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Global Positioning Systems (GPS) Use for Interferometric Radar Validation and Geometric Correction

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ABSTRACT: The 1996 INDonesian Radar EXperiment (INDREX) Campaign studied several types of high-resolution (1.5 meter) Dornier Synthetic Aperture Radar (DO-SAR) data/images, e.g. intensity, coherence, and interferometric. The campaign was sponsored by the European Space Agency (ESA) and facilitated by the Indonesian Ministry of Forestry and Wageningen University. The campaign was directed to develop a "Remote Sensing Monitoring System for Forest Management and Land Cover Change in Indonesia". The radar group at the Department of Environmental Sciences, Wageningen University has several research activities to investigate radar tree mapping and data integration, and one of them is the study of "Global Positioning Systems (GPS) Use for Interferometric Radar Validation and Geometric Correction". The objective of this study is to validate the height data derived from the orthorectified interferometric SAR (InSAR) data/images and to understand the errors produced by the conventional geometric correction process using available commercial Remote Sensing (RS) and Geographic Information Systems (GIS) software (e.g. ENVI and Arc/Info). The results showed that the height of 3D Differential GPS (DGPS) data was agreed with the height of InSAR data both in the line form and values, but the height of 3D absolute positioning GPS data was only agreed in the line form. This study learned that a good positional accuracy radar data needed further validation investigations to locate the precise position of an individual tree.

1. INTRODUCTION

1.1 Background

The Indonesian Ministry of Forestry (MoF) and Wageningen University (WU-R) have been initiated a co-operation in remote sensing technology for forest management and monitoring since 1995. In 1996, the first research radar campaign in Indonesia has been done by Dornier Company, Germany and sponsored by the European Space Agency. MoF, Wageningen University, PT. Mapindo Parama, and Indonesian Ministry of Defence facilitated the campaign called as the INDonesian Radar EXperiment (INDREX). This campaign is to develop a "Remote Sensing Monitoring System for Forest Management and Land Cover Change in Indonesia". The radar system namely Dornier Synthetic Aperture Radar (DO-SAR) has several modes, but Radar Group of Wageningen University has only used the 1.5-meter resolution of C-band interferometric mode to develop the 3D tree mapping algorithm (Wooding, 2000; Grim *et al.*, 2000). This algorithm is able to map individual 3D-tree in an accurate way. The future benefit of this algorithm is the continuous individual tree monitoring and this will lead to support the intensive forest certification process and evaluation. For example, the performance of re-planting activities could be monitored regularly day or night, rainy or clear weather, because radar is an active system that has its own illumination and could penetrate clouds.

1.2 Objectives

The study was conducted in two provinces (Jambi and East-Kalimantan) with the objective are as follows:

1. *to validate the altitude data derived from the orthorectified interferometric SAR (InSAR) data/images using GPS, and*
2. *to understand the errors produced by the conventional geometric correction process using available commercial Remote Sensing (RS) and Geographic Information Systems (GIS) software (e.g. ENVI and Arc/Info).*

2. APPLIED THEORY

2.1 Extraterrestrial Positioning

During the radar campaign, Global Positioning Systems (GPS) was used to record the corner reflector positions that would be used for radar calibration. After the campaign, GPS was regularly used for validation processes during the fieldwork activities. Consequently, the use of GPS is very important, especially when users and green customers require an accurate information about their ecolabeling certified wood products.

GPS is a satellite based positioning and navigation system known as NAVSTAR (NAVigation Satellite Time And Raging) developed by the United States Departement of Defense (DoD). This system consists of three segments: the satellites (24 satellites), the control systems (5 control stations), and the users (around the world). The 24 satellites arrayed in 6 orbital planes inclined 55^{o} to the Equator with nominal altitude 20,183 Km. Each satellite has two radio frequencies, L1 on 1575.42 MHz and L2 on 1227.6 MHz (Wells *et al*., 1986).

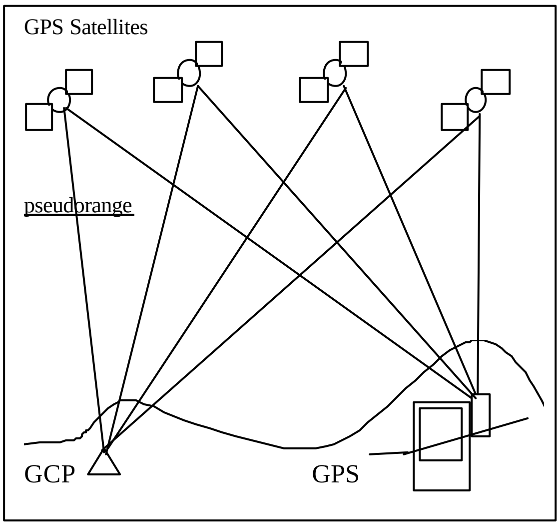

Figure 1. The Differential GPS Measurement

A country like Indonesia with 17,000 islands could not rely on the terrestrial positioning solely. Therefore, GPS could give many possibilities to connect many islands without being seen in a single network (Abidin, 1995). It is obvious that the Ministry of Forestry uses GPS equipment to assist their surveying activities. More than four GPS satellites could be seen simultaneously in several locations those kilometres away from each other's. This situation is possible because GPS satellites are very high and they are not interrupted due to cloud problems comparing to the traditional extraterrestrial positioning system using stars or sun. Generally speaking, GPS measurements could be performed at any time and any condition for 24 hours a day.

The accuracy of GPS positioning measurements is obviously high (less than 50m), especially when users are able to use more than four satellites. In addition, GPS users could obtain 3D data (x,y,z or Longitude, Latitude, Altitude) by using four satellites. This study used two techniques of GPS measurements, those were absolute and differential positioning (Figure 1). The absolute positioning is the basic measurement using pseudorange data with accuracy around 20 m in circular/spherical error probability (CEP/SEP). The differential GPS (DGPS) is a relative measurement which also use the ground control point (the reference position) with same pseudorange and/or phase data (Abidin, 1995).

Detail explanations about absolute GPS and DGPS positioning method can be obtained from various papers, webs or texts of GPS, e.g. Leick, A. (1990) or in many sources from internet, e.g. http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html.

2.2 Interferometric SAR

Radio detection and ranging (radar) is defined as a technique that emits electromagnetic pulse in the radio and microwave region and detects the returns/reflections of these pulses from objects in its line of sight. The Synthetic Aperture Radar (SAR) is a radar system that has azimuth resolution and it is achieved through computer operations on a set of coherently recorded signals that an antenna is able to function as a large aperture antenna. Interferometric SAR is a system that use two radar antenna to acquire different path of images and the antenna deduces information from the coherence interference between two signals (Liliesand and Kiefer, 2000). Therefore, interferometric SAR (InSAR) would produce a 3D data and it is usually known as Digital Elevation Model (DEM) or Digital Terrain Model (DTM). This means that a very high-resolution InSAR data could map individual 3D tree (Hoekman and Varekamp, 2001).

The microwave region has several bands that each of it has its own convention name from ITU (International Telecommunication Union). C-band, L-band, and P-band are the common notation for the radar remote sensing wavelength. Each band could have several polarisation, e.g. Horizontal emits and horizontal received (HH), Vertical emits and vertical received (VV). Polarisation is defined as the orientation of the electric (E) vector in an electromagnetic wave, frequently horizontal (H) and vertical (H) in conventional imaging radar systems (Henderson and Lewis, 1998).

Detail explanation about radar theory and interferometric could be found in various texts, e.g. Henderson and Lewis (1998) or http://www.asf.alaska.edu/reference_documents/sensor_references/sar_theory.html

2.3 Map Projection

A map projection is needed for mapping and spatial data integration purposes. It is a mathematical system of projecting a spheroid of the Earth onto a flat plane. Common mapping and GPS uses geographic coordinates that are expressed as spherical coordinates of longitude and latitude (Verbyla, 1995).

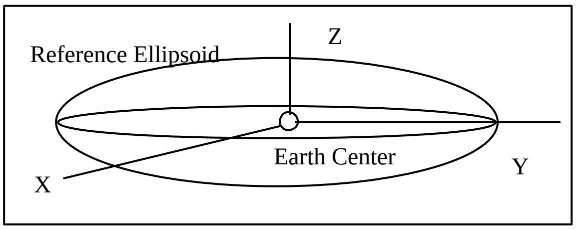

Figure 2. WGS 1984 DATUM (Abidin, 1995)

Using GPS means to use Global DATUM of WGS 1984 (World Geodetic System) that is defined as a Cartesian Coordinate System (Figure 2) with (Abidin, 1995):

- the center is closed to the center of the Earth
- Z-axis is closed to the Earth Rotate Axis through CTP (Conventional Terrestrial Pole)
- X-axis is located on the zero meridian of Greenwich
- Y-axis is perpendicular to X and Z-axis and forms the right-hand system.

2.4 Assumption

This study assumes that GPS measurements are obviously accurate enough to produce 3D line data with errors ranging from 2-10 meters for the Differential GPS (DGPS) method and 20-30 meters for absolute positioning GPS method. In addition, the received radar data have been orthorectified by the Dornier Company.

3. MATERIALS AND METHOD

3.1 GPS Data

The GPS 3D line data were digitised/acquired on the logging road identified in the InSAR image/data during the fieldwork activities. Both absolute positioning GPS and DGPS methods were used during data acquisition. In addition, this study used Magellan Pro Mark X-CP and Trimbel Geo Explorer II. The DGPS reference data in Jambi were supplied by PT. Lontar Papyrus, Tebingtinggi, Jambi.

3.2 DO-SAR Data

The Dornier SAR system has several operating modes (Table 1). This study used C-band interferometric of 6 looks with VV polarisation and 2-km swath width of 1.5-m resolution (Mode 4). Altitude data were recorded in the Height Above Ellipsoid (HAE) type.

Table 1. DO-SAR Operating Modes

	Mode 1	**Mode 2**	**Mode 3**	**Mode 4**	**Mode 5**	**Mode 6**
Frequency	C-band	C-band	X-band	C-band	C-band	C-band
Polarisation	VV	VV	VV	VV	VV	Polar
Interferometry	No	No	Yes	Yes	No	No
Resolution	3 m	1.5 m	1.5 m	1.5 m	0.8 m	3 m
Swath width	9.5 km	4 km	2 km	2 km	2 km	2 km
Looks	11	6	6	6	4	11

Source: INDREX 96 Experimenters Handbook

3.3 Test Sites

There were total 8 sites (3 sites in Jambi Province and 5 sites in East-Kalimantan Province). This study used only one site for each province. In this paper, only Jambi Province is discussed (Figure 3).

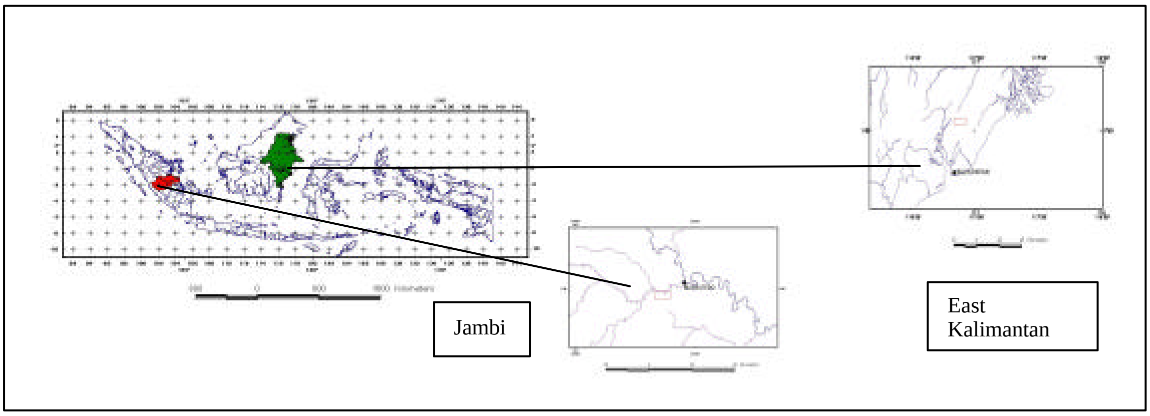

Figure 3. Test sites in Indonesia

3.4 Method

The acquired GPS data were transformed into a GIS data format using Arc/Info software and they were built in the line form. These data were transformed into shapefile format of ArcView to be read in a remote sensing software (ENVI) and in an ASCII format to be read in any statistical (SPSS) or spreadsheet (MS EXCEL) software (Figure 4). The DO-SAR images (power, coherence and height) were geometrically corrected using the GPS data in order to have the same projection. The profile of terrain altitude was manually drawn from the correct images closed to the GPS line overlaid on top of the image. The key tone for manual drawing is the logging road and soil association features.

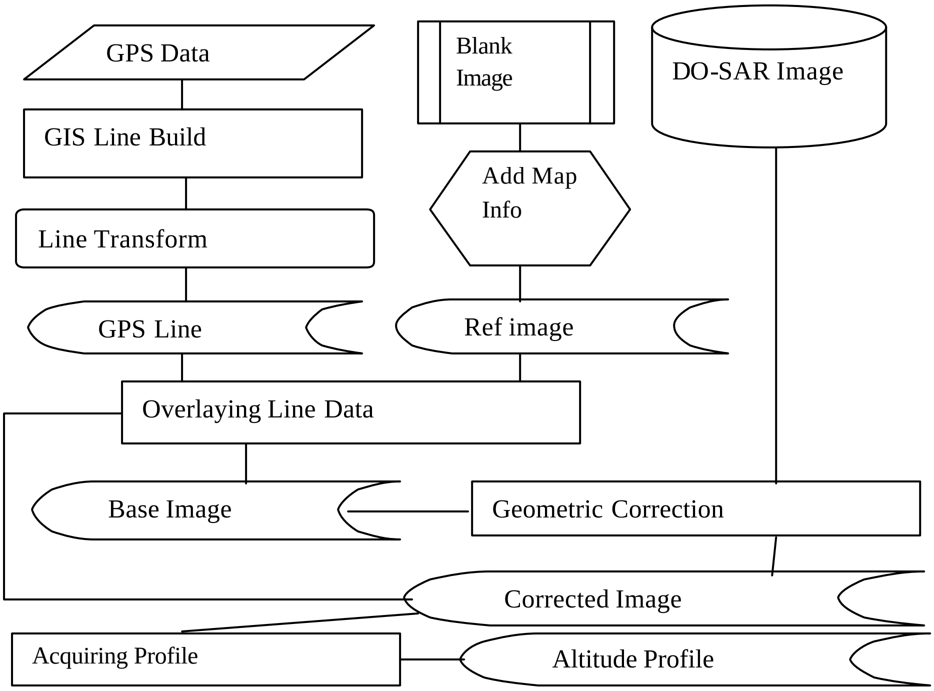

Figure 4. Procedure of Geometric Correction

5. RESULTS

5.1 Jambi Province

The site in Jambi province is the Gajah Mada University (UGM) training forest area. This site was chosen because of its secondary forest structure and less illegal logging disturbances during the last four years. The DO-SAR image covers also the base camp known as SYLVA GAMA Camp (Figure 5).

GPS data of logging road were acquired during May 2000 fieldwork. These GPS data were used for validating the terrain altitude of InSAR data and studying their errors (the objectives of this study).

In this site, the logging road is clearly visible in the power image. Houses and trees are clearly seen and they could be distinguished separately. The GPS data (dark line) were plotted on the geo-corrected image and the profile of terrain altitude (logging road) would be easily drawn manually (bright line) using the knowledge of logging road feature (Figure 5). The geometric correction of the first order polynomial (the lowest order in ENVI) process required 7 points with Root Mean Square Errors (RMSE) less than 1 pixel (0.9398).

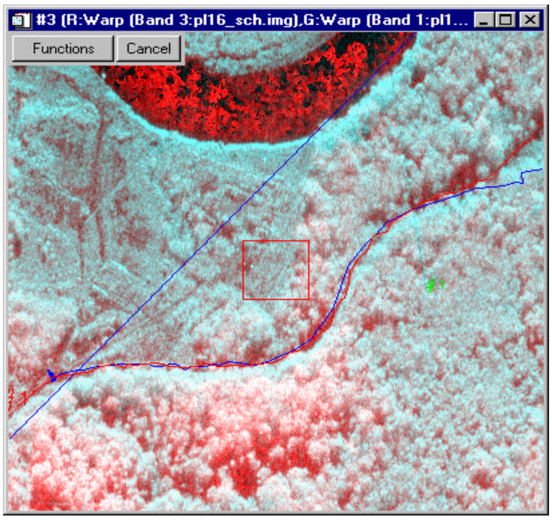

Figure 5. Sylva Gama Site (Power Image)

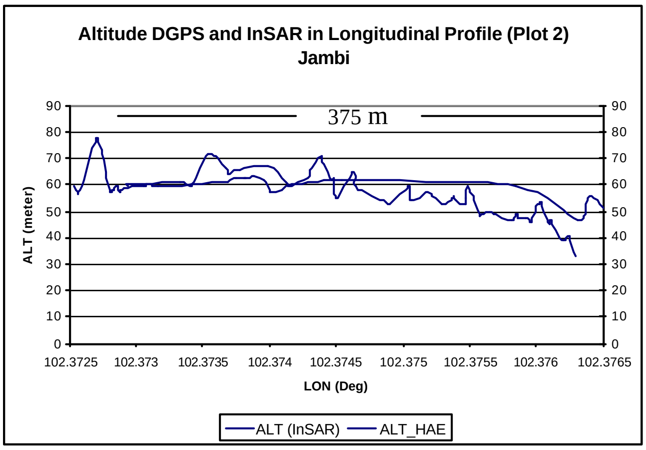

Figure 6. DGPS and InSAR Altitude

The results of DGPS data in the Sylva Gama site showed that between terrain altitude of InSAR data and DGPS measurement in the longitudinal profile showed agreement in both form-line and values (Figure 6). As expected, the absolute GPS data obviously showed less accurate agreement between GPS and InSAR altitude data than the DGPS data (Figure 7).

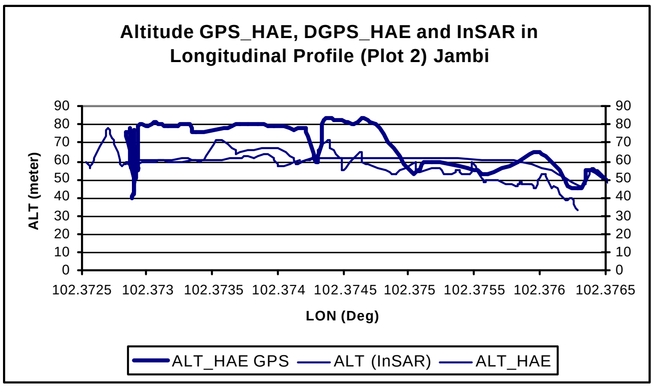

Figure 7. GPS, DGPS and InSAR Altitude

6. DISCUSSION

The geometric correction processes are essentially crucial to obtain the high accuracy corrected images. The lesser positional errors could reduce the false individual tree(s) recognition. The errors produced by geometric correction processes should be known in order to maintain the quality of InSAR altitude data.

Two sites or two InSAR images were geometrically corrected using the two types of GPS data (absolute versus differential). The altitude difference between using absolute GPS data and DGPS data showed varied from 20m to 30m (Figure 7). These differences could be tolerated because they are obviously tolerable errors based on this study assumption.

Abidin (1995) and Wells *et al*. (1986) indicated that relative positioning (DGPS) acquired more accurate altitude or height than the absolute positioning. In addition, Abidin (1995) showed that height (z) data would have 2-5 times less accurate than the horizontal (x,y) data. This could be happened because of one-sided geometry and effects of ionosphere and troposphere.

The uses of DGPS data with HAE altitude were highly agreed with the altitude of InSAR data. This still could be improved if future DGPS measurements could consider the ionosphere and troposphere factors indicated by Abidin (1995). The available and commercially GIS and remote sensing software showed that they were good enough to show that InSAR altitude data could be validated using DGPS data (objective 1) and errors could be estimated and/or analysed in a simple descriptive statistics approach (objective 2). Thus, foresters could imitate this simple and practical method from this study for their monitoring activities using InSAR data/images.

7. CONCLUSIONS

This study of the GPS and InSAR data validation and geometric correction concluded that:

1. DGPS data are suitable to be used for validating the InSAR of DO-SAR data/image;
2. The errors of geometric correction and altitude of InSAR images are smaller in the DGPS measurements than in the absolute GPS measurements;
3. The available and commercially software and instrument are good enough to produce a good quality geo-corrected InSAR image.

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