A PRODUCTION OF DIGITAL ELEVATION MODEL (D.E.M.) BY MEANS OF SAR TANDEM IMAGES IN A VOLCANIC LANDSCAPE AND ITS QUALITY ASSESSMENT

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ABSTRACT

A Digital Elevation Model (DEM) of the volcanic Island of Nisyros (SE Aegean Sea - Greece) has been produced using SAR tandem images. Quantitative evaluations were made by means of coherence analysis and interferogram estimation.

Qualitative comparison of the resulted DEM with an existing high accuracy DEM (20 m resolution) of the area, used to evaluate the accuracy of the final product.

In regions correspond to steep slopes mainly in the western part of the calderas ring, where the coherence is poor, the resulted DEM diverse from the real topography of about 40-60 m. In the rest part of the island, even to regions of high coherence, the produced DEM has a constant overestimated difference of ≈40 m, compare to the real topography. Differences of <10 m from the true topography has been obtained for pixels correspond to the top of the volcanic cones and the crater rim, where the coherence is very high.

KEY WORDS: Nisyros Island (Greece), SAR Interferometry, Digital Elevation Model (DEM), Coherence analysis

1. INTRODUCTION TO SAR INTERFEROMETRY

Interferometry is a process of using interfence effects to determine heights or changes in heights. This implies that digital elevation models can be generated using SAR interferometry in a faster way than the optical techniques. However, the complexity of the height restitution and the accuracy of the result strongly depend on the orbital geometry at the time of the data acquisition, and certain parameters to take in consideration as the baseline, atmospheric conditions, the surfacial characteristics and the morphology of the area.

Experiments conducted with SAR images have shown that SAR interferometry is an accurate technique for measuring surface altitudes and has the potential for accurate topographical mapping on a global scale. In 1970's, Zisk (1972) used interferometry for generating a height map of the Moon. Graham (1974) was the first that used an Airborne SAR system to generate topographic contours with interferometric mode. Using data from JPL aircraft SAR Zebker and Goldstein (1986) applied digital processing techniques to implement a correlation interferogram based on two complex images. Later, Goldstein et al. (1993), demonstrated that this technique could be applied to satellite SAR data acquired over several days.

SAR interferometry calculates the phase difference between two images of the same area taken on two different satellite passes (1500m> baseline >100m). This generates the difference between the two phase-signals; then the phase-difference of any point on the ground will have a value ranging from 0 to 360 degrees. To successfully apply interferometric process, a correlation must exist in the surface properties between the two image acquisitions. Coherence is a measure of the correlation between the two scenes used for the interferometric computation. The coherence is affected by the computation parameters, the

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perpendicular baseline (Bperp) and spatial changes (not displacement)(Capes and Haynes 1996).

The present study describes the procedure applied to produce DEM starting from Single Look Complex Tandem (temporal separation 24 hours) by the satellites ERS-1 and ERS-2 data in a volcanic landscape. Quantitive evaluations were also made by means of coherence analysis and DEM assessment.

2. DESCRIPTION OF THE STUDY AREA

The island of Nisyros is a strato-volcano at the southeastern end of the Hellenic Volcanic Arc (HVA) with a large central caldera (Davis 1968; Di Paola 1974; Papanikolaou & Lekkas, 1990; Vougioukalakis 1993). The volcano was raised up above sea level about 66,000 years ago and may have risen as high as 1000 meters 24,000 years ago. The main central cone of the volcano collapsed during a plinian eruption of dacite pumice, to leave the caldera. After the caldera formed, eruptions produced the lava domes. Pumice from this eruption may be found in 100m thick beds on the higher parts of the island.

The base of the island is made of hyaloclastite, lava flows, and breccias, mostly of andesite composition. Pyroclastic deposits and volcanic domes of dacite composition cap these rocks. The pyroclastic deposits are related to two explosive phases of the volcano.

