SENSITIVITY OF TOPOGRAPHY ON INSAR DATA COREGISTRATION

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ABSTRACT

In interferometric data coregistration, both the windows and polynomial approaches influence the offsets calculation and coregistration results because of the topography in the area of a SAR image. In this paper, by using precise orbit data of ERS satellite and topographic information, we analyze qualitatively the relation between offsets difference and several influence factors as elevation, distance from near range to far range and perpendicular baseline and the selection of the order of polynomial in different topographies. The results show the DEM influence in range direction has a direct ratio relation with the elevation and perpendicular baseline but an inverse ratio relation with the distance from near to far range, the DEM influence in azimuth direction has a direct ratio relation with the elevation but small correlation with the perpendicular baseline and the distance from near to far range. Moreover, in the polynomial approach different orders of the polynomial are needed in different topographies to achieve more accurate offset result.

1. INTRODUCTION

Coregistration is a crucial step in interferometric SAR data processing, influencing the quality of all consecutive products. Traditionally, the (complex or amplitude) correlation of the two data sets is evaluated in a number of windows distributed over the scene, searching for maximization of the estimated correlation as a function of local offset parameters. After determining the offset parameters for every window position, a two-dimensional polynomial function is evaluated to determine the actual offset for every pixel needed for the resampling of the slave image[1,2,3].

Both the windows distribution and the polynomial evaluation introduce errors in the resampling. First, in the windows approach, only at the window positions the offsets are evaluated, which is not representative for the entire topography of an area. This implies that rough terrain with a large range in altitude will be suboptimally sampled leading to suboptimal results in the coregistration. Second, the polynomial approach requires choosing the polynomial order. In general, for a smooth terrain a low order resampling polynomial might be sufficient, whereas a rough terrain might require a higher order approximation. A suboptimal choice will either lead to a description which is too smooth or which shows overshoot, both affecting coregistration quality. Moreover, in general, the altitude variability may even be non-stationary. This phenomenon can be observed in many interferograms with both flat and mountainous areas-smooth fringes in the flat area but noisy in mountainous areas. This decorrelation may be partly caused by misregistration.

Based on these problems, in this paper the effect of topography on InSAR data coregistration is discussed. In section two, we compare the coregistration offsets calculated with and without a DEM in the azimuth and range directions for one line of SAR data and discuss the relation between the difference between offsets and elevation, distance from near to far range, and perpendicular baseline. In section three we use polynomials of different order to resample the slave coordinates in one line and compare the results. In section four the maps of topographic influence on coregistration are generated corresponding to a real SAR interferometric pair. In section five we give some suggestions to compensate for this topographic influence. Section six contains conclusions and the description of our future work on this topic.

2. TOPOGRAPHIC INFLUENCE ON THE INSAR DATA COREGISTRATION IN THE RANGE DIRECTION

In order to evaluate the influence of topography of the earth surface on the InSAR coregistration, the offsets between the master and slave are calculated with and without topographic information. Without DEM we force point P (Fig.1) on the real earth surface to the corresponding point P_{ell} on the ellipsoid which has the same slant range. Then the coordinate system (line, pixel) of point P_{ell} on the master SAR image is converted to earth-centered Cartesian coordinates (x, y, z) and back to the coordinate system of slave SAR image. In this process the points on real earth surface are forced to lie on an ellipsoid. Definitely this approximation will lead to errors in the results of offsets; the elevation and baseline may influence the calculation of the offsets, in the following this question is discussed starting with one-dimension case for simplicity.

