Use of ERS tandem data to produce digital elevation models by interferometry and study land movements by differential interferometry in Calabria and Jordan

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Abstract

This paper summarises 2 case-studies of neotectonic in Calabria and Dead Sea area. Their scope is the evaluation of ERS 1-2 interferometry and differential interferometry products. We show the successive steps of the realization, correction and georeferencing of these interferometric products.
After this technical approach we present some examples of geomorphometric exploitation of the DEM to detect structural, lithological and active or passive neotectonic influences. The results of these applications are compared with those reached using traditional DEMs to evaluate qualitatively the validity of the interferometric products.
Keywords: SAR, interferometry, DEM, geomorphometry, neotectonics, seismic risk

Introduction

This summary presents the work of our laboratory concerning the uses of radar interferometry in the aim of morphological analysis and natural hazards evaluation. The technique of radar interferometry is promising since it theoretically allows the realization of digital elevation models (DEM) and even the measure of displacements of the ground with a good precision [Ref. 1, 2, 3 and 4].

In this study, the technique was tested essentially in Calabria and Jordan. Some image correction and geomorphological analysis techniques have also been developed. This step of geomorphological applications of SAR DEMs is obviously essential. In fact, the quality of a DEM must be evaluated quantitatively by the estimation of an absolute precision (RMS error), but has also to be validated qualitatively in function of the use that we can do of this DEM [Ref. 5 : geomorphometry, hydrologic network analysis, or analogical interpretation of morphostructural features, for instance.

Studied sites

For this study, two test sites were selected, one in southern Italy (Calabria) and one in the Dead Sea area (Jordan). Those sites were selected because of several reasons :

- Jordan : the Dead Sea graben in Jordan was selected first because of its very active tectonics connected with the pull-apart rift along the Jordan River strike slip fault system. The system is characterized by focal mechanisms mainly normal and transverse [Ref. 6-13]. But another quality is the desert nature of this area which is particularly appropriate for radar interferometry. Our objective was also to detect structural features potentially correlated with brittle behavior of the upper crustal regions and sudden seismic movements as well as slow pre, inter and post seismic deformations with differential interferometry. The dynamic aspect is also influenced by diapiric deformations [Ref. 13] of ground in the Dead Sea graben.

- Calabria : we have a good coverage of this zone with topographical maps, geological maps and aerial pictures, what is an advantage to compare with the digital elevation model obtained by interferometry; this area of Southern Calabria and particularly the Strait of Messina is one of the most seismically active in the Mediterranean basin, and the geomorphic record of tectonic activity is particularly perceptible [Ref. 14-20]; lastly, this zone is ideal to apply some 3D analysis methods because of the high slopes gradients.

Introduction to radar interferometry

A radar image is primarily composed of two components : an amplitude value, which is correlated with the physical properties of the ground, and a phase value, which represents the path length of the signal. The purpose of the interferometry is to use this phase value to calculate DEMs and even ground displacements (differential interferometry).

The basic principle is to use two frames of the same zone and coregistrate them in order to produce an interferogram, which is an image of the phase differences between the two frames. This interferogram, in the general case (two frames sensed at two different times from two different places) represents as well the parallax as the displacement of the ground between these two frames. So it is directly related to the elevation at the cost of an ambiguity of $2k\pi$. Thus, after the coregistration which eliminates the influence of the distance between the frames, an intermediate operation, the *phase unwrapping*, is necessary to eliminate this ambiguity. This is generally a step by step algorithm where the altitude of a pixel is arbitrarily fixed and the altitude of its neighbors is derived from it, postulating the continuity of the surface. As radar images are exposed to layover and shadowing phenomena, this hypothesis is not always verified, so one obtains generally a set of polygons where the altitude is coherent inside but not between them.

The same technique can be used for monitoring the displacements of the earth crust. It is necessary, in that case, to use three or more images. The technique we used with this project was to use two pairs of ERS tandem images. The images within a pair were taken by ERS-1 and ERS-2 within a short interval, but the two pairs were separated by a long interval. This permits to minimize the influence of other factors such as humidity or land cover variations.

