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Digital Elevation Model (DEM) Generation with Repeat Pass Interferometry Method Using TerraSAR-X/Tandem-X (Study Case in Bandung Area)

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Abstract. Technological developments have developed to monitor and map the activities of earth movements. One of the technologies developed for deformation monitoring is using Synthetic Aperture Radar Interferometry (InSAR) technology. InSAR is an effective method for measuring surface deformation with sub-centimeter precision. Image processing with this technique produces DEM. DEM is a 3D digital elevation model that shows the physical situation and topography of the earth which is defined as a digital model dimensions obtained from surface elevation using the selected interpolation method. The resulting DEM will be validated in the test area using the appropriate reference DEM. The case study area used is the Bandung area. Data processing with SNAP software where image recording on June 12, 2018 is used as a master image and June 23, 2018 as a slave image. The difference in angle of incidence between the two images is 42^0 where the master image is Tandem-X and slave image Terrasar-X. Acquisition scenario for DEM generation, several data sets obtained in different TerraSAR-X modes with different incidences of angle combinations in different of times. The baseline value of these two data is 322 meters. Stages of processing starting from coregistration, interferogram generation, goldstein phase filtering, phase unwrapping, phase to elevation and geocoding with DEM output for the Bandung region. From 24 field data points, 20 points are use as validation correction and 4 points as accuracy correction. The DEM generated from the TerraSAR-X corrected using regression corrected and shifting correction. DEM generation from shifting correction is better than regression corrected with absolut error 3,24 m and RMSE 5,52 m.

Keywords: Terrasar-X, InSAR, Coregistration, DEM

1. Introduction

Technological developments have monitored and mapped the activities of earth movements. The activity of earth movement related to the deformation phenomenon. One of the technologies developed for deformation monitoring is using technology of Interferometry Synthetic Aperture Radar (InSAR). InSAR is an effective tool and method used for measuring deformation on the ground surface with sub-centimeter accuracy. Radar (Radio Detection and Ranging) is one of remote sensing system not affected by weather and time. During the process, which is an active recording method, where the signal on this radar records its own energy reflected by objects on the earth's surface, it is not dependent on solar radiation [1].

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Technology of SAR can used during the day or night on all types of weather condition because the SAR system uses radio waves for observation of the earth's surface. The process of sending microwave energy pulses to the desired object and recording the original strength of the reflection received by the object in the imaging area [7].

Fringes pattern interferograms that represent different distances overlap through the phase cycle. As long as the wavelength used is around 10^{-2}, the phase difference allows the process of estimating the distance from the antenna to the object with an accuracy of about 10^{-2} to 10^{-3}. TerraSAR-X and TanDEM-X are Earth Radar Synthetic Observers (SAR) satellites launched in June 2007 and June 2010. The satellites carry high frequency X-band SAR sensors, which can be operated in flexible imaging modes. The main purpose of the TDX mission is to produce a global digital improvement model (DEM) to collect static SAR data simultaneously, which makes it possible to produce interferograms with high coherence.

1.1 SAR Image Phase

The key to interferometry techniques is the phase measurement of radar signals [9]. Phase is a condition of oscillation of an electromagnetic wave signal with a certain wavelength that repeats every 2π. Figure 1 shows an illustration of a wave propagating from point I to j.

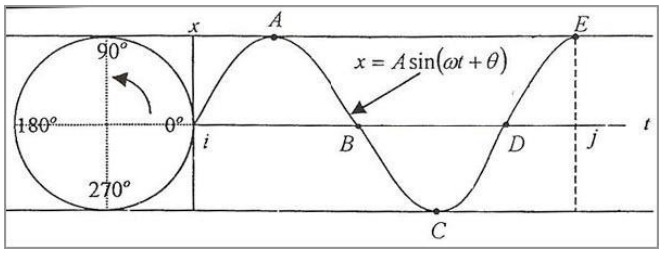


Figure 1. Image Phase [1].