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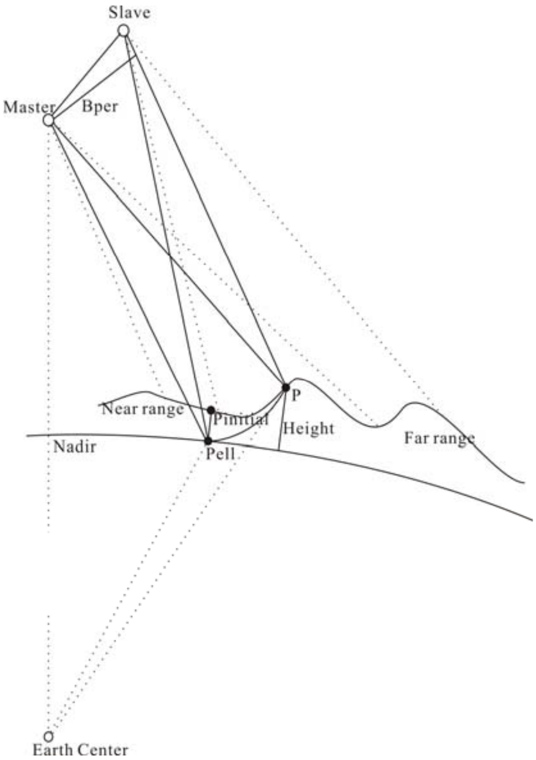

Fig.1. The geometry of offsets calculation in the InSAR coregistration

2.1 Offsets calculation in two cases: ellipsoid approximation and real earth surface

The approaches to derive the coregistration offsets in two cases are described here respectively:

1. Coarse offset derivation with precise orbit data and ellipsoid approximation [3]

Generally there are three steps to calculate the coregistration offsets. First for a point *P*, with certain line and pixel in the master SAR image, the position of point P_{ell} on the ellipsoid is calculated in the coordinate system of orbits. Second, based on the Doppler equation the position of slave satellite corresponding to point P_{ell} is determined, followed by the line and pixel coordinate in the slave SAR image. Third, the offsets are derived by differencing the line and pixel coordinates in master and slave SAR image.

2. Offsets derivation with precise orbit data and digital elevation model

When we take the height of the pixel into account, the position of point *P (x, y, z)* on the real earth surface needs to be derived. In this process, the key step is to find the coordinate (*x, y, z*) of point *P* on the earth surface from a initial point $P_{initial}$. This algorithm can be described as following:
The inputs of this approach include:

- The DEM (e.g. SRTM)
- SAR image parameters (pulse repetition frequency (PRF), range sampling rate (RSR), time interval to first pixel, time of the first line of SAR image in second of the day, geodetic coordinate of scene center)
- Precise orbit data during master and slave acquisition
- Semi-major and semi-minor axis of ellipsoid

We convert the coordinates $(line, pixel)_M$ in master SAR system of the first and last pixel in one line to earth centered Cartesian coordinates *(x, y, 0)* on the ellipsoid and to geodetic coordinates *(lat, lon, 0)*. Using the geodetic coordinates of the first and last pixel we extract a profile corresponding to this line from the SRTM DEM.

We calculate the slant range S_P of point *P* and convert point P $(line, pixel)_M$ to geodetic coordinate of point P_{ell} and find the point $P_{initial}$, normal to P_{ell} in the DEM profile. From near to far range we calculate the earth-centered Cartesian coordinates and slant ranges of every pixel of DEM profile from point $P_{initial}$ till the slant range is longer than the slant range of point *P*, we assume this DEM pixel number is *n*, then we interpolate the DEM profile from pixel *n*-2 to *n*+2 to 32 pixels and calculate the earth-centered Cartesian coordinate *(x, y, z)* and slant range *S* of every pixel, so *x, y, z* are functions of slant range *S*, we can find the coordinate $(x, y, z)_P$ of point *P* by interpolation.

Finally we convert the coordinates of point *P*, $(x, y, z)_P$ to $(line, pixel)_S$ in slave SAR image coordinate system. Using precise orbit data of slave satellite, the offset equals $(line, pixel)_S-(line,pixel)_M$.

Using this approach the offsets in azimuth and range directions of one line of the SAR image can be calculated with precise orbit data, and precise orbit data together with DEM respectively. In order to test this procedure the precise orbit data, parameters of a real interferometric pair with orbits 22388 and 13236 and SRTM DEM covering the SAR image are used. The perpendicular baseline of this interferometric pair is –1776m, see Fig.2.

