



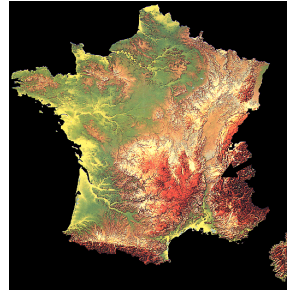
**Principles of remote sensing based on
SAR data: data access, processing tools**
Virginie Pinel

Who I am:

Virginie Pinel: Research Scientist at IRD
Virginie.Pinel@ird.fr



I work at Chambéry (France)



Magma storage and transport through the crust

- Deformation study by InSAR
- Modeling (analytical + numerical) of magmatic plumbing systems beneath volcanoes

You can download this presentation on my web page.

<http://isterre.fr/staff-directory/member-web-pages/virginie-pinel/>

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

Advantages:

- Can cover large areas (ideal for remoted areas).
- Information is acquired safely.

Key information:

- Repeat time
- Ground resolution (pixel size)

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- 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. SAR data description + where (how) to access the data
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	Passive systems	Active systems	
		Ranging	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)

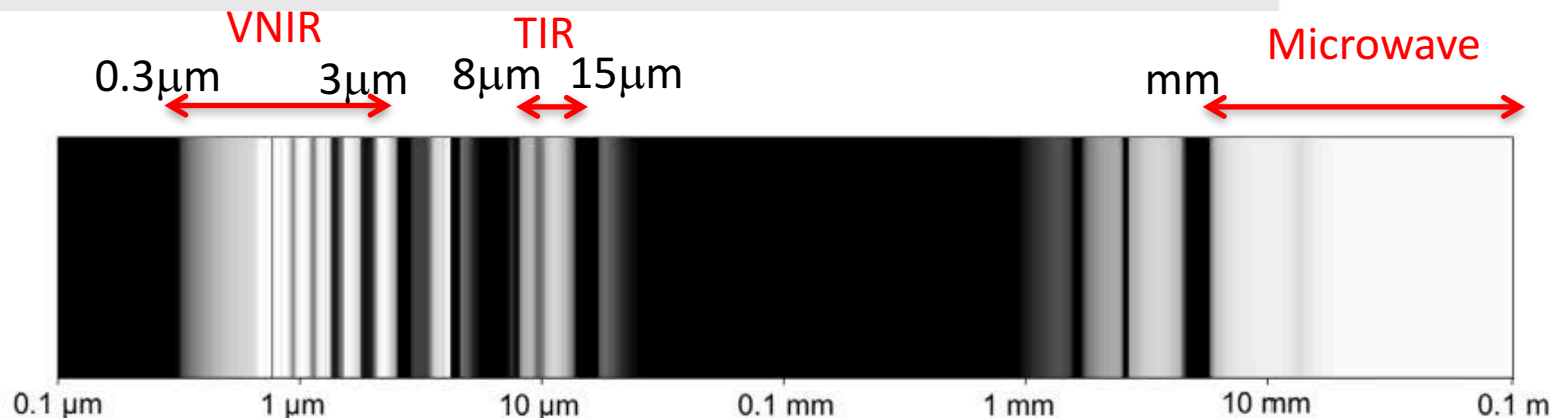
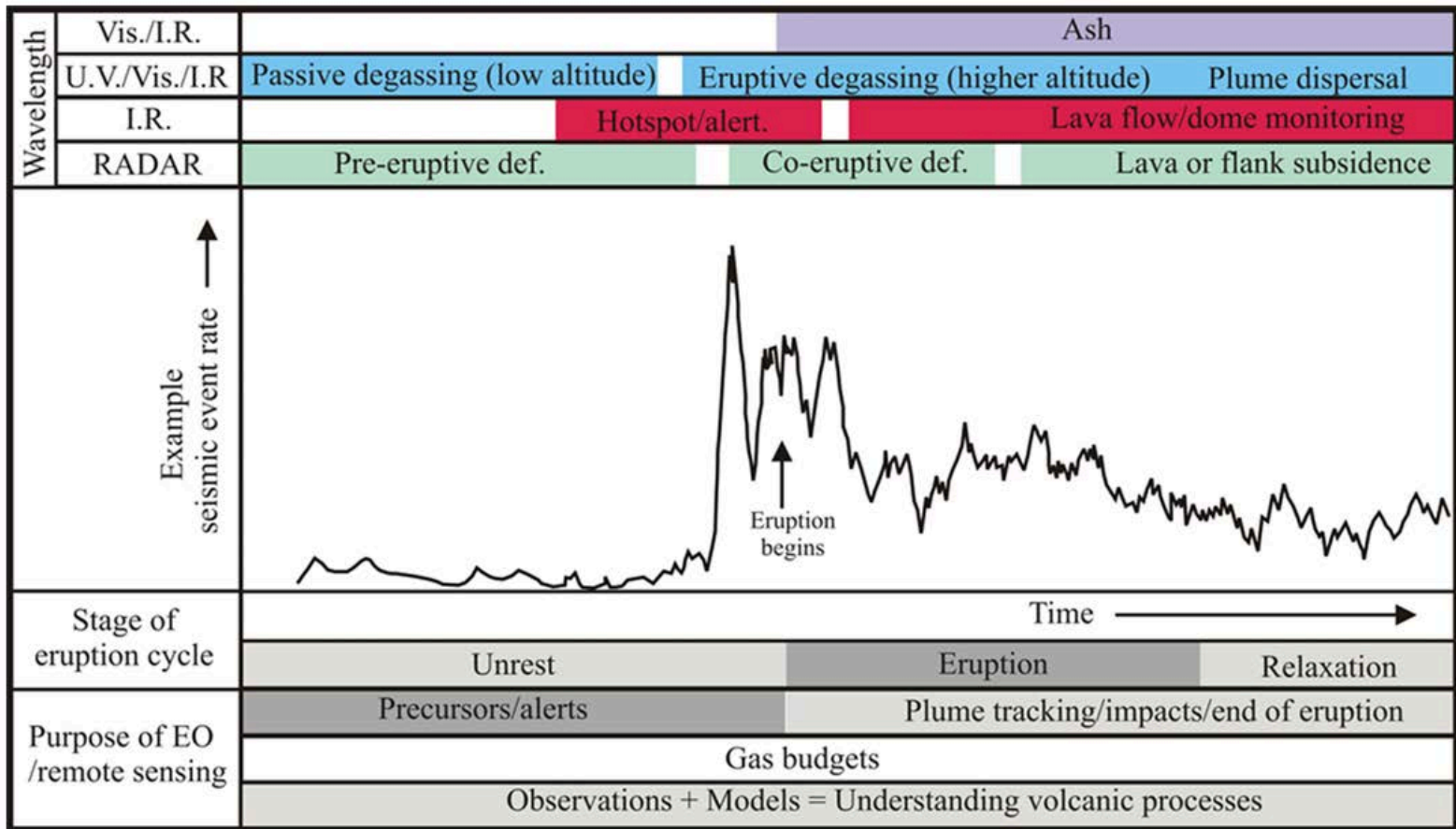


Figure 1.5. Transparency of the Earth's atmosphere as a function of wavelength (schematic). Black regions are opaque, white regions transparent.



Pyle et al, 2013

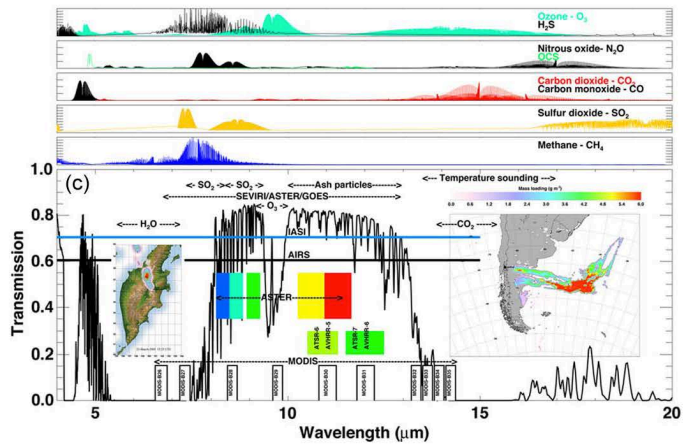
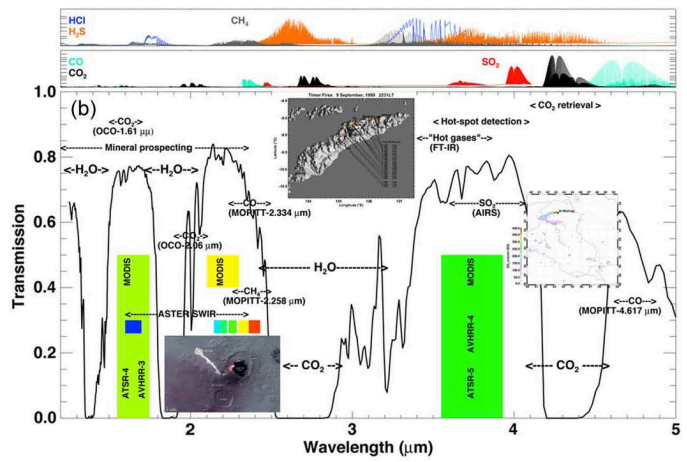
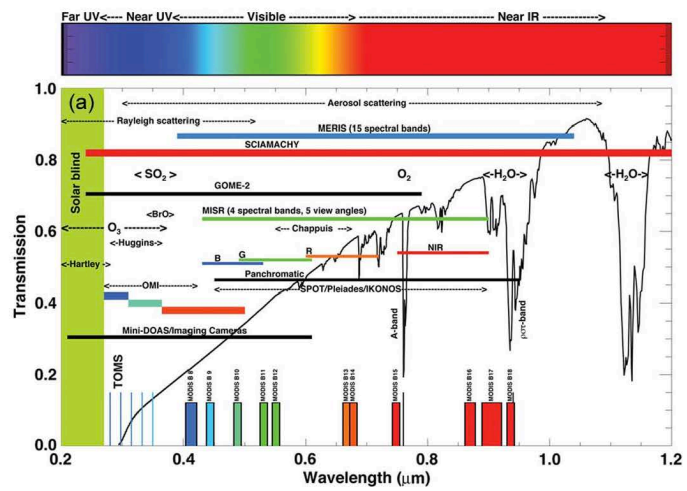
Remote sensing :
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Satellite platform	Launch date	Sensor/Technology	Spatial resolution	Sampling frequency (d ⁻¹)	Main application
Landsat-1	23.07.1972	Whiskbroom imaging	80 m	1/16	Mapping
NOAA	26.06.1979 ¹	AVHRR Multi-spectral	1 km	4	Meteorology
Landsat-5	01.03.1984	Mid-range IR imaging	30–120 m	1/16	Mapping
SPOT-1	22.02.1986	Pushbroom imaging	10–30 m	1/16	Crises
Earlybird	24.12.1997	1st commercial imaging	1 m	1/16	Crises
Landsat-7	15.04.1999	Opto-mechanical, whiskbroom	0.03–0.12	1/16	Mapping
IKONOS-2	24.09.1999	1 m spatial resolution commercial imagery	1 m	On demand	Crises
Quickbird-2	18.10.2001	Commercial imagery	1 m	On demand	Crises
Terra	18.12.2001	MODIS/ASTER Earth observers	0.25–1 km	2	Hot-spots, ash, SO ₂
Aqua	04.05.2002	MODIS/AIRS Earth observers	0.25–14 km	2	Hot-spots, ash, SO ₂
IKONOS-2	24.09.2004	0.5 m spatial resolution commercial imagery	0.5 m	on demand	Crises
MSG-2	21.12.2005	SEVIRI 15 min multispectral imagery	1–4 km	96	Hot-spots, ash, SO ₂
MetOp	19.10.2006	IASI High-spectral resolution IR interferometer	10 km	2	Ash, SO ₂

¹Date of first launch.
¹Signal-to-Noise Ratio.
²Noise-equivalent temperature difference

Historical Highlights in Spectroradiometric Imaging of Earth and the Atmosphere

From Hooper et al., 2012



From Hooper et al., 2012

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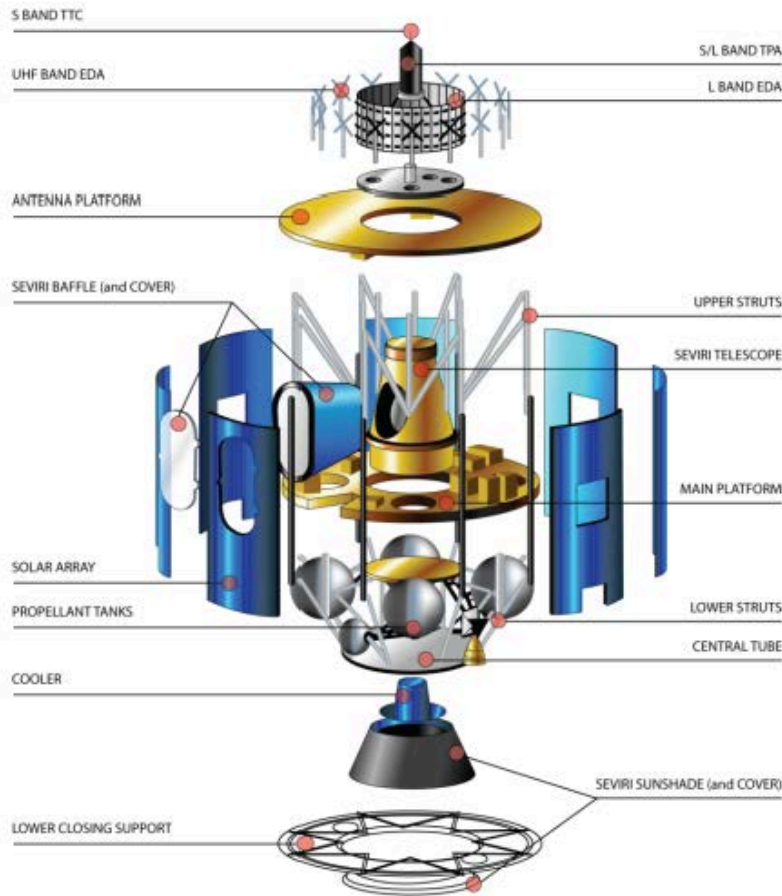
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Meteosat Second Generation

4 geostationary meteorological satellites ($\text{Ø}=3.2\text{m}, h=2.4\text{m}$)

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**.



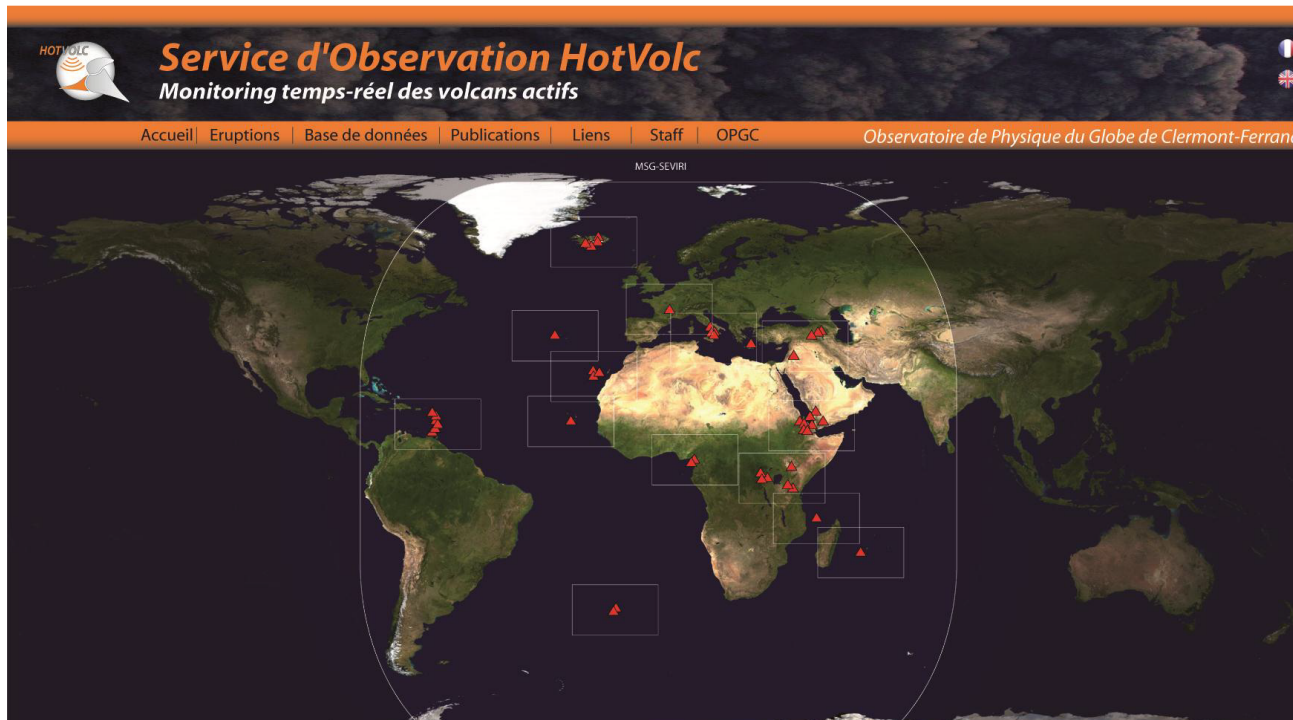
Repeat time: 15 min

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

Meteosat Second Generation

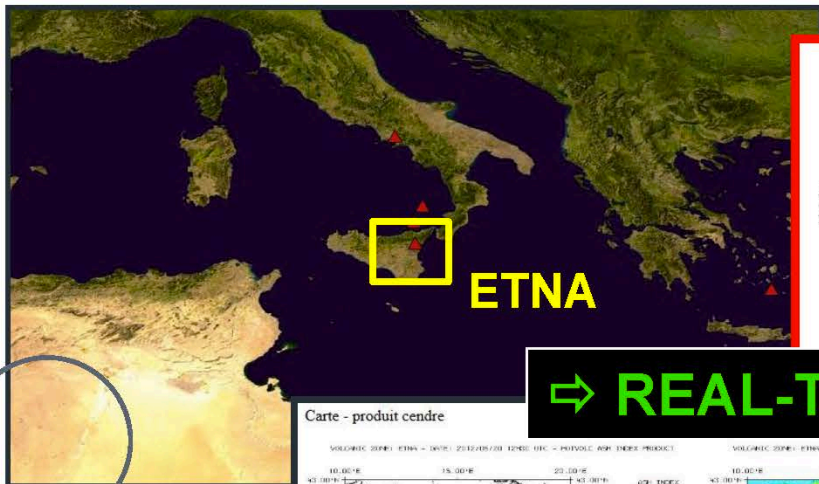
Can be used to :

- detect ash and estimate ash concentration (*Prata et al, 89*)
- detect and estimate SO₂ concentrations (less efficient than UV absorption)
- to detect lava flows and estimate flow rates (thermal anomalies)

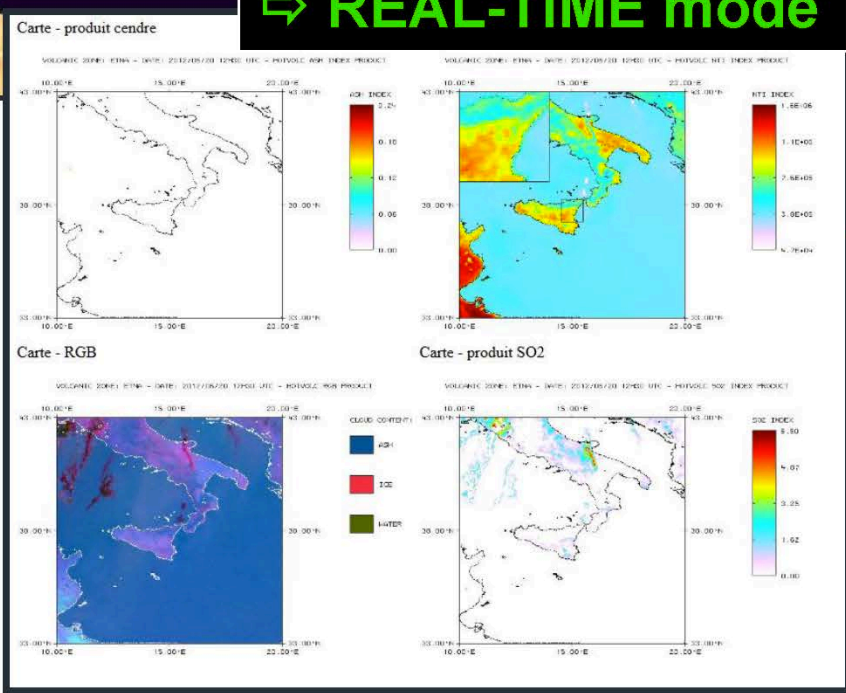
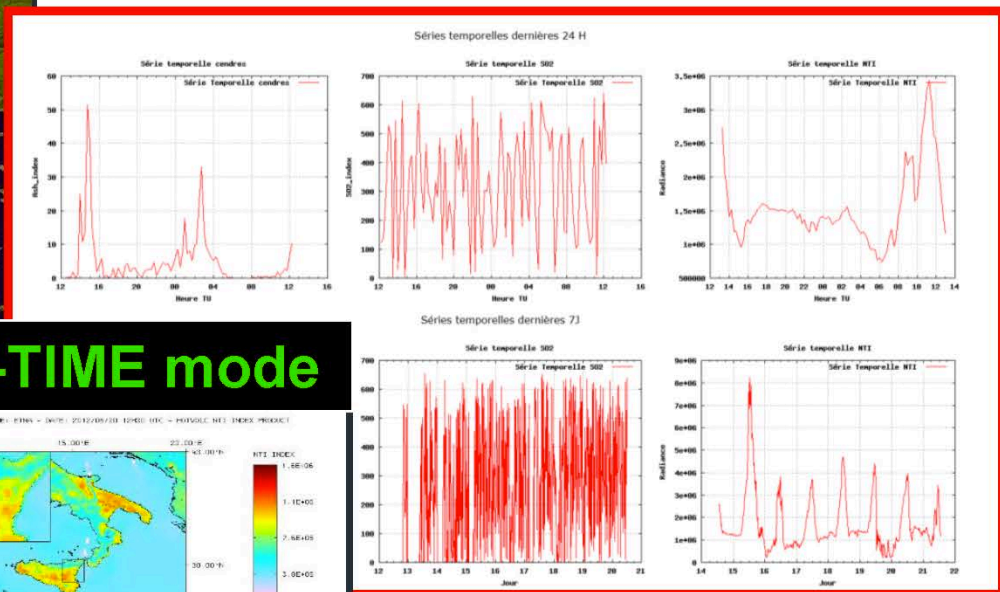


<http://www.obs.univ-bpclermont.fr/SO/televolc/hotvolc/index.php>

Time series

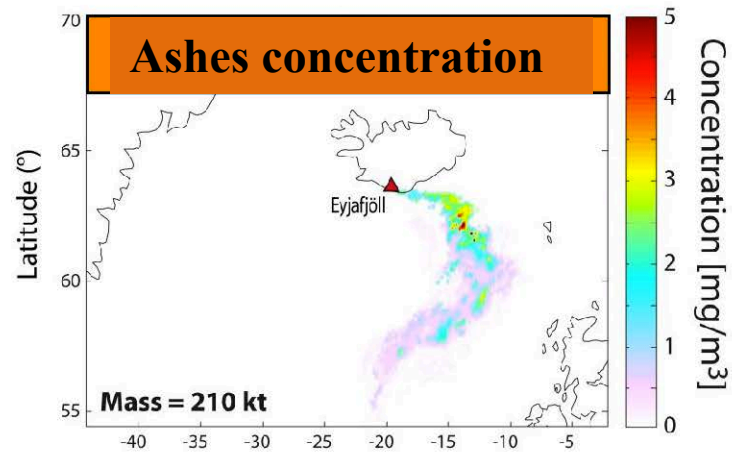
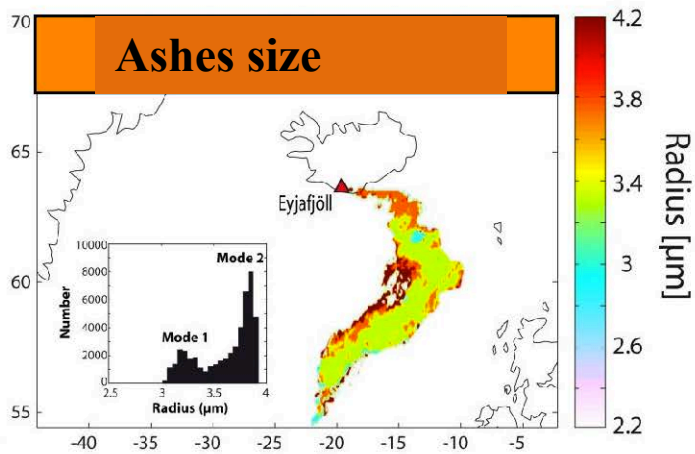
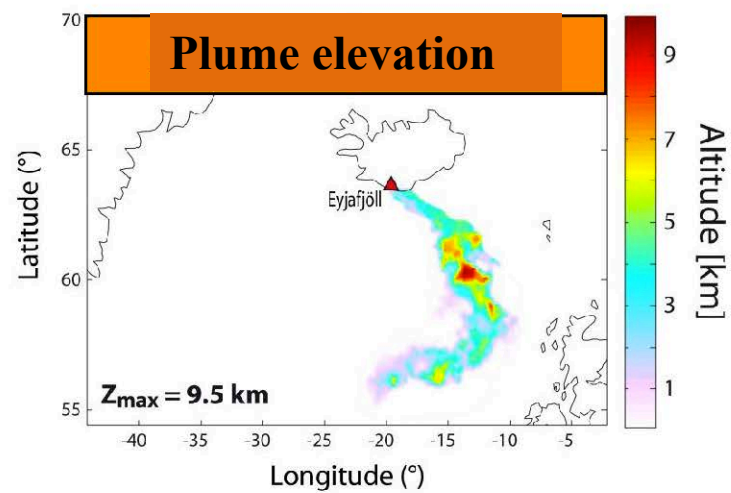
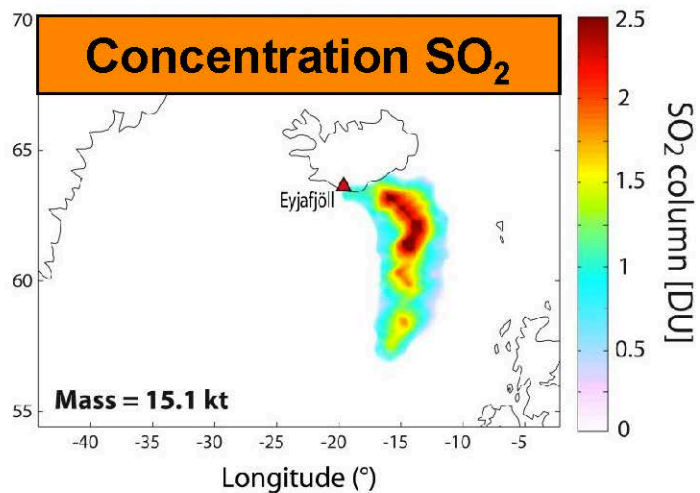


⇒ REAL-TIME mode



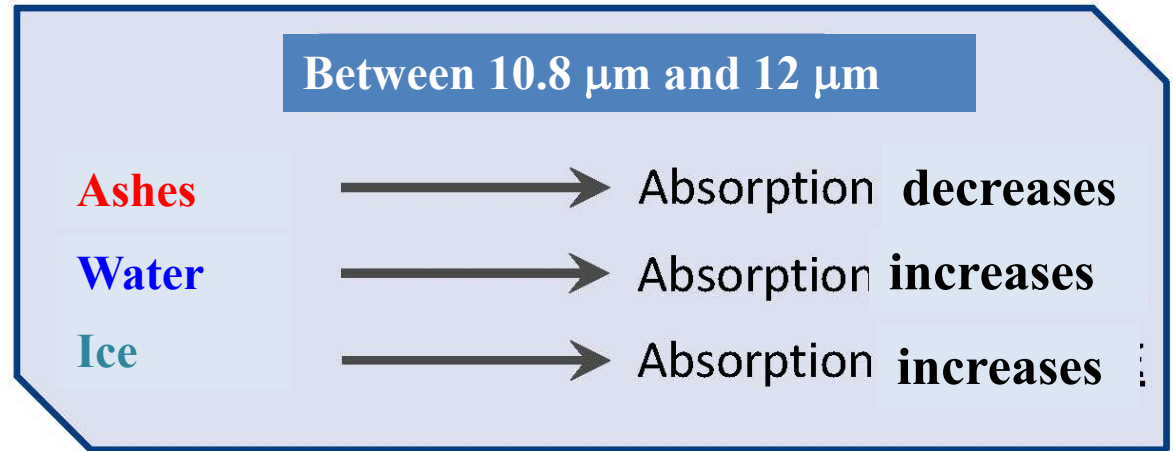
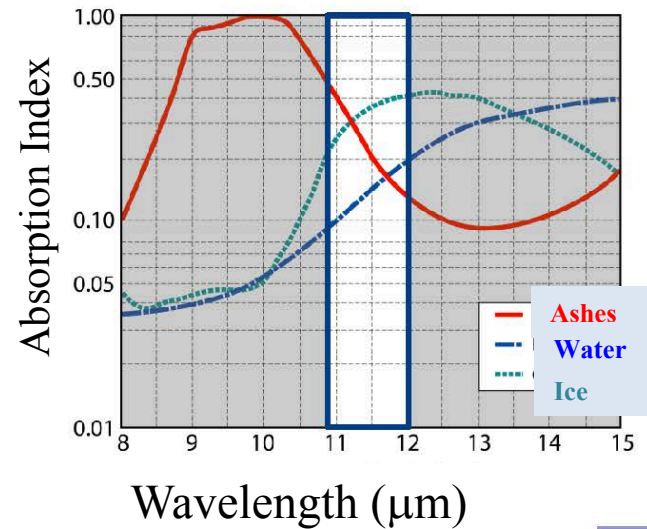
Maps

HotVolc



From Gouhier et al., CNFGG, 2012

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



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

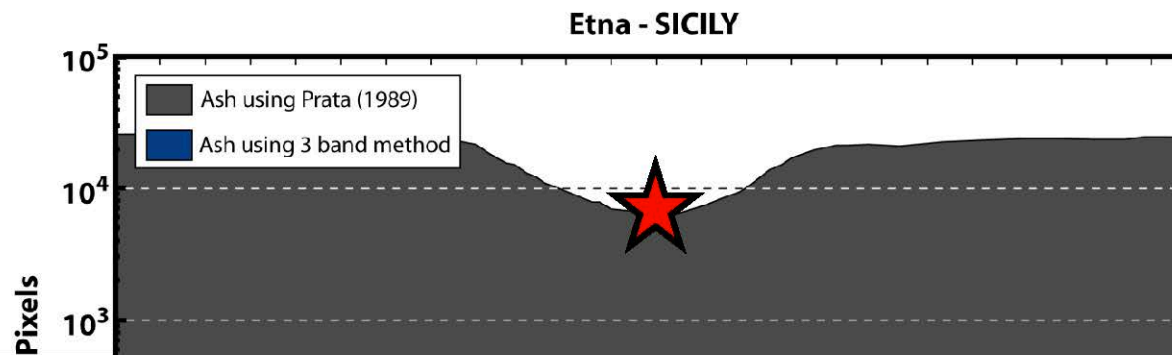
Ash clouds

BTD[10.8-12] → NEGATIVE

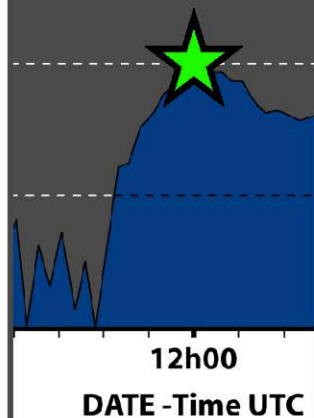
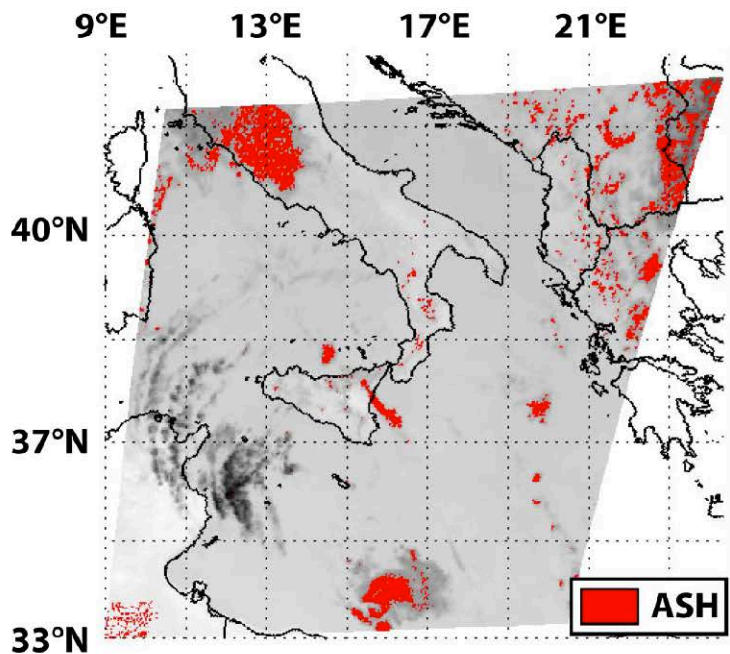
Meteorological clouds

BTD[10.8-12] → POSITIVE

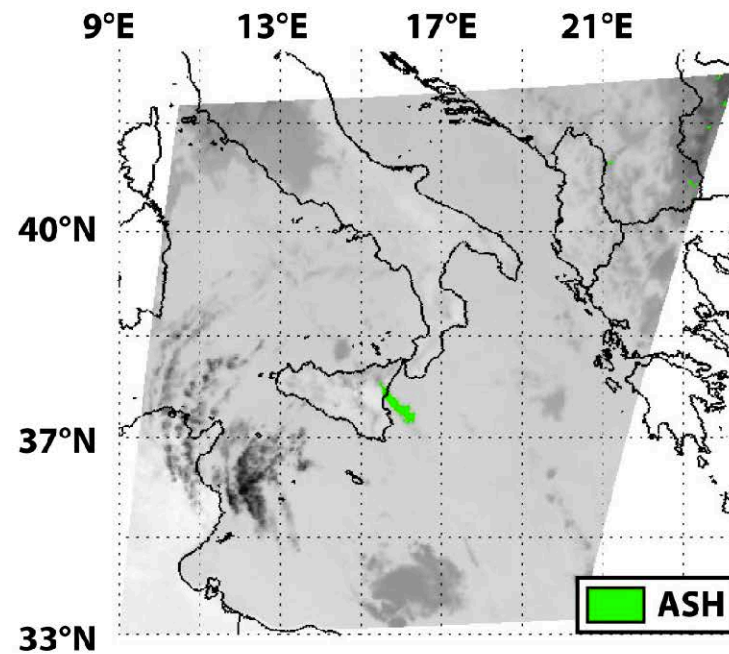
Ash detection: enhancement of the « Split-window » method



Mount Etna - 24 November 2006 - 12:00 UTC



Mount Etna - 24 November 2006 - 12:00 UTC



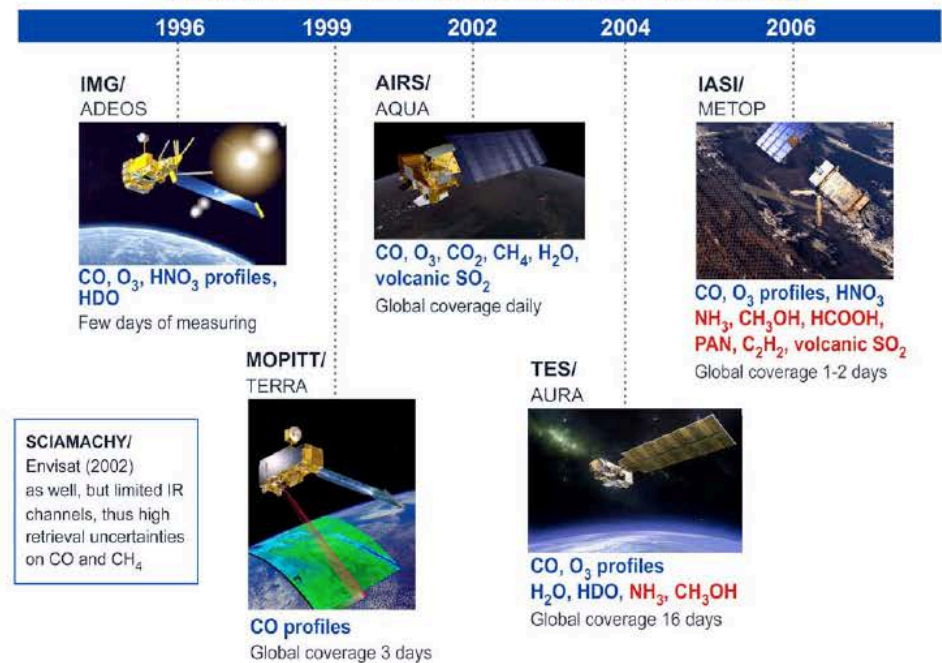
From Guehenneux et al., CNFGG, 2012

Meteorological Satellites available for IR-visible-UV observations

Atmospheric measurements from UV-visible



Atmospheric measurements from nadir IR sounding

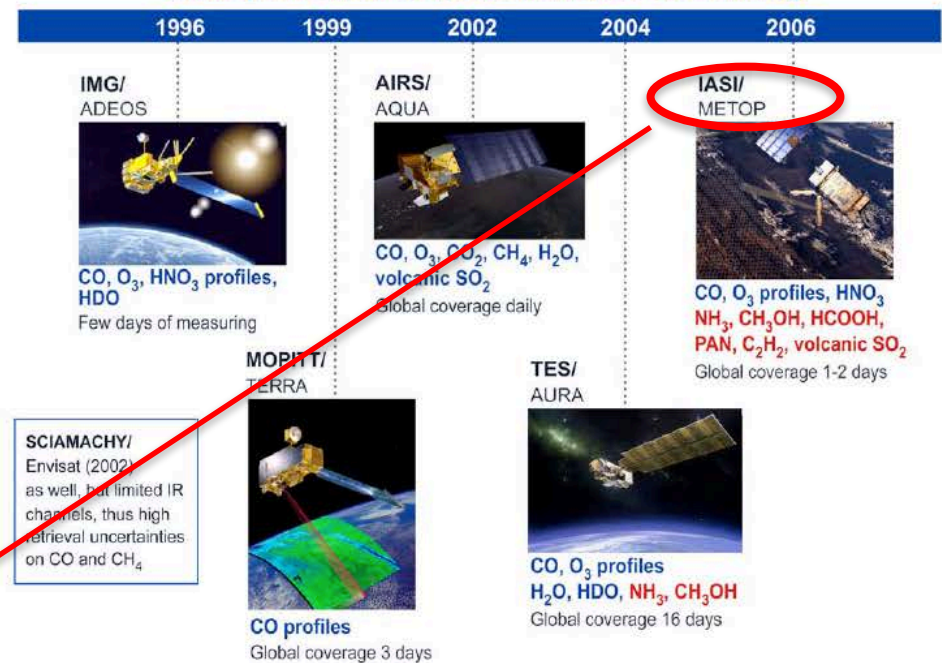


Meteorological Satellites available for IR-visible-UV observations

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Atmospheric measurements from nadir IR sounding



