Ground deformation monitoring in a basin, of intensive agricultural activity, in the era of climate change

Subtitle:Efficiency assessment by SAR Interferometry of mitigation actions through a re-flooded lake in an area of high ground subsidence vulnerability due to water pumping.

SAR interferometry

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From hazard monitoring to risk response

The compaction of unconsolidated aquifer systems that can accompany excessive ground-water pumping is by far the single largest cause of subsidence. Land subsidence due to large amount of water withdrawal from an aquifer occurred in numerous regions throughout the world and is characterized, as a potential risk especially in the case the overlapping surface is a build up area.

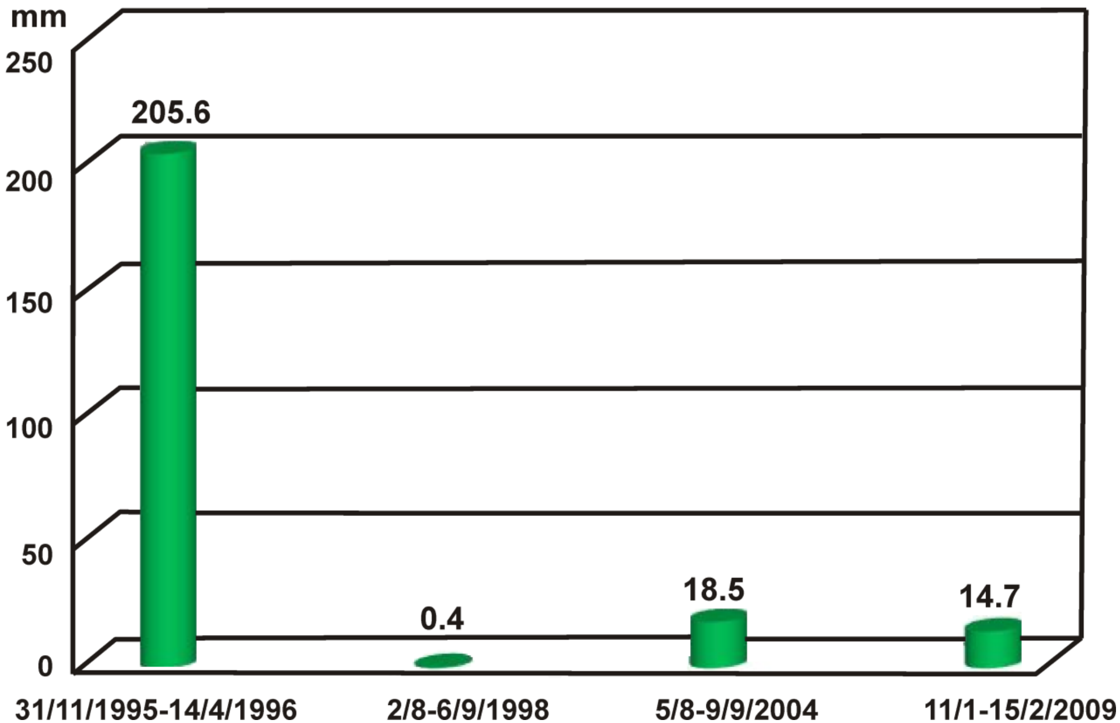
The aim of this study is to investigate surface deformation signals associated with annual precipitations and groundwater withdrawal, demonstrating the suitability of DInSAR for examining dewatering induced subsidence. Specifically, we attempt to measure seasonal deformation and its spatial distribution. Displacement maps were generated for the broader Larissa Plain using SAR acquisitions from **SENTINEL-1**.

Larissa Plain is characterized as the most cultivated and productive agricultural region in Greece. The extensive cultivation has lead to a remarkable increase of water demand, which is usually fulfilled by the over-exploitation of ground-water resources.

The above increased water demand has been associated with severe extreme and persistent droughts during the period from mid to late 1970s and the period from late 1980s to mid 1990s, interrupted by the wet 1990-1991, which mostly affected the northern part of Thessaly Basin.

These dry conditions result in irrigation cutbacks, overexploitation of groundwater and significant losses of crop yields. The subsidence phenomenon caused considerable damages to buildings in the area. Field observations made by the authors' indentified subsidence induced ground fissures in locations like Larissa-Airport, Kambos, Nikea and Melia villages

