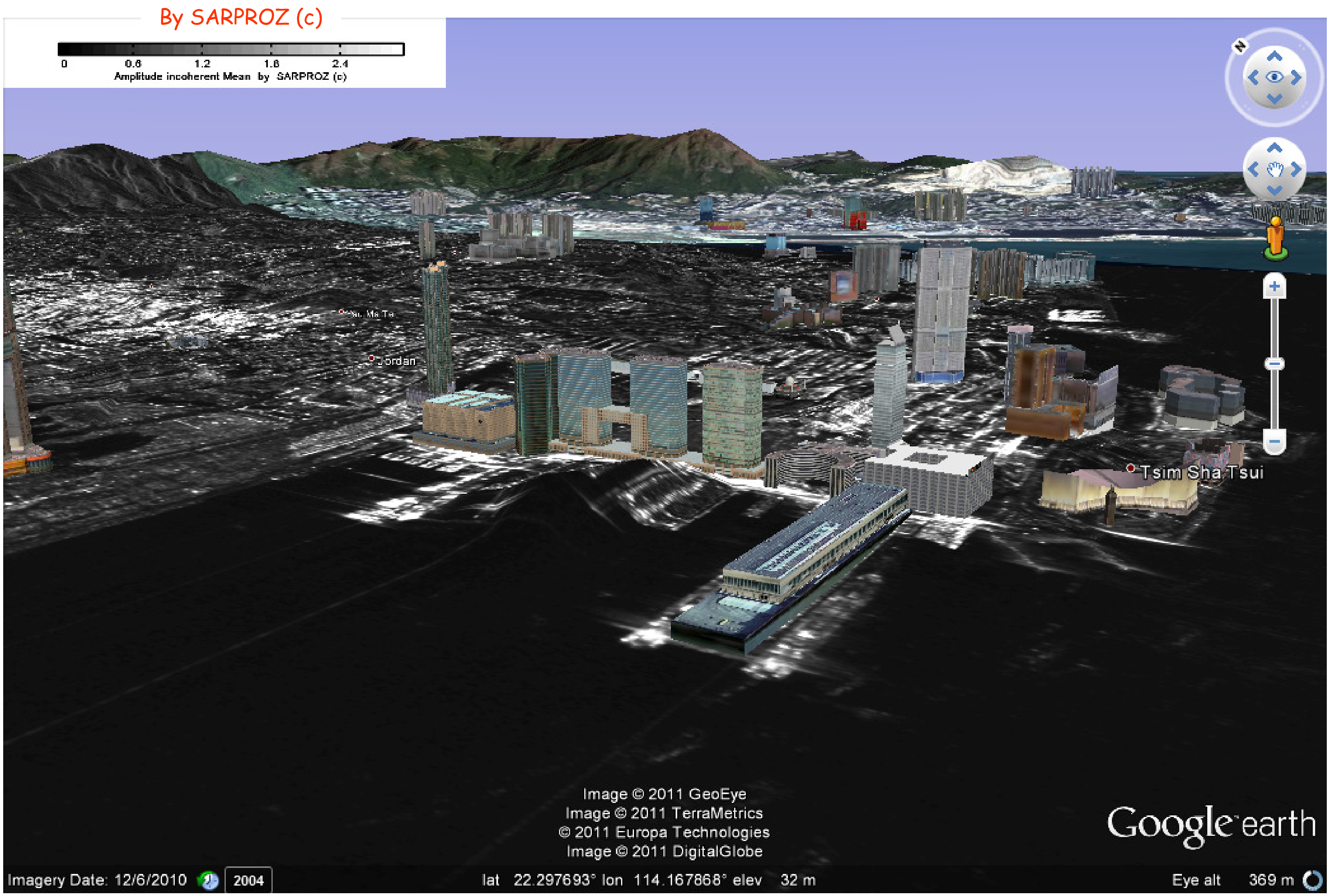
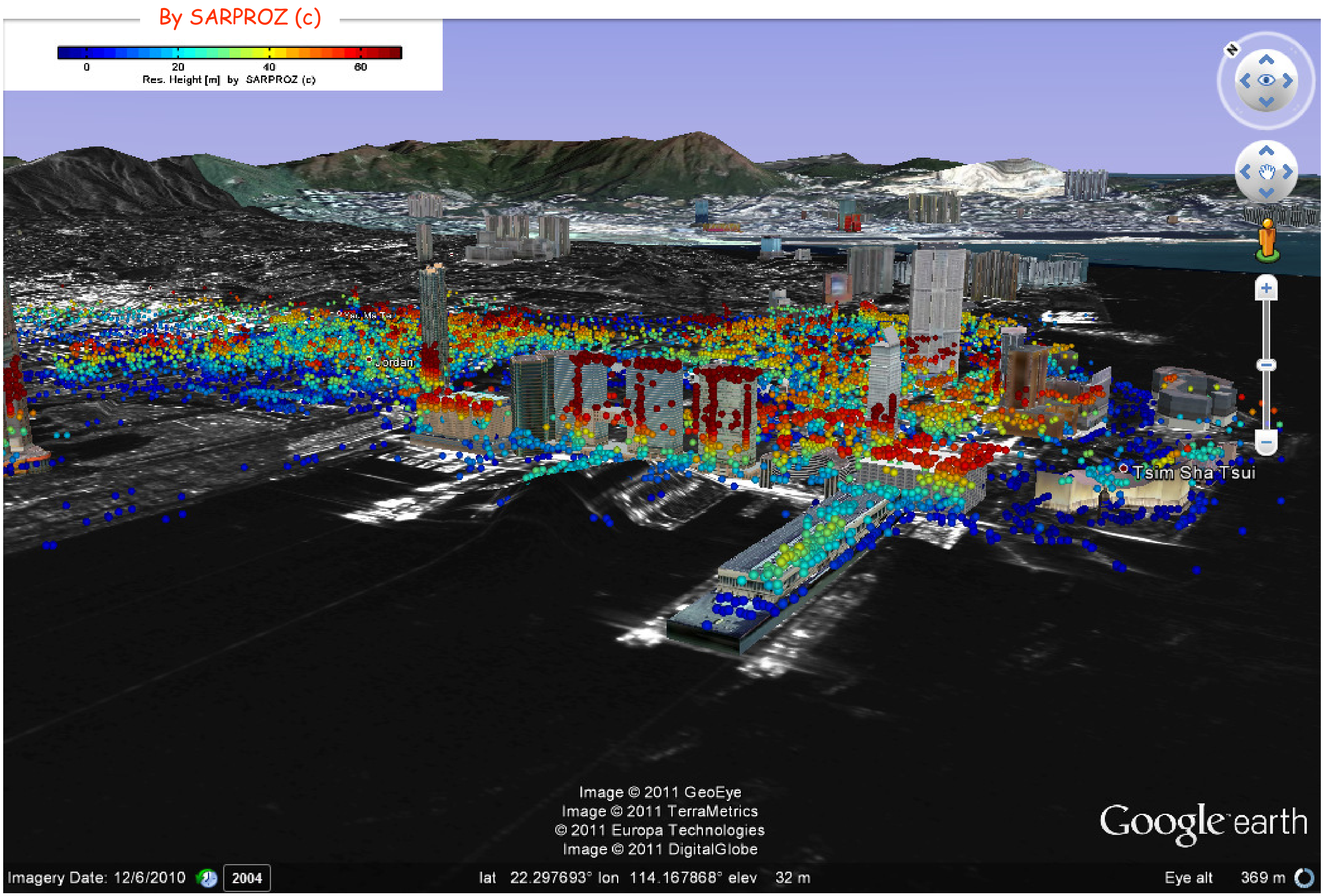
# Part II

# SAR Interferometry (InSAR)

## concepts and examples


By SARPROZ (c)
0 0.6 1.2 1.8 2.4
Amplitude incoherent Mean by SARPROZ (c)
Jordan
Tsim Sha Tsui
Image © 2011 GeoEye
Image © 2011 TerraMetrics
© 2011 Europa Technologies
Image © 2011 DigitalGlobe
Google earth
Imagery Date: 12/6/2010
2004
lat 22.297693° lon 114.167868° elev 32 m
Eye alt 369 m


By SARPROZ (c)
0
20
40
60
Res. Height [m] by SARPROZ (c)
Jordan
Tsim Sha Tsui
Image © 2011 GeoEye
Image © 2011 TerraMetrics
© 2011 Europa Technologies
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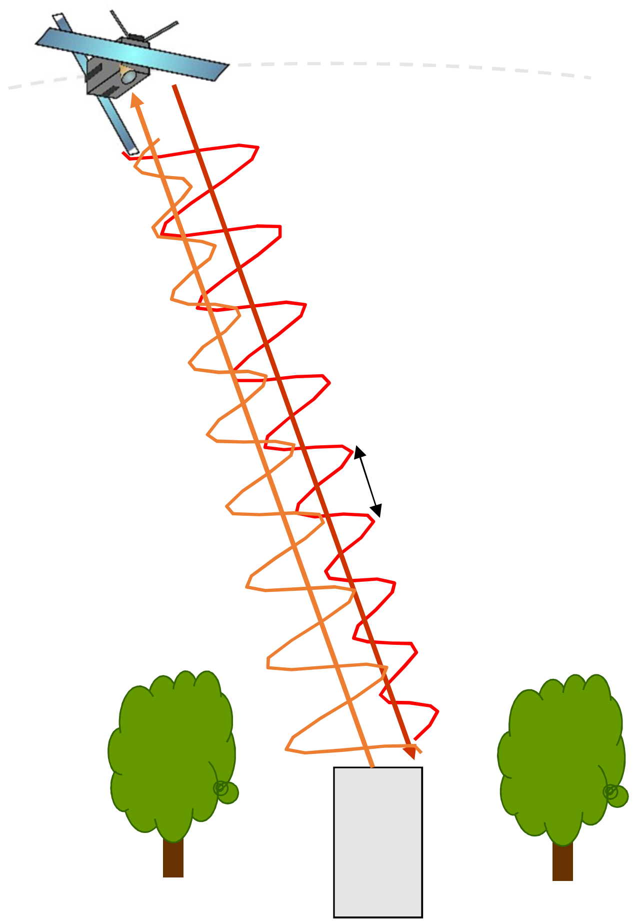
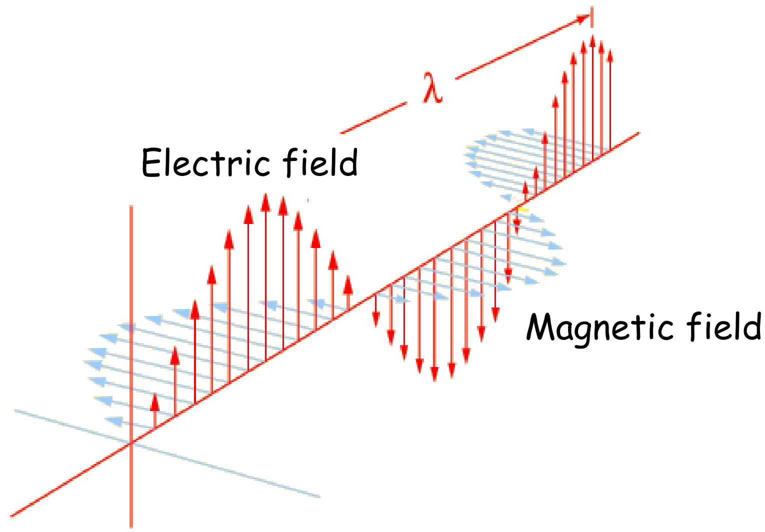
Google earth
Imagery Date: 12/6/2010
2004
lat 22.297693° lon 114.167868° elev 32 m
Eye alt 369 m

# The phase of a SAR image

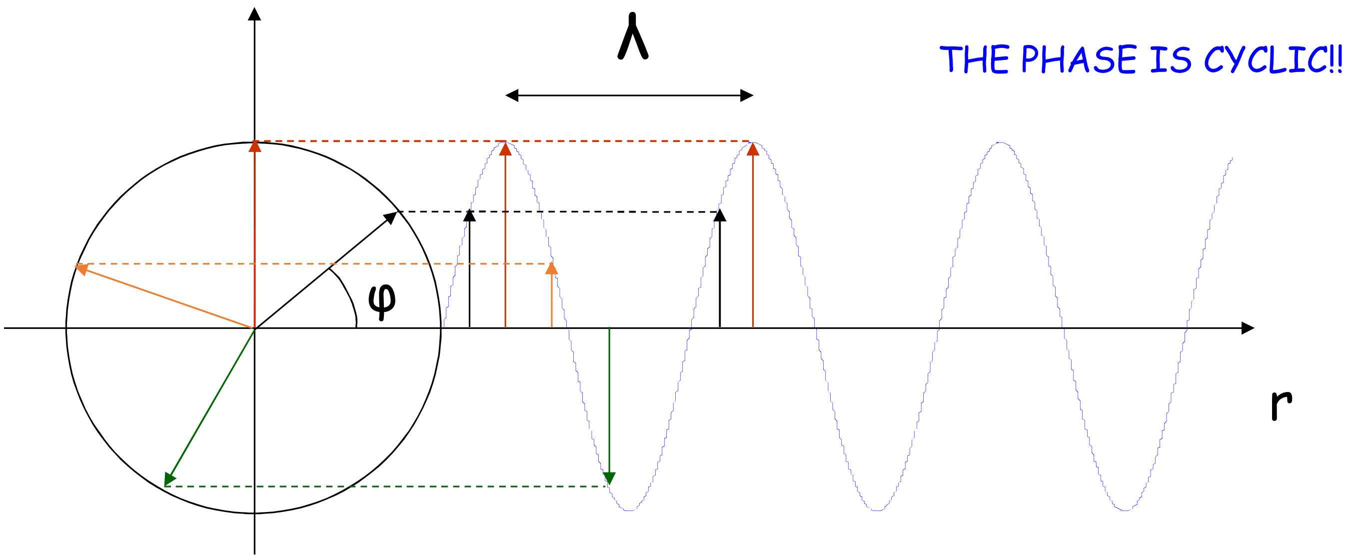
# Electromagnetic waves





# Electromagnetic waves

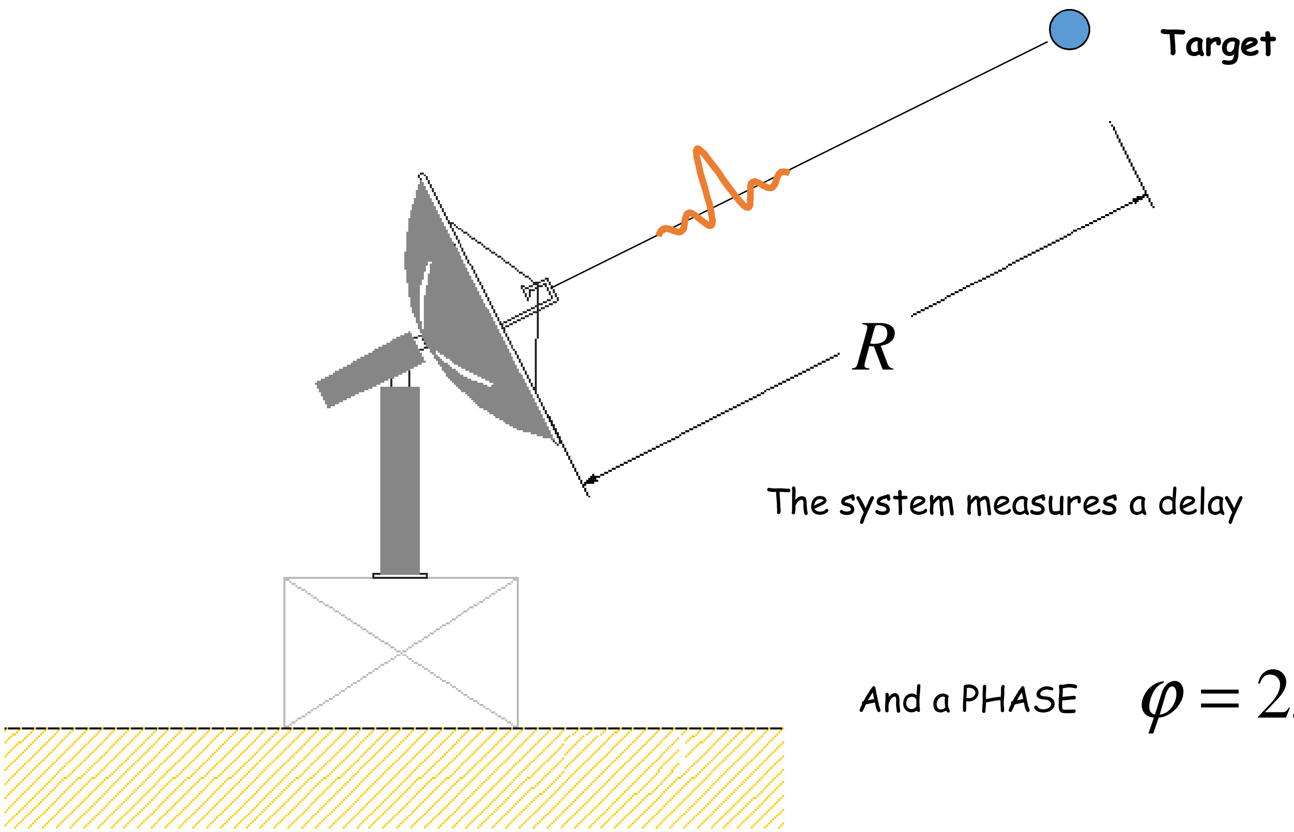
## The PHASE




ERS, C-band, wave length: 5.66 cm

# RADAR

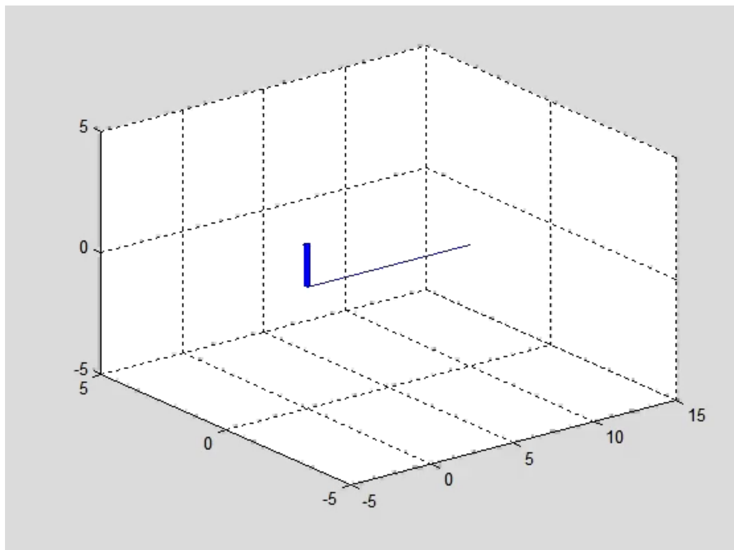
Coherent system: it measures Intensity and Phase




The system measures a delay $$\tau = \frac{2R}{c}$$

And a PHASE $$\varphi = 2\pi \frac{R}{\lambda}$$

## The phase of an E.M. wave in the Complex space




Signal traveling from the radar to a target

$$v = c$$

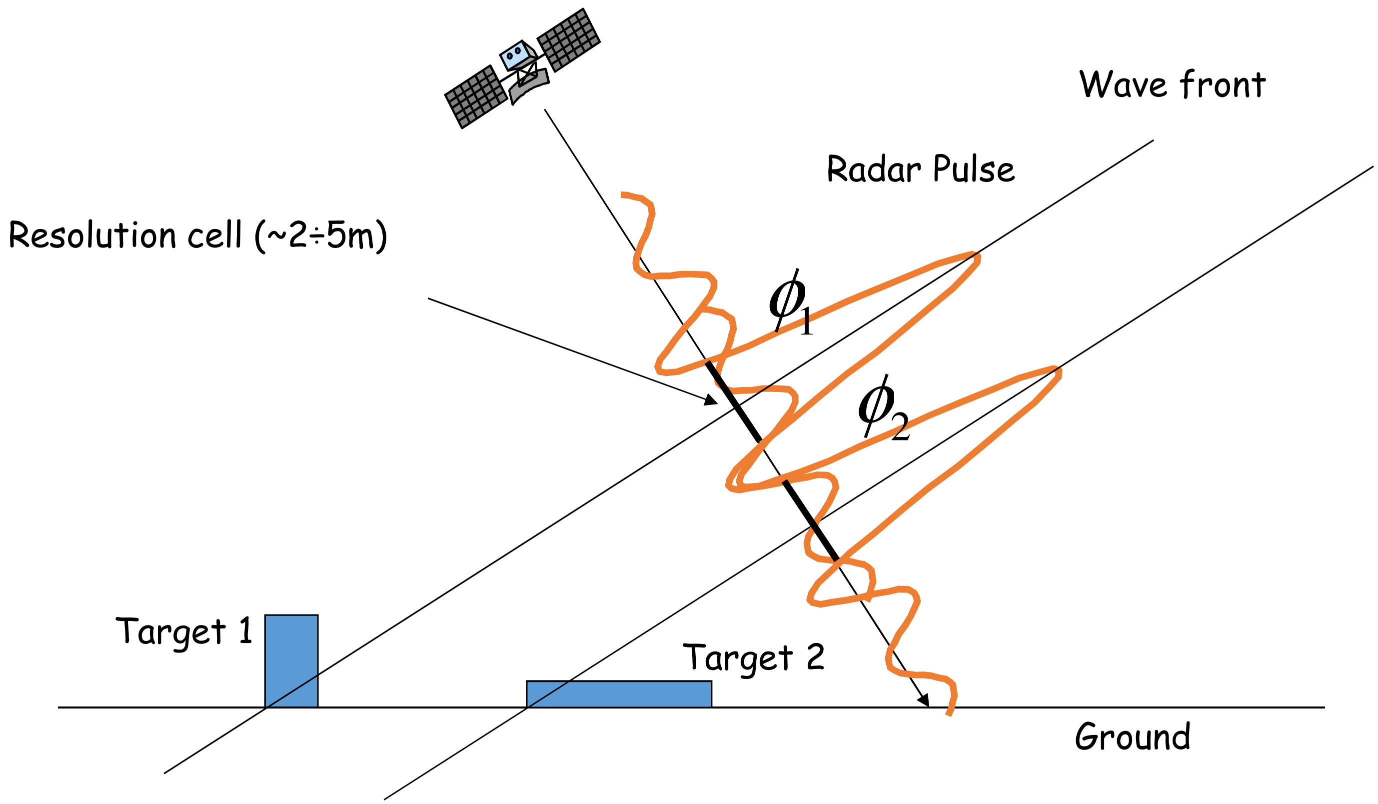
$$\omega = 2\pi f$$

$$f = \frac{c}{\lambda}$$

$$\varphi = 2\pi \frac{R}{\lambda}$$

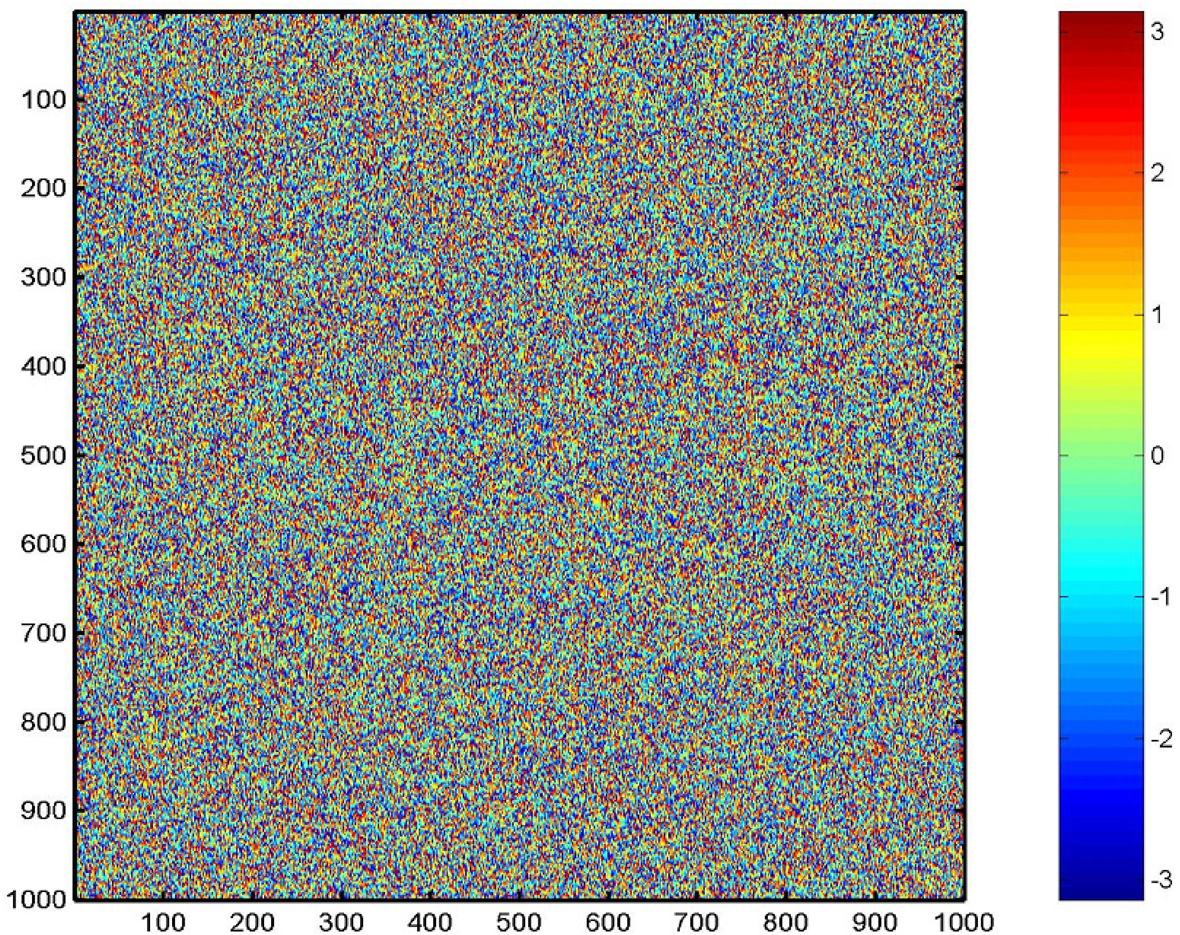
# RADAR

## Acquisition system and the PHASE



# SAR

Phase of the SAR image

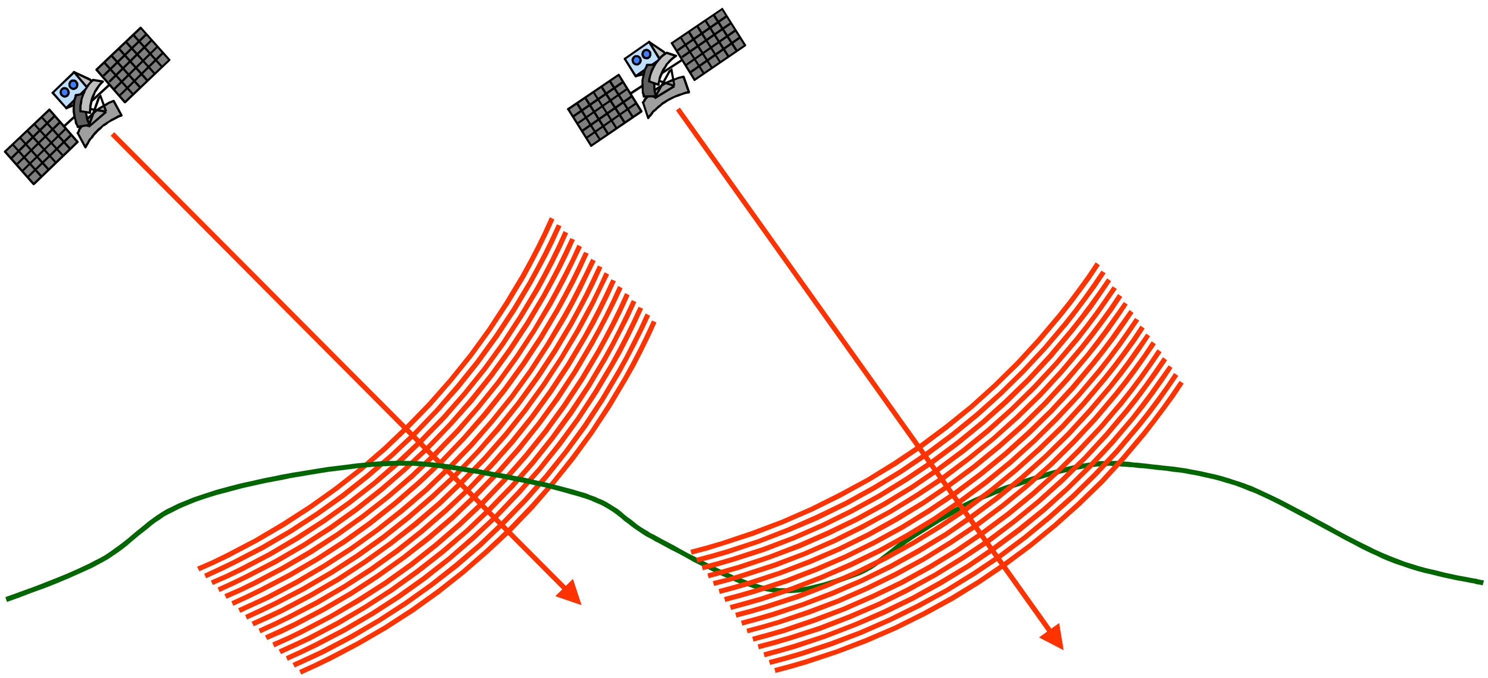


# Synthetic Aperture Radar Interferometry

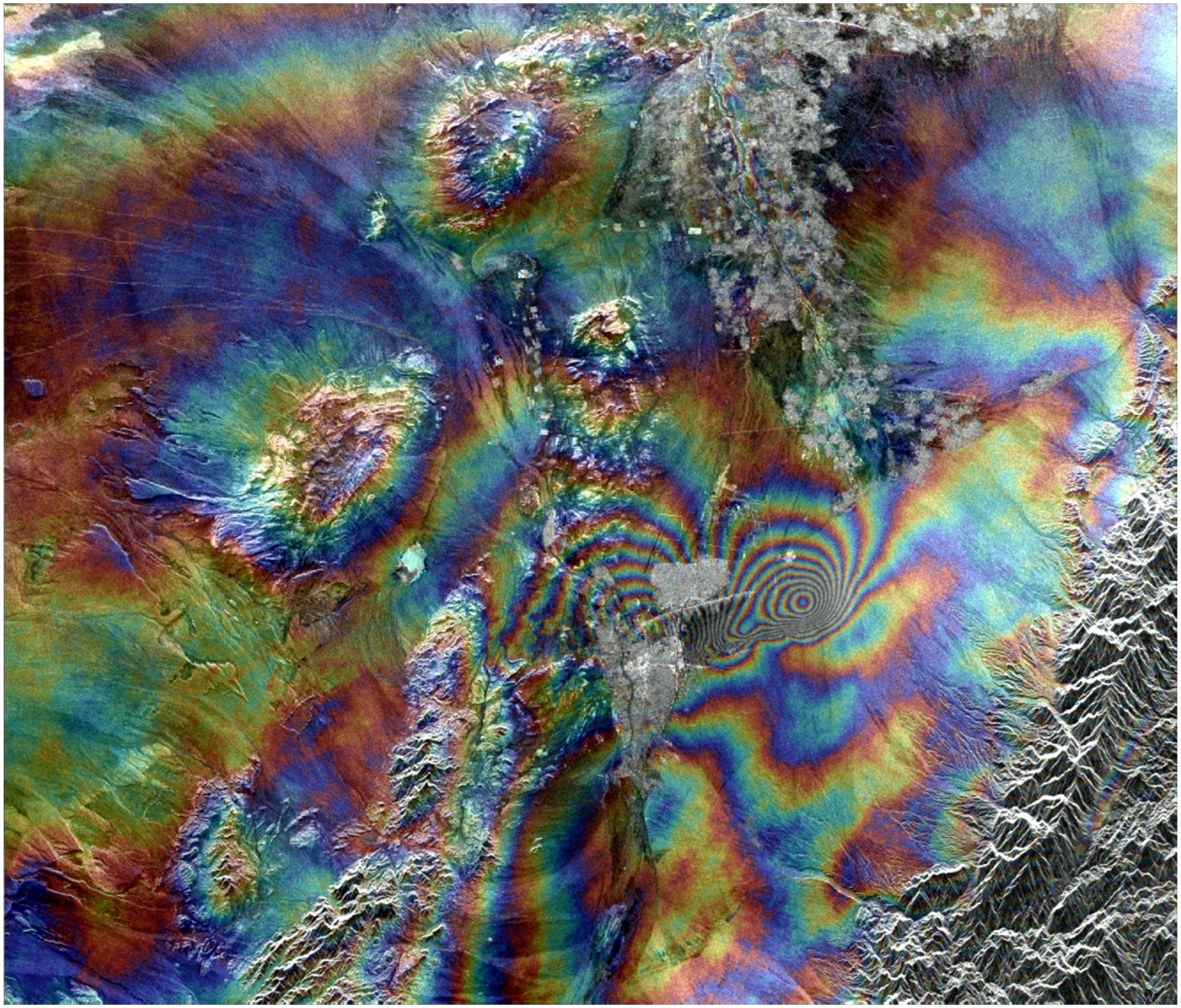
# InSAR

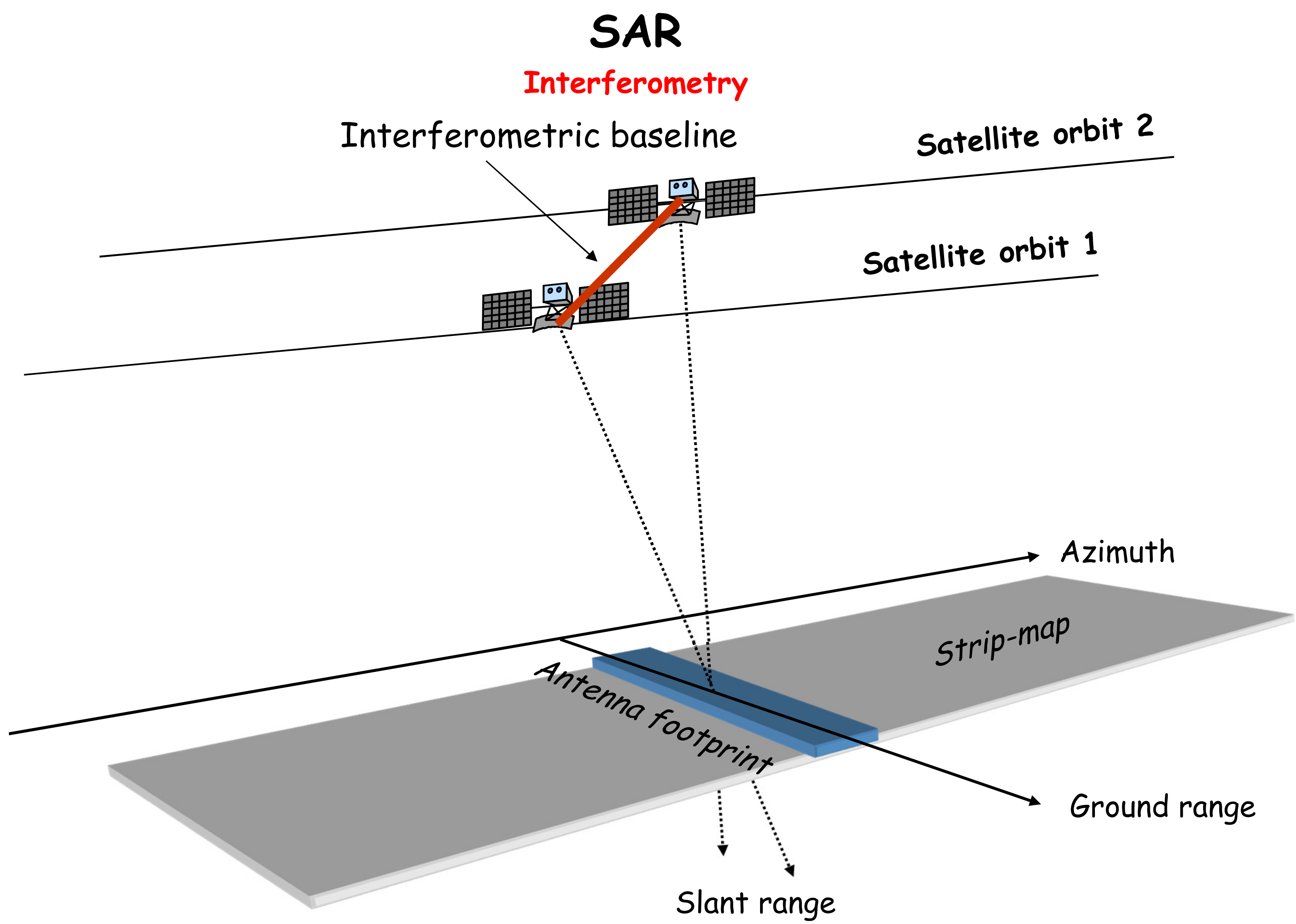
# InSAR

Interferometric phase



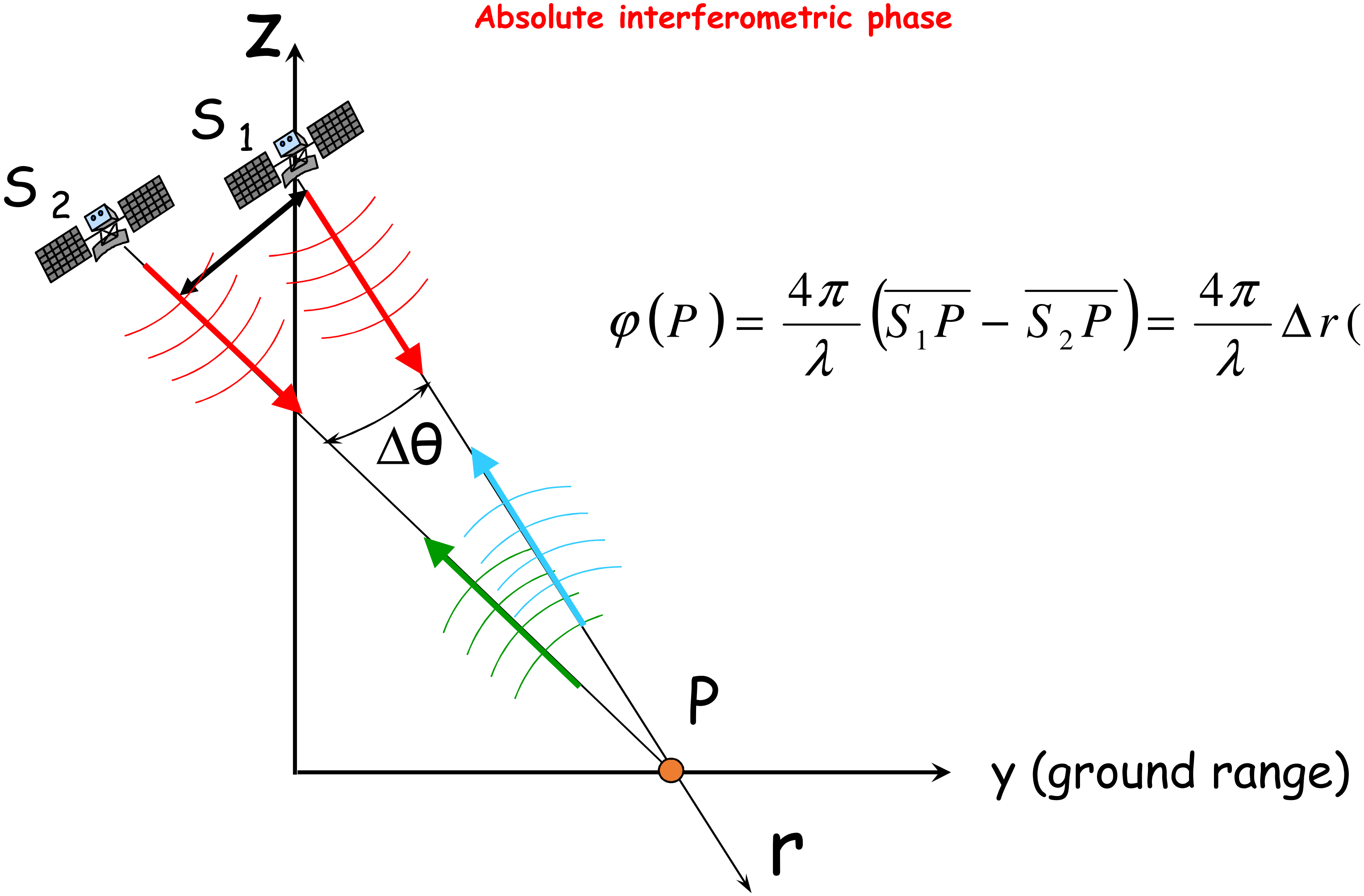
Interferogram




SAR
Interferometry
Interferometric baseline
Satellite orbit 2
Satellite orbit 1
Azimuth
Strip-map
Antenna footprint
Ground range
Slant range

InSAR

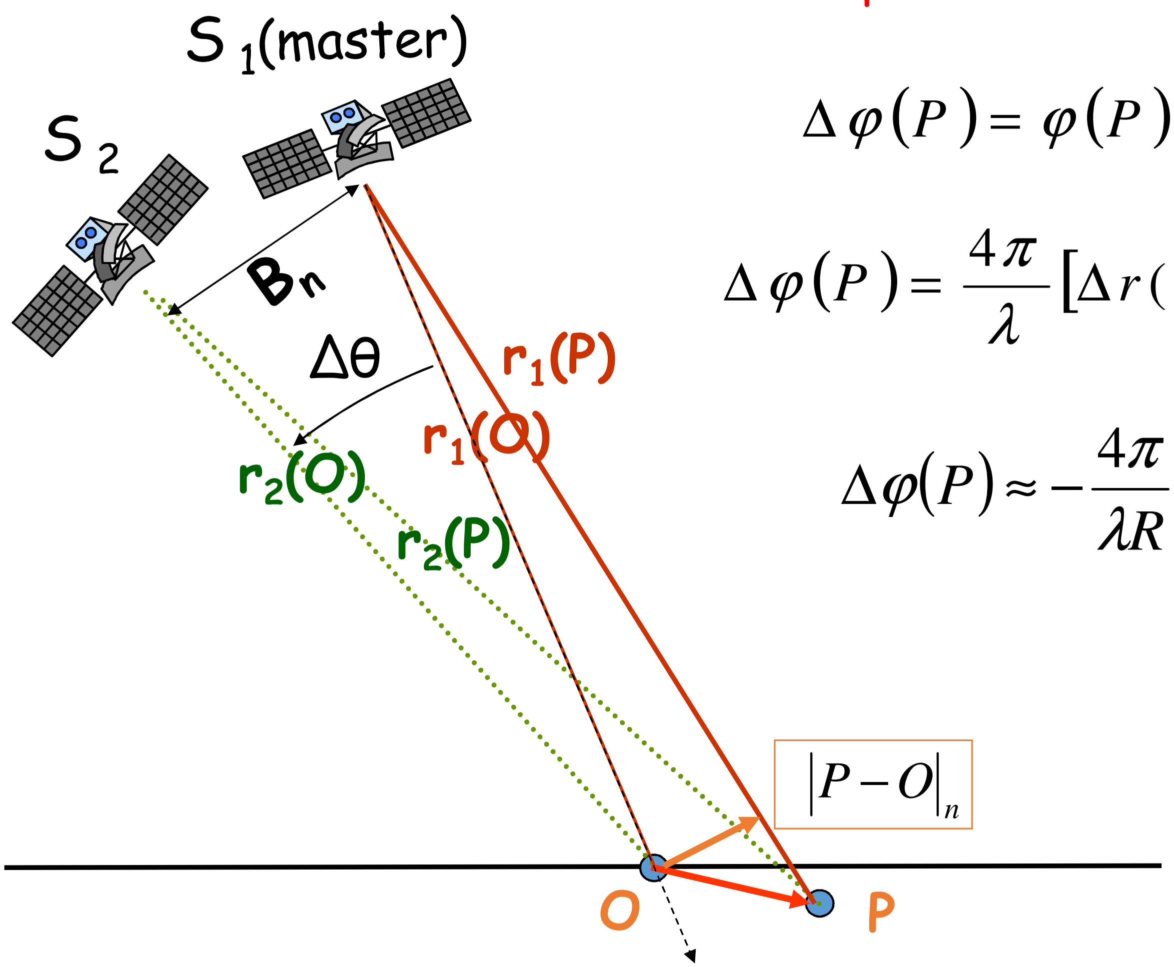
Absolute interferometric phase




$$\varphi(P) = \frac{4\pi}{\lambda}\left(\overline{S_1 P} - \overline{S_2 P}\right) = \frac{4\pi}{\lambda}\Delta r(P)$$

# InSAR

## Relative interferometric phase




$$\Delta\varphi(P) = \varphi(P) - \varphi(O)$$

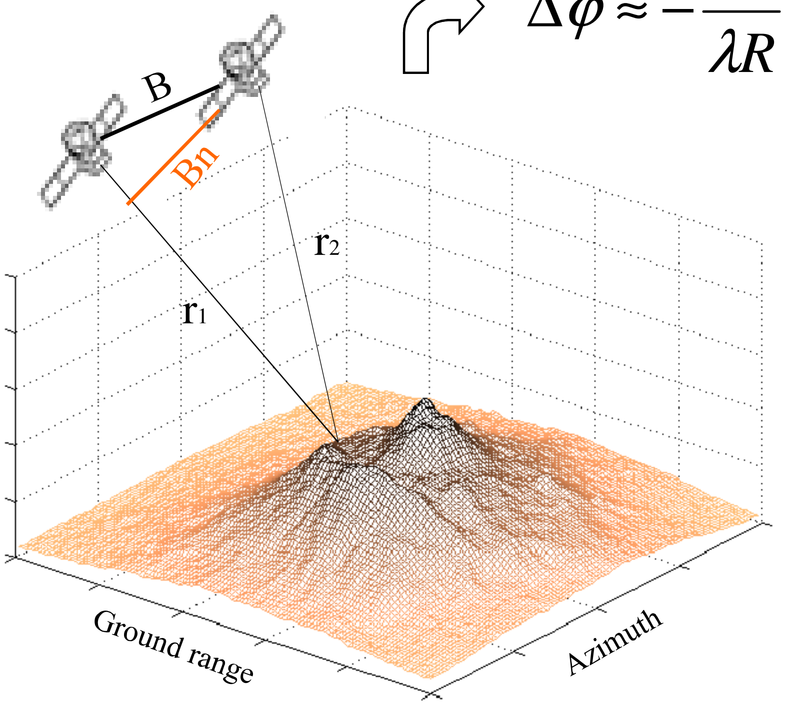
$$\Delta\varphi(P) = \frac{4\pi}{\lambda}\left[\Delta r(P) - \Delta r(O)\right]$$

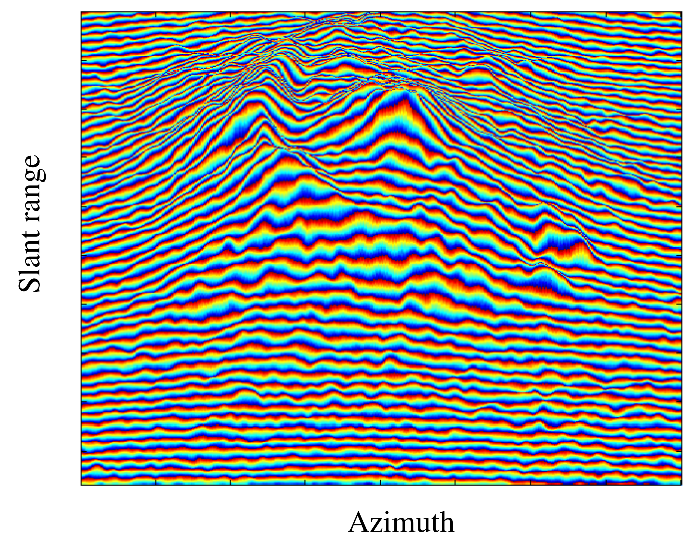
$$\Delta\varphi(P) \approx -\frac{4\pi}{\lambda R} B_n \left|P - O\right|_n$$

**InSAR**

**Relative interferometric phase: example**

$$\Delta\varphi \approx -\frac{4\pi}{\lambda R} B_n \left| P - O \right|_n$$



## InSAR

**The relative interferometric phase geometric components**

The relative int. phase can be decomposed into:

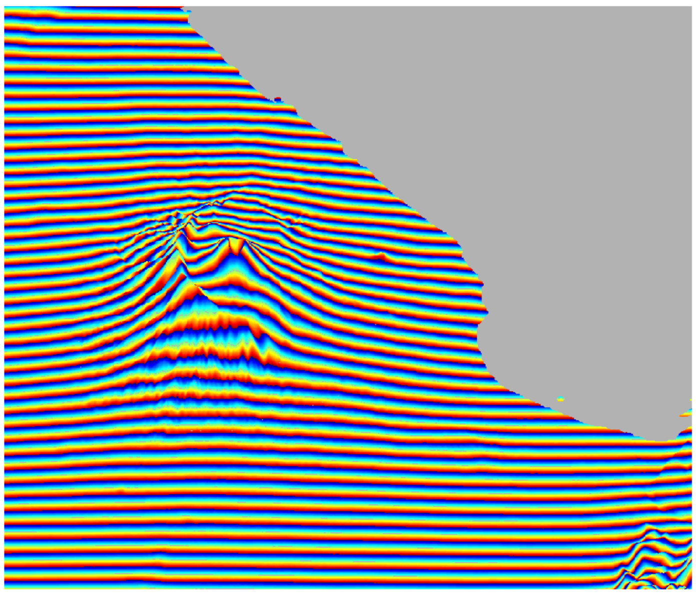
- the phase due to the horizontal distance *r* between points O and P
- and the phase due to their height difference $\Delta q$

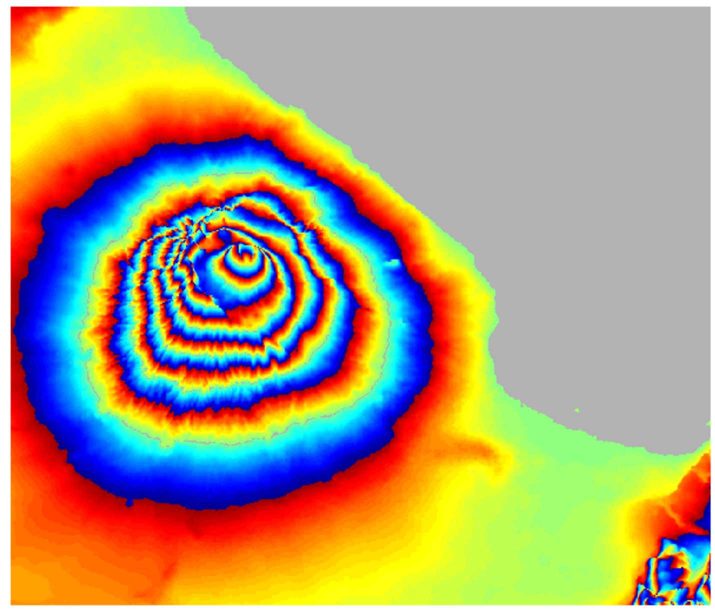
$$\Delta\varphi = -\frac{4\pi}{\lambda}\left|P-O\right|_n \frac{B_n}{R} = \Delta\varphi_{flat} + \Delta\varphi_{height}$$

$$\boxed{-\frac{4\pi}{\lambda}\frac{B_n r}{R\tan\theta}} \qquad \boxed{-\frac{\Delta q}{\sin\theta}\cdot\frac{B_n}{R}\cdot\frac{4\pi}{\lambda}}$$

# InSAR

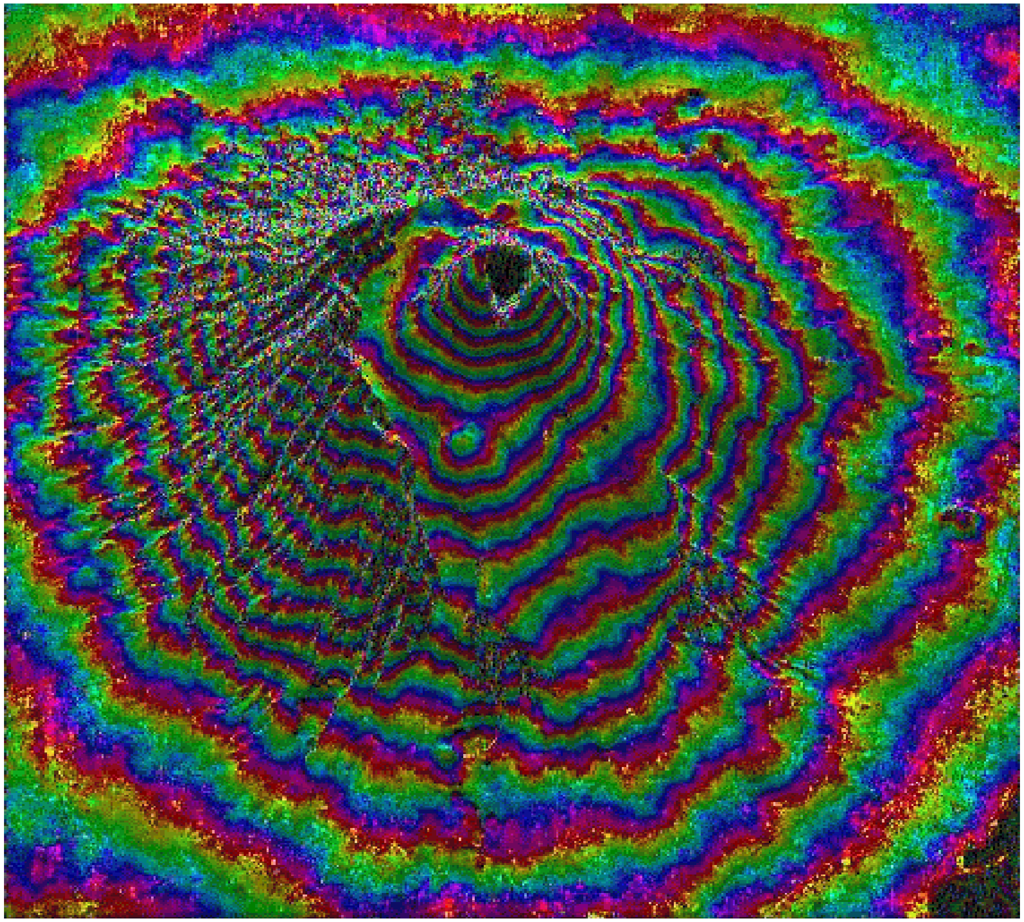
## Compensation for flat terrain





# InSAR

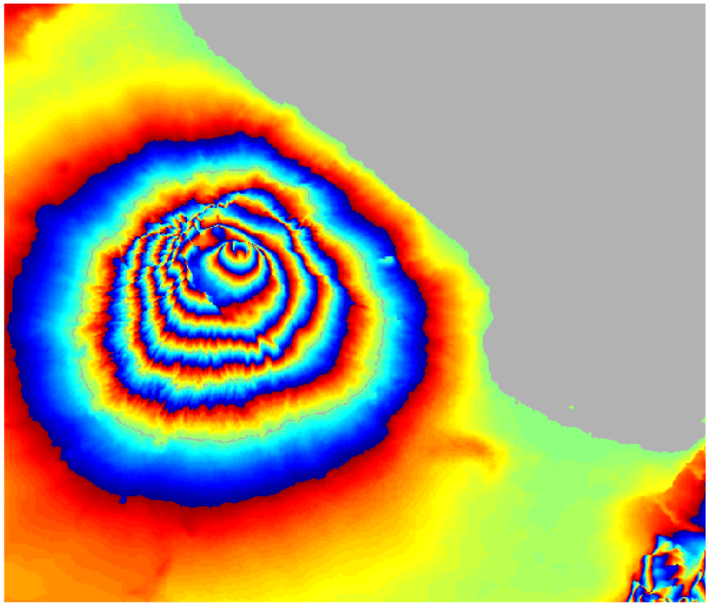
## Topographic phase term



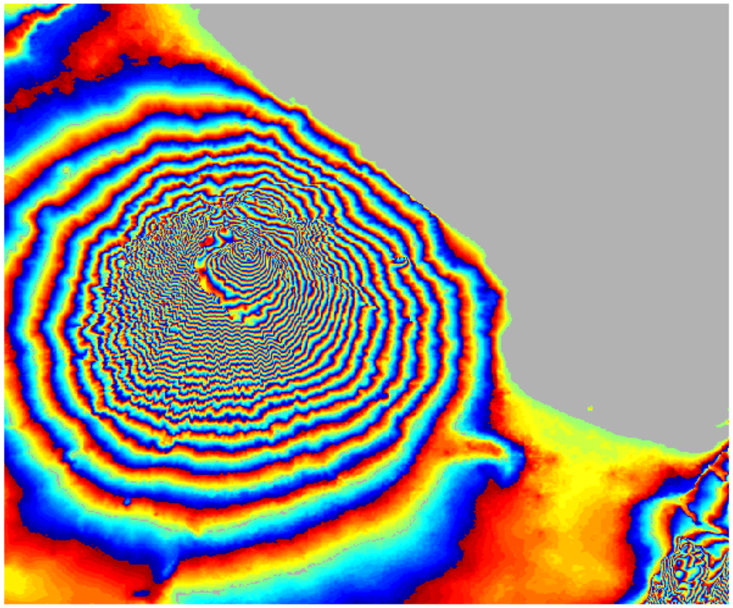
Mt. Vesuvius,
Bn =250m

# InSAR

## The role of normal baseline



Bn =50m



Bn =250m

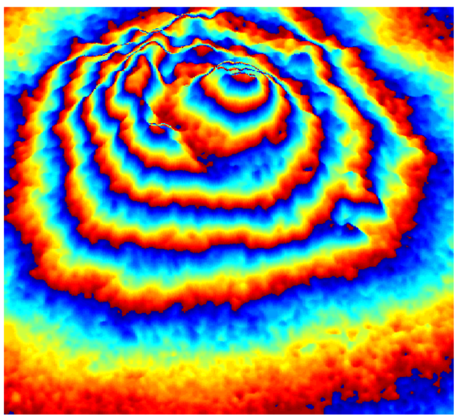
# InSAR

## Height of ambiguity

The phase is periodic, with cycle 2π.

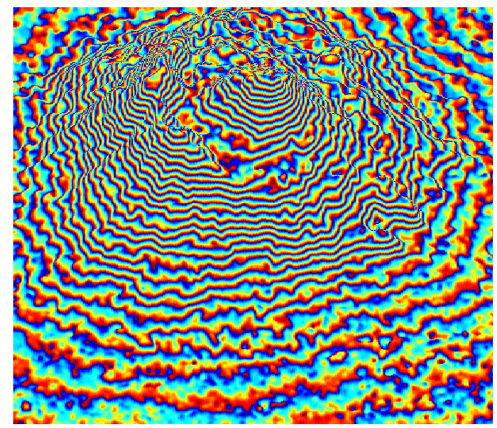
The height that generates a phase cycle is called height of ambiguity $\Delta h_a$

***Bn***=50m $\Delta h_a \approx 188m$



$$\Delta h_a \times B_n = \frac{\lambda}{2} \sin\theta\, R$$

***Bn***=250m $\Delta h_a \approx 37m$

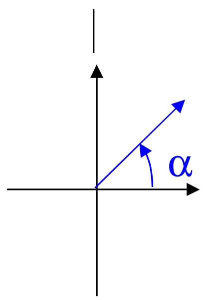


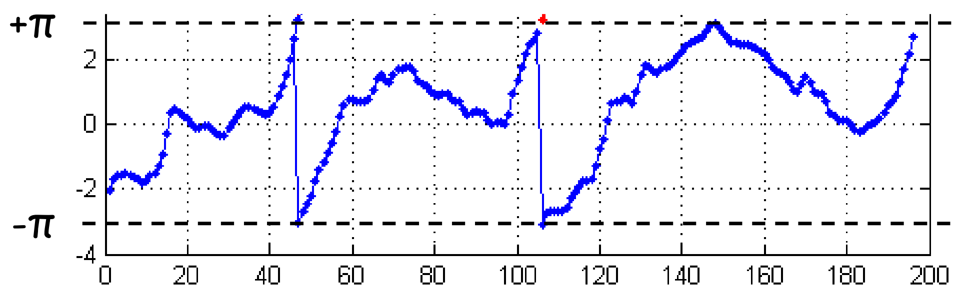
The operation that solves height ambiguities (if possible) is called ***phase unwrapping***

# Phase Unwrapping

# InSAR

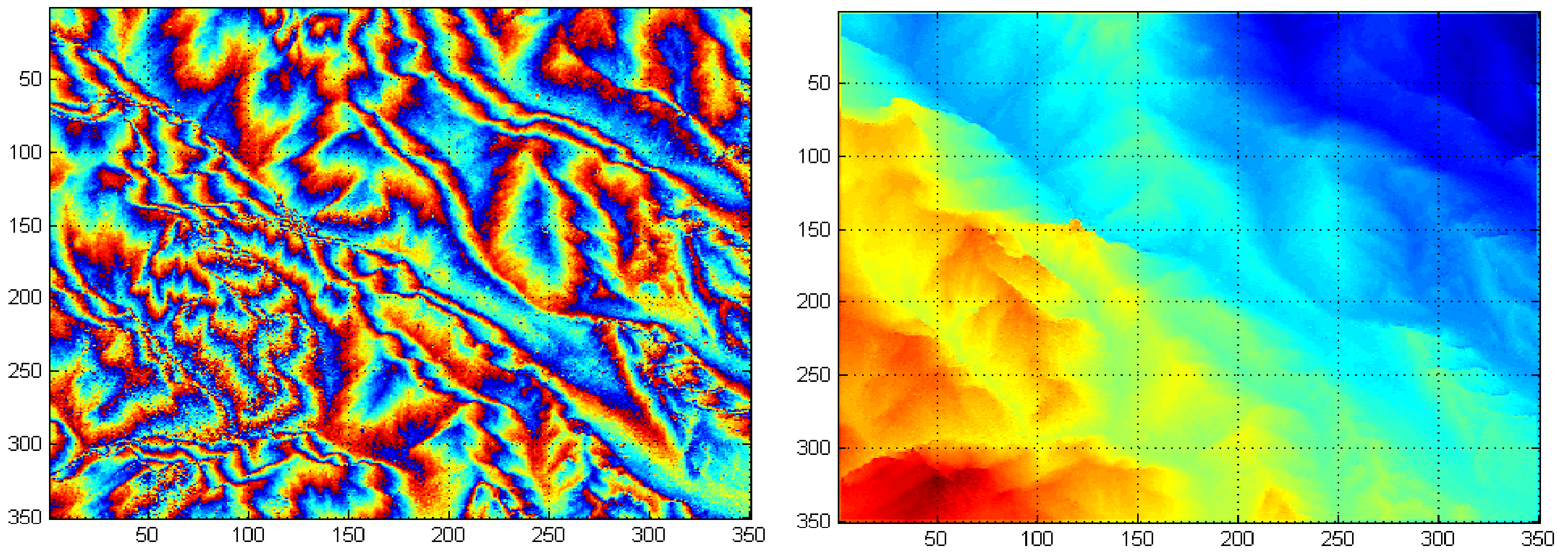
## 1D Phase unwrapping



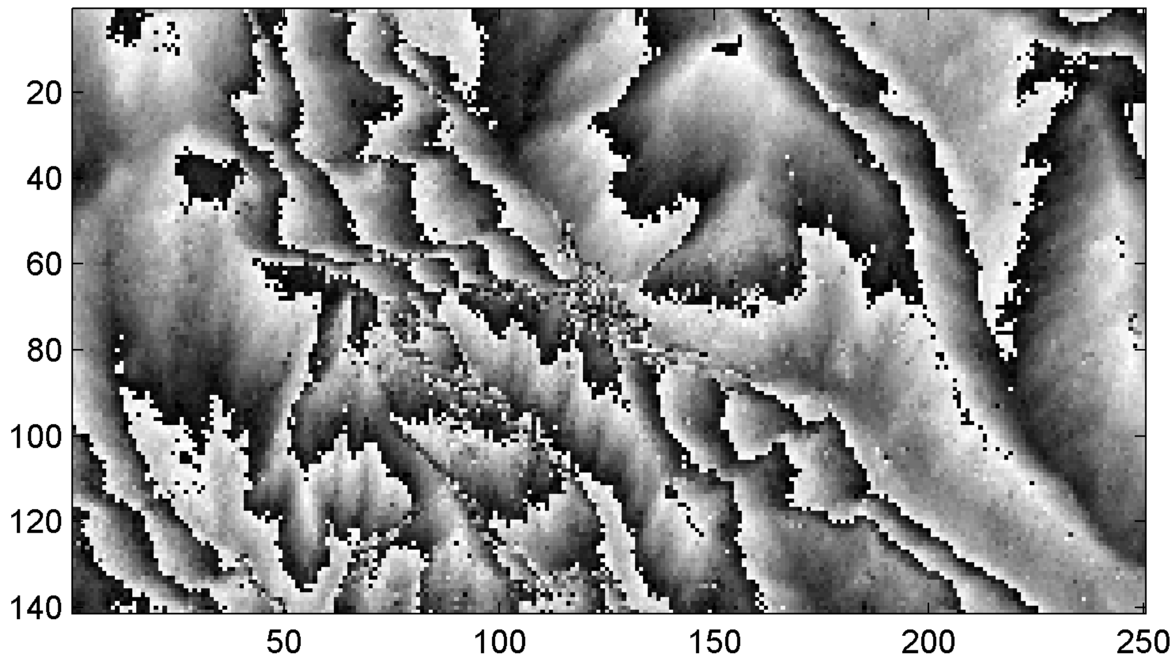
# InSAR

## 2D Phase unwrapping



# InSAR

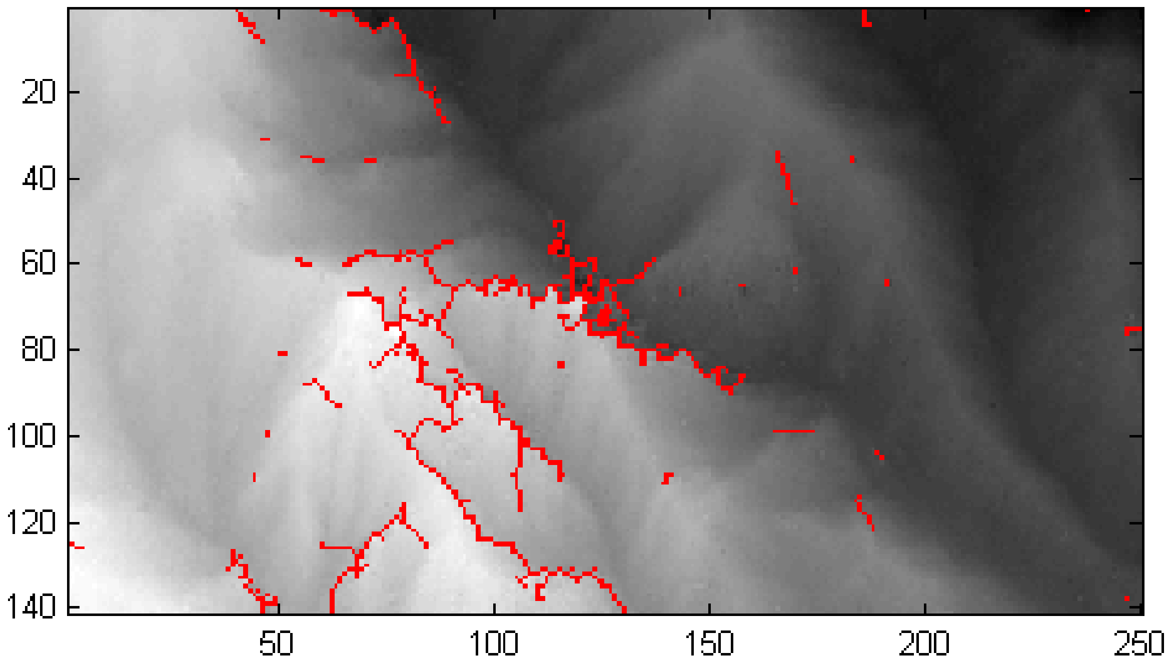
## 2D Phase unwrapping




What happens in presence of noise

# InSAR

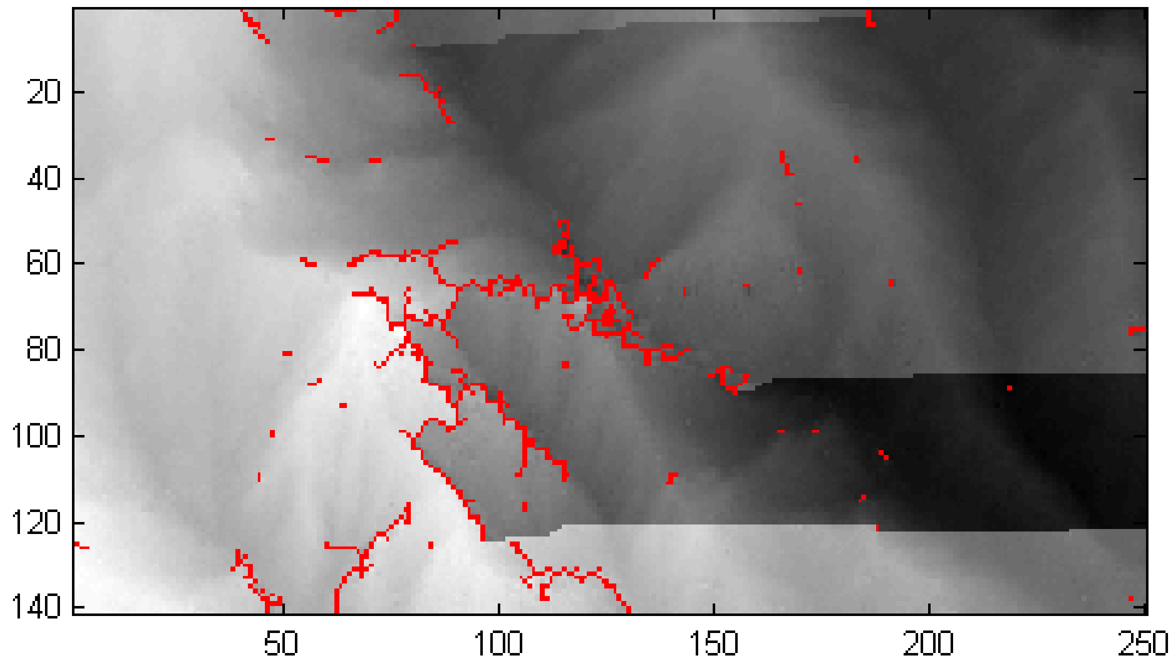
## 2D Phase unwrapping




Identification of critical points

# InSAR

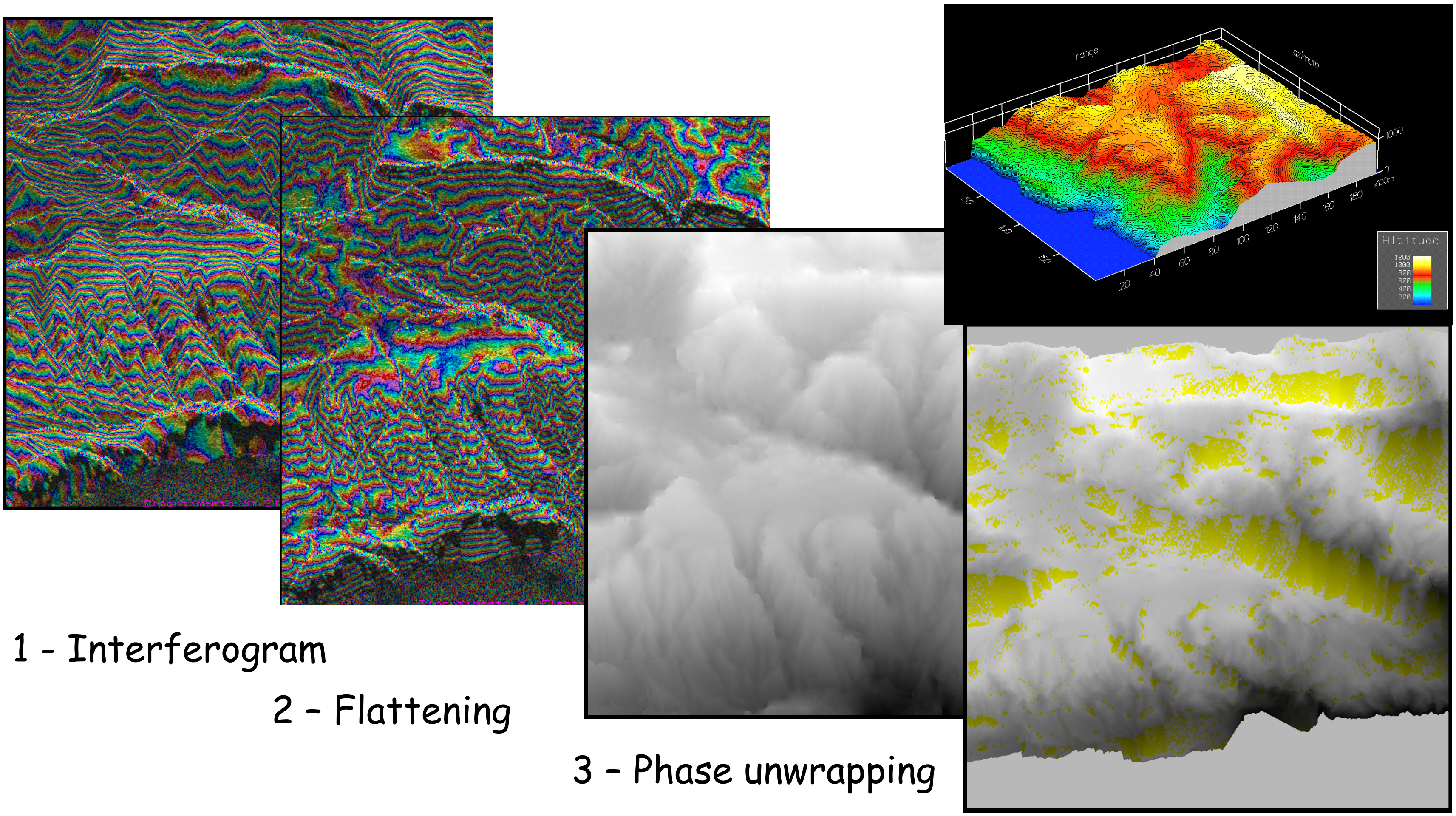
## 2D Phase unwrapping




Possible errors

# Estimating the DEM

## From InSAR to DEM



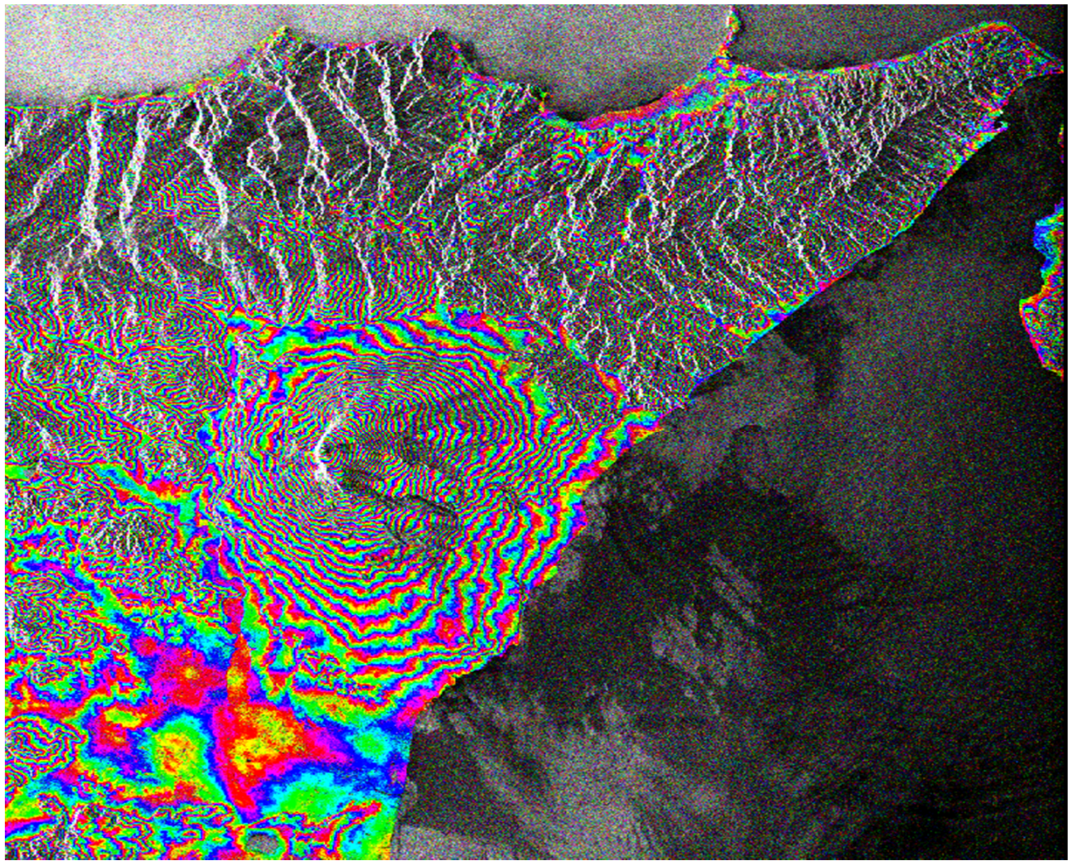

1 - Interferogram

2 – Flattening

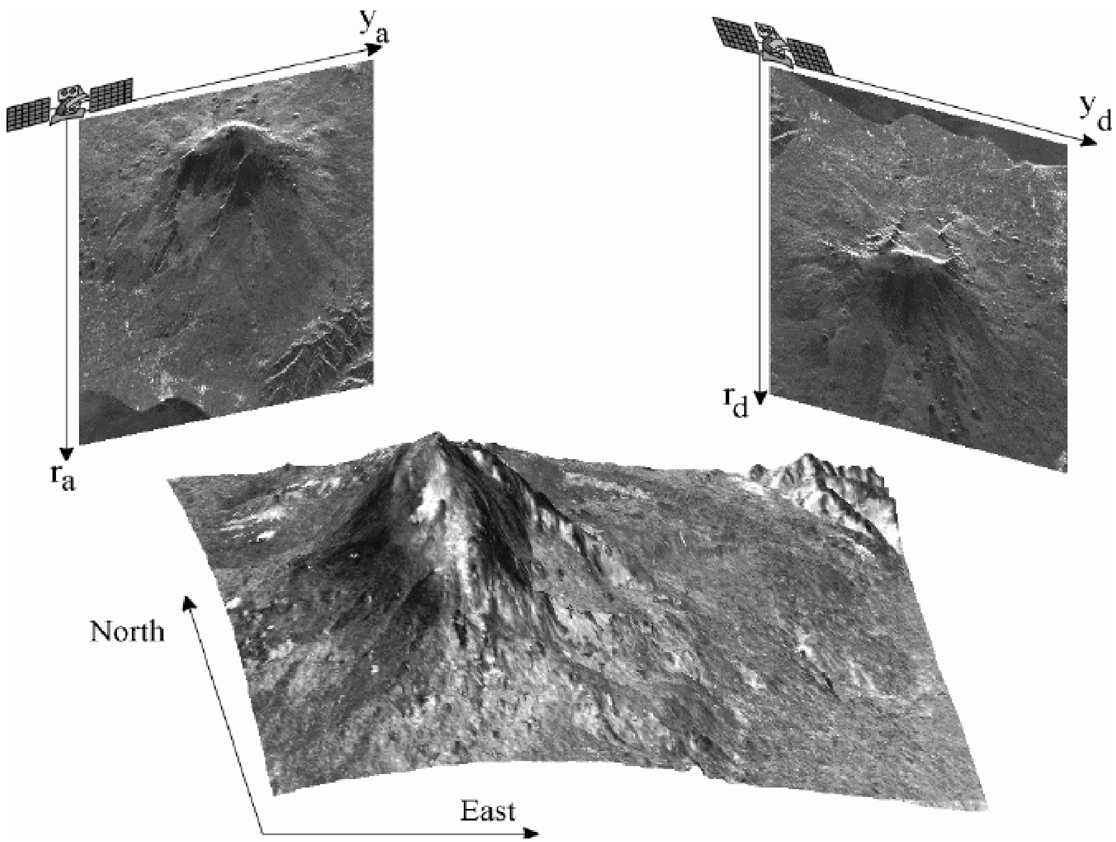
3 – Phase unwrapping

4 – Geocoding

ERS interferogram of Etna, Italy

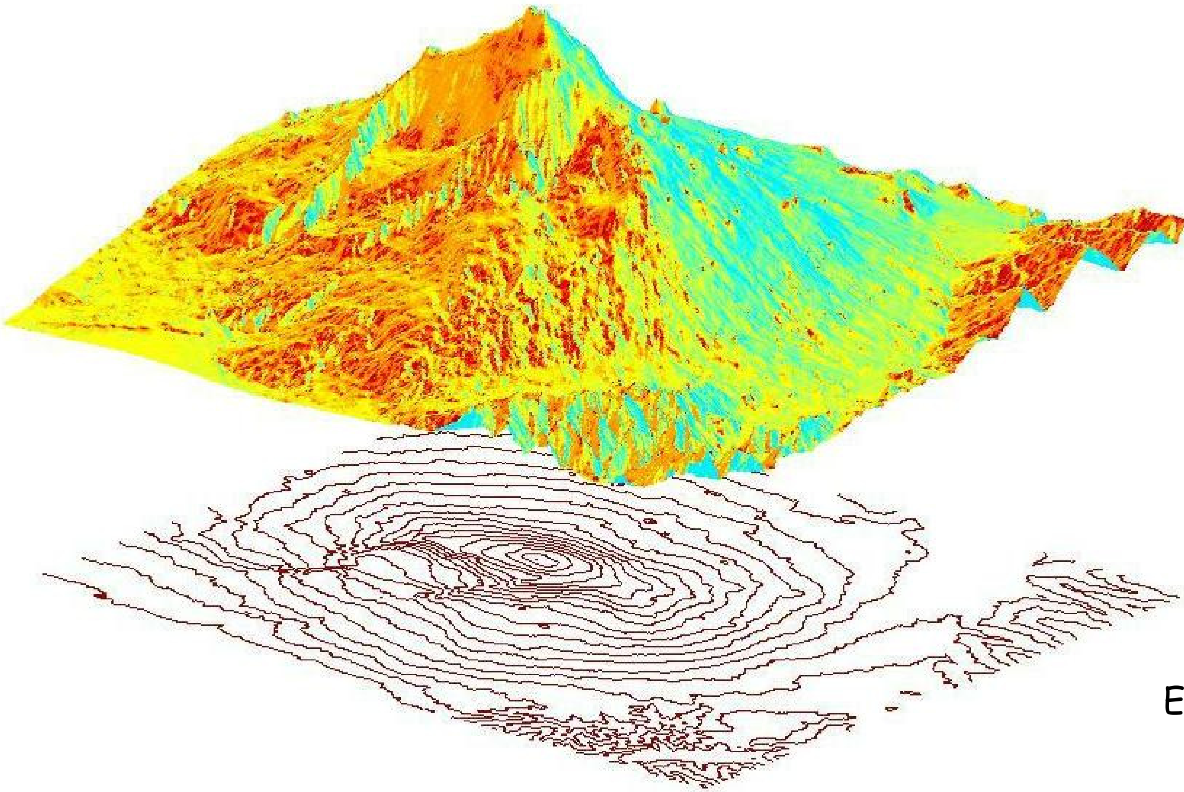


## Etna: DEM from ascending and descending passes



# InSAR

## Digital Elevation Models

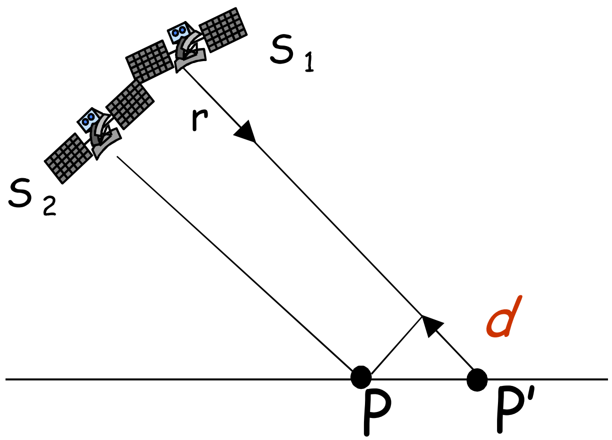


Etna

# Detecting ground movement

# InSAR

**Phase term due to target motion**




$$\Delta\varphi_{motion} = \frac{4\pi}{\lambda} d$$

# InSAR

## Sensitivity to target motion

Assuming the ERS case (λ=5.6cm), normal baseline 150m

$$\Delta\varphi = \Delta\varphi_{motion} + \Delta\varphi_{height} = \frac{4\pi}{\lambda}\left(d - \frac{\Delta q}{\sin\theta}\cdot\frac{B_n}{R}\right) =$$

$$= \frac{4\pi}{\lambda}\left(d - \frac{\Delta q}{2150}\right)$$

A height difference of 21.5m has the same effect of a displacement of 1cm

## InSAR

### Phase components

$$\Delta\varphi = \Delta\varphi_{flat} + \Delta\varphi_{height} + \Delta\varphi_{motion} + \Delta\varphi_{noise}$$

$$-\frac{4\pi}{\lambda}\frac{B_n r}{R\tan\theta}$$

$$-\frac{\Delta h}{\sin\theta}\cdot\frac{B_n}{R_0}\cdot\frac{4\pi}{\lambda}$$

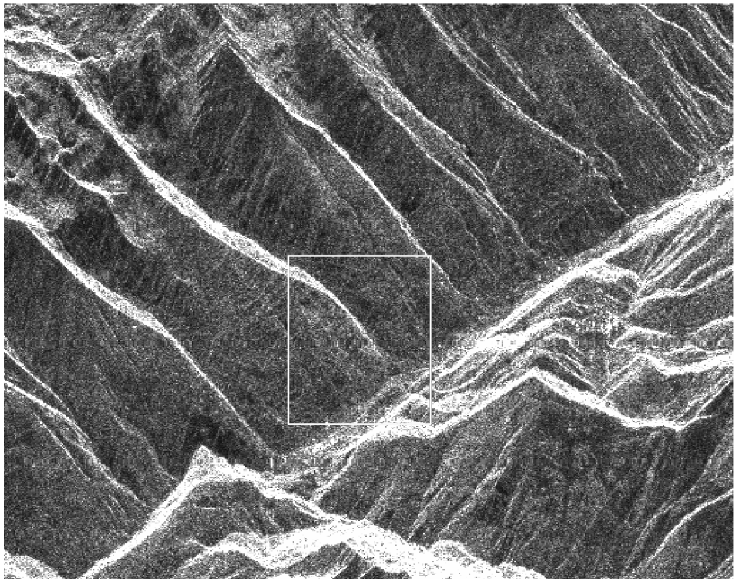
$$+\frac{4\pi}{\lambda}d$$

### Differential interferometric phase

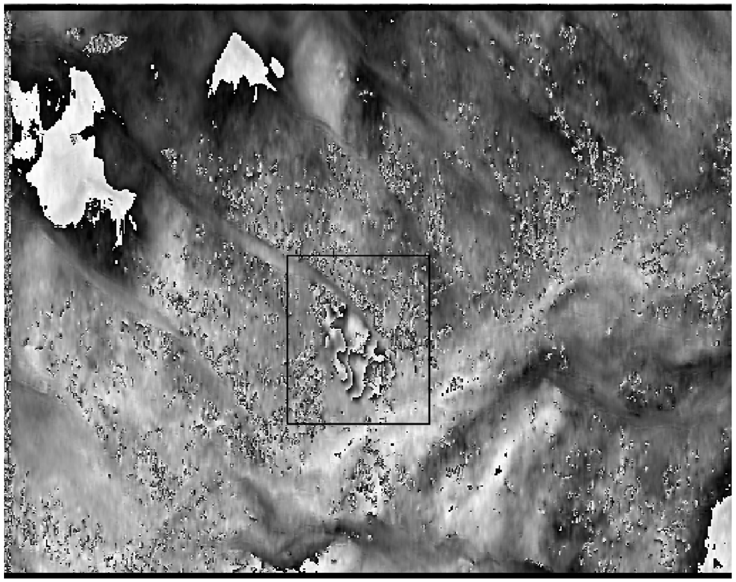
$$\boxed{\Delta\phi = \Delta\varphi - \Delta\varphi_{height} - \Delta\varphi_{flat} = \Delta\varphi_{motion} + \Delta\varphi_{noise}}$$

# InSAR

## The St. Etienne de Tinee landslide



Amplitude

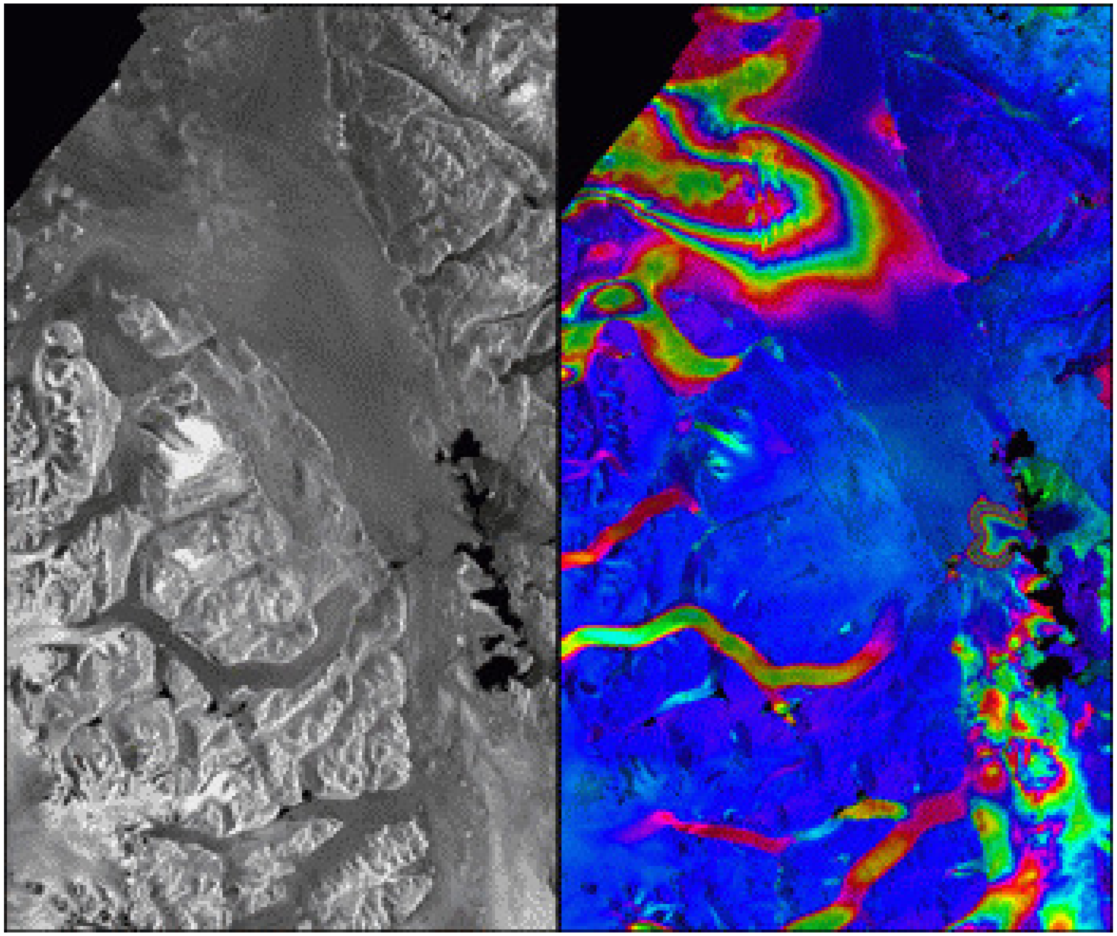


Phase

6m normal baseline; 3days temporal baseline

# InSAR

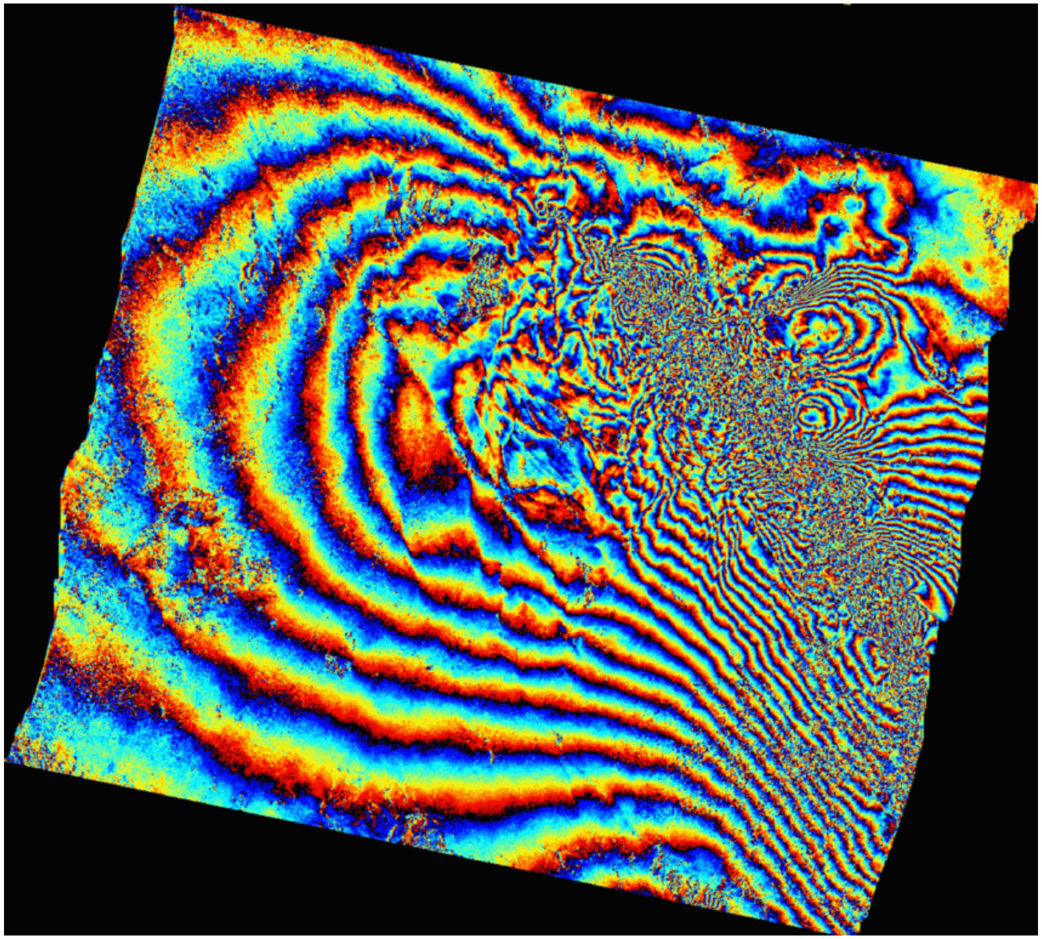
**Glaciers motion**



ERS1-ERS2
Tandem
interferogram
(Bt=1day)

# InSAR

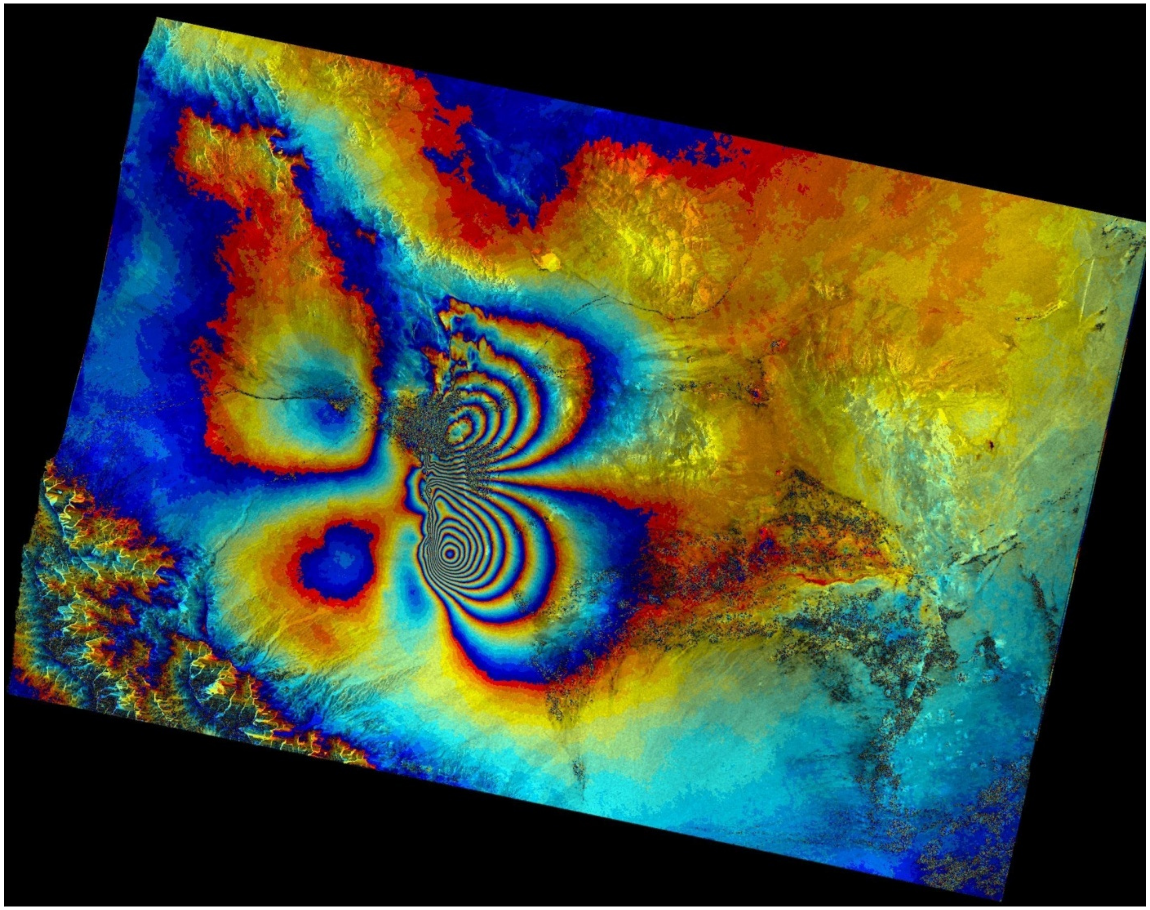
**Landers Landslide (N-E of Los Angeles) in 1992**



ERS2 geocoded interferogram compensated for the topography

# InSAR

## Bam (Iran) Earthquake in 2003

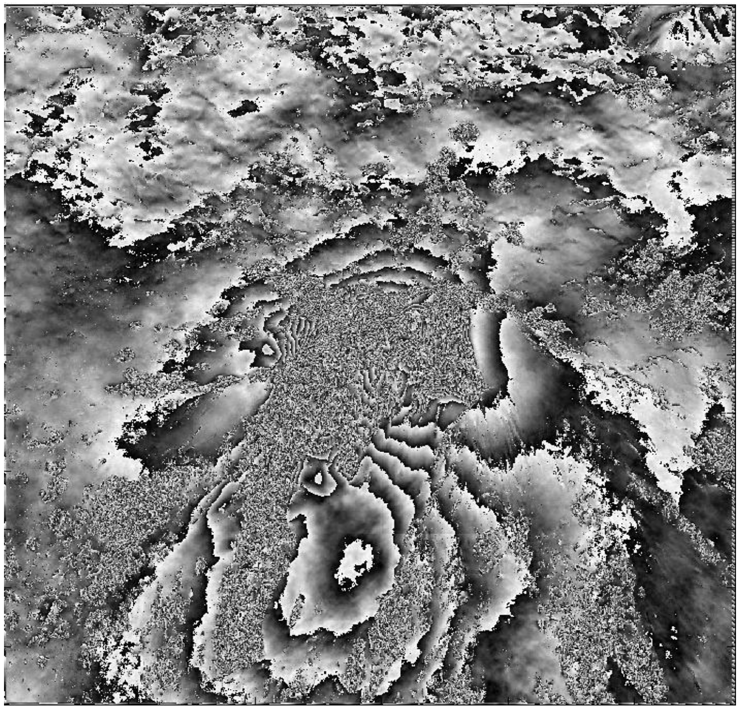


ENVISAT geocoded interferogram (not compensated for the topography)

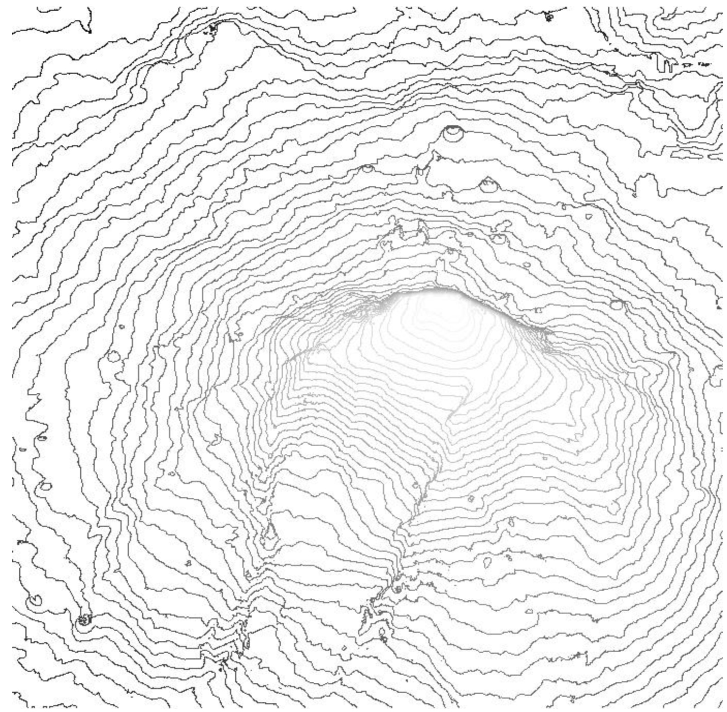
## InSAR

**Etna (Italy) Eruption July 2001**

Differential ERS interferogram



Etna DEM

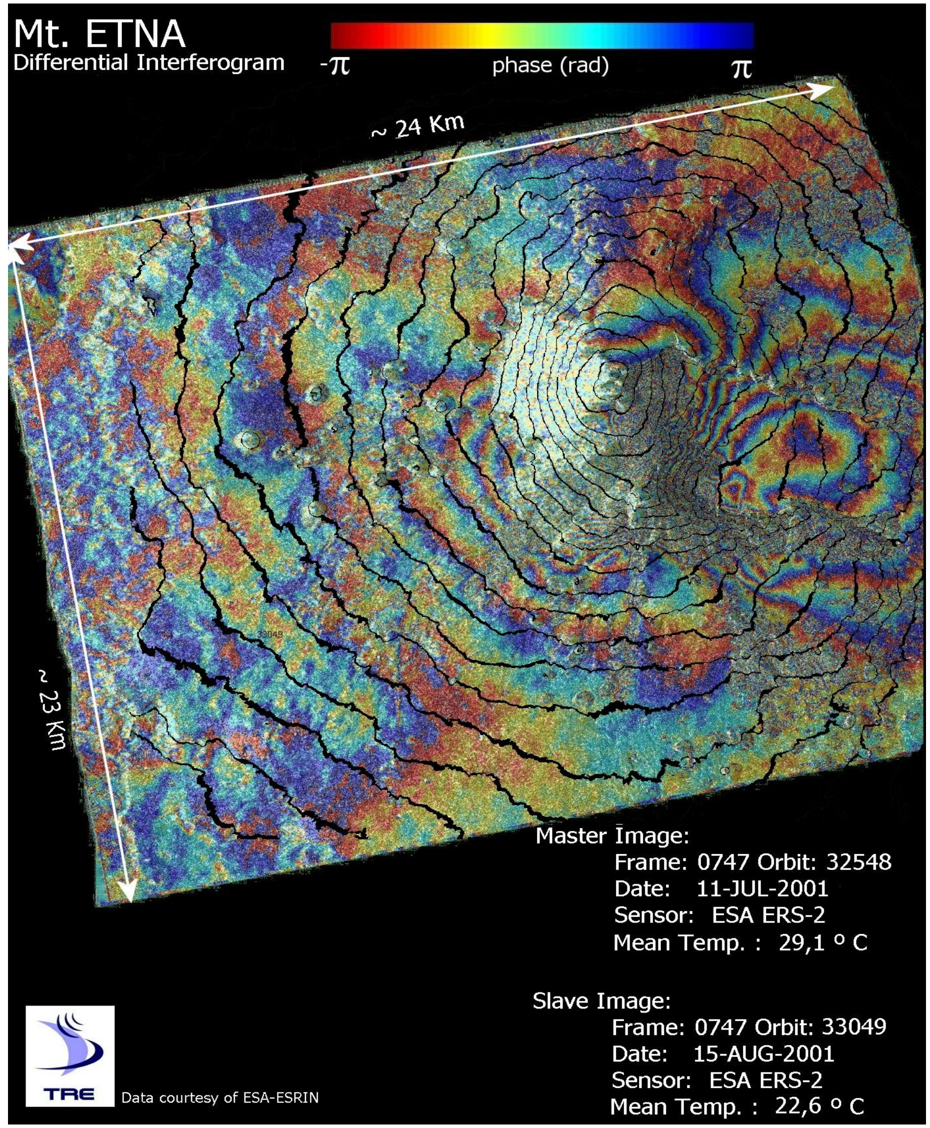


**Bn = 200 m**
**Bt = 35 days (July-August 2001)**

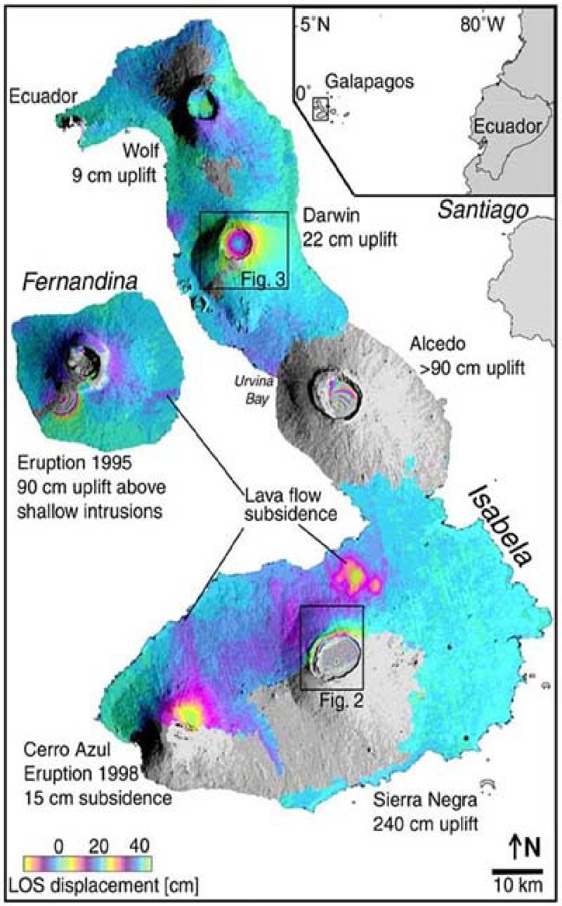
## InSAR

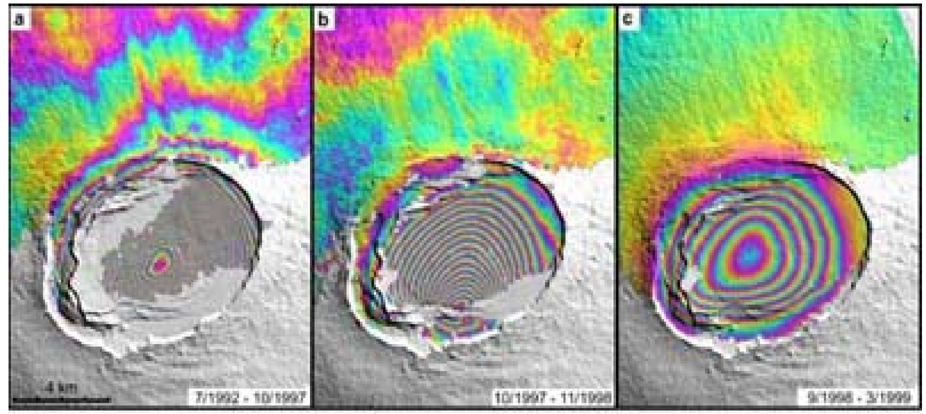
**Etna (Italy) Eruption July 2001**

Geocoded differential ERS interferogram



# Volcanoes monitoring



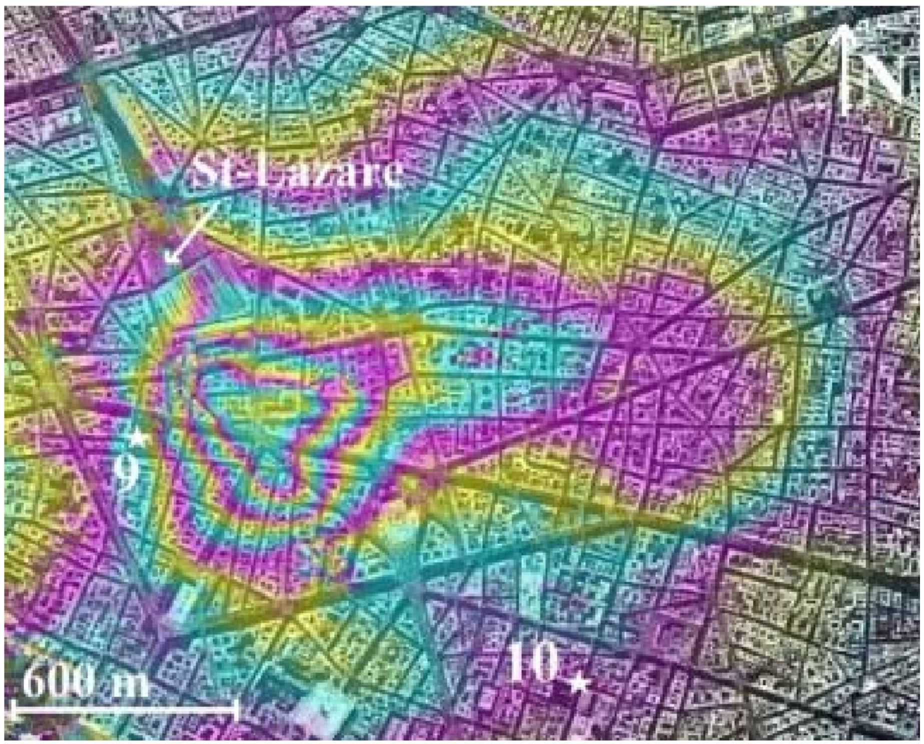




**Galapagos Island Volcanoes**

Deformation after 5 years (left).

Sequence of the deformation after
5.3, 1.1, and 0.5 years
(top right).

**DInSAR applications:**
**Ground subsidence due to constructions**




**Centre of Paris**
**(France)**

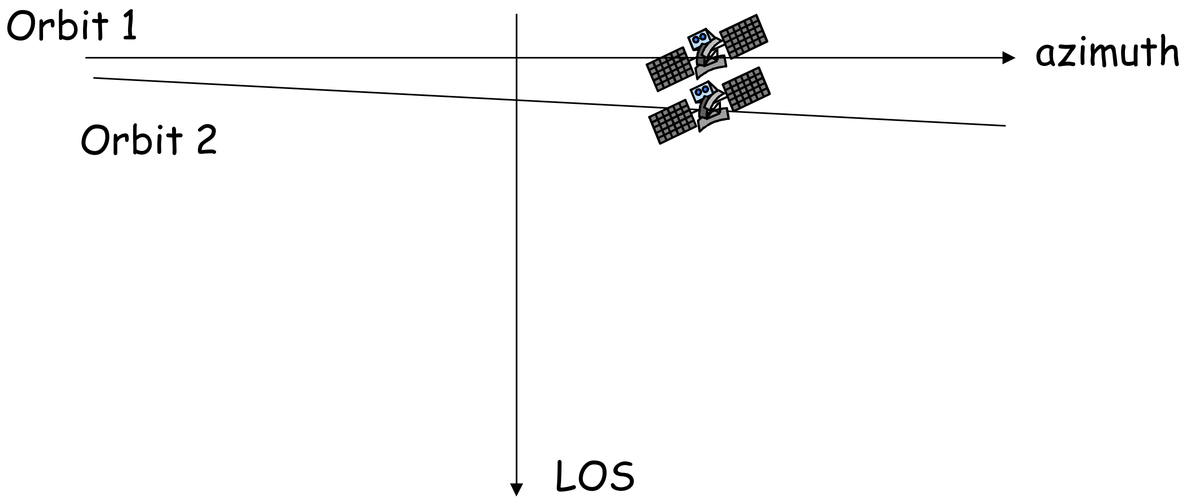
Ground deformation
due to active reduction
of the ground water level
during construction of an
underground line

Temporal baseline: 3 months
Scale: 1 fringe = 2.8 cm

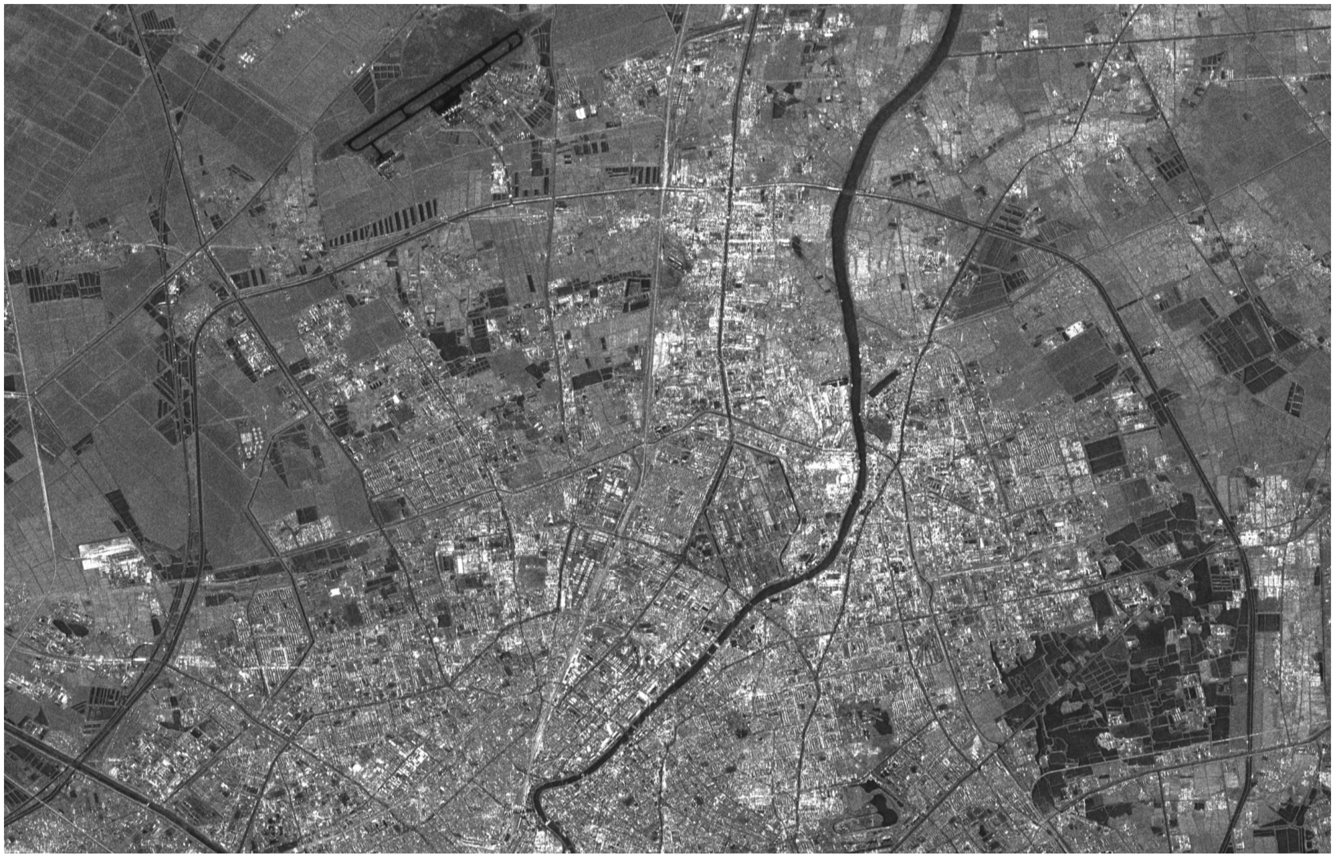
# Sources of errors (I)
# Orbit uncertainties

# InSAR

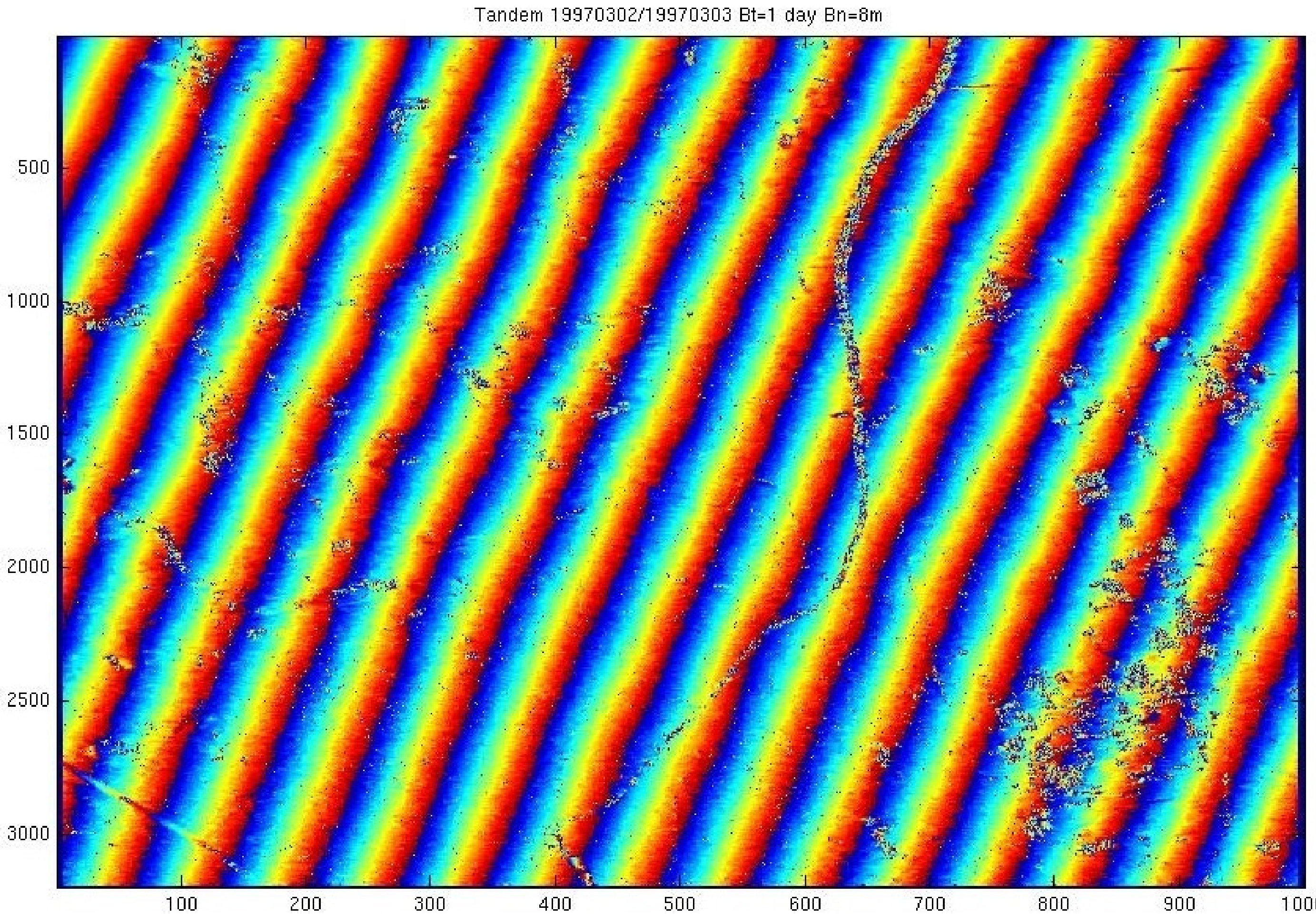
**Consequences of orbit inaccuracies**
**Non parallel – crossing orbits**



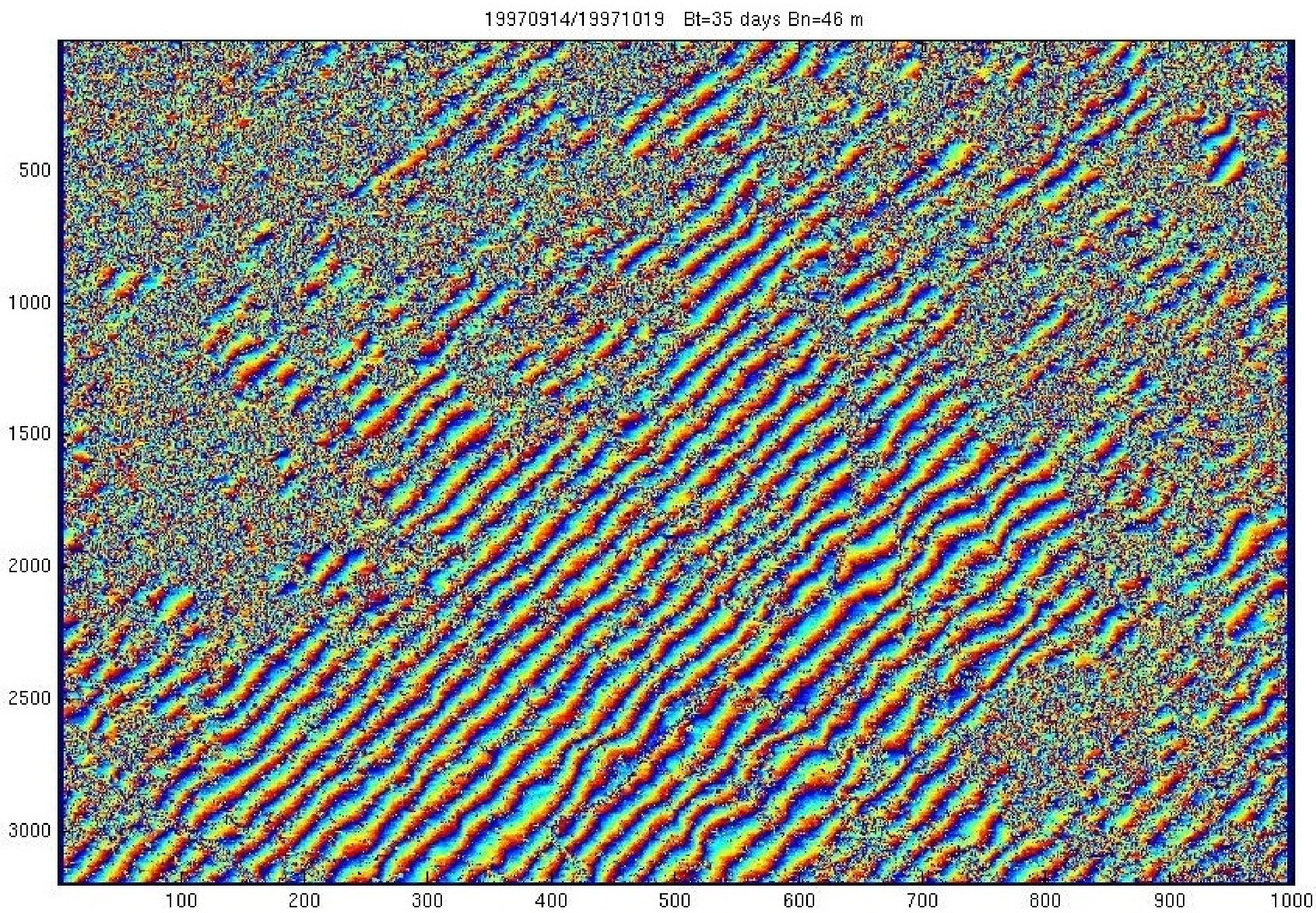
## Tianjin



# Tianjin


Tandem 19970302/19970303 Bt=1 day Bn=8m
500
1000
1500
2000
2500
3000
100
200
300
400
500
600
700
800
900
1000

# Tianjin



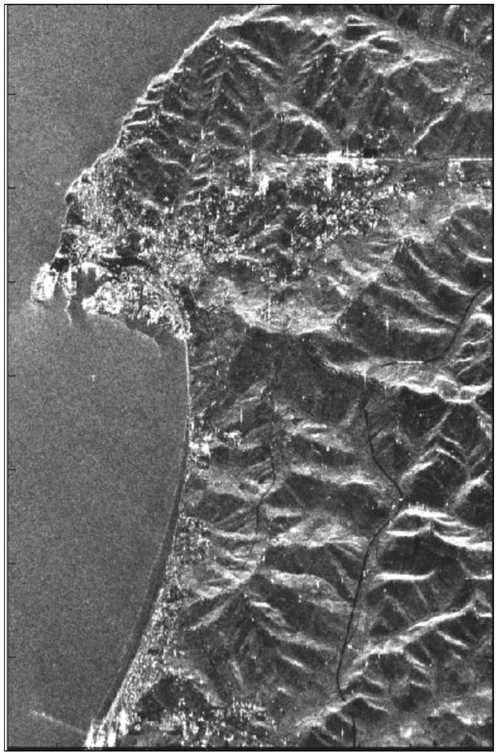
19970914/19971019 Bt=35 days Bn=46 m
500
1000
1500
2000
2500
3000
100
200
300
400
500
600
700
800
900
1000

# Sources of errors (II)

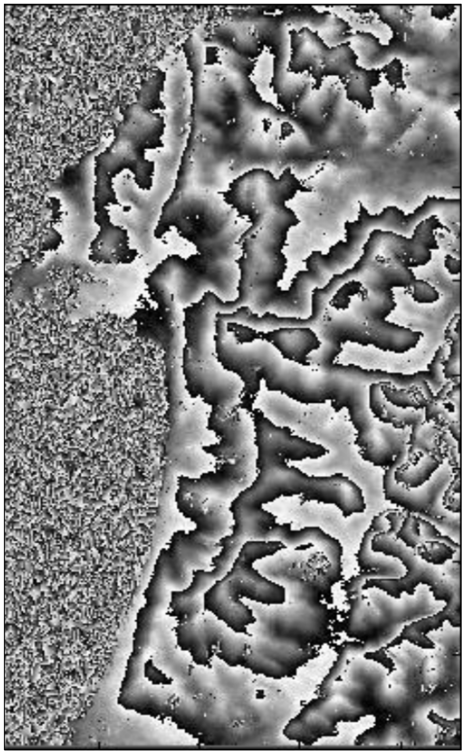
# Decorrelation

# InSAR

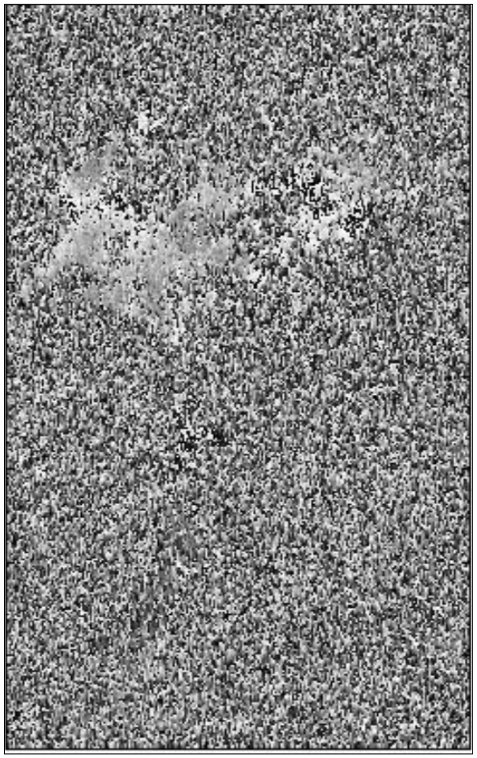
**Main limits of SAR Interferometry: temporal and geometrical decorrelation**



SAR amplitude



tandem interferogram



... after 15 months

## The interferometric coherence

Given two SAR images $v_1(r,a)$ and $v_2(r,a)$ forming an interferometric pair, the **complex coherence** of the interferometric pair is defined as follows:

$$\gamma = \frac{E[v_1 v_2^*]}{\sqrt{E[v_1 v_1^*]}\sqrt{E[v_2 v_2^*]}}$$

$$\hat{\gamma} = \frac{\sum_{i=1}^{N} v_{1i} v_{2i}^* e^{-j\phi(i)}}{\sqrt{\sum_{i=1}^{N} |v_{1i}|^2}\sqrt{\sum_{i=1}^{N} |v_{2i}|^2}}$$

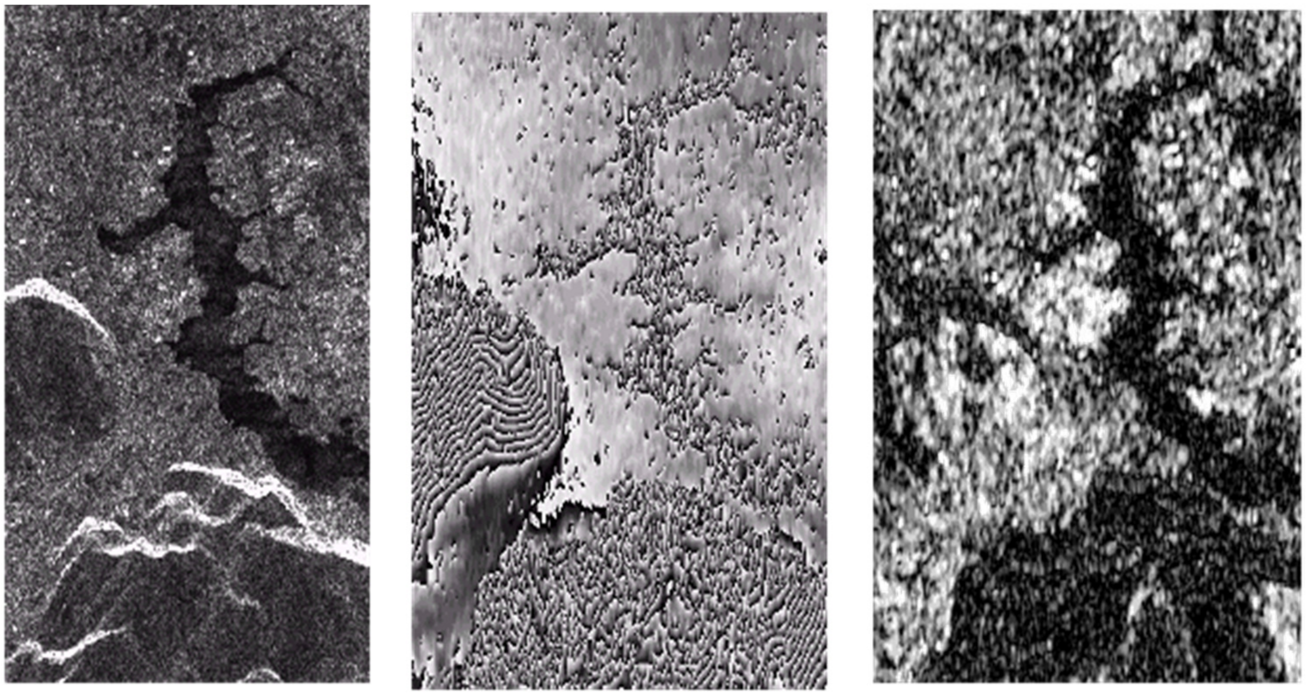
$v_1$ *complex pixels of the first SAR image (master)*

$v_2$ *complex pixels of the second SAR image (slave)*

$E[\ ]$ *Expected value*

# InSAR

## Coherence maps

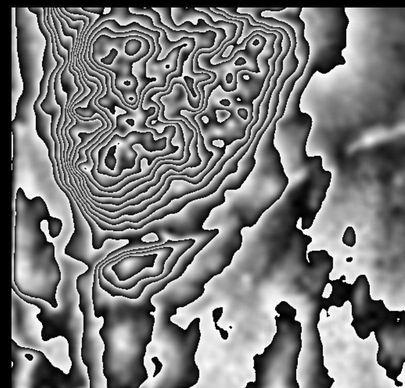


Amplitude Phase Coherence

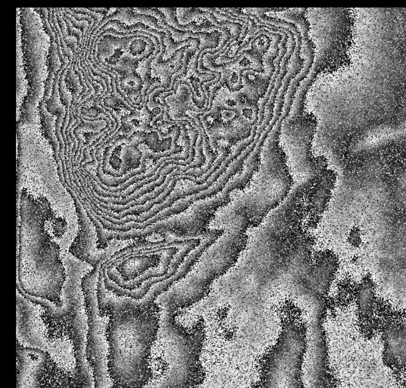
# Example: Interferograms with low coherence

*Simulation*

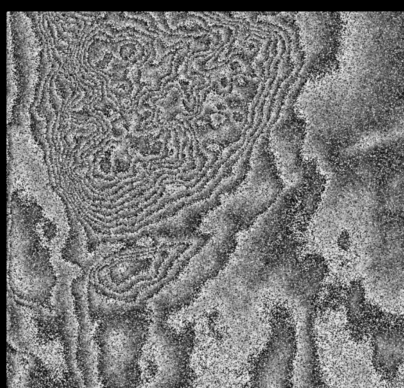
Absolute Phase



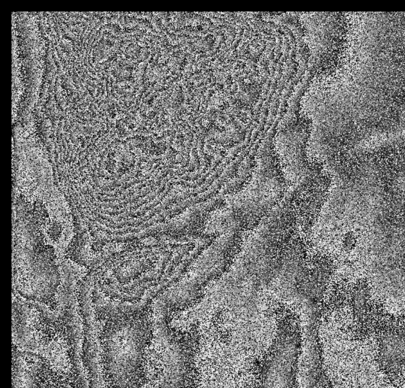
Coherence=1.0



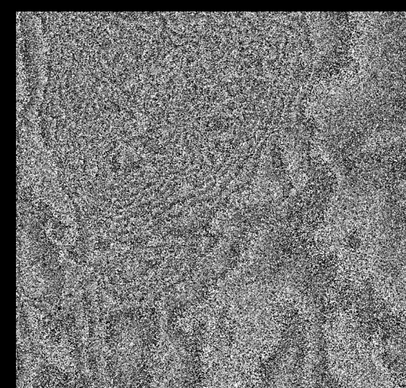
Coherence=0.8



Coherence=0.6

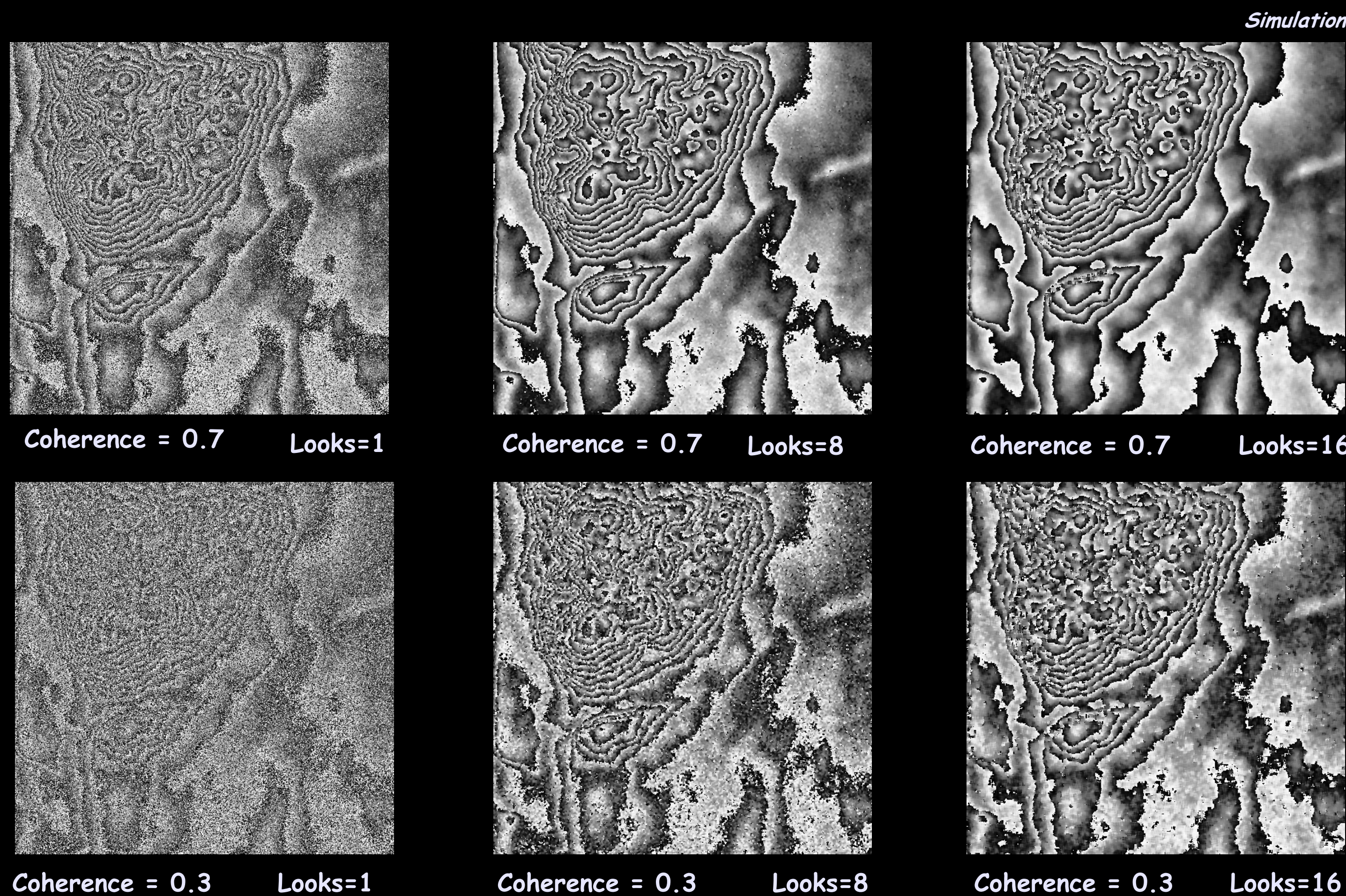


Coherence=0.4



Coherence=0.2

# Example: Phase Filtering



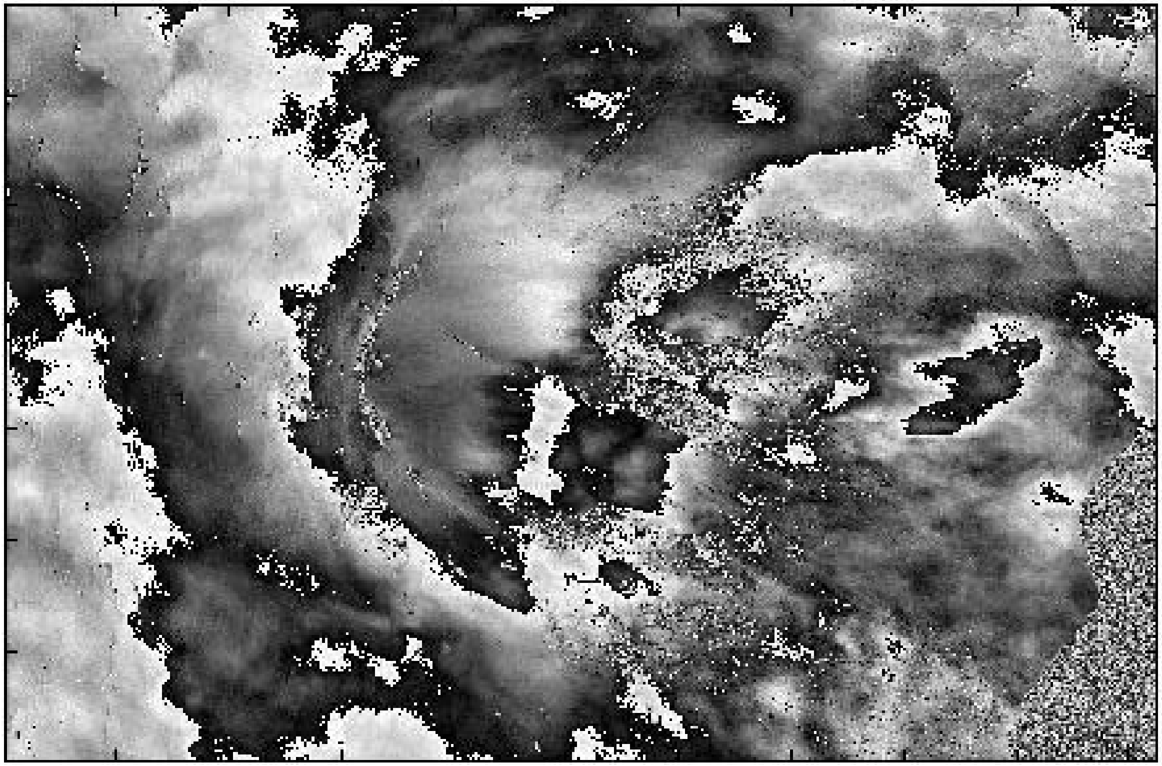
# Sources of errors (III)

# Atmospheric delay

# InSAR

## Main limits of SAR Interferometry

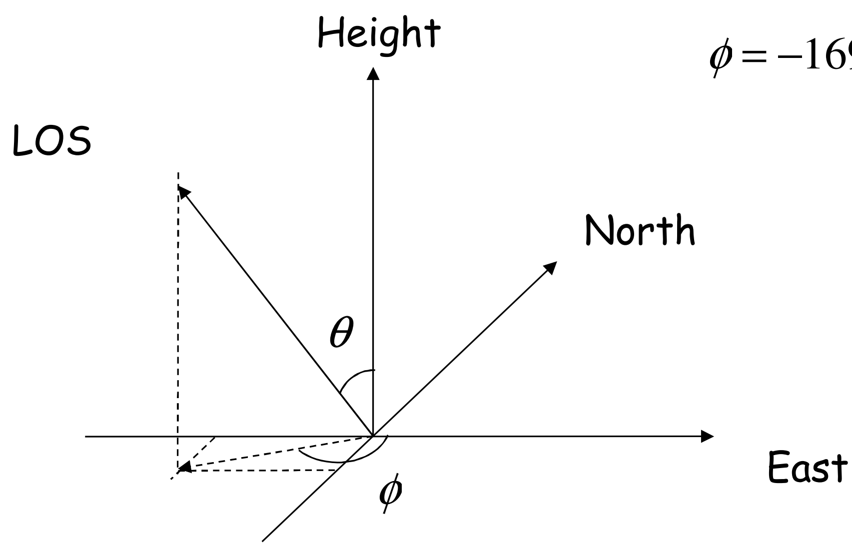
### Atmospheric effects



# Sensitivity direction

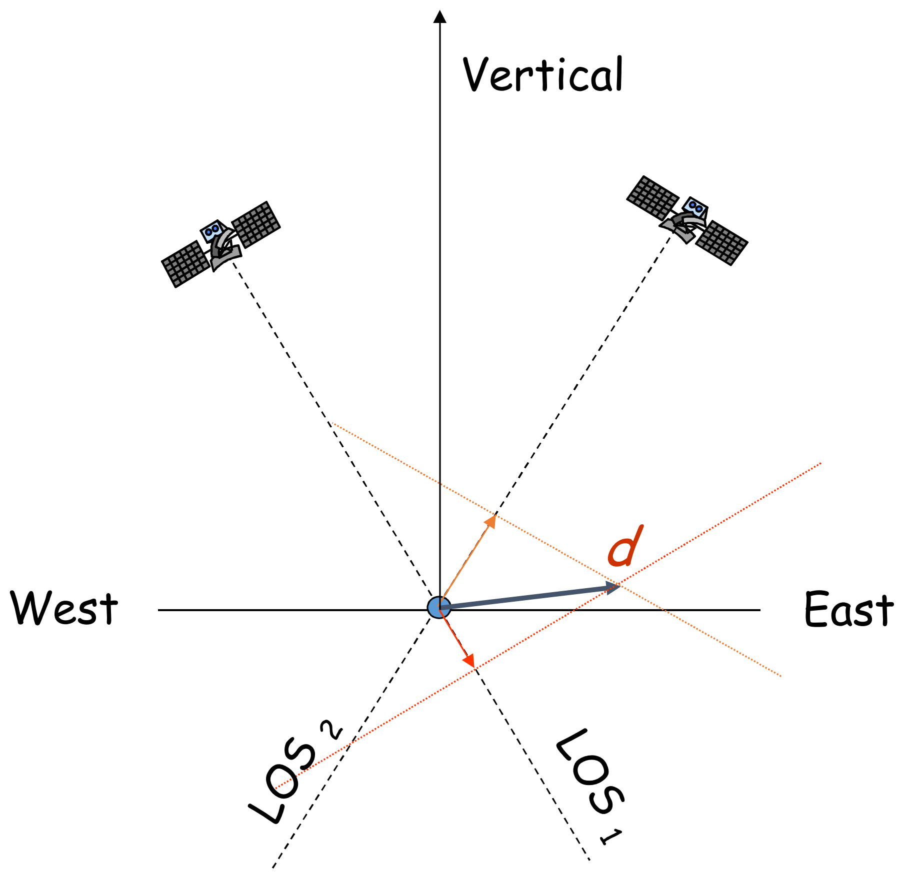
# Sensitivity only along LOS

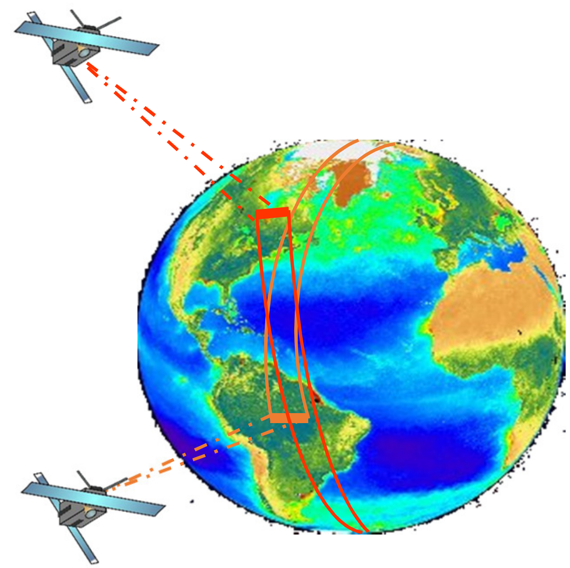
$$\theta = 37.5\,\deg$$
$$\phi = -169.7\,\deg$$




With a single geometry we cannot distinguish between vertical and horizontal movements

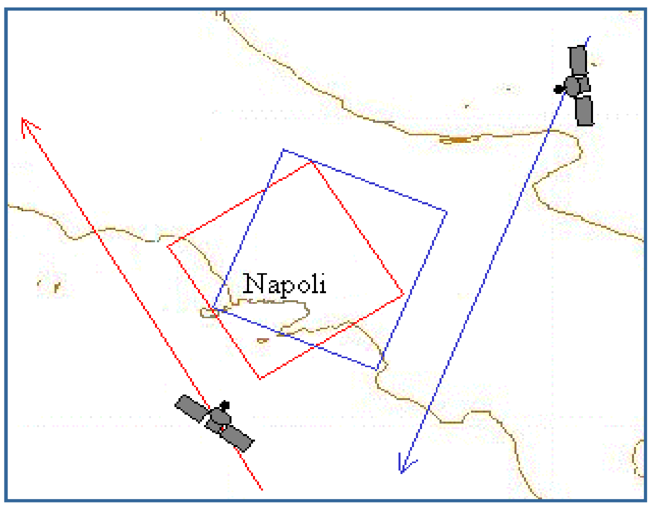
## Horizontal and vertical motion detection

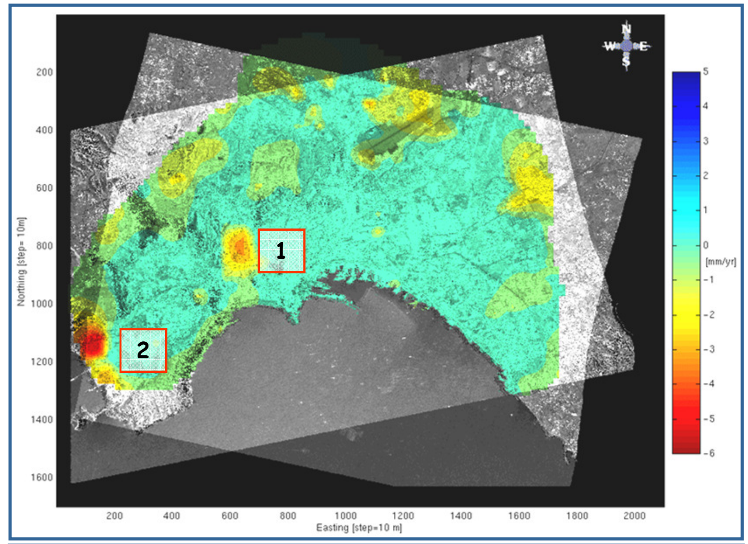


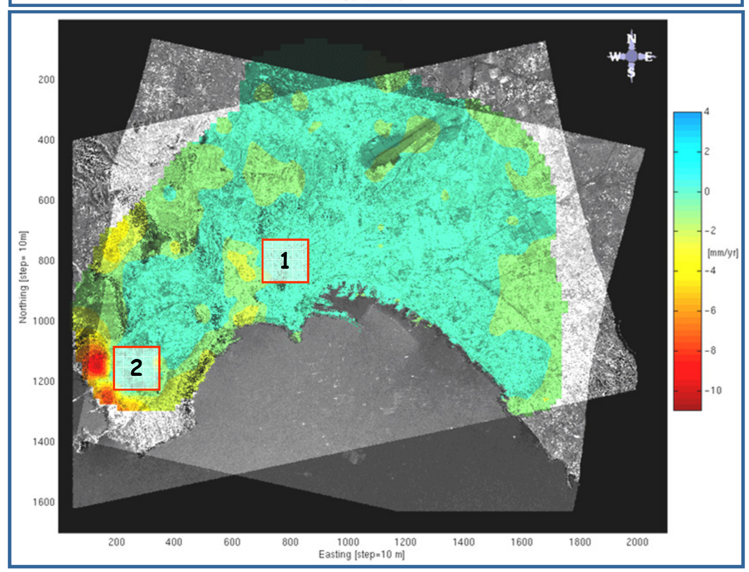



# Horizontal and vertical motion decomposition

| | |
|---|---|
| 1 | Subway excavations |
| 2 | Landslide |

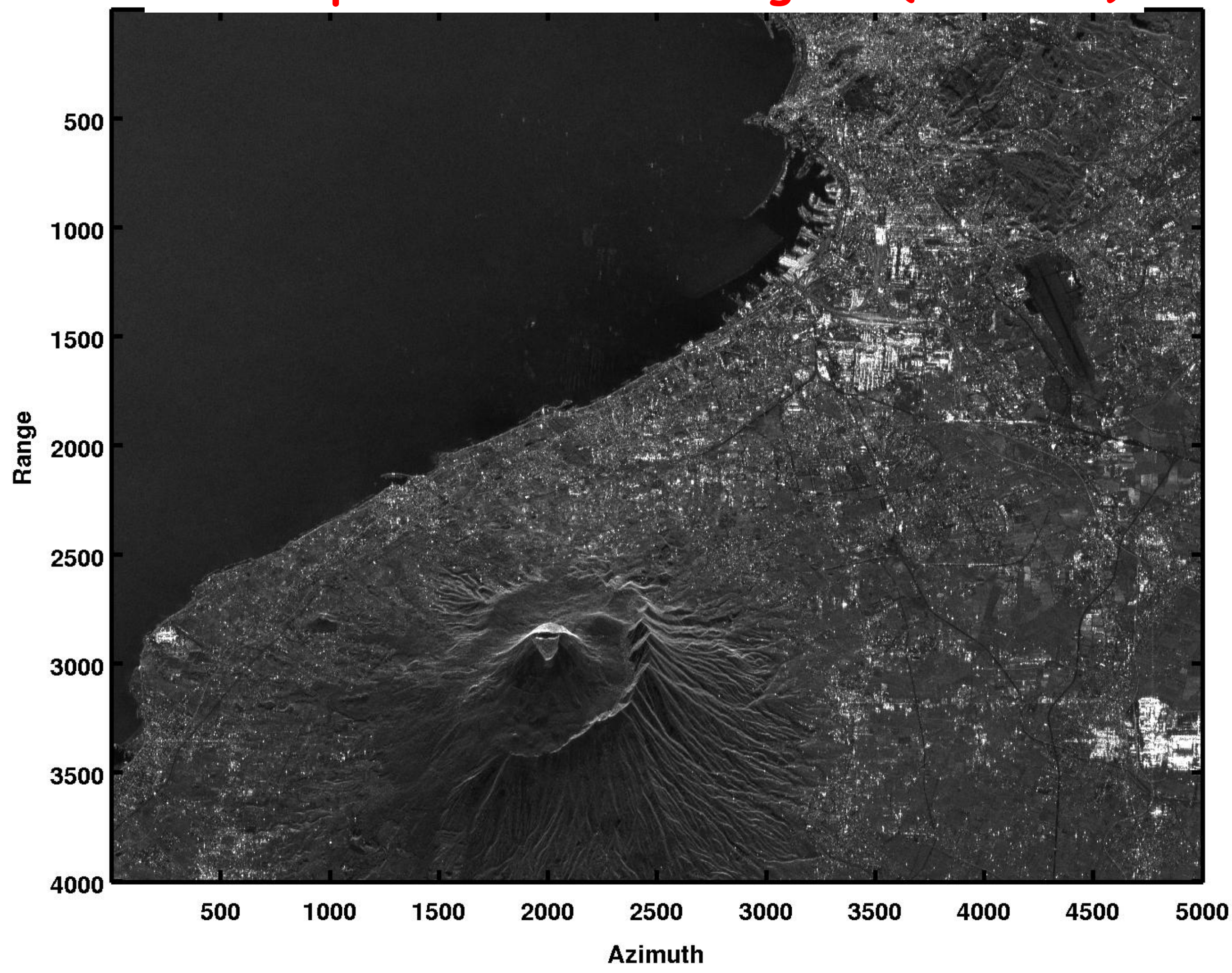


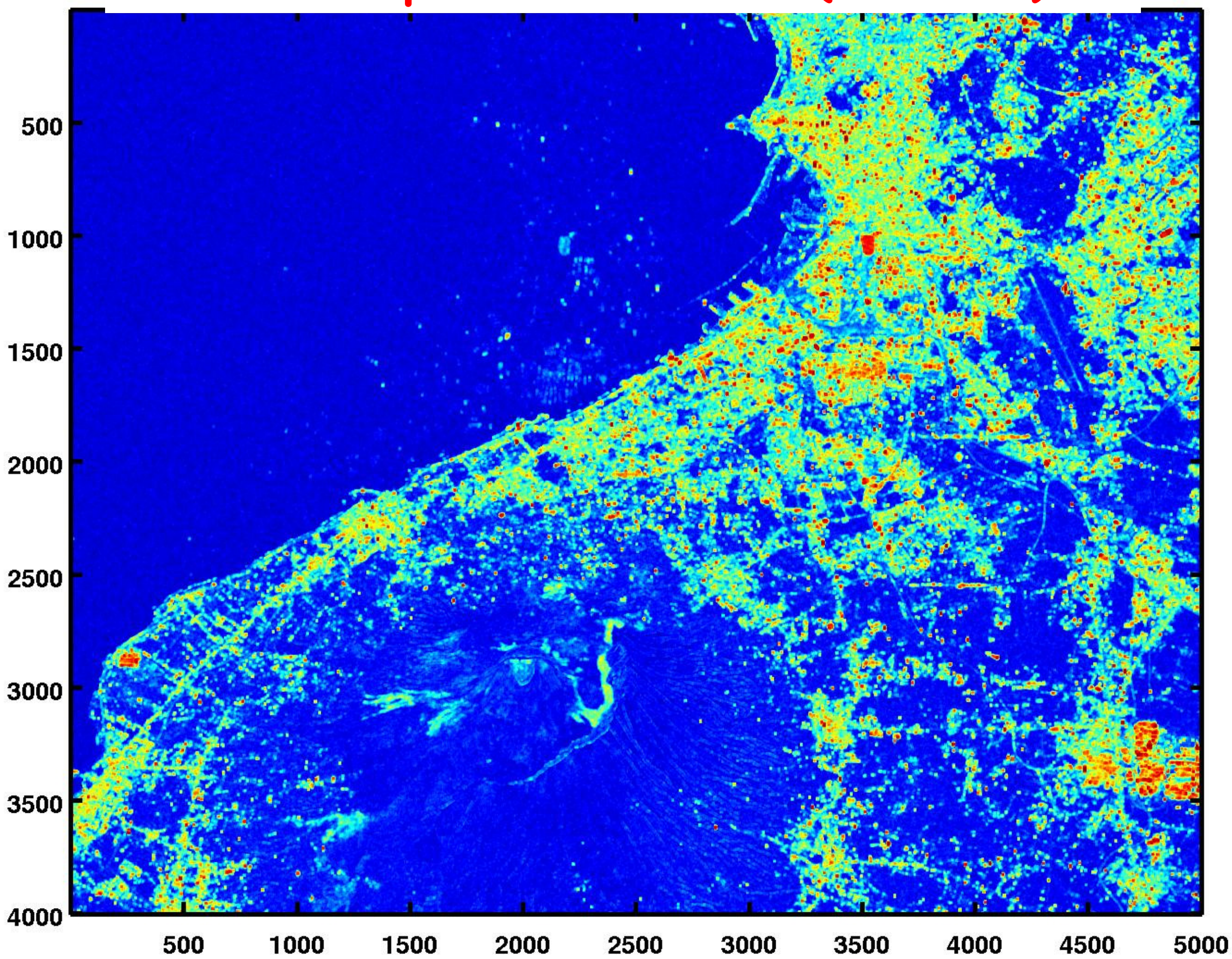



# Coherence as an additional information

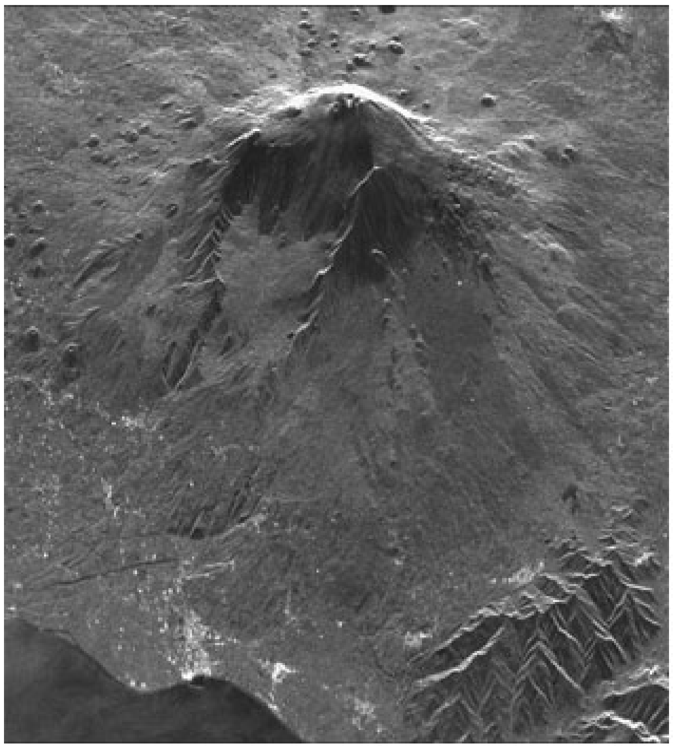
# The amplitude of SAR images… (Vesuvius)



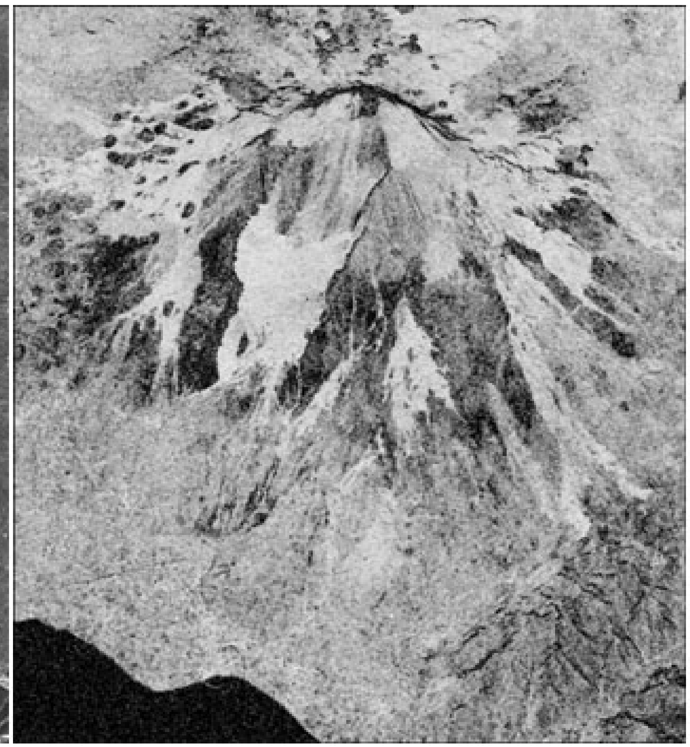
## … and the spatial coherence (Vesuvius)



**The joint use of amplitude and coherence**



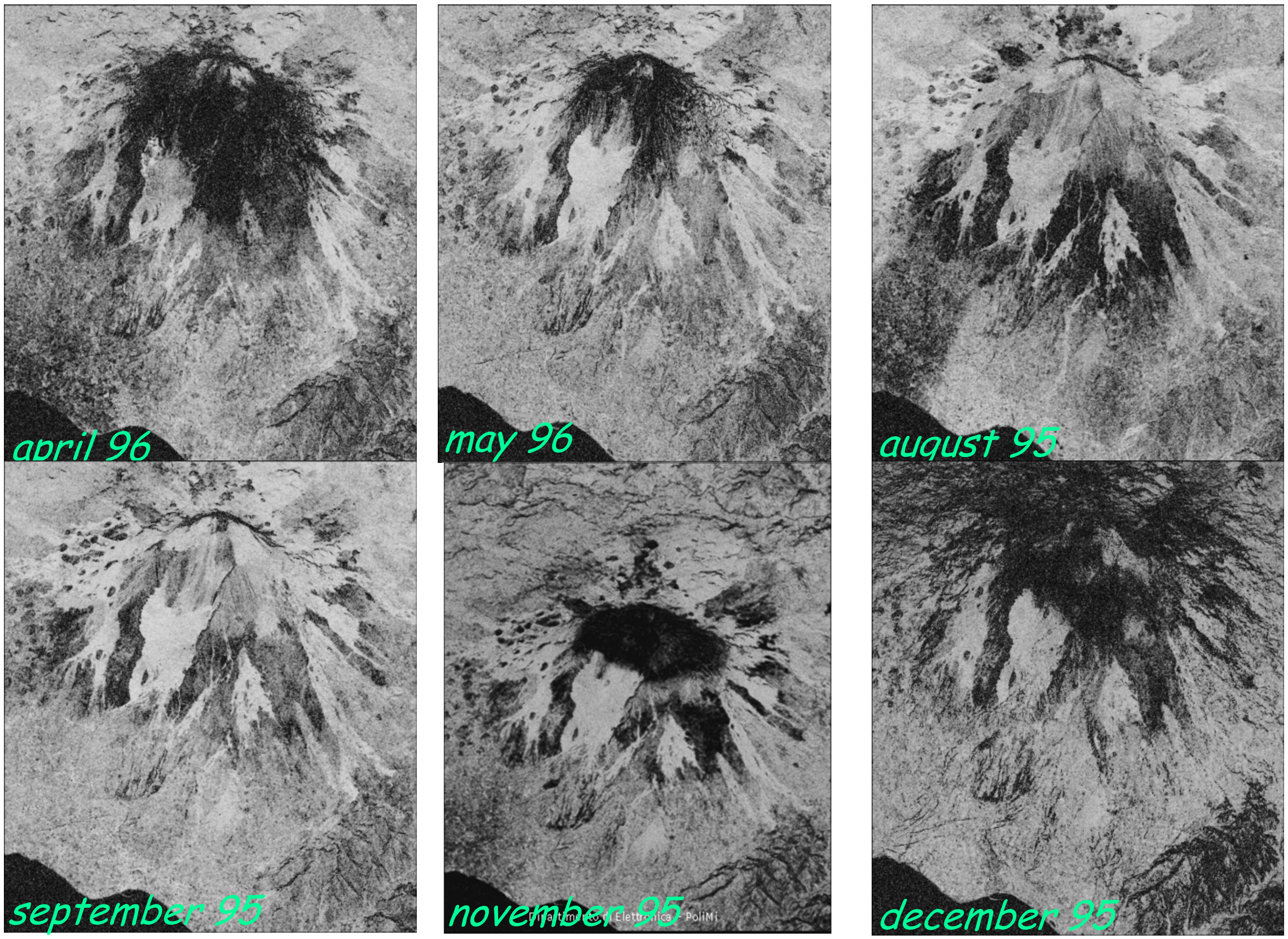
Amplitude



Coherence

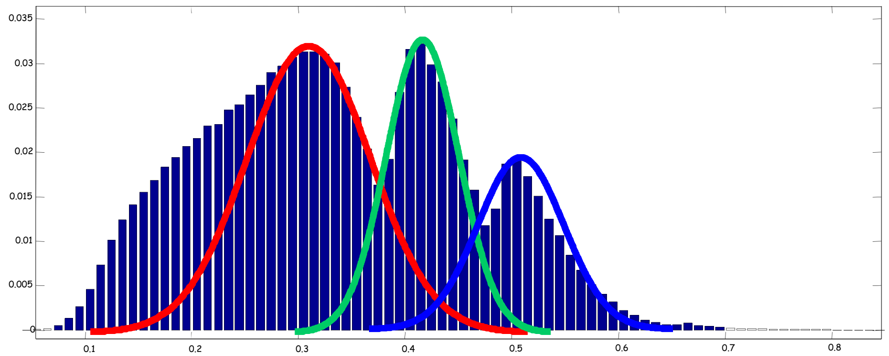
Etna

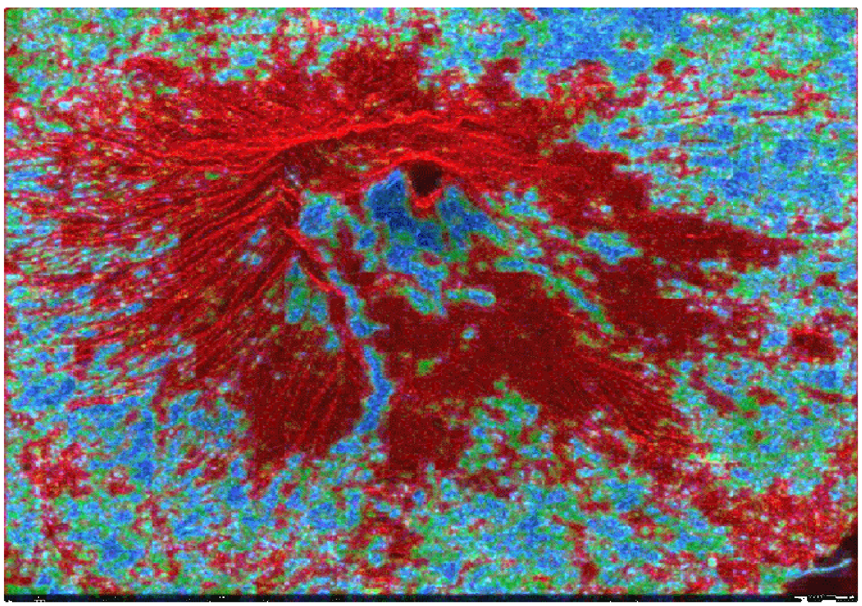
# Change detection with coherence maps

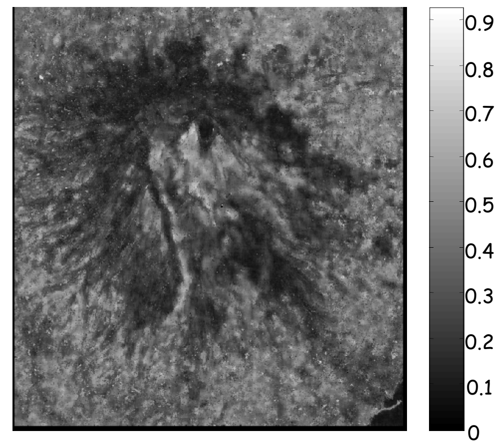



Etna

# Classification through coherence modes






Mt. Vesuvius segmentation

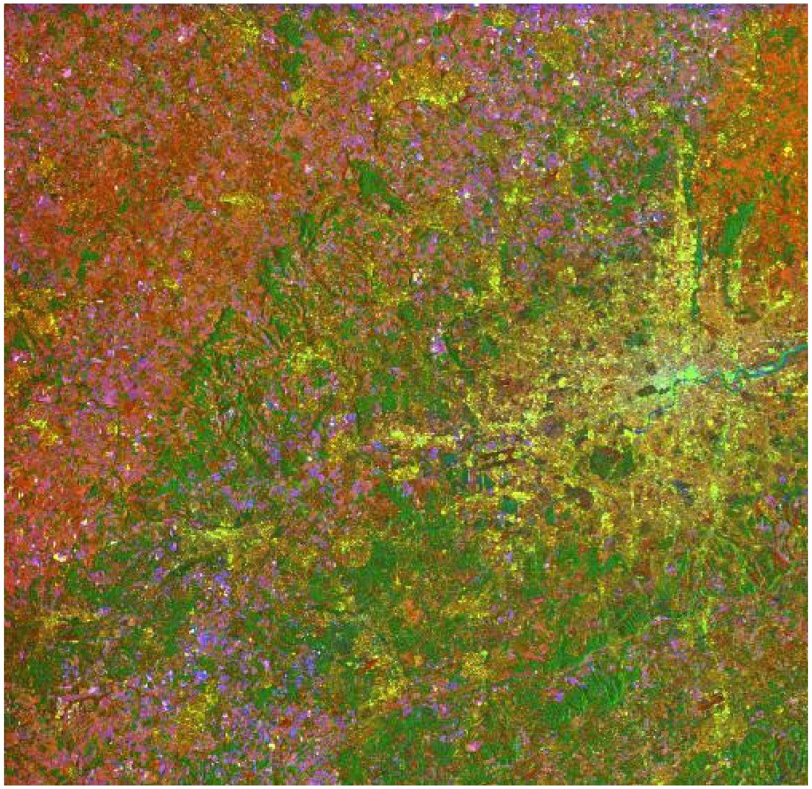
# Interferometric Land-Use Images (1)

The ILU image is an RGB image where the separate channels have been coded such that:

**Red** = Interferometric coherence

**Green** = Average intensity of the two acquisitions

**Blue** = Intensity change between the two acquisitions



**Green** areas correspond to heavily vegetated (forests) or layover areas

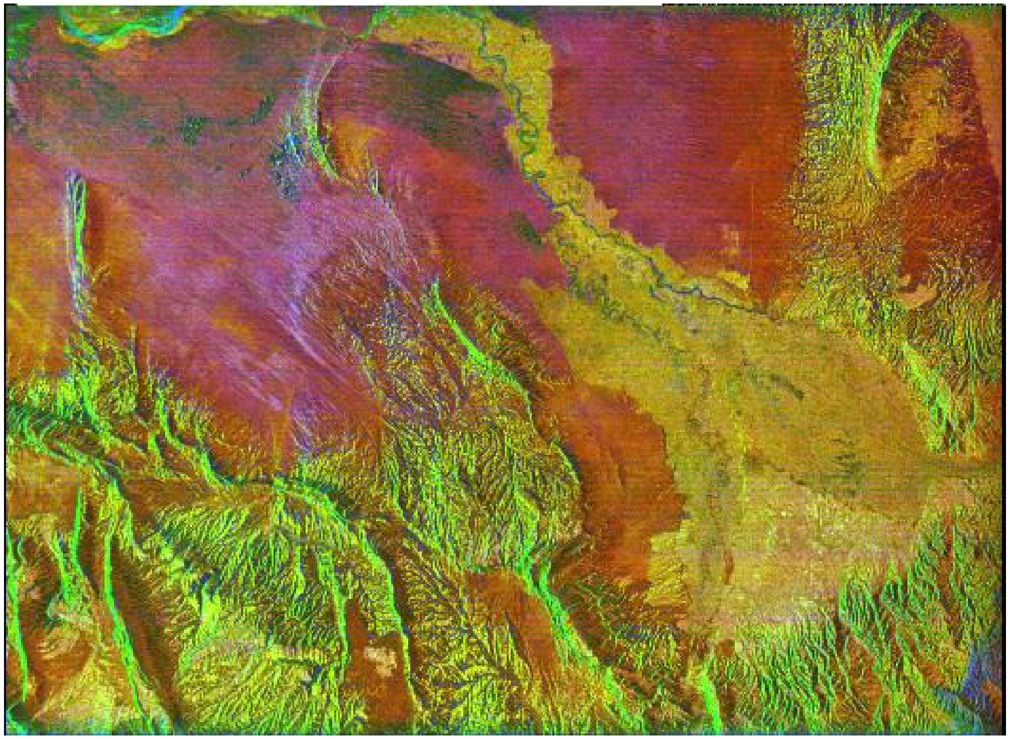
**Blue** areas correspond to water surfaces (sea & inland water)

**Red** areas correspond to bare rock and stable agricultural fields.

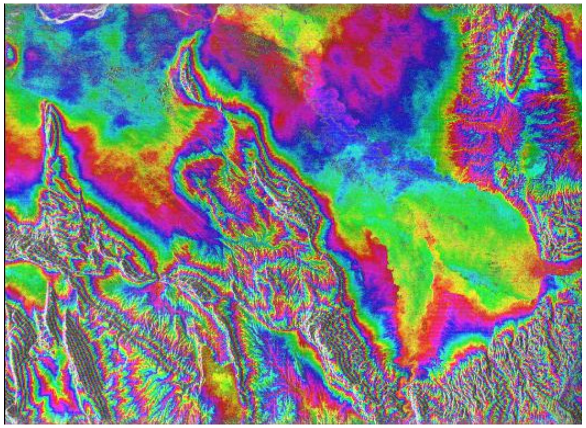
**Yellow** areas correspond to urban centers.

# Interferometric Land-Use Images (2)

ILU image



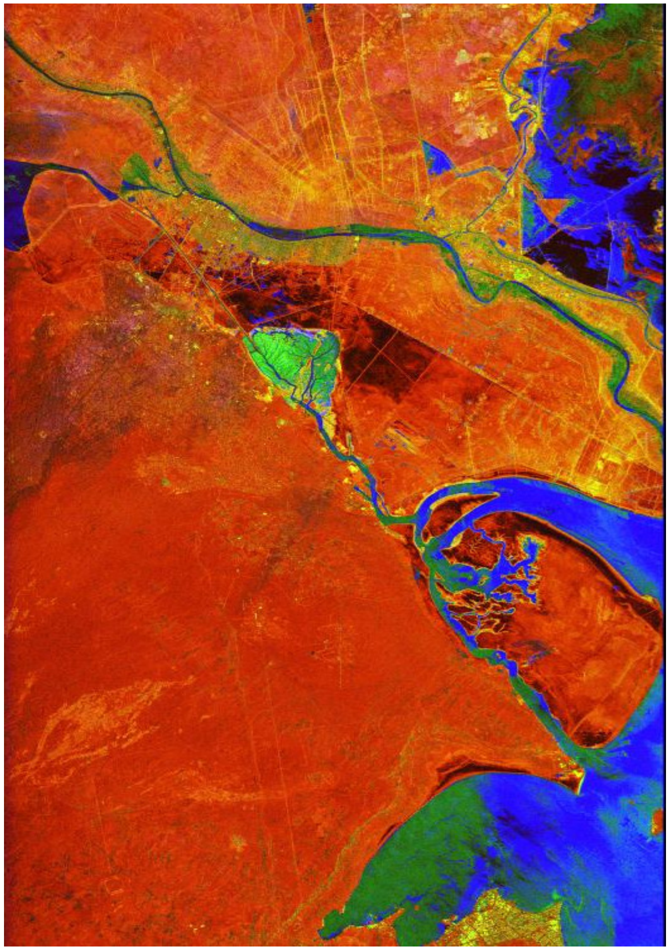
Interferogram



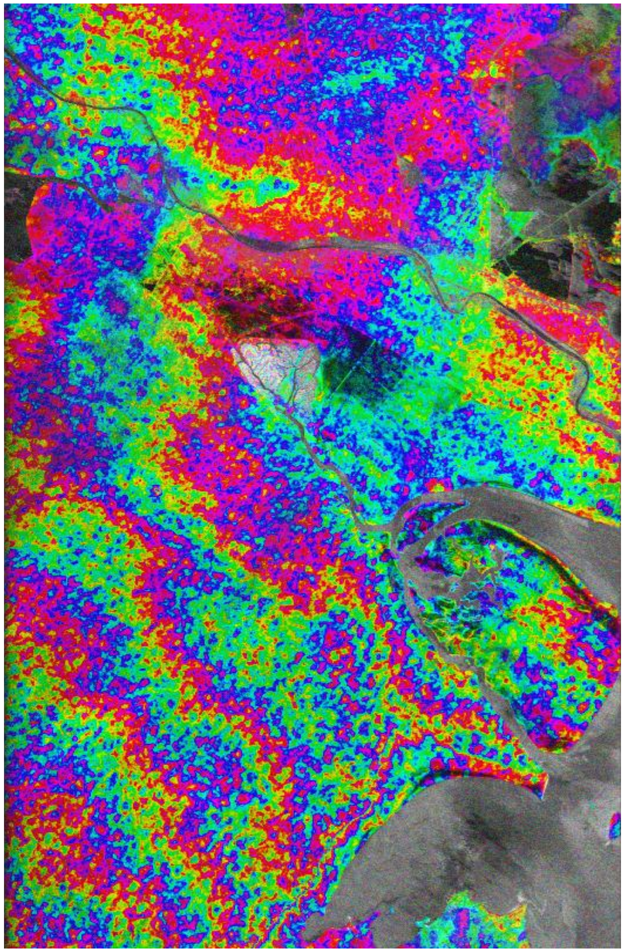
**Green** areas correspond to heavily vegetated (forests) or layover areas
**Blue** areas correspond to water surfaces (sea & inland water)
**Red** areas correspond to bare rock and stable agricultural fields.
**Yellow** areas correspond to urban centers.

# Interferometric Land-Use Images (3)

ILU image

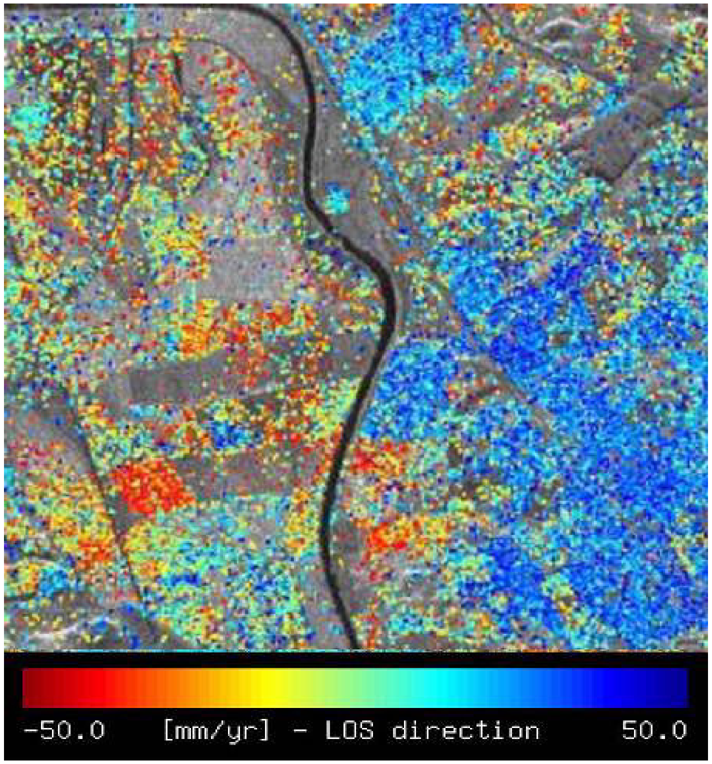


Interferogram



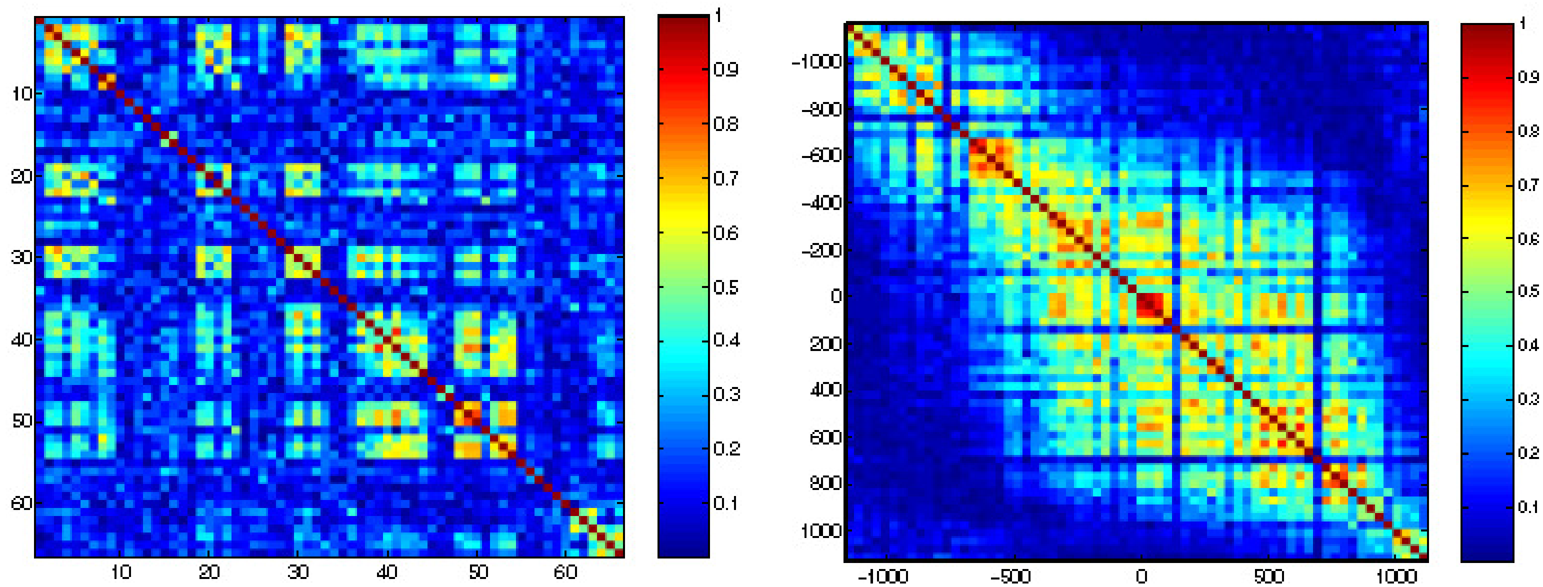
# Interferometry for field characterization

**3days ERS data, Rome**



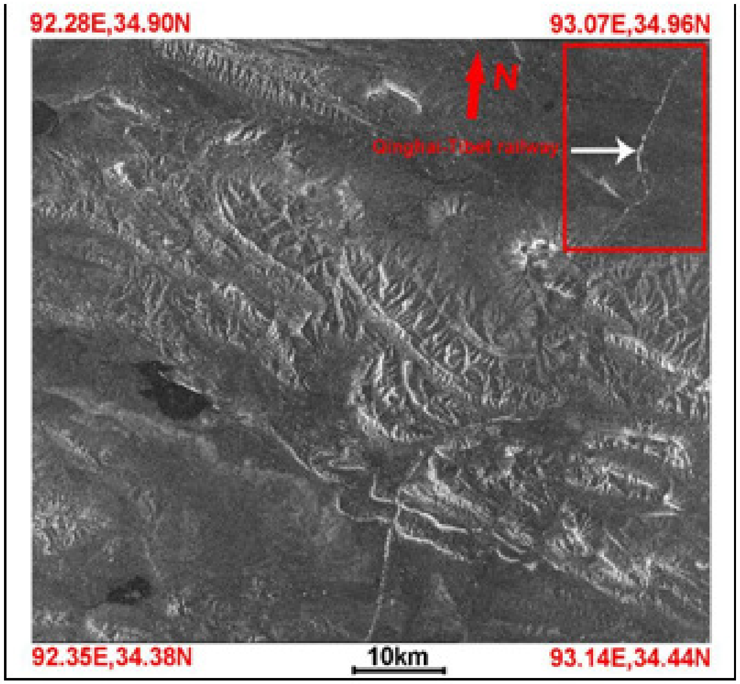

# Coherence matrices for terrain characterization (1)

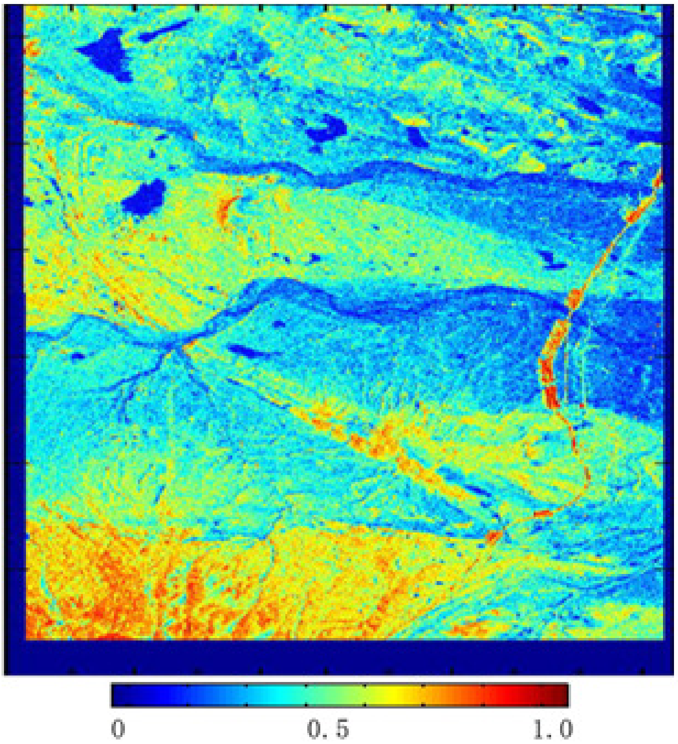
**Studying the decorrelation of distributed targets**



# Coherence matrices for terrain characterization (2)

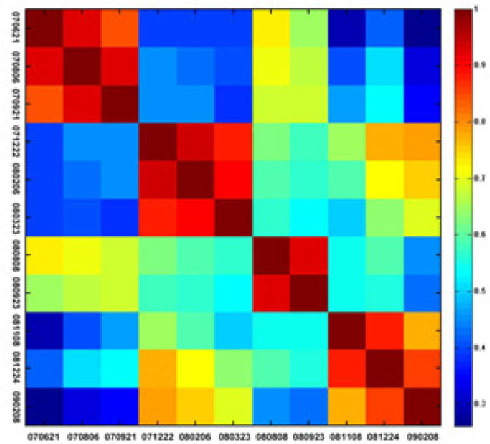
**ALOS data on the railway in Tibet**



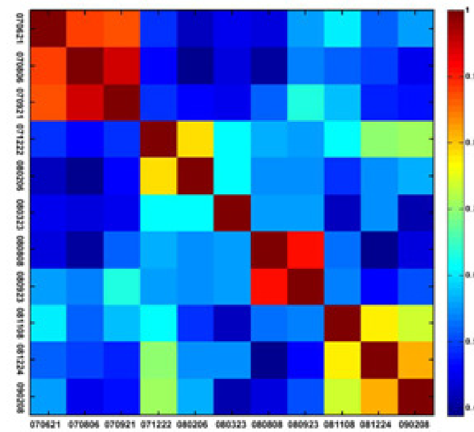



# Coherence matrices for terrain characterization (3)

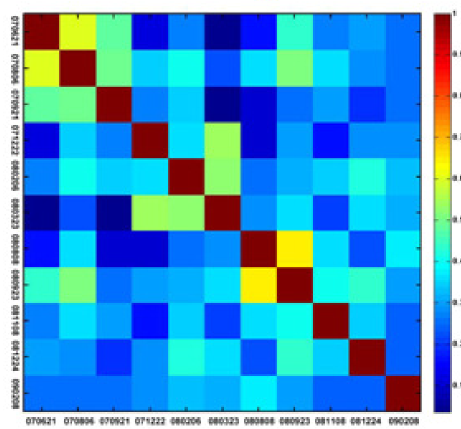
**ALOS data on the railway in Tibet**

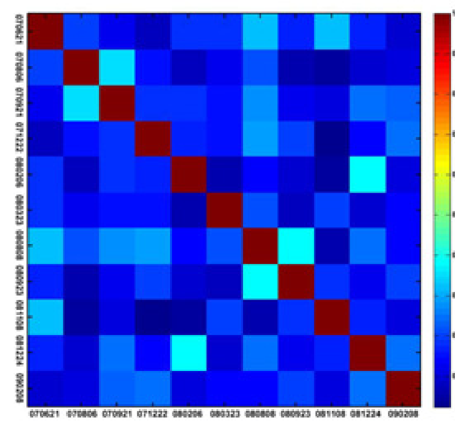



Railway




Rock



# TERRASAR-X data in HONG KONG