# The use of Earth Observation data in preventing and overcoming the environmental risk

Laura-Ionela MUNTEANU*

***Abstract:*** *In recent years, the various methods of combining and exploring the Earth observation data provided valuable information for monitoring and evaluating both the natural environment, but also the anthropic one. In this paper, we focus on digital elevation modeling using SAR images and the opportunities they provide to improve the economic life of the society.*

***Keywords:*** *environmental challenges; sustainable development; satellite images; digital elevation modeling;*

***JEL Classification:*** *Q01; Q24; Q56*

The increased pace of industrialization and urbanization along with the irresponsible exploitation of natural resources has caused an increasing number of disasters. Disasters, even if we refer to the natural ones or those caused by people, imply material damages and human life losses which represents a major obstacle in achieving a sustainable development. In this context, in the last decades, scientists from all over the world have tried to find and develop new technologies to help in all phases of disaster management, from preparedness and risk management to recovery and reconstruction. According to the World Meteorological Organization, with the investment of one dollar in disaster preparedness, the society can prevent a seven dollars' worth of disaster-related economic losses.

Analysing the past events for understanding the causes and the disasters evolution helps establishing prevention measures and efficient strategies for population preparedness, which in the long run lead to reduction in live losses and spending for recovery and reconstruction. The forecasting and early warning

---

* *Military Equipment and Technologies Research Agency, e-mail: laura.tarita@gmail.com.*

systems are complex systems which require concise and accurate data provided by multiple organizations, and an imperative factor in developing them is the cooperation between regional and global authorities and decision-making factors.

Most of the concise and accurate data needed for disaster risk management is provided by the Earth Observation systems, which in the past decades became more and more accessible. Earth Observation (EO) data are offering valuable information on the physical and chemical nature of the planet as well as about the biodiversity and the anthropic activities of the society. EO data can be provided as topographic measurements, point clouds obtained by laser scanning, topographic maps and plans, numerical measurements taken by thermometer, altimeter or barometer, aerial and satellite images, etc.

In this paper we are focusing on satellite images, more specifically on synthetic aperture radar (SAR) images and how they can be used in preventing and overcoming the environmental challenges. In the last two decades, SAR images have proved to be very useful instruments for analyzing and monitoring our environment on various scales because unlike the optical ones, SAR systems are active systems which can collect data also during the night and in bad weather conditions. Using a special technique called interferometry, SAR images can be used for simulating the Earth surface (digital elevation models), monitoring crops and forests (coherence images), determining the topographic surface deformation/displacement, evaluating the effect of events such as earthquakes (differential interferometry) and landslides and many others applications.

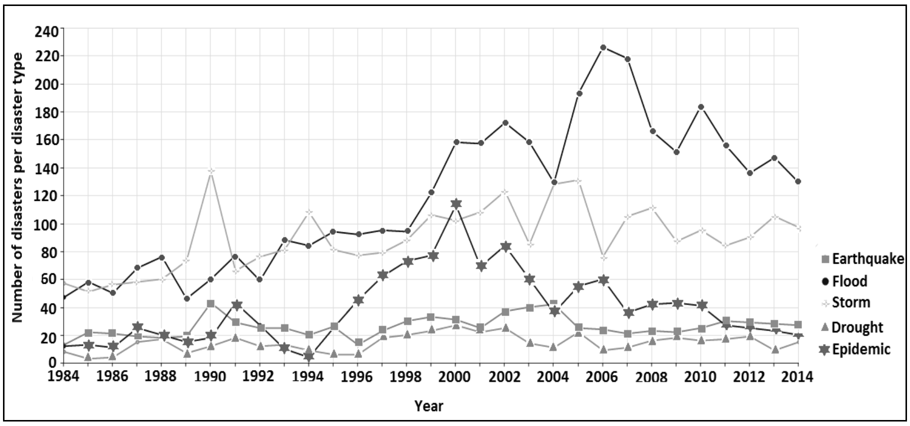
Establishing preventive measures and action plans in the areas prone to disasters must be based on precise and accurate risk maps and an important step in generating them is the digital modeling of terrain (Munteanu, 2014). The main goal of this paper is to present a methodology for generating digital elevation models using SAR interferometry and open-source software and also to highlighting their importance in preventing and overcoming the environmental problems.