2.2. Factors influencing the offsets difference

In order to know the relation of coregistration offsets difference with distance on range, elevation and perpendicular baseline, we need to investigate these factors respectively. Several simulations are listed here.

1. Offsets difference with distance from near range to far range in one line

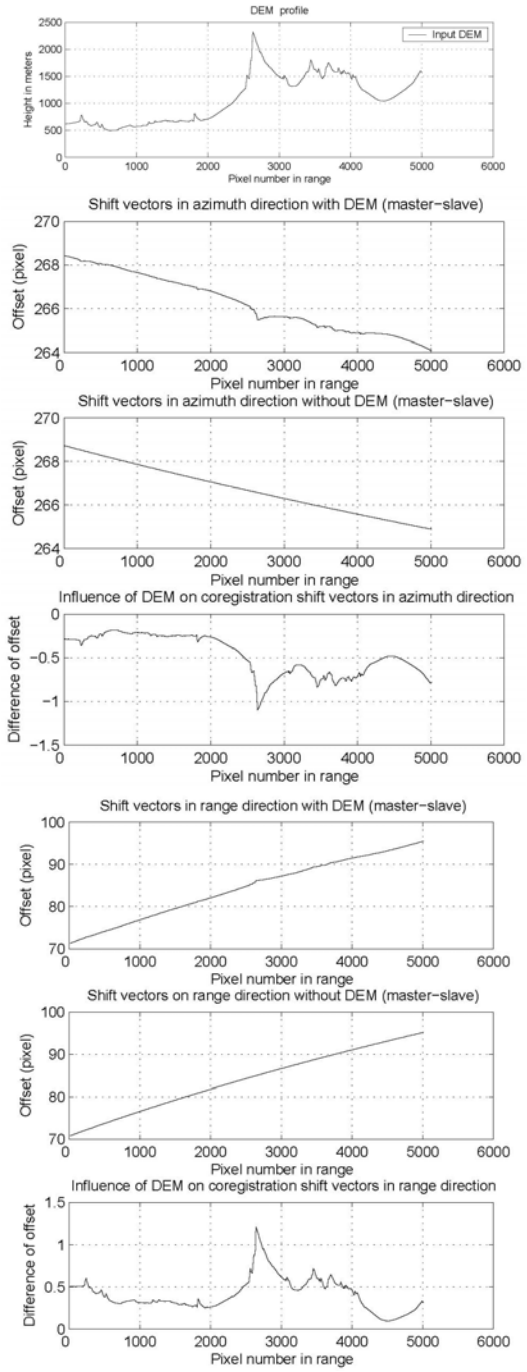

Fig.2. Offsets in two cases and their differences in one line

In this simulation, the elevation of DEM profile is kept as a constant of 3000 meters, the perpendicular baseline is –1776 meters, and we calculate the offsets with and without DEM information. The offset differences from pixel 1 to 5001 in range direction are shown in Fig.3. The range offset differences decrease from 2.42 pixels to 1.10 pixels from near to far range, whereas the absolute values of azimuth offset differences first decrease from 1.54 pixels to 1.45 pixels and then increase from 1.45 pixels to 1.51 pixels in the range direction