Realization of digital elevation models

The digital elevation models of Calabria and Jordan were processed by the « Centre Spatial de Liège » with the technique described above [Ref. 21]. The drawback of the process is that the digital elevation model is in slant range projection (fig. 1a). So it was necessary to geometrically correct the model to be able to compare it with other cartographic sources.

We performed this correction by using a local spherical approximation of the WGS84 ellipsoid, considering a sphere with a radius equivalent to the earth radius (measured on the ellipsoid) at the center of the scene. Each pixel is projected on this sphere in function of its azimuthal projection which determines the position of the antenna and in function of its height. The corrected positions (in planimetry) are then coherent in a polygon but not between two or more polygons, and the relative position of independent polygon is not the same as on a map. After this process, it is required to perform an interpolation in order to obtain a continuous surface (fig.1b). This operation was achieved with the module MODEL MAKER from the ERDAS IMAGINE software. We had to take into consideration the fact that the spatial resolution is not the same in range and azimuth but is defined by the CSL to get unspeckled interferograms, and also for the range direction by the operations of geometrical correction and interpolation.

This technique was applied only on the digital elevation model of Jordan, because the DEM of Calabria was too uneven to apply this technique.

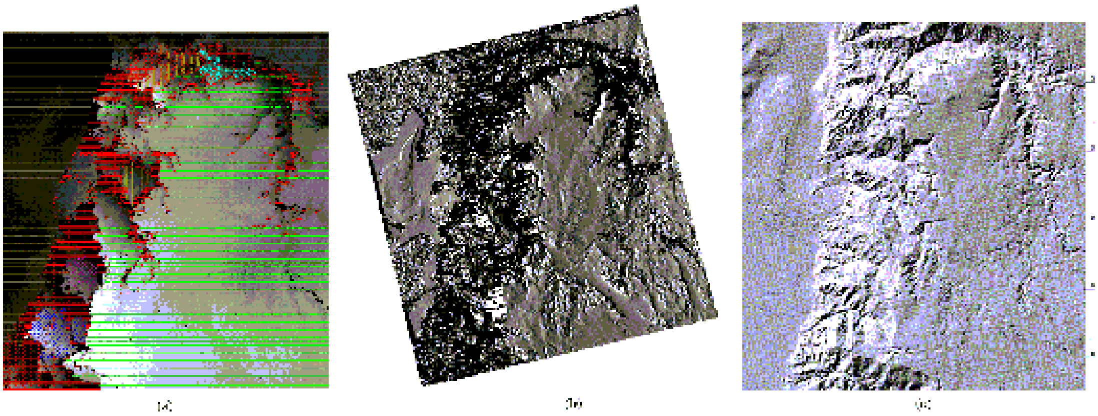

Figure 1 : from left to right : (a) DEM in slant range projection (independent zones in different colors); (b) geometrically corrected DEM in shaded relief; (c) DEM from the Geological Survey of Israel in shaded relief.

Results and validation

Thanks to this correction procedure, we obtain satisfactory results when the topography is not too uneven, because in that case the coherence zones (where the phase has been unwrapped uniformly) are broad enough. But in the zones with major topographic variations, where the third dimension of geomorphologic features is useful, this procedure is globally unsatisfactory.

The digital elevation model in *slant range projection* of Calabria has been compared with a DEM produced by digitization of topographic maps. This permitted us to validate the results by comparing the respective altitudes of some control points. Those control points are very difficult to determine and the spatial representativity of the topographical surface is not satisfying. We obtain a standard error of estimation of 40.23 and 51.30 m for the two DEMs produced by interferometry (2 and 4 SAR images DEMs) (see fig.2). We also noticed some artefacts in the shape of the section of some valleys by the formation of double and parallel valleys (fig.3). This phenomenon , which can influence negatively the analogical interpretation of the DEM (digitization of lineaments) is due to the *lay-over* of some sides oriented to the sensor.