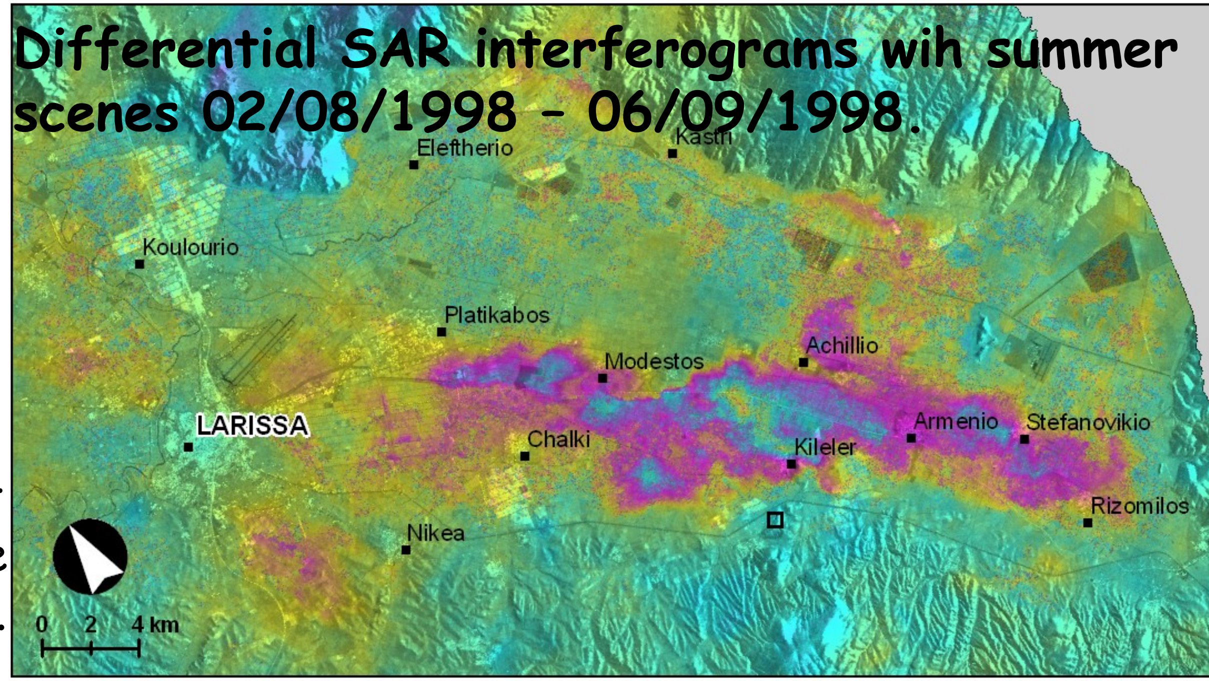
Previous work

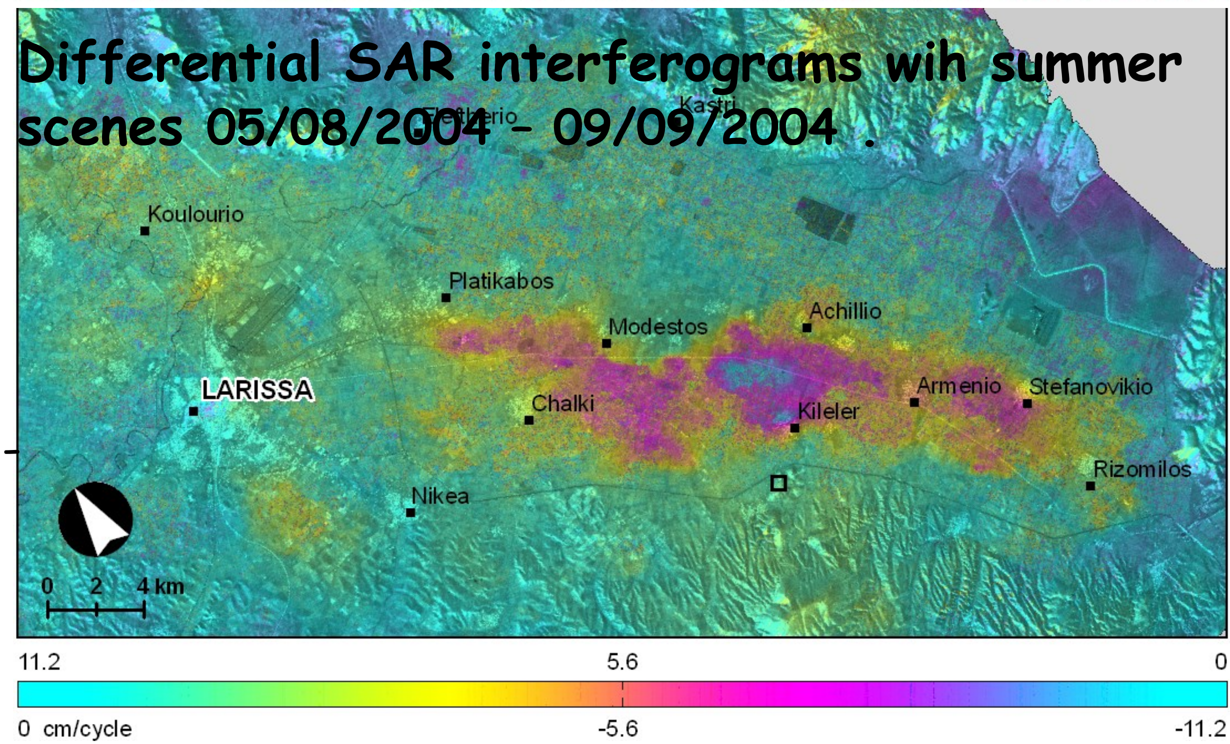


The meteorological station at the airport of the city of Larissa accumulated 205.6 and 14.7 mm during the winter periods (31/12/1995 – 14/04/1996 and 11/01/2009 – 15/02/2009) and 0.4 and 18.5 mm during the summer periods

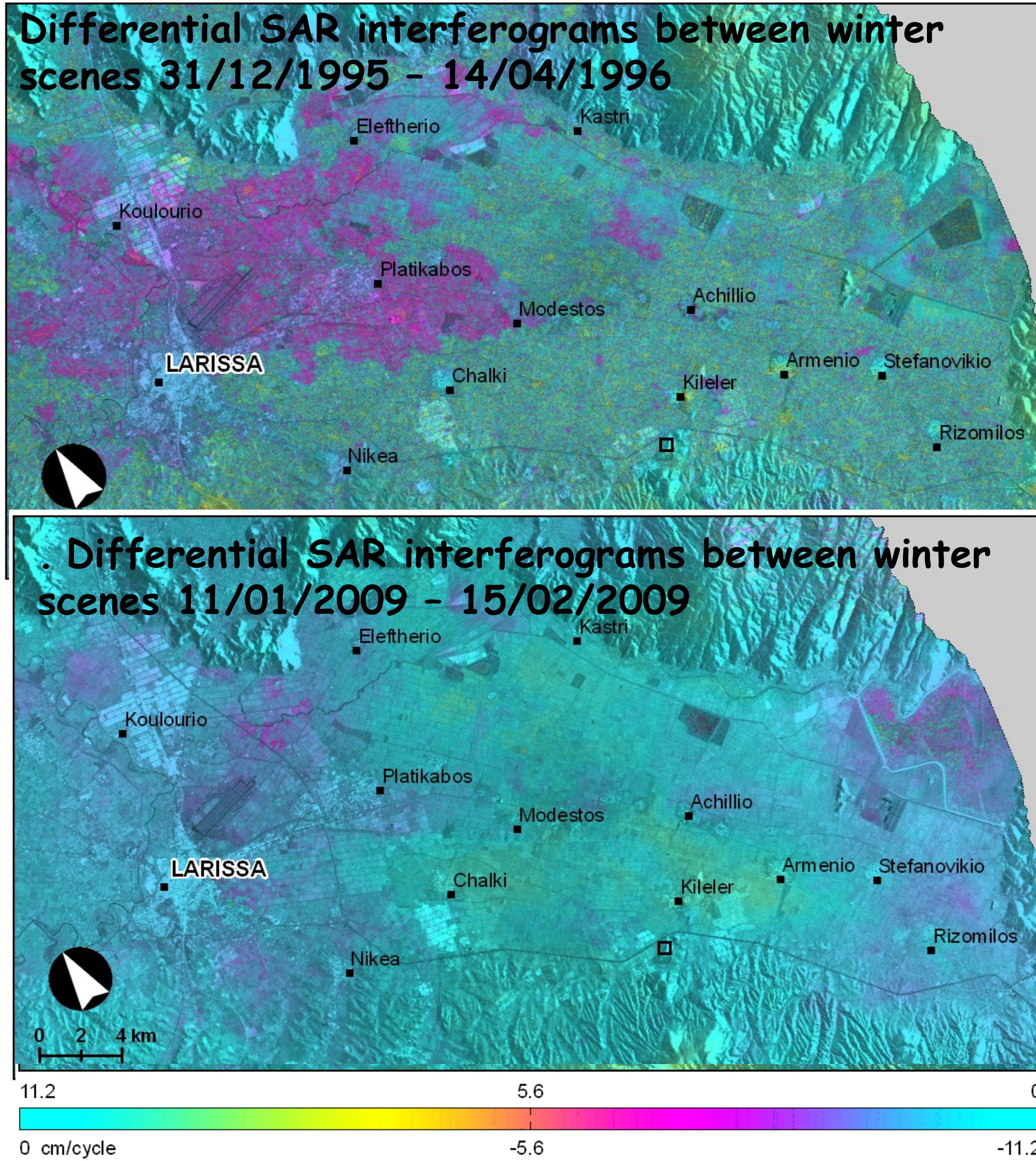
Sensor	Track	Dates	Total months	Bp (m)	Orbit
ERS	279	31/12/1995 – 14/04/1996	3.5	11.1	descending
ERS	279	02/08/1998 – 06/09/1998	1.2	-1.4	descending
ENVISAT	143	05/08/2004 – 09/09/2004	1.2	-23.3	ascending
ENVISAT	279	11/01/2009 – 15/02/2009	1.2	330.9	descending