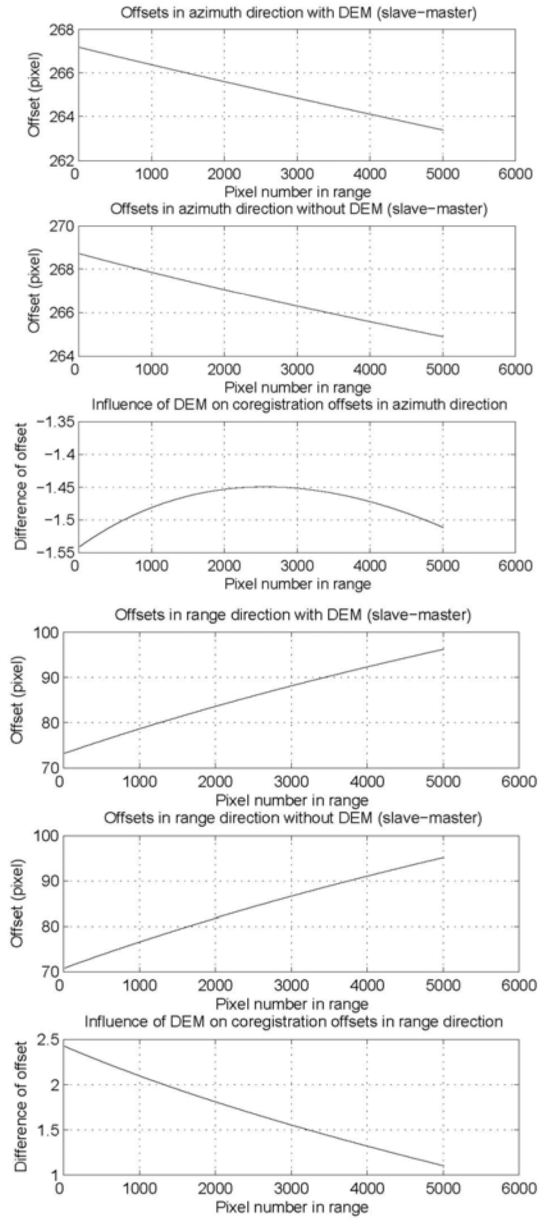

Fig.3. Offsets difference with distance (from near range to far range)

.2. Offset differences with heights of points on the earth surface

In this simulation, we keep the distance in the range direction a constant but increase the elevation linearly from 100 to 8000 meters and use the perpendicular baseline of –1776 meter. The results are shown in Fig.4 showing the elevation influence on coregistration increasing along with the increase of elevation in both azimuth and range directions.

The offset differences in azimuth direction increase from 0.02 pixels to 4.21 pixels, the absolute values of offset differences in range direction increase from 0.09 pixels

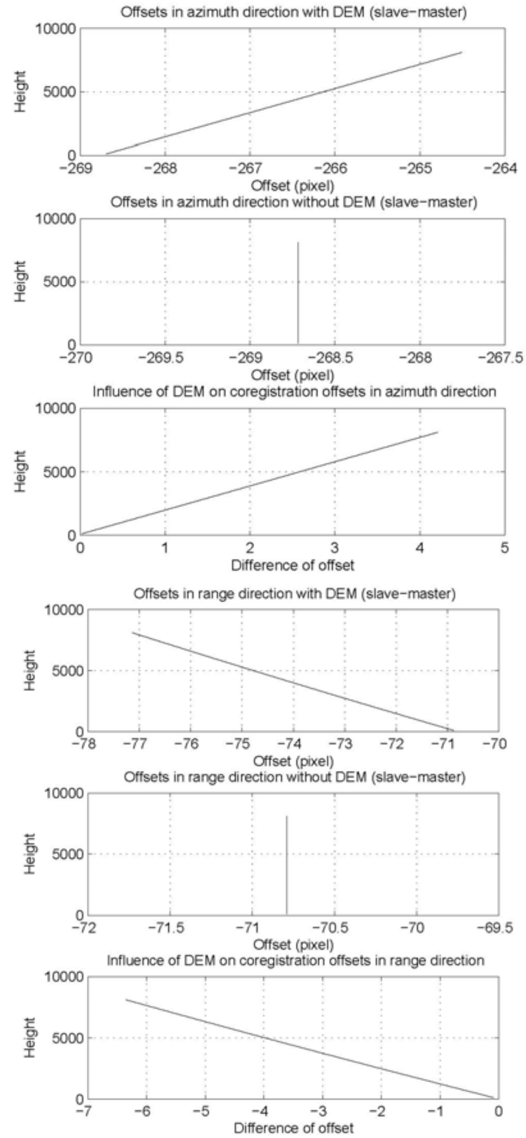

Fig.4. Offset differences with height

to 6.35 pixels when the elevation increase from 100 to 800 meter. The offset difference is almost a linear function of elevation.