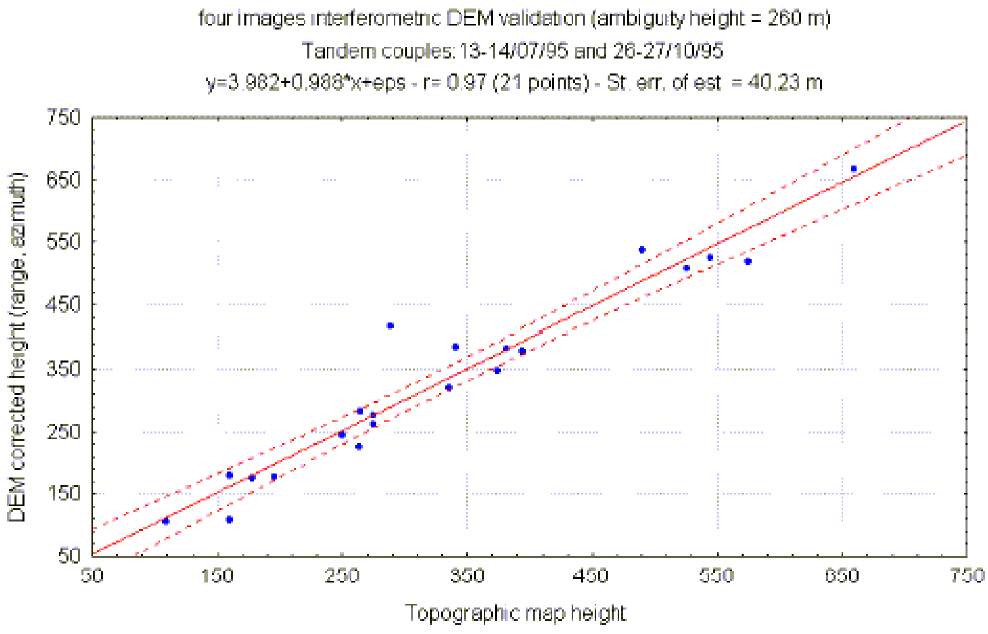

Figure 2 : Validation of the DEM of Calabria.