## 1. Environmental challenges

In the past decades, the number of natural disasters related to climate changes (floods, storms) recorded a sustained rise. According to the Centre for Research on the Epidemiology of Disasters (2015), since 2000 an average of 341 climate-related disasters per year have been recorded, which is almost twice the level between 1890 and 1989. The trend of climate-related disasters during 1984 – 2014 period can be seen in Figure 1, along with the trend of geophysical disasters (earthquakes) and epidemics. The data used for generating the graphic in figure 1 were provided by the Centre for Research on the Epidemiology of Disasters (CRED). CRED provides free and open access to the International Disaster Database EM-DAT which contains data on disasters such as floods, storms, landslides, earthquakes, volcanic activity, epidemics, wildfires, industrial accidents, transport accidents and others. In addition to the information regarding the impact on human population (number of deaths, number of affected people), the database also offers information on the economic impact of the events.

Analyzing the data in Figure 1, we can see that while the number of earthquakes and droughts remains almost constant over the entire analyzed period, in the first ten years the number of floods has doubled and a peak of about 220 events was reached in 2006. Even if after that year the number of recorder floods decreased, they are still a very frequent natural disaster which claims hundreds of victims every year.

***Figure 1. Number of natural disasters by disaster type between 1984 and 2014***

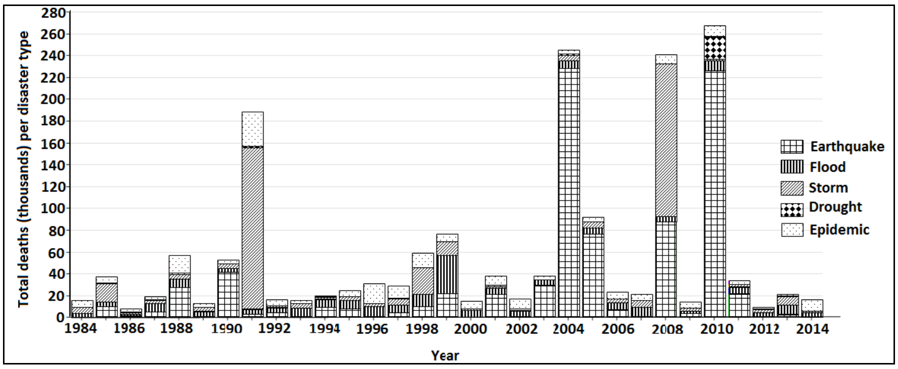



Source: line chart created on www.emdat.be by selecting the data of interest. D. Guha-Sapir, R. Below, Ph. Hoyois - EM-DAT: International Disaster Database – www.emdat.be – Université Catholique de Louvain – Brussels – Belgium.

Unfortunately, natural hazards can occur all over the world and they can easily turn into natural disasters destroying many lives and assets, especially in the underdeveloped regions where the existing infrastructure does not meet the required standards and the population is not instructed for such situations.

Analyzing the number of deaths caused by natural disasters between 1984 and 2014 (represented in Figure 2), we can see that, even if the floods were the most frequent events, the earthquakes are more deadly. In the last three decades, more than 830 thousand people died during the earthquakes (including tsunamis), of which nearly 750 thousand in the last 20 years [Centre for Research on the Epidemiology of Disasters (2015)].

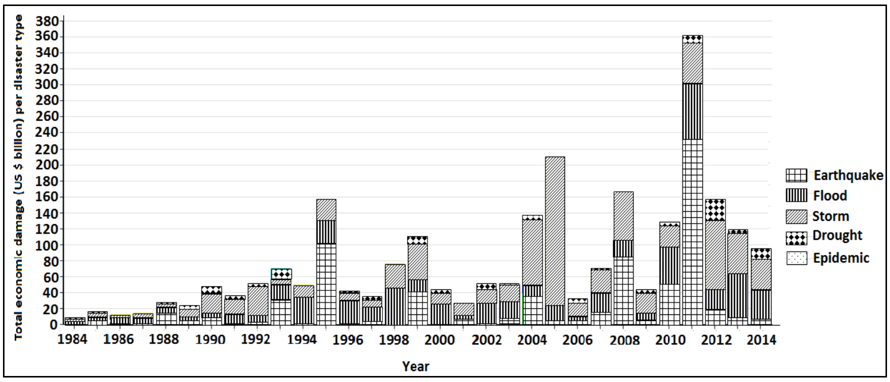
***Figure 2. Number of deaths (thousands) by disaster type between 1984 and 2014***




Source: histogram created based on data from www.emdat.be. D. Guha-Sapir, R. Below, Ph. Hoyois - EM-DAT: International Disaster Database – www.emdat.be – Université Catholique de Louvain – Brussels – Belgium.

