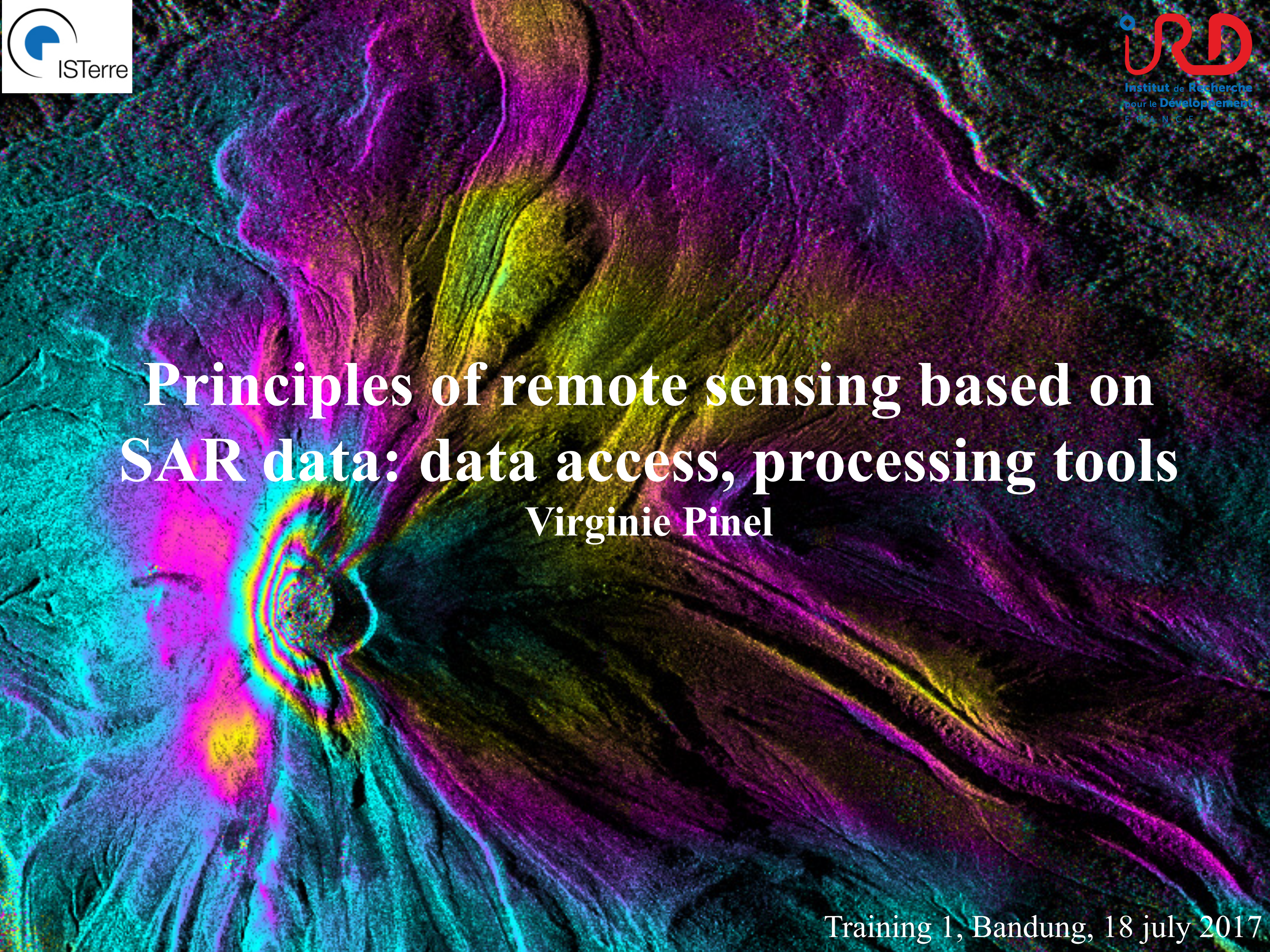


Principles of remote sensing based on SAR data: data access, processing tools

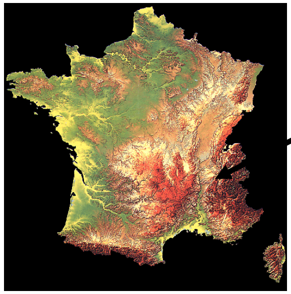
Virginie Pinel

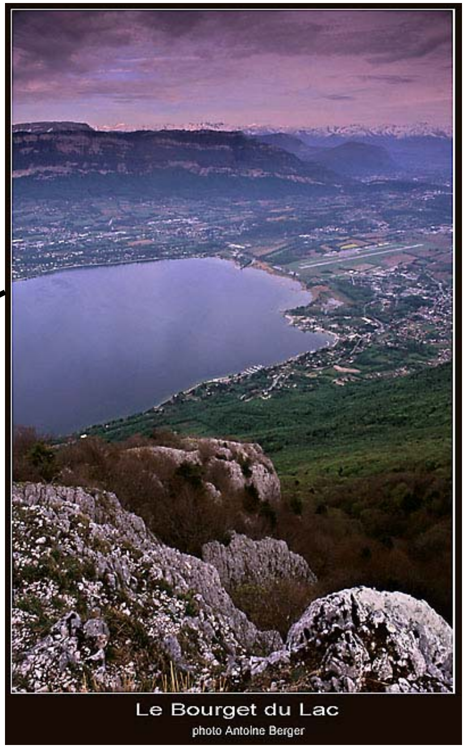
Training 1, Bandung, 18 july 2017

Who I am:

<u>Virginie Pinel</u>: 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)

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

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

	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)

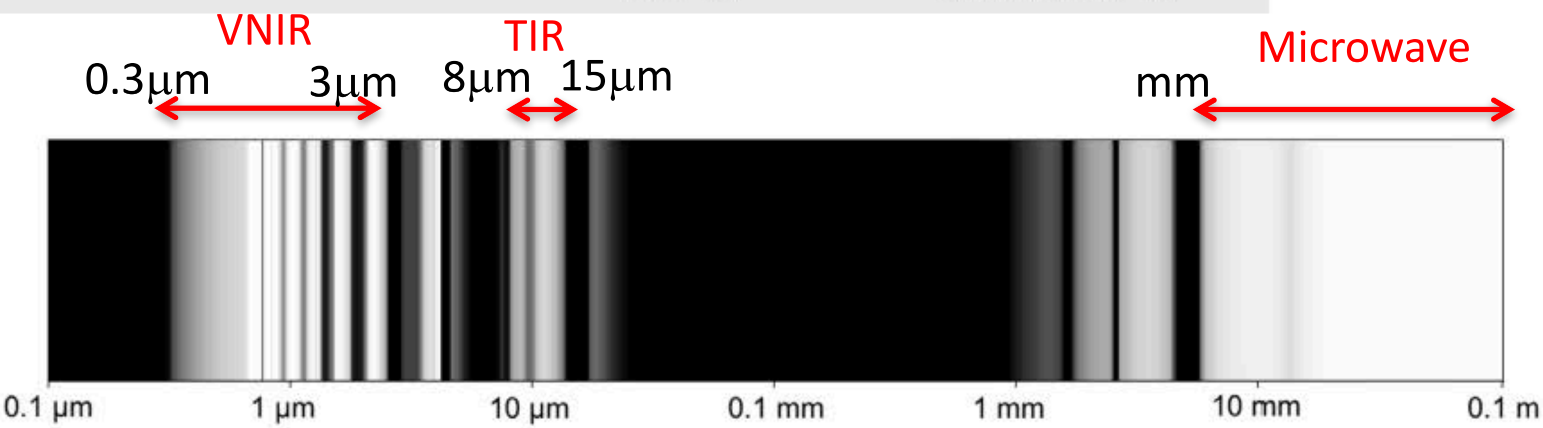
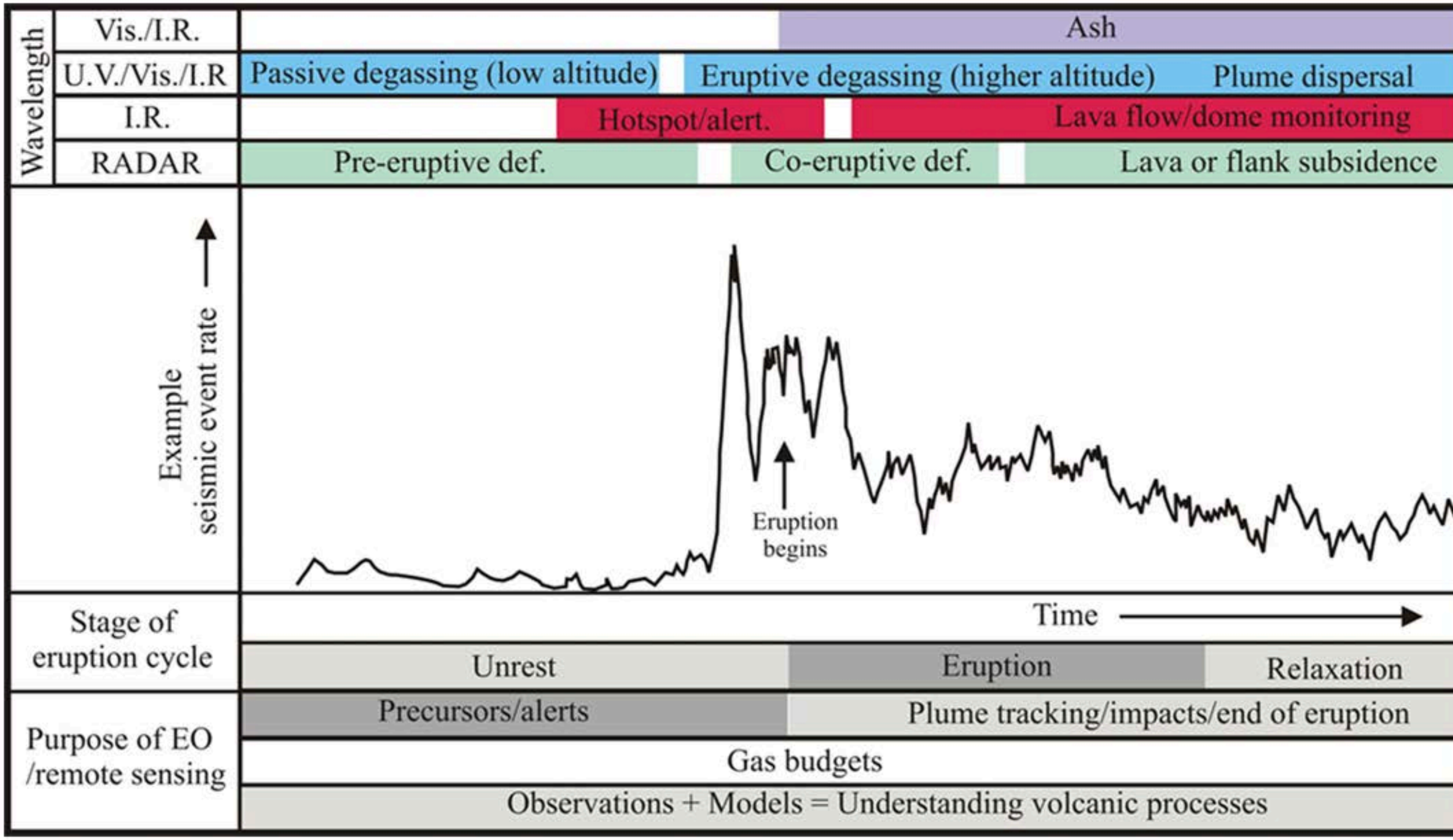


Figure 1.5. Transparency of the Earth's atmosphere as a function of wavelength (schematic). Black regions are opaque, white regions transparent.



Pyle et al, 2013

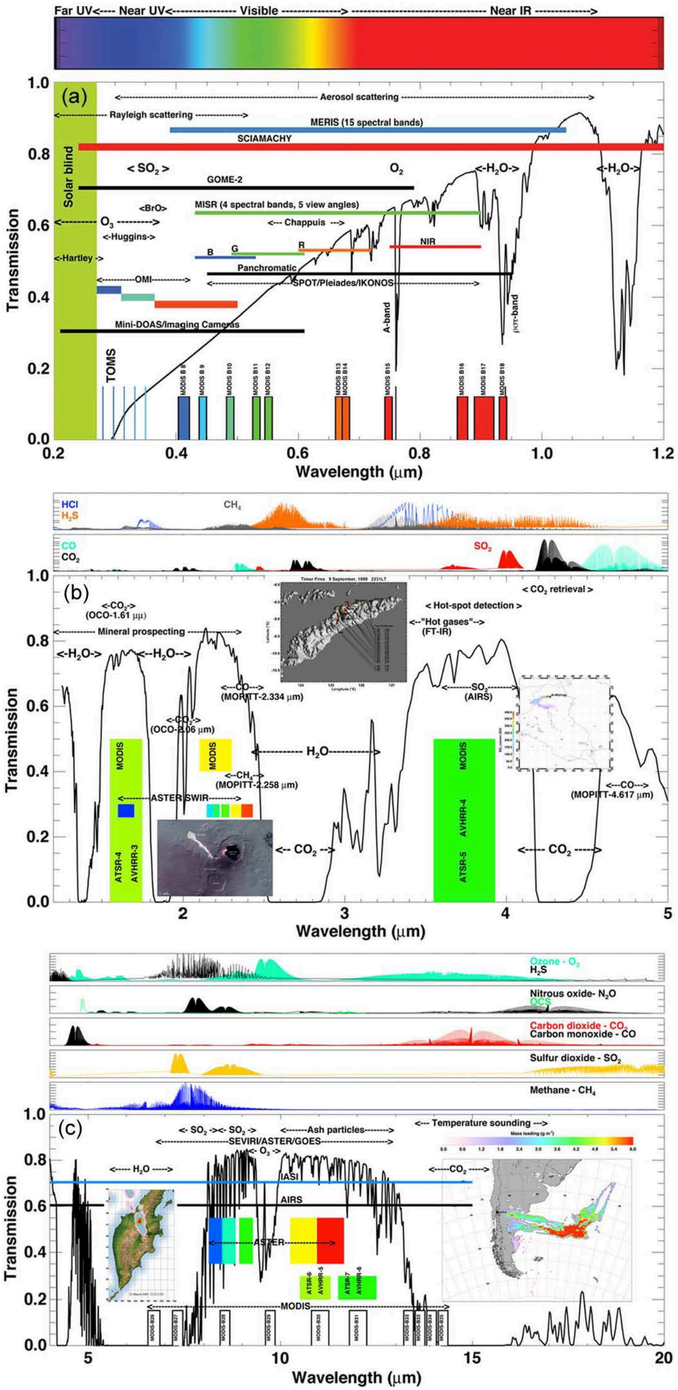
Remote sensing : observation of Earth from space, a complementary approach to in-situ field measurements.

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

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

Historical Highlights in Spectroradiometric Imaging of Earth and the Atmosphere

From Hooper et al., 2012



From Hooper et al., 2012

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

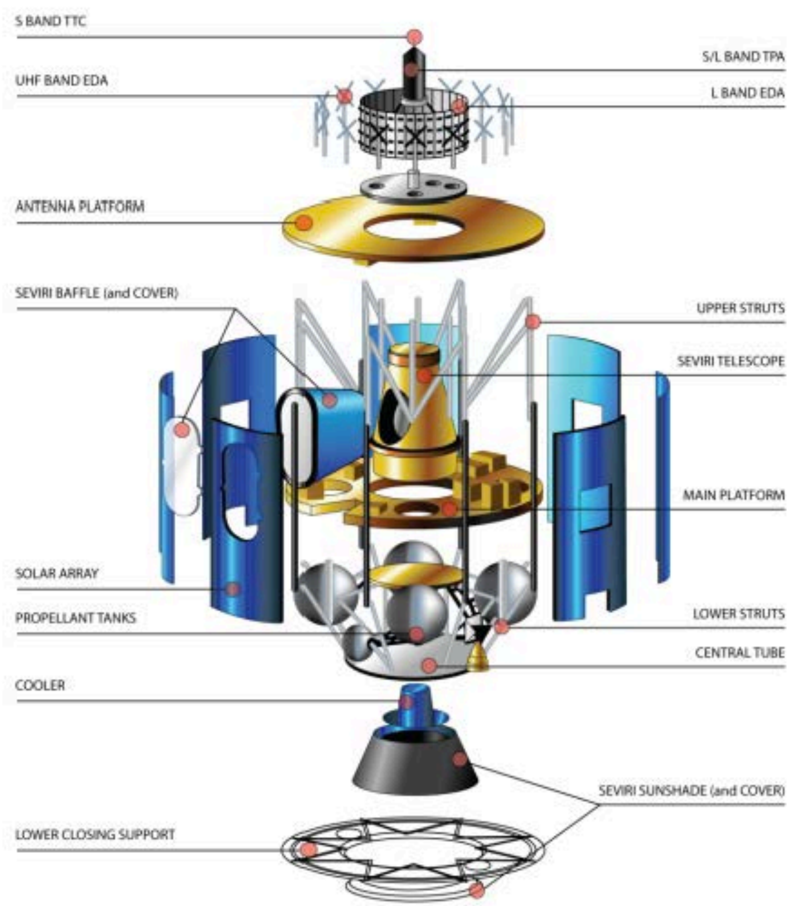
A Passive measurements : Require sunlight except for thermal measurements
- 1 Meteorological satellites (ash, gas detection and quantification)
- 2 Thermal measurements (eruption detection, effusion rate)
- 3. Optical imagery (DEM, structural studies, eruptive deposits characterization)

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

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**.



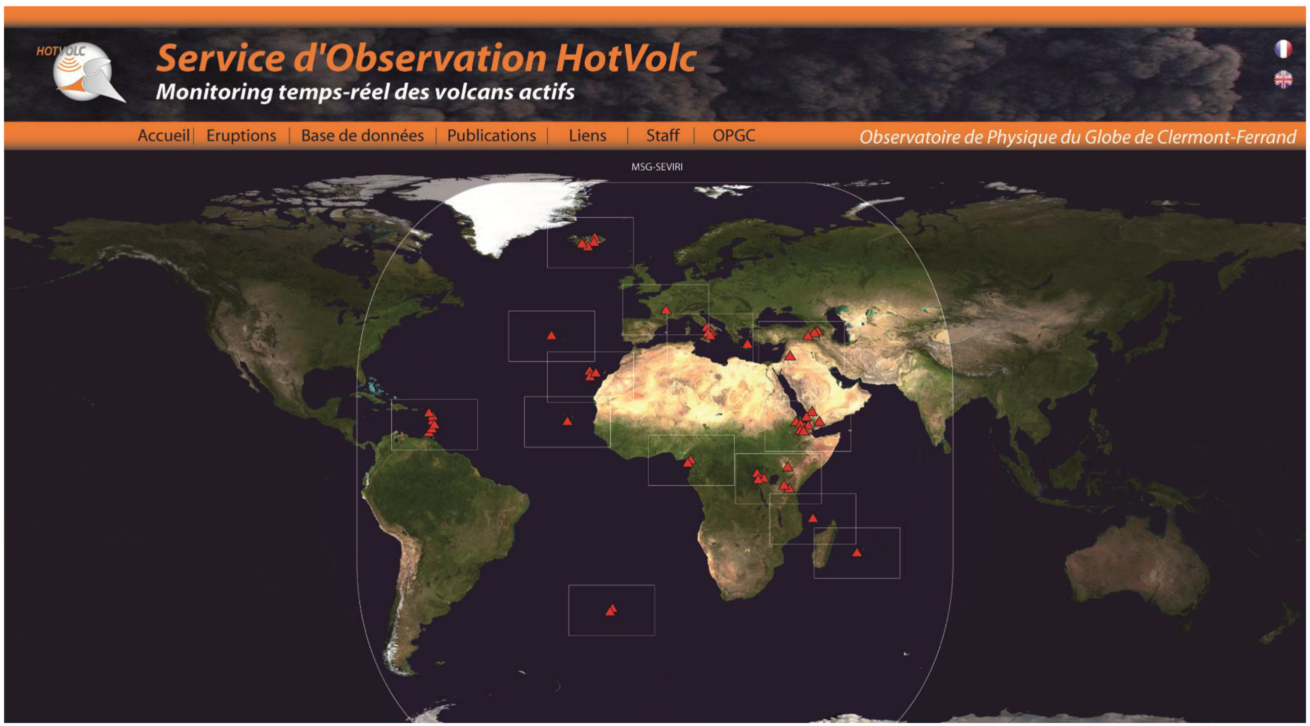
Repeat time: 15 min

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>

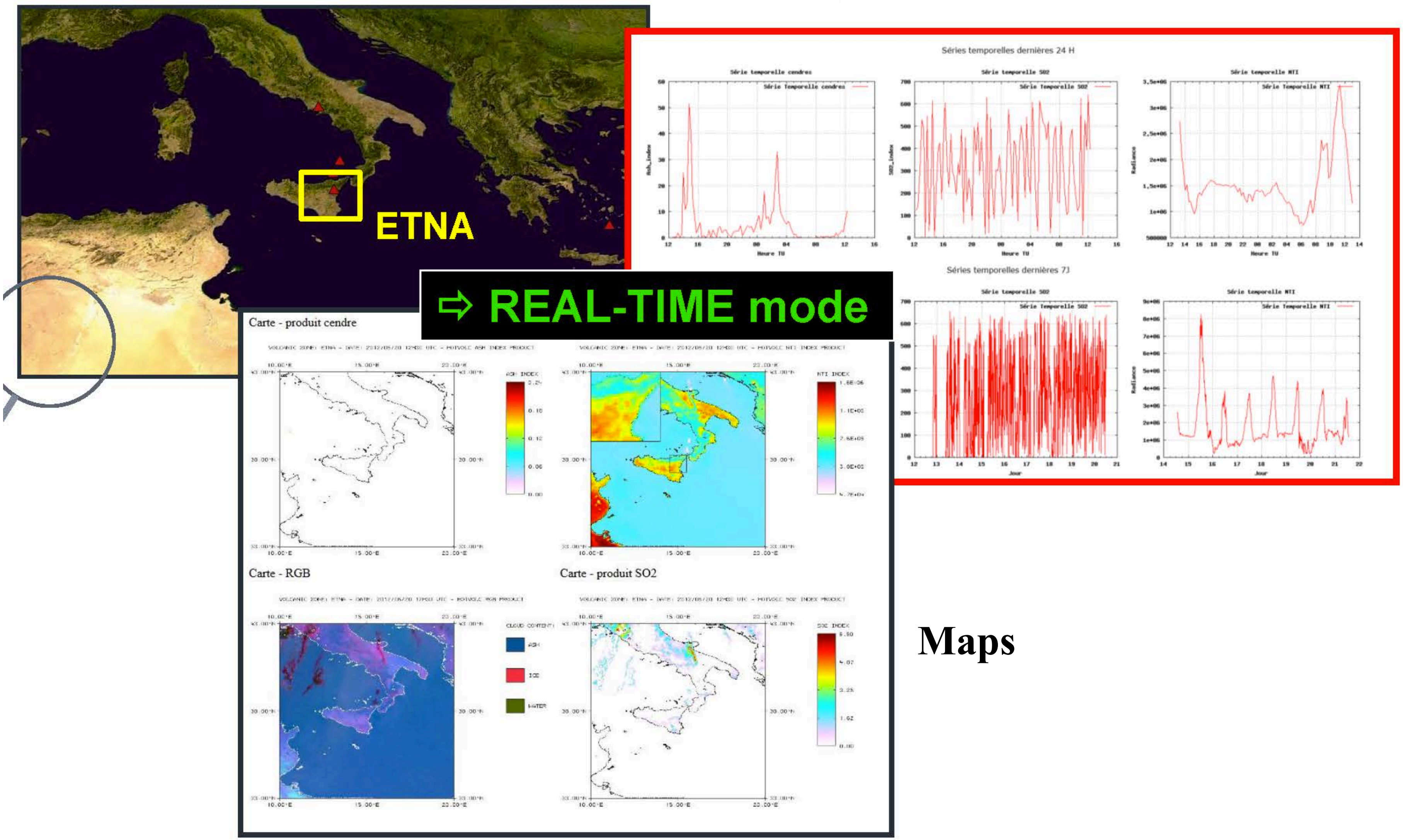
-detect ash and estimate ash concentration (*Prata et al, 89*)
-detect and estimate SO_2 concentrations (less efficient than UV absorption)
-to detect lava flows and estimate flow rates (thermal anomalies)



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

HotVolc

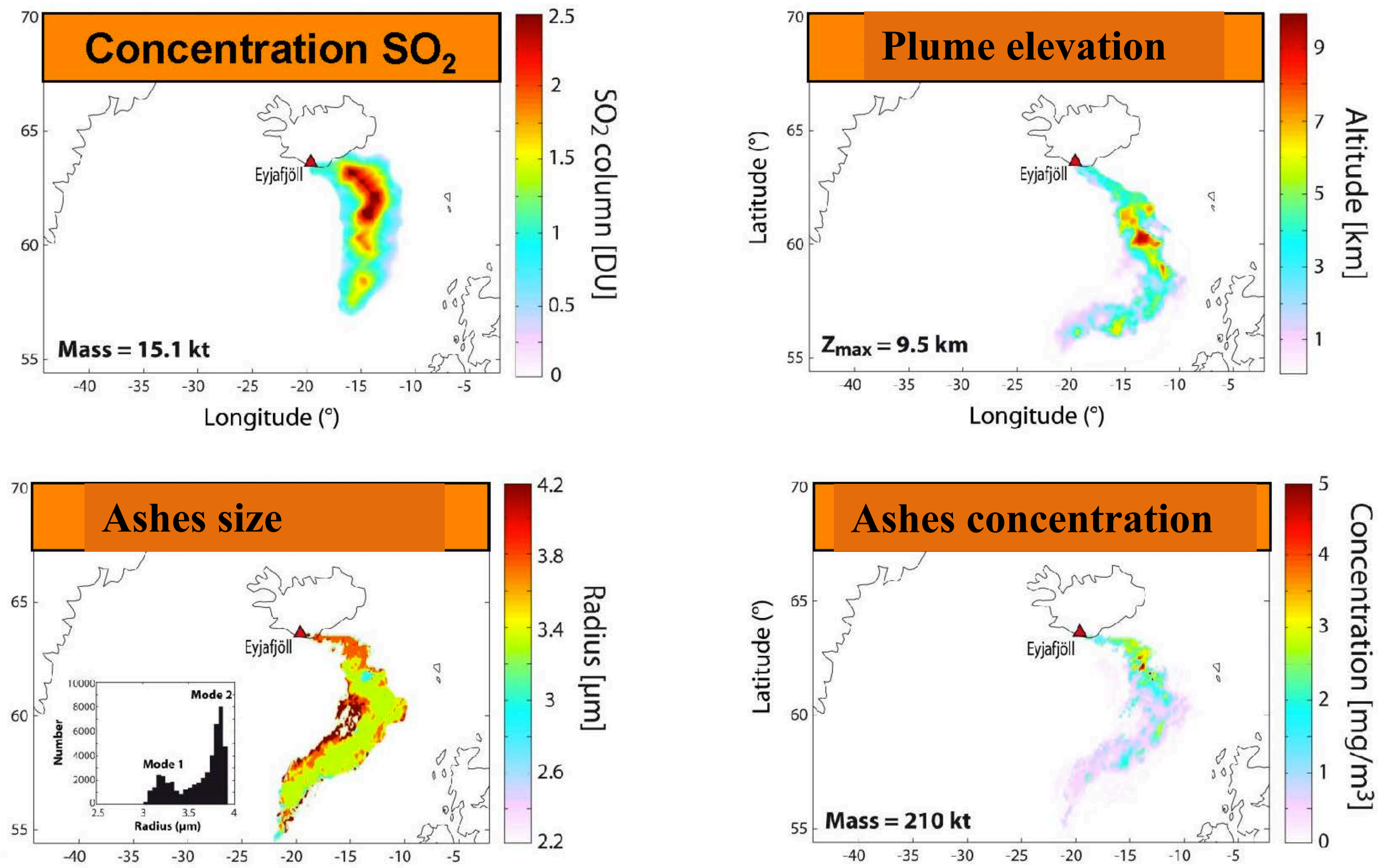
Time series



Maps

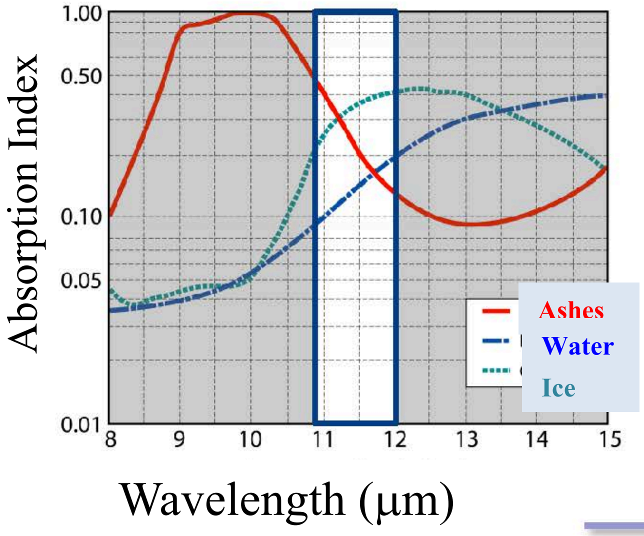
From Gouhier et al., CNFGG, 2012

HotVolc



From Gouhier et al., CNFGG, 2012

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



Between 10.8 µm and 12 µm

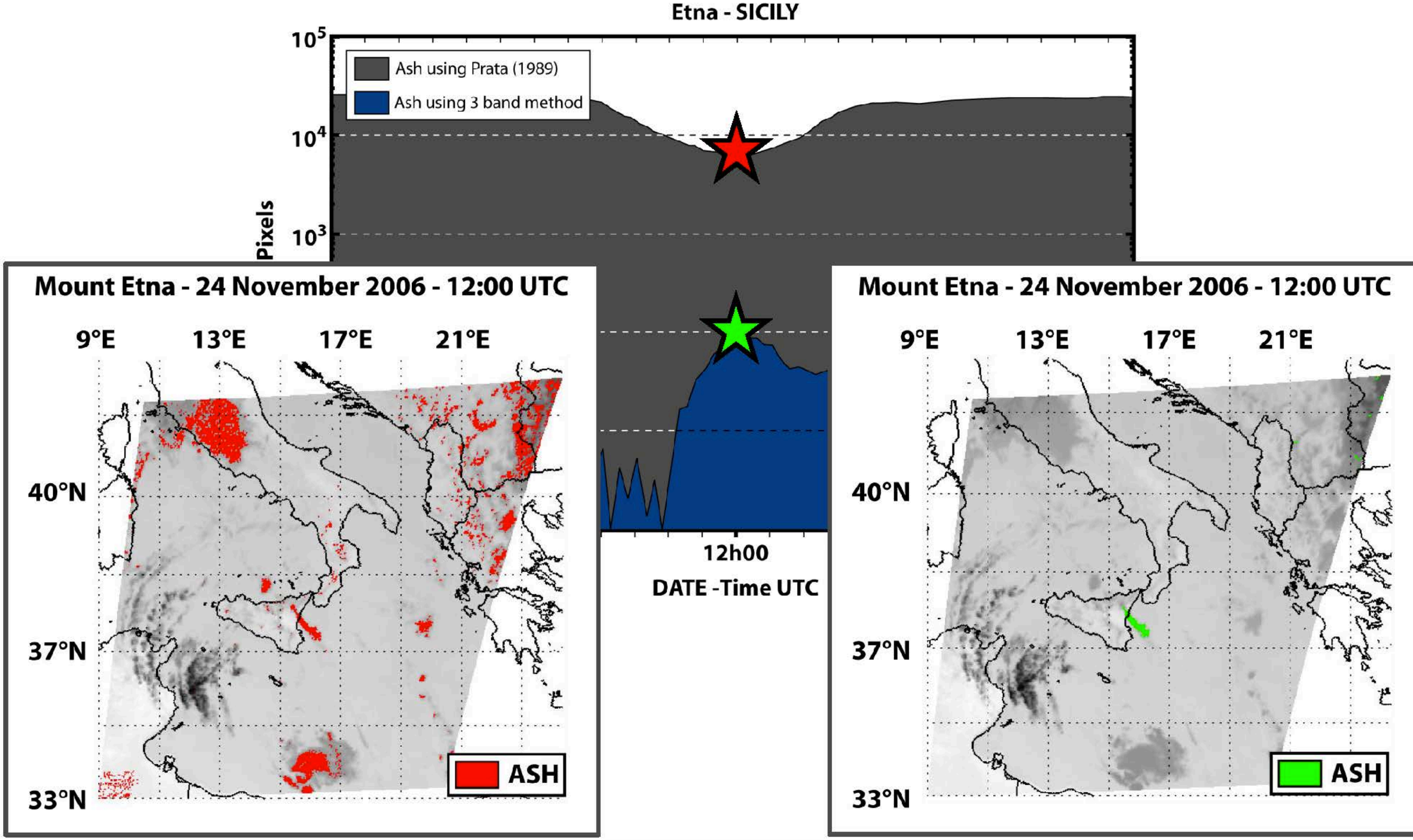
- **Ashes** → Absorption **decreases**
- **Water** → Absorption **increases**
- **Ice** → Absorption **increases**

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

Ash clouds	**Meteorological clouds**
BTD[10.8-12] → **NEGATIVE**	BTD[10.8-12] → **POSITIVE**

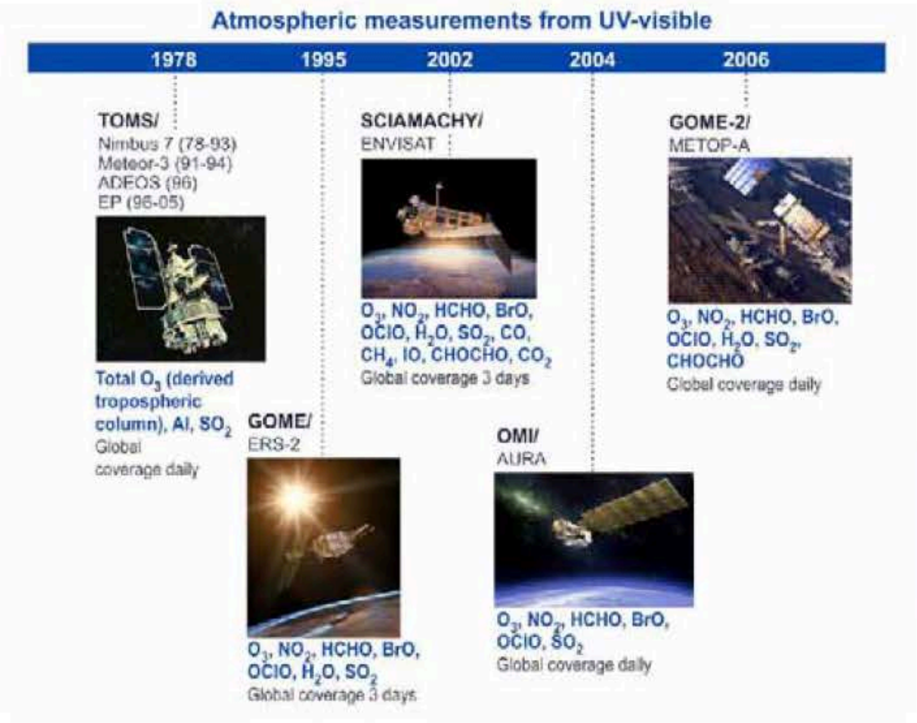
From Guehenneux et al., CNFGG, 2012

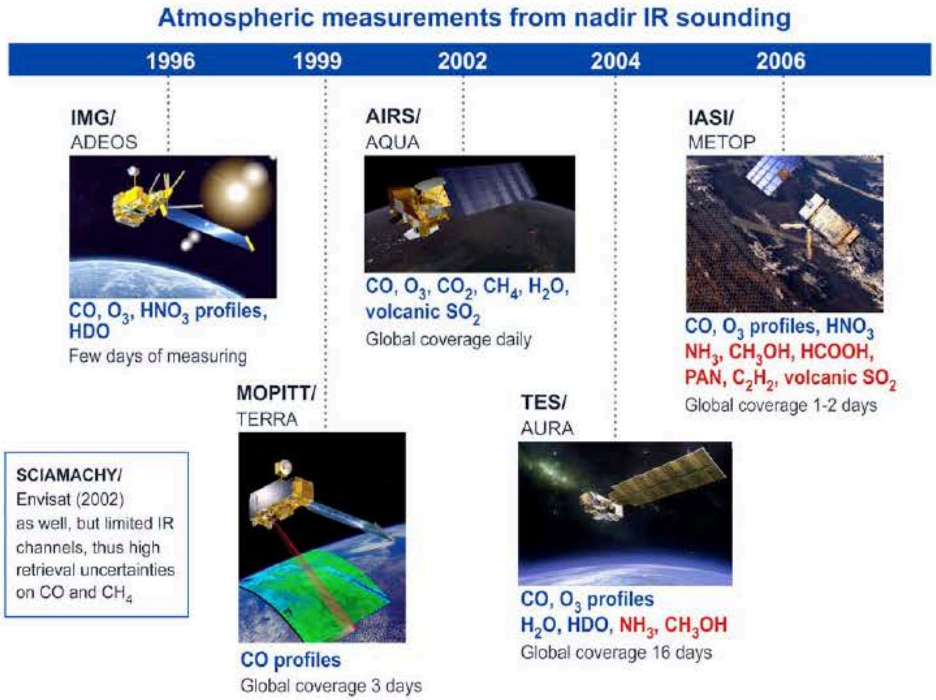
Ash detection: enhancement of the « Split-window » method



From Guehenneux et al., CNFGG, 2012

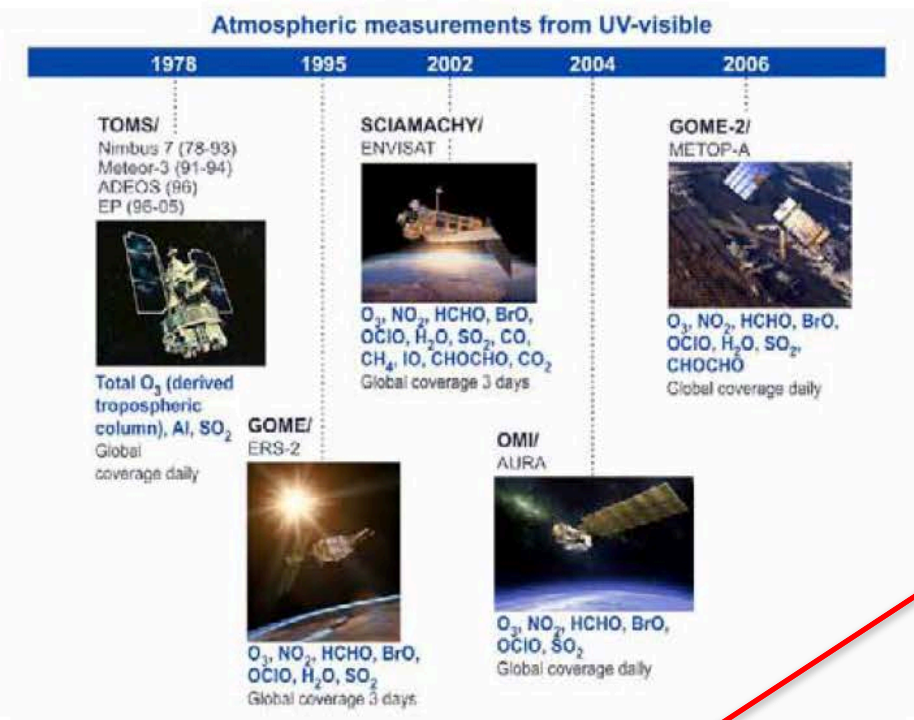
Meteorological Satellites available for IR-visible-UV observations

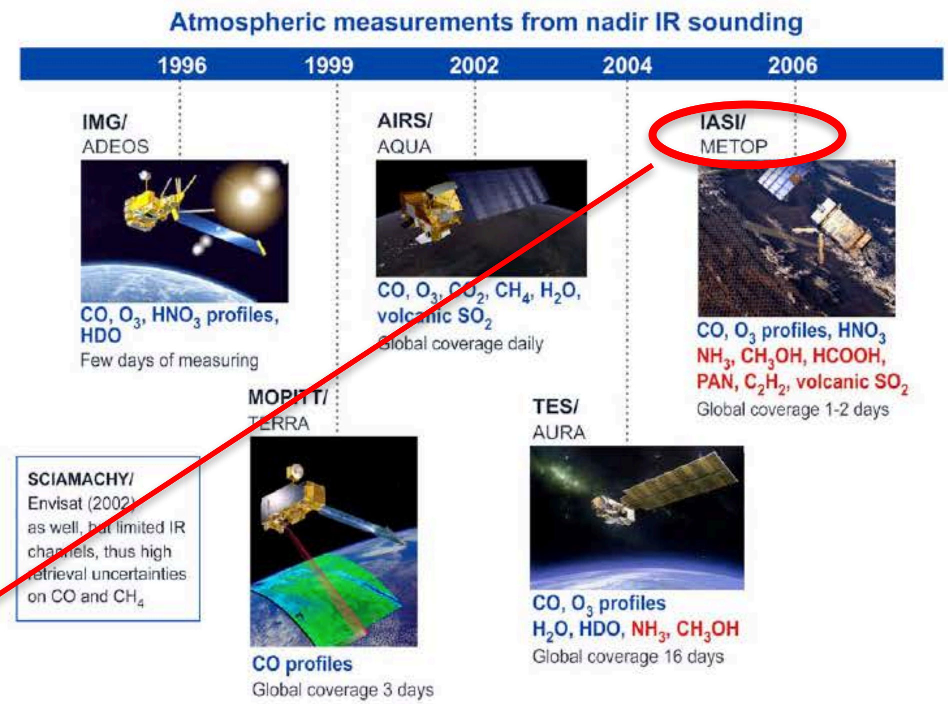




From Jegou et al., CNFGG, 2012

Meteorological Satellites available for IR-visible-UV observations





IASI (Infrared Atmospheric Sounding Interferometer)

–Infrared(3.62 μm to 15.5 μm)

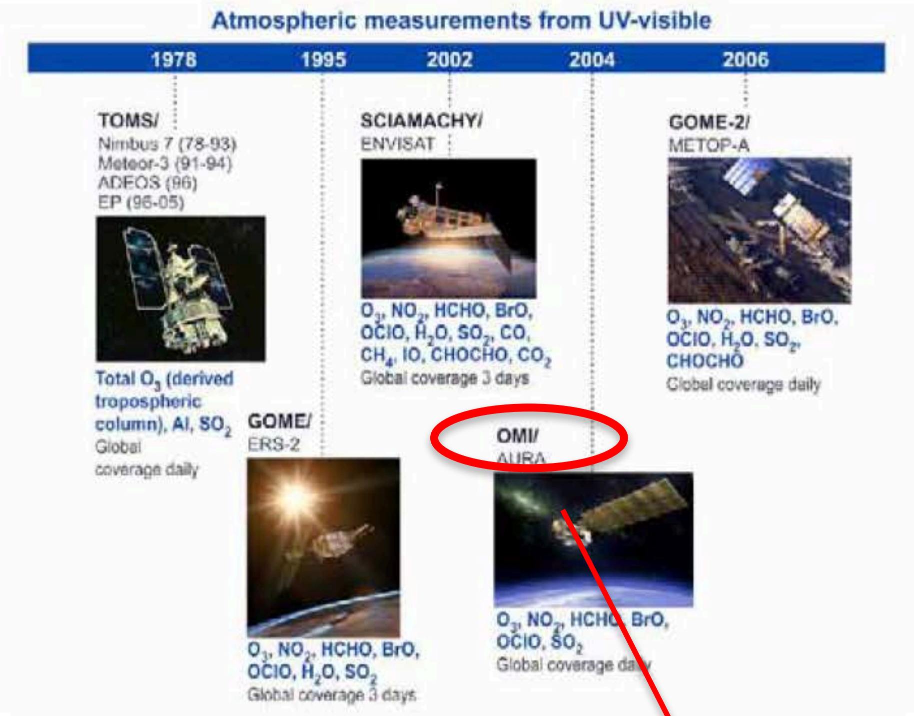
–⇒2 overpasses per day (9:30am, 9:30 pm local time)