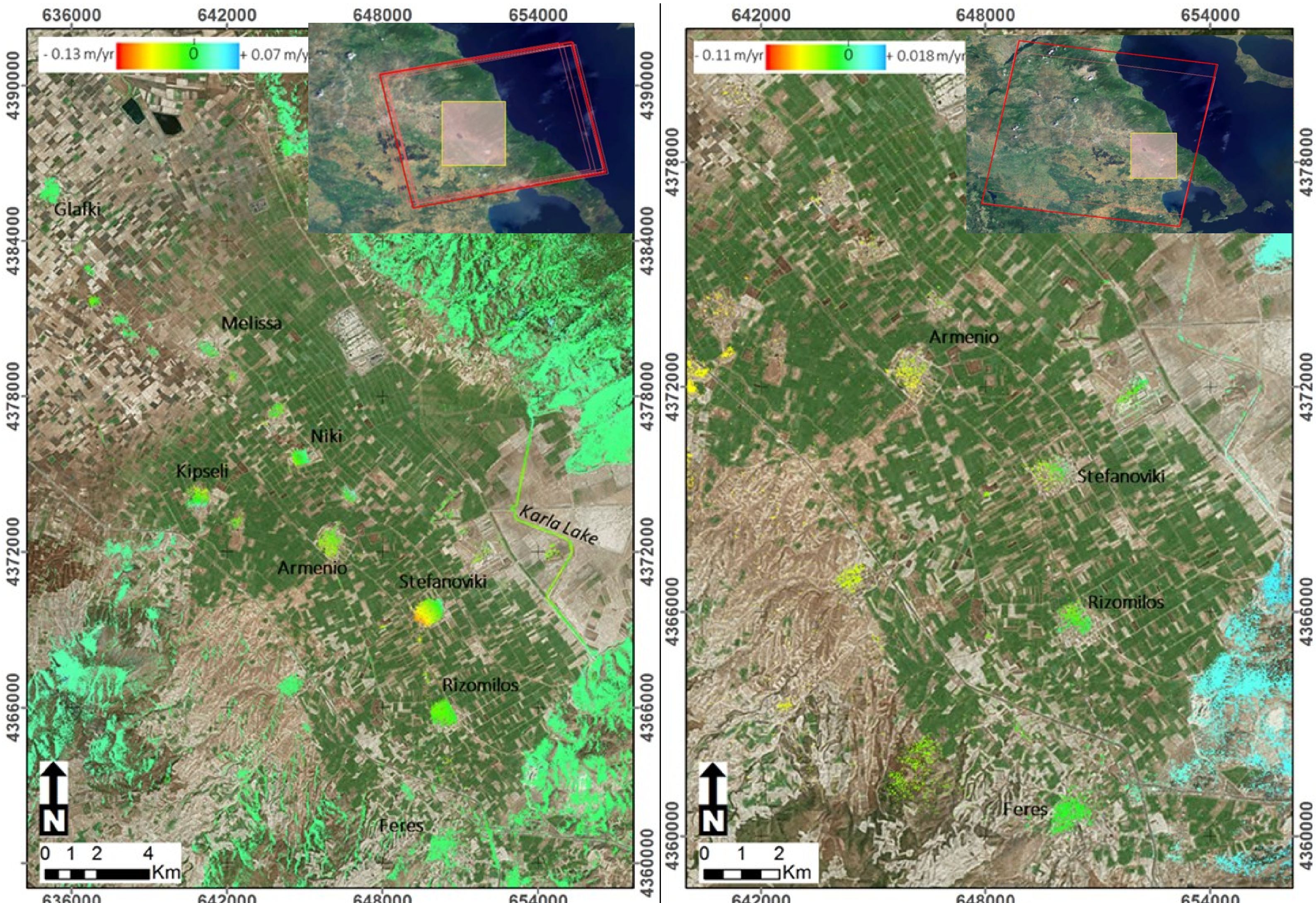
Deformation patterns corresponding to ground subsidence are evident in interferograms covering the period between May and October. The deformed area (about 180 km2) retains an elongated shape with NW-SE orientation (major axes almost 25 km), while covering only the southeastern part of the plain. The area of maximum deformation is located to the North of Kileler village, reaching -17.5 cm along the line of site in the summer of 1998 (from August to September), whereas for the same period in 2004 lower but also significant magnitudes of -12.7 cm are observed.



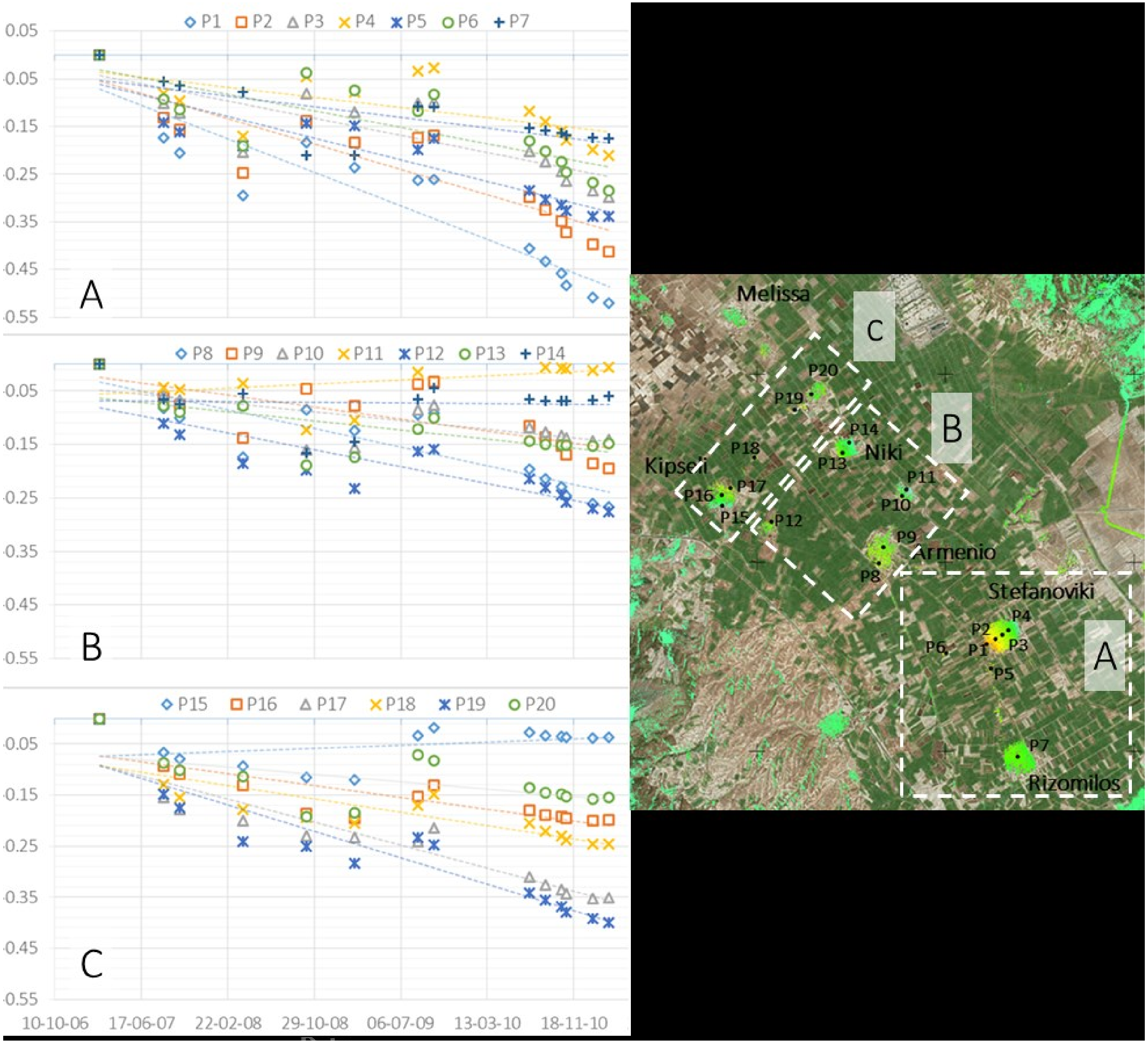


During winter seasons deformation is considerably reduced to -0.5 cm and -0.1 cm for 3.5 months (Dec.1995 – April 1996) and 1.2 months (Jan. – Feb. 2009) period respectively. Rebound phenomena with significantly lower values were observed during high precipitation periods mainly at the NE of the basin.