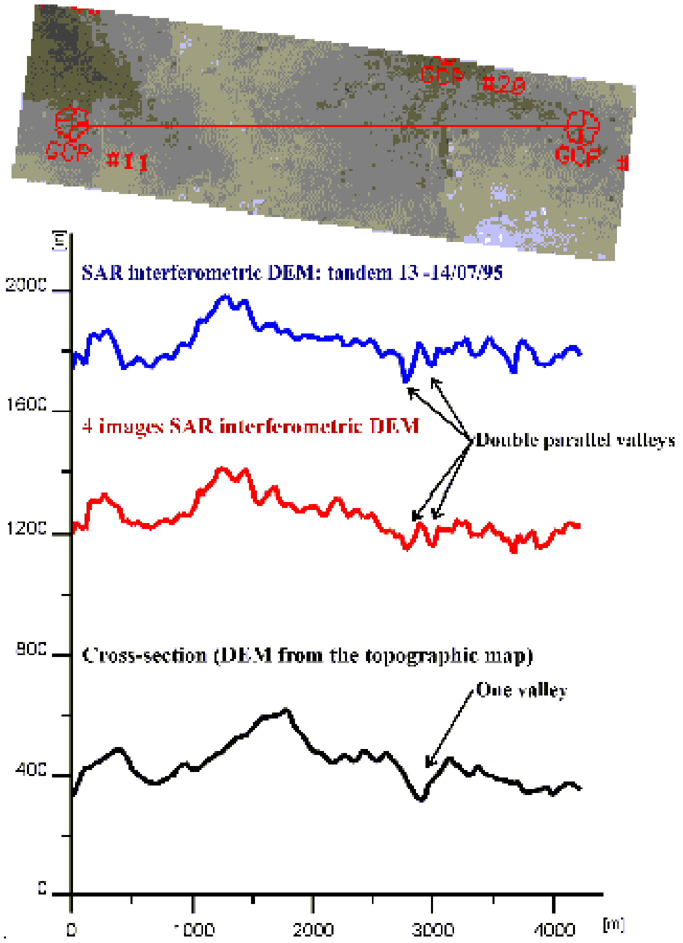

Figure 3 : Double parallel valleys on the SAR interferometric DEM (4 SAR images interferometric DEM - A.H.= 260 m -, tandem 13-14/07/95 - A.H. = 400 m -and the corresponding topographic cross-section)

In the Dead Sea area, we didn't dispose of reliable topographic maps so we were not able to produce a cartographic DEM. The DEM produced by interferometry was composed of many independent polygons where the altitude is coherent but related each with a different altitude. That's why we studied essentially the larger coherent zone which covers most of the Jordan plateau in the vicinity of Kerak. We can see visually (fig.1b) that the technique of radar interferometry puts well in evidence the topography of the plateau and particularly the graben of Wadi El Batra. The comparison of the corrected DEM with a poster of a DEM provided by the Geological Survey of Israel (fig.1c) shows also a good conformity in a planimetric point of view, even of the deep valley that incises the plateau in the north-east part.

Geomorphological analysis of the DEMs
Coplanarity analysis

This geomorphometric application of SAR interferometric DEM is inspired by [Ref.22]. We have described the technical aspects of this procedure [Ref.23]. Nevertheless, some corrections and refinements have been adopted : distance tolerance to test the multiple coplanarity of lineaments and planimetric representation of the determined planes by computation of the intersections between selected planes and the DEM used to detect and digitize the lineaments. The orientation of the planes depends on the number of coplanar lineaments per plane and the dip of these planes (fig.4). We then have to select the planes before the analysis of their planimetric representation (fig.5). We have to maximize the number of coplanar lineaments per plane and to extract only the planes with high dip value because of the predominant strike slip and normal faulting system of the area. The results obtained in Jordan from SAR interferometric DEM (fig.6) are unfortunately less accurate and less rich in geomorphologic information than those obtained in Calabria from a DEM computed on the basis of the digitized hypsometry. Nevertheless, the main structural orientations are enhanced by this kind of analysis applied on interferometric DEM but the low rate of height variation that allow the continuity of the interferometric DEM avoids the computation of planes defined by high dip value.