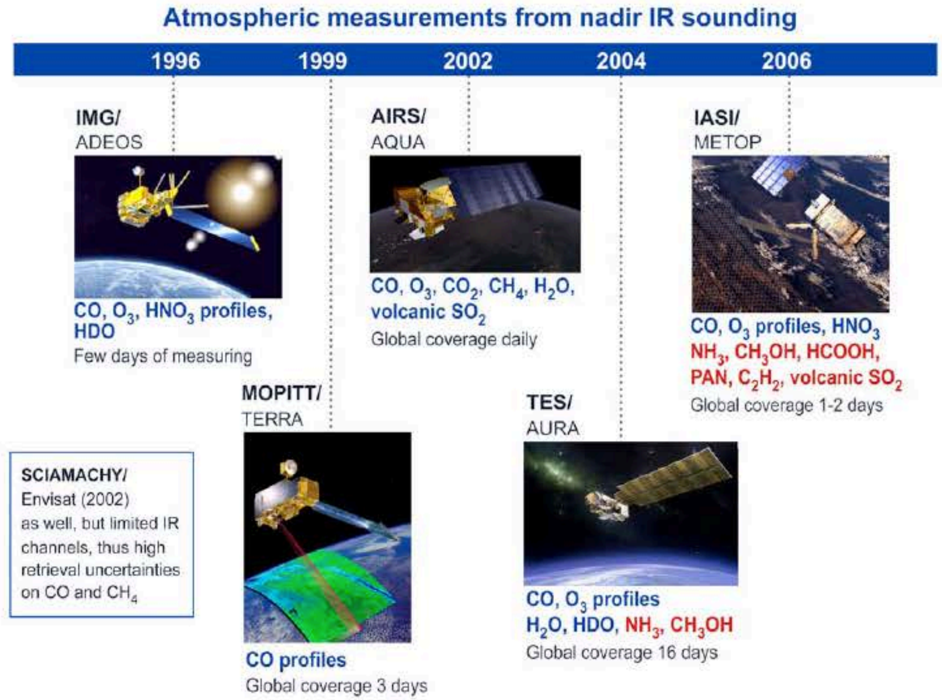
–Spatial resolution: (12 km x 12 km)

–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)

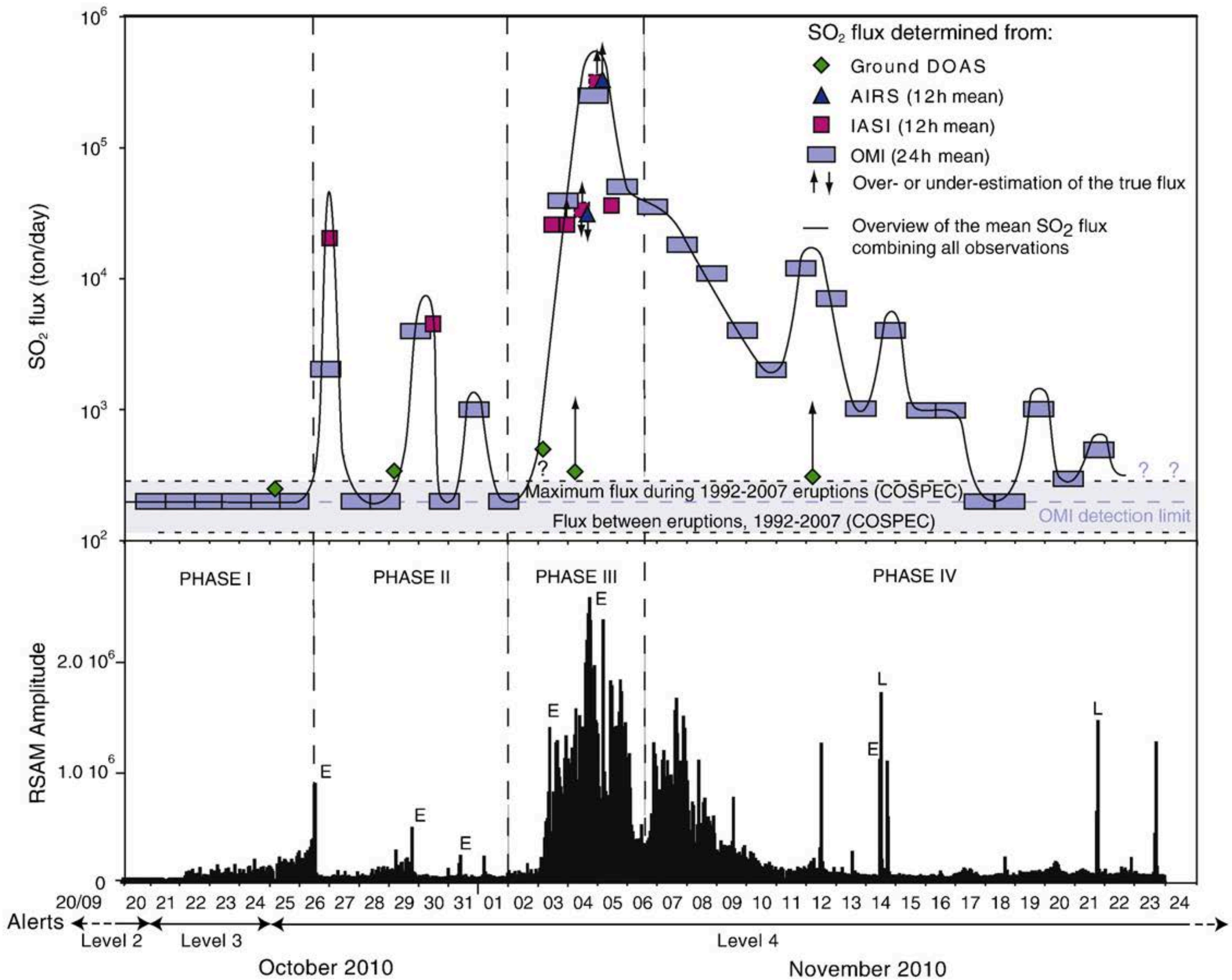
–⇒1 overpass per day (1h45pm local time)

–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

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

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/

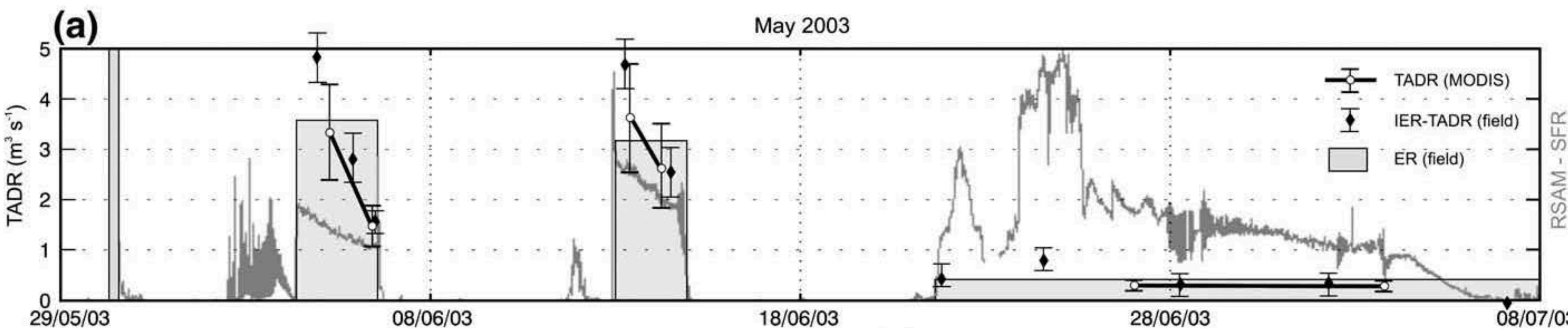
*AVHRR ***Advanced Very High Resolution Radiometer*** NOAA
Spatial resolution 1*1 km

*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)

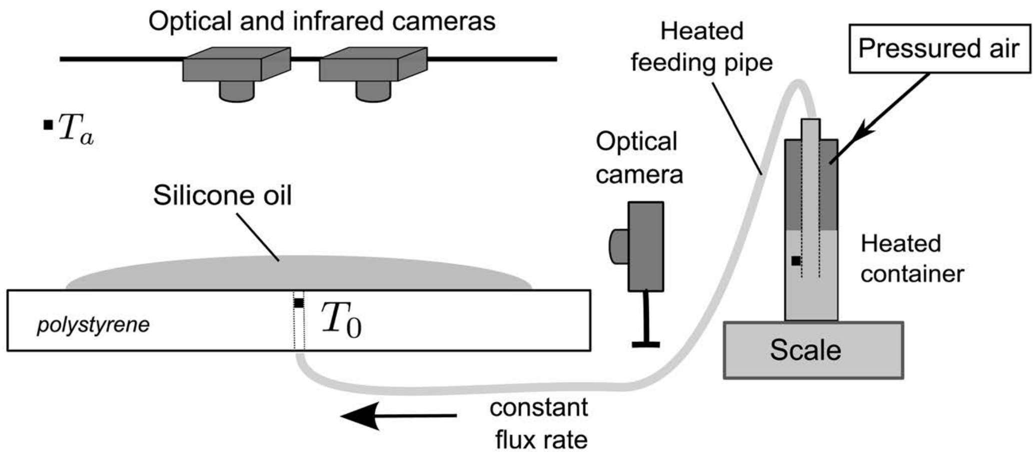
From Coppola et al, 2009

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.

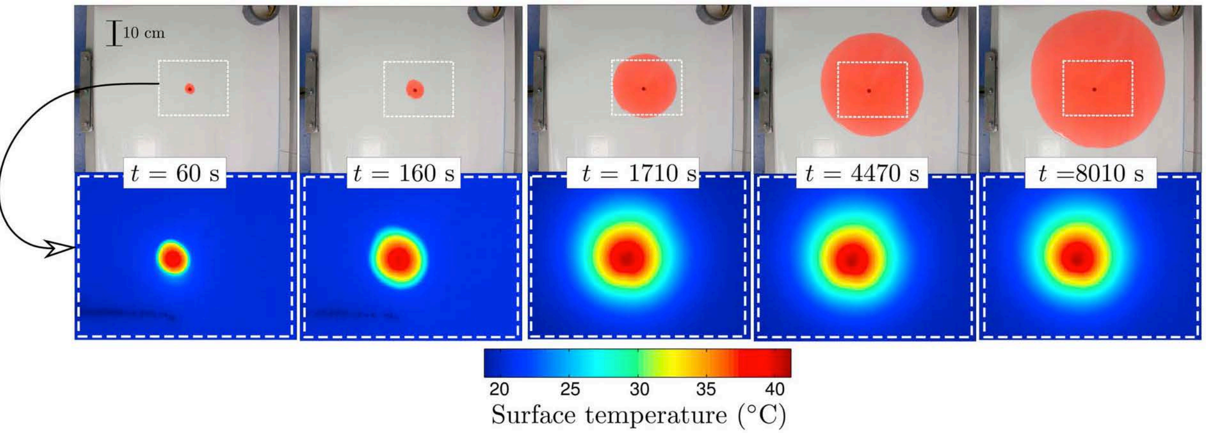


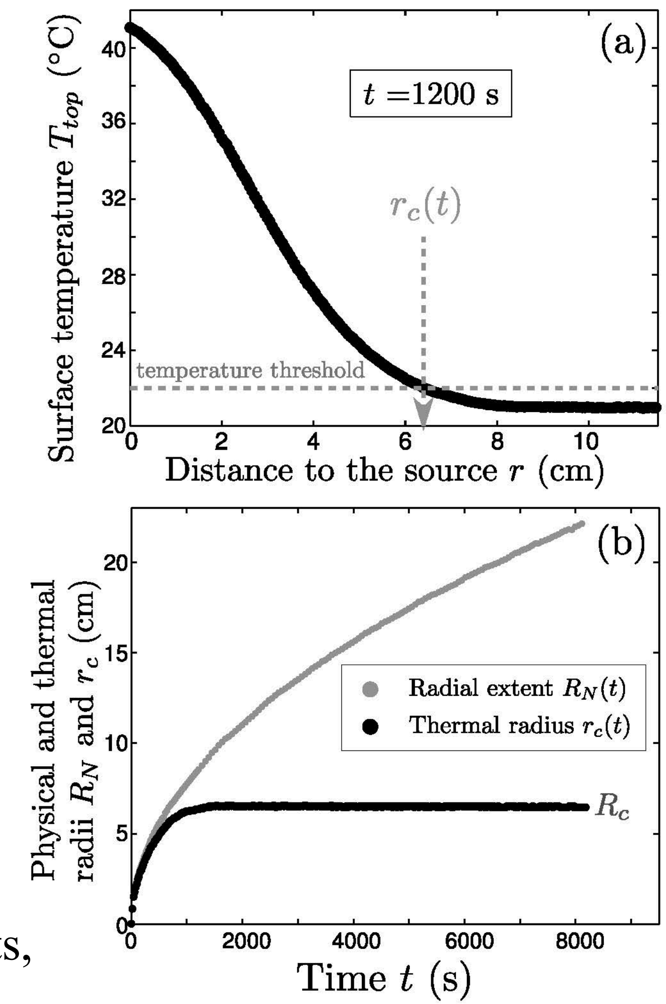
Experimental setup

Thermal signature of lava flows

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

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

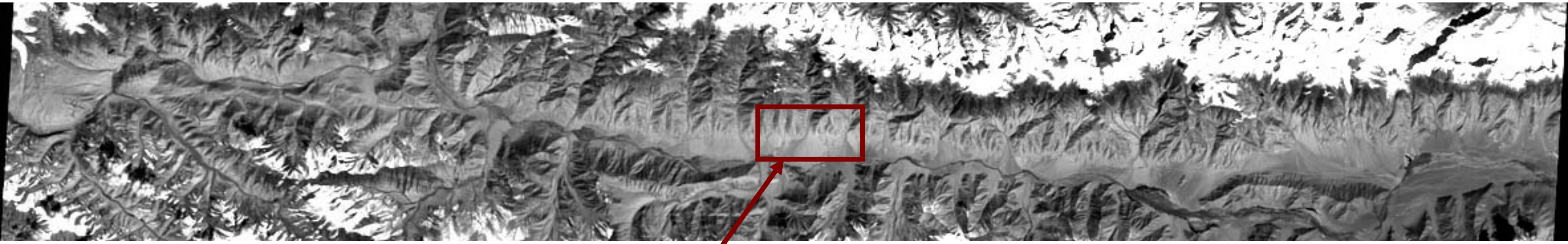
2. How to measure displacement

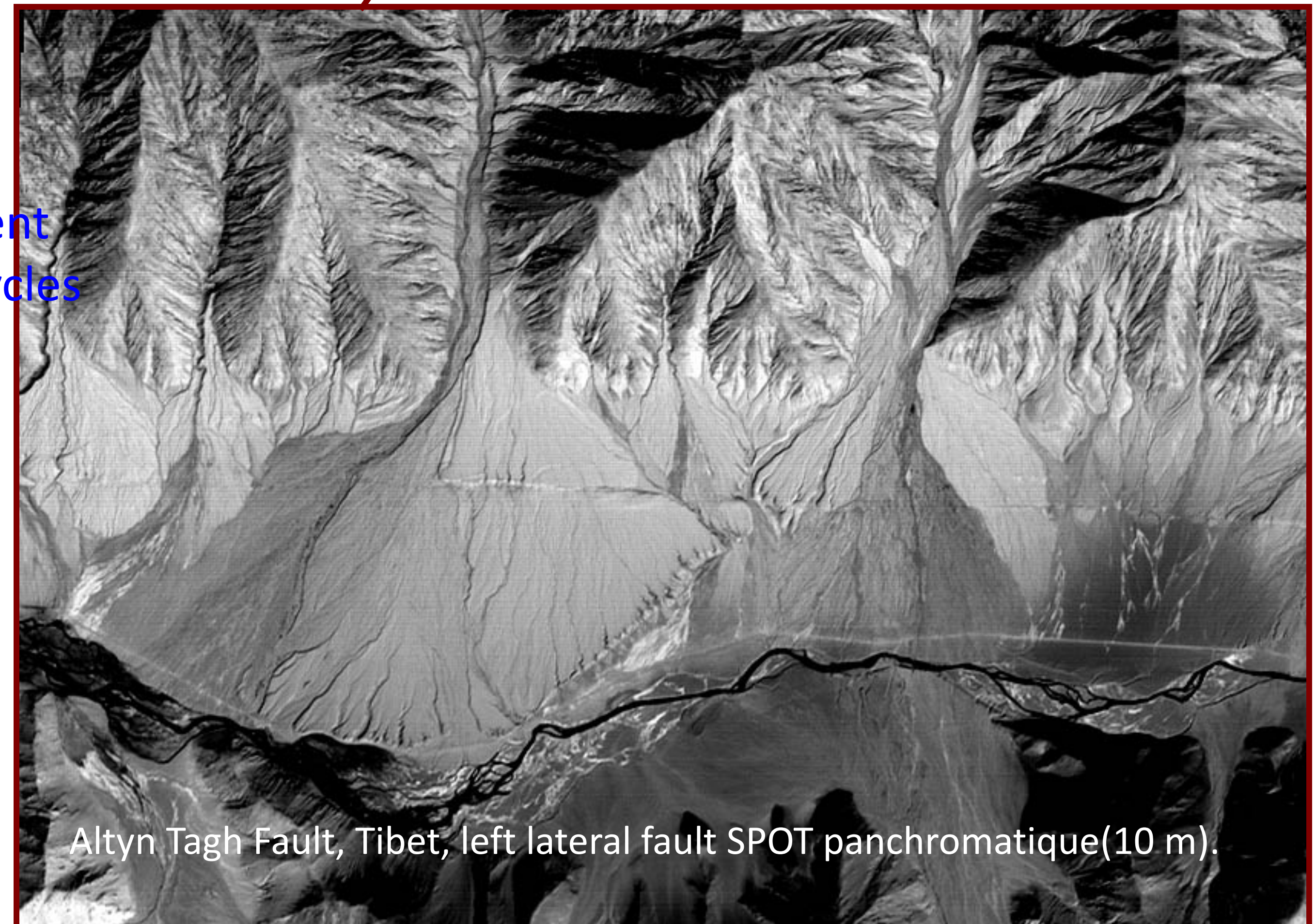
3. Processing methods and tools

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**





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

Cumulated displacement
over several seismic cycles

Courtesy of C. Lasserre

Image from Pleiades (visible)

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

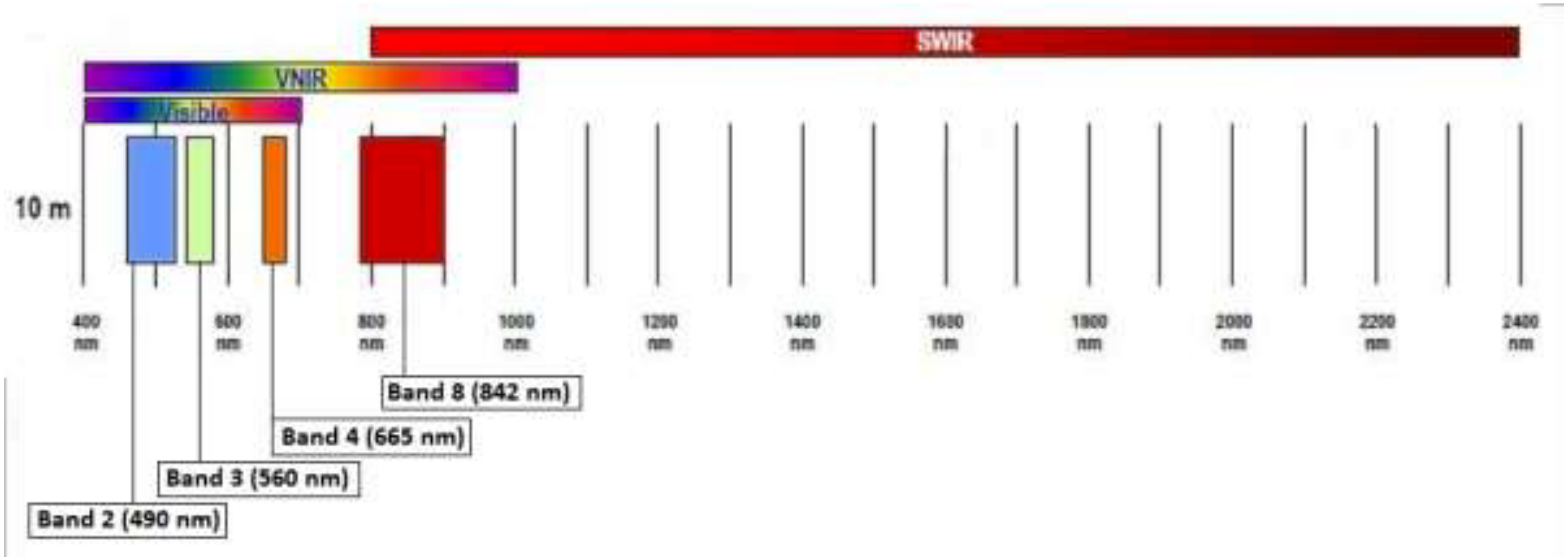
(Level 1-C 100x100 km^2 ortho-images in UTM/WGS84 projection)

- 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

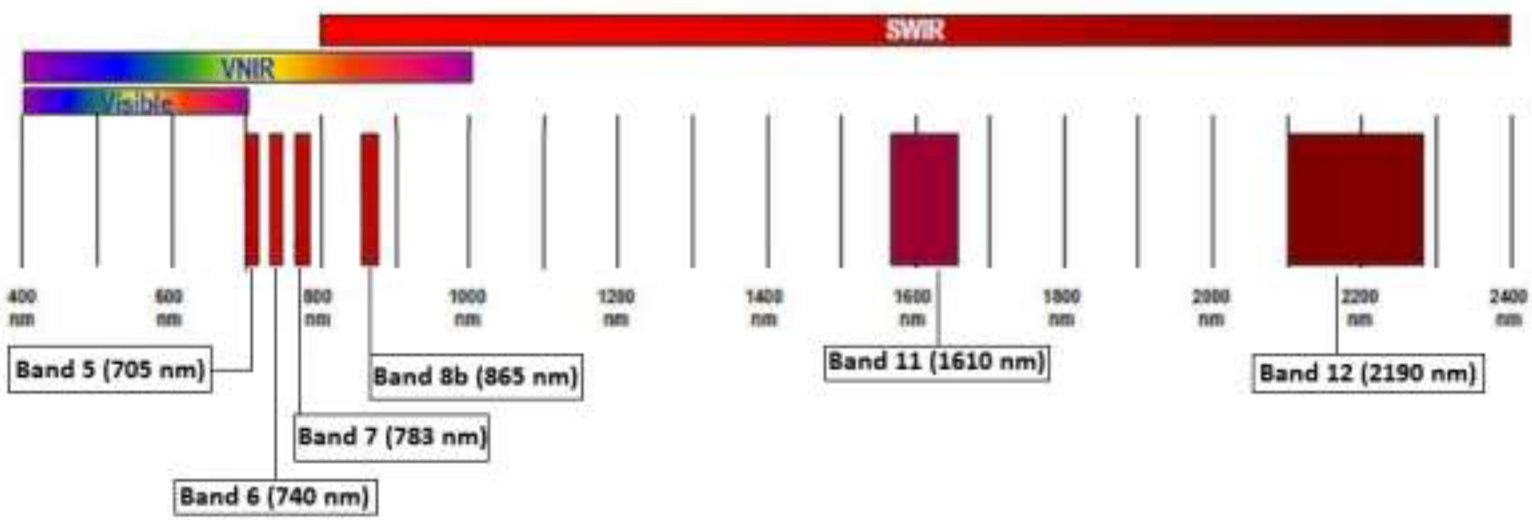
https://sentinel.esa.int/web/sentinel/missions/sentinel-2



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

Optical data
Sentinel-2

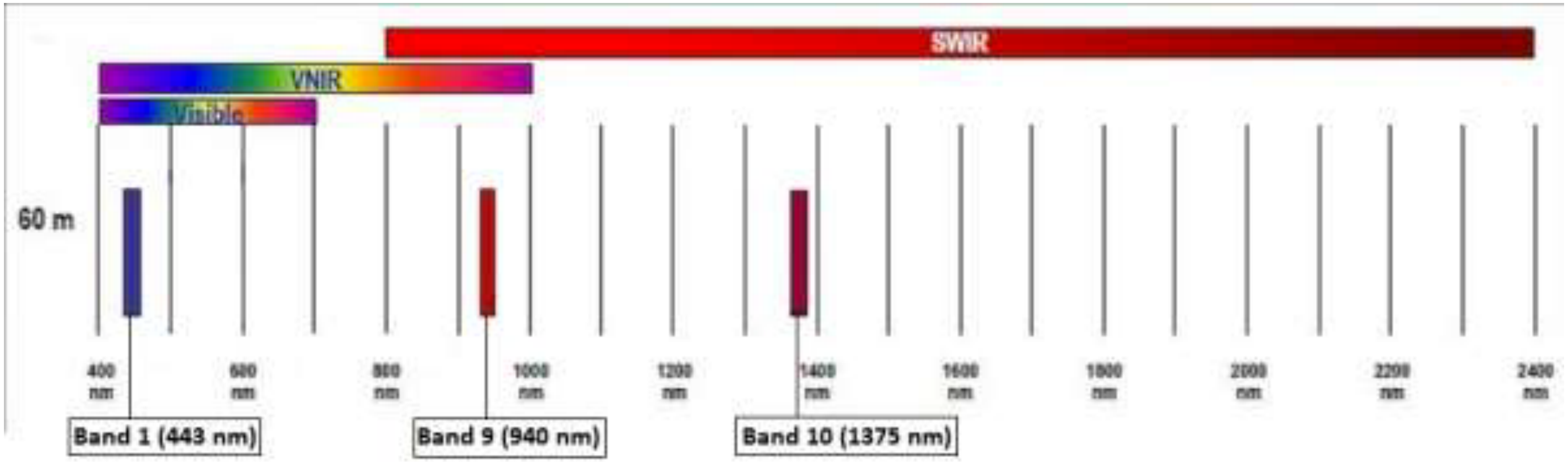
https://sentinel.esa.int/web/sentinel/missions/sentinel-2



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

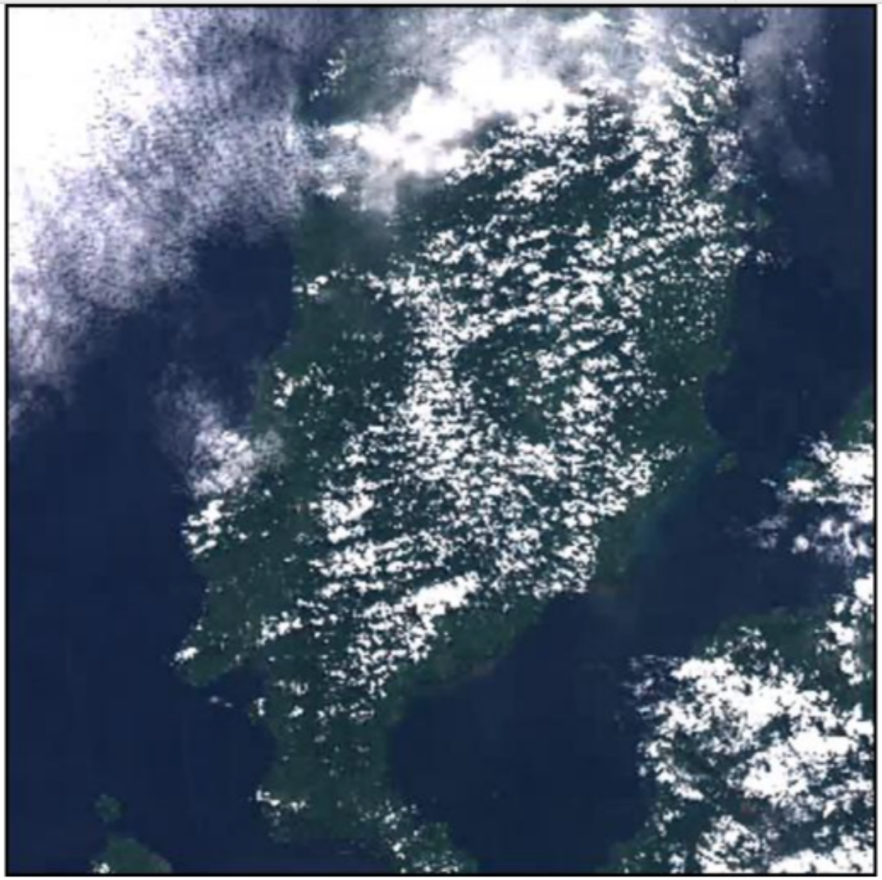
https://scihub.copernicus.eu/dhus/#/home

True Colour Images (TCI)

Optical data
Sentinel-2

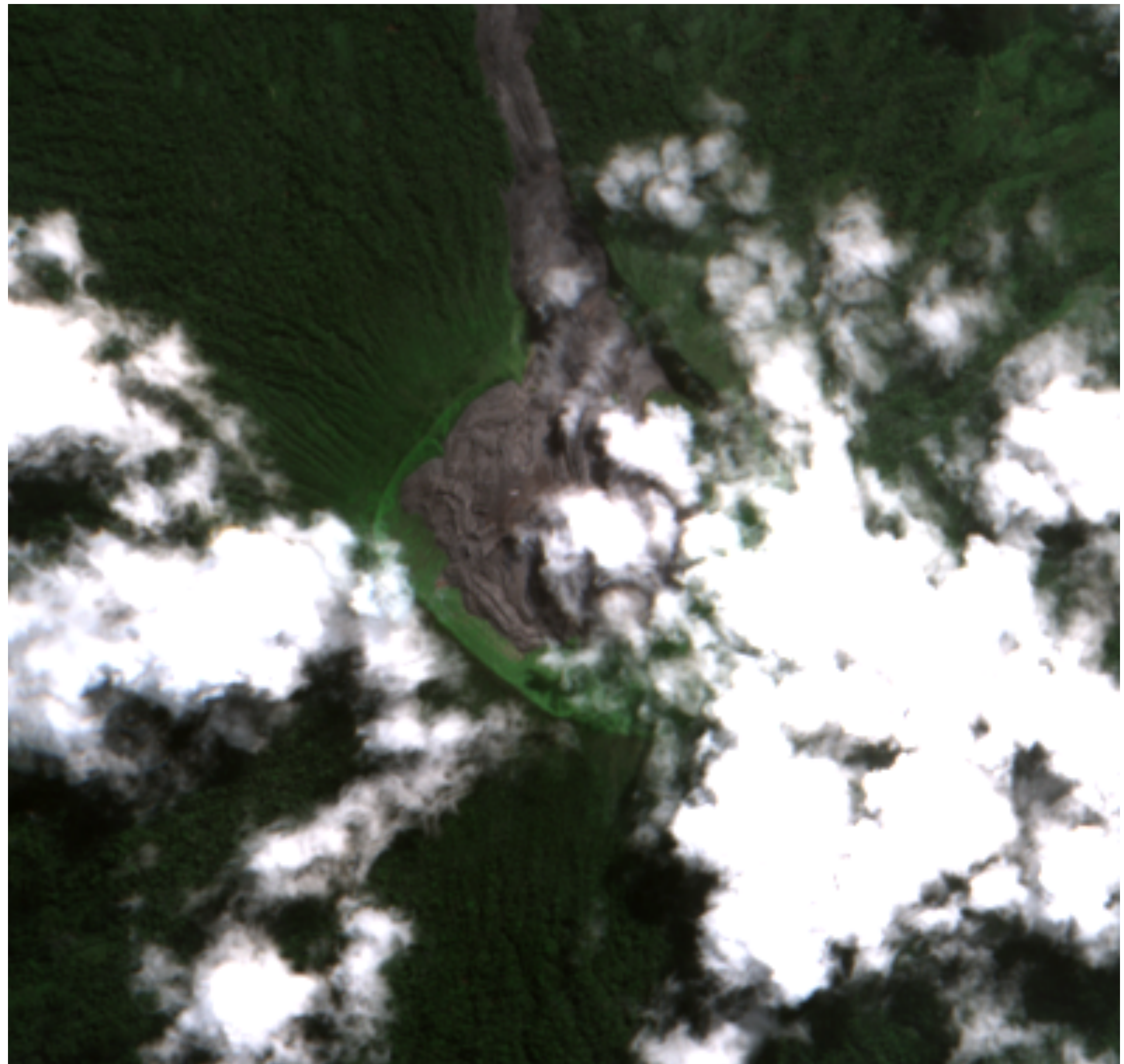
https://sentinel.esa.int/web/sentinel/missions/sentinel-2

Exemple: North Maluku,
Halmahera Island
10 June 2017

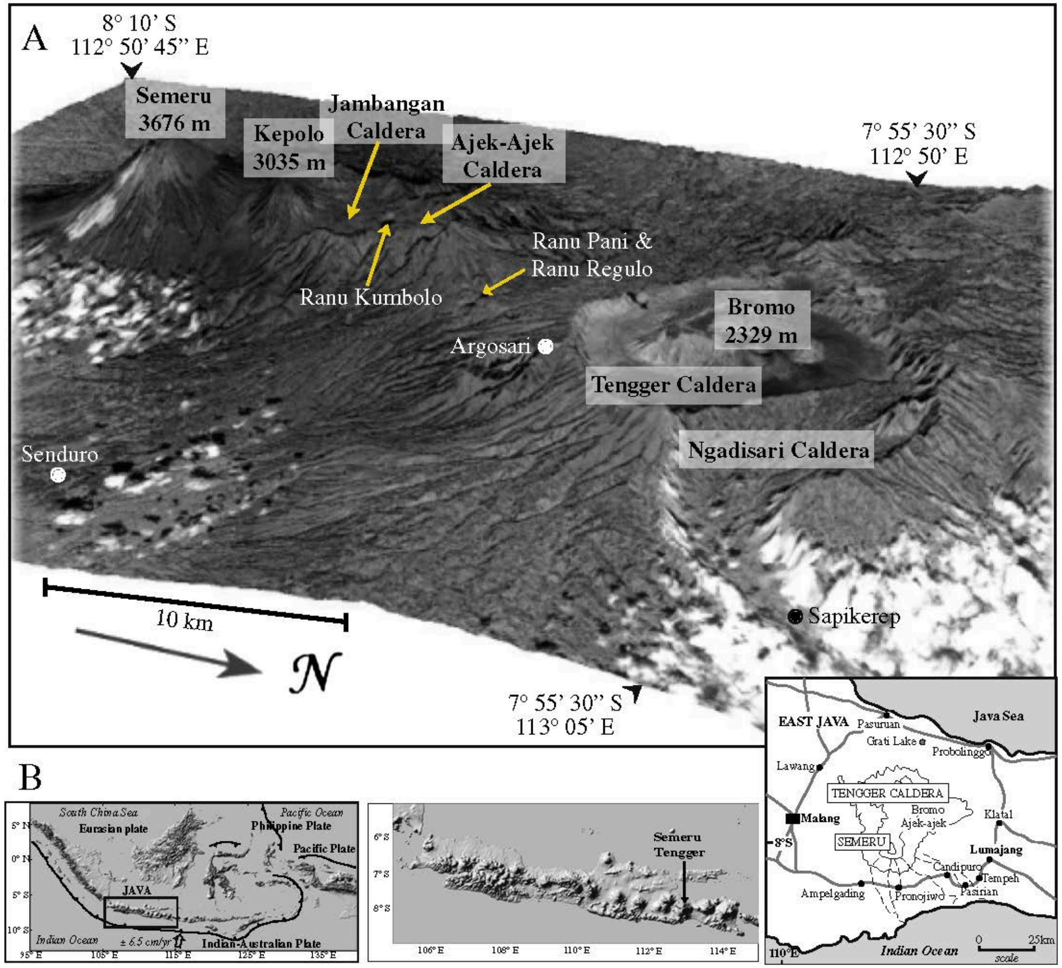


Optical data
Sentinel-2

Exemple: Ibu: 10 June 2017



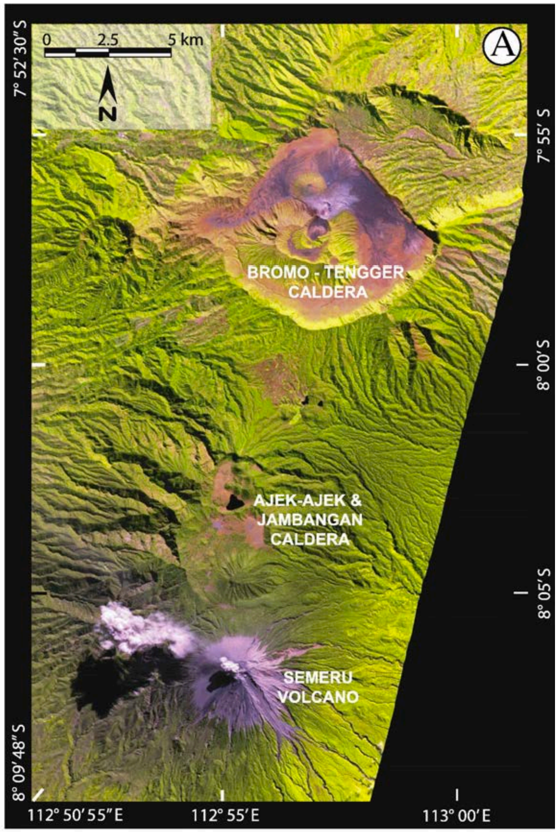
Structural analysis of Semeru



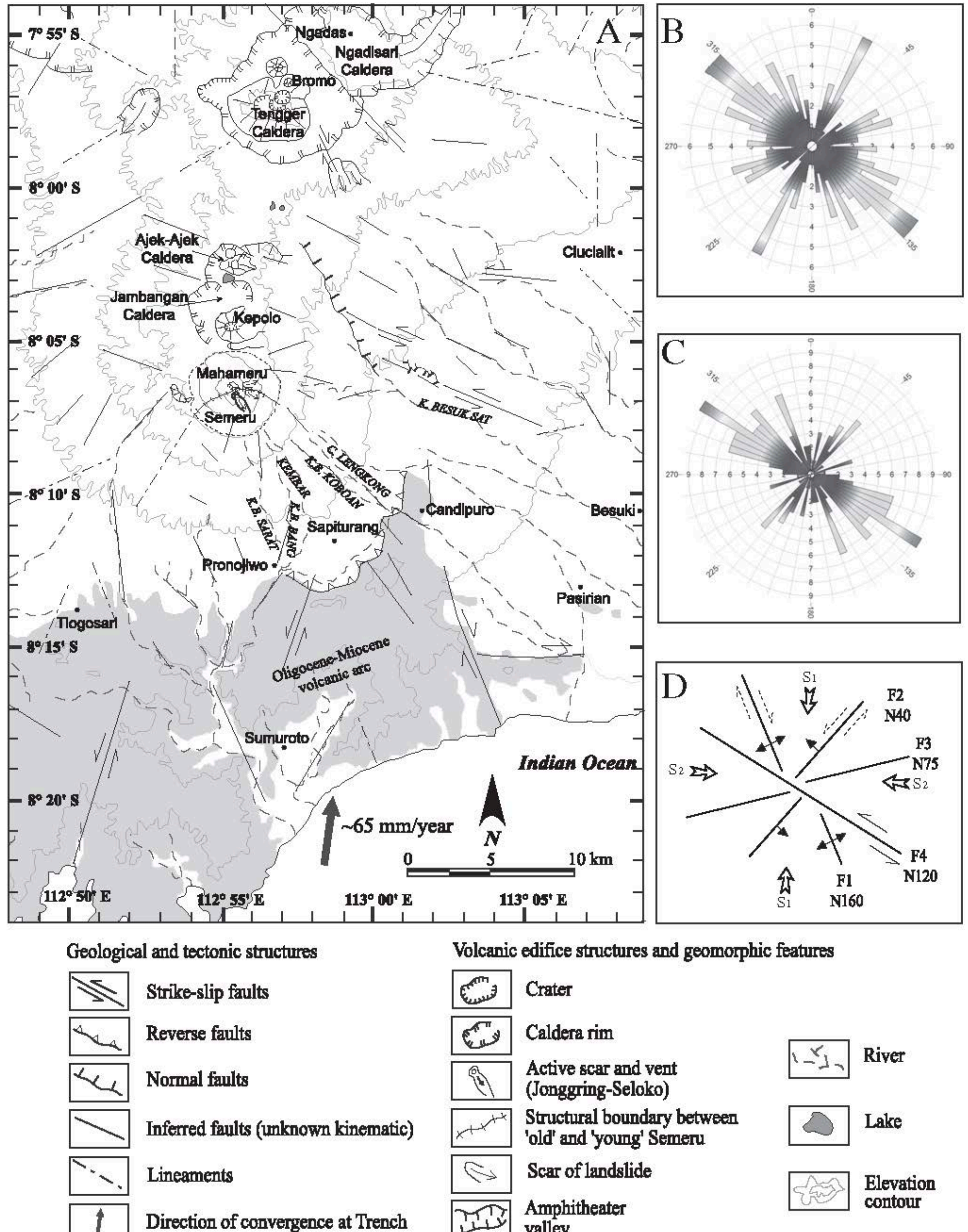
The 11/08/2003 SPOT5 image, looking SW and draped on the SRTM DEM

From Solikhin et al, 2012

Structural analysis of Semeru

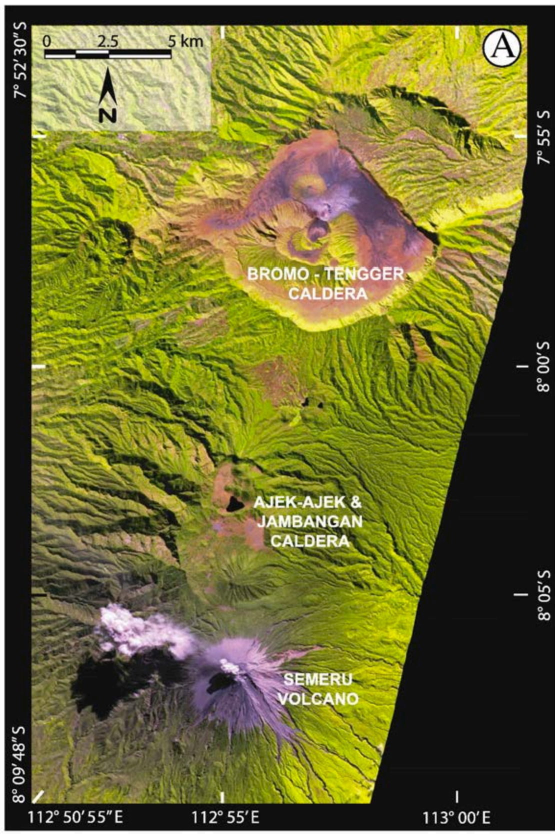


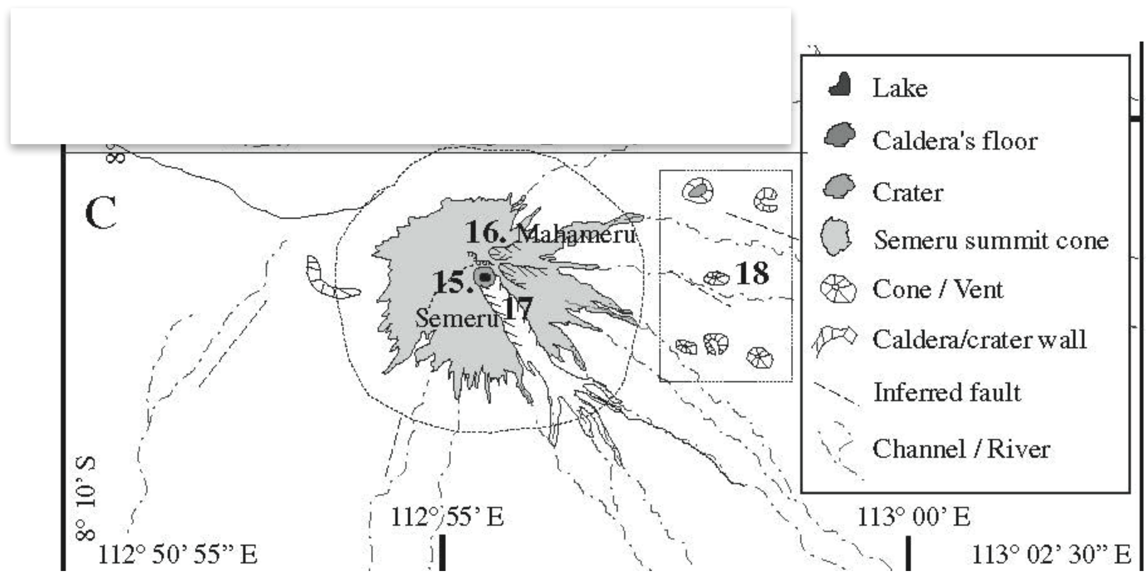
Spot 5 (2.5m)