In Figure 1, the wave Equation:

$$x = A\sin(\omega t + \theta) \quad (1)$$

Where A is the amplitude (maximum value of x), ω is the angular velocity of the wave, t is time and θ is the initial phase, in the initial phase of the visible figure 1 is zero Phase itself is the price (ωt + θ). From i to the point D called a full wave. Projecting the wave at the left circle. it brings that point A measurable phase is 90 ° or π rad ½, at point B measured 180 ° or π, at point C the measured 270 º or 1 ½ π, at point D measurable 360 º or 2 π. and on point E will be measured the phase of 360 º +90 º or ½ of 2 π rad. The reflection of the signals phase received by two sensors it can expressed with equation 2 [3].

$$\varphi = \frac{4\pi}{\lambda} r \quad (2)$$

Where φ is the phase difference and r is the r1 – r2. If the phase is already known, then leaning distance can calculated with the equation 3:

$$r = \lambda(\varphi + k) \quad (3)$$

Where k is the ambiguity of the previous phase should find through the process of phase unwrapping in order to get the absolute phase, through the equation 4[9]:

$$\varphi_{abs} = \varphi + k2\pi \quad (4)$$

Where φ is relative phases. The phase difference image is generated on the InSAR is called interferogram, as in Figure 2

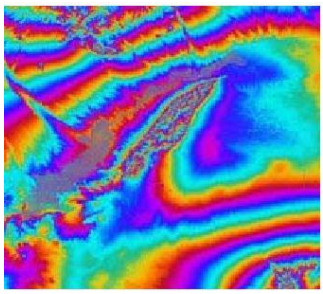


Figure 2. Interferogram in New Mexico, USA [1].



Figure 3. Radar Image in New Mexico, USA [1].

Based on Figure 2 and 3 it can be seen that the differences of colors in the interferogram is 1 wavelength of the radar image is visible and that intensity is black is not reflected.

1.2. Phase Unwrapping and DEM Generation

Interferogram average yields the measurement phase of the plains relatively ambiguous because it has a cyclic π 2 value of phase interferometry [3]. The phase unwrapping can be easily performed by integrating the phase differences [2]. Phase variation between any two points in the interferogram flat provides the measurement of the variation of the actual height, after it removed the number of integer ambiguity (equivalent to an integer number of cycles of π phase 2). The process of adding the correct integer multiplier of 2 π be the fringe interferometry called the opening phase. The opening phase of the example shown in the following figure, where the SAR interferometry phase, a version that is not wrapped phase and map with integer multiples of π 2 right added to the original phase coexist.

2. Method

2.1. Interferometry SAR

SAR is a type of radar used for remote sensing and ways of working with radar systems. SAR using amplitude and phase differences between the signal and signal return are create [3]. The method of interferometry to detect the radiation reflected from each route (more than one path) on the same orbit to the center of the antenna. Synthetic aperture radar interferometry (InSAR) exploit the difference in phase between the two SAR radar observations taken from a complex position sensor and a slightly different extracts information about Earth's surface. SAR signal amplitude and phase information. The amplitude is the strength of the radar response and phase is the fraction of a cycle the full sine wave (one SAR wavelength). SAR image phase is mainly determined by the distance between the satellite antenna and ground targets [5]. By combining the two phases of this image after coregistration, the interferogram can be produced a phase is correlated with the topography of the terrain.

2.2. Digital Elevation Mode (DEM)

To monitor any point coordinates or elevation of digital data you must have a digital elevation model (DEM) [4]. DEM is the method, generally made from stereo image or satellite image or from a digital scale plate, etc. To create a DEM in advance you need to learn some specific coordinates and translation became a projection model [6]. Then it can be interpolation. As the result of interpolation have DEM type of point clouds to reach all points on it. Dispersion phase can used to estimate the height of the theoretical dispersion (limited to high spatial frequencies) of DEM produced from SAR Interferometry [3]:

$$\sigma_h = \sigma_\emptyset \frac{R\lambda \sin\theta}{4\pi B} \qquad (5)$$

Low spatial frequencies of DEM errors could not predict from the map since coherence estimation carried out in a small window. The information carried by the map of coherence can used in beneficial to help image segmentation.