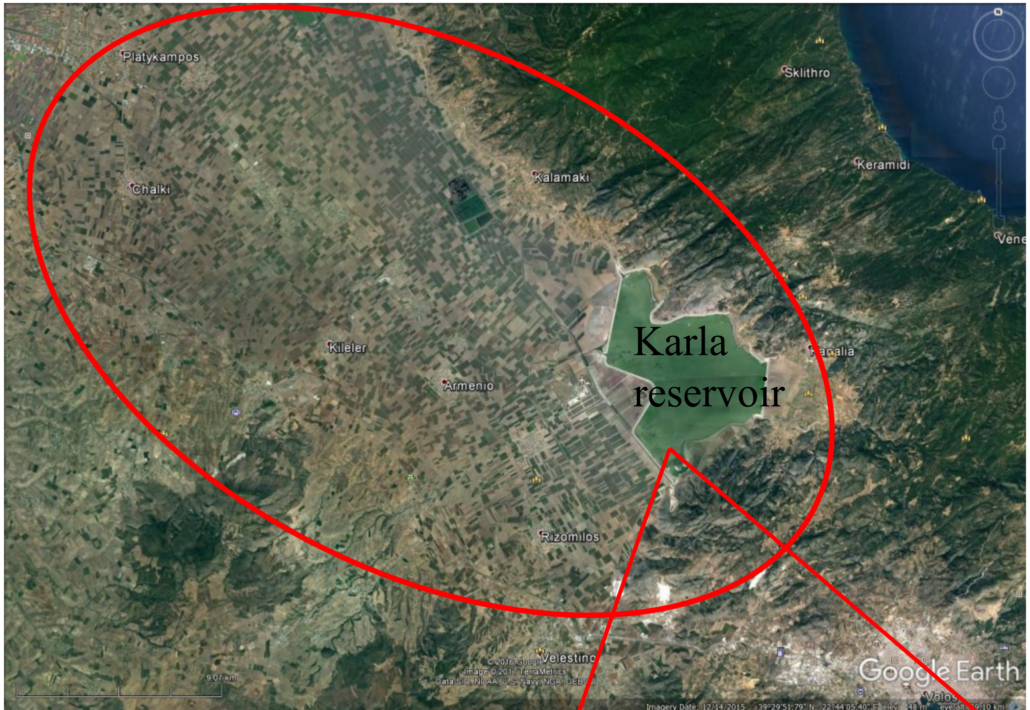




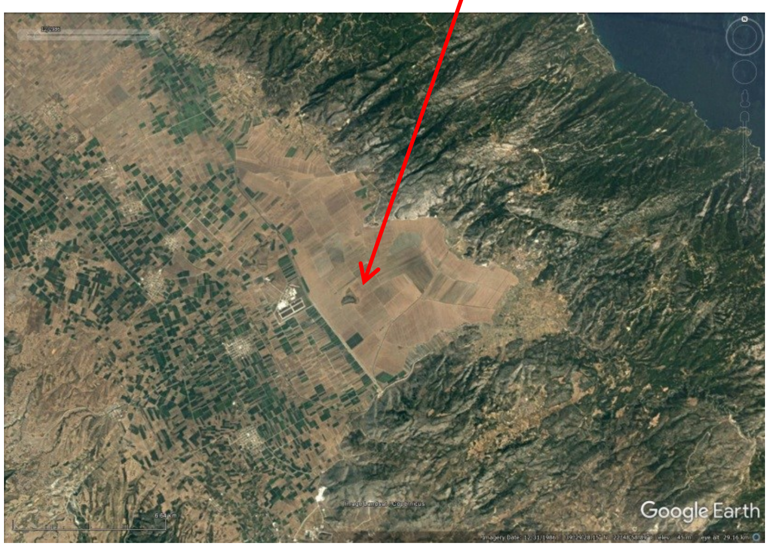
Average deformation rate (LOS component) determined from ALOS PALSAR data between 2-Feb-2007 and 28-Feb-2011 (on the left) and from ASAR/ENVISAT data between 2-Oct-2002 and 28-Jun-2010 (on the right) over Thessaly plain. (Benekos G., Derdelakos K. , Bountzouklis Ch. , Parcharidis I.)



Deformation Time Series from PS from ALOS PALSAR data between 2-Feb-2007 and 28-Feb-2011 over Thessaly



Landsat true color image 2016
In order to mitigate the phenomenon the old lake of Karla was re-flooded.



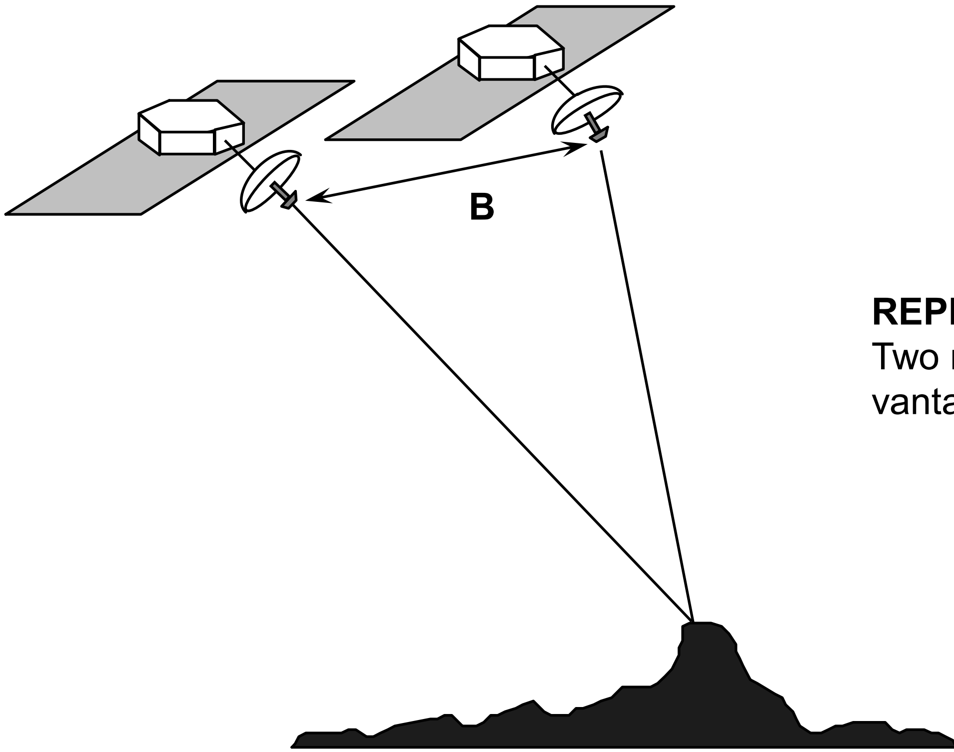
Landsat true color image 1986

Landsat true color image 2009

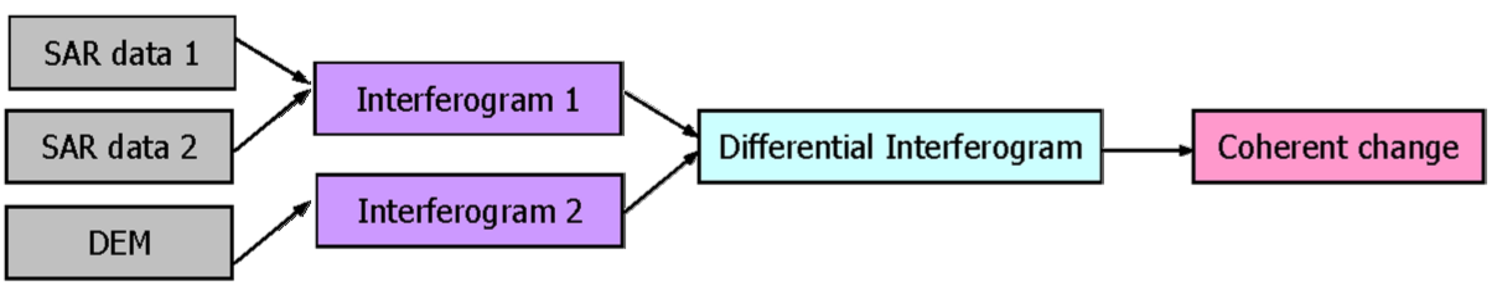
How

Differential SAR Interferometry (DInSAR) is a technique in which the phase component of the returning radar signals of two or more synthetic aperture radar (SAR) scenes from Radar satellites of the same location are processed to allow the detection of ground movements.

