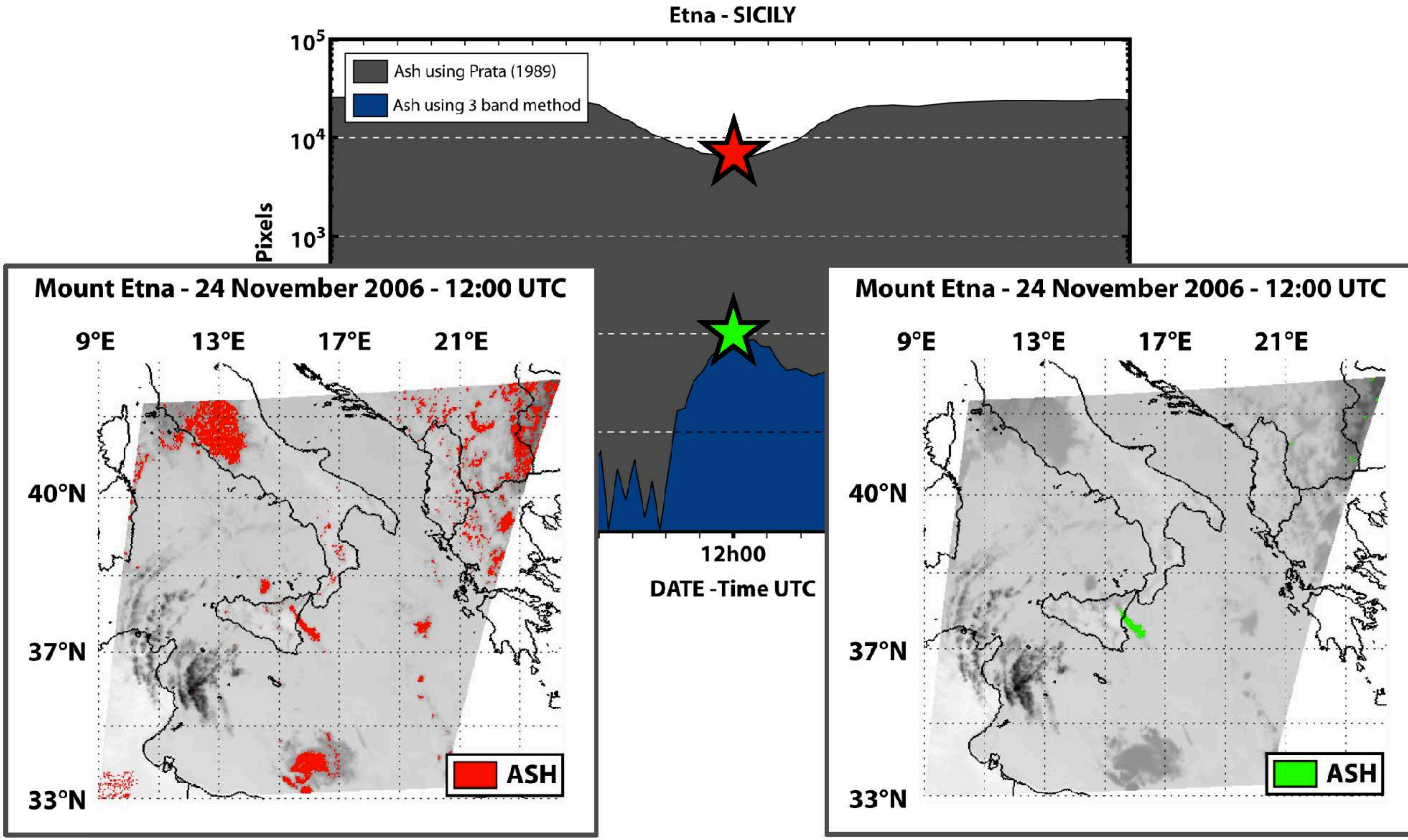
BTD[10.8-12] → **NEGATIVE**

Meteorological clouds

BTD[10.8-12] → **POSITIVE**

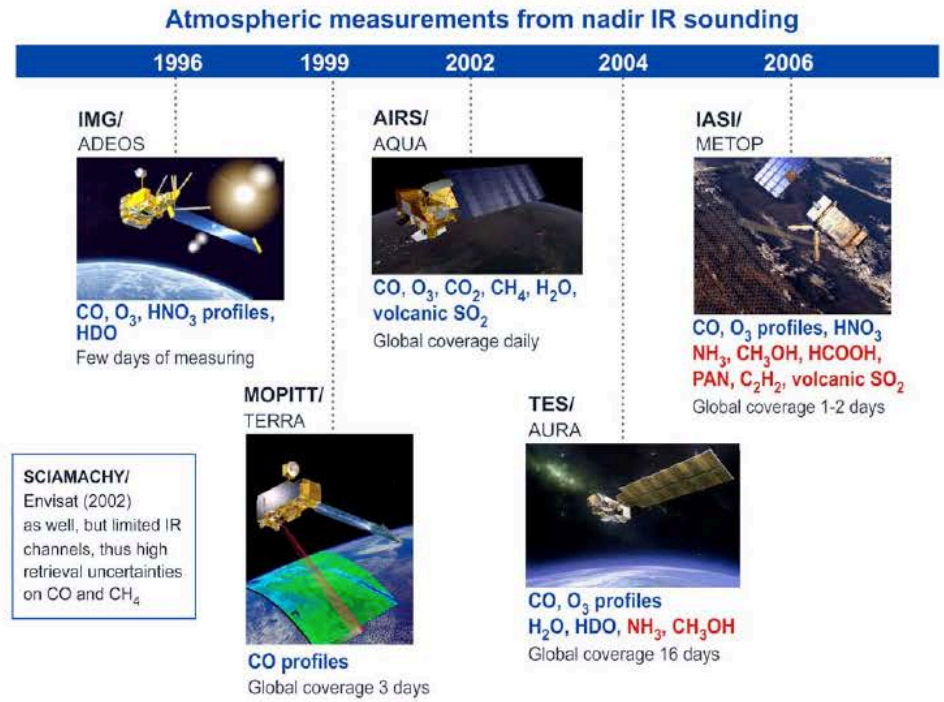
From Guehenneux et al., CNFGG, 2012

Ash detection: enhancement of the « Split-window » method



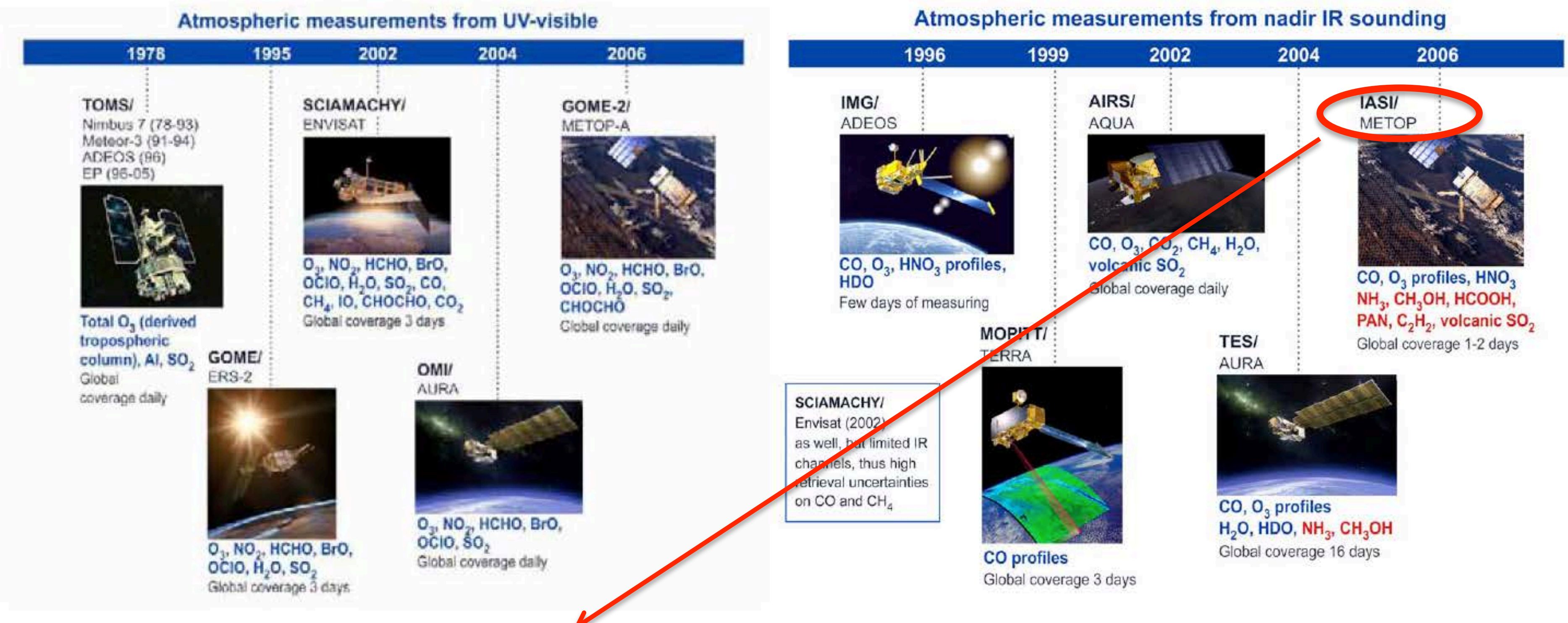
From Guehenneux et al., CNFGG, 2012

Meteorological Satellites available for IR-visible-UV observations



From Jegou et al., CNFGG, 2012

Meteorological Satellites available for IR-visible-UV observations



IASI (Infrared Atmospheric Sounding Interferometer)

–Infrared(3.62 μm to 15.5 μm)

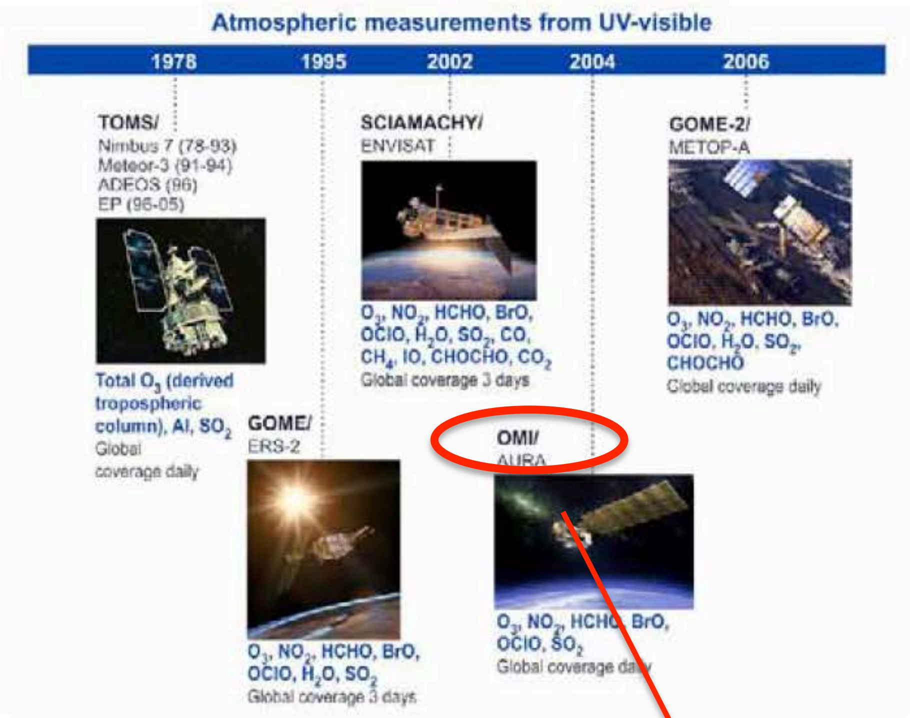
–⇒2 overpasses per day (9:30am, 9:30 pm local time)

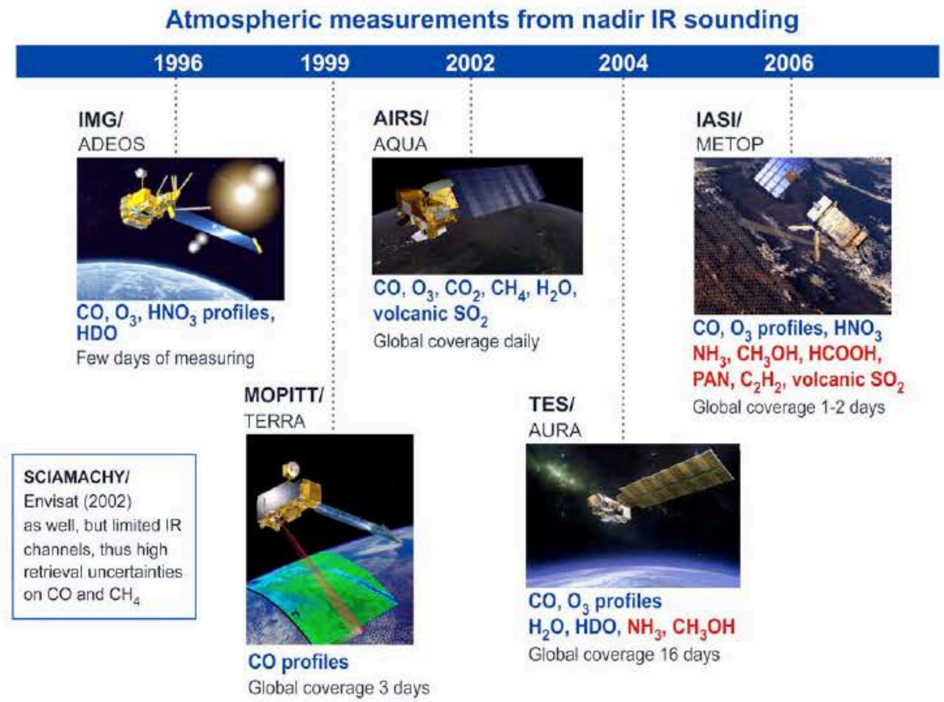
–Spatial resolution: (12 km x 12 km)

–Retrieval of SO_2 assuming a 7 km high plume.(Clerbaux et al. 09)

Detection of SO_2 above 5 km

Meteorological Satellites available for IR-visible-UV observations





OMI (Ozone Monitoring Instrument) NASA

–UV (306-380nm)