From economic point of view, in the last three decades, the damages caused by storms accounted for about 1 trillion dollars, followed by those caused by earthquakes (near 700 billion $) and floods (near 650 billion $). The distribution of the total economic damage produced by the major types of disasters during the period 1984-2014 can be seen in Figure 3.

***Figure 3. Total economic damage (US $ billion) per type of disaster between 1984 and 2014***




Source: histogram created based on data from www.emdat.be. D. Guha-Sapir, R. Below, Ph. Hoyois - EM-DAT: International Disaster Database – www.emdat.be – Université Catholique de Louvain – Brussels – Belgium.

## 2. Earth Observation data and digital elevation modeling

In the past years, scientists from all over the world have tried to develop new technologies and techniques for measuring and monitoring the Earth more easily, more accurately and faster. In this context, there were many satellite missions equipped with sensors that could acquire information from hundreds of kilometers away using different wavelengths of the electromagnetic spectrum (visible, infrared, microwave, radio). All these new EO satellites have become important instruments for the decision-makers, especially for the teams in charge in case of disasters. Each one of these sensors has its advantages, being more suitable for certain applications and by combining them we can learn and understand a wide range of information about the environment and about the challenges that may arise.

In case of disasters, the most used EO satellite data are the optical and SAR images. Unlike the optical systems that are measuring angles, the SAR systems measure distances using the time difference between the emission and reception of the signal. In order to avoid the overlapping of two targets situated at the same distance from the sensor, the radar points in lateral direction. The angle between the radar beam and the normal to the surface is called incidence angle and it gradually increases with the distance from the sensor.

SAR systems are equipped with active sensors which can be operated day and night, in all seasons, being able to “see” through clouds, fog and smoke and depending on the wavelength, even through some types of vegetation. These properties, especially, make them be the first choice in case of major emergencies. For example, when floods happen, usually in the first days the sky is covered with clouds and the atmosphere is full of water vapors so it is very difficult for the optical satellites to obtain a clear view of the area. SAR sensors overcome these obstacles, allowing for the imaging of the affected area more quickly. Having a clear "picture" of the event allows the emergency teams to determine the most affected area without wasting time by going on site and to draw up rescue plans more quickly.

Digital elevation models (DEM) are a very important source of data for a wide range of domains such as hydrology, geology, transportation, archeology, communications, urban planning, agriculture, etc. Generating digital elevation models to match the topographic surface as accurately as possible is a current concern of both the international scientific community and the commercial sector (Munteanu, 2014).

Numerical modelling of terrain involves the approximation of a topographic surface area using appropriate mathematical models based on known ($X_i$, $Y_i$, $Z_i$) coordinates of several points.

In the literature, there are many studies that demonstrate the usefulness of digital elevation models in the context of natural disasters. For example, Apurba (2014), Ozdemir (2009), Seyler (2009) and Youssef (2011) show the importance of digital elevation models in extracting the drainage network and determining the flood risk degree using morphometric parameters.

DEMs can be used for river basins modelling, but also for establishing quick access routes for the emergency teams. By means of digital elevation models and various hydrological parameters, flood-risk areas can be determined by generating and analysing 3D simulations. From the socio-economic point of view, accurate delineation of the flood-risk areas will reduce flood damages by helping improve the protection measures.

DEMs, along with the monitoring in time of topographic surface stability, can also provide important knowledge about the soil instability phenomena in the area, being of real help in deciding where to place new constructions. Avoiding to construct important objectives (such as factories, bridges) but also houses in areas with soil instability will minimize the number of possible industrial disasters and the damages in case of hazards.