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 SO₂ assuming a 7 km high plume.(Clerbaux et al. 09)

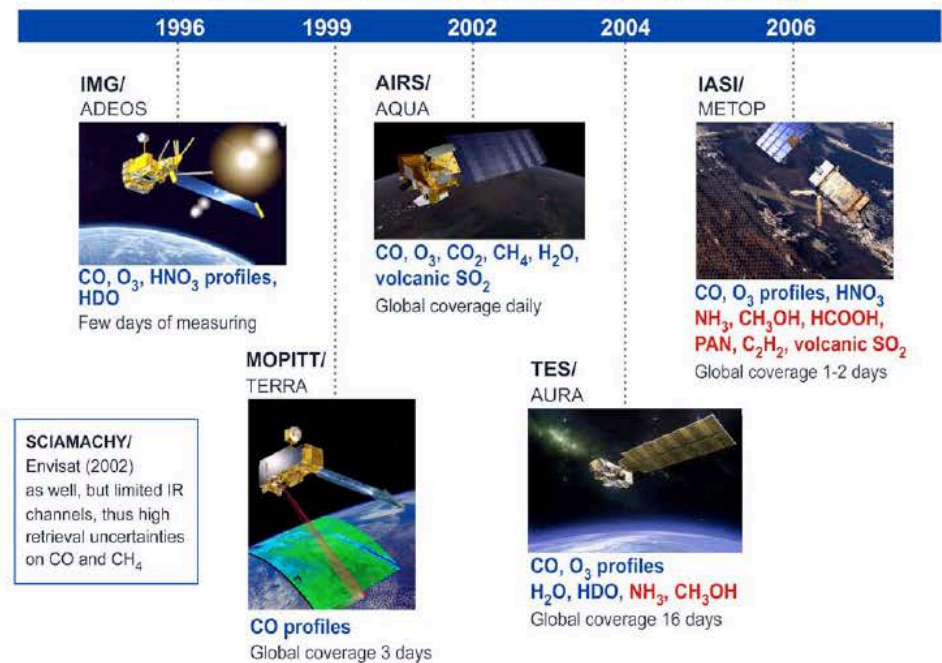
Detection of SO₂ above 5 km

Meteorological Satellites available for IR-visible-UV observations

Atmospheric measurements from UV-visible



Atmospheric measurements from nadir IR sounding



OMI (Ozone Monitoring Instrument) NASA

–UV (306-380nm)

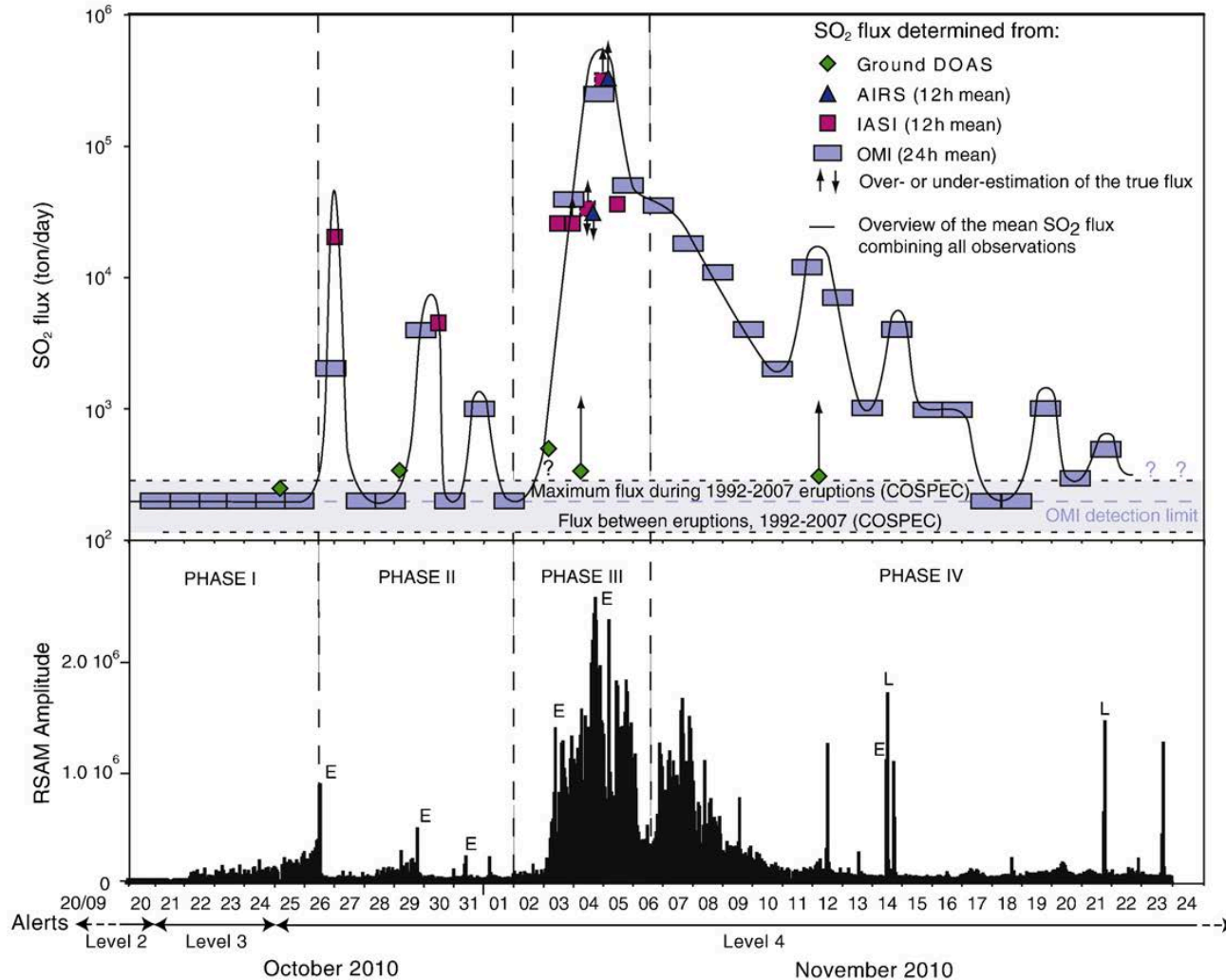
–⇒1 overpass per day (1h45pm local time)

–Spatial resolution: (13 km x 24 km)

Detection of SO₂ in the lower troposphere

Gas measurements for the 2010 Merapi eruption

Surono et al, 2013



E: explosion, L: Lahar

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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/>

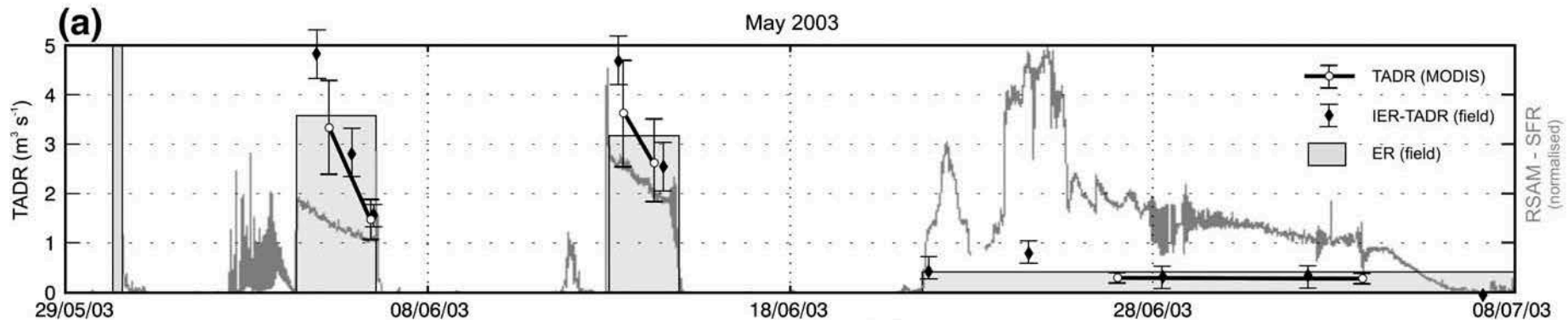
*AVHRR *Advanced Very High Resolution Radiometer* NOAA
Spatial resolution 1*1 km

*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 $T_{\text{surf}} - T_{\text{amb}}$



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

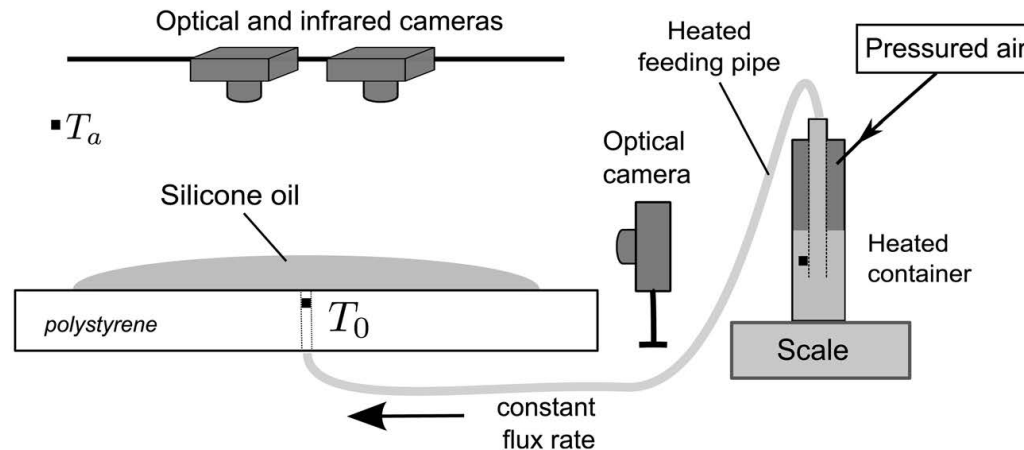
From Coppola et al, 2009

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 ($\mu=\text{constant}$) injected at a constant flow rate.

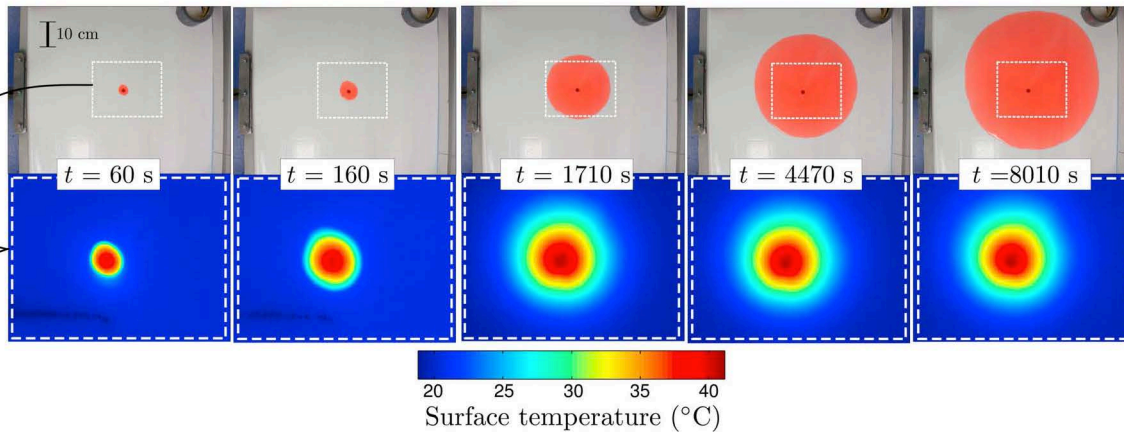


Experimental setup

Thermal signature of lava flows

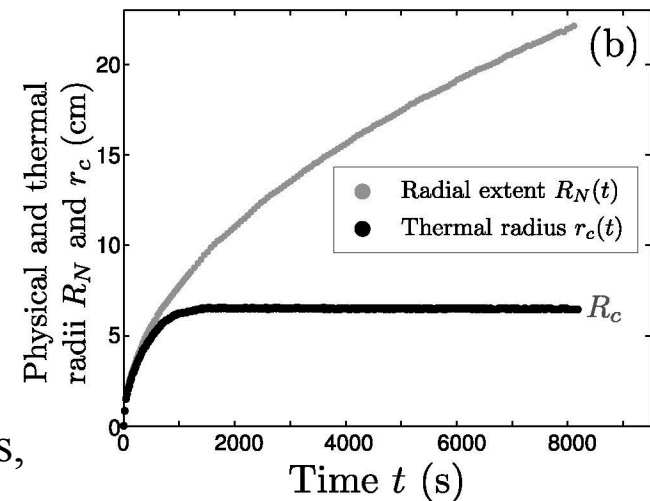
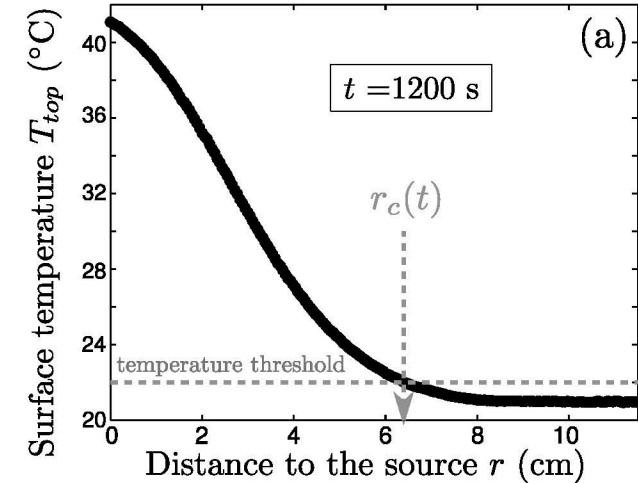
Garel et al, 2012

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 stationary state (highly dependant on magma viscosity: a few days for basalts, A few years for lava domes)



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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

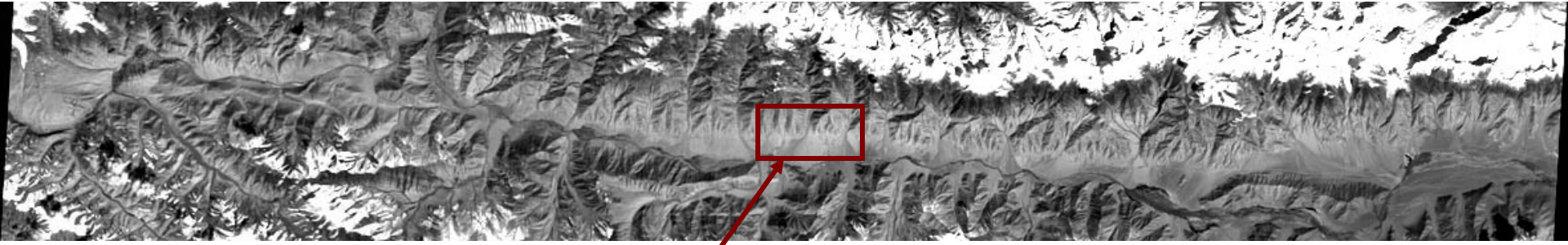
*Quickbird (2001)

Spatial resolution 0.6m

*Geoeye1 (2008)

Spatial resolution 0.5m

- 1986 : Satellite SPOT



Cumulated displacement
over several seismic cycles

Courtesy of C. Lasserre

Altn Tagh Fault, Tibet, left lateral fault SPOT panchromatique(10 m).

Image from Pleiades (visible)



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

Optical data

- **SPOT 6-7** (1.5 m, free access) and **Pléiades** (0.70 m, free access after project acceptation for French researchers) images (archived + new acquisitions)

Online form:

<http://www.satelliteimageaccess.teledetection.fr/>

- GEOSUD archive (SPOT 6-7 and Pléiades) :

<http://ids.equipex-geosud.fr/web/guest/catalog>

Optical data

Sentinel-2

<https://sentinel.esa.int/web/sentinel/missions/sentinel-2>

13 spectral bands, 290 km swath width

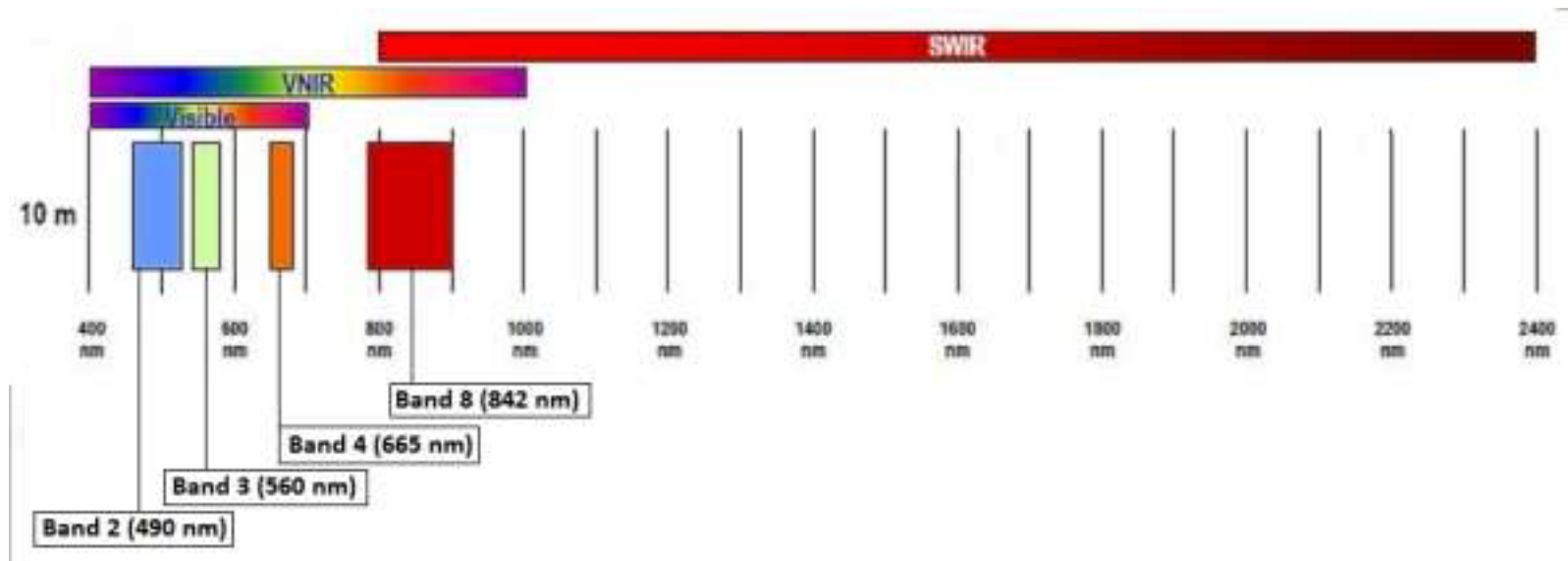
(Level 1-C 100x100 km² ortho-images in UTM/WGS84 projection)

- Every 10 days at the equator (with 1 satellite), every 5 days with 2 satellites
- 10 m resolution in TCI (3 bands in the visible)
- Band 10, 11 et 12 IR

(2H55 TU on Merapi, 10Ham)

Optical data Sentinel-2

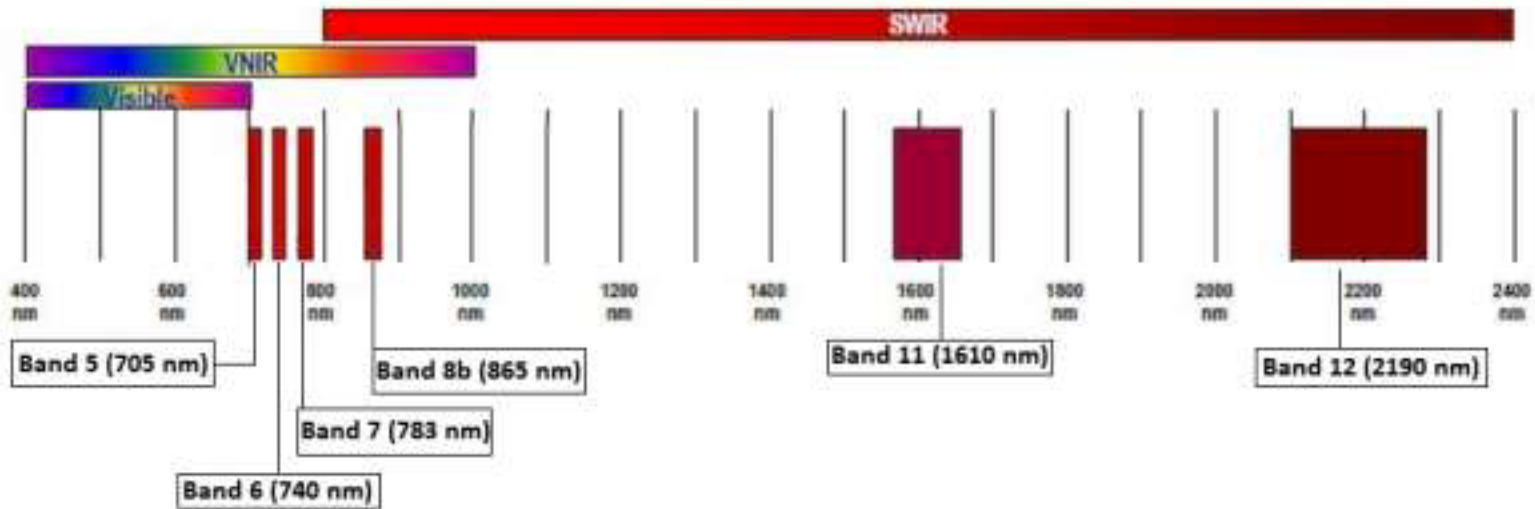
<https://sentinel.esa.int/web/sentinel/missions/sentinel-2>



Sentinel-2: 10 m Spatial Resolution Bands: B2 (490 nm), B3 (560 nm), B4 (665 nm) and B8 (842 nm)

Optical data Sentinel-2

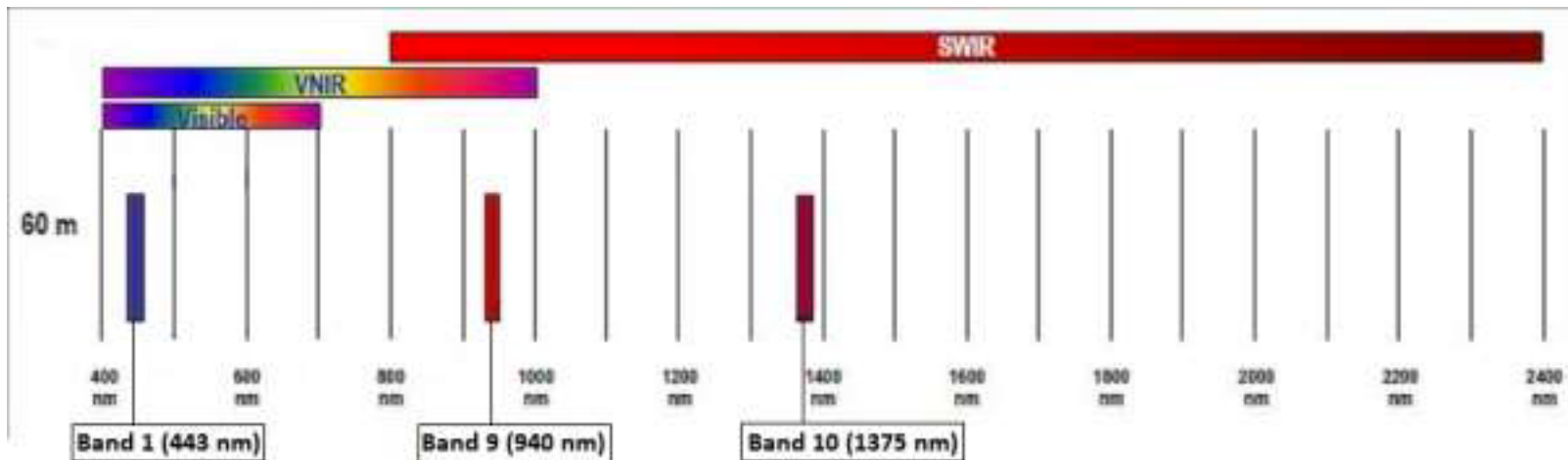
<https://sentinel.esa.int/web/sentinel/missions/sentinel-2>



Sentinel-2 20 m Spatial Resolution Bands: B5 (705 nm), B6 (740 nm), B7 (783 nm), B8b (865 nm), B11 (1610 nm) and B12 (2190 nm)

Optical data Sentinel-2

<https://sentinel.esa.int/web/sentinel/missions/sentinel-2>



Sentinel-2 60 m Spatial Resolution Bands: B1 (443 nm), B9 (940 nm) and B10 (1375 nm)

Optical data

Sentinel-2

<https://sentinel.esa.int/web/sentinel/missions/sentinel-2>

<https://scihub.copernicus.eu/dhus/#/home>

True Colour Images (TCI)

Optical data

Sentinel-2

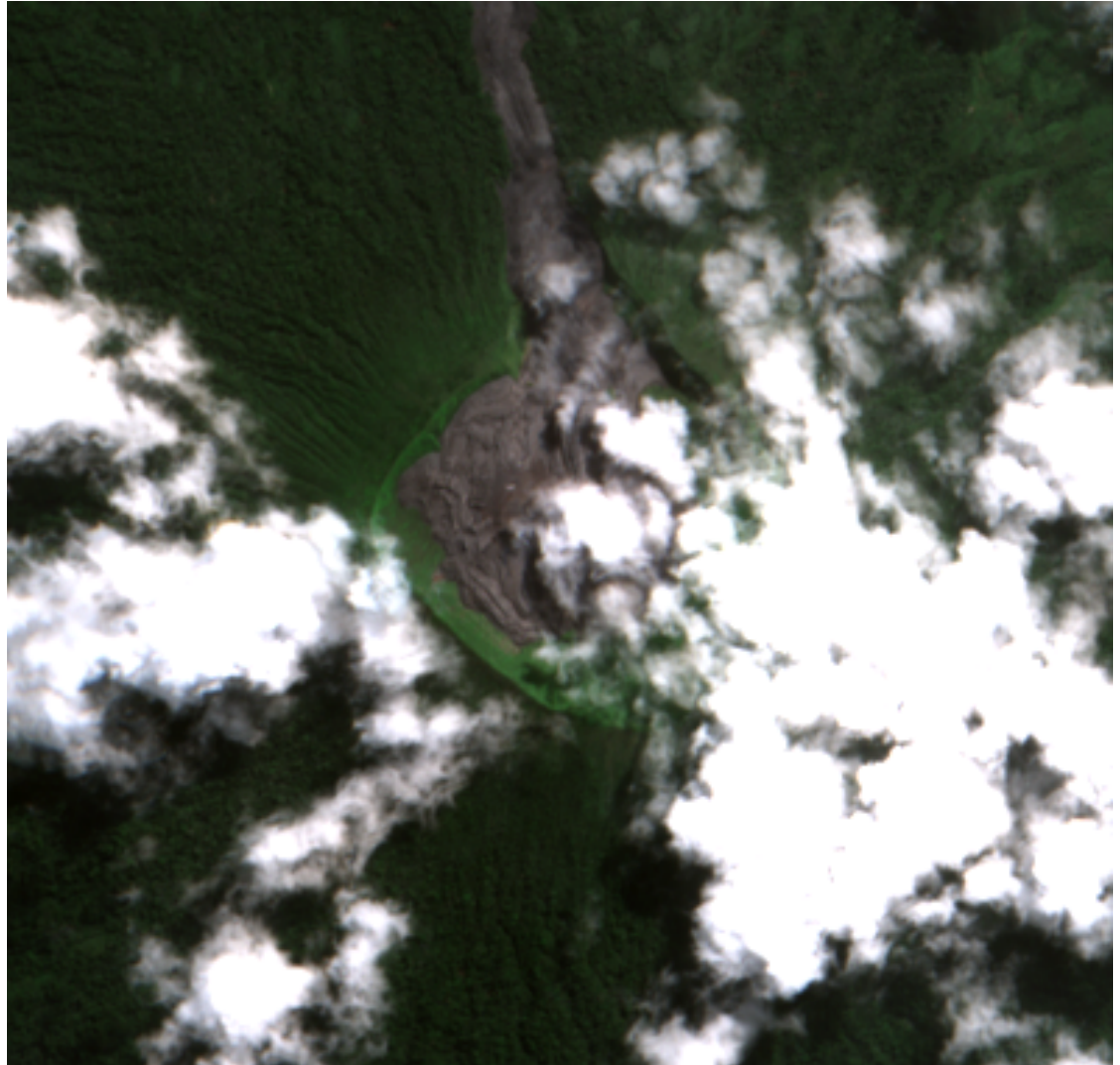
<https://sentinel.esa.int/web/sentinel/missions/sentinel-2>

Exemple: North Maluku,
Halmahera Island
10 June 2017

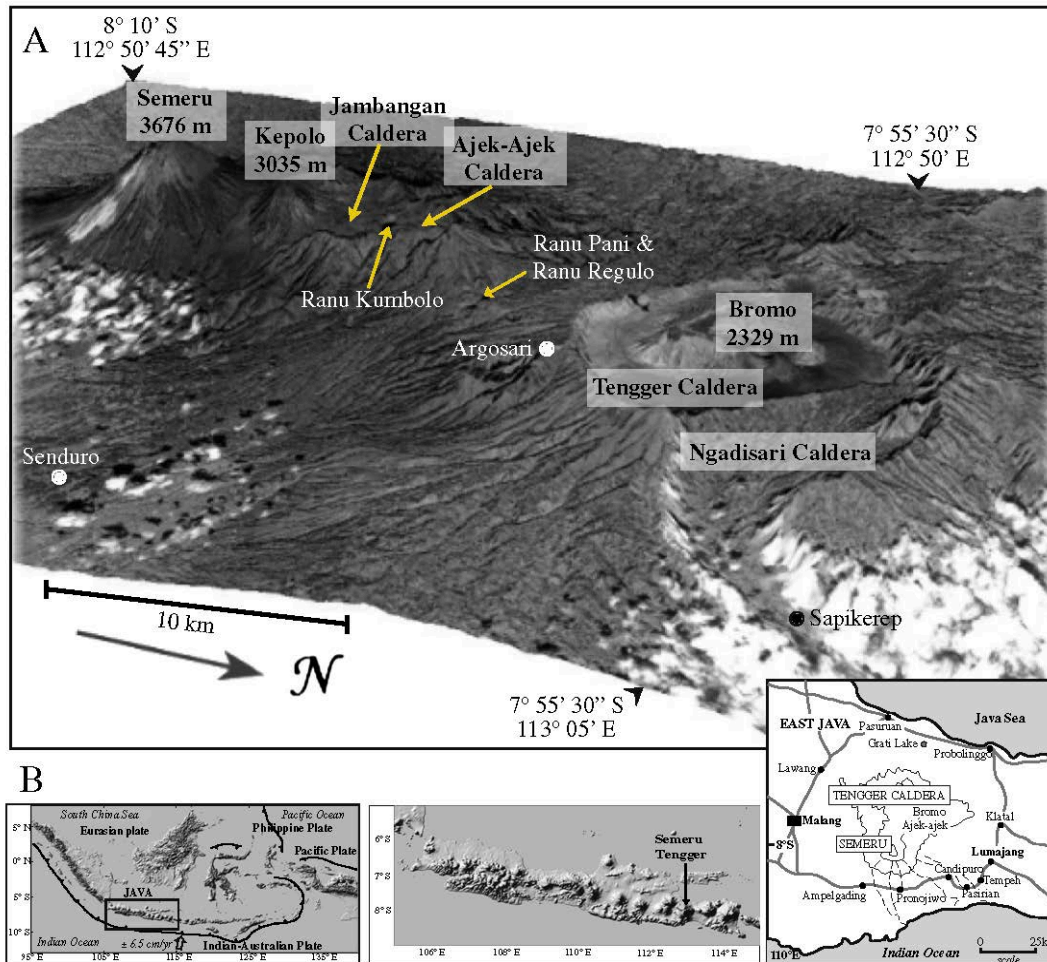


Optical data Sentinel-2

Exemple: Ibu: 10 June 2017

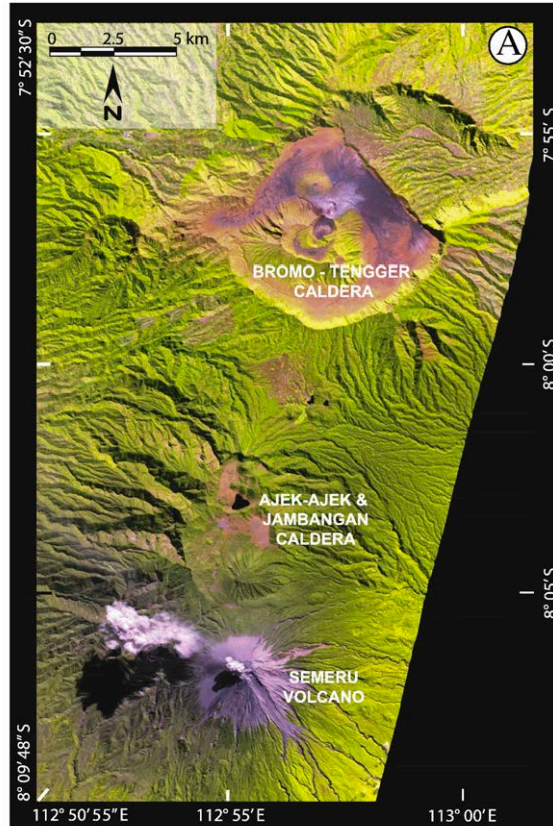


Structural analysis of Semeru

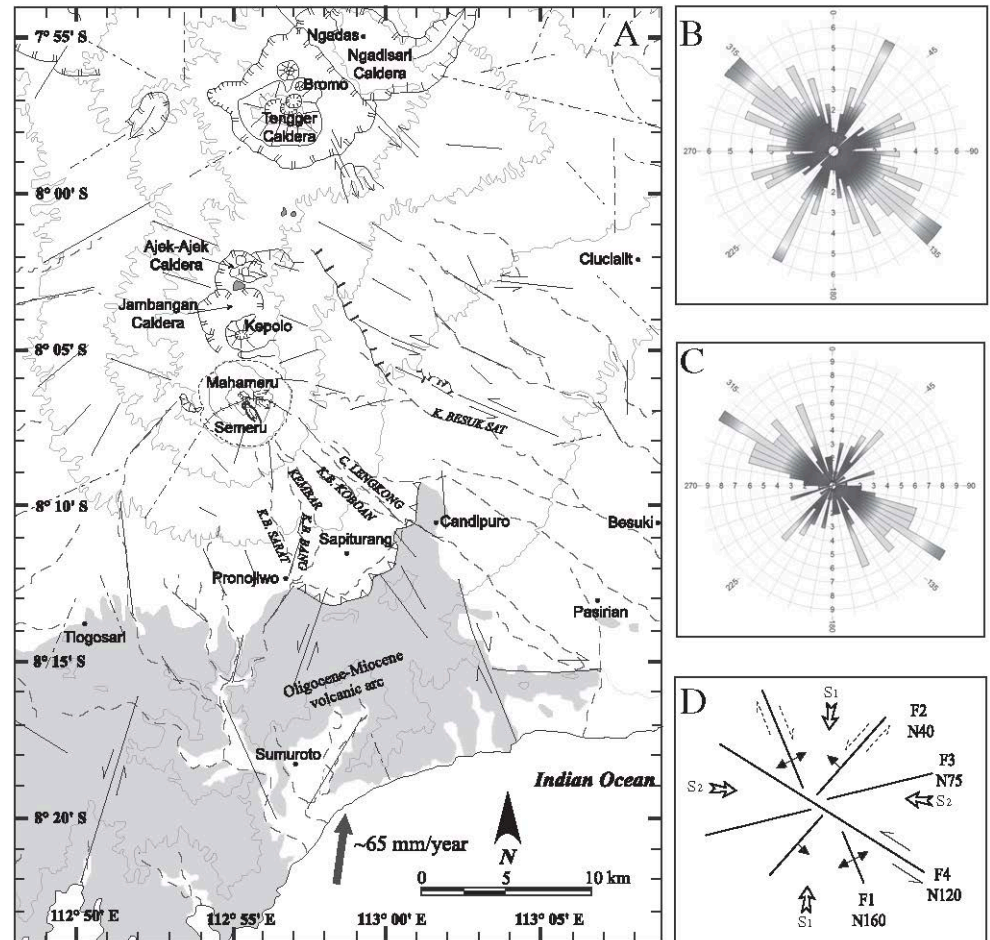


The 11/08/2003 SPOT5 image, looking SW and draped on the SRTM DEM

Structural analysis of Semeru



Spot 5 (2.5m)