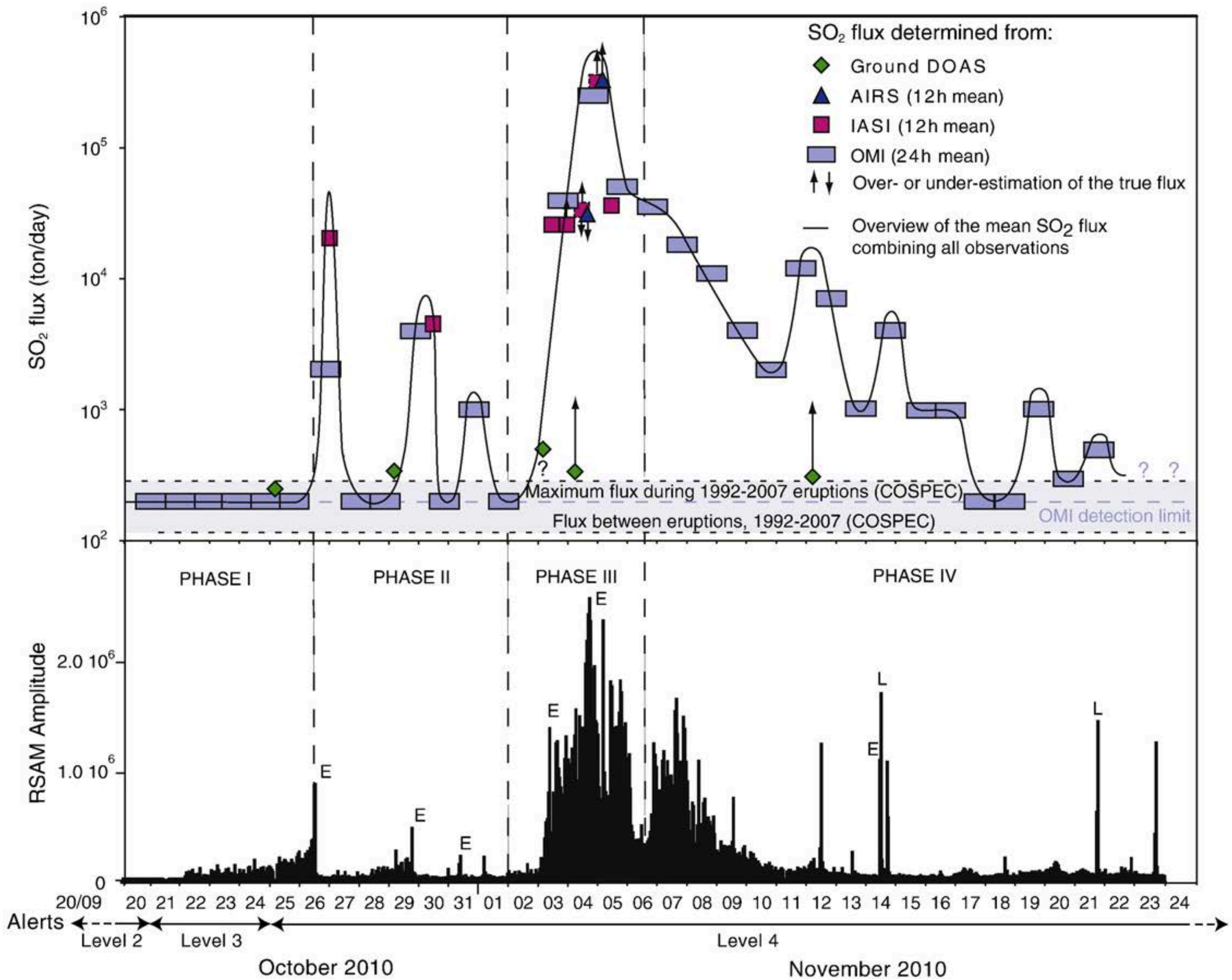
–⇒1 overpass per day (1h45pm local time)

–Spatial resolution: (13 km x 24 km)

Detection of SO_2 in the lower troposphere

Gas measurements for the 2010 Merapi eruption

Surono et al, 2013



E: explosion, L: Lahar

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DEM

Deposit surface and thickness

IR satellites are used to detect temperature anomalies

*MODIS (**Moderate Resolution Imaging Spectroradiometer**): NASA on Terra and Aqua
Spatial resolution 1*1 km

Information here: http://modis.higp.hawaii.edu/

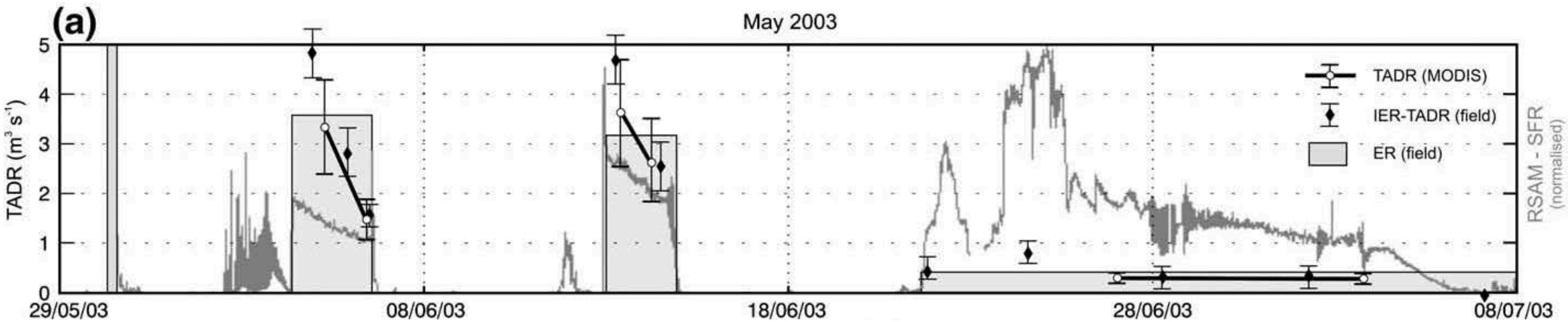
*AVHRR ***Advanced Very High Resolution Radiometer*** NOAA
Spatial resolution 1*1 km

*Landsat TM (Thematic Mapper), ETM+ (Enhanced Thematic Mapper Plus) NASA
Spatial resolution 30 m*30 m (resampled)

*ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) NASA on Terra
TIR Spatial resolution 90m*90m

IR satellites are used to estimate magma discharge rate

From T_{surf} -T_{amb}



Example for Piton de la Fournaise (Reunion Island) based on MODIS data (10% can be used)

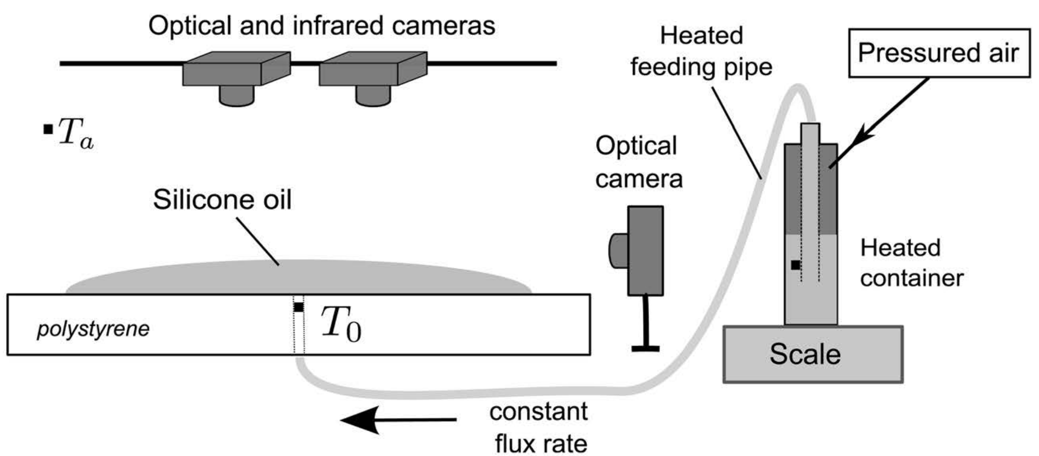
From Coppola et al, 2009

Experimental study to validate the use of thermal data

Garel et al, 2012

Aim of the study: to make the link between magma flow rate and the thermal signal measured by remote sensing.

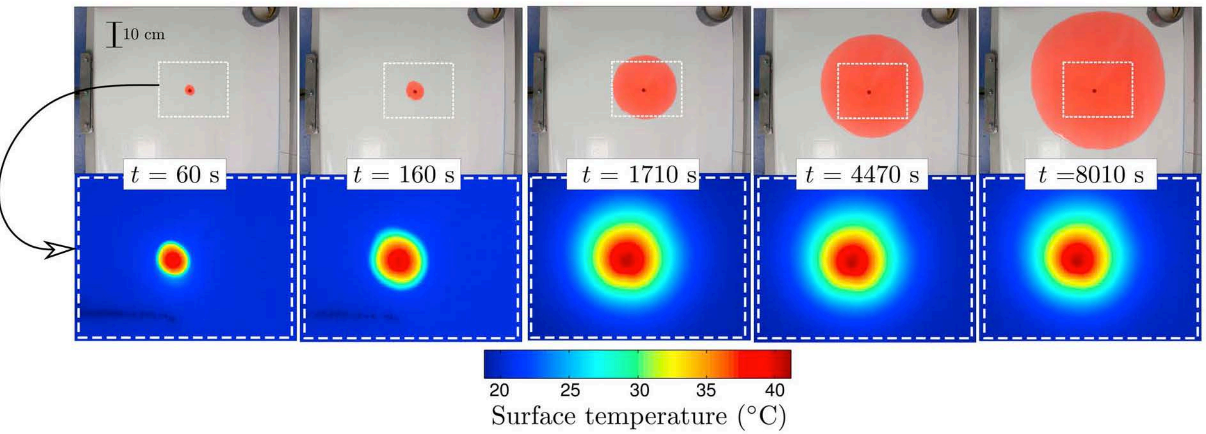
Study of flow and cooling of a fluid (μ=constant) injected at a constant flow rate.

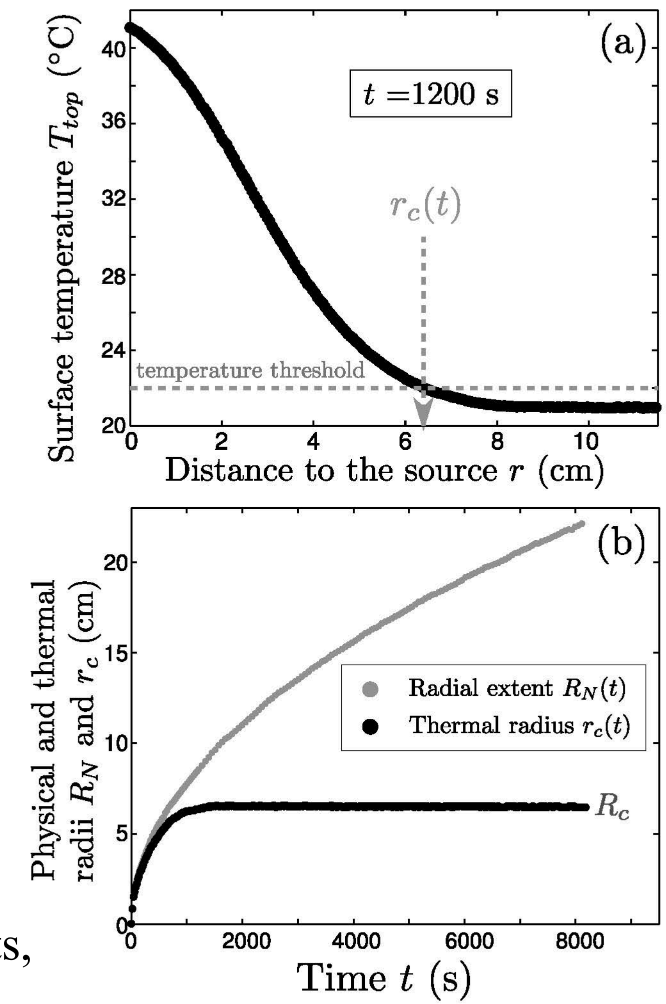


Experimental setup

Thermal signature of lava flows

Experimental results:





Analytical and numerical studies allow to quantify:

-the coefficient between r_c and magma flow rate (weakly dependant on magma viscosity)

-the time required to be in the stationnary state (highly dependant on magma viscosity: a few days for basalts, A few years for lava domes)

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DEM

Deposit surface and thickness

Optical Satellites (visible)

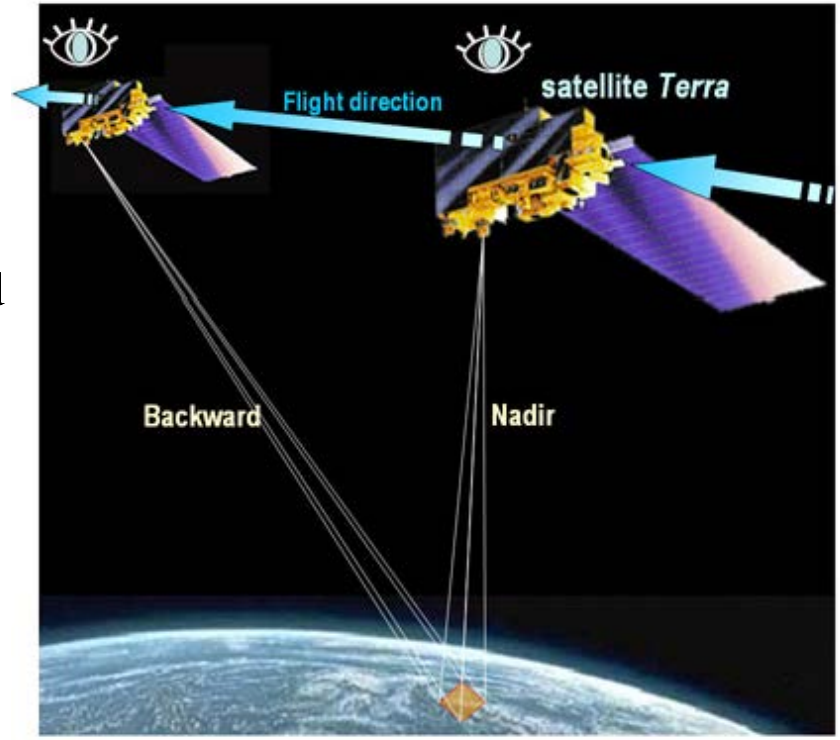
*Landsat: 1st satellite dedicated to Earth Observation (1972) (NASA)
Spatial resolution 15m
*ALOS AVNIR-2 (JAXA)
Spatial resolution 10 m, revisit rate of 2 days
*IRS (Indian Remote Sensing) (1995)
Spatial resolution 5.8m
*SPOT (CNES) (1986)
Spatial resolution 2.5m
*Pleiades (CNES) soon
Spatial resolution 0.5m
*IKONOS (1999)
Spatial resolution 0.84m
*Quickbird (2001)
Spatial resolution 0.6m
*Geoeye1 (2008)
Spatial resolution 0.5m