From the slope map of the area (Fig. 1; produced from the true DEM of the island within the framework of the EU project GEOWARN) it is deduced that the main steep slopes are located in the eastern part of the domes (approximately 40-55°). The western, southern and southeastern coast zones of the island appear extremely steep. Additionally steep slopes appear to the inner part of the caldera ring with slope values of 20-45°, as well, along the main fracture zones with similar slope values.

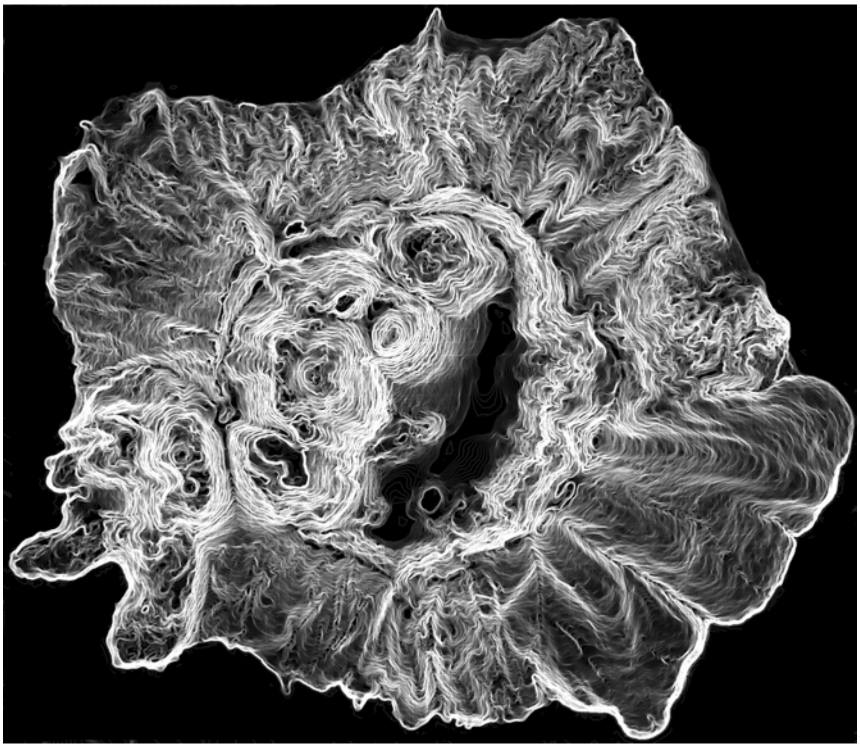


Figure 1. The slope map of Nisyros island produced from a high accuracy DEM of 2 m resolution (Vassilopoulou and Hurny, 2001). The brighter areas indicates the steep slopes, while the darker sections correspond to the smoother slopes.

The most characteristic morphologies of the island of Nisyros are:

- The Caldera with almost circular shape, that lies at the collapsed top of an andesitic stratovolcano. The caldera lays 100m above sea level and is walled by 150 to 400m high walls of andesite and dacite lava rock. Volcanic domes of dacite composition cover the larger part of the calderas bottom while in the remain area there are products of disintegration.
- The Domes located in the western part in the caldera. Five domes that have risen inside the caldera to cover half the floor area, can be identified. The largest is St. Elias dome, 698m high and a few thousand years old.
- The lava flows, in the SE part of the island creating a smooth morphology towards the sea.