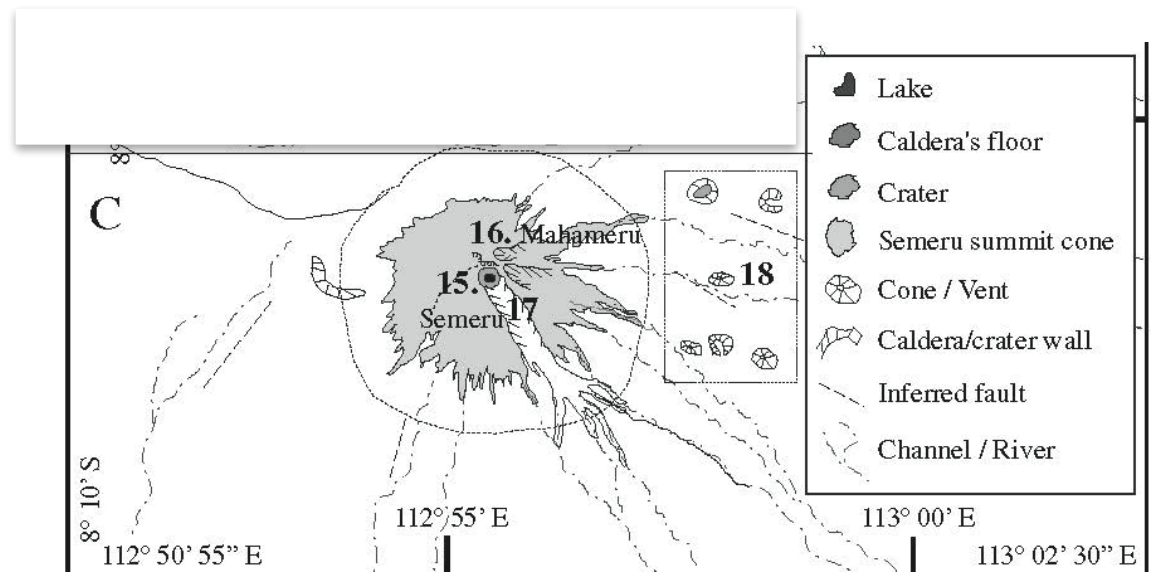
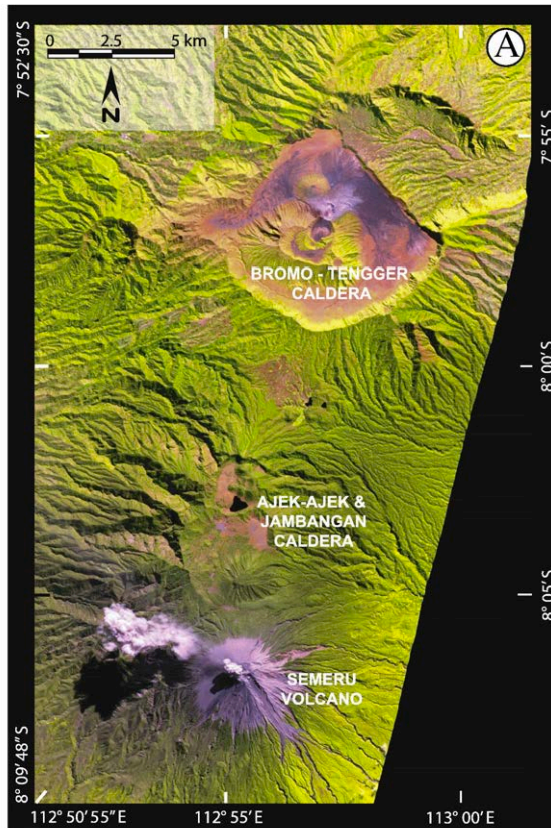
Geological and tectonic structures

- Strike-slip faults
- Reverse faults
- Normal faults
- Inferred faults (unknown kinematic)
- Lincaments
- Direction of convergence at Trench

Volcanic edifice structures and geomorphic features

- Crater
- Caldera rim
- Active scar and vent (Jonggring-Seloko)
- Structural boundary between 'old' and 'young' Semeru
- Scar of landslide
- Amphitheater valley
- River
- Lake
- Elevation contour

Deposits study

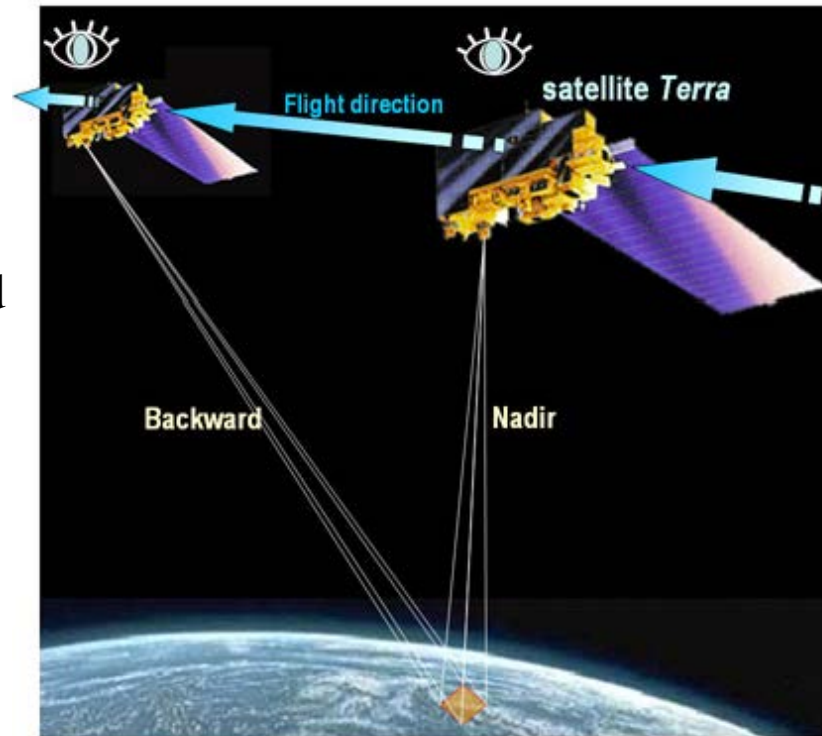


Spot 5 (2.5m)

Use of optical images to produce DEM

Ex: ASTER

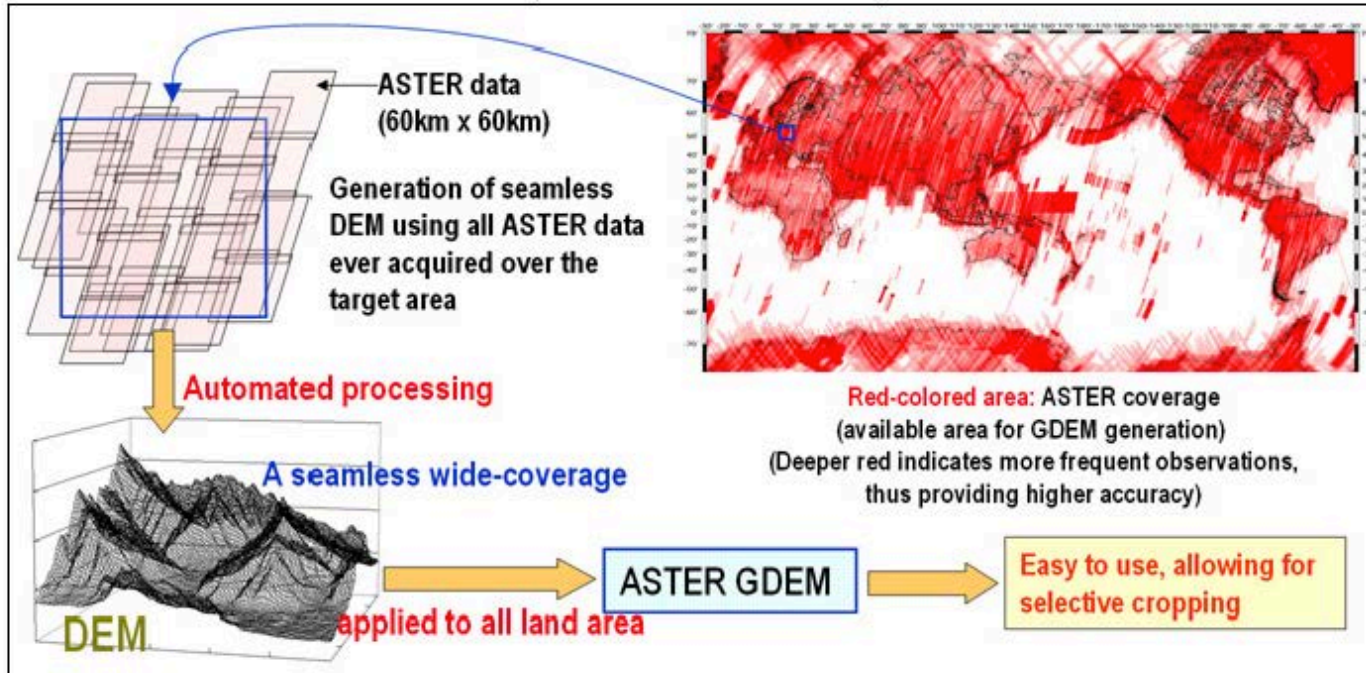
DEM is generated from a stereo-pair of images acquired with nadir and backward angles over the same area



Use of optical images to produce DEM

Ex: ASTER

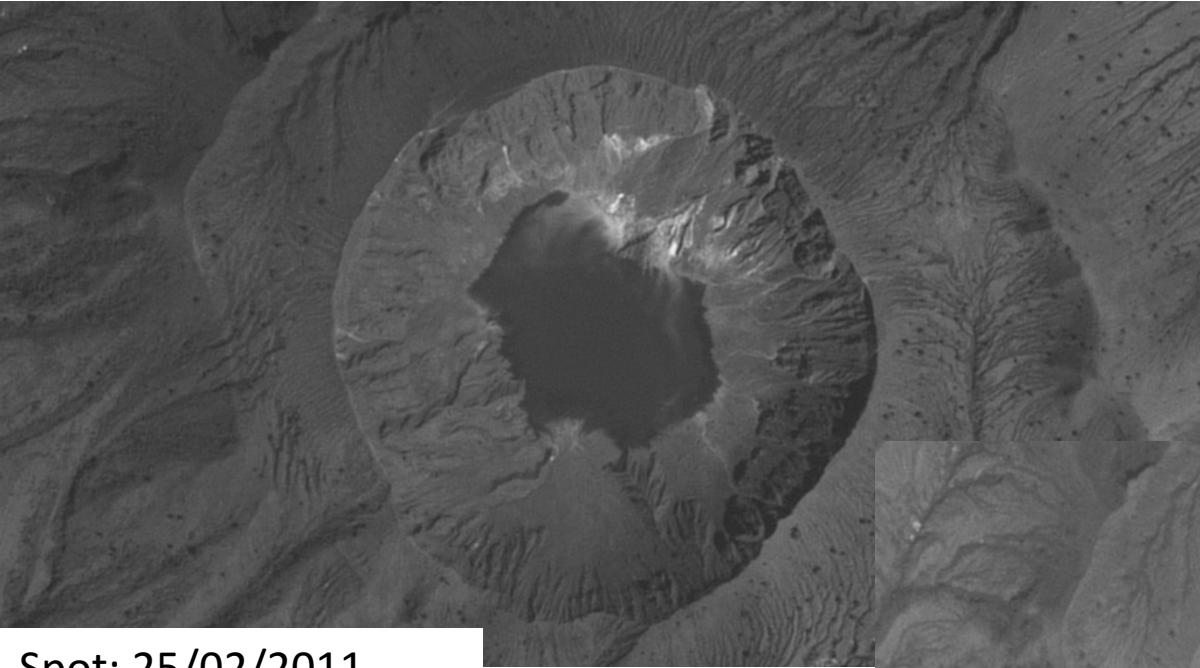
Concept of ASTER G-DEM development



Images spatial resolution : 15 m

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

Stereogrammetry (SPOT 2.5m)

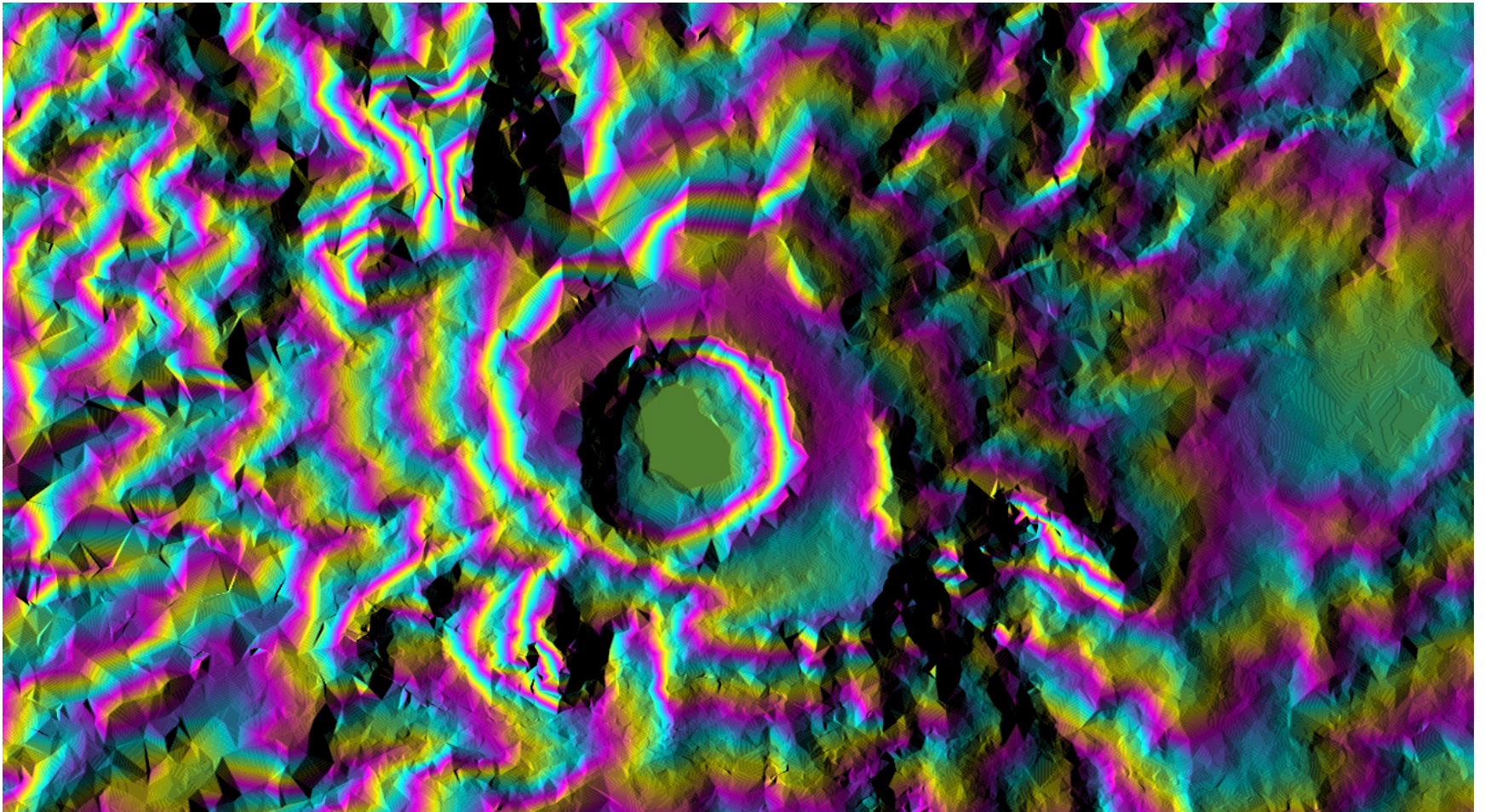


Spot: 6/03/2008
Incidence angle=28.75°



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

Stereogrammetry (SPOT 2.5m)



1 fringe is for 100 m

DEM from optical images (Ames Stereo Pipeline) AMS

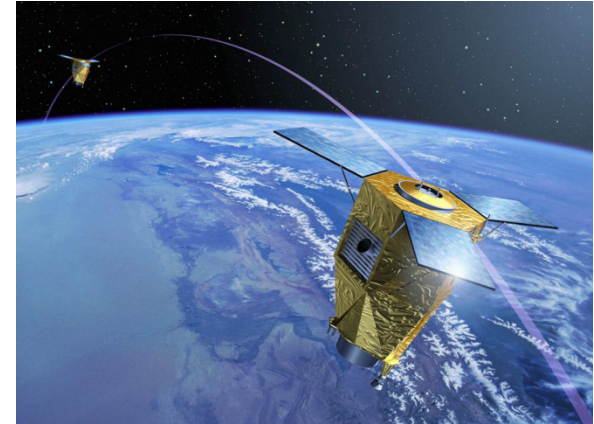
- http://byss.arc.nasa.gov/stereopipeline/daily_build/

Pléiades DEM from ASP

Pléiades Satellite

- Pléiades 1A (launched on 17/12/2011) and Pléiades 1B (2/12/2012)

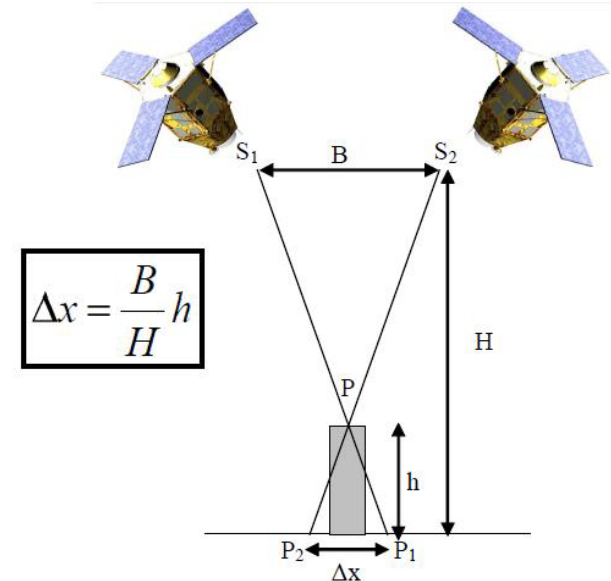
Spectral band	Spatial resolution
Panchromatic: 450-800 nm	0.7 m
B1 (blue): 450-510 nm	2.8 m
B2 (green): 510-580 nm	
B3 (red): 655-690 nm	
B4 (NIR): 780-920 nm	



- Multiple acquisitions over target on a single pass (multi-stereo acquisition)



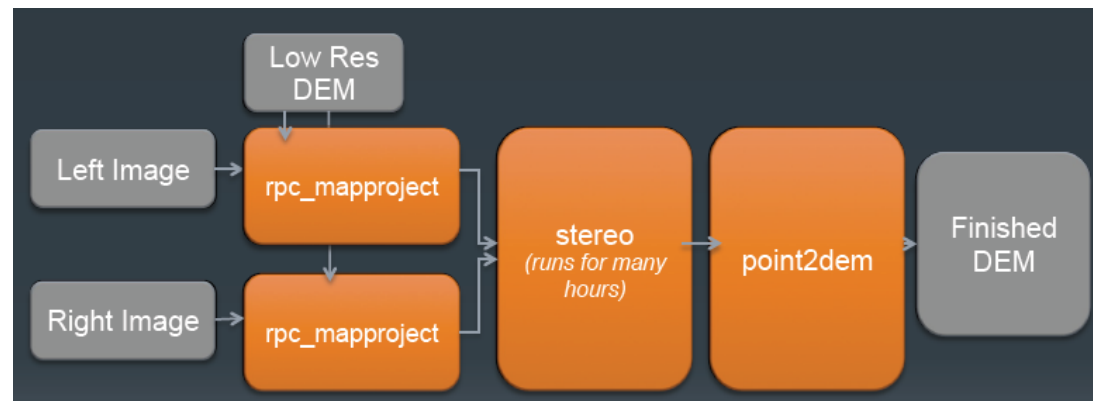
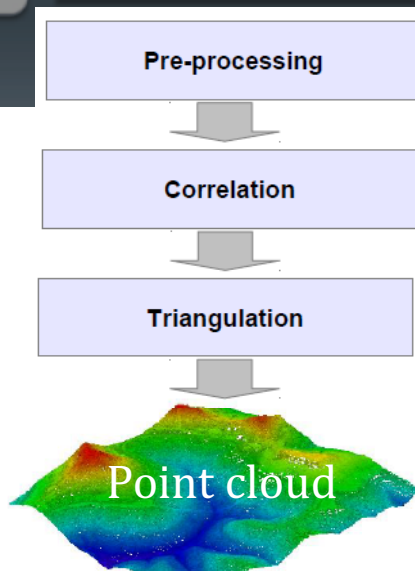
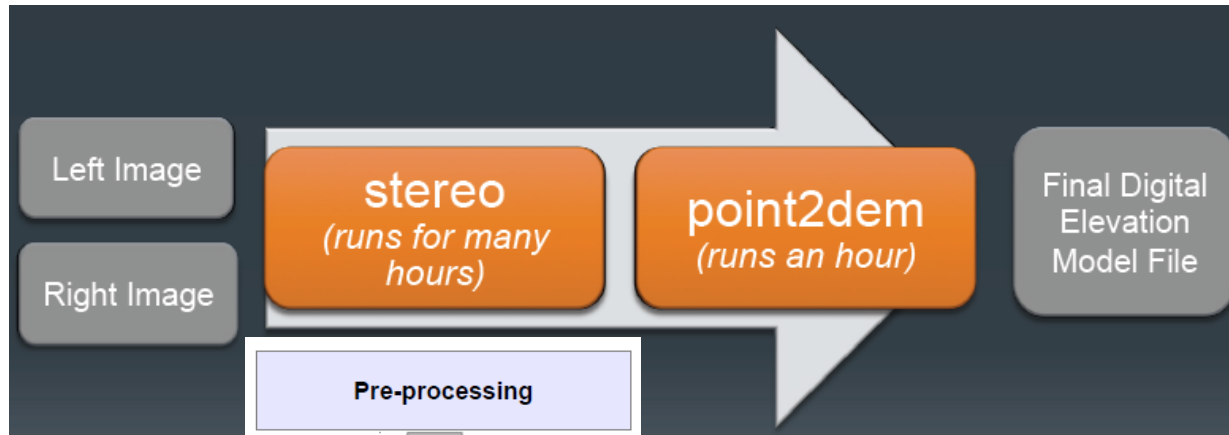
Agility:
5° in 8 sec
10° in 10 sec
60° in 25 sec



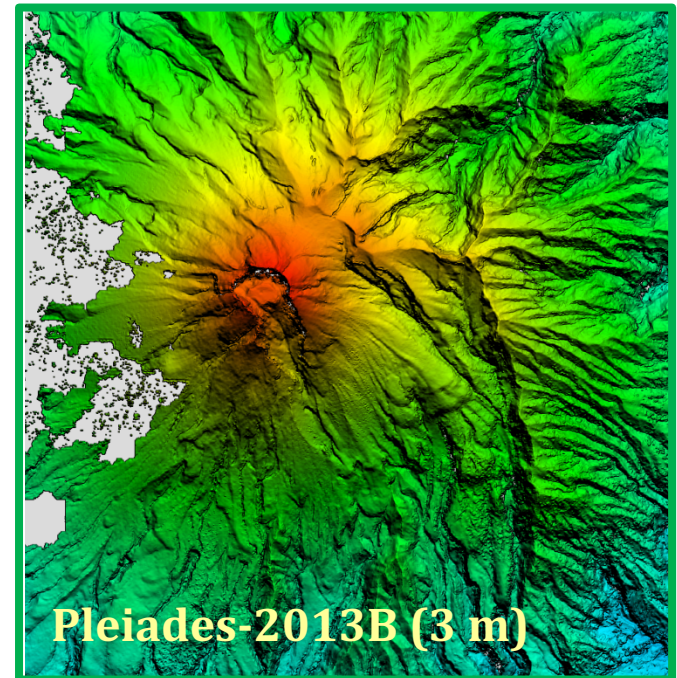
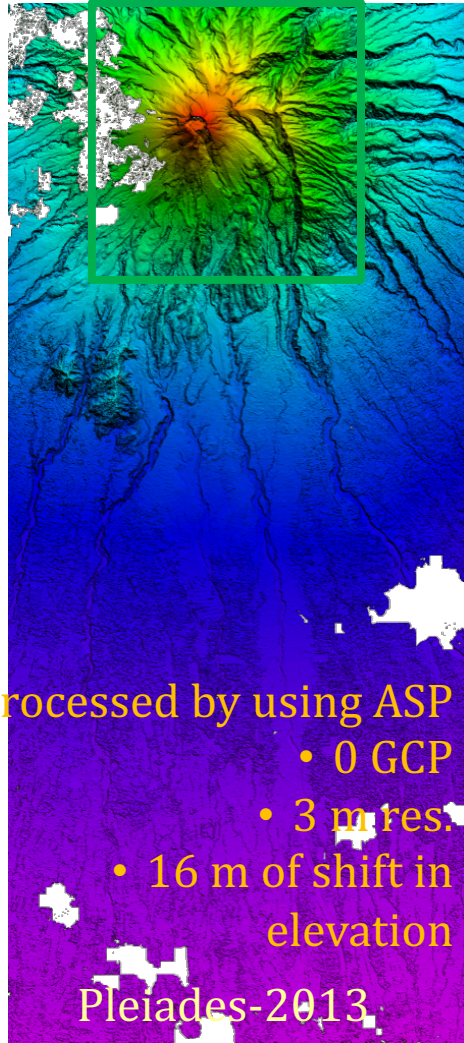
Pléiades DEM from ASP

AMES Stereo Pipeline

- Automatic Stereo Correlation (*matching all pixels between two images*) for large satellite images.
- Developed by NASA for terrestrial imaging
- Open source; work on UNIX derived platforms (Linux, Mac OSX, etc)



Post-Eruption DEM



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

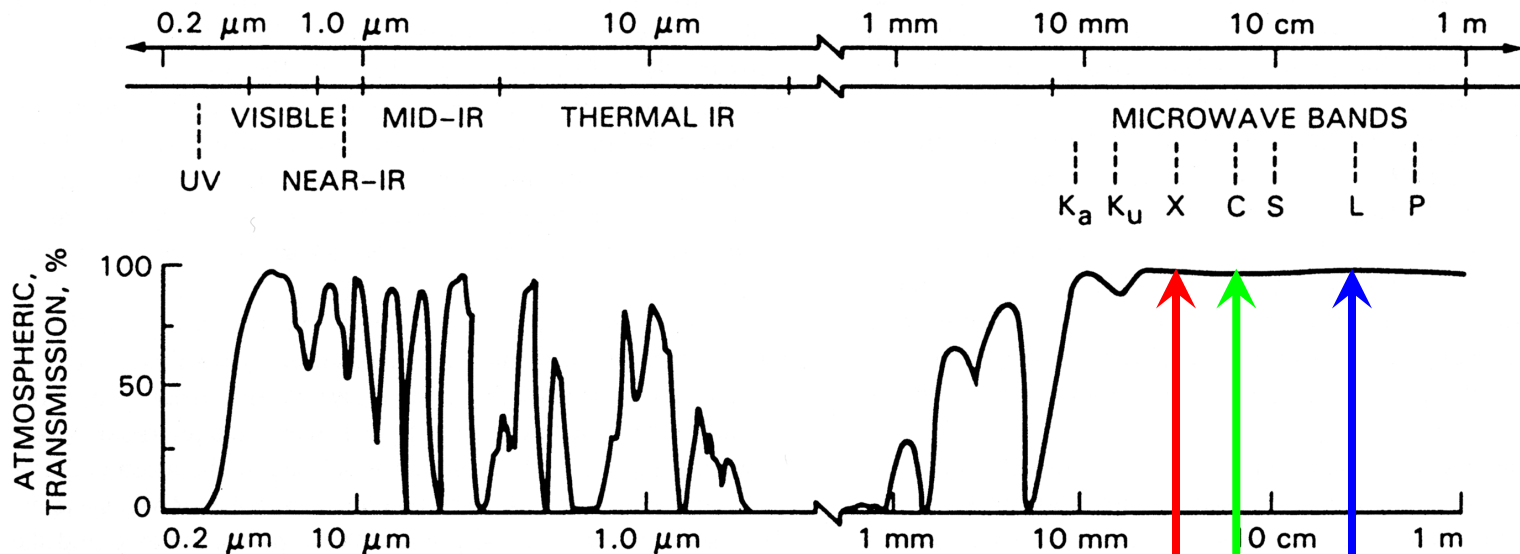
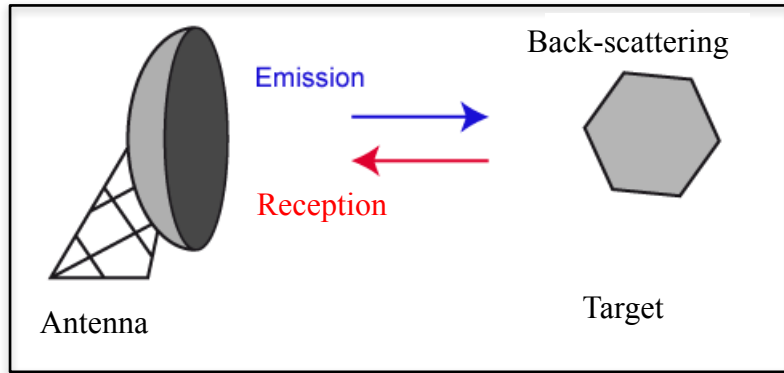
A Passive measurements : **Require sunlight except for thermal measurements**

- 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. SAR data description + where (how) to access the data
2. How to measure displacement
3. Processing methods and tools

Radar imagery → Distance



TerraSARX, CosmoSkymed
(3 cm)

Sentinel, ENVISAT, RADARSAT, ERS1-2 (6 cm)

ALOS, ALOS2, JERS1 (24 cm)

Principle of SAR (Synthetic Aperture Radar)

Resolution is limited in azimuth by antenna length :

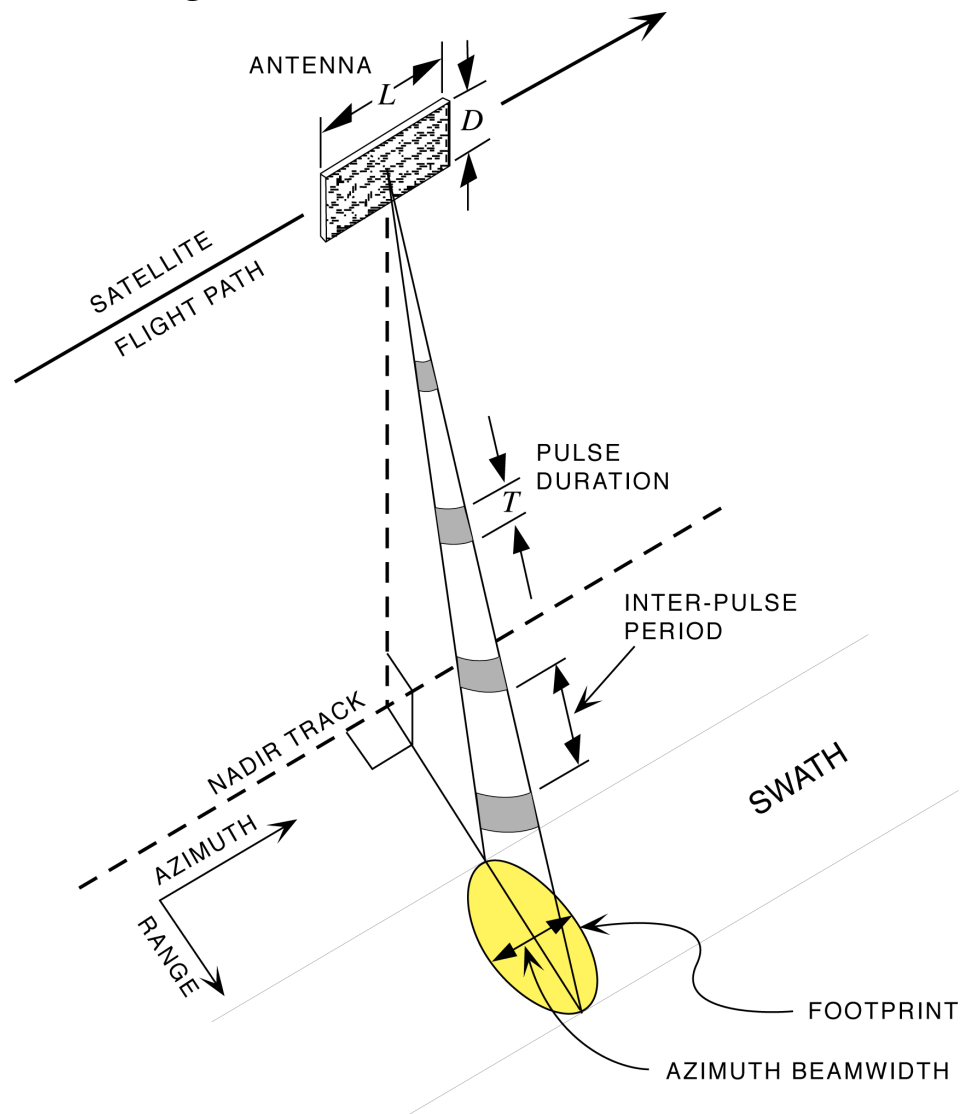
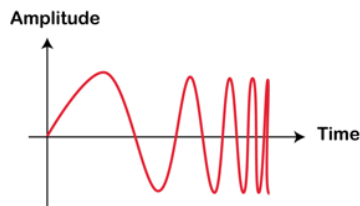
$R\lambda/L \rightarrow 5\text{km}$ for ERS

and in range by impulsion duration

This resolution is improved par Synthetic Aperture processing:

-Using Doppler effect in azimuth =azimuth compression

-Using frequency modulation of the signal in range=range compression

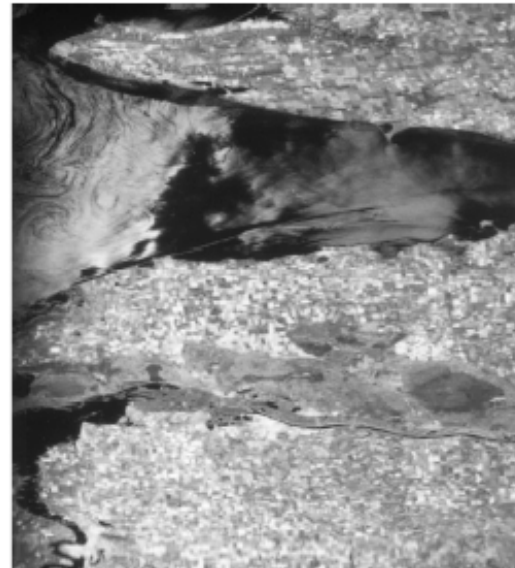


Images SAR

SAR Synthesis



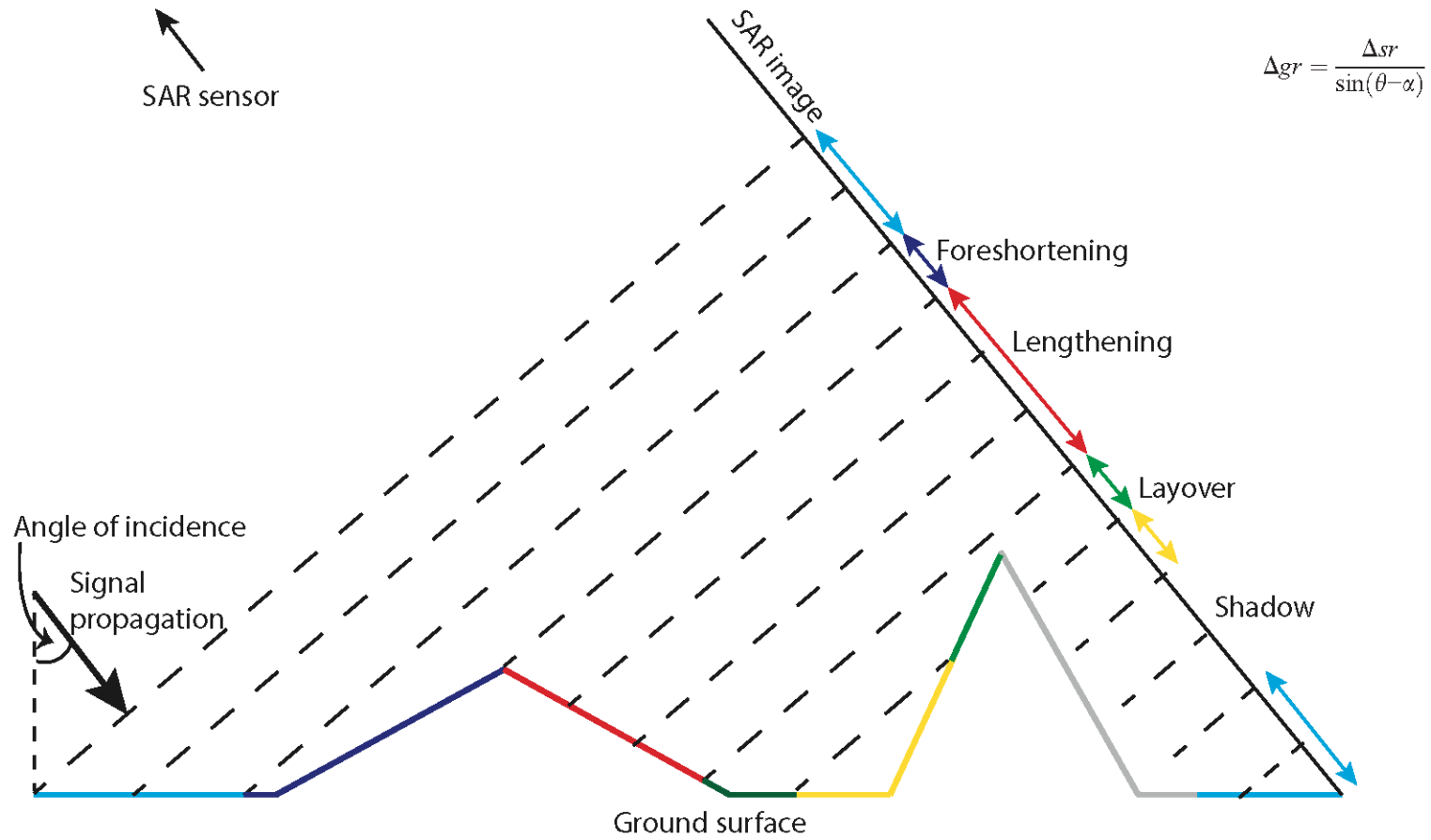
Raw data
Resolution
5km in azimuth
14km in range
For ERS



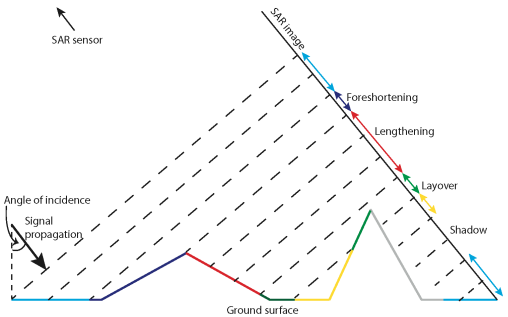
Single look complex (SLC) Image
=focused image
Resolution
5 m in azimuth
20 m in range