Image from Pleiades (visible)

Image Pleiades, Egypt, *2012 CNES Distribution Astrium Services / Spot Image*

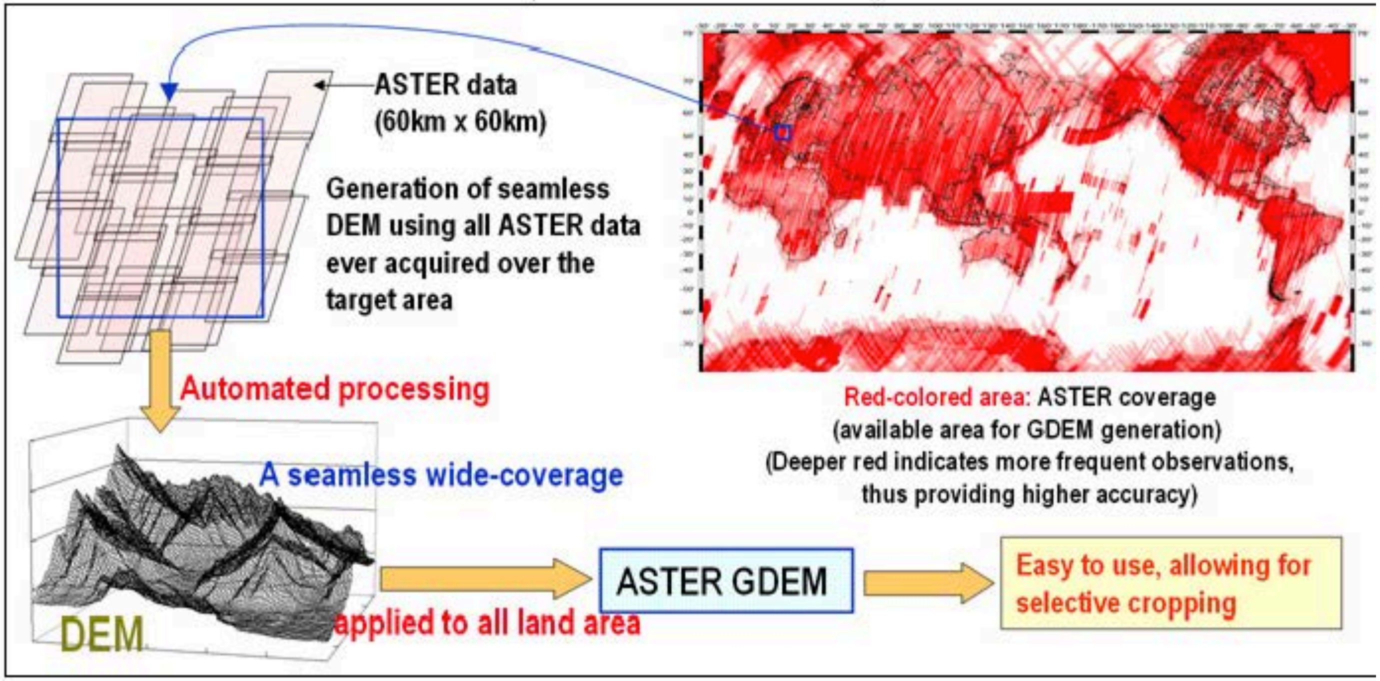
Use of optical images to produce DEM
Ex: ASTER

DEM is generated from a stereo-pair of images acquired with nadir and backward angles over the same area



Use of optical images to produce DEM
Ex: ASTER

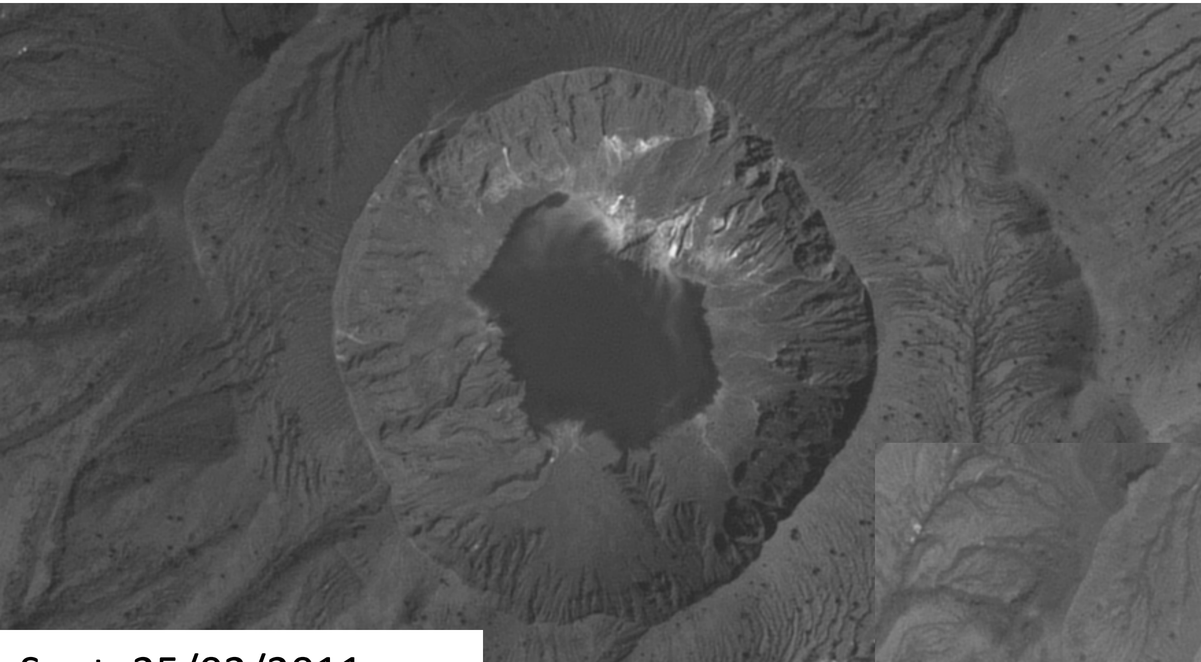
Concept of ASTER G-DEM development



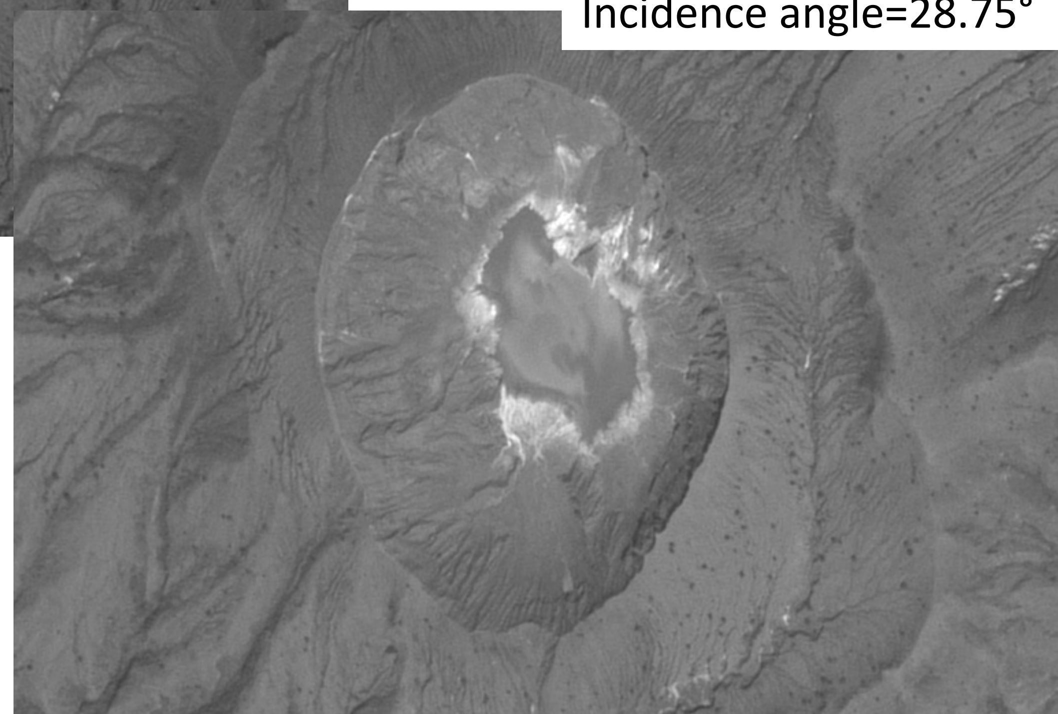
Images spatial resolution : 15 m

DEM with 30 m spatial resolution, you can download it for free

Stereogrammetry (SPOT 2.5m)

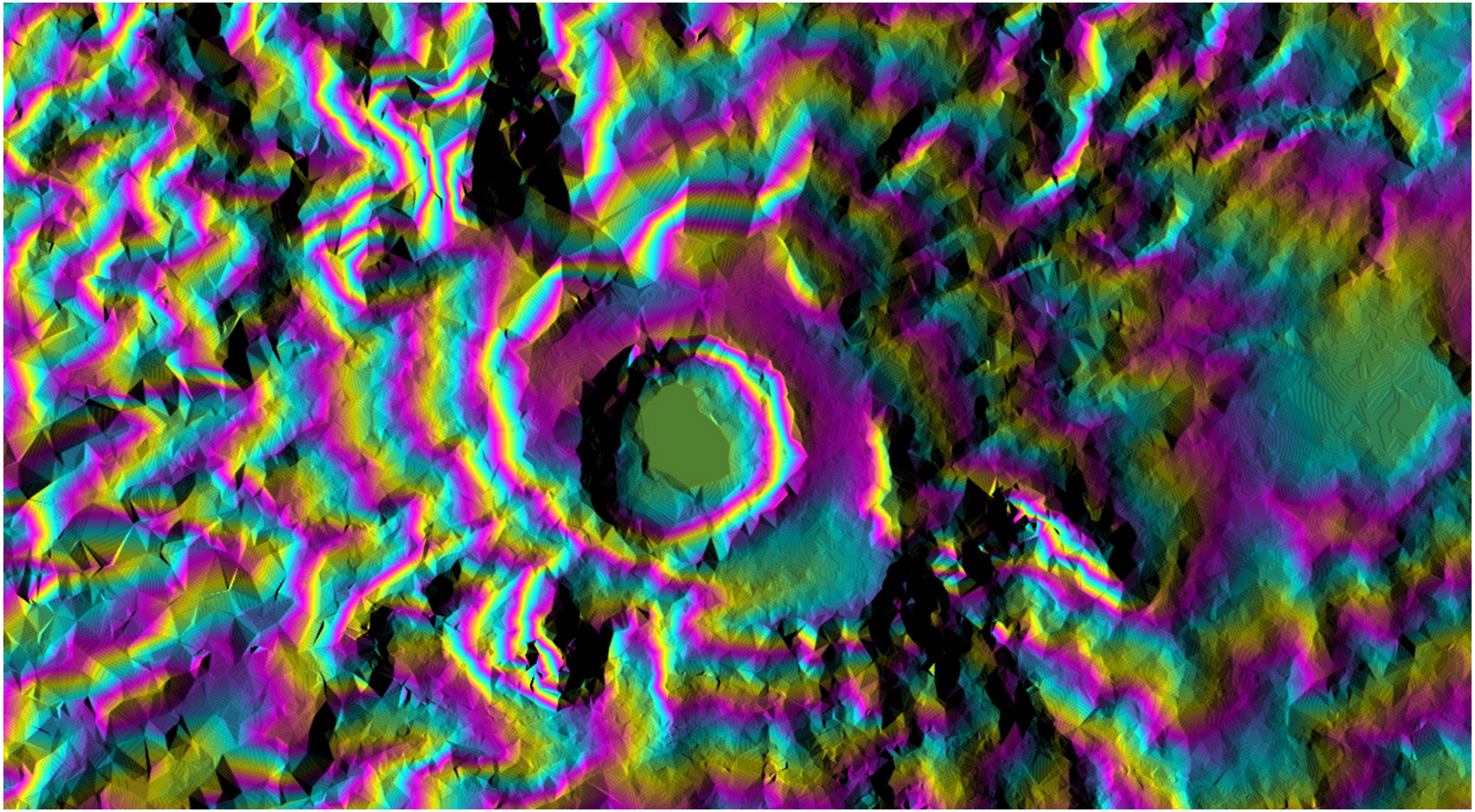


Spot: 25/02/2011
Incidence angle= 1.38°



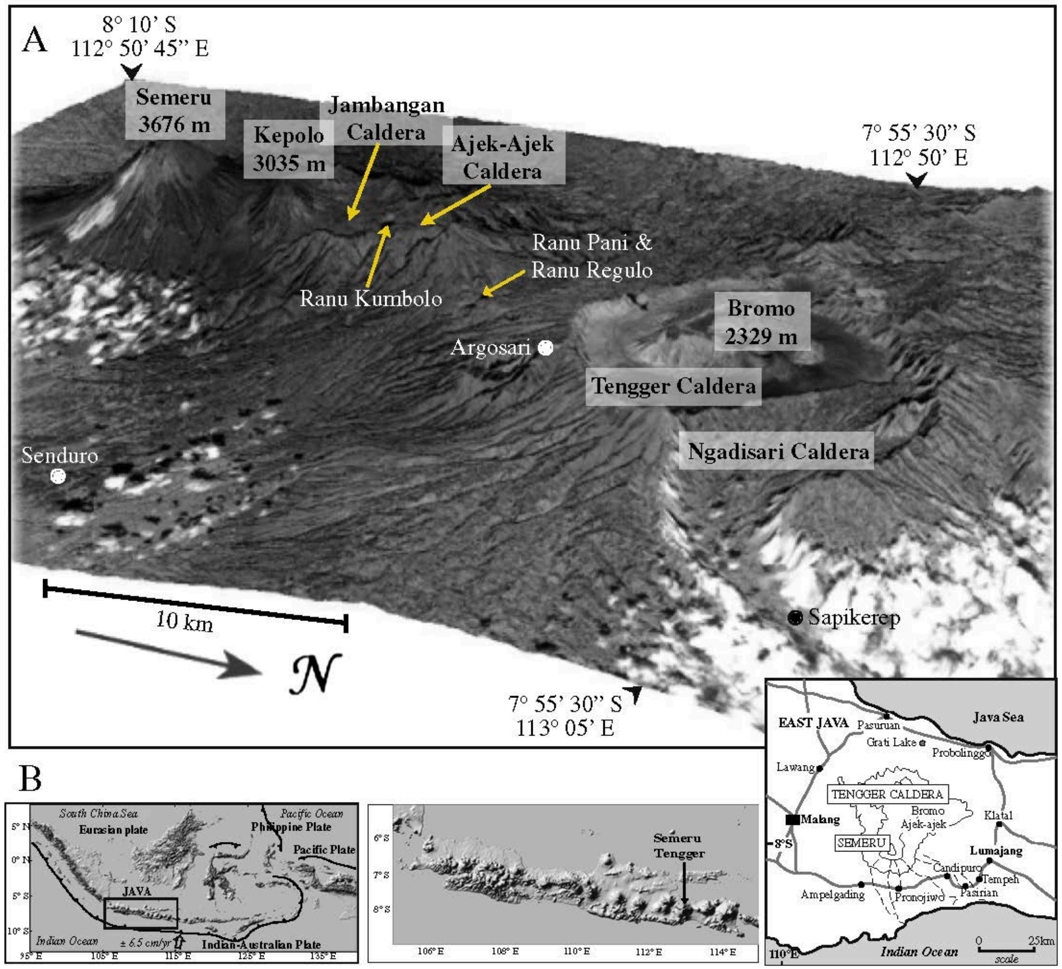
Spot: 6/03/2008
Incidence angle=28.75°

Stereogrammetry (SPOT 2.5m)