From Solikhin et al, 2012

Deposits study



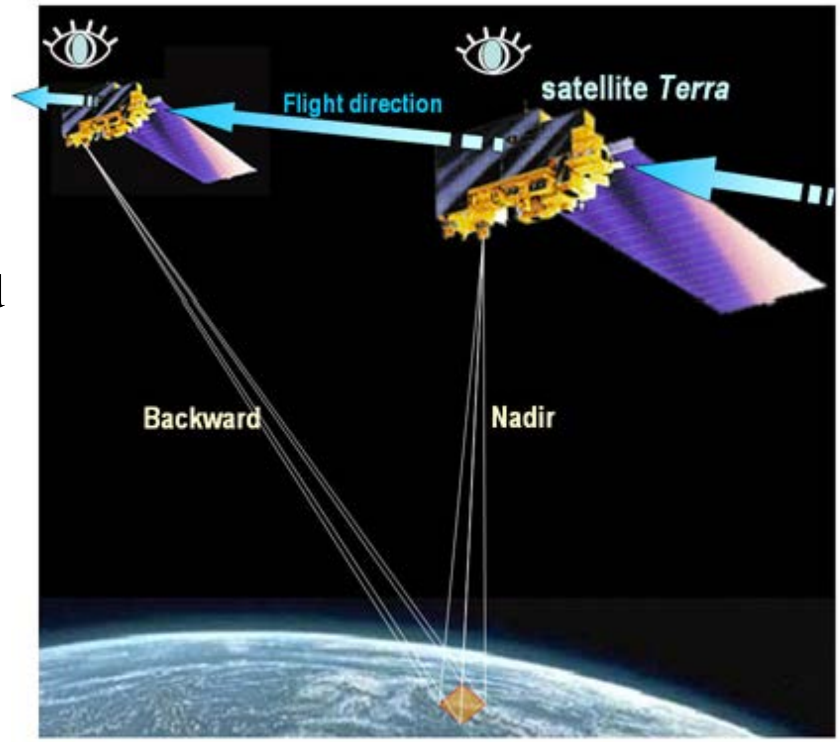


Spot 5 (2.5m)

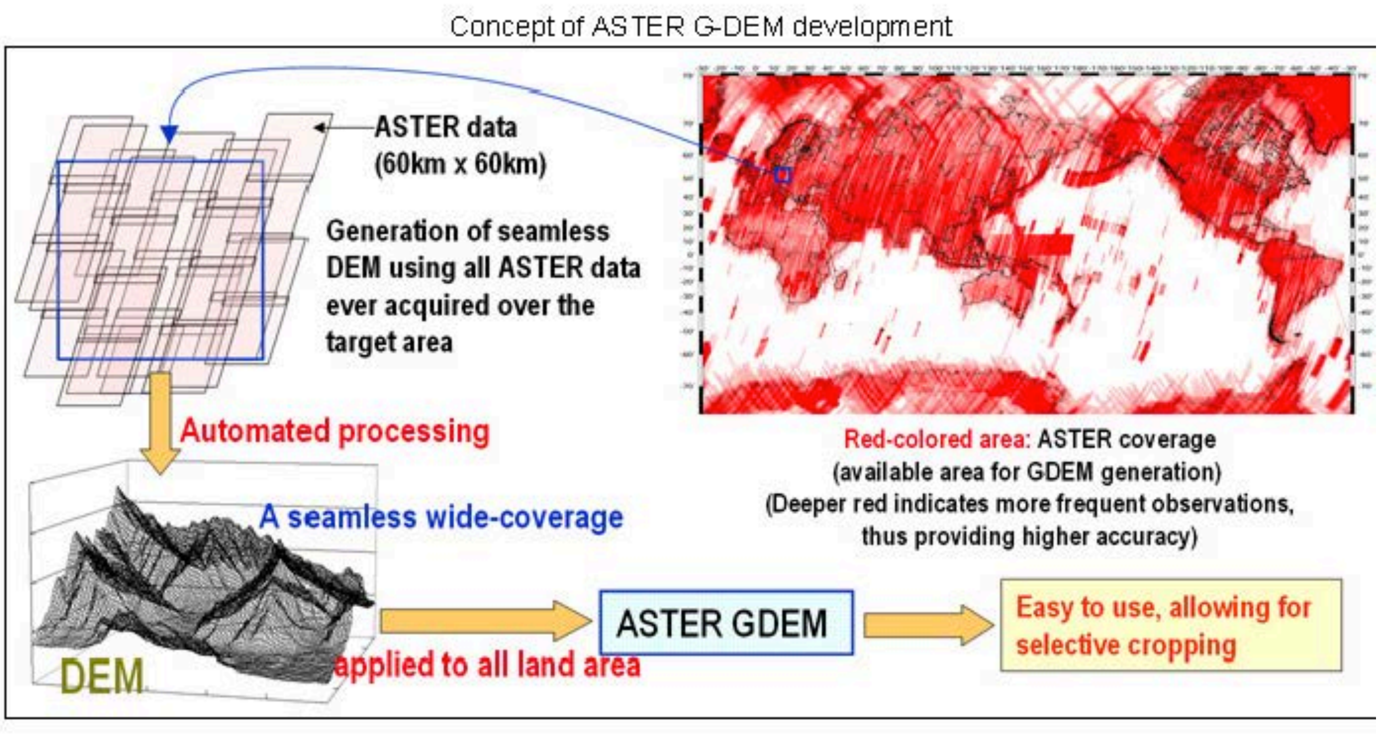
From Solikhin et al, 2012

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



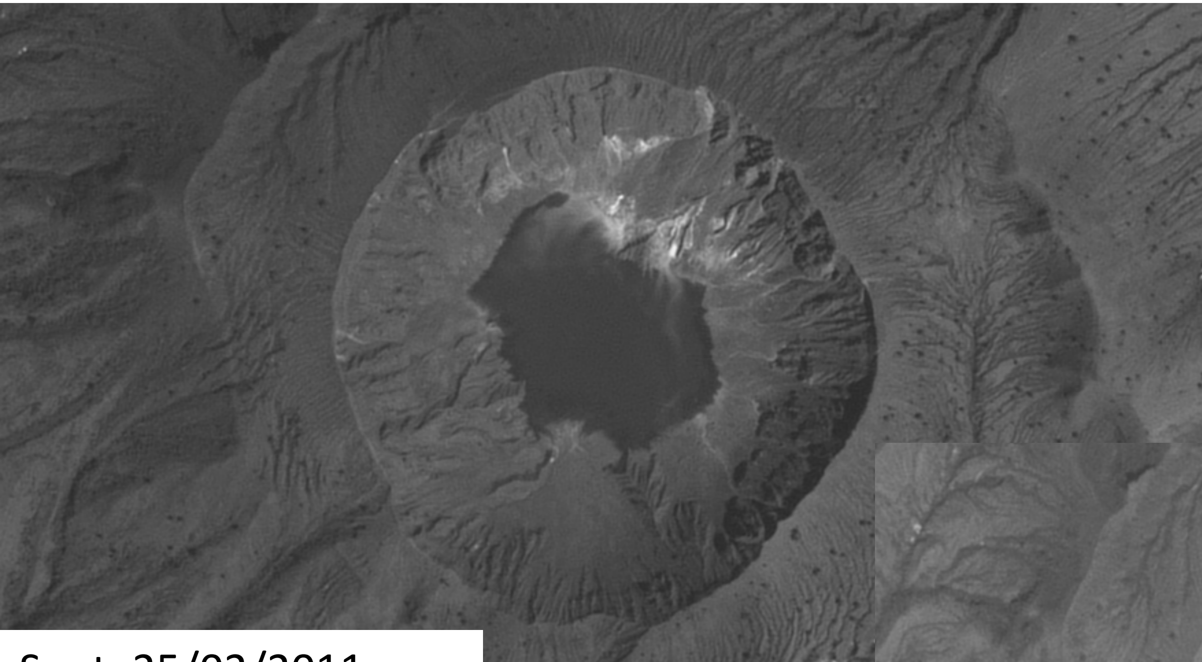
Use of optical images to produce DEM
Ex: ASTER



Images spatial resolution : 15 m

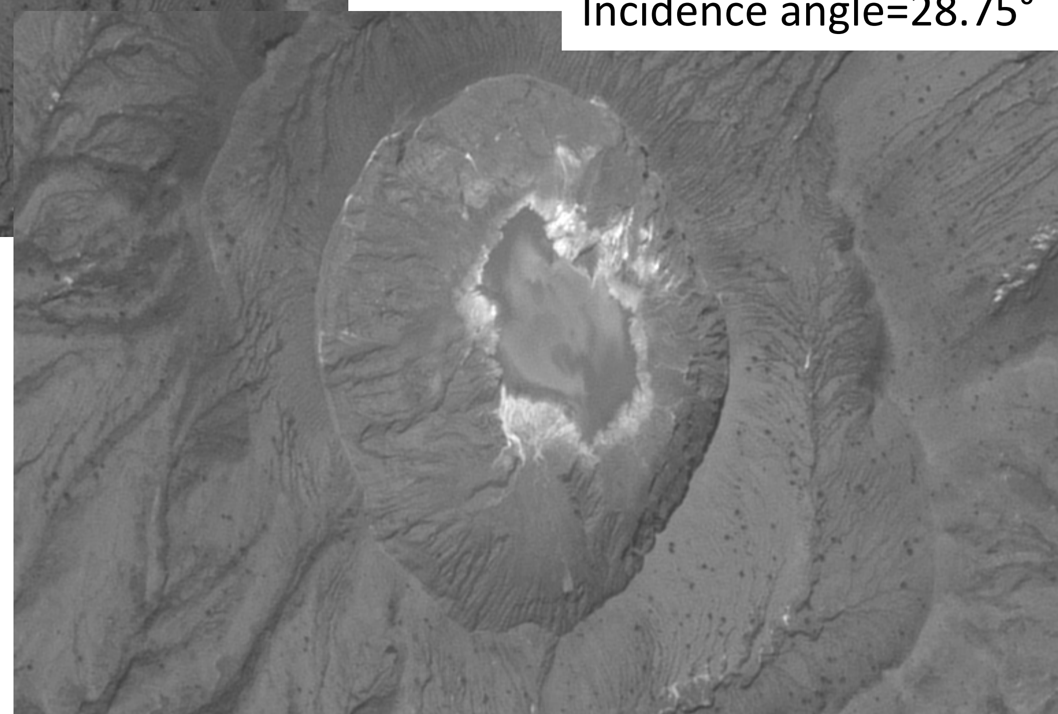
DEM with 30 m spatial resolution, you can download it for free

Stereogrammetry (SPOT 2.5m)

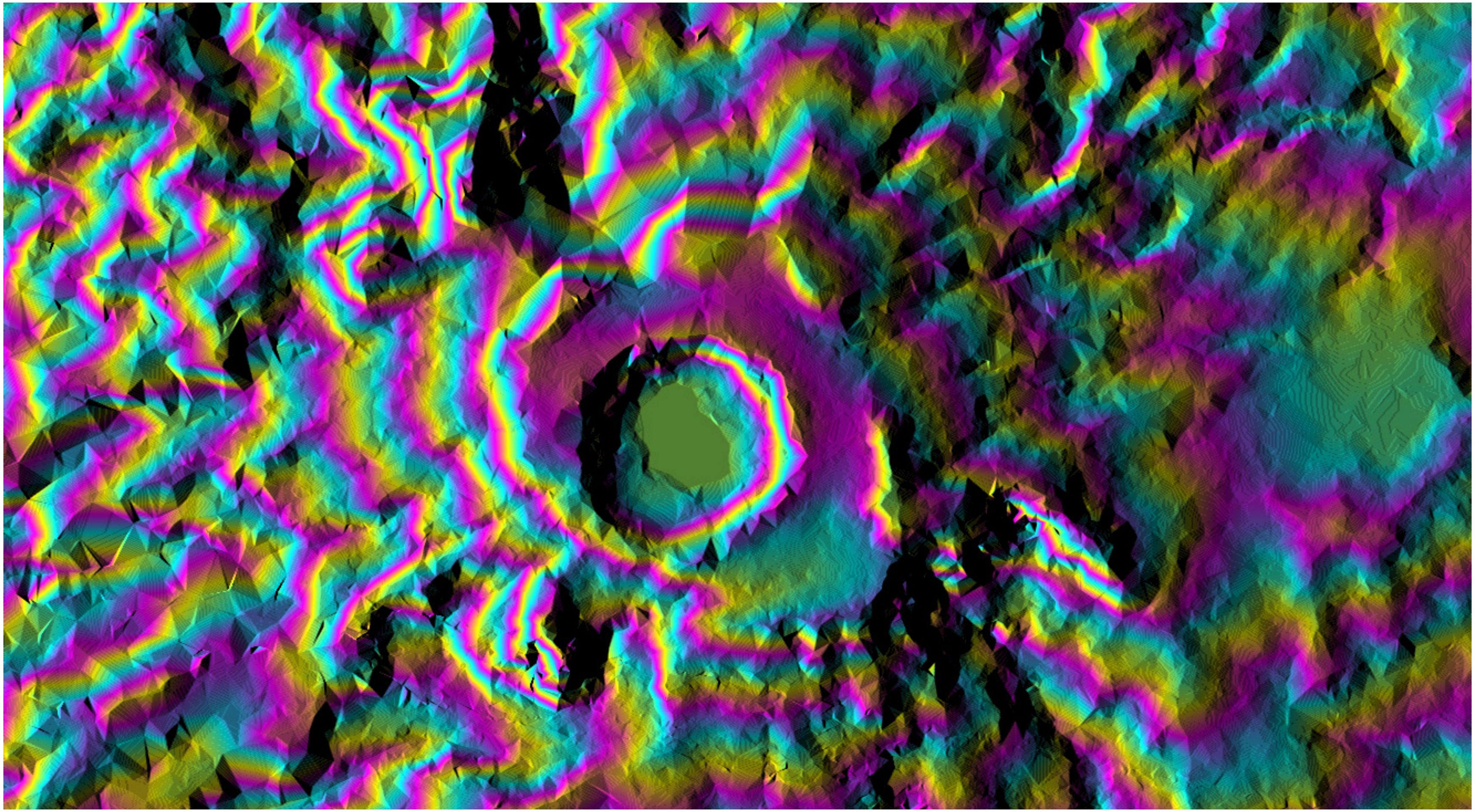


Spot: 25/02/2011
Incidence angle= 1.38°

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



Stereogrammetry (SPOT 2.5m)



1 fringe is for 100 m

DEM from optical images (Ames Stereo Pipeline) AMS

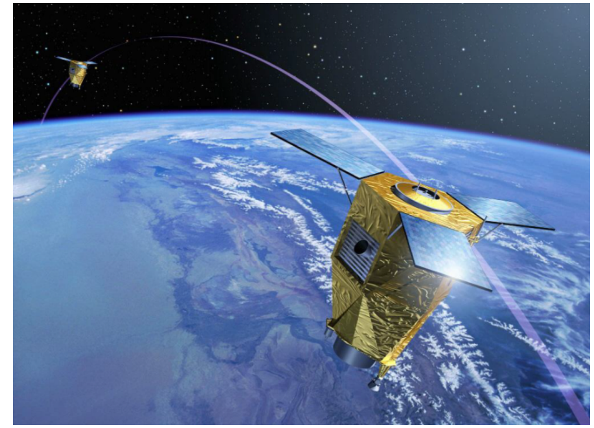
- http://byss.arc.nasa.gov/stereopipeline/daily_build/

Pléiades DEM from ASP

Pléiades Satellite

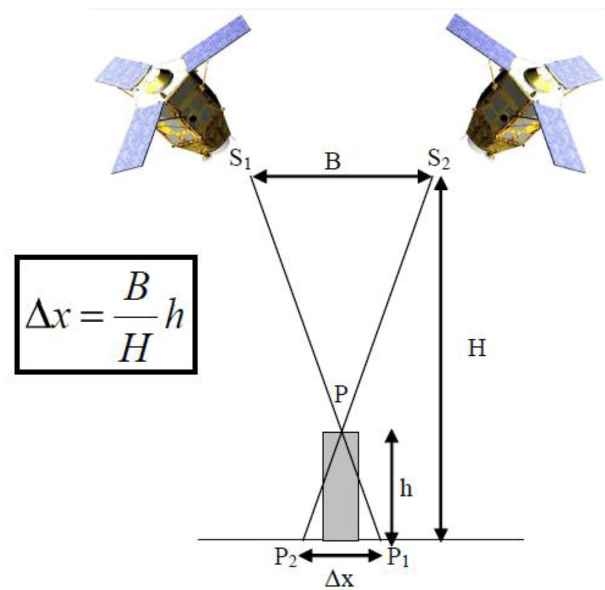
- Pléiades 1A (launched on 17/12/2011) and Pléiades 1B (2/12/2012)

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



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

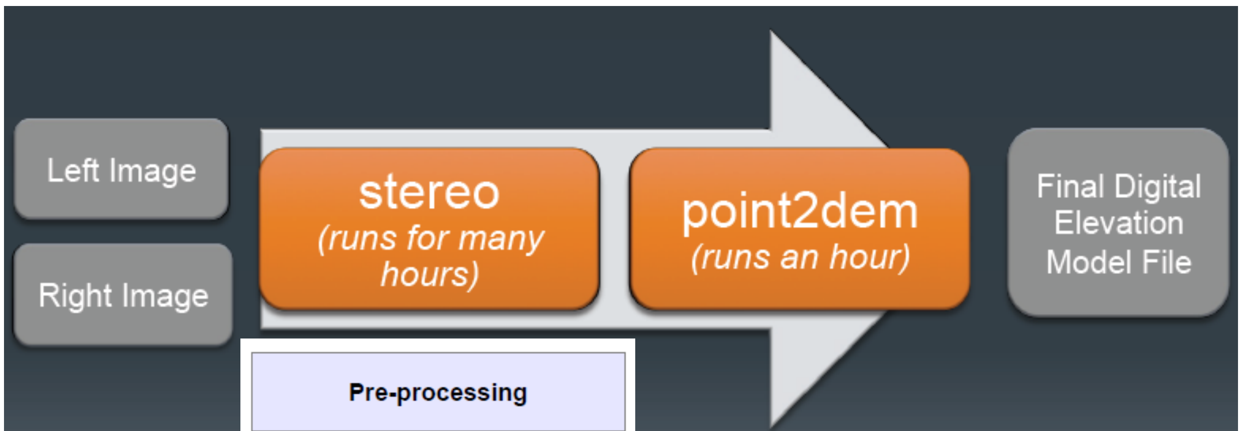
Agility:
5° in 8 sec
10° in 10 sec
60° in 25 sec

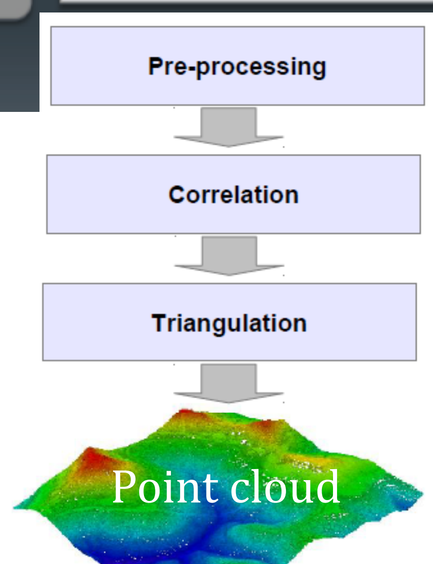


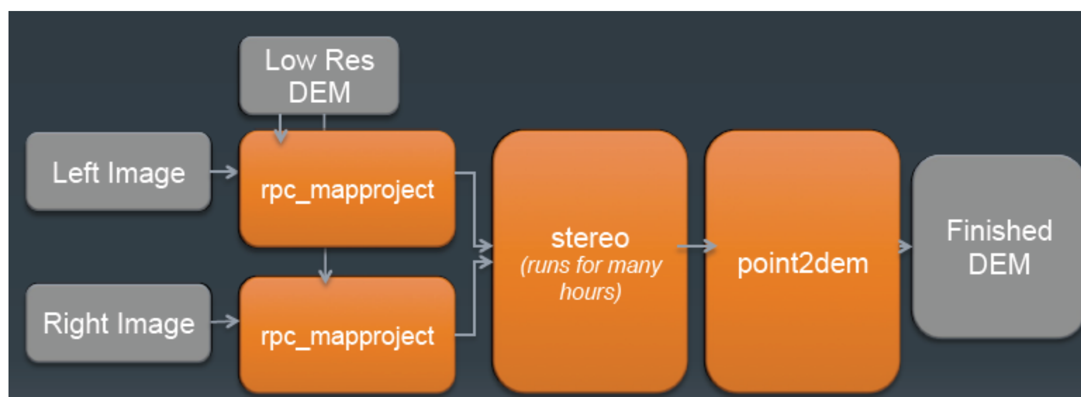
Pléiades DEM from ASP

AMES Stereo Pipeline

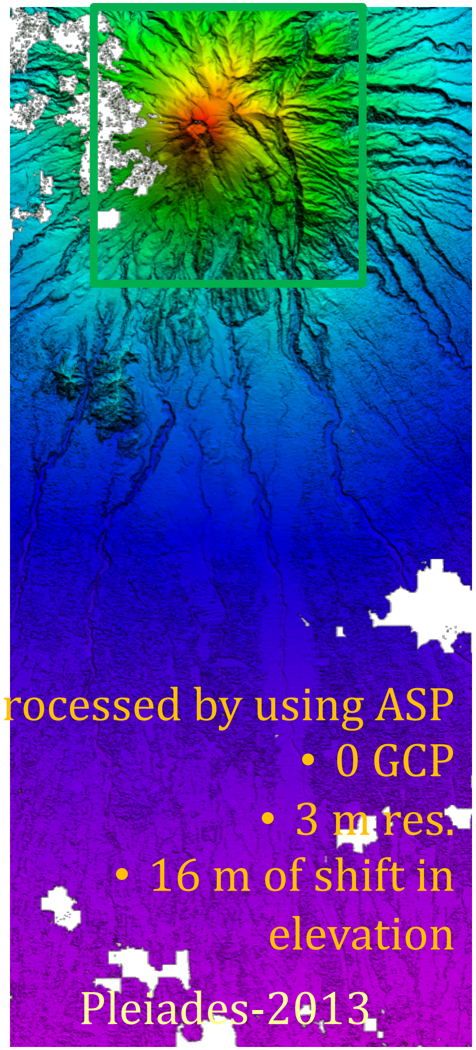
- Automatic Stereo Correlation *(matching all pixels between two images)* for large satellite images.
- Developed by NASA for terrestrial imaging
- Open source; work on UNIX derived platforms (Linux, Mac OSX, etc)



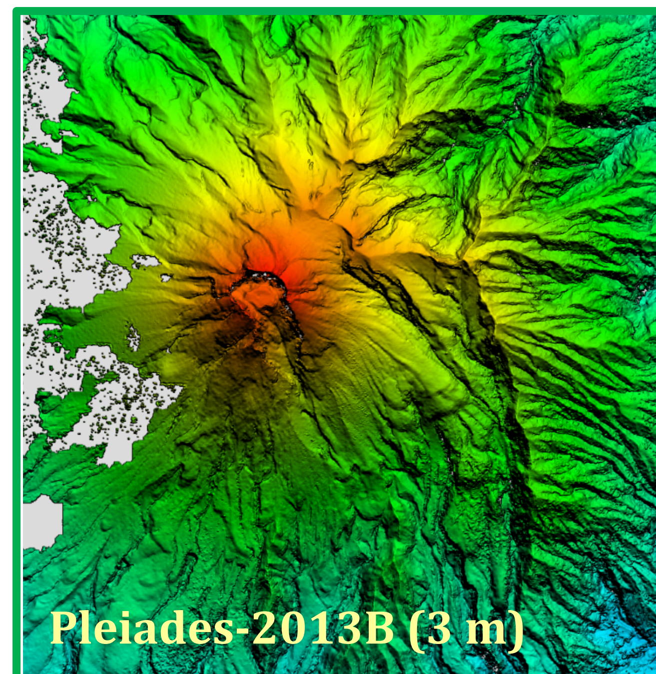




Post-Eruption DEM



- Processed by using ASP
  - 0 GCP
  - 3 m res.
  - 16 m of shift in elevation



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)

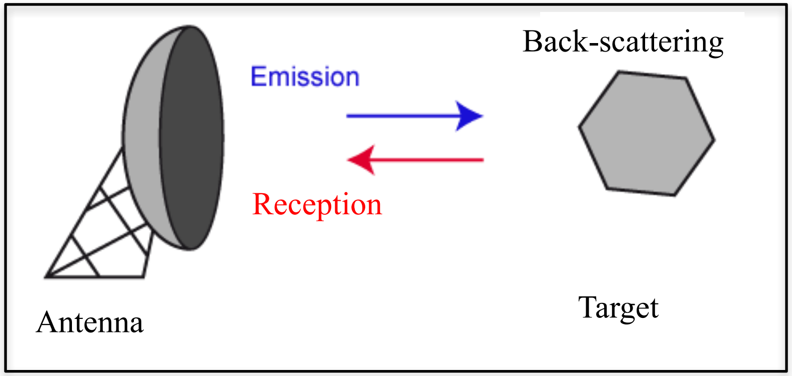
B Active measurements (radar): Do not require sunlight

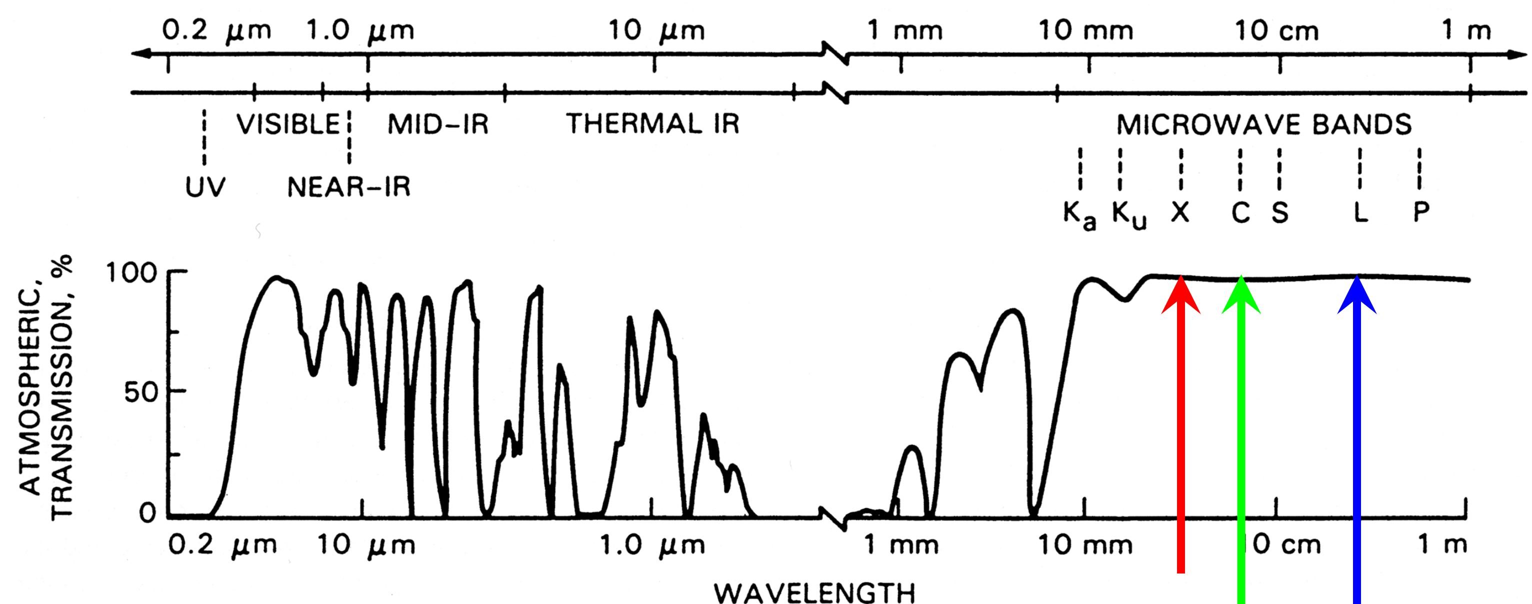
1. SAR data description + where (how) to access the data

2. How to measure displacement

3. Processing methods and tools

Radar imagery → Distance





TerraSARX, CosmoSkymed (3 cm)

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

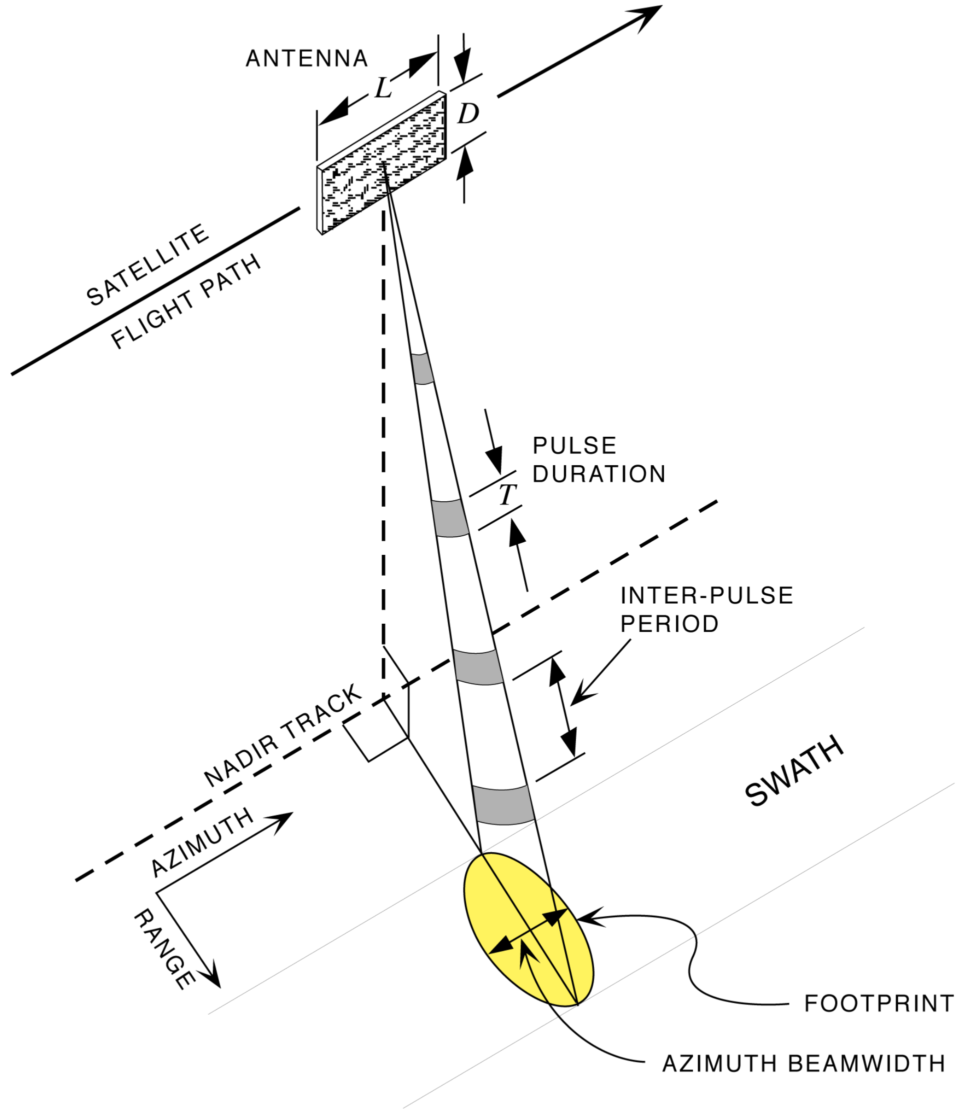
ALOS, ALOS2, JERS1 (24 cm)

Principle of SAR (Synthetic Aperture Radar)

Resolution is limited in azimuth by antenna length :

Rλ/L→ 5km for ERS

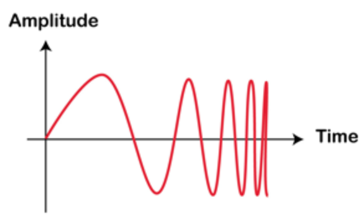
and in range by impulsion duration



This resolution is improved par Synthetic Aperture processing:

-Using Doppler effect in azimuth =azimuth compression

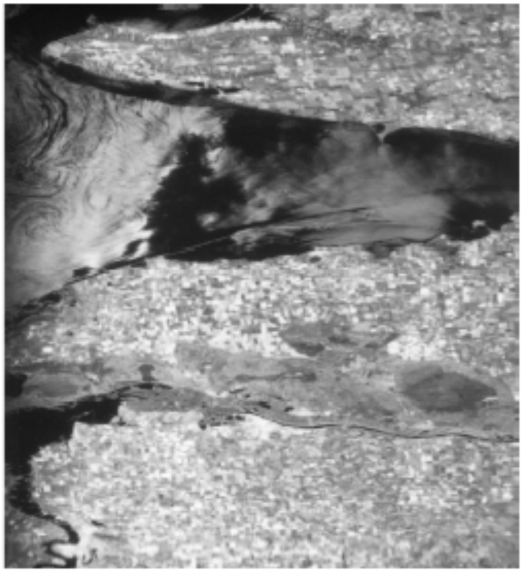
-Using frequency modulation of the signal in range=range compression



Images SAR

SAR Synthesis

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

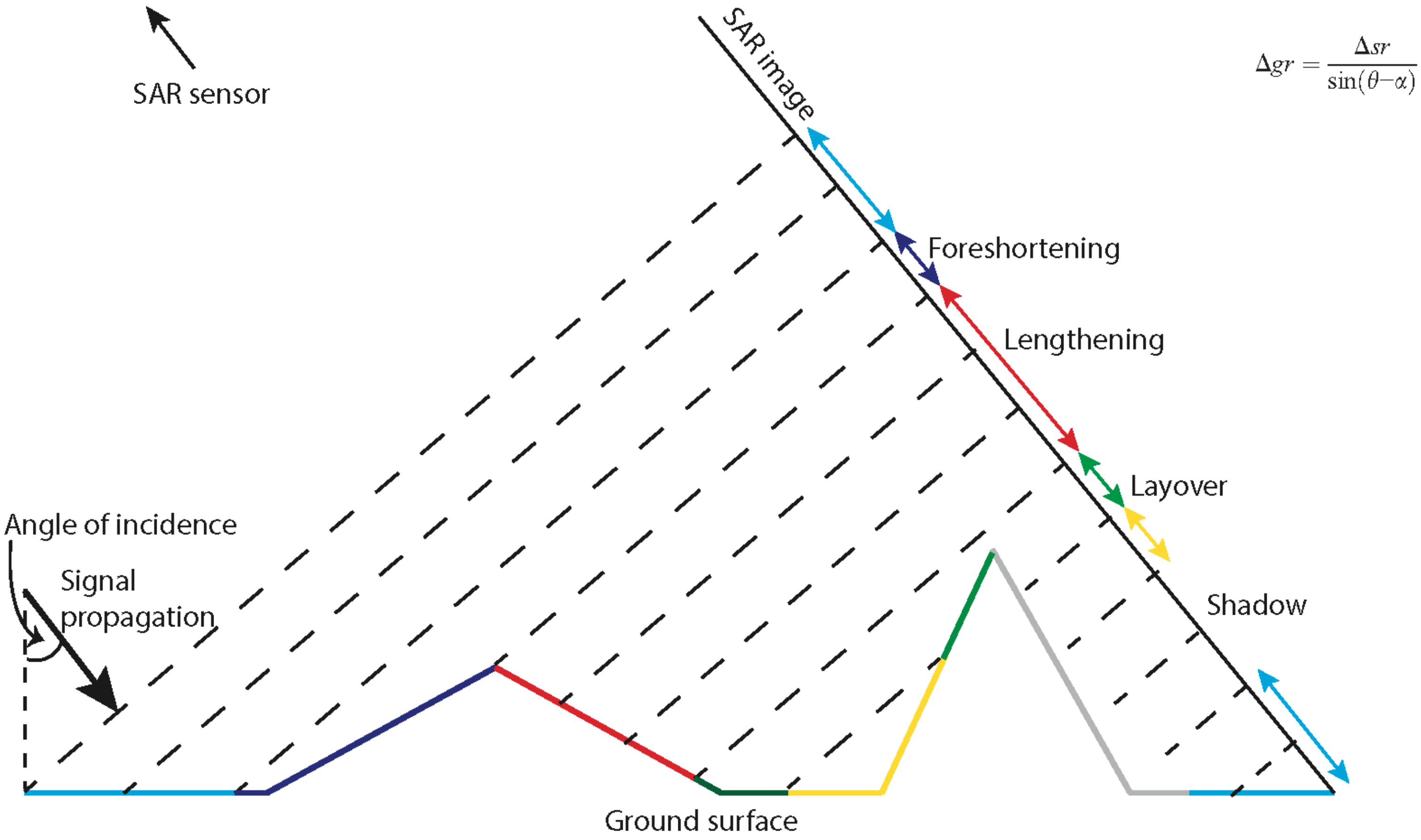


ERS scene
100*100km
140 millions of pixels

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

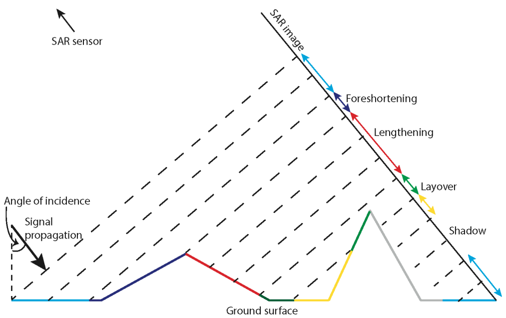
(Massonnet et al., 1998)

The radar "vision"

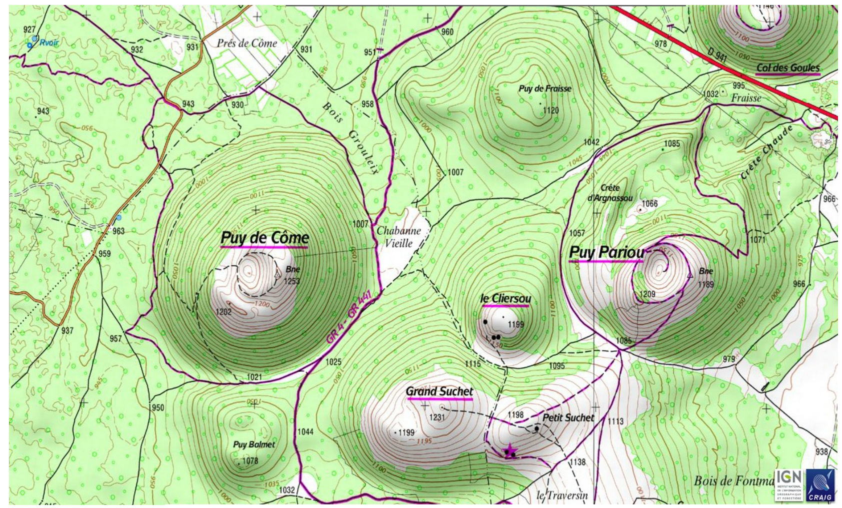


(Pinel et al., 2014)

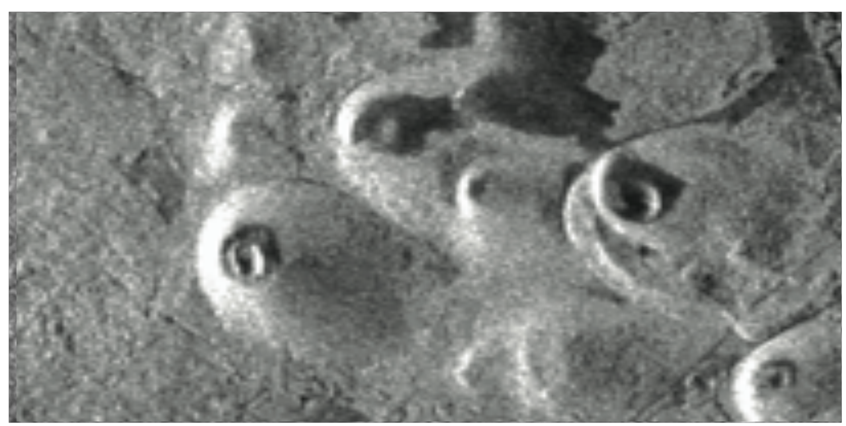
The radar "vision"



Ascending

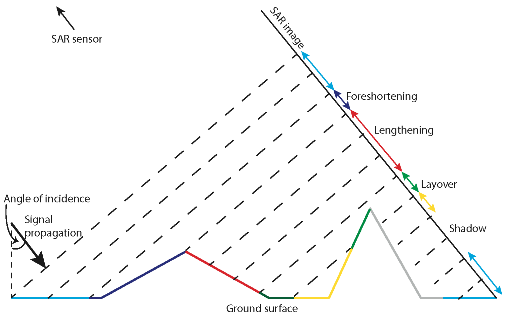


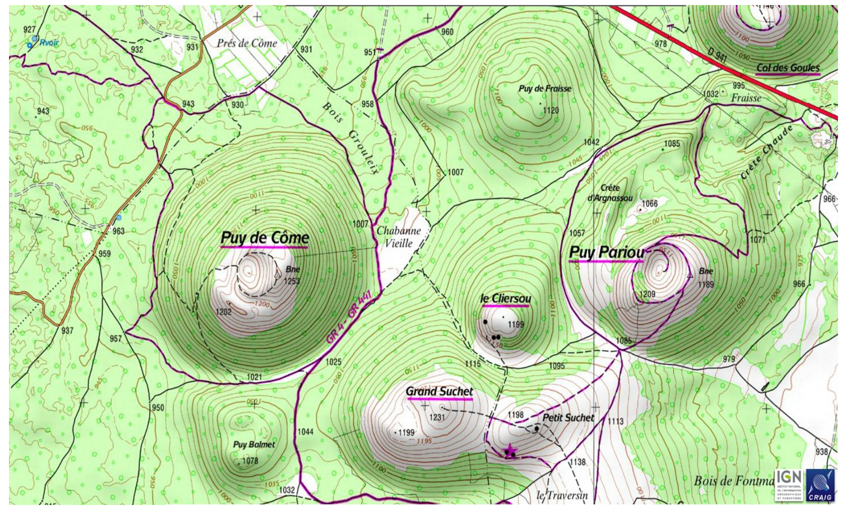
Line of sight



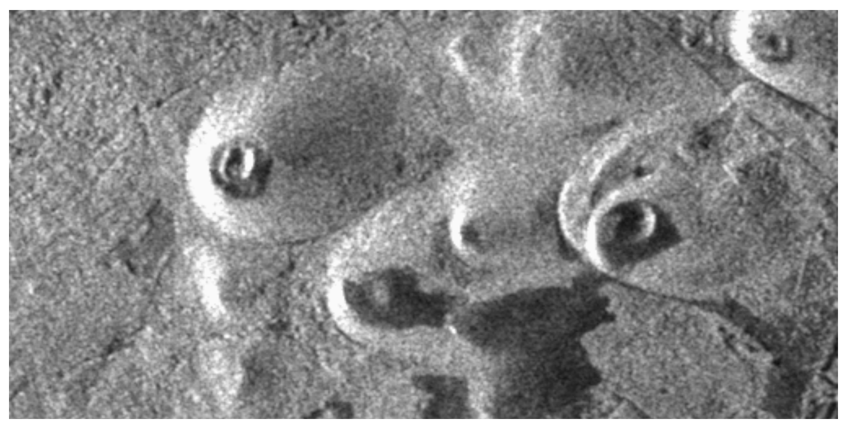
(Tupin et Nicolas, 2016)