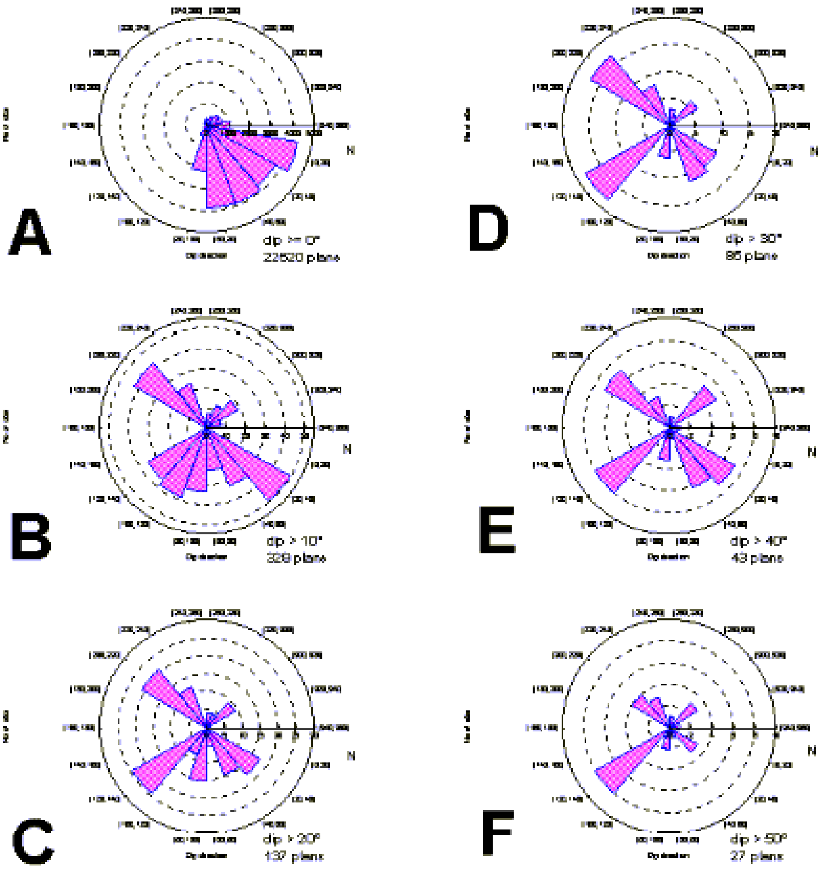

Figure 4 : Planes frequency in function of their dip direction (Jordan). A : dip > 0°; B : dip > 10°; C : dip > 20°; D : dip > 30°; dip > 40°; dip > 50°

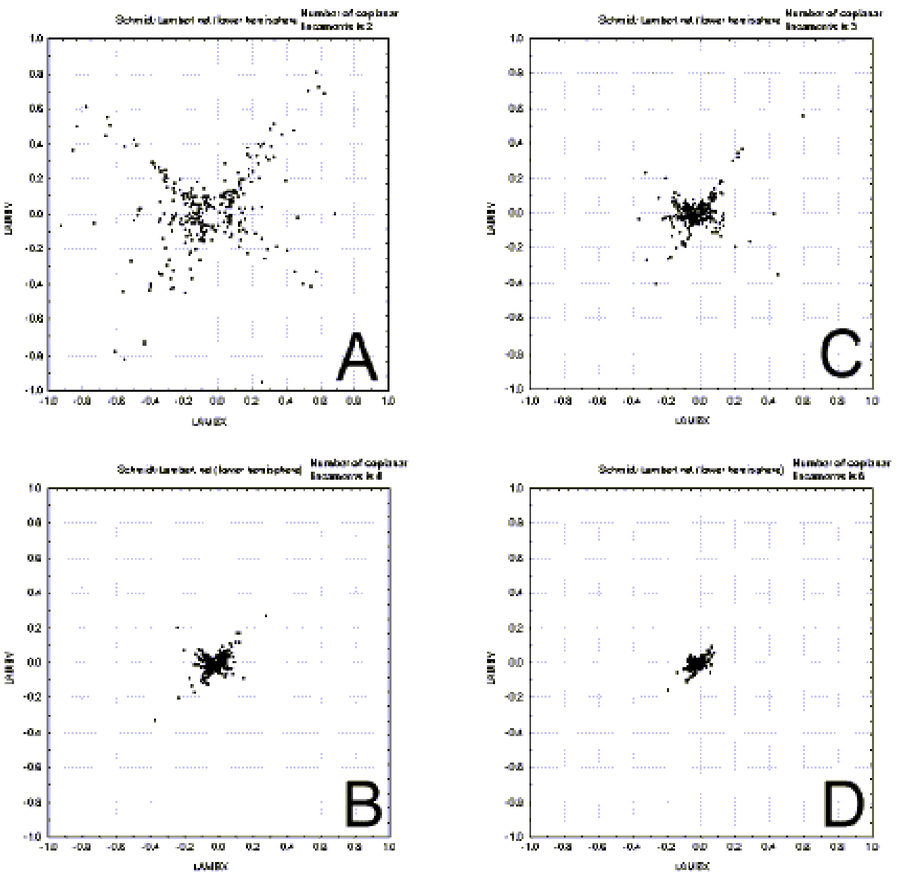

Figure 5 : Schmidt-Lambert representation of the planes in function of the number of coplanar lineaments (Jordan). Poles of planes resulting of 2 (A), 3 (C), 4 (B), 6 (D) coplanar lineaments.