1 fringe is for 100 m

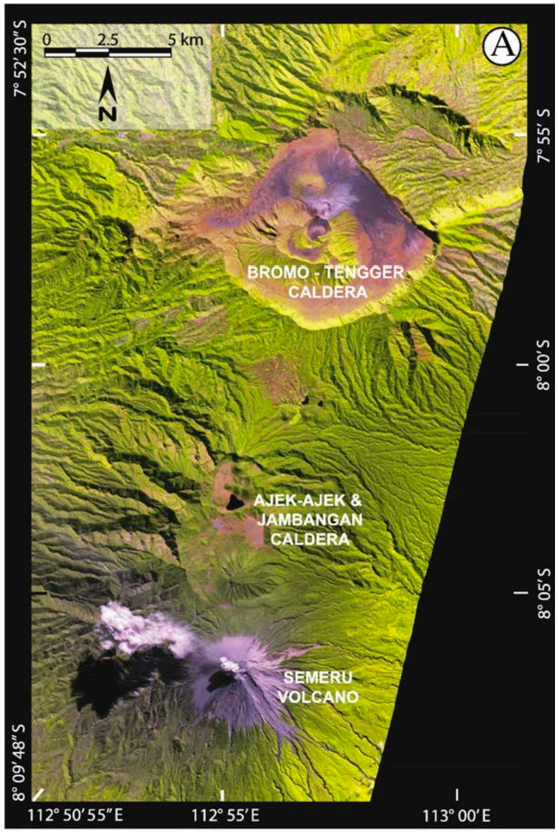
Structural analysis of Semeru



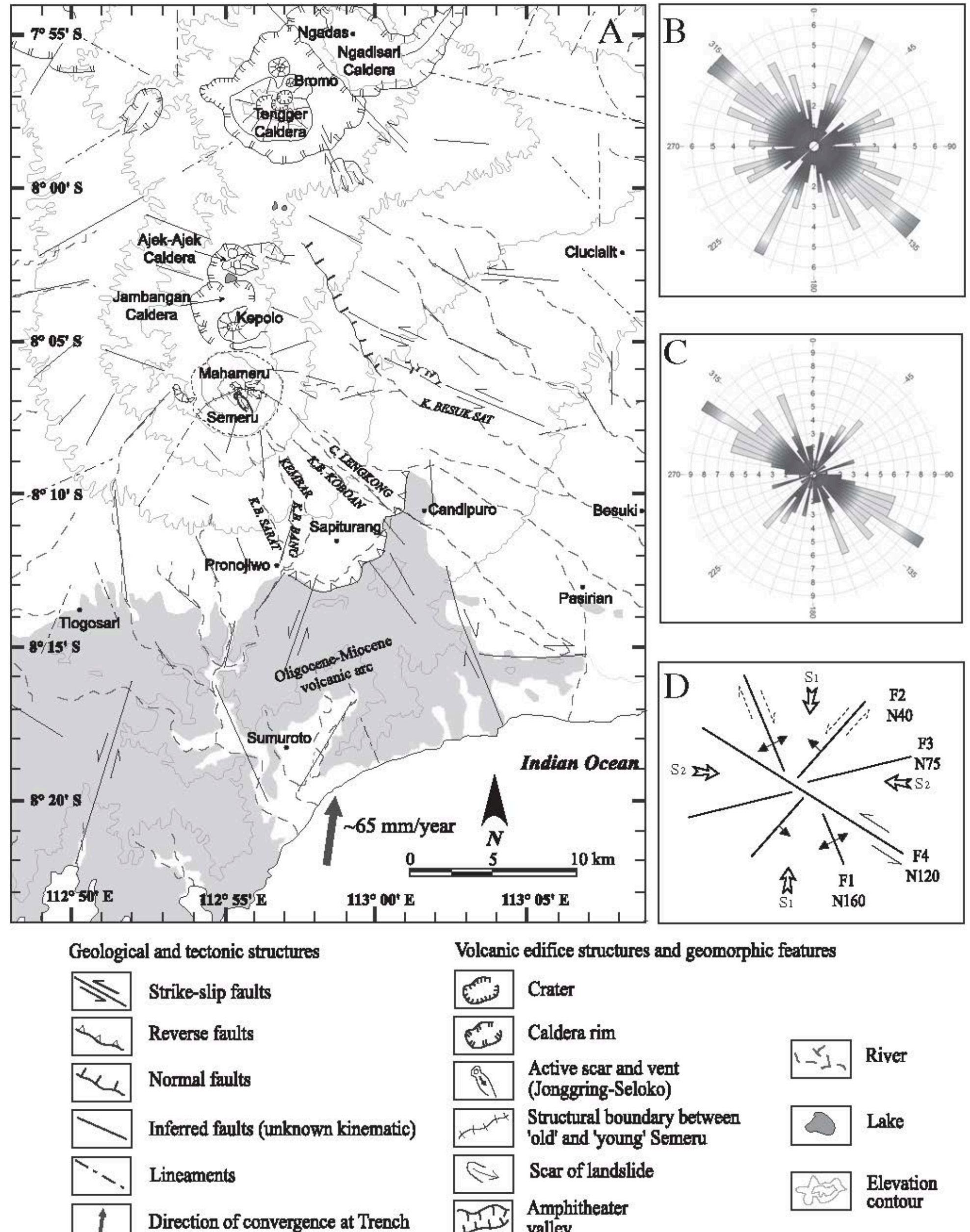
The 11/08/2003 SPOT5 image, looking SW and draped on the SRTM DEM

From Solikhin et al, 2012

Structural analysis of Semeru

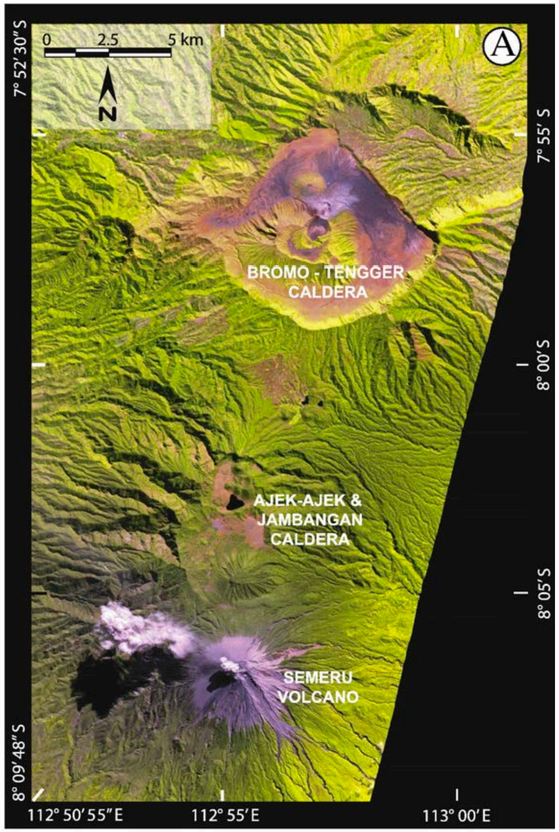


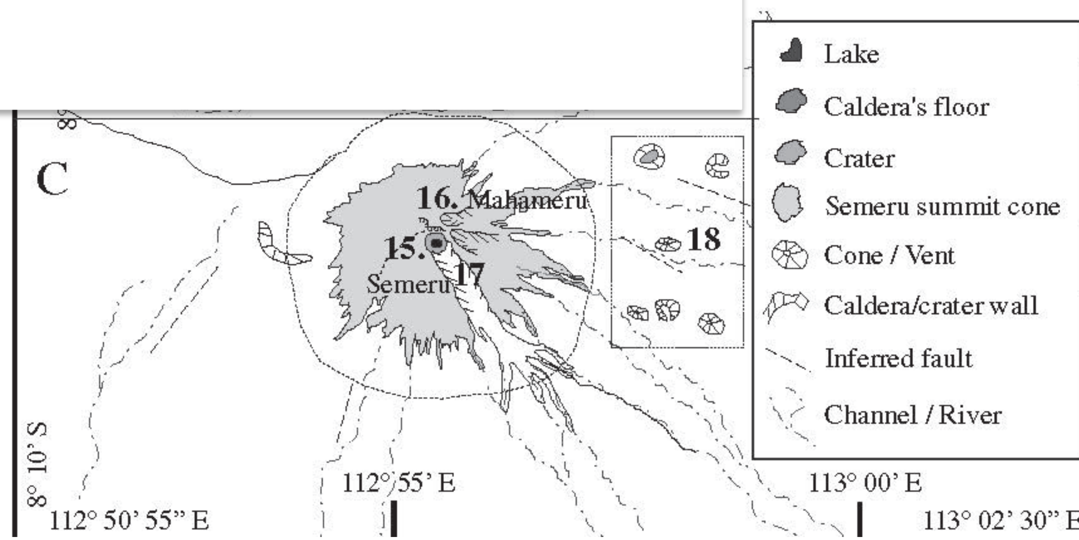
Spot 5 (2.5m)



From Solikhin et al, 2012

Deposits study





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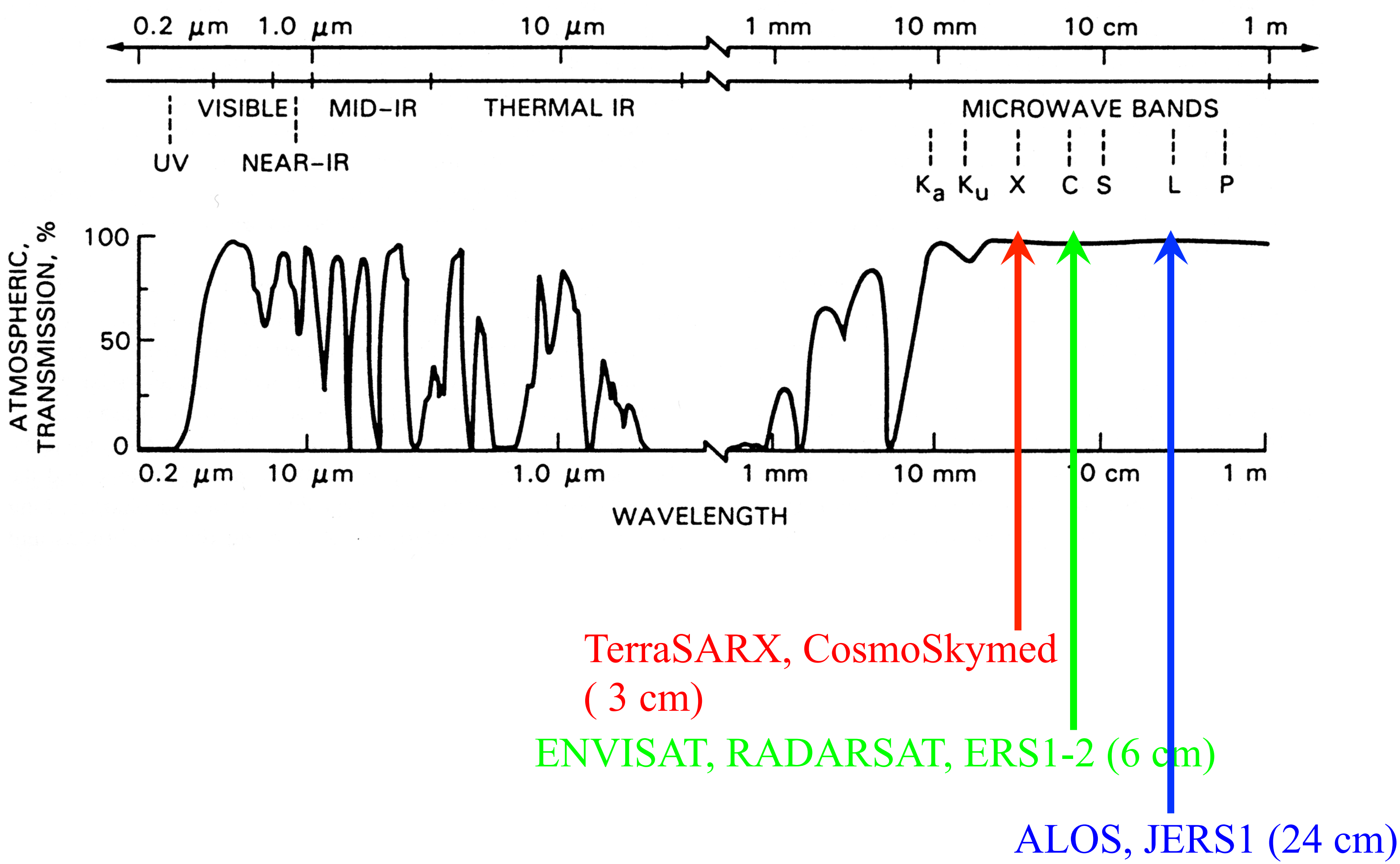
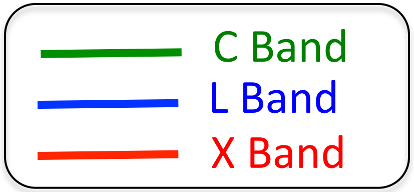
Wavelength used by SAR imagery