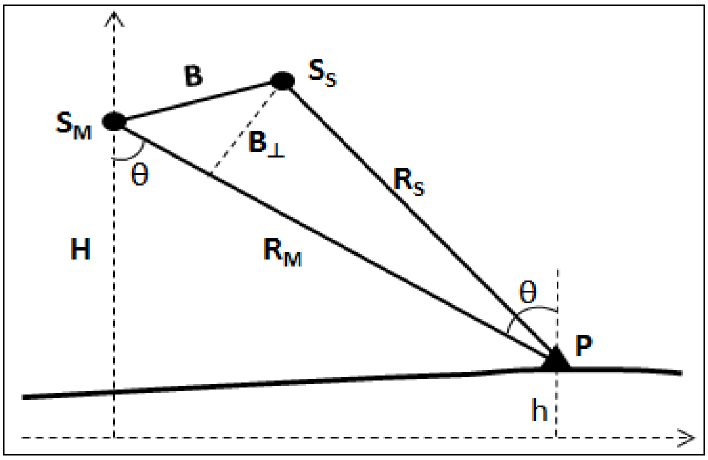
Providing a 3D image of the terrain reality, DEM has also proved to be an important tool in developing the transport infrastructure, the water supply infrastructure and the sewage systems, reducing the decision time and minimizing the costs.

## 3. InSAR for DEM generation

SAR interferometry (InSAR) is a technique that uses the phase information from at least two SAR complex images, acquired simultaneously from almost identical positions or with a separation in time, to measure the distances between the sensor and the target. Theoretical information about SAR interferometry can be found in [Ferretti (2007), Maitre (2008), Massonnet (2008), Richards (2007)].

Figure 4 shows the most used geometric configuration for acquiring the interferometric images.

***Figure 4. InSAR acquisition geometry***




Source: Own creation, adapted after Ferretti (2007), pp. A-18.

where:

$S_M$ and $S_S$ are the sensor positions at the acquisition time of the two images;

$R_M$ and $R_S$ are the distances between sensor and target;

B is the interferometric baseline;

$B_\perp$ is the perpendicular baseline;

θ is the incidence angle;

H and h are the heights of sensor, respectively of target in relation with the reference plane.

By multiplying a complex image with the complex conjugate of the second image a complex interferogram is obtained. The amplitude of the interferogram will therefore be equal to the product of the amplitudes of the two images, whereas the interferometric phase will be the phase difference between the two.

The interferometric phase is influenced by a series of factors such as: the path followed by the wave, the atmosphere, the relative position of points in the field, etc.).That is why phase is highly variable from one pixel to another, even for a homogeneous surface (Polidori1999).

Every time the radar wave travels a distance equal to the wavelength λ, phase increases with 2π. Thus, when considering generating DEMs by interferometry, an important parameter is the altitude of ambiguity which is the topographic height that produces a fringe in the interferogram. The altitude of ambiguity is inversely proportional with the perpendicular baseline (Massonnet, 2008) and is given by:

$$h_a = \frac{\lambda R sin\theta}{2B_1} \quad (1)$$

where:

$\lambda$ - wavelength

$R$ – distance from sensor to the pixel centre

$\theta$ – incidence angle

$B_1$ - perpendicular baseline

The processing chain used to produce InSAR DEMs varies from a software application to another but in general it contains the following steps, not necessarily in this order:

- Orbit interpolation
- Registration
- Complex interferogram generation
- Coherence estimation
- Phase unwrapping
- Phase to height conversion

- Geocoding
- DEM visualisation

The orbit interpolation is a necessary step for accurately determining the sensor position at the time of image acquisition, and therefore of perpendicular baseline. If there is no information about the precise ephemerides, for correcting the baseline ground control points (points with known 3D coordinates in terrain) can be used.

A step of major importance in DEM generation is the registration of two images containing the same scene and viewed from different positions, which consist in finding the offset and differences in geometry between them. After computing the registration model, the secondary image (slave image) is resampled so that the corresponding pixels from both images represent the same ground area.

As mentioned before, the interferogram generation consists in multiplication of each pixel from the two images. The interferometric phase that results is a sum of five terms (Roca F., 2009):

$$\Delta\Phi = \Phi^{ellips} + \Phi^{topo} + \Phi^{displ} + \Phi^{atm} + \Phi^{speckle} \quad (2)$$

where:

$\Phi^{ellips}$ is the interferometric phase component due to the curvature of the Earth

$\Phi^{topo}$ is the interferometric phase component due to terrain topography

$\Phi^{displ}$ is the interferometric phase component due to terrain displacement (deformation)

$\Phi^{atm}$ is the interferometric phase component due to the atmosphere

$\Phi^{speckle}$ is the interferometric phase component due to speckle noise

For accurate DEM generation, all the terms except that related to terrain topography must be removed. The process of removing the component related to the curvature of Earth is called interferogram flattening. If the two images are acquired in a short period of time, then we can assume that the terrain did not changed and we can neglect the phase component related to terrain displacement (deformation).