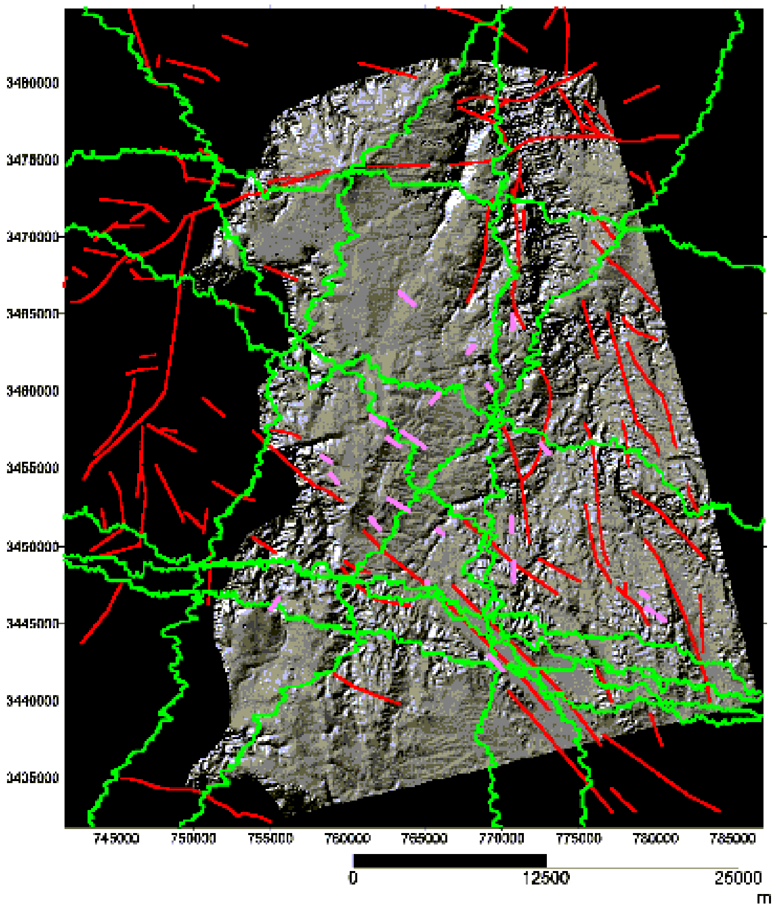

Figure 6 : Results of the coplanarity test (angle tolerance : 2°, distance tolerance : 61 m, dip : 30°, number of coplanar lineaments : 3) : green : intersections between planes and SAR interferometric DEM; fuchsia : coplanar lineaments; red : structural features (see references)

Hydrologic analysis

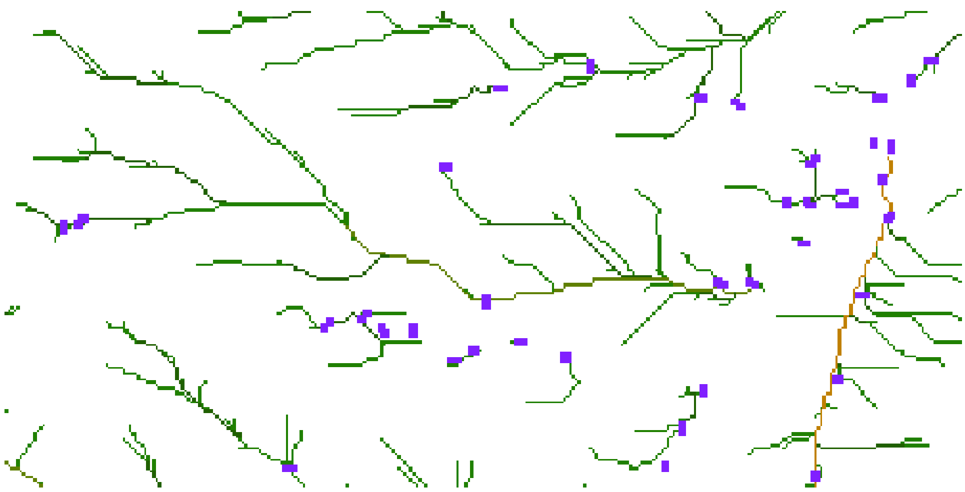

Figure 7 : Hydrographic network.