Differential SAR Interferometry - DInSAR



REPEAT TRACK
Two radars acquire data from different vantage points at different times



Conventional or repeat-pass interferometry DInSAR

Normally this interferometric methode is used to map ground deformation caused by a natural event like earthquakes or landslides etc.

What we need is the minimum of two SAR images one before and one after the event and also a DEM of the area under study. This method is called two-pass interferometry +DEM.

The basic idea of differential interferometric processing is to separate the topography and displacement related phase terms allowing, in particular, the retrieval of a differential displacement map. This goal is achieved by subtracting the topography related phase. The topography related phase can be calculated from a conventional DEM.

Data used

Sentinel 1 Wide swath (IW) SLC scenes

Two images during the dry period dated

21/7/2016

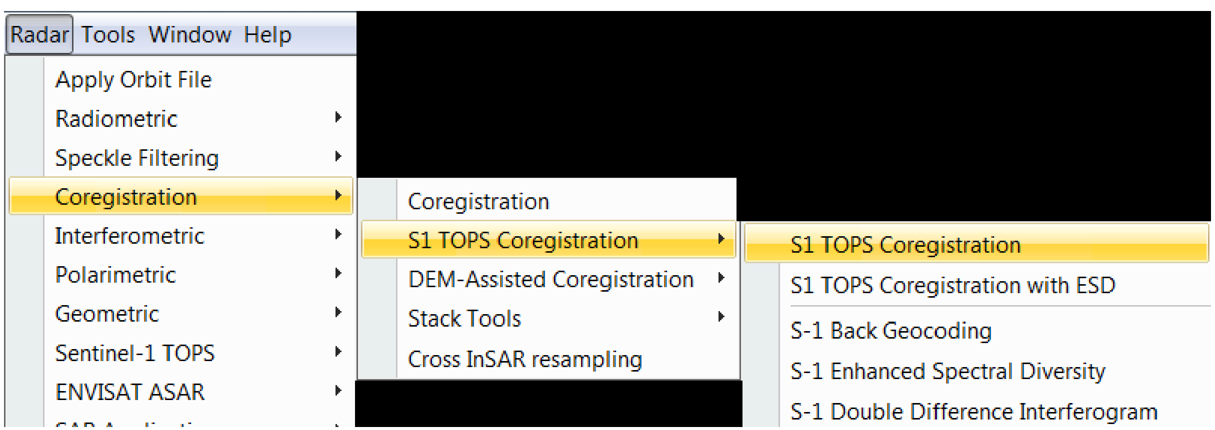
26/8/2016

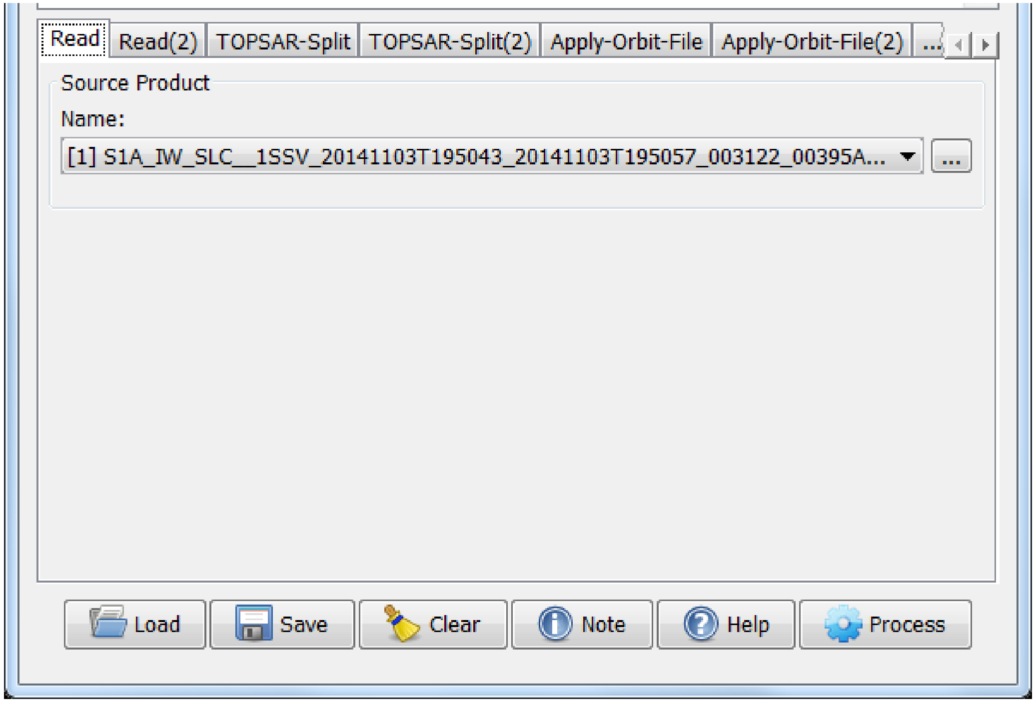
Processing steps

1. **Coregistration**, For interferometric processing, two or more images must be coregistered into a stack. One image is selected as the master and the other images are the slaves. The pixels in slave images will be moved to align with the master image to sub-pixel accuracy.

Radar → Coregistration → S1 TOPS Coregistration

Our area belongs to IW 1





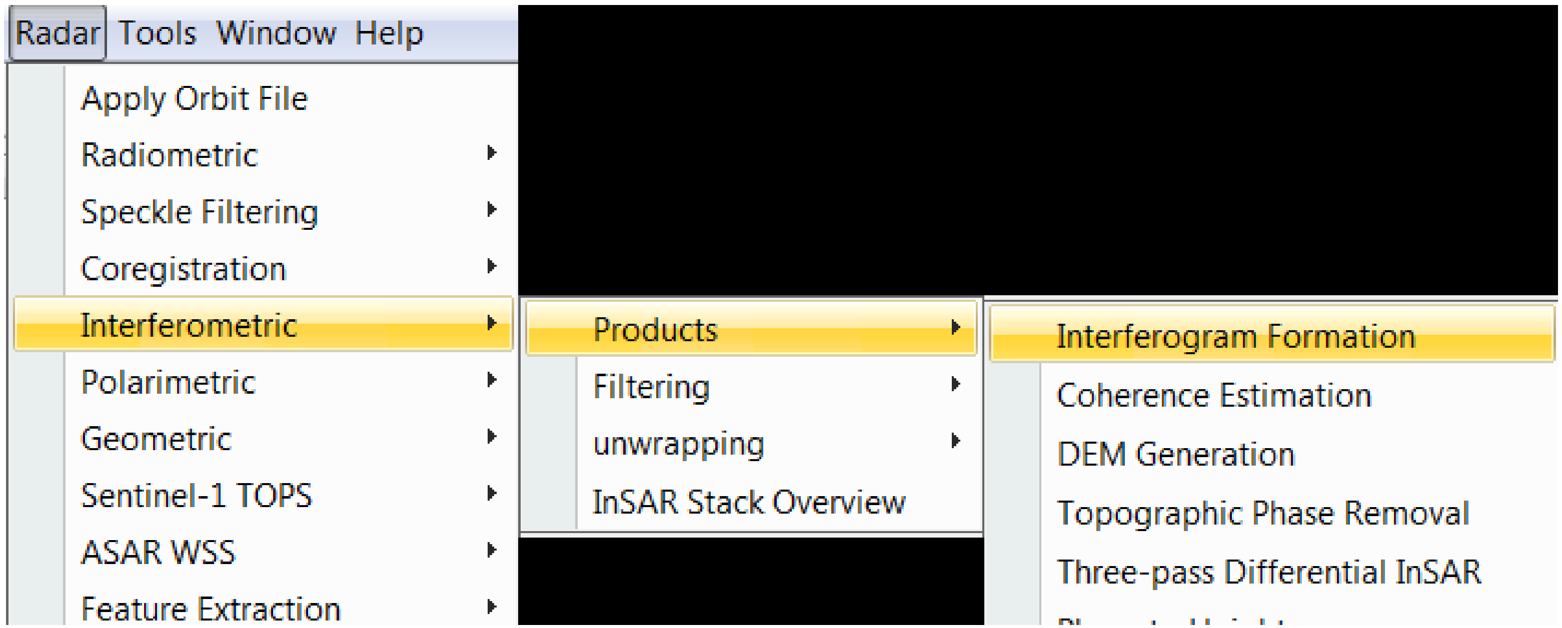
- In the first Read operator, select the first product [1]. This will be your **master** image. In Read(2) select the other product. This will be your **slave** image.
- In the TOPSAR-Split tab, select the IW1 subswath for each of the products.
- In the Apply-Orbit-File tab, select **Sentinel Precise Orbits**. Orbit auxiliary data contain information about the position of the satellite during the acquisition of SAR data.
- In the Back-Geocoding tab, select the Digital Elevation Model (DEM) to use and the interpolation methods.
- Areas outside the DEM or in the sea may be optionally masked out.