## 4. Methodology and results

For demonstrating the potential of SAR images to model the topographic surface, in this study, two ENVISAT ASAR complex images, provided by the European Space Agency, were used. The studied area is the BAM region from Iran, characterized by rocky and barren surfaces, but also built regions and mountains. The images characteristics are presented in table 1.

**Table 1 – The main characteristics of the two ENVISAT images**

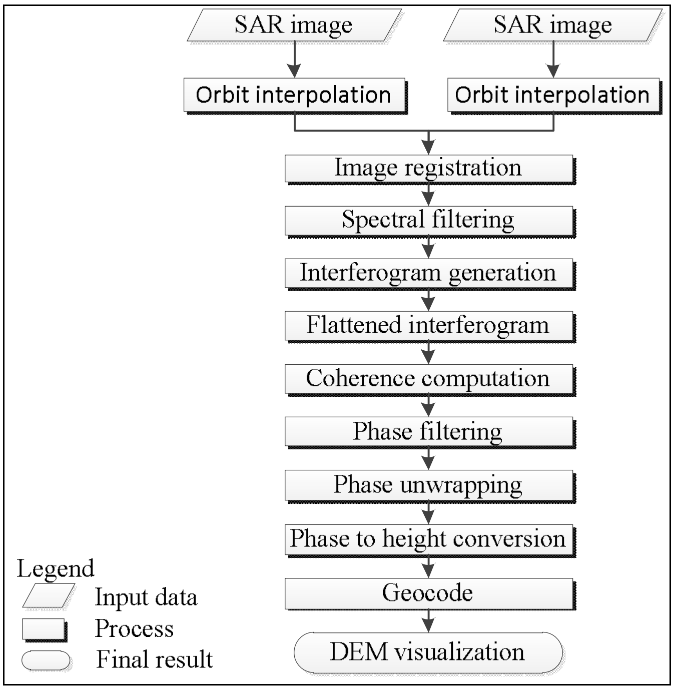
| CHARACTERISTICS | ENVISAT-ASA_IMS_20031203 | ENVISAT-ASA_IMS_20030611 |
|---|---|---|
| **Sensor** | ASAR | ASAR |
| **Acquisition date** | 03.12.2003 | 11.06.2003 |
| **Orbit** | descendent | descendent |
| **Polarisation** | VV | VV |
| **Range resolution** | 7.803975 | 7.803975 |
| **Azimuth resolution** | 4.051959 | 4.052007 |

Source: own creation based on data from images metadata

The InSAR DEM generation is a very complex process mainly because of the nature of the SAR images which are affected by speckle noise. Furthermore, given that SAR sensors are pointing in lateral direction, there are a series of geometric distortions of images (shadows, foreshortening, layover), in general related to the terrain characteristics.

From the two SAR images, a subset of 20000 x 4000 pixels was extracted and then, following the steps presented in figure 5, the digital elevation model of the area was generated using an “in-house” software application.

***Figure 5. Workflow for DEM generation***




Source: own creation.

