DEM GENERATION FROM SAR IMAGE – AN EXPERIMENT IN KAGOSHIMA REGION, SOUTH JAPAN

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ABSTRACT

Radar technology has advanced rapidly and has contributed much to mapping, updating, and topographical simulation. Synthetic Aperture Radar (SAR) is one of great advance, the image are able to be acquired in inclement weather or during the night. SAR systems take advantage of the long-range propagation characteristics of radar signal and the complex information processing capability of modern digital electronics to provide high resolution imagery.

This paper describes about DEM generation using InSAR. The data has been used in this study is JERS-1 image of Kagoshima, south of Japan. Like all Synthetic Aperture Radar (SAR), JERS-1 is very sensitive to the terrain shape. With two pass raw signal data in L-bands synthetics aperture Radar instrument acquired in 2nd March 1997 and 15th April 1997, height map has been generated based on the ground control points (GCPs) derived from topographical map. The DEM was generated using two methods unwrapped phase (Branch Cut algorithm, Minimum Cost Flow). The results have been compared with reference DEM 50m to confirm the sufficient accuracy.

1. INTRODUCTION

Since the first space borne system, DEM generation has been mainly based on optical imagery and photogrammetry techniques. SAR images recently have gained progress in technology the DEM can be generated using the phase of the Radar signal (Interferometric techniques).

SAR interferometry for DEM generation was proposed by Graham in 1974 [Graham 1974] and applied airborne data for the first time in 1986 [Zebker and Goldstein 1986], and continued by Li and Goldstein (1990), Rodriguez and Martin (1992) and Zebker et al. (1994). Today SAR data from several space borne sensors (e.g. SIR-A, B, C; ERS-1, 2; JERS and Radasat) are available and large number of research groups are working on InSAR DEM generation. There is some software for Radar processing, among them GAMMA is one of the robust software with proven abilities. GAMMA supports the entire processing from SAR raw data to products such as digital elevation models, deformation, and land use maps. For DEM generation function, we have MSP module, ISP module and Geocoding (DIFF&GEO) module available.

2. OVERVIEW ABOUT THE SAR INTERFEROMETRY AND DEM GENERATION

A Synthetic Aperture Radar (SAR) works by illuminating the earth with a beam of coherent microwave radiation. This radiation can be described by three properties; wavelength, amplitude and phase. The wavelength is the distance between peaks on the wave. The amplitude is the displacement of the wave at the peak that corresponds to the brightness

of light for SAR images and show mountains, rivers, lakes, cities and other useful information. The phase describes the shift of the wave from some other reference wave. Phase is usually measured in angular units, such as degrees or radians. If two waves are not shifted with respect to one another, they oscillate together and are "in phase" or have a phase shift of 0 degrees. However, if two waves are oriented oppositely, or one wave is at a peak while the other is at a trough, they are "out of phase", or have a phase shift 180 degrees.

We suppose that, if there is a region that has been imaged twice at two different positions, then the phase will be different. These phase differences can be used to generate the DEM of the surface. This is the basic concept of SAR Interferometry and such a phase difference image, called interferogram, is the basis for this technique. Since the phase difference can be measured only in the interval $[0, 2\pi]$, the interferogram is characterized by a pattern of fringes, each one representing the difference in distance corresponding to a phase cycle.

In order to obtain an analytical estimation of the required orbit accuracy for In SAR applications, the mathematical dependency of the interferogram phase from the SAR sensor and the object position have to be understood. Basic geometry for repeat-pass JERS −1 SAR shows in figure 1
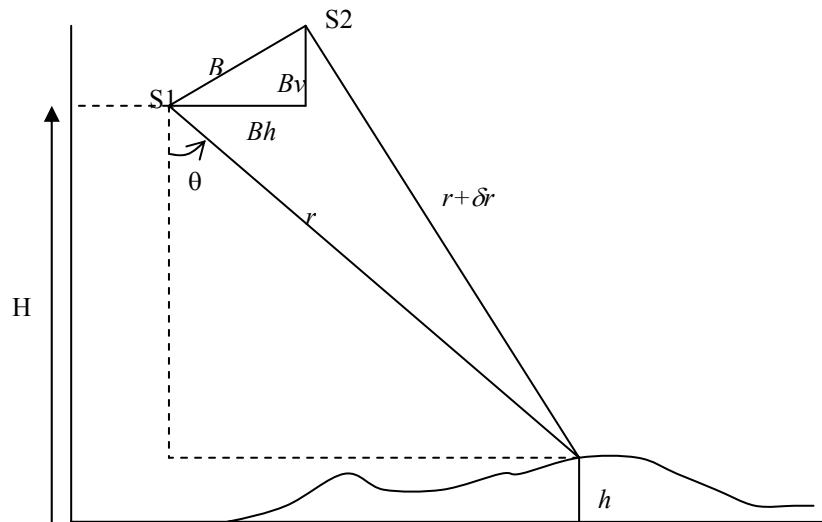