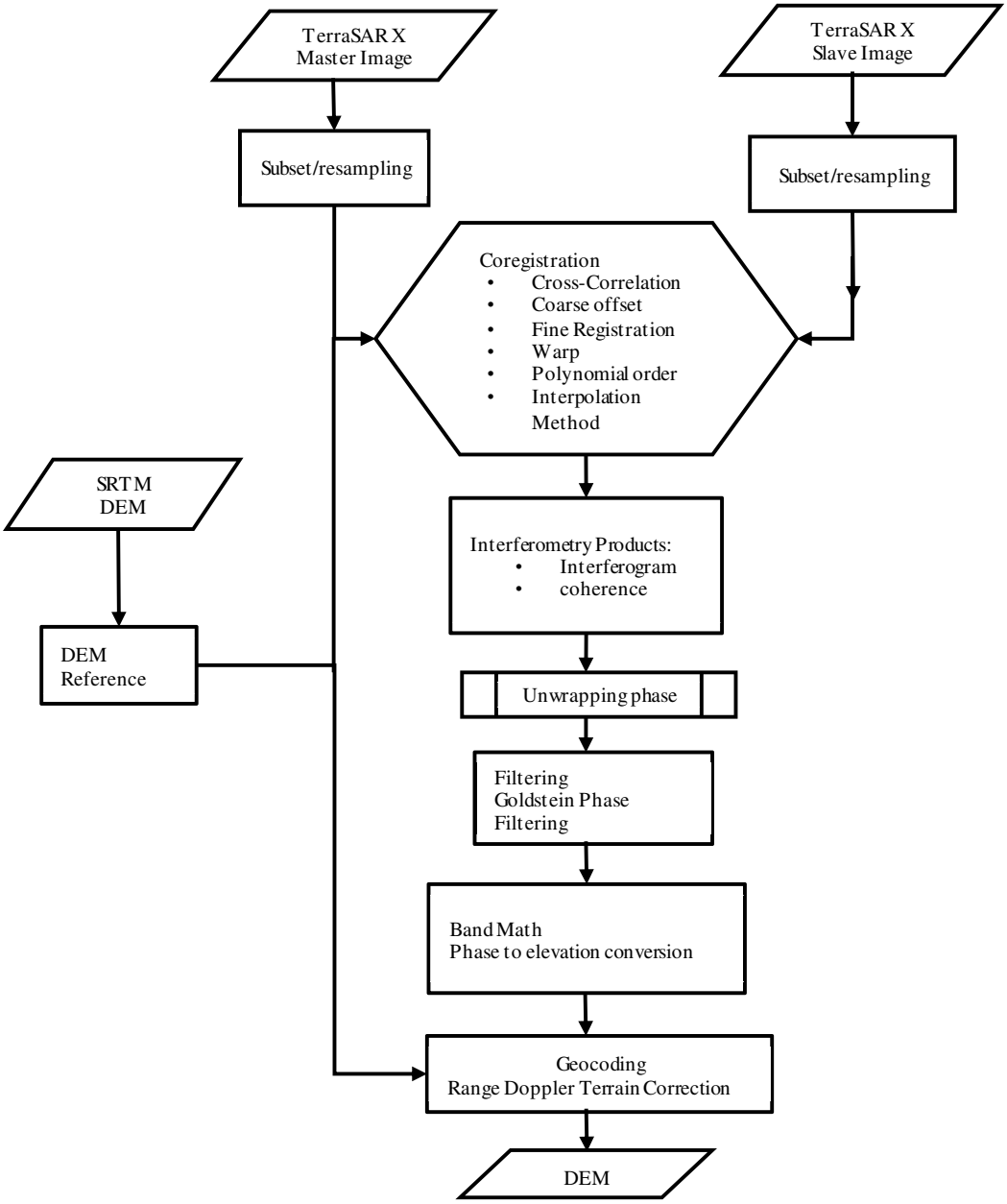


Figure 4. Flowchart of SAR Image Processing.

3. Result and Analysis

The results of the satellite images that record the Earth's surface in the area of case studies on 12 June and 23 June 2018 2018 after at coregistration. The method used is interferometry. Case study area is the area of Bandung with 7^0 14' 9,6" S 107^0 38' 52,8" E to 6^0 38' 16,8" S 107^0 27' 50,4" E. Processing performed with the coregistration between the two images by setting the RMS threshold 1 so that fringe interferogram on the results later. Description of the data can look in the table below.

Table 1. Characteristic of TerraSAR-X Image in Bandung Area

Characteristic	Master	Slave
Product Name	TDX1_SAR	TSX1_SAR
Mission	Stripmap	Stripmap
Acquisition date	2018-06-12 11:09:50	2018-06-23 11:09:51
Product Type	SSC	SSC
Polarization	HH	HH
Pass	Ascending	Ascending
Incident Angle	42^0	42^0
Orbit	44230	61127

In table 1 is a description of the data used as the research in the area of Bandung, where these data have the same angle of incidence between the image of the master and slave. Baseline perpendicular between the two images is 342 m this image is great for interferometry methods. DEM Generation can produce with the techniques of Interferometry with the terms of the second incident angle difference between master and slave is not too large. The smaller the difference in the angle and the distance between the two perpendicular baseline images will be increasingly good. At the time of coregistration the value of the threshold used must be greater than 0.5 so that fringe interferogram on the outcome looks obvious. The value of the FFT used based on the height of the surface. The higher the area of research on the processing value of FFT used are also getting bigger. The results of the DEM to Bandung with polygons areas 7^0 14' 9,6" S 107^0 38 ' 52,8" E to 6^0 38' 16,8" S 107^0 27 ' 50,4" E. 2321m is the maximum value and minimum 130 m.