The radar “vision”



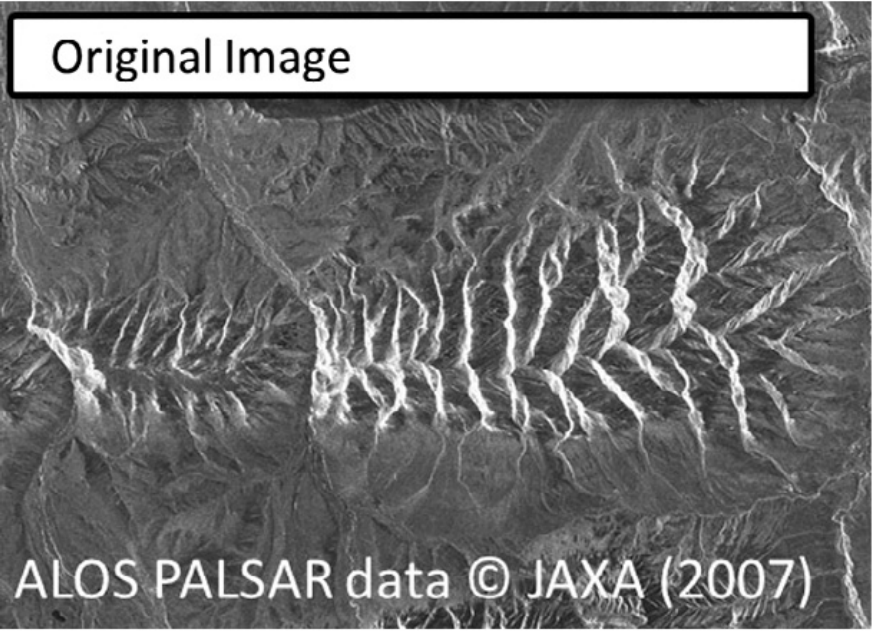


Ascending

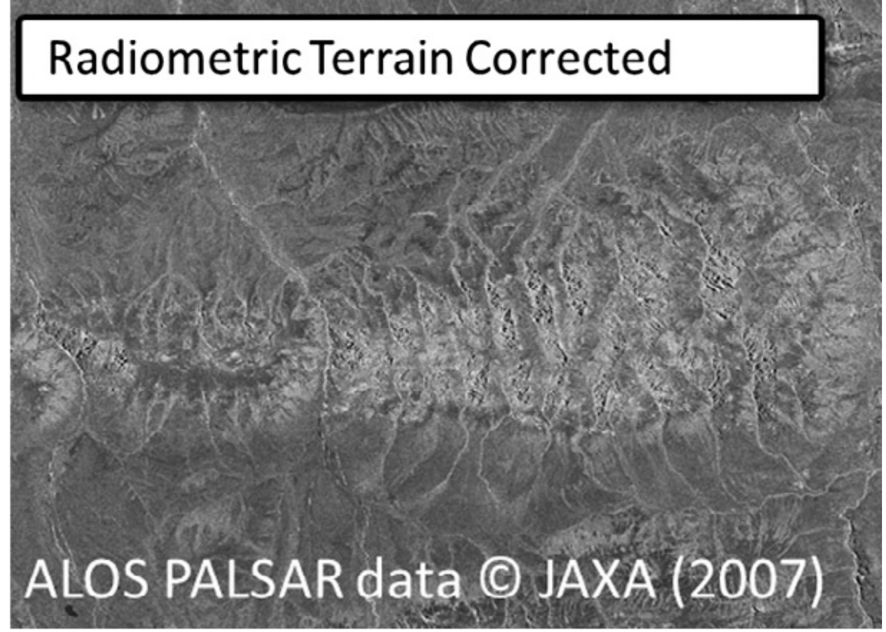


Line of sight

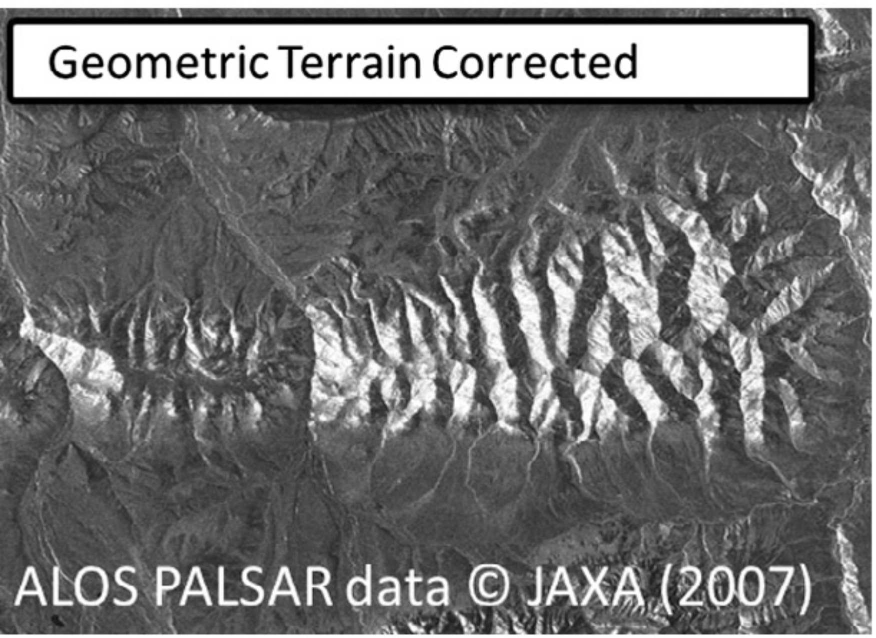
(Tupin et Nicolas, 2016)



(a)



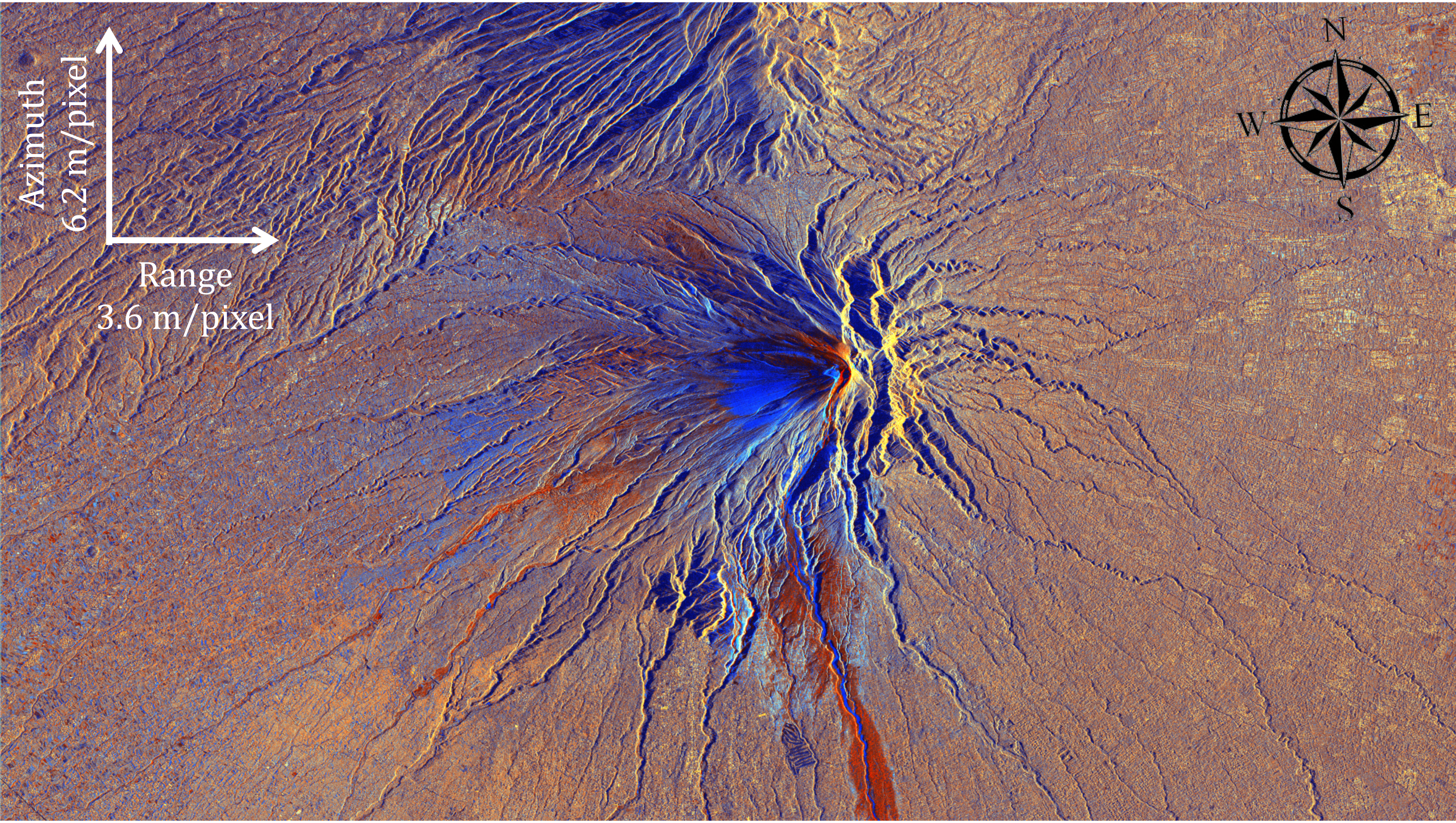
(c)



(b)

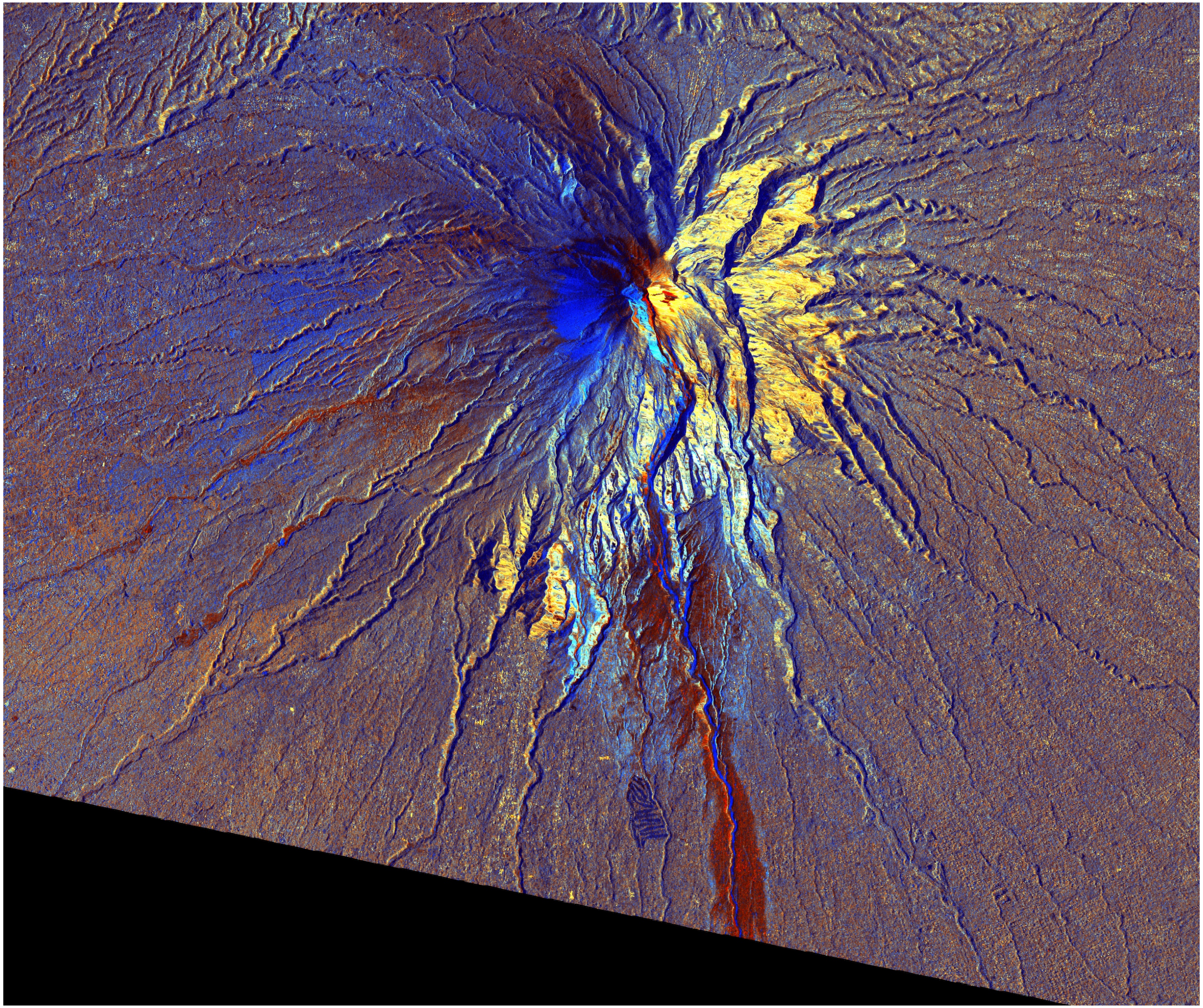
Meyer et al, 2015

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

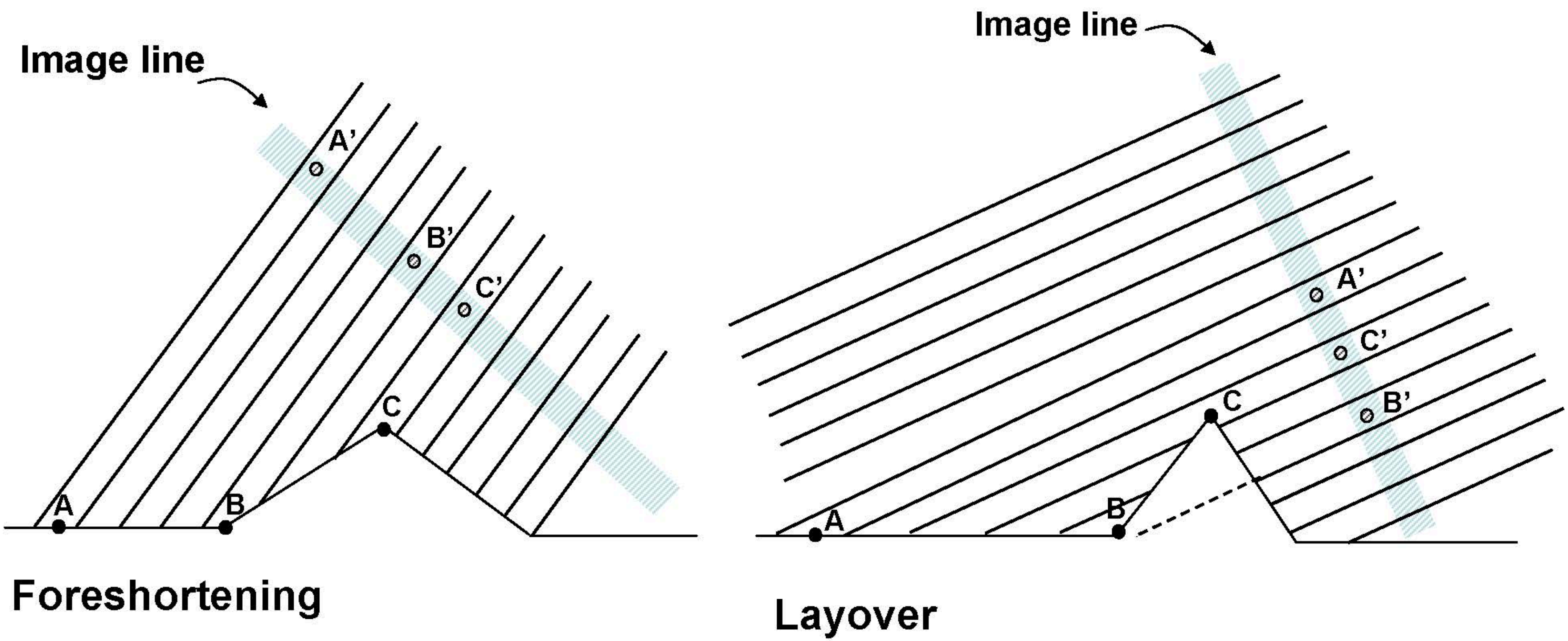
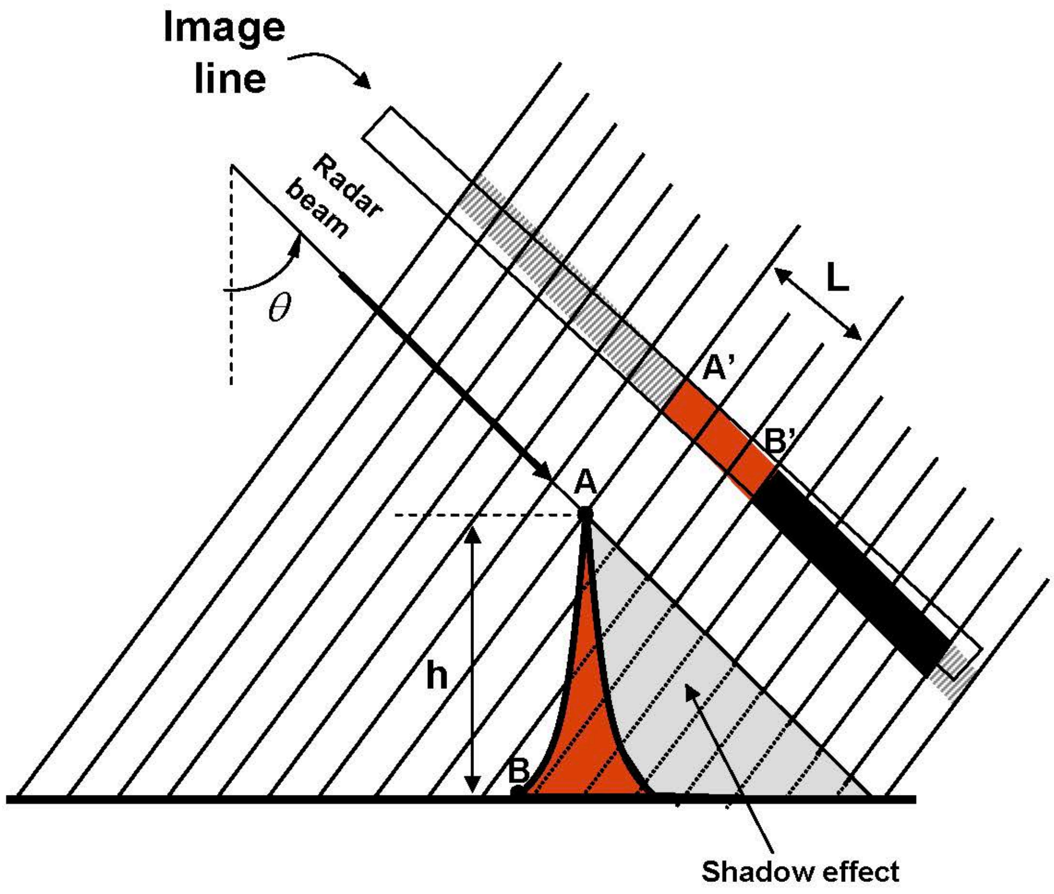
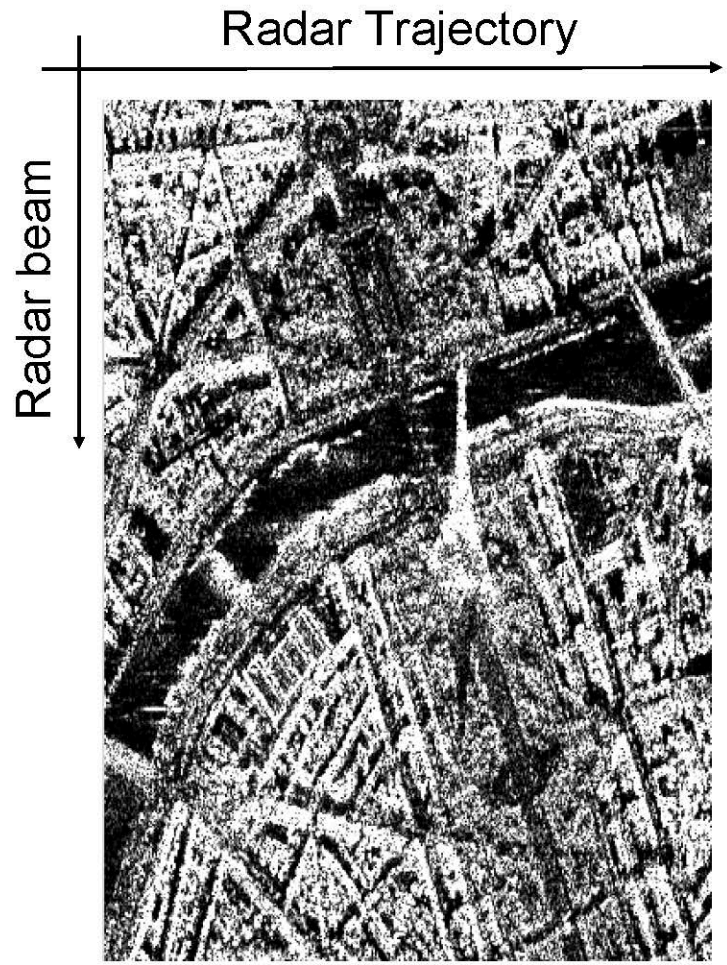


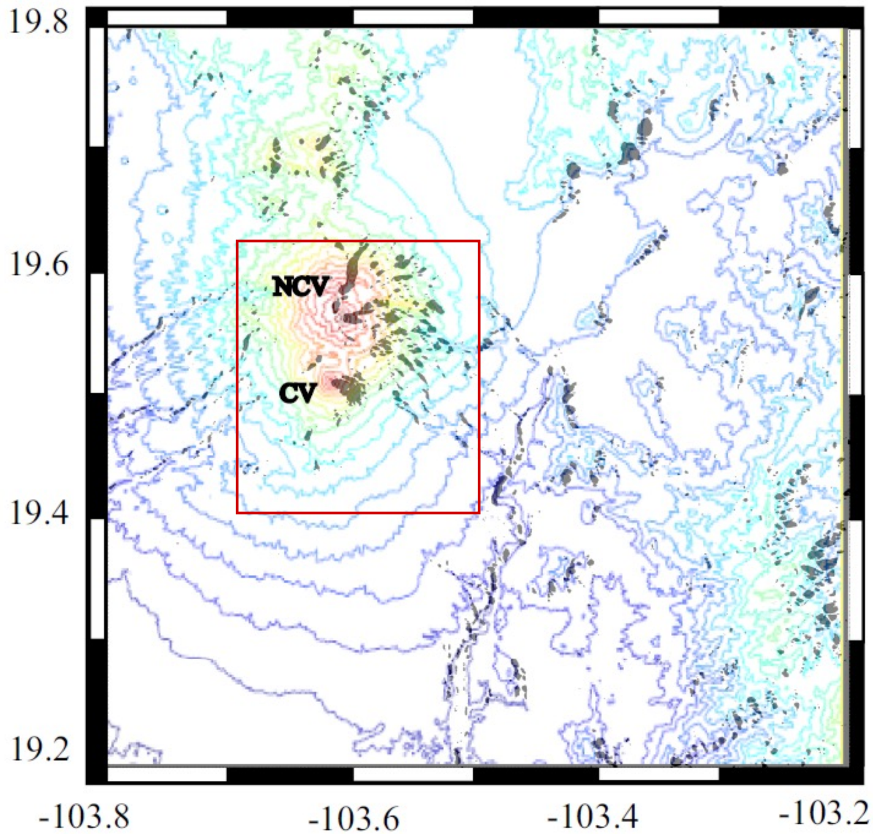
Image quality: geometry

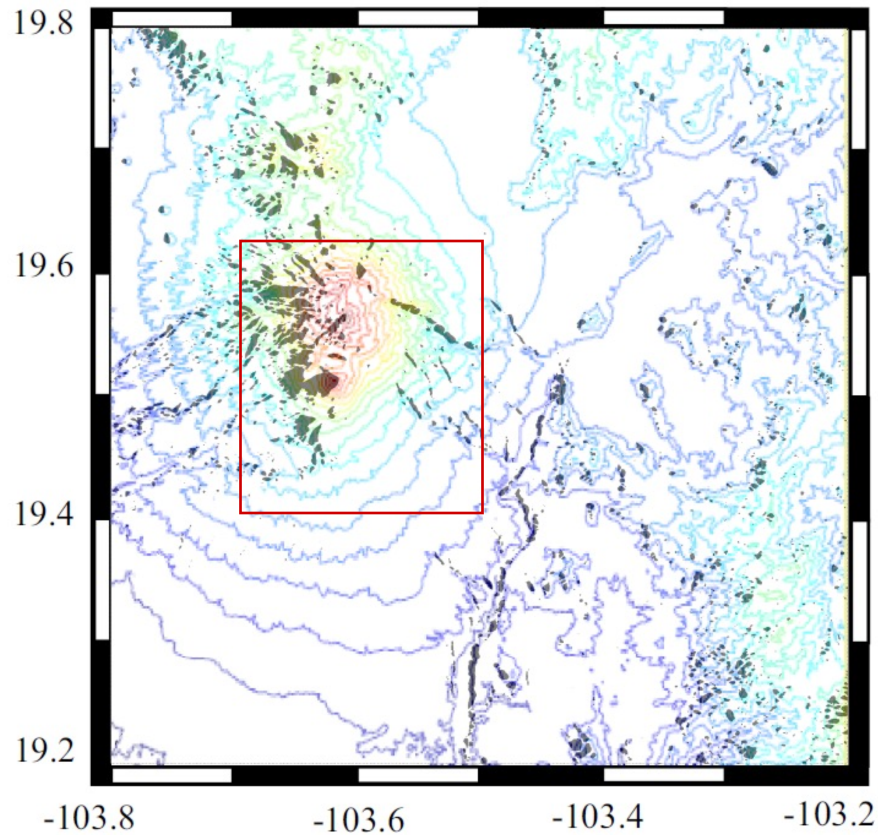
➔ example of layover effect





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





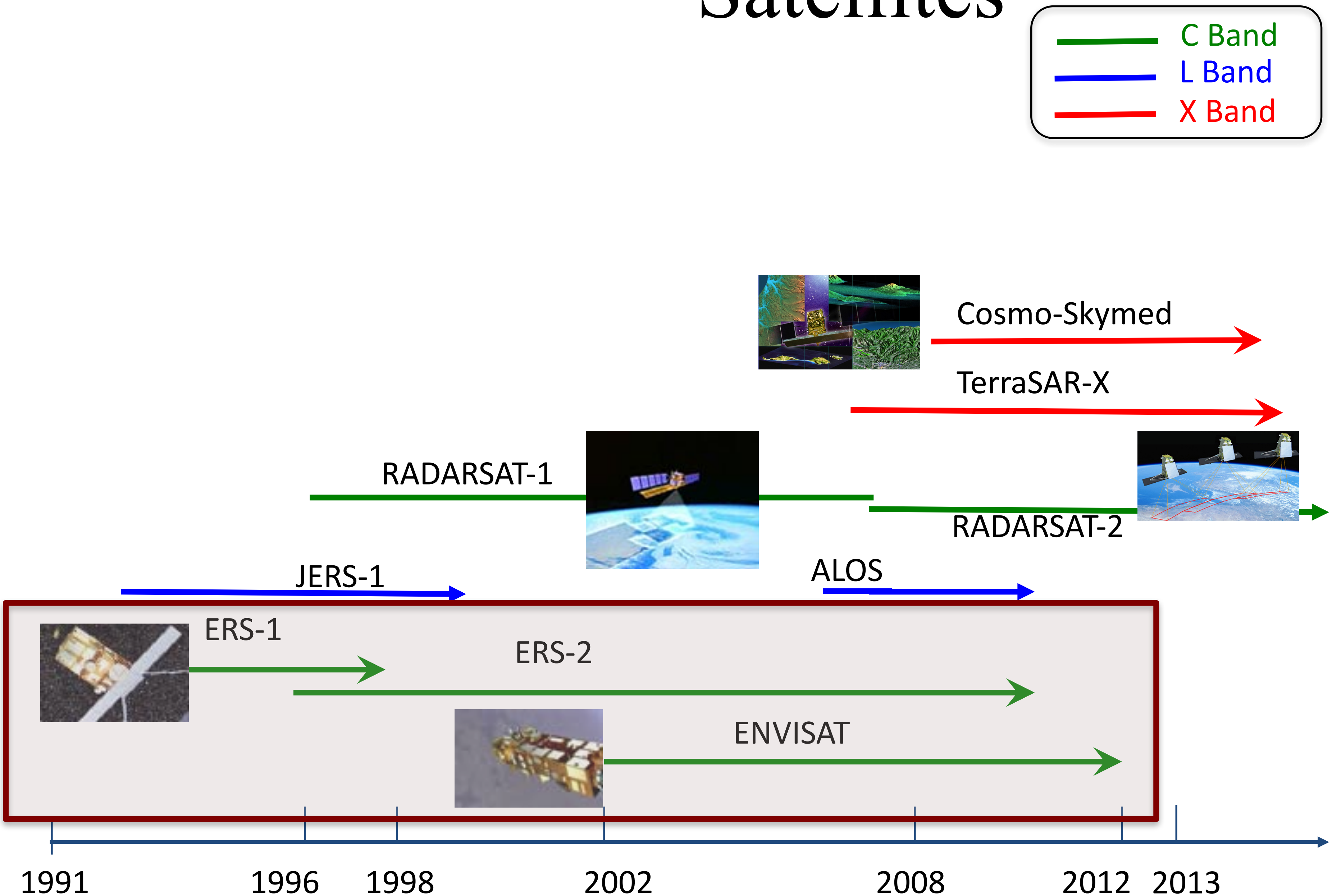
Descending (3.6 % of image)
7%

Ascending (4.9 % of image)
12%

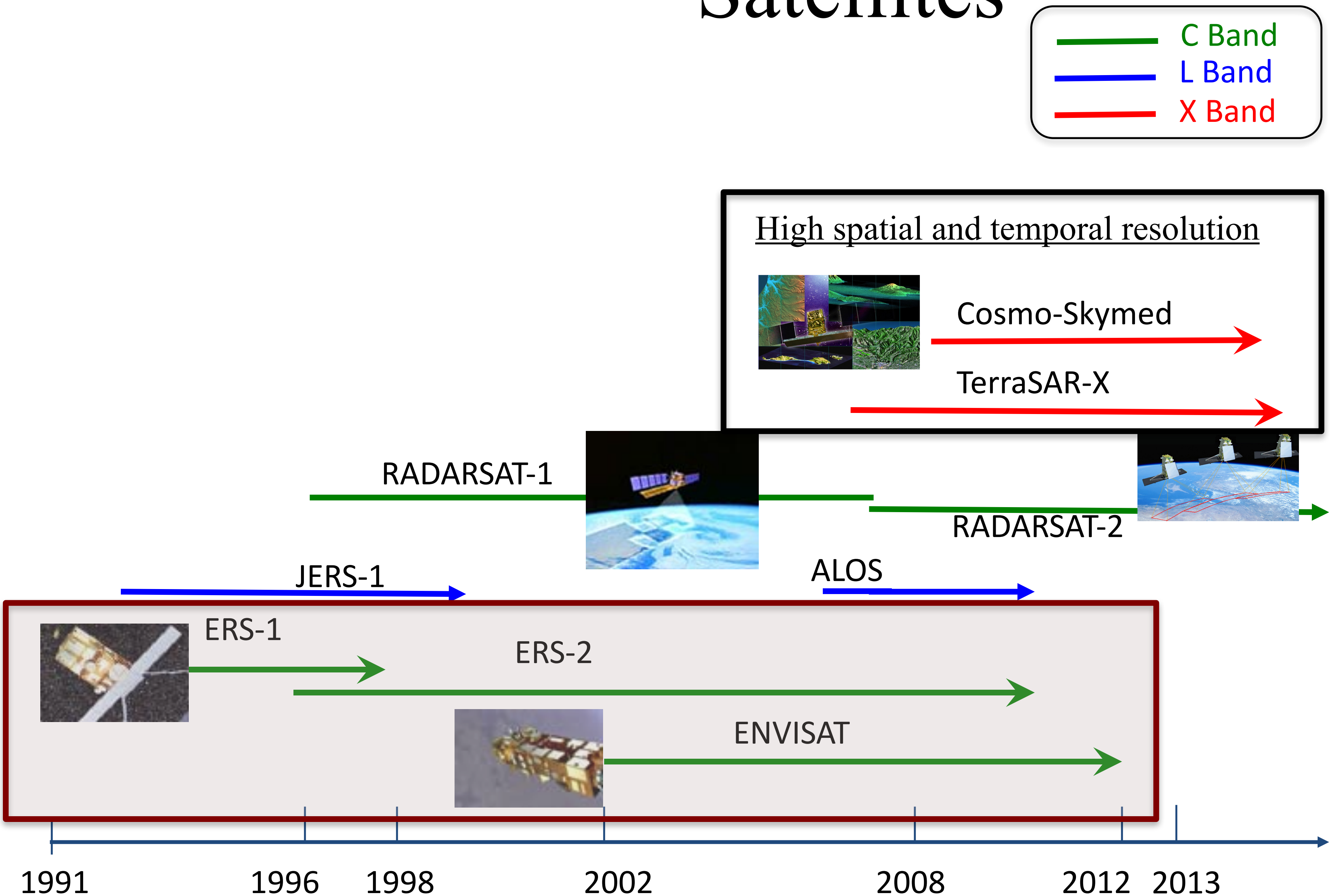
Satellite providing SAR data

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
ALOS2	~~2013-~~	14	628	1.2	L	8-70	25-350
Sentinel1 (2)	~~2013-~~ ? 2014	12	6935	5.4	C	>25	>250

Satellites

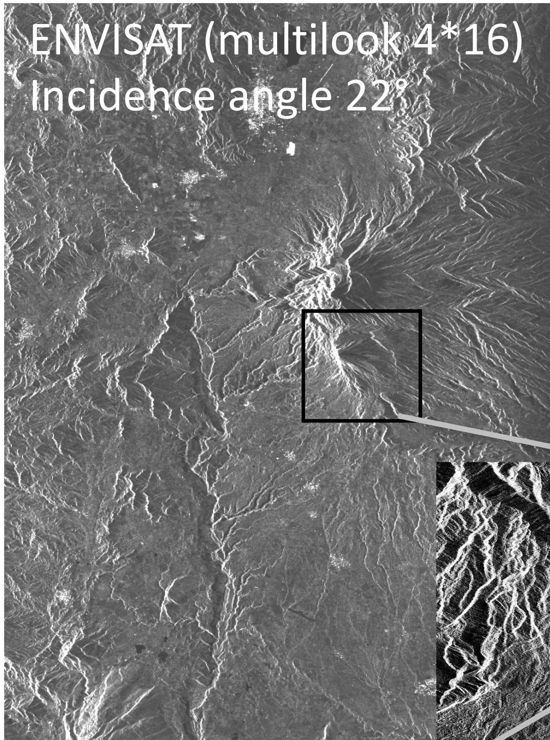

C Band
L Band
X Band
Cosmo-Skymed
TerraSAR-X
RADARSAT-1
RADARSAT-2
JERS-1
ALOS
ERS-1
ERS-2
ENVISAT
1991
1996
1998
2002
2008
2012
2013

Satellites

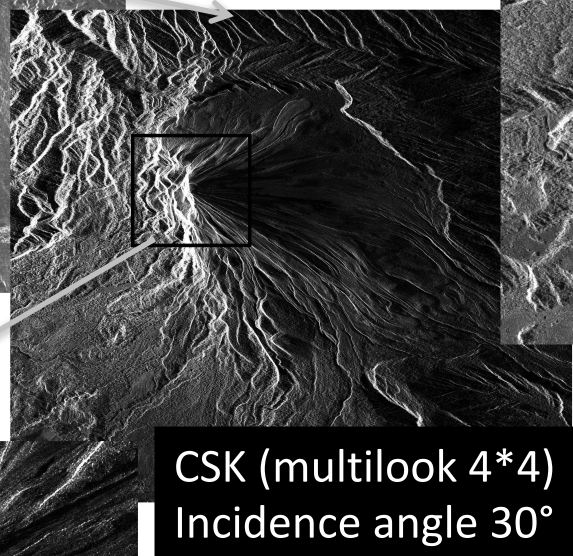


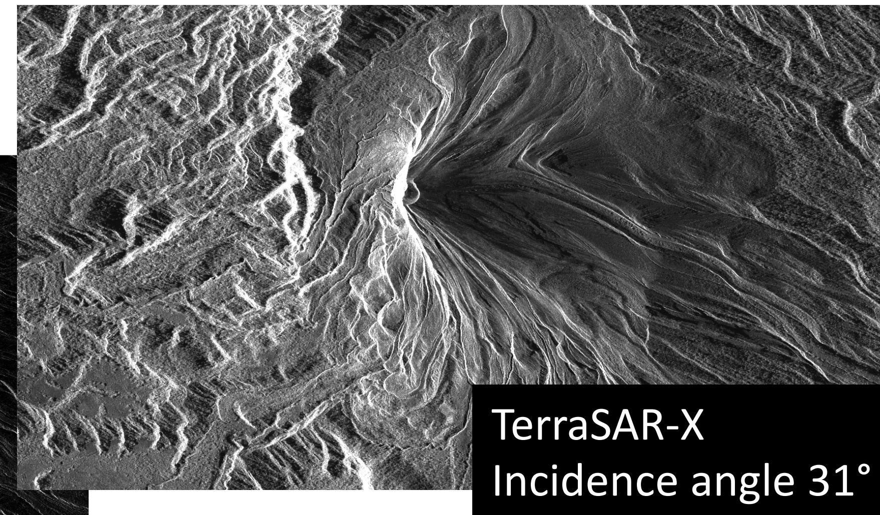
C Band
L Band
X Band
High spatial and temporal resolution
Cosmo-Skymed
TerraSAR-X
RADARSAT-1
RADARSAT-2
JERS-1
ALOS
ERS-1
ERS-2
ENVISAT
1991
1996
1998
2002
2008
2012
2013

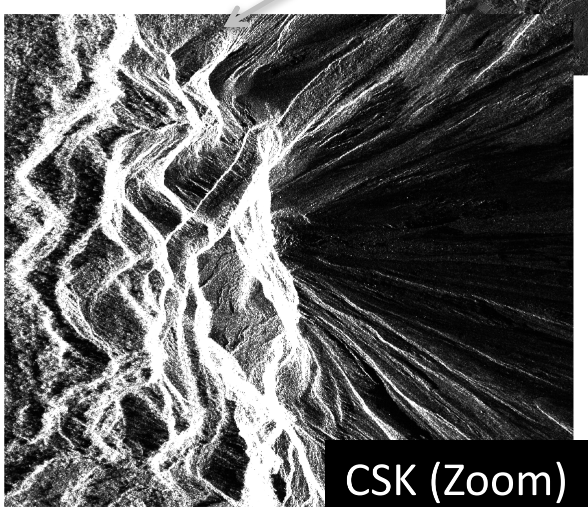
High Resolution SAR imagery



a)





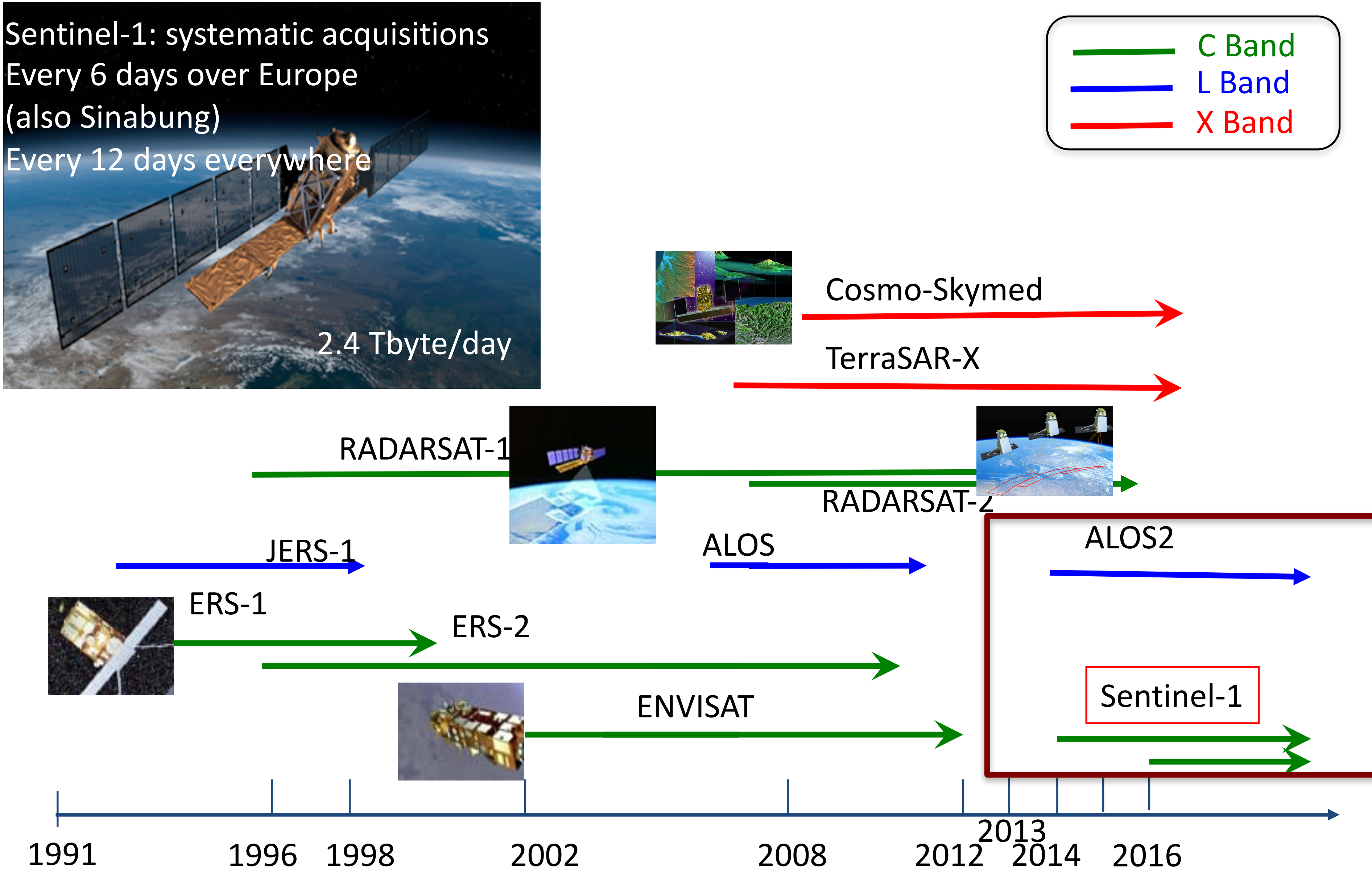


c)