Figure 1: JERS-1 SAR geometry

The phase difference between two Radar signals acquired from the same surface element at the two antenna positions according to Li and Goldstein, 1990, can be calculated as:

$$\phi = 4\pi(\delta r)/\lambda = 4\pi(B_h\sin\theta - B_v\cos\theta)/\lambda \tag{1}$$

where λ is the wavelength, δr is the range difference, B_h, B_v are baseline horizontal component, baseline vertical component and θ is the look angle

Based on the range difference and the look angle changes through the scene, the phase difference (interferometric phase) between two sensor positions and the target terrain point (pixel wise) can be generated

After we have the interferogram phase, the next task is height conversion from phase. The terrain height may be determined using several methods that convert phases into terrain heights. The below equation using normal base line method operates on unwrap phase where change in the height of the terrain is related to the change in the phase (Rao and Rao, 1999)

$$\Delta h = \frac{\lambda r \sin \theta}{4\pi B} \Delta \phi \qquad (2)$$

r is the range in the first image, $\Delta \phi$ is the change in phase
B is normal base line

Thus, utilizing the above mentioned step, the relationship between the heights and the phase differences can be determined. The height determined for each pixel of SAR image form the necessary DEM in raster form. In order to get high accuracy the base line has to be estimated more exactly, there fore the number of the ground control points should be enough and distributed in the entire image.

3. DEM GENERATION BY GAMMA SOFTWARE, STUDY AREA IS KAGOSHIMA

Kagoshima is located in Kyushu Island. Two JERS-1 L band have been acquired on 2nd March 1997 and 15th April 1997. The cover location of the image about 31^0 30 N, 129^0 59' E and 32^0 30' N, 131^0 00 E

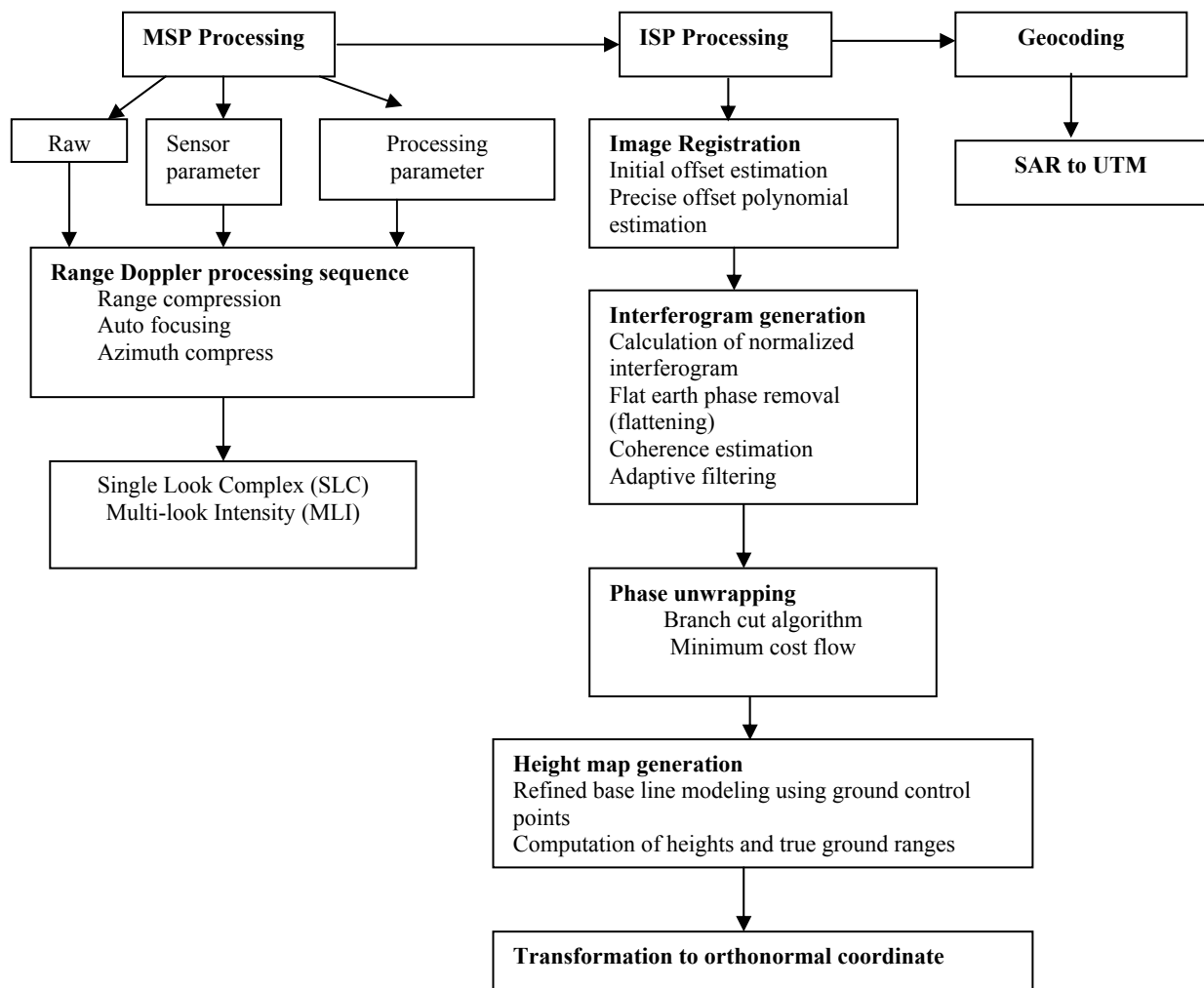With Gamma software, the DEM generation has the flow chart in Figure 2.