Tips: S1 TOPS coregistration with ESD can be also used. After this step a rang and azimuth filtering can be apply to improve Signal to Noise ratio (be careful: it takes long time)

Interferogram generation

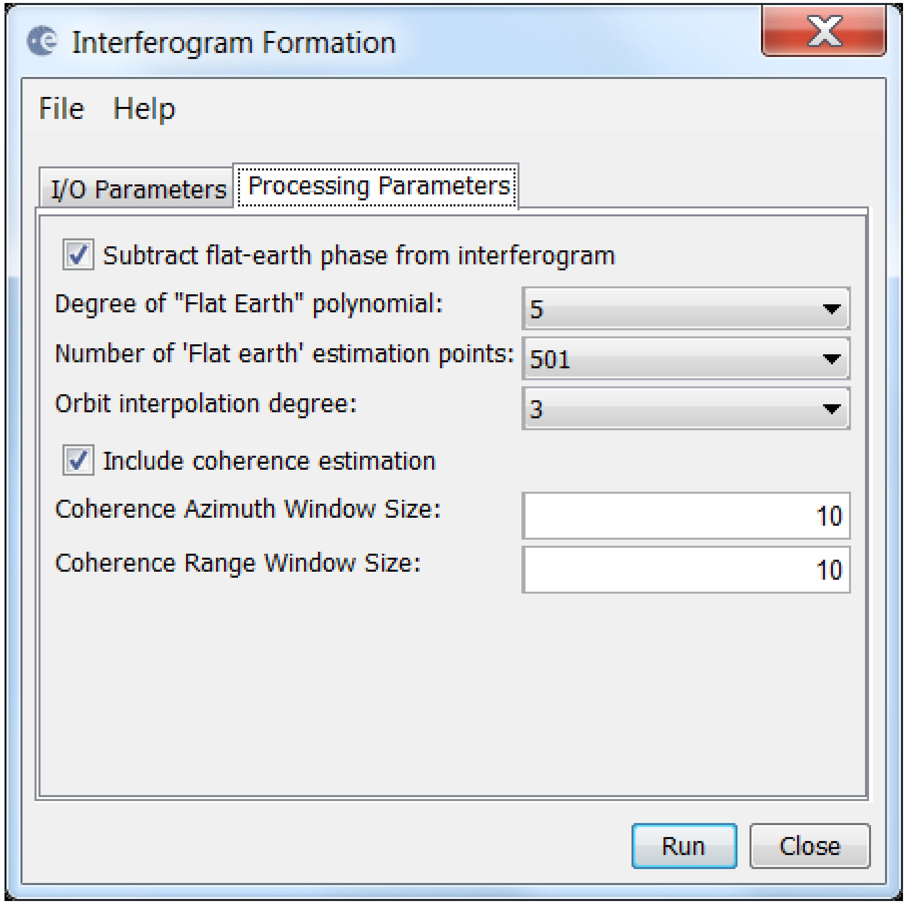
The interferogram is formed by cross multiplying the master image with the complex conjugate of the slave. The amplitude of both images is multiplied while the phase represents the phase difference between the two images.

The interferometric phase of each SAR image pixel would depend only on the difference in the travel paths from each of the two SARs to the considered resolution cell.



The phase difference can have contributions from five different sources:

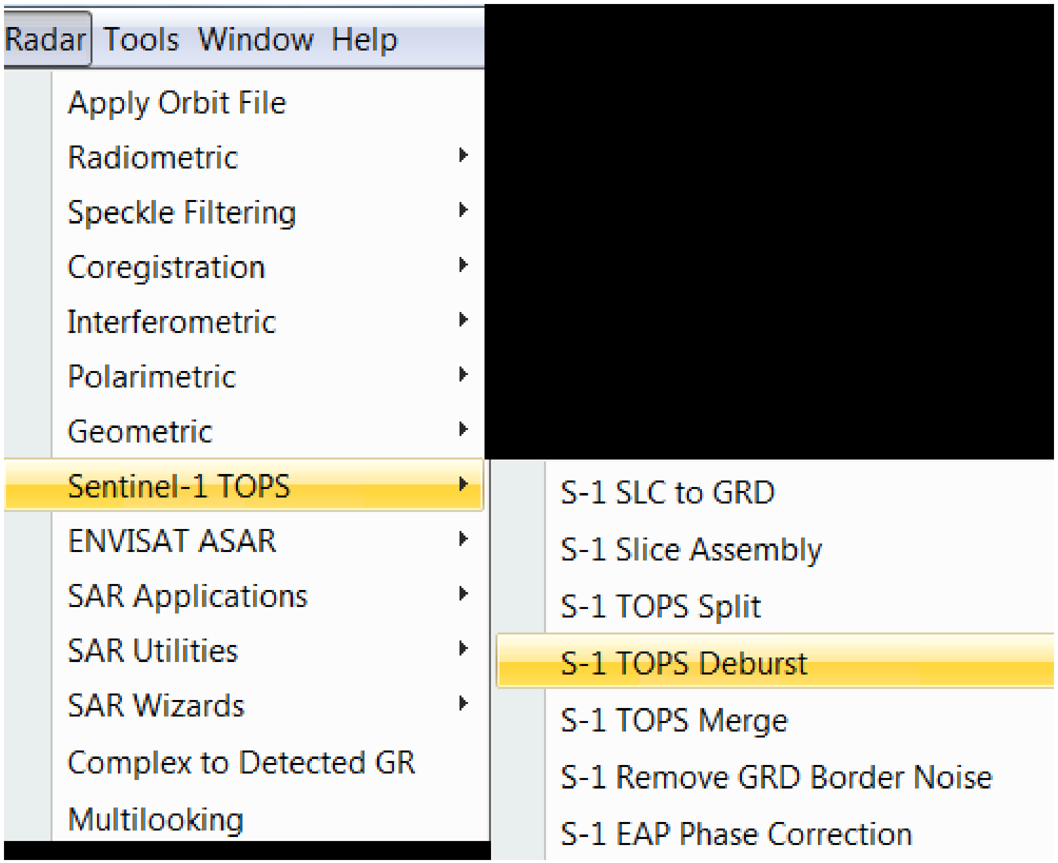
- *Δϕflat* is called flat Earth phase which is the phase contribution due to the earth curvature.
- *Δϕelevation* is the topographic contribution to the interferometric phase.
- *Δϕdisplacement* is the surface deformation contribution to the interferometric phase.
- *Δϕatmosphere* is the atmospheric contribution to the interferometric phase. It is introduced due to the atmospheric humidity, temperature and pressure change between the two acquisitions.
- *Δϕnoise* is the phase noise introduced by temporal change of the scatterers, different look angle, and volume scattering.