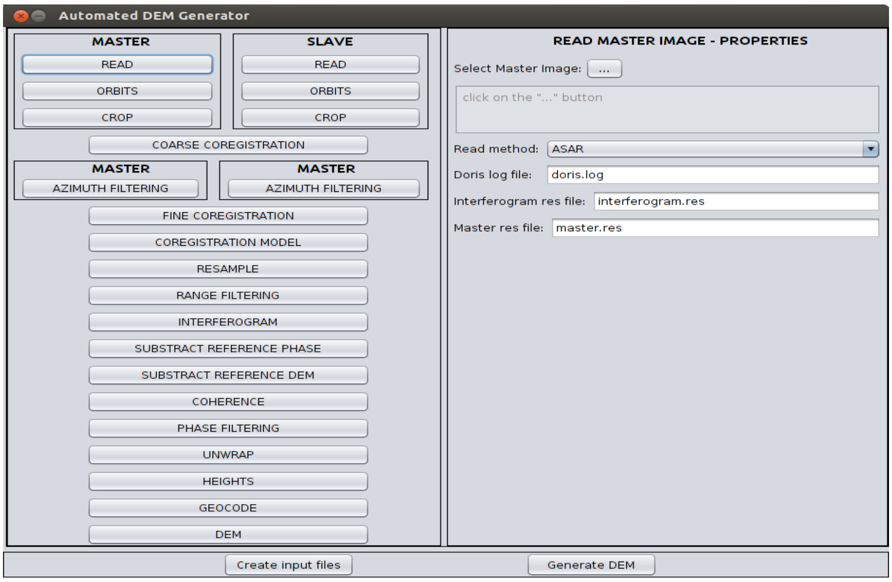
The satellite orbit data show the location of the satellite in the WGS84 coordinate system only for several points, so it is crucial for the next processing steps to find an interpolation method for computing the accurate position at every imaging location (Bin, 2010). The precise orbits were previously downloaded from the internet. For orbit interpolation, a cubic spline function was used. To obtain accurate results for the entire image area, there were considered 15 seconds extra time before the first image line and after the last one. This resulted in a total of 47 interpolated points.

The proposed methodology was applied to an “in-house” software application developed based on DORIS processor created by Delft Institute of Earth Observation and Space Systems. DORIS functions can be called using UNIX commands inside the terminal (Kampes, 2003). This implies that the users know UNIX language and because of that, a solution with a friendly GUI was implemented. Its main purpose is to simplify the process of DEM generation using simple input controls (textboxes, buttons, etc.). The “in-house” software –

Automated DEM generator, was developed in Java language; NetBeans 8.0.2 was used as IDE; SWING library was used to create the graphical user interface.

Basically, the application presents all the necessary steps in order to generate DEMs, for each step the user being able to configure its parameters. For example, as you can see in the image below, for the first step (reading the master image) the user can choose the master image's path, the sensor type, the names of the .log and the results files.

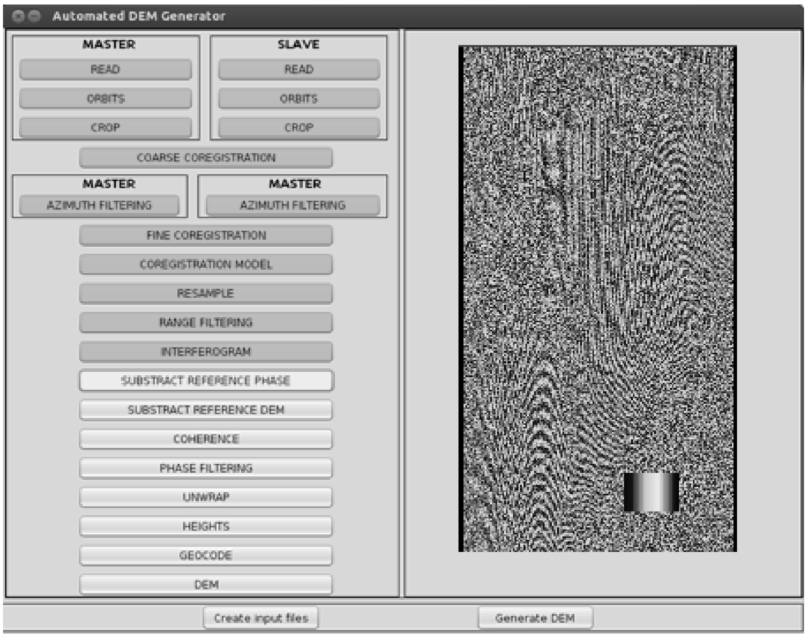
***Figure 6. Graphic interface of Automated DEM Generator application***




Source: preview of the "in-house" software interface.

The application has two main functions: to create the input files from the user input and to generate the DEM. The first function is simply used to test if the selected parameters are well written in the input files. The second function first generates the input files and then, using shell scripts, it calls the corresponding DORIS functions. As this process can take a while, the user can always see which steps where already performed and which step in progress using color coding (green meaning step performed; yellow – step in progress). In the right side we have the preview of the result generated in the last performed step; for example in the image below, the application executes the "Substract reference phase” step and it shows the interferogram obtained in the last step (“Interferogram”).