Figure 2: Flow chart showing the GAMMA SAR processing chain for the production of an interferometric DEM

3.1 MSP processing

The raw data has been processed with the functions: Doppler ambiguity estimation, missing line detection, filtering, range compression, auto focus azimuth compression. The results are single look complex file and multi look complex file, Figure 3(a) showed the multi look complex file of Kagoshima.
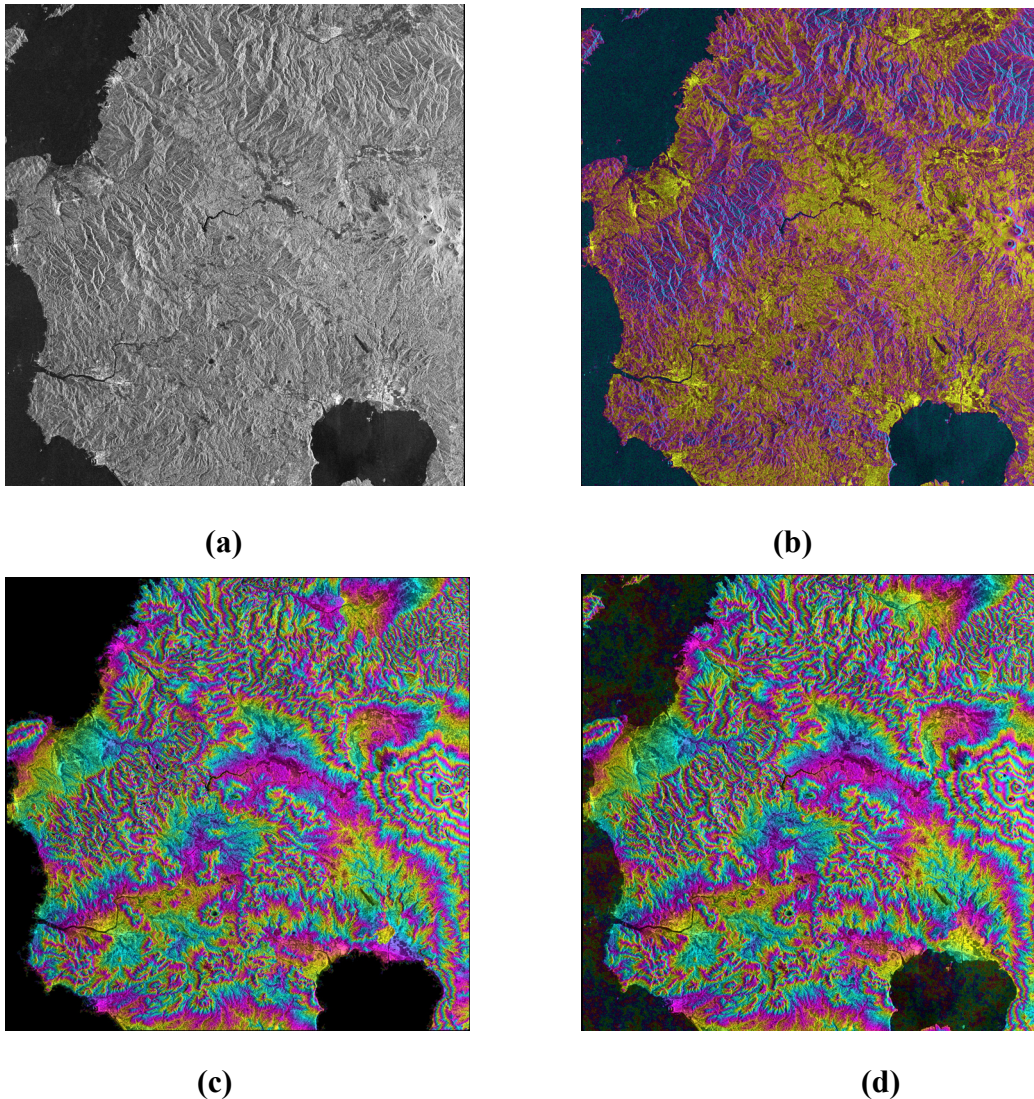

