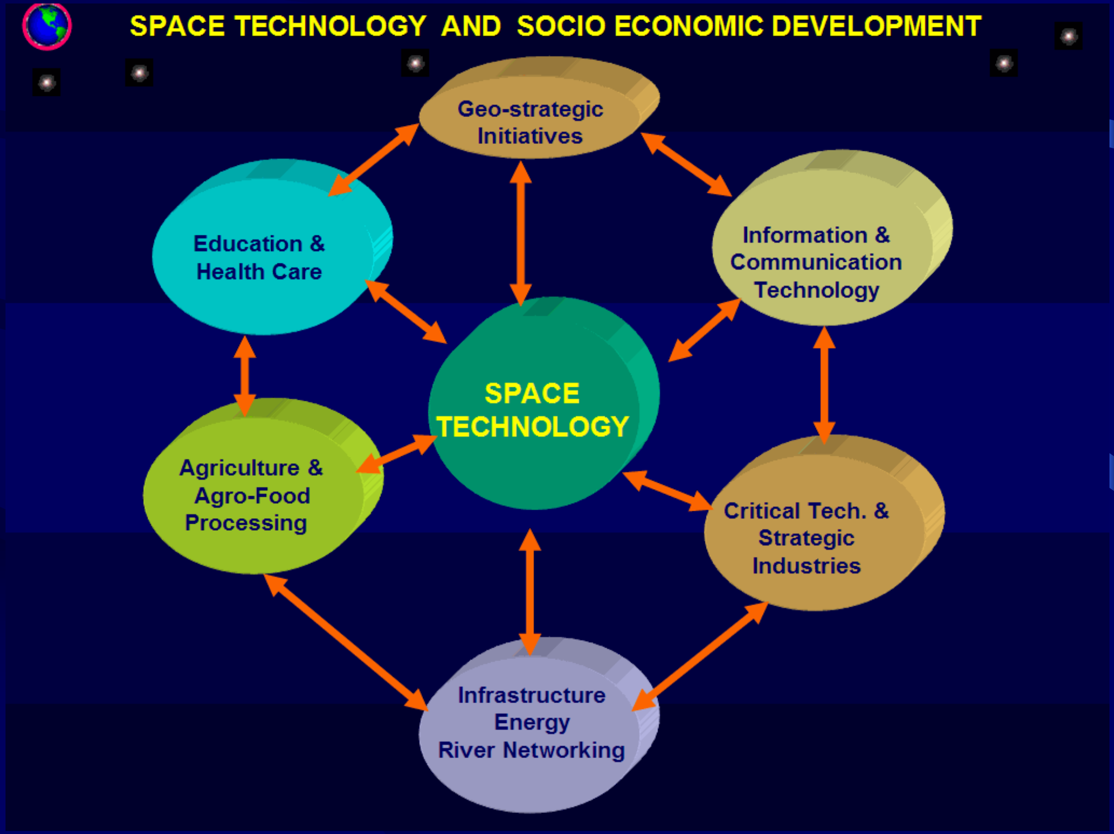
Use of new microwave satellite technologies in the environmental monitoring

REGIONAL EXPERT MEETING/TRAINING WORKSHOP ON
"Monitoring Global Environmental Changes through the Application of Remote Sensing for OIC and IOR-ARC Region Countries"
Islamic Republic of Iran, Tehran
24-27 October 2010

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

- Rapid and dynamic changes in technologies in recent decades
- Space technologies and exploration is avant-garde
- Sensing and detecting phenomena from long distance is of great importance and effect.
- Electromagnetic waves the tool for long range sensing of the phenomena
- Radar Remote Sensing an effective mean that uses Electromagnetic waves characteristics for SAR Interferometry

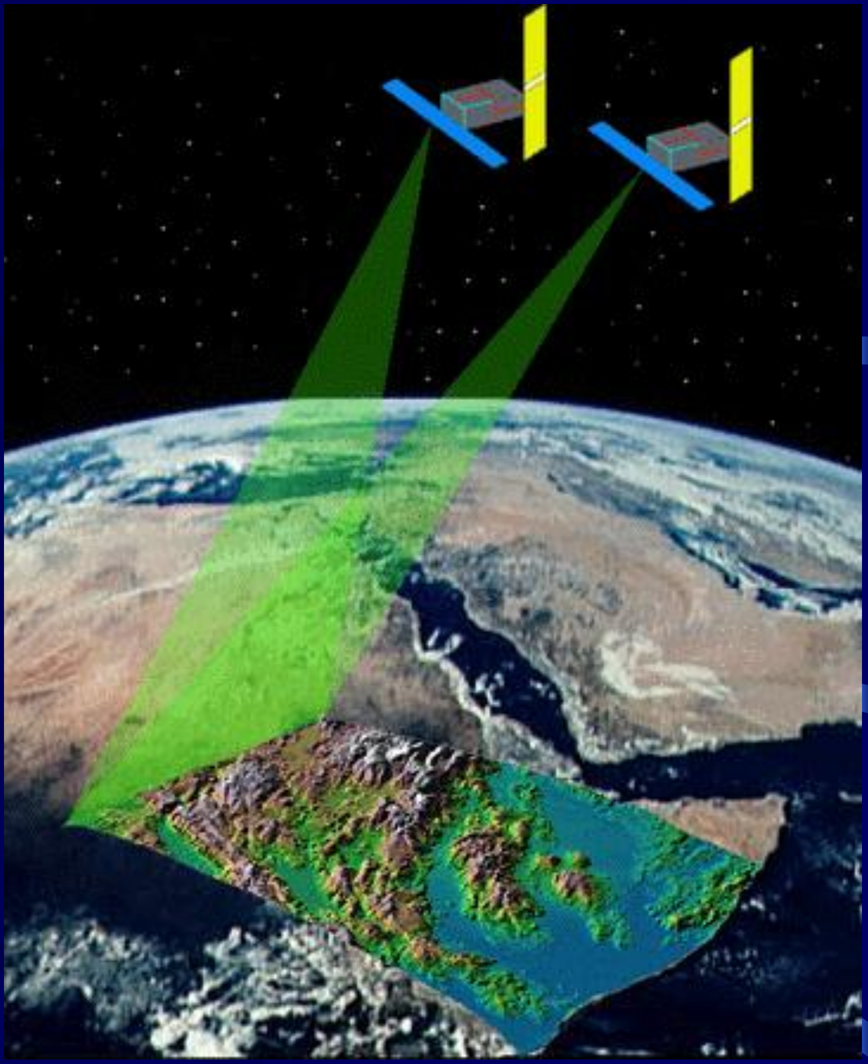
Interrelation between space technologies and social and economical development



Investigating and monitoring of environment and the natural disasters emerges as a vital concern for sustainable development, welfare and safety.

Newly emerging InSAR techniques bridge the gaps

Radar remote sensing technology and the Synthetic Aperture Radar (SAR) technology in particular is an efficient tool for monitoring and investigation of dynamic phenomena on Earth.



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

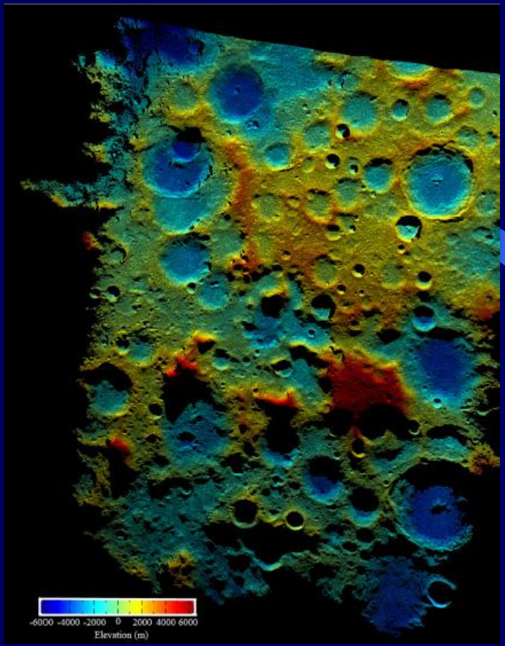
For interferometry, two radar images of the same area with slightly different imaging angles is required.

Historical review

- 1969: Rogers and Igalis use InSAR in observation of Venus and the Moon
- 1974: Graham, the first to introduce SAR for topographic mapping
- 1985: Zebker and Goldstein start a research at JPL, California. They mount two SAR antennas on an aircraft with a baseline of 11.1 m. Antennas receive the signals sent from one antenna simultaneously.
- 1988: Goldstein extends the concept of the airborne images to the SEASAT data
- 1988: Gabriel and Goldstein adapt InSAR to the shuttle SIR-B
- 1991: ESA launch ERS-1 with its C-band SAR
- 1995: ERS-2 is launched. Its launch leads to use ERS-1 and ERS-2 in tandem mode
- 1995: RADARSAT is launched successfully, its data become available for InSAR
- 2002: ESA’s Envisat is launched
- 2006: Japanese ALOS is launched
- 2008: German TerraSAR-X is launched

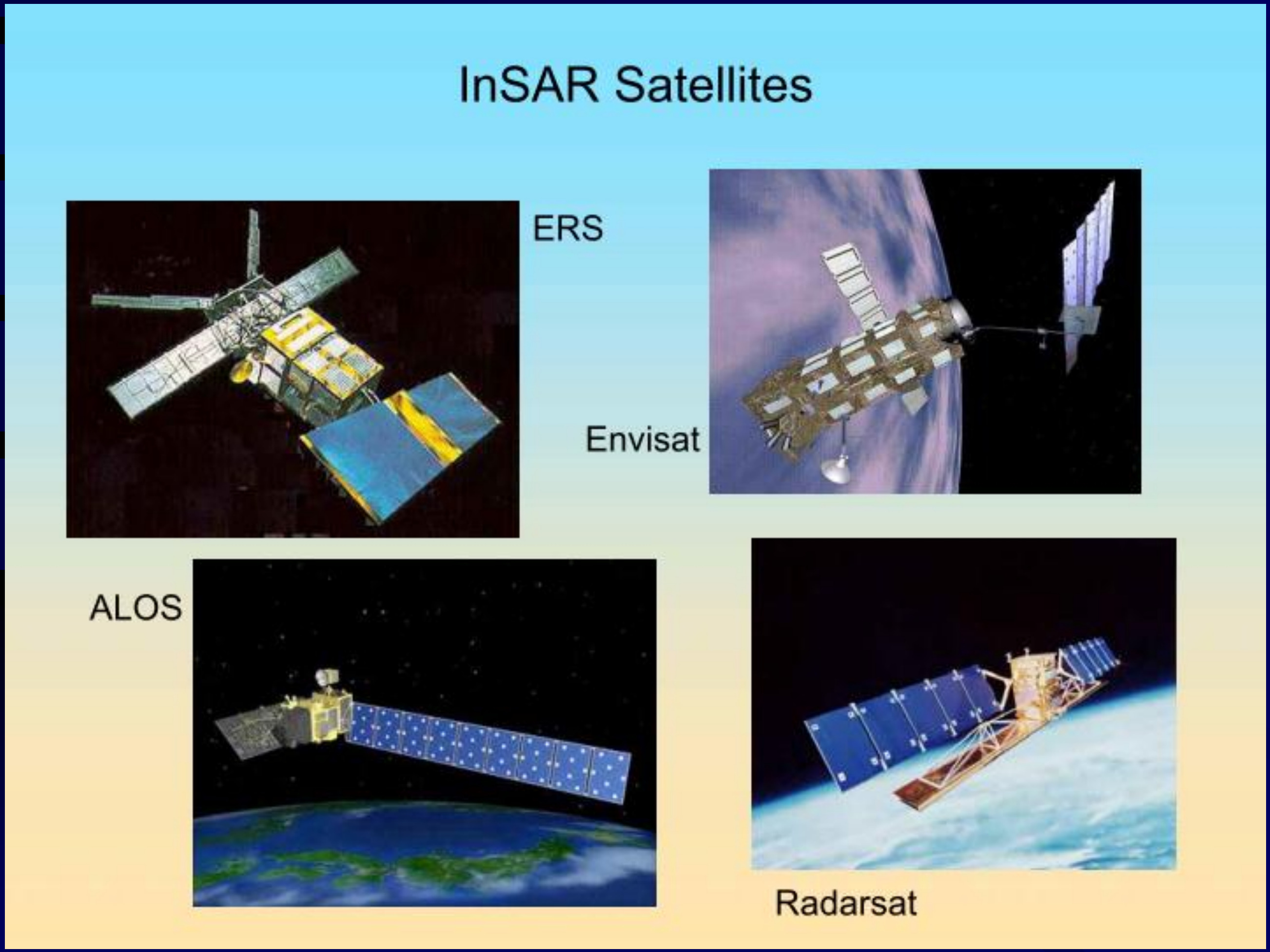
High-resolution topographic map of the Moon generated by SAR

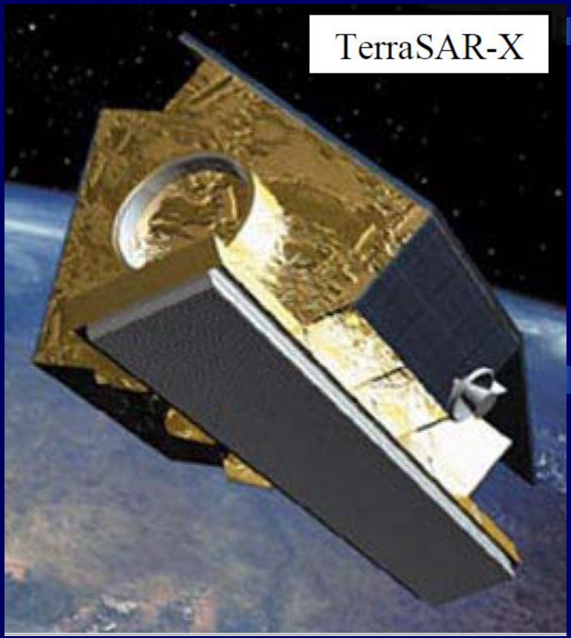
The surface of Venus, as imaged by the Magellan probe using SAR

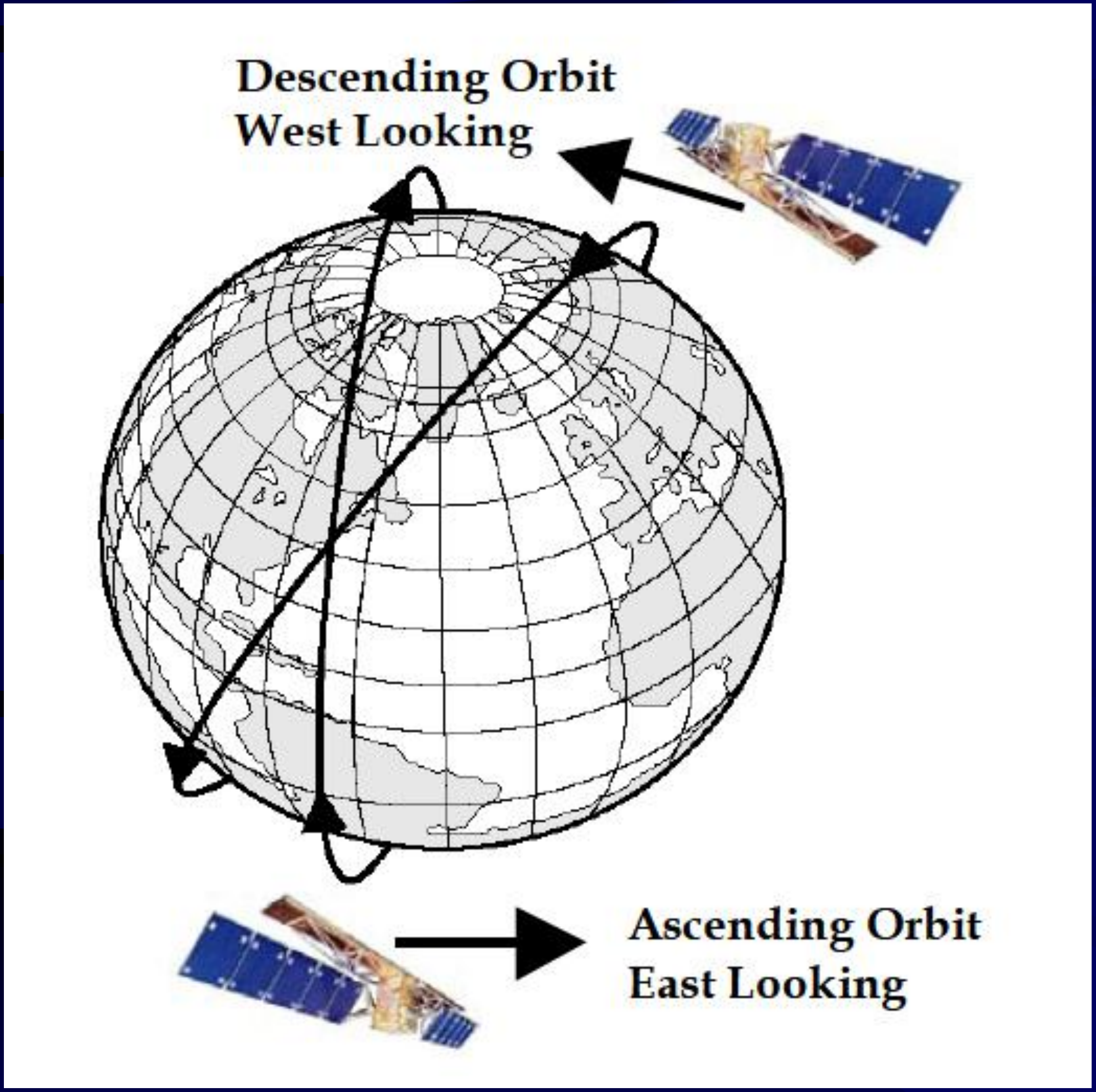


SAR systems

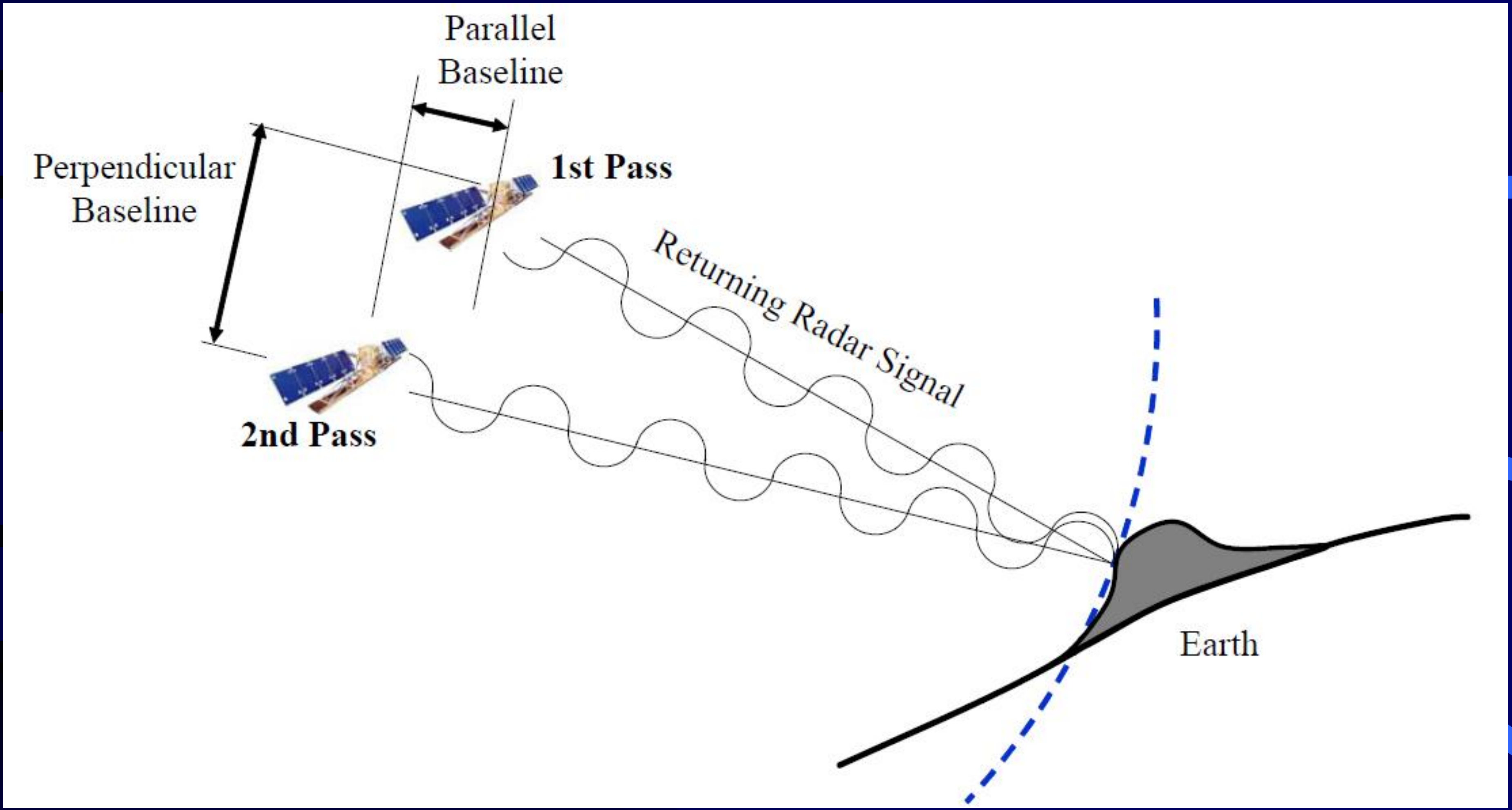
Spaceborne Imaging RADAR Systems







Polar orbiting satellites have an east looking and west looking perspective.



Orbit baseline changes can produce varying phase shifts.

INSAR software

There are several software packages that can process SAR data into interferometric products for many applications.

The list of common InSAR software packages

- EPSIE 2000 , Indra Espacio, Spain
- DIOPSON, French Space Agency (CNES)/Altamira Information, France
- ERDAS Imagine (ERDAS InSAR), Leica Geosystems, USA
- Earth-View (EV) InSAR, Atlantis Scientific Inc. of Canada/USA
- GAMMA, GAMMA Remote Sensing and Consulting AG, Switzerland
- ROI PAC, NASA's Jet Propulsion Laboratory and CalTech., USA
- SARscape, ENVI, Germany
- PulSAR and DRAIN, Phoenix Systems Ltd., UK
- SAR-E2, JAXA, Japan (developed for JERS SAR data examining)
- DORIS, Delft University of Technology, The Netherlands, (*Delft Object-oriented Radar Interferometer Software*)

SAR Toolbox, BEST (Basic Envisat SAR Toolbox), NEST (Next ESA SAR Toolbox)

InSAR is a set of successive steps to produce a height image called DTM.

- To generate DTM’s, deformation maps or thematic maps,

two or more SAR datasets of the same area acquired by the same sensor systems are needed.

datasets are in such a format that they still contain the ***phase and magnitude information*** *of the radar signal and also the* ***orbit, timing, calibration and other essential parameters*** *of these data are available*

- To produce a DTM

The following basic steps should be carried out successively

Data search, selection and pre-processing

Co-registration of the data sets

Coherence map generation

Interferogram generation

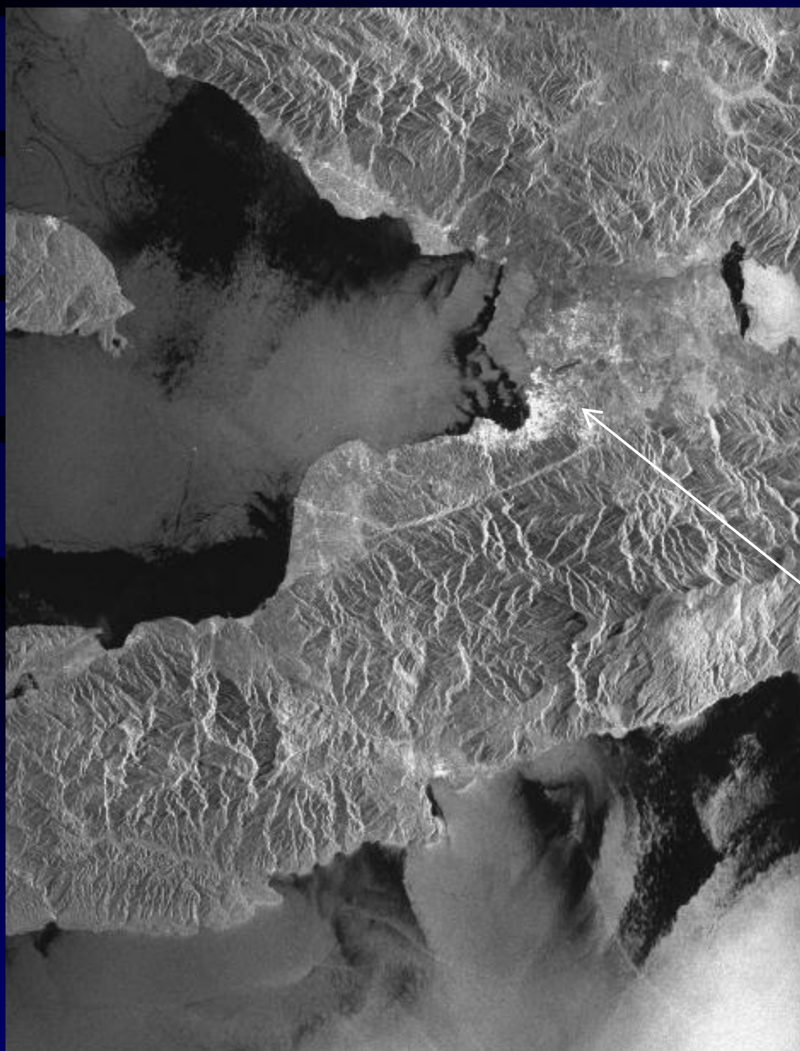
Phase unwrapping

DTM generation

Data search, selection and pre-processing

PORT-AU-PRINCE/ Jan 12, 2010: A huge quake measuring 7.0 hits Haiti. **Baseline: 279.98m**

Master image dated 26 January 2010

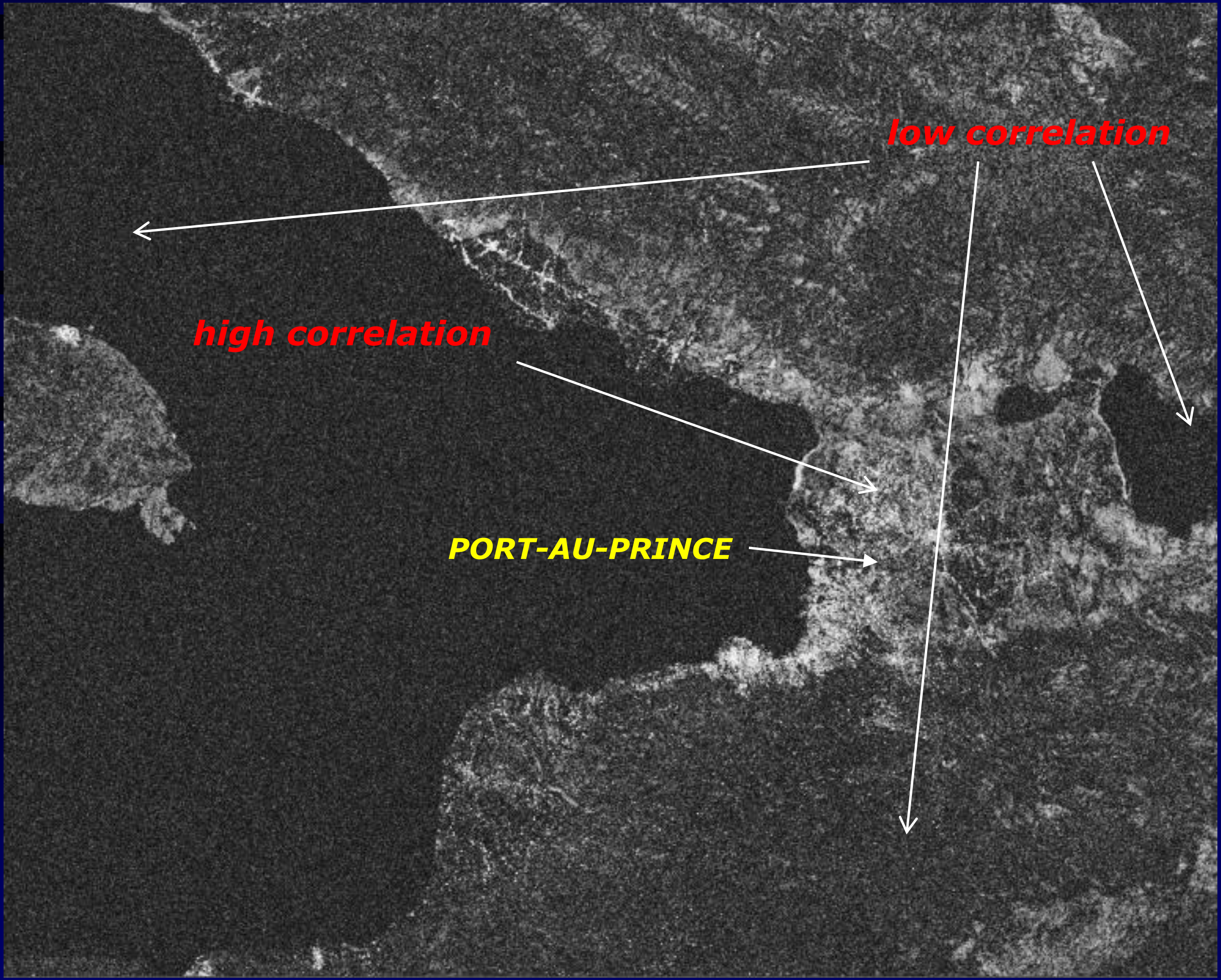


Slave image dated 2 March 2010

PORT-AU-PRINCE

Coherence map generation

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

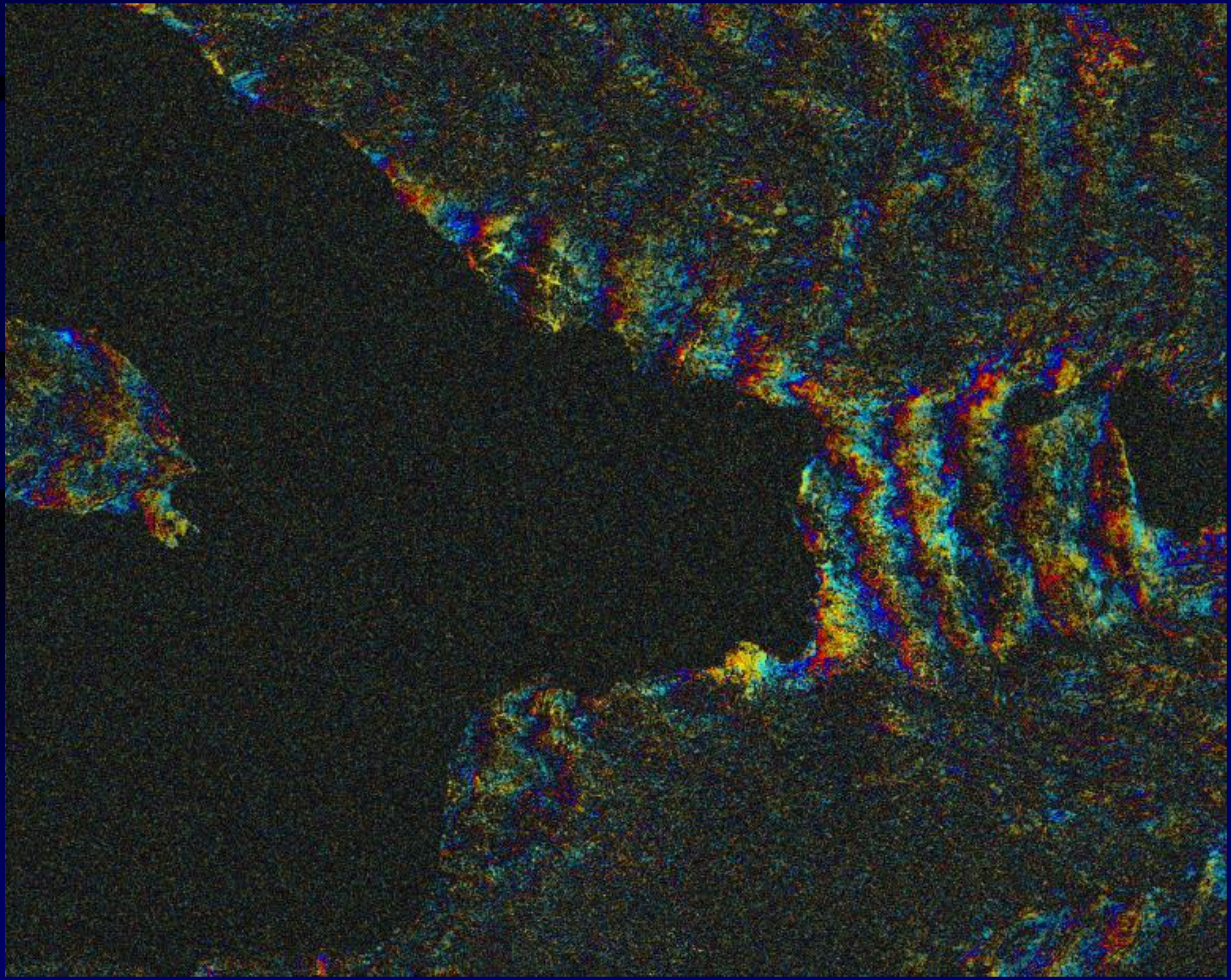


Measure for the correlation of corresponding signals

Ranges from 0 to 1

Interferogram generation

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



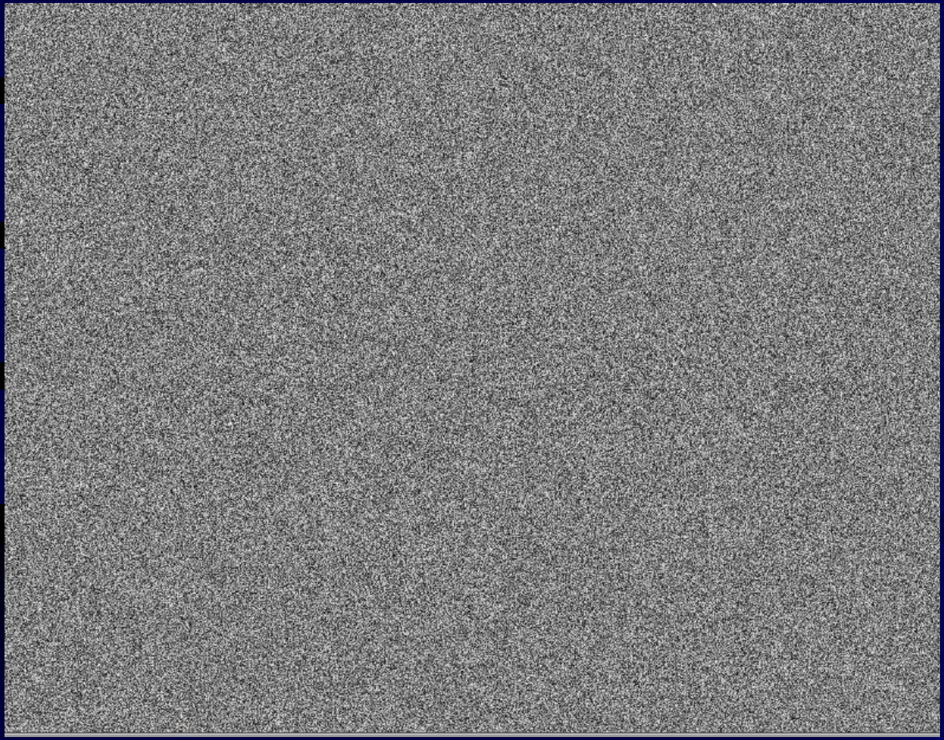
PORT-AU-PRINCE, Haiti

Baseline: 279.98m

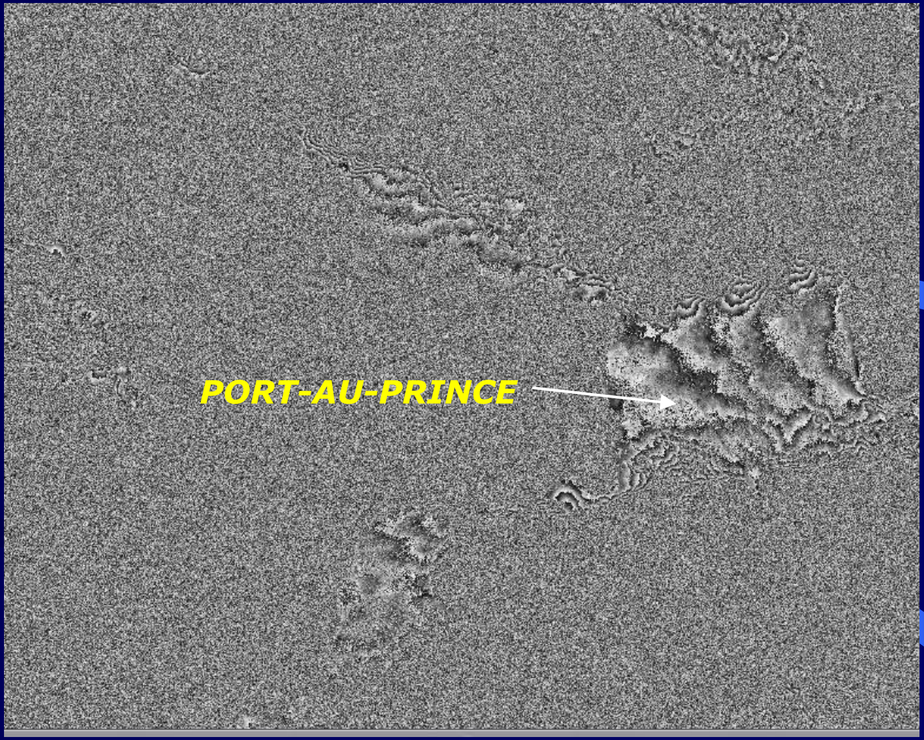
Phase unwrapping

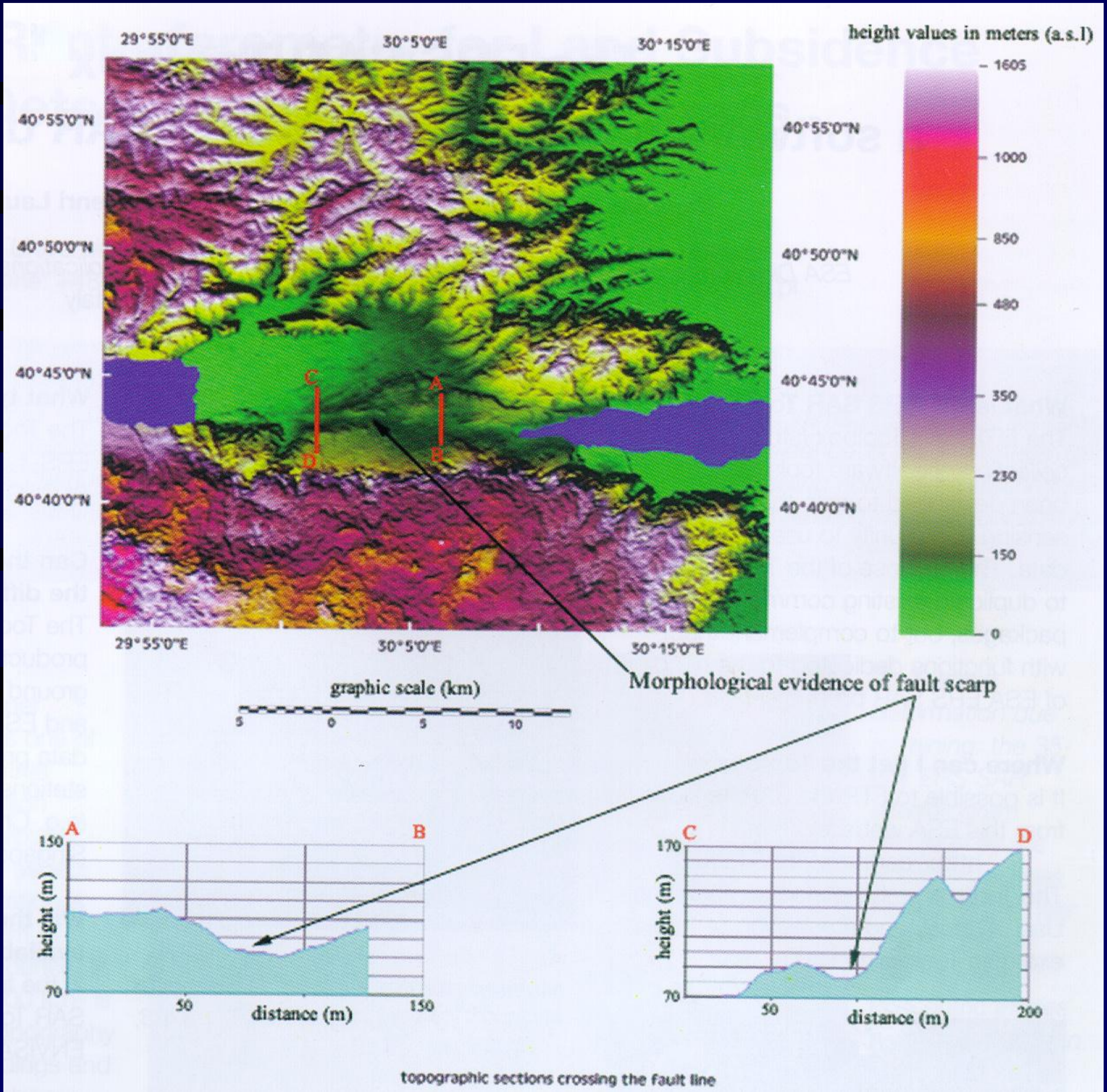
Phase image and unwrapped phase of the data pairs of master image dated 26 January 2010 and slave image dated 2 March 2010

Phase image



unwrapped phase image





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.

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.

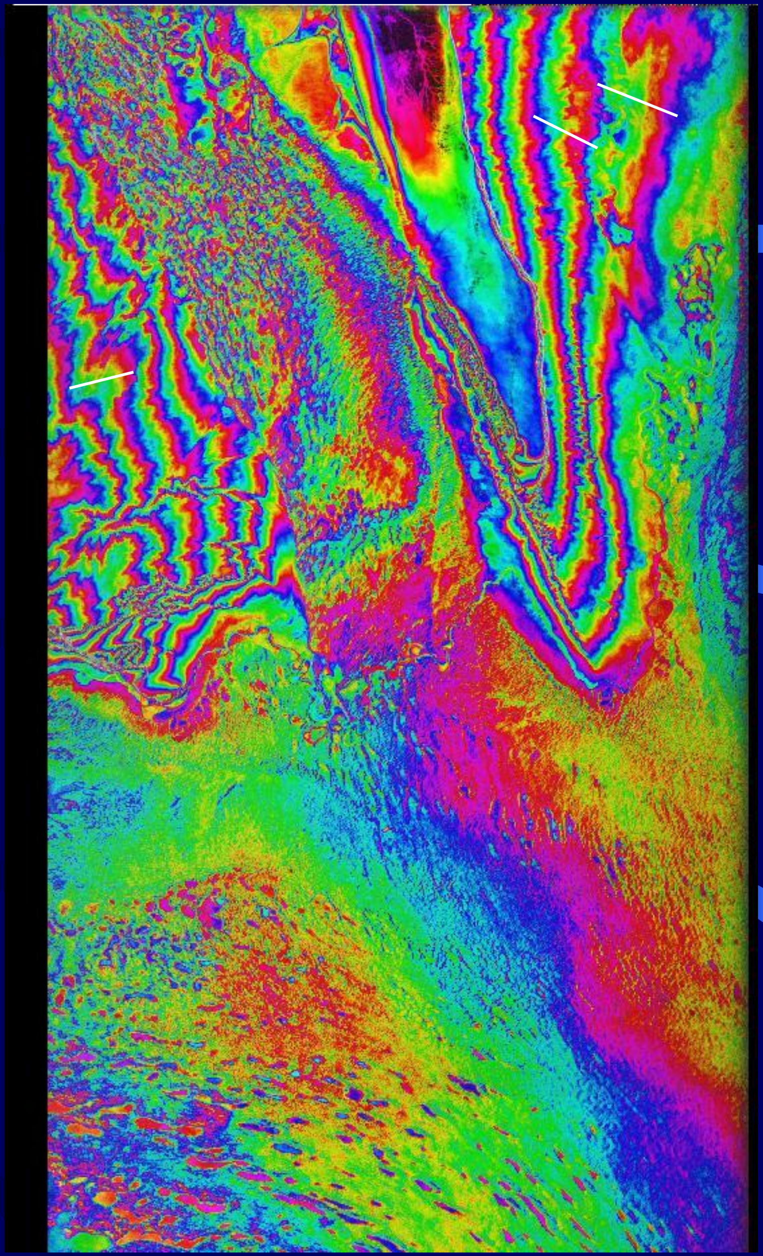
Representing the whole range of the phase from 0 to 2π in a full color cycle

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

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



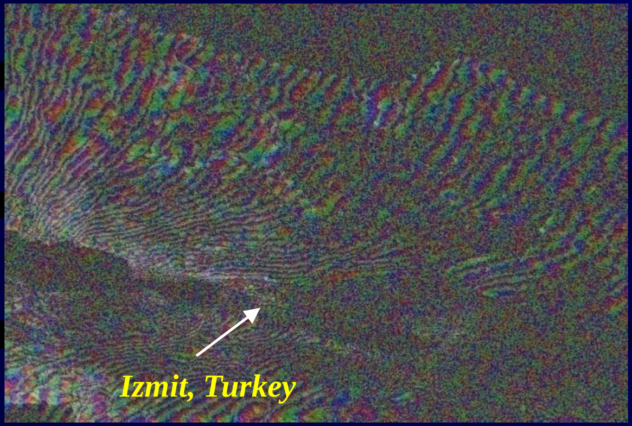


Image pair of 12 Aug. and 16 Sept. 1999
(4 days before and a 29 days after quake)
normal baseline: 121.640m
parallel baseline: 67.725m
fringe number: 40

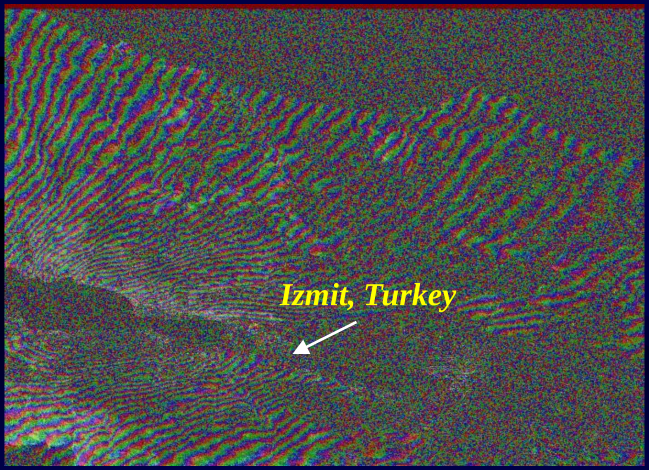


Image pair of 13 Aug. and 17 Sept. 1999
(3 days before and a month after quake)
normal baseline: 11.401m
parallel baseline: 53.558m
fringe number: 43

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

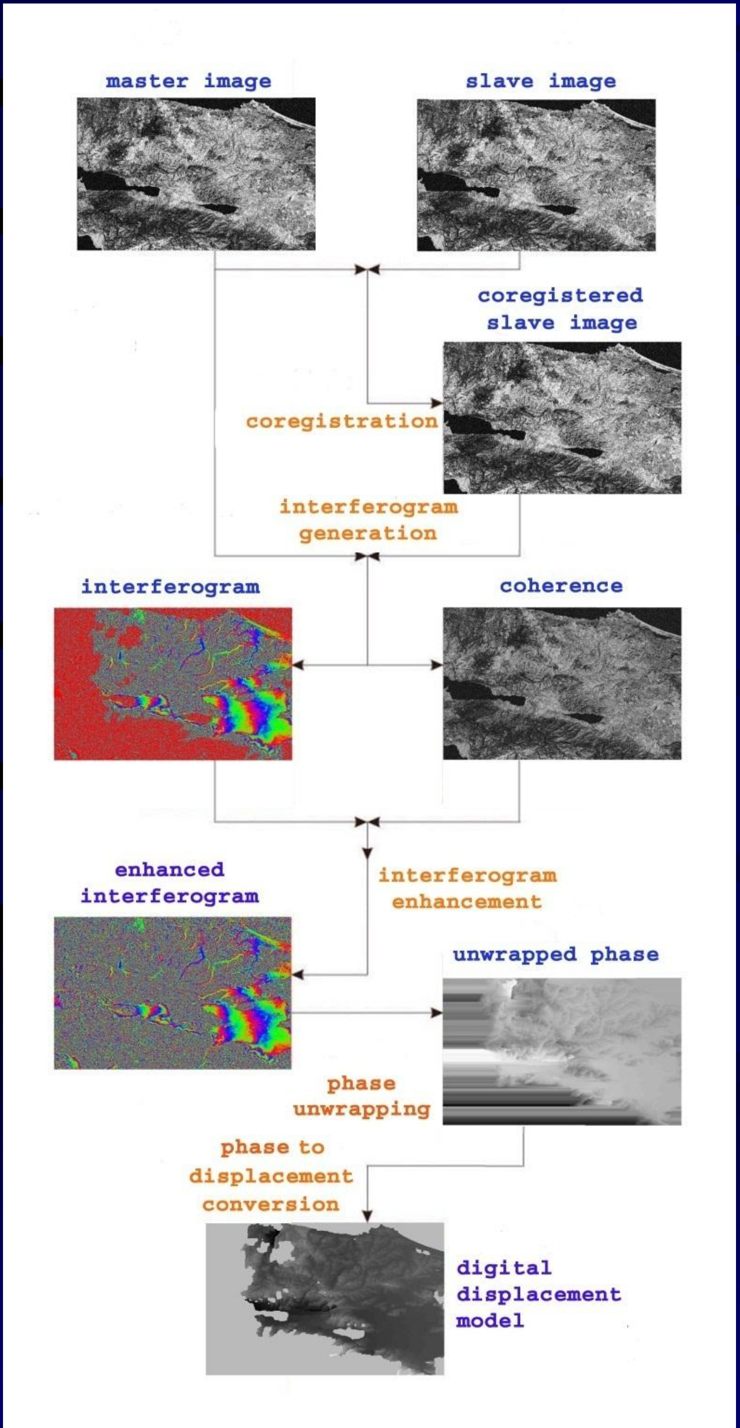
43 x 28mm = 1204mm~ 120.4cm

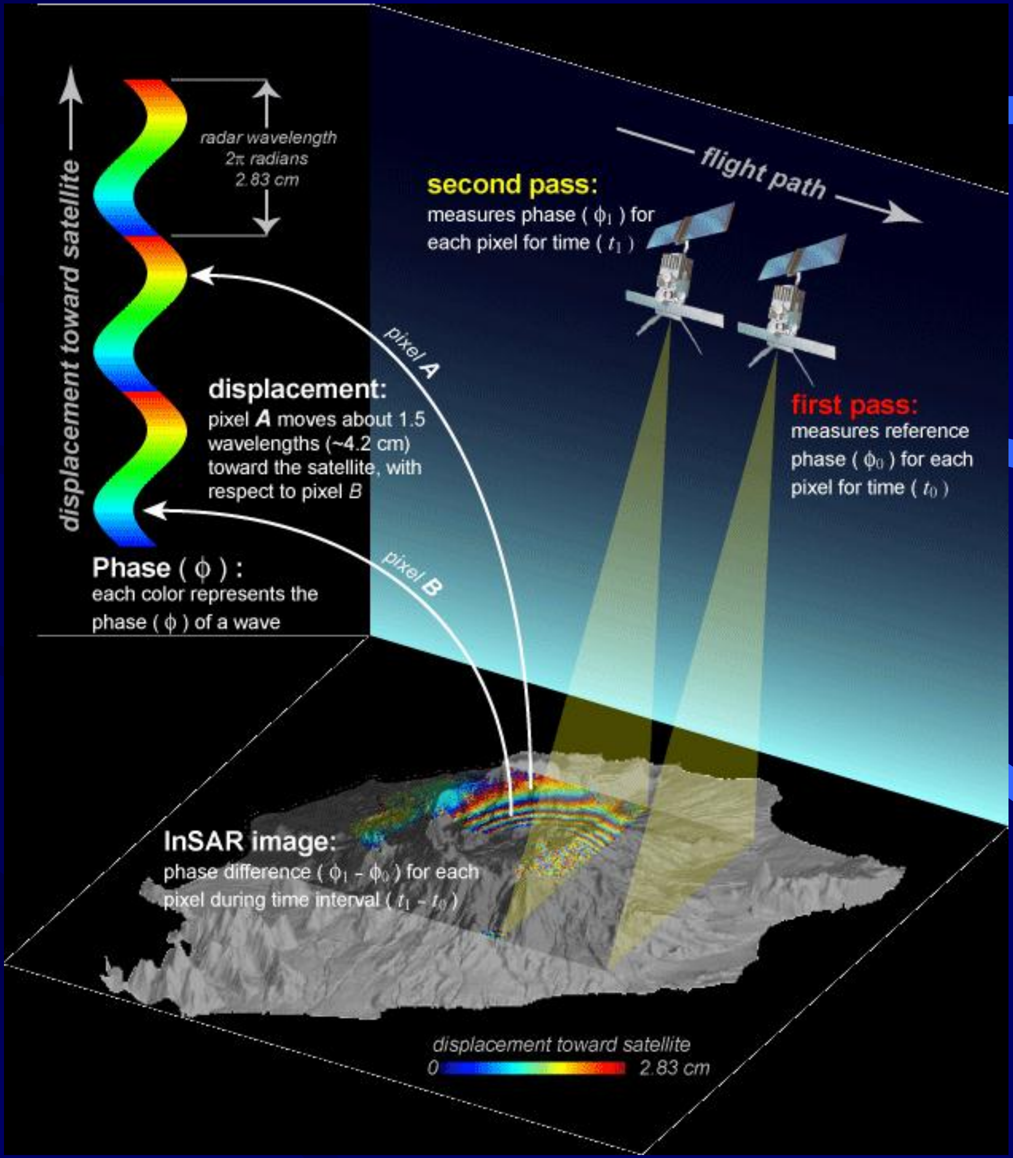
slant range displacement = 120.4cm

slant range displacement / cos 67 = surface displacement

120.4 / 0.39 = 308.72cm

DInSAR Method





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.

Methods

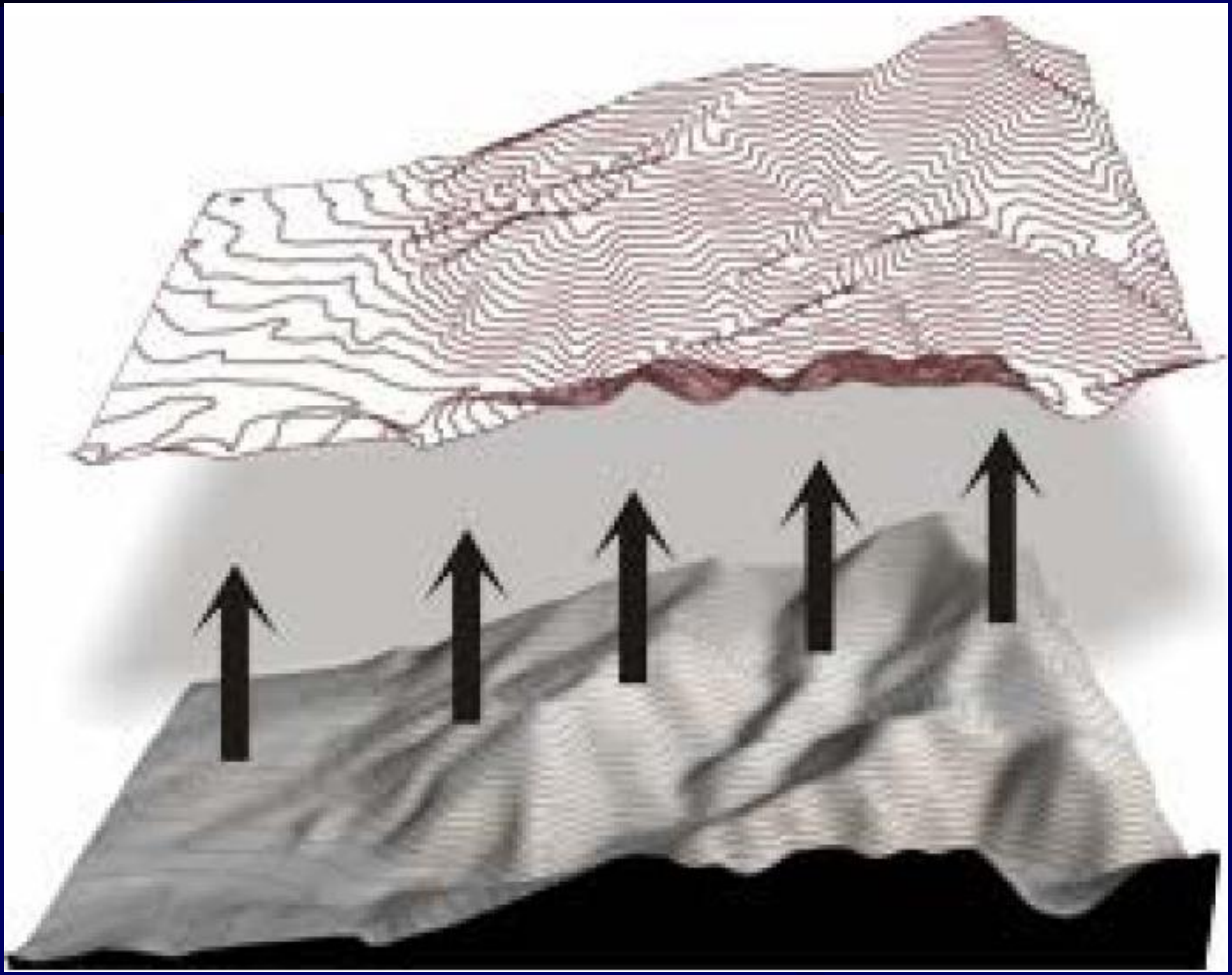
- DEM is important for surveying and other applications in engineering.
- Paramount accuracy; for some applications high accuracy does not matter but for some others it does.
- Use of numerous DEM generation techniques with different accuracies for various means
- DEMs can be generated through different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

geodesic measurements,

photogrammetry and

remote sensing.

DEM generation

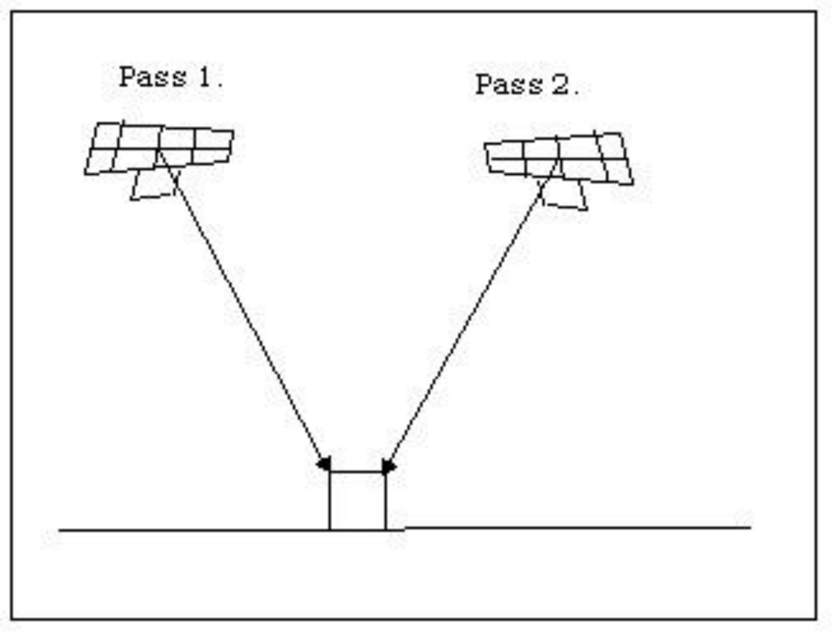


Methods

- 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.

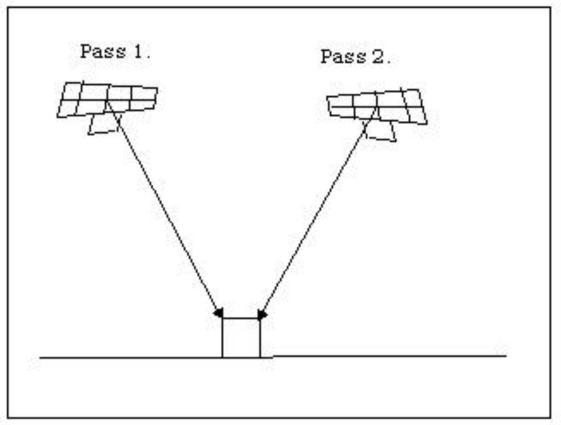
- For DEM generation by photogrammetry, the photographs are taken from an aircraft or spacecraft and evaluated as stereo-pairs and consequently 3-D height information is obtained.

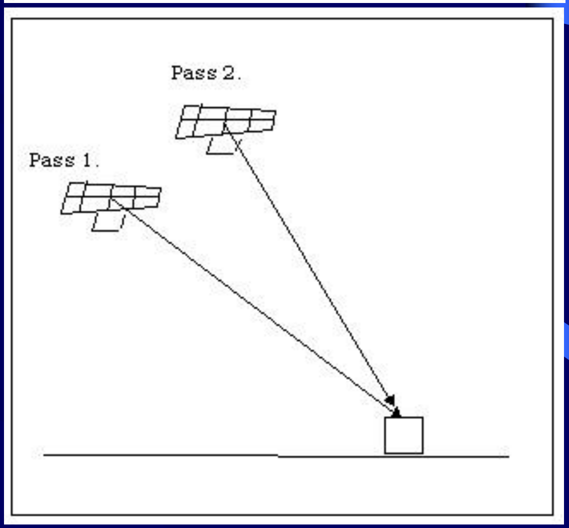


Methods

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

stereo-pairs
laser scanning (LIDAR)
InSAR





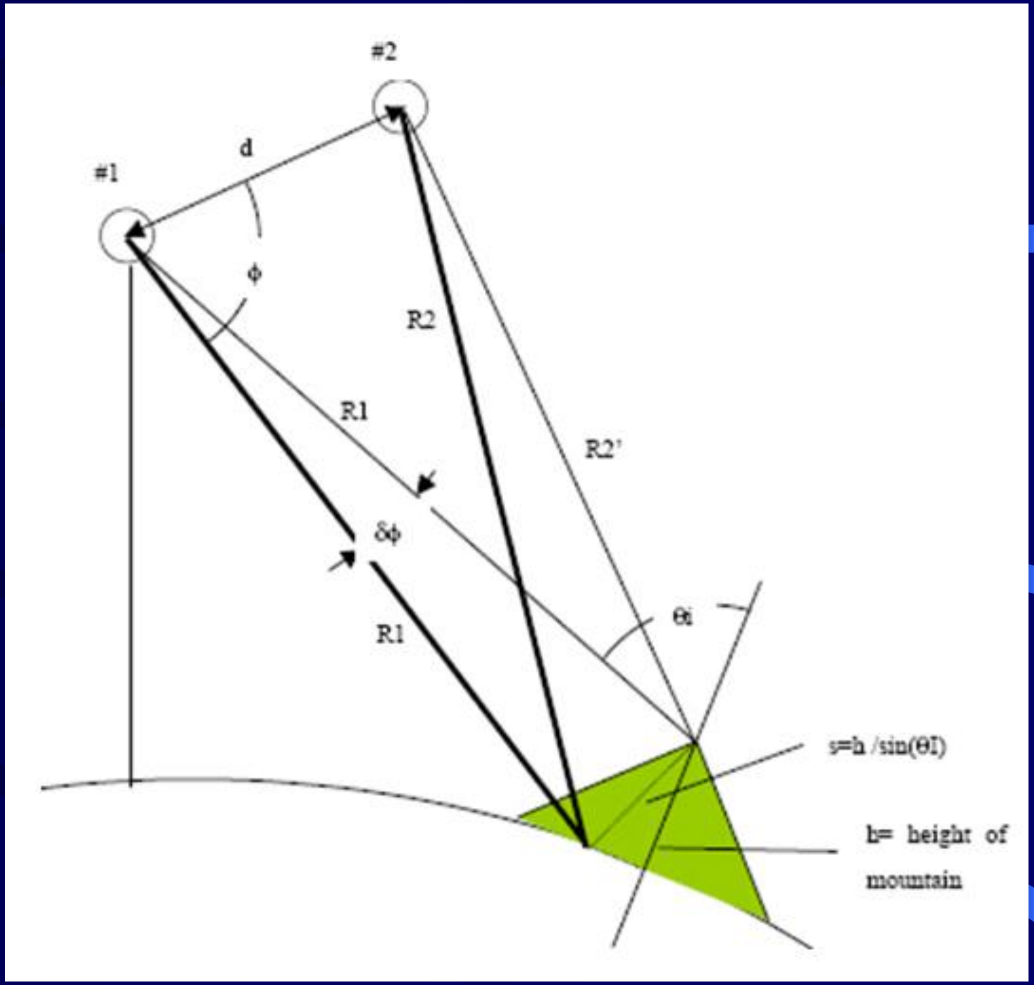
There are three types of InSAR technique

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

Methods

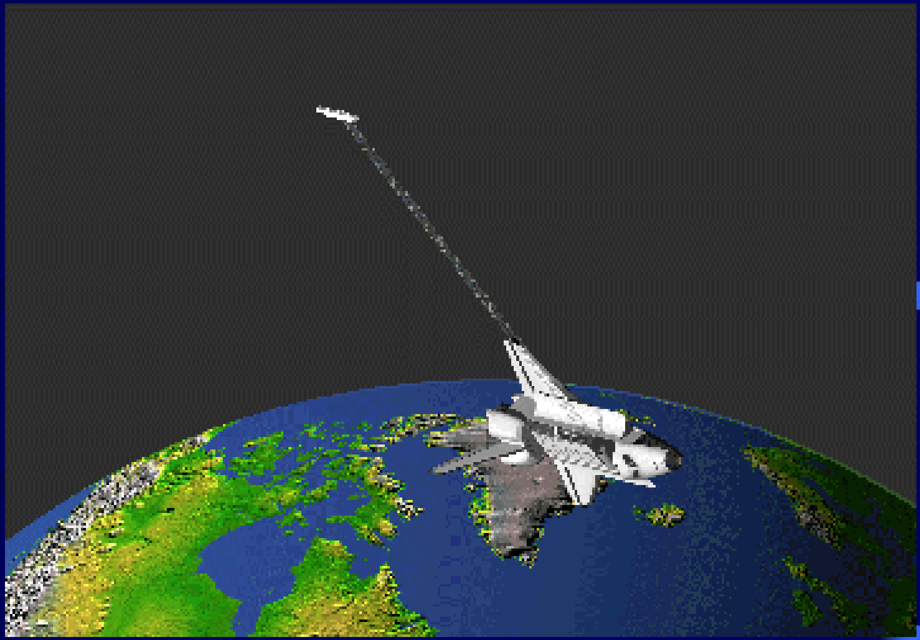
- In double-pass InSAR, a single SAR instrument passes over the same area two times while through the differences between these observations, height can be extracted.

- 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.

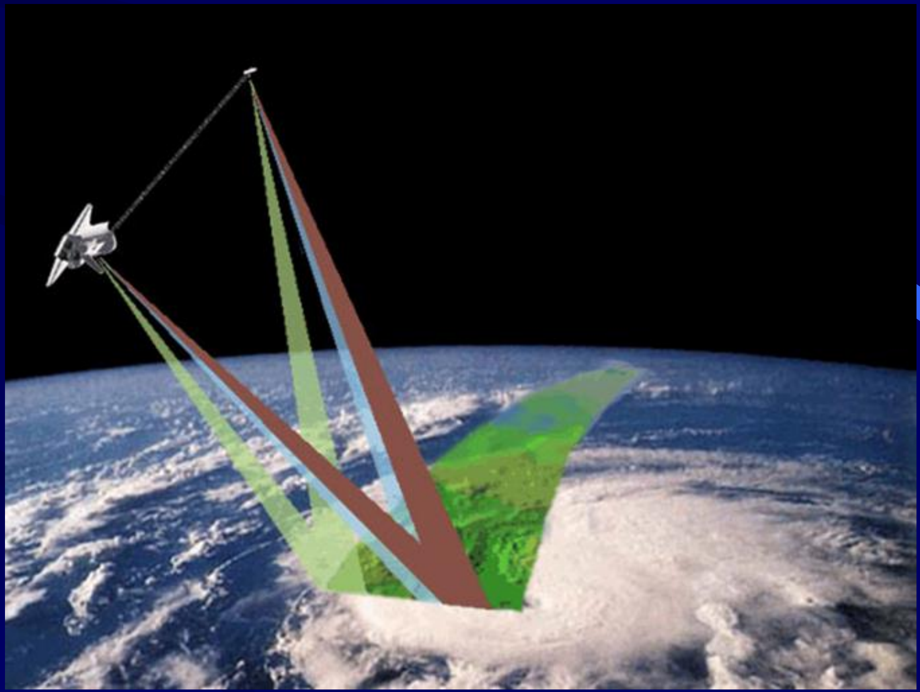


Methods

- 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.

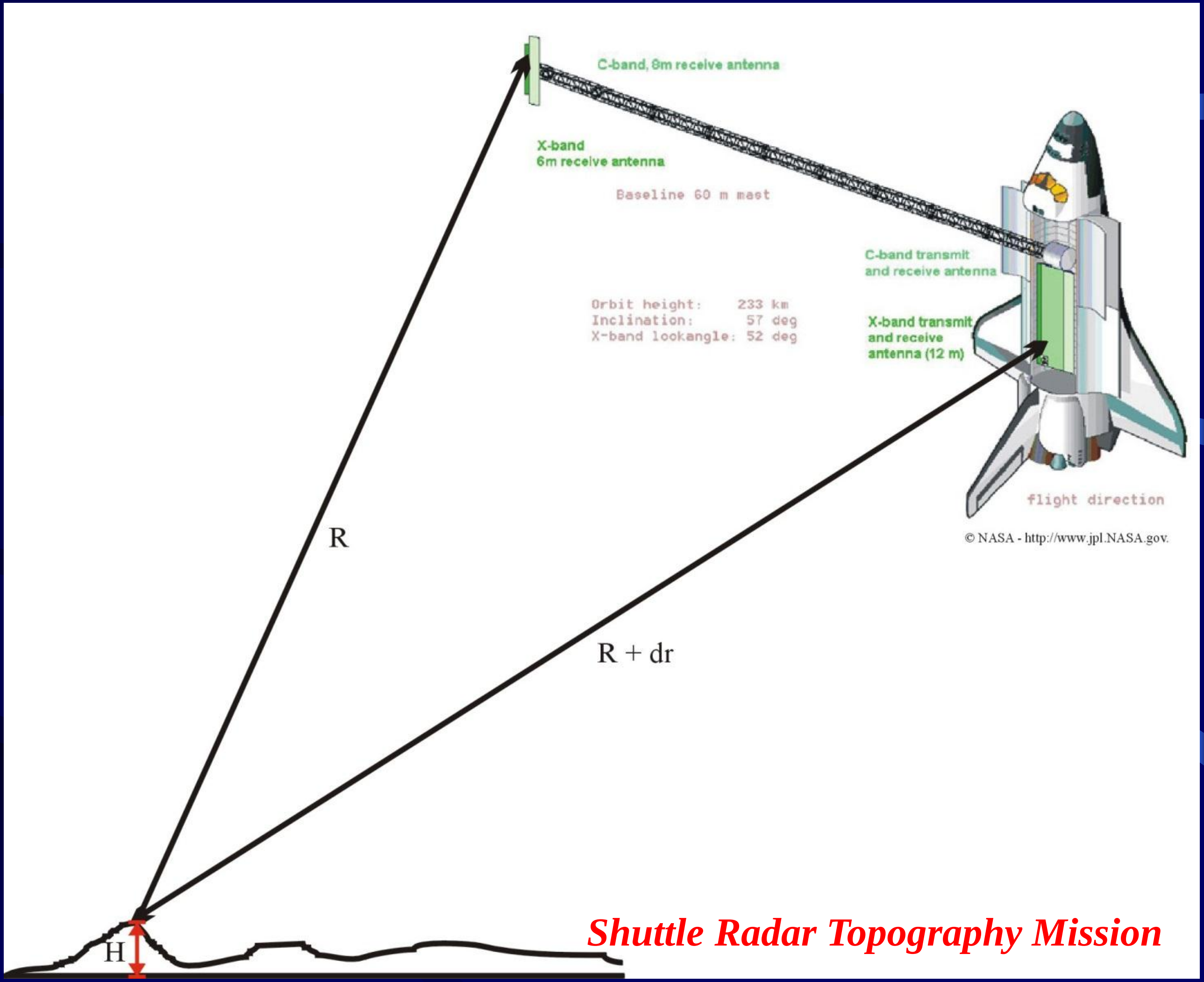


- With single-pass, third dimension can be extracted and the phase difference between the first and second radar imaging instruments give the height value of the point of interest with some mathematical method.

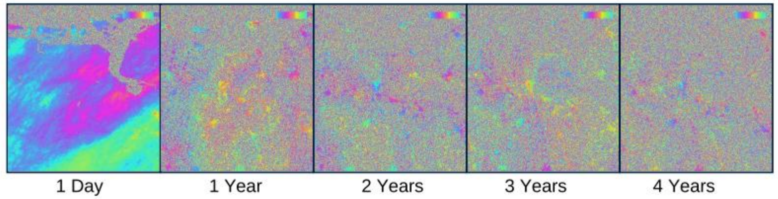


Methods

- **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.



Results of conventional InSAR



Error sources:

- Temporal decorrelation,
- Geometric decorrelation,
- Atmospheric disturbances.

Consider:

- Magnitude of signal of interest,
- Spatial cover versus signal coherence.

Conventional InSAR application is limited in semi-urban/non-urban areas:

- Area sensible to error sources (vegetation changes, atmosphere).
- Subsidence due to gas extraction is low: <1 cm/year.

InSAR; advantages & disadvantages

InSAR -
Interferometric Synthetic Aperture Radar

pros:

Spatial Resolution (4x20m)

Accuracy (mm-cm scale)

Spatial coverage

cons:

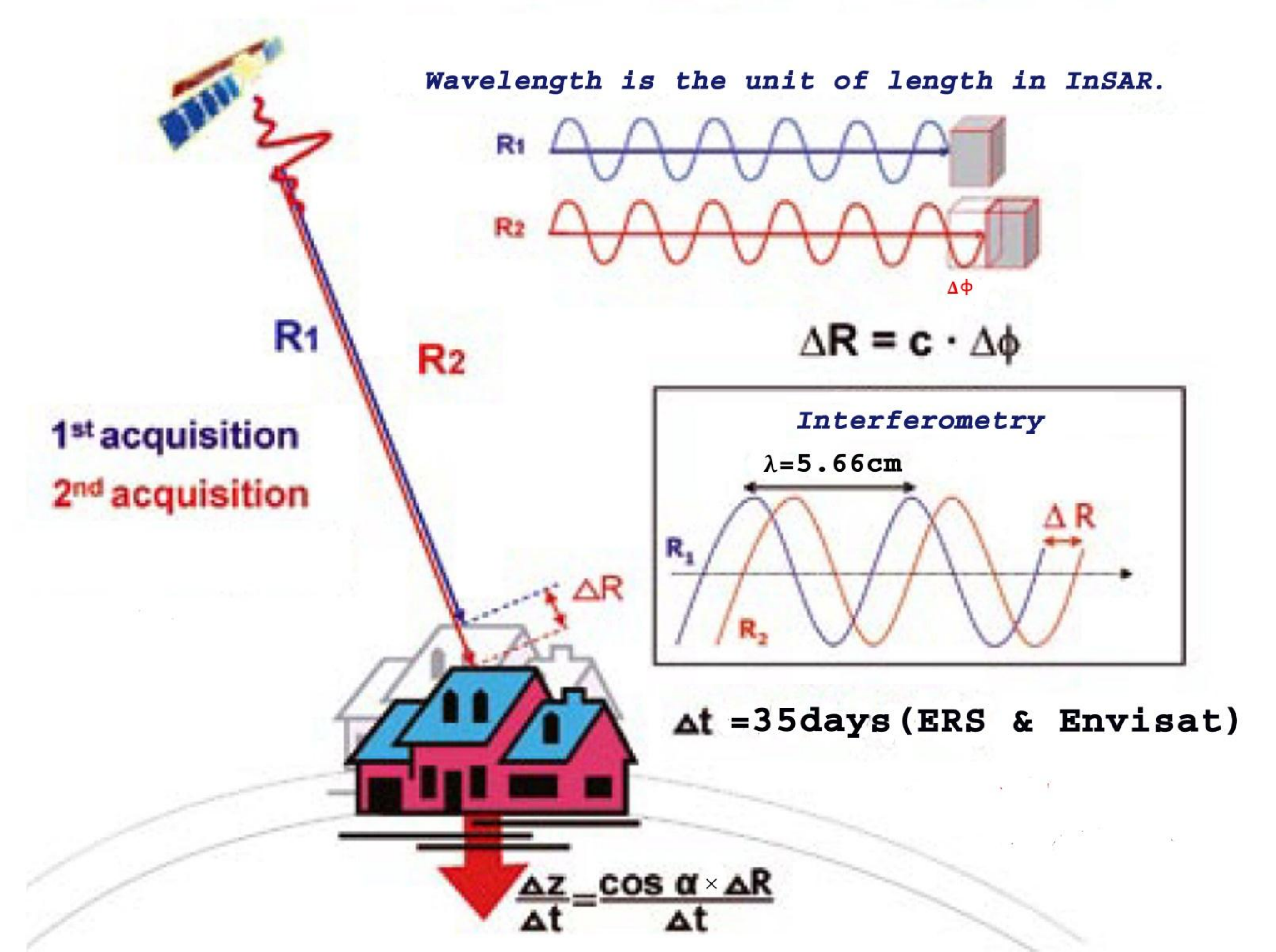
LOS ambiguity (1D measurement)

Decorrelation (slopes, vegetation, unstable ground, large deformation gradients, etc)

Low sensitivity to horizontal displacement parallel to trajectory

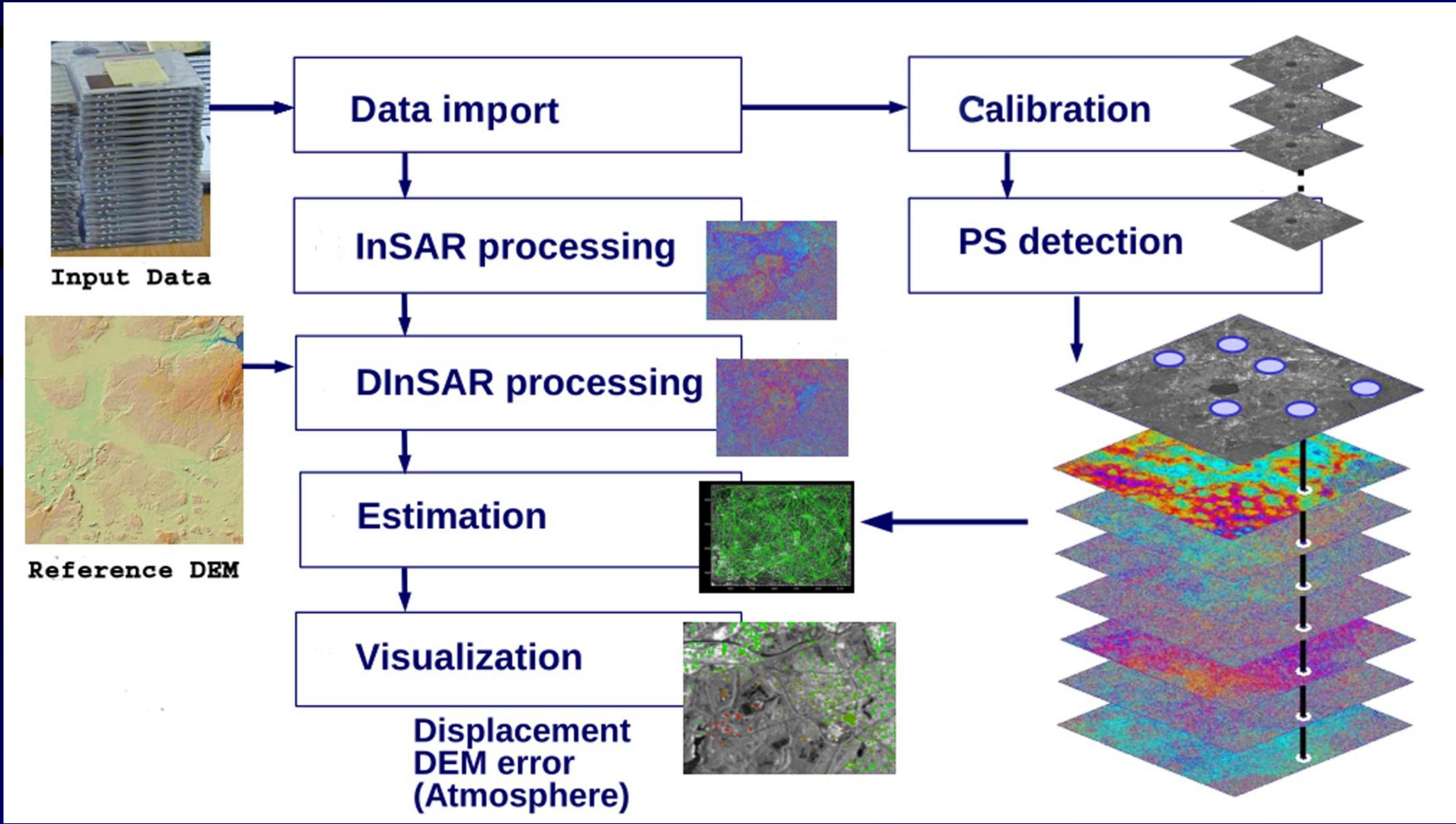
- **Persistent or Permanent Scatterer** techniques are the recent development from conventional InSAR. It relies on studying pixels which remain coherent over a sequence of interferograms.
- It was first emerged in **1999,** when the Polytechnic University of Milan (POLIMI) in Italy, produced and patented its **PSInSAR algorithm**. It was a new multi-image approach in which the stack of images are inspected for objects on the ground providing consistent and stable radar reflections back to the satellite.
- The objects could be the size of a pixel or sub-pixel, and are present in every image in the stack.
- These techniques are collectively referred to as Persistent Scatterer Interferometry or PSI techniques.
- The term Persistent Scatterer Interferometry (PSI) created by ESA to define the second generation of radar interferometry techniques.
- PSI makes measurements of ground movement on naturally occurring permanent scattering points.
- Persistent Scatterers are features such as the roofs of buildings, metallic structures and prominent natural features.
- In urban areas, there can be as many as 600 persistent scatterers per square kilometers.
- Uniquely, this technique provides the motion history (up to 12 years) for each individual persistent scatterer.

Basic principle of PSInSAR



Persistent Scatterer Interferometry (PSI) is a revolutionary new technique for measuring ground displacements to a degree of accuracy and over time periods previously unachievable using conventional interferometry methods.

PSInSAR processing flowchart



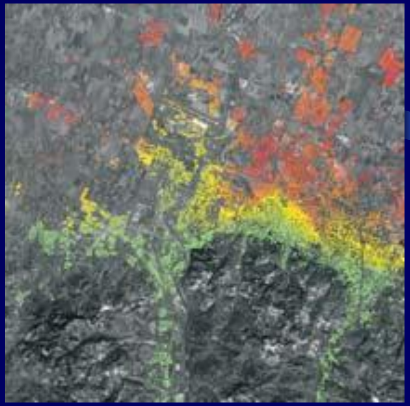
PSInSAR Applications :

•Subsidence or uplift

Whether by natural failure (e.g. karst limestone cavity collapses) or from manmade activities (e.g. extraction of water/gas/oil), the PS Technique provides **monthly updates on displacement patterns**. It is particularly suited to monitoring urban subsidence where conventional methods of survey cannot match the information density, at similar cost.

•Seismic faults and volcanic areas

The ease with which PS data can be updated suits the improvement of **early warning systems** in matters of Civil Protection. TRE's substantial data processing centre can respond quickly in providing urgently needed data in emergency situations.



• Managing land use

The PS Technique facilitates the planning of major capital works such as **pipelines**, **transmission lines**, **highways and railways** by identifying stable corridors for these facilities. Similarly, updates of town planning schemes can benefit from PS data which, in urban areas, have a high density of scatterers.

PSInSAR Applications :

- **Assessing a claim**

An historical archive of radar data can contribute to verifying the **cause-effect connection** between, for example, the **construction of a new tunnel and damage occurring to facilities in the neighbourhood of the excavation area**. PS data have already been used as evidence in lawsuits. Insurance companies are showing interest in the technology as a risk allocation tool.

- **Checking the stability of buildings**

While PS data cannot substitute for site surveys, they are nevertheless becoming a powerful monitoring tool for large urban areas, where a regular check of all of the buildings would not be feasible. PS data can be used in the **design of mitigative measures to offset the effects of a potential geohazard**.

- **Slow landslides and instability phenomena**

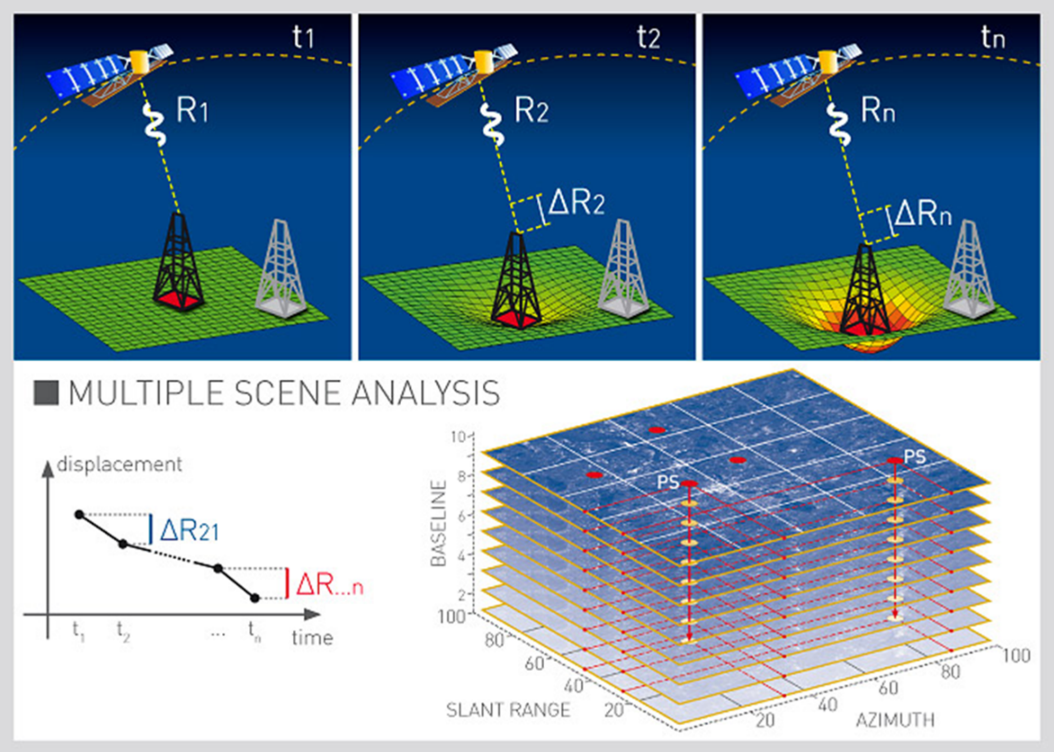
The PS Technique identifies the **extent of unstable land and the corresponding rate of movement**, when slow movements occur. The integration of PS data within a GIS and regular updating of PS data have significantly increased the potential of radar remote sensing for **landslide investigations**.

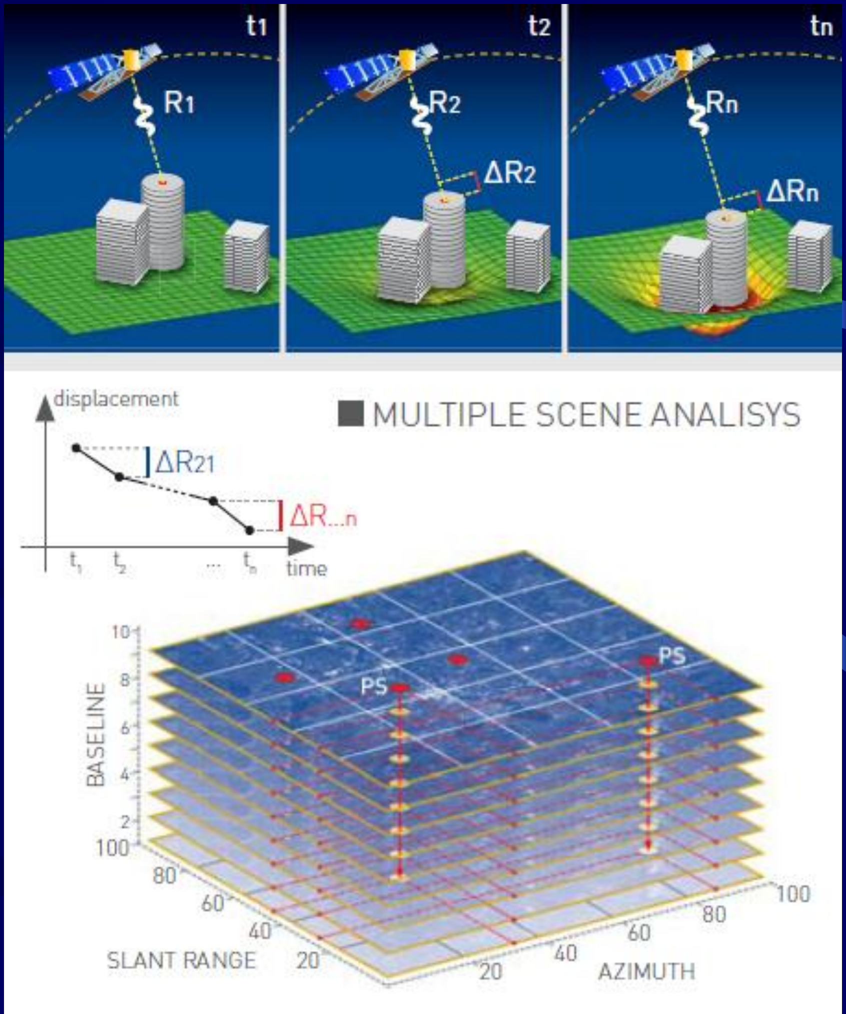
PSInSAR Applications examples:

- **Surface deformation measurement**
- **Slope instability**
- **Landslide inventory**
- **Flood protection**
- **Oil field monitoring**
- **CO_2 Sequestration**
- **Seismic faults**

PSInSAR Applications :

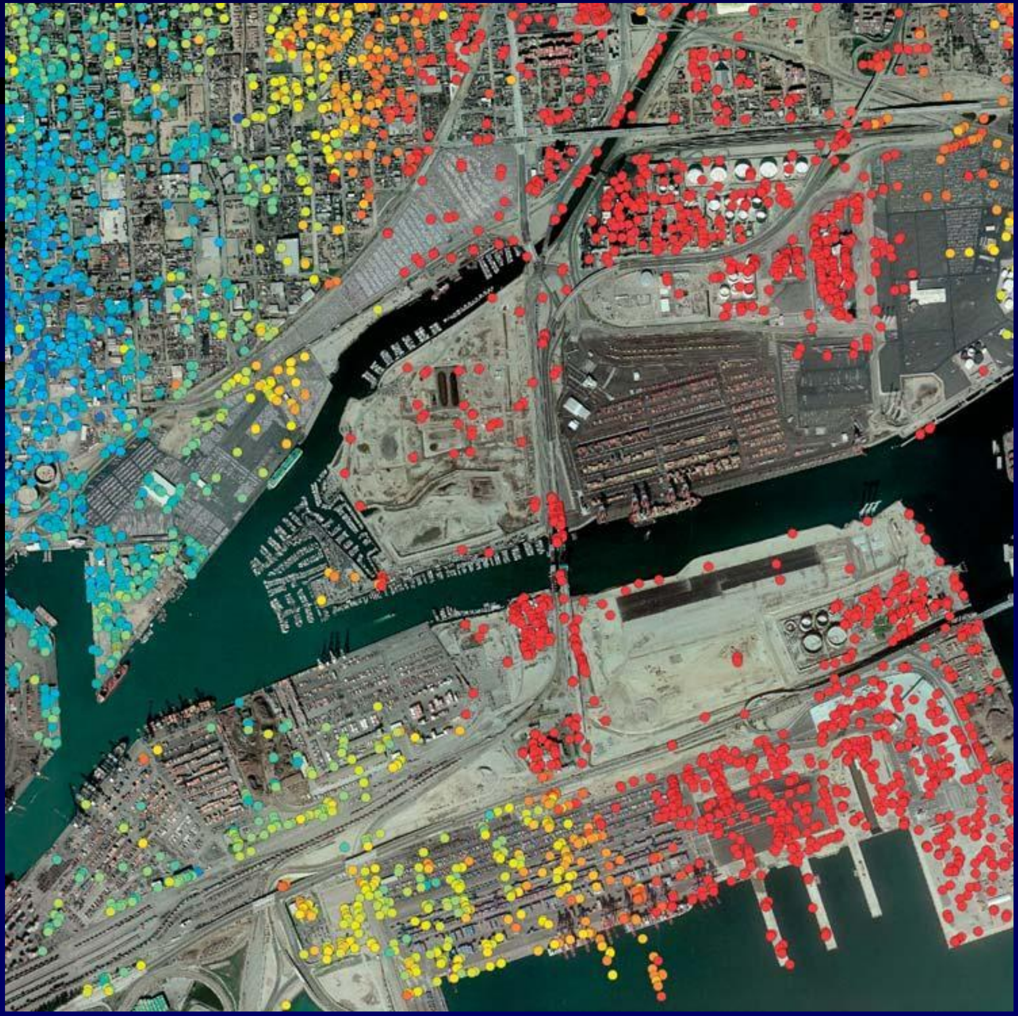
Surface deformation measurement

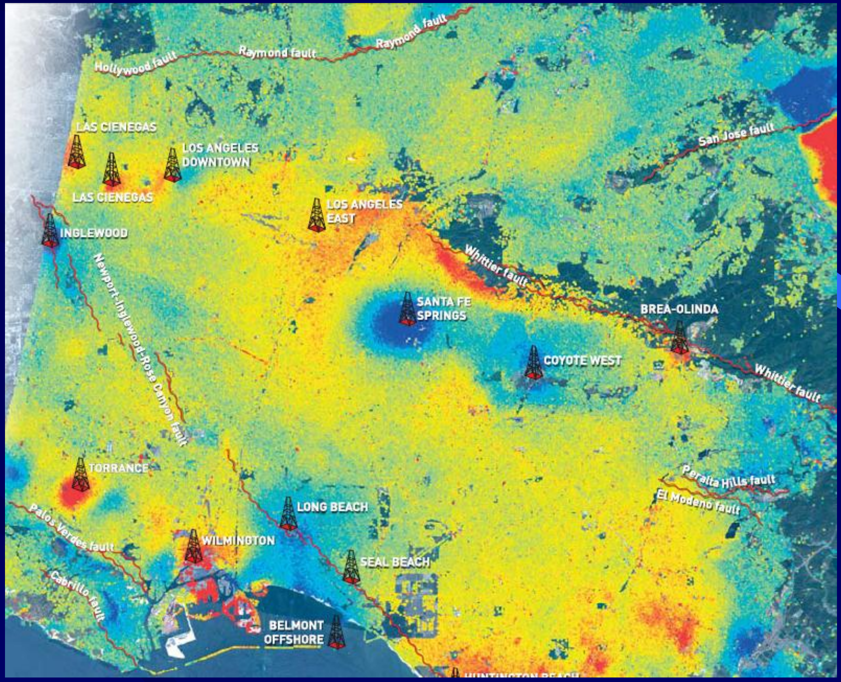




PSInSAR Applications :

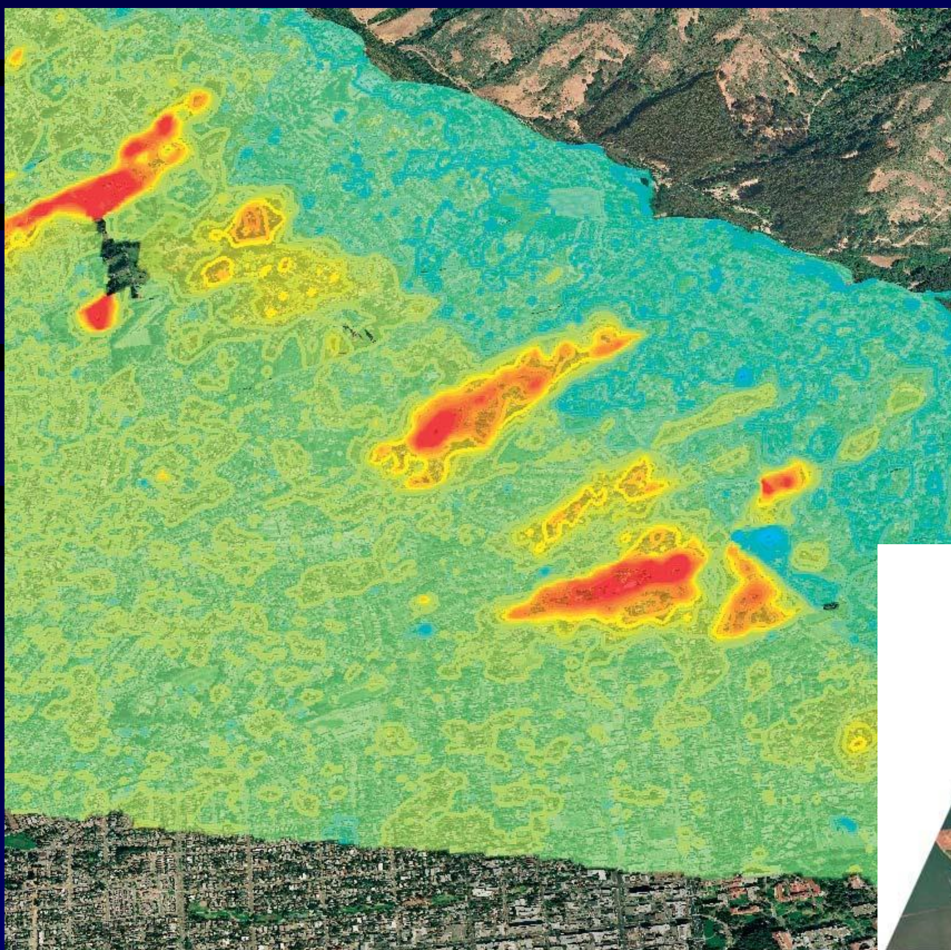
Surface Deformation Fields, Los Angeles Basin

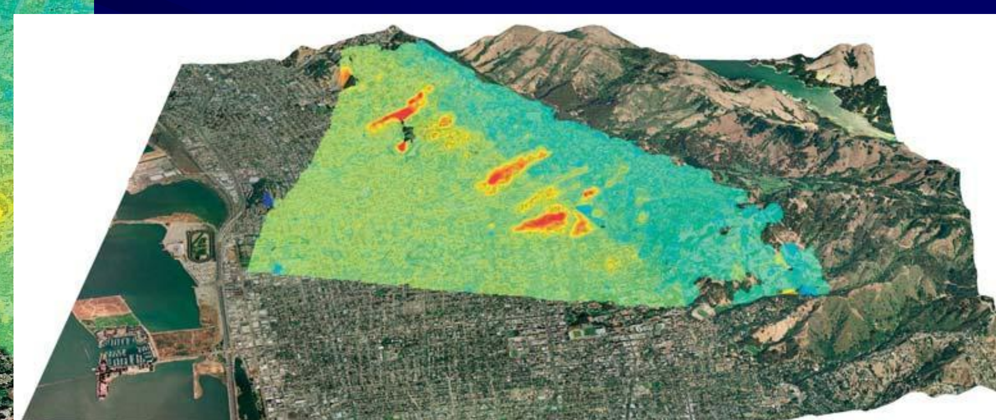




PSInSAR Applications :

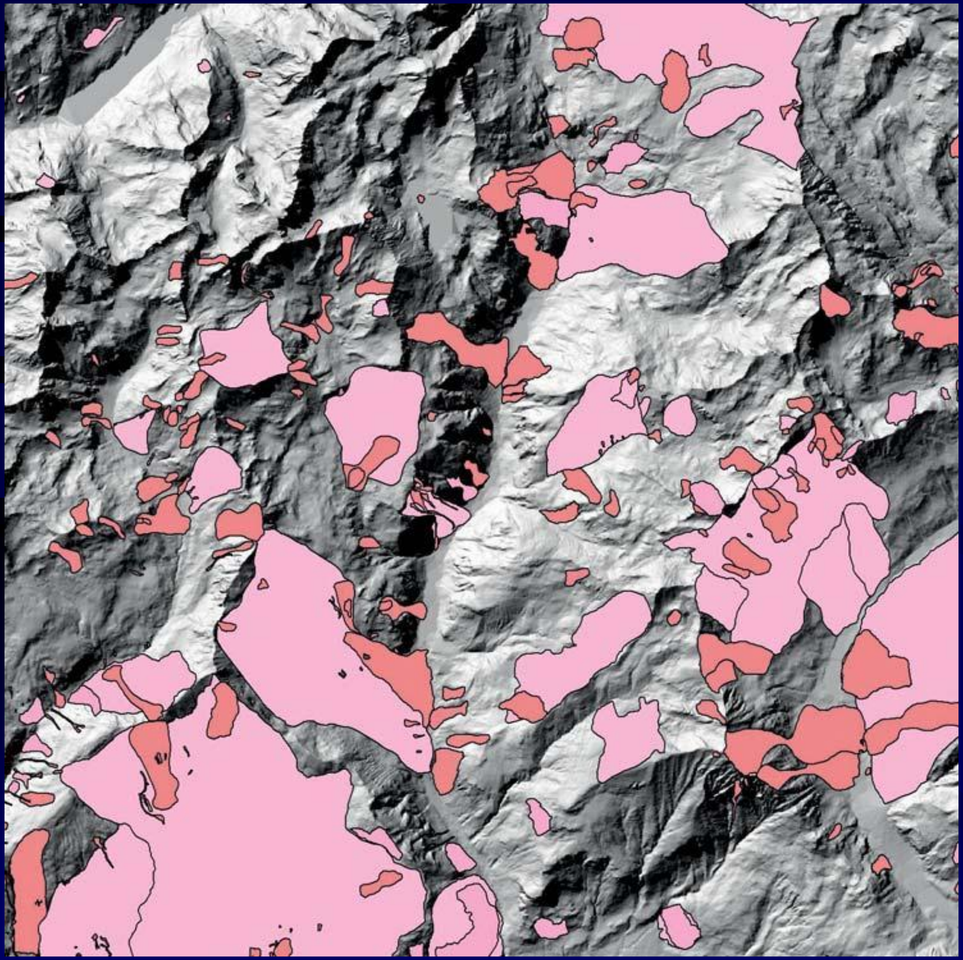
Slope instability, Berkley

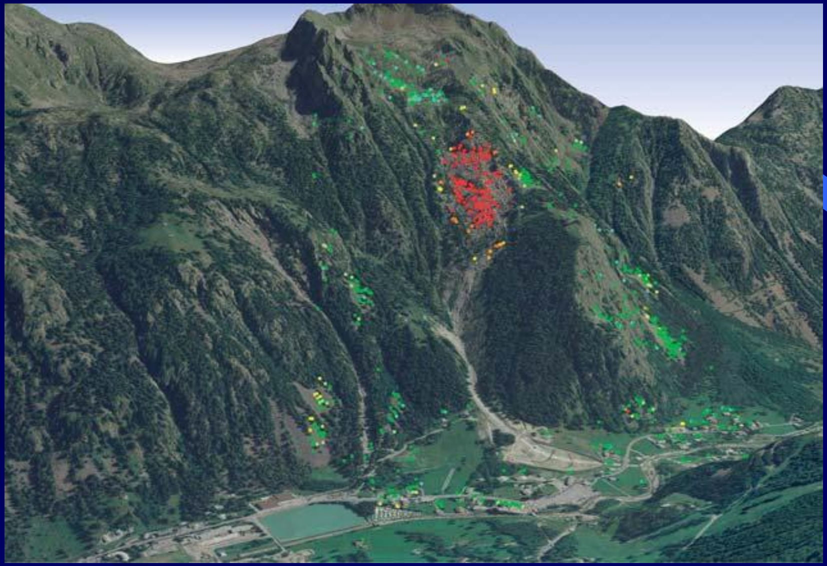




PSInSAR Applications :

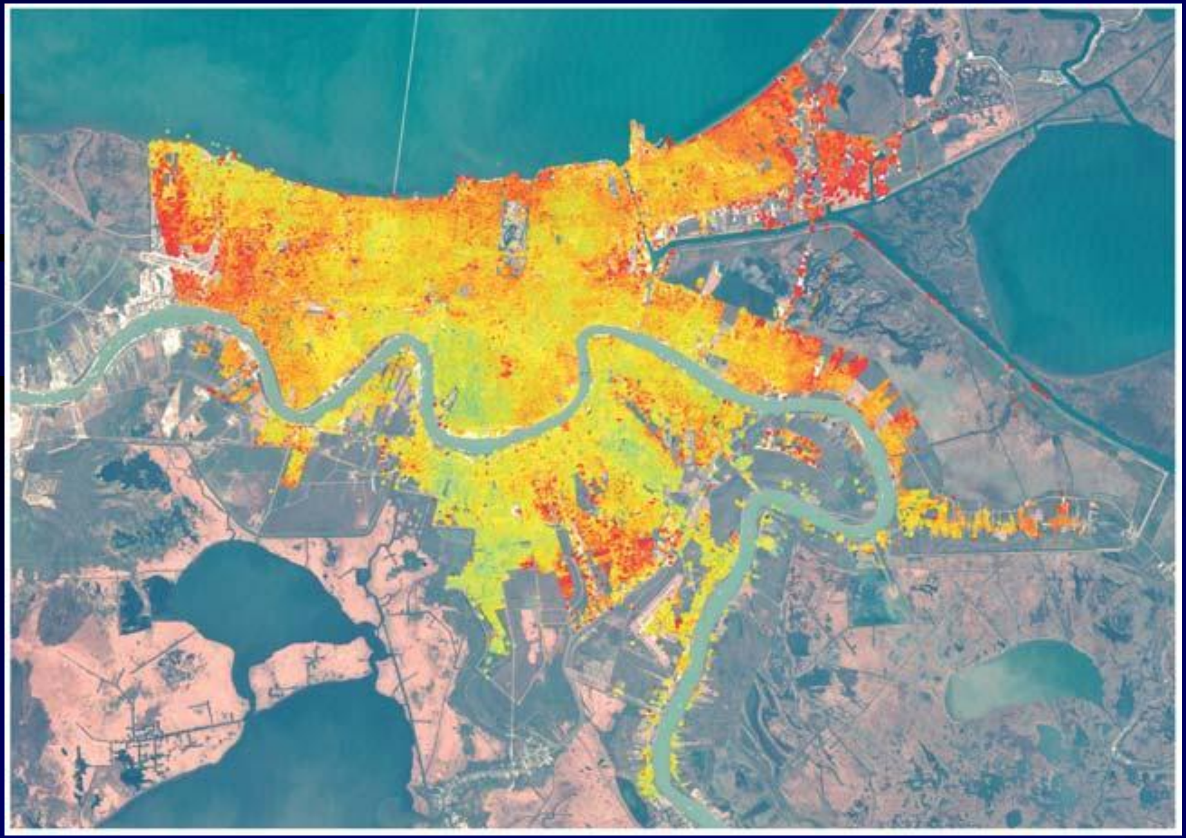
Landslide inventory, The Italian Alps

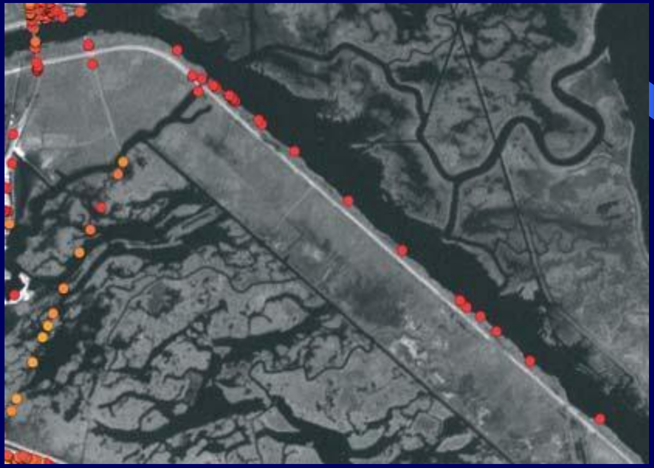




PSInSAR Applications :

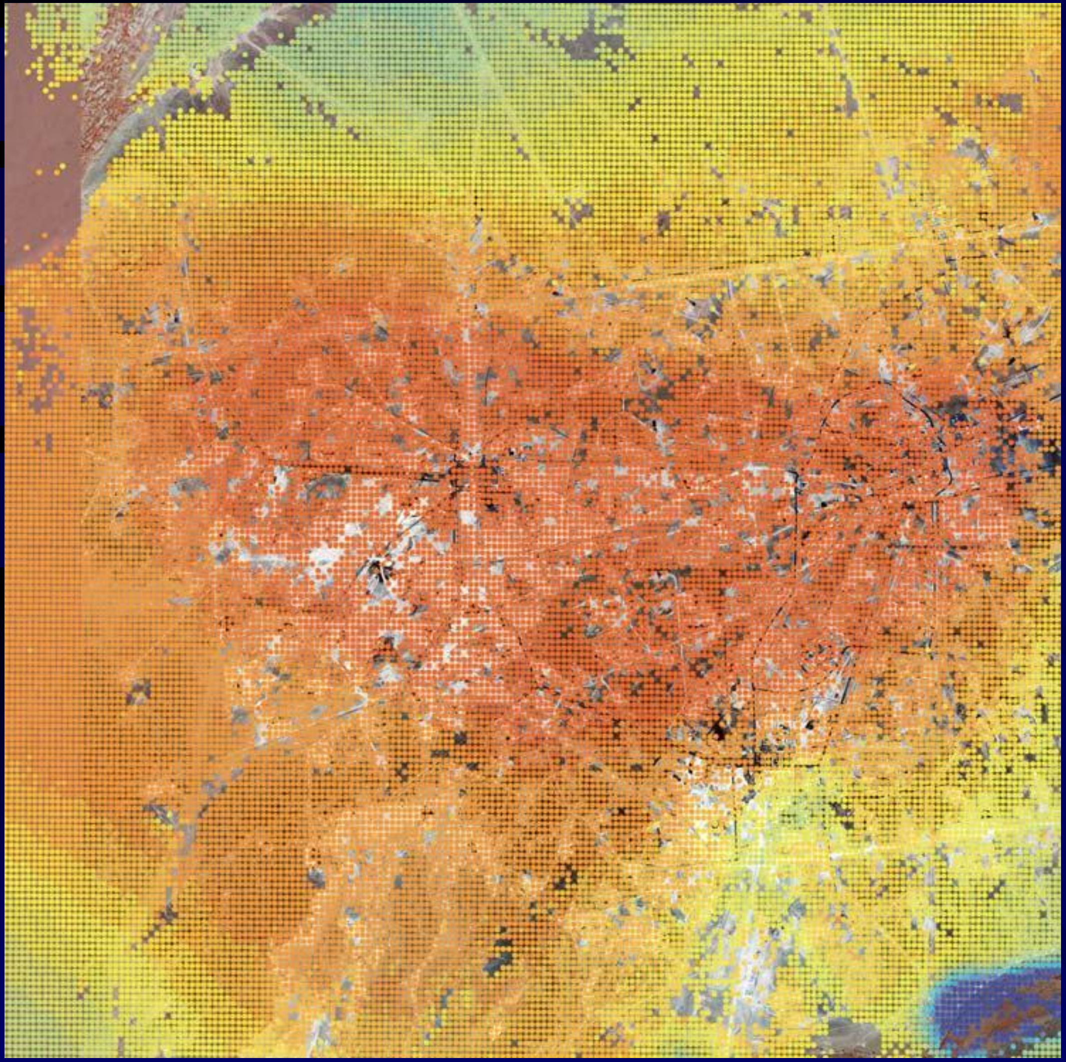
Flood protection, New Orleans

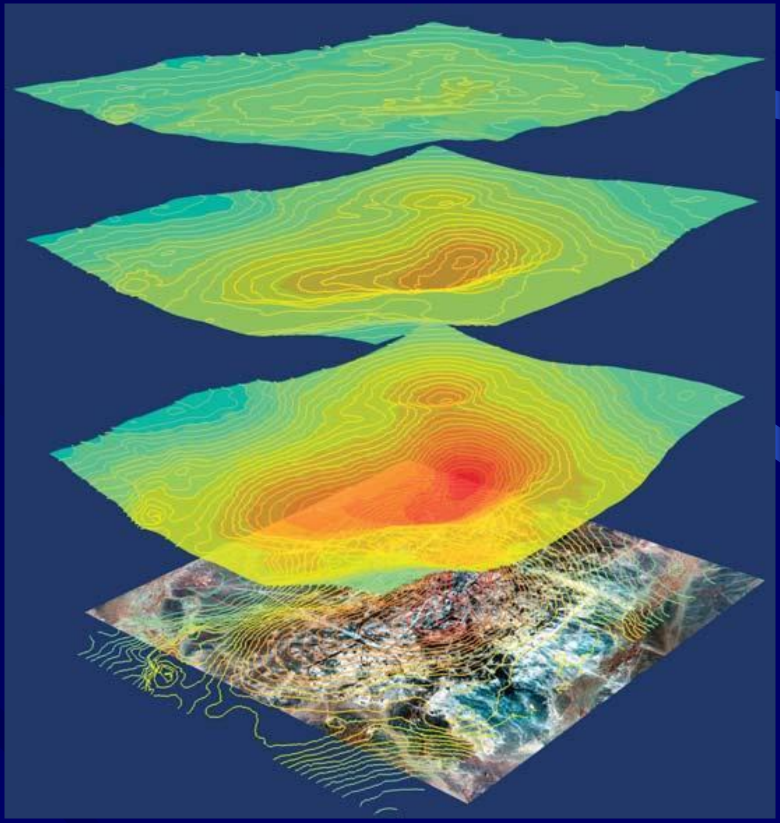




PSInSAR Applications :

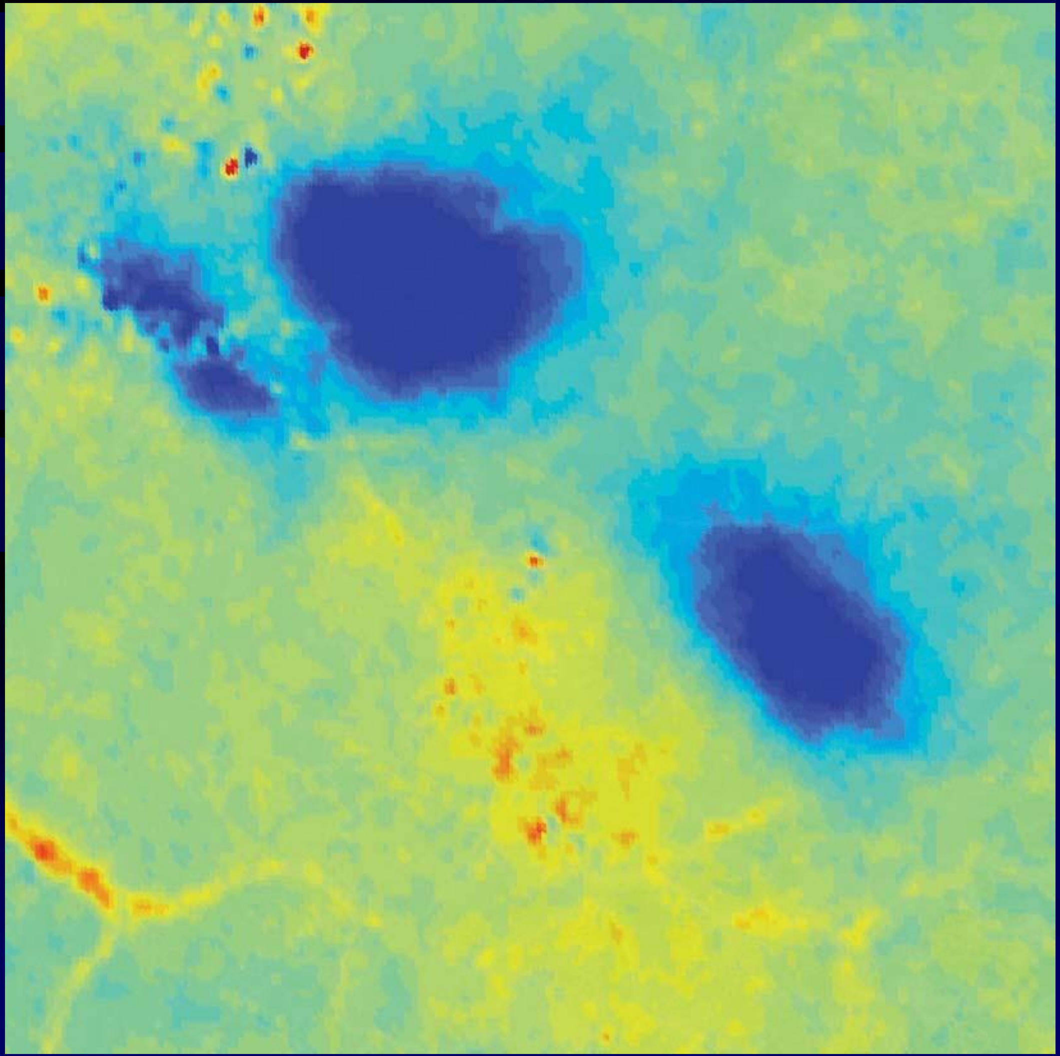
Oil field monitoring, Middle East

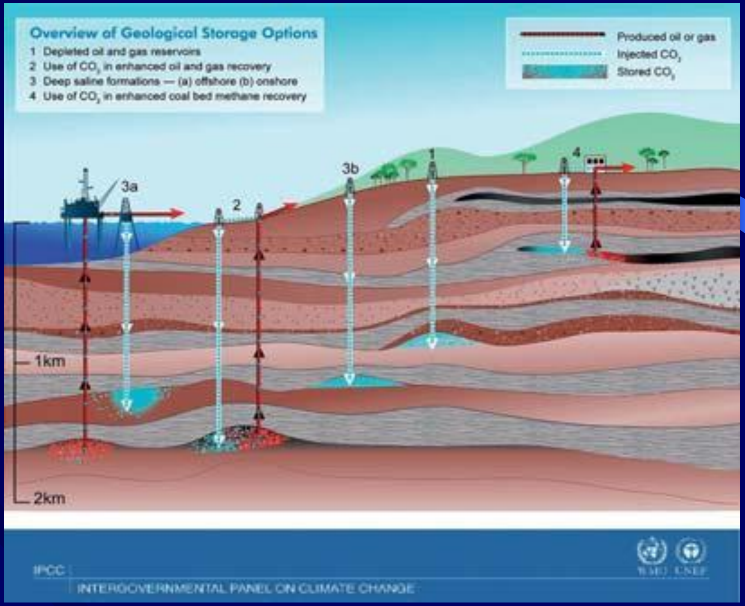




PSInSAR Applications :

Co2 Sequestration, North Africa





PSInSAR Applications :

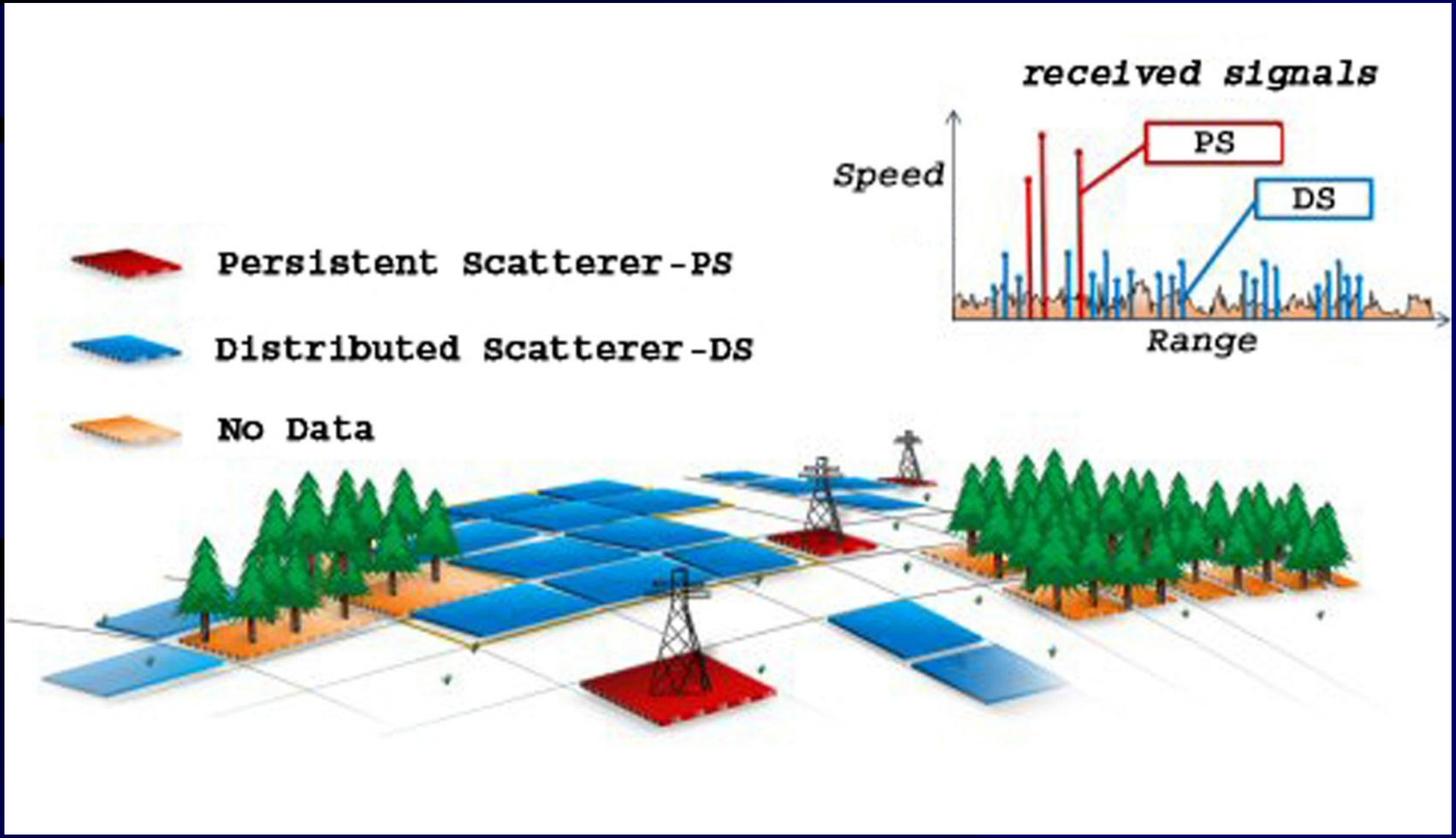
Seismic faults, San Francisco Bay Area

Advantages and limitations of PSInSAR

Advantages	Limitations
Regular and financially acceptable measurements of larger areas	Vegetated areas disable the use of PSInSAR
High density of PS (up to 1.000 PS/km^2)	Inapplicability on continous surfaces
Fast data processing / little need for inclusion of end user	Time measurements are limited with the satellites' orbiting intervals
High accuracy	Detection of slow deformations (< 10 cm/year in the LOS direction)
Simple export into GIS	

(Ferretti & Crespa, 2006)

SqueeSAR
the next step in development of **InSAR**
following **PSInSAR**



SqueeSAR Method

- **Ten years after PSInSAR, in 2009 TRE *(Tele-Rilevemento Europa)* has developed a new algorithm, namely SqueeSAR.**
- **Beyond PS, distributed scatterers also exist.**
- **They can be used for monitoring ground movement.**
- **Distributed scatterers or DS consist of an extensive area where the back-scattered energy is less strong, but statistically homogeneous within the area.**
- **SqueeSAR algorithm, allows detecting the movement of areas dominated by DS, with the same accuracy as analysis with PS.**
- **DS typically correspond to debris areas, non-cultivated lands and desert areas.**
- **PSInSAR processing chain is maintained and used within the SqueeSAR algorithm**
- **The result is an enhancement of the information output capacity, meaning PS plus DS, to gain an enhanced insight into ground deformation and associated surface movements.**

SqueeSAR algorithm in summary:

- Ground points identified: PS and DS
- High density of ground measurement points identified in urban areas (PS)
- High density of ground measurement points identified in non-urban areas (PS and DS)
- Time series provided for each ground point (PS and DS)
- Millimetre accuracy on ground displacement values
- Time series standard deviation reduces – i.e. coherence increases and noise decreases
- Increased confidence on ground behaviour due to increased coverage of points – especially significant for landslides, outcrops and generic areas with low reflectivity

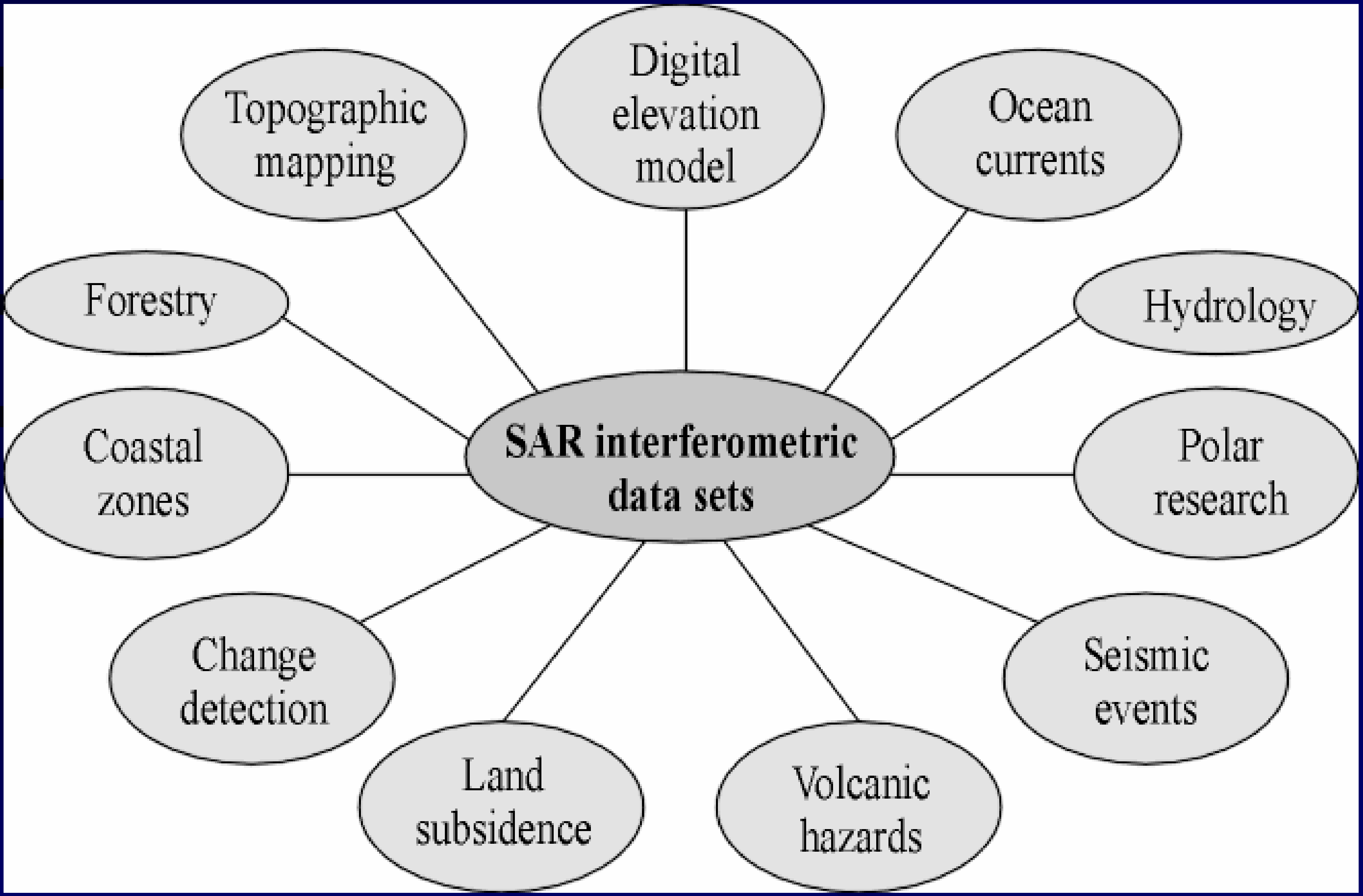
SqueeSAR Applications:

Areas subject to slow landslides or slope instability
Monitoring E&P activities
Areas subject to subsidence and uplift
Monitoring of major capital works
Seismic faults and volcanic areas
Checking the stability of buildings

SAR applications

- Reconnaissance, surveillance, and targeting
- Treaty verification and nonproliferation
- Navigation and guidance - Sandia National Lab. 4-inch SAR
- Foliage and ground penetration
- Moving target detection
- target detection and recognition
- Oceanography – Ocean wave, ocean currents, wind, circulation, bathymetry
- Hydrology – Wetland assessment,
- Glaciology – Glacier motion, polar research
- Seismology – Co-seismic displacement field
- Volcanology – Prediction of volcano eruption
- Subsidence and uplift studies
- Change detection
- coastal zones
- Forestry – Forest classification, deforest monitoring
- Cartography – DEM, DTM, topographic mapping
- Geology – Geological Mapping, tectonic applications
- Soil Science – Soil moisture
- Agriculture – Crop monitoring
- Environment – Oil spill, hazard monitoring
- Archaeology – Sub-surface mapping

Civil Interferometric applications

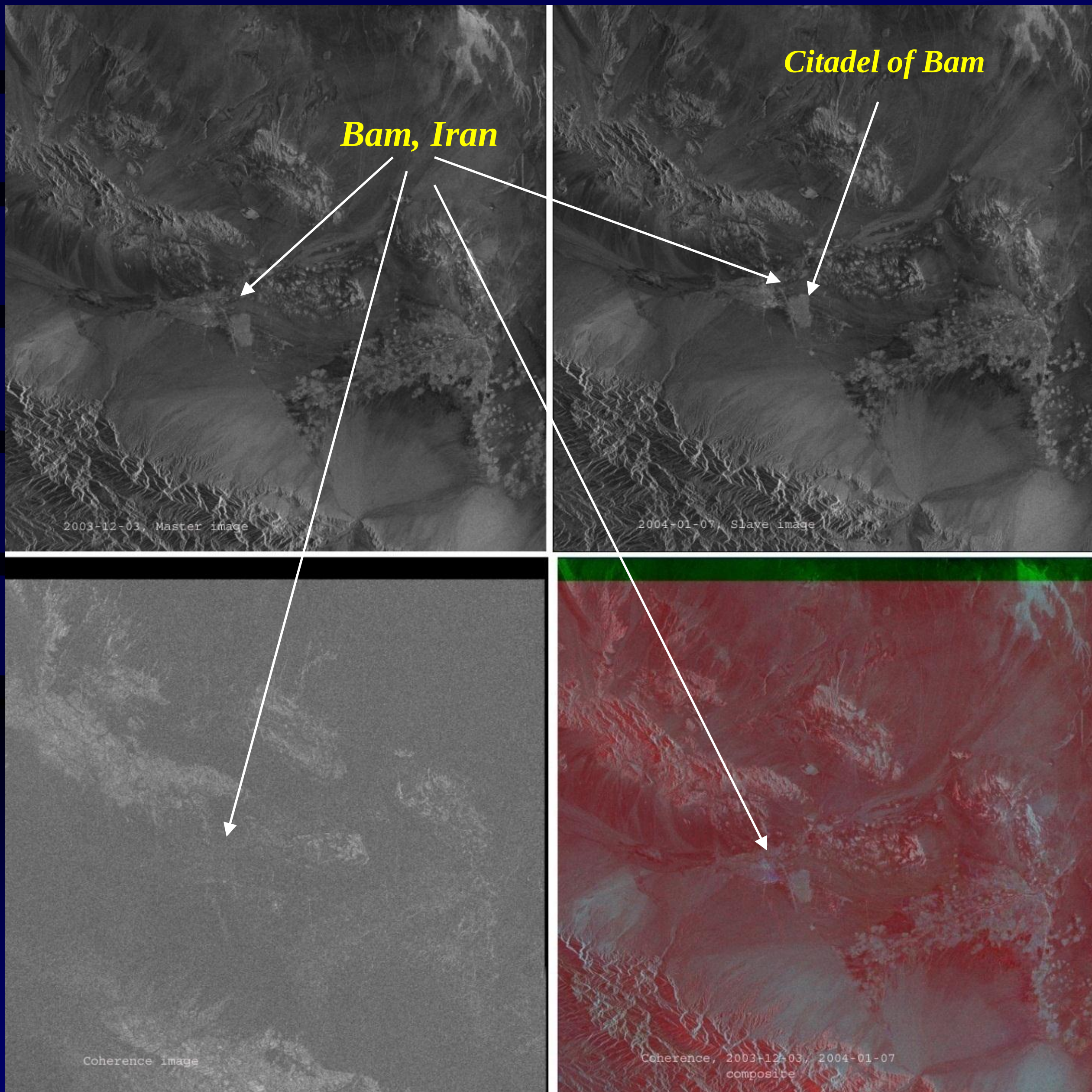


Examples of our practical studies and achievements

In course of the years of studies and verifications by our Microwave Remote Sensing Group good and valuable achievements gained on InSAR technology applications. Here the experience gained on this new satellite technology in course of the continuous research work since 1994 in the Iranian Remote Sensing Center and the Iranian Space Agency is given.

Bam Quake, 26th December 2003…magnitude: 6.6 Richter

Bam Quake, 26th December 2003



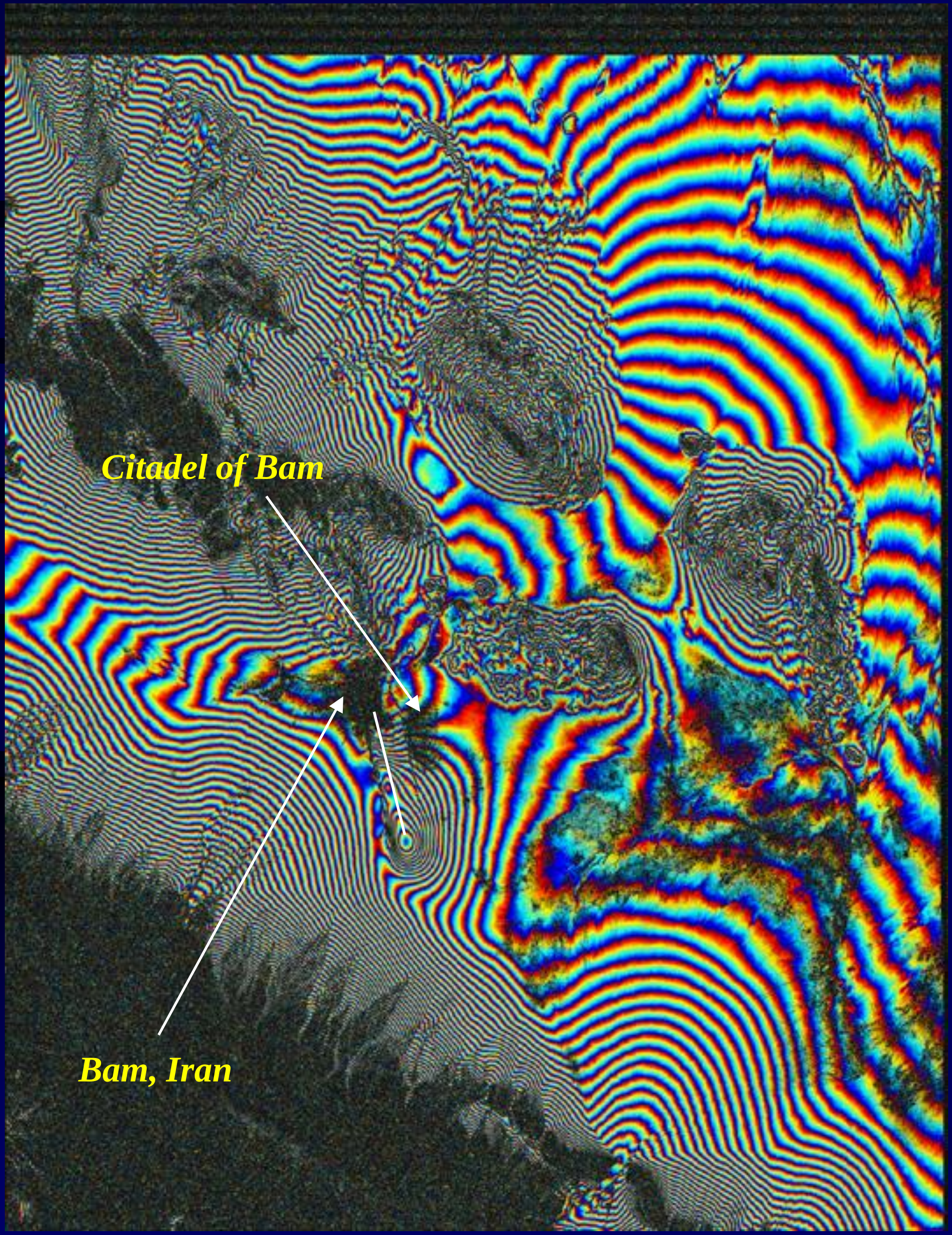
Baseline components:

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)

Bam Quake, 26th December 2003

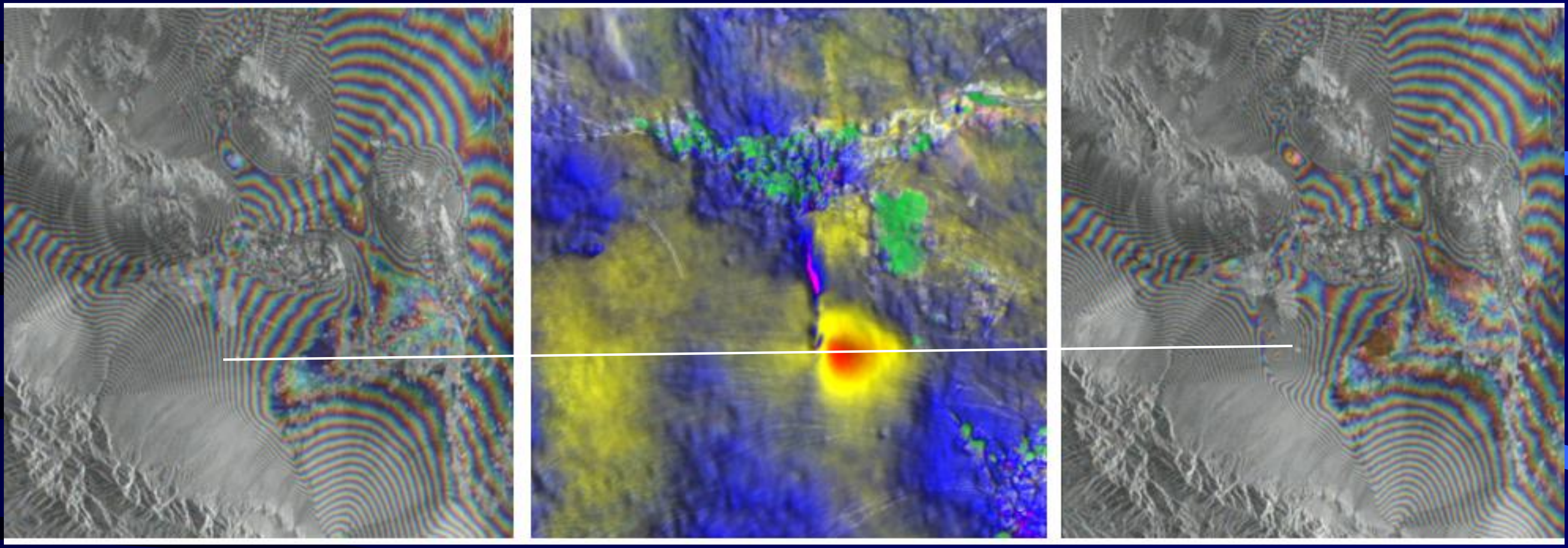


Coherence-DInSAR composite of the image pairs of
3 Dec. 2003 and 7 Jan. 2004

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)

Bam Quake, 26th December 2003



Left image: topo-DInSAR product of Envisat-ASAR data of 11 Jun and 3 Dec 2003 (nbsl. 476.9m, pbsl. 141.6m)

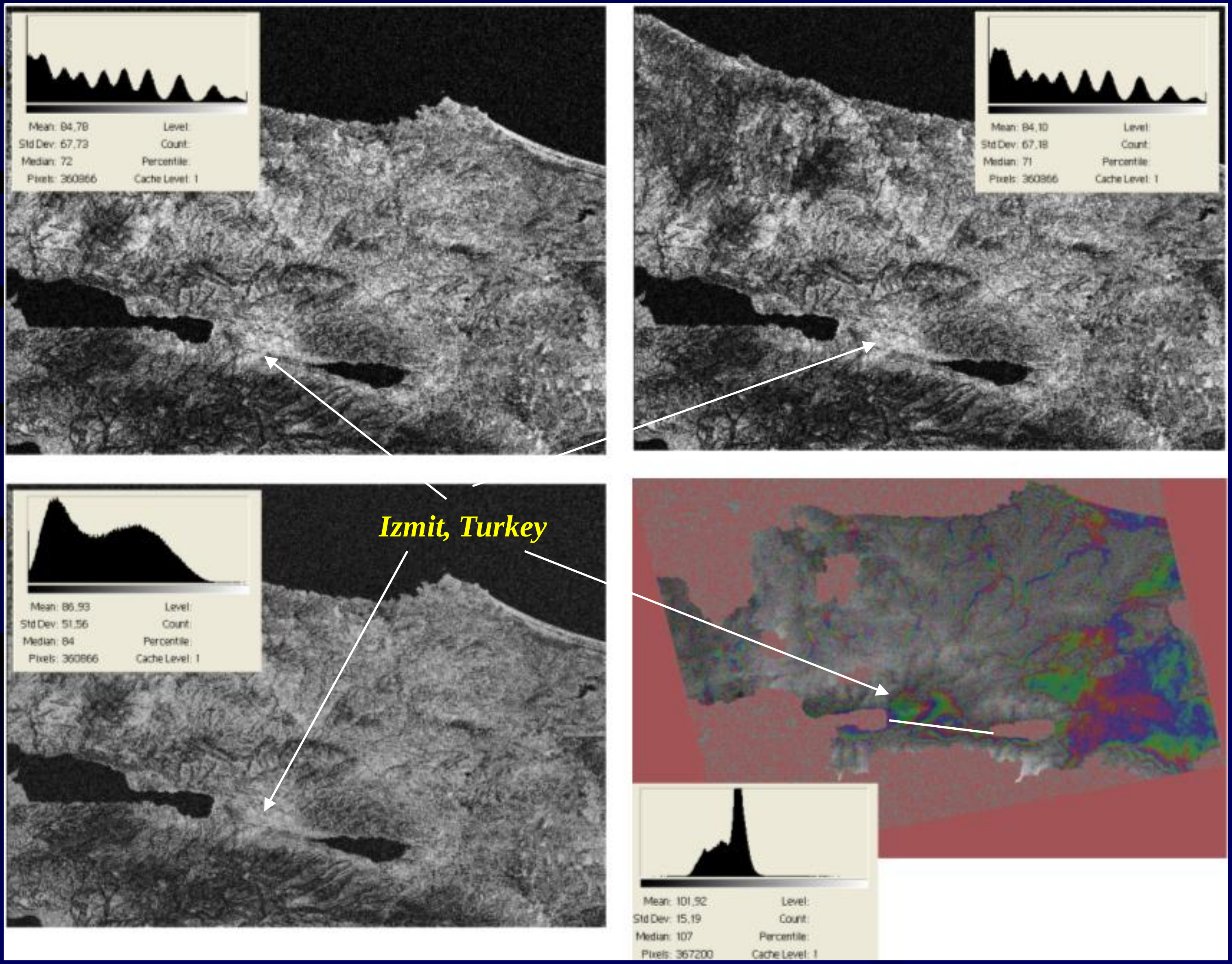
Right image: topo-DInSAR product of the 3 Dec 2003 and 7 Jan 2004 (nbsl. 521.9 m, pbsl. 268.3 m).

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

Turkey, Izmit quake of August 17, 1999...M:7.4

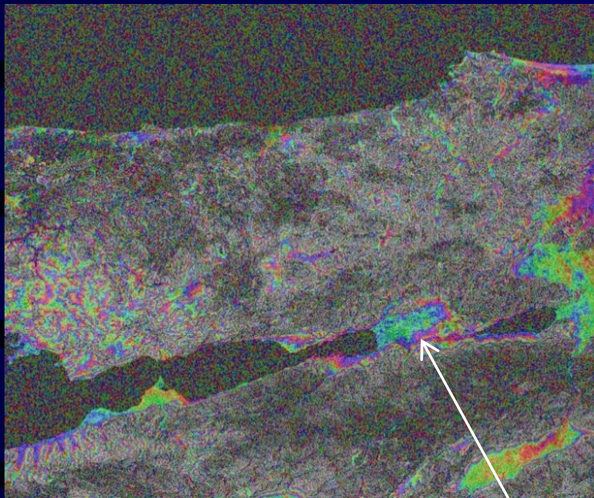


phase image overlaid on height image (DEM)

- **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)

InSAR applications

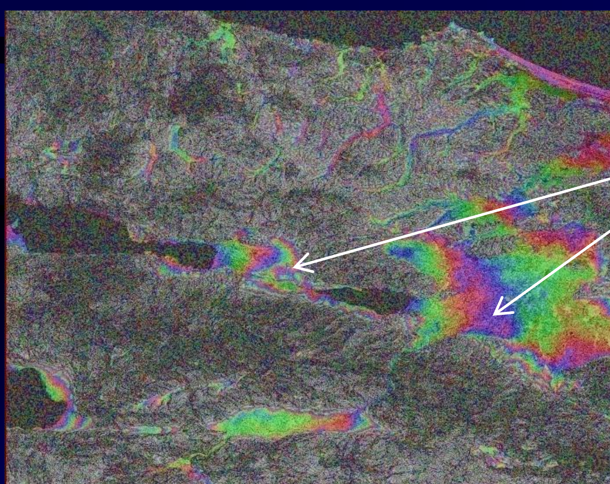
Comparison of the image pairs of before and after quake (Izmit area)



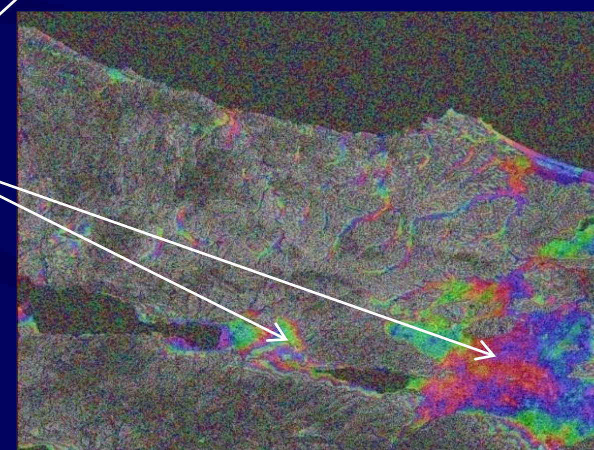
Tandem images of: 10 and 11 Sept. 1999
(23 and 24 days after quake)
normal baseline: 183.313m
parallel baseline: 73.239m

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

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



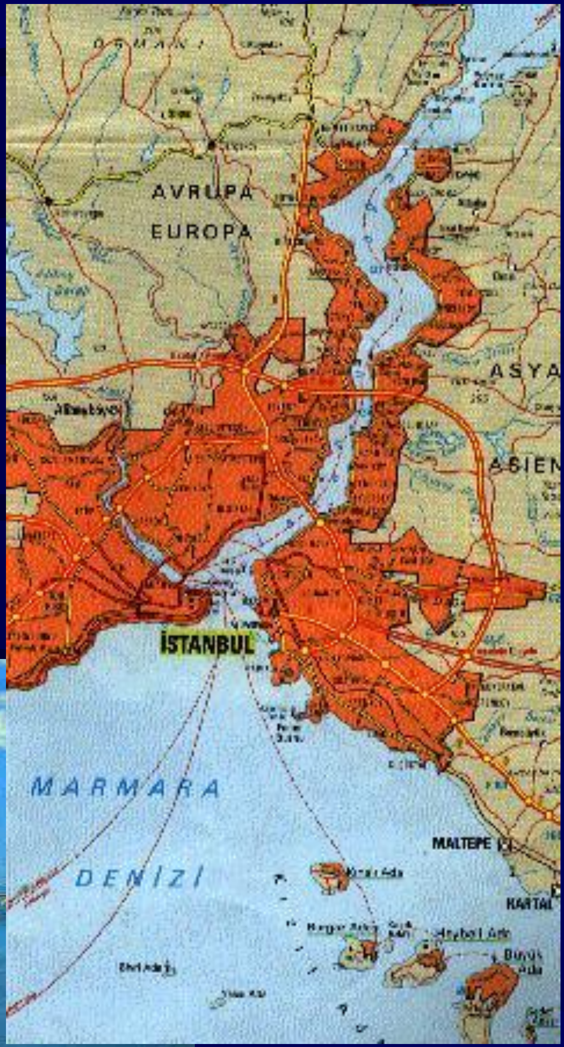
Tandem images of: 16 and 17 Sept. 1999 (1 month after quake)
normal baseline: 234.443m
parallel baseline: 103.386m

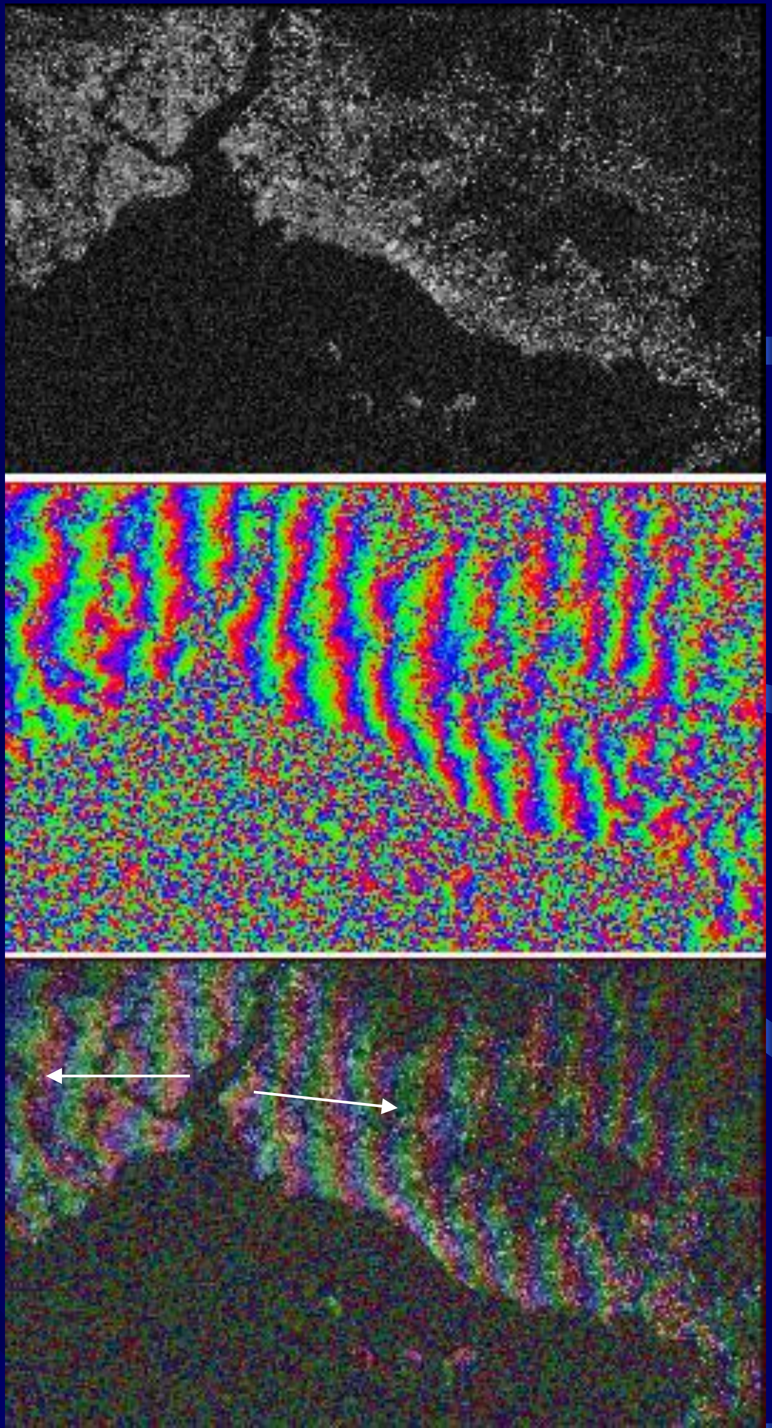


Tandem images of: 12 and 13 Aug. 1999 (4 and 5 days before quake)
normal baseline: 224.190m
parallel baseline: 91.097m

New Technologies in monitoring and management of calamities and dynamic changes

Bosporus Strait

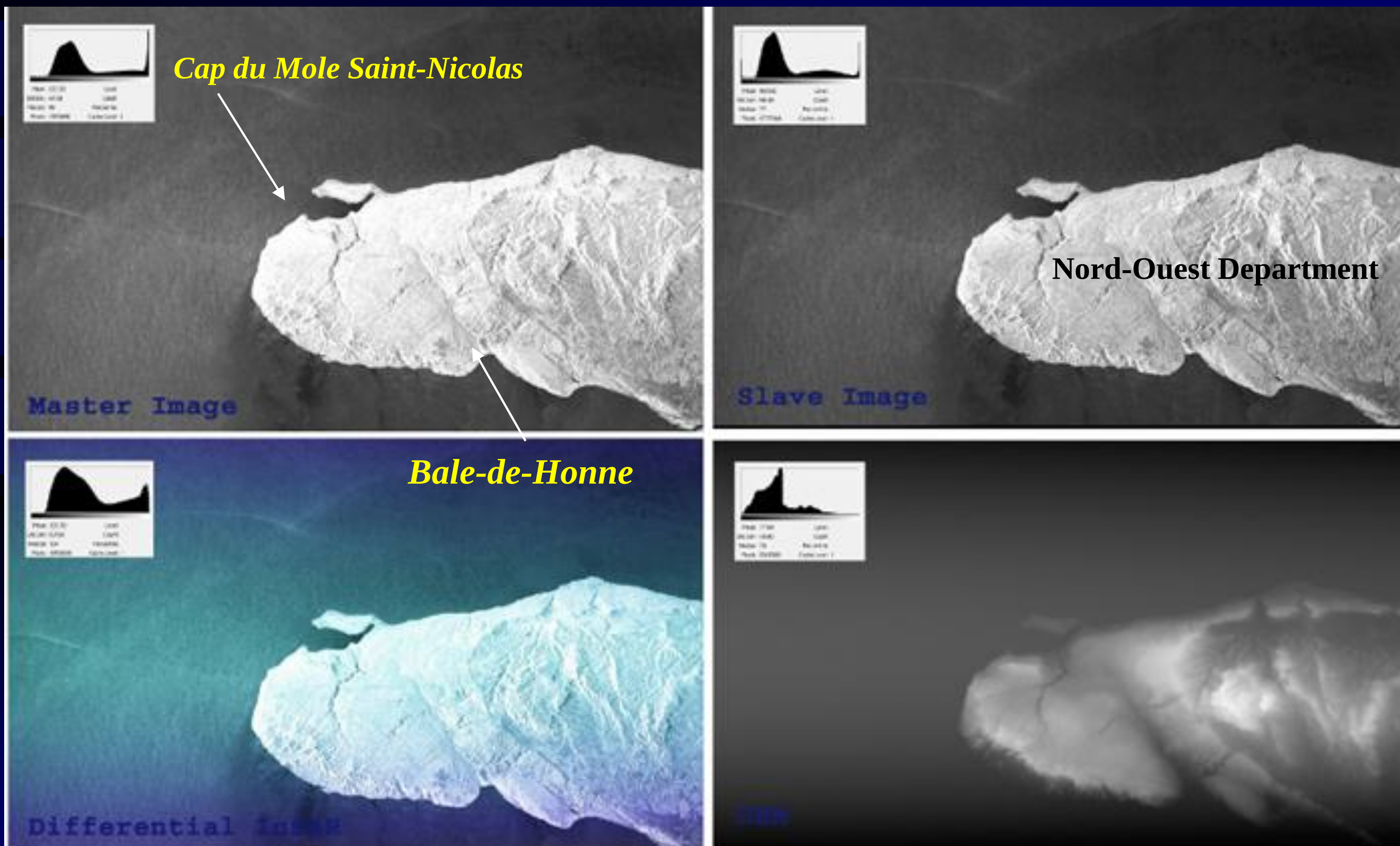




Quake of August 17, 1999
Magnitude: 7.4
combination of the images of 24 December 1998 (ERS-2) and 25 August 1999 (ERS-1)

***30.8 cm* displacement in the right side and *14 cm* displacement in the left side**

Haiti earthquake, January 12, 2010/ magnitude 7.0/ data: 47 SLCIs of the C-band ASAR
DEM of Nord-Ouest Department (North-West Province)
The cities of Cap du Mole Saint-Nicolas and Bale-de-Honne are seen.
Combined Envisat ASAR images of 4 March 2010 with 8 seconds of time delay virtual baseline of 13.23m while the parallel baseline amounts only 2.1cm



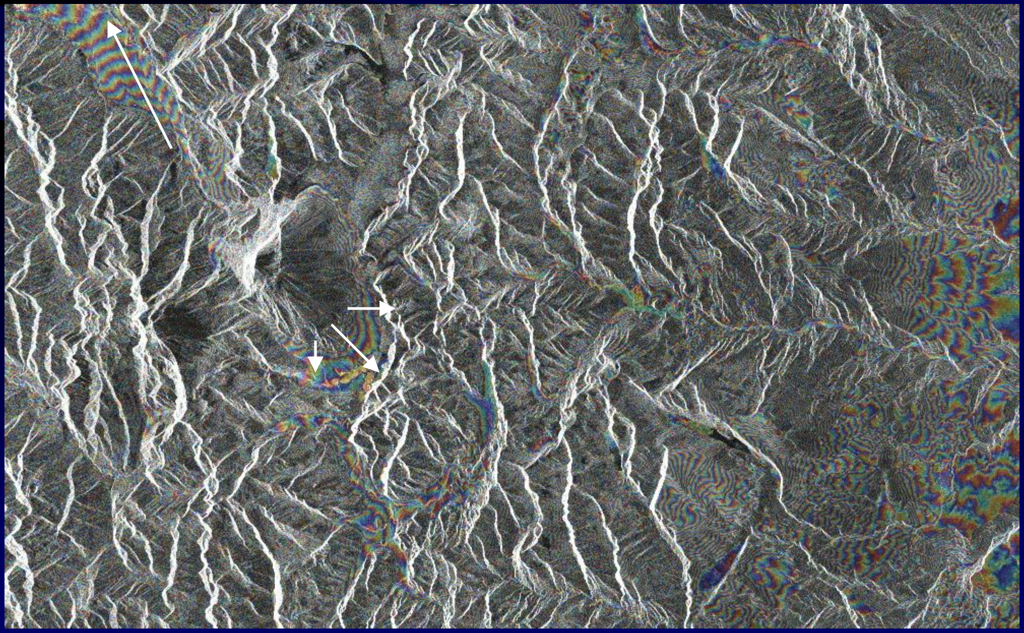
Chile earthquake of February 27, 2010

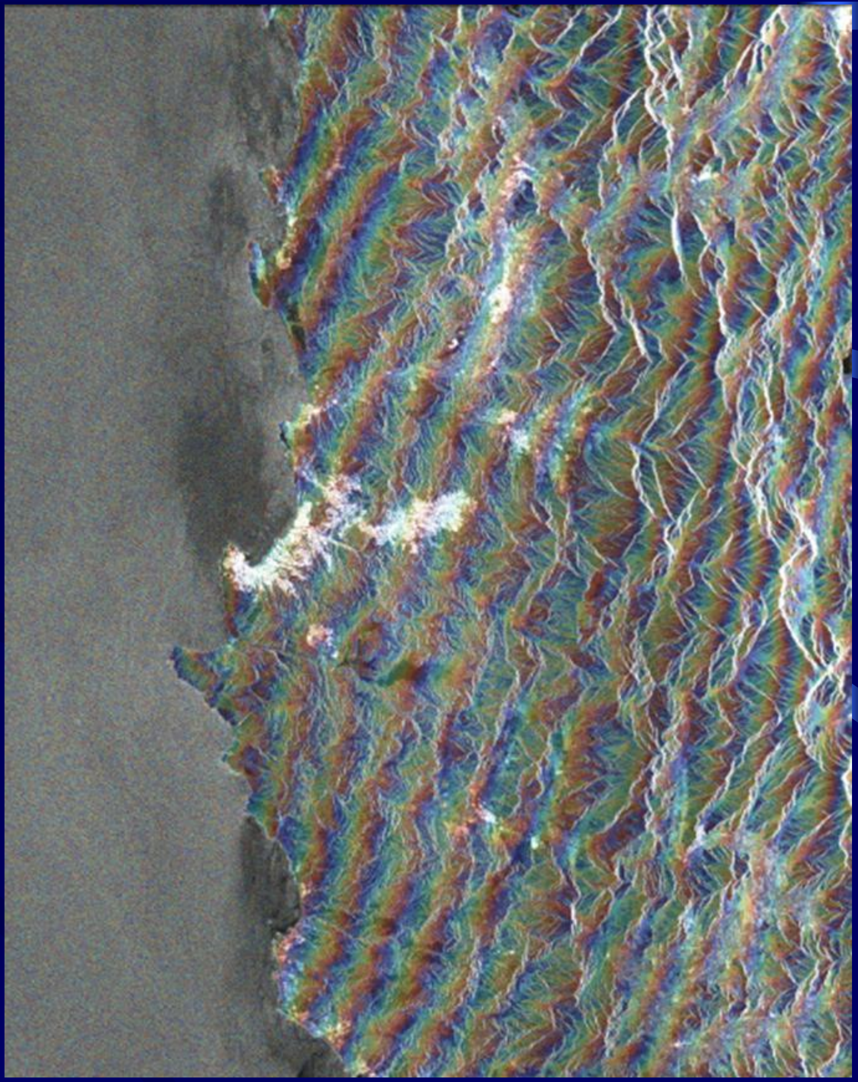
magnitude: 8.8 Richter

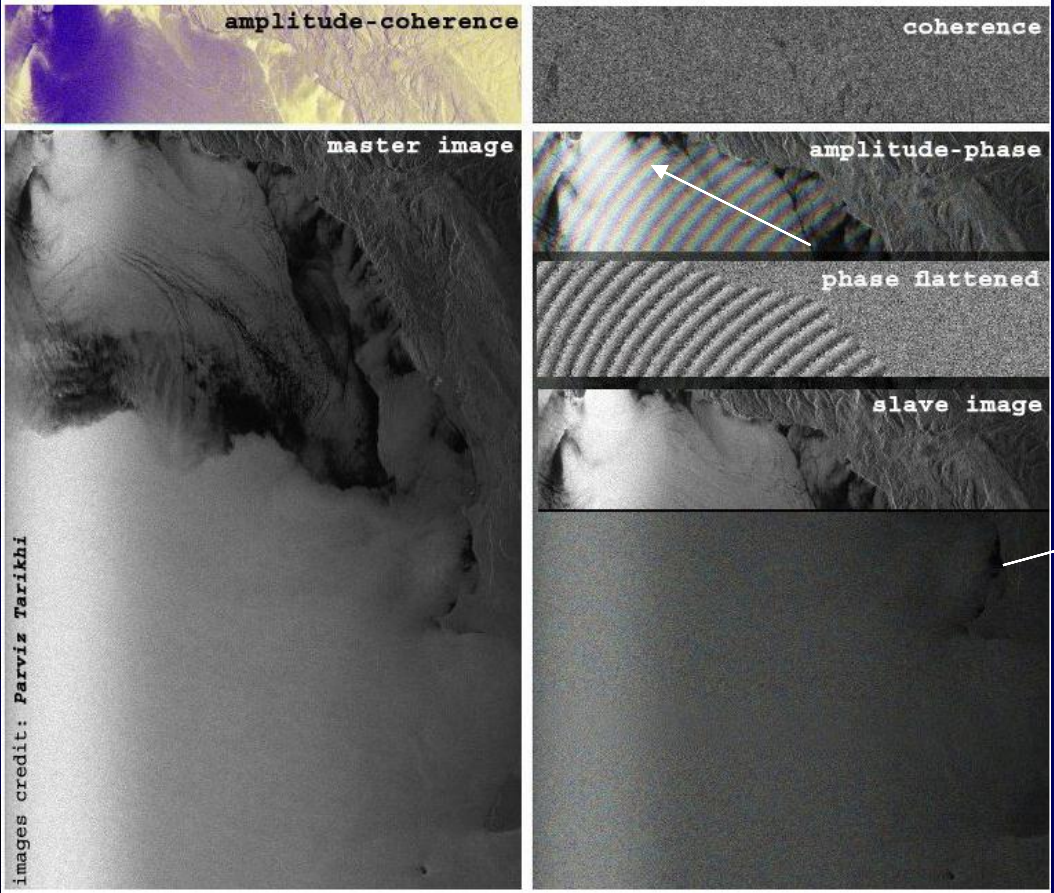
data: 34 SLCIs of the C-band ASAR

Combination of images of 20100326 and 20100430
BL: 251.05m

Combination of image of 20100306 and 20100410.
BL: 448.74m







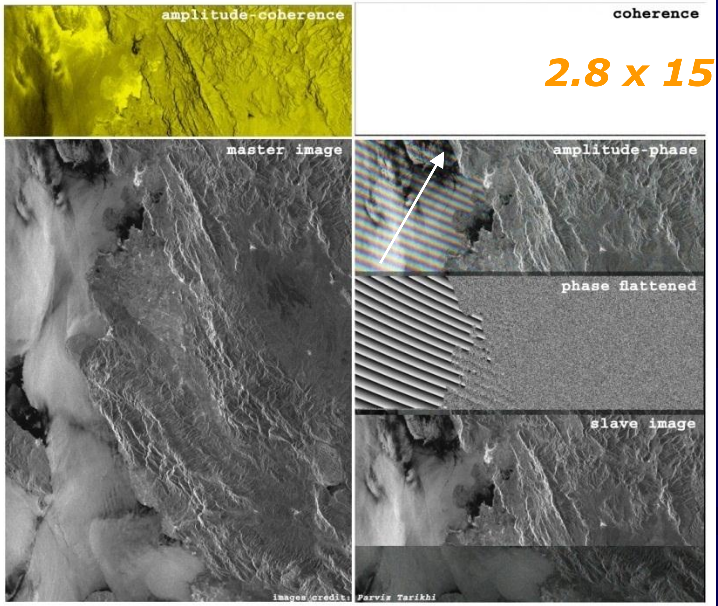
SAR Interferometric combination of the ascending image pair of 20100119_00104_13 and 20100119_00104_14 (January 19, 2010, Haiti, a week after earthquake of January 12, 2010)
Virtual Baseline: 44972.56m
Parallel Baseline: 1087.71m
Normal Baseline: 44959.41m
Temporal Baseline: 15s

SAR Interferometry of water bodies…***un/less explored***

Haiti

Combination of the successive ascending images acquired on January 19, 2010 with 15s temporal baseline. Parallel baseline is estimated to be 1087.71m

2.8 x 20 = 56cm



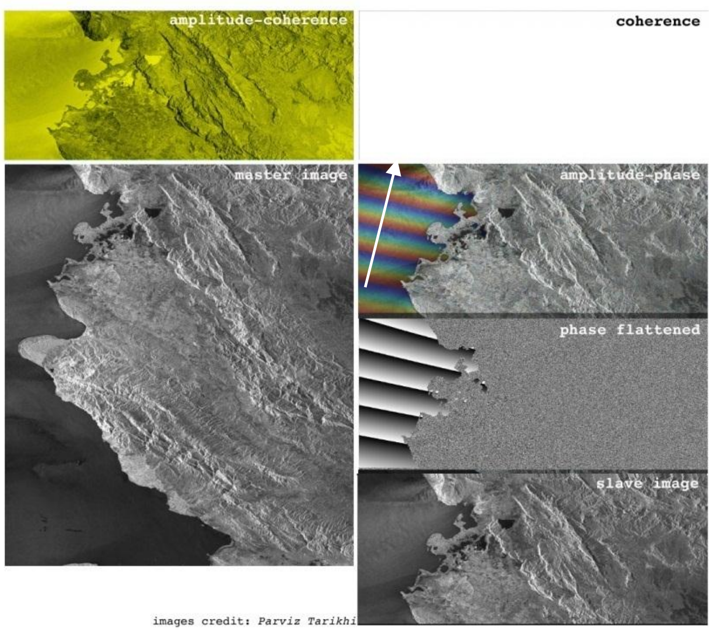
SAR Interferometric combination of the ascending image pair of 20100314_00376_47 and 20100314_00376_48 (March 14, 2010, Haiti, 61 days after the earthquake of January 12, 2010)
Virtual Baseline: 26917.54m
Parallel Baseline: 380.36m
Normal Baseline: 26914.85m
Temporal Baseline 12s

2.8 x 15 = 42cm

SAR Interferometry of water bodies, Haiti

up left: Combination of the successive ascending images that is acquired on March 14, 2010 with 12s temporal baseline. Parallel baseline is estimated to be 380.36m

bottom left: Combination of the successive ascending images that is acquired on April 24, 2010 with 10s temporal baseline. Parallel baseline is estimated to be 113.01m



SAR Interferometric combination of the ascending image pair of 20100424_00462_110 and 20100424_00462_111 (April 24, 2010, Haiti, 102 days after the earthquake of January 12, 2010)
Virtual Baseline: 16000.98m
Parallel Baseline: 113.01m
Normal Baseline: 16000.58m
Temporal Baseline: 10s

2.8 x 6 = 16.8cm

Thank you!

KNOWLEDGE SHOULD BE SHARED, OTHERWISE IT IS USELESS.