QUANTIFICATION OF THE TOPOGRAPHIC SLOPE FROM RADAR SATELLITE IMAGERY

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1. AIM OF THE WORK

A specificity of Synthetic Aperture Radar (SAR) scenes is to display geometric distortions depending on both the system of acquisition ant its relation with the topography [1]. Establishing the geometric relationship between the radar sensor parameters and the related surface deformation should therefore provide quantitative information on the topographic surface. Here, we propose a new technique for the computation of the terrain slope, which is based on the quantification of geometric deformation generated during the acquisition of a SAR scene.

2. APPROACH

Our method is based on the identification of homologous ground segments on both SAR native and orthorectified scenes to compute the local topographic slope. The slope α of a ground segment can be calculated from its azimuth θ relative to the sensor line of sight, its azimuth θ' in the sensor geometry, and the ground incidence angle i of the beam (eq. 1) :

$$\alpha = \arctan\left[\left(\cos\theta - \frac{\sin\theta}{\tan\theta'}\right)\tan i\right] \qquad (eq.\ 1)$$

For each column of the radar scene, the ground incidence angle i is computed from the beam emission angle ε assuming an average ground swath of about 100 km in a spherical Earth model :

$$i = -\arcsin\left[\frac{R_T + h}{R_T}\sin\varepsilon\right] \qquad (eq.\ 2)$$

with R_T = 6371008.7714 m as being the mean value of the semi-major axis of the WGS84 ellipsoid and h the satellite altitude.

For a given ground incidence angle i, we quantified the effect of the topographic slope on the geometric distortion of a SAR image (Figure 1). The graph shows that increasing slope angles produces increasing deviation between the orthorectified and SAR azimuths, leading to a greater distortion of the topography. The amplitude of the distortion is even more enhanced while approaching the sensor line of sight. When the slope angle is larger than the ground incidence angle, the layover effect prevents the identification of any ground segment.

3. TEST SITE

The ENE-WSW-trending Bliji anticline located in the south-central Tunisian Atlas (Jabbour et al., 2007) was chosen as a test site to test and validate our method because it displays large inclined structural surfaces with various dip angles and dip directions [2]. We compared the slope measurements taken in the field with those computed from homologous ground segments identified on radar scenes.