(a)

(b)

(c)

(d)

Figure 3: (a) Multi look image, (b) Coherence image (blue color is low coherence, yellow color is high coherence), (c) Unwrapping phase by Branch cut algorithm, (d) Unwrapping phase by Minimum cost flow (height map with 160 m for one color circle)

3.2 ISP processing

3.2.1 Image registration

Interferometric processing of complex SAR data combines two single look complex (SLC) image S1 and S2 in to an interferogram.

The image registration offsets are modeled as bilinear function in range and azimuth. Determination of the offset polynomial coefficients is the first step in interferometric processing (Zebker et al., 1994). The co-registration of the images is performed by calculation of the local spatial correlation functions for up to some 1000 small areas throughout the images.

3.2.2 Interferogram Computation

The two co-registered single look complex (SLC) are used to create the interferogram through common spectral band filtering. Then base line is estimated determination for flattening the interferogram purpose. The next step is coherence estimation. The cross correlation operation is performed over a small local area surrounding each pixel in the interferogram. The area size should be large enough to get a good correlation estimation, but small enough to produce a coherence image with good spatial resolution. Over 80% coverage of full scene has coherence greater than 0.5 that permitted a quite accurate SLCs co-registration. Figure 3(b) illustrates the coherence of Kagoshima data.

3.2.3 Phase unwrapping

As the height of the terrain increases, the phase also increases steadily. Since phase's value is periodic function of 2π, they automatically get wrapped after reaching 2π, which is not desirable situation. Phase unwrapping is a technique that permits retrieving the unwrapped phase from the wrapped phase, which is necessary step for the generation DEM from InSAR (Fornalro et al., 1996)

GAMMA provides two methods Branch cut algorithm and Minimum cost flow algorithm

Branch cut algorithm

The principle of branch cut algorithms is to restrict the integration through the image to paths with local phase differences in the interval (-π, π). Summing the phase finite differences about short circular paths permits localization of discontinuities in the wrapped phase field. If the sum is non-zero, a so-called "residue" lies in the region. The residue value or "charge" can be positive (+1) or negative (-1) depending on the sign of the sum. Line segments (branches) are drawn between positive and negative residues in a systematic way to function as barriers during the path integration that can not be crossed. This discharging of residues results in a discharging, path independent solution. The basic idea of the *branch cut* algorithm and first implementation were presented by Goldstein (Goldstain et al., 1988). The goal of the algorithm is to connect residues in such a way that minimizes the net length of branches. Construction of new tree begins by finding an unvisited residue and connecting to its nearest residue neighbor, regardless of sign. A line "branch cut" is drawn connecting this residue to the neighbor.

Figure 3(c) shows phase unwrapping by *Banch cut algorithm* of Kagoshima data

Minimum cost flow and triangulation

The *Minimum cost flow* problem defines a network consisting of nodes and directed arcs. Associated with each of the arcs are a flow, a cost per unit flow, and an arc capacity. Flow moves from source nodes to sink nodes though the network arcs. Nodes that are neither sources nor sinks are trans-shipment nodes. The MCF problem solution gives the optimum flow in each of the arcs that minimize the total cost. The total cost is defined as the sum of cost for all the arcs flows. In the MCF paradigm flows are integer quantities.
With this method a nodes is associated with each of the local closed paths used to evaluate the residues. Sources nodes are associated with the positive residues and sink nodes with the negative residues. The network is not a rectangular network but a triangular irregular network (TIN) that is more flexible, for example incase of disconnected areas of high coherence. The pixels lie between the network arcs and nodes. When calculating the unwrapped phase by summing along the path, the gradient is adjusted if there is flow in the arc crossing the path of integration