3. Offset differences with perpendicular baseline

In this simulation, we keep the distance a constant and elevation 3000 meter but increase the perpendicular baseline from 0 to 2000 meter. The offset differences in azimuth and range are shown in Fig.5. The results show that changing the perpendicular baseline has a very small influence in the azimuth offset differences, which is as expected--theoretically this influence should be zero. However for the range offset differences, it increases from 0.28 pixels to 1.11 pixels with an increase of perpendicular baseline from 0 to 2000 meter, The offset differences in the range direction is also almost a linear function of perpendicular baseline.

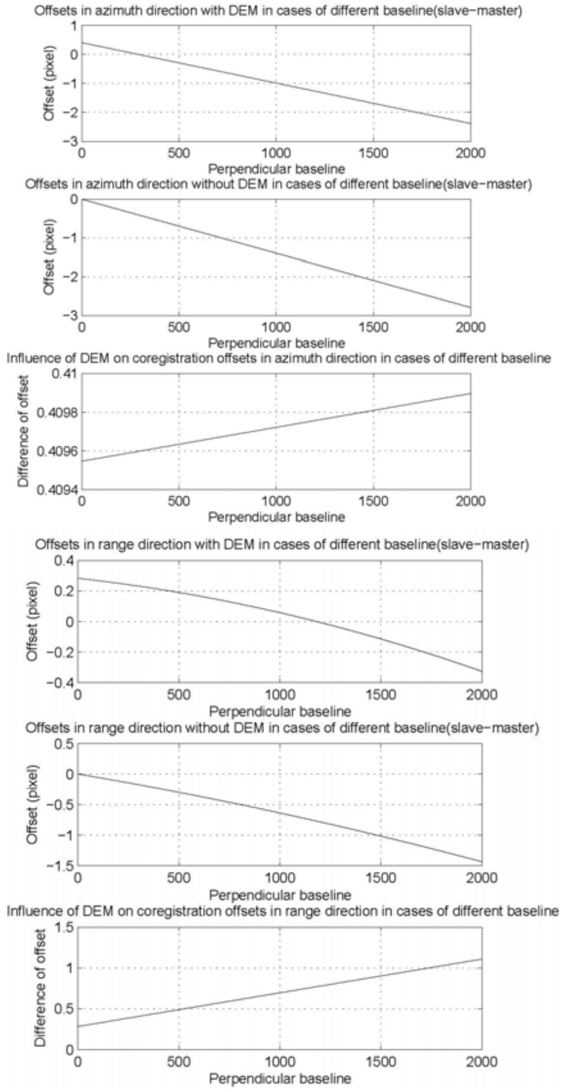

Fig.5. Offset differences with perpendicular baseline

4. Offset differences with height and perpendicular baseline

Here we keep the distance the nearest range constant and increase the perpendicular baseline from 0 to 2000 meter, and the elevation from 200 to 4200 meter. The results are shown in Fig.6. The offset differences in the azimuth direction have almost no correlation with the perpendicular baseline, which is the same result as in Fig.5--it only increases with increasing elevation. The offset differences in the range direction increases with both the increase in elevation and perpendicular baseline. In order to see the exact values, a contour map of the offset differences in the range direction is shown in Fig.7A.