***Figure 7. Preview of the complex interferogram while executing the subtaction of the reference phase***




Source: preview of the “in-house” software interface during processing.

The correlation between the images was computed in the spectral domain, using 21 correlation windows with a dimension of 64x64 pixels. The total estimated offset was about 212 lines and 19 pixels. The image registration has proven to be the most time consuming step.

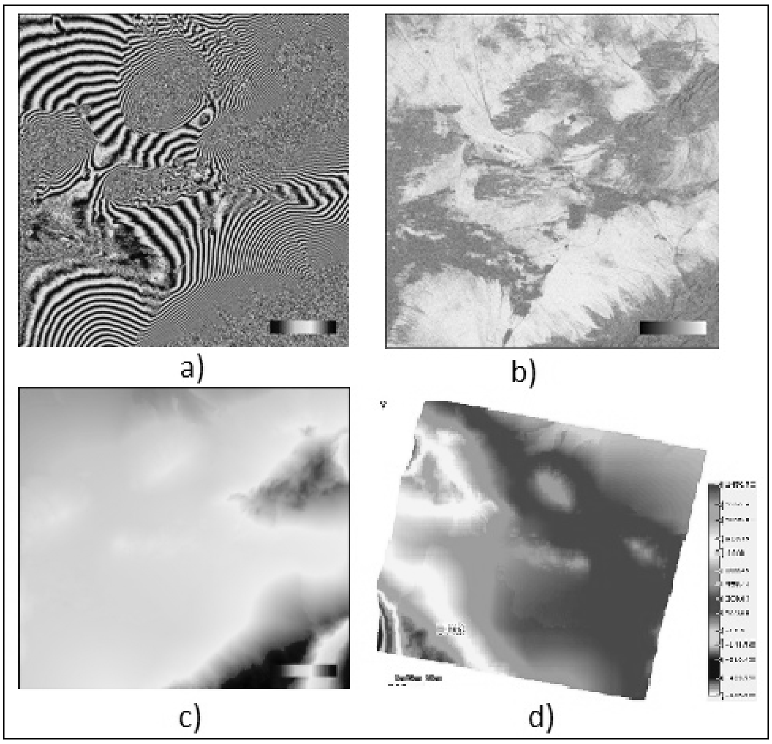
After the interferogram generation, the phase was corrected for the component related to the WGS84 ellipsoid (substract reference phase step). The reference phase corrected interferogram was then multilooked by a factor of 5 in azimuth and 1 in range, which reduced the image dimension to 4000x4000 pixels. Further, the application computed the coherence image, needed by the phase unwrapping function.

For unwrapping the phase, the application automatically calls the SNAPHU (Statistical-Cost, Network-Flow Algorithm for Phase Unwrapping) application which is also an open-source software. For computing the absolute interferometric phase, the MST algorithm implemented in SNAPHU was used.

After phase unwrapping step, the absolute phase values were transformed into heights. The results were represented in the coordinate system of the radar image so in order to be able to compare them with other sources, they were geocoded.

The main results of the InSAR DEM generation process are presented in figure 8.

***Figure 8. Results of the InSAR DEM generation process: a) reference phase corrected interferogram; b) coherence image; c) unwrapped phase; d) final DEM***




Source: own creation; images obtained during the DEM generation process. The original data are copyright to European Space Agency.

Analyzing the coherence map, it was determined that barren surfaces and areas covered with rocks and stones presented a better coherence, while in the mountainous areas, the coherence level was low, mainly due to the slopes and regions where there was no information from the sensor. These areas also caused holes in the final DEM. In the future, it will be of great help to implement in the software application an algorithm for hole filling for obtaining more precised DEMs.

This study has demonstrated that, even if the InSAR DEM generation is a complex process, there can be solutions for automating the process using open-source applications so that it becomes more accessible to anyone, despite the training, to model the topographic surface using SAR data.

## Conclusions

In the past three decades, the increasing number of natural disasters related to climate changes (floods, storms), but also of earthquakes and landslides, led to many deaths and material damages of hundreds of billions US $. All these tragic events represent a major obstacle in achieving a sustainable development so in order to increase the resilience to future disasters new ways must be found and developed to support in all phases of disaster management, from preparedness and risk management to recovery and reconstruction.

An important role in disaster management is played by Earth Observation systems which provide most of the concise and accurate data needed in such unfortunate situations.