In order to analyze qualitatively the digital elevation model, we also achieved a simple hydrographic network analysis. This allowed us to characterize the continuity of the surface. We can see on the figure above that many streams are discontinuous because of small dips in the DEM (in blue on the picture)

Differential interferometry

As we mentioned above, the interferometry technique can also be used in order to detect movements of the earth crust. This technique was tested here on the images of Jordan with two ERS-1 & ERS-2 tandem pairs (November 10-11, 1995 and December 15-16, 1995). In the end we obtained what is called a *differential interferogram*, composed of closed polygons where the phase has been unwrapped independently. So, the differential movements are consistent only within each polygon and not between the polygons. Because of the residual noise of the radar images, we first had to eliminate the smallest ones in order to preserve only the interpretable information.

However, this study could not put in evidence significant movements. The few observed fringes could only be related to optical path variations due to variations in humidity and variation of the distance between the satellite and the earth [Ref.24]. The reduced time interval between the scenes (one month) is probably the main explanation for this.

We couldn't apply this technique for the region of Calabria because we didn't have a couple of usable interferograms. In fact, only one couple of images did produce a usable interferogram (with well developed fringes); on the other couples, the phase was preserved only on the villages and some dry streams.

Fieldwork

In order to facilitate the interpretation of the differential interferogram and the features observed or completed from the DEM, a field study was conducted in Jordan from September 17 to October 2, 1996. We particularly centered our investigations about : (i) the global and local fracturation, after an interpretation on the satellite images; and (ii) the landslides and natural wells which could eventually generate fringes on the interferograms.

Despite the fact that this zone is seismically very active, and that several earthquakes have affected the Dead Sea valley during the period of interest, this study was not able to show movements at a detectable scale occurring during this too short period.

The graben of Wadi El Batra (visible in the South-west of the image) has been studied by a student of the University of Jordan in Amman. It seems to be inactive since a long time.

Conclusions

The geometrical quality of interferometric products expressed in function of the geomorphologic and geomorphometric mapping possibility must be estimated in function of the application. In our case two cases of potential applications of SAR interferometric DEMs and differential interferograms have been described. The first case is a geomorphometric analysis of which the result is the static determination of morphostructural features. The comparison of this kind of analysis performed on an interferometric DEM and computed from digitized hypsometry shows the actual limits of the first one however after correction and georeferencing : height incoherence, variable planimetric accuracy due to layover and shadowing (discontinuities), isolated noisy pixels... Moreover, some artifacts on SAR interferometric DEM (double valleys) can lead to misinterpretation of geomorphologic features.

The second case is the automatic extraction of hydrographic network from SAR interferometric DEM. The discontinuity of the network is regrettable and the use of this kind of product must be considered with care in an operational 2 and 3D analysis of the hydrographic network to detect abnormalities that could be investigated on the tectonical point of view.

The two instances presented above are static, the dynamic or cinematic point of view of tectonics has been investigated using differential interferometric products computed in Jordan. Till now we got no exploitable information on pre-, co-, post- and inter-seismic motions (brittle and epeirogenic deformations) of the superficial crust. In Calabria no satisfying differential interferogram has been computed. These results leads us to the following operational establishment : in such seismic areas the monitoring must go on but the actual question is how is it possible to get enough SAR frames that allow the interferometric processing in function of orbit geometry and terrain condition and how is it possible to insure the results before ordering SAR data to avoid trial and error procedure.

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