The processing will continue with the interferogram flattened, Goldstein phase filtering [8] and unwrapping. After unwrapped the product is unwrapped phase. On the unwrapping set the output as TOPO because topo phase was the phase which product the elevation. Phase to elevation or DEM during the preprocessing of DEM. DEM ALOS with resolution 30 m will use as DEM reference. Results each processing can look in the picture below

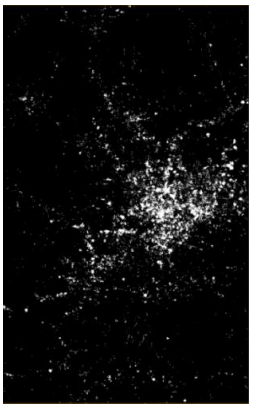


Figure 5. Intensity

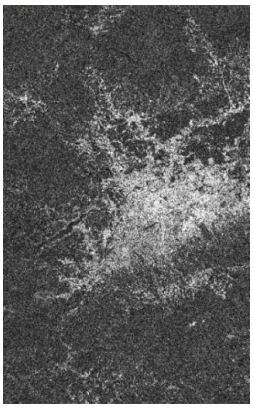


Figure 6. Coherence

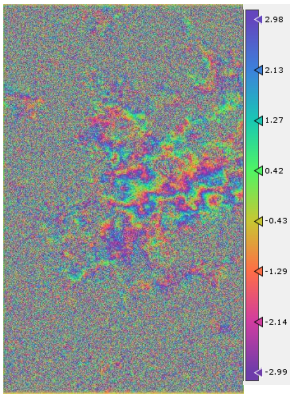


Figure 7. Interferogram

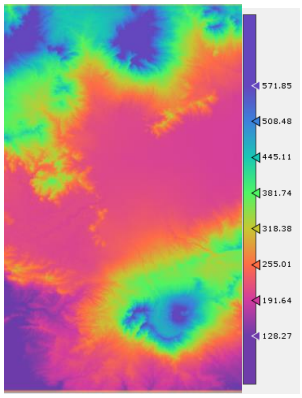


Figure 8. Topo phase

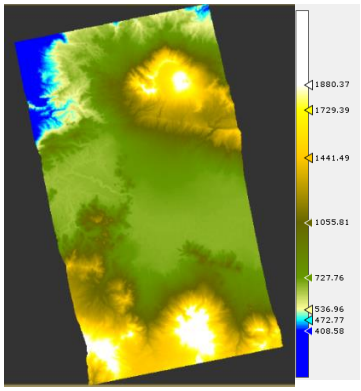


Figure 9. DEM Generation of Bandung

In Figure 5 is intensity between master and slave image from coregistration. In Figure 6 is the coherence between the two images. Figure 7 is interferogram, fringe on the phase interferogram will clearly when the images are absolute difference for examples, the phenomenon of the earth, earthquake, landslide, etc. Figure 8 is the phase of the topo phase, this phase we can calculated from equation (2). Topo phase is the phase will generate the elevation value using dem reference. We use DEM alos 30m and SRTM 30m as the reference.

Figure 9 is a DSM generation with resolution 3 m pixel spacing for the area of Bandung. The maximum elevation is 2321 m and minimum 130m. The DSM already has geocoding. For this DSM there are several nan values caused by the using of parameter coefficient coherence. This DSM still need geoid component EGM 96 and ellipsoid WGS 84. Geoid component will be 2 steps are adding geoid and subtract geoid.