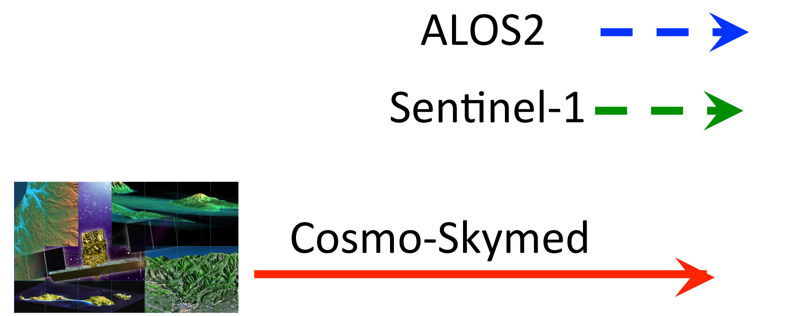


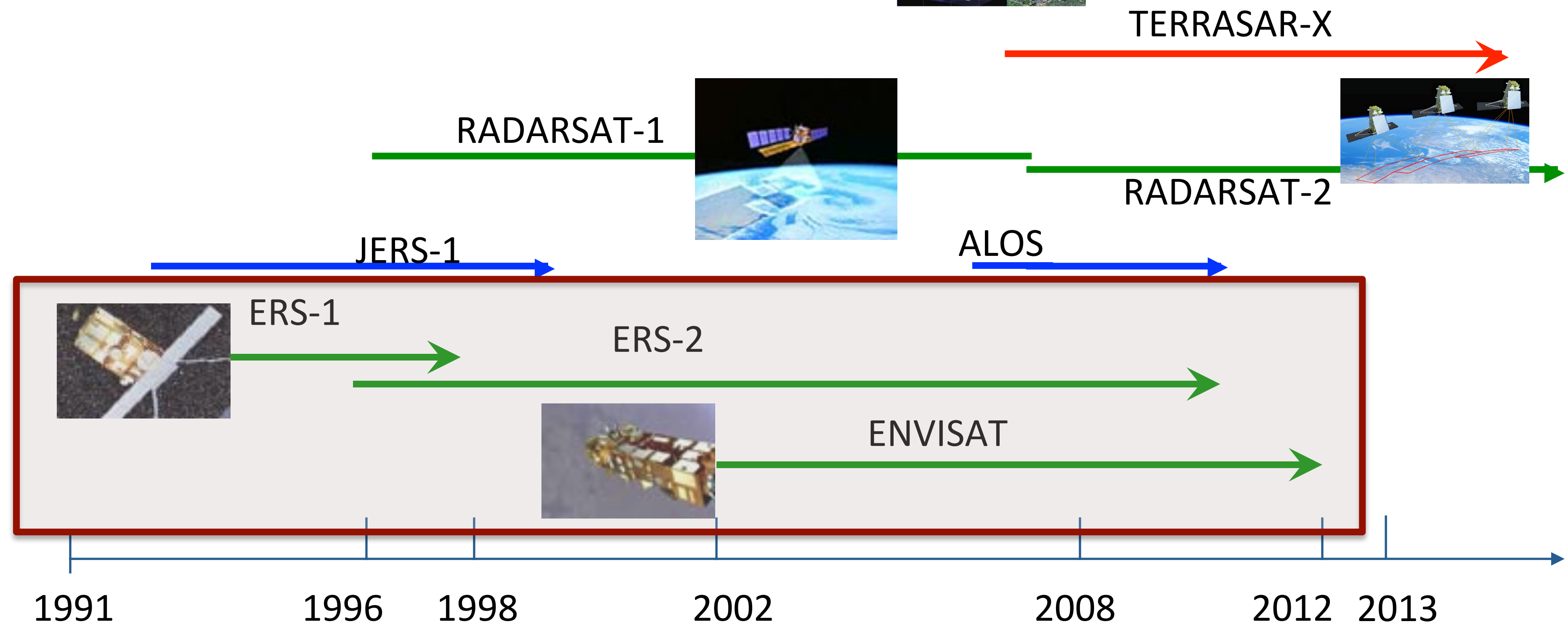
Satellites



Spatial and temporal resolution is improving

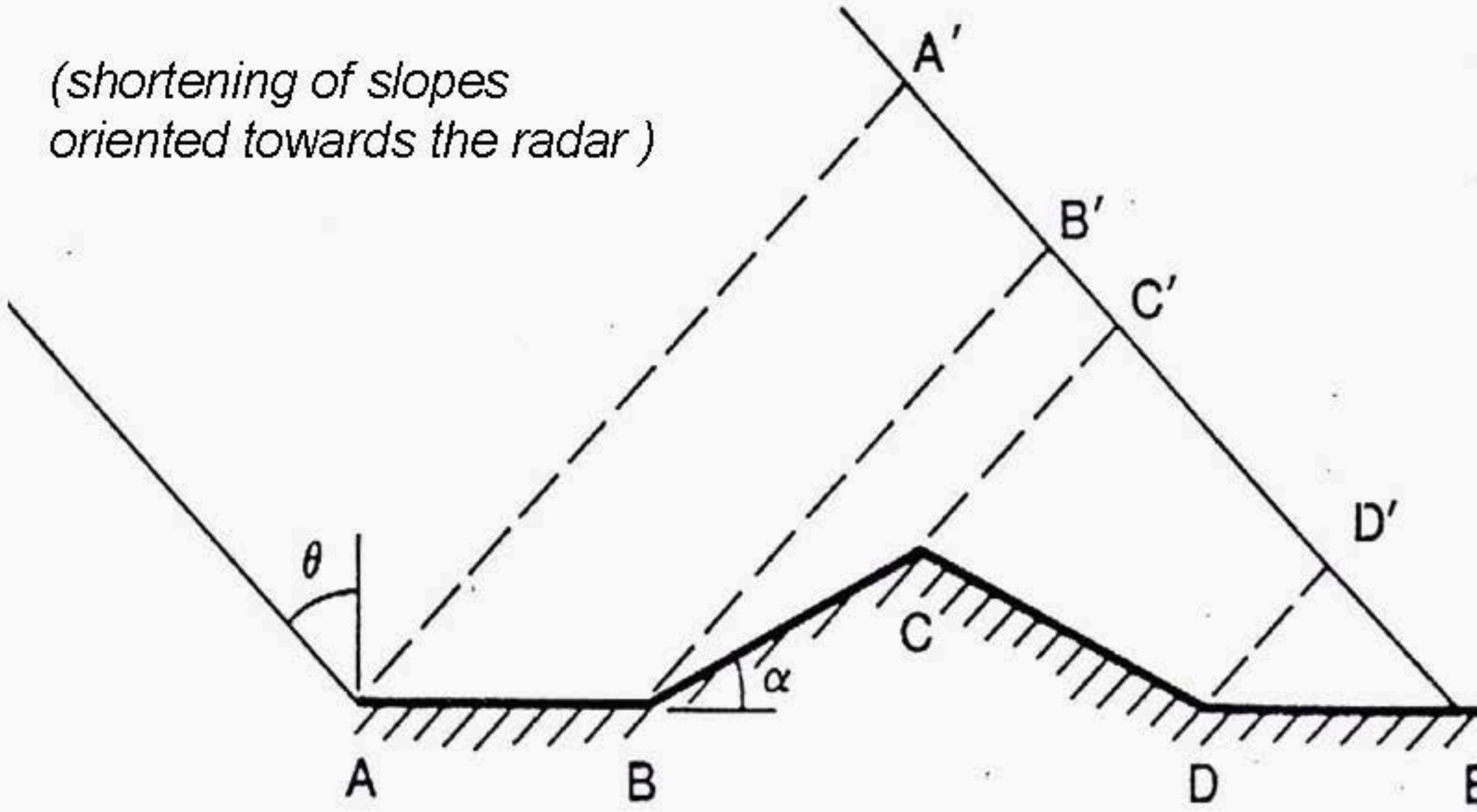
A large amount of data is expected around 2015 with Sentinel 1





SAR geometry

- **Foreshortening**



$$A'B' = AB \sin\theta,\ B'C' = BC \sin(\theta-\alpha),\ C'D' = CD \sin(\theta+\alpha)$$

InSAR provides maps of surface displacement in Line of Sight

Exemple ENVISAT images on Colima volcano

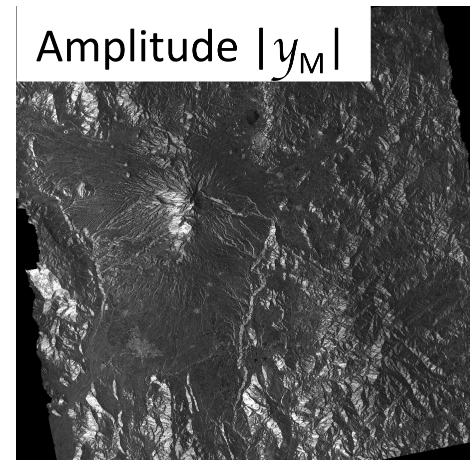
2 acquisitions radar: → Master Image (M)
→ Slave Image (S)

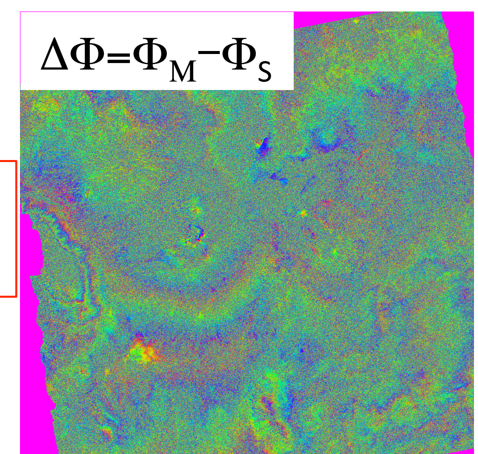
Couple of images characterized by: B⊥, ΔT

$$Int = y_M y_S^* = |y_M||y_S| exp(j(\phi_M - \phi_S))$$

$$\Phi_M - \Phi_S = \Delta\Phi = \Delta\Phi_{spatial}(B_{perp}, z) + \Delta\Phi_{atmo} + (4\pi/\lambda)\, d + \Delta\Phi_{noise}$$

1 fringe corresponds to a displacement of λ/2 in the Line of Sight
Precision around 1 cm





InSAR can also be used to produce DEM

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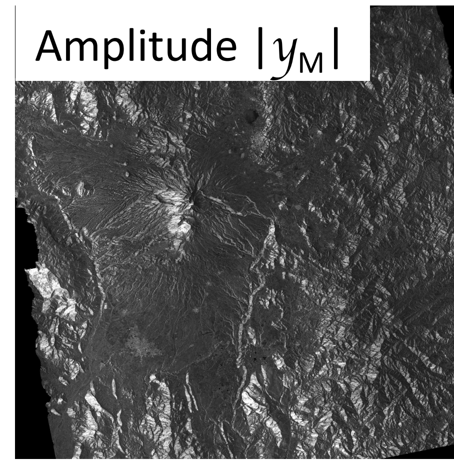
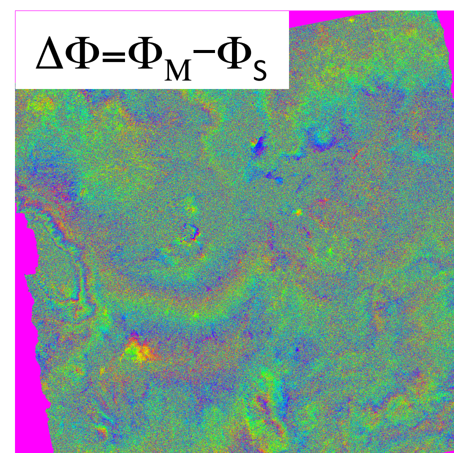
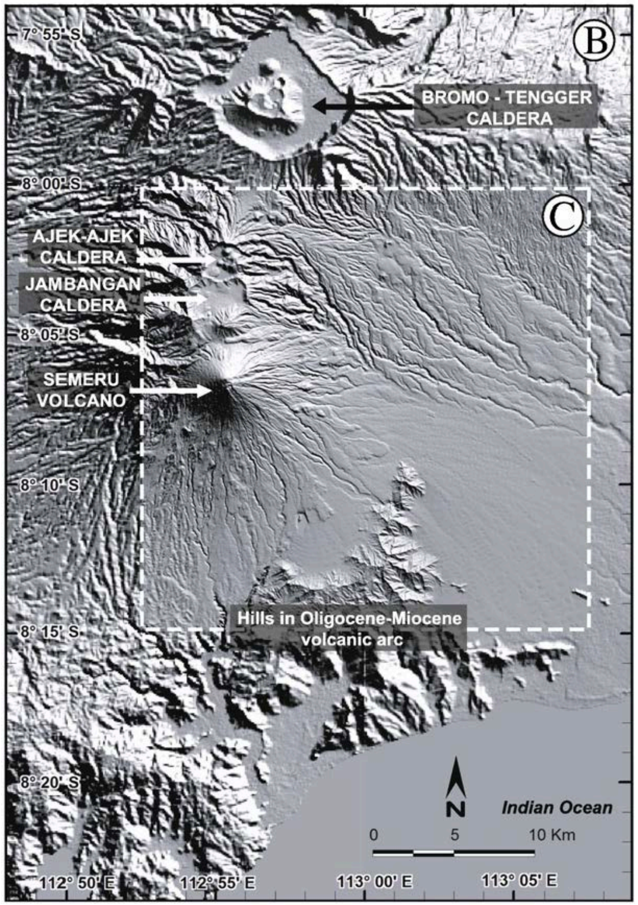
$$\Delta\Phi_{spatial} = (4\pi h B_{perp},) / (\lambda R \sin\theta)$$