3. DATA PROCESSING

In order to create the Digital Elevation Model, we have elaborated images of Nisyros Island, which were acquired in the year 1995 by the satellites ERS-1 and ERS-2 in tandem mission.
The 2 images used, had the following characteristics:

Satellite:	**ERS-1**
Date:	04/09/1995
Time:	08:53:05
Orbit:	21638
Frame:	2871
Satellite:	**ERS-2**
Date:	05/09/1995
Time:	08:53:07
Orbit:	1965
Frame:	2871

Perpendicular Baseline=84 m

Moreover, we have used a Digital Elevation Model with 4m/pixel created by digitizing the isolines from the topographical map (scale 1:10000)

The SAR processing and analyses were based on the Atlantis software package. Primarily, the initial orbit state vectors have been downloaded from the Delft Institute(NL) for Earth-Oriented Space Research (DEOS) for both scenes. DEOS precise ERS-1 and ERS-2 orbits are based on the DGM-EO4 gravity field model and the SLR and OPR2 altimeter crossovers and normal points (Scharroo & Visser 1998). In the co-registration step the master (set the 04-Sep-1995 image) and slave scene (05-Sep-1995) were validated; a co registration refinement was also performed between the two scenes of bilinear polynomial order, and the orbit/Earth geometric analysis was calculated. A phase coherence map was created (fig. 2) and the raw interferogram was enhanced (fig. 3).

During the processing, the data were checked step by step and the related information, (master and slave images spatial and spectral overlapping, baseline estimation, GCP’s and RMS of the co registration) were recorded for further elaboration.

4. COHERENCE ANALYSIS

The similarity between the two radar images is determined using the parameter of coherence. In the coherence map for every pixel the similarity of the two images is shown as a gray scale value (Fig.2). Coherence is a significant parameter to measure the interferogram quality and the capability of applying efficiently phase unwrapping procedures (Zebker et al. 1992). Coherent areas are represented by bright pixels, while areas with a low coherence, like open water, are represented in dark colors (Fig.2). It is not possible to determine altitude values of in-coherent regions.

It has been suggested that a reason for poor coherence may be the long time of separation between the two images used to compute the interferogram. In this study, the temporal difference between the two images is only a day, so the coherence is independent of time separation.

Coherence is depended largely by nature of terrain and land cover. The higher coherence corresponds to the bare soil and rock. In contrast, the forested and vegetated areas coincide with low or no coherence. The vegetated areas not only change with time (especially with season and rainfall) but also move in the wind destroying the possibility to record a simple phase shift in the two signals. Standing water and moist areas show no coherence. In Nisyros island the vegetation is limited to open scrub and to small cultivated parcels in the caldera's floor, not affecting significantly the coherence.

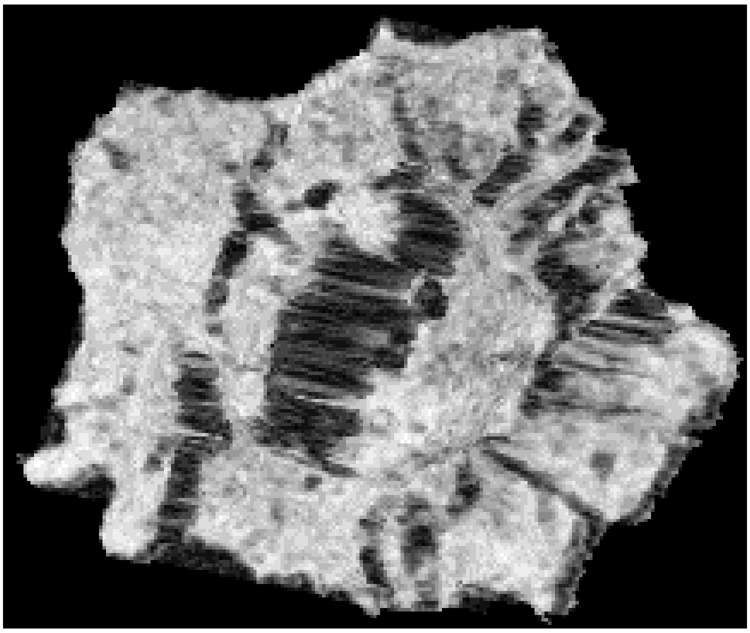


Figure 2. The coherence image of Nisyros island. Bright areas represent high coherence, while the steep slopes (darker areas) in the central domes are zones of low coherence.