ERS scene
100*100km
140 millions of pixels

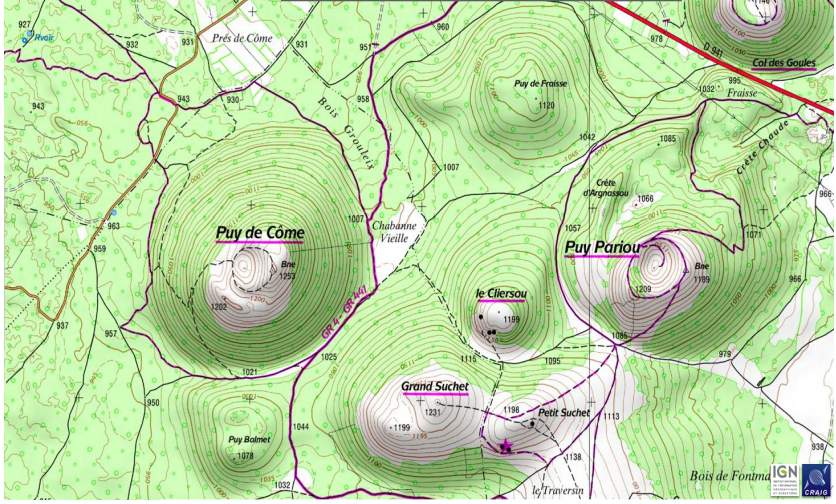
The radar “vision”



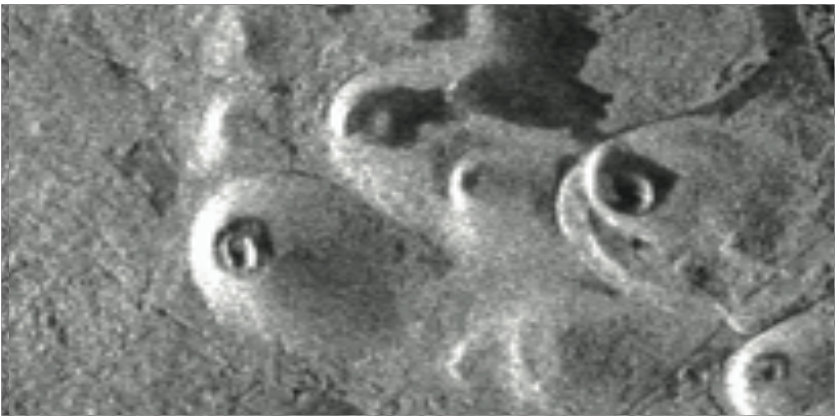
The radar “vision”



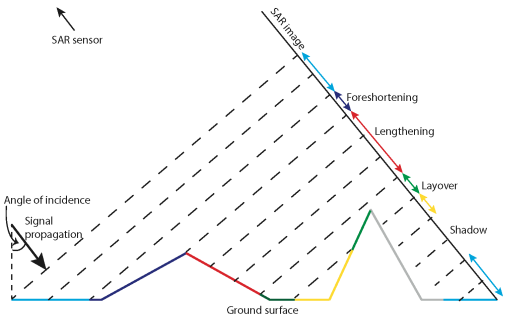
Ascending



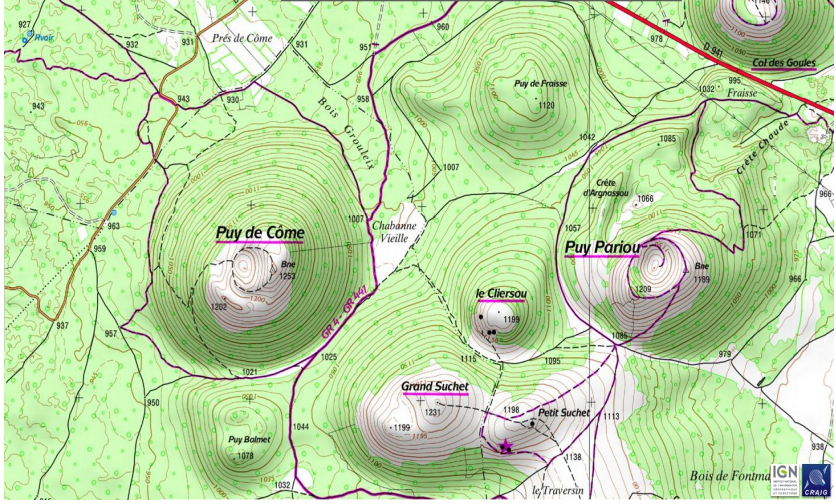
Line of sight



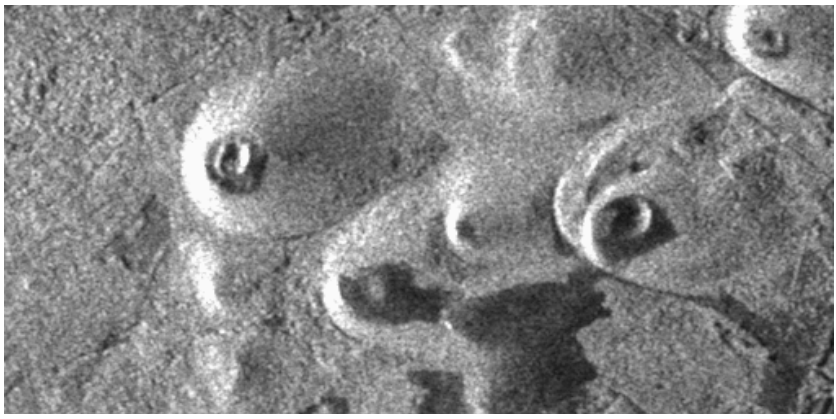
The radar “vision”



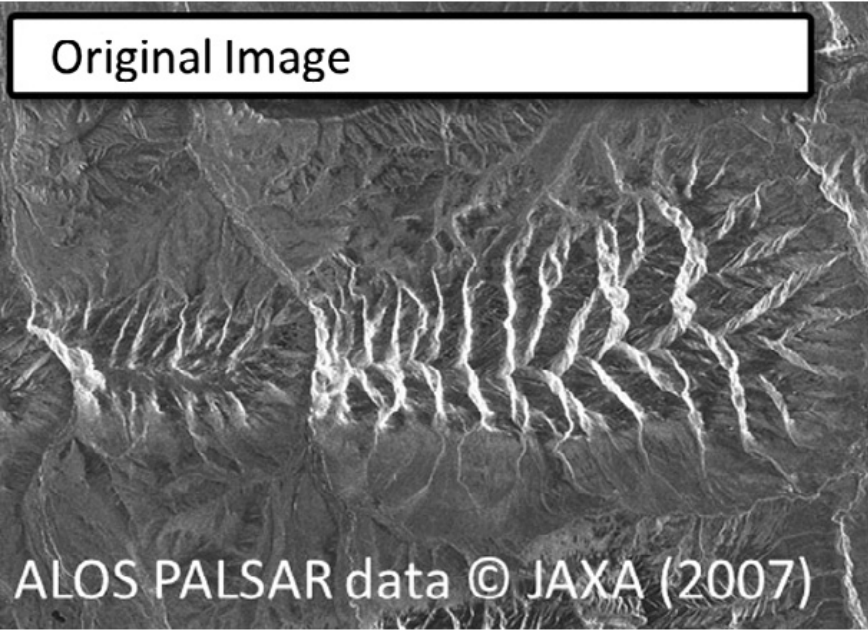
Ascending



Line of sight



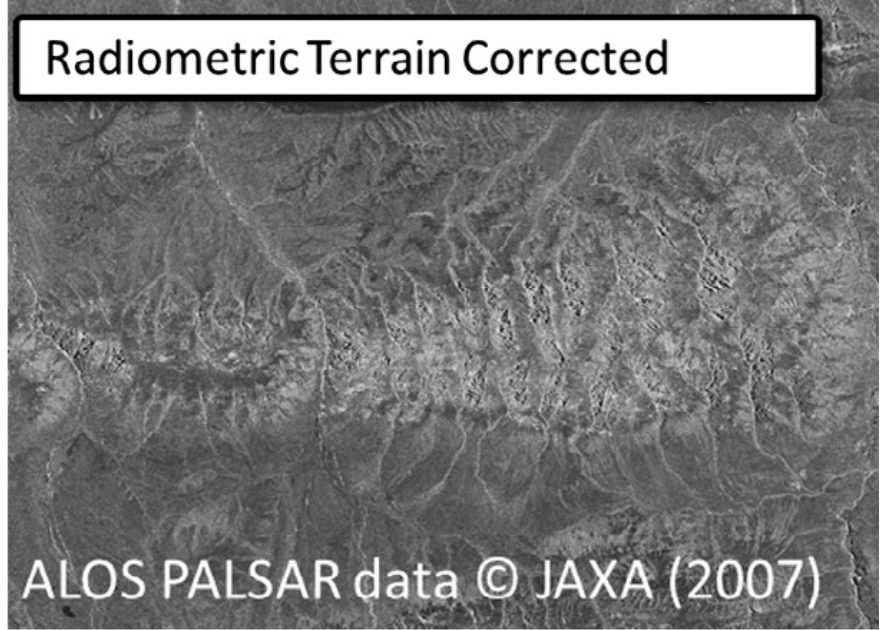
Original Image



ALOS PALSAR data © JAXA (2007)

(a)

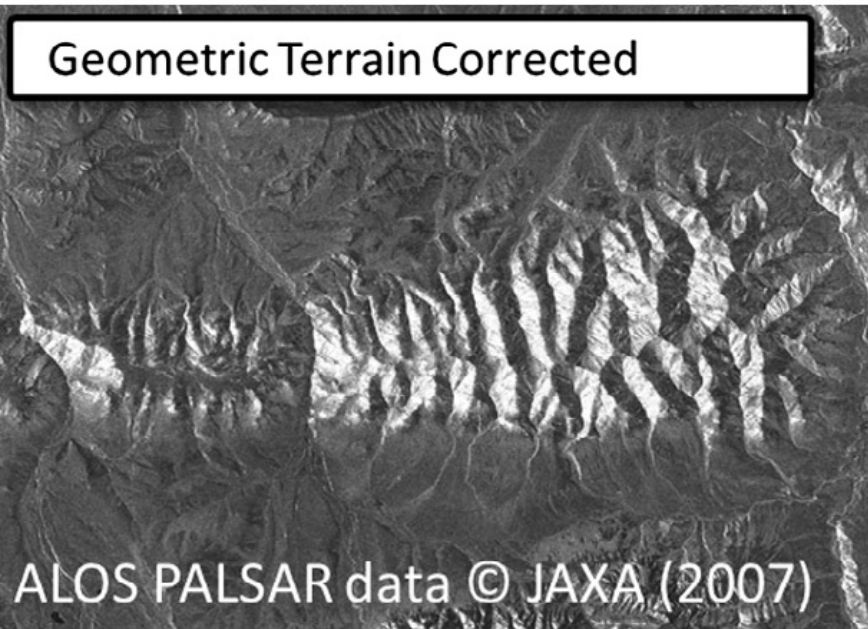
Radiometric Terrain Corrected



ALOS PALSAR data © JAXA (2007)

(c)

Geometric Terrain Corrected

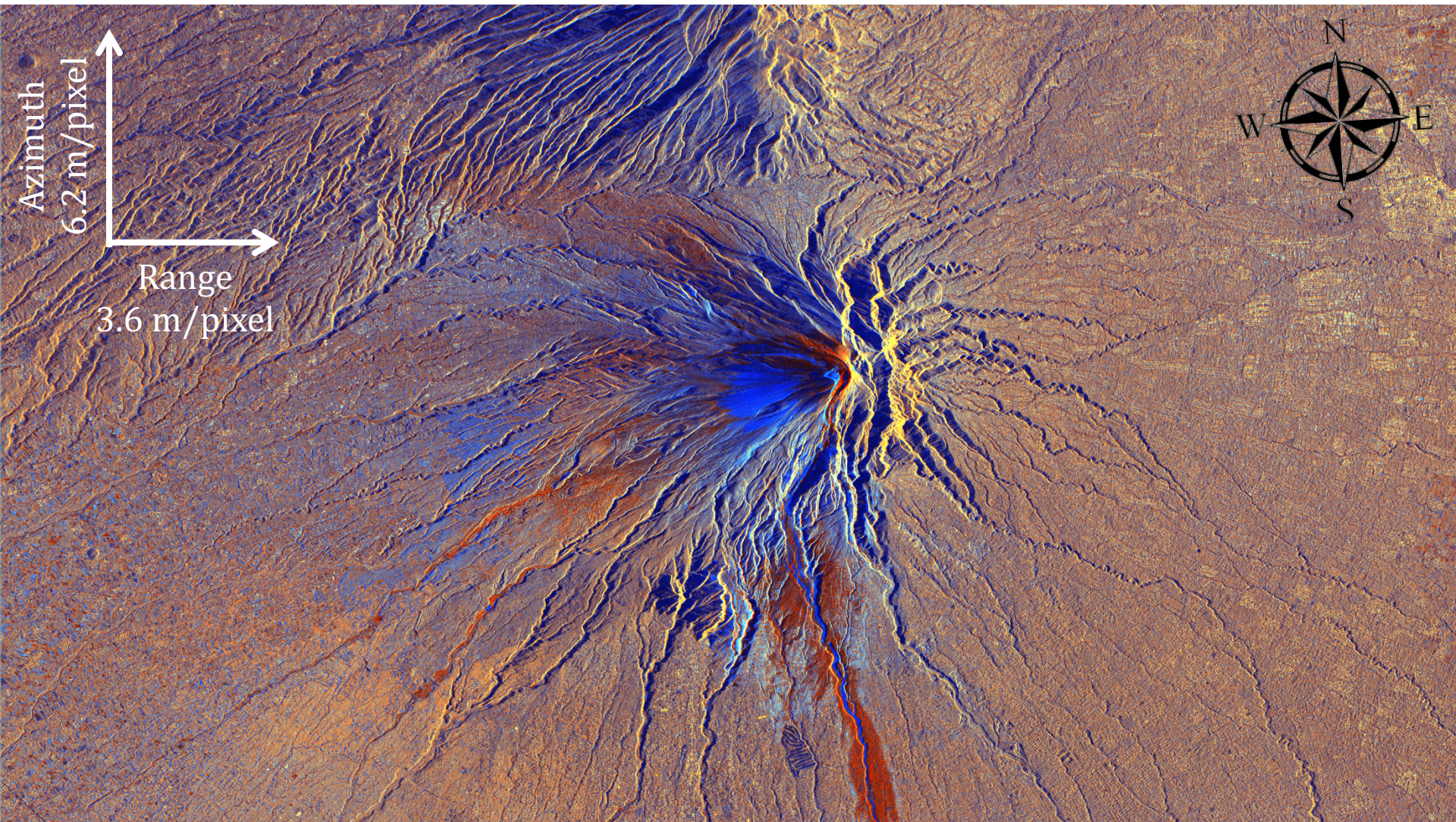


ALOS PALSAR data © JAXA (2007)

(b)

Meyer et al, 2015

TerraSAR-X on the 2010 Merapi eruption

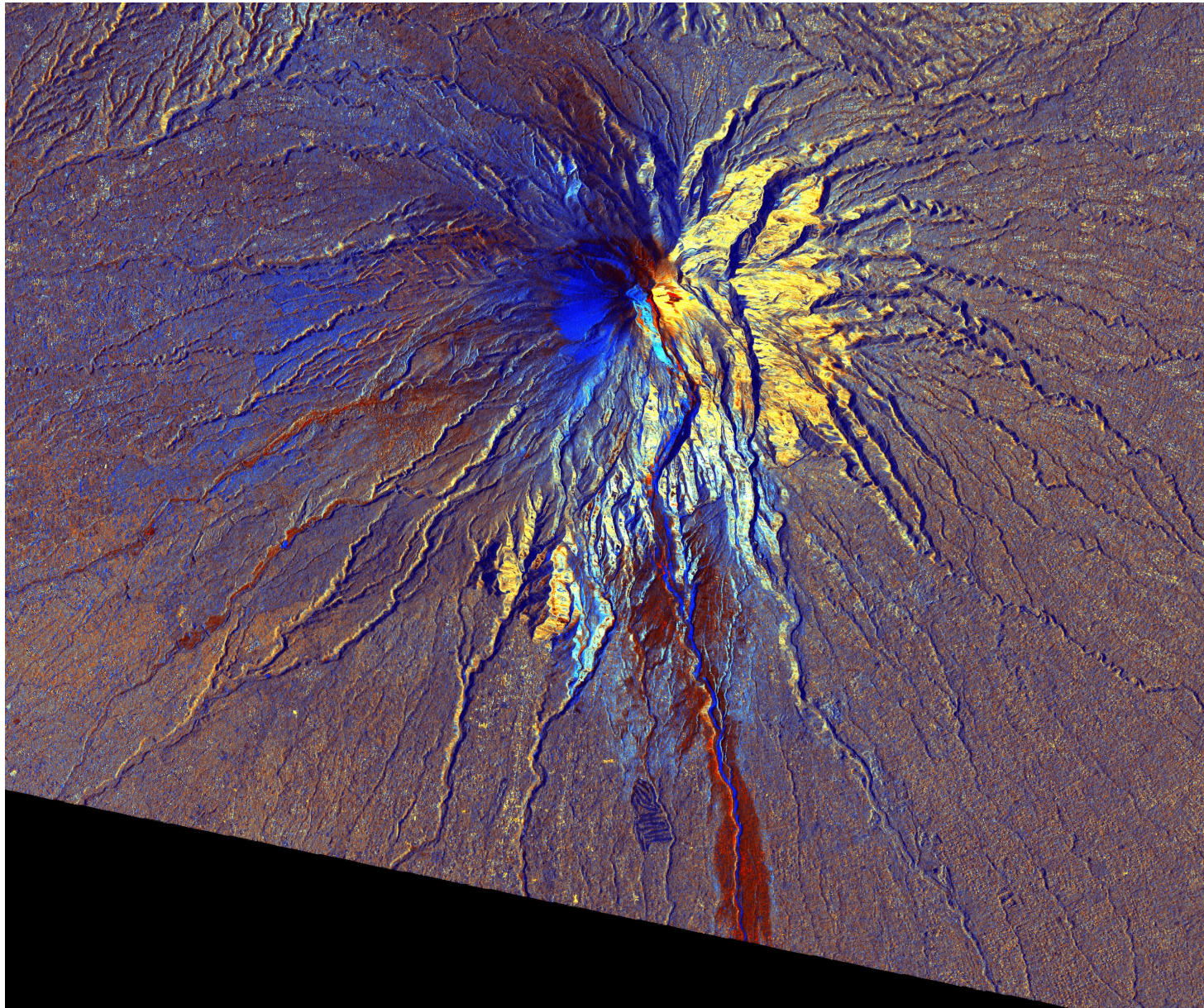


R: 26-10-2010

G: 06-11-2010

B: ratio (06-11-2010/26-10-2010)

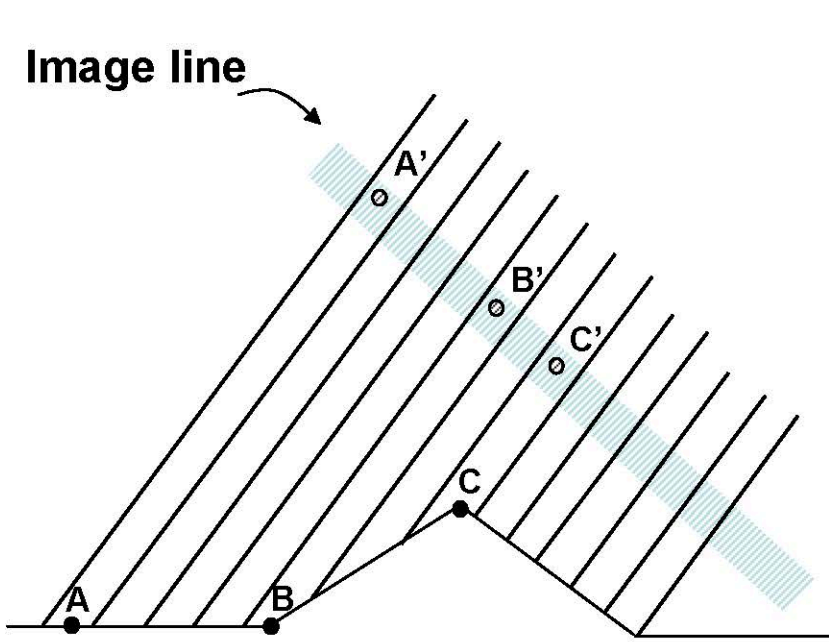
TerraSAR-X on the 2010 Merapi eruption



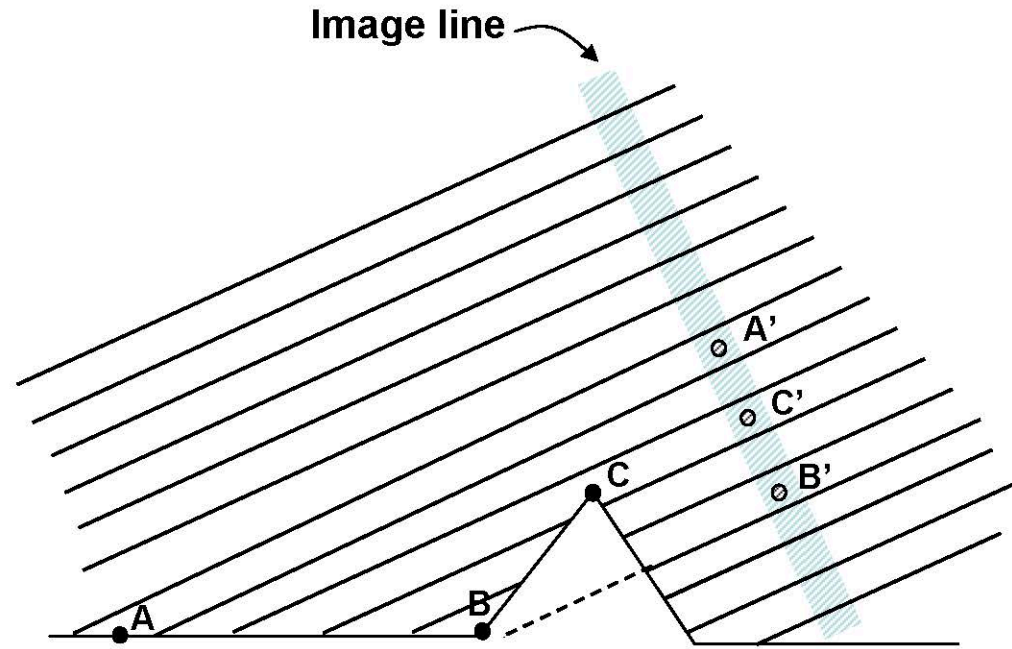
R: 26-10-2010 **G: 06-11-2010** **B: ratio (06-11-2010/26-10-2010)**

Image quality: geometry

→ foreshortening et layover effect



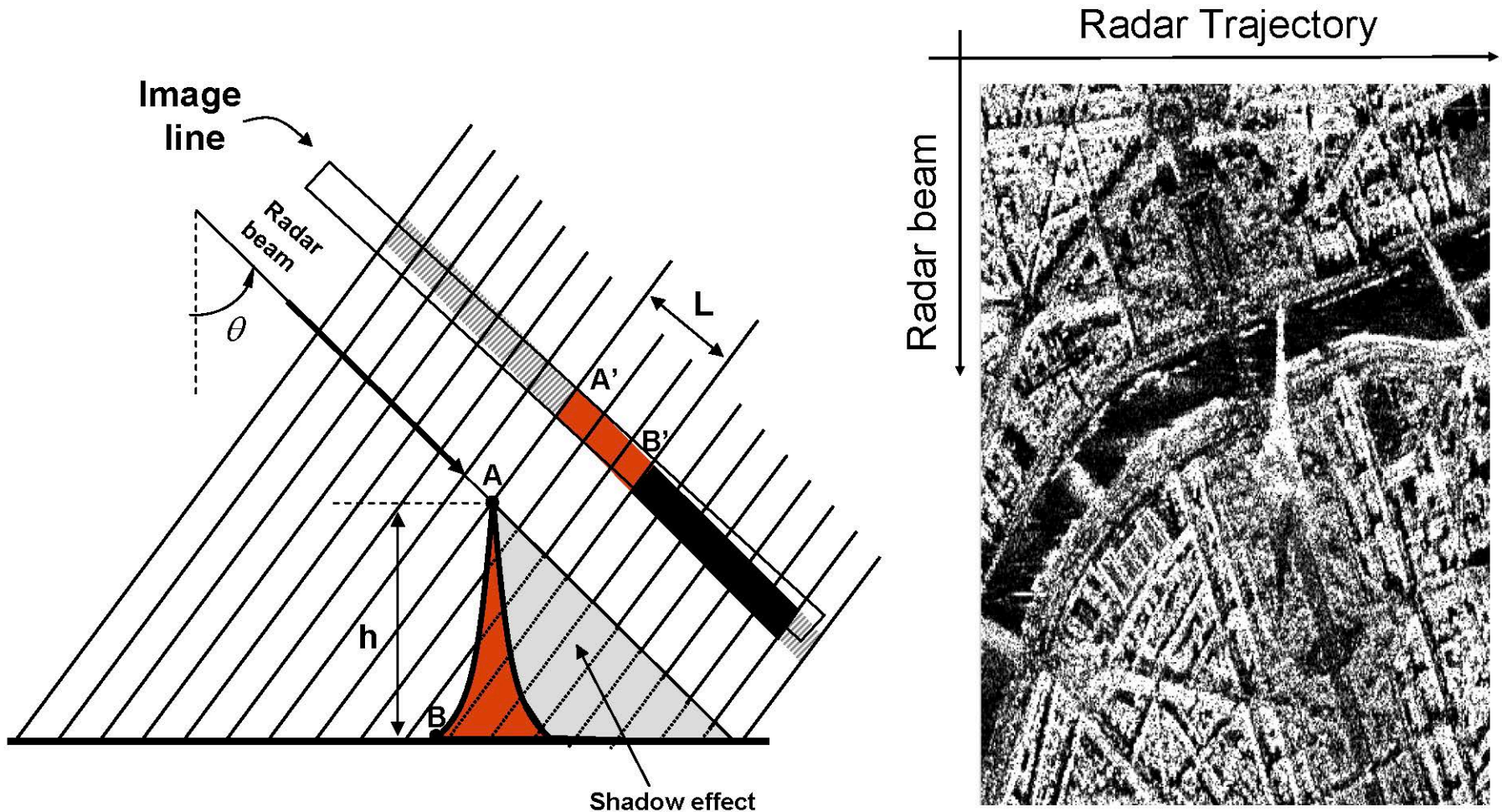
Foreshortening



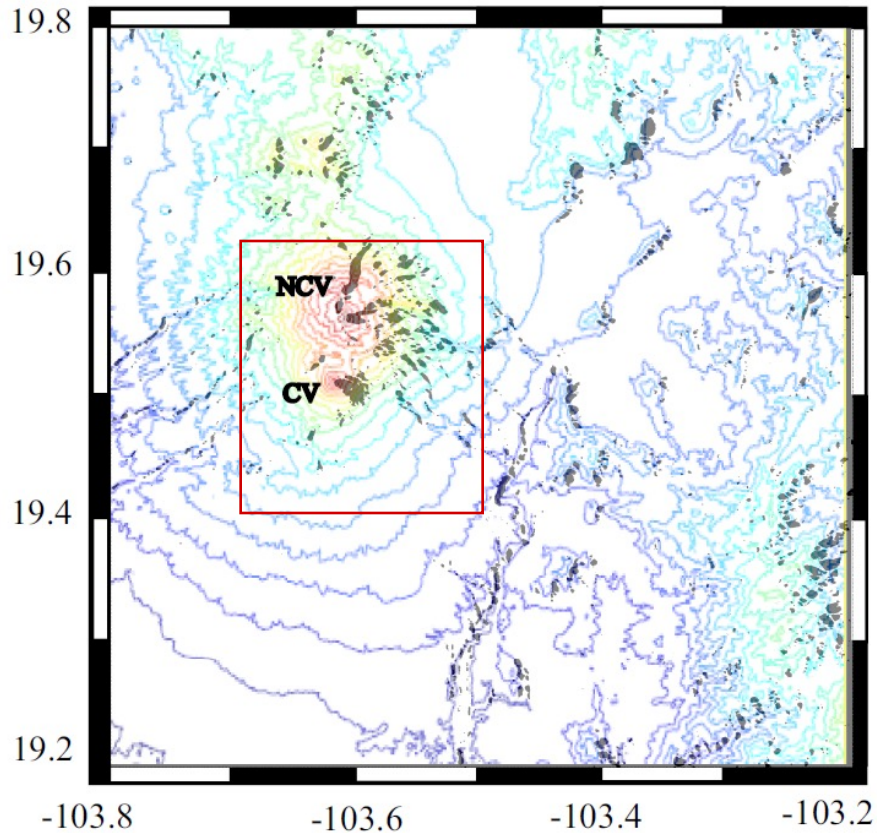
Layover

Image quality: geometry

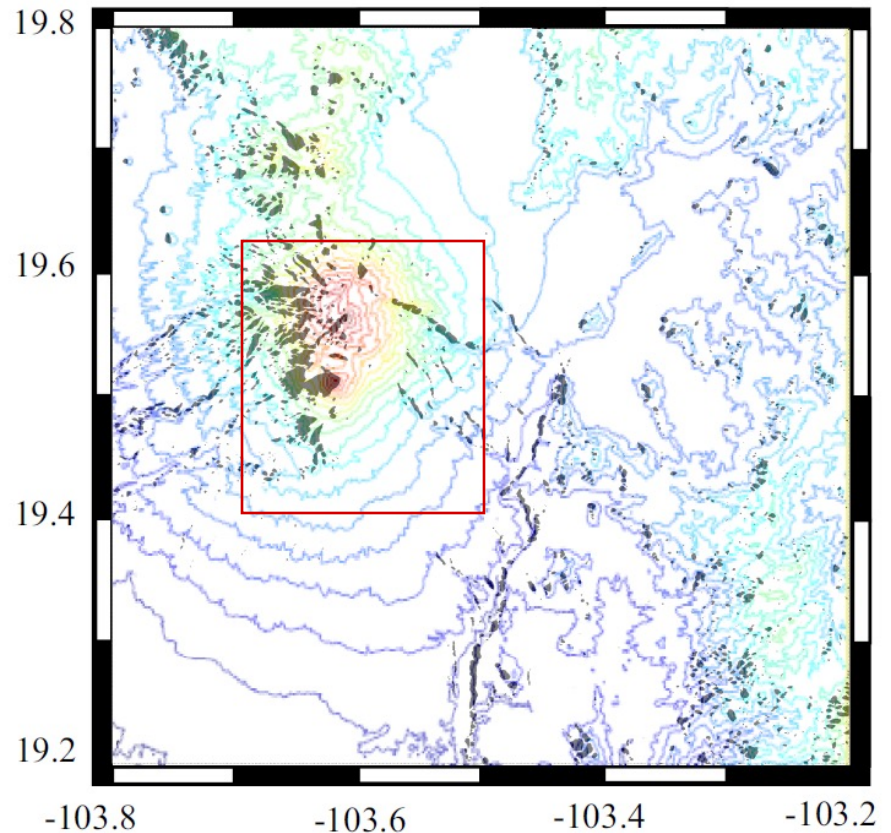
→ example of layover effect



Difficulty: There are some « holes » in the signal.



Descending (3.6 % of image)
7%

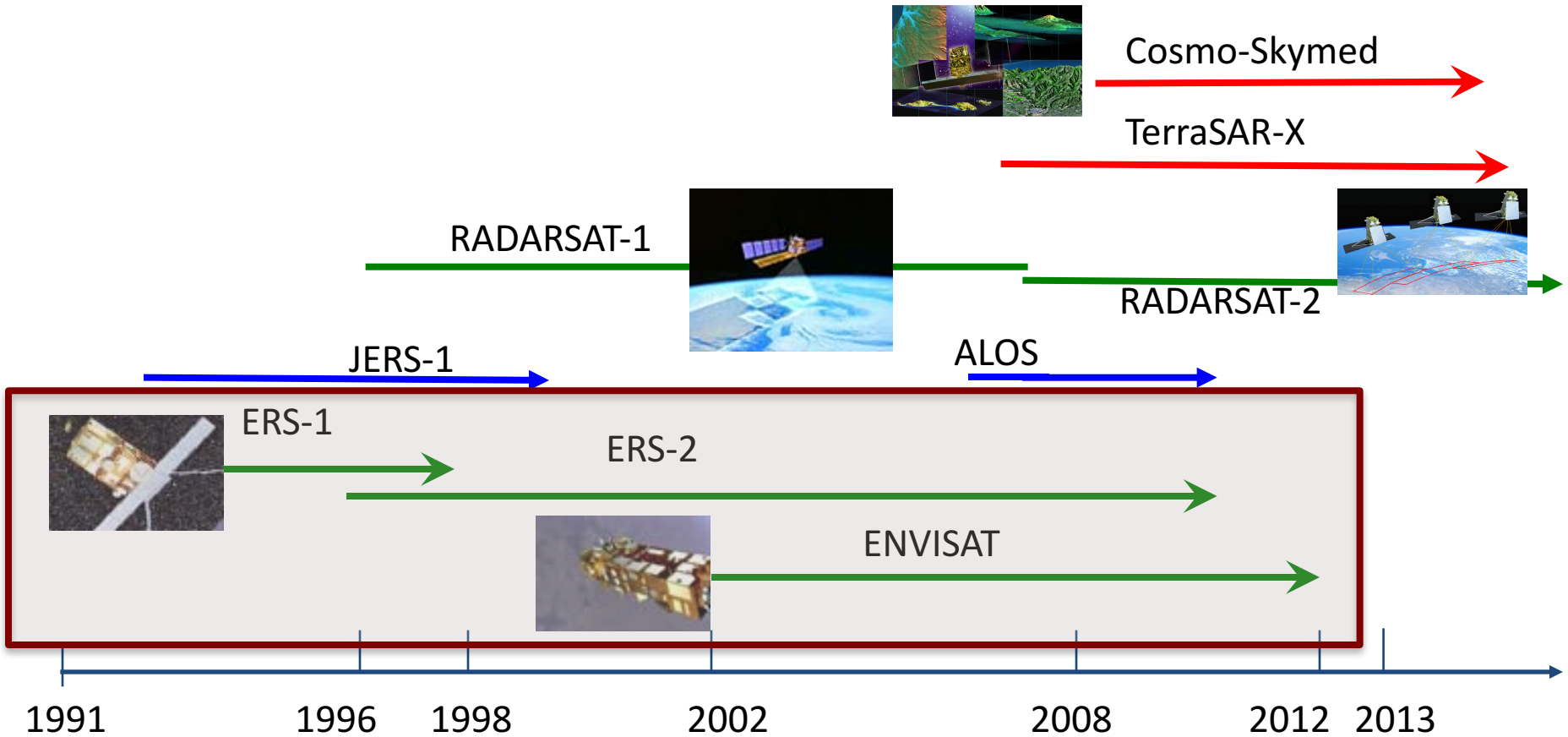
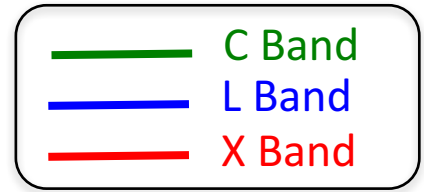


Ascending (4.9 % of image)
12%

Satellite providing SAR data

Satellite	Period	Revisit time (days)	Altitude (km)	Frequency (GHz)	Band	Incidence Angle (deg)	Swath (km)
ERS-1	1991-1996	35	790	5.3	C	23	100
ERS-2	1995-2011	35	790	5.3	C	23	100
JERS-1	1992-1998	44	568	1.275	L	39	85
Radarsat	1995-	24	792	5.3	C	20-49	10-500
ENVISAT	2001-	35	800	5.3	C	20-50	100-500
ALOS	2002-2011	45	700	1.27	L	8-60	40-350
Radarsat 2	2007-	24	798	5.3	C	20-60	20-500
TerraSAR-X (2)	2007-	11	514	9.65	X	20-55	10-100
Cosmo-Skymed (4)	2007-	16	619.61	9.6	X	40-50	10-200
<i>ALOS2</i>	2013-	14	628	1.2	L	8-70	25-350
<i>Sentinel1</i> (2)	2013 ?	12	6935	5.4	C	>25	>250
2014							

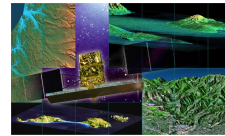
Satellites



Satellites

- C Band
- L Band
- X Band

High spatial and temporal resolution



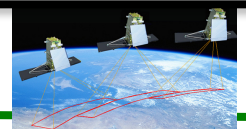
Cosmo-Skymed

TerraSAR-X

RADARSAT-1



RADARSAT-2



JERS-1

ALOS

ERS-1

ERS-2

ENVISAT

1991

1996

1998

2002

2008

2012

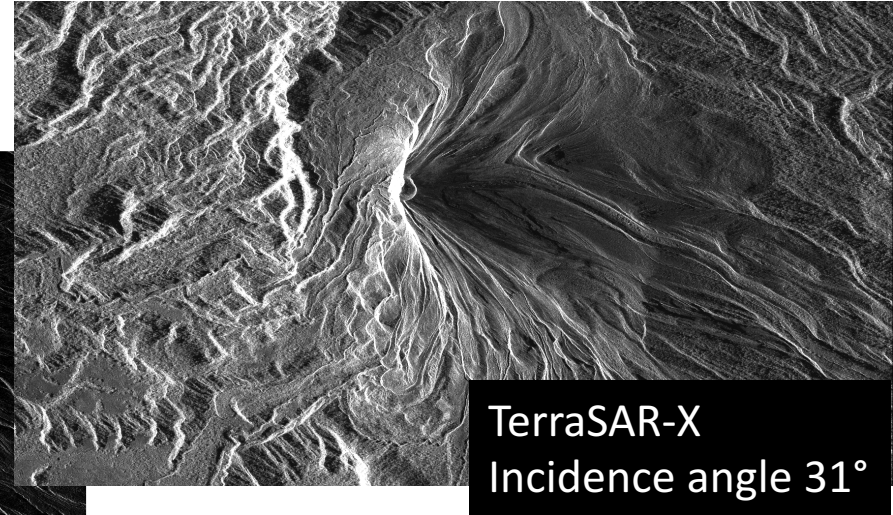
2013

ENVISAT (multilook 4*16)
Incidence angle 22°



High Resolution SAR imagery

a)