In agricultural areas coherence constitutes the biggest problem due to temporal decoralation. For this reason pairs with short temporal separation are selected otherwise advanced interferometric techniques should be applied.

TOPS Deburst and TOPS Merge

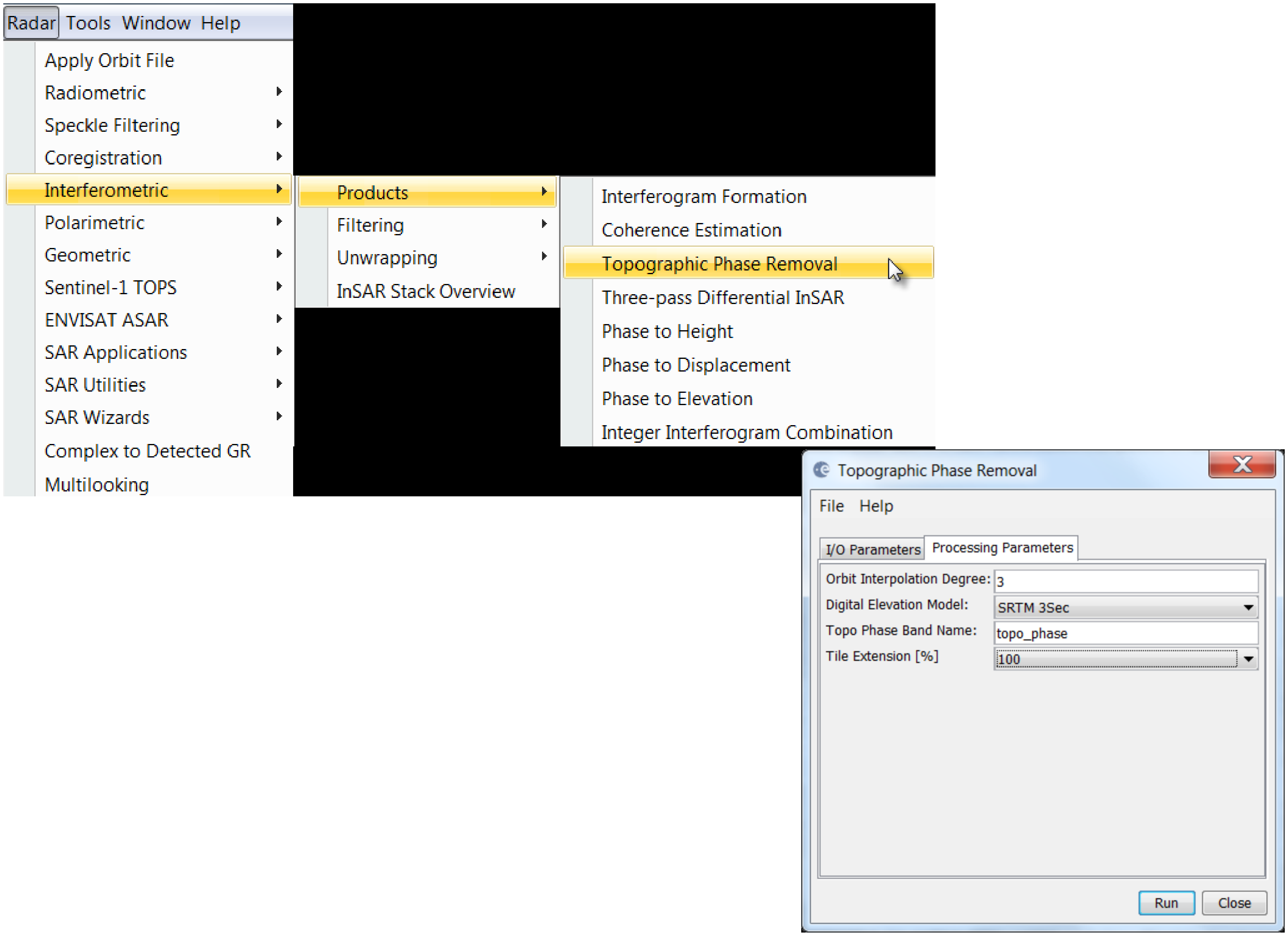
To join all burst data into a single image



Check the result: *Open the resulting deburst interferometric phase band and deburst coherence band.* ***At this step we can apply a first Goldstain filter 3x3 (optional)***.

Topographic Phase Removal

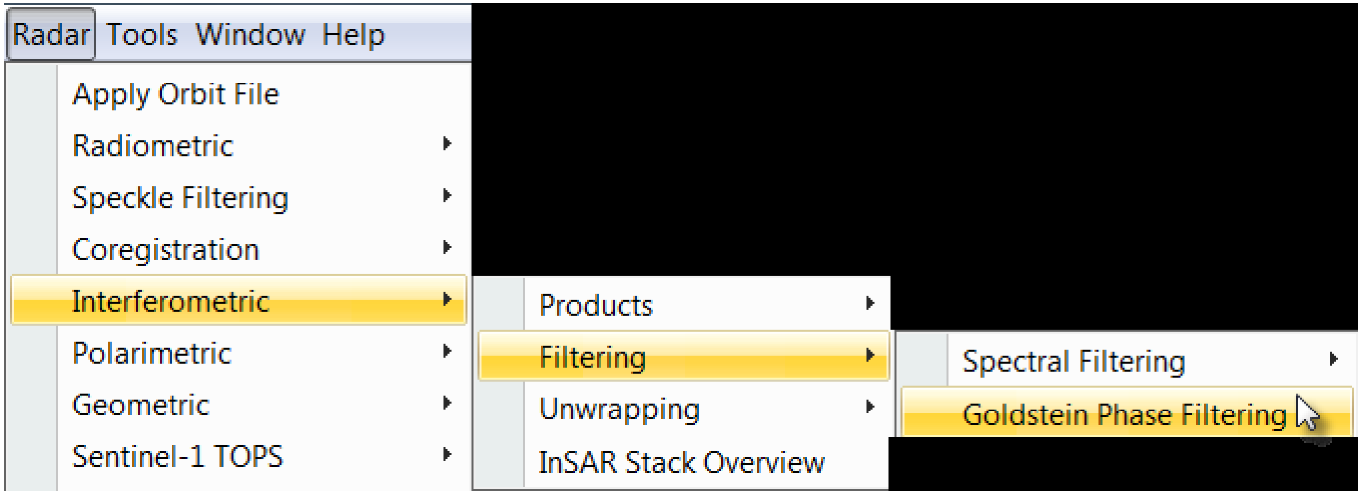
The Interferogram can then be flattened by removing the topographic phase. The operator will simulate an interferogram based on a reference DEM and subtract it from the processed interferogram.