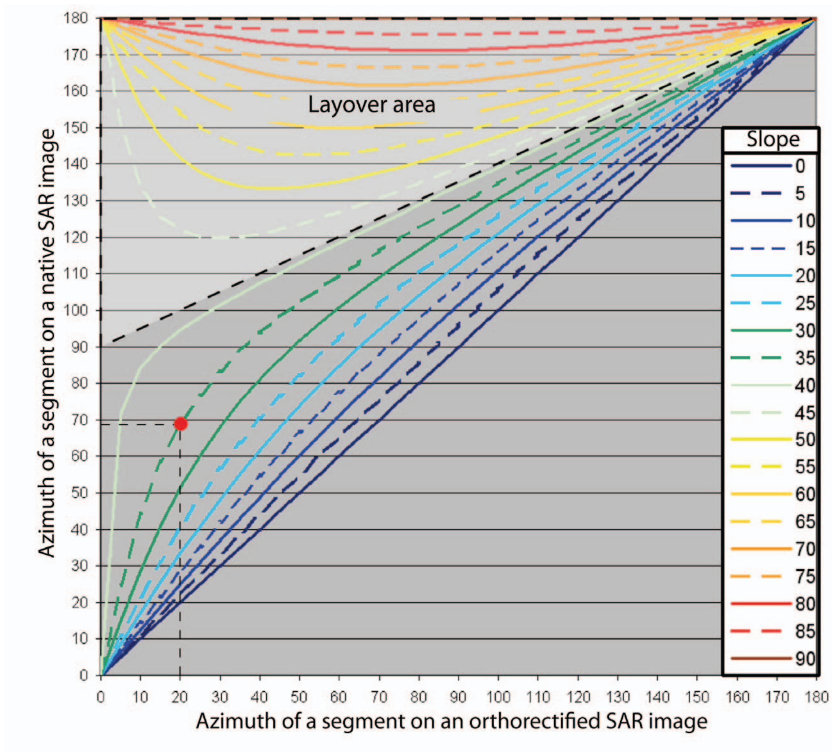

Fig. 1. Graph showing the relationship between the terrain slope angles (vertical chart) and the geometric distortion for the ENVISAT ASAR IS6 beam (incidence angle of 40.95°). The topographic slope depends on both the ground orthorectified *vs.* native radar azimuths and on the ground incidence angle, which increases from near to far range. The different colored lines represent the slope angles for each pixel located on the central row of the image. For instance, homologous ground segments oriented at 20° and 38° on the orthorectified and native SAR images, respectively, indicate a local topographic slope of 35°.

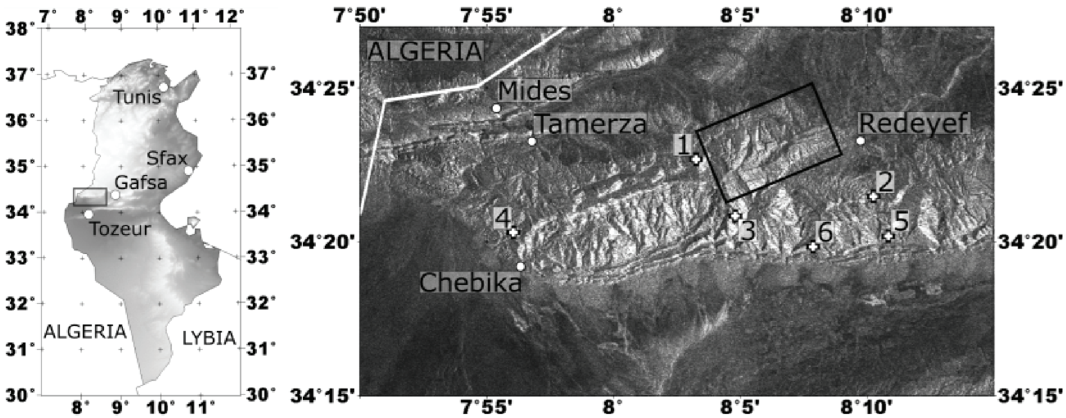

Fig. 2. Left : Location map of the test site area in south-central Tunisia. Right : Extract of a ENVISAT-ASAR image showing the Bliji anticline. The white crosses refer to local test sites. The black rectangle is the location of the high resolution TerraSAR-X image used to refine our measurement.

In order to test our method with different radar acquisition geometries, we used a set of six ENVISAT-ASAR scenes in VV polarization, combining ascending-descending orbits of low (24°, IS2 acquisition mode) and high (41°, IS6 acquisition mode) beam emission angles. We defined six sites as case studies to explore the relationships between the beam angle and the surface geometry (Figure 3). In each site, homologous segments were identified on both orthorectified and sensor geometry images to compute the local slope of the strata. To refine our results in the eastern periclinal termination of the anticline where the dip of the layers changes rapidly, we used a pair of high-resolution (3 m pixel size) TerraSAR-X scene acquired in high incidence mode and an orthorectified radar image generated from a TerraSAR-X DEM at 4.5 m ground resolution. Our results have been ultimately compared with topographic slopes derived for the STRM 3'' and the TerraSAR-X DEM.

4. RESULTS AND CONCLUSIONS

The comparison between the maximum slopes computed from our method and those measured in the field show that the best precision is obtained for hillsides backing the radar illumination using a pair of orthorectified and non-orthorectified images acquired with high incidence angles. In this case, the computed slopes are close to field measurement with an error of only 1.4+/-1.2° and 1.5+/-1.3° for ENVISAT-ASAR (IS6 mode, incidence angle of 40°) and TerraSAR-X (incidence angle of 36°) images, respectively. Such accuracy cannot be obtained neither with the traditional SRTM 3" (error of 10.7 ± 6.9°) nor with the 4.5 m high ground resolution TerraSAR-X DEM (error of 7.9 ± 4.9°). TerraSAR-X data allow identifying smaller geologic objects. However, high resolution radar data may generate low-contrasted scenes, leading to difficulties in the identification of homologous segments and errors in the slope computation.