The cost per unit flow assigned to each arc is critical parameter in the optimization process. The cost should be low at the place of a real discontinuity. Generally, it should rather be expensive to cause of phase jump in an area of low phase noise and inexpensive in noisy regions. In the implementation weight factors in the interval (0.0, 1.0) can be indicated; for simplicity the cost are calculated in such a way that the coherence or a similar quantity can be used as weight factors.

Figure 3(d) show phase unwrapping of Kagoshima by *Minimum Cost Flow* method

3.2.4   Phase to height conversion

Phase to height conversion is a method to convert from unwrapped phase image to a height image with unit of meters. A first estimate of the interferometric base line was determined from the orbit (tract) data or the average interferogram fringe frequency. Refined base line was estimated using the ground control points (GCP) base on least square method. The GCPs with heights has been chosen on the topographical map. The unwrapped interferometric phase together with the precision base line is then used to derive the topographic height and true ground range.

In the study area, the digital topographical map 1/50,000 has been used; we chose 54 points in the entire image.

3.3   Geocoding

Geocoding, that is a transformation between the coordinate of an imaging system; in this case range Doppler coordinate of SAR, and orthonomal UTM coordinates. Geocoding is necessary to combine information retrieved by the imaging system (e.g. the SAR image and products derived from it) with information in map coordinates (e.g. a digital elevation model, a land-use inventory, geocoded information from optical remote sensing, etc.). The position of SAR image point (pixel) is on a specific circle around the velocity vector of the sensor (intersection of Doppler cone and sphere for constant range). The intersection of this circle with the ground surface together with the knowledge that the SAR is either right or left looking determines the target location and the look vector.

DEM for Kagoshima region was transformed to UTM coordinate (WGS84, zone 52), figure 4(a) shows the DEM produced using Minimum Cost Flow method

4.   ACCURACY EVALUATION

With 54 points of heights that was chosen on topographical map, the base line was estimated with the mean square height error 26.739 m (Minimum Cost Flow method) and 32.546 m (Branch cut algorithm method)

The precision of the DEM generation from InSAR image are assessed by using the reference DEM, 50 m resolution has been made from topographical map, figure 4(b)

Two DEM of Kagoshima after geocoding in to UTM system have been imported to GRASS GIS. Figure 4(a) shows the DEM from Minimum cost flow method.

Using function *r.mapcalc* in GRASS for analysis, overlaying two DEM with the reference DEM and find out the difference of elevation between Branch cut method with reference DEM and Minimum cost Flow method with reference DEM.

Table 1 shows the comparison by percent, with the Branch cut method the different elevation at -2 m to 2 m is 23.2 % and Minimum cost Flow is 25.1 %, it is quite near, but at the different elevation -50 to -25 m the first method is 25.6% and the second method is only 11.8 %. We also show the difference in elevation between Minimum cost Flow with the reference DEM in Figure 4(d)

Methods Different elevation	Branch cut Algorithm	Minimum Cost Flow
-50 m to -25 m	25.6%	11.8 %
-25 m to -2 m	12.4%	16.2%
-2 m to 2 m	23.2%	25.1%
2 m to 20 m	13.3%	19.7%
20 m to 40 m	11.5%	16.6%
40 m to 70 m	14%	10.6%