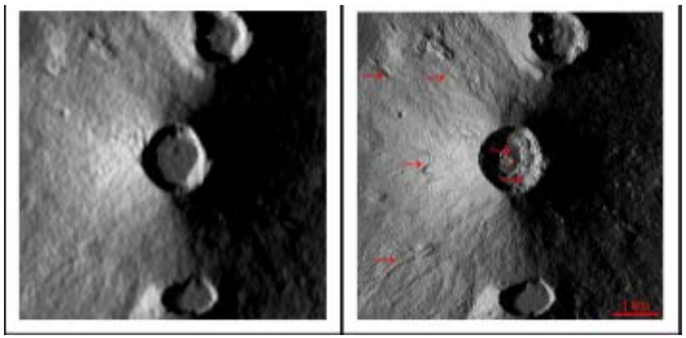
SRTM DEM



Resolution : 90m
Precision: 10 m

Produced in 2000
Can be downloaded for free

Tandem-X



SRTM Tandem-X

From Albino & et Kervyn,CNFGG, 2012

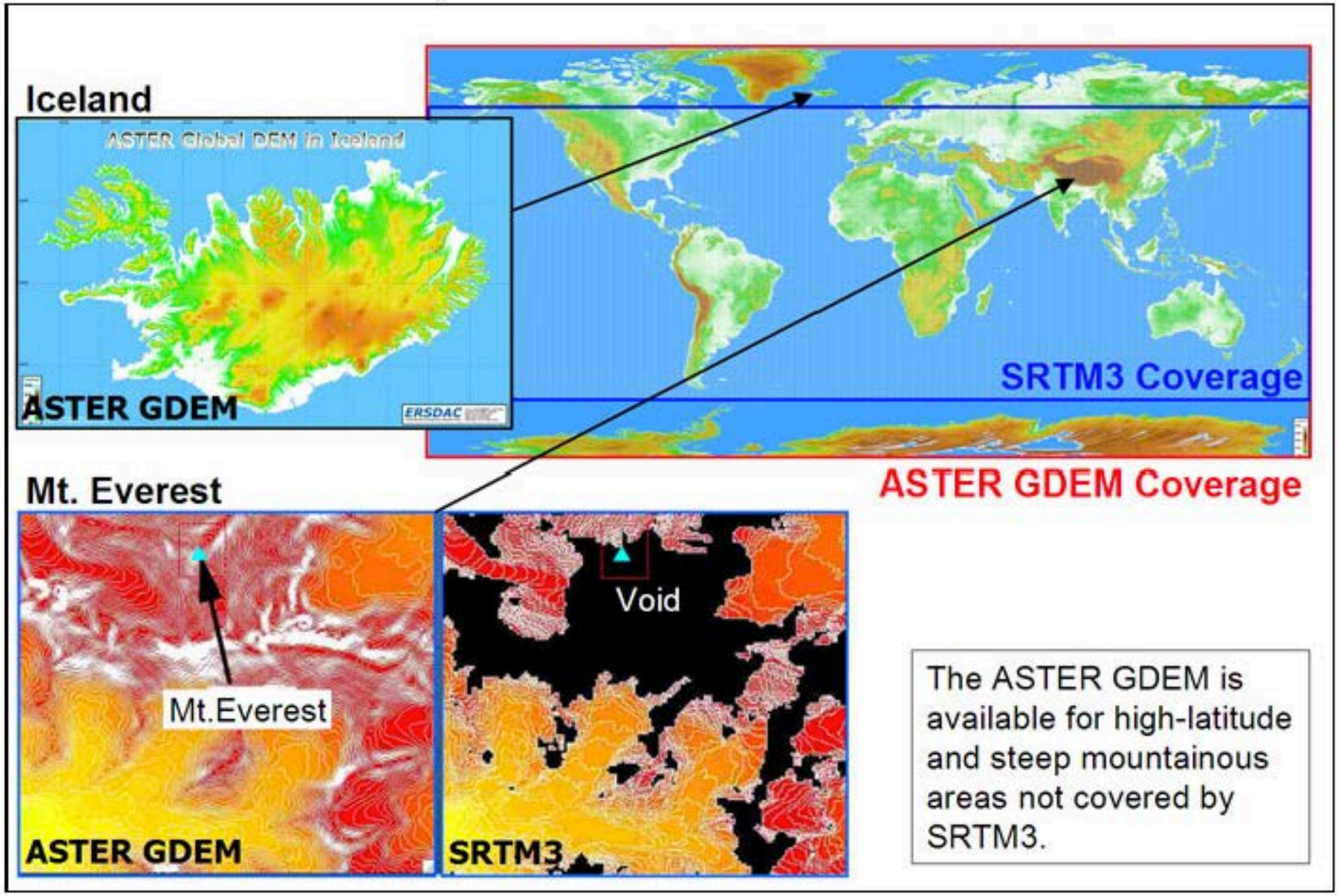
Comparison of available DEM

	ASTER GDEM	SRTM3*	GTOPO30**	10 m mesh digital elevation data
Data source	ASTER	Space shuttle radar	From organizations around the world that have DEM data	1:25,000 topographic map
Generation and distribution	METI/NASA	NASA/USGS	USGS	GSI
Release year	2009 ~	2003 ~	1996 ~	2008~
Data acquisition period	2000 ~ ongoing	11 days (in 2000)		
Posting interval	30m	90m	1000m	about 10m
DEM accuracy (stdev.)	7~14m	10m	30m	5m
DEM coverage	83 degrees north ~ 83 degrees south	60 degrees north ~ 56 degrees south	Global	Japan only

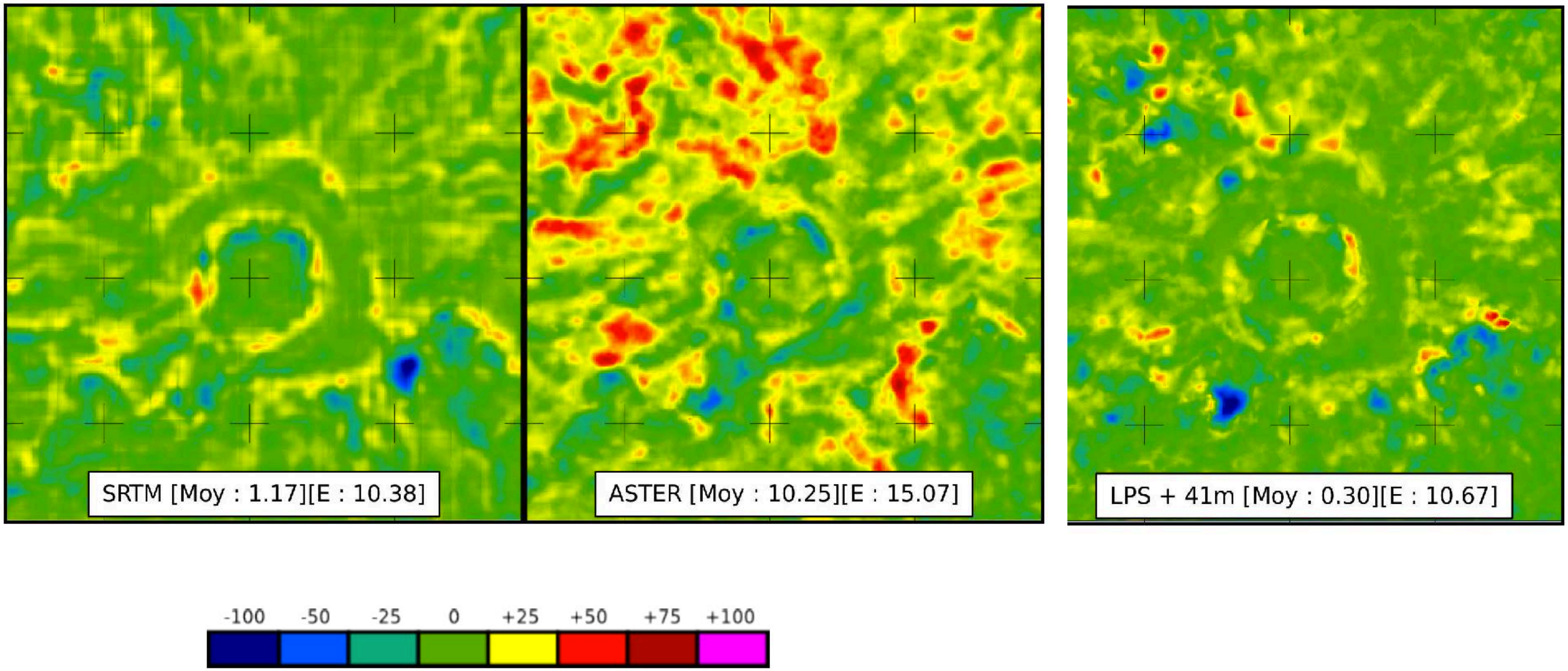
Limitations: Clouds Steep slopes

Comparison of available DEM

Comparison between ASTER GDEM and SRTM3



Comparison of available DEM

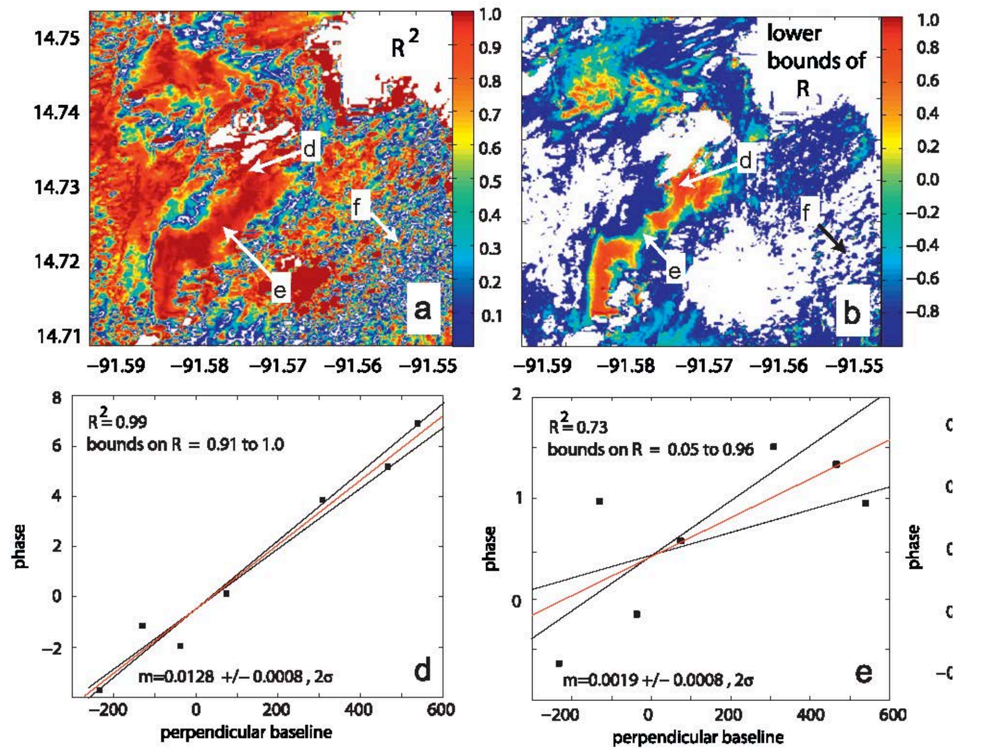


Difference to the DEM provided by SPOT (resolution 20m)

InSAR can also be used to quantify lava flow thickness

$\Phi_M - \Phi_S = \Delta\Phi = \Delta\Phi_{spatial}(B_{perp}, z) + \Delta\Phi_{atmo} + (4\pi/\lambda)\, d \quad + \; \Delta\Phi_{noise}$

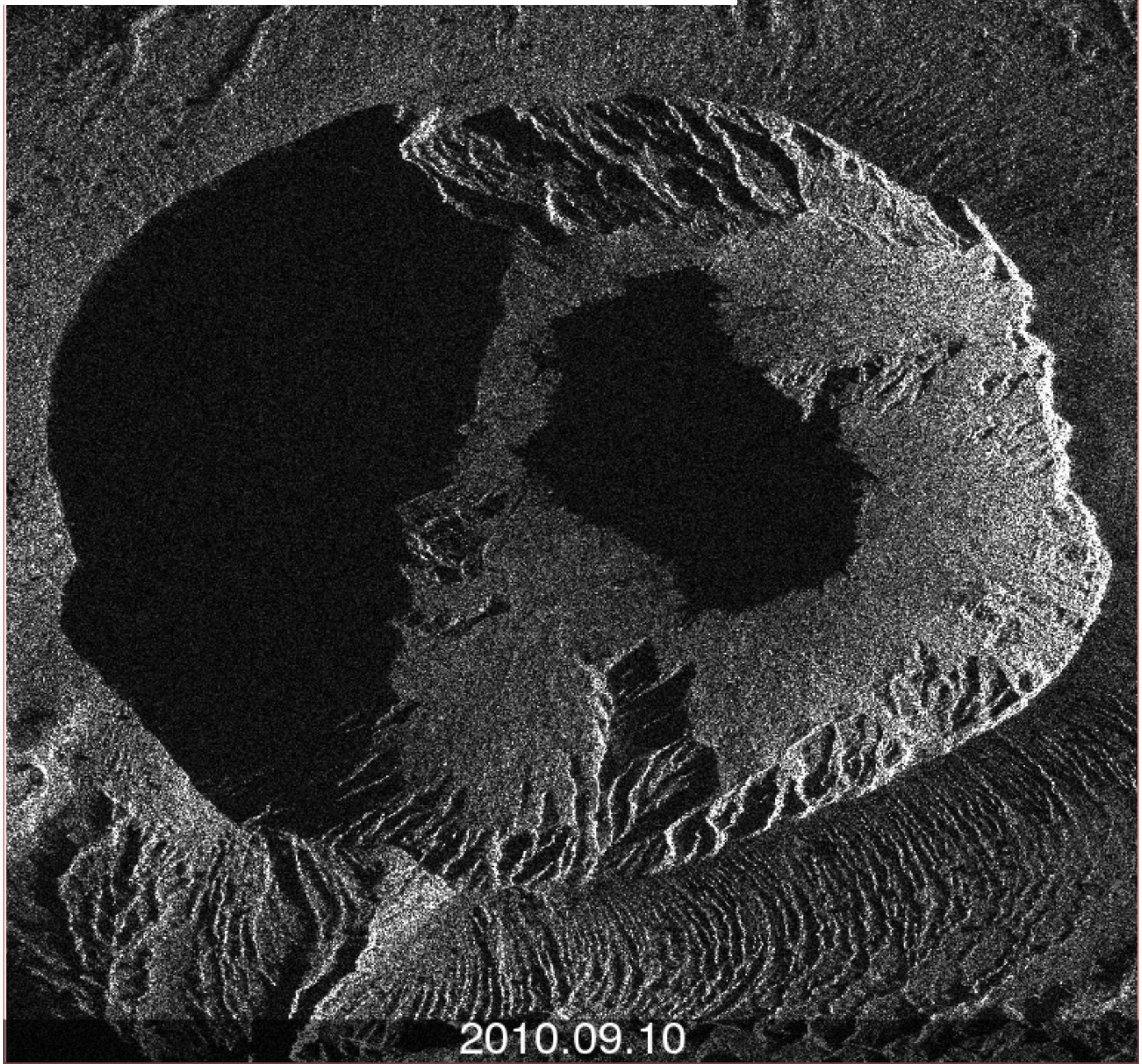
$\Delta\Phi_{spatial} = (4\pi h B_{perp},) \,/ (\lambda R \sin\theta)$