Colima volcano, Mexico

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

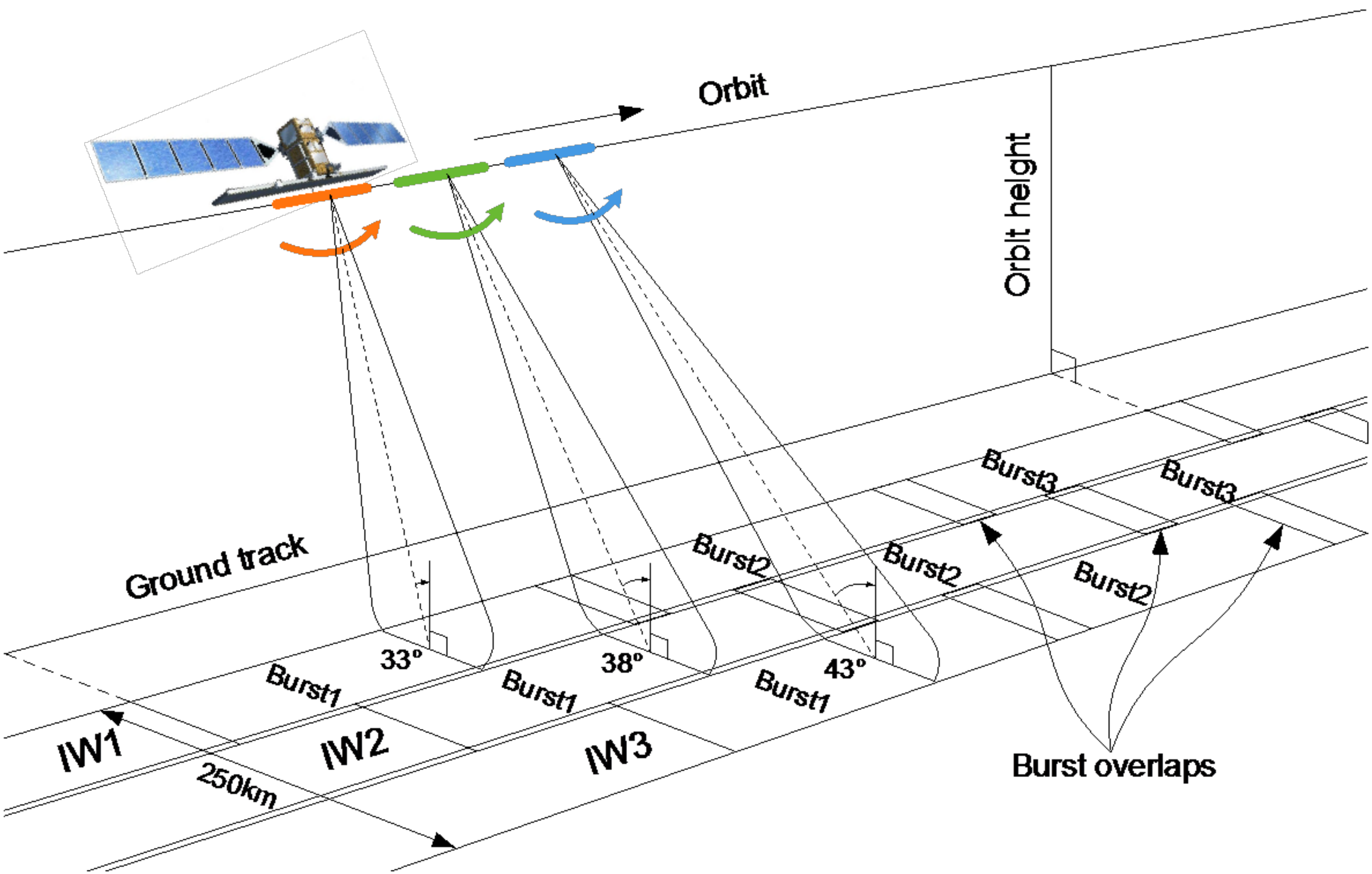
Since 2014: Sentinel-1



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 plateforms:
  – 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 Plateform)

- On national plateforms:
  – PEPS developped 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
Virginie PINEL	ISTerre, France	virginie.pinel@univ-smb.fr
Asep SAEPULOH	ITB, Indonesia	saepuloh@gc.itb.ac.id
AGUSTAN	BPPT, Indonesia	uttank@gmail.com
Devy K. SYAHBANA	CVGHM – GA, Indonesia	devy.syahbana@gmail.com
Estu KRISWATI	CVGHM – GA, Indonesia	estukriswati@gmail.com
Agus Budi SANTOSO	CVGHM – GA, Indonesia	zantozo@gmail.com

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:

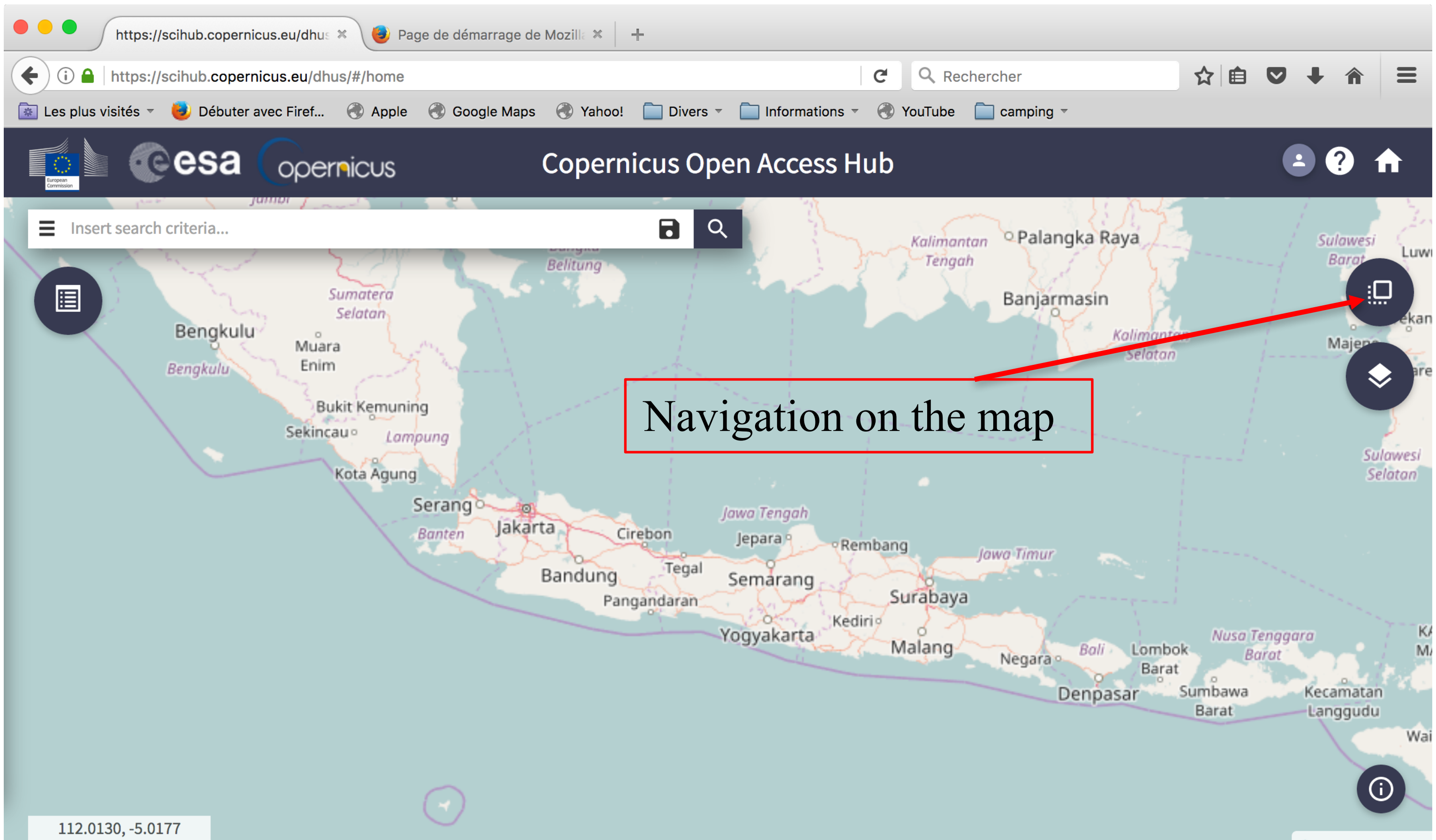
- Kassouk, Z., Thouret, J.-C., Gupta, A., **Solikhin, A.**, & Liew, S.C. (2014). Object-oriented classification of a high-spatial resolution SPOT5 image for mapping geology and landforms of active volcanoes: Semeru case study, Indonesia. *Geomorphology, 221*, 18-33.
- Lê, T.T., Atto, A.M., Trouvé, E., **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., Vandemeulebrouck, J., Thouret, J.-C., & Hendrasto, M. (2015a). Mapping the 2010 Merapi pyroclastic

Sentinel-1

ESA Platform:
https://scihub.copernicus.eu/dhus/#/home
https://scihub.copernicus.eu/userguide/

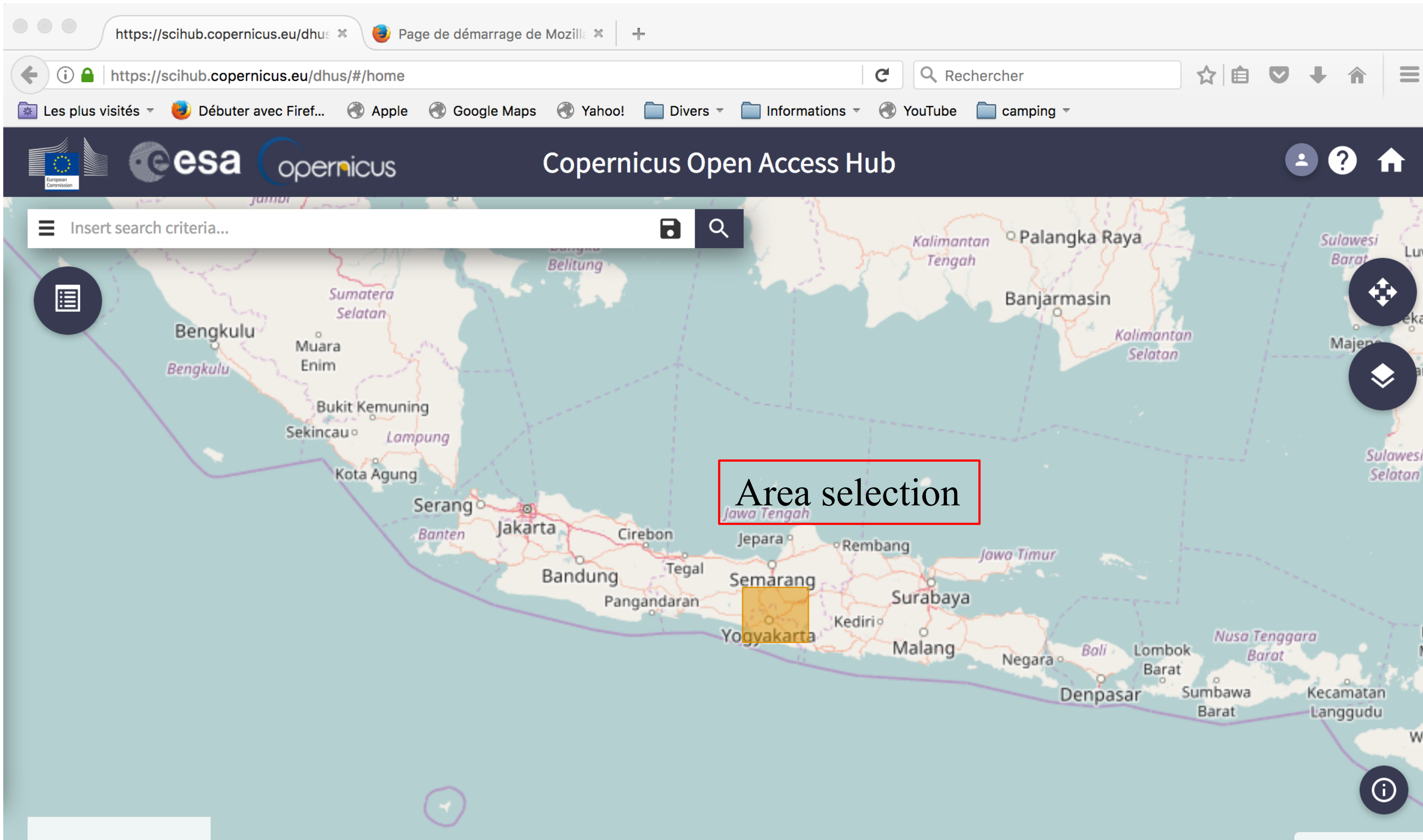
CNES Platform: PEPS (In French only)
https://peps.cnes.fr/rocket/#/home

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

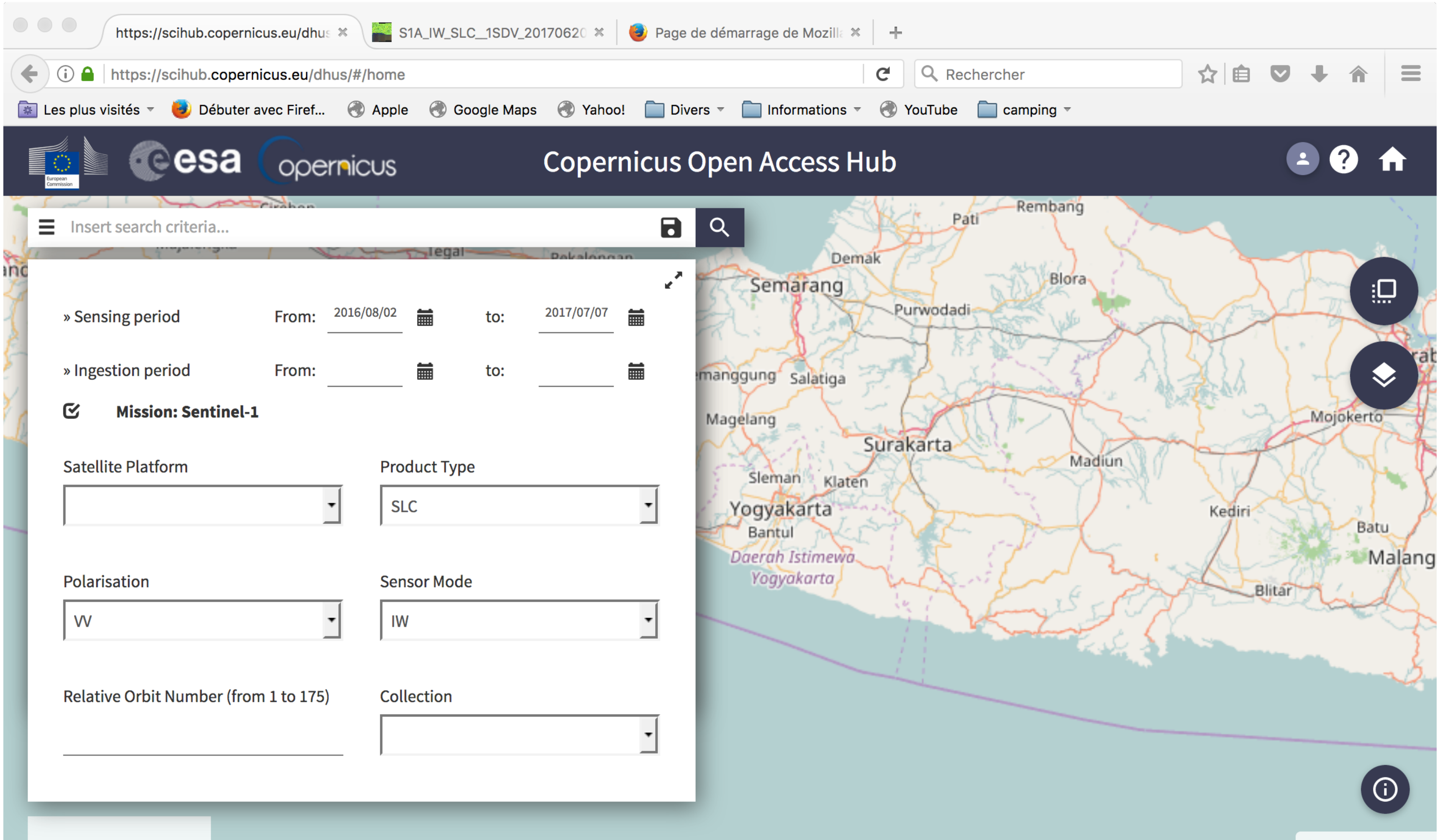


ESA Platform:

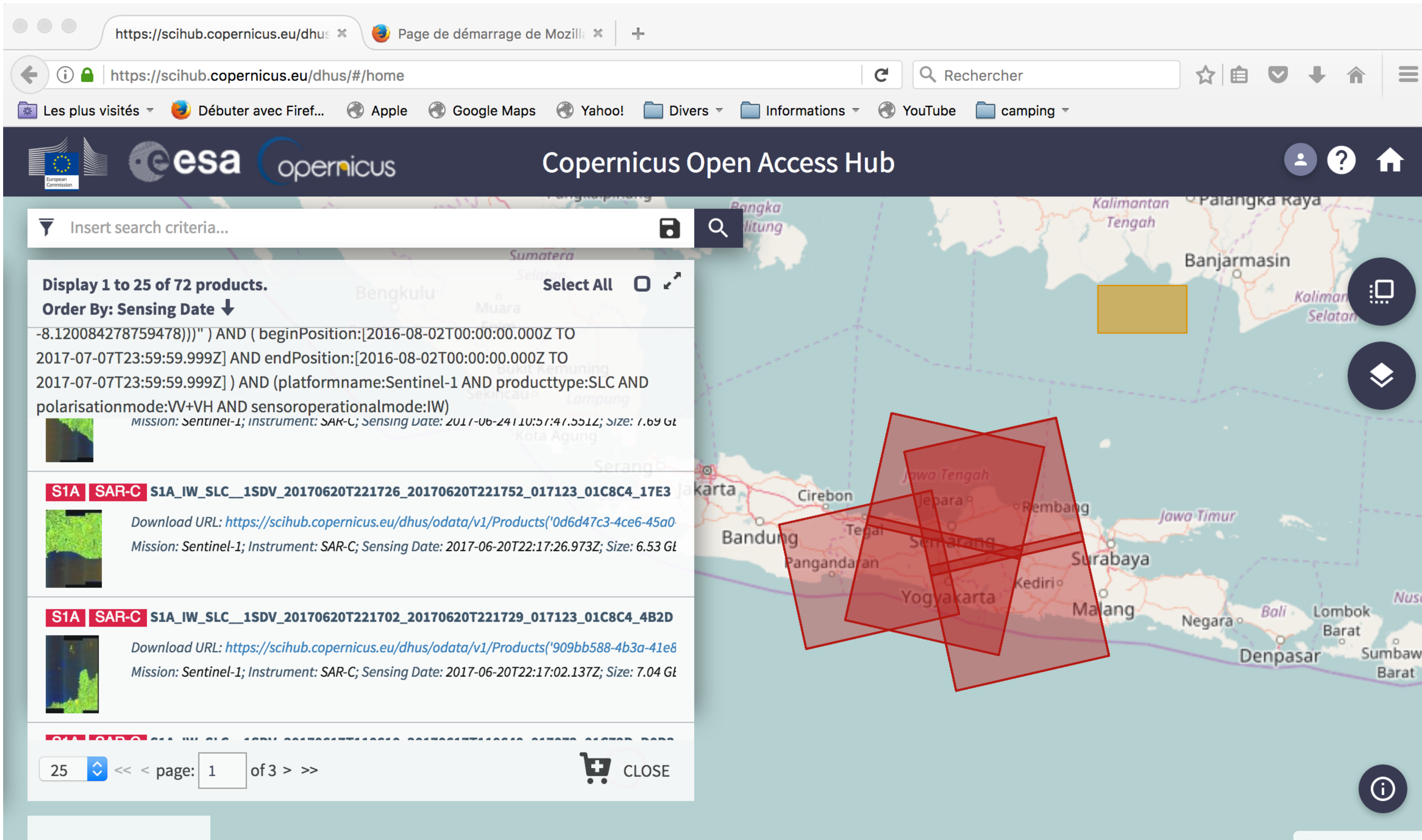
https://scihub.copernicus.eu/dhus/#/home



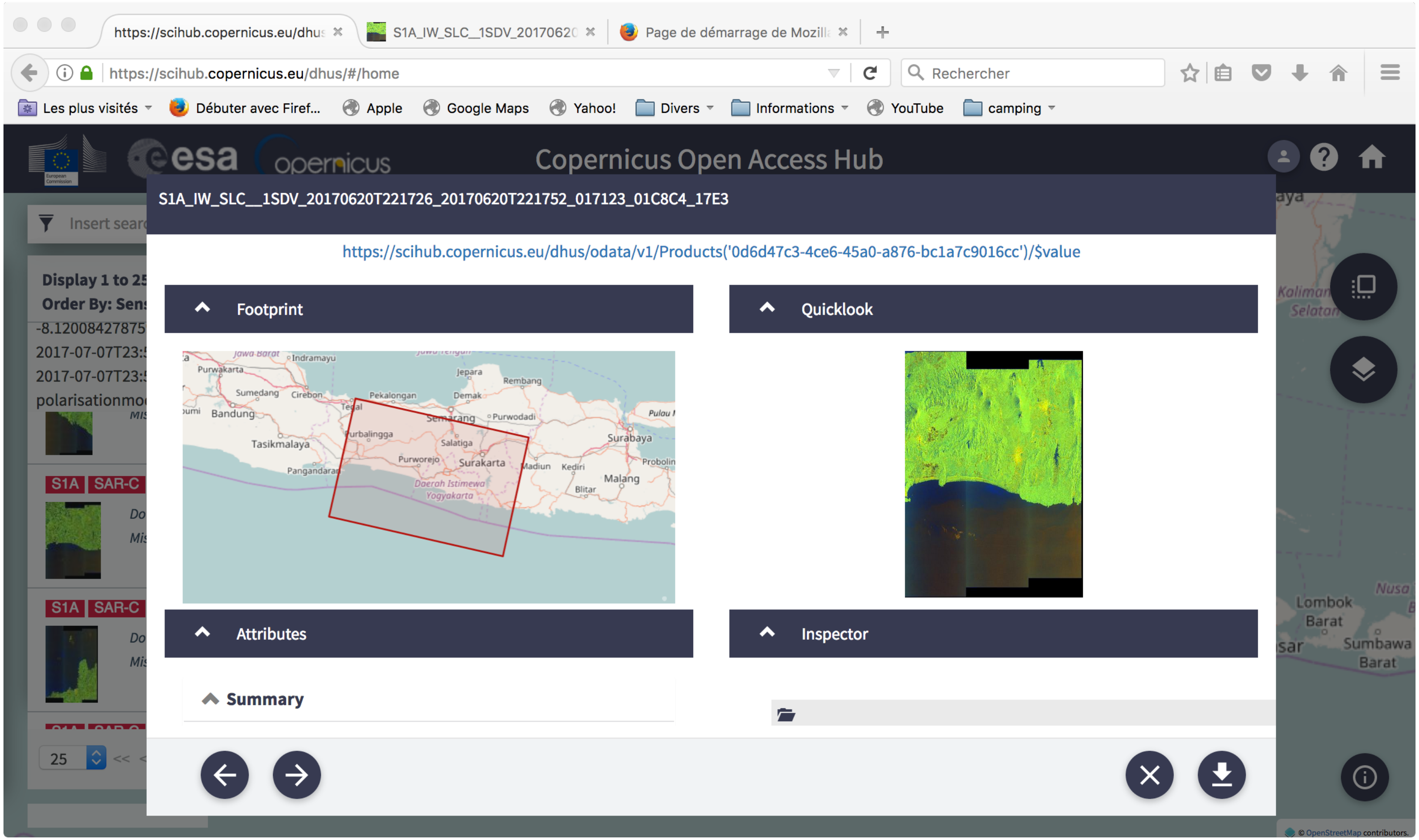
ESA Platform: https://scihub.copernicus.eu/dhus/#/home



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

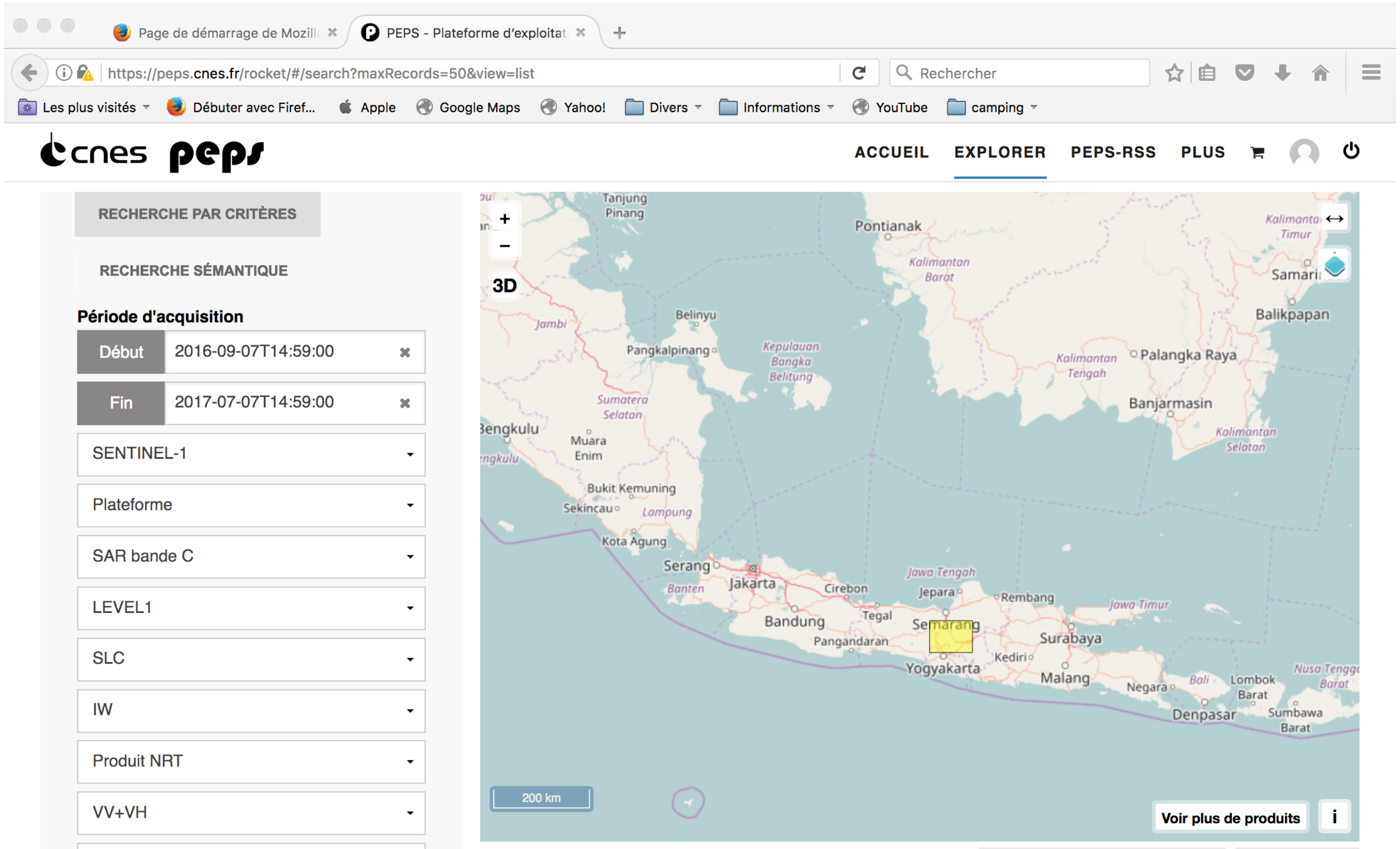


ESA Platform:
https://scihub.copernicus.eu/dhus/#/home



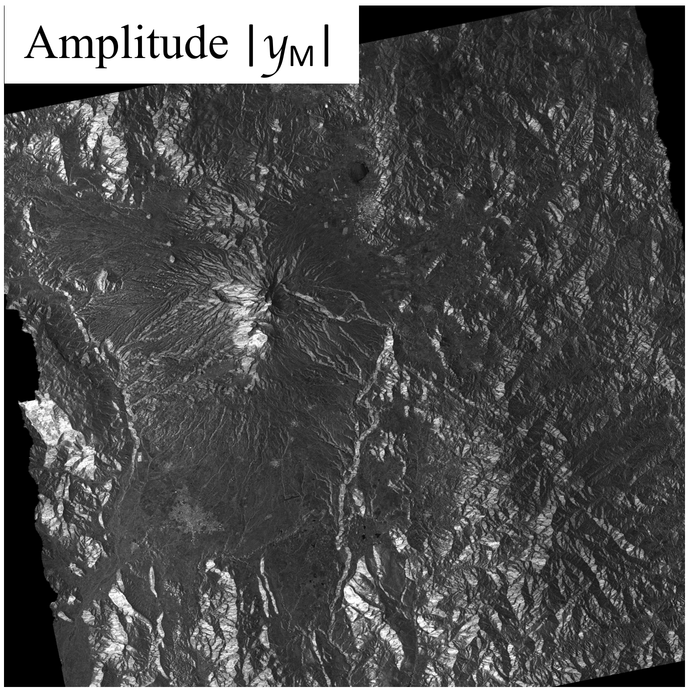
CNES Platform: PEPS

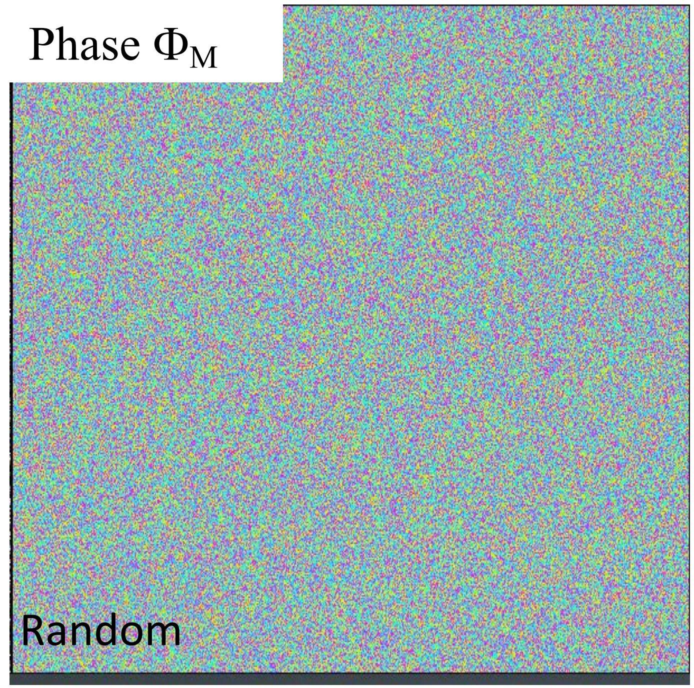
https://peps.cnes.fr/rocket/#/home



A complex signal

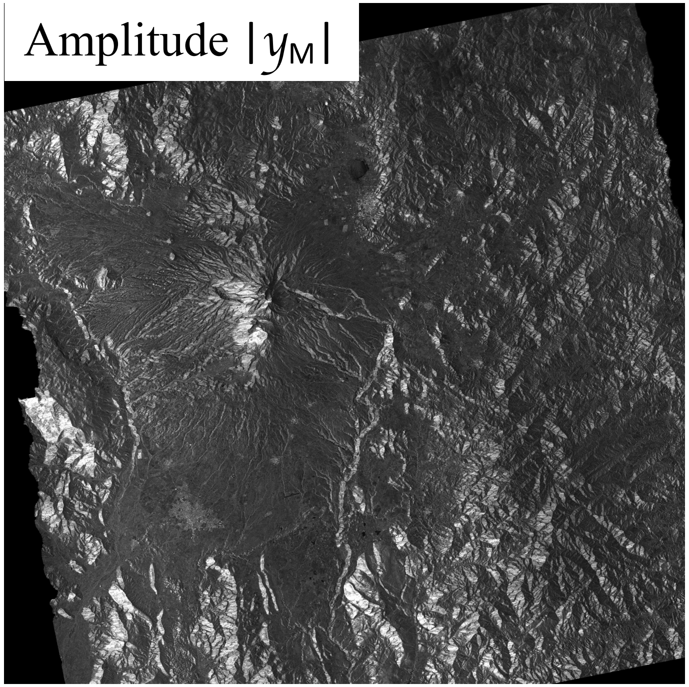
$y_M = |y_M| e^{i\phi_M}$

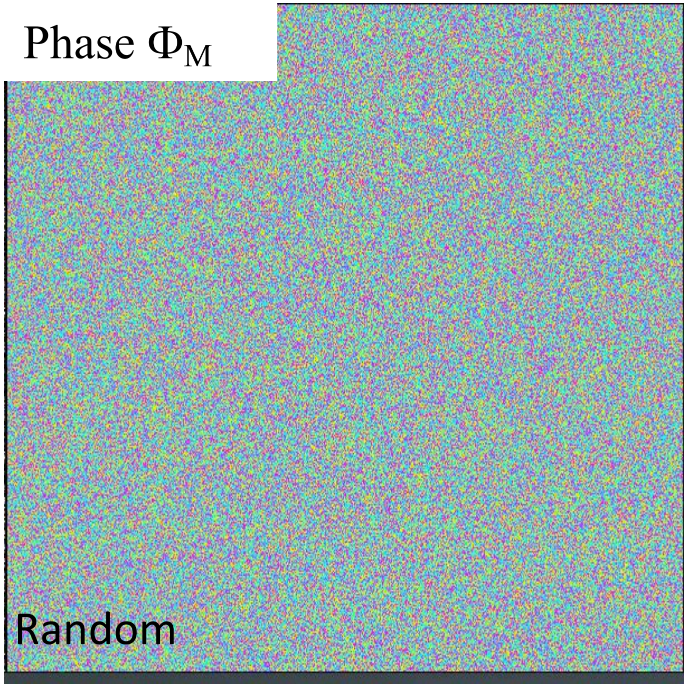




A complex signal

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

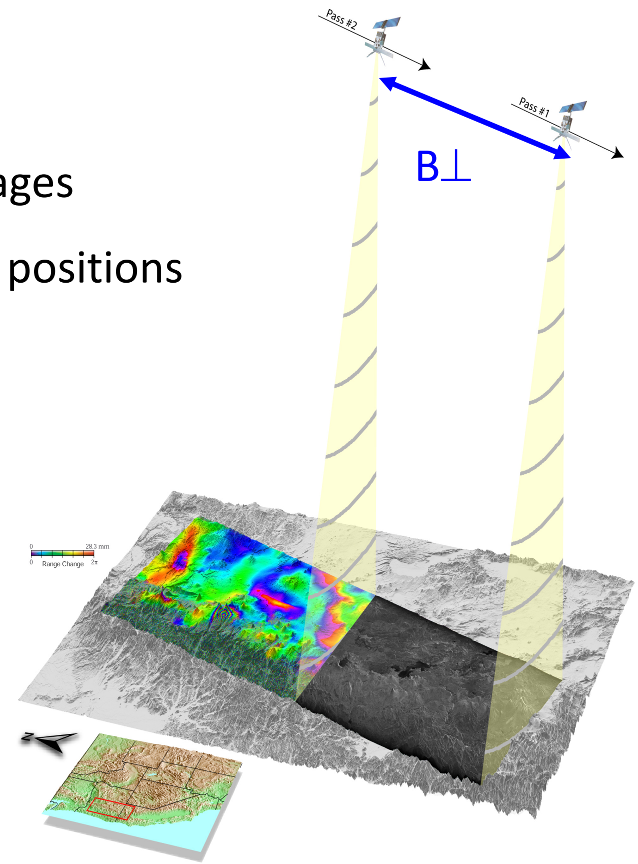




How can we measure displacement?

Combining 2 images

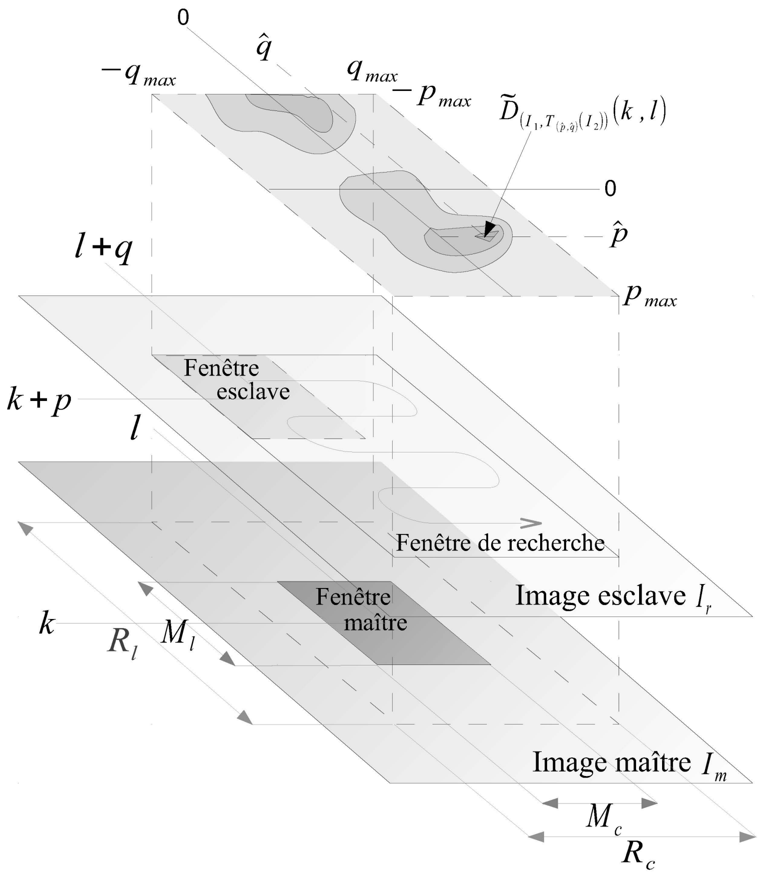
2 dates of acquisitions → Master image (M) / Slave image (S)



-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

Exemple ENVISAT images on Colima volcano

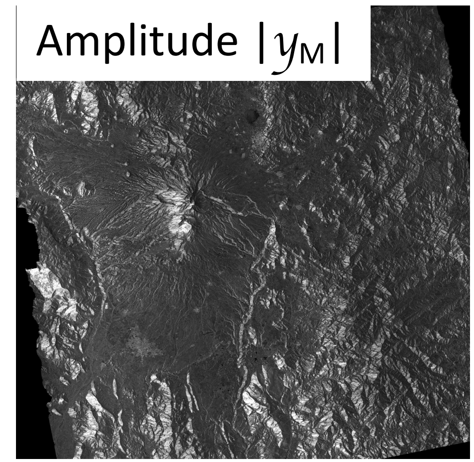
2 acquisitions radar: → Master Image (M)
↘ Slave Image (S)

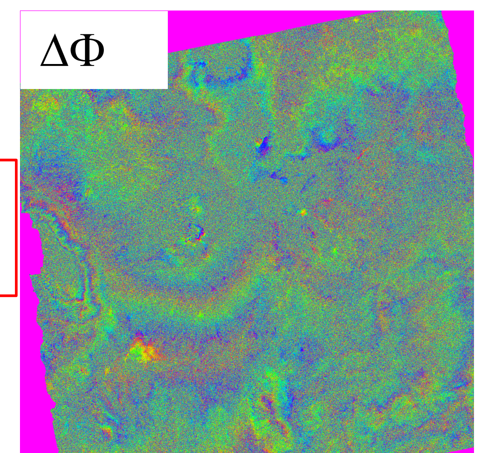
Couple of images characterized by: $B\perp$, ΔT

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

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

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



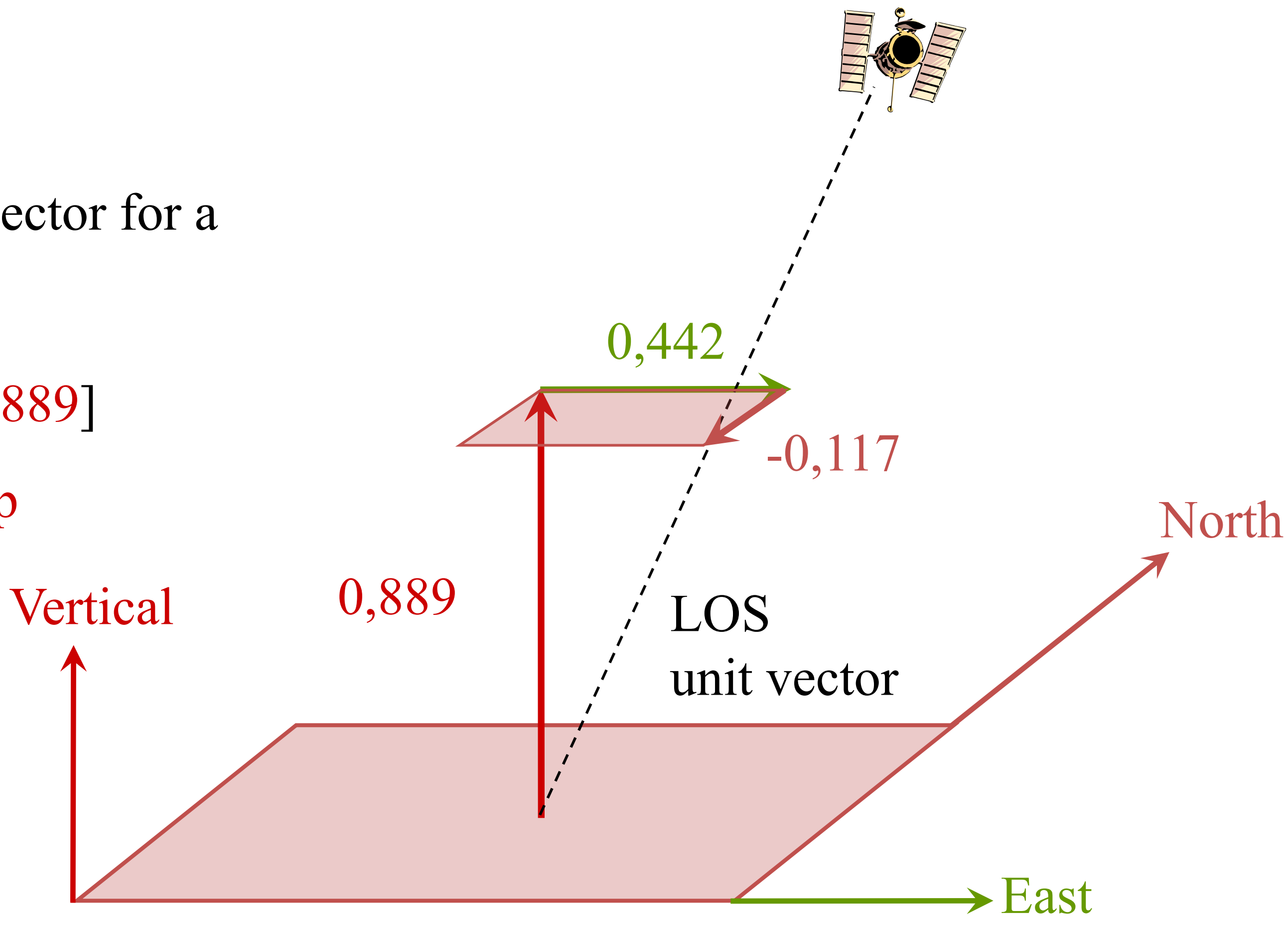


Displacement in Line of Sight

Example of unit vector for a descending track:

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

East North Up

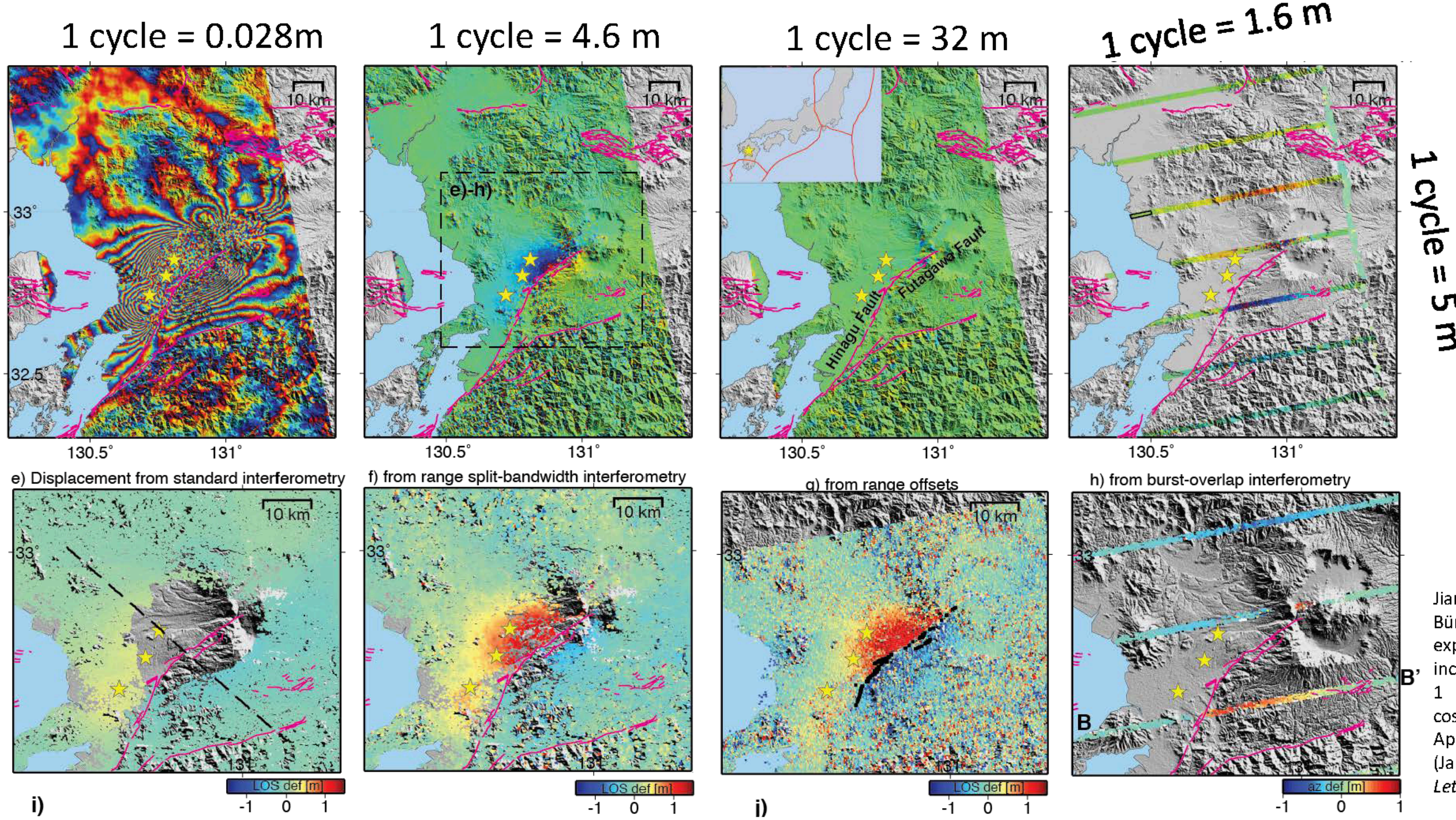


Enable to measure vertical and E-W displacements.

From R. Pedersen

Sentinel-1
Other possibilities to measure displacement field

All the information from a TOPS image pair

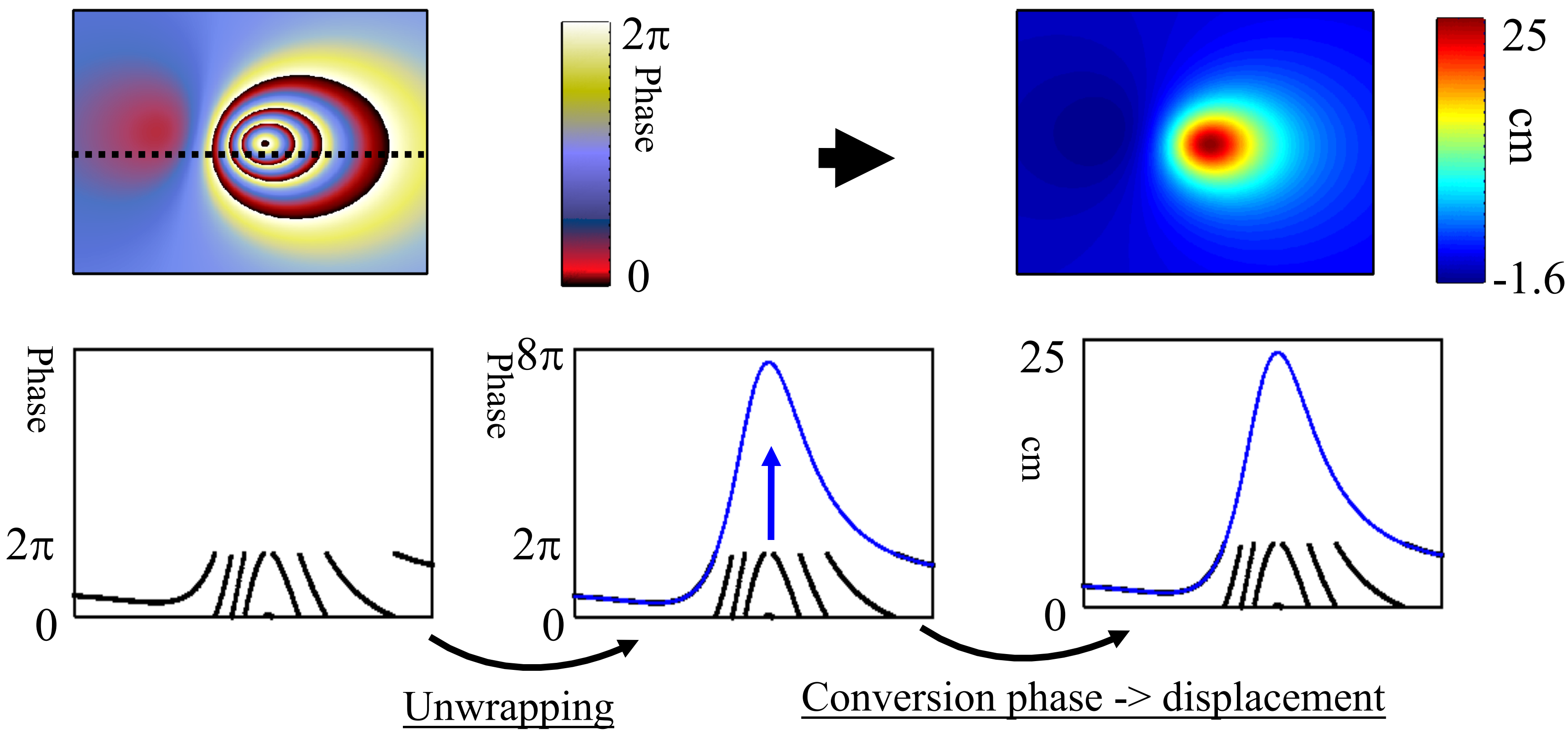


Jiang, H, Feng, G., **Wang, T.***, and Bürgmann, R. Towards full exploitation of coherent and incoherent information in Sentinel-1 TOPS data for retrieving coseismic displacement: Application to the 2016 Kumamoto (Japan) earthquake (*Geophys. Res. Lett.*)

Ambiguity of phase information

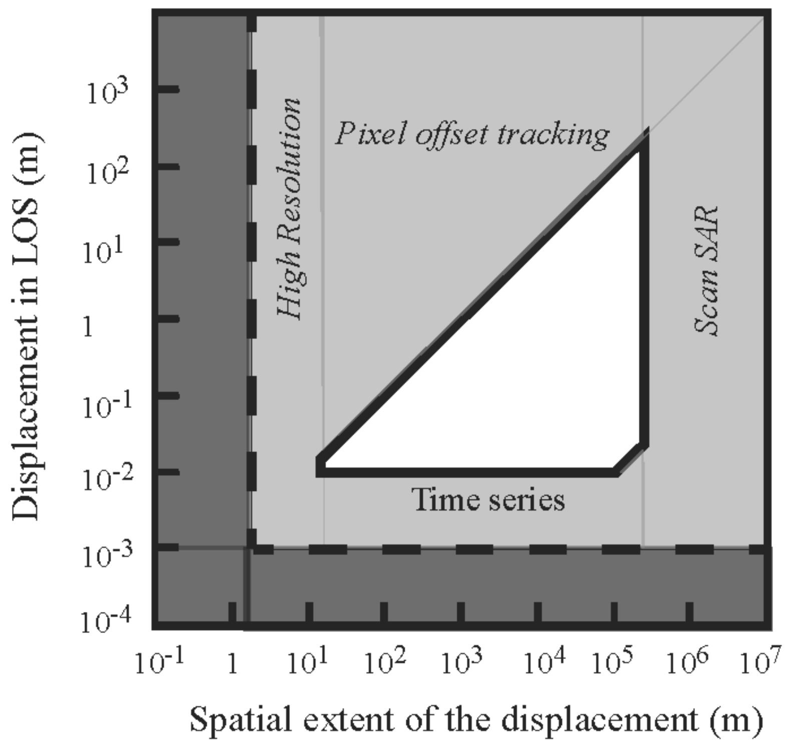
ΔΦ is known with an ambiguity of 2π

Phase unwraping is required to obtained displacement with regards to a reference point

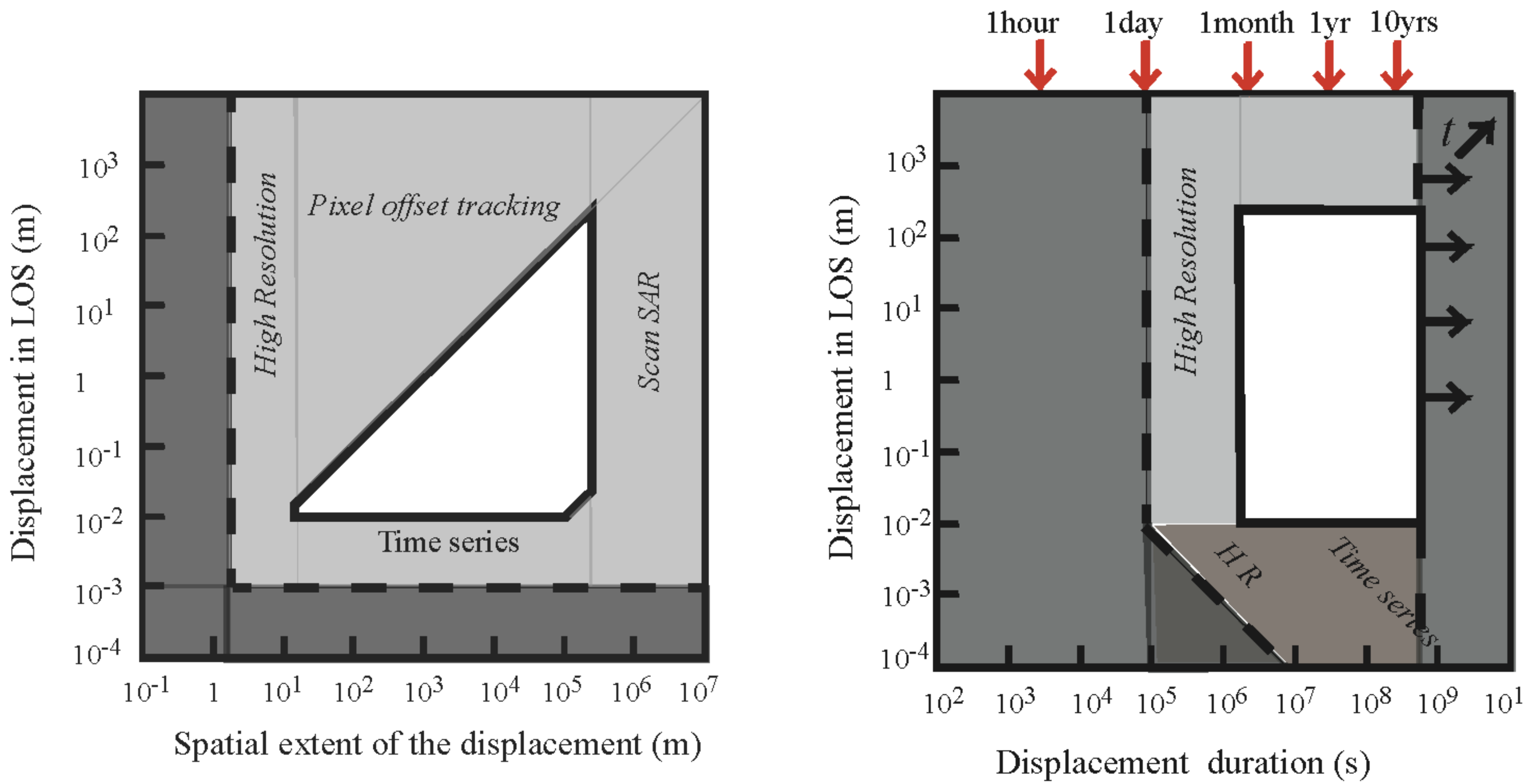


From V. Cayol lecture notes

InSAR performance

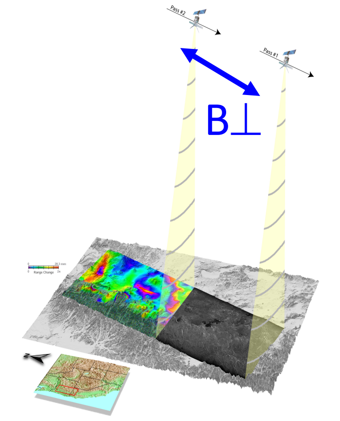


InSAR performance

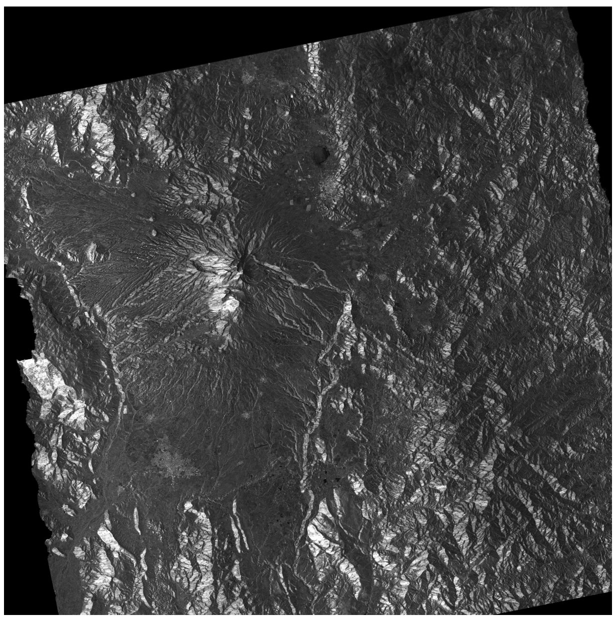


Coherence

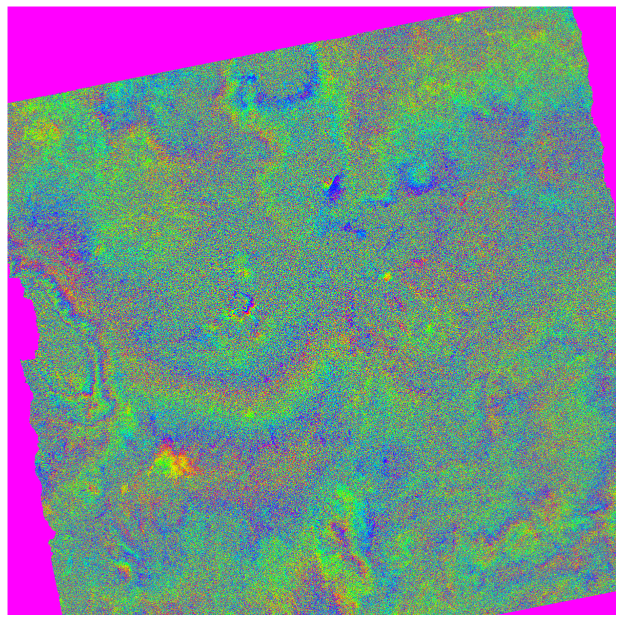
$$coherence = \gamma = \frac{\left|\sum M_i . E_i^*\right|}{\sqrt{\sum |M_i|^2 . \sum |E_i|^2}} \quad ; \quad 0 \le \gamma \le 1$$



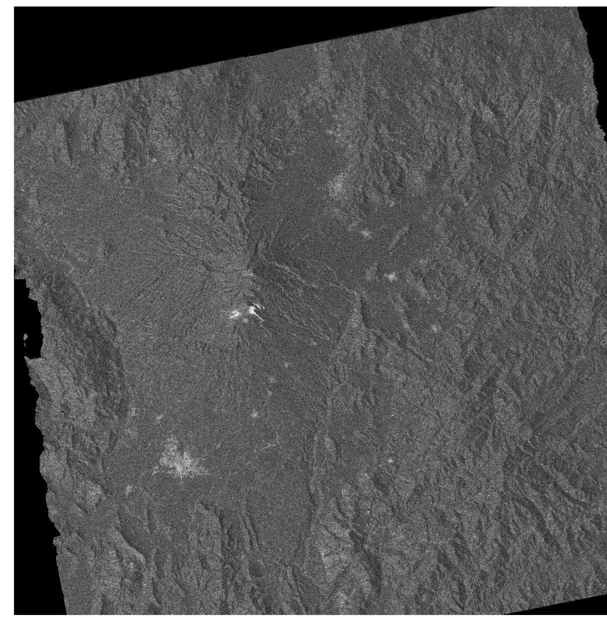
Spatial Resolution : 40 m * 40 m



Mean Amplitude

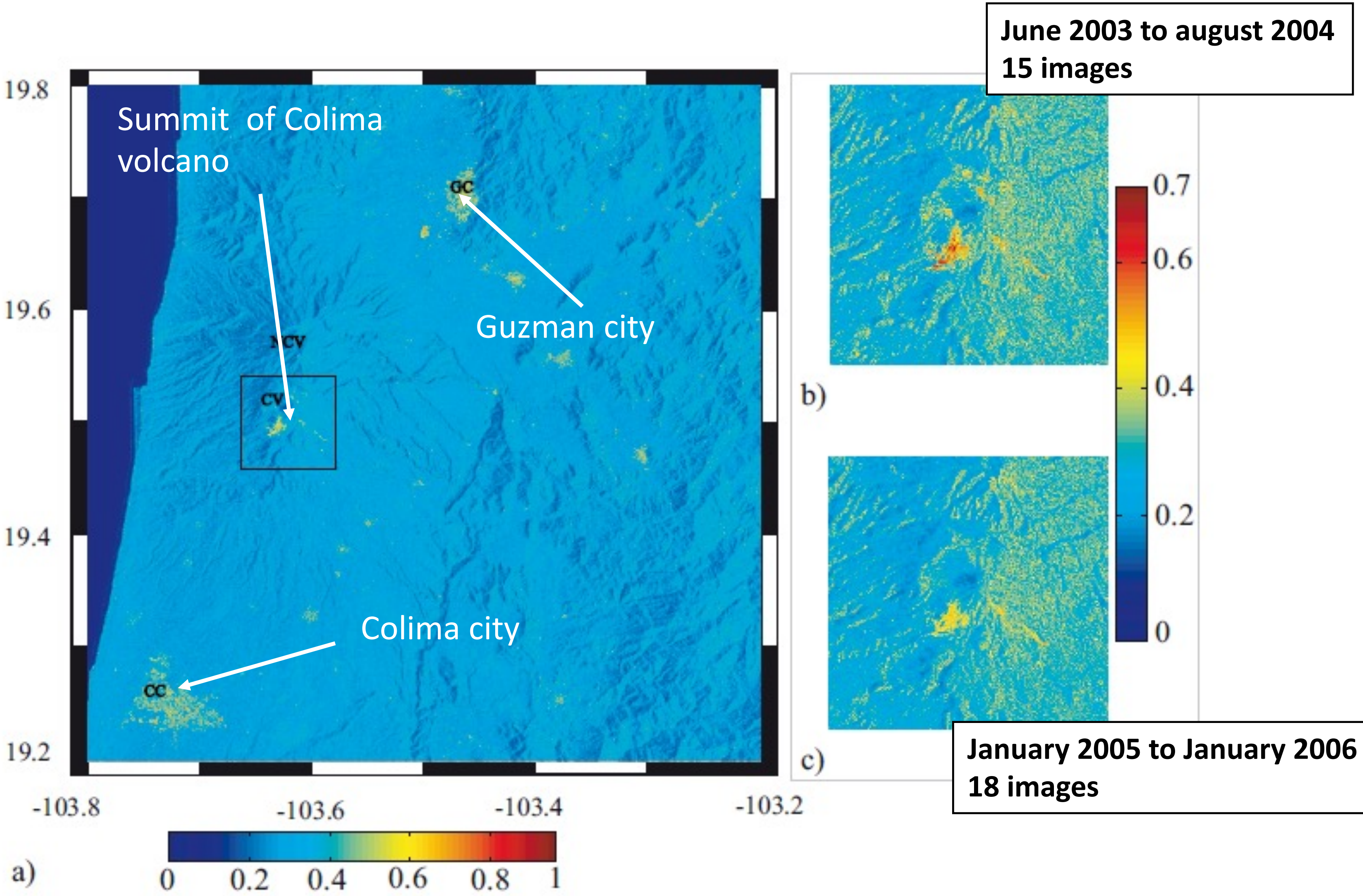


Phase difference $\Delta\phi$



Coherence

Coherence


June 2003 to august 2004
15 images
19.8
19.6
19.4
19.2
-103.8
-103.6
-103.4
-103.2
Summit of Colima
volcano
GC
Guzman city
NCV
CV
Colima city
CC
a)
0
0.2
0.4
0.6
0.8
1
b)
c)
0.7
0.6
0.4
0.2
0
January 2005 to January 2006
18 images

Coherence

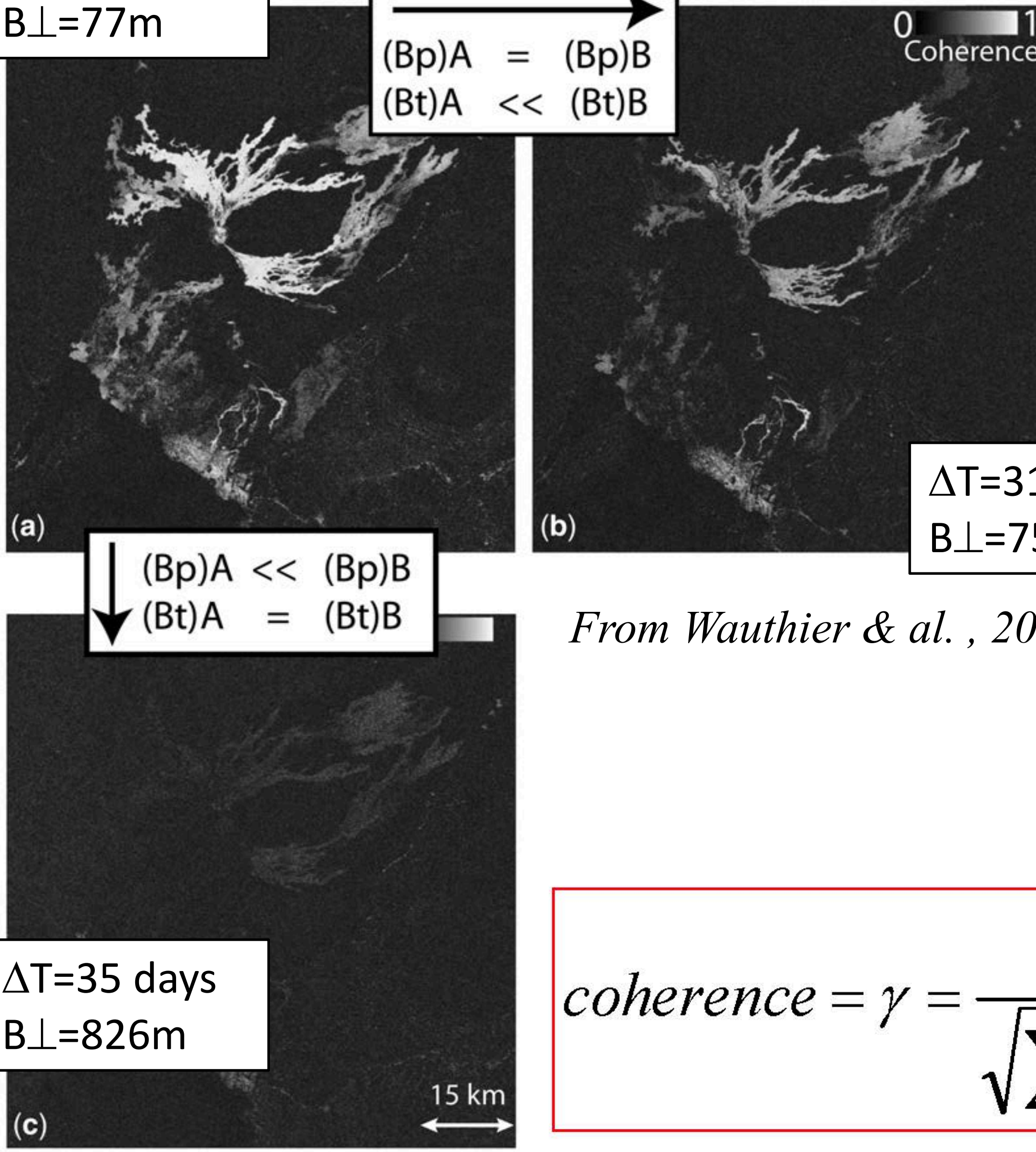
ΔT=35 days
B⊥=77m

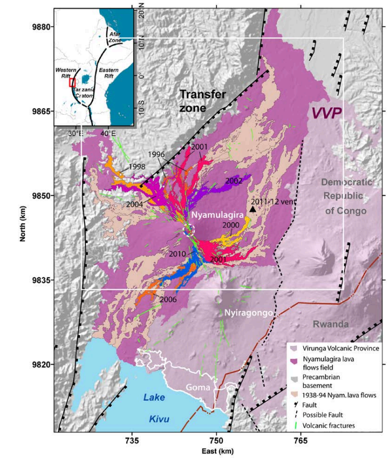
(Bp)A = (Bp)B
(Bt)A << (Bt)B

ΔT=315 days
B⊥=75m

(Bp)A << (Bp)B
(Bt)A = (Bt)B

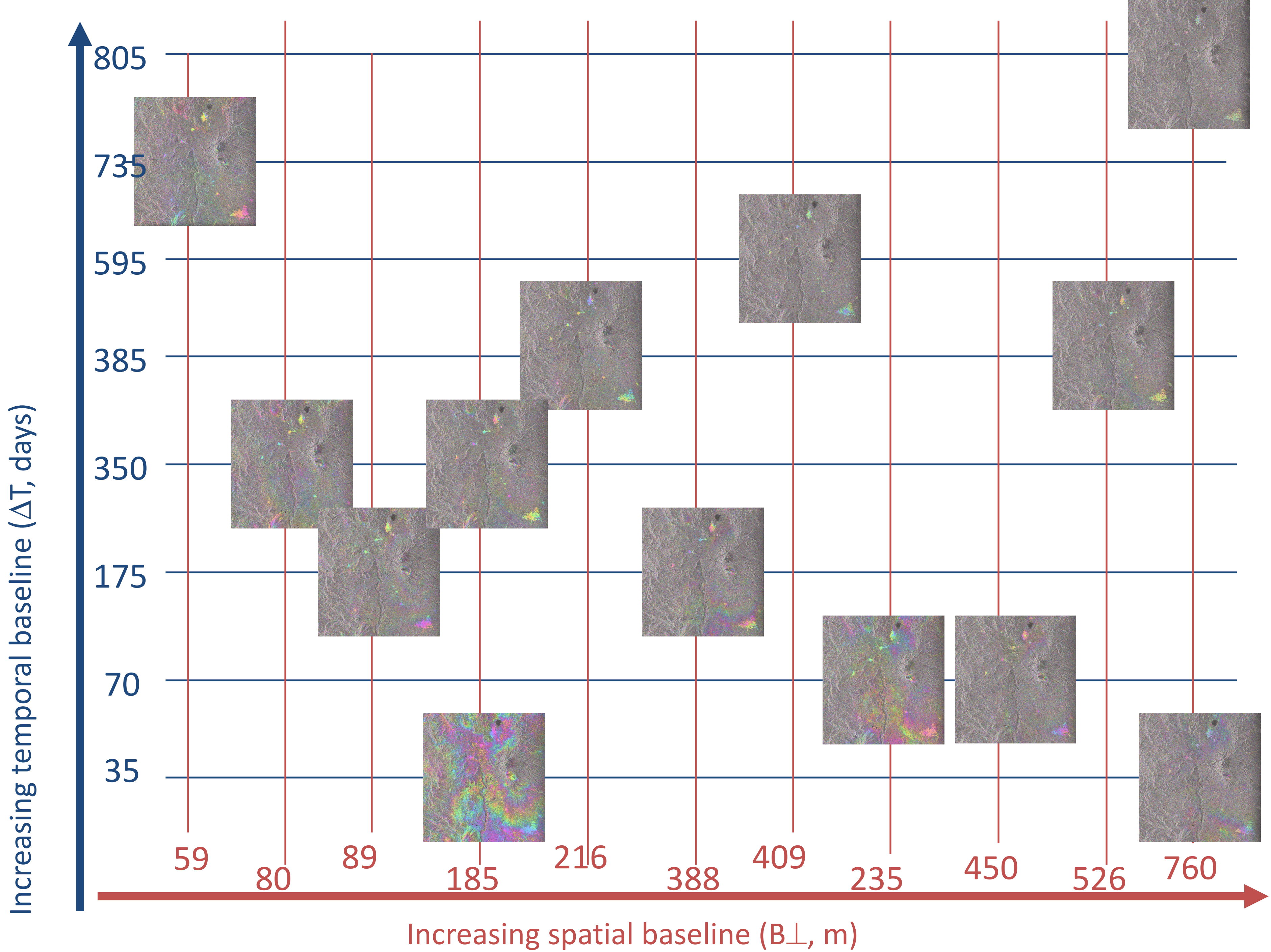
ΔT=35 days
B⊥=826m





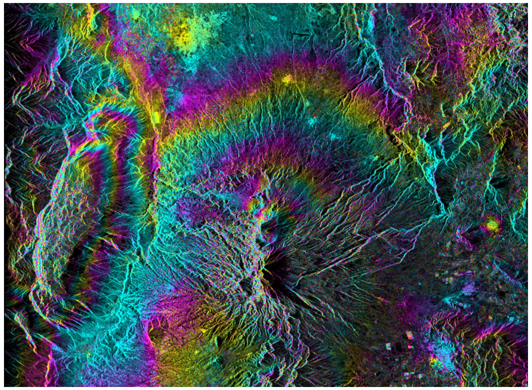
From Wauthier & al. , 2013

$$coherence = \gamma = \frac{\left|\sum M_i . E_i^*\right|}{\sqrt{\sum |M_i|^2 . \sum |E_i|^2}} \quad ; \quad 0 \le \gamma \le 1$$



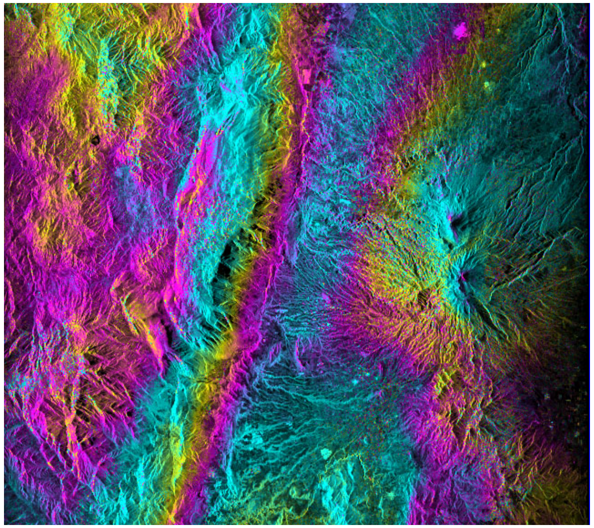
Increasing temporal baseline (ΔT, days)
805
735
595
385
350
175
70
35
59
80
89
185
216
388
409
235
450
526
760
Increasing spatial baseline (B⊥, m)

Coherence is better with L-band over vegetated areas



ENVISAT: ΔT=385 days
B⊥=5m

C-band

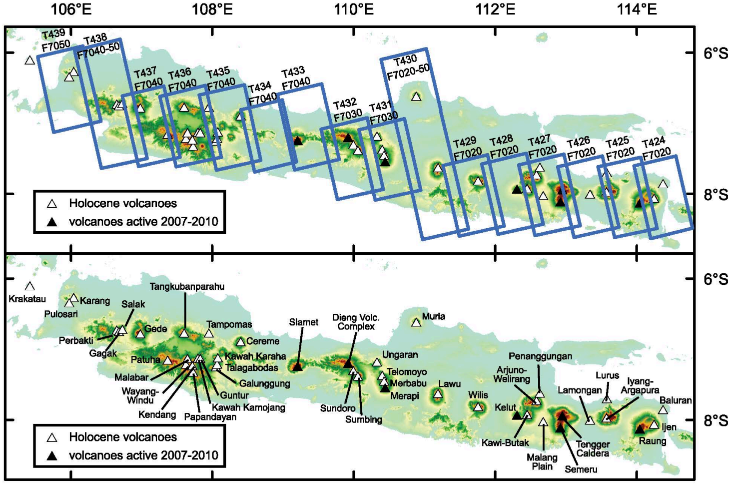


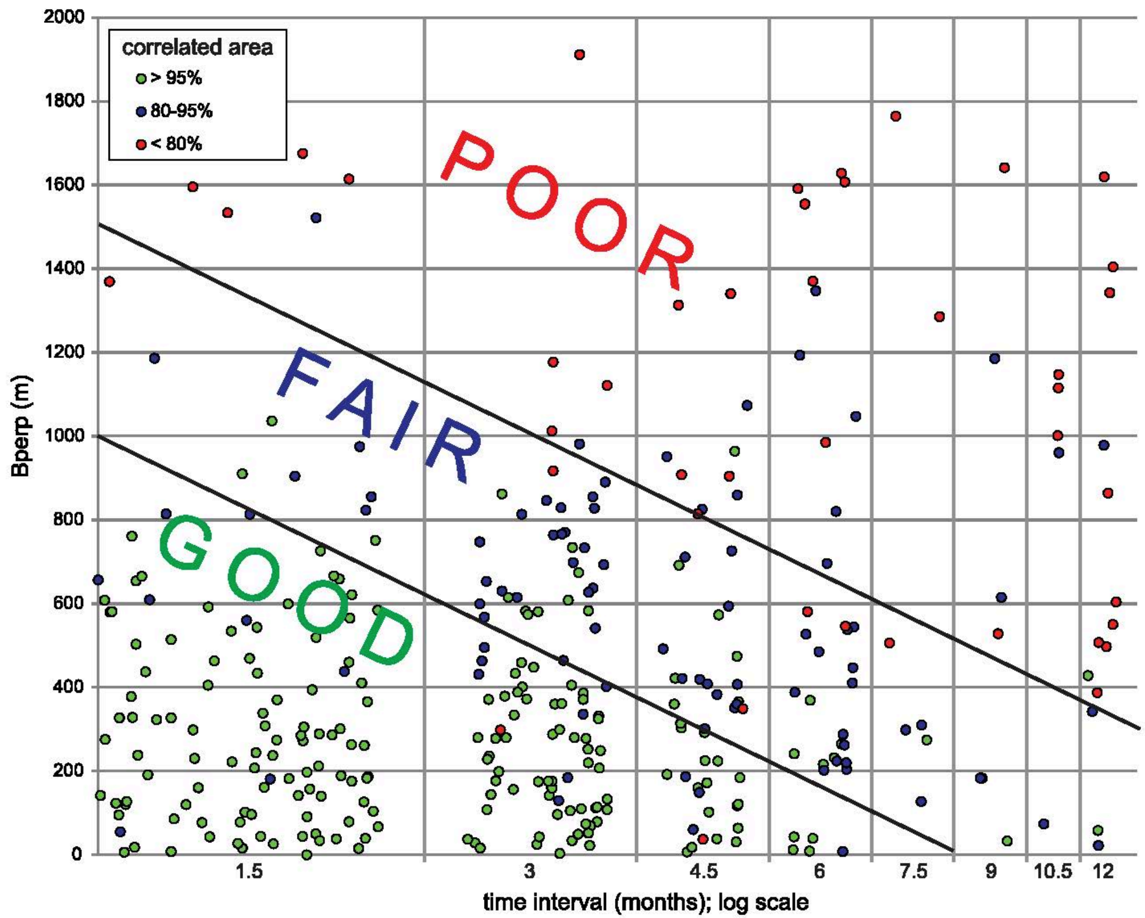
ALOS: ΔT=873 days
B⊥=177m

L-band

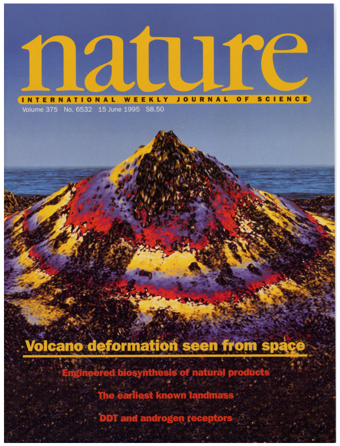
Coherence with L-band over Java

From Philibosian & Simons , 2011





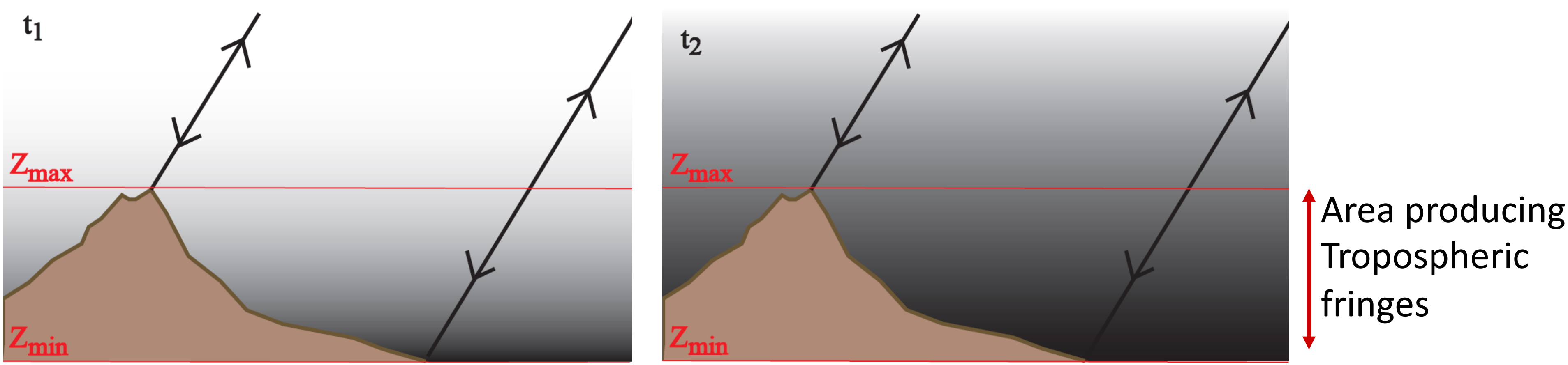
Main limitation is due to atmospheric artefacts



(Massonnet et al., 1995)

Only half of the observed signal was due to the volcanoe deflation
(Delacourt et al., 1998)
Some interferograms were 100% tropospheric effects as the Nature cover image!
(Beauducel et al., 2000)

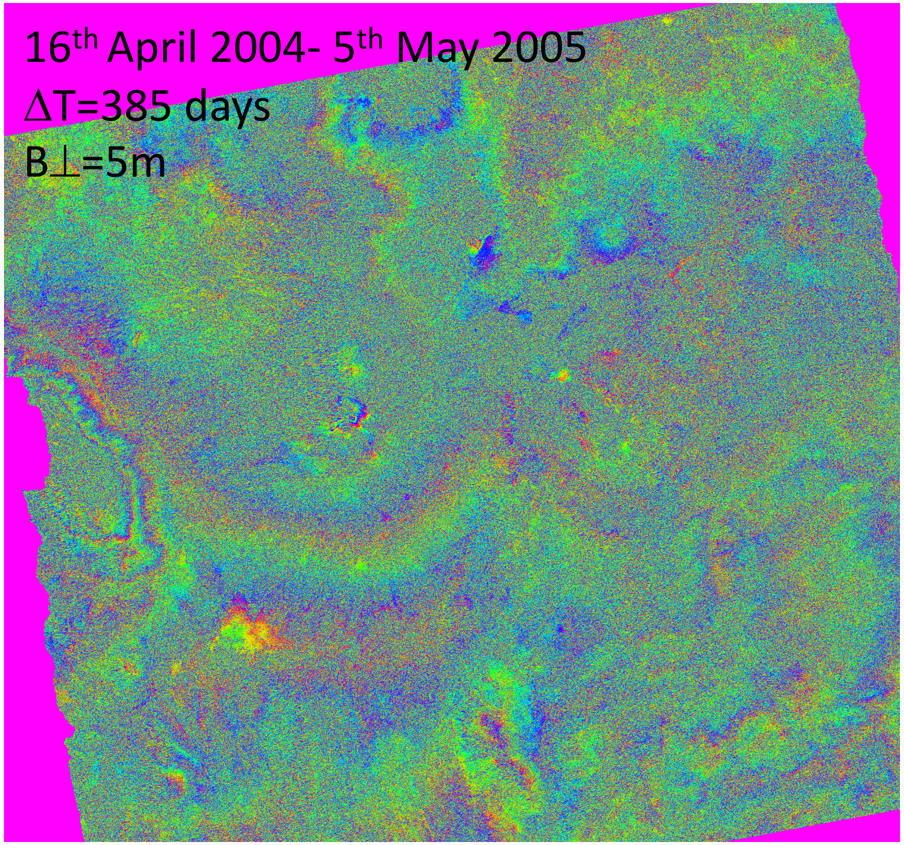
Variation in the water content of the troposphere induce « tropospheric fringes» correlated with topography.



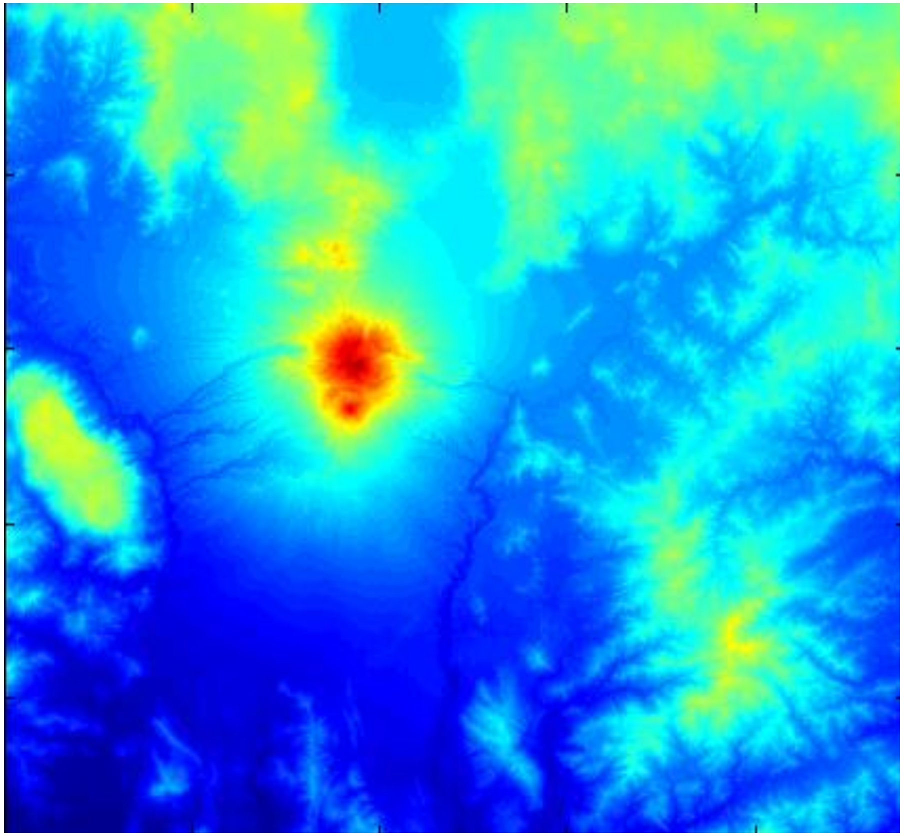
Main InSAR limitations

*Poor temporal resolution

*Atmospheric artefacts:



DEM-SRTM



Some products are already available online

- On space agencies plateforms:
  - GEP Volcano Trial Case

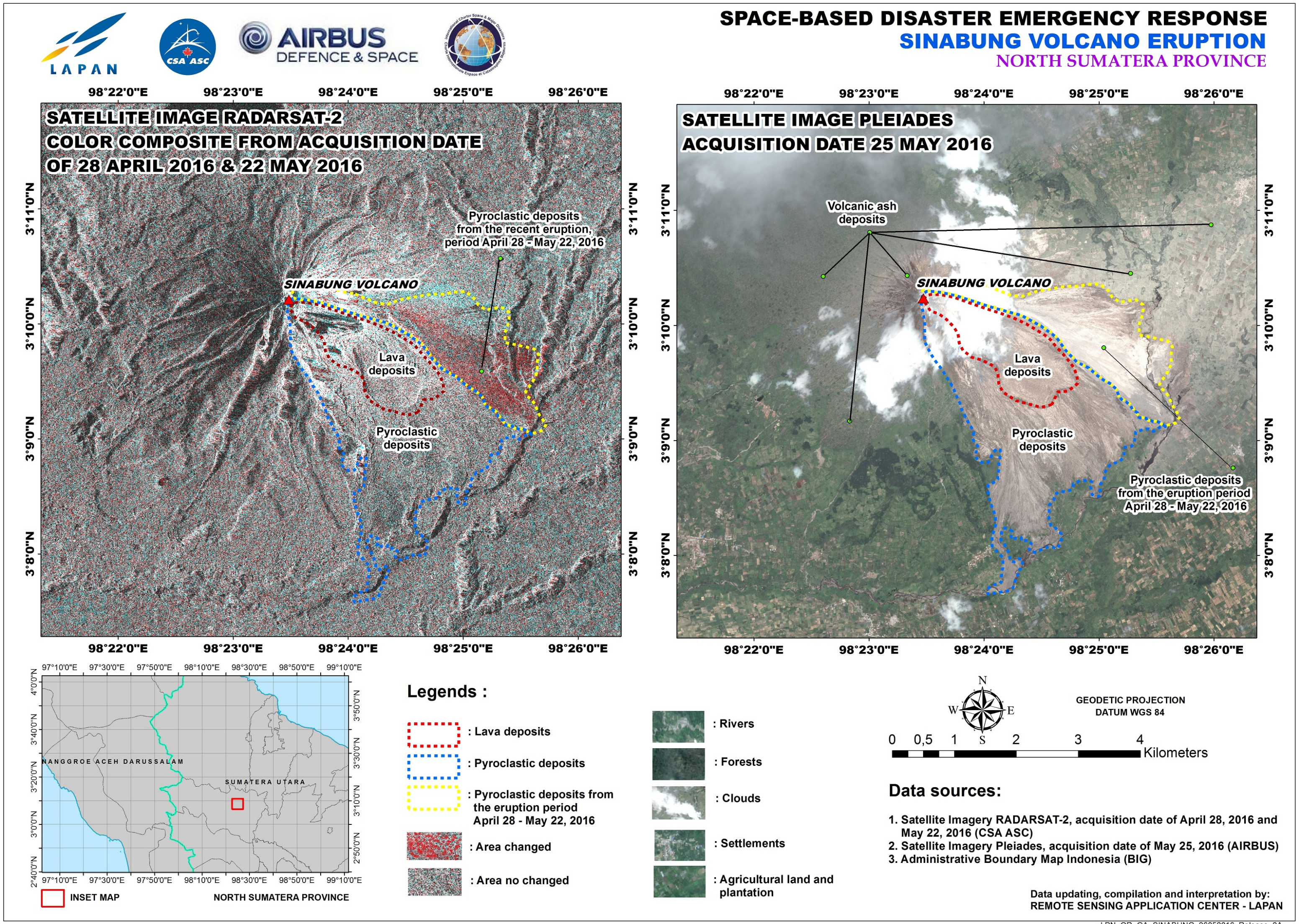
- On specific plateforms: Miami Supersites: http://insarmaps.rsmas.miami.edu/?startDataset=ALOS_SM_422_7010_20070221-20090226_0000_00000

In case of crisis:

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

Ex activated on Sinabung by LAPAN in april 2016

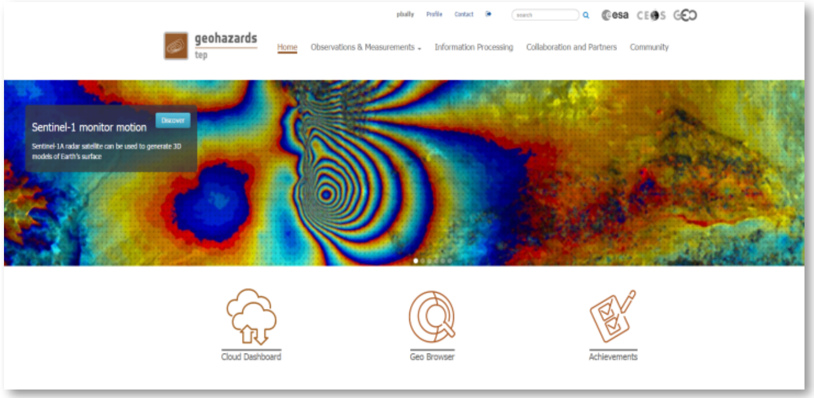
In case of crisis:



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

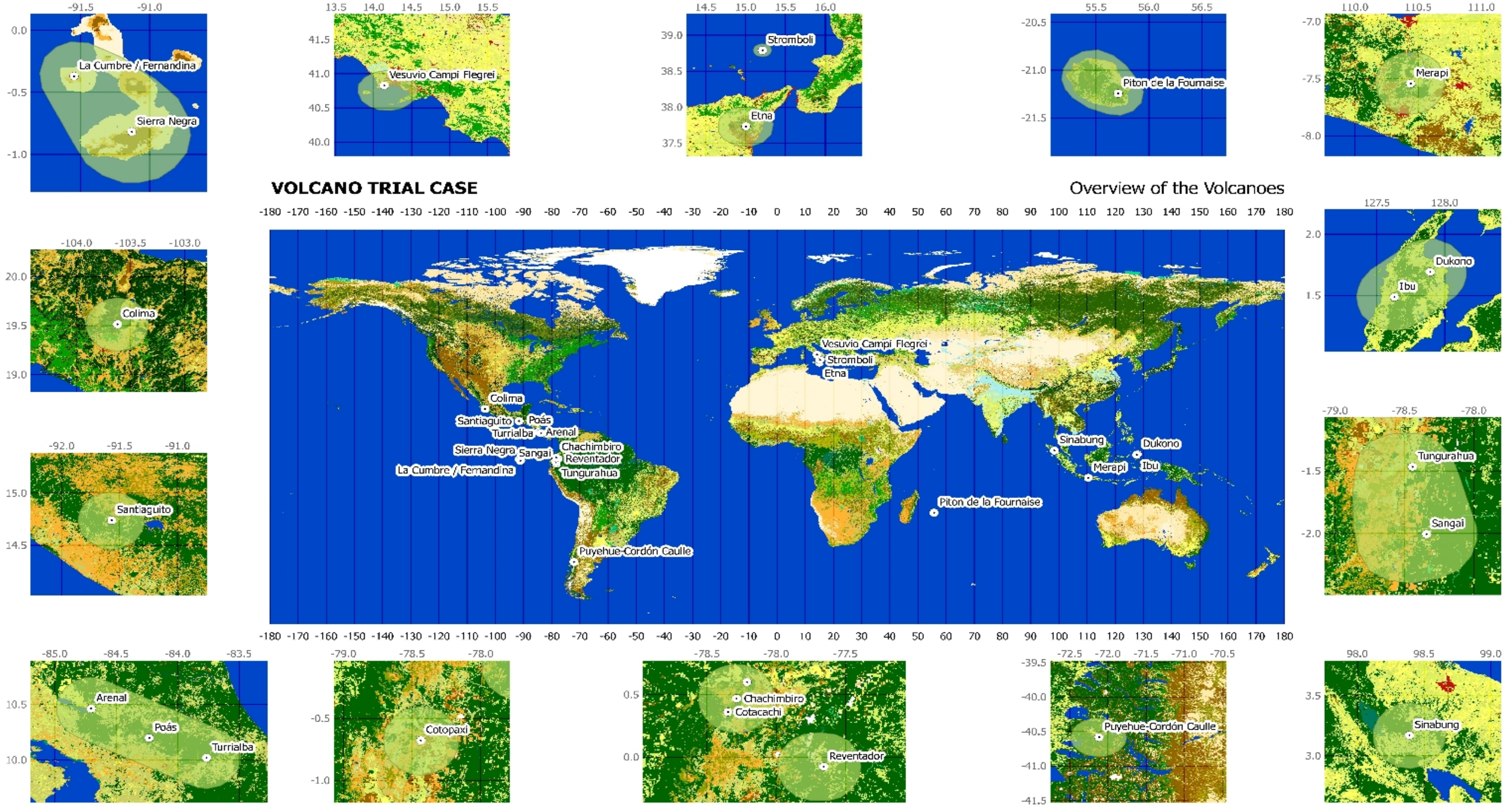
-**radar images** (Sentinel-1 amplitude and 12 day (or 6 day) coherence) to assess surface changes at volcanoes

3 processing chains will be tested:

-STEM developped by INGV for Surface Temperature mapping,

-VEGAN for Hot spot detection and vegetation vigour mapping

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



POST-FLOODING OR IRRIGATED CROPLANDS (OR AQUATIC)
RAINFED 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.

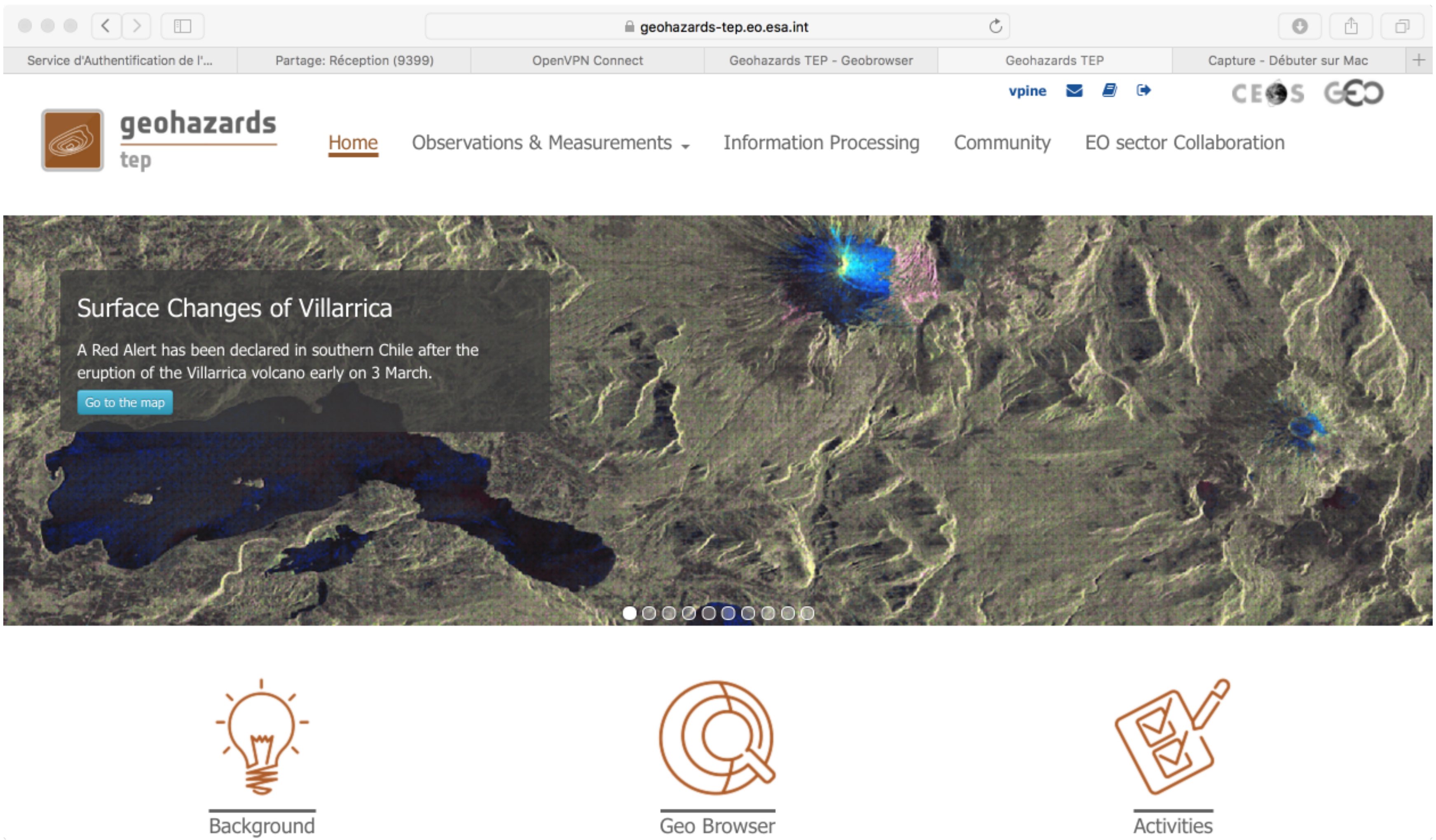
GEP access
https://geohazards-tep.eo.esa.int

- Inscription on ESA website:
  https://eo-sso-idp.eo.esa.int/idp/umsso20/admin

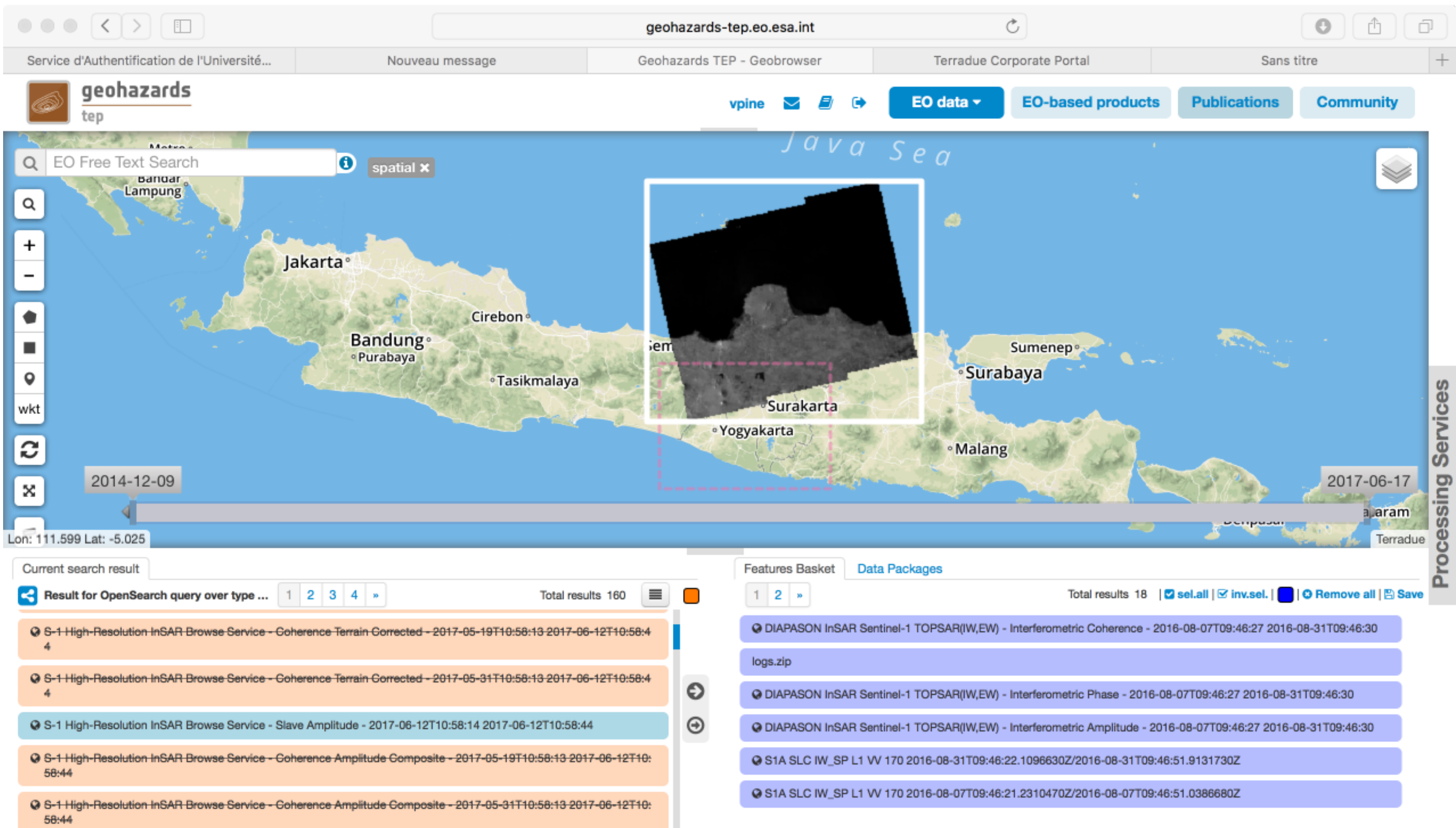
- Inscription on GEP platform
- Through a User Form URF =Early Adopter Registration Document
- Installation of the vpn to download products

GEP access

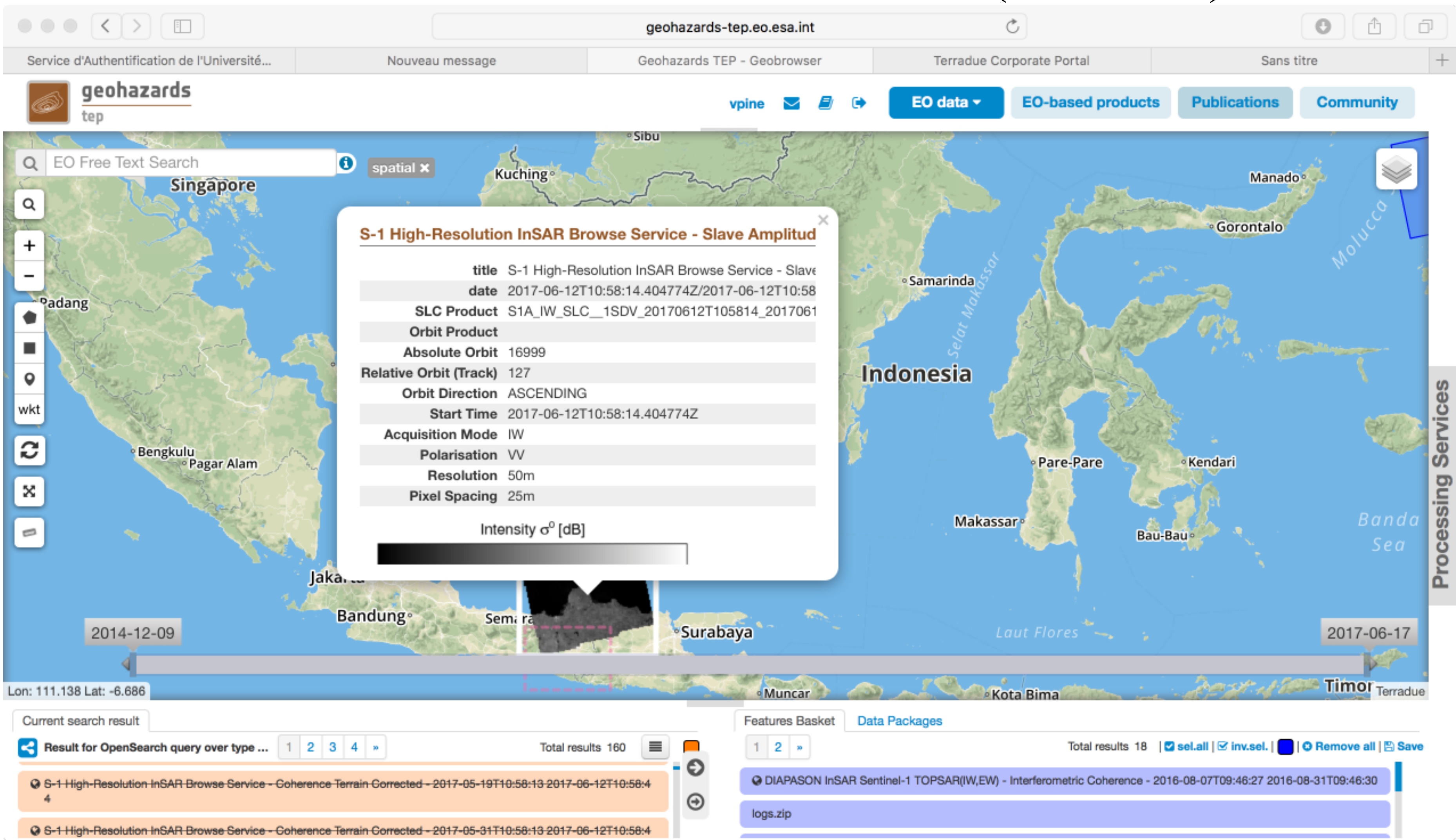
https://geohazards-tep.eo.esa.int



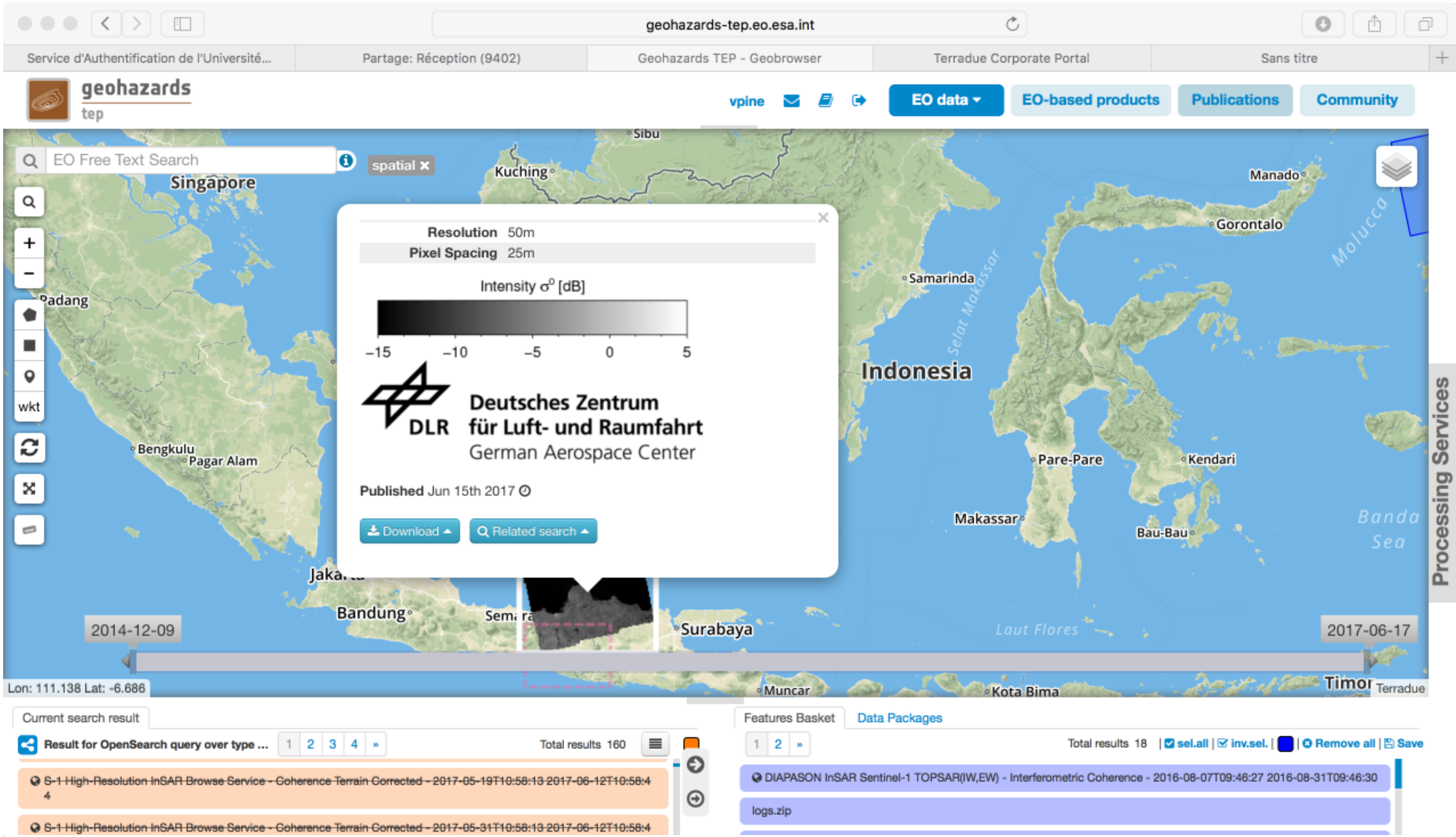
Products of the Volcano Trial Case: DLR InSAR Sentinel-1 Browse (HR:50m)



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



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



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)

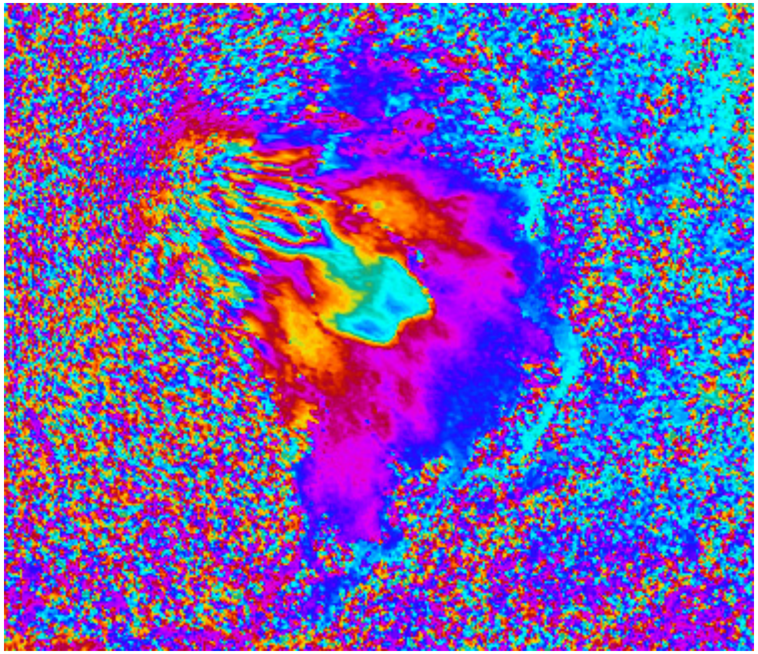
5. amplitude coherence composite (displaying the master calibrated amplitude in Green and Blue and, in Red, the interferometric correlation i.e. the coherence of the S-1 pair)

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)

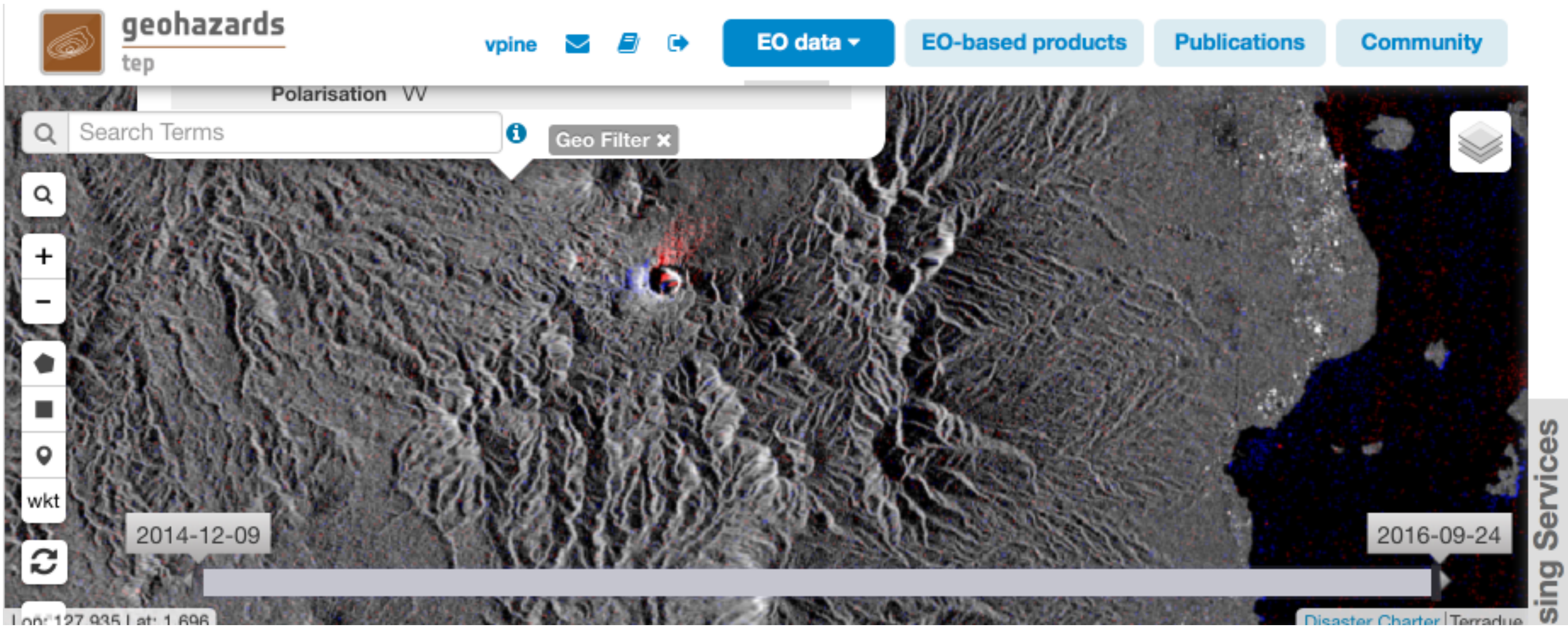
Interferogram	Geotiff image: 4 bands: 3 bands (RGB phase) 1 band (mask 255 where information,0 elsewhere)

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 plateforms:
  - GEP
- On your own computer ressources
  - 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/

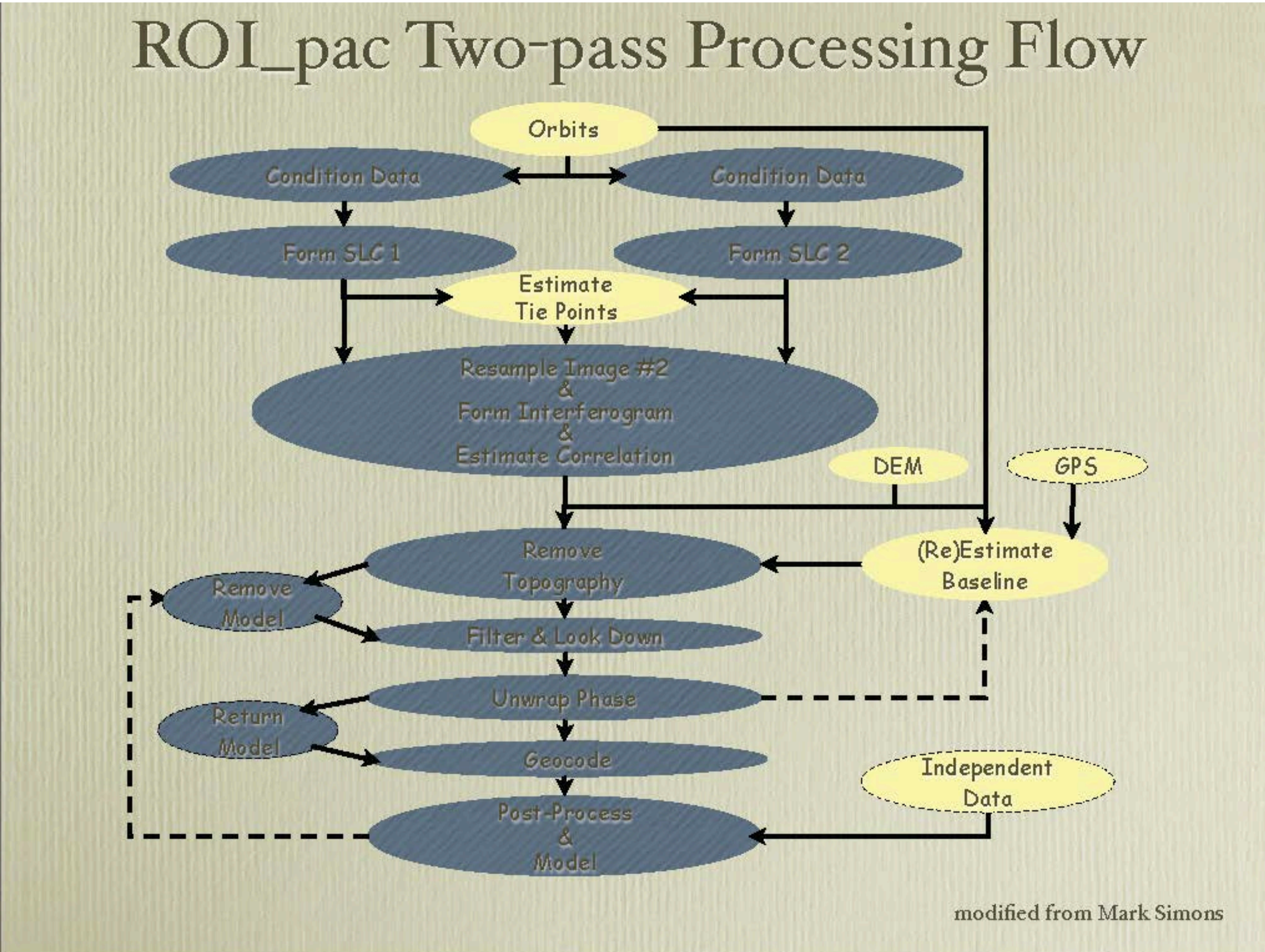
A geotiff file can be downloaded

(also SRTM3 90 m for automatic download

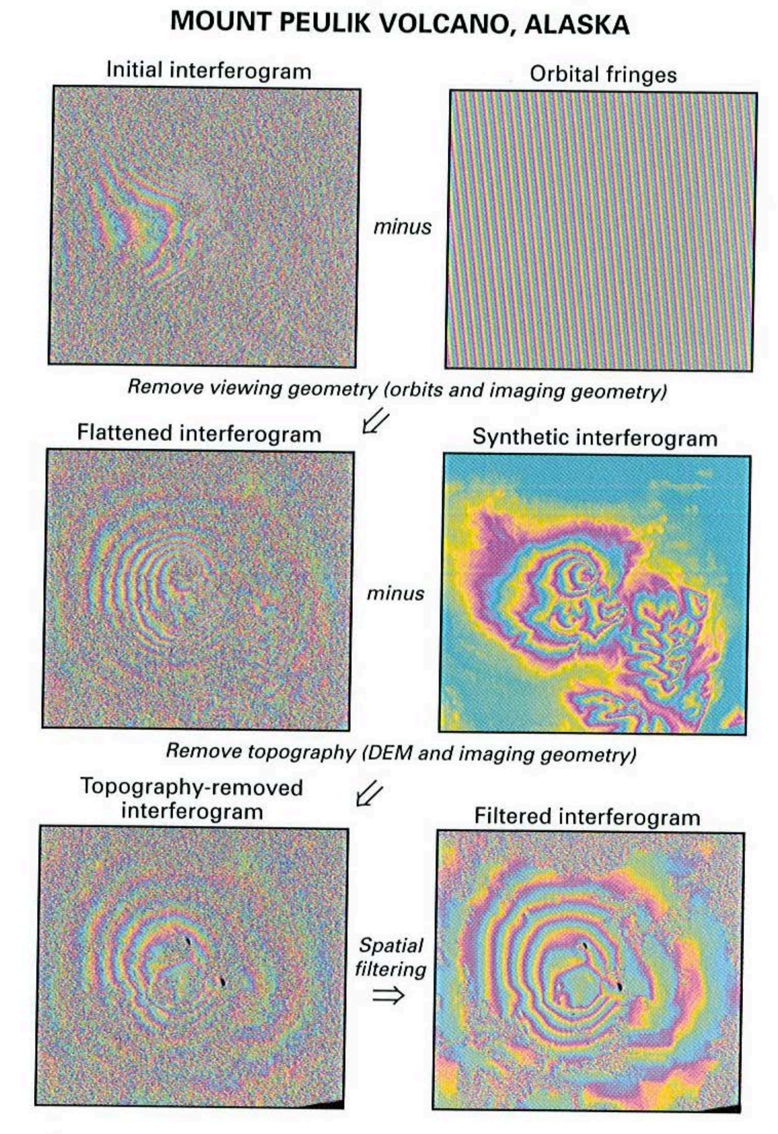
https://dds.cr.usgs.gov/srtm/version2_1)

- 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).

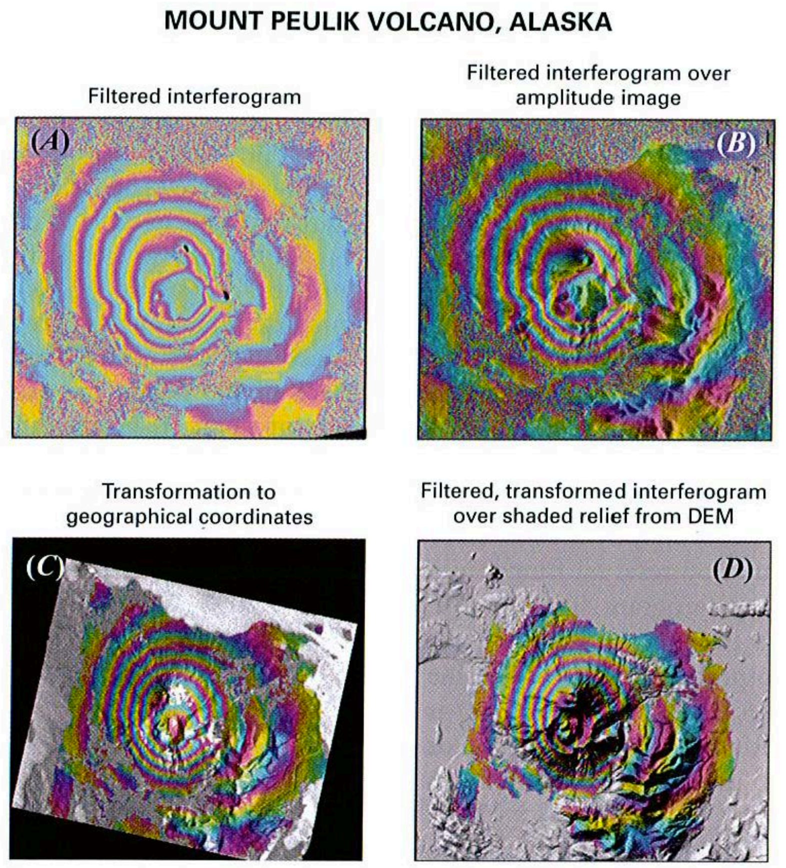


Processing chain (ROIPAC example).



From Dzurizin, 2007

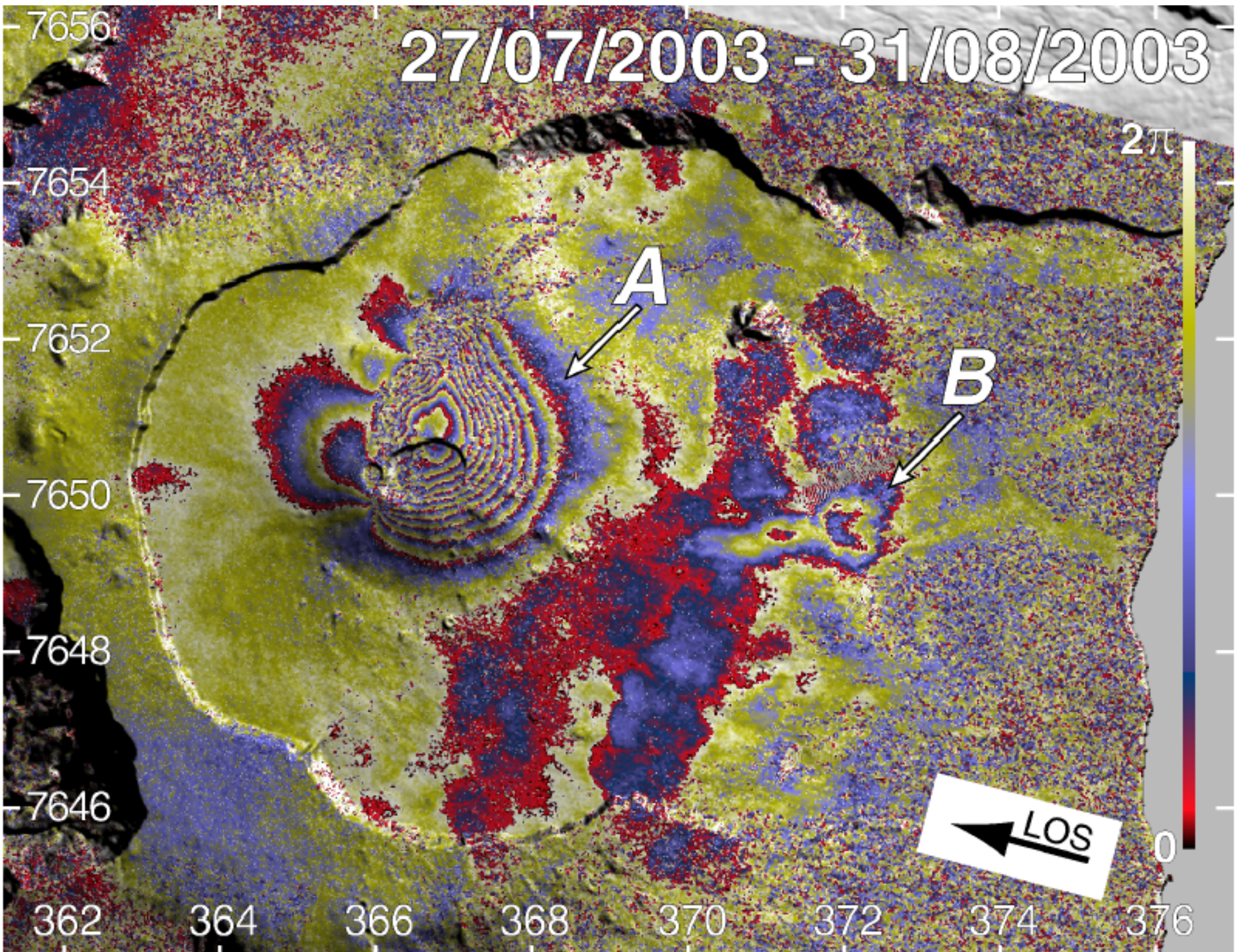
Processing chain (ROIPAC example).



From Dzurizin, 2007

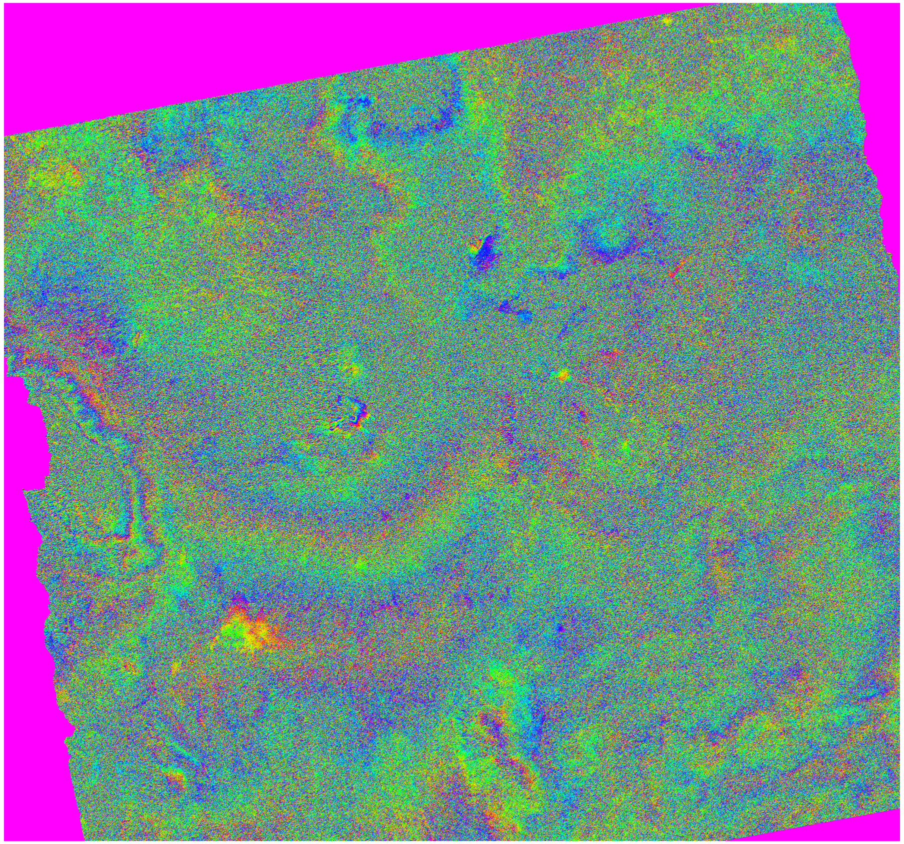
An example of interferogram

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



From Froger et al, 2004

Signal is not always so obvious



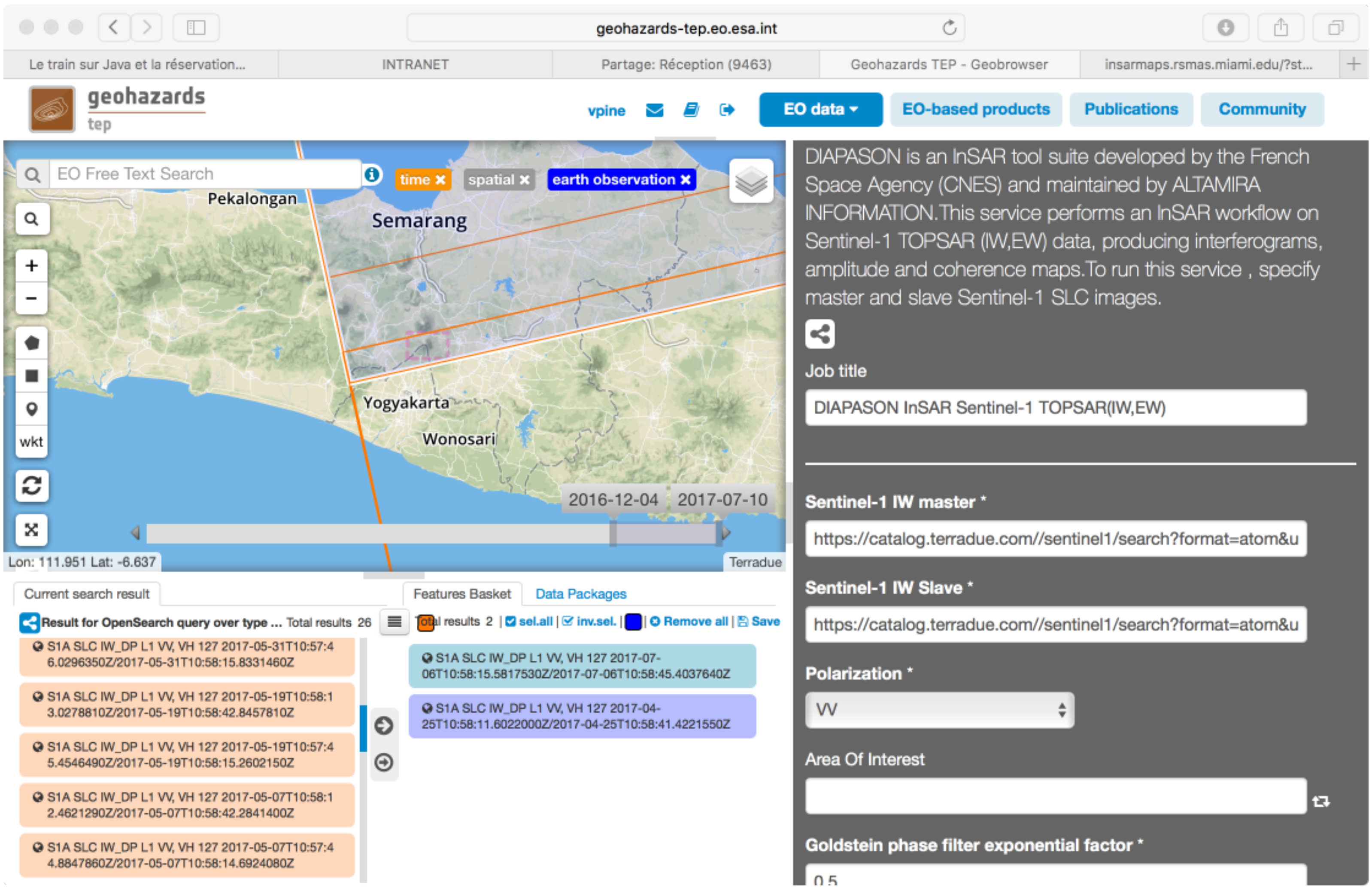
Atmospheric, orbit and DEM errors

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

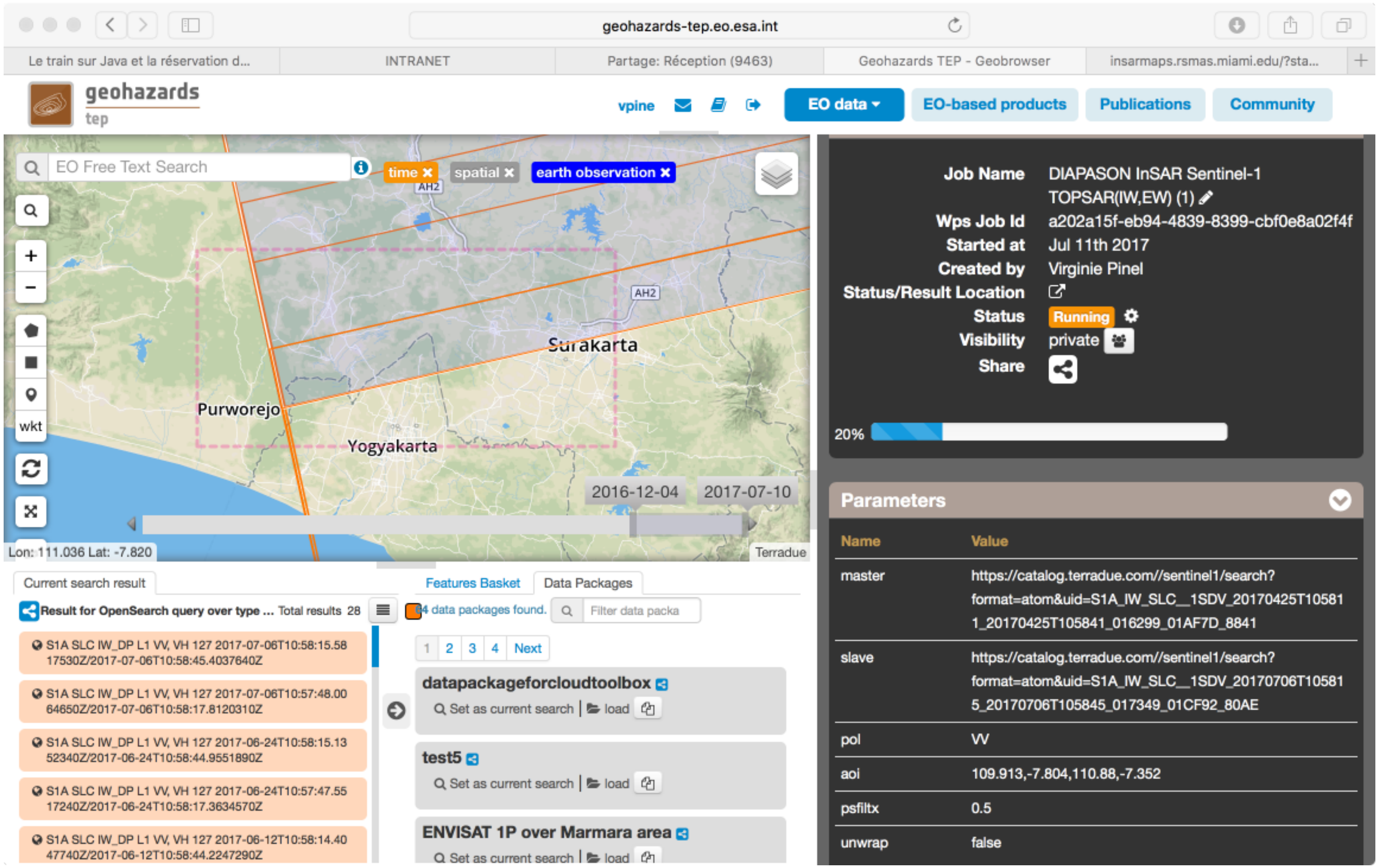
Interferogram production using Diapason on GEP

- 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)

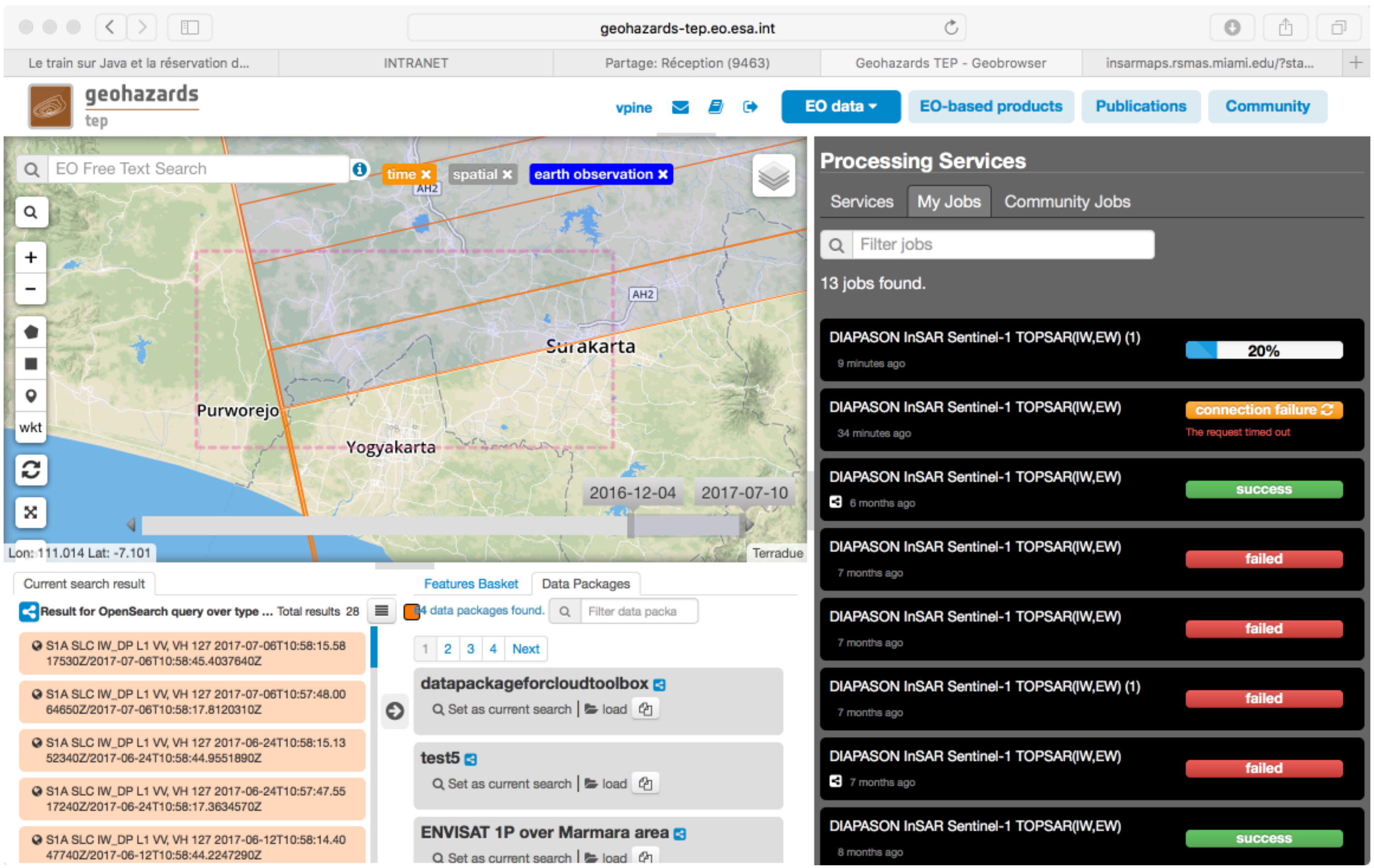
Interferogram production using Diapason on GEP



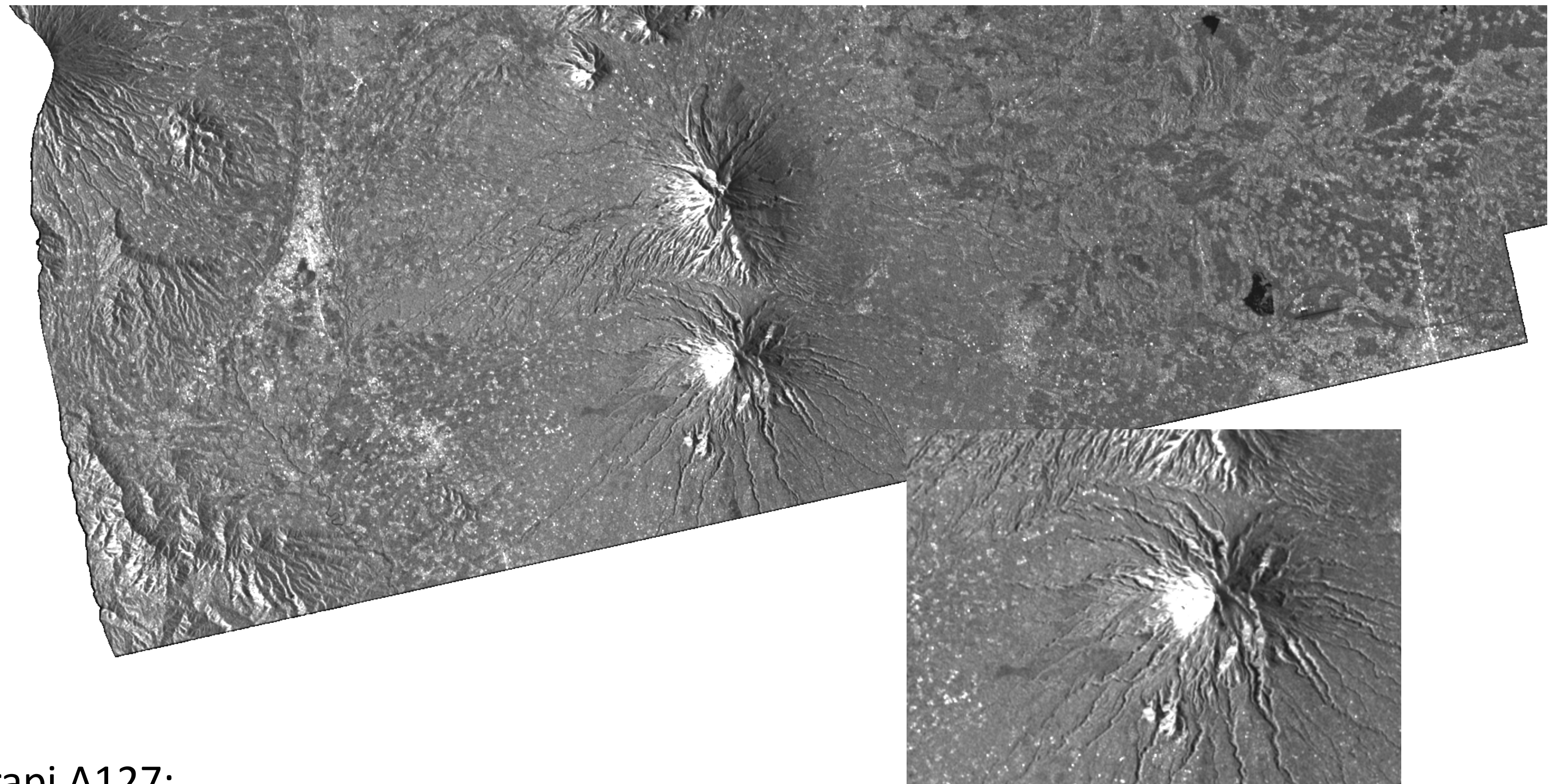
Interferogram production using Diapason on GEP



Interferogram production using Diapason on GEP

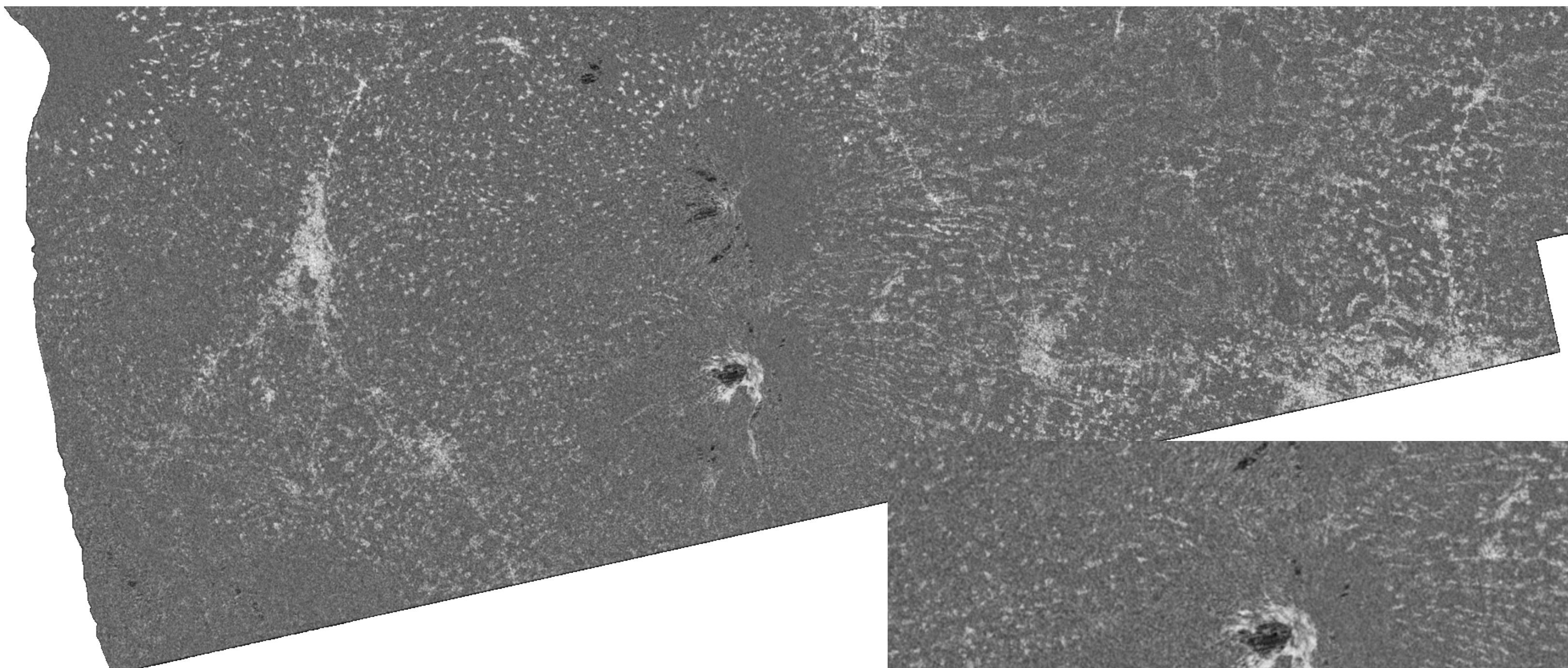


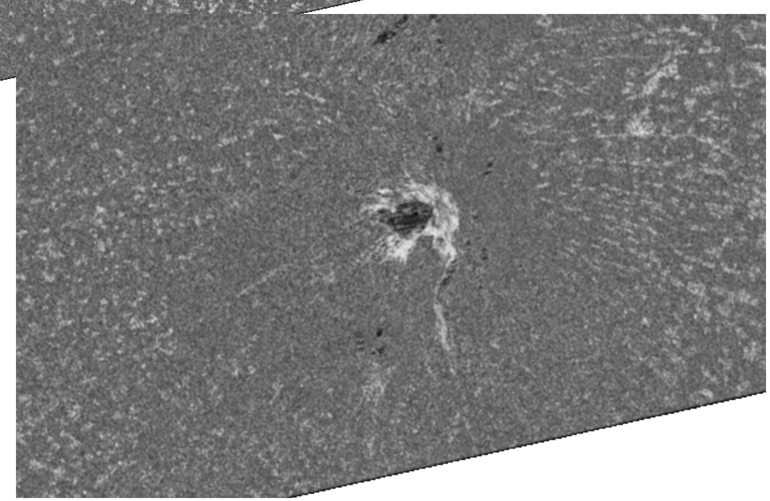
Interferogram production using Diapason on GEP



Merapi A127:
25 April 2017-6 july 2017

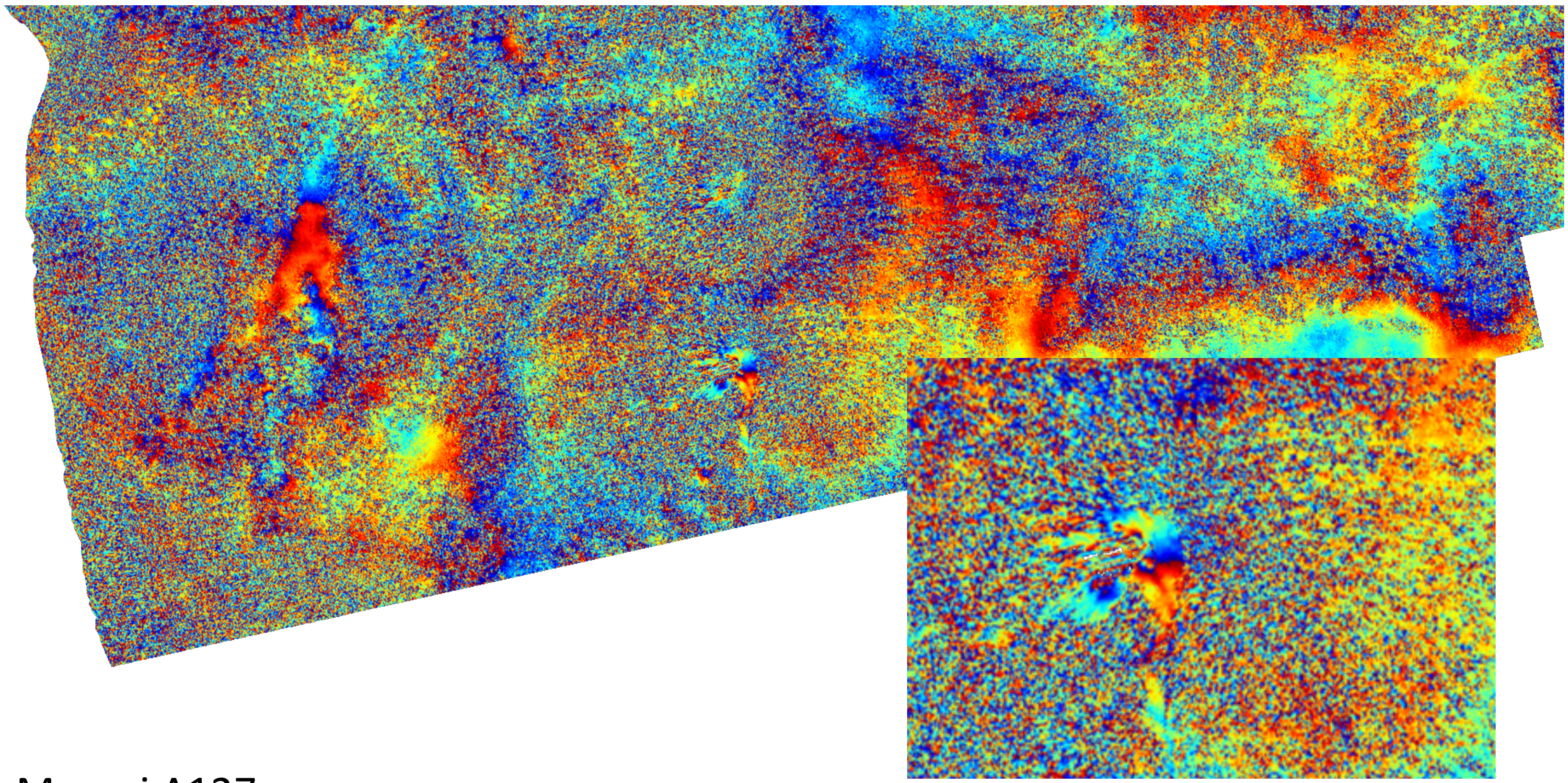
Interferogram production using Diapason on GEP





Merapi A127:
25 April 2017-6 july 2017

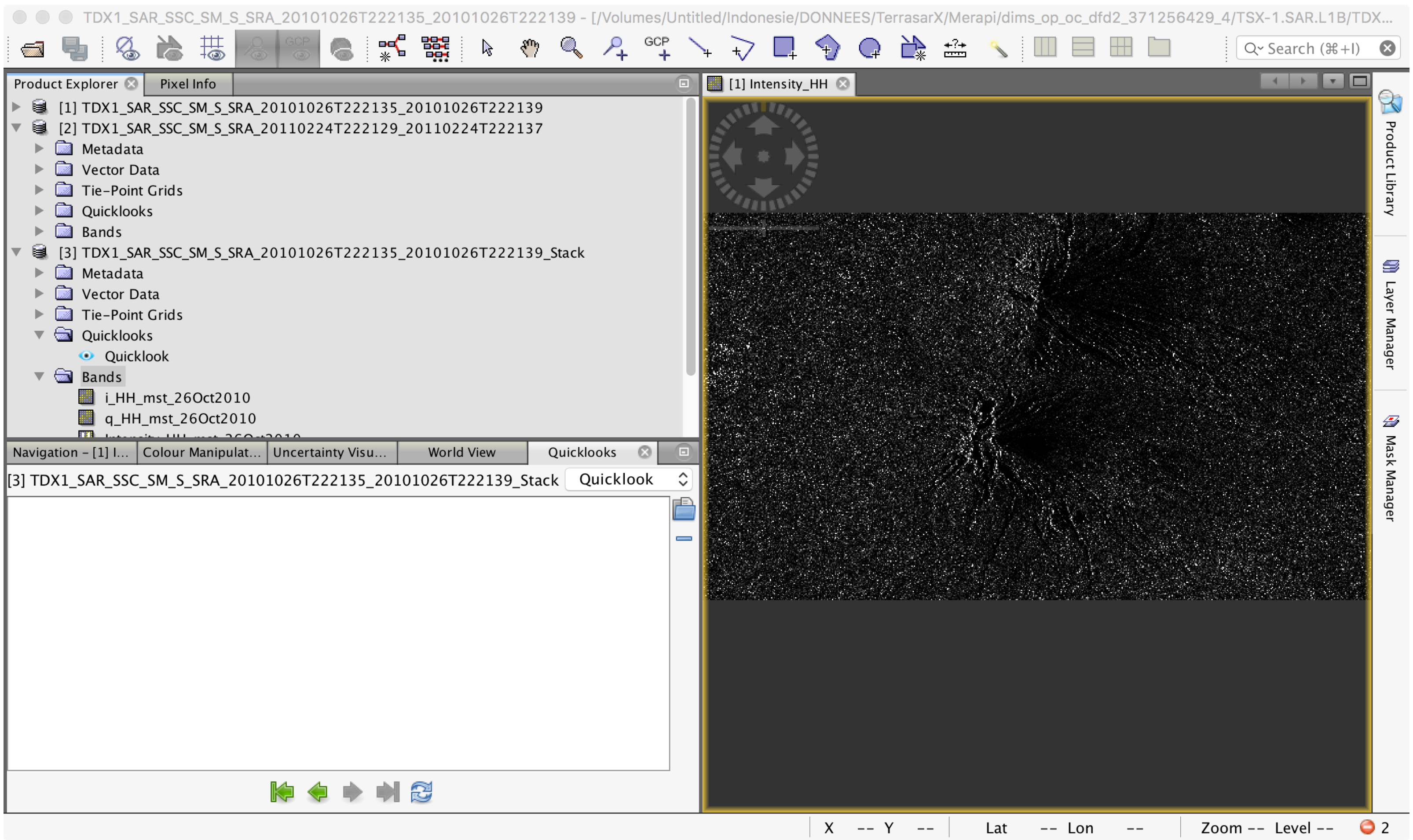
Interferogram production using Diapason on GEP



Merapi A127:
25 April 2017-6 july 2017

SNAP:

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



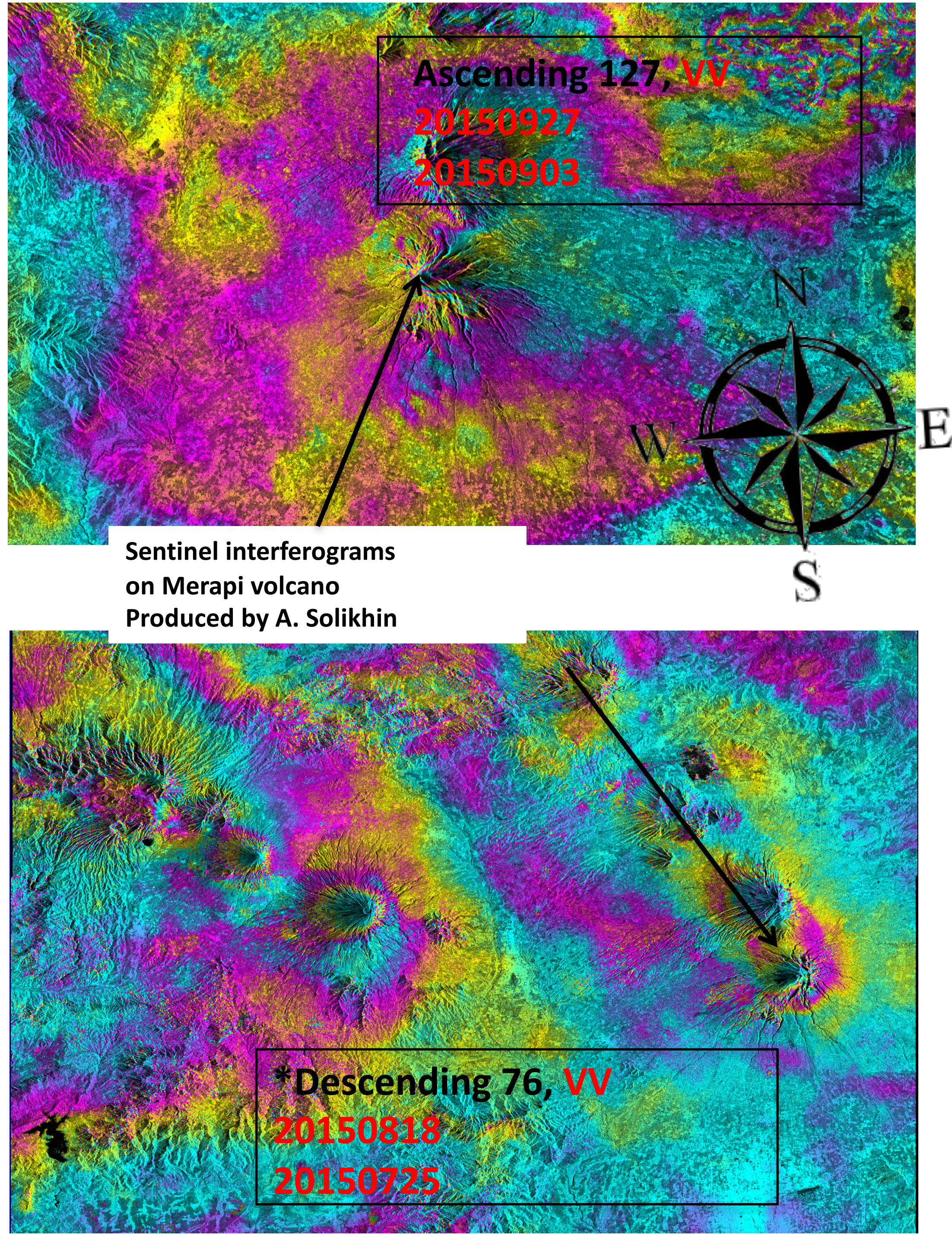
GMTSAR

- 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.

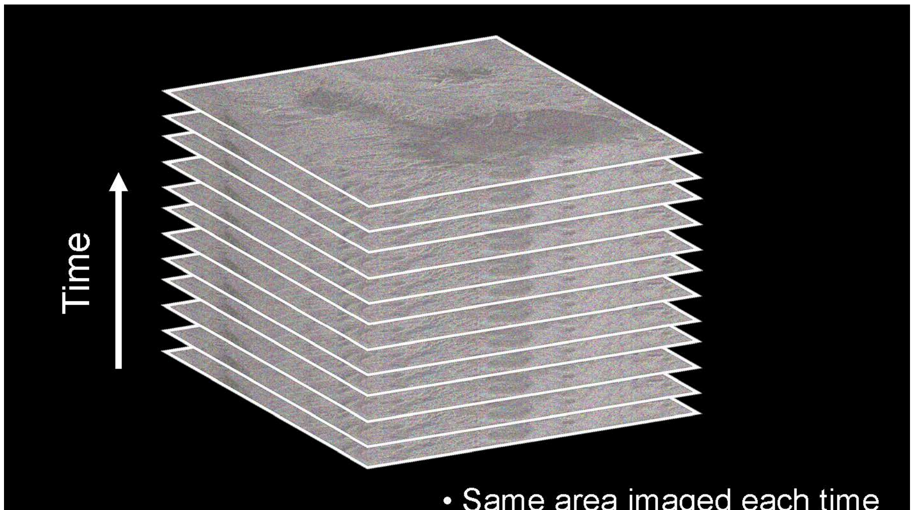
- Also see UNAVCO courses: http://www.unavco.org/education/professional-development/short-courses/course-materials/insar/2015-insar-gmtsar-course-materials/2015-insar-gmtsar-course-materials.html

InSAR processing using ROIPAC



Sentinel interferograms
on Merapi volcano
Produced by A. Solikhin

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



From Hooper, Fringe 2007

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

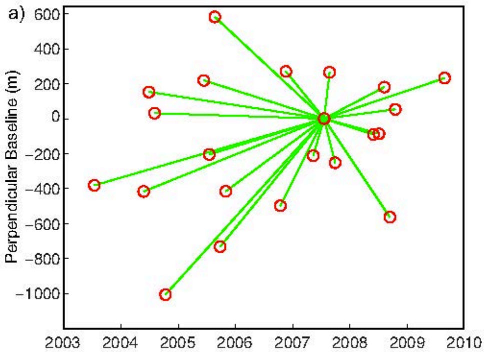
Any InSAR method using multiple images of the same area acquired at different time.

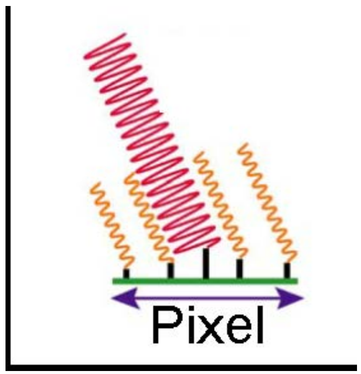
Two families of Time series studies

(see Hooper et al, Tectonophysics, 2012)

*Persistent Scatterer methods

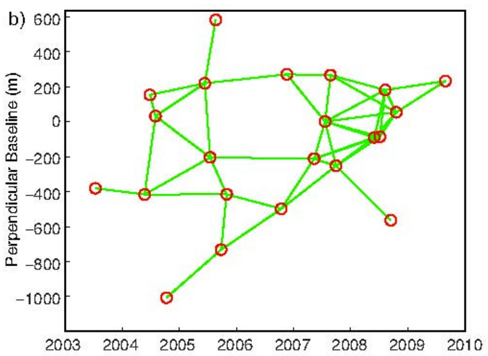
optimized for pixels dominated by a single scatterer

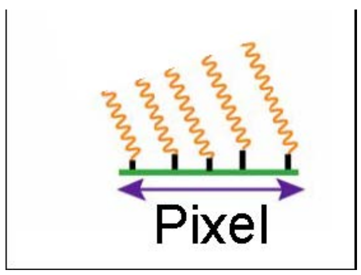




*Small Baseline methods:

optimized for pixels with a Gaussian distribution of scatterers



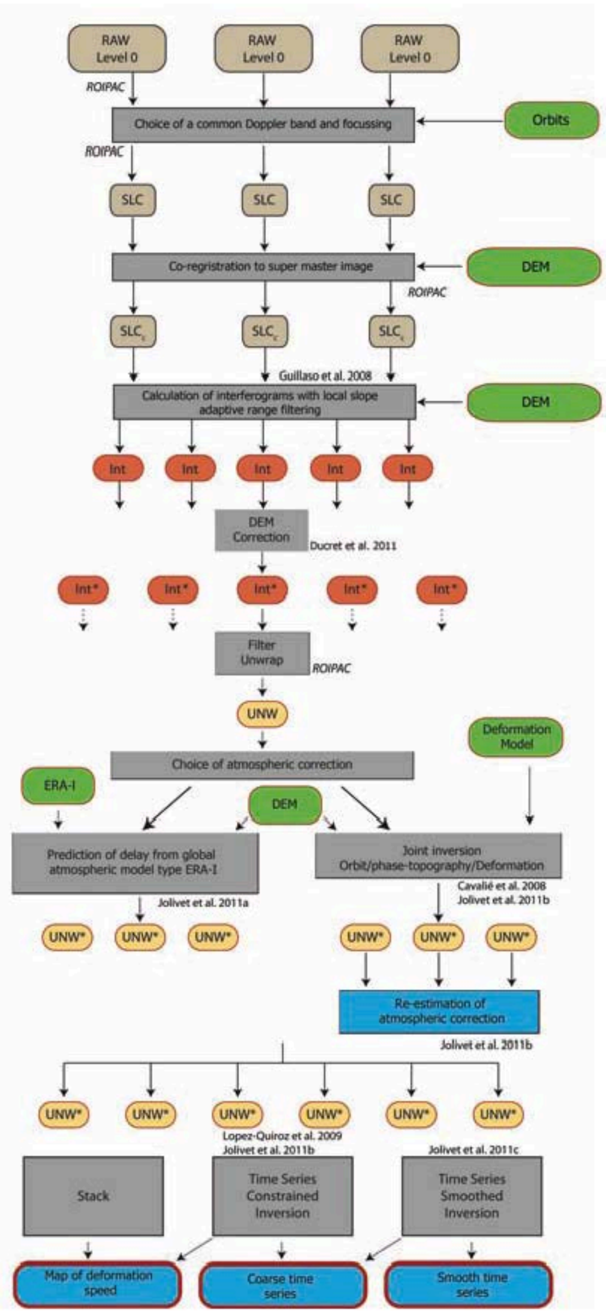


Processing chains
SAR time series

- 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

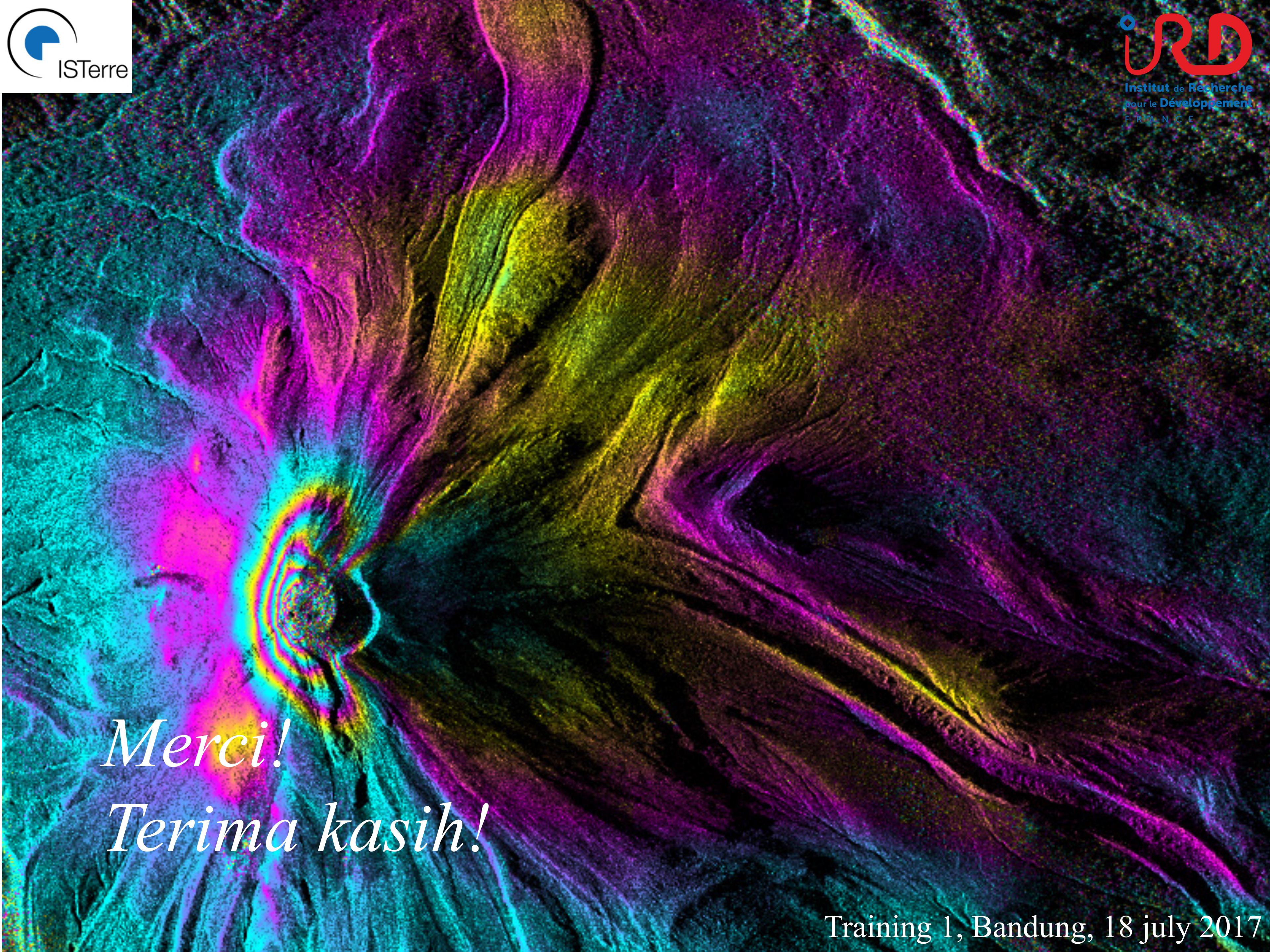
C. Elachi, Spaceborne radar remote sensing : applications and techniques, IEEE Press, 1988

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!