CSK (multilook 4*4)
Incidence angle 30°

Colima volcano, Mexico

Cosmo-Skymed or TerraSAR-X data
1*1m in Spotlight mode

CSK (Zoom)

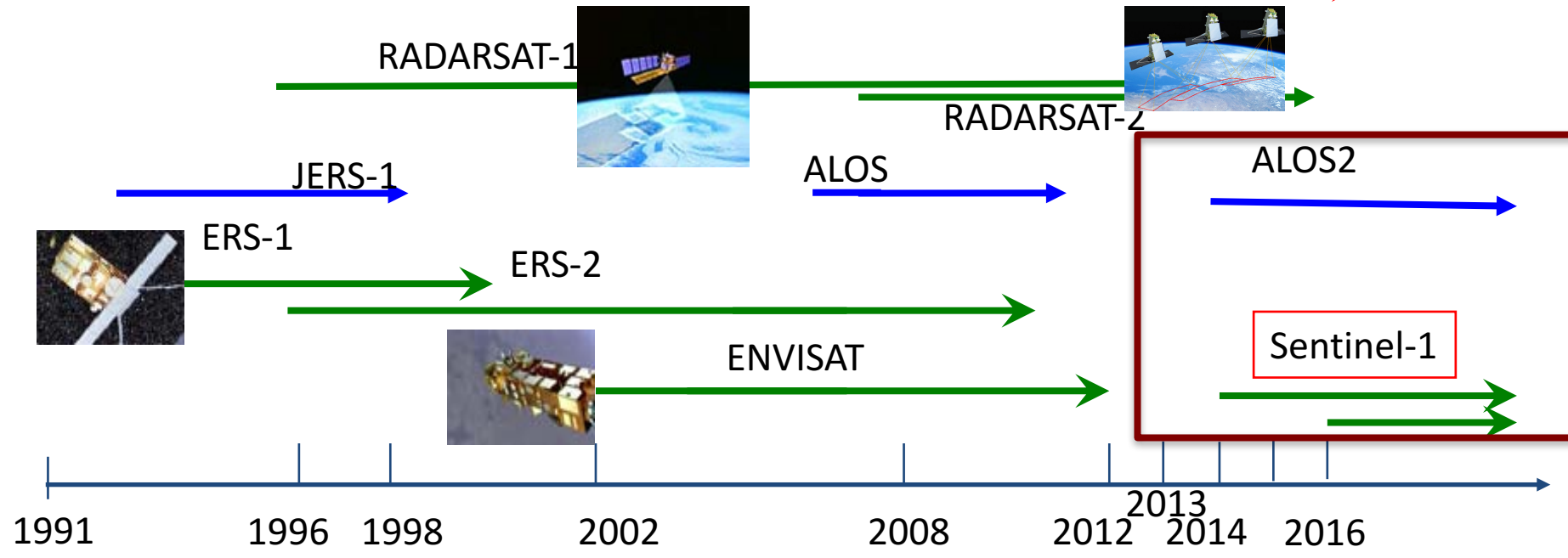
c)

Since 2014: Sentinel-1

Legend for Sentinel-1 bands:

- C Band (Green line)
- L Band (Blue line)
- X Band (Red line)

Sentinel-1: systematic acquisitions
Every 6 days over Europe
(also Sinabung)
Every 12 days everywhere
2.4 Tbyte/day

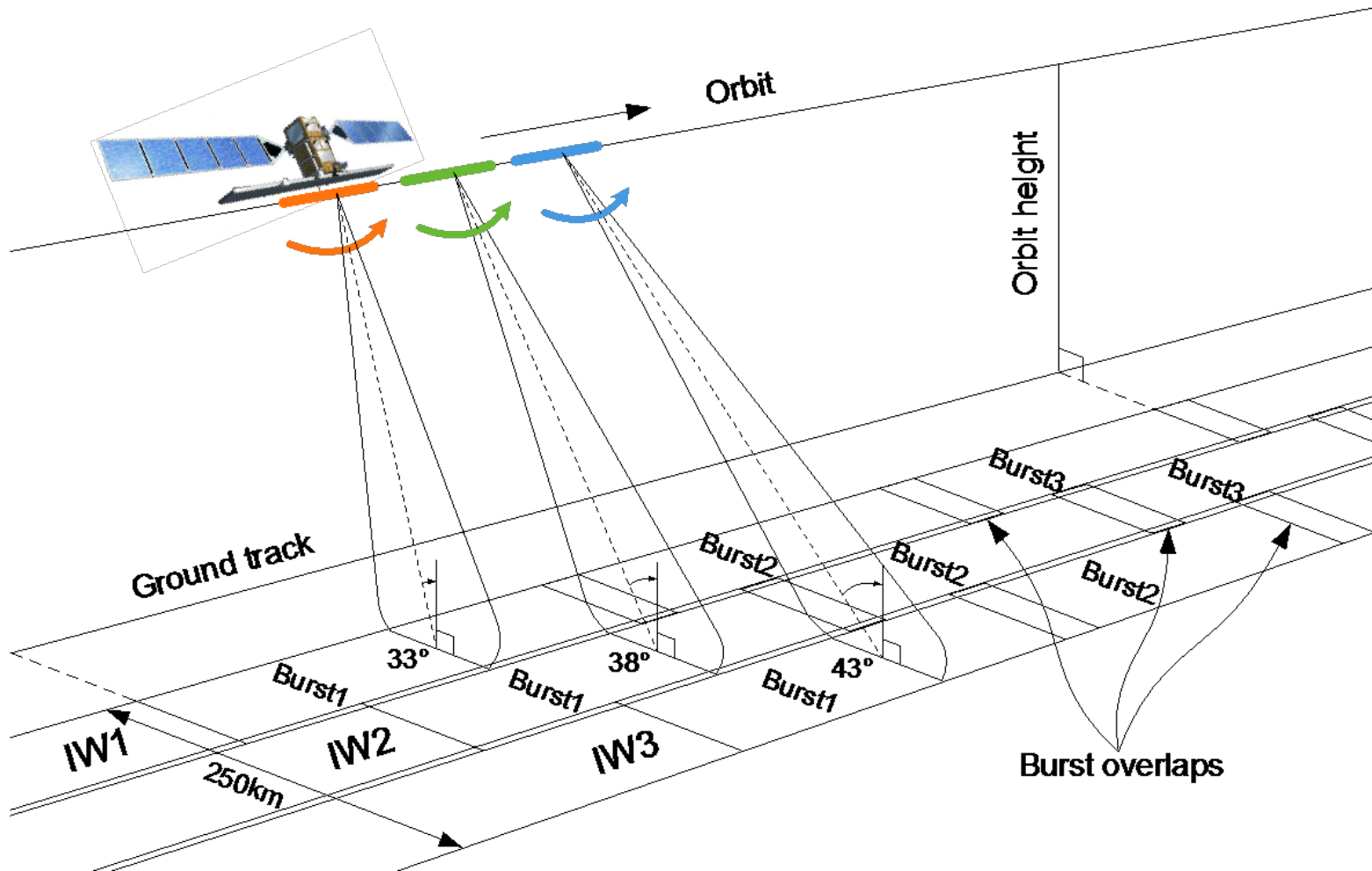


Sentinel-1

Mode	Width (km)	resolution (m) Range x Azimuth	Incidence angle
Strip Map (SM)	80	5x5	18.3° - 46.8°
Interferometric Wide Swath (IM)	250	5x20	29.1° - 46.0°
Extra Wide Swath (EW)	400	20x40	18.9° - 47.0°

Sentinel-1

Terrain Observation by Progressive Scan (TOPS) imaging mode



Where to find the data?

- On space agencies platforms:
 - DLR: TSX+ TandemX:
<http://www.dlr.de/eoc/en/desktopdefault.aspx/tabid-5356/>
 - Tandem-X: <https://tandemx-science.dlr.de>
 - JAXA
 - ESA
 - GEP (Geohazard Exploitation Platform)
- On national platforms:
 - PEPS developed by the French Space Agency (CNES)

ENVISAT

SLC images available free of charge

Catalogue:

<https://earth.esa.int/web/guest/eoli>

TerraSAR-X, TanDEM-X

***EOWEB** operated by DLR:

<https://centaurus.caf.dlr.de:8443>

*new portal: EGP:

<https://geoservice.dlr.de/egp/>

First: Write a proposal:

-TerraSAR-X :

<http://sss.terrasar-x.dlr.de>

- TanDEM-X:

<https://tandemx-science.dlr.de>

Data Sets	EGP	EOWEB
Multispectral		
AVHRR Images		X
AVHRR LST, SST, NDVI	X	X
CORINE Land Cover, 2000 & 2006	X	
FireBIRD		X
IRS Images (1C/D, P5/6, Resourcesat-2)	X	X
MERIS Chlorophyll Concentration and NDVI		X
MODIS Germany Mosaic	X	
RapidEye Science Archive	X	X
Radar		
Airborne Radar Images (AIRRS)		X
SRL X-SAR Images		X
SRTM X-SAR DEM Mosaics	X	
SRTM X-SAR Image and DEM Tiles		X
TanDEM-X Images and DEMs		X
TerraSAR-X Images	X	X
TerraSAR-X Future Acquisitions		X
Atmospheric		
METOP GOME-2 Trace Gases (O3M-SAF)	X	X
Other		
SWACI Space Weather Products	X	X
ZKI Crisis Maps	X	

TerraSAR-X, TanDEM-X

-How to order the data:

EOWEB: <https://centaurus.caf.dlr.de:8443>

(**userid and passwd from proposal,**
Option defined for each file: SSC and Science)

-How to download the data:

With Filezilla (**userid and passwd from proposal**)

ALOS and ALOS-2

-How to check the data:

-Jaxa Website:

<https://auig2.jaxa.jp/ips/home>

-Other site:

<https://vertex.daac.asf.alaska.edu/#>

ALOS and ALOS-2

Write a proposal:

*JAXA proposal n°1188 « Study of andesitic stratovolcanoes topographic changes, eruptive deposits and deformation through L-band Synthetic Aperture Radar imagery : an insight into the magmatic plumbing system » PI V. Pinel

(100 images until March 2018)

* “Study of deformation, morphological changes and eruptive deposits of persistently active volcanoes in Indonesia based on L-band Synthetic Aperture Radar imagery: an insight into eruption processes and hazard assessment” PI A. Solikhin

ALOS and ALOS-2

Akhmad Solikhin

Form 1

Proposal No.
(Leave blank for JAXA use)

< Cover Sheet > Researcher Profile

Principal Investigator, PI:

Name: Akhmad SOLIKHIN
Title: Dr.
Department: _____
Organization: Center for Volcanology and Geological Hazard Mitigation (CVGHM), Geological Agency
Address: Jalan Diponegoro, 57, Bandung 40122
Country: Indonesia Tel: +62 22 7271402
E-mail 1: aksolikhin@vsi.esdm.go.id E-mail 2*: ak.solikhin@gmail.com

* If you have the second e-mail address, please fill in for clerical contact in case.

Co-Investigator, CI:

Name	Organization	E-mail address
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<u>Asep SAEPULOH</u>	<u>ITB, Indonesia</u>	<u>saepuloh@gc.itb.ac.id</u>
<u>AGUSTAN</u>	<u>BPPT, Indonesia</u>	<u>uttank@gmail.com</u>
<u>Devy K. SYAHBANA</u>	<u>CVGHM – GA, Indonesia</u>	<u>devy.syahbana@gmail.com</u>
<u>Estu KRISWATI</u>	<u>CVGHM – GA, Indonesia</u>	<u>estukriswati@gmail.com</u>
<u>Agus Budi SANTOSO</u>	<u>CVGHM – GA, Indonesia</u>	<u>zantozo@gmail.com</u>

Biographical Information, Experience, Papers in Related Fields of Principal Investigator:

Akhmad Solikhin (Researcher) belongs to the 'Remote Sensing' working group at CVGHM, an institution that responsible for volcano monitoring and mitigation of geological hazard (volcanic eruption, earthquake, tsunami and landslide) in Indonesia. A. Solikhin has completed a PHD thesis at Université Blaise Pascal Clermont Ferrand II in France with expertise in remote sensing for volcanoes. He is specialized in the geological structure mapping and classification of volcanic deposits based optical and radar satellite imagery (Solikhin et al., 2012, Kassouk et al., 2014, Solikhin et al., 2015a and b, Lê et al., 2015). He also has experience in generating interferograms from SAR data using ROIPAC and SARscape softwares. A. Solikhin has been involved in several research projects, namely the STIC ASIA "Imager le Risk" research and exchange project (2009-2011), and CNES-TOSCA Project "Merapi" (2012 and 2014). He was also Co-I of the JAXA project n°1188 entitled "Study of andesitic stratovolcanoes topographic changes, eruptive deposits and deformation through L-band Synthetic Aperture Radar imagery : an insight into the magmatic plumbing system".

References:

- Kassouk, Z., Thouret, J.-C., Gupta, A., **Solikhin, A.**, & Liew, S.C. (2014). Object-oriented classification of a high-spatial resolution SPOT5 image for mapping geology and landforms of active volcanoes: Semeru case study, Indonesia. *Geomorphology*, 221, 18-33.
- Lê, T.T., Atto, A.M., Trouvé, E., **Solikhin, A.**, & Pinel, V. (2015). Change detection matrix for multitemporal filtering and change analysis of SAR and PolSAR image time series, *Journal of Photogrammetry and Remote Sensing*, 107, 64-76.
- **Solikhin, A.**, Thouret, J.-C., Gupta, A., Harris, A.J.L., & Liew, S.C. (2012). Geology, tectonics, and the 2002–2003 eruption of the Semeru volcano, Indonesia: Interpreted from high spatial resolution satellite imagery. *Geomorphology*, 138, 364-379
- **Solikhin, A.**, Pinel, V., Vandemaulbrayck, J., Thouret, J.-C., & Handrasto, M. (2015a). Mapping the 2010 Merapi pyroclastic

Sentinel-1

ESA Platform:

<https://scihub.copernicus.eu/dhus/#/home>

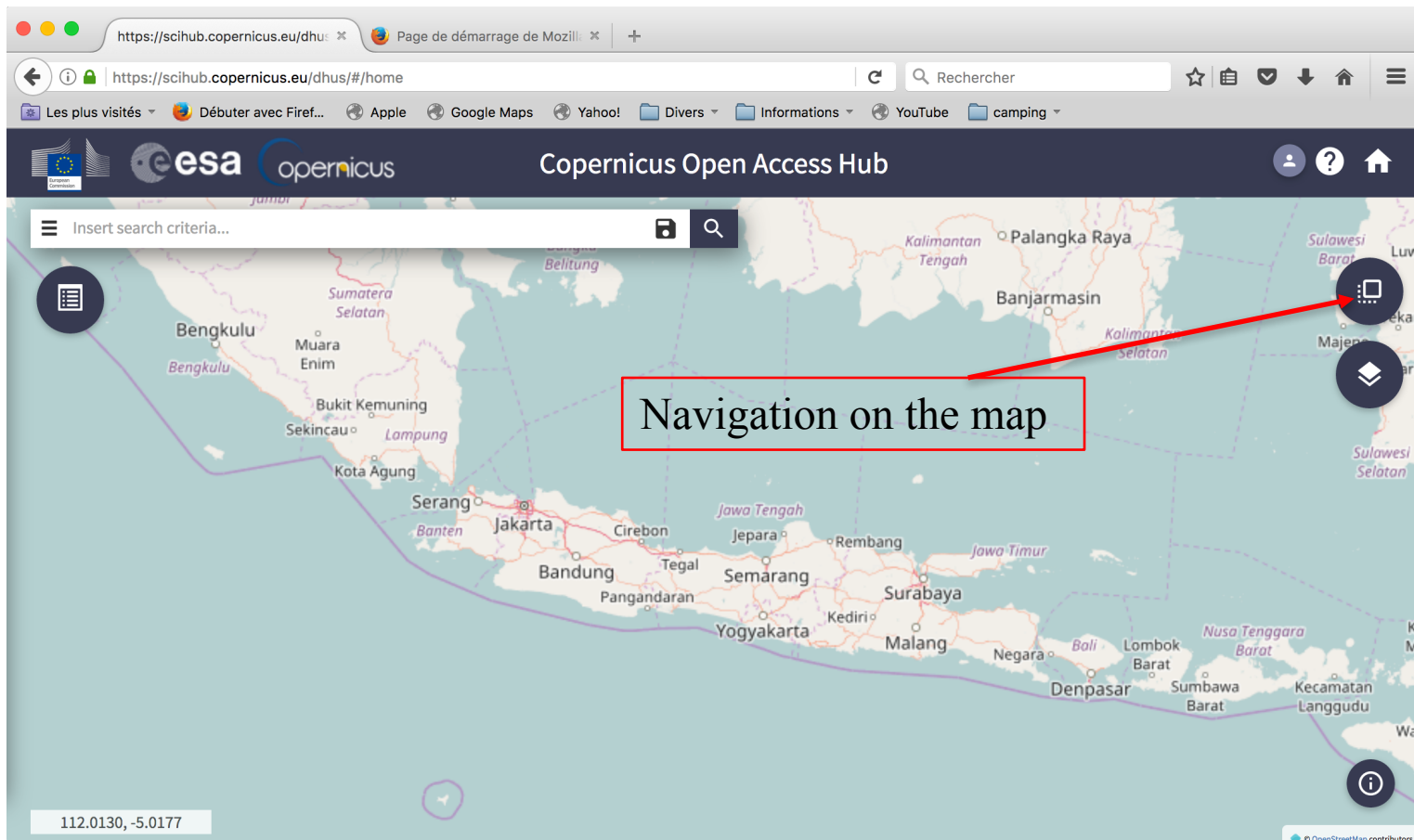
<https://scihub.copernicus.eu/userguide/>

CNES Platform: PEPS (In French only)

<https://peps.cnes.fr/rocket/#/home>

ESA Platform:

<https://scihub.copernicus.eu/dhus/#/home>



ESA Platform:

<https://scihub.copernicus.eu/dhus/#/home>

The screenshot displays the Copernicus Open Access Hub (Dhus) interface. At the top, the browser address bar shows the URL <https://scihub.copernicus.eu/dhus/#/home>. The page header includes the ESA and Copernicus logos, the title "Copernicus Open Access Hub", and navigation icons for user profile, help, and home. Below the header is a search bar with the placeholder text "Insert search criteria...". The main content area features a map of Indonesia. A red rectangular box labeled "Area selection" is drawn over the Yogyakarta region on the island of Java. The map shows various cities and provinces, including Jakarta, Semarang, Surabaya, and Yogyakarta. The bottom right corner of the map includes a copyright notice for OpenStreetMap contributors.

ESA Platform:

<https://scihub.copernicus.eu/dhus/#/home>

The screenshot displays the Copernicus Open Access Hub search interface. The browser address bar shows the URL <https://scihub.copernicus.eu/dhus/#/home>. The page header includes the ESA and Copernicus logos and the text "Copernicus Open Access Hub".

The search criteria panel is open, showing the following settings:

- » Sensing period: From: 2016/08/02 to: 2017/07/07
- » Ingestion period: From: to:
- ☑ Mission: Sentinel-1
- Satellite Platform: (empty dropdown)
- Product Type: SLC
- Polarisation: W
- Sensor Mode: IW
- Relative Orbit Number (from 1 to 175): (empty input field)
- Collection: (empty dropdown)

The background shows a map of Central Java, Indonesia, with cities like Semarang, Surakarta, and Yogyakarta labeled. The map is overlaid with a grid and a purple line representing a satellite orbit. The bottom right corner of the map area contains the text "© OpenStreetMap contributors."

ESA Platform:

<https://scihub.copernicus.eu/dhus/#/home>

The screenshot shows the Copernicus Open Access Hub interface. The browser address bar displays <https://scihub.copernicus.eu/dhus/#/home>. The page header includes the ESA and Copernicus logos, the title "Copernicus Open Access Hub", and navigation icons. A search bar at the top left contains the text "Insert search criteria...". Below the search bar, a list of search results is displayed, showing 1 to 25 of 72 products. The results are ordered by sensing date. The first result is a Sentinel-1 SAR-C product with a download URL and mission details. The second result is another Sentinel-1 SAR-C product with a download URL and mission details. The background of the page is a map of Indonesia with several red rectangular overlays indicating search areas. A yellow rectangle is also visible on the map. The bottom of the page shows a pagination control indicating "25" items per page, "page: 1 of 3", and a "CLOSE" button.

https://scihub.copernicus.eu/dhus/#/home

Page de démarrage de Mozill... +

Rechercher

Les plus visités Débuter avec Firef... Apple Google Maps Yahoo! Divers Informations YouTube camping

esa copernicus Copernicus Open Access Hub

Insert search criteria...

Display 1 to 25 of 72 products. Order By: Sensing Date ↓ Select All

-8.120084278759478))") AND (beginPosition:[2016-08-02T00:00:00.000Z TO 2017-07-07T23:59:59.999Z] AND endPosition:[2016-08-02T00:00:00.000Z TO 2017-07-07T23:59:59.999Z]) AND (platformname:Sentinel-1 AND producttype:SLC AND polarisationmode:VV+VH AND sensoroperationalmode:IW)

Mission: Sentinel-1; Instrument: SAR-C; Sensing Date: 2017-06-24T10:51:41.551Z; Size: 1.69 Gi

S1A SAR-C S1A_IW_SLC__1SDV_20170620T221726_20170620T221752_017123_01C8C4_17E3

Download URL: [https://scihub.copernicus.eu/dhus/odata/v1/Products\('0d6d47c3-4ce6-45a0-2017-06-20T22:17:26.973Z'\)](https://scihub.copernicus.eu/dhus/odata/v1/Products('0d6d47c3-4ce6-45a0-2017-06-20T22:17:26.973Z'))

Mission: Sentinel-1; Instrument: SAR-C; Sensing Date: 2017-06-20T22:17:26.973Z; Size: 6.53 Gi

S1A SAR-C S1A_IW_SLC__1SDV_20170620T221702_20170620T221729_017123_01C8C4_4B2D

Download URL: [https://scihub.copernicus.eu/dhus/odata/v1/Products\('909bb588-4b3a-41e6-2017-06-20T22:17:02.137Z'\)](https://scihub.copernicus.eu/dhus/odata/v1/Products('909bb588-4b3a-41e6-2017-06-20T22:17:02.137Z'))

Mission: Sentinel-1; Instrument: SAR-C; Sensing Date: 2017-06-20T22:17:02.137Z; Size: 7.04 Gi

25 << >> page: 1 of 3 >> CLOSE

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ESA Platform:

<https://scihub.copernicus.eu/dhus/#/home>

The screenshot displays the Copernicus Open Access Hub interface. The browser address bar shows the URL <https://scihub.copernicus.eu/dhus/#/home>. The page title is "Copernicus Open Access Hub". The main content area displays the product ID "S1A_IW_SLC__1SDV_20170620T221726_20170620T221752_017123_01C8C4_17E3" and the OData URL [https://scihub.copernicus.eu/dhus/odata/v1/Products\('0d6d47c3-4ce6-45a0-a876-bc1a7c9016cc'\)/\\$value](https://scihub.copernicus.eu/dhus/odata/v1/Products('0d6d47c3-4ce6-45a0-a876-bc1a7c9016cc')/$value). The interface is divided into several sections:

- Footprint:** A map of Indonesia with a red rectangular box highlighting the area of interest, primarily covering the island of Java.
- Quicklook:** A thumbnail image showing a synthetic aperture radar (SAR) image of the highlighted area, displaying a green and yellow color scheme.
- Attributes:** A section for displaying the product's metadata.
- Inspector:** A section for inspecting the product's data.
- Summary:** A section for displaying a summary of the product.

The interface also includes a search bar, navigation icons, and a sidebar on the left with a search filter set to "S1A SAR-C".

CNES Platform: PEPS

<https://peps.cnes.fr/rocket/#/home>

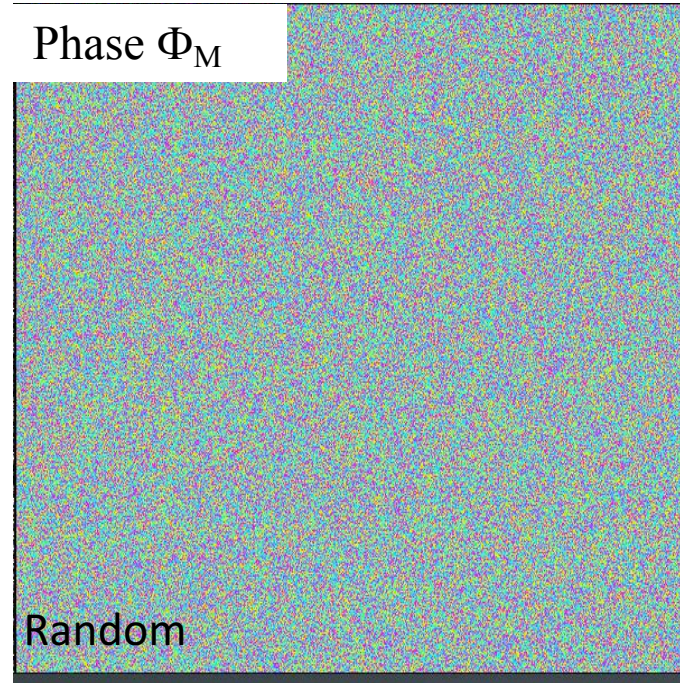
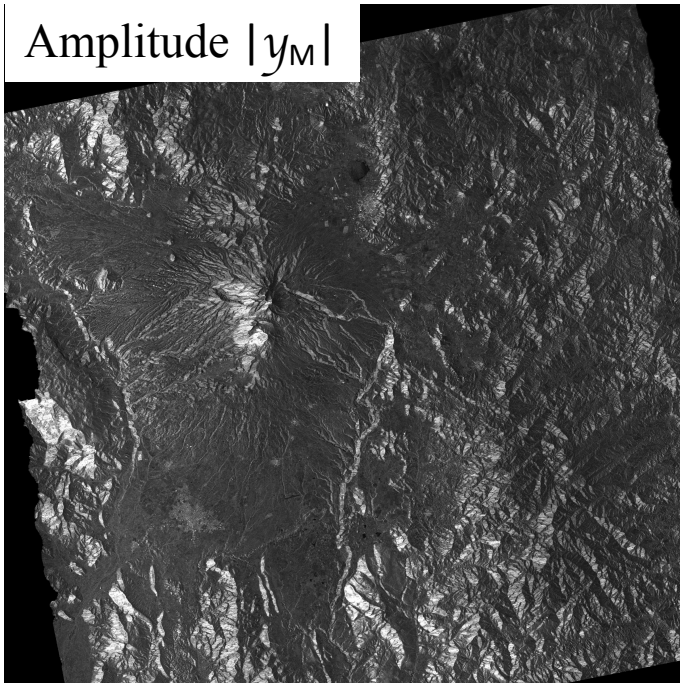
The screenshot displays the PEPS web application interface. At the top, the browser address bar shows the URL <https://peps.cnes.fr/rocket/#/search?maxRecords=50&view=list>. The page header includes the CNES and PEPS logos, and navigation links for ACCUEIL, EXPLORER, PEPS-RSS, and PLUS. A search bar is located in the top right corner.

On the left side, there is a search filter panel titled "RECHERCHE PAR CRITÈRES". Under the "RECHERCHE SÉMANTIQUE" section, the "Période d'acquisition" is set from "Début: 2016-09-07T14:59:00" to "Fin: 2017-07-07T14:59:00". Other filters include "SENTINEL-1", "Plateforme", "SAR bande C", "LEVEL1", "SLC", "IW", "Produit NRT", and "VV+VH".

The main content area features a 3D map of Indonesia. The map shows various regions and cities, with a yellow box highlighting the area around Semarang. A scale bar indicates 200 km. At the bottom of the map, the coordinates are displayed: "Haut-gauche: 7° 08' 40" S 110° 06' 28" E Bas-droite: 7°". A button labeled "Voir plus de produits" is visible in the bottom right corner of the map area.

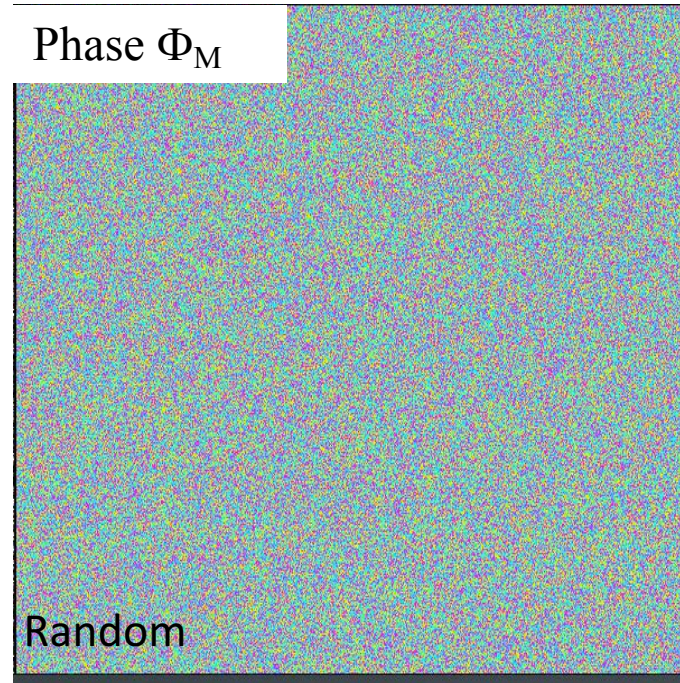
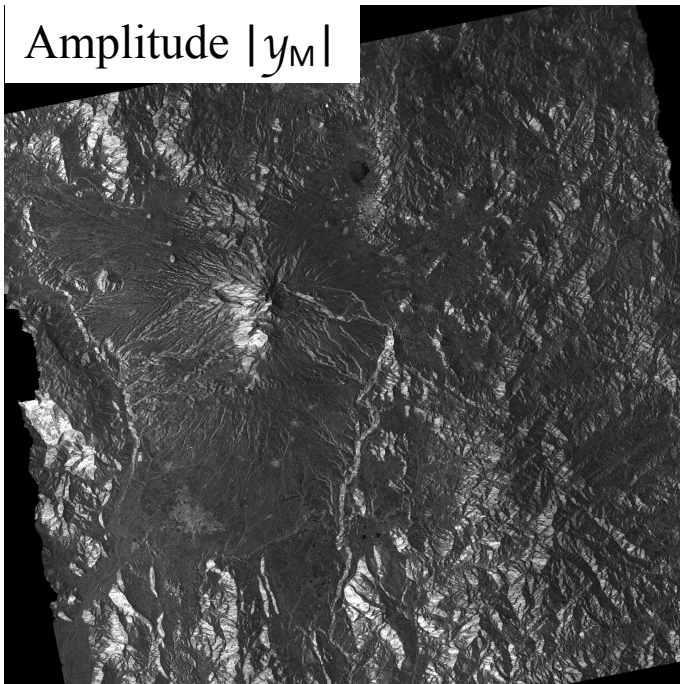
A complex signal

$$y_M = |y_M| e^{i\phi_M}$$



A complex signal

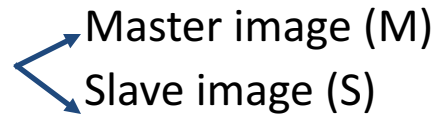
$$y_M = |y_M| e^{i\phi_M}$$



How can we measure displacement?

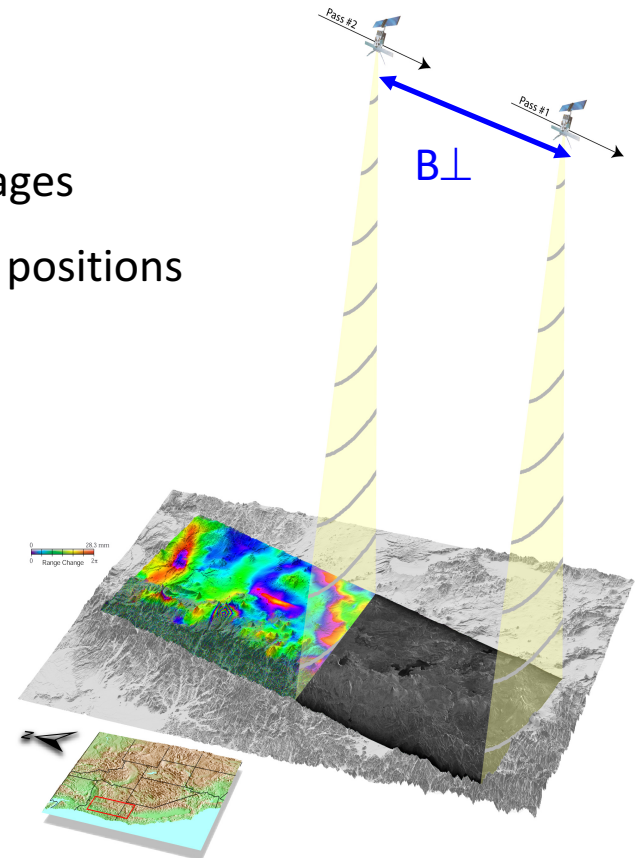
Combining 2 images

2 dates of acquisitions

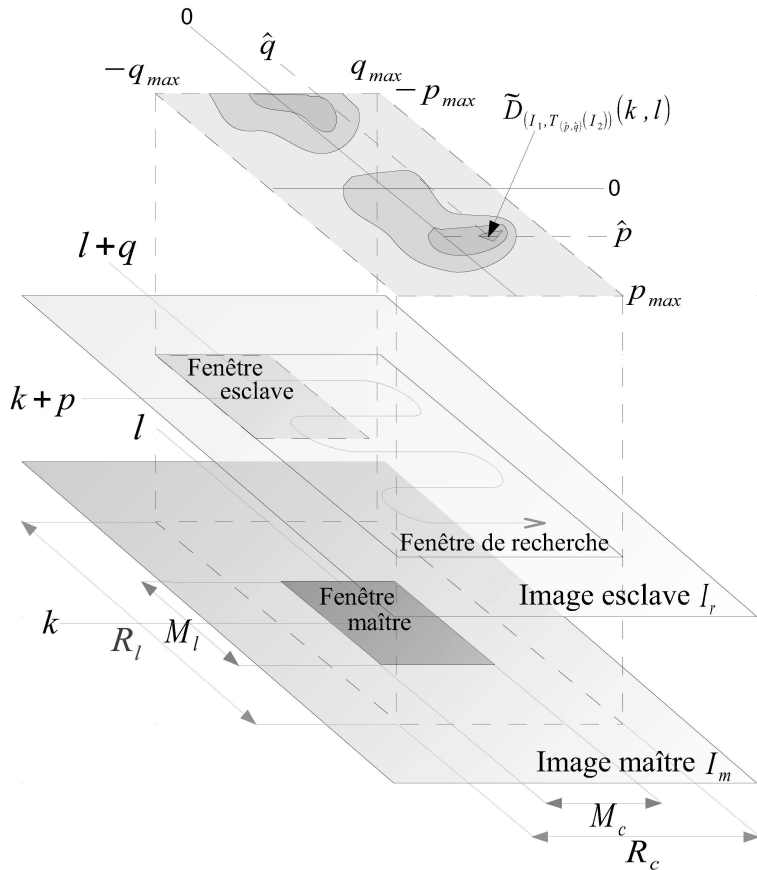


-Temporal baseline(ΔT) : time difference between 2 images

-Spatial baseline (B_{\perp}) : distance between the 2 satellite positions



Pixel offset tracking on amplitude images



- Pixel displacements are quantified by techniques of image correlation
- Displacement in 2 directions (azimuth and range)
 - Resolution of the order of 1/10 of the pixel size

InSAR provides maps of surface displacement in Line of Sight

2 acquisitions radar: \rightarrow Master Image (M)
 \searrow Slave Image (S)

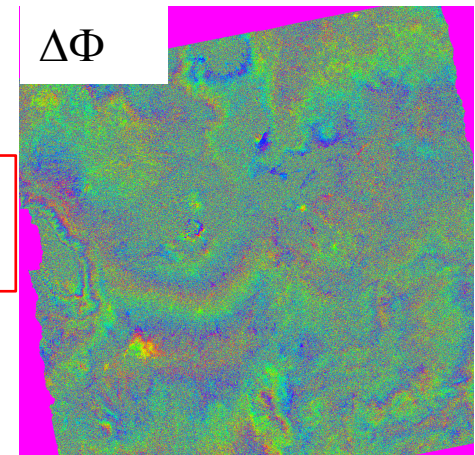
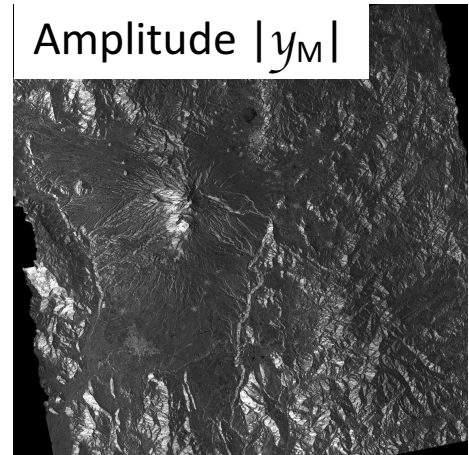
Couple of images characterized by: B_{\perp} , ΔT