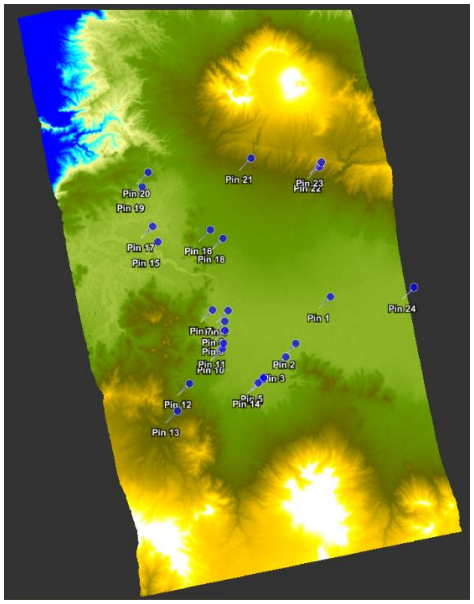


Figure 10. DEM Looking with Ground Control Points Using GPS

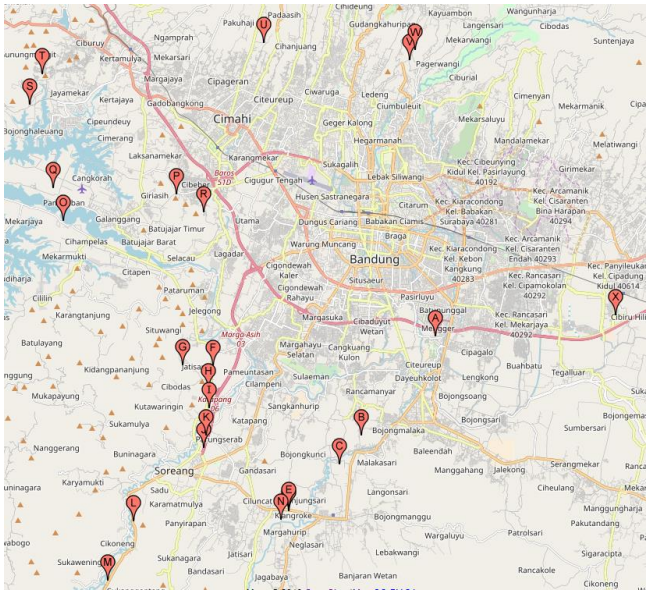


Figure 11. Map Looking Ground Check Points Using GPS

Figure 10 there is ground points measurements was measure in Bandung using GPS. there are 24 points where the 24 points are the results of field measurement points which are used as reference points for

validation testing of DEM accuracy with the INSAR Method. TerraSAR-x data is done multi-looking for resolution of 6m, 12m and 24m, which will be corrected with GPS and SRTM30m data, 4 points are use as validation and the other use for correction.

Two of them are take on low areas and the others in areas with high slope. On this research, DEM used as reference was ALOS 30m with GEOID projection. The height model of SRTM 30 Data and GPS field data has a similar trend. The average difference in height of TSX and (GPS) data is around 3.24m. Based on differences in height values RMSE 4.77 m is obtained. There are several points that have very high difference values, namely at point 7, based on field measurements, point 7 is a region that has a fairly high slope or slope area, it can be assumed that the position at the time of measurement has several errors. DSM INSAR 24m is 9x11 multi looking from 3m resolution.

There nan value of the DSM at point 24 that is not a missing value, but it is a limitation of TerraSAR-X data. In this case with a resolution of 24m, the absolute error value is 5.38m and RMSE 7.42 compared to SRTM. ≈ 3m. In the DSM with 24m resolution there are several error points, one of which is at point 7, which is also similar to SRTM but there are also 2 other points, namely points 19 and 23. Based on the data slope from INSAR dem point 19 and 23 are slope areas with slope level 2, and point 7 with level slope 3. DSM INSAR 24m is 5x5 multi looking from 3m resolution.

The nan value at point 24 is not a missing value, but it is a limitation of TerraSAR-X data. In this 12m resolution, the absolute error value is 6.98m and RMSE 9.33 when compared to SRTM there are differences RMSE ≈ 5m. In this 24M DEM there are several points of error, but point 7 has a difference of 2m at 12m resolution, the point that has a difference value above 10m for field measurements is 12, 15, 16, 18, 22 and 23. At point 23 there is an error very high with a difference of 22.32m. Based on the data slope from DEM INSAR these points are slope areas with slope level 2 to level slope 3.

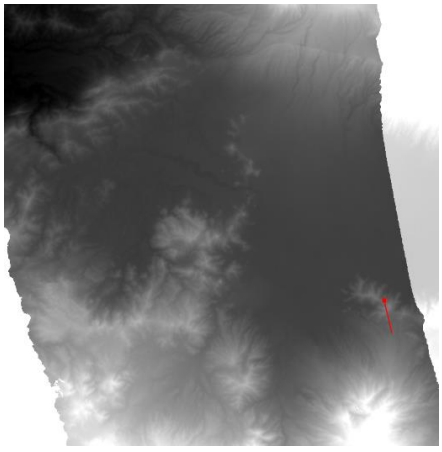


Figure 12. Plotting Profiles on DEM for Higher Regions

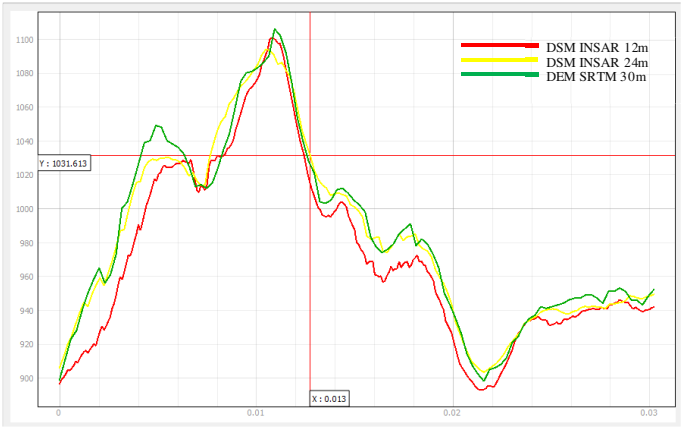


Figure 13. Trend of Plotting Profiles on DEM in Higher Regions

Figure 12, is a line to compare the elevation values of each dem in the area. Figure 13 is a profile form of a comparison of 3 DEMs namely SRTM30, INSAR 12m and 24m. It can be seen in the profile that the INSAR with a resolution of 24m has the same trend towards SRTM, it can be assumed that the DEM has a slight error value.

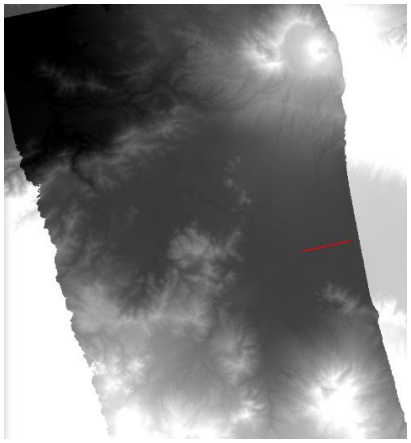


Figure 14. Plotting Profiles on DEM for Flat Area

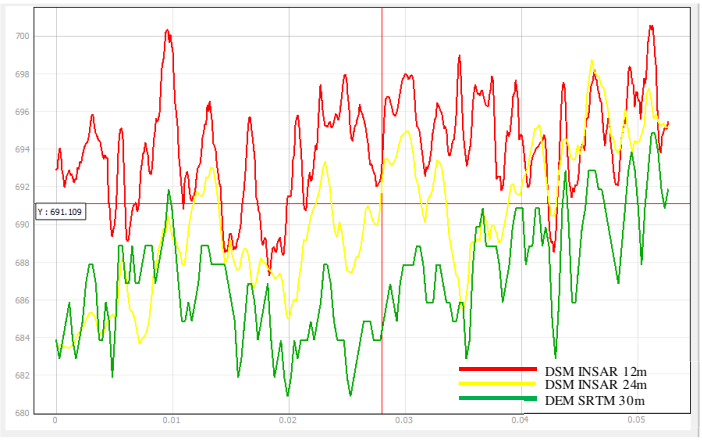


Figure 15. Trend of Plotting Profiles on DSM in Flat Area

Figure 14 is a line to compare the elevation values of each dem in the area. Figure 15 is a profile form of a comparison of 3 DEMs namely SRTM30, INSAR 12m and 24m. It can be seen in the profile that the INSAR dem with 24m resolution has an average elevation trend between SRTM with INSAR 12m.

4. Conclusion

In this paper, explained that the higher the resolution or multi looking the smaller the error value. From the results of this study, the DSM generation data carried out EGM 96 geoid subtraction against references for 12m and 24m resolution so that the elevation value increased by an average of 20m. The results of the discussion and discussion, the DSM INSAR is 24m more accurate than the 12m INSAR DSM, but the greater the resolution, the better. this is because processing is limited to 24m resolution and compared to SRTM 30 then (a) spatial resolution of higher TSX and (b) TSX acquisition date adjacent to field data, although TSX: DEM generation developed based on repeat pass interferometry with time differences 11 days, while SRTM bistatic DEM generation.

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