A good coherence for almost the entire island of Nisyros is indicated from the deduced image of coherence (Fig. 2). Low coherence regions correspond mainly to steep reliefs along the caldera's steep slopes and particularly in its western part. Additionally linear belts of low coherence are observed corresponding to the main fracture zones of the island that exhibit a morphology with steep slopes.
These steep slopes, especially the ones perpendicular to the signal propagation, generate phenomena like layover and shortening. Thus for these slopes there is no signal information.

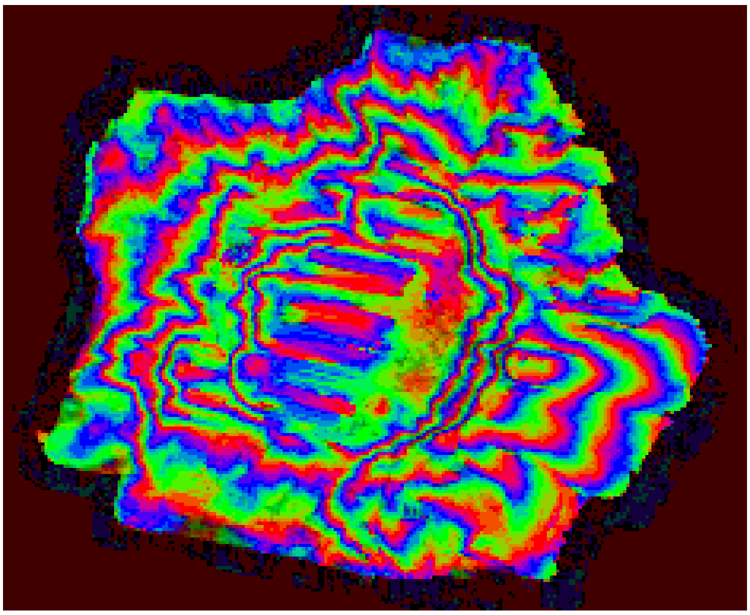


Figure 3. The interferogram image of Nisyros island

5. PHASE UNWRAPPING

The phase unwrapping step concerns the unwrapping of the phase differences (cycles of 360 degrees) to obtain the absolute phase that with further processing is converted to DEM.

The enhanced interferogram was unwrapped using the Disk Masking algorithm (EVInSAR Manual 1999). This method applies circular or elliptical disks centered on phase's residues and pixels of low coherence. A number of unwrapping cycles have been performed, where the disks are enlarged in the first cycle, until no phase unwrapping discontinuity was detected. Furthermore, some unwrapping errors, occurring in the low coherence areas, were analyzed.

Areas having a light gray color (Fig. 4) cover almost the entire island. These areas have been already unwrapped, while in zones that the color of the image is dark gray correspond to areas with low coherence (see Fig.2 and 3), these parts are masked. Negative or positive phase residues are also presented inside the dark gray areas, where as mentioned before, the coherence is low.