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

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

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

Exemple ENVISAT images on Colima volcano

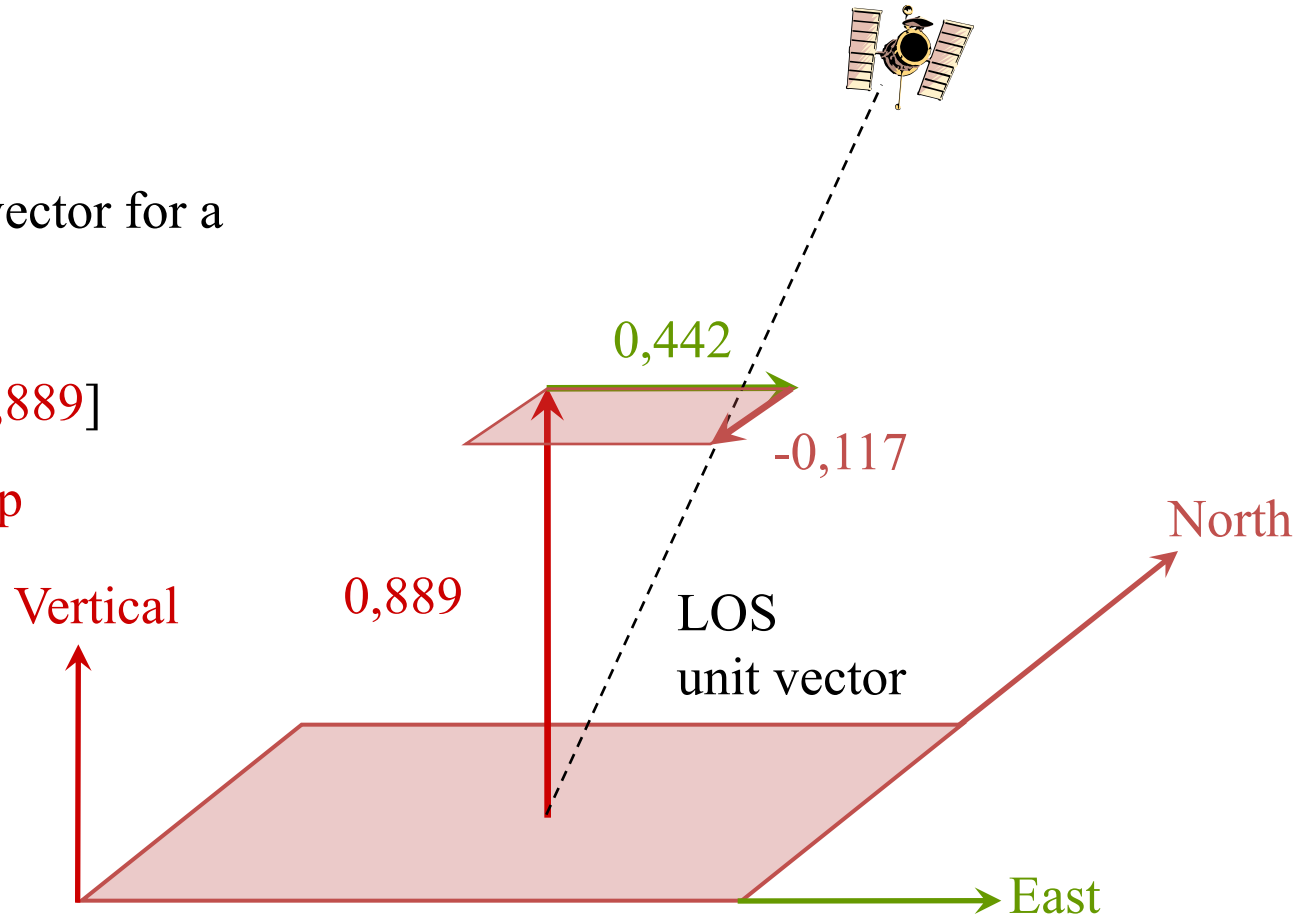


Displacement in Line of Sight

Example of unit vector for a
descending track:

[0,442; -0,117; 0,889]

East North Up



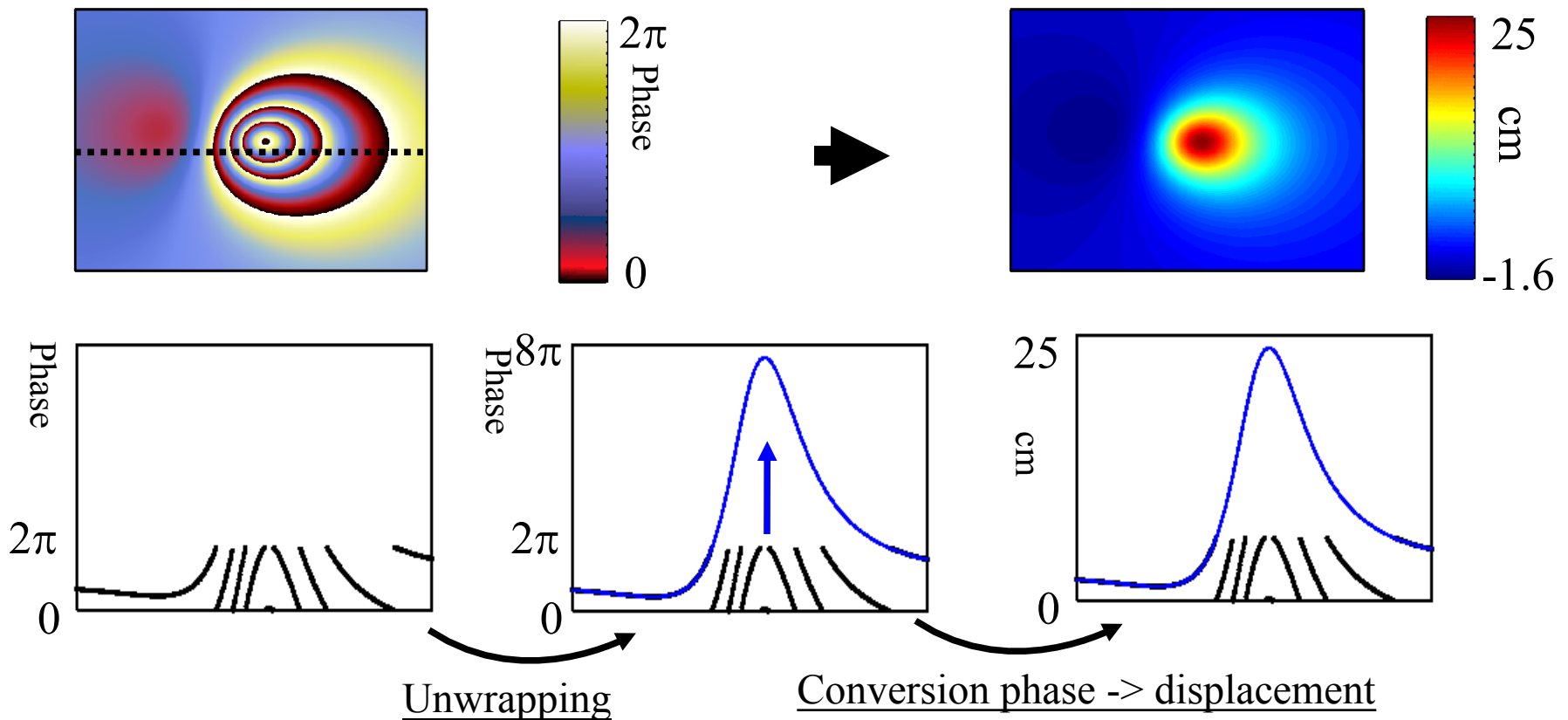
Enable to measure vertical and E-W displacements.

From R. Pedersen

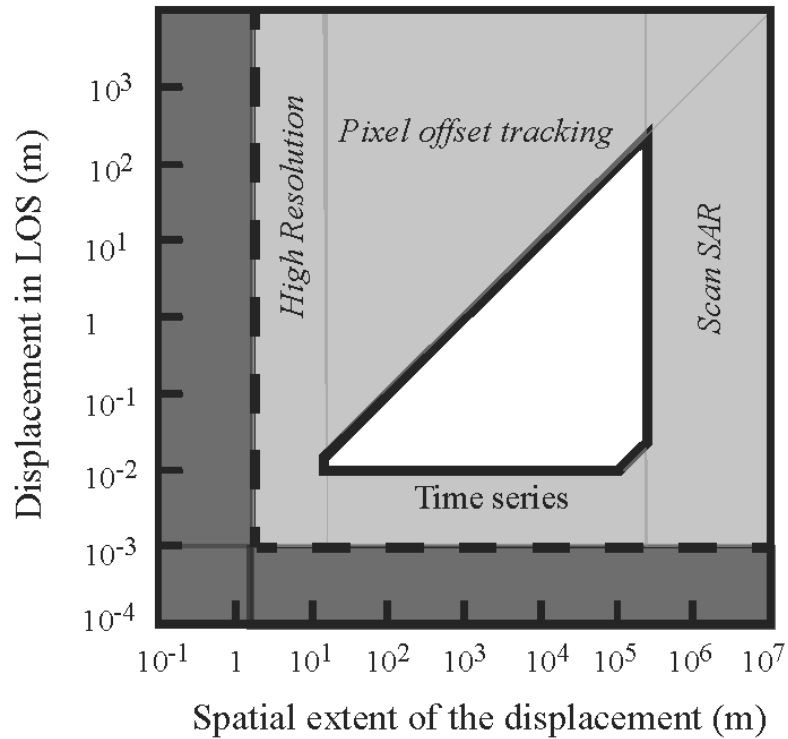
Ambiguity of phase information

$\Delta\Phi$ is known with an ambiguity of 2π

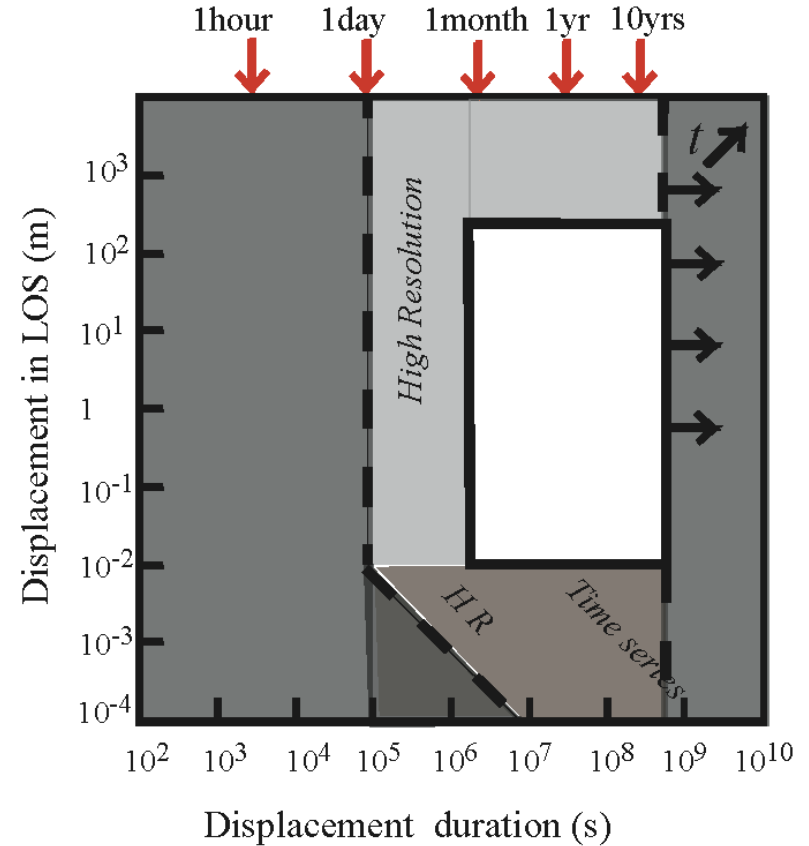
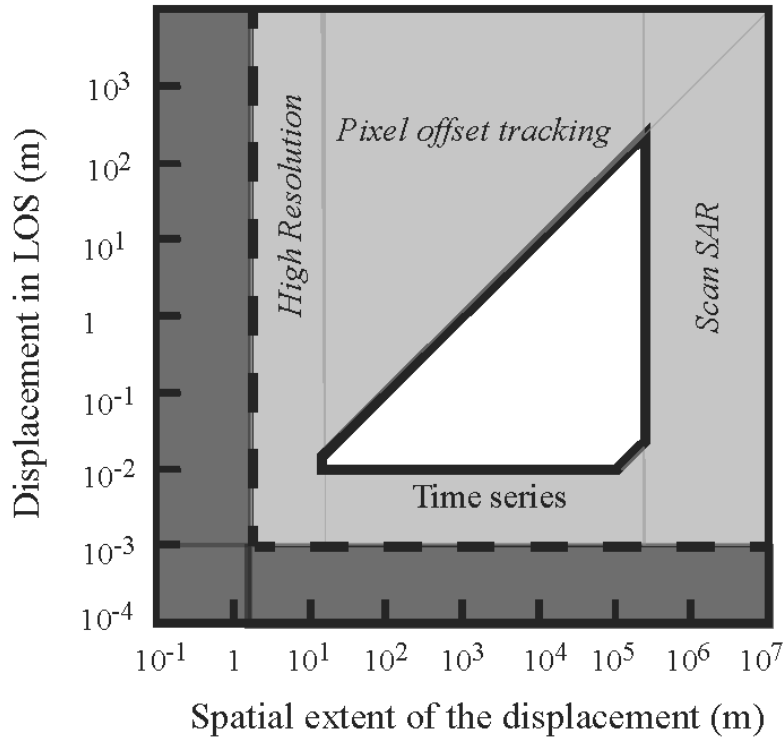
Phase unwrapping is required to obtain displacement with regards to a reference point



InSAR performance

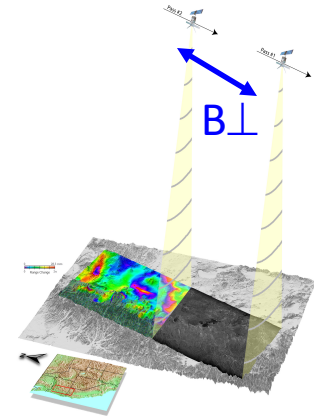


InSAR performance

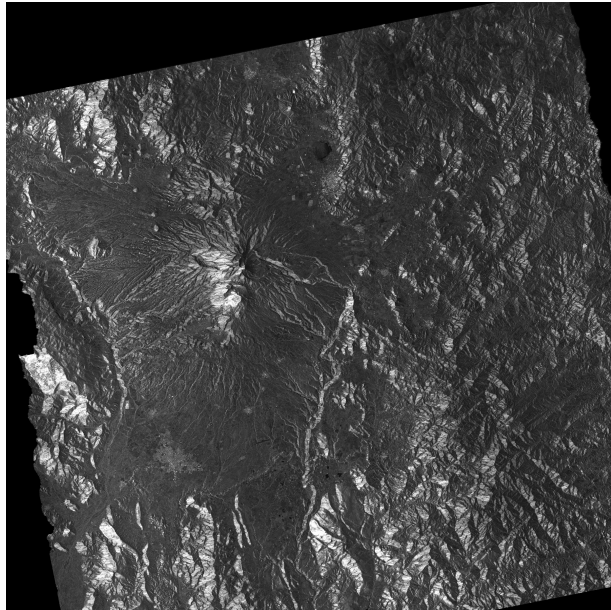


Coherence

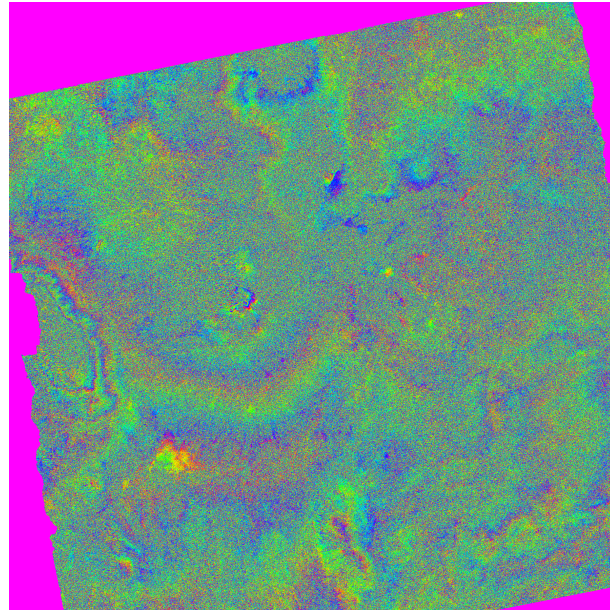
$$\text{coherence} = \gamma = \frac{|\sum M_i \cdot E_i^*|}{\sqrt{\sum |M_i|^2 \cdot \sum |E_i|^2}} \quad ; \quad 0 \leq \gamma \leq 1$$



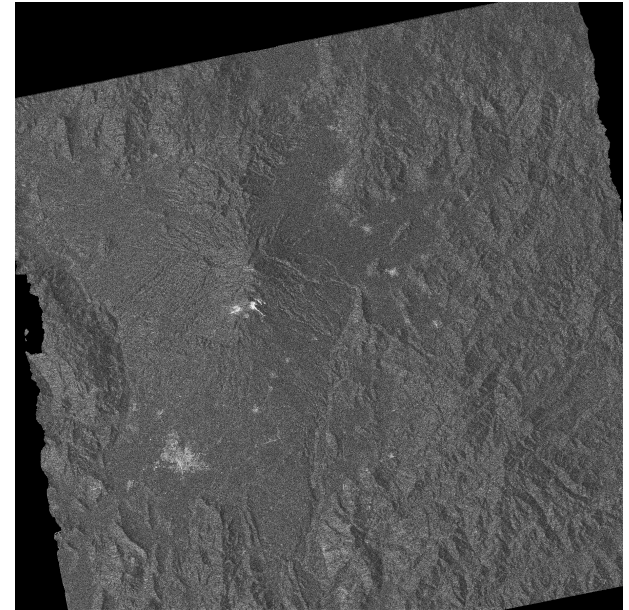
Spatial Resolution : 40 m * 40 m



Mean Amplitude



Phase difference $\Delta\phi$



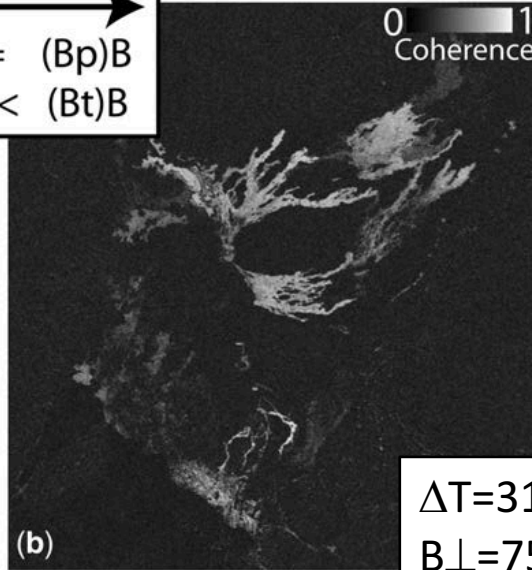
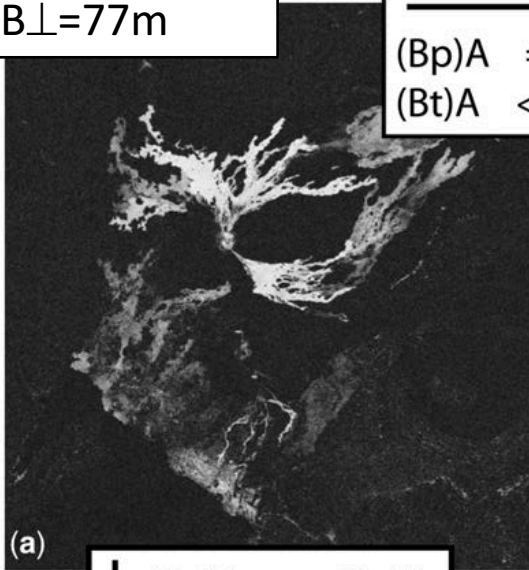
Coherence

Coherence

$\Delta T = 35$ days

$B_{\perp} = 77$ m

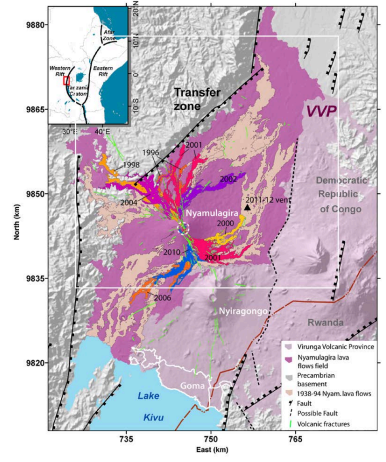
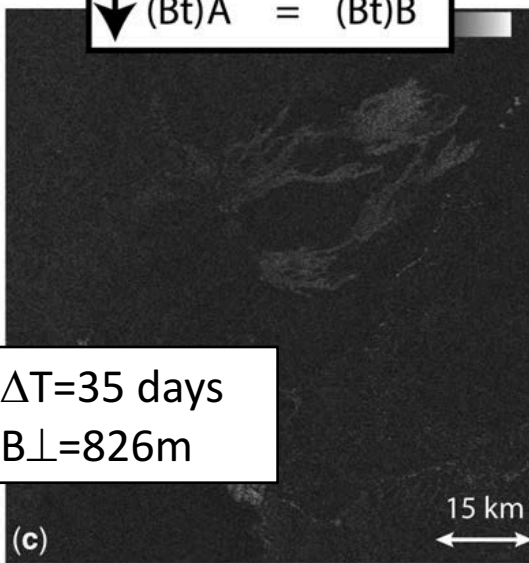
→
 $(B_p)A = (B_p)B$
 $(B_t)A \ll (B_t)B$



$\Delta T = 315$ days

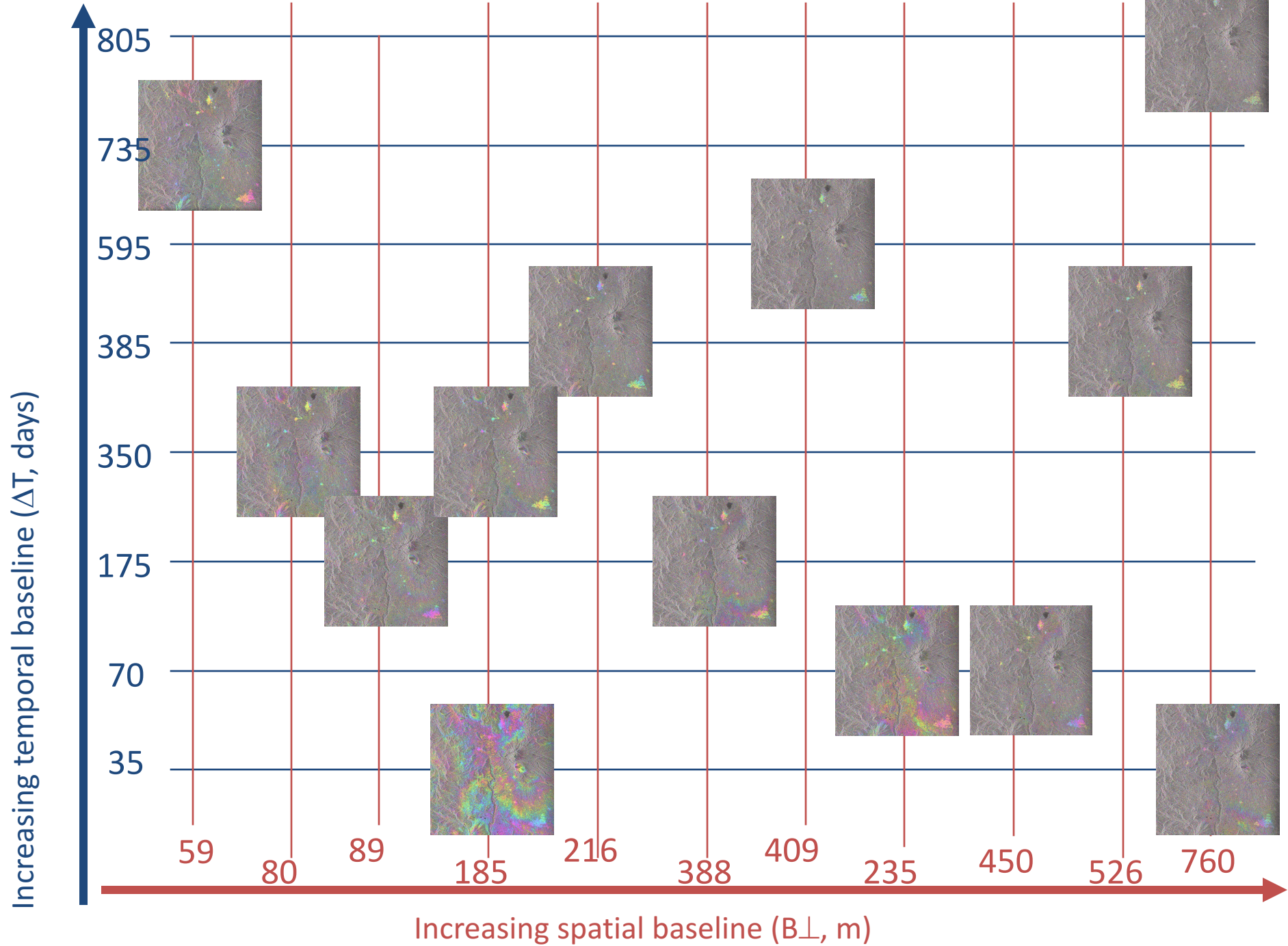
$B_{\perp} = 75$ m

↓
 $(B_p)A \ll (B_p)B$
 $(B_t)A = (B_t)B$

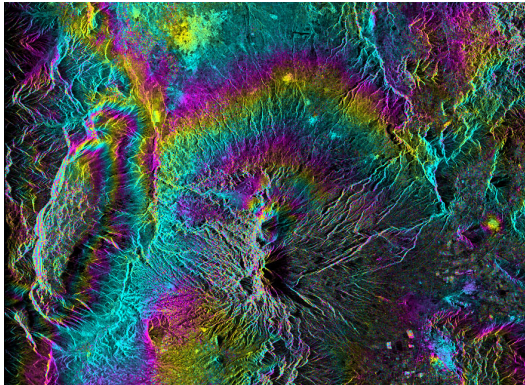


From Wauthier & al. , 2013

$$coherence = \gamma = \frac{|\sum M_i \cdot E_i^*|}{\sqrt{\sum |M_i|^2 \cdot \sum |E_i|^2}} ; 0 \leq \gamma \leq 1$$

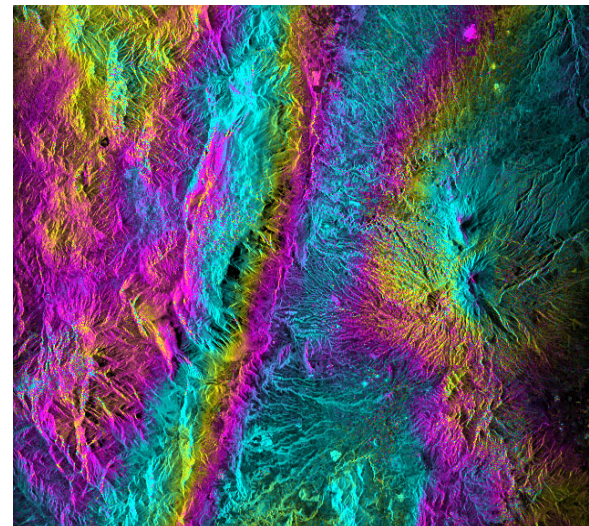


Coherence is better with L-band over vegetated areas



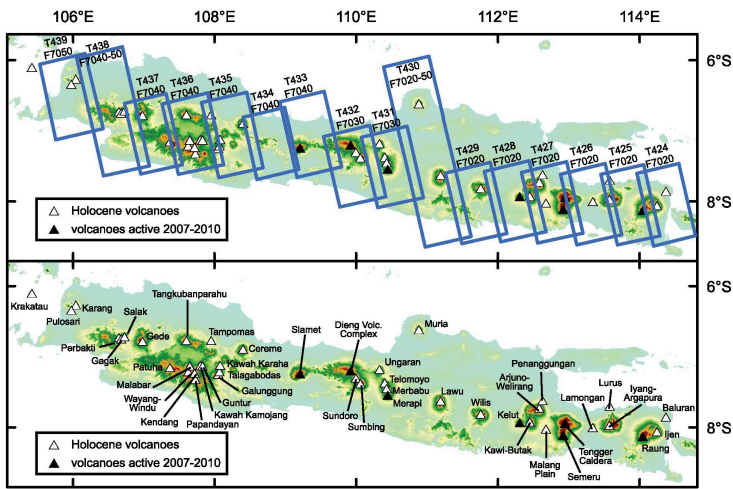
ENVISAT: $\Delta T=385$ days
 $B_{\perp}=5$ m

C-band



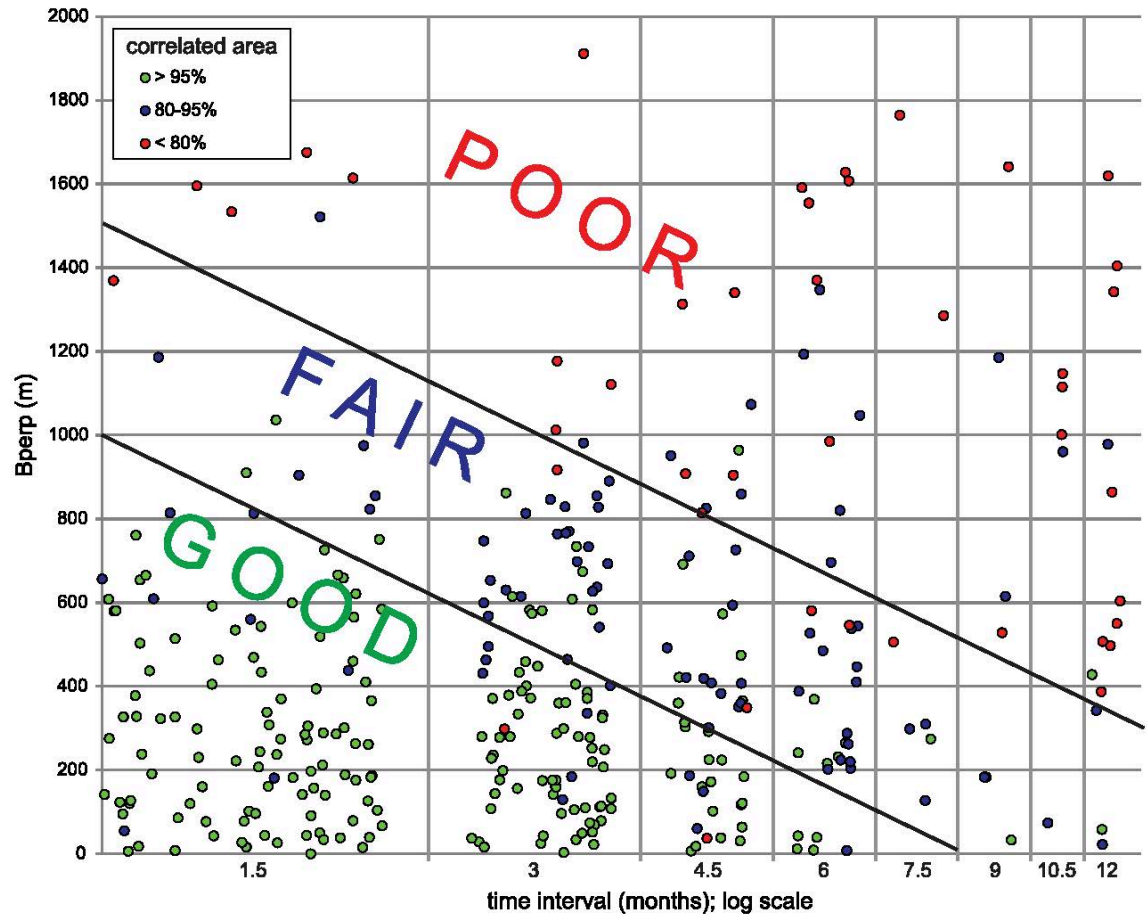
ALOS: $\Delta T=873$ days
 $B_{\perp}=177$ m

L-band



Coherence with L-band over Java

From Philibosian & Simons, 2011



Main limitation is due to atmospheric artefacts



Only half of the observed signal was due to the volcano deflation

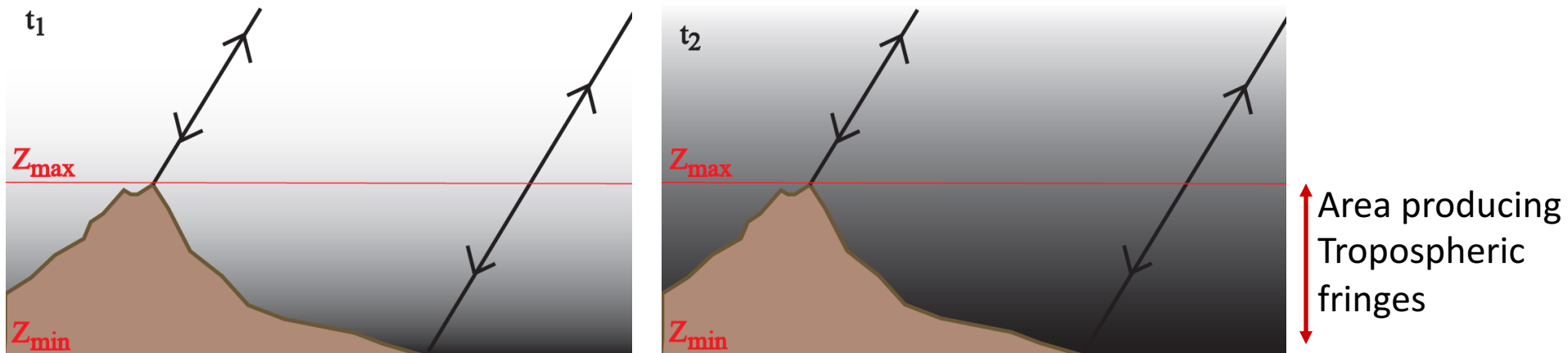
(*Delacourt et al., 1998*)

Some interferograms were 100% tropospheric effects as the Nature cover image!

(*Beauducel et al., 2000*)

(*Massonnet et al., 1995*)

Variation in the water content of the troposphere induce « tropospheric fringes » correlated with topography.