Table 1: Comparing the different height between two methods with reference DEM

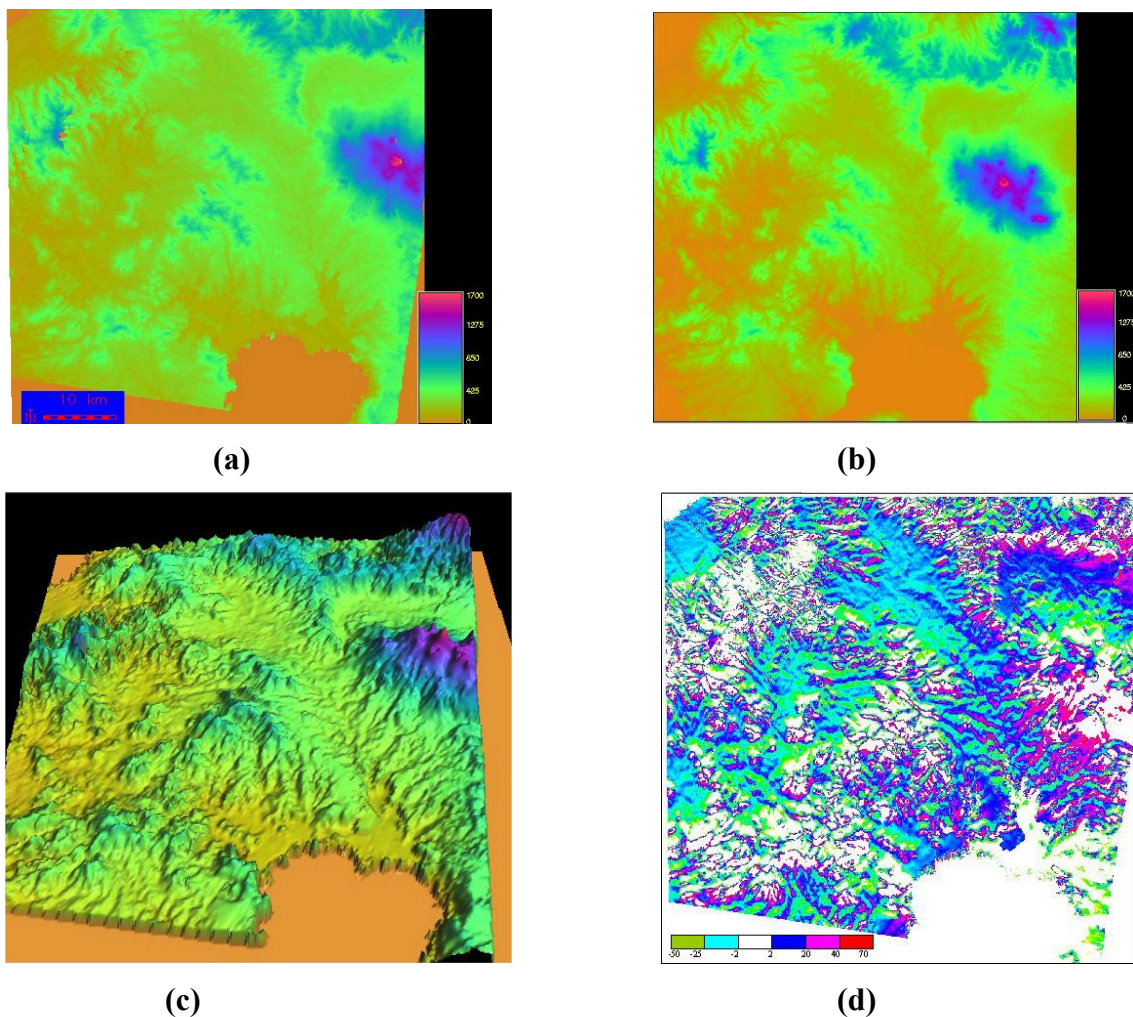**(a)**

(b)

(c)

(d)

Figure 4: (a) DEM from Minimum Cost Flow, (b) reference DEM from topographical map, (c) 3D view from Minimum Cost Flow method (d) The difference between DEM from Minimum Cost flow method with the reference DEM.

5.   CONCLUSION

After carrying out DEM generation from SAR using GAMMA we have some conclusions:

The first important problem for making DEM from SAR is the coherence between two images. It is a decision for unwrapped phase good or bad, if the low coherence has been used then the unwrapped phase would be bad and the accuracy of DEM generation is also bad.

The second problem is not so less important that is unwrapped phase, when high coherent phase was created, choosing unwrapped phase method is a decision for DEM generation with high precision. With *Branch cut Algorithm*, the processing with layover, foreshortening and shadowing will create a lot of gaps. In order connecting such gaps, the "bridge" function has been used, but it is not advantage, the optimization is done on a local rather than on a global basis. The *Minimum cost flow* method supported the global optimization and automated in unwrapping of disconnected areas of high coherence, the result has been proved with our practice in Kagoshima.

The last one is the control points (GCPs), in order to get the high accuracy in elevation interpolation, the GCPs should be distributed over the image. The height of each GCP is chosen on topographical map will be less precise than the height which measured on the field by GPS instrument. Therefore with the tasks high accuracy DEM requirement, we should collect the GCP from the field.

In general, for DEM generation excepting the software and the method we need very careful in choosing the parameter, this fact requires users to have a deep understanding about theory and basis of SAR and algorithm used in software clearly.

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