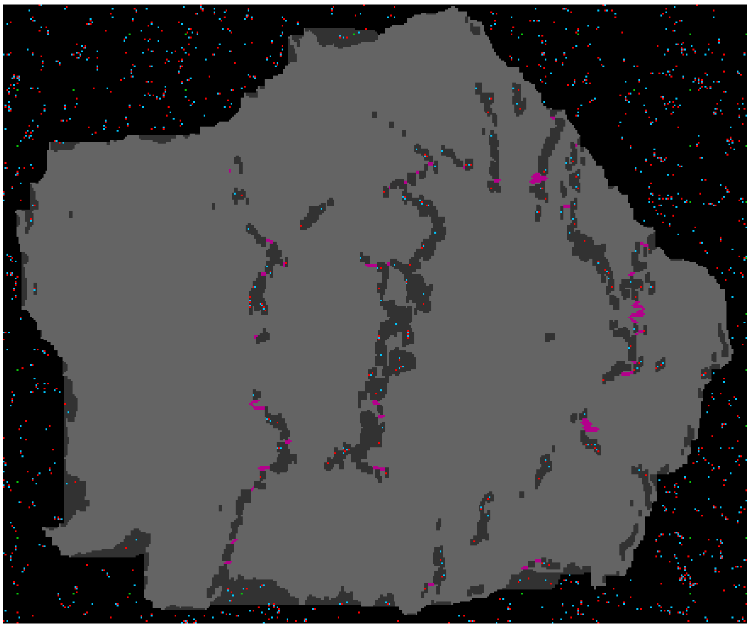


Figure 4. The phase unwrapping image of Nisyros island. The light gray areas represent the unwrapped sections of the phase, while the dark gray are zones that are masked.

The black colors represent areas that have not been unwrapped. Although the phase unwrapping algorithm is designed to minimize the length of phase discontinuities, erroneous discontinuities might occur in mountainous terrain resulting to low coherent interferograms. Areas of layover are not masked out and thus appear as dark gray. Since the phase discontinuities appear only in the low coherent areas, then for the current pair of images, the phase unwrapping can be considered as successful.

6. DEM GENERATION AND EVALUATION

The resulted Digital Elevation Model from Nisyros Island (Fig. 5) appears that differs from the true topography of the area, especially in sections of complex morphology, that as mentioned above, corresponds to areas of low coherence. The zones that are extremely poor resolved are the steep edges of the coastline to the south part of the island, as well the steep slopes of the calderas ring. In these sections the resulted values of the pixels have been generated from the interpolation of the pixels in the neighborhood since there is no information concerning the pixels close to the sea, or the pixels that are masked in the areas of low coherence (steep slopes).

A qualitative evaluation of the produced DEM can be made by comparing it with the true DEM of the area (Fig. 6; resampling to 20 m resolution to obtain similar resolution), (Vassilopoulou and Hurni, 2001). From the comparison of the two elevation models it appears that pixels that correspond with edges (top of volcanic cones) the differences between the calculated and real values are between 10-20m , overestimated to the produced DEM. In flat areas like the calderas floor the differences is quite larger (about 40 m) but it appears constant. In the southern and northern slopes of the island the differences are also significant (20-40 m) but strongly depending to the coherence values. Finally, in masked areas the produced DEM gives artificial values that have been originated from the interpolation of the surrounded pixels, and the differences from the real topography varies between 10-60 m, according to the slopes. Always the produced DEM assigned overestimated values to the pixels.