DEMs are key element in measuring and monitoring the environment, representing a basic element for 3D simulations of real situations (floods, landslides, etc.) and for calculating the morphological parameters of land.

The automation of DEM generation process is of great importance, enabling us to obtain very useful information about the topographic surface with less effort and without being specialized in remote sensing. Also developing an open-source application, with a user friendly interface, can convince more people to use SAR data for support in disasters management and not only.

### Acknowledgement

This paper has been financially supported within the project entitled "Horizon 2020 - Doctoral and Postdoctoral Studies: Promoting the National Interest through Excellence, Competitiveness and Responsibility in the Field of Romanian

Fundamental and Applied Scientific Research", contract number POSDRU/ 159/1.5/S/140106. This project is co-financed by European Social Fund through Sectoral Operational Programme for Human Resources Development 2007-2013. Investing in people!

## References

Apurba K. Bera, Vishal Singh, Niteenkumar Bankar, Sagar S. Salunkhe, J. R. Sharma (2014), "Watershed Delineation in Flat Terrain of Thar Desert Region in North West India – A Semi Automated Approach Using DEM", *Journal of the Indian Society of Remote Sensing*, March 2014, Volume 42, Issue 1, pp 187-199

Kampes, B., Hanssen, R., Perski, Z., (2003),"Radar Interferometry with Public Domain Tools", in: *Proceedings of FRINGE 2003*, December 1-5, Frascati, Italy

Bin, A., Xia, L., Zheng, X., (2010), "Recontructing high-accuracy DEM with precise orbit data and external DEM", *Progress in Electromagnetics Research M*, Vol. 14, 15–32, 2010

Centre for Research on the Epidemiology of Disasters (2015) "Human cost of natural disasters 2015: A global perspective", Centre for Research on the Epidemiology of Disasters, viewed 28 March 2015, <http://apo.org.au/node/53603>.

Ferretti, A., Monti Guarnieri, A., Prati, C., Rocca, F., Massonnet, D. (2007) – "InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation", ESA Publications, ESTEC, isbn 92-9092-233-8, Noordwijk, Olanda.

Maitre, H. (2008), "Processing of Synthetic Aperture Radar (SAR) Images", Wiley-ISTE Inc., ISBN: 978-1-84821-024-0.

Massonnet, D., Souyris, J.C., 2008 – "Imaging with Synthetic Aperture Radar", EPEL Press, CRC Press, Taylor&Francis Group, ISBN 978-2-940222-15-5.

Munteanu, L-I, Boda, F. (2014), "Environment monitoring using digital elevation models based on satellite data – A tool for sustainable development", Annales Universitatis Apulensis Series Oeconomica, (ISSN 1454-9409), 16(2), 2014, pp. 244-251.

Ozdemir H, Bird D (2009),"Evaluation of morphometric parameters of drainage networks derived from topographic maps and DEM in point of floods". *Environ Geol* 56(7), pp. 1405–1415

Polidori L., Kasser M., 1999 – ''L'interferometrie radar peut elle contribuer au suivi des risques geologiques?'' *Teledetection*, 1999, vol. 1, pp. 95-137

Richards, M.A. (2007), "A Beginner's Guide to Interferometric SAR Concepts and Signal Processing [AESS Tutorial IV]," *Aerospace and Electronic Systems Magazine, IEEE* , vol.22, no.9, pp.5,29, Sept. 2007, doi: 10.1109/MAES.2007.4350281

Rocca F., (2009), "DInSAR and Permanent Scatterers", *ESA Advanced Training Course on Land Remote Sensing*, Prague,Czech Republic

Seyler F., Muller F., Cochonneau G., Guimaraes L. and Guyot J. L. (2009) – "Watershed delineation for the Amazon sub-basin system using GTOPO30 DEM and a drainage network extracted from JERS SAR images". *Hydrological Processes*, vol. 23, 3173–3185.

Youssef, A.M., Pradhan, B., Hassan, A.M. (2011), "Flash flood risk estimation along the St. Katherine road, southern Sinai, Egypt using GIS based morphometry and satellite imagery", *Environmental Earth Sciences*, February 2011, Volume 62, Issue 3, pp 611-623

World Meteorological Organization, "Natural Hazard", viewed April 2015 http://www.wmo. int/pages/themes/ hazards/index_en.html.