The minimum value of offset difference in range direction is 0.28 pixels and the maximum value is 3.71 pixels. In Fig.7A, the contour step is 0.5 pixels, in the area of values smaller than 0.5 pixels, although the

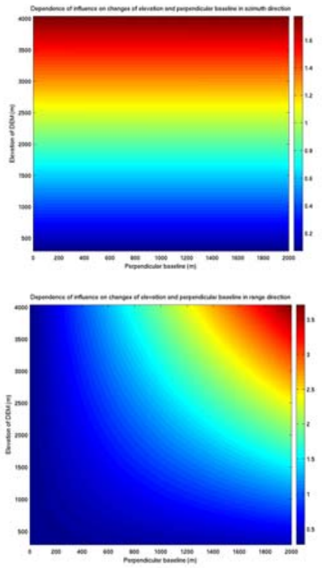

Fig.6. Offset differences in azimuth and range directions with height and perpendicular baseline

influence of perpendicular baseline and elevation is not large enough to blur the interferogram totally, it still need to be compensated for. In order to see the elevation influence corresponding to the critical baseline of ERS SAR, we plot an offsets difference profile of 1030 meters perpendicular baseline in Fig.7B. An elevation increase from 200 meter to 4200 meter results in an offset difference increasing from 0.37 pixels to 2.05 pixels.

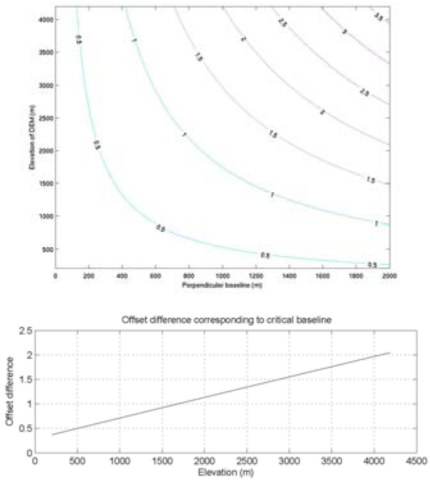

Fig.7. (A)Contour map of offset differences in range direction as a function of elevation and perpendicular baseline, (B) Offset difference corresponding to critical baseline

3. DIFFERENCE BETWEEN OFFSETS CALCULATED WITH TOPOGRAPHIC INFORMATION AND BY POLYNOMIAL RESAMPLING

Traditionally we use windows in the SAR image in the coregistration and calculate the offsets on the position of these windows; the offsets are used to calculate the parameters of a two-dimension polynomial which is used to resample the slave image to the coordinate system of master image. The offsets on the position of these windows can't represent the entire topography in the SAR image, but the coregistration offsets are correlated with the elevation and distance from near to far range as the analysis we did above, there should be a difference between the offsets calculated with DEM information on every pixel and those determined by polynomial resampling. This difference should have a relation with topography. In order to demonstrate this, we calculate the offsets with DEM and precise orbit data on 5000 pixels in one line, and use the offsets every 100 pixels to calculate the parameters of polynomial and result offsets by polynomial resampling. In this computation the perpendicular baseline we used is –1776 meters, the input DEM profile is the same one as in Fig.2. We resample the offsets by polynomials with the second (red curve), fourth (green curve) and eighth orders (magenta curve) respectively, the results are shown in Fig.8.

We first use a second order polynomial to resample the offsets, in most parts of this offset profile corresponds to smoother topography the second order polynomial can fit the offsets curve well, which can be seen from the upper figure of Fig.8, but there is a much steeper topography from 2500 pixel to 3000 pixel corresponding to a mountain, the second order polynomial can not fit the offsets well in this part. Then the fourth and eighth order polynomial are used to resample the offsets, the comparison results are shown in the lower figure of Fig.8, which is zoomed in from the part in the rectangle of the

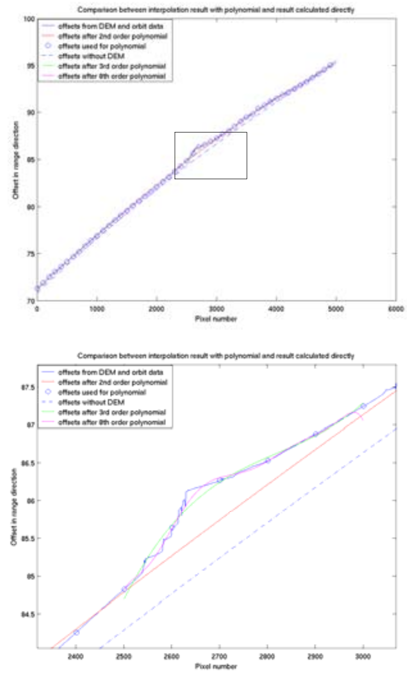

Fig.8. Difference between offsets calculated with DEM and that by different order polynomial resampling

upper figure. In the lower figure of Fig.8, the fourth order polynomial fits the offsets curve better than the second order polynomial does, the eighth order polynomial fits the offsets curve best but costs much more time. The analysis shows different orders of the polynomial are needed in different topographies in order to get more accurate coregistration offsets.