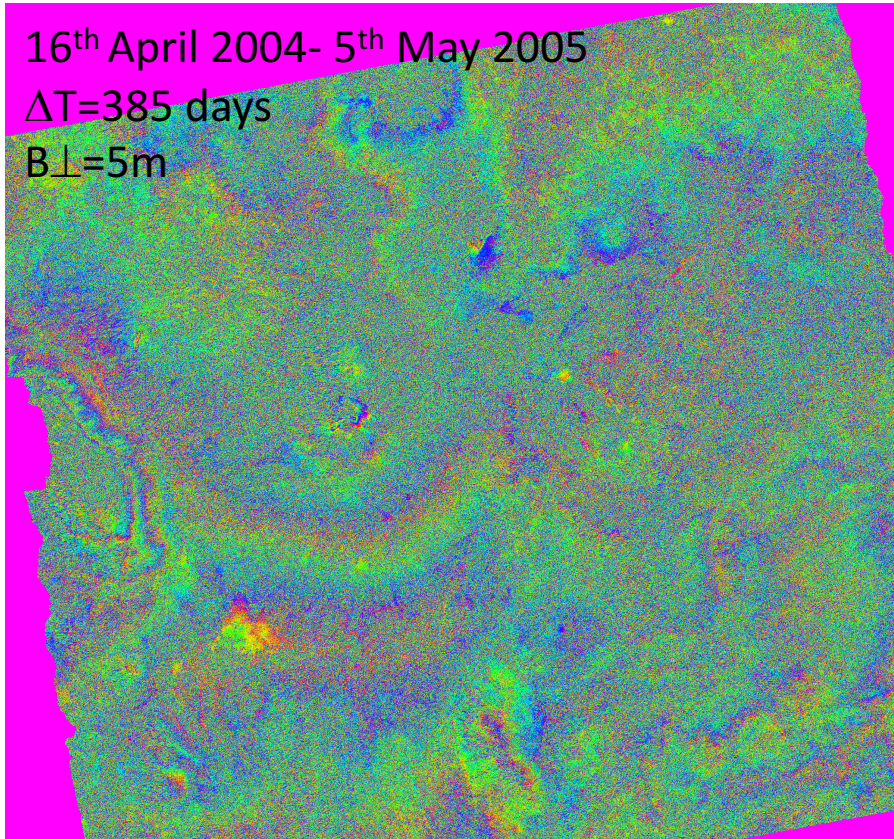


Main InSAR limitations

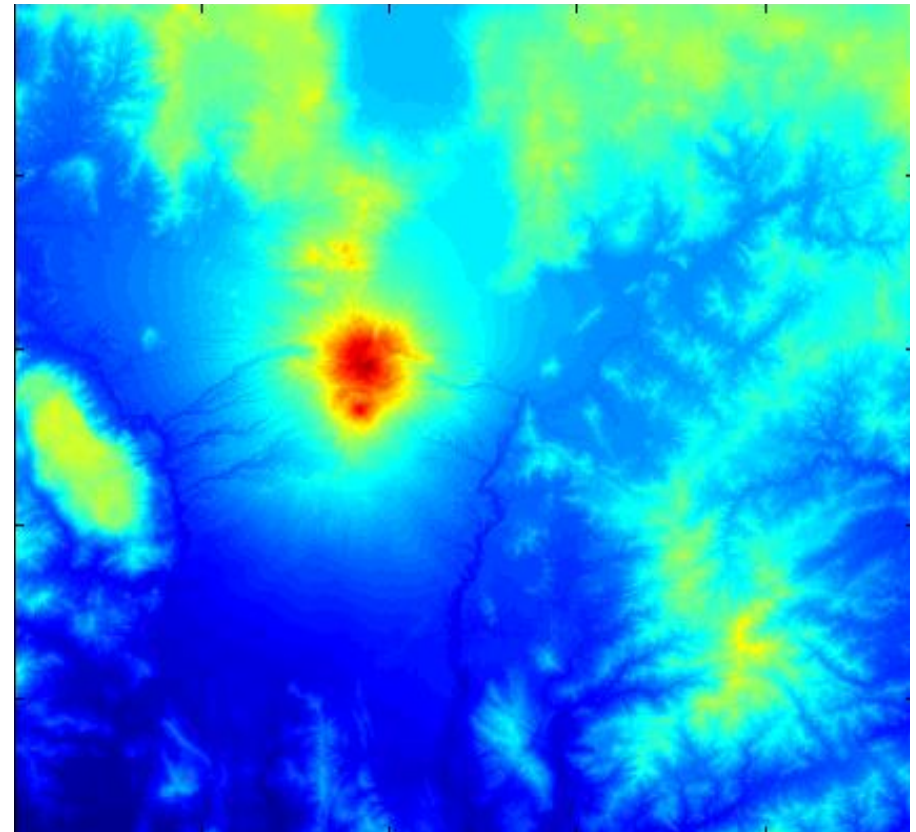
*Poor temporal resolution

*Atmospheric artefacts:

16th April 2004- 5th May 2005
 $\Delta T=385$ days
 $B_{\perp}=5$ m



DEM-SRTM



Some products are already available online

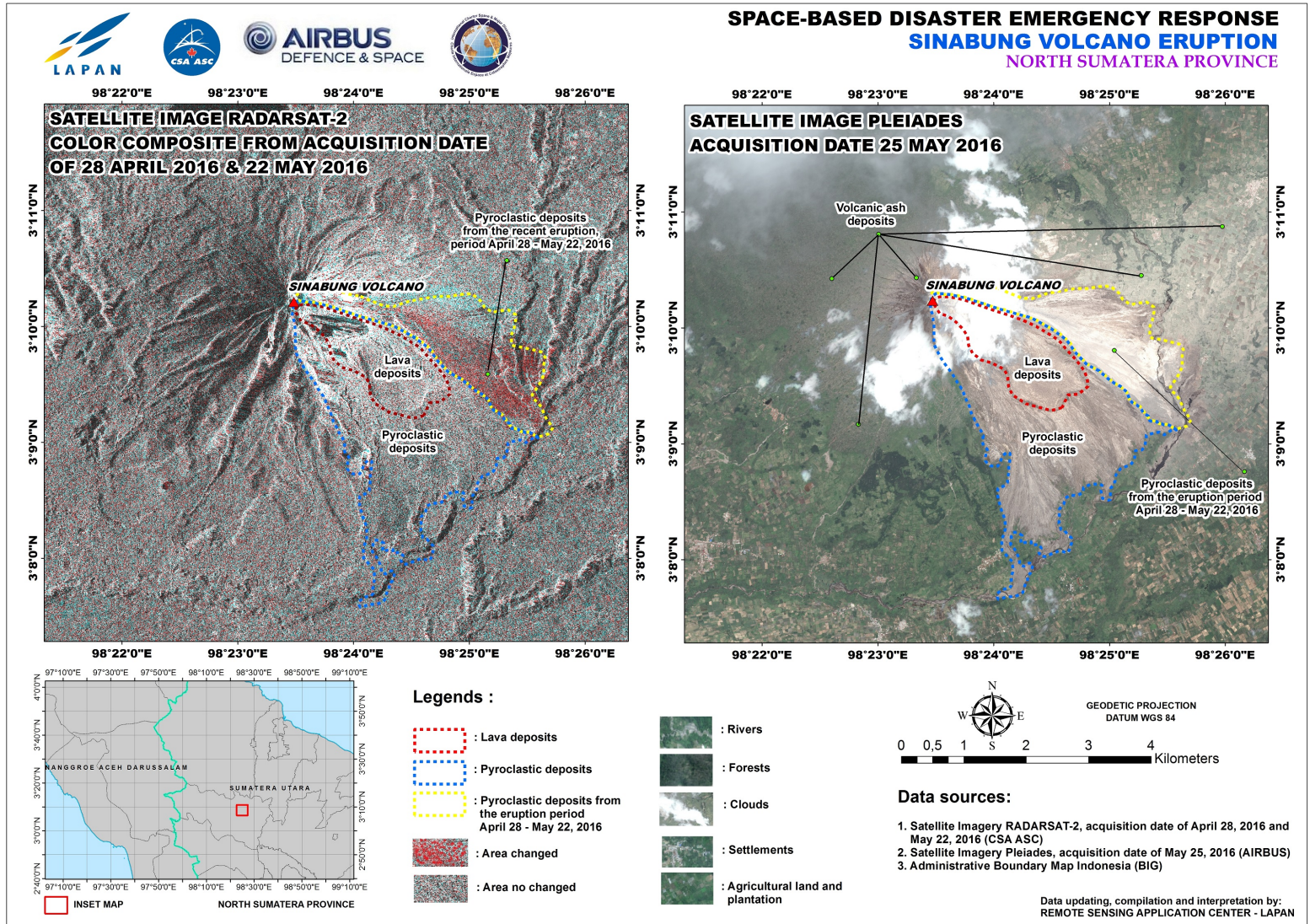
- On space agencies platforms:
 - GEP Volcano Trial Case
- On specific platforms: Miami Supersites:
http://insarmaps.rsmas.miami.edu/?startDataset=ALOS_SM_422_7010_20070221-20090226_0000_00000

In case of crisis:

Activation of the **International Charter Space & Major Disasters**

Ex activated on Sinabung by LAPAN in april 2016

In case of crisis:

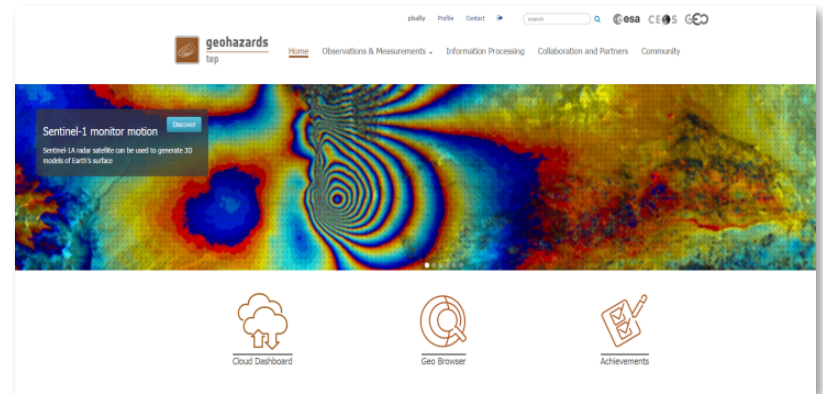


Use of derived product provided by the European Space Agency through to the **Volcano Trial Case**

Indonesian Targets selected by ESA: **Merapi, Ibu, Dukono, Sinabung**

Using the **Geohazards Exploitation Platform**

developed by the European Spatial Agency (online data access and processing)



A wide range of remote sensing data available:

-**optical images** (Landsat-8, SPOT-5, IRS-P6/LISS-III and Sentinel-2 HR data (Visible-NIR-SWIR)) to assess surface changes at volcanoes

-**thermal images** (Sentinel-2 (NIR-SWIR), Landsat-8 (TIR))

for computing and mapping High-Temperature thermal anomalies at erupting volcanoes

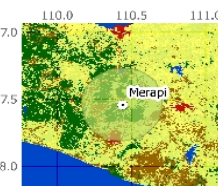
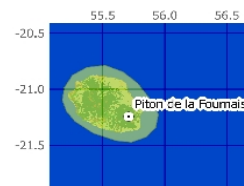
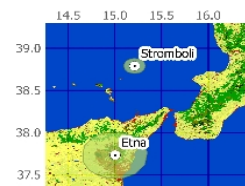
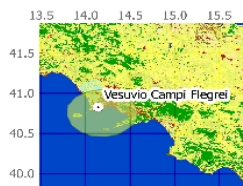
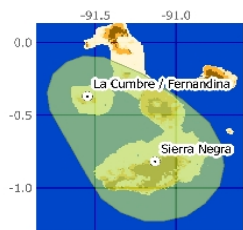
-**radar images** (Sentinel-1 amplitude and 12 day (or 6 day) coherence) to assess surface changes at volcanoes

3 processing chains will be tested:

-STEM developed by INGV for Surface Temperature mapping,

-VEGAN for Hot spot detection and vegetation vigour mapping

-InSAR Sentinel-1 Browse at 50 m resolution developed by DLR for surface change detection based on SAR data



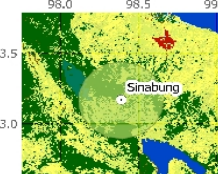
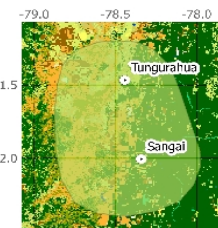
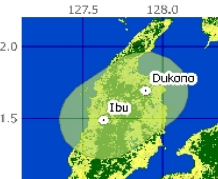
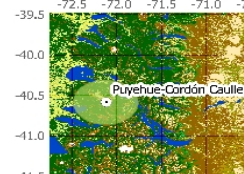
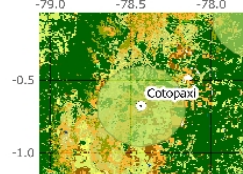
VOLCANO TRIAL CASE

Overview of the Volcanoes

-180 -170 -160 -150 -140 -130 -120 -110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180



-180 -170 -160 -150 -140 -130 -120 -110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180



- FCST-FLOODING OR IRRIGATED CROPLANDS (ORAQUATIC)
- FAINED CROPLANDS
- MOSAIC CROPLAND (50-70%) / VEGETATION (GRASSLAND/SHRUBLAND/FOREST) (20-50%)
- MOSAIC VEGETATION (GRASSLAND/SHRUBLAND/FOREST) (50-70%) / CROPLAND (20-50%)
- CLOSED TO OPEN (>15%) BROADLEAVED EVERGREEN OR SEMI-DECIDUOUS FOREST (>5M)
- CLOSED (>40%) BROADLEAVED DECIDUOUS FOREST (>5M)
- OPEN (15-40%) BROADLEAVED DECIDUOUS FOREST/WOODLAND (<5M)
- CLOSED (>40%) NEEDLELEAVED EVERGREEN FOREST (>5M)
- OPEN (15-40%) NEEDLELEAVED DECIDUOUS OR EVERGREEN FOREST (>5M)
- CLOSED TO OPEN (>15%) MIXED BROADLEAVED AND NEEDLELEAVED FOREST (>5M)
- MOSAIC FOREST OR SHRUBLAND (50-70%) / GRASSLAND (20-50%)
- MOSAIC GRASSLAND (50-70%) / FOREST OR SHRUBLAND (20-50%)

- CLOSED TO OPEN (>15%) BROADLEAVED OR NEEDLELEAVED, EVERGREEN OR DECIDUOUS SHRUBLAND (<5M)
- CLOSED TO OPEN (>15%) HERBACEOUS VEGETATION (GRASSLAND, SAVANNAS OR LICHENS/MOSSES)
- SPARSE (<15%) VEGETATION
- CLOSED TO OPEN (>15%) BROADLEAVED FOREST REGULARLY FLOODED (SEMI-PERMANENTLY OR TEMPORARILY) - FRESH OR BRACKISH WATER
- CLOSED (>40%) BROADLEAVED FOREST OR SHRUBLAND PERMANENTLY FLOODED - SALINE OR BRACKISH WATER
- CLOSED TO OPEN (>15%) GRASSLAND OR WOODY VEGETATION ON REGULARLY FLOODED OR WATERLOGGED SOIL - FRESH BRACKISH OR SALINE WATER
- ARTIFICIAL SURFACES AND ASSOCIATED AREAS (URBAN AREAS >50%)
- BARE AREAS
- WATER BODIES
- PERMANENT SNOW AND ICE
- NO DATA (BURNT AREAS, CLOUDS...)

by Andreas Baumann, ESA/ESRIN 2016

World Map 1:125'000'000
Detail Maps 1: 3'000'000

Sources
Points: List of Volcanoes for GEP
Background Map: GlobCover 2009 (Global Land Cover Map),
http://due.esrin.esa.int/page_globcover.php

GSP VO-2 Trial Case — Areas Of Interest



Systematic Services — for Volcanoes Monitoring (1)

➤ S-1 High-Resolution InSAR Browse Service

- ✓ S1 IWS mode InSAR processing at 50m resolution
- ✓ Input: S1 IWS mode SLC products, precise and restituted S1 orbit products
- ✓ Output: 5 product layers (master and slave calibrated amplitudes, terrain corrected interferometric coherence, amplitude change and amplitude coherence composites)
- ✓ Output Format: GeoTIFF

➤ STEMP Landsat-8

- ✓ Surface Temperature Maps from LANDSAT 8 data
- ✓ Input: Landsat-8
- ✓ Output: Surface temperature Maps
- ✓ Output Format: GeoTIFF

Systematic Services — for Volcanoes Monitoring (2)

- **VEGAN-HSP - Sentinel-2 based high temperature phenomena mapping**
 - ✓ Generation of hot spots detection maps at 20m resolution from S-2 data
 - ✓ Input: Sentinel-2 L1C
 - ✓ Output: Hot spots detection Maps
 - ✓ Output Format: GeoTIFF

- **VEGAN-VHON - Sentinel-2 based vegetation vigor mapping**
 - ✓ Generation of vegetation vigor maps at 10m resolution from S-2 data
 - ✓ Input: Sentinel-2 L1C
 - ✓ Output: Vegetation Vigor Map (NDVI)
 - ✓ Output Format: GeoTIFF

Systematic Services — Results Collections

- For each systematic service a **collection** in the “**EO data**” menu of the GEP geobrowser allows discovering and accessing the related results (first products on February 2017). These collections are named:
 - ✓ **STEMP L8 – Surface Temperature Maps**
 - ✓ **Sentinel-1 High-Resolution InSAR Browse**
 - ✓ **VEGAN HSP – Hot Spots Detection Maps**
 - ✓ **VEGAN VHON – Vegetation Vigor Maps (NDVI)**
- Help and support can be requested to the Terradue support team (support@terradue.com) via the ticketing system area assigned to you during the on-boarding process. Some guidance is also provided in next slide.

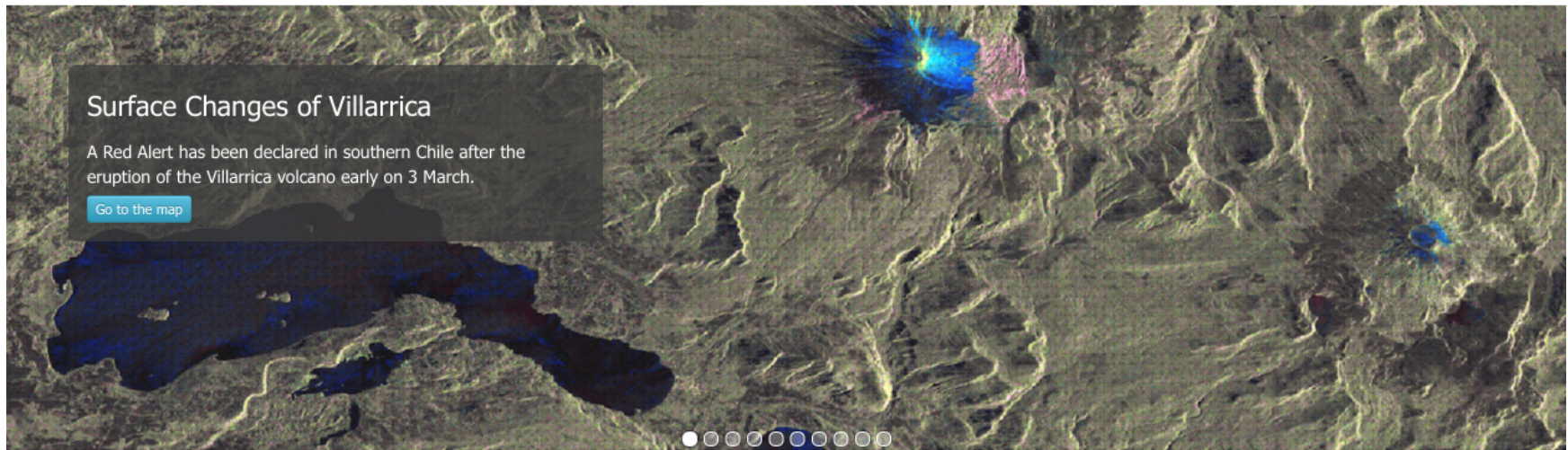
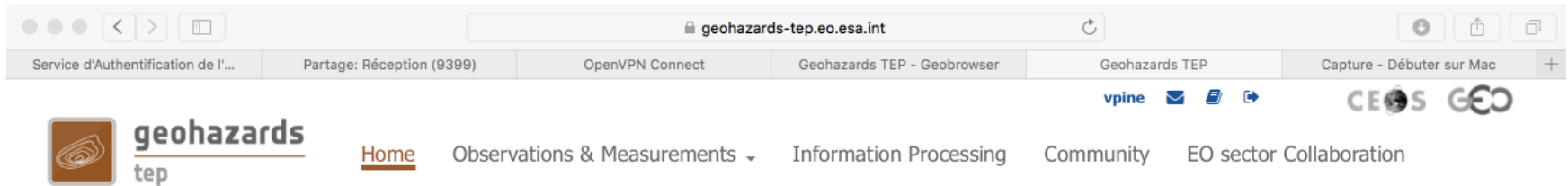
GEP access

<https://geohazards-tep.eo.esa.int>

- Inscription on ESA website:
<https://eo-ssoidp.eo.esa.int/idp/umsso20/admin>
- Inscription on GEP platform
- Through a User Form URF =Early Adopter Registration Document
- Installation of the vpn to download products

GEP access

<https://geohazards-tep.eo.esa.int>



Background



Geo Browser



Activities

Products of the Volcano Trial Case: DLR InSAR Sentinel-1 Browse (HR:50m)

The screenshot displays the web interface of the geohazards-tep.eo.esa.int application. The main map shows the island of Java, Indonesia, with a white box highlighting a specific area over the Merapi volcano region. A red dashed box indicates the search area. The map includes labels for major cities like Jakarta, Bandung, and Surabaya, and the Java Sea. The interface features a search bar with the text "EO Free Text Search" and a "spatial" filter. Below the map, there are two result lists:

- Current search result:** Total results 160. The list includes several entries for "S-1 High-Resolution InSAR Browse Service" with various parameters and dates.
- Features Basket Data Packages:** Total results 18. The list includes entries for "DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) - Interferometric Coherence", "DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) - Interferometric Phase", "DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) - Interferometric Amplitude", and "S1A SLC IW_SP L1 WV 170" data packages.

The interface also includes a navigation sidebar on the left with zoom and search tools, and a "Processing Services" sidebar on the right. The top navigation bar includes links for "EO data", "EO-based products", "Publications", and "Community".

Products of the Volcano Trial Case: DLR InSAR Sentinel-1 Browse (HR:50m)

geohazards tep

EO Free Text Search

S-1 High-Resolution InSAR Browse Service - Slave Amplitud

title	S-1 High-Resolution InSAR Browse Service - Slave
date	2017-06-12T10:58:14.404774Z/2017-06-12T10:58
SLC Product	S1A_IW_SLC__1SDV_20170612T105814_2017061
Orbit Product	
Absolute Orbit	16999
Relative Orbit (Track)	127
Orbit Direction	ASCENDING
Start Time	2017-06-12T10:58:14.404774Z
Acquisition Mode	IW
Polarisation	VV
Resolution	50m
Pixel Spacing	25m

Intensity σ^0 [dB]

2014-12-09 2017-06-17

Lon: 111.138 Lat: -6.686

Current search result

Result for OpenSearch query over type ... Total results 160

- S-1 High-Resolution InSAR Browse Service - Coherence Terrain Corrected - 2017-05-19T10:58:13 2017-06-12T10:58:4
- S-1 High-Resolution InSAR Browse Service - Coherence Terrain Corrected - 2017-05-31T10:58:13 2017-06-12T10:58:4

Features Basket Data Packages

Total results 18 | se.lal | inv.sel. | Remove all | Save

- DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) - Interferometric Coherence - 2016-08-07T09:46:27 2016-08-31T09:46:30
- logs.zip

Products of the Volcano Trial Case: DLR InSAR Sentinel-1 Browse (HR:50m)

The screenshot displays the web browser interface for the geohazards-tep.eo.esa.int portal. The browser's address bar shows the URL. The page header includes navigation links for 'vpine', 'EO data', 'EO-based products', 'Publications', and 'Community'. The main content area features a map of Southeast Asia, specifically Indonesia, with a search bar and various map controls. A metadata popup window is centered over the map, providing details for the selected data:

- Resolution: 50m
- Pixel Spacing: 25m
- Intensity σ^0 [dB]: A color scale from -15 to 5.
- DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center logo.
- Published: Jun 15th 2017
- Buttons for 'Download' and 'Related search'.

The map shows a data overlay over the island of Sumatra, with a timeline at the bottom ranging from 2014-12-09 to 2017-06-17. The bottom of the page contains search results and a features basket.

Current search result: Result for OpenSearch query over type ... Total results 160

- S-1 High-Resolution InSAR Browse Service - Coherence-Terrain Corrected - 2017-05-19T10:58:13-2017-06-12T10:58:44
- S-1 High-Resolution InSAR Browse Service - Coherence-Terrain Corrected - 2017-05-31T10:58:13-2017-06-12T10:58:44

Features Basket: Data Packages Total results 18

- DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) - Interferometric Coherence - 2016-08-07T09:46:27-2016-08-31T09:46:30
- logs.zip

Products of the Volcano Trial Case: DLR InSAR Sentinel-1 Browse (HR:50m)

Each new acquisition is combined with the last one (acquired 12 days before) and sometimes with the one acquired 24 days before.

Products of the Volcano Trial Case: DLR InSAR Sentinel-1 Browse (HR:50m)

1. master calibrated amplitude

Geotiff image: 4 bands: 3 bands (same information= amplitude byte format)
1 band (mask 255 where information,0 elsewhere)

2. slave calibrated amplitude

Geotiff image: 4 bands: 3 bands (same information= amplitude byte format)
1 band (mask 255 where information,0 elsewhere)

3. terrain corrected coherence

Geotiff image: 4 bands: 3 bands (same information= coherence byte format)
1 band (mask 255 where information,0 elsewhere)

4. amplitude change composite (displaying the master calibrated amplitude in grey and superimposing areas of backscatter increase in Red or decrease in Blue within the S-1 pair dates; decrease and increase are detected using a threshold)

Geotiff image: 4 bands: band 1 amplitude or larger value if amplitude increase
band 2 amplitude
band 3 amplitude or smaller value if amplitude decrease
band 4 (mask 255 where information,0 elsewhere)

5. amplitude coherence composite (displaying the master calibrated amplitude in Green and Blue and, in Red, the interferometric correlation i.e. the coherence of the S-1 pair)

band 1 coherence
band 2 amplitude
band 3 amplitude
band 4 (mask 255 where information,0 elsewhere)

Products of the Volcano Trial Case: DLR InSAR Sentinel-1 Browse (HR:50m)

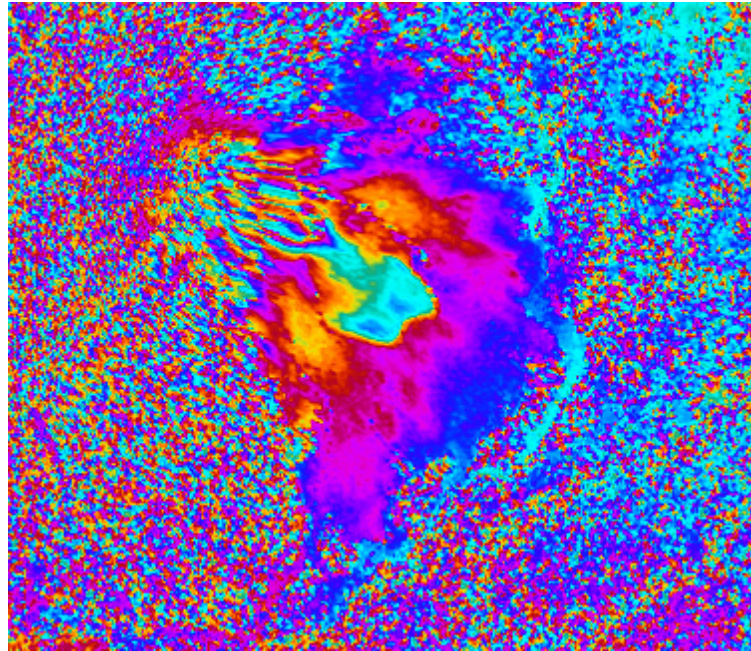
Interferogram

Geotiff image: 4 bands:

3 bands (RGB phase)

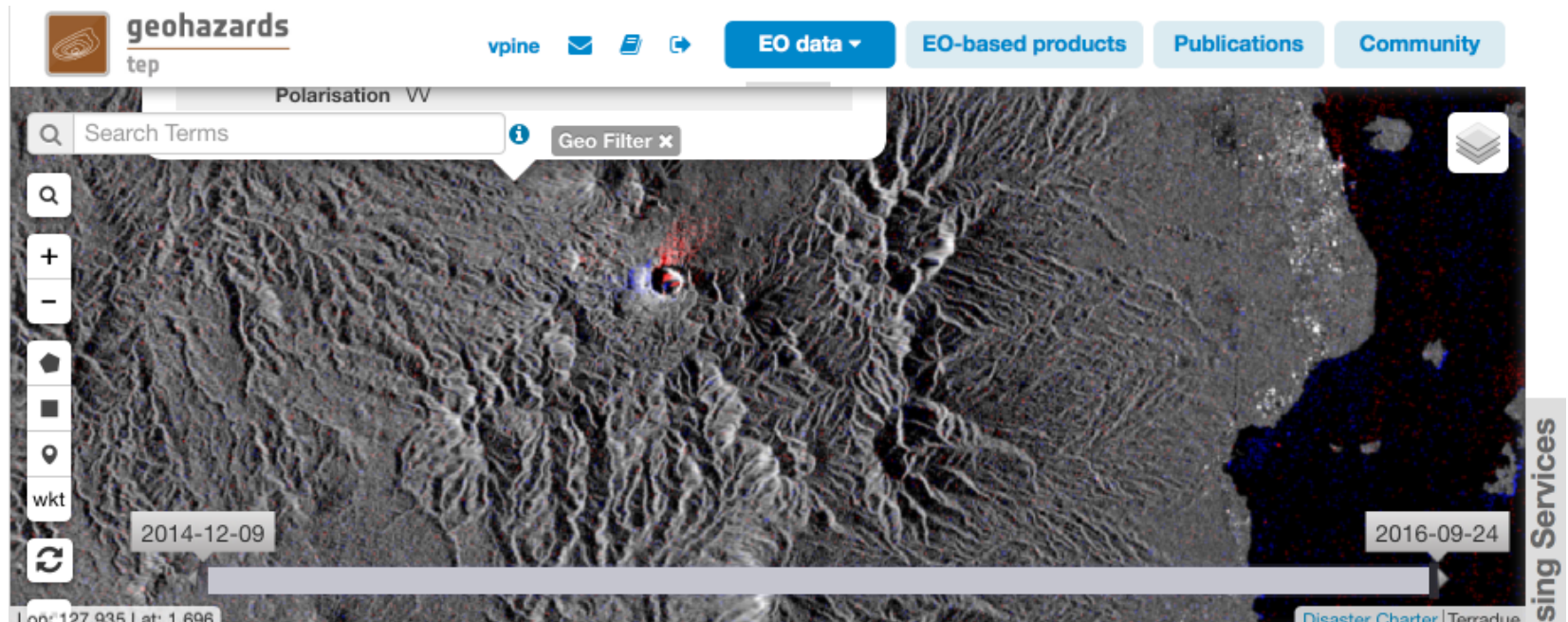
1 band (mask 255 where information,0 elsewhere)

Products of the Volcano Trial Case: DLR InSAR Sentinel-1 Browse (HR:50m)



Interferogram obtained at Sinabung from images acquired on February 13, 2017 and on February, 19 2017 (phase increases when going towards the center of the lava flows).

Products of the Volcano Trial Case: DLR InSAR Sentinel-1 Browse (HR:50m)



Amplitude change image at Dukono obtained from images acquired on August, 7 2016 and on August, 31 2016 (increase of amplitude in red, decrease of amplitude in blue).

Where and how to process the data?

- On space agencies platforms:
 - GEP
- On your own computer resources
 - Buying a commercial software: Diapason, Gamma
 - Using a free software: **RoiPAC**, SNAP, GMTSAR

DEM is always required

- SRTM 30 m: (SRTM1)

<http://earthexplorer.usgs.gov/>

A geotiff file can be downloaded

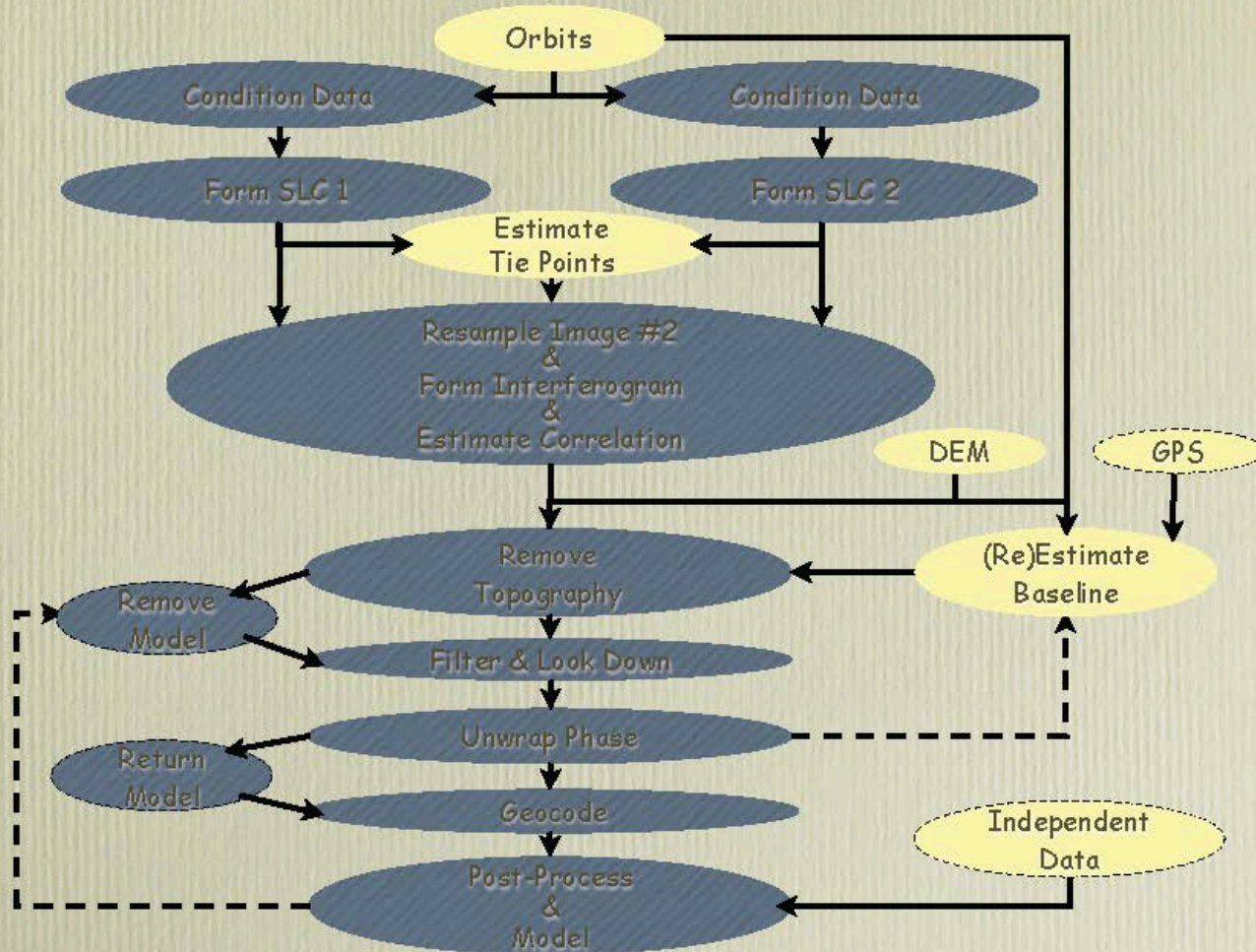
(also SRTM3 90 m for automatic download

https://dds.cr.usgs.gov/srtm/version2_1)

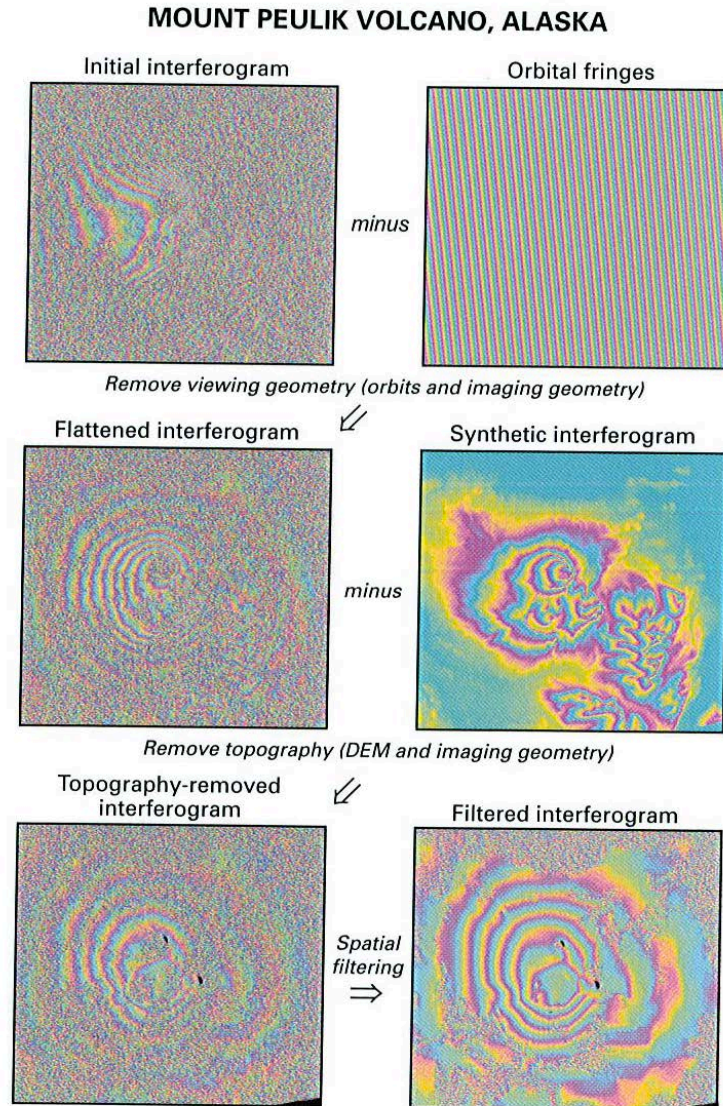
- JAXA 30m resolution
- Link to check:
- http://www.eorc.jaxa.jp/ALOS/en/aw3d30/l_map.htm
- Information here:
- <http://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm>

Processing chain (ROIPAC example).

ROI_pac Two-pass Processing Flow



Processing chain (ROIPAC example).

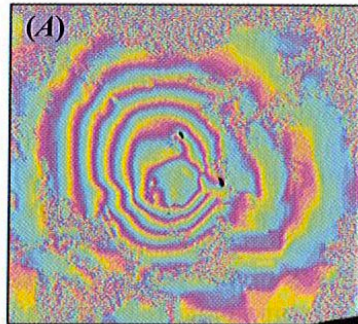


From Dzurizin, 2007

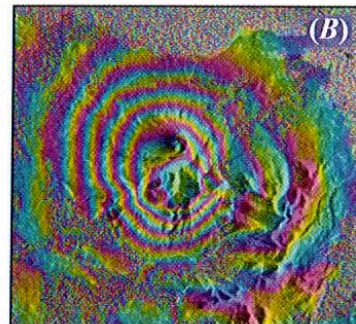
Processing chain (ROIPAC example).

