HEIGHT MODEL INTEGRATION USING ALOS PALSAR, X SAR, SRTM C, AND ICESAT/GLAS

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Abstract. The scarcity of height models is one of the important issues in Indonesia. ALOS PALSAR, X SAR, SRTM C, and ICESAT/GLAS are free available global height models. Four data can be integrated the height models. Integration takes advantage of each characteristic data. The spatial resolution uses ALOS PALSAR. ICESAT/GLAS has a minimal height error because it is DTM. SAR has advantages of minimal error in the highland and need a low pass filter on the lowland. DSM uses X SAR and DEM from ALOS PALSAR. Characteristics and penetration of vegetation objects can be seen from the wavelength type of SAR data. This research aims to make height model integration in order to get the vertical accuracy better than vertical accuracy of global height models and minimum height error. The study area is located in Karo Regency. The first process is to crop the height models into Karo Regency, geoid undulation correction using EGM 2008. The next step is to detect pits and spires by using radius value 1000 m and depth $\underline{+}1.96\sigma$ ($\underline{+}5$ m) with uncertainty 95,45%. Then generate HEM and height model integration. To know the accuracy of this height model, 100 reference points measured using GNSS, altimeter, and similar point observed on the height model integration are selected. The accuracy test covers RMSE, accuracy (z), and height difference test. The result of this study shows that the height model integration has a vertical accuracy in 1.14 m. This height model integration can be used for mapping scale 1: 10.0000.

Keywords: *integration, height model, SAR data, scale 1:10.000*

1 INTRODUCTION

Currently survey and mapping have entered extraterrestrial technological developments, marked by many satellites are used for various purposes mappings. This extraterrestrial mapping interests includes aerial mapping, space, and outer space surveys. The development of this technology affects the various height models include Digital Surface Model (DSM), Digital Elevation Model (DEM), Digital Terrain Model (DTM), Digital Ground Model (DGM), Digital Height Model (DHM), Digital Terrain Elevation Model (DTED) and the Earth Gravitational Model (EGM) (Li, Z. *et al.*, 2005).

Height models can be created from optical, radar, microwave, lidar, and sonar data (Bhardwaj *et al.*, 2013): (Mitchell and MacNabb, 2010). Height model of the optical data using optical satellite imagery data, aerial photographs, video (Deilami and Hashim, 2011). In the optical data, height model using stereo models (Saldana *et al.*, 2012): (Aguilar *et al.*, 2012), videogrammetry, and depth cue perceptive. Radar data can use Synthetic Aperture Radar (SAR) of satellite imagery data (Delaimi and Hashim, 2011), Interferometry Synthetic Aperture Radar (IFSAR), LIght Detection And Ranging (LIDAR) (Forkuor, 2014). Making of height model on the radar data using stereo models, interferometry, and depth cue perceptive. Height models are made by sonar can use data Interferometry Synhetic Aperture Sonar (IFSAS) data (Julzarika, 2011b).

Height models or also known as 3D model is a view of a model with the 3D coordinate system (polar, geodetic, raster and cartesian) with field-defined reference to a specific projection and datum (Julzarika and Sudarsono, 2009). A height model can be created from radar and optical data. Height models can also be defined as a digital model that gives information about the earth surface shape (topography) in the form of raster or vector data (Freeden *et al.*, 2010). Height models consist of two information, namely: height data and the data of such height position coordinates on the earth's surface (Honikel, 1998).

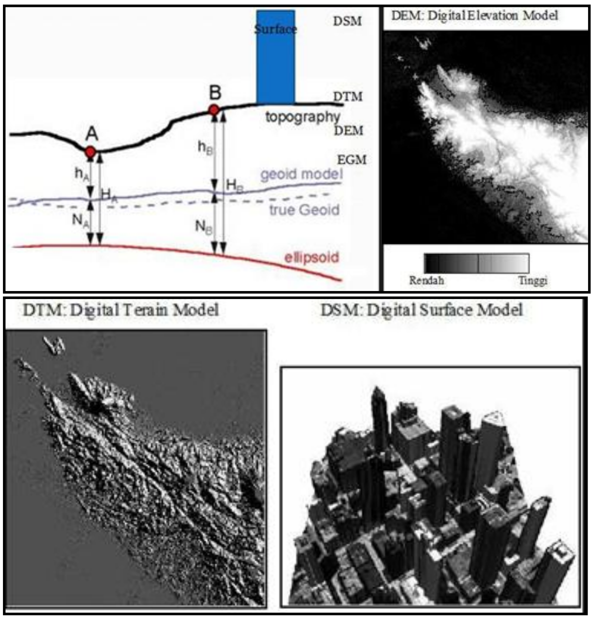

Figure 1-1: Appearance of DSM, DEM, DTM, and EGM (Trisakti and Julzarika, 2010)

DSM is the elevation models including roof building, trees, and other objects, as well as the usual canopy models (Li *et al.*, 2005). DEM is an elevation model (bare earth) or autocorrelation surface without any vegetation, buildings, and other objects (Petrie and Kennie, 1987). DTM is DEM already equipped river, contours, and features that exist in nature (Li *et al.*, 2005). EGM is a geoid model of the Earth, describes the equipotential field which coincides with the mean sea level (Vanicek and Krakiwsky, 1986). There are several examples of height models ie SRTM C, X SAR, ICESAT/GLAS, ASTER GDEM, ALOS Prism, LIDAR, ALOS PALSAR, and GeoSAR.

Formulation of the problem in this study is related to the integration of height model using ALOS PALSAR, SRTM C, X SAR, and ICESAT/GLAS. They can be used to overcome the scarcity of accurate height models in Indonesia. Integration of height models is also expected to obtain a free error of height model and can be used for various applications in accordance with certain standards. The available of Indonesian height model data in a condition not yet ready for use. Data are not yet ready for use is also a commercial character and has not been renewed more than 20 years. It also has not been a lot of reports of height model accuracy, integration of height models, and the fusion of height models. This study aims is to produce better accuracy and minimal vertical height error with geoid field EGM 2008 of height model integration using ALOS PALSAR, SRTM C, X SAR, and ICESAT/GLAS.

2 MATERIALS AND METHODOLOGY

The originality of this research is on the method modification. The method modification is by using 1,96σ for its weight. All of the data using SAR in a different bands, i.e. P, L, C, and X bands. The location is in highland areas of more than 800 m above mean sea level.

The study area is located in Karo Regency, North Sumatra, Indonesia. The hypothesis is after the integration of height models, it results high vertical accuracy of height models better than previous global models. Integration of height model data also has a minimal height error.

PALSAR is an active micro-wave sensors in the L-band (1270 MHz center frequency/ 23.6 cm), which was developed in cooperation with Japan Aerospace Exploration Agency (JAXA) and Japan Resources Observation Systems Organization (Zhao *et al.*, 2013). PALSAR sensor has a capability, variable off-nadir between 10 to 51 degrees by using the technique of active phased array with 80 modules for transmitting/receiving. Palsar is an instrument that fully parametric, working with one of the modes: single polarization (HH or VV), double polarization (HH + HV or VV + VH) or a full polarimetric (HH + VV + HV + VH). Incidence angle is variable between 7 and 51 degrees (the angle of incidence 8-60 degrees), average of incidence angle is 34.2 degrees. In the polarization mode, a wide coverage of units of the image is 30 km with a spatial resolution of 6 m occur in conditions of data rates of 240 Mbps (JAXA, 2006).

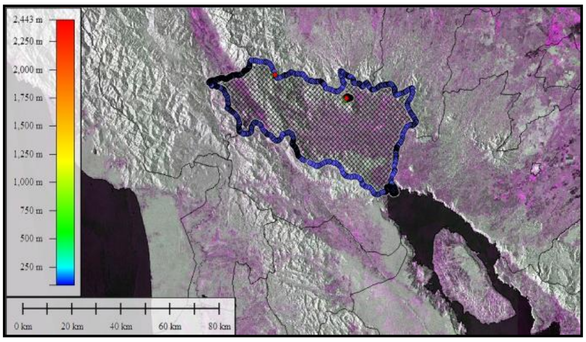

Figure 2-1: Research study area

Shuttle Radar Topography Mission (SRTM) data is a form of data that provides information about the height place or commonly called DSM. This data was obtained from the radar system mounted on Spacecraft during the 11-day mission in February 2000. This data has a spatial resolution 3 seconds (≈90m). X SAR has a spatial resolution of 1 arc second (≈25m) (DLR, 2010). Globally, X SAR has a vertical accuracy 9 m (relative) and ~15 m (absolute) for 90% of the data (DLR, 2003). SRTM C has a vertical accuracy of 10 m (relative) and ~16 m (absolute) for 90% of the data (NASA, 2005; Gesch D., 2005).

Making DSM uses SRTM C and X SAR interferometry method. Data from SRTM C and X-SAR performed by ERS-tandem integration in order to do interferometry (Miliaresis and Paraschou, 2005).

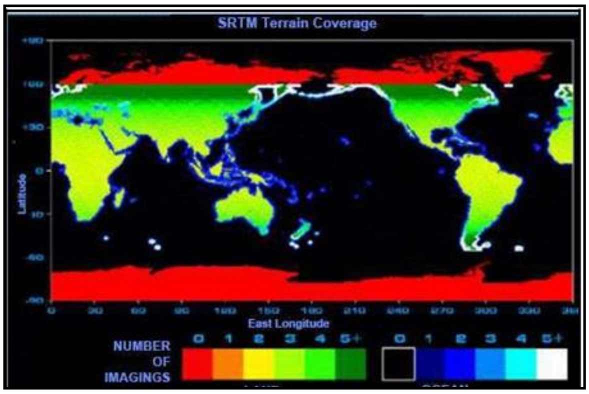

Figure 2-2: Coverage of SRTM C and X SAR

ICESAT/GLAS is one of the Geodesy satellites. Its mission is to provide elevation data needed to determine ice sheet mass balance as well as cloud property information, especially for stratospheric cloud common over polar area. It provides topography and vegetation data around the globe, in addition to the polar specific coverage over the Greenland and Antartic ice sheets. The satellite was found useful in assessing important forest characteristic, including tree density (NASA, 2011).

Height error is random error in the form of blunders that occur due to the high value anomaly closest eight neighbors. Height error can be caused by incorrect contour interpolation, point spread as a result of uneven height or can be caused by height point value that does not correspond to the truth. Height error is pointed, lines, or areas that have high value, but that value does not represent the situation in the field (Julzarika, 2011a).

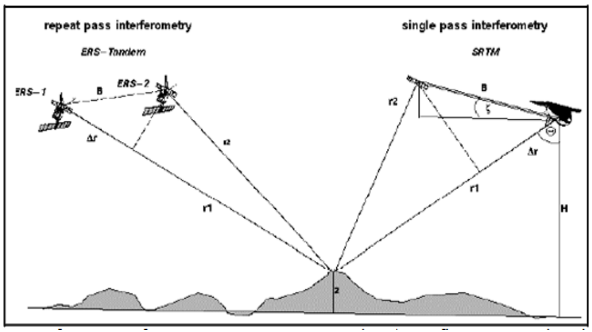

Figure 2-3: Interferometry of SRTM C, X SAR, ERS-Tandem (Knopfle, Strunz, and Roth, 1998)

Merging height model using two methods, namely integration and fusion (Sidek and Quadri, 2012). The concept of integration and fusion refers to the concept developed by previous studies (Hoja and d'Angelo, 2010; Hoja *et al.*, 2006). Some modifications were made such as height error correction, making height error maps, weight, detection methods and the elimination of error/void, CoKriging interpolation.

The philosophy of height model integration is getting height model by using the various advantages of each model based on characteristics such as high penetration into the objects, spatial resolution, and minimal height error in lowland and highland. This integration uses the advantages of each of the characteristics of the model that was used in the integration. Height Model of X SAR, SRTM, ICESAT/GLAS, and ALOS PALSAR are alternative to height model integration (Forkuor, 2012; Rexer *et al.*, 2014). The spatial resolution used in this integration is the ALOS PALSAR of 5 m. DSM is used, then X SAR and SRTM C, while DEM used is ALOS PALSAR.

DTM uses ICESAT/GLAS, highland region using ALOS PALSAR, then SRTM C and/or X SAR. SAR data have weaknesses in the lowlands that required the use of low pass filter. Overall, SAR still has advantages over the optical data (Kolecka *et al.*, 2013). Characteristics of ALOS PALSAR, X SAR, SRTM C, and ICESAT/ GLAS can be seen based on the wavelength and object penetration into the vegetation.

ALOS PALSAR using an L band, SRTM C using C band, X SAR uses X band, ICESAT/GLAS uses P band.

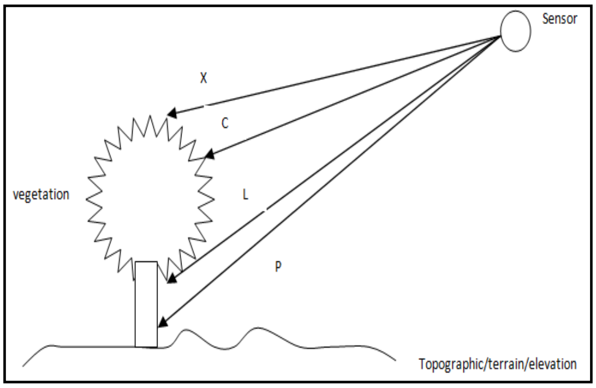

Figure 2-4: Height model method from different SAR band (Julzarika, 2011b)

Procedures for implementing the integration of height models adapted to the conditions DSM/DEM/DTM is used. At this integration method, it can minimize height error in several ways. One of the models is height models (1) extraction of high value randomly and evenly. The height extraction can be by making the contour or contour added with height point with a certain distribution. After that just made a new height model of the contours result and the height point. The new height models will also produce HEM.

Then HEM is used to minimize errors that occur in the height model (1). Height model (1) has made height error minimized. Then making HEM in other models (eg height models 2). Making HEM of this model can be done by means of a height anomaly detection to at least eight pixel surrounding neighbors. After the height model (2), height error correction against the HEM. Flow diagram of the height models of integration methods is shown in Figure 2-5.

Extraction height point needs to be done if the height models (2) have been completed minimized errors. The extraction of height value point is used for filling voids in height models (1). Void contents can be known from the distribution models that do not meet the height vertical tolerances, ie 2σ. The CoKriging interpolation process is then performed so as to produce DSM/DEM/DTM combined. Interpolation method is performed with semivariogram Kriging method linear and normalization with linear models (Yastikh *et al.*, 2006).

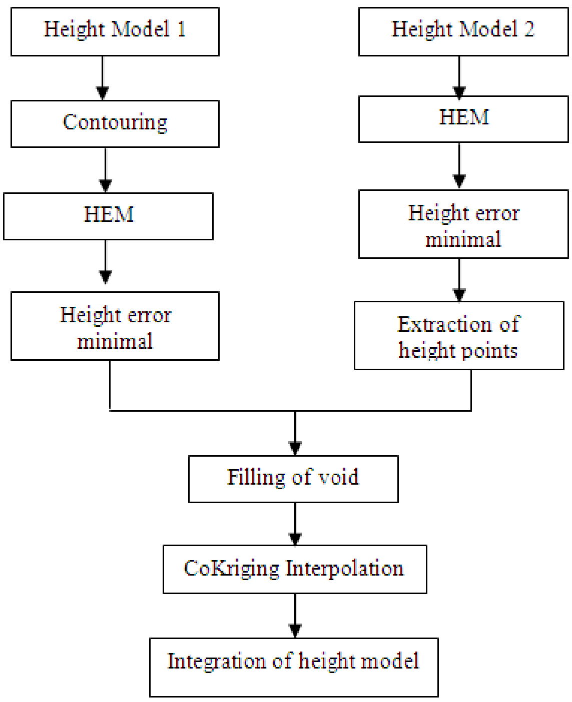

Figure 2-5: Integration of height model methods

Integration of height models is necessary to extract the difference between the two models. It aims to maximize the potential of the height error checking that occurred in the two height models. If the height error checking different way, then the possibility of a wide range of height errors will be detected patterns vary. Another advantage gained from this is the optimal integration of each height model at the time of filling the void. This will impact on better vertical accuracy and height error minimal.

This study uses a standard map of ASPRS Accuracy Data for Digital Geospatial Data. In this study only focused on the vertical accuracy. The formula of vertical accuracy test is given by:

a. *Root Mean Square Error* (RMSE)

$$RMSE_{(z)} = Sqrt[(\Sigma(\mathbf{Z}_{data(i)} - \mathbf{Z}_{check(i)})^2)/n] \quad (2\text{-}1)$$

b. Vertical accuracy in level of confidence 95%

$$Accuracy_{(z)} = 1.9600 * RMSE_{(z)} \quad (2\text{-}2)$$

After the vertical accuracy values obtained, then made adjustments to the standards set by the ASPRS that takes into account RMSEz in terrain without vegetation and terrain vegetation. Confidence level used is 95% or 1.96 σ. (Uotila, 1985).

Trend surface analysis involves mounting surface (polynomial models) through a set of points in X, Y, Z space coordinate. Surface mounted likely will not pass right through each point, so that the least-squares regression is used to minimize the distance between the measured values Z and surface mounted directly above or below. The difference is expressed as the root mean square (RMS or r^2). The smaller the value of "r-squared", the closer the match between the point and the surface (Li *et al.*, 2005).

Local anomaly detecting trends surface smooth. Polynomial order of trend surface control complexity, higher order more flexible. The number of coefficients in the trend surface equation controls the level of detail. Order polynomial 1 is an inclined plane, while order polynomial 12 is a curved surface and very complex. Simple surface (the lower order polynomial, usually 3 to 5) is most often interpreted in geomorphic applications.

Trend surface analysis suitable for regional data, such as the delineation of the groundwater, checking the height difference, or to reconstruct ancient geomorphic surface is degraded by erosion, or to visualize the direction paleoflow of a large watershed. Z outlier values and areas with a large gap between the value of Z can disrupt methods. The edge of the map can cause problems as well. Trend surface analysis requires more than 10 points. It also always uses the same coordinate system for all inputs and when comparing one surface to the other surface trends. Residue analysis can also be evidenced by the trend surface analysis (Jones, 2013).

3 RESULTS AND DISCUSSION

A height error correction needs to be made to the height models of various data inputs (Mukherjee *et al.*, 2013). Height Error Correction aims to eliminate anomalous high values different from neighbors and be a blunder and cause false contour conditions. The shape of height error are pits and spires. There are three methods for height error correction, namely Fill Sink, Cut Terrain, and Height Error Maps (HEM). The first process is to crop the height models, data into a Karo Regency area. Then, the next process is geoid undulation correction. It uses EGM 2008 for the geoid undulation correction. The next step is to detect the pits and spires by using radius value 1000 m and depth ±1,96σ (±5 m) with uncertainty 95,45%. The next process is to generate HEM and display the height error of the height model.

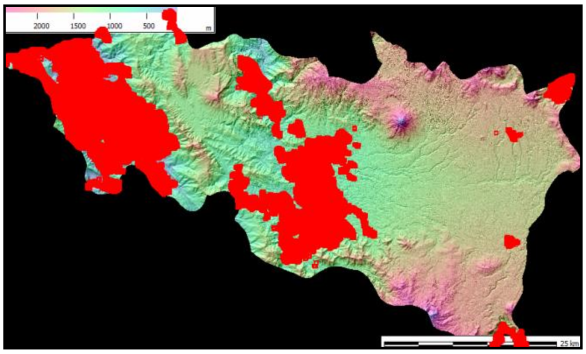

Figure 3-1: Checking of height error (pits and spires)

Height error was made of a standard deviation or vertical error in the height model data (Zimmerman and Cressie, 1992). Height error can be made from its own data. Fill sink is a method for removal of height anomaly against the basin area, while Cut Terrain is removed of height anomaly method on a convex/steep region.

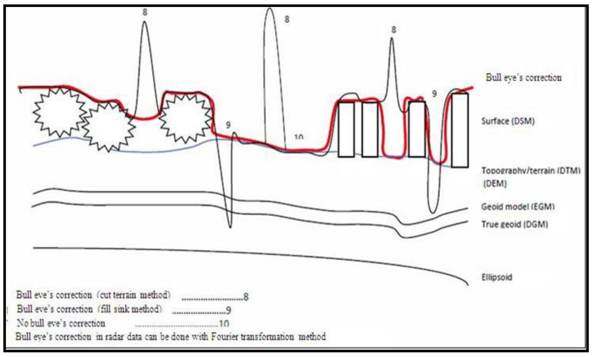

Figure 3-2: Height error correction

The Height Error Maps method produces output data with better accuracy and precision than Fill Sink and Cut Terrain methods. The Fill Sink method has advantages in charging a high value anomaly in the valley area, but cannot correct the data region of the convex/steep, whereas the opposite applies Cut Terrain and Fill Sink methods (Honikel, 1998). If four height model data have been completed and height error has been corrected, the next process is to integrate the height models.

After testing the accuracy of the two methods specified, then the next process is necessary to check the accuracy of the test results are in accordance with the hypothesis or not consistent with the hypothesis.

Vertical accuracy of test results of the formula (a) and (b) compared with the value of the relative vertical accuracy of a global height model. Relative vertical accuracy value can be known for the publication of the data provider. Information about the SRTM C obtained from NASA, X SAR from DLR, ICESAT/GLAS from NASA, and ALOS PALSAR from JAXA. SRTM C has a relative accuracy of 10 m, X SAR has 9 m vertical accuracy. ICESAT/GLAS has vertical accuracy < 1 m. ALOS PALSAR has a vertical accuracy of 1-3 m. Hypothesis appropriate if the value of the vertical accuracy of integration is lower than the vertical accuracy value of global height models. If the value of the vertical accuracy of integration is higher than the vertical accuracy value of global height models do not appropriate the hypothesis.

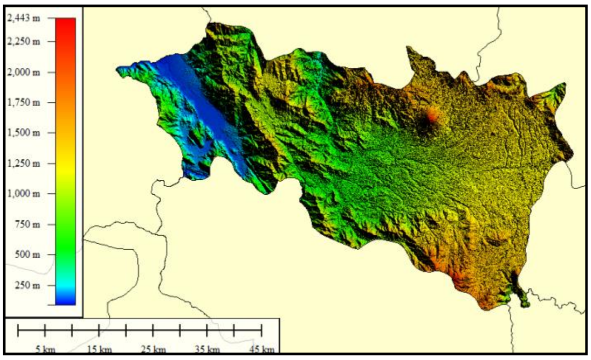

Figure 3-3: Height model integration

This height model integration is appropriate with the hypothesis, better vertical accuracy than previous accuracy and minimal height errors. The ideal combination of height model is ALOS PALSAR and ICESAT GLAS. Vertical accuracy obtained from the second test method accuracy is 1.14 m and 1.65 m.

This combination is efficient in cost and time of execution, effective in the use of the data because it only requires two higher models will produce the most optimal vertical accuracy values. SAR data are recommended for making height model integration.

Based on the ASPRS standard, the result of this integration of height model can be used to map scale of 1: 10.000 to 1: 25.000. The priority of this integration of height model is to use a combination of height models of the ALOS PALSAR and ICESAT/GLAS. Checking the height difference between the 100 test points on the integration of height models also produce a total height difference of the minimum (zero). 100 test points is made closed polygon. Then, between the point of the reduction of height value. After all the difference between points within the polygon has been completed, then summed all the excess value. The result is a total height difference of the minimum (zero). It indicates that this models of the height point have the relative height of the plane of the same datum. It is also useful in removing the systematic errors that still exist in height models.

4 CONCLUSION

Height model integration of ALOS PALSAR, ICESAT/GLAS, X SAR, and SRTM C can be done with better vertical accuracy than the vertical accuracy of the previous global height model. Integration of height models also has a height error in minimal.

This height model integration has a vertical accuracy of 1.14 and 1.65 m. This combination is efficient in cost and time of execution, as well as effective in the use of the data because it will produce the most optimal vertical accuracy values.

SAR data are recommended for creating height model integration, and the vertical accuracy is optimal (appropriate). It is due to there are less pits and spire on this data, despite the height error correction with tolerance and weight in 1.96σ.

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