4. DEM INFLUENCE ON THE INSAR COREGISTRATION IN BOTH AZIMUTH AND RANGE DIRECTIONS

In section two, the topographic influence on InSAR coregistration is analyzed only in range direction, now we extend this analysis to two dimensions of both range and azimuth directions. We input a SRTM DEM with 30 meter resolution and resample the DEM to the resolution of 113 meter. Fig.9 is the DEM corresponding to the calculation area of the SAR image. We use the parameters of interferometric pair of orbit 22388 and 13236, with a perpendicular baseline of –1776 meter. The result of offsets calculated with and without DEM and offset differences in both azimuth and range direction are shown in Fig.10.

We calculate the offset differences line by line. It has been demonstrated in section 2 that the offset differences is consistent with the topography in range direction. In Fig.10 the DEM influence on coregistration has the same figure with the DEM in both azimuth and range directions, the maximum influence of DEM is 1.5 pixels in azimuth direction, 1.6 pixels in range direction. Using precise orbit data and topographic information in the area of SAR image, we can tell the range of topographic influence on the coregistration for any interferometric pair.

5. CONCLUSIONS

This paper describes the topographic influence on the InSAR data coregistration and orders selection of the polynomial in condition of different topographies. Several factors such as elevation, distance from near range to far range and perpendicular baseline are analyzed, their relations to the coregistration offsets difference are described qualitatively, the absolute values of the offset differences in the range direction has a direct ratio relation with the perpendicular baseline and elevation but a inverse ratio relation with the distance, whereas the absolute values of the offset differences in the azimuth direction has a direct ratio relation with the elevation but no relation with the perpendicular baseline theoretically. By calculating the topographic influence in two-dimension case, we can tell the magnitude of the topographic influence corresponding to the area of SAR image. Our purpose is to compensate the topographic

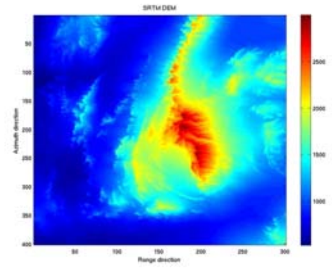

Fig.9. SRTM DEM corresponding to the calculation area of SAR image

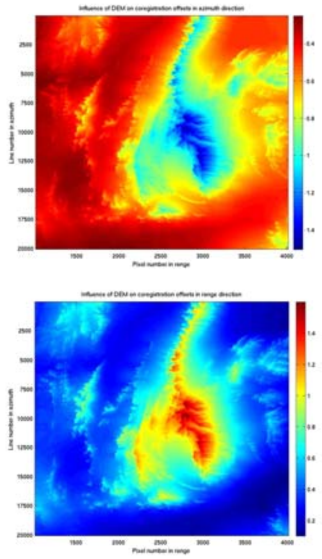

Fig.10. DEM influence on InSAR coregistration in both azimuth and range directions

influence in the InSAR data coregistration to get more accurate offsets, the qualitative analysis of the influencing factors is not enough for us to do the compensation, the next step of our research is to explore a quantitative relation between these factors and the offset differences, a mathematic analysis is needed in the topographic compensation in InSAR coregistration.

In the polynomial approach of the coregistration, it is clear to see from our analysis that different topographies need different orders of the polynomial, but how to determine the order of polynomial for a certain topography is still a question, the roughness, incidence angle and other factors need to be investigated further.

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