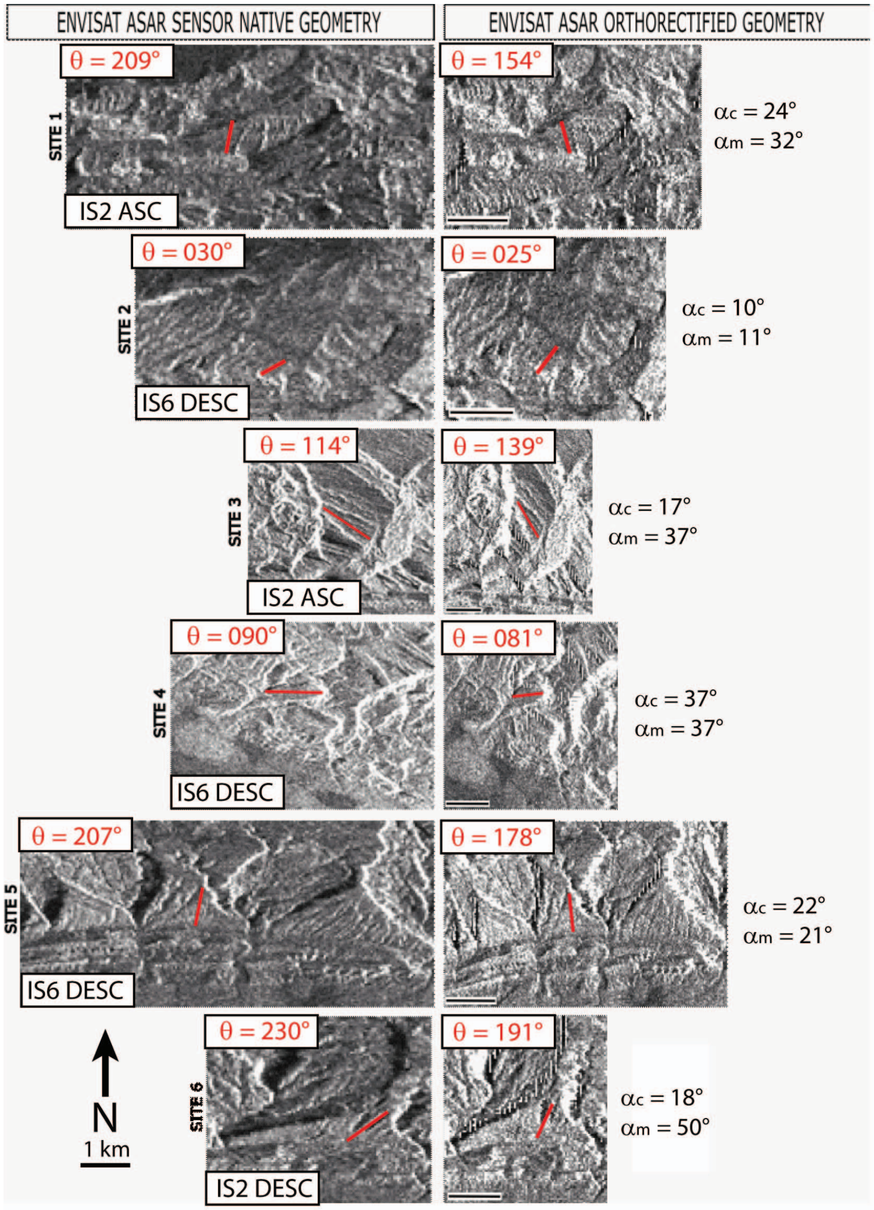

Fig. 3. Azimuths of homologous ground segments (in red) for different SAR native (IS2 and IS6 incidence angles, ascending (ASC) and descending (DESC) orbits) and orthorectified geometries in six sites of the Bliji anticline (see figure 2 for the location of each site). The computed maximum slope (α_c) is compared to the slope measured in the field (α_m).

5. REFERENCES

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