MOUNT PEULIK VOLCANO, ALASKA

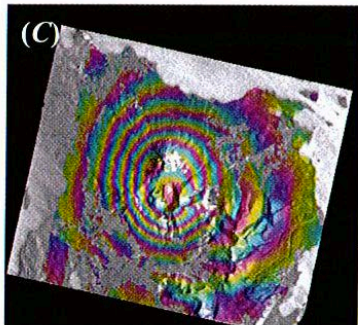
Filtered interferogram



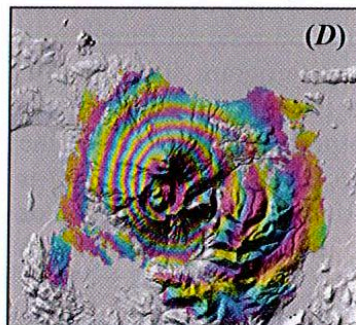
Filtered interferogram over amplitude image



Transformation to geographical coordinates

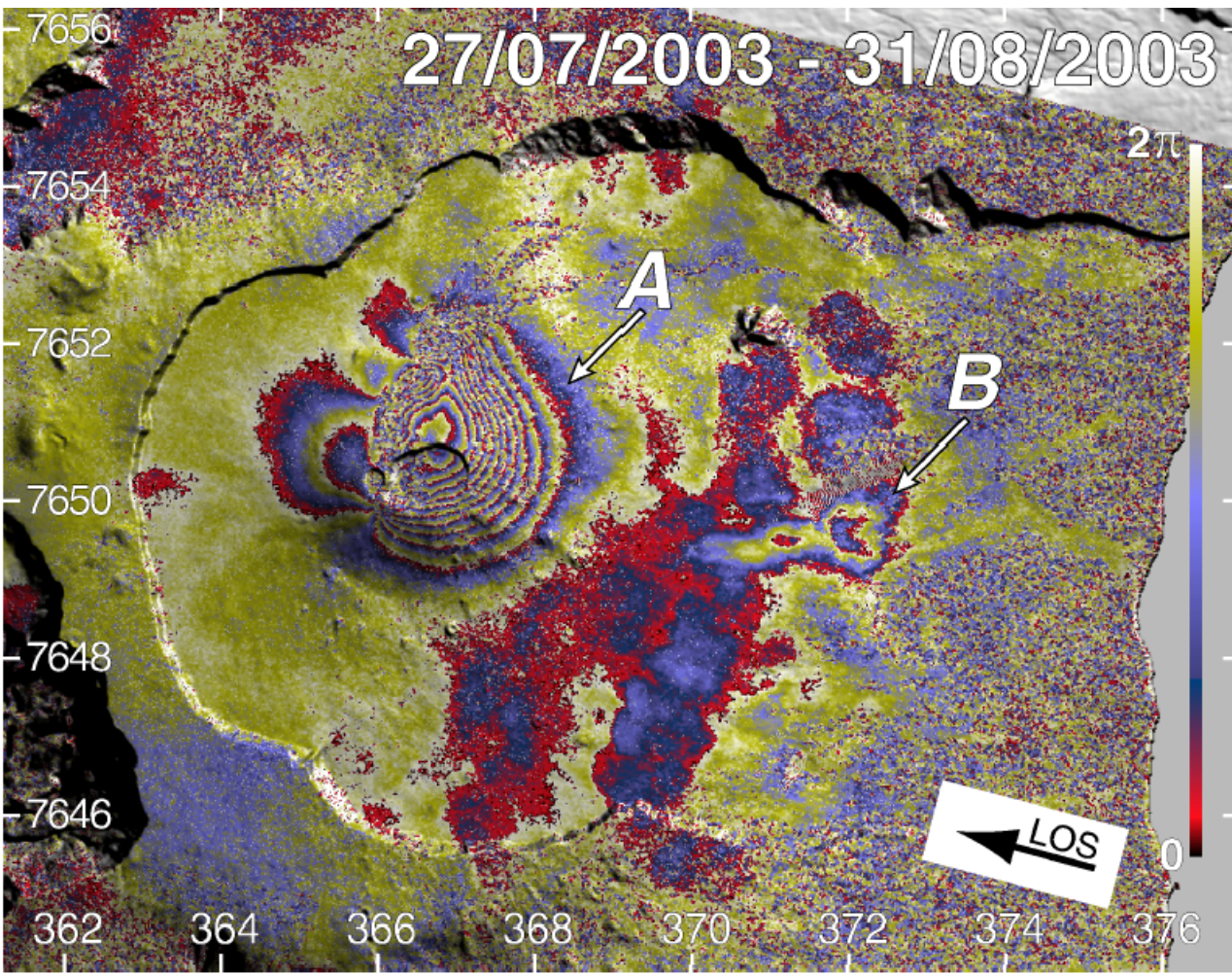


Filtered, transformed interferogram over shaded relief from DEM



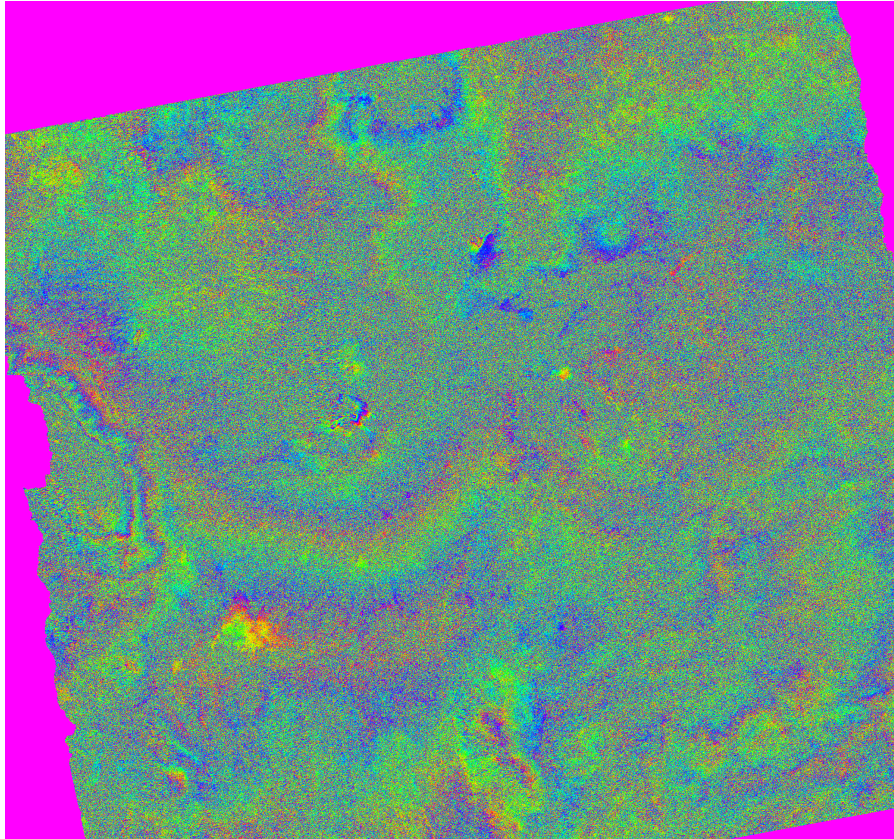
An example of interferogram

Piton de la Fournaise, Reunion Island
Eruption on the 23rd of August 2003



From Froger et al, 2004

Signal is not always so obvious



Atmospheric, orbit and DEM errors

Errors can become larger than the signal
for low strain and short time intervals

Interferogram production using Diapason on GEP

- Choose the area
- Choose the data (2 dates on the same track)
- Run the calculation
- Results (pixel size=90m):
 - Phase file in terrain geometry (Byte)
 - Amplitude file in terrain geometry (Float)
 - Coherence file in terrain geometry (Float between 0 and 255)

Interferogram production using Diapason on GEP

The screenshot displays the web interface for geohazards-tep. The browser address bar shows `geohazards-tep.eo.esa.int`. The page header includes navigation links for `EO data`, `EO-based products`, `Publications`, and `Community`. The main content area features a map of Java, Indonesia, with search results for Sentinel-1 SLC IW images. The search results are displayed in a table with columns for image ID, acquisition date, and processing date. The configuration panel on the right side of the interface includes fields for `Job title`, `Sentinel-1 IW master *`, `Sentinel-1 IW Slave *`, `Polarization *`, `Area Of Interest`, and `Goldstein phase filter exponential factor *`.

EO Free Text Search [time x] [spatial x] [earth observation x]

Current search result [Features Basket] [Data Packages]

Result for OpenSearch query over type ... Total results 26

- S1A SLC IW_DP L1 VV, VH 127 2017-05-31T10:57:4 6.0296350Z/2017-05-31T10:58:15.8331460Z
- S1A SLC IW_DP L1 VV, VH 127 2017-05-19T10:58:1 3.0278810Z/2017-05-19T10:58:42.8457810Z
- S1A SLC IW_DP L1 VV, VH 127 2017-05-19T10:57:4 5.4546490Z/2017-05-19T10:58:15.2602150Z
- S1A SLC IW_DP L1 VV, VH 127 2017-05-07T10:58:1 2.4621290Z/2017-05-07T10:58:42.2841400Z
- S1A SLC IW_DP L1 VV, VH 127 2017-05-07T10:57:4 4.8847860Z/2017-05-07T10:58:14.6924080Z

Features Basket [Data Packages]

- S1A SLC IW_DP L1 VV, VH 127 2017-07-06T10:58:15.5817530Z/2017-07-06T10:58:45.4037640Z
- S1A SLC IW_DP L1 VV, VH 127 2017-04-25T10:58:11.6022000Z/2017-04-25T10:58:41.4221550Z

DIAPASON is an InSAR tool suite developed by the French Space Agency (CNES) and maintained by ALTAMIRA INFORMATION. This service performs an InSAR workflow on Sentinel-1 TOPSAR (IW,EW) data, producing interferograms, amplitude and coherence maps. To run this service, specify master and slave Sentinel-1 SLC images.

Job title

DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW)

Sentinel-1 IW master *

<https://catalog.terradue.com/sentinel1/search?format=atom&u>

Sentinel-1 IW Slave *

<https://catalog.terradue.com/sentinel1/search?format=atom&u>

Polarization *

VV

Area Of Interest

Goldstein phase filter exponential factor *

0.5

Interferogram production using Diapason on GEP

The screenshot displays the geohazards-tep web interface. The main map shows a region in Java, Indonesia, with a search area highlighted in orange. The search results list several Sentinel-1 SLC IW_DP L1 VV, VH datasets. The right panel shows the job configuration for 'DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) (1)'. The job is currently 'Running' and is private. The parameters section lists the master and slave URLs, along with other settings like 'pol', 'aoi', 'psfiltx', and 'unwrap'.

Job Name: DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) (1)

Wps Job Id: a202a15f-eb94-4839-8399-cbf0e8a02f4f

Started at: Jul 11th 2017

Created by: Virginie Pinel

Status/Result Location: [Link]

Status: Running

Visibility: private

Share: [Share icon]

Progress: 20%

Parameters:

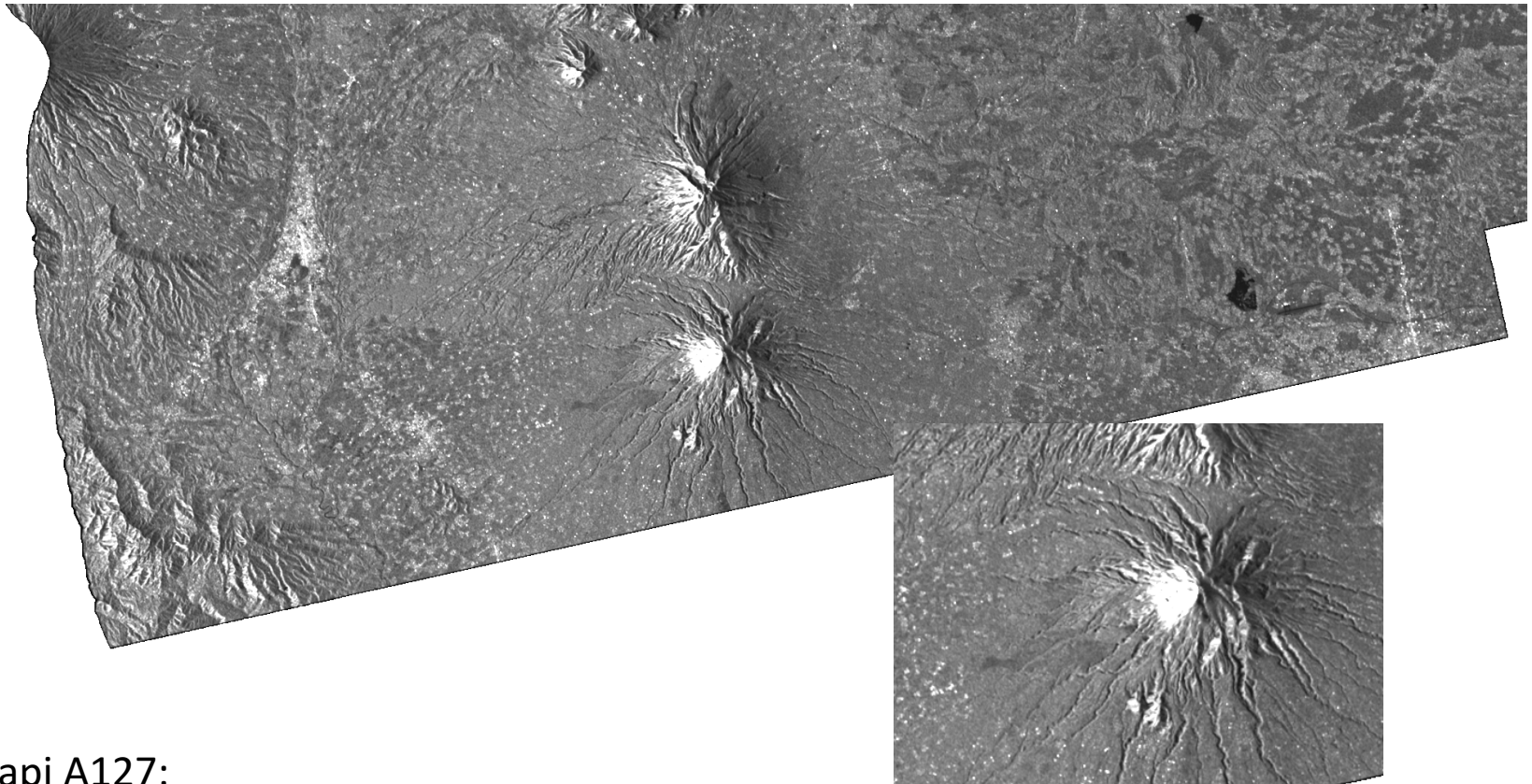
Name	Value
master	https://catalog.terradue.com/sentinel1/search?format=atom&uid=S1A_IW_SLC_1SDV_20170425T105811_20170425T105841_016299_01AF7D_8841
slave	https://catalog.terradue.com/sentinel1/search?format=atom&uid=S1A_IW_SLC_1SDV_20170706T105815_20170706T105845_017349_01CF92_80AE
pol	VV
aoi	109.913,-7.804,110.88,-7.352
psfiltx	0.5
unwrap	false

Interferogram production using Diapason on GEP

The screenshot displays the geohazards-tep web interface. The top navigation bar includes the logo, search bar, and menu items like 'EO data', 'EO-based products', 'Publications', and 'Community'. The main map area shows a satellite view of Java, Indonesia, with a search box and filters for 'time', 'spatial', and 'earth observation'. The map highlights a region around Surakarta, Yogyakarta, and Purworejo. Below the map, there are sections for 'Current search result' and 'Features Basket'. The 'Current search result' section shows a list of search results for 'S1A SLC IW_DP L1 VV, VH 127' with various timestamps. The 'Features Basket' section shows a list of data packages found, including 'datapackageforcloudtoolbox', 'test5', and 'ENVISAT 1P over Marmara area'. On the right side, the 'Processing Services' panel shows a list of jobs with their status and progress. The jobs are:

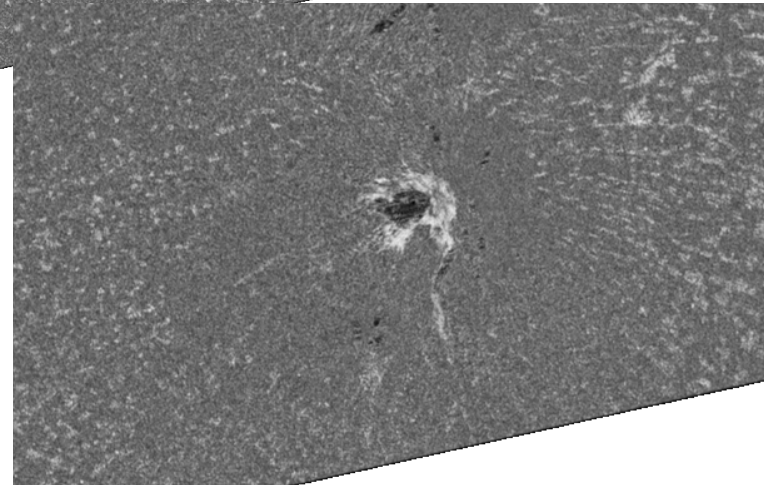
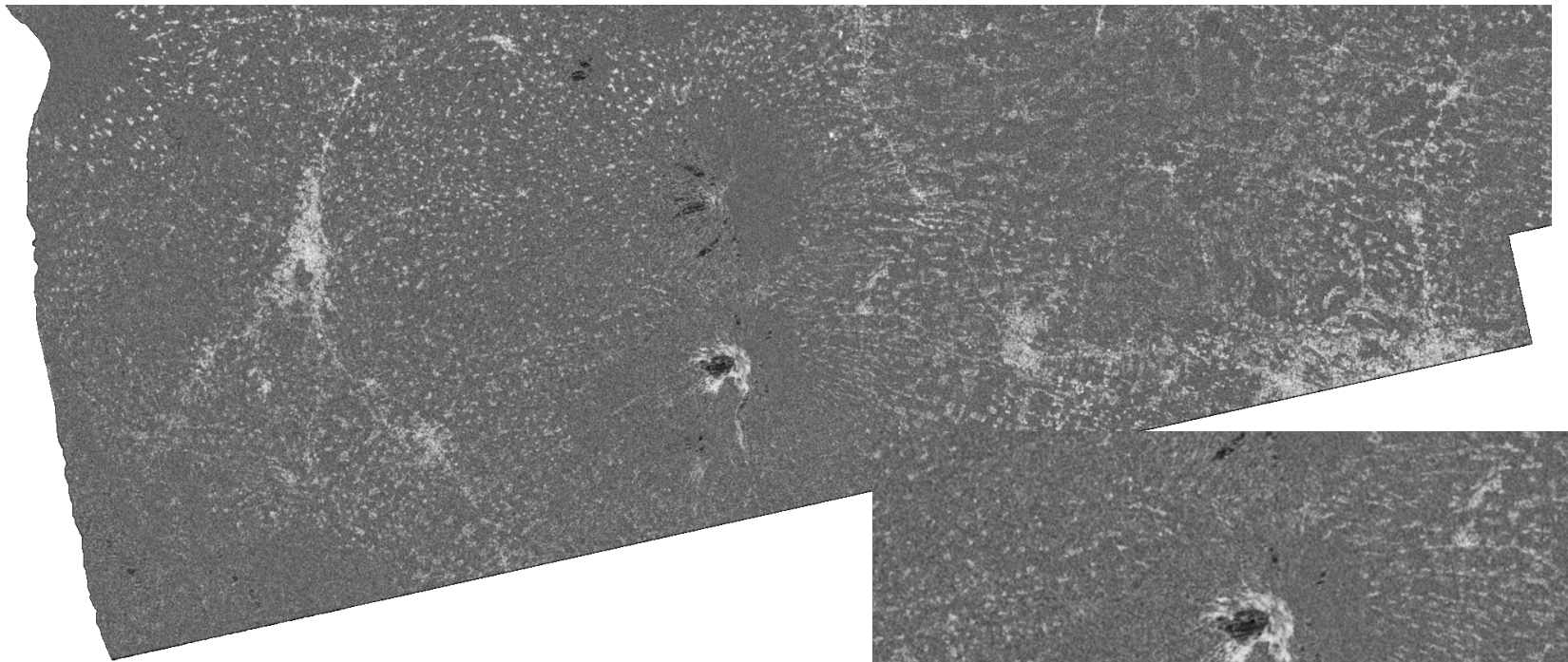
- DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) (1) - 9 minutes ago - 20% progress
- DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) - 34 minutes ago - connection failure (The request timed out)
- DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) - 6 months ago - success
- DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) - 7 months ago - failed
- DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) - 7 months ago - failed
- DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) (1) - 7 months ago - failed
- DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) - 7 months ago - failed
- DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW) - 8 months ago - success

Interferogram production using Diapason on GEP



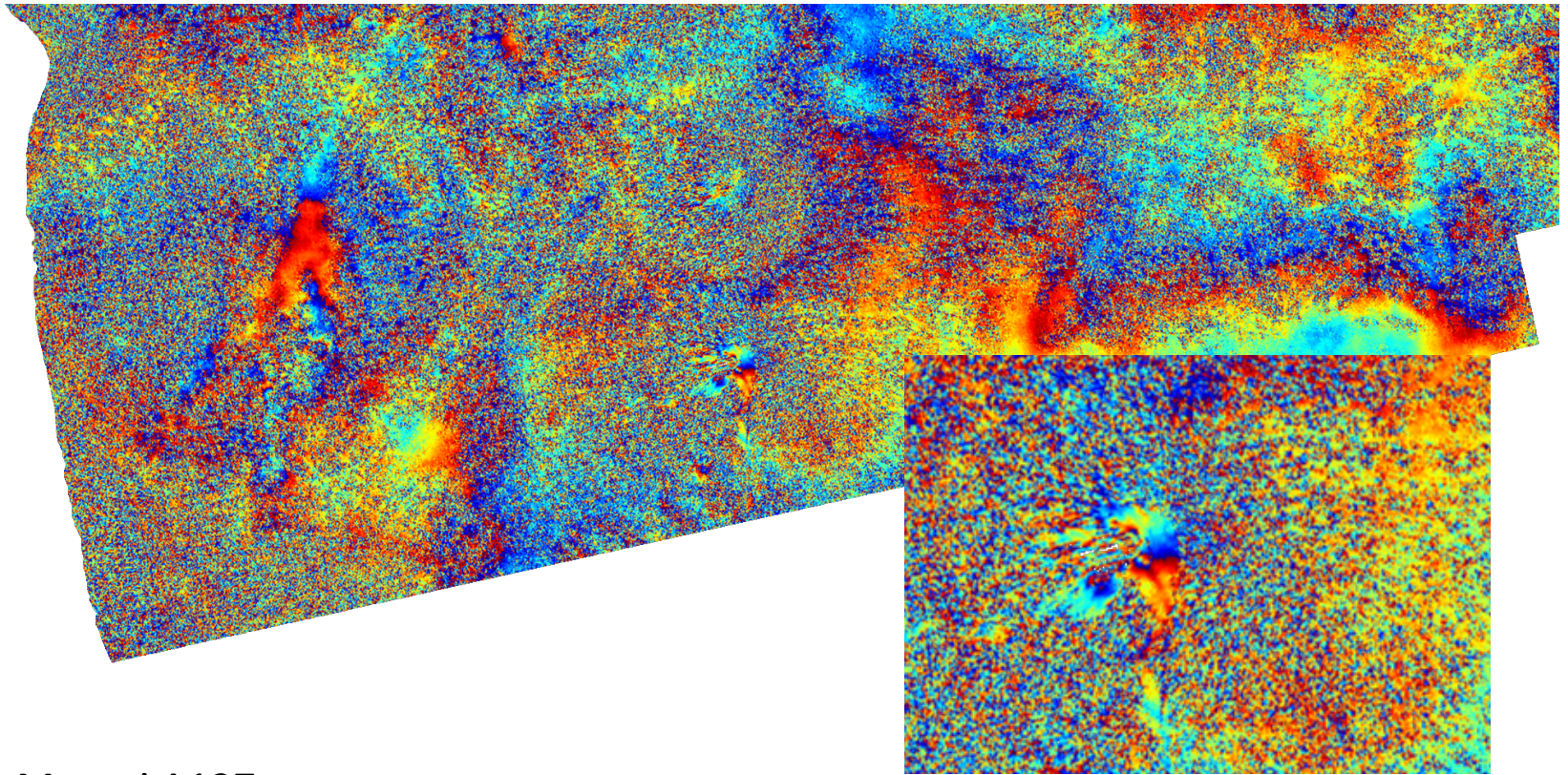
Merapi A127:
25 April 2017-6 July 2017

Interferogram production using Diapason on GEP



Merapi A127:
25 April 2017-6 July 2017

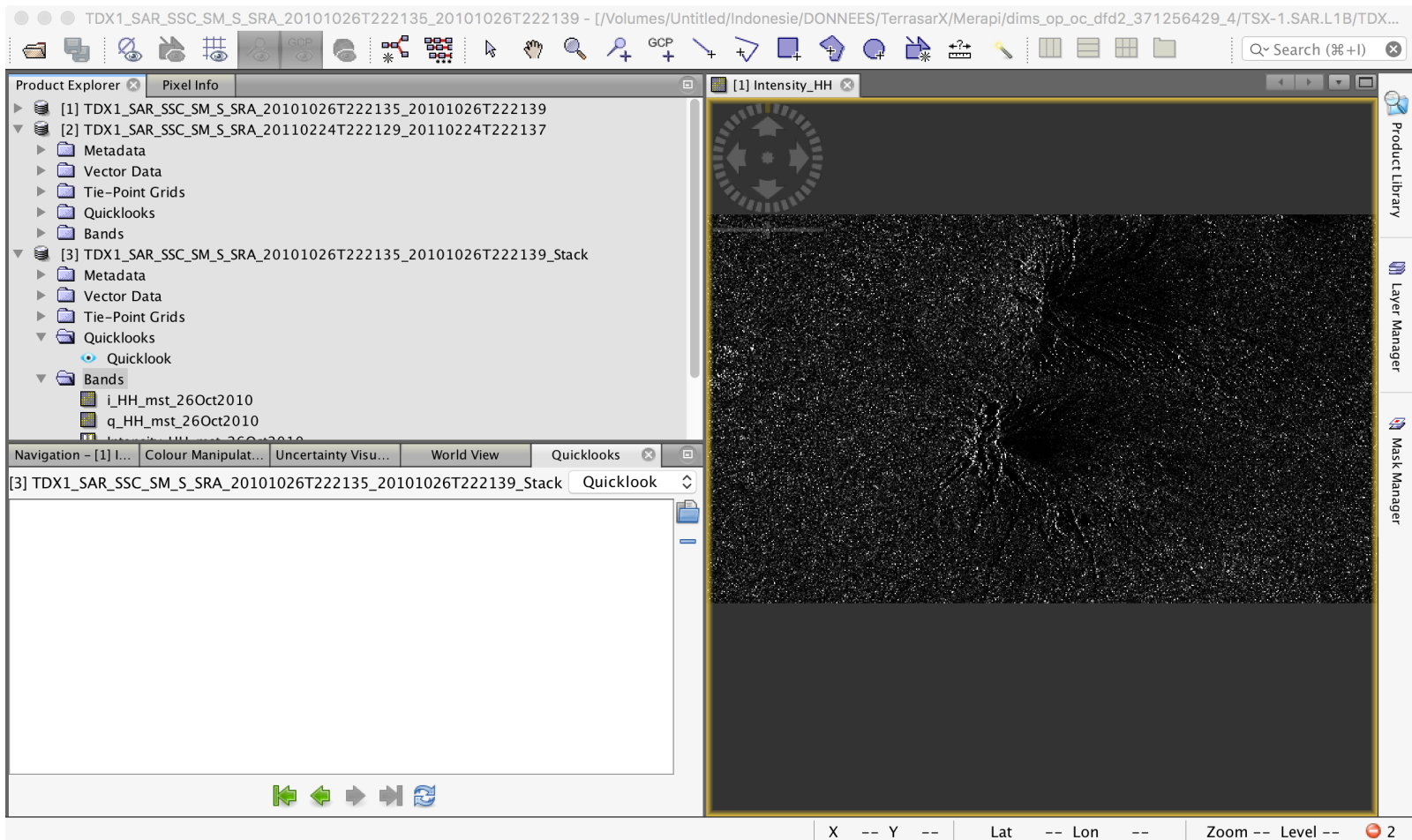
Interferogram production using Diapason on GEP



Merapi A127:
25 April 2017-6 July 2017

SNAP:

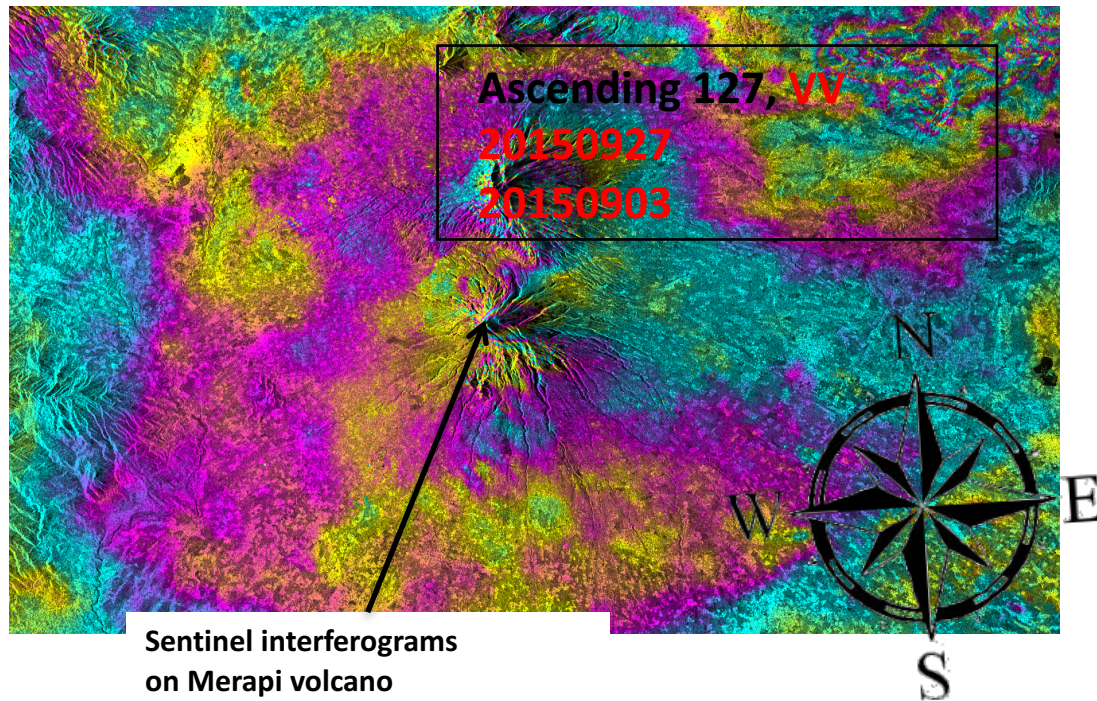
<http://step.esa.int/main/toolboxes/snap/>



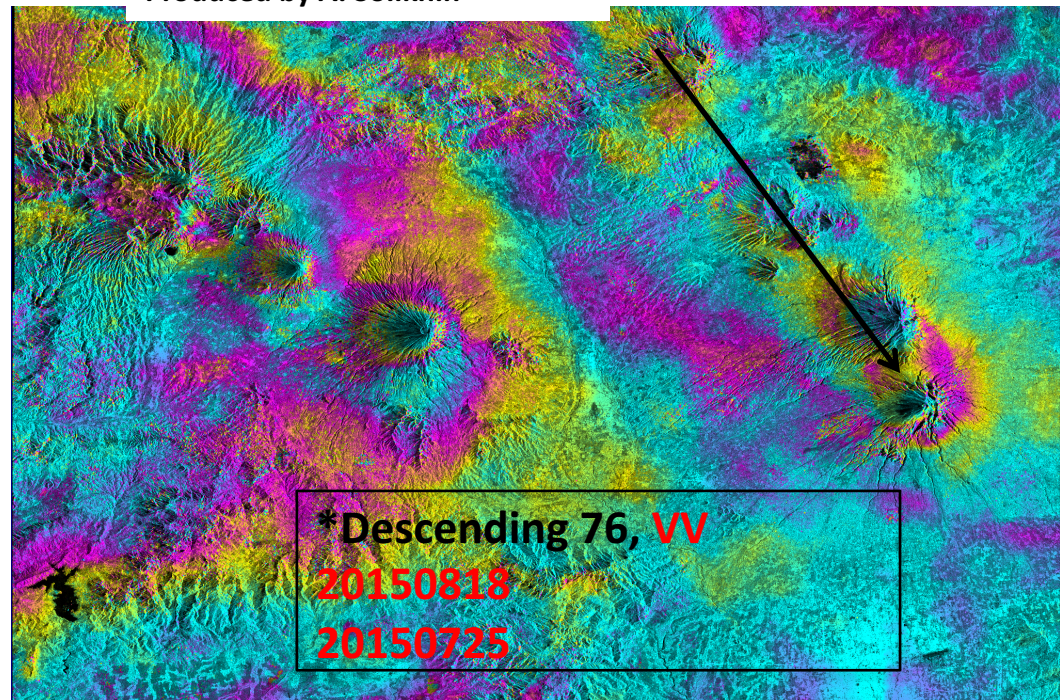
GMTSAR

- <http://topex.ucsd.edu/gmtsar/>
- GMTSAR is an open source (GNU General Public License) InSAR processing system designed for users familiar with [Generic Mapping Tools \(GMT\)](#). The code is written in C and will compile on any computer where GMT and NETCDF are installed. The system has three main components:
- a preprocessor for each satellite data type (ERS-1/2, Envisat, ALOS-1, TerraSAR-X, COSMOS-SkyMed, Radarsat-2, Sentinel-1A/B, and ALOS-2) to convert the native format and orbital information into a generic format;
- an InSAR processor to focus and align stacks of images, map topography into phase, and form the complex interferogram;
- a postprocessor, mostly based on GMT, to filter the interferogram and construct interferometric products of phase, coherence, phase gradient, and line-of sight displacement in both radar and geographic coordinates;
- GMT is used to display all the products as postscript files and KML images for Google Earth. A set of C-shell scripts has been developed for standard 2-pass processing as well as image alignment for stacking and time series.
- Also see UNAVCO courses: <http://www.unavco.org/education/professional-development/short-courses/course-materials/insar/2015-insar-gmtsar-course-materials/2015-insar-gmtsar-course-materials.html>

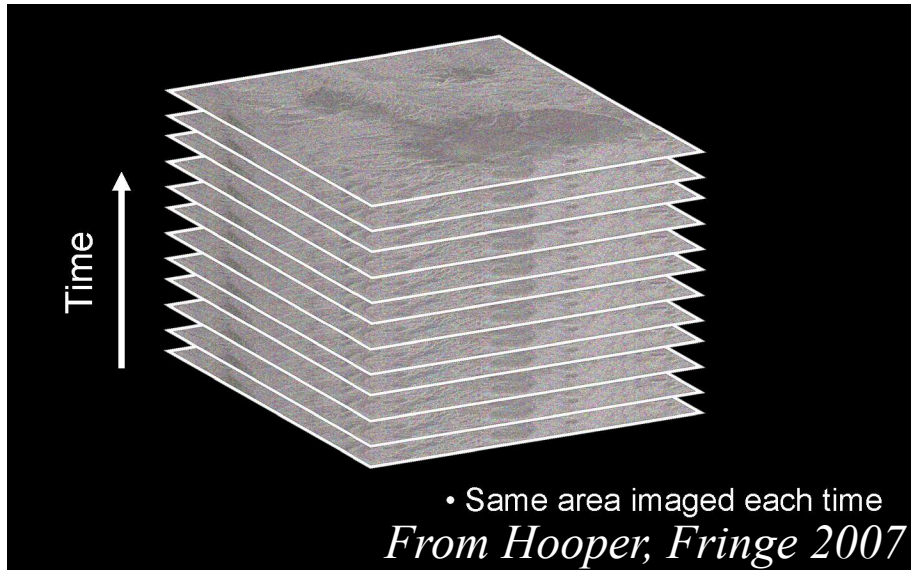
InSAR processing using ROIPAC



Sentinel interferograms
on Merapi volcano
Produced by A. Solikhin



SAR Time series analysis: a way to improve signal/noise



Allow picking of coherent pixels.
DEM estimation error is possible
Other errors are reduced by filtering
in time.

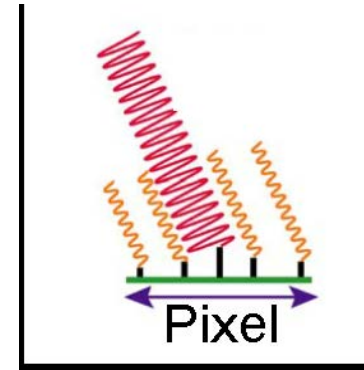
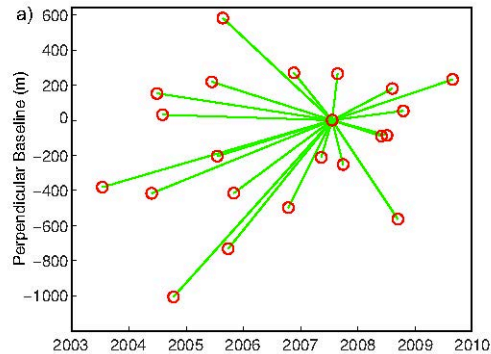
Any InSAR method using multiple images of the same area acquired at different time.

Two families of Time series studies

(see Hooper et al, *Tectonophysics*, 2012)

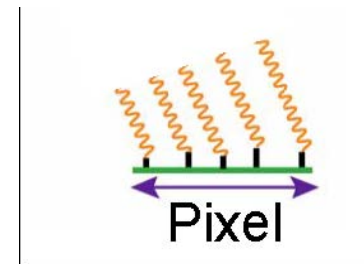
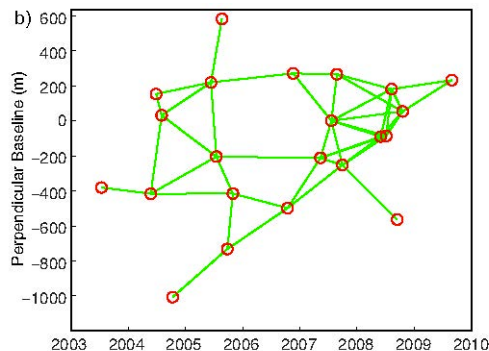
*Persistent Scatterer methods

optimized for pixels dominated by a single scatterer



*Small Baseline methods:

optimized for pixels with a Gaussian distribution of scatterers



Processing chains

SAR time series

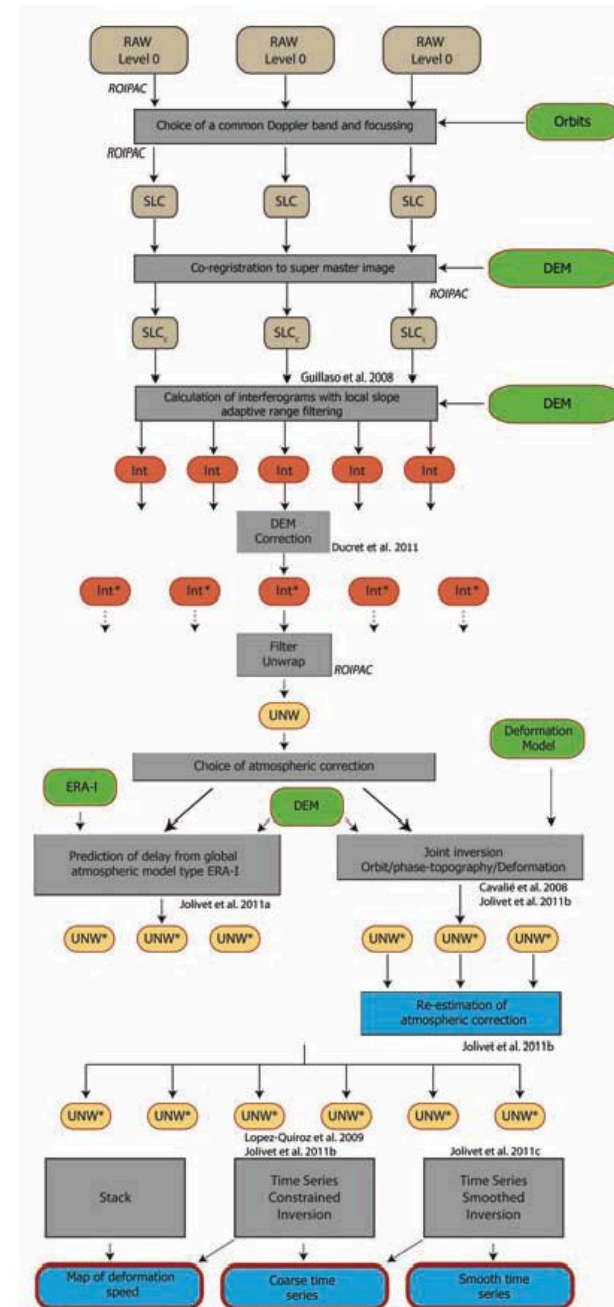
- StaMPS Andy Hooper

<http://radar.tudelft.nl/~ahooper/stamps/index.html>

- NSBAS Marie-Pierre Doin and EFIDIR team

<http://www.efidir.fr/>

Example of Small Baseline Approach



From Doin et al, 2011

Bibliography

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Curlander, J.C., McDonough, R.N., Synthetic Aperture Radar: Systems and Signal Processing. Wiley Series in Remote Sensing and Image Processing, 1992

C. Elachi & J.J. van Zyl , Introduction to the physics and techniques of remote sensing, 2006

R. F. Hanssen, Radar interferometry, Data Interpretation and Error Analysis, Kluwer Academic Publishers, 2001

Imaging with Synthetic Aperture Radar, D. Massonnet & J.-C. Souyris, EPFL Press, 2008

Merci!
Terima kasih!