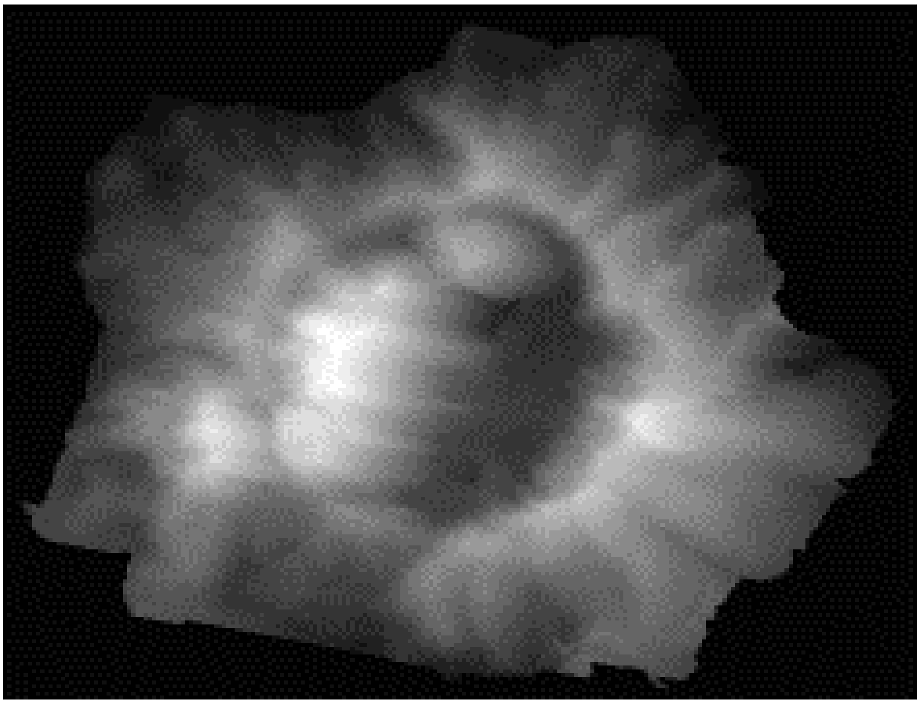


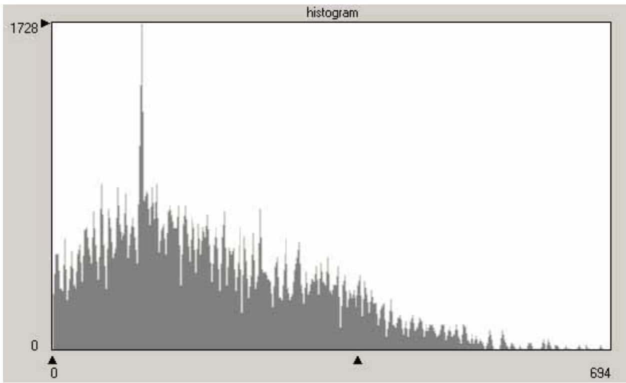
Figure 5. The resulting Digital Elevation Model from the SAR tandem images of Nisyros island

The histograms of the two models (Fig 6) can illustrate also the discrepancy between the two products. The minimum and maximum values of the elevation are different. The produced DEM has a minimum value of 10 m representing the weakens of the technique to define the coastline, while the maximum elevation is underestimated (660m to the produced DEM, 691 m to the true model). The whole of the histogram for the resulted DEM seems that has been sifted towards higher values, since as it has been described above, the resulted elevation pixel values appear overestimated from 10 to 60 m. It has to emphasized that the pixels correspond to the higher points of the topography have the smaller differences between the two elevation models (< 10 m).

7. CONCLUSIONS

In this study presented the procedure for DEM generation using SAR tandem images. The method was applied to the volcanic area of Nisyros island (SE Aegean sea). The island is a typical volcano landscape, with an almost circular caldera, steep inner slopes and volcanic domes lay on an almost flat floor.

The quality of the produced DEM based on ERS tandem pair seems to be strongly affected by the topography (layover and foreshortening phenomena) and external parameters that affect the signal propagation (meteo conditions). Although it appears that the coherence is high in the larger part of the study area, the resulted DEM exhibited significant variances from the real topography of the island.



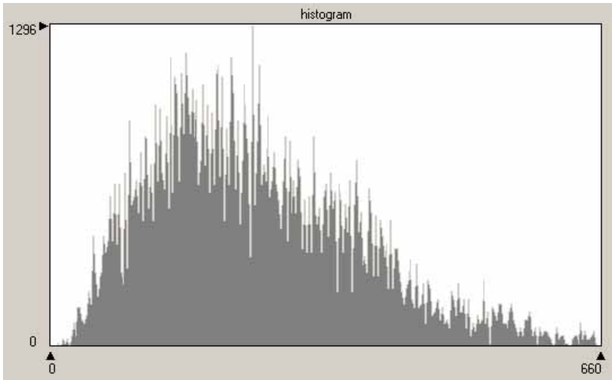


Figure 6. The histograms of the 20 m DEM from the Topographic data of the area (left diagram) and of the produced DEM from the SAR tandem images with pixel size 20 m (right diagram). The X axis represents the elevation value of the pixels, and the Y axis the number of the pixels. Note the different scale in the Y axis between the two histograms.

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