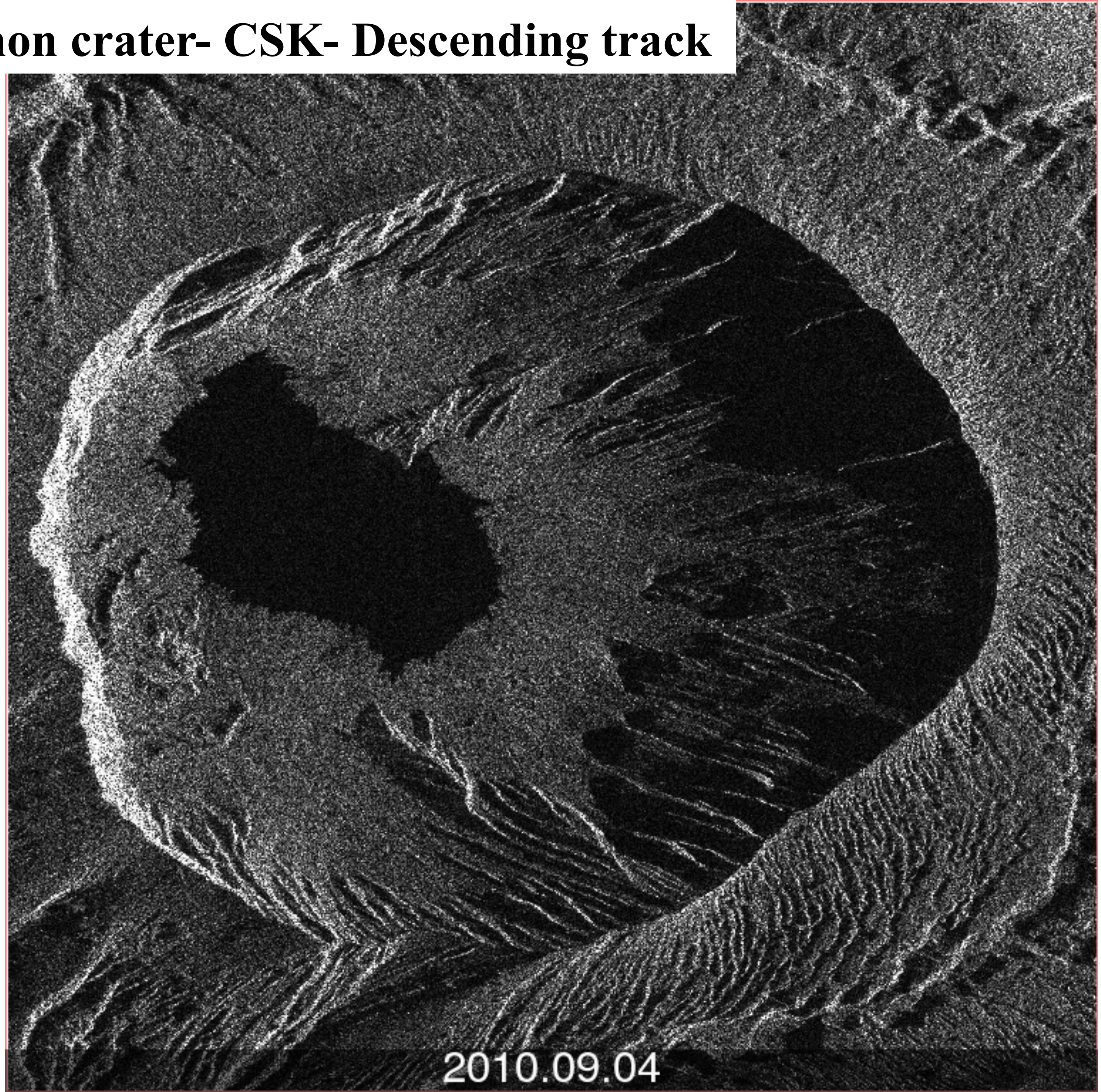
Estimation of DEM variation
with a precision around 9 m
(5 images with large perpendicular baselines)
From Ebmeier et al, 2012

Amplitude images are useful for monitoring
(all images can be used)

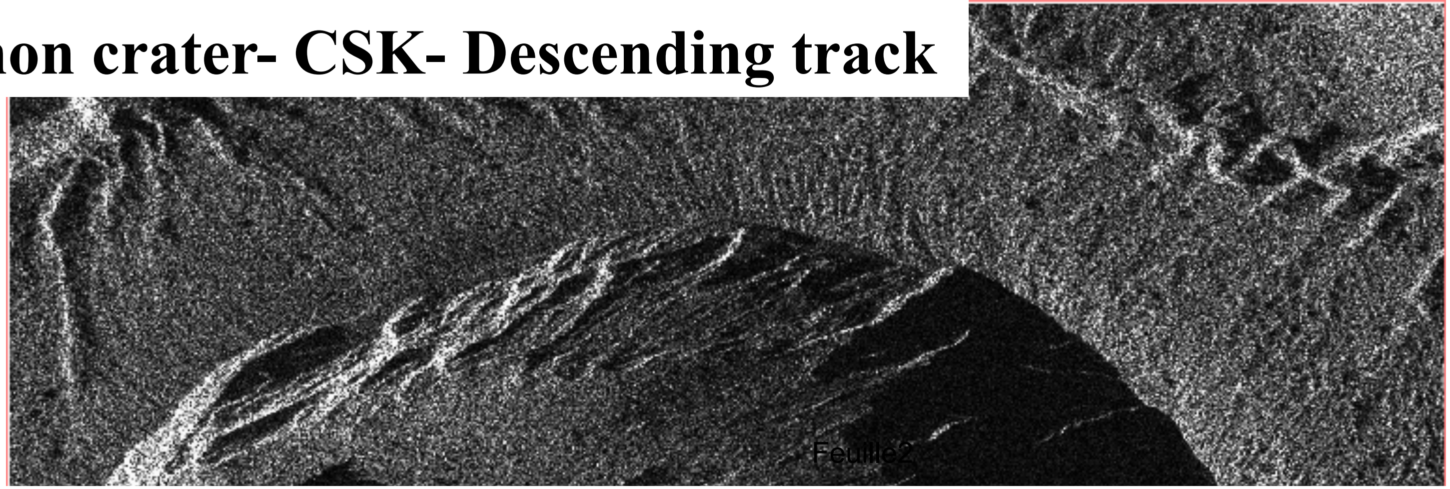
El chichon crater- CSK- Ascending track

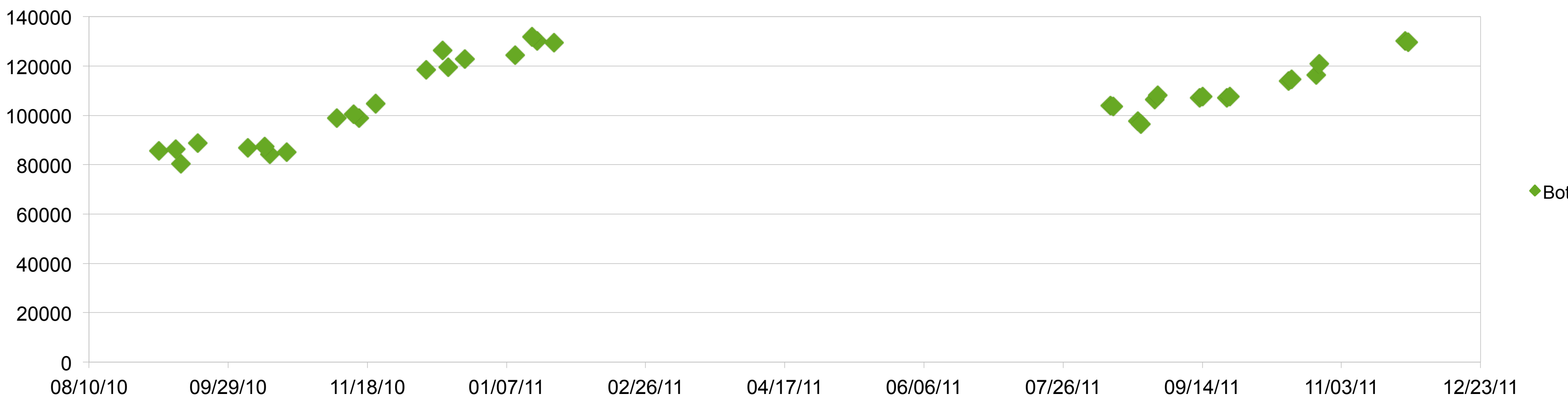


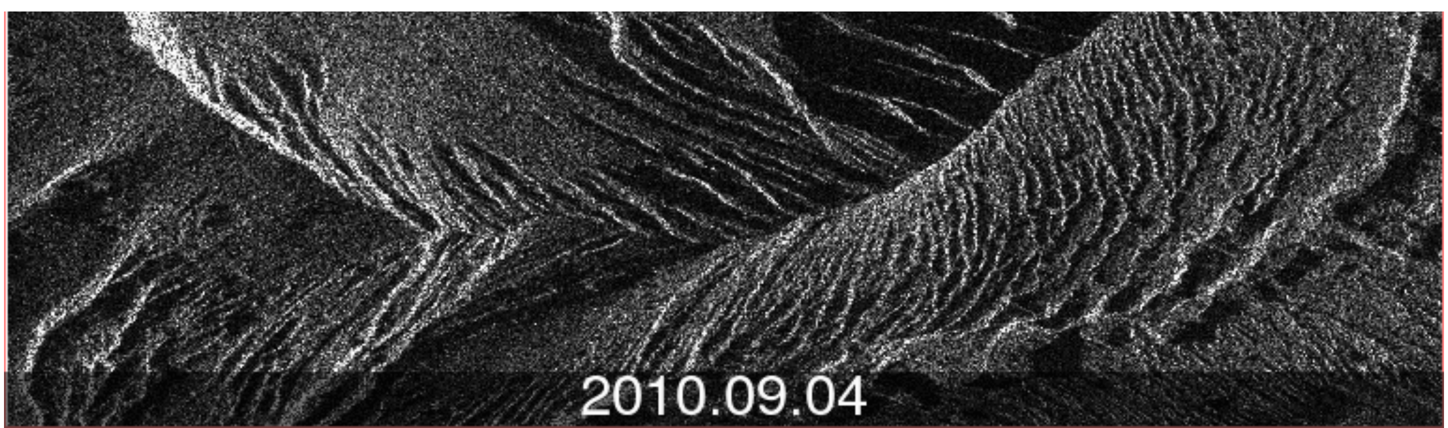
El chichon crater- CSK- Descending track



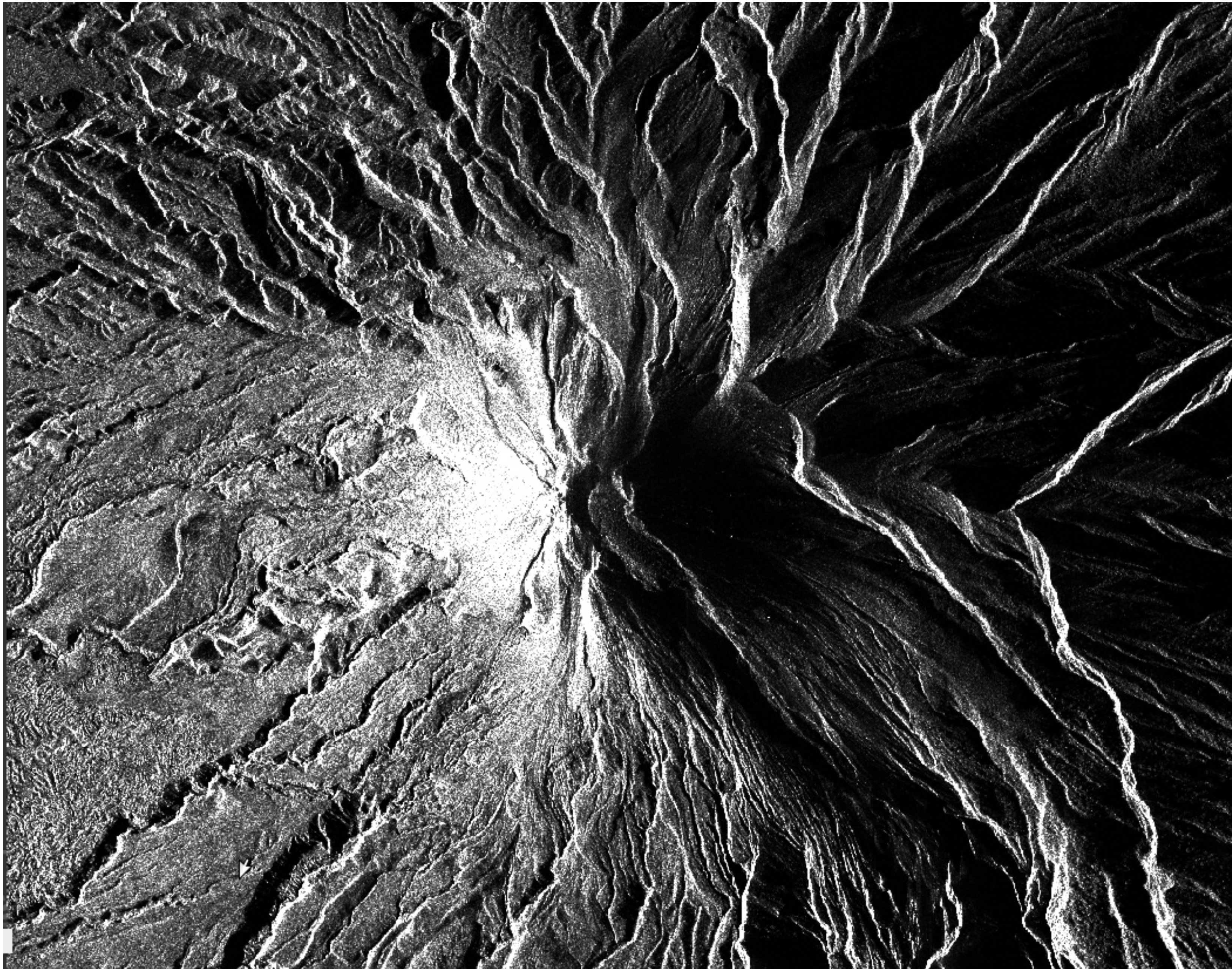
El chichon crater- CSK- Descending track



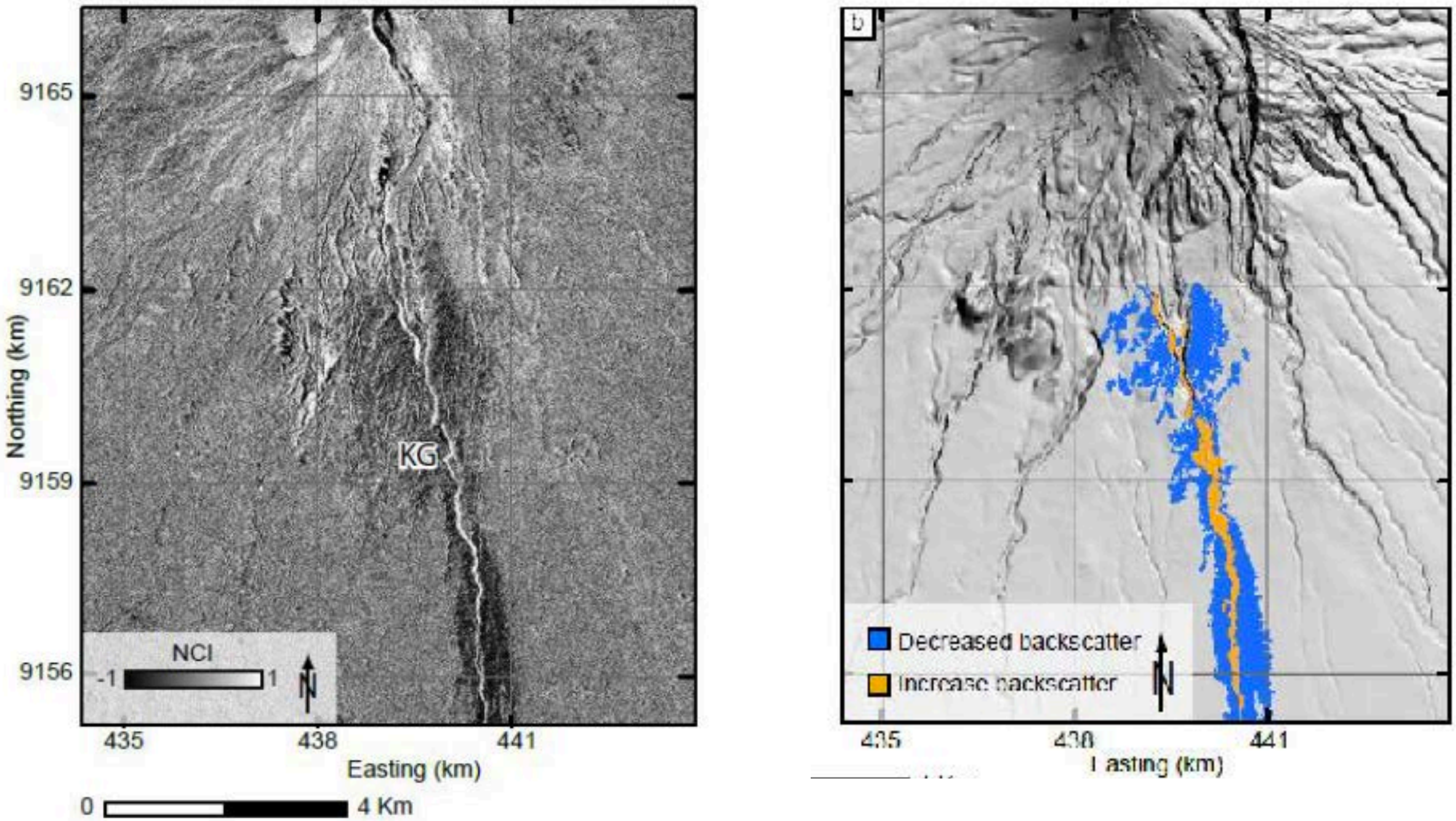




Merapi volcano, TerraSAR-X image acquired on 4th November 2010

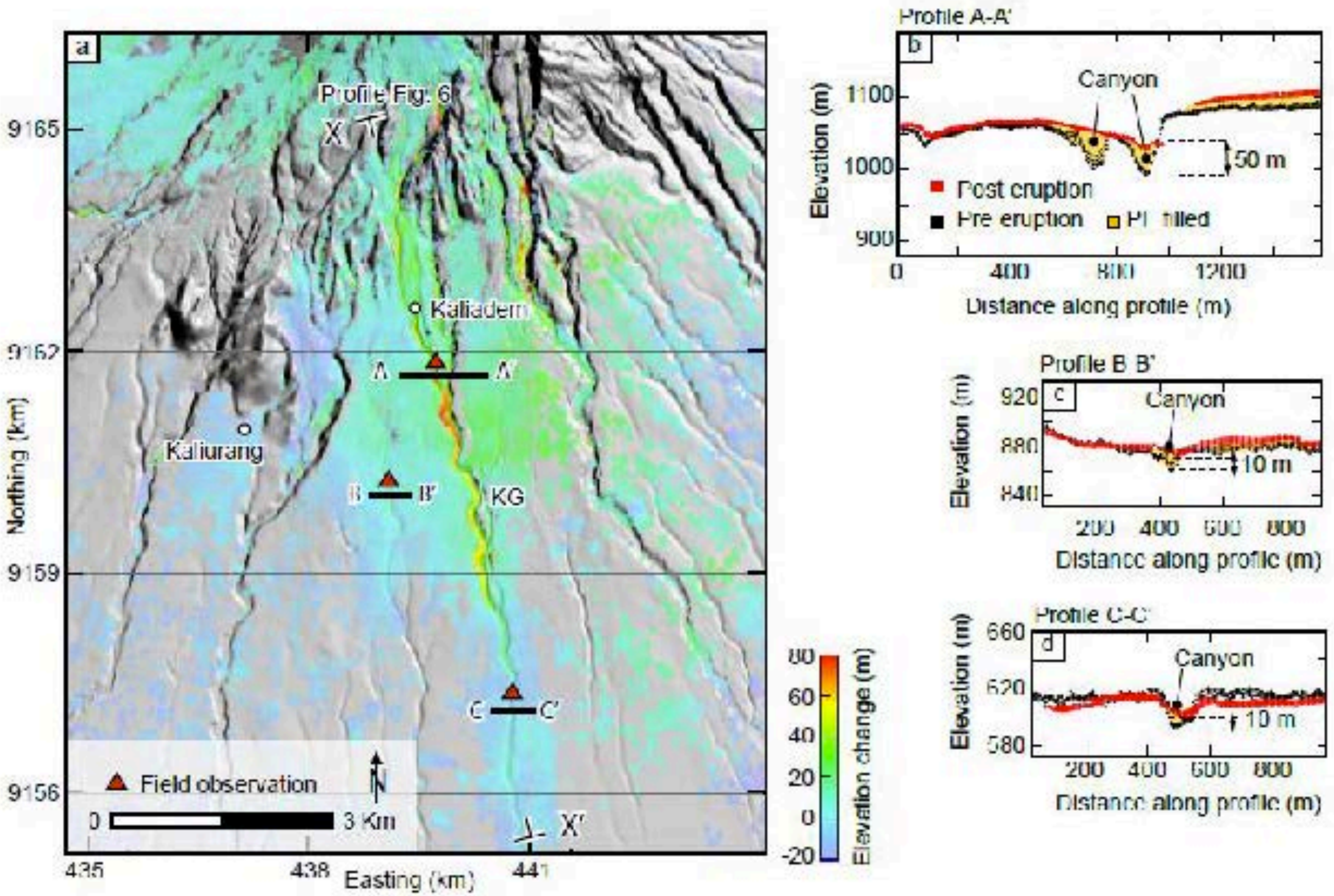


Merapi volcano, CosmoSkymed images
Use of amplitude to detect changes



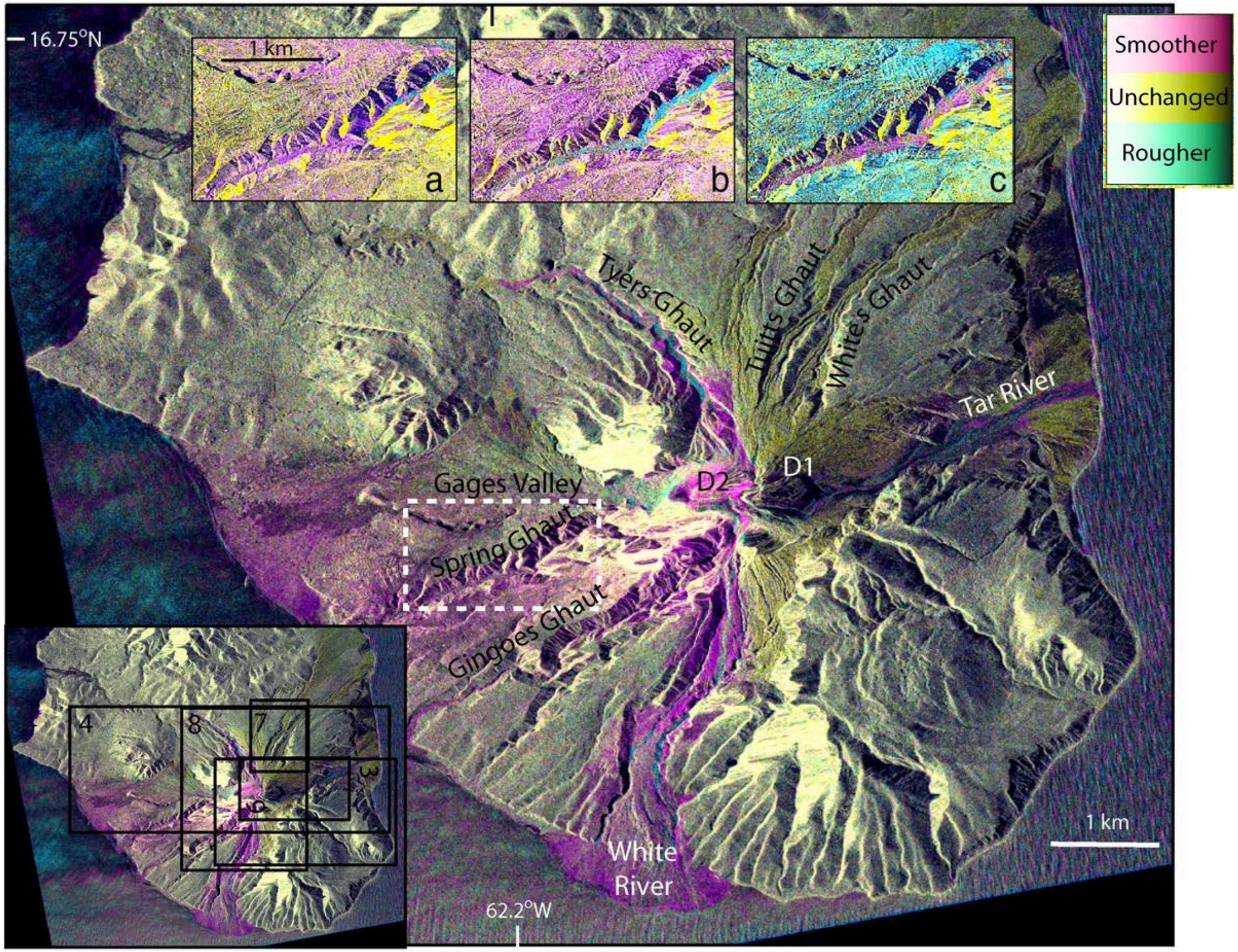
From Bignami et al, 2013

Merapi volcano, CosmoSkymed images
Use of interferometry to quantify elevation change



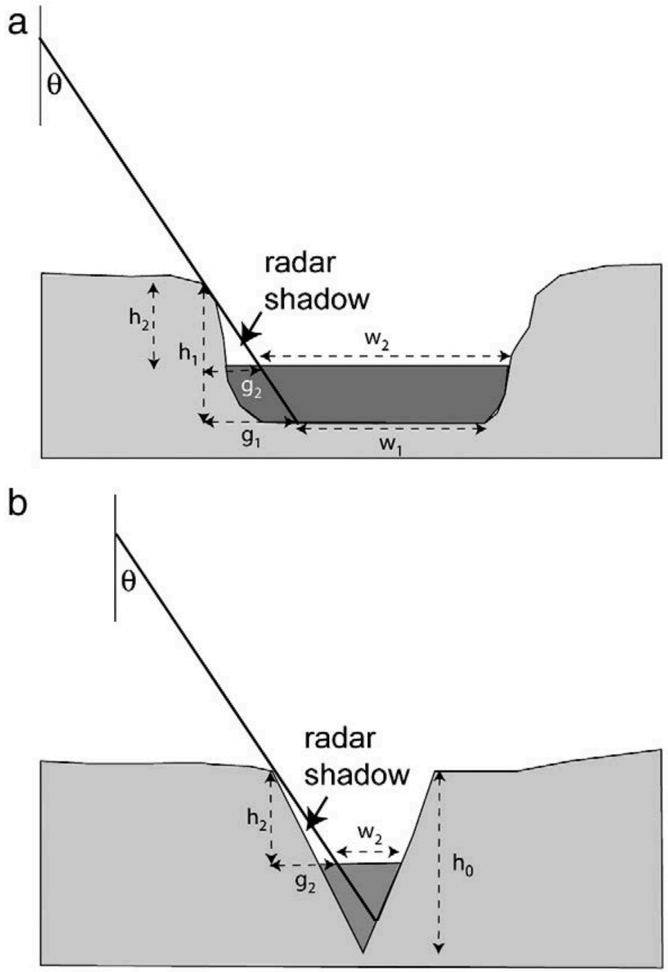
From Bignami et al, 2013

Montserrat volcano, TerraSAR-X images
Use of amplitude to detect change



From Wadge et al, 2011

Montserrat volcano, TerraSAR-X images
Use of shadow extension to detect deposit thickness



$$\text{Area}_{\text{trap}} \approx 0.5(h_1 - h_2) \cdot (w_1 + w_2)$$

$$\text{Area}_{\text{triang}} \approx 0.5(h_0 - h_2) \cdot w_2$$

From Wadge et al, 2011

Conclusion:

Remote sensing can be useful to:

- Detect long term (deformation and gas)

and short terms precursors (gas)

- Detect eruptions
- Assess hazards during eruptions
- Follow edifice destructions, deposits emplacements

Two main advantages: -global monitoring
-cannot be destroyed by the eruption

Bibliography:

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-Physical Principles of Remote Sensing, 3rd edition, W. G. Rees, 2012