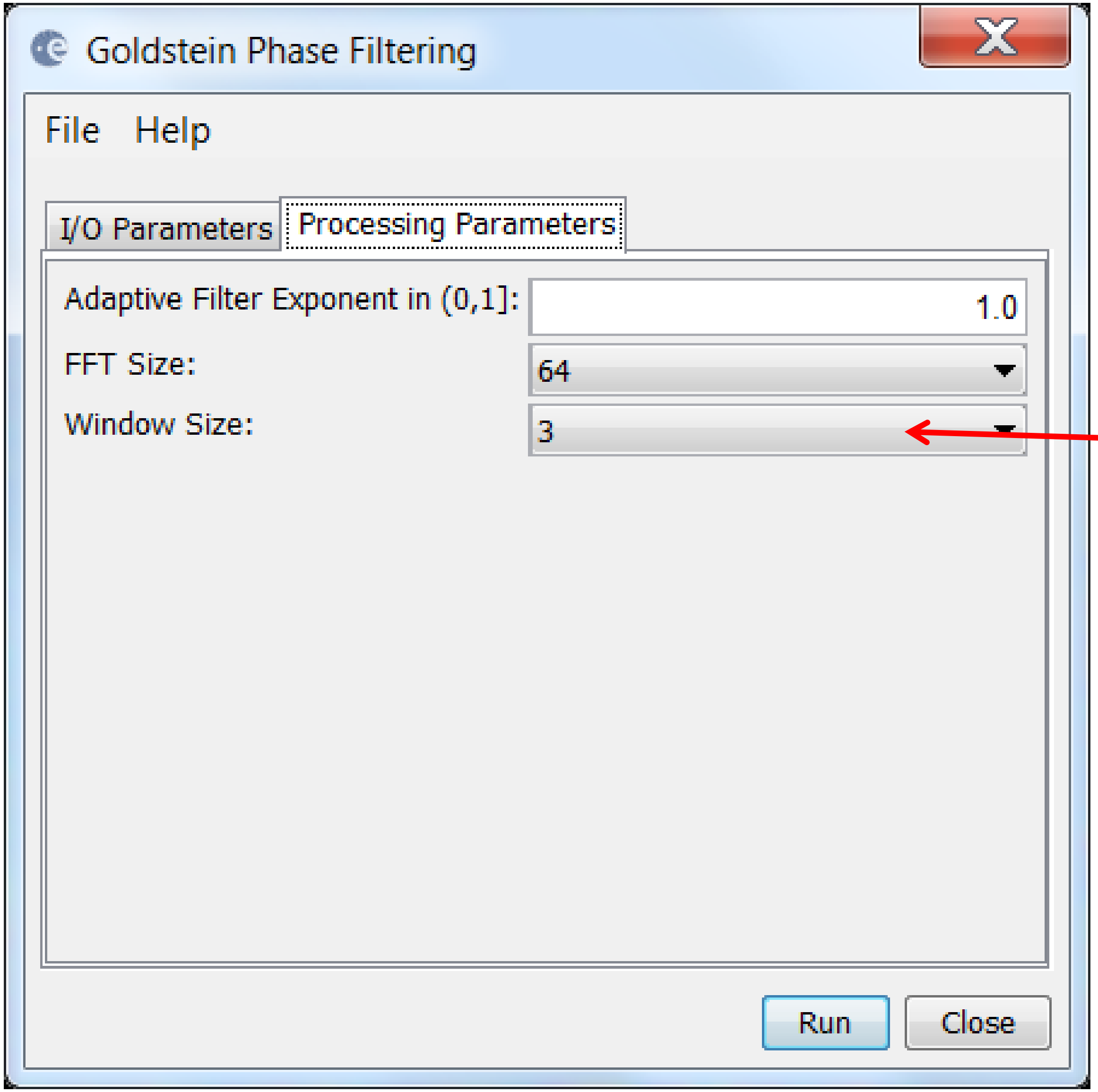


Phase Filtering

- Interferometric phase can be corrupted by noise from:
- Temporal decorrelation
- Geometric decorrelation
- Volume scattering
- Processing error

signal-to-noise ratio needs to be increased by filtering the phase



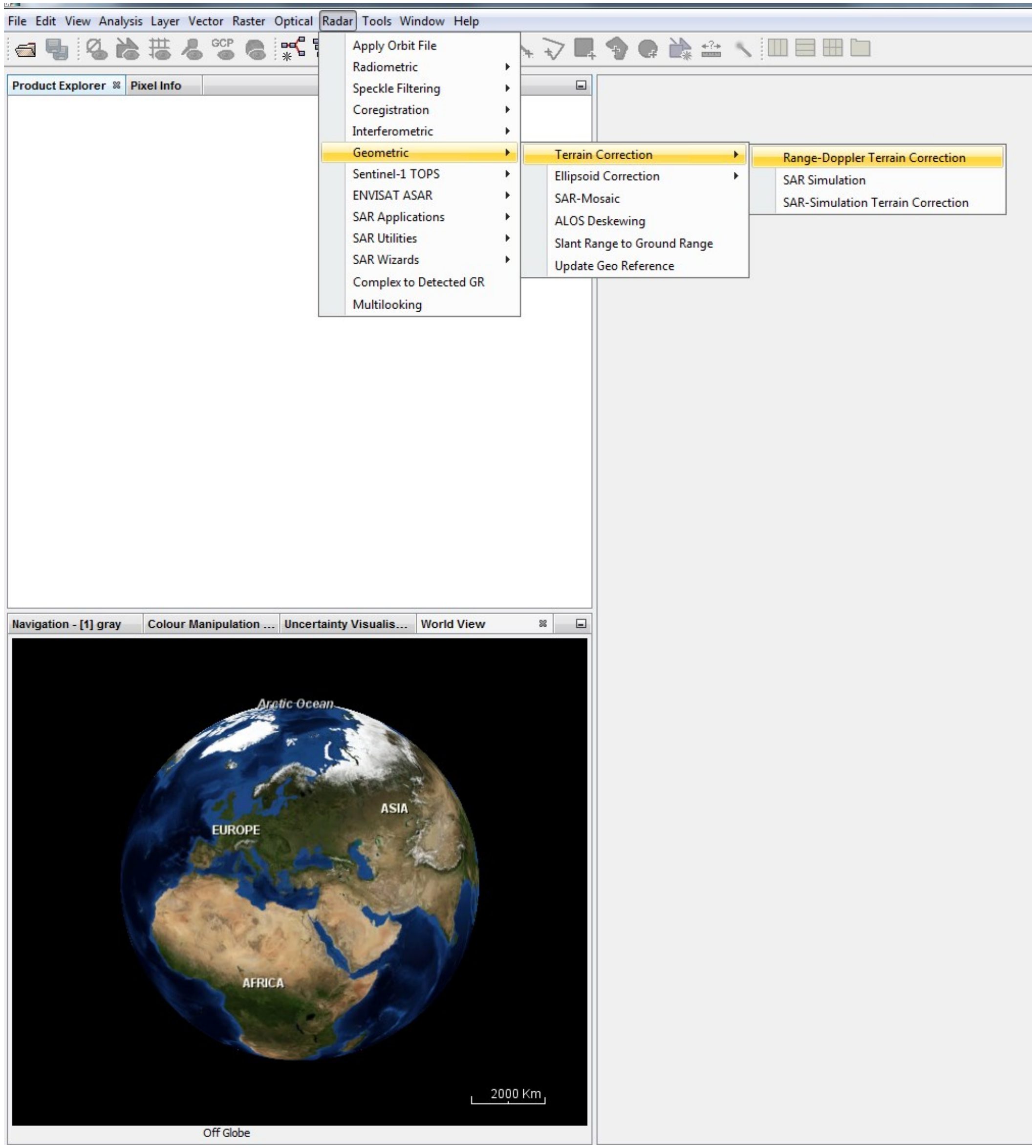

Goldstein Phase Filtering
File
Help
I/O Parameters
Processing Parameters
Adaptive Filter Exponent in (0,1]:
1.0
FFT Size:
64
Window Size:
3
Run
Close

or 5x5

Subset
Raster
Subset
Using coordinates

North Latitude: 39.642
West Long.: 22.485
South Lat.: 39.389
East long.: 22.816

Geometric correction



The image is in SAR geometry
The Range Doppler orthorectification method (Small and Schubert 2008) is used for geocoding the SAR images from 2D raster radar geometry, considering for this purpose available information in the images' metadata about orbit state, radar timing annotation, slant to ground range conversion parameters in combination with DEM (SRTM 3sec Arc)* to derive precise geolocation information. The map projection type of the output images was expressed in **WGS84** geographic coordinates.
* *We can use also a high resolution external DEM*

Convert the final image in KMZ file and check the result over a high resolution optical image in Google Earth environment.

Summarizing processing steps

TOPS S1 Coregistration (with ESD optional)
Interferometry generation
Deburst
Goldstain filtering (optional)
Topo phase removal
Differential phase filtering (Goldstain 5x5)
Subset if needed
Range Doppler terrain correction
Export to kmz (optional)

Discussion