Synthetic Aperture Radar Differential Interferometry (DInSAR) Technique

(*Lecture II- Wednesday 12 May 2010*)

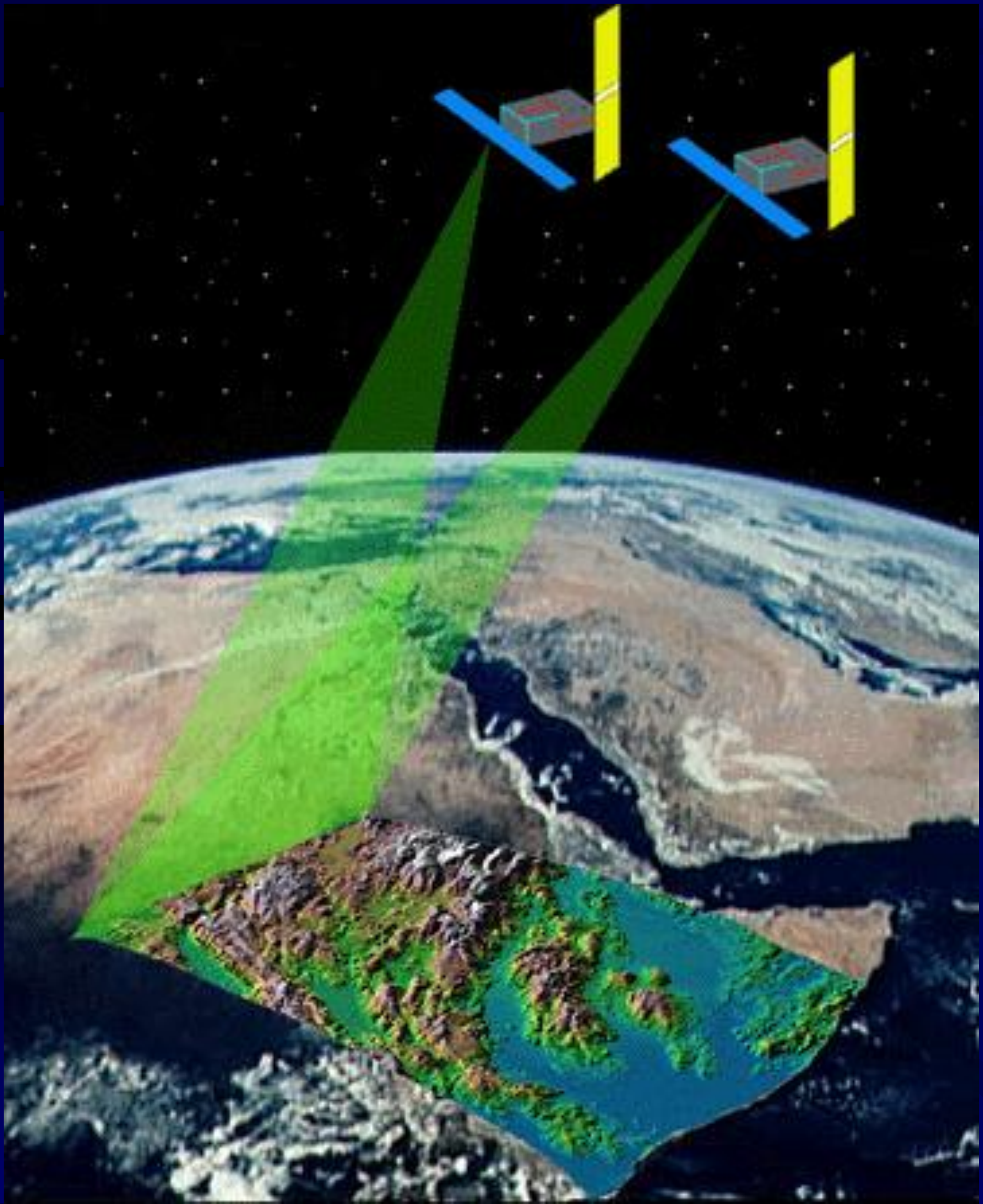
ISNET/CRTEAN Training Course on Synthetic Aperture Radar (SAR) Imagery: Processing, Interpretation and Applications
3-14 May 2010, Tunis, Tunisia

Parviz Tarikhi, PhD
parviz_tarikhi@hotmail.com
http://parviztarikhi.wordpress.com
Mahdasht Satellite Receiving Station, ISA, Iran

OUTLINE

- INTRODUCTION
- CONCEPT
- SAR INTERFEROMETRY PRINCIPLES
- STEPS
- DATA INVESTIGATION
- INFORMATION ANALYSIS
- RESULTS
- METHODS

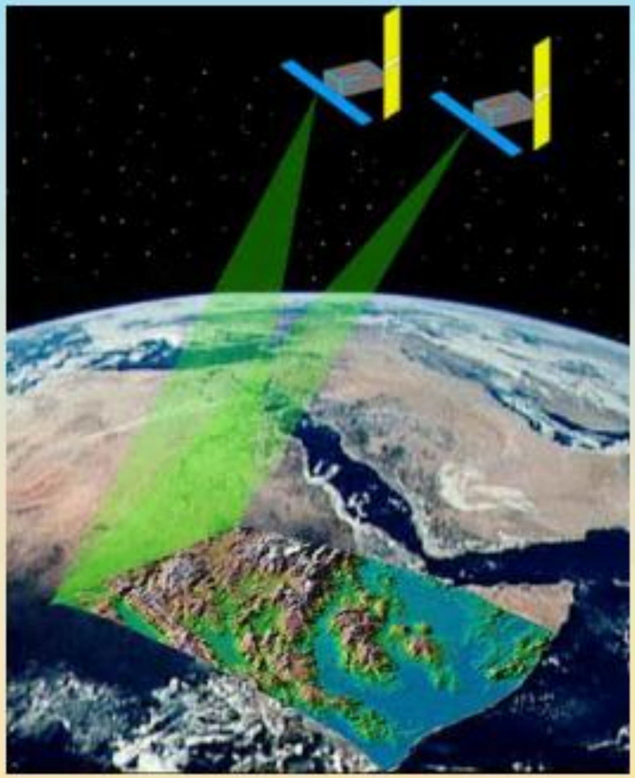
DInSAR



- SAR interferometry in recent years proves to be a strong method for change detection, DEM generation, classification and…

- For interferometry, two radar images of the same area with slightly different imaging angles is required.

Interferometric Synthetic Aperture Radar (InSAR)

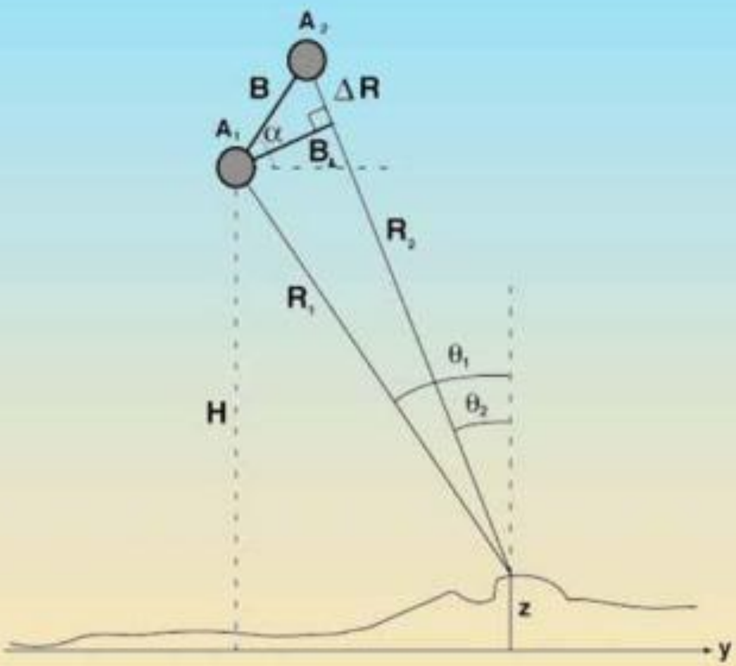


Spaceborne radar satellites

Multiple observations of surface
- Simultaneously
- Spaced in time

Applications
- Hi-res topography
- Motions
- Crustal deformation

InSAR method

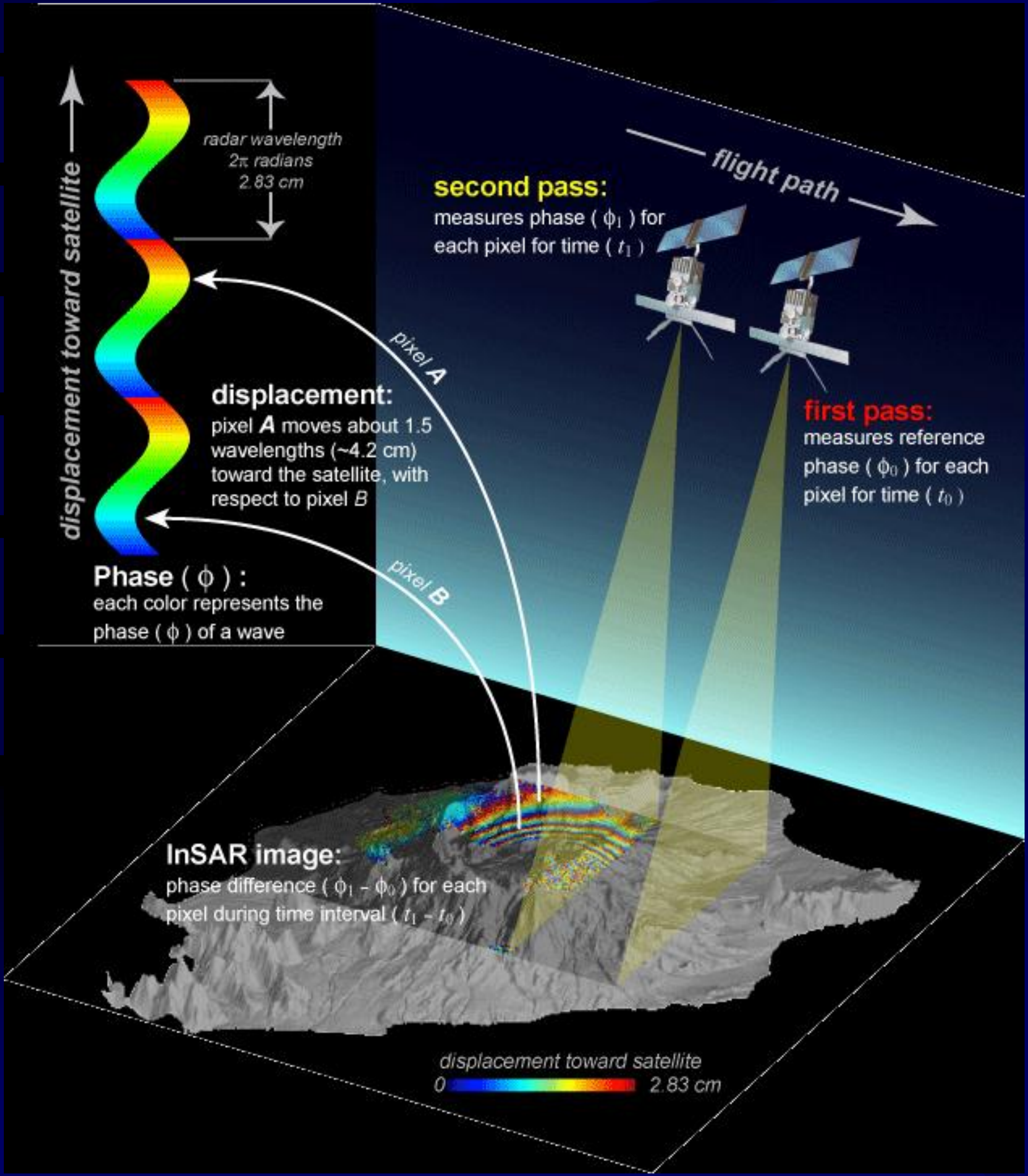


Imaging geometry

Phase changes from
- Parallax
- Motion of points between observations

Measure changes to λ/100
- m-scale topography
- cm-scale motions

DInSAR

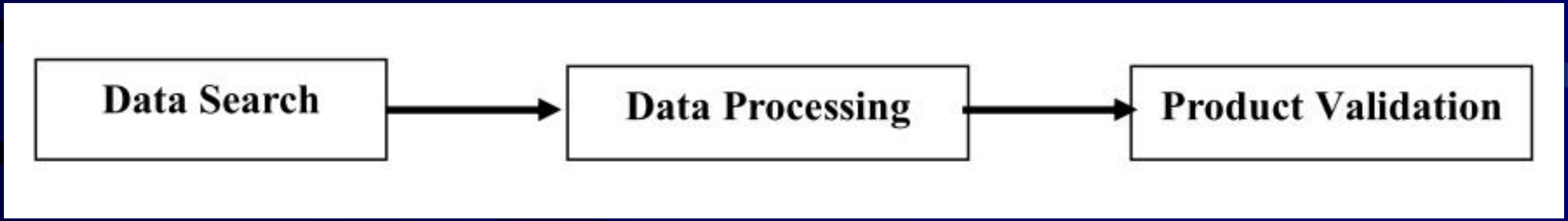


InSAR Method

DEM generation steps

- The procedure for producing interferograms involves applied software and needed precision, but it usually includes some basic steps.
- InSAR operational steps for DEM generation from SLC-SAR data are performed in three major stages including
- data search and selection
- processing
- product validation

InSAR operational steps for DEM generation



Data search and selection

Missions

Mission	SEASAT	JERS-1	ERS-1	ERS-2	ENVISAT	RADARSAT 1
Owner	JPL	Japan	ESA	ESA	ESA	CSA
Launch Date	June 07, 1978	Feb. 11, 1992	July 16, 1991	April 20, 1995	2002	1995
Ended Date	Oct '10, 1978	Oct' 12, 1998	2000			
Band	L(23.5 cm, 1.275 GHZ)	L(23.5 cm, 1.275 GHZ)	C(5.7 cm, 5.25 GHZ)	C(5.7 cm, 5.25 GHZ)	C(5.7 cm, 5.25 GHZ)	C(5.7 cm, 5.35 GHZ)
Polarization	HH	HH	VV	VV	All	HH
Look angle	20 (23)	35° (38°)	20-26	20-26	16-45	20-50
Swath	100km	75 km	100km	100km	50km-400km	45-500km
Range resolution	25	18 m	20m	20m	20m	10-100m
Azimuth resolution	25	18 m	30m	30m	30m	10-100m
Left/Right looking		Right	Right	Right	Right	Right
Looks	4	3	4	4	4	
Orbit	Altitude: 800 km in near polar orbit	Altitude: 568km, inclination: 98 degrees	Altitude: 785km, inclination 98.5 degrees	Altitude: 785km, inclination 98.5 degrees	Altitude: 785km, inclination 98.5 degrees	Altitude: 798 km, Inclination 98.6 degrees.

Data search and selection

http://earth.esa.int/EOLi/EOLi.html

esa

EOLi Screenshots

EOLi "ESA's Link to Earth Observation"

EOLi (Earth Observation Link) is the European Space Agency's client for Earth Observation Catalogue and Ordering Services.

Using EOLi, you can browse the metadata and preview images of Earth Observation data acquired by the satellites ENVISAT, ERS, Landsat, IKONOS, DMC, ALOS, SPOT, Kompsat, Proba, JERS, IRS, Nimbus, NOAA, SCISAT, SeaStar, Terra/Aqua.

Scientific Users with a registered account can order or download products of various processing levels.

Contacts

For any question on using EOLi, on the catalogue and ordering service, on registration, or any other EO related information, please contact our Help Desk:

Data search and selection

http://earth.esa.int/object/index.cfm?fobjectid=5225

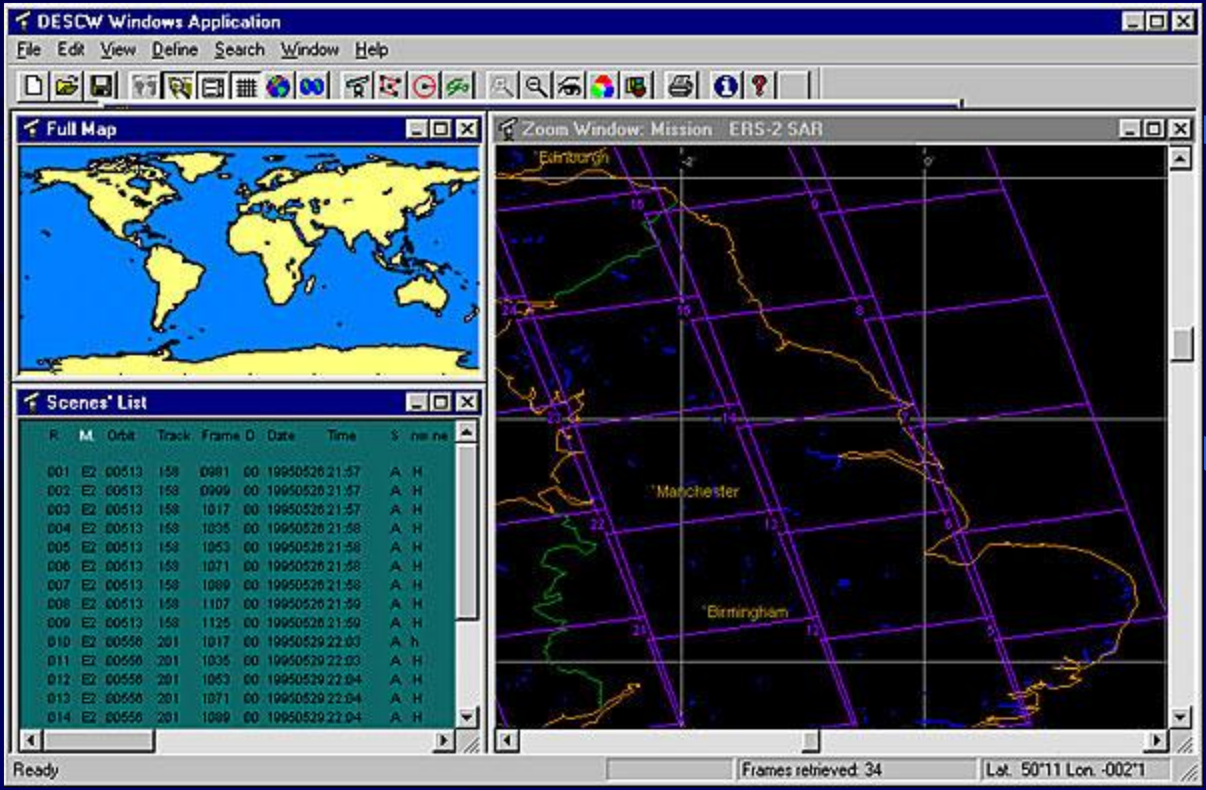
EOLI Web - Multi-Provider Interoperable Catalogue Service

The EOLI Web Client provides access to ESA catalogues of EO products via a standard web browser, as well as to the catalogues of other data providers (for example DLR and NASA ECHO) and is part of ESA's eoPortal. This tool doesn't allow online ordering (use EOLI-SA), but it allows to browse the meta data and obtain further information about the collections and products available from ESA and other providers.

Data search and selection

http://earth.esa.int/descw/

DESCW (Display Earth remote sensing Swath Coverage for Windows) is a multi-mission software tool created to allow you to display Earth Observation satellites (ERS-1, ERS-2, LANDSAT-5, LANDSAT-7, JERS-1, TERRA/MODIS and, preliminarily, ENVISAT) coverage over the Earth Map. It will help you in selecting and ordering your remote sensing products from several missions at once.



DInSAR

Data search and selection

Table 1: List of the ERS-SAR data input to the project

Data name	Date (mm/dd/yy)	Platform	Track	Frame	Orbit	Product type
B0r	06/07/1995	ERS-1	336	2781	20364	RAW
B9s	06/08/1995	ERS-2	336	2781	00691	SLCI
B8r	10/15/1998	ERS-2	336	2781	18226	RAW
B7s	12/24/1998	ERS-2	336	2781	19228	SLCI
B6s	03/04/1999	ERS-2	336	2781	20230	SLCI
B5s	03/20/1999	ERS-2	064	2781	20459	SLCI
B4p	04/05/1999	ERS-2	293	2781+2 nodes	20688	PRI
B3s	04/24/1999	ERS-2	064	2781	20960	SLCI
B2s	08/12/1999	ERS-1	157	819-4 nodes	42229	SLCI
B1s	08/13/1999	ERS-2	157	819-4 nodes	22556	SLCI
	08/17/1999	**EARTHQUAKE**				
A1p	08/23/1999	ERS-2	293	2781+2 nodes	22692	PRI
A2s	08/25/1999	ERS-1	336	2781	42408	SLCI
A3s	08/26/1999	ERS-2	336	2781	22735	SLCI
A4s	09/10/1999	ERS-1	064	2781	42637	SLCI
A5s	09/11/1999	ERS-1	064	2781	22964	SLCI
A6s	09/16/1999	ERS-1	157	819-4 nodes	42730	SLCI
A7s	09/17/1999	ERS-2	157	819-4 nodes	23057	SLCI

Table 2: List of the Landsat TM data input to the project

Data name	Date (mm/dd/yy)	Platform	Sensor	Details
B	03/27/1999	Landsat	TM	Path 179 Row 32
	08/17/1999	**EARTHQUAKE**		
A	08/18/1999	Landsat	TM	

Data search and selection

Table 3: *The information on the status of co-registration of ERS-SAR image pairs and their correspondent baseline*

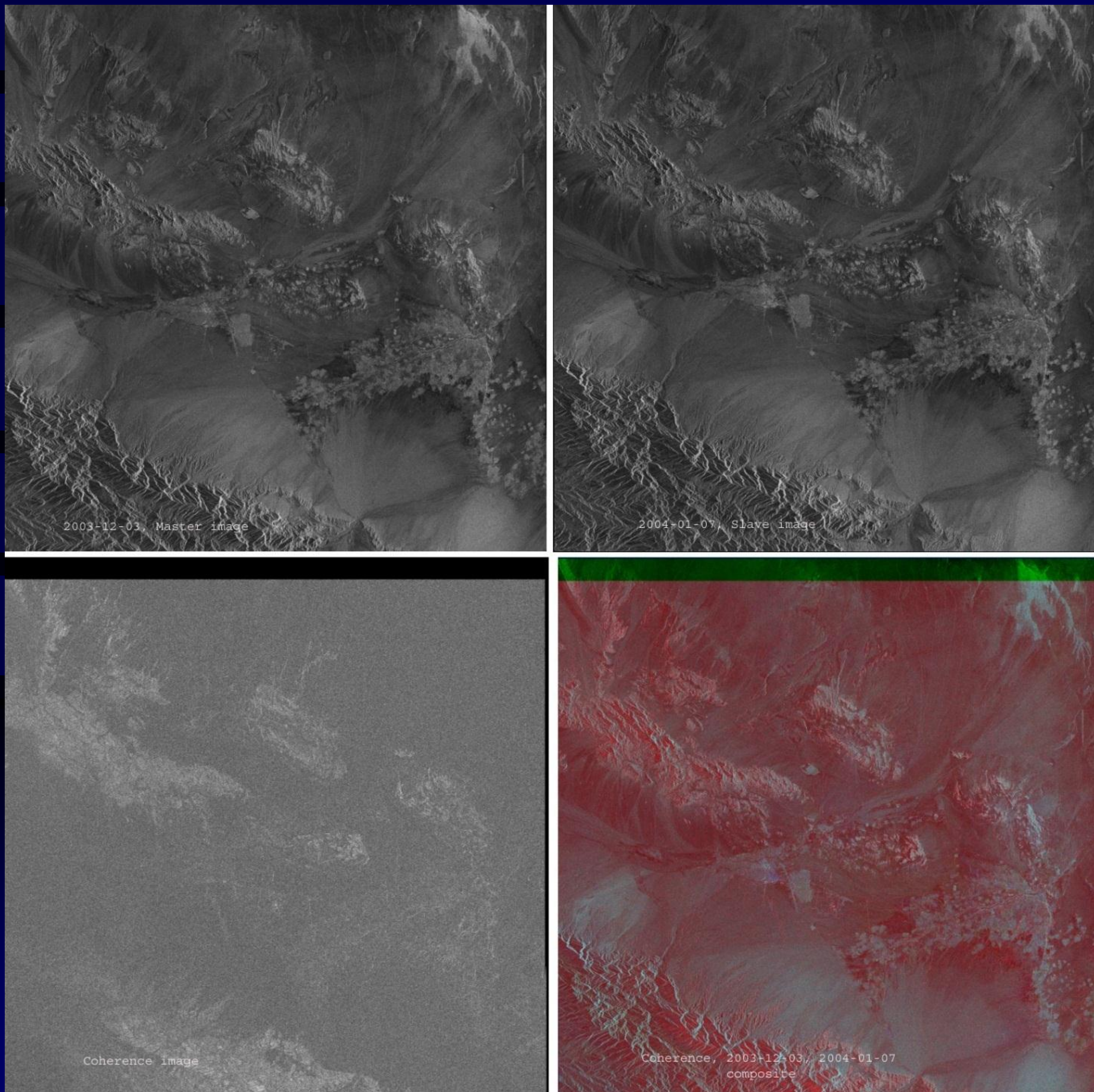
	B0r	B9s	B8r	B7s	B6s	B5s	B4p	B3s	B2s	B1s	A1p	A2s	A3s	A4s	A5s	A6s	A7s
B0r	@@@@																
B9s		@@@@		-55.634 -102.390	-1063.286 -461.205							-87.269 16.147	-445.234 -122.945				
B8r			@@@@														
B7s		64.125 102.392		@@@@	-1003.453 -365.355							40.250 118.674	-410.253 -21.291				
B6s		1063.260 462.550		1003.254 365.367	@@@@							1055.158 479.624	625.582 340.265				
B5s						@@@@		-228.269 -27.607	Node Overlapp id	Node Overlapp id				-612.951 -217.482	-793.571 -290.704	Node Overlapp id	Node Overlapp id
B4p							@@@@				779.090 328.528						
B3s						227.307 27.618		@@@@	Node Overlapp id	Node Overlapp id				-387.704 -189.965	-569.447 -263.207	Node Overlapp id	Node Overlapp id
B2s									@@@@	224.190 91.097				Node Overlapp id	Node Overlapp id	-121.640 -67.725	-7
B1s							-779.954 -328.555		-224.191 -91.091	@@@@				Node Overlapp id	Node Overlapp id	-238.318 -154.753	-11.401 -53.558
A1p											@@@@						
A2s		87.979 -16.140		-34.913 -118.706	-1055.915 -478.325							@@@@	-429.218 -140.735				
A3s		445.251 121.916		411.008 22.122	-625.800 -340.405							429.460 140.986	@@@@				
A4s						613.056 214.287		387.797 189.929						@@@@	-182.313 -73.239	Node Overlapp id	Node Overlapp id
A5s						793.534 290.780		569.706 263.179						182.284 73.229	@@@@	Node Overlapp id	Node Overlapp id
A6s									70.912 66.023	7						@@@@	234.443 100.386
A7s									7	13.971 53.767						-234.419 -100.433	@@@@

Data search and selection

Image Parameters	Master	Slave
Frame number	22	23
Orbit number	9192	9693
Acquisition date	03-Dec-2003	07-Jan-2004
Acquisition Time [UTC]	06:13	06:13
Number of lines	26897	26580
Number of range pixels	5167	5167
Radar wavelength (m)	0.0562356	0.0562356
Sensor Platform Mission Identifier	ENVISAT-ASAR-SLC	ENVISAT-ASAR-SLC
Product Type	ASAR	ASAR

Bam Quake, 26th December 2003

DInSAR



Baseline components:

x= 429.50 m
y= - 386.92 m
z= 93.67 m

Normal= 519.60 m
Parallel= 270.13 m

Produced at ISA by ESA's Basic Envisat SAR Toolbox (BEST)

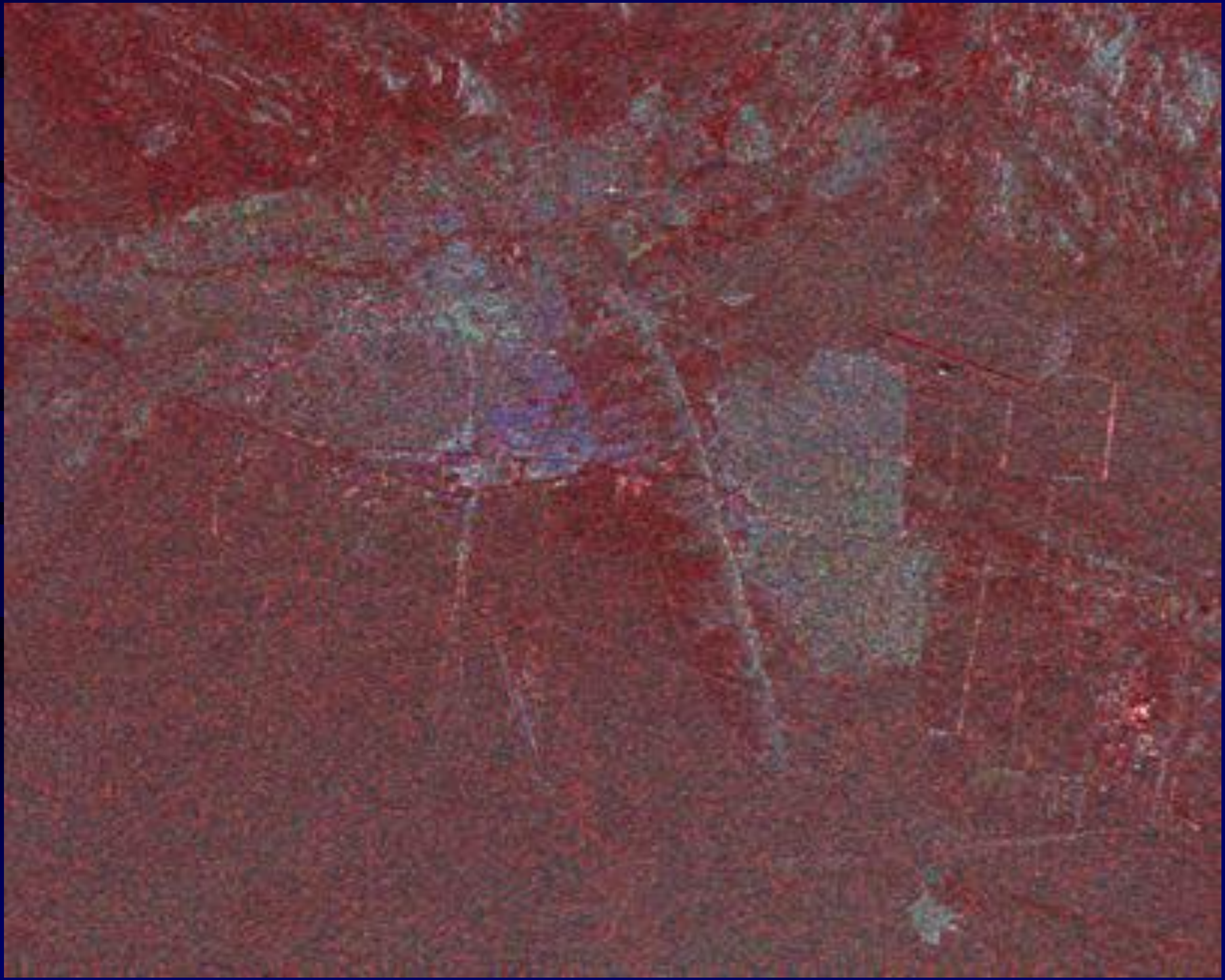
Coherence map generation

$$\gamma = \frac{\sum_{NL}(y_1 . y_2^{*})}{\sqrt{\sum_{NL}(|y_1|^2) . \sum_{NL}(|y_2^{*}|^2)}}$$

- The sums are over L=5 looks in frequency and N spatially adjacent pixels.
- Generally large values of N will give poor spatial resolution but will help to reduce the zero coherence bias and the speckle noise.
- A value of N= 3 × 3 is the compromise, which gives a zero coherence bias of approximately 0.21.
- Values of N greater than 1 also introduce a negative bias for high phase slopes.
- This leads to an under-estimate of the coherence in regions of high slope.
- The coherence is always a non-negative real number limited between 0 (for totally different images) and 1 (for completely identical images).
- Due to the moving window transient, the coherence image shows a border which size is half the moving window size, consisting of null pixels.

Bam Quake, 26th December 2003

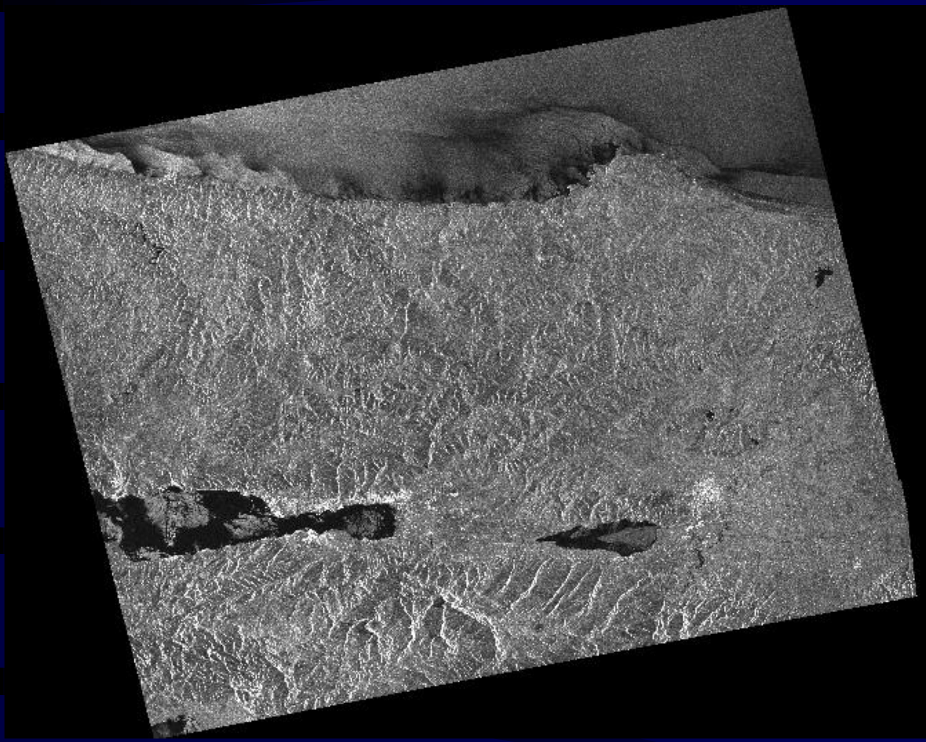
DInSAR



DInSAR

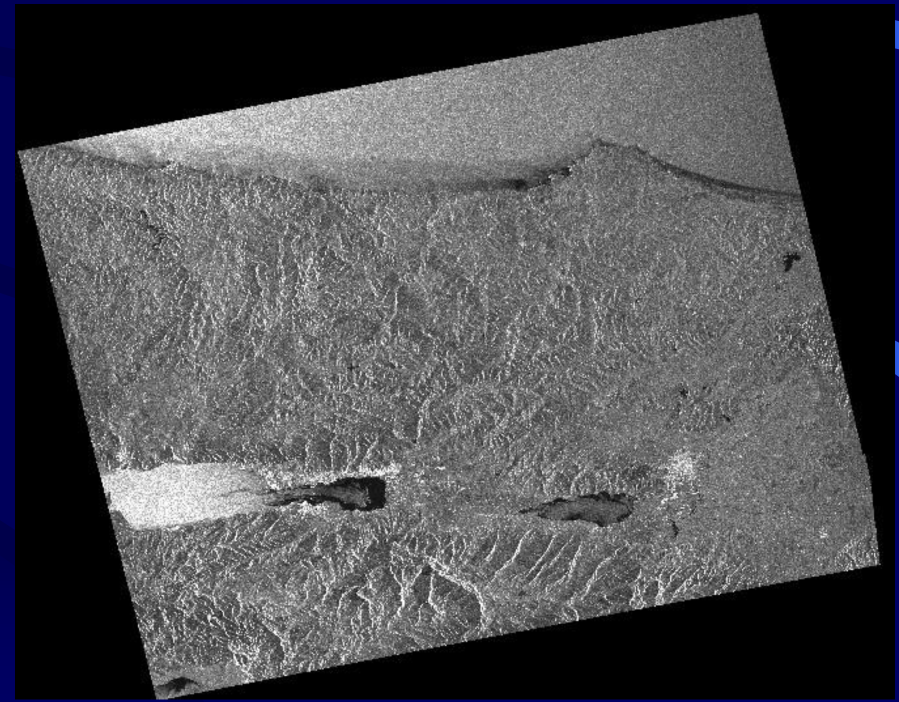
Image pairs of:

(1) 13 Aug. 1999, and
(2) 17 Sept. 1999
(3 days before and a month after quake)

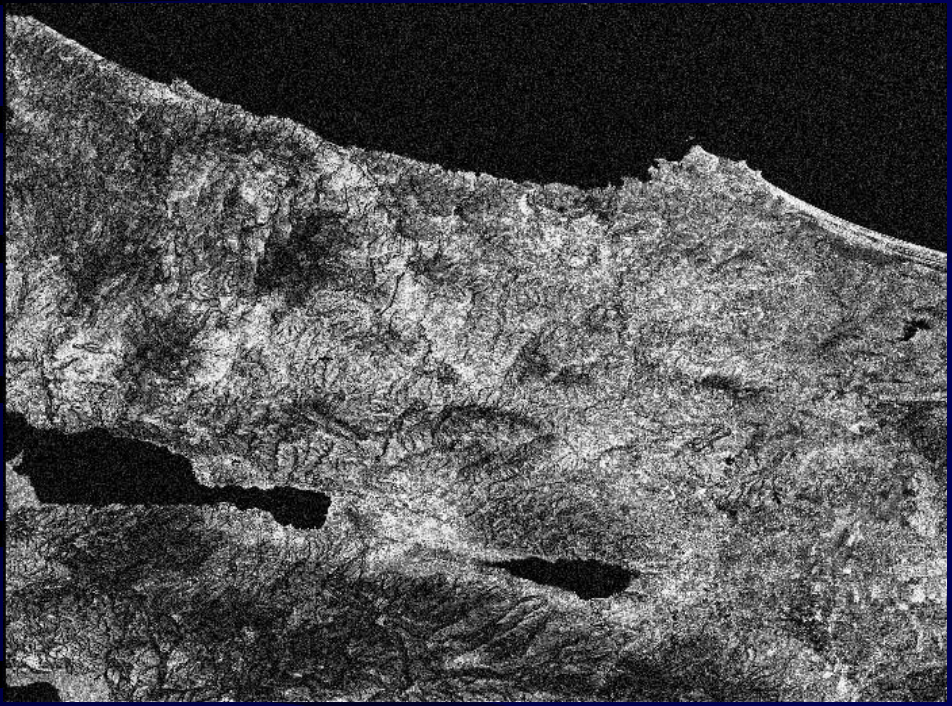


master image

slave image



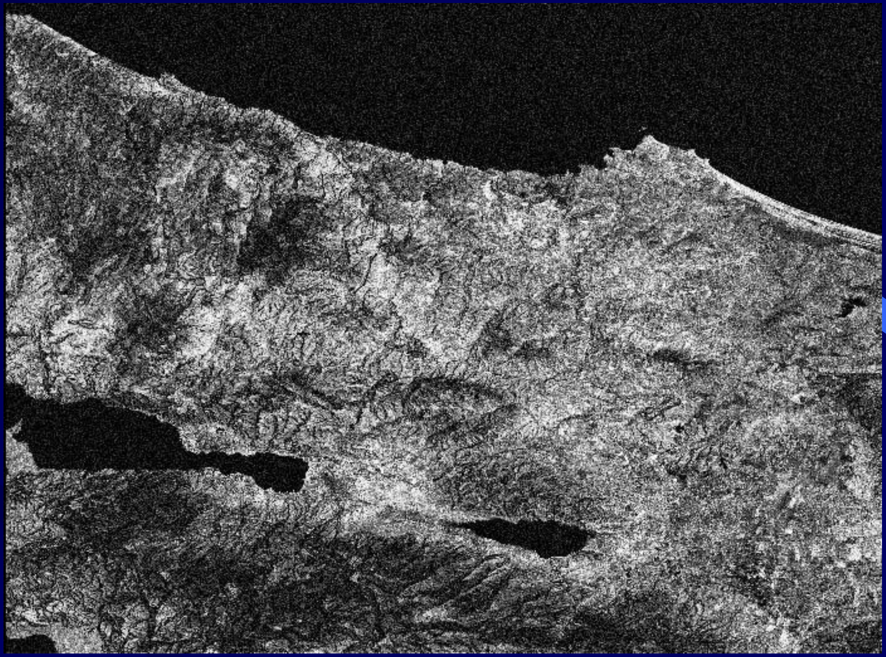
DInSAR



master image

- **Tandem images of:**
  12 and 13 Aug. 1999
  (4 and 5 days before quake)

- normal baseline: 224.190m
- parallel baseline: 91.097m

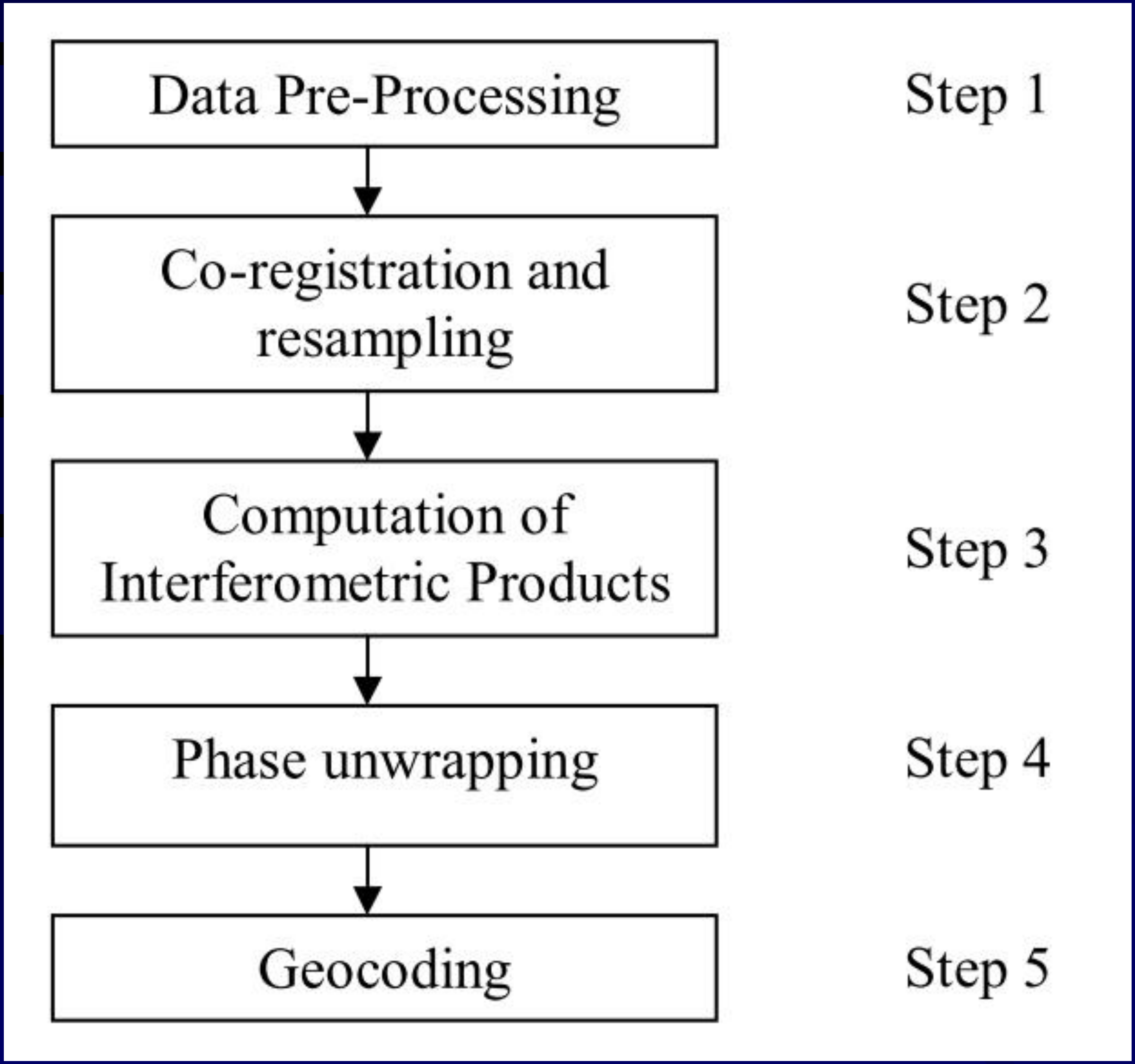


slave image

DEM generation steps

data processing stage comprises of five steps

- data pre-processing
- co-registration
- interferogram generation
- phase unwrapping
- geo-coding



DEM generation steps

DEM generation steps

- Two coherent SAR images are required to produce an interferogram.
- The images are first co-registered for finding the offset and difference in geometry between two amplitude images.
- Normally the baselines of 80-300m are suitable for DEM generation.
- One SAR image is then re-sampled to match the geometry of the other, meaning each pixel represents the same ground area in both images.

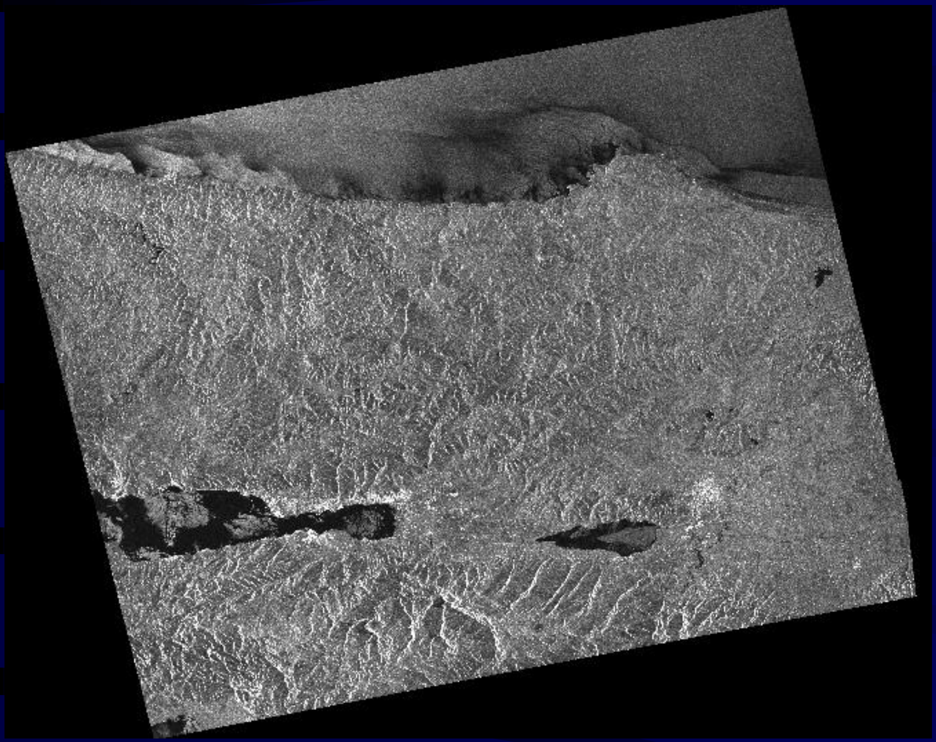
Coregistration of the data sets

By the conventional image coregistration methods

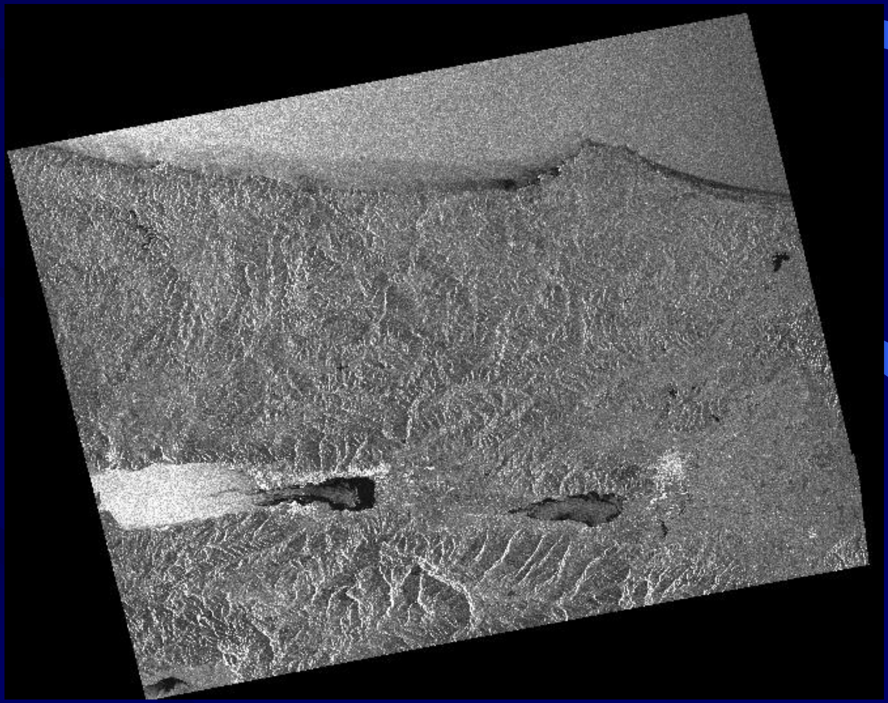
DInSAR

Image pairs of:

(1) 13 Aug. 1999, and
(2) 17 Sept. 1999
(3 days before and a month after quake)



master image



slave image

DEM generation steps

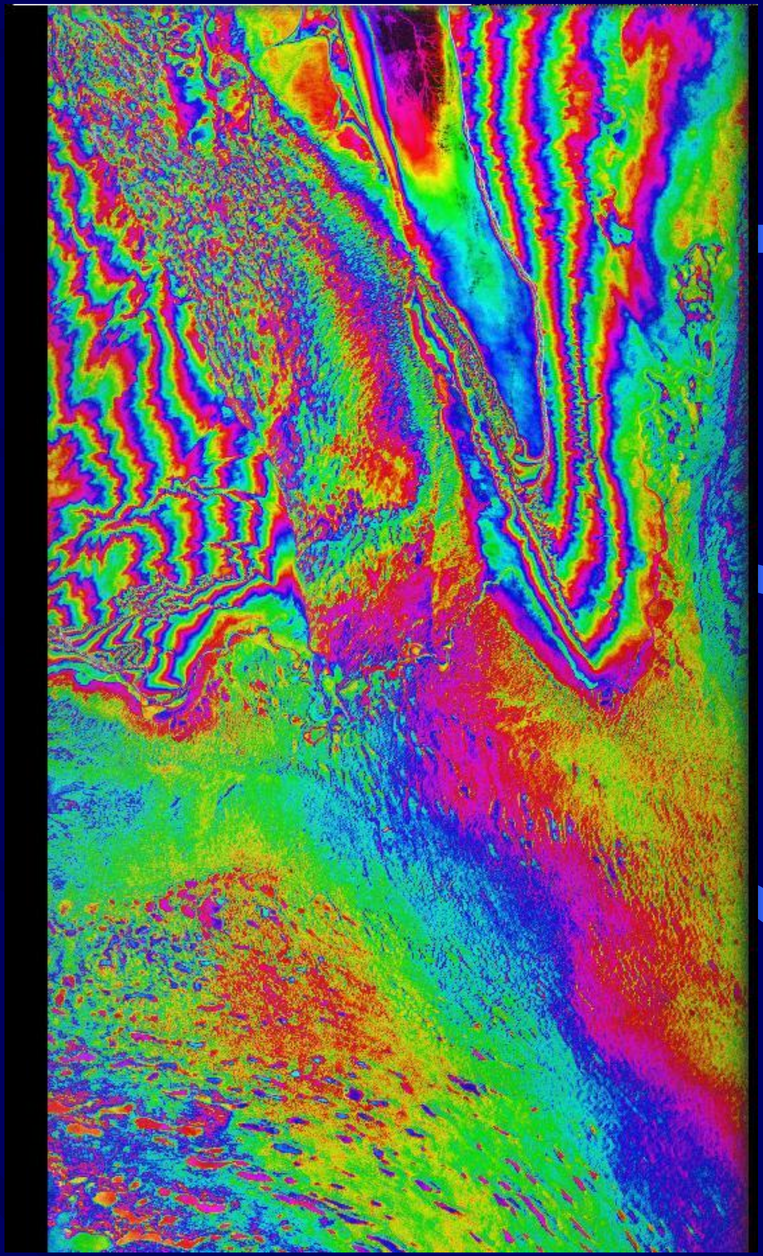
- The interferogram is generated by multiplication of the first image (master) to the complex conjugate of the second image (slave), and the interferometric phase due to the reference ellipsoid is removed; the process is referred to as flattening.
- The interferogram is then filtered using an adaptive power-spectrum filter to amplify the phase signal.
- For most quantitative applications the consecutive fringes present in the interferogram have to be unwrapped, which involves interpolating over the 0-2π phase jumps to produce a continuous deformation field.
- At some point, before or after unwrapping, incoherent areas of the image may be masked out.

Interferogram:

- can be generated by complex computerized processes from phase data of two radar imagery of a common area of the Earth surface collected in two different times.
- consists of the fringes cycling from yellow to purple to turquoise

  and back to yellow.

Each cycle represents a change in the ground height in the direction of platform that depends on satellite geometry.



Interferogram generation

$$I(m,n) = A_1(m,n)\, A_2{}^*\,(m,n)\, e^{i\Phi(m,n)}$$

The complex pixel (*m*, *n*) of a SAR image can be written as an amplitude *A* and phase term Φ.

The phase term in above equation represents the difference in phase shift caused by the two-way propagation of the radar signal to the ground.

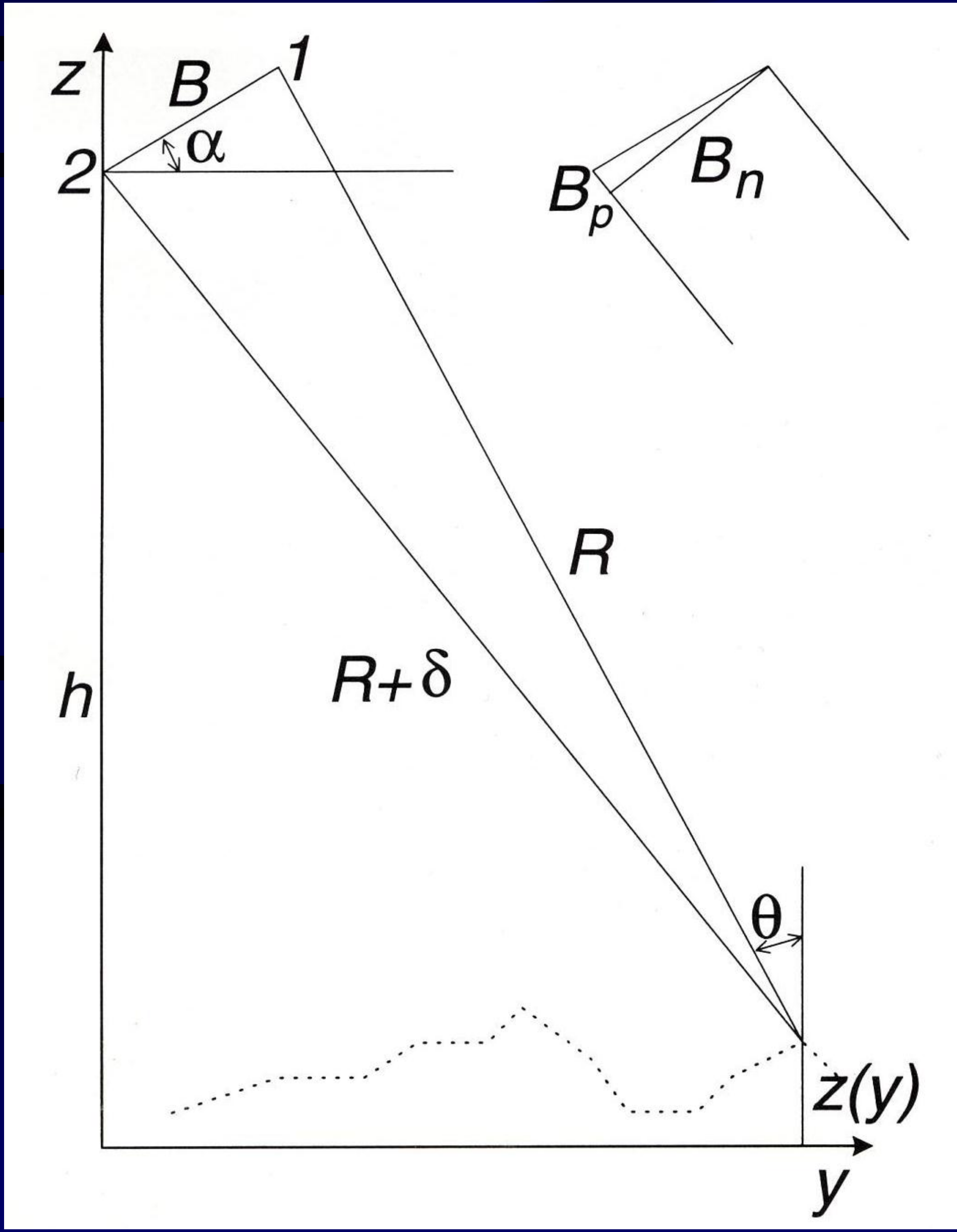
$$d\Phi = \frac{4\pi B_n}{\lambda R\, sin\,\theta}\,[dz + cos\,\theta\, dR] \;=\; d\phi_z + d\phi_R$$

B_n normal baseline, λ radar wavelength, R range and dR change in range, dz change in surface height, θ the local incidence angle

$$dz = \frac{\lambda R \sin\theta}{2B_n}$$

DInSAR

InSAR Geometry



Data selection

PORT-AU-PRINCE/ Jan 12, 2010: A huge quake measuring 7.0 hits Haiti.

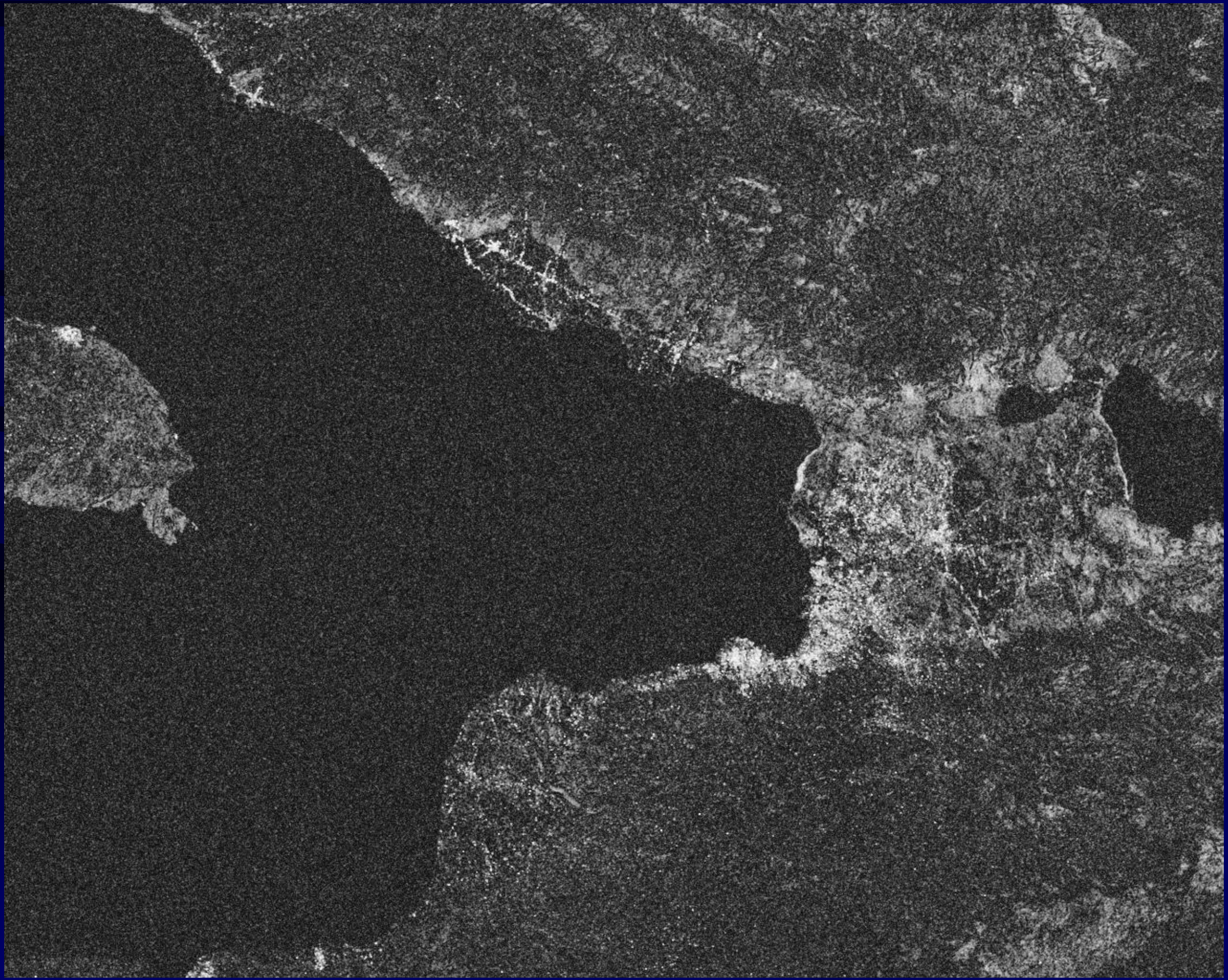
Baseline: 279.98m

Master image dated 26 January 2010

Slave image dated 2 March 2010

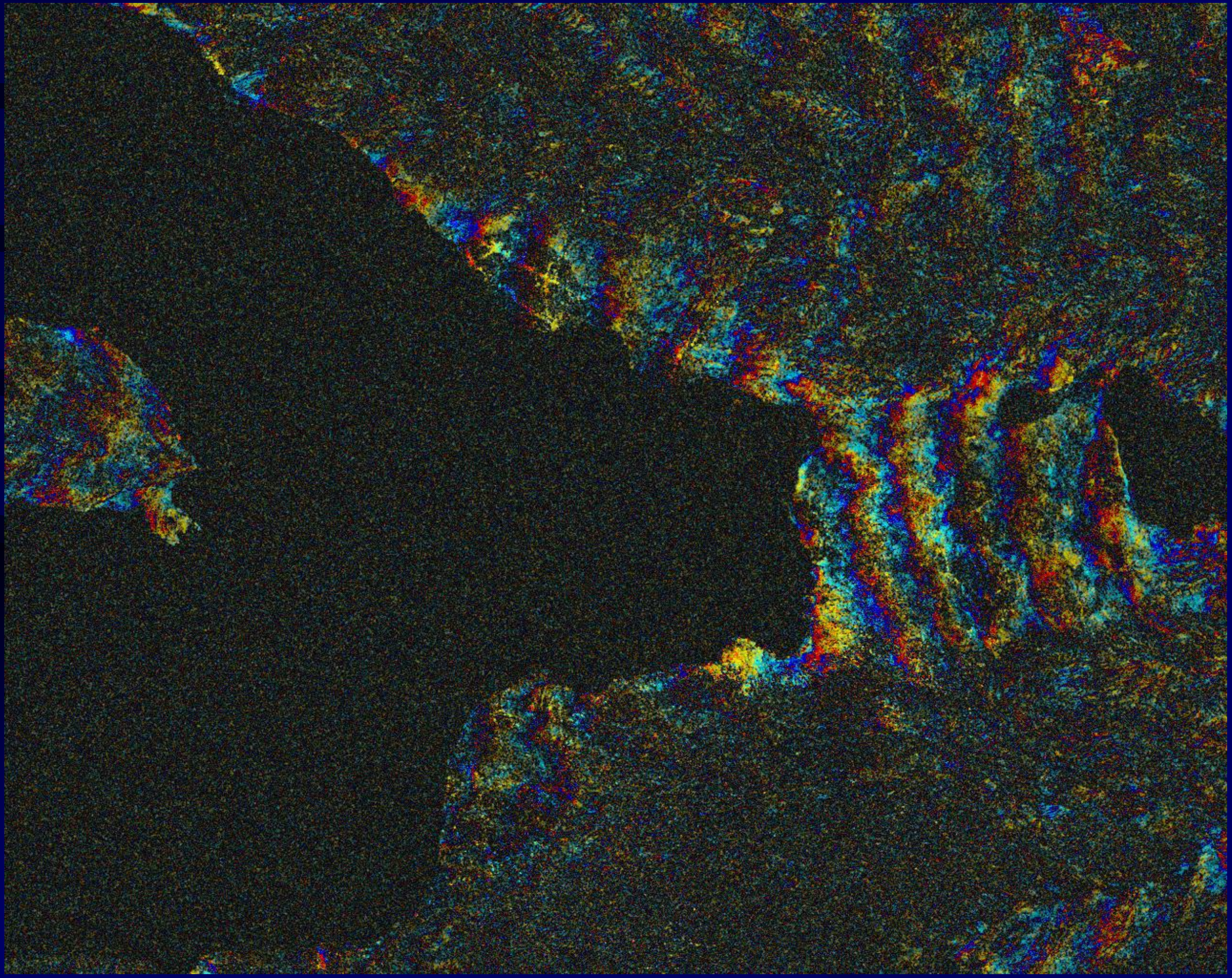
Coherence map generation

Coherence image of the data pairs of
master image dated 26 January 2010 and slave image dated 2 March 2010



Interferogram generation

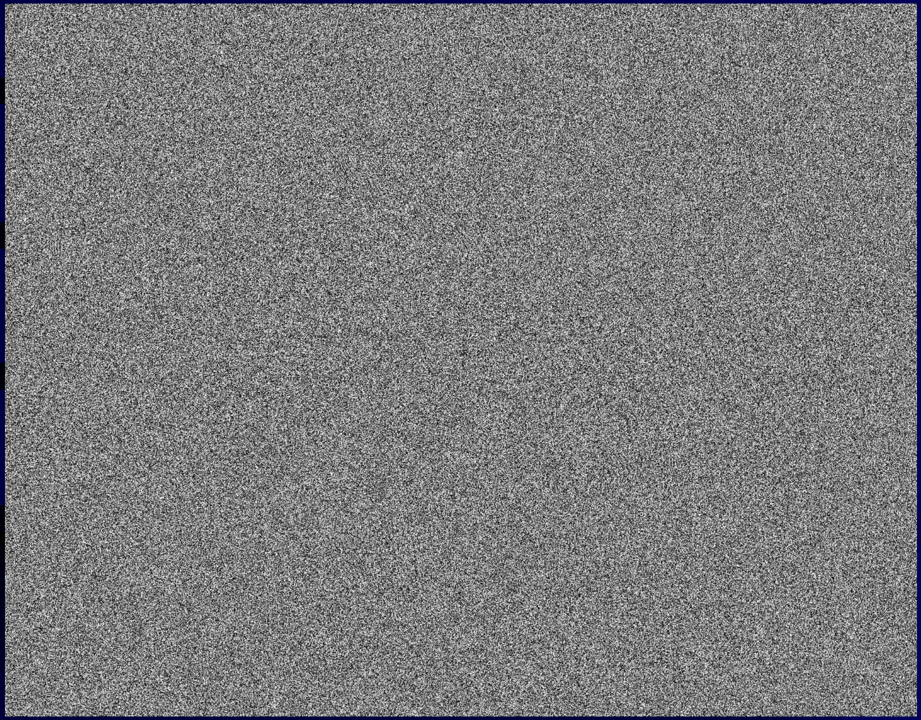
**Interferogram of the data pairs of
master image dated 26 January 2010 and slave image dated 2 March 2010**



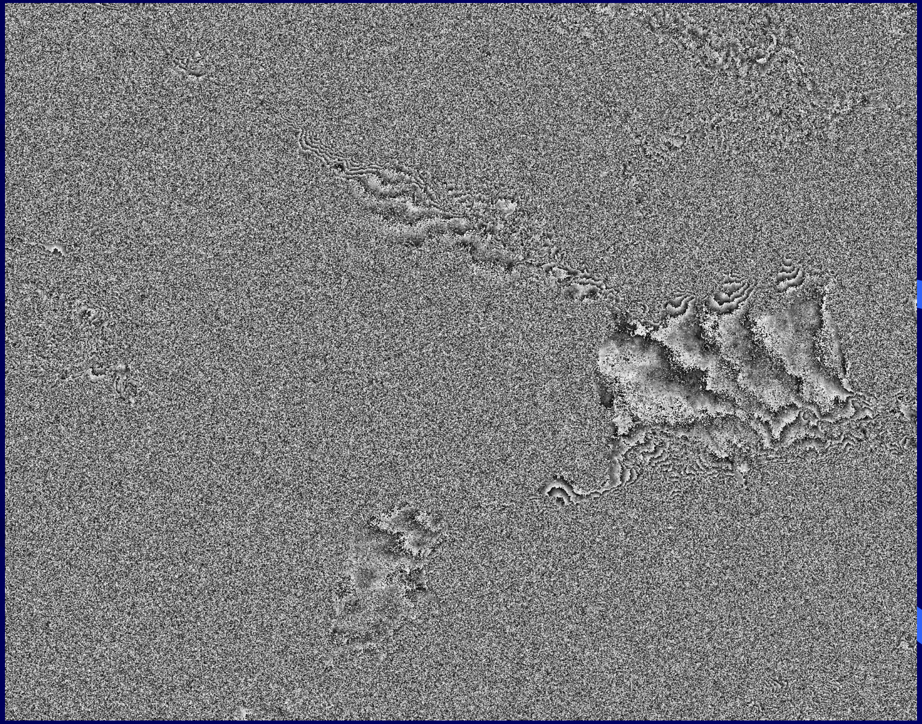
Phase unwrapping

Phase image and unwrapped phase of the data pairs of master image dated 26 January 2010 and slave image dated 2 March 2010

Phase image

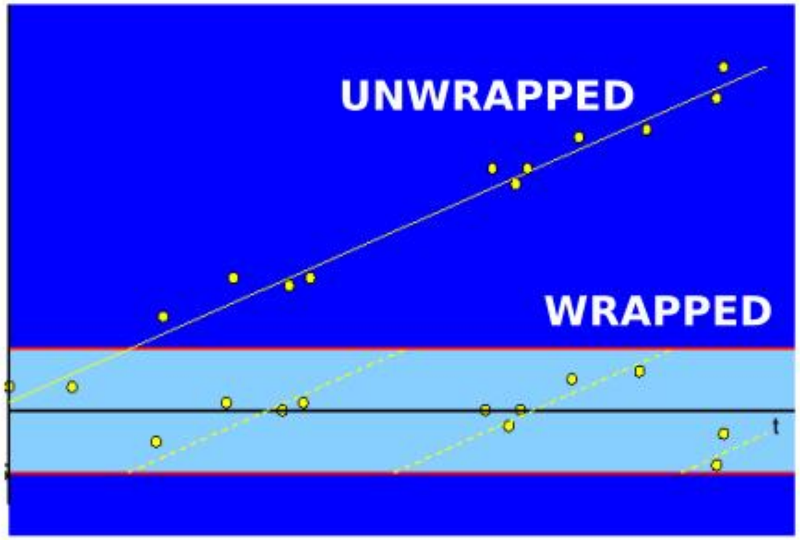


unwrapped phase image



Interferometric phase notion: a simplified example

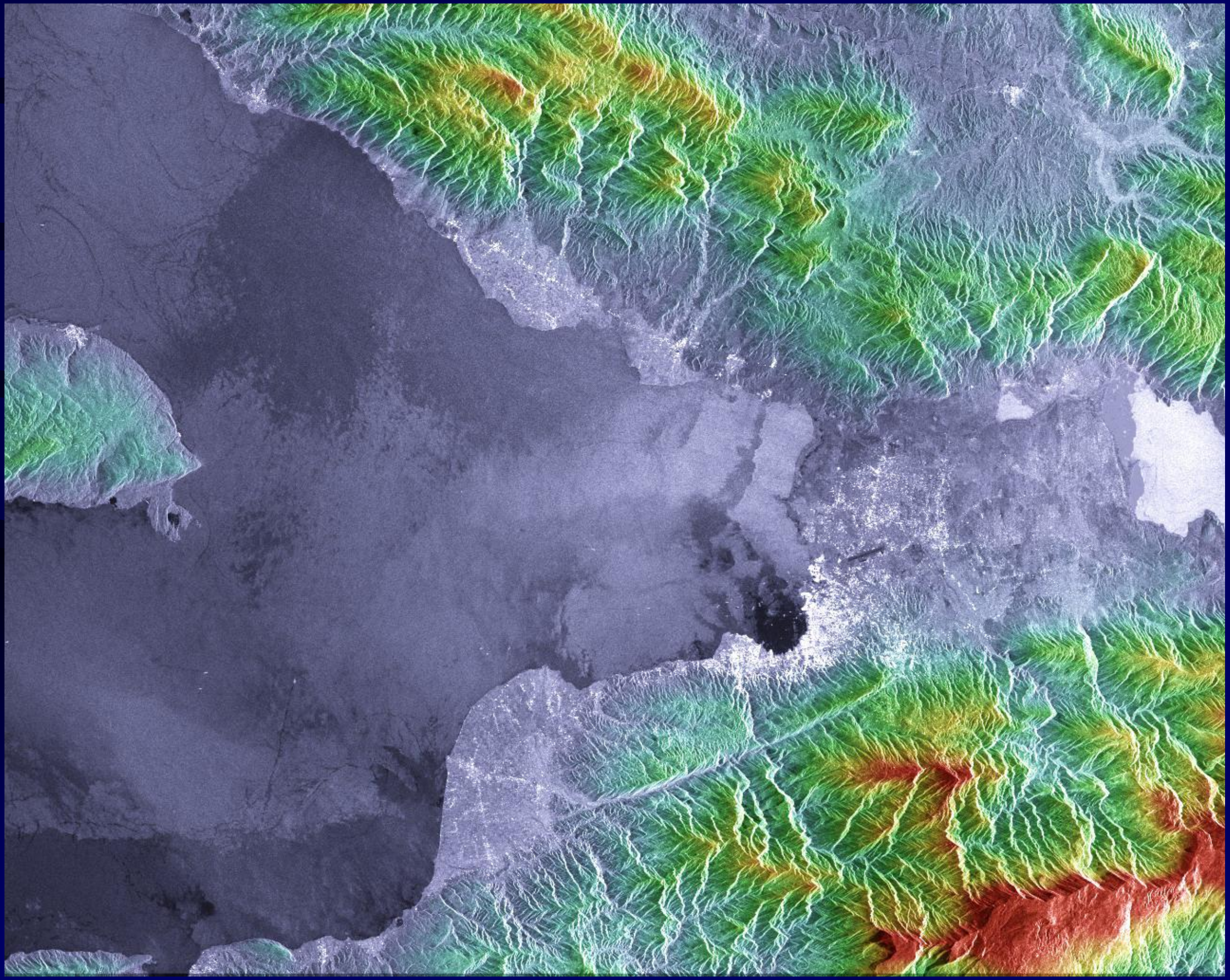
- **The observed phase is wrapped in [-pi,+pi]**
- **Interpretation requires the absolute phase**
- **Simplified example:**
  - a point is moving away from the radar with constant velocity,
  - phase unwrapping is the most complicated processing step.
  - hampered by decorrelation and dense fringes



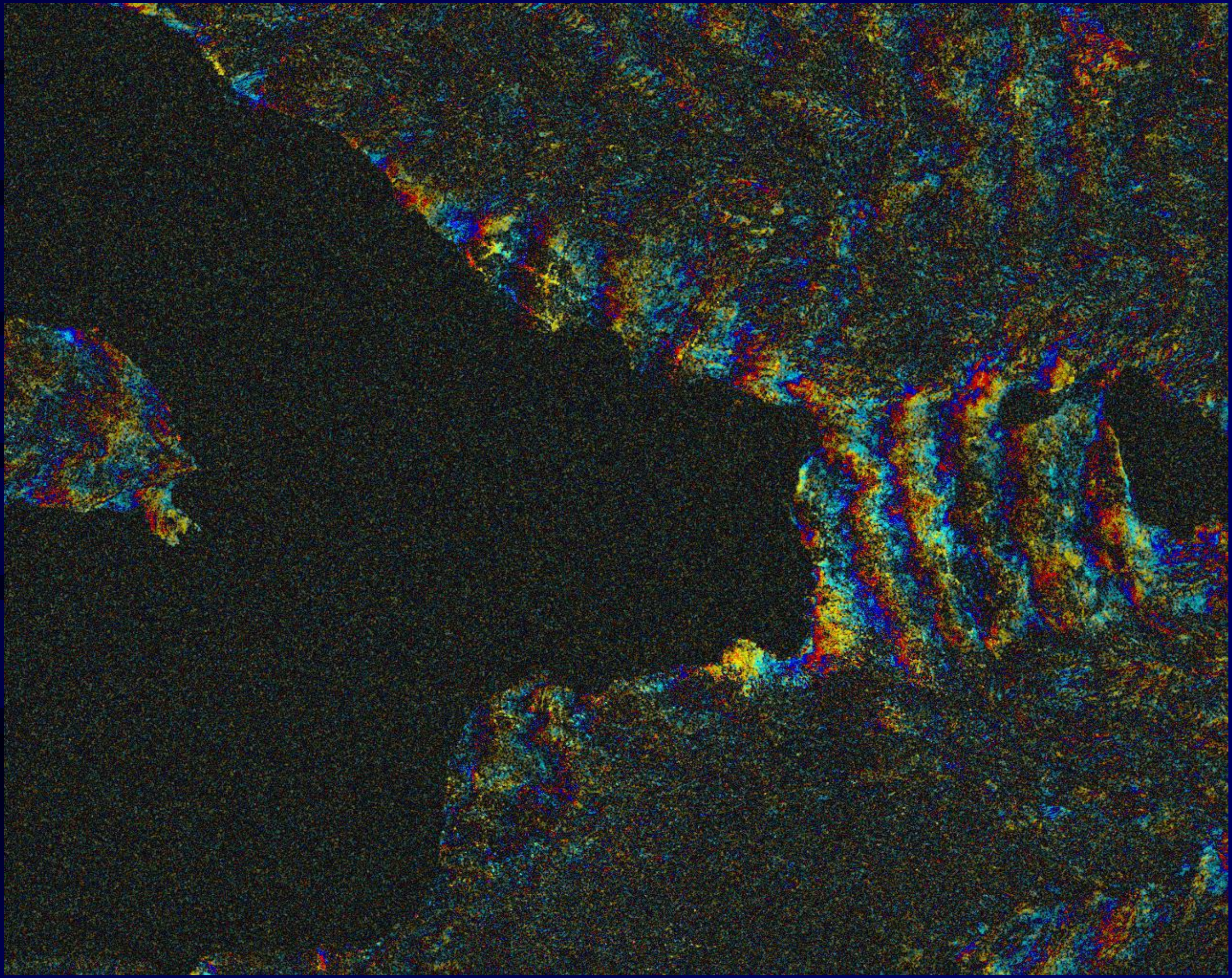
DTM generation

Topo-map of the data pairs of

master image dated 26 January 2010 and slave image dated 2 March 2010



InSAR



Interferogram of the data pairs of master image dated 26 January 2010 and slave image dated 2 March 2010

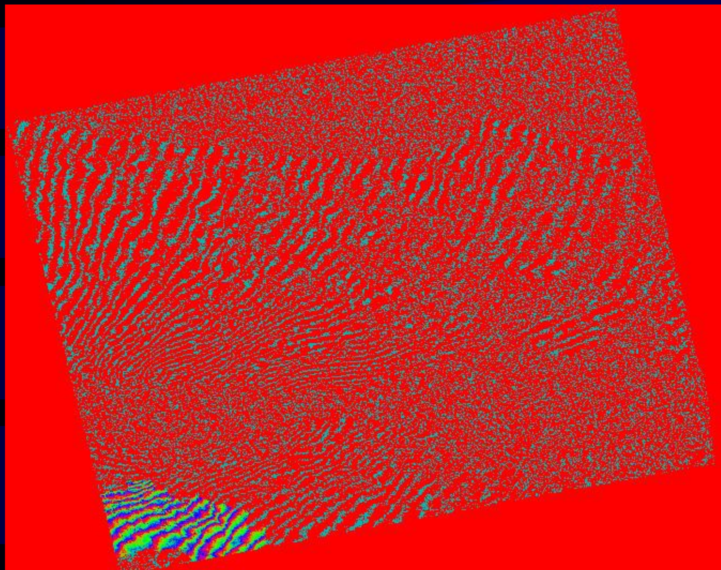
PORT-AU-PRINCE, Haiti **Baseline: 279.98m**

DInSAR

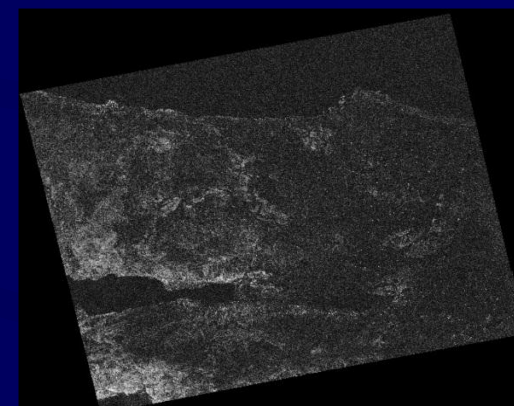
Image pairs of: 13 Aug. 1999, and 17 Sept. 1999 (3 days before and a month after quake)

- normal baseline: 11.401m
- parallel baseline: 53.558m

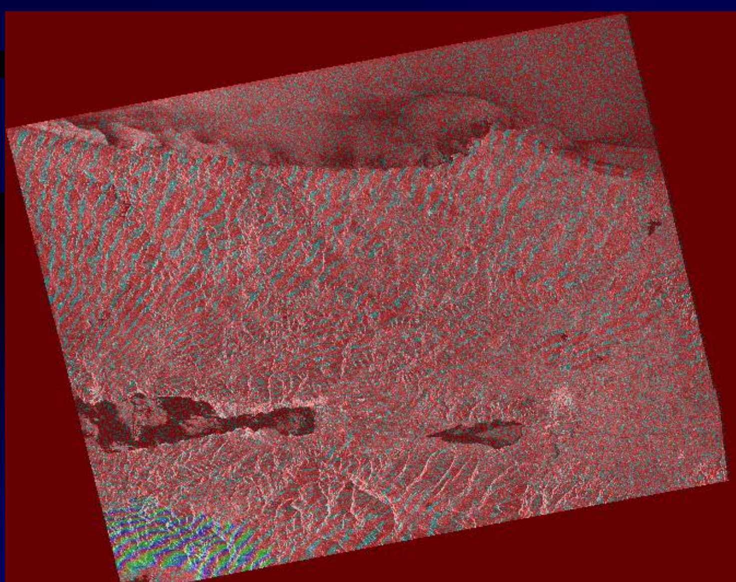
- good coherence
- very small baseline



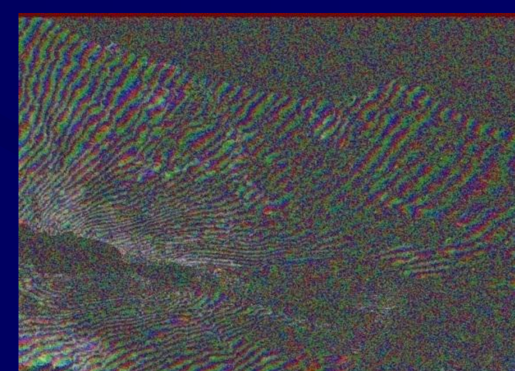
phase image



coherence image



interferogram



phase image overlaid on coherence image

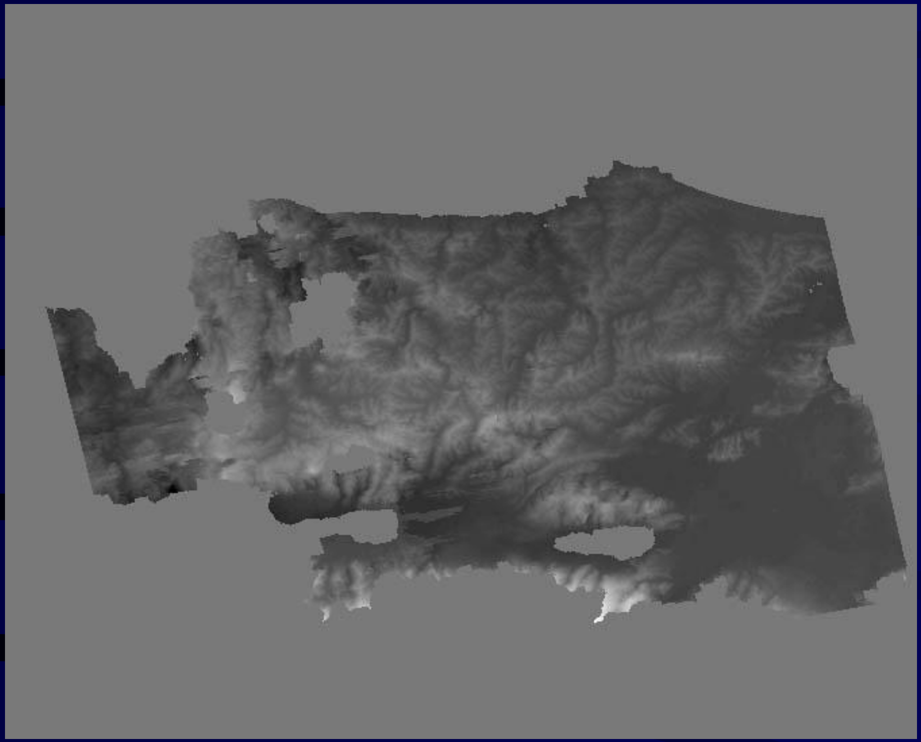
DEM generation steps

- The final processing stage requires geo-coding, which involves re-sampling the interferogram from the acquisition geometry related to direction of satellite path into the desired geographic projection.
- By applying phase information in the interferogram, extraction of DEM with meter accuracy, height change information, and fine scale temporal change measurements will be possible.

DEM generation steps

Product Parameters	Value
Scene size [km]	100 x100
Scene center longitude [deg]	58.5219
Scene center latitude [deg]	29.1385
Perpendicular baseline [m]	520.6
Parallel baseline [m]	269.1
Height ambiguity [m]	15.1
Temporal baseline [day]	35
Base line orientation [deg]	-7.1
Look angle [deg]	20.1
Incidence angle [deg]	22.8

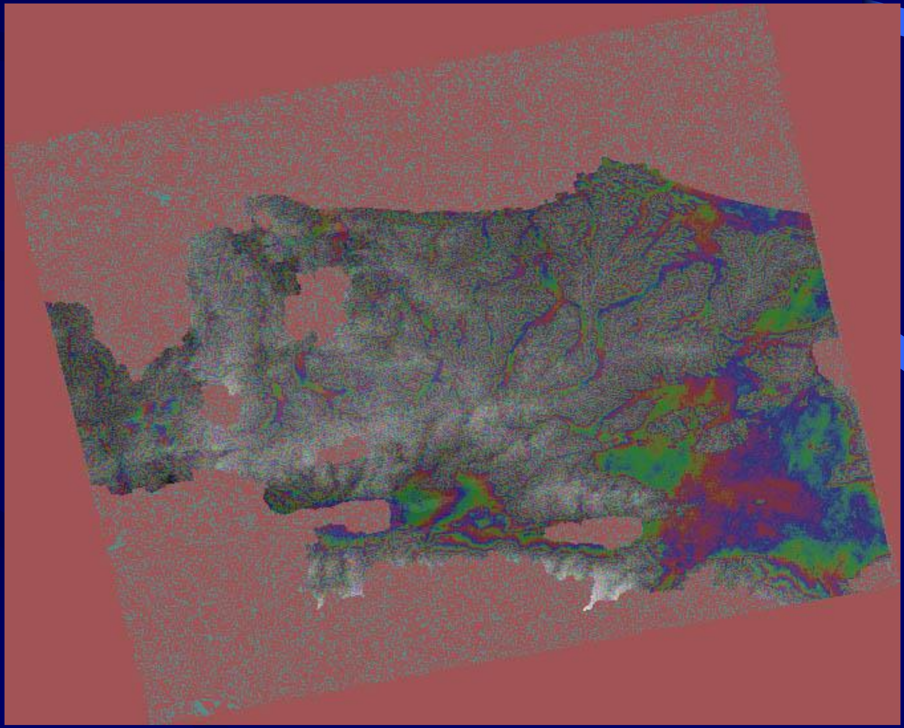
DInSAR



- **Tandem images of:** 12 and 13 Aug. 1999 (4 and 5 days before quake)

- normal baseline: 224.190m
- parallel baseline: 91.097m

- good height image or digital elevation model (DEM)



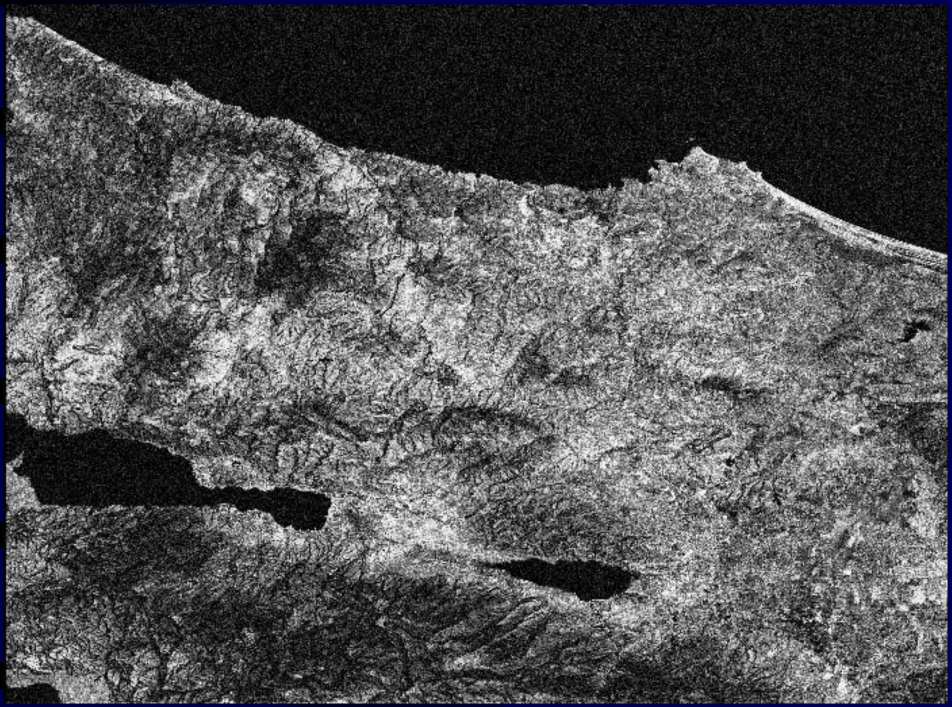
height image (DEM)

phase image overlaid on height image (DEM)

DInSAR

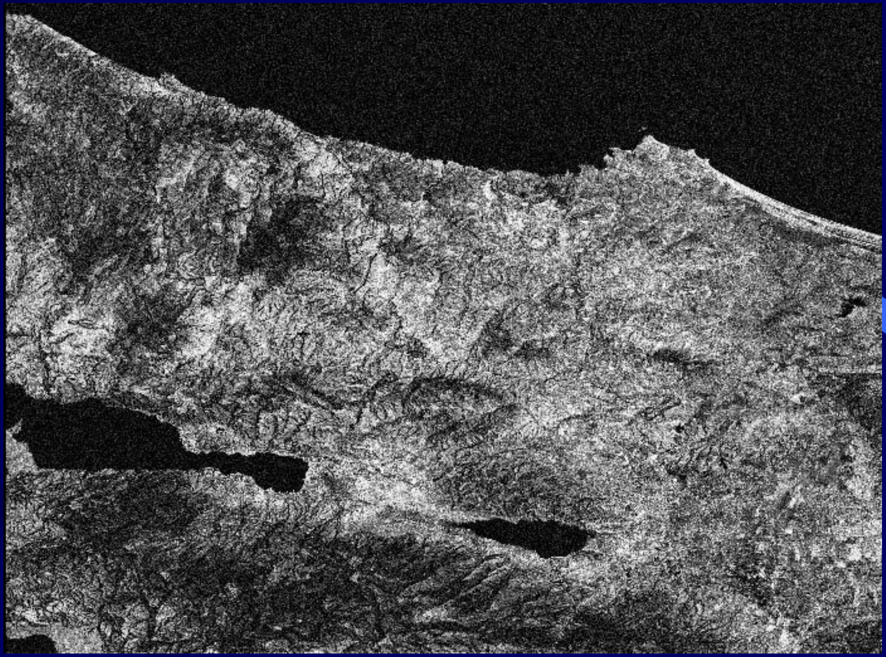
- **Tandem images of:**
  12 and 13 Aug. 1999
  (4 and 5 days before quake)

- normal baseline: 224.190m
- parallel baseline: 91.097m



master image

slave image



Methods

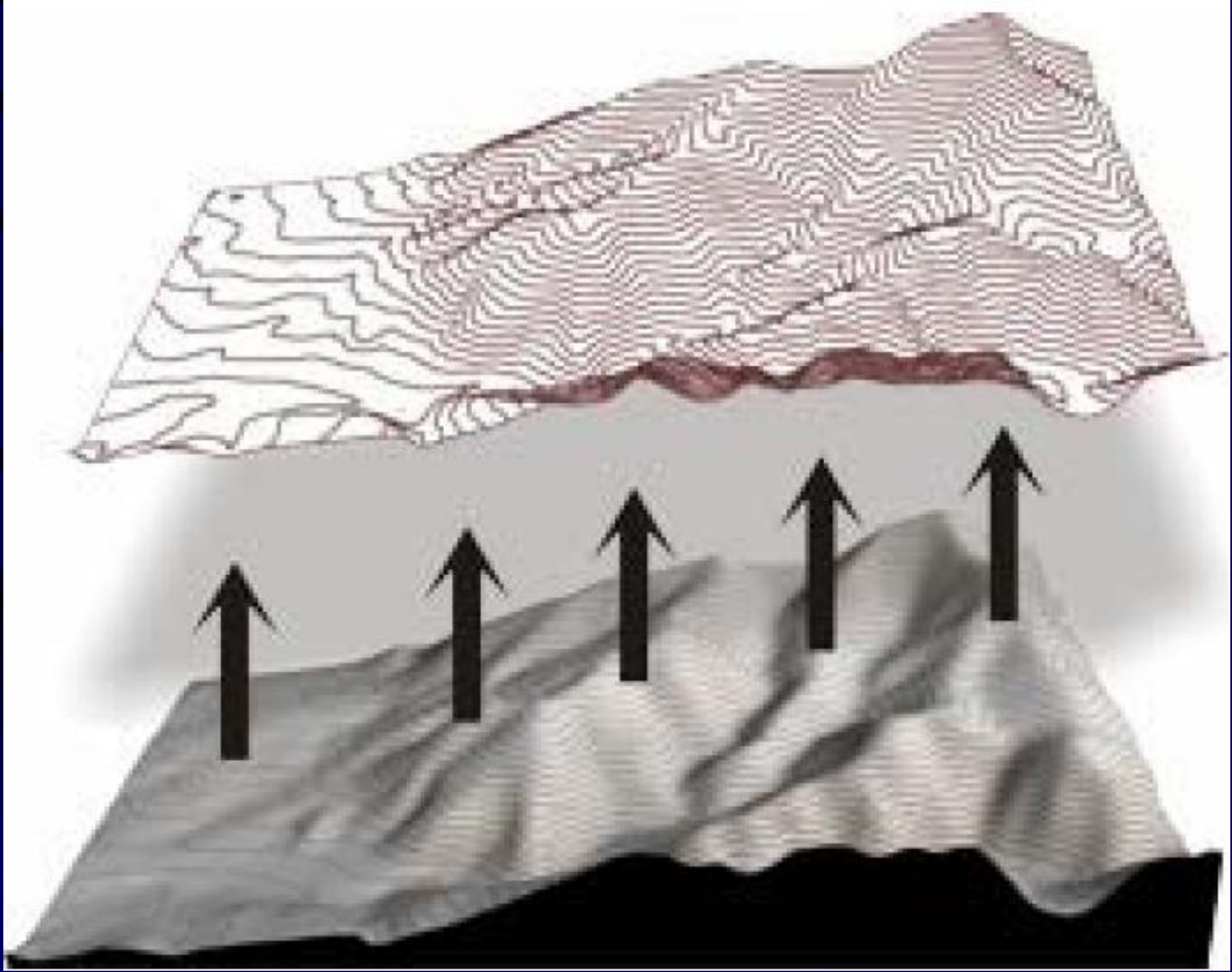
- DEM is important for surveying and other applications in engineering.
- Its accuracy is paramount; for some applications high accuracy does not matter but for some others it does.
- Numerous DEM generation techniques with different accuracies for various means are used.
- DEMs can be generated through different methods which are classified in three groups that are DEM generation by

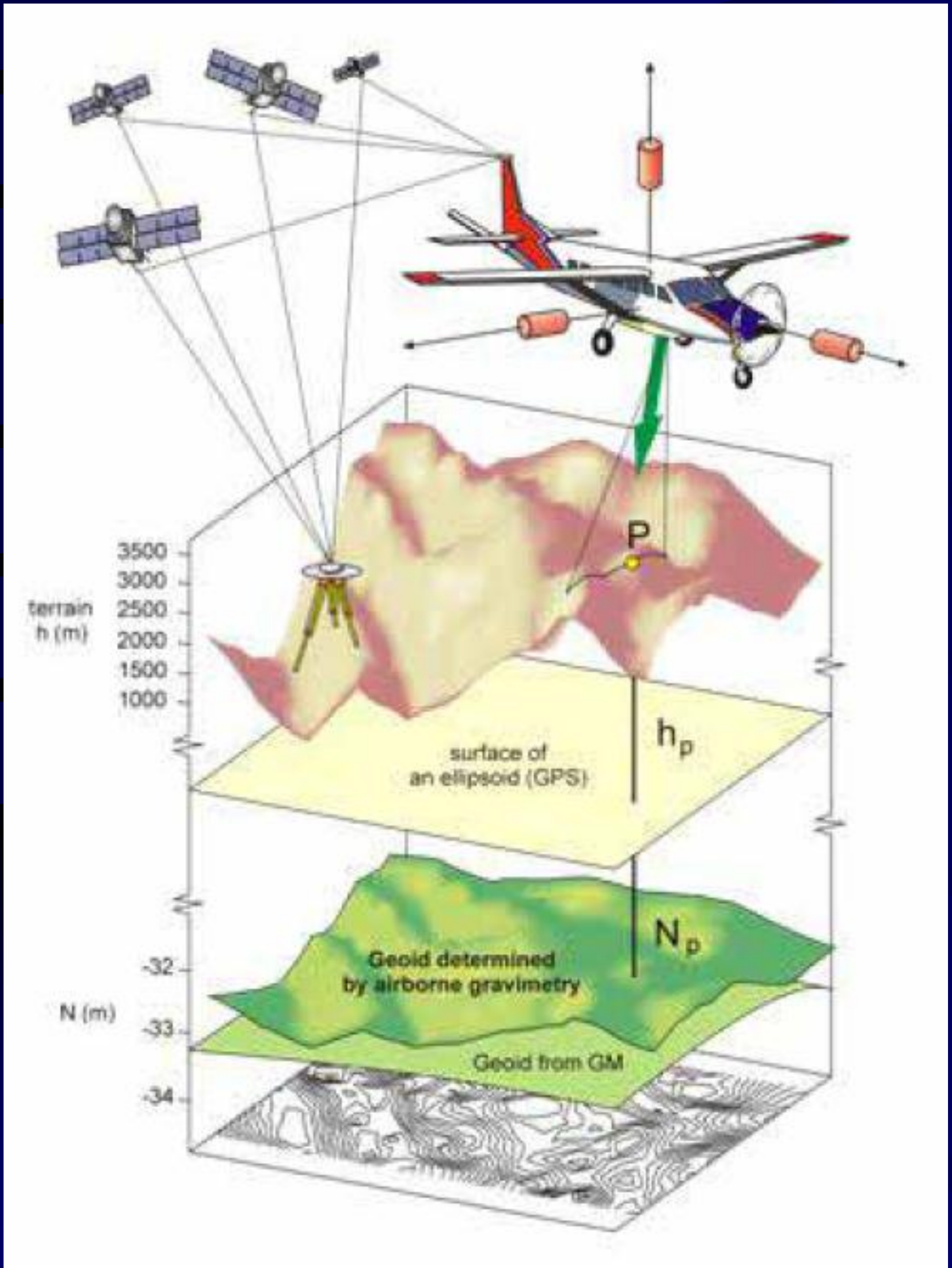
geodesic measurements,

photogrammetry and

remote sensing.

DEM generation





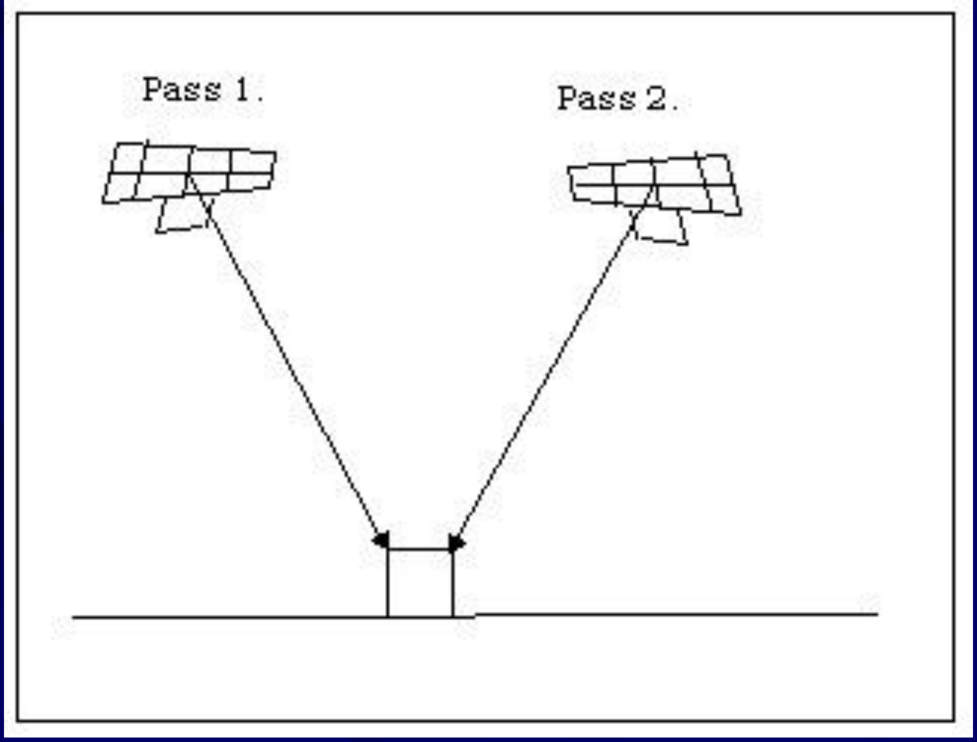
DEM generation

Methods

- In DEM generation by geodesic measurements, the planimetric coordinates and height values of each point of the feature are summed point-by-point and using the acquired data the topographic maps are generated with contour lines.
- The 1:25000-scale topographic maps are common example. The method uses contour-grid transfer to turn the vector data from the maps into digital data.

Methods

- For DEM generation by photogrammetry, the photographs are taken from an aircraft or spacecraft and evaluated as stereo-pairs and consequently 3-D height information is obtained.



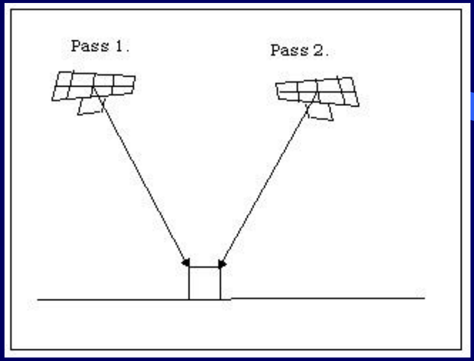
Methods

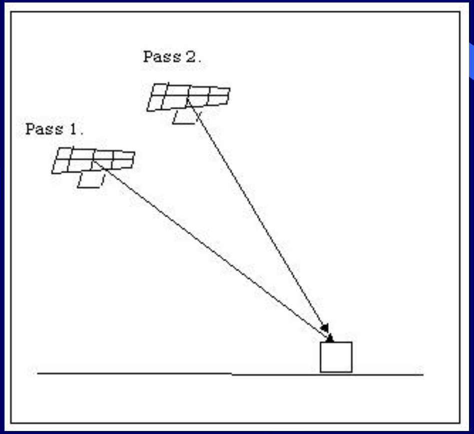
- **DEM generation by remote sensing can be made in some ways, including**

stereo-pairs

laser scanning (LIDAR)

InSAR





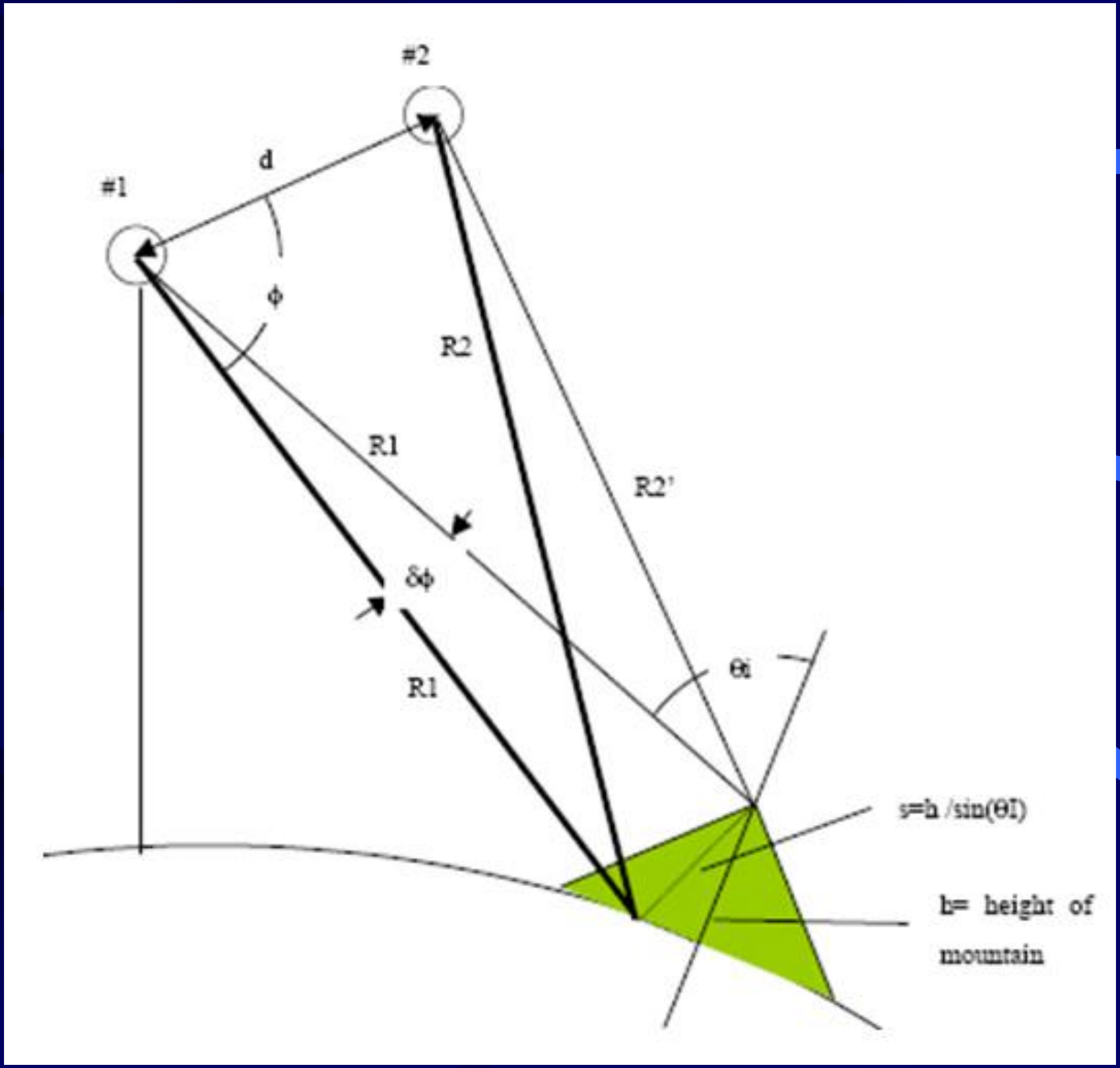
Methods

There are three types of InSAR technique

- single-pass
- double-pass
- three-pass

Methods

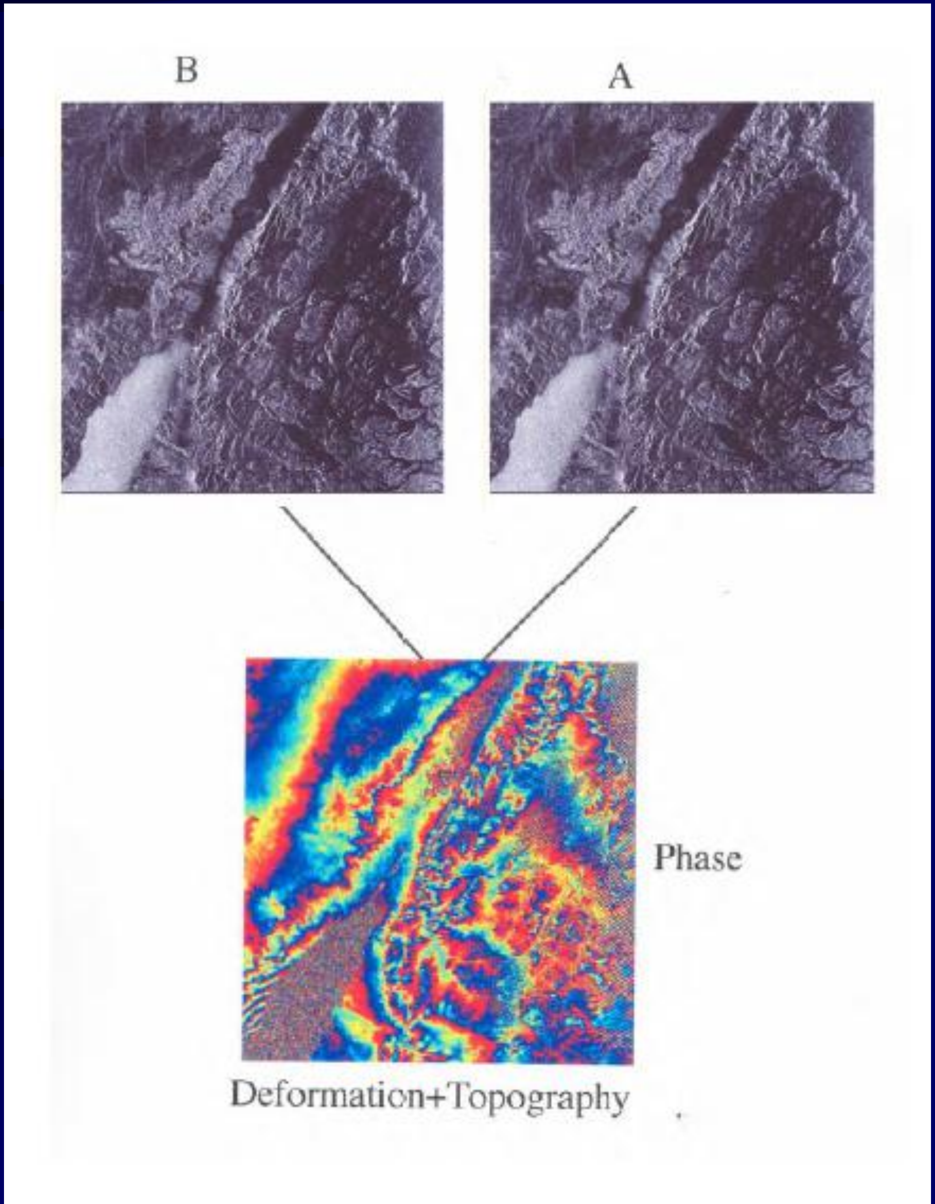
- In double-pass InSAR, a single SAR instrument passes over the same area two times while through the differences between these observations, height can be extracted.



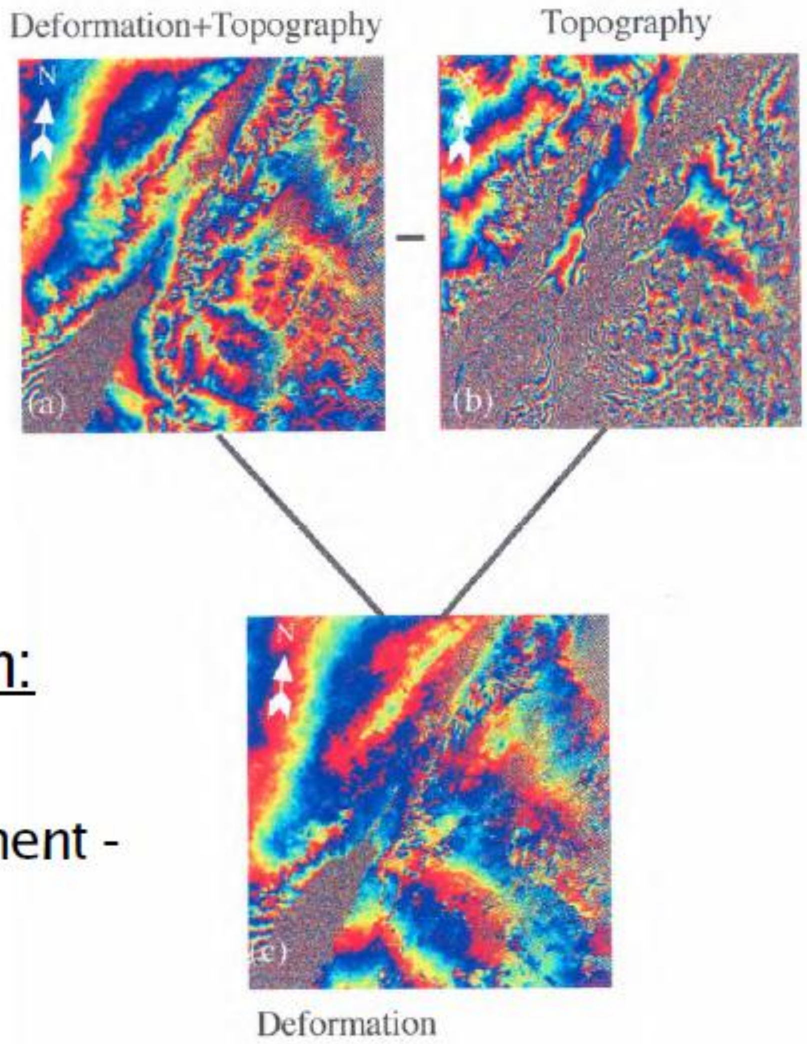
Methods

- **In three-pass interferometry (or DInSAR) the obtained interferogram of a double-pass InSAR for the commonly tandem image pairs is subtracted from the third image with wider temporal baseline respective to the two other images.**

producing a deformation + topography interferogram…



…then remove topography and make a differential interferogram



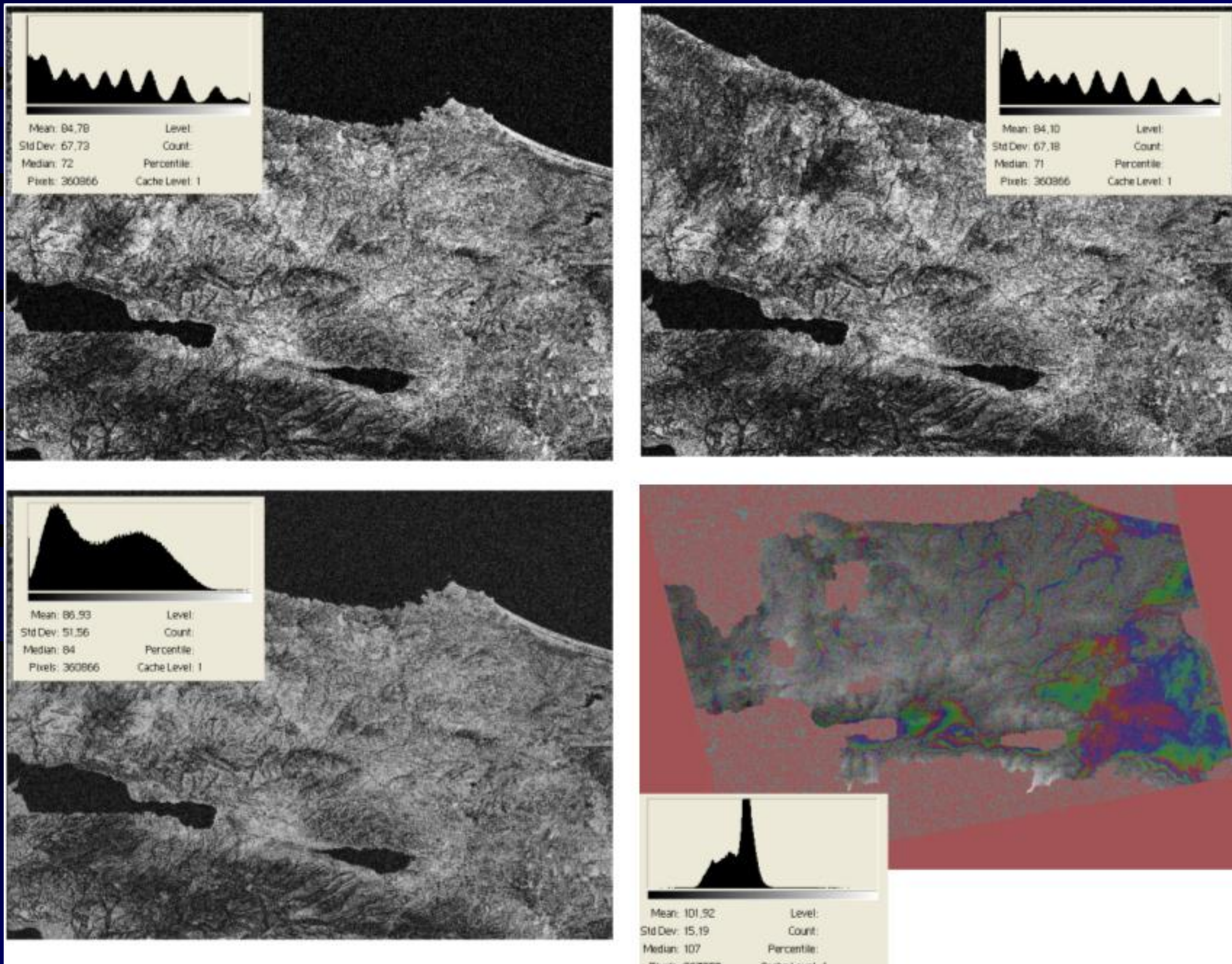
interferogram:

LOS Displacement -

contour map

DInSAR

DInSAR

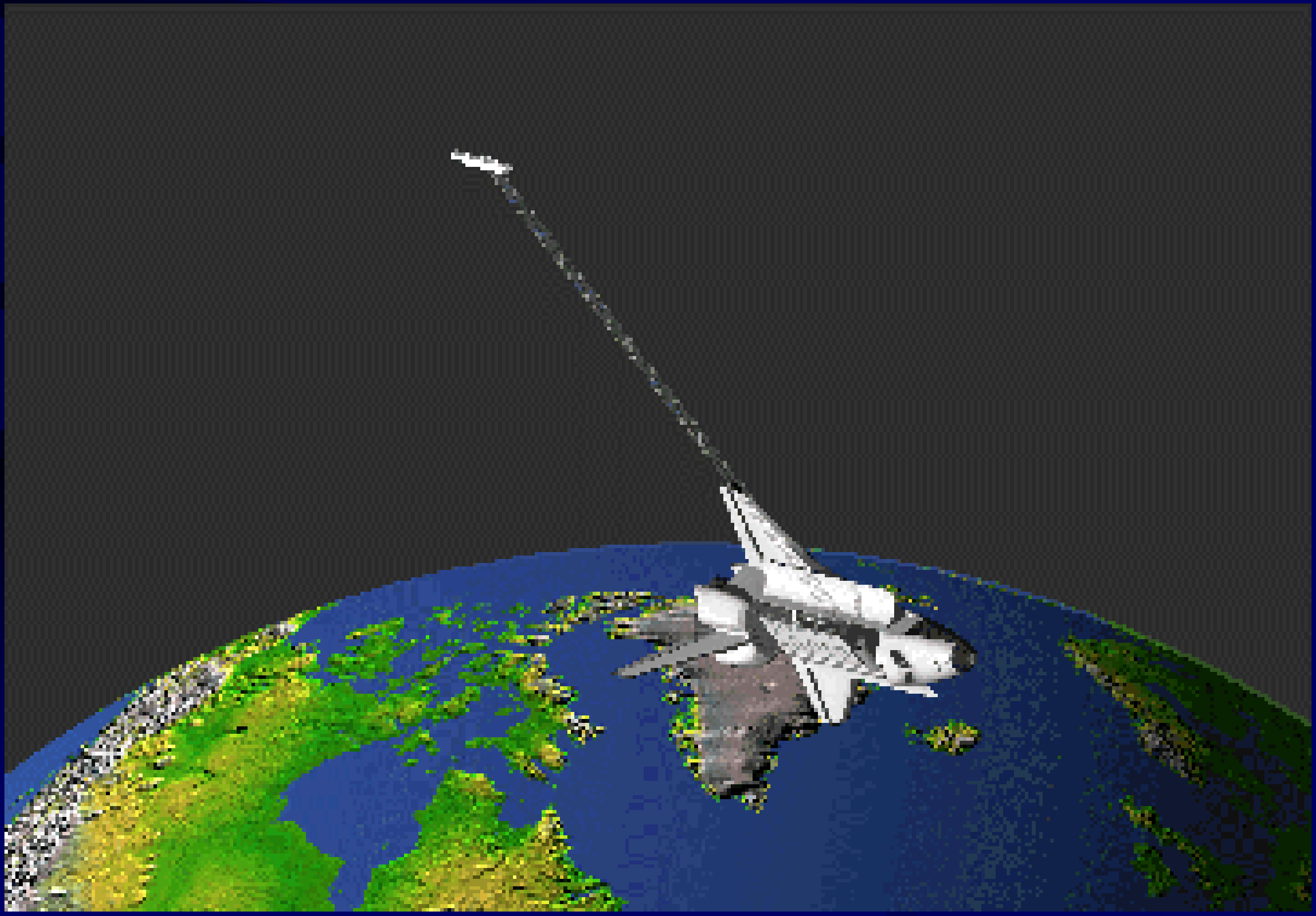


phase image overlaid on height image (DEM)

- **Tandem images of:** 12 and 13 Aug. 1999 (4 and 5 days before quake)
- normal baseline: 224.190m
- parallel baseline: 91.097m
- good height image or digital elevation model (DEM)

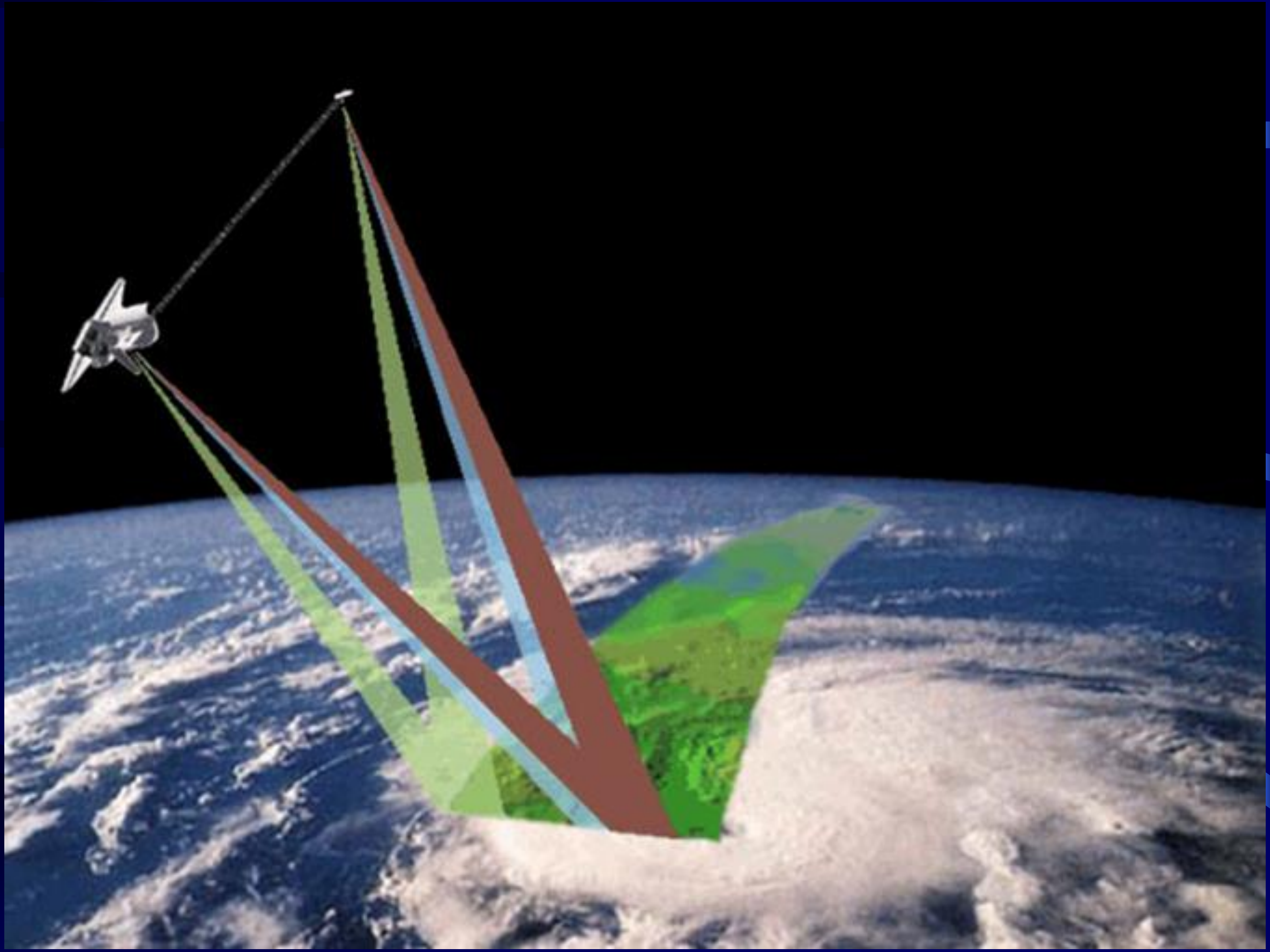
Methods

- **In single-pass InSAR, space-craft has two SAR instrument aboard which acquire data for same area from different view angles at the same time.**



Methods

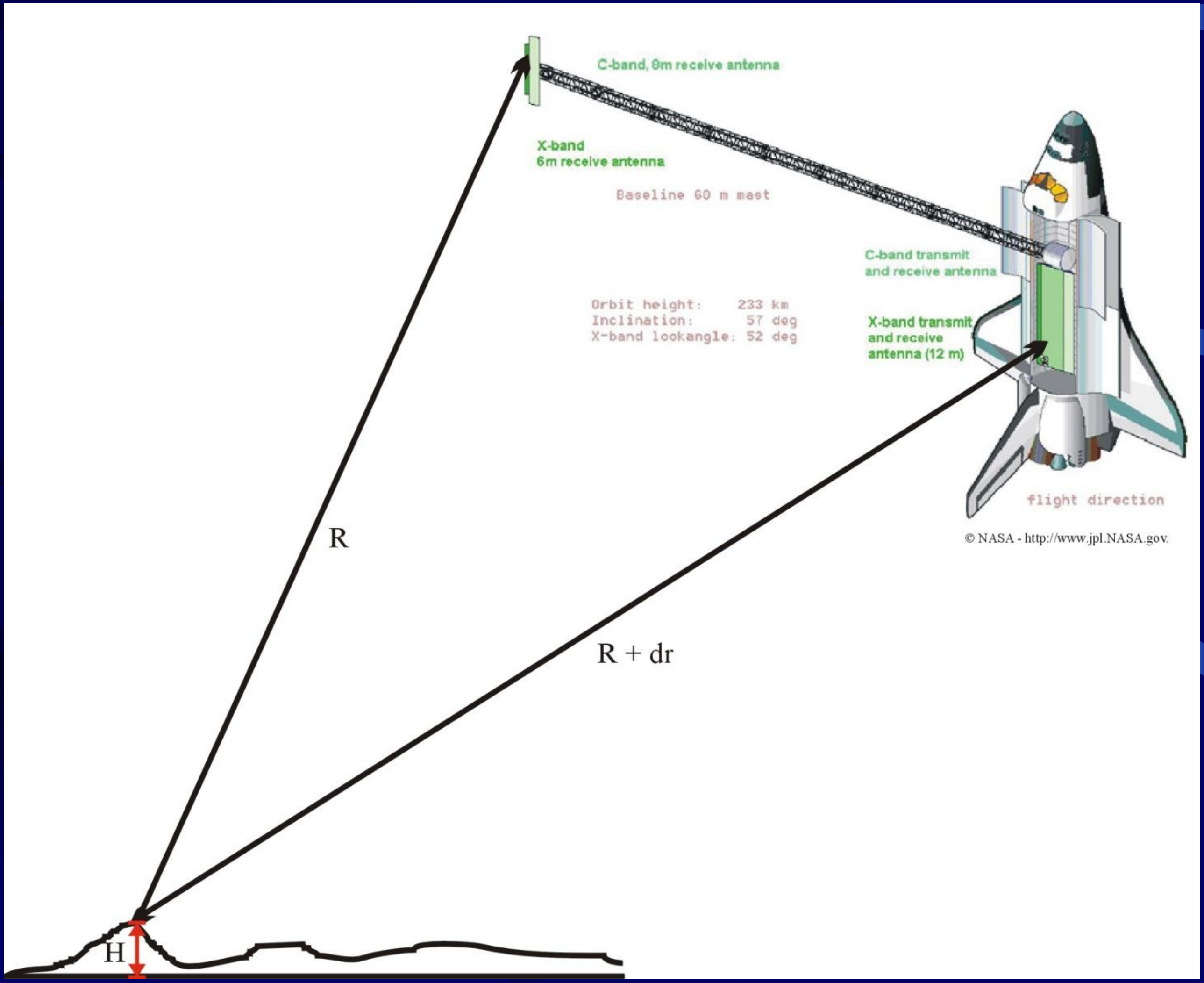
- With single-pass, third dimension can be extracted and the phase difference between the first and second radar imaging instruments give the height value of the point of interest with some mathematical method.

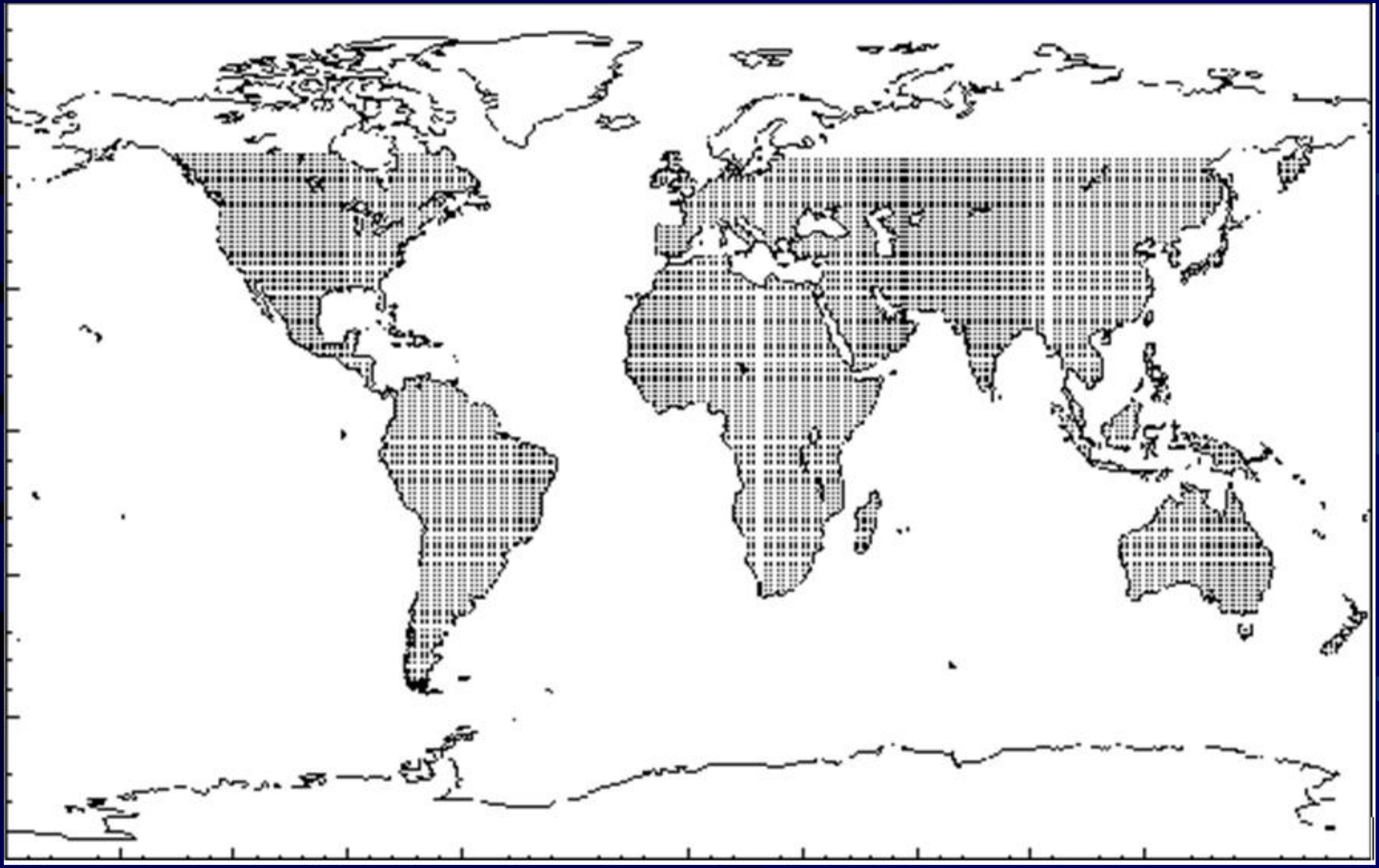


Methods

- SRTM used the single-pass interferometry technique in C- and X-band.
- Earth's height model generated by InSAR-SRTM with 90-m horizontal resolution is available while the DEM with 4-to-4.5-m relative accuracy is also available for restricted areas

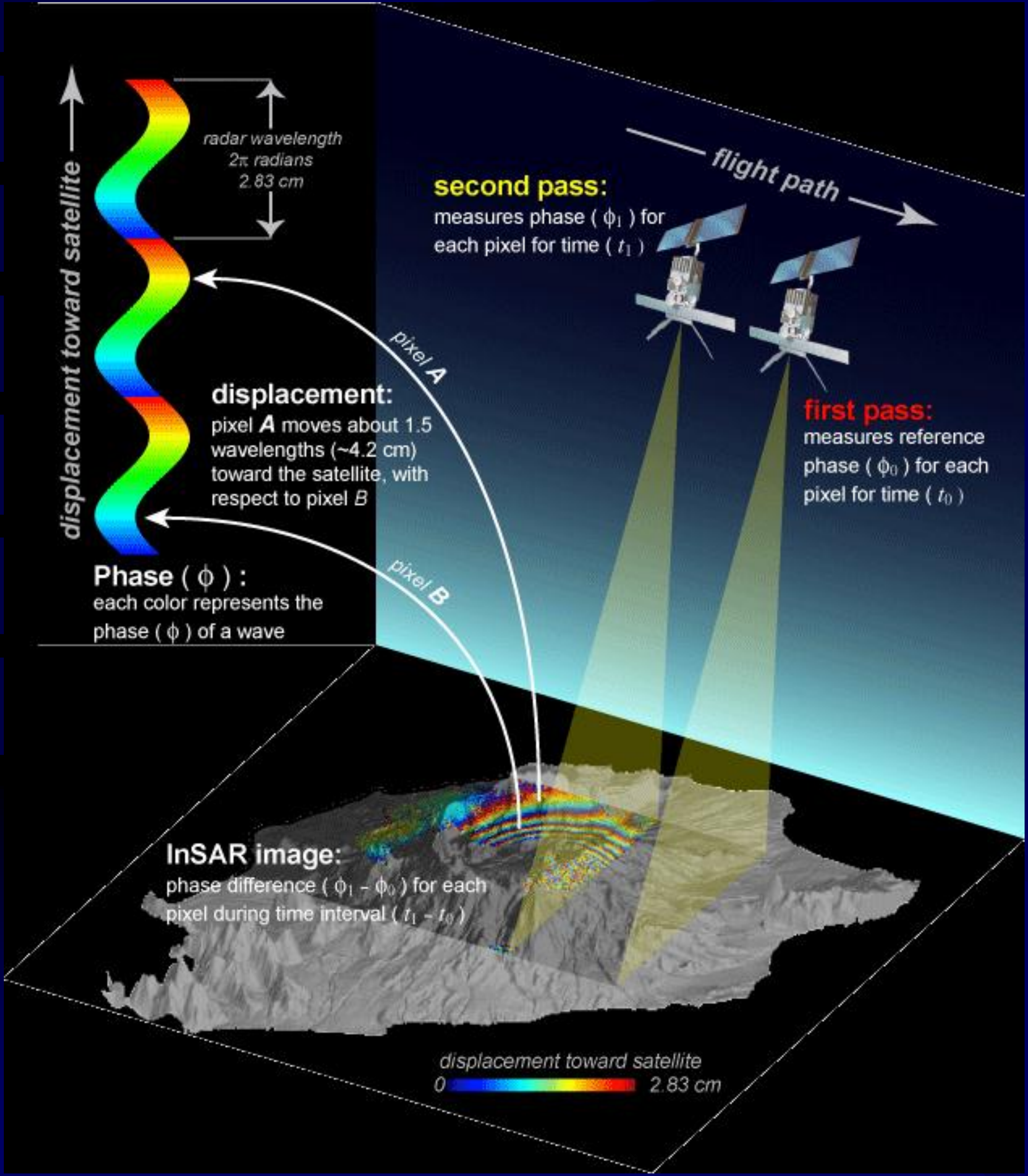
  around the world.





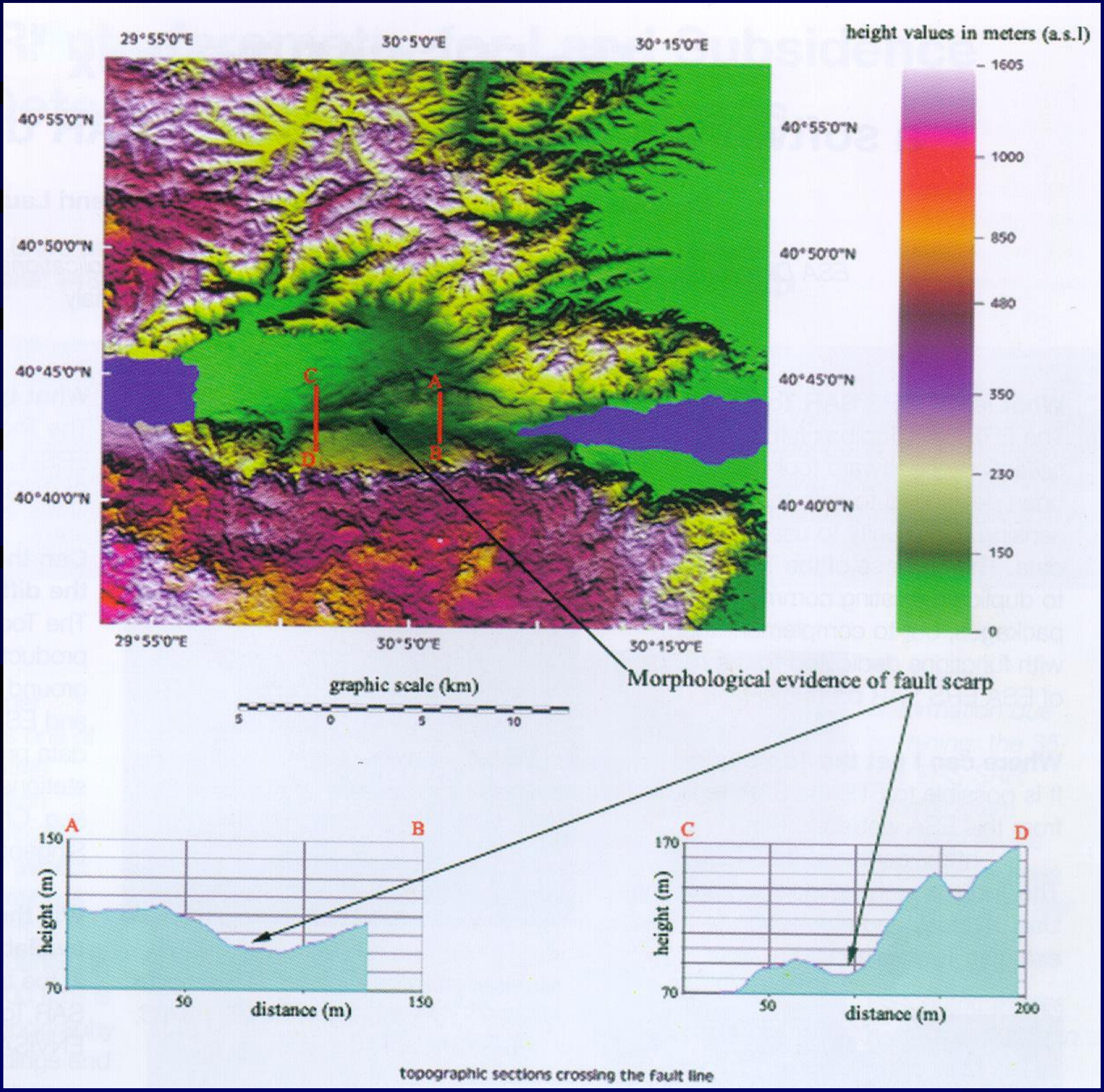
The areas of the Earth for which the height model is generated by InSAR-SRTM

DInSAR



InSAR Method

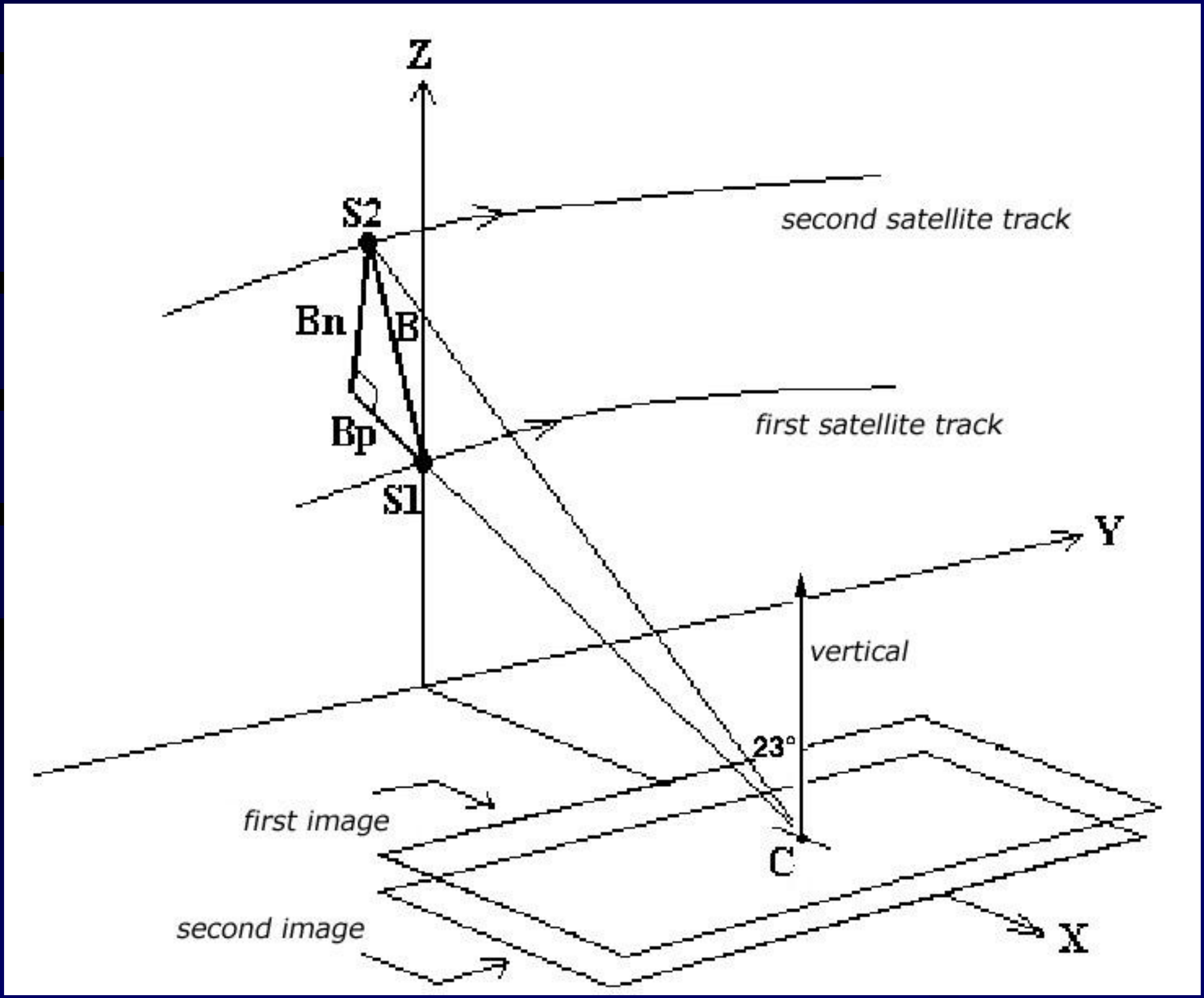
DInSAR



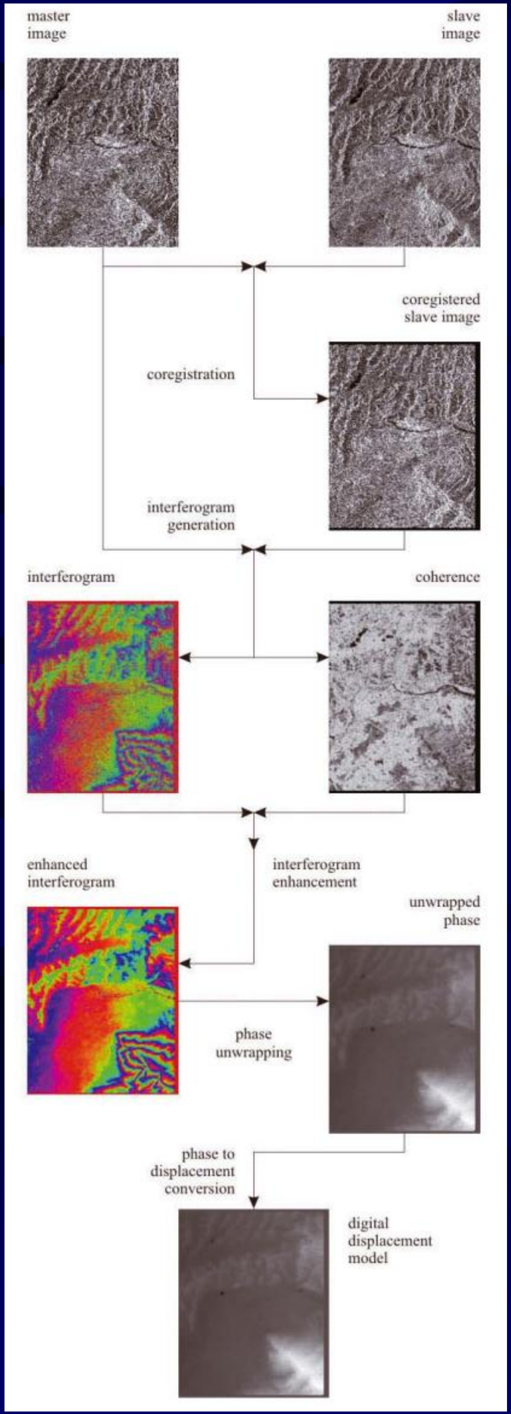
Shaded-relief image that was generated from the ERS SAR interferometric DEM. This image product can be used in studies relating the recognition of tectonic and morphological lineaments.

DInSAR

Geometry of interferometry



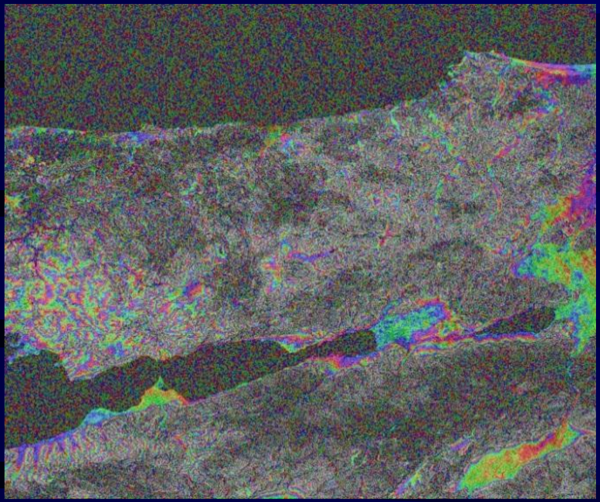
Satellite orbit is very important for successful application of SAR interferometry. In general a normal baseline larger than 400m is usually not suitable for interferometry. Also baselines smaller than 40m may not be suitable for DEM generation but this data are very good for differential interferometry.



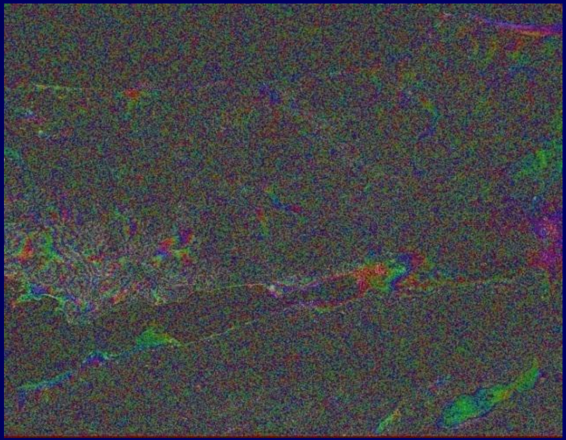
DInSAR Method

DInSAR

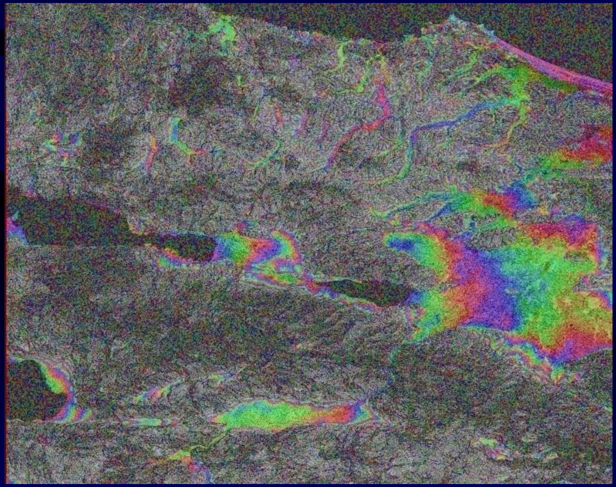
Comparison of the image pairs of before and after quake (Izmit area)



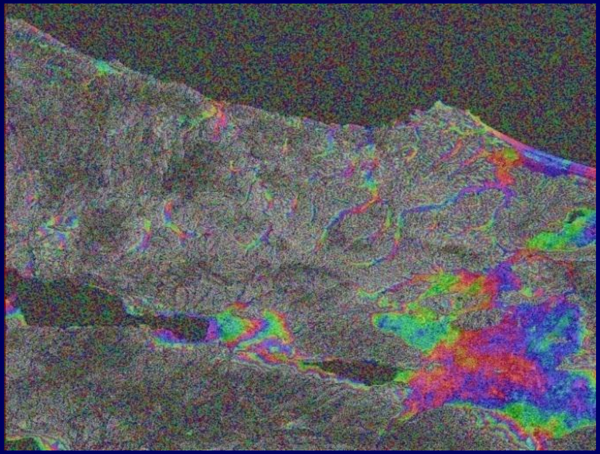
Tandem images of: 10 and 11 Sept. 1999 (23 and 24 days after quake)
normal baseline: 183.313m
parallel baseline: 73.239m



Images of: 20 Mar. 1999, and 24 Apr. 1999 (3 months+23 days and 4 months+24 days before quake)
normal baseline: 228.264m
parallel baseline: 27.607m



Tandem images of: 16 and 17 Sept. 1999 (1 month after quake)
normal baseline: 234.443m
parallel baseline: 103.386m



Tandem images of: 12 and 13 Aug. 1999 (4 and 5 days before quake)
normal baseline: 224.190m
parallel baseline: 91.097m

- In all of the cases the anomaly around the place where the quake was occurred is visible apparently.

DInSAR

Comparison of the interferograms of the image pairs of one before and the other after quake (Izmit area)

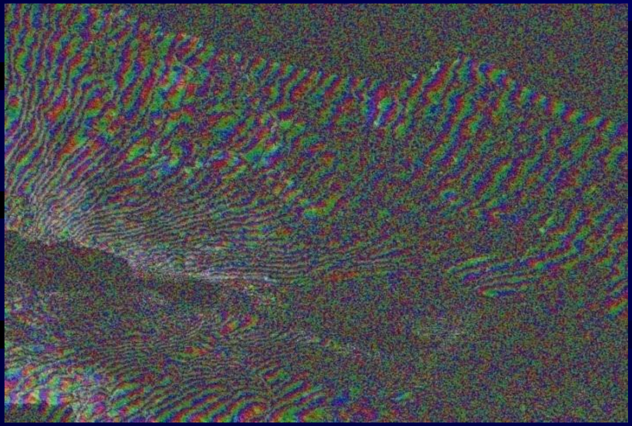


Image pair of 12 Aug. and 16 Sept. 1999
(4 days before and a 29 days after quake)
normal baseline: 121.640m
parallel baseline: 67.725m
fringe number: 40

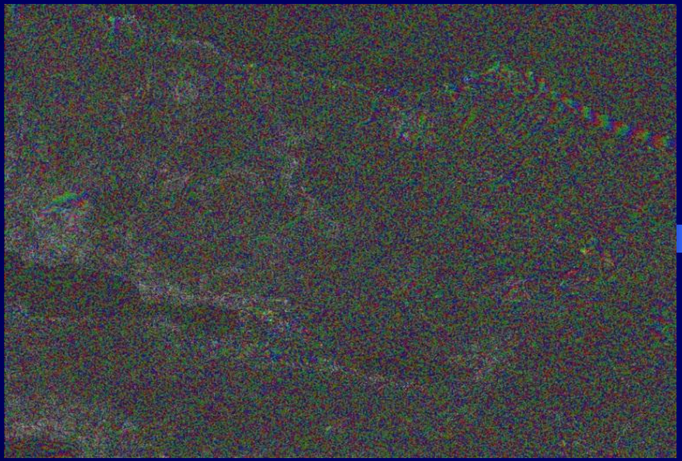


Image pair of 12 Aug. and 17 Sept. 1999
(4 days before and a month after quake)
normal baseline: ?
parallel baseline: ?

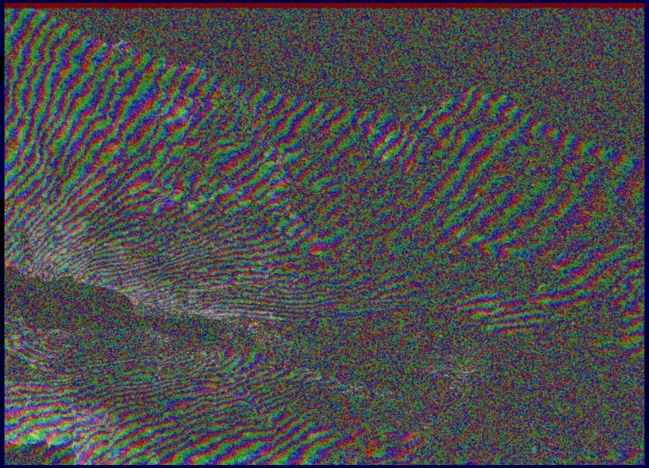


Image pair of 13 Aug. and 17 Sept. 1999
(3 days before and a month after quake)
normal baseline: 11.401m
parallel baseline: 53.558m
fringe number: 43

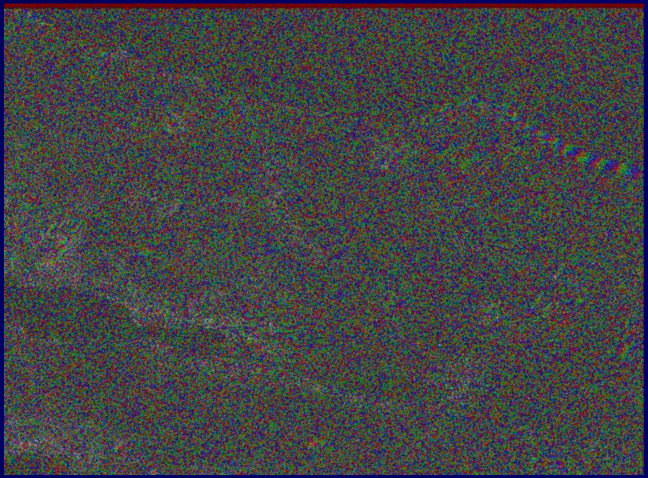


Image pair of 13 Aug. and 16 Sept. 1999
(3 days before and 29 days after quake)
normal baseline: 238.318m
parallel baseline: 154.753m

DInSAR

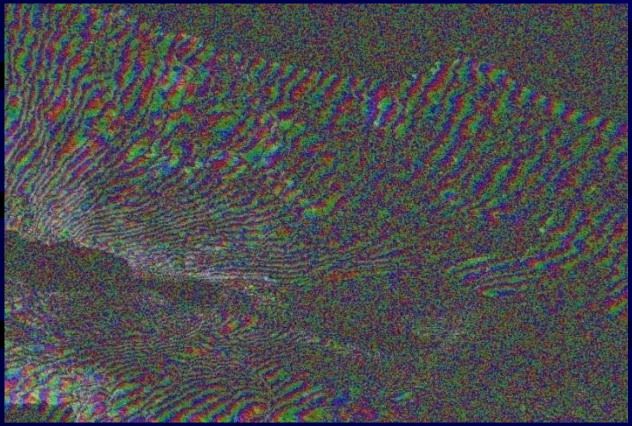


Image pair of 12 Aug. and 16 Sept. 1999
(4 days before and a 29 days after quake)
normal baseline: 121.640m
parallel baseline: 67.725m
fringe number: 40

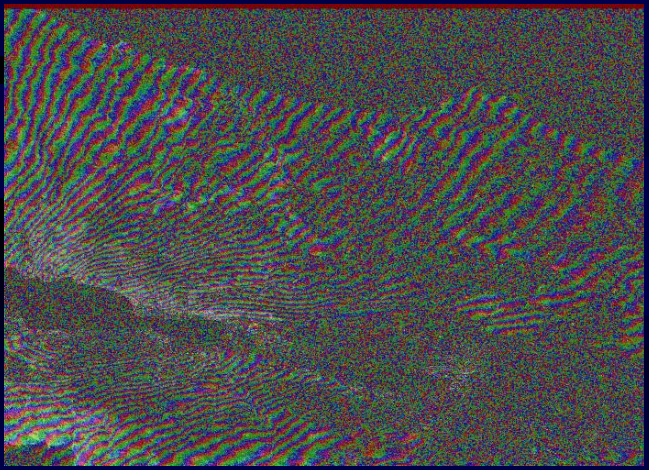


Image pair of 13 Aug. and 17 Sept. 1999
(3 days before and a month after quake)
normal baseline: 11.401m
parallel baseline: 53.558m
fringe number: 43

displacement assessment

fringe numbers x Half the wavelength

40 x 28mm = 1120mm~ 112cm

slant range displacement = 112cm

slant range displacement / cos 67 =

surface displacement

112 / 0.39 = 287.18cm

fringe numbers x Half the wavelength

43 x 28mm = 1204mm~ 120.4cm

slant range displacement = 120.4cm

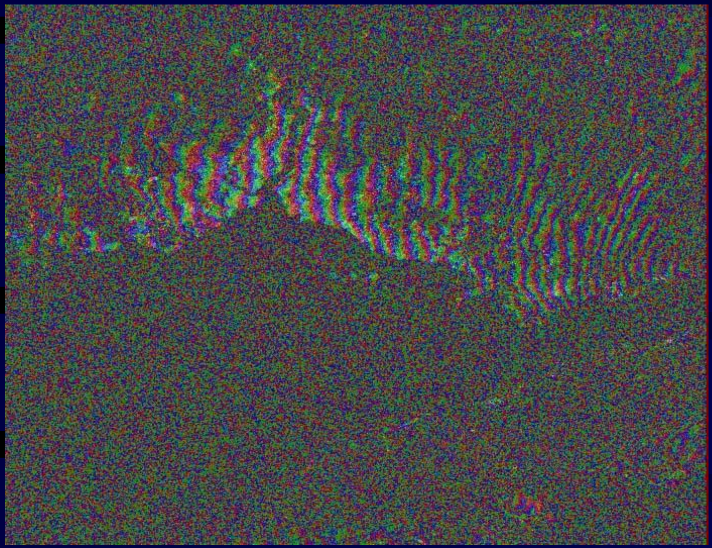
slant range displacement / cos 67 =

surface displacement

120.4 / 0.39 = 308.72cm

DInSAR

displacement assessment



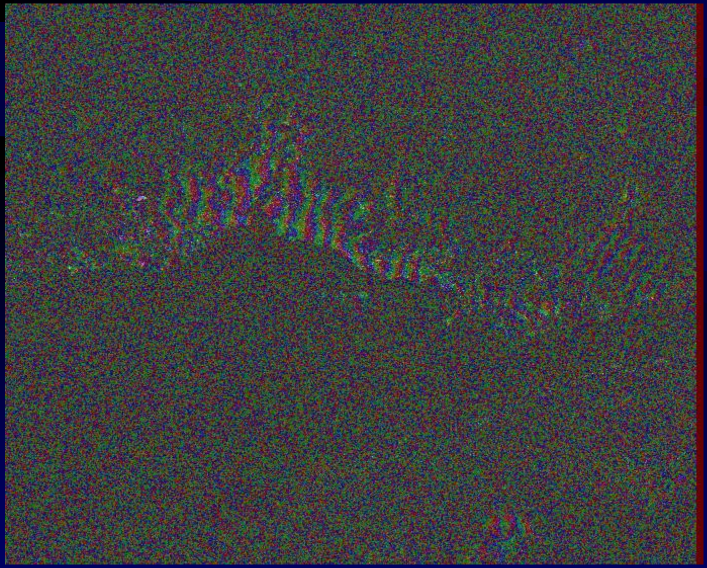
fringe numbers x Half the wavelength

39 x 28mm = 1092mm~ 109.2cm

slant range displacement = 109.2cm

slant range displacement / cos 67 = surface displacement

109.2 / 0.39 = 280cm



fringe numbers x Half the wavelength

30 x 28mm = 840mm~ 84cm

slant range displacement = 84cm

slant range displacement / cos 67 = surface displacement

84 / 0.39 = 215.3cm

Comparison of the interferograms of the image pairs of one before and the other after quake (Istanbul area)

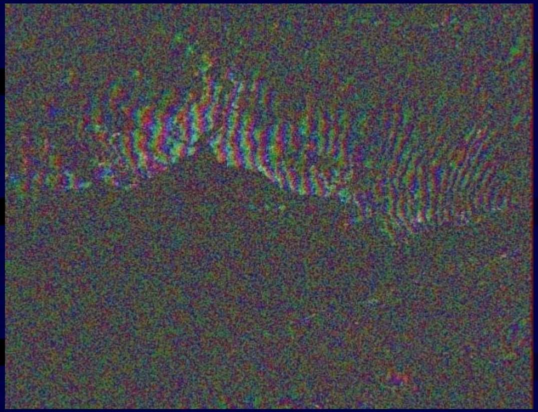
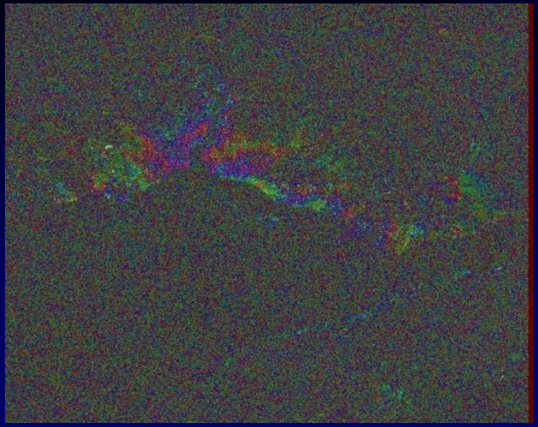


Image pair of 24 Dec. 1998, and 25 Aug. 1999
(7 months and 24 days before and 8 days after quake)

- normal baseline: 40.850m
- parallel baseline: 118.674m
- fringe number: 39

Image pair of 8 Jun. 1995, and 25 Aug. 1999
(4 years and 69 days before and a 8 days after quake)

- normal baseline: 87.869m
- parallel baseline: 16.147m
- fringe number: 30

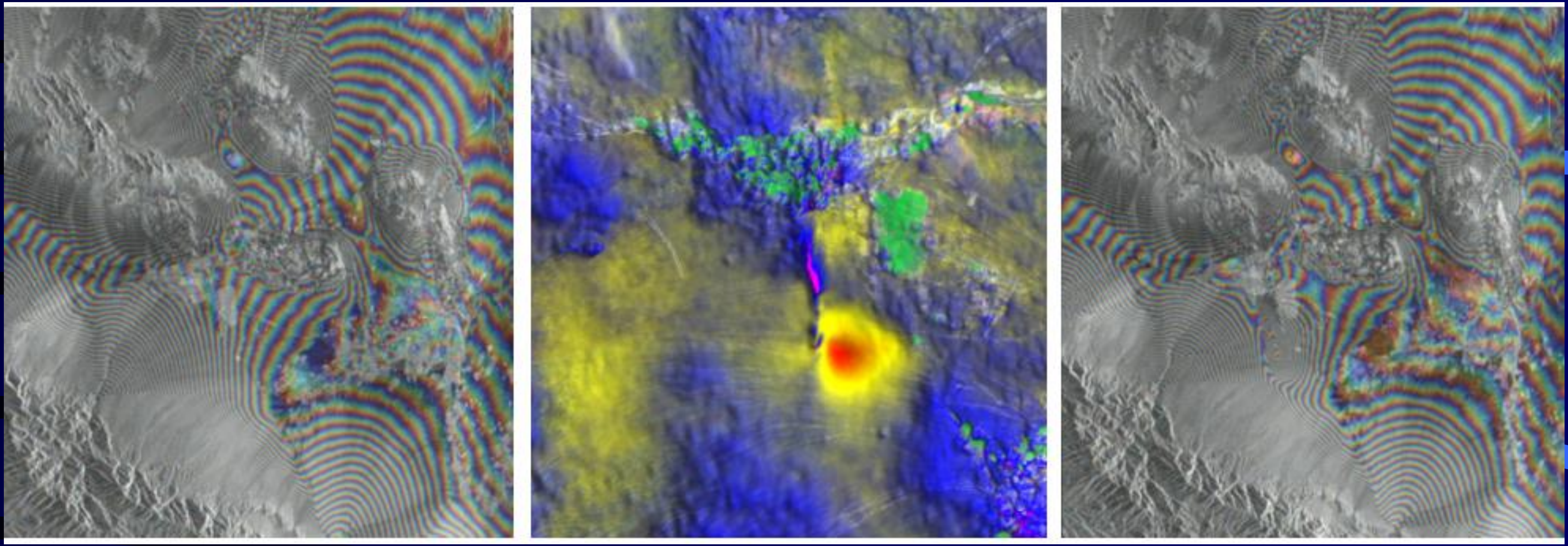


Images of 8 Jun. 1995, and 24 Dec. 1998
(4 years+69 days and 7 months+24 days before quake)

- normal baseline: 55.634m
- parallel baseline: 102.390m

Bam Quake, 26th December 2003

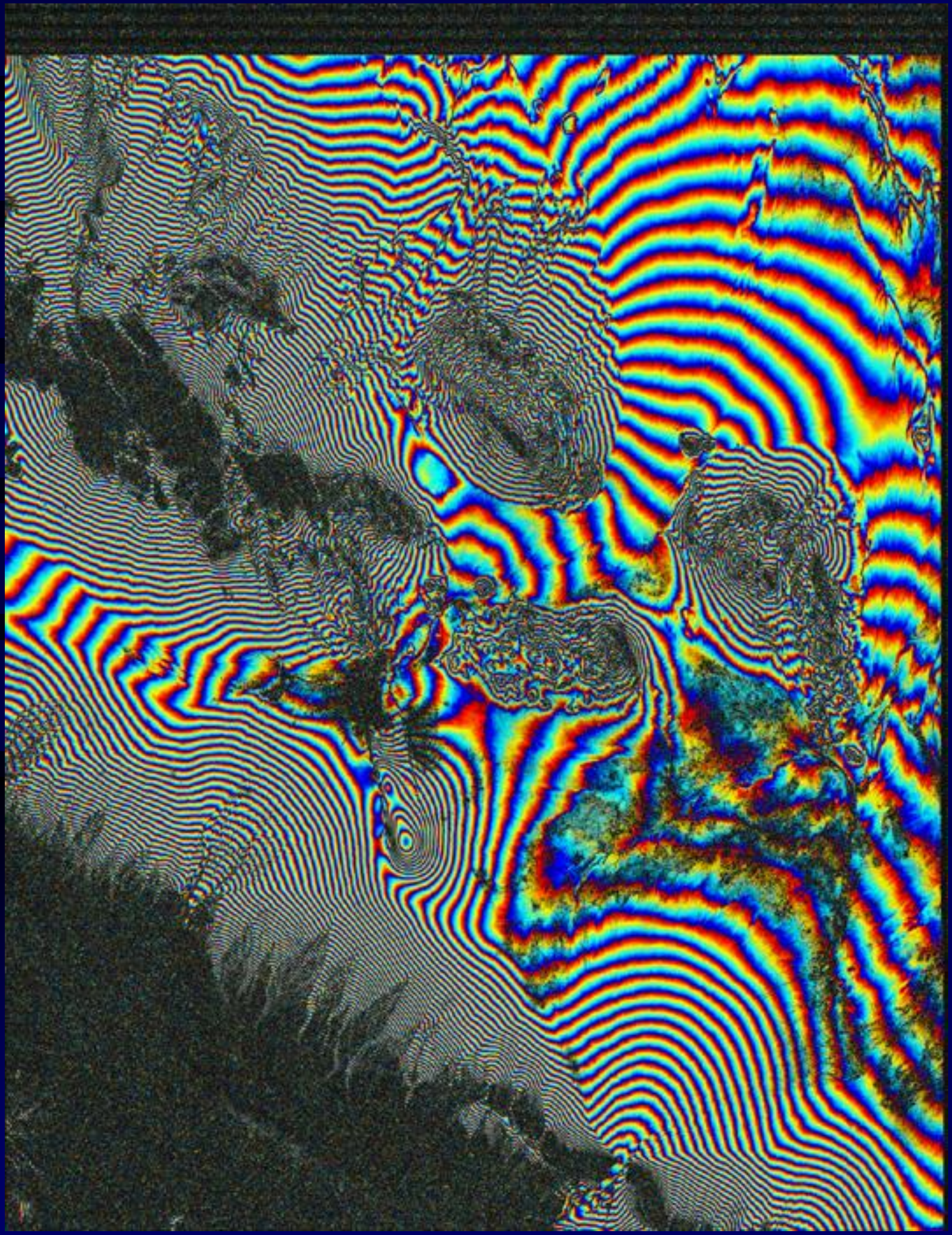
DInSAR



Left image: topo-DInSAR product of Envisat-ASAR data of 11 Jun and 3 Dec 2003 (nbsl. 476.9m, pbsl. 141.6m)
Right image: topo-DInSAR product of the 3 Dec 2003 and 7 Jan 2004 (nbsl. 521.9 m, pbsl. 268.3 m).
Middle image: 3-D perspective view of vertical displacement of south of Bam (during the 3.5 years after the 6.6 earthquake)
Displacements along the radar line-of-sight direction: 30 cm and 16 cm at south-east and north-east lobes of the interferogram
Displacement to the western part of the area, about 5cm along the radar line-of-sight direction

Bam Quake, 26th December 2003

SAR Interferometry



Coherence-DInSAR composite of the image pairs of 3 Dec. 2003 and 7 Jan. 2004

Virtual baseline: 587.2 m
Vertical baseline: 522.5 m
Parallel baseline: 267.9 m

Produced at ISA by the InSAR Deformation Inspection and Observation Tool (IDIOT)

New Technologies in monitoring and management of calamities and dynamic changes

Bosporus Strait

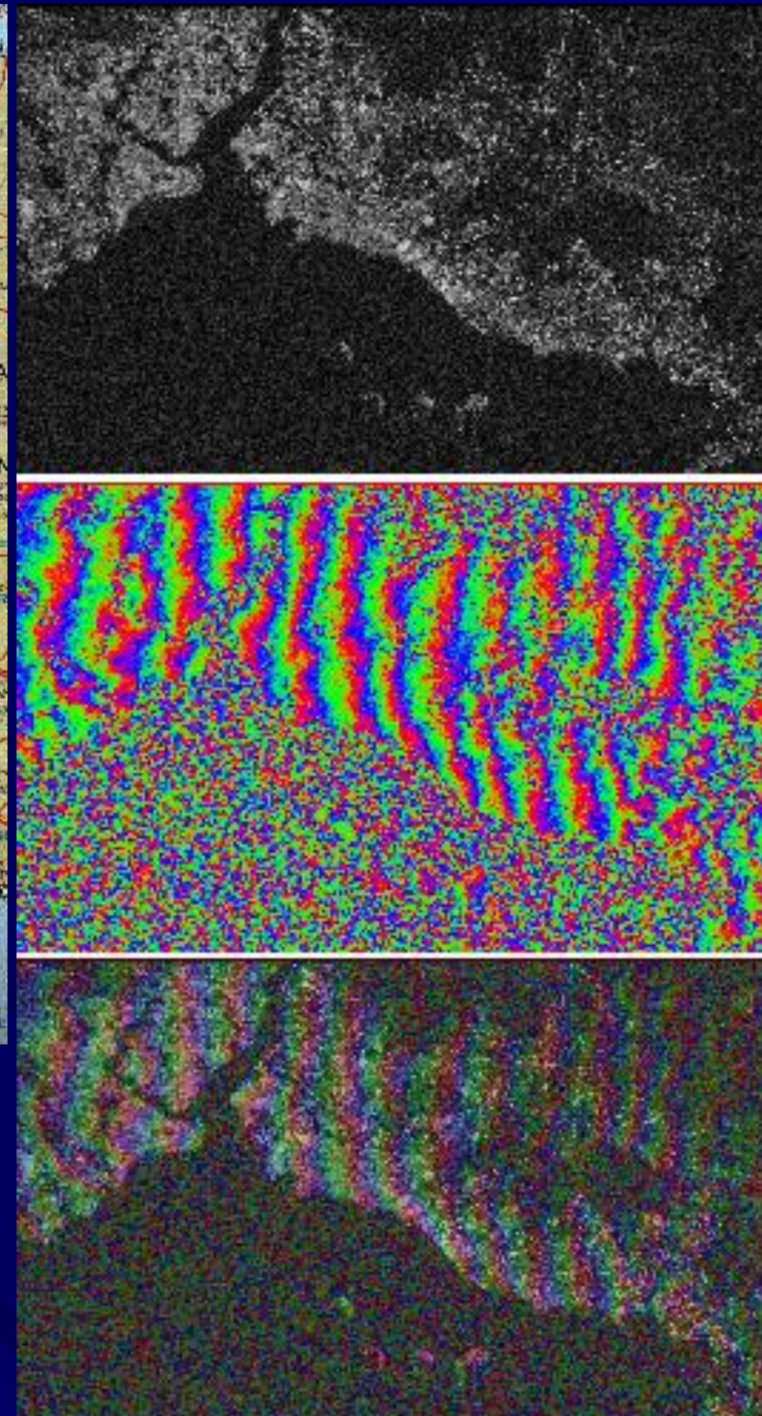


Image pairs of before and after for example a quake are used to generate the interferograms to estimate surface displacement.

Tandem images are used to generate accurate DEMs.

Differential interferometry is used for displacement mapping in vertical and horizontal directions.

Thank you!

KNOWLEDGE SHOULD BE SHARED, OTHERWISE IT IS USELESS.